The DTU 10-MW Reference Wind Turbine

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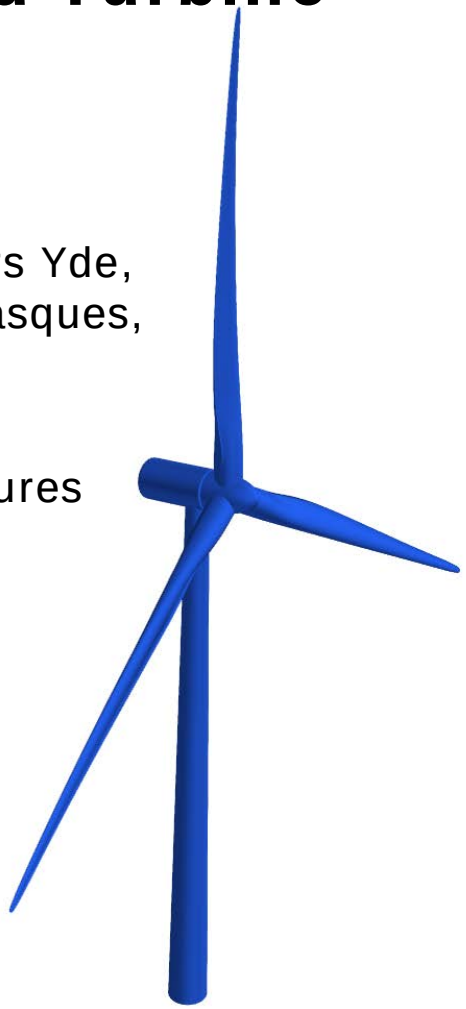
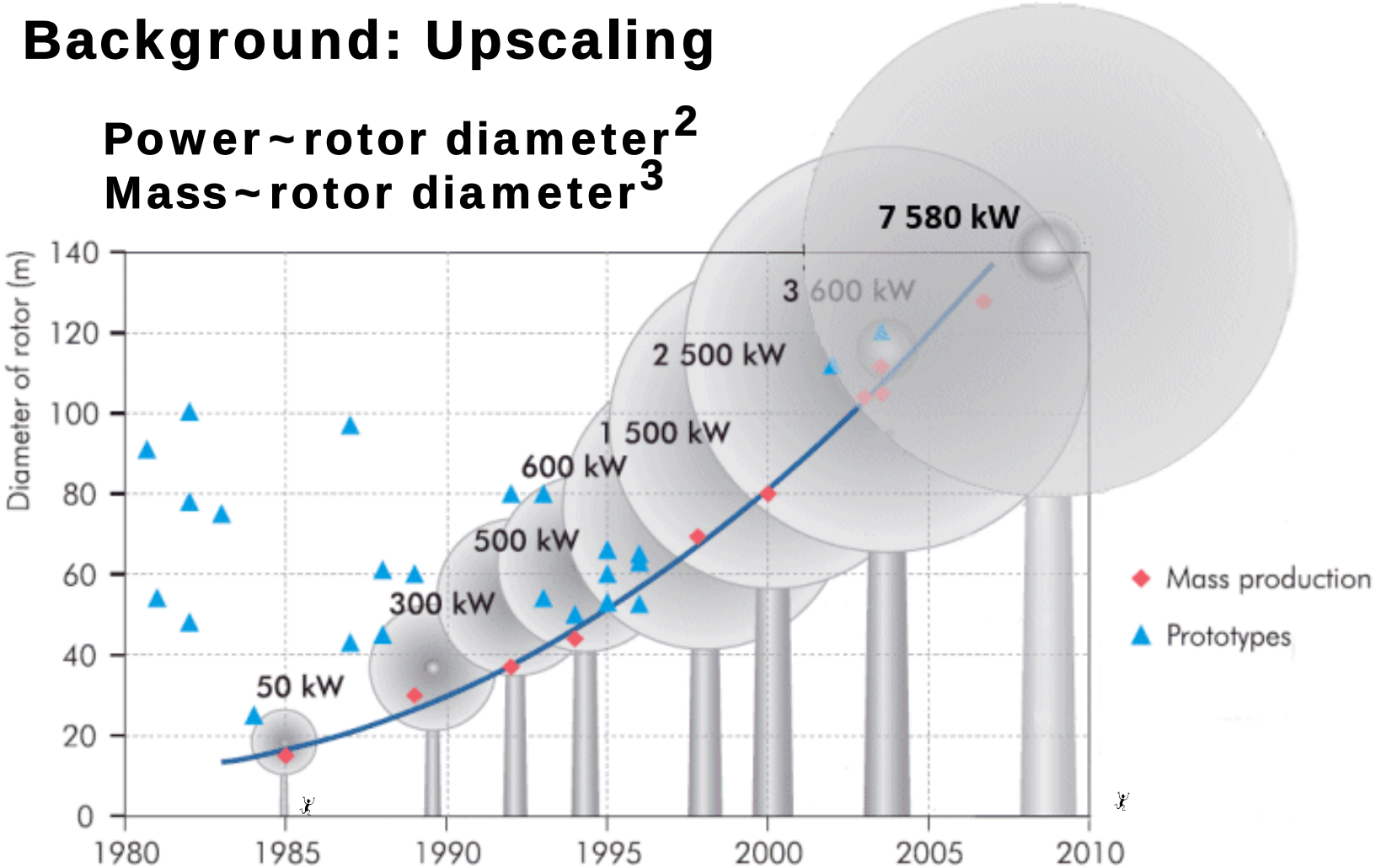


DTU Wind Energy
Department of Wind Energy

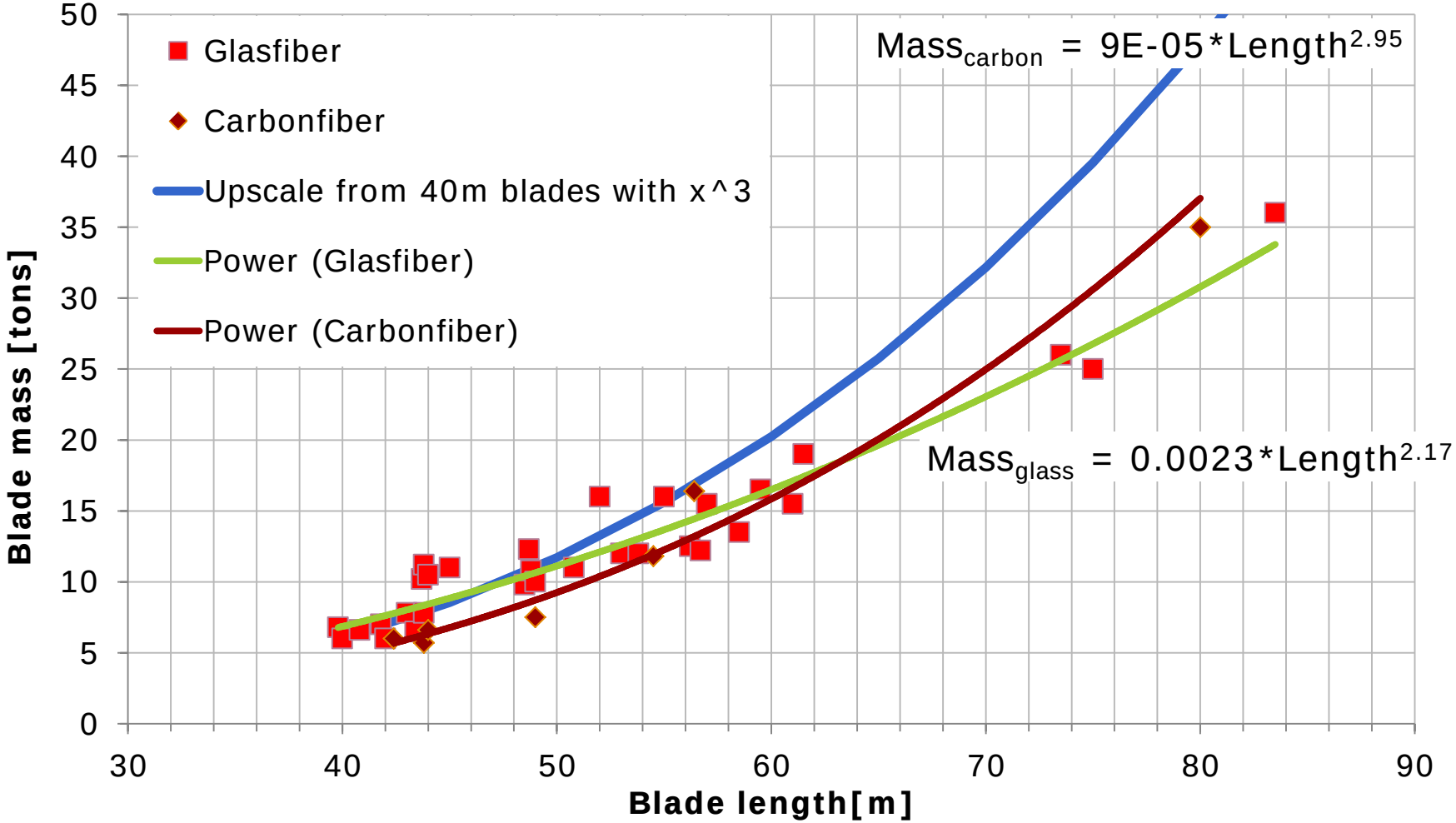
The DTU 10 MW Reference Wind Turbine
Background: Upscaling

Power~rotor diameter^2
Mass~rotor diameter^3



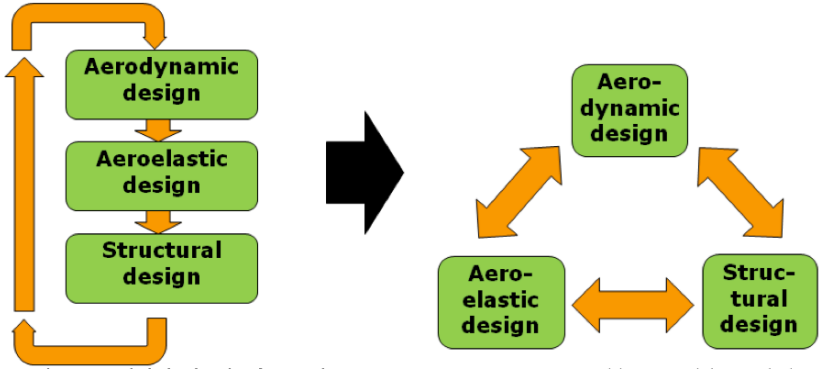
Source: International Energy Agency (IEA)

The DTU 10 MW Reference Wind Turbine Background: Upscaling blades



The DTU 10 MW Reference Wind Turbine Objective of the Light Rotor project

- The Light Rotor project aims at creating the design basis for next-generation wind turbines of 10+ MW.
- Collaboration with Vestas Wind Systems
- The project seeks to create an integrated design process composed of:
  - Advanced airfoil design taking into account both aerodynamic and structural objectives/constraints,
  - Aero-servo-elastic blade optimization
  - High fidelity 3D simulation tools such as CFD and FEM,
  - Structural topology optimization.
- **We need a reference wind turbine to compare our designs against**



The DTU 10 MW Reference Wind Turbine Objectives

- **The purpose with the design is:**
  - To achieve a design made with traditional design methods in a sequential MDO process
  - Good aerodynamic performance and fairly low weight.
  - To provide a design with high enough detail for use for comprehensive comparison of both aero-elastic as well as high fidelity aerodynamic and structural tools,
  - To provide a publicly available representative design basis for next generation of new optimized rotors.

- **The purpose is not:**
  - To design a rotor pushed to the limit with lowest weight possible,
  - To push the safety factors as much as possible,
  - Provide a design of a complete wind turbine – focus is on the rotor,
  - To provide a design ready to be manufactured; the manufacturing process is not considered.

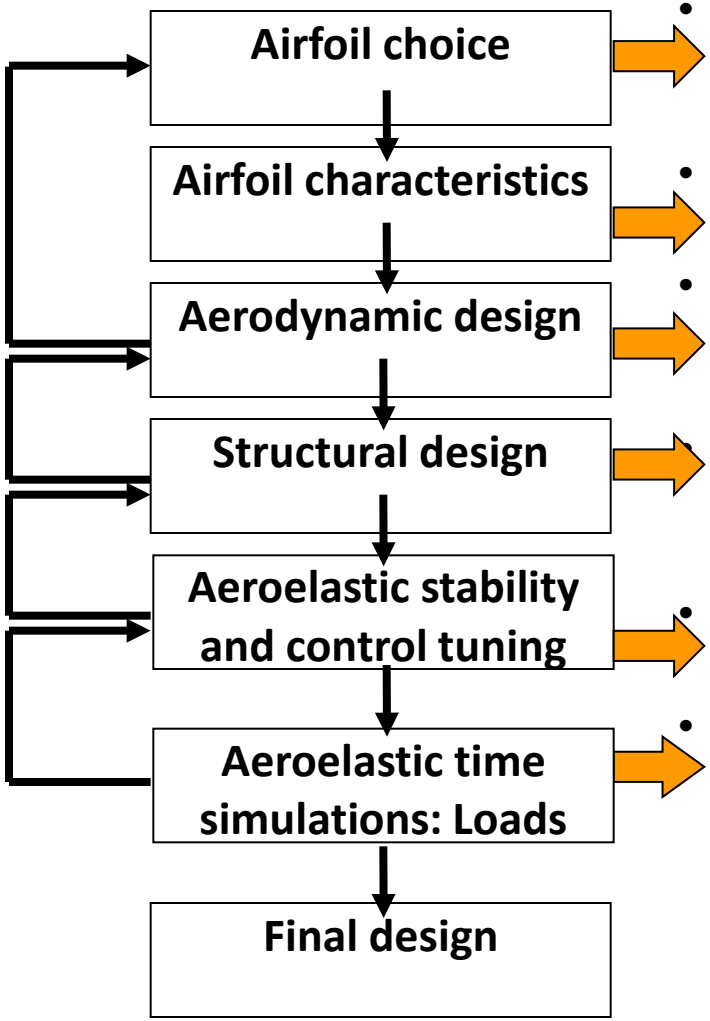
The DTU 10 MW Reference Wind Turbine
The Design Process

- DTU Wind Energy is responsible for developing a number of wind turbine analysis codes that are all used by industry in their design of wind turbines and use them in the design of the DTU 10MW RWT:
  - **HAWC2** (multibody time domain aeroelastic code)
  - **HAWCstab2** (Aero-servo-elastic modal analysis tool)
  - **BECAS** (Cross-sectional structural analysis tool)
  - **HAWTOPT** (Wind turbine optimization code)
  - **EllipSys2D / 3D** (RANS / DES / LES Navier-Stokes solvers)
- Other solvers used: Xfoil, ABAQUS
- In our normal research context we do not normally use these tools in a synthesized manner in a design process.
- The exercise for us was to apply our tools and specialist knowledge in a comprehensive design process of a 10 MW wind turbine rotor, something we have not done to this level of detail before.
- Identify areas in the design process suited for more integrated MDO architectures.

The DTU 10 MW Reference Wind Turbine Design Summary

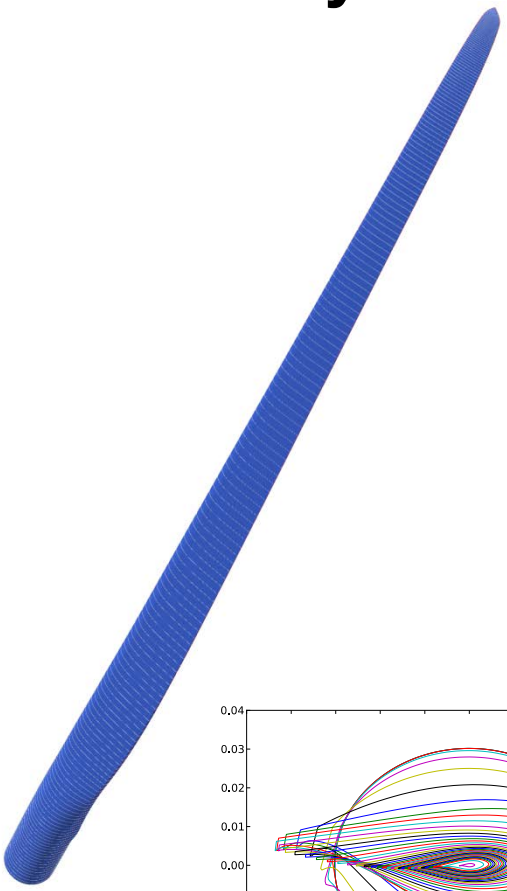
Description	Value
Rating	10MW
Rotor orientation, configuration	Upwind, 3 blades
Control	Variable speed, collective pitch
Drivetrain	Medium speed, Multiple stage gearbox
Rotor, Hub diameter	178.3m, 5.6m
Hub height	119m
Cut-in, Rated, Cut-out wind speed	4m/s, 11.4m/s, 25m/s
Cut-in, Rated rotor speed	6RPM, 9.6RPM
Rated tip speed	90m/s
Overhang, Shaft tilt, Pre-cone	7.07m, 5°, 2.5°
Pre-bend	3m
Rotor mass	229tons (each blade ~41tons)
Nacelle mass	446tons
Tower mass	605tons

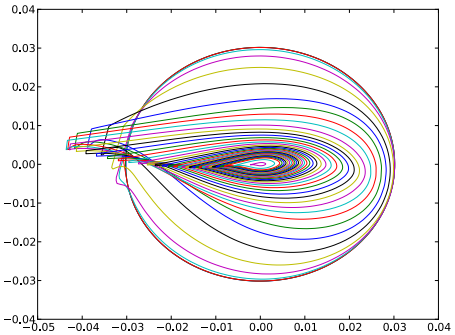
The DTU 10 MW Reference Wind Turbine
The method

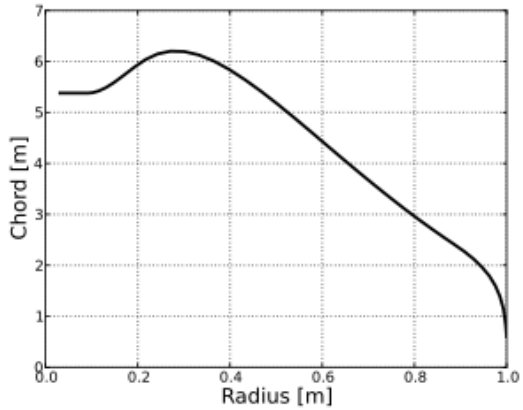


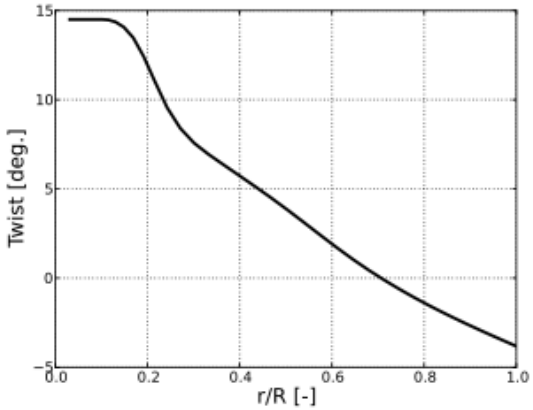
- FFA-W3-xxx airfoils. 24.1% to 36.0% relative thickness, 48% and 60% airfoil scaled from FFA-W3-360 and cylinder.
- 2D CFD computations at *Re* 9×10^6 to 13×10^6 3D corrected
- HAWTOPT numerical optimizations. Max tip speed = 90m/s, λ=7.5, min relative airfoil thickness = 24.1%
- ABAQUS (6.11) FEM computations. Uniaxial, biaxial and triaxial laminates were used together with Balsa as sandwich core material
- HAWCSTAB2 (aero-servo-elastic stability tool) computations including controller tuning.
- HAWC2 (aeroelastic code) computations. Class IA according to IEC-61400-1 standard for offshore application

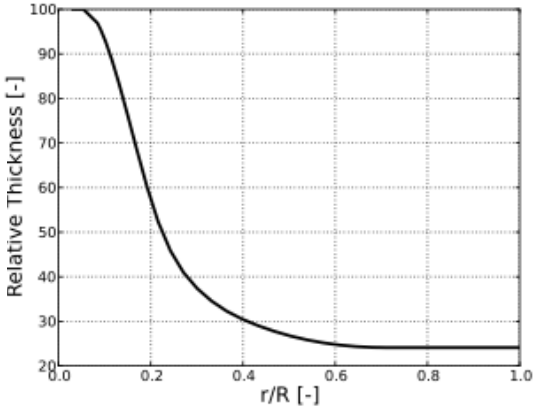
The DTU 10 MW Reference Wind Turbine Aerodynamic Design: Geometry

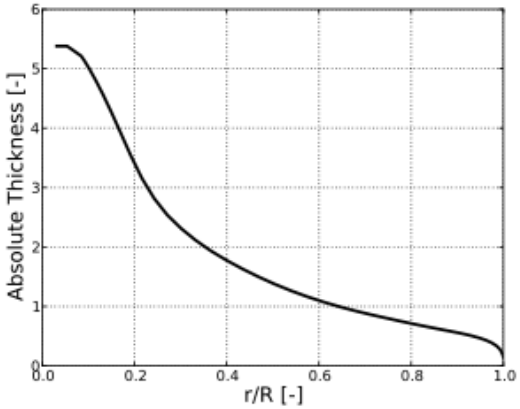




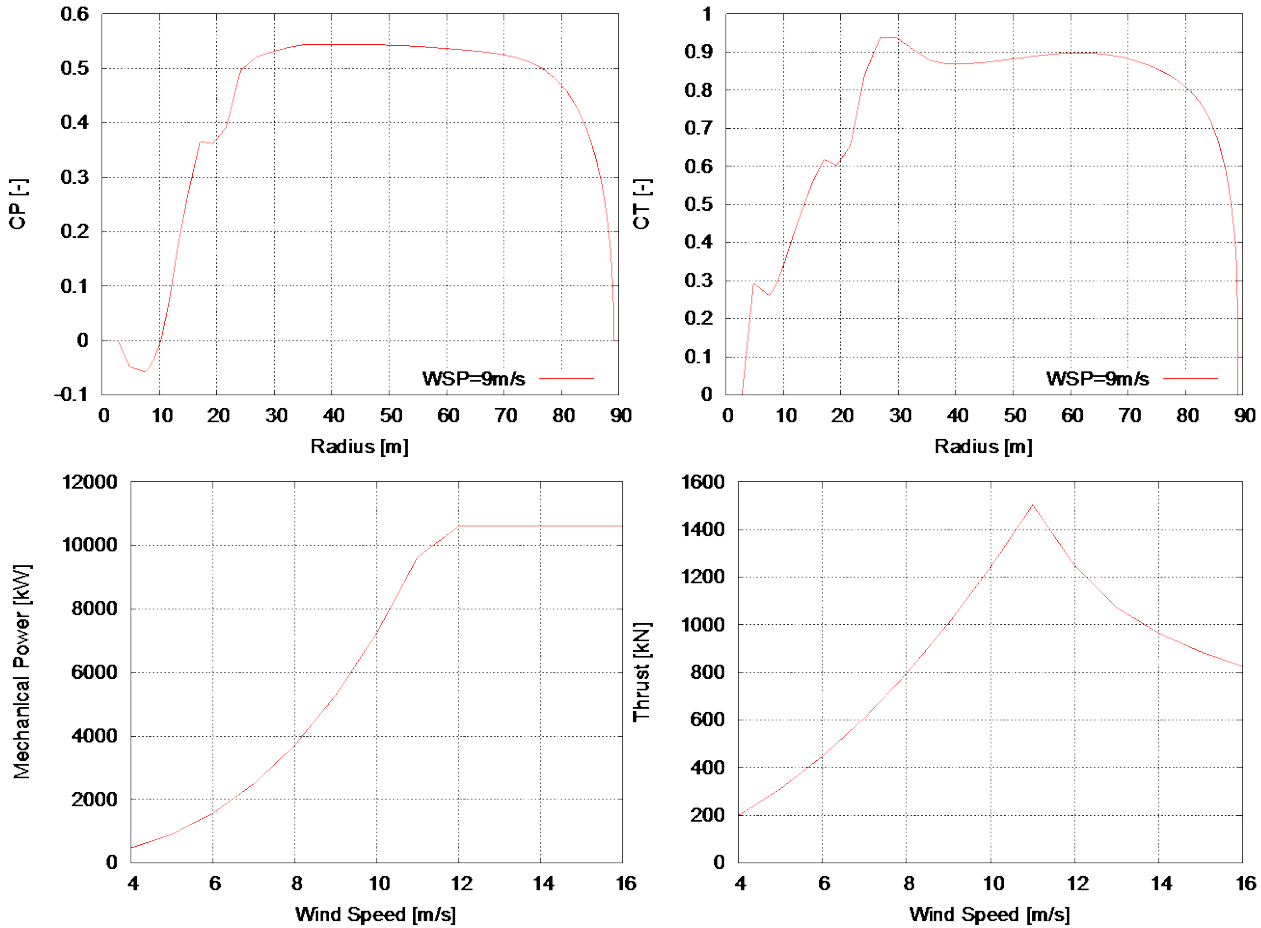




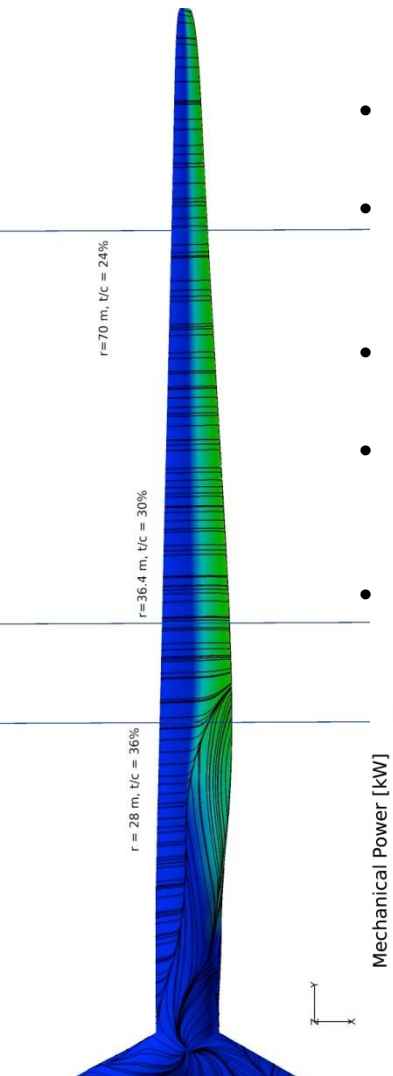




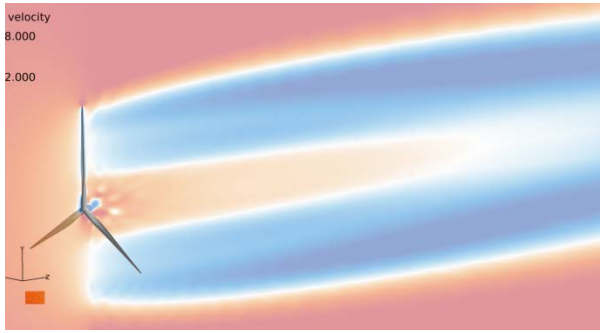
The DTU 10 MW Reference Wind Turbine Aerodynamic Design: Performance

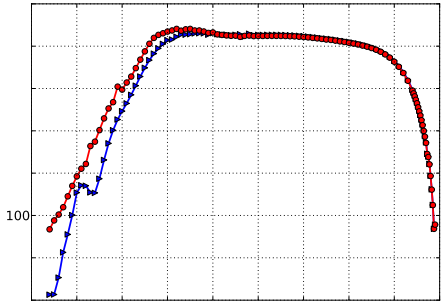


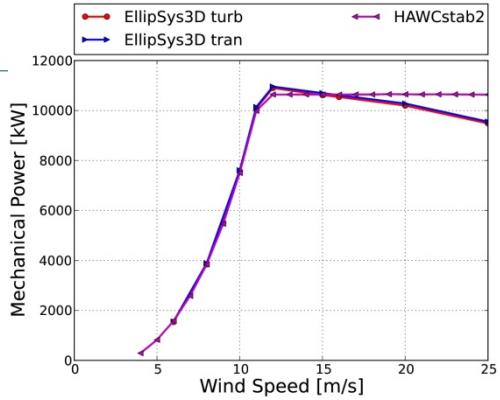
The DTU 10 MW Reference Wind Turbine Aerodynamic Design: 3D CFD analysis

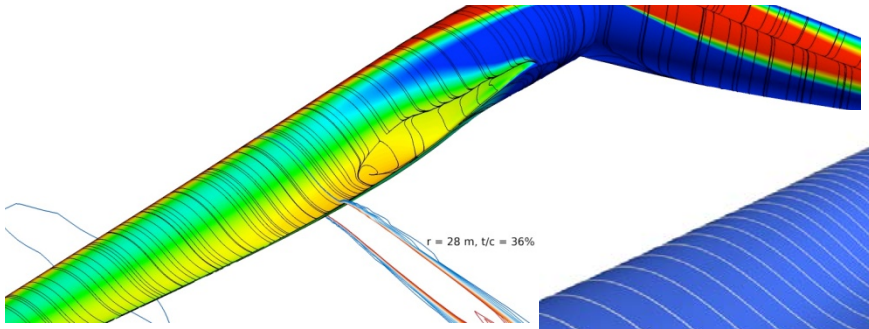


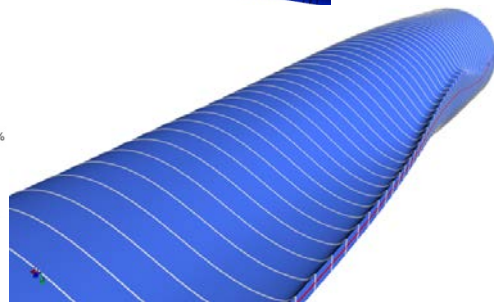
- Automated workflow from 2D blade definition/airfoil family -> 3D shape -> 3D volume mesh,
- 3D CFD validation of performance predicted using BEM,
- Blade performance in the root area was not satisfactory due to use of thick airfoils (t/c > 0.36 for r/R < 0.30).
- Gurney flap were used to remedy this, increase in CP of 1.2% at design TSR.
- Resulted in adjustment of airfoil data and new design iteration adopting the modified root layout.
- (Automated derivation of 3D airfoil data).





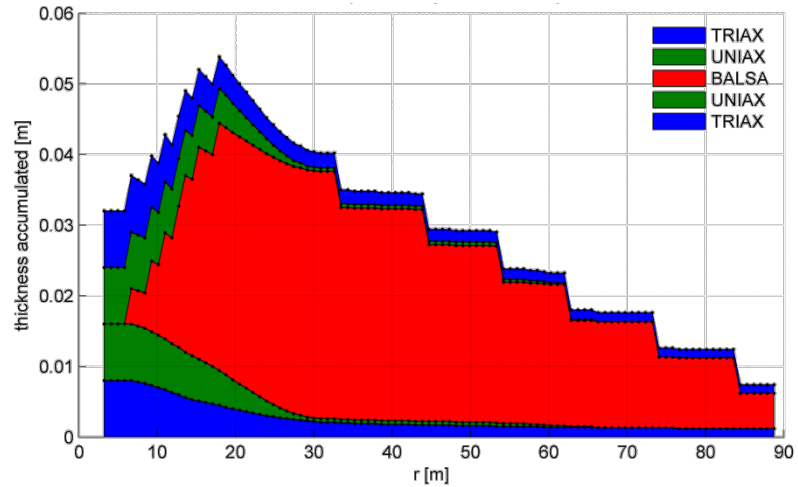


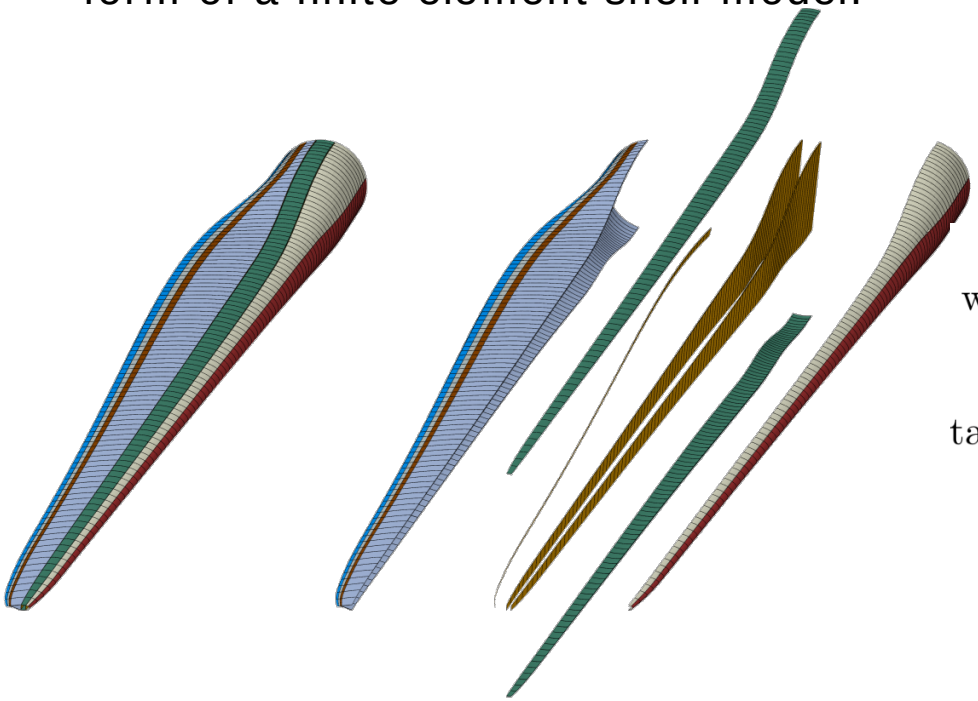


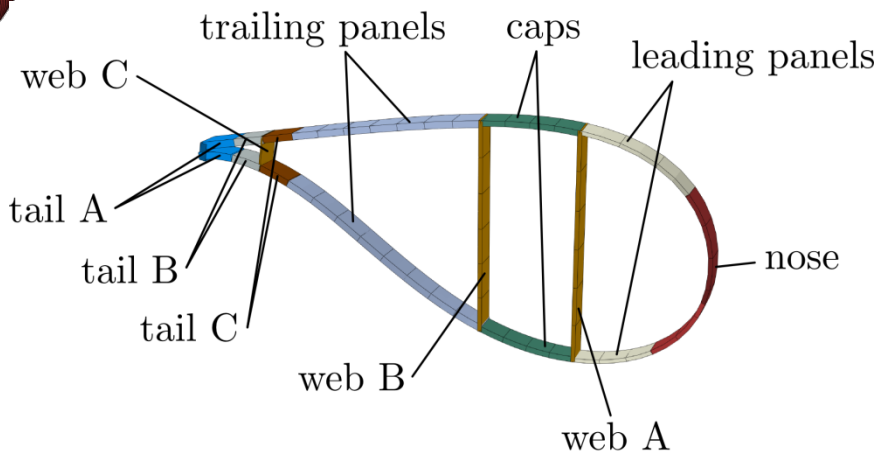


The DTU 10 MW Reference Wind Turbine Structural Design: Basic design choice

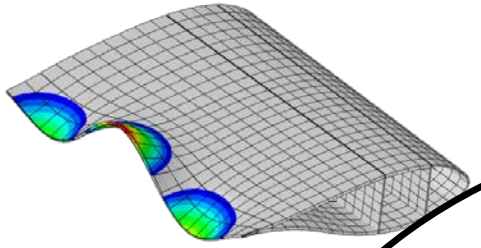
- A ”box-girder” design approach is used.
- For layup definition the blade is partitioned into 100 regions radially and 10 regions circumferentially.
- A complete description of the blade’s geometry and layup is generated in the form of a finite element shell model.

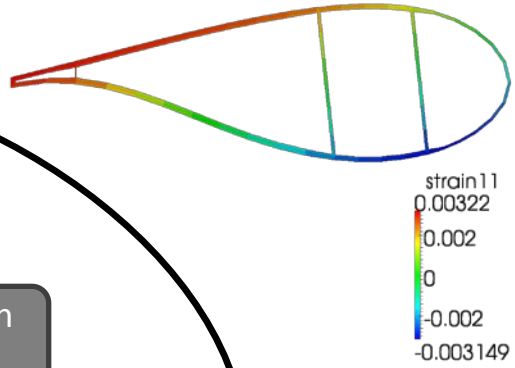






The DTU 10 MW Reference Wind Turbine Structural Design: Design loop





Geometry, material and composite layup definition

Automatic generation of ABAQUS input files

Automatic generation of BECAS input files

Buckling

ABAQUS: layered shell model

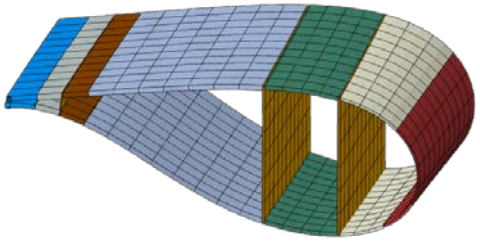
BECAS: cross section analysis

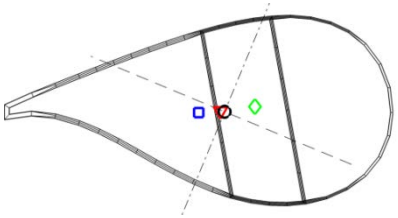
Local stress and failure

Cross section stiffness properties

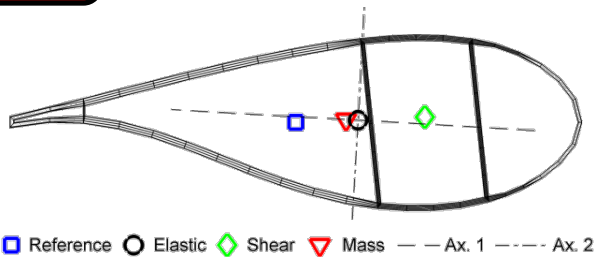
Ultimate loads

HAWC2: aeroelastic analysis

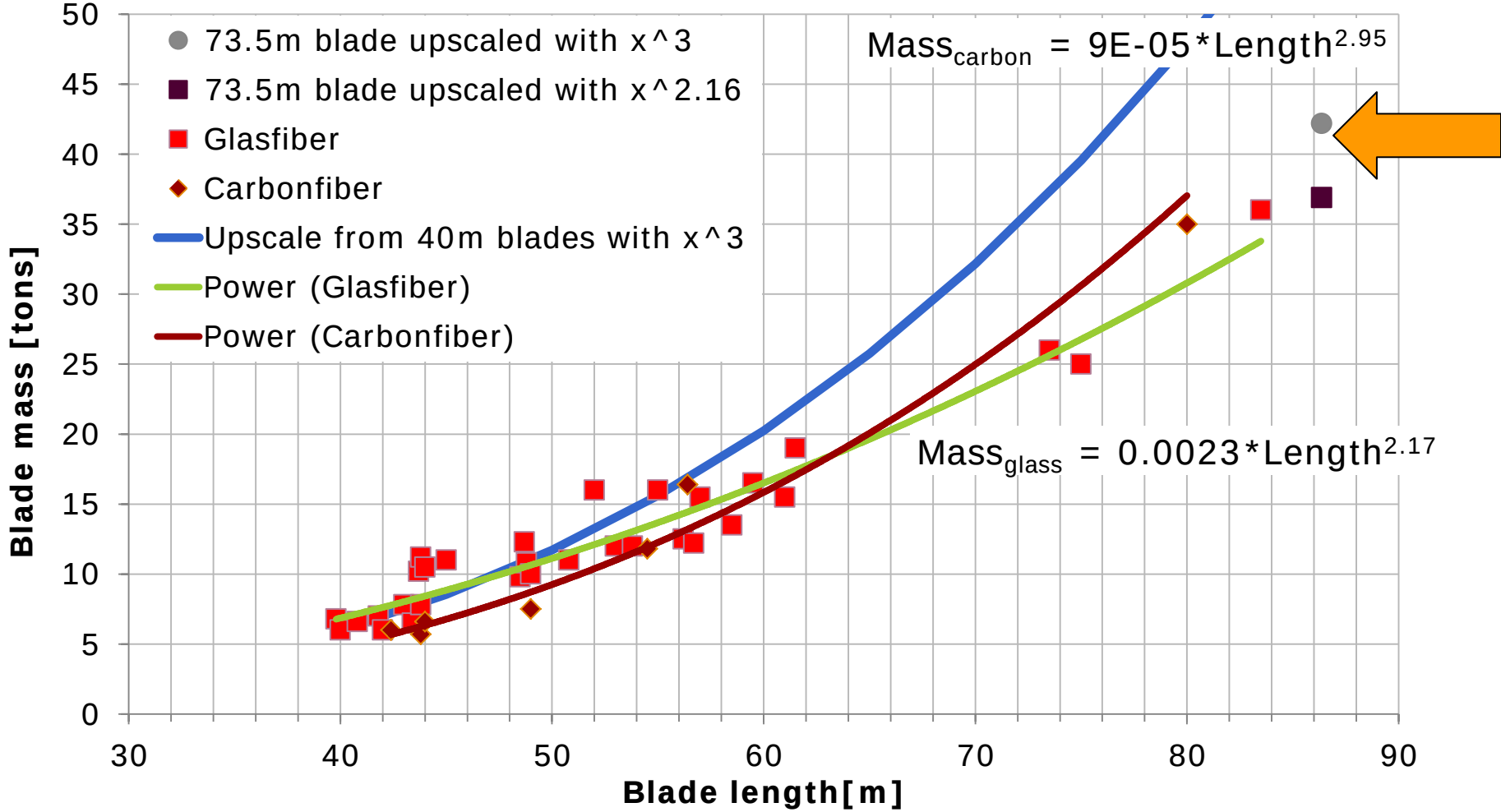




		Load case	γ_F [–]	F_x [MN]	F_y [MN]	F_z [MN]	F_{res} [MN]	M_x [MNm]
F_x	max	dlc5.1	1.35	0.9531	-0.2915	1.0163	0.9967	25.2834
	min	dlc1.3	1.35	-0.8724	0.3672	2.2653	0.9465	-8.9863
F_y	max	dlc1.3	1.35	0.4949	1.6055	2.4138	1.6801	-52.9810
	min	dlc6.1	1.35	-0.0504	1.1862	0.2782	1.1872	44.0922

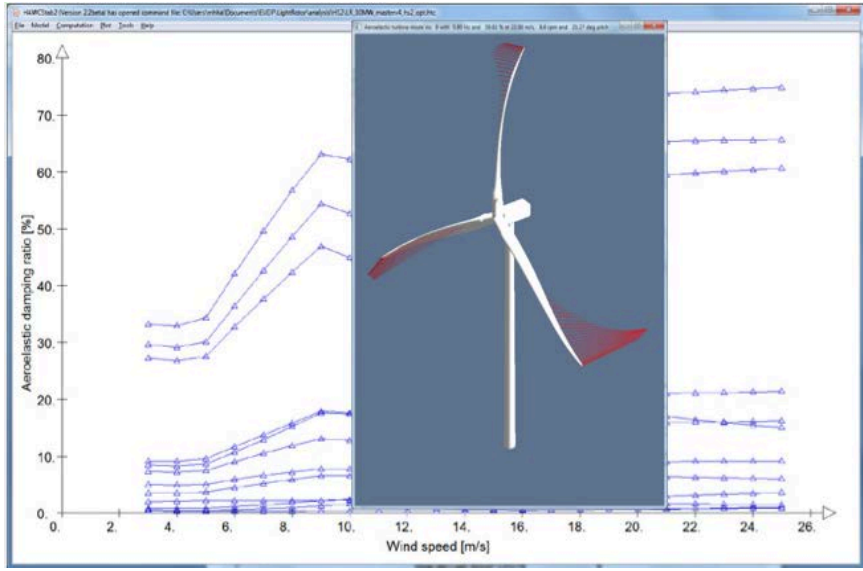


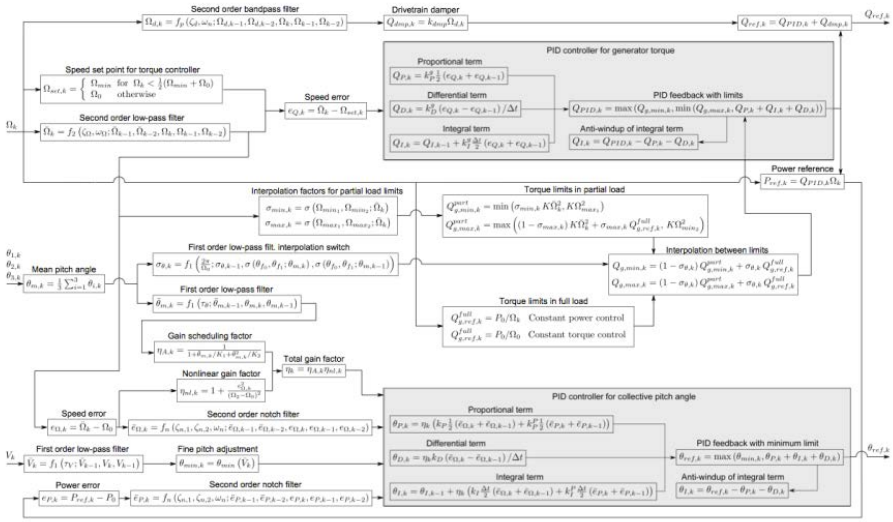
The DTU 10 MW Reference Wind Turbine
How the blade compares to existing ones



The DTU 10 MW Reference Wind Turbine Aero-servo-elastic analysis

- HawcStab2 used to analyze the modal properties of the wind turbine:
  - frequencies, damping ratios, and mode shapes.
- The DTU Wind Energy controller was revised and tuned specifically for the DTU 10 MW RWT.
- To avoid tower mode excitation from 3P frequency, minimum RPM = 6.
- Report and source code on controller available.





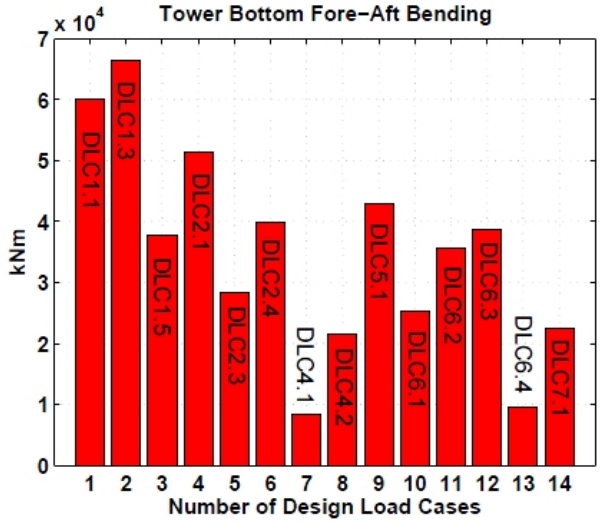
The DTU 10 MW Reference Wind Turbine Load calculations: HAWC2

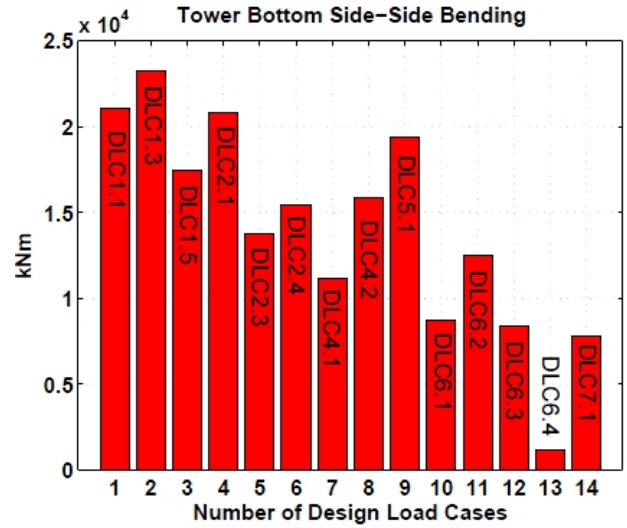
- DTU 10MW RWT: IA according to IEC-61400-1 (3rd edition)

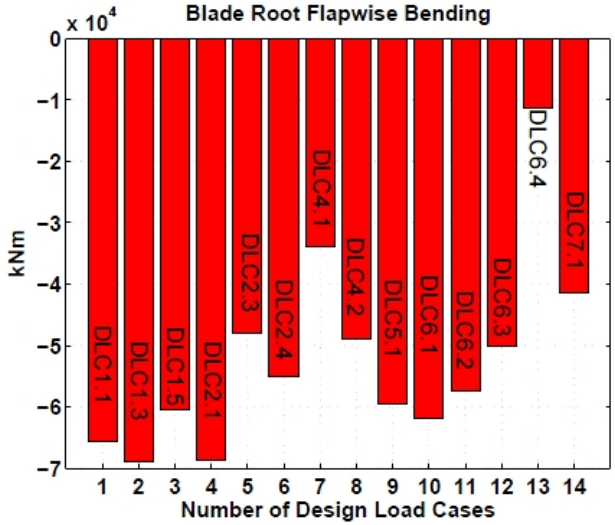
- The suggested load cases by IEC standard must be verified in order for withstanding all loading situations during its life time.

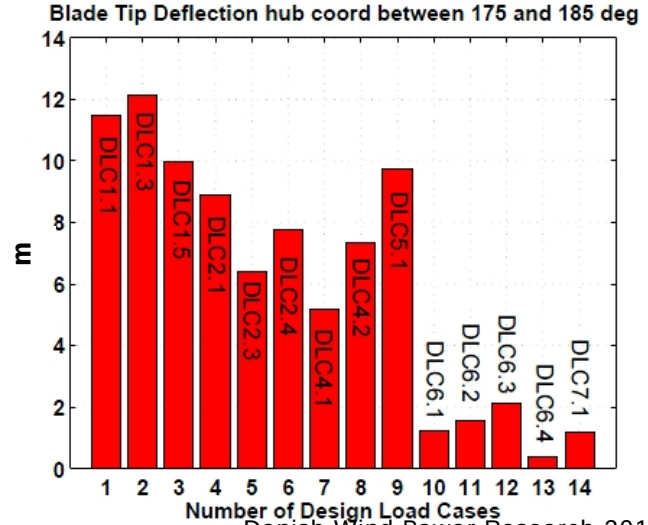
- Most of design load cases are considered except DLC8, which is for transport, assemble, maintenance, and repair cases, and DLC 1.4, DLC 2.2, DLC 3.1, DLC 3.2, and DLC 3.3 which are very depending on controller.

The DTU 10 MW Reference Wind Turbine Load calculations: HAWC2









The DTU 10 MW Reference Wind Turbine Summary of design challenges

- Transition from laminar to turbulent flow in the boundary layer of the airfoils:
  - The result is uncertainty of the aerodynamic performance and thereby on loads and especially the power
- The efficiency of thick airfoils, i.e. airfoils with relative thickness greater than 30%, is significantly better when using Gurney flaps,
  - The result is an increase of the power of several percent
- To reduce the blade weight, the blade design needs to be ”stress/strain” driven rather than ”tip deflection” driven.
  - The result is a pre-bend design,
- The control of the rotor must take several instability issues into account, e.g. coinciding frequencies from the tower eigen frequency and 3P at low wind speeds,
  - The result is determination of the minimum rotational speed
- Blade vibrations in stand still
  - Vibrations at 90 degrees inflow direction can probably be avoided by pitching each blade differently
  - Vibrations at 30 degrees inflow direction can be reduced by ensuring “smooth” airfoil characteristics

The DTU 10 MW Reference Wind Turbine Availability

- The DTU 10 MW RWT has been released to the European InnWind project for review and will be used as the reference turbine in this project.
- Within days it will be available as a comprehensive release consisting of
  - Fully described 3D rotor geometry,
  - Basic tower and drive train,
  - 3D corrected airfoil data (based on engineering models),
  - 3D CFD surface/volume meshes,
  - Comprehensive description of structural design,
  - Controller,
  - Load basis calculations using HAWC2,
  - Report documenting the design.

- Go to: **dtu-10mw-rwt.vindenergi.dtu.dk**

The DTU 10 MW Reference Wind Turbine Acknowledgements

- Thanks to:
  - EUDP for partly financing the EUDP 2010 I Light Rotor
  - The EU project InnWind for reviewing the wind turbine
  - A lot of people that has been a part of the discussions.

Thank you for the attention!