Very Large Offshore Blade Challenges

~~94m~~ 97m Blade as case

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IWES Virtual Wind, April 29th 2020

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Large Offshore Blade Design Innovation Challenges

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Challenges of Very Large Offshore Blades

What made it difficult?

- Structural performance
  - Technical challenge in modelling new behaviors
  - Material and design challenge to meet cost and AEP targets
- Manufacturing Technology
  - Integral blade concept is cross section driven with improved footprint utilization
  - Only minor technical challenge from length, mass and chord increase
  - Significant CapEx challenges from footprint utilization

First B94 Prototype Blade

Design Challenges

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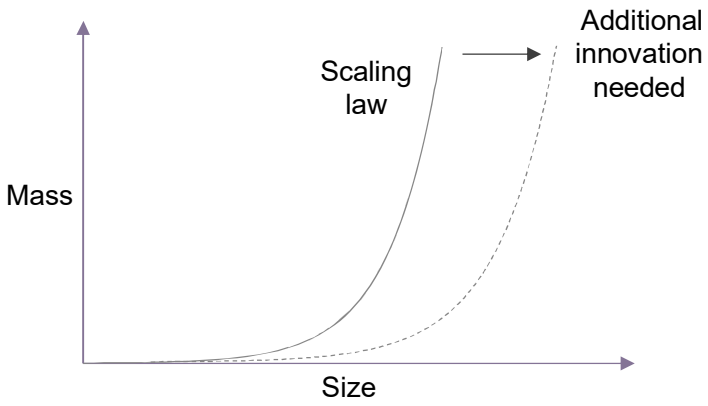
Design Challenge for Very Large Blade Development

Blade mass scaling

- Scaling of a blade with 50% in length leads to 2.4 times the blade mass



Design Challenges

- Square cube law → Need to be aggressive on new technologies to stay competitive
- Time to market → B81 was the most sold OF blade before prototyping ended
- Cost & Risk → Failures are (even more) expensive offshore
- Risk management during design and process control during manufacturing are paramount!

Constant innovation and disruption is needed to break the basic scaling laws – "more of the same" will not work!

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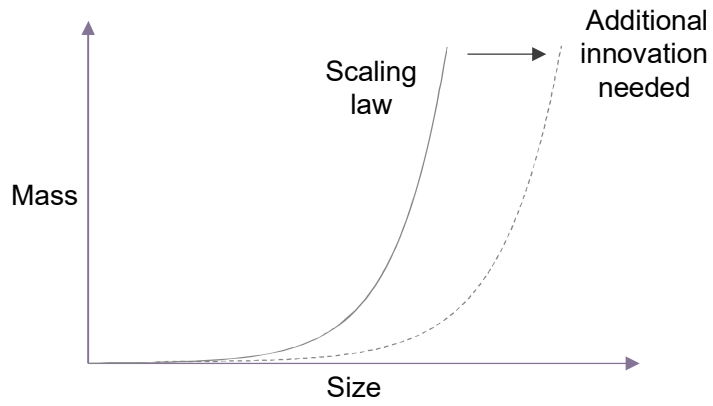
B97: Balance Risk and Opportunities

Blade mass scaling

- Increasing blade length by ~3% would normally lead to a ~8% increase in mass
- Challenge was to do it mass moment neutral



Design Challenges

- Opportunity based on optimization of design rules and structural design during prototyping
- Very agile project setup with direct management access
- Limited structural validation feedback from B94
- Commercial upside versus certification challenges for customers and sales projects

- All in all – the upgrade to SG 11-200DD is successful in the market

Constant innovation and disruption is needed to break the basic scaling laws – "more of the same" will not work!

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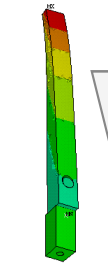
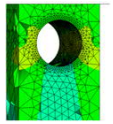
Product Development

Building Block Approach

- Start design at system level concepts and detail down to material level
- Start test from material level and move up to full system level integration
- DFMEA to have a structured approach to risk and Verification & Validation planning
- Main Challenges on B94:
  - Doing Integrated Design - close link from structure and planform to turbine loads & control in concept phase
  - Full carbon beam design
  - Lightning Protection

V-model break down for Blades





Concept definition

Component Design

Material & Test Specification

B97

Blade Structural Testing

Component Testing

Material Qualification

Transition from design to validation can have several learning loops

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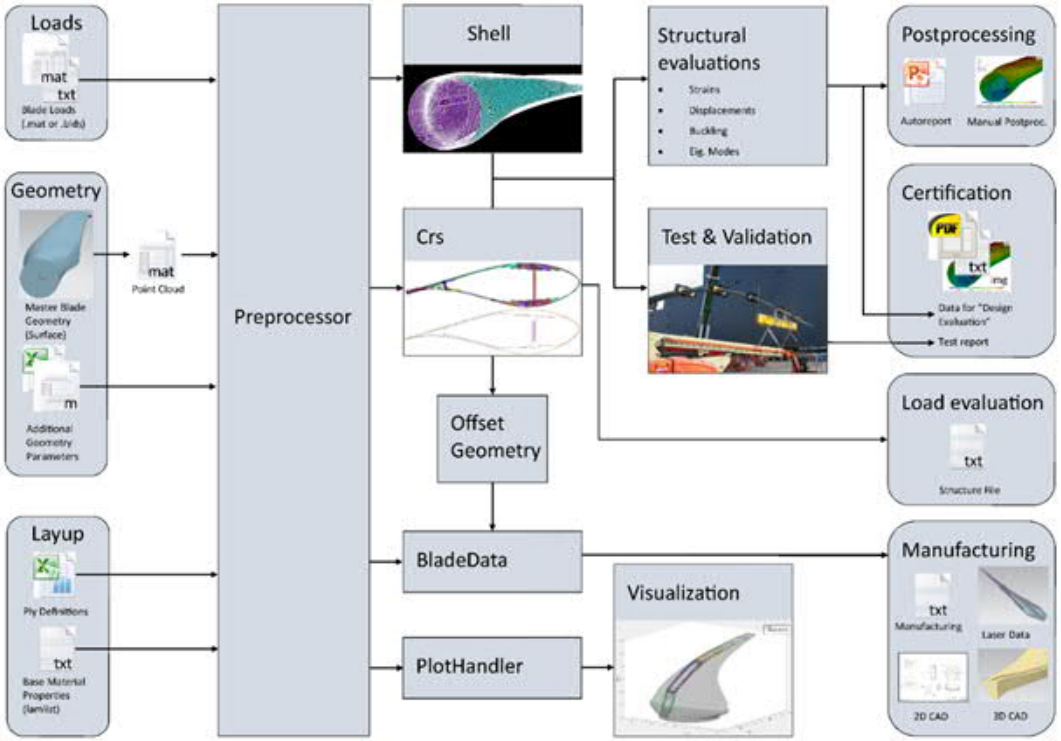
Integrated Design

Integrated Design Approach

- An internal structural design tool suite that facilitates automation and cooperation
  - Improved time-to-market with lower risks as single database drives all outputs
  - Backwards integrated with aero and loads optimization tools for concept design phase
- Higher efficiency and quality
  - Certification deliverables gone from 3 weeks for 3 engineers to 2 days for 1 engineer
- Integrated feedback loop from prototyping
  - Layup corrections are implemented in the model on the mold as they are laid up
  - Structural models are recalculated directly so changes are captured

Tool Architecture



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Main Design Challenges

B94 Challenges

- Full carbon beam design
  - Initial concept characterization
  - Virtual System Design → feedback to concept
  - Sub-component validation followed by B55 technology blade full structural validation
- Verify B94 operational stability through prototype operation in Østerild and 1-1 modelling
- Lightning Protection System
  - More challenging than structural design
  - Modelling, subcomponent and full scale testing
  - Certified on technology blade to de-risk timeline

Manufacturing Challenges

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Manufacturing Challenge for Very Large Blade Development

Factory space scaling

- Increasing blade length by 50% will mean factory space will increase by a factor ~2

Factory size for 50% additional blade length (est.)

At constant effectiveness (kg of material placed per hour) the 2x factory space will have only approx. half the blade output due to higher mass and corresponding increase in cycle time.

That is 4x higher binding of CapEx per blade!

Manufacturing Challenges

- Cost and effectiveness → Integrate manufacturing into the design with focus on cycle time
- Carbon → New material with different behavior, handling and sourcing strategy
- Complexity → Remove human error and increase process capability to get stable flow

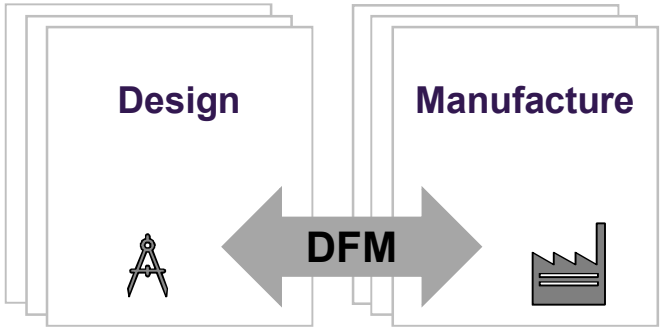
Constant innovation and disruption is needed to break the basic scaling laws – "more of the same" will not work!

Manufacturing has to be integrated into the design

Design to Manufacture (DFM) best practice

- Focus on manufacturing and product life cycle
- Focus on concept phase
- Structured approach involving 7 domains
- Identify synergies and if none, best compromise
- Set common transparent objectives for product & manufacturing
- Our biggest leap was from B75 to B81
  - 20% lower takt time for a 25% heavier blade
  - increasing effectivity by more than 50%

Design for Manufacture



1. Do the right thing → 2. Do things right

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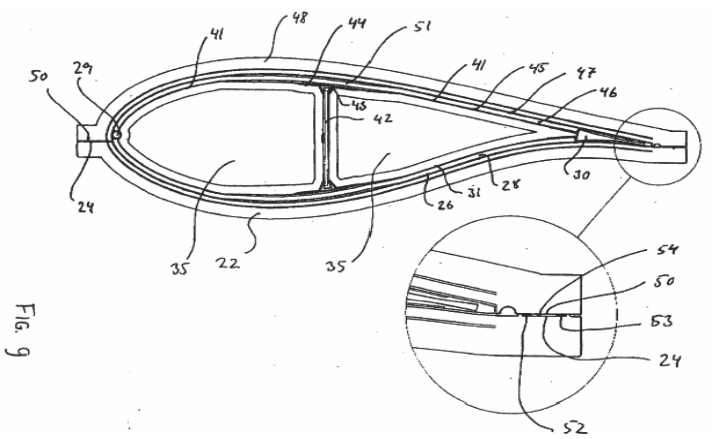
IntegralBlade® Concept

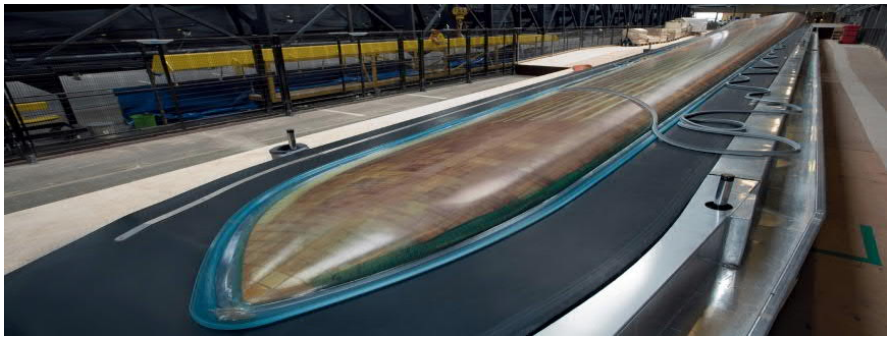
Overall Concept

- Layup is ~80% dry by mass with some pre-cast elements like the beam
- Layup is using round-going mats eliminating joints
- Large freedom in profile shape including aggressive flatback shapes



Manufacturing Concept

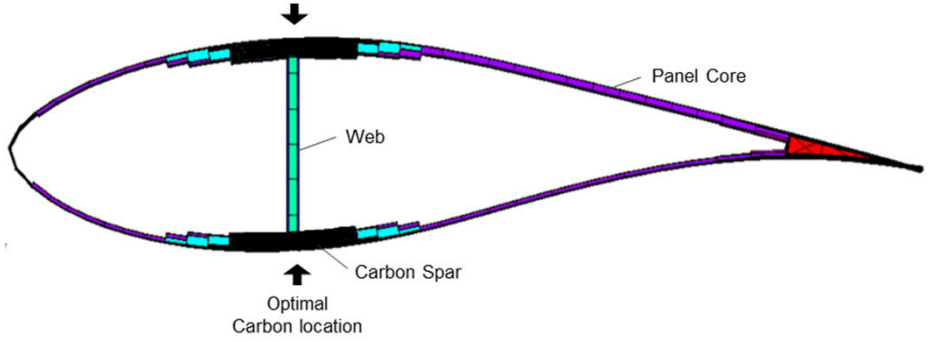
- Mold is closed with an internal mandrel
- Infusion is done as one cycle
- Very high EHS standard with completely closed resin system
- Footprint utilization is higher with two lower molds and shared upper mold vs. two full butterfly molds



IntegralBlade® Concept

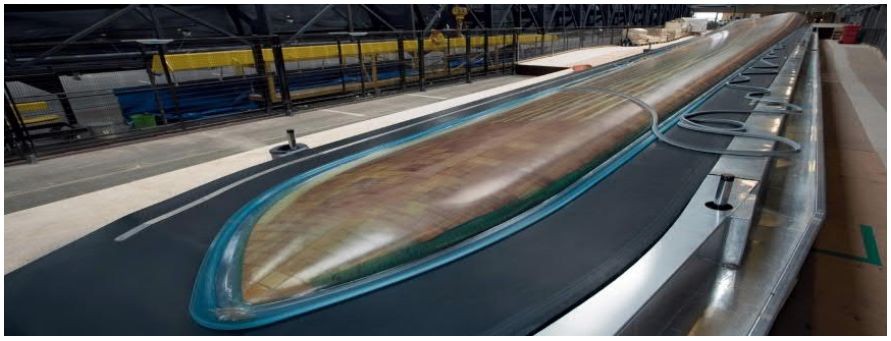
Structural Performance

- Elimination of bonds is 3% - 4% mass saving
  - Higher strain allowable allow for better material utilization
  - Higher buckling stability allows for thinner shell panels
- One-web design by default for better control of brazier effects and utilization of spar cap



Quality Performance

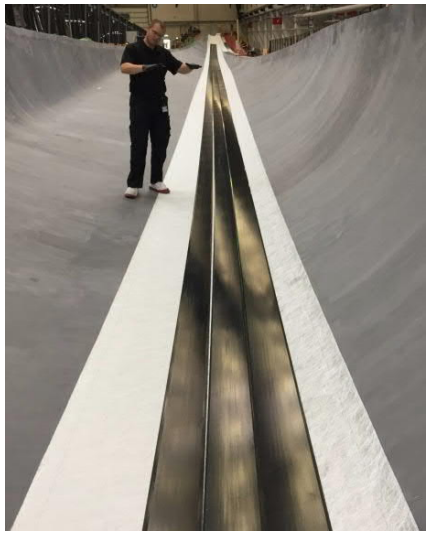
- Target is for casting quality to be used-as-is with no repairs
  - 90% reduction in errors from B75 initial serial production to B81 initial serial production
  - Target is further 90% reduction through the serial production of the B97



Main Manufacturing Challenges

Drapability of carbon

- Stiffness is very high chordwise → Beam has to be straight
- Multiparameter optimization: Manufacturing – loads – AEP

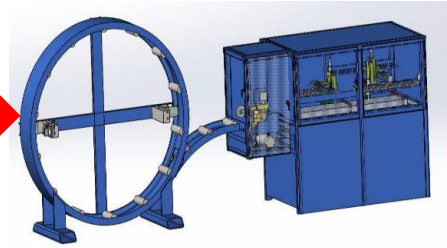


Ergonomics and EHS

- Fiber matts are getting larger due to blade size: Structural efficiency vs. ergonomics for operators (cranes a bottleneck)
- Carbon can not be treated like glass fiber so new processes are needed to handle and machine it

Material supplied in coils

Decoiler + cutting + scarfing + peel-ply removal + QC

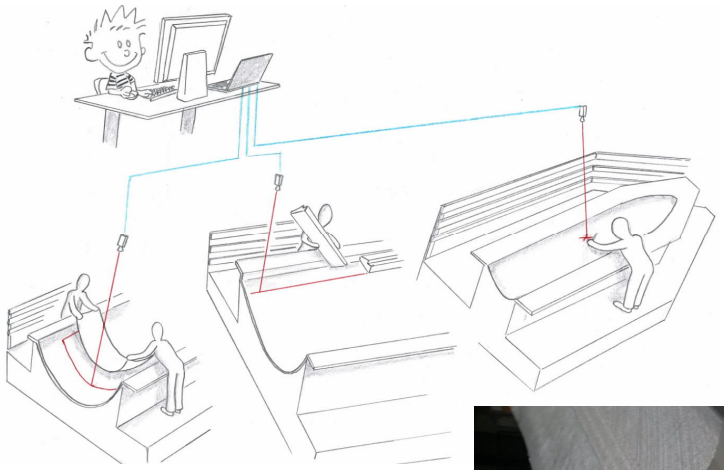


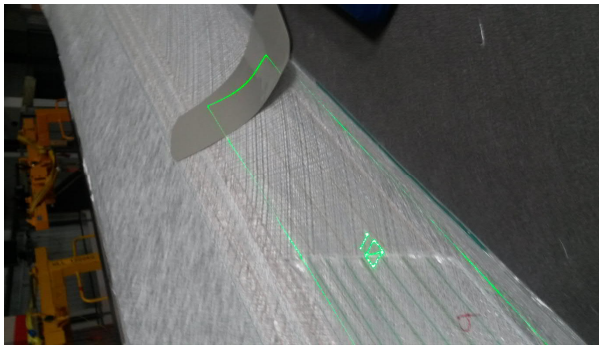
Main Manufacturing Challenges

Complexity

- Largest single cast composite component ever
  - Surface Area is 750+ sqm
  - 3000+ Glass layers
  - Very few references for placement & maintaining tight tolerances
- Digitalization approach using laser marking
  - Make design tools available on the mold
  - Auto generation for laser from known data
  - Remove human error in layup process
  - On-the-fly update of design on the mold during prototyping

B97 Blade Production Laser System





Outlook on innovation challenge for even larger blades…

- Integrated blade design – focus on rotor turbine interaction and optimization
- Risk management to support safe introduction & time-to-market
- Upscaling of technologies and preparing for the unknown already in the concept phase
- Broad value chain focus to facilitate Design for Manufacturing
- Focus on CapEx reduction

Questions?

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