Technische Universität München
Wind Energy Institute

IEA Wind Task 37 on Systems Engineering in Wind Energy

WP2 – Reference Wind Turbines

Pietro Bortolotti, Carlo L. Bottasso
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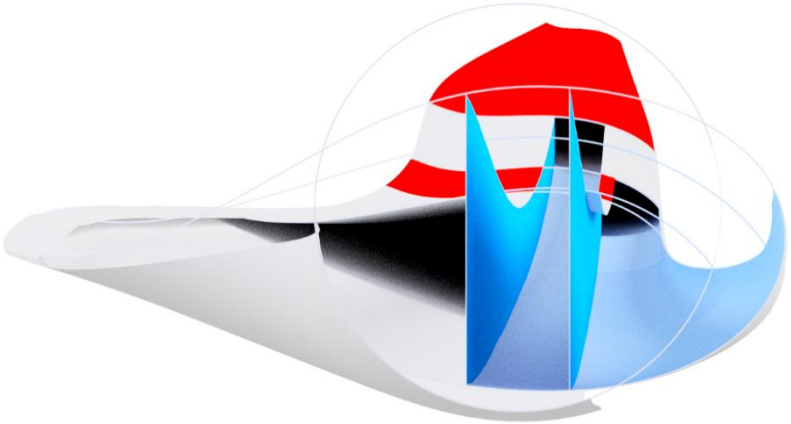
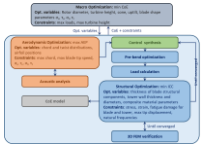


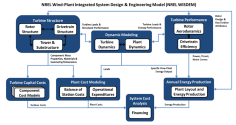
4th Wind Energy Systems Engineering Workshop
DTU Risø Campus, Roskilde
14th September 2017

Agenda

Motivation
IEA Wind Task 37, WP 2

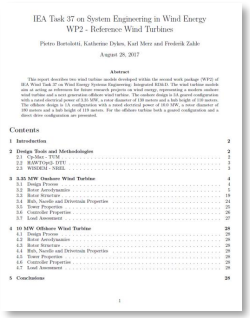


Overview of tools
Cp-Max, HAWTOpt2, WISDEM



3.35 MW onshore wind turbine
Assumptions, final design

10 MW offshore wind turbine
Initial configuration, final design


IEA Task 37 on System Engineering in Wind Energy
WP2 - Reference Wind Turbines

Pietro Bortolotti, Katherine Dykes, Karl Merz and Frederik Zahle

August 28, 2017

Abstract

This report describes two wind turbine models developed within the second work package (WP2) of IEA Wind Task 37 on Wind Energy System Engineering. Integrated RNA/S. The wind turbine models are the 3.35 MW onshore reference wind turbine and a 10 MW offshore reference wind turbine and a next generation offshore wind turbine. The onshore design is 3.6 geared configuration with a rated electrical power of 3.35 MW, a rotor diameter of 130 meters and a hub height of 110 meters. The offshore turbine is a 10 MW direct drive with a rated electrical power of 10.0 MW, a rotor diameter of 190 meters and a hub height of 119 meters. For the offshore turbine both a geared configuration and a direct drive configuration are presented.

Contents

Conclusions and outlook

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Motivation

International Energy Agency (IEA) Wind Agreement:
Founded in 1977, it sponsors the cooperation in the research, development, and deployment of wind energy systems

iea wind

Task 37:
Wind Energy Systems Engineering: Integrated research, design and development (RD&D)
Work Packages

- WP2: Reference wind energy systems (both turbines and plants)
  - **3.X MW onshore wind turbine**
  - **10.0 MW offshore wind turbine**

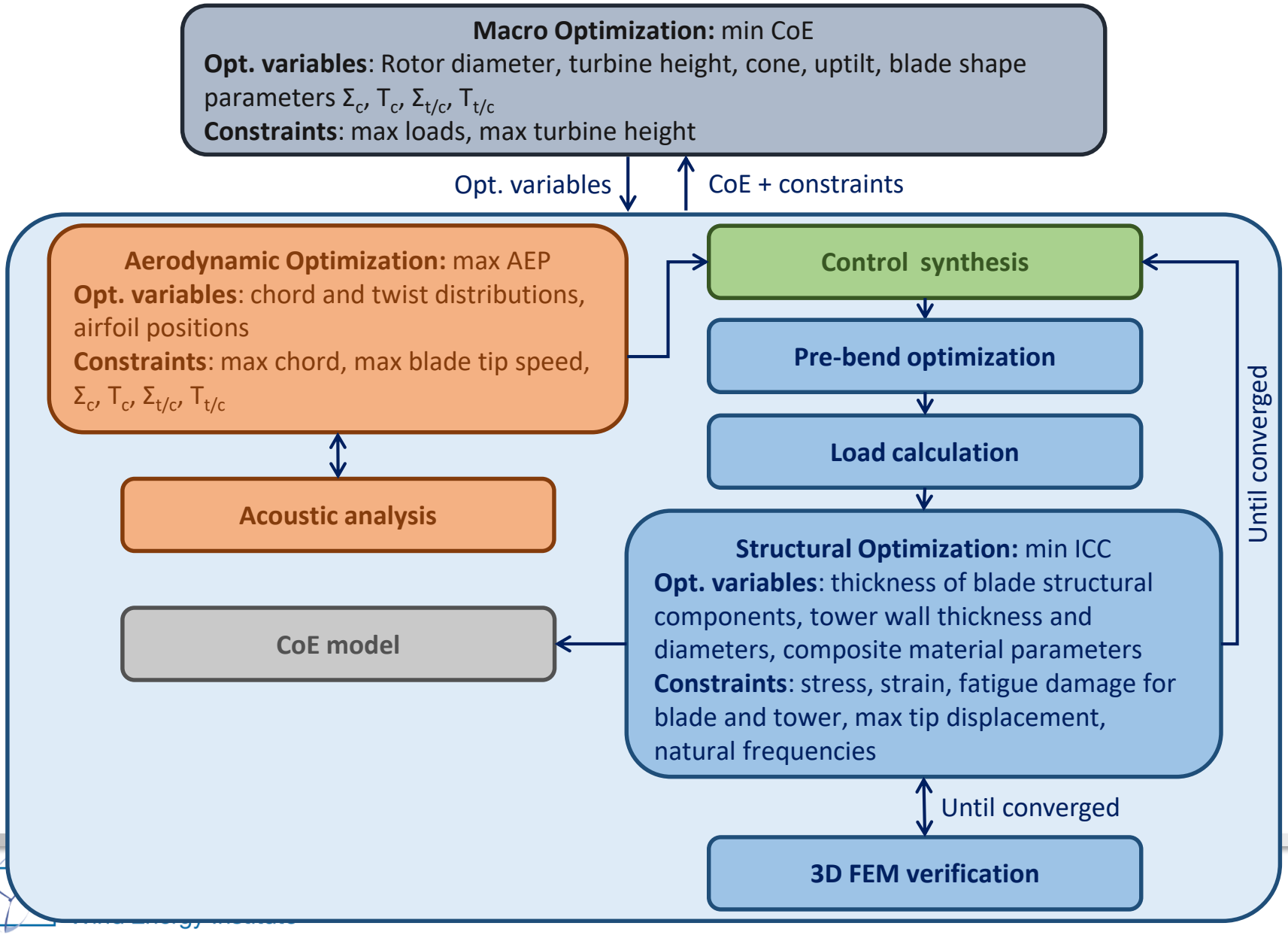
Link: http://www.ieawind.org/

Contacts: K. Dykes (NREL), P. E. Rethore and F. Zahle (DTU Wind Energy), K. Merz (SINTEF)

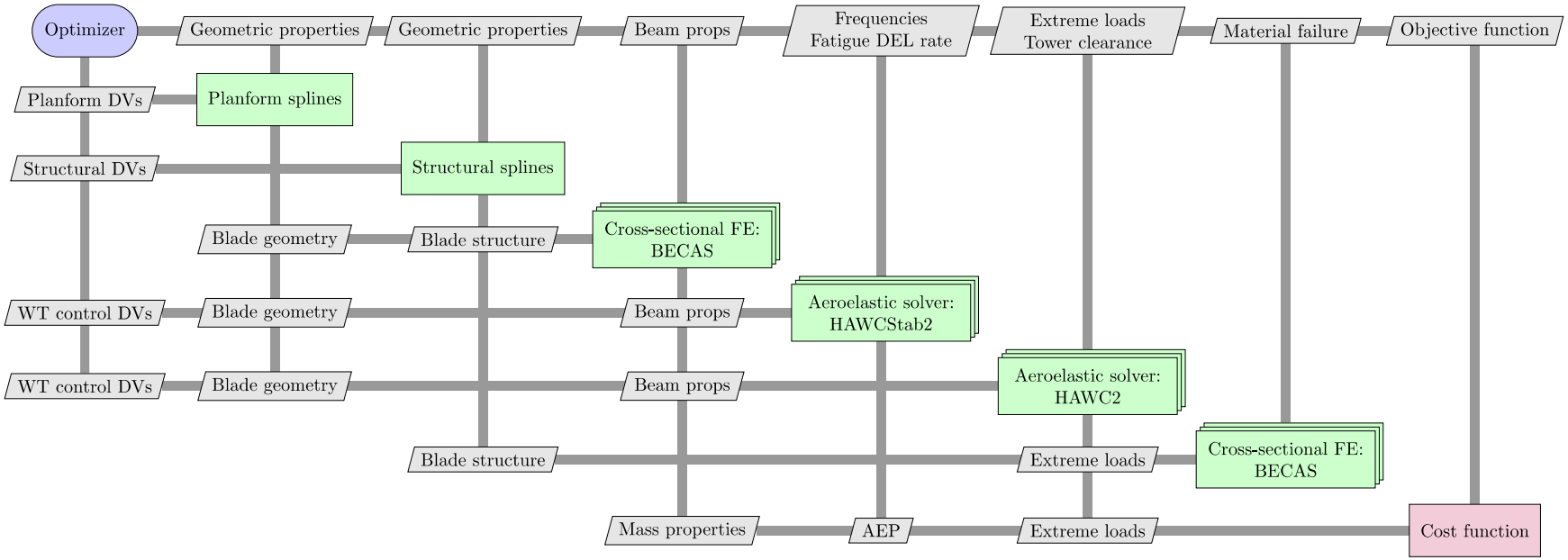
DTU SINTEF TU Delft CENER NREL NATIONAL RENEWABLE ENERGY LABORATORY Universität Stuttgart

Overview of tools

Cp-Max Framework

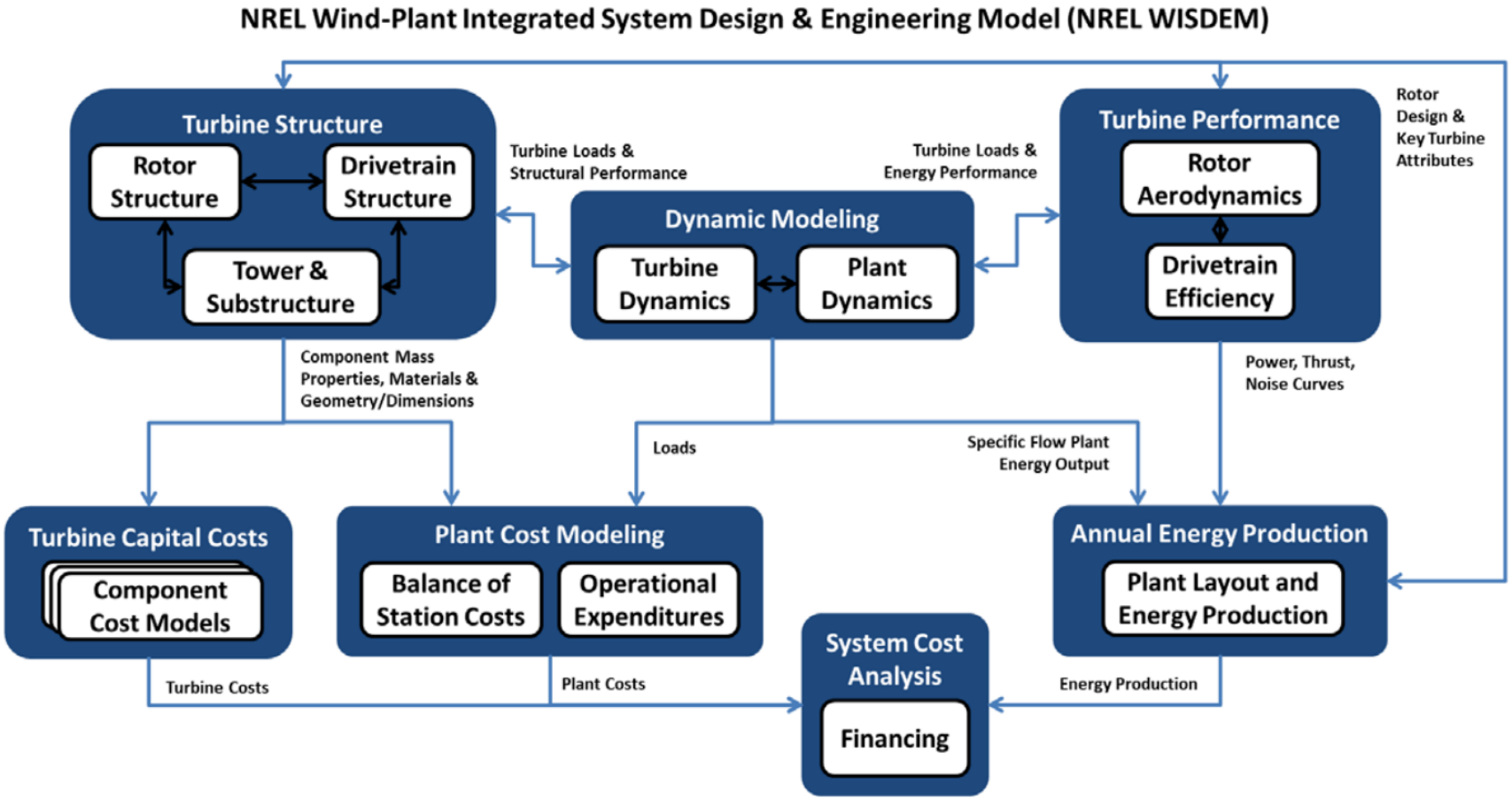


HAWTOpt2



Source: *Zahle F, Tibaldi C, Pavese C, McWilliam M, Blasques J, Hansen M. Design of an Aeroelastically Tailored 10 MW Wind Turbine Rotor. Journal of Physics: Conference Series. 2016;753. doi: 10.1088/1742-6596/753/6/062008.*

WISDEM



Source: *https://nwtc.nrel.gov/system/files/SE%20Webinar%202014-10-08.pdf*

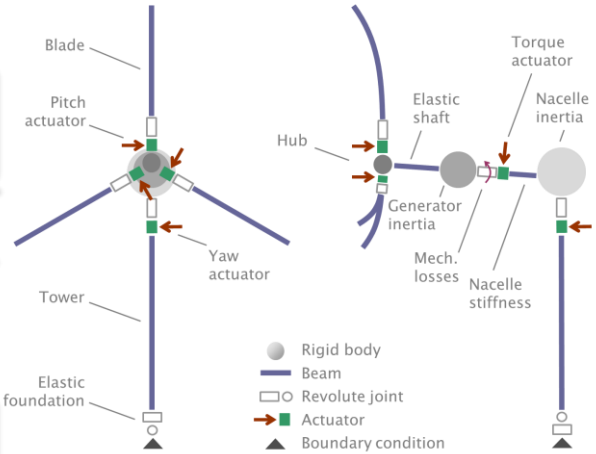
Design Reference Configurations

Onshore 3.35 MW – Assumptions I

Set of values assumed by the partners through an industrial survey

Data	Value
Wind Class	3A
Rated Electrical Power [MW]	3.35
Rated Aerodynamic Power [MW]	3.60
DT & Generator Efficiency	93 %
Rotor Diameter [m]	130.00
Hub Height [m]	110.00
Maximum Tip Speed [m/s]	80.0
Drive train configuration	eep
Generator	DFIG

Traditional WT configuration



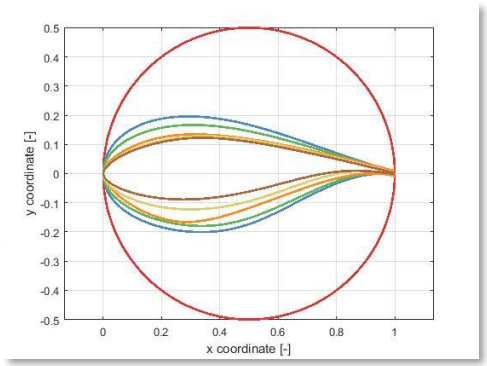
DT, generator and nacelle: data initially scaled from industrial 2 MW WT, now redesigned with DriveSE from NREL

	Mass		Inertia		
Component	2 MW	3.35 MW		2 MW	3.35 MW
Hub	27000 kg	55000 kg	About shaft axis	19100 kg·m²	60131 kg·m²
				86000 kg·m²	300650 kg·m²
Nacelle	21750 kg	46500 kg	About yaw axis	355000 kg·m²	1210200 kg·m²
Generator	50000 kg	80600 kg	About shaft axis	40180 kg·m²	100110 kg·m²
				24720 kg·m²	61584 kg·m²

Assumed | Scaled from 2.0 MW design | Optimized by Cp-Max for min CoE

Onshore 3.35 MW – Assumptions II

DU airfoil family



Airfoil	Thickness
Circle	100 %
DU00-W2-401	40.1 %
DU00-W2-350	35.0 %
DU97-W-300	30.0 %
DU91-W2-250	25.0 %
DU08-W-210	21.0 %
DU08-W-180	18.0 %

Blade structural topology from the 2.0 MW design, composites from the INNWIND 10 MW blade

Blade Components	From (% span)	To (% span)	Material Type	E_{11} [MPa]	E_{22} [MPa]	G [MPa]
External shell	0	100	Triax glass	21790	14670	9413
Spar caps	10	96	UD glass	41630	14930	5047
Shear webs	10	96	Biax glass	13920	13920	11500
TE and LE reinf.	10	80	UD glass	41630	14930	5047
Sandwich core	5	96	Balsa	50	50	150

Steel tower

Tower	Young's modulus [MPa]	Density [kg/m³]	Yield strength [MPa]
Pile of steel truncated cones	210	8500	355

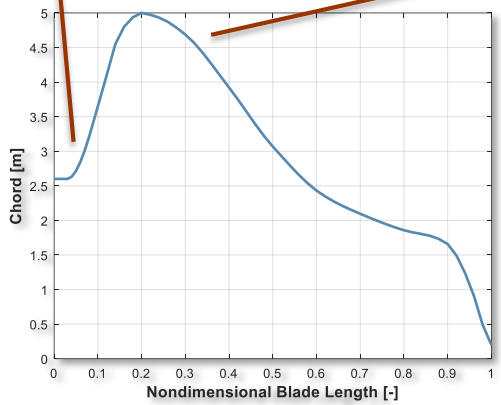
Assumed Scaled from 2.0 MW design Optimized by Cp-Max for min CoE

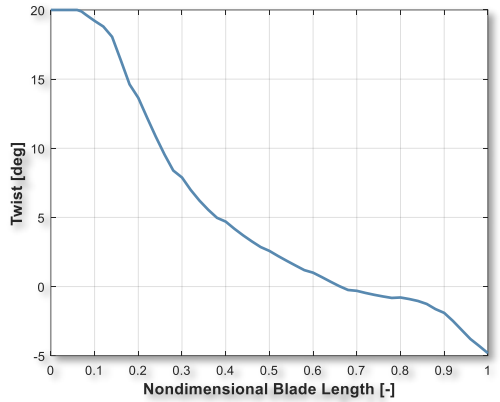
Onshore 3.35 MW – Design I

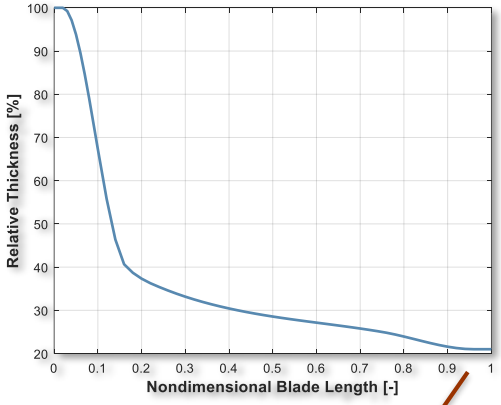
Data	Value
Wind Class	3A
Rated Electrical Power [MW]	3.35
Rated Aerodynamic Power [MW]	3.60
DT & Generator Efficiency	93 %
Rotor Diameter [m]	130.00
Hub Height [m]	110.00
Maximum Tip Speed [m/s]	80.0
Drivetrain	4 stages eep
Generator	DFIG
Rotor Overhang [m]	5.00
Length Blade Root Flange [m]	2.00
Hub Mass [ton]	55.0
Nacelle Mass [ton]	46.5
Generator Mass [ton]	80.6
Rotor Cone Angle [deg]	3.00
Nacelle Uptilt Angle [deg]	5.00
Blade Mass [kg]	16039
Tower Mass [ton]	513
Blade Cost [k$]	121.6
Tower Cost [k$]	769.6
Aerod. AEP static [GWh]	14.96
Electrical AEP static [GWh]	13.91
Aerod. AEP turbulent [GWh]	13.98
Electrical AEP turbulent [GWh]	13.00
NREL CoE [$/MWh]	43.76

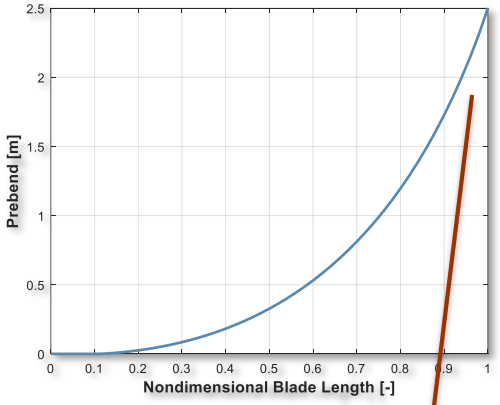
Blade root D = 2.6 m

Max chord = 5.0 m









Min thickness 21%

Max prebend = 2.5 m

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Assumed

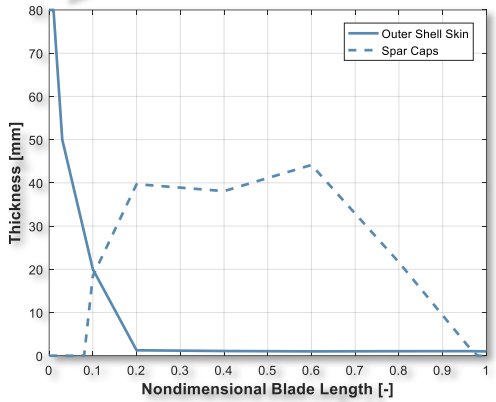
Scaled from 2.0 MW design

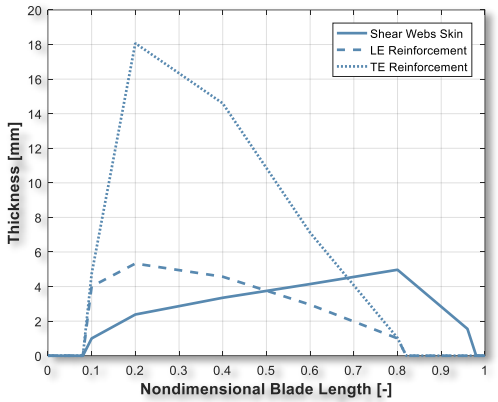
Optimized by Cp-Max for min CoE

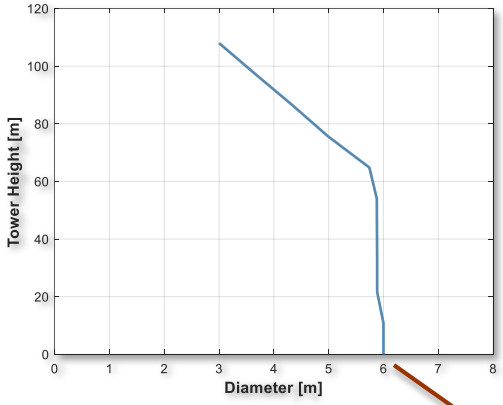
Onshore 3.35 MW – Design II

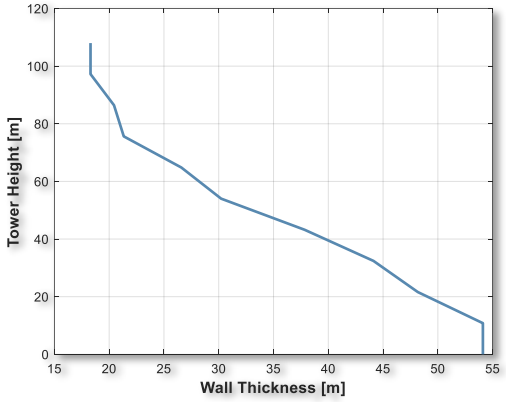
Data	Value
Wind Class	3A
Rated Electrical Power [MW]	3.35
Rated Aerodynamic Power [MW]	3.60
DT & Generator Efficiency	93 %
Rotor Diameter [m]	130.00
Hub Height [m]	110.00
Maximum Tip Speed [m/s]	80.0
Drivetrain	4 stages eep
Generator	DFIG
Rotor Overhang [m]	5.00
Length Blade Root Flange [m]	2.00
Hub Mass [ton]	55.0
Nacelle Mass [ton]	46.5
Generator Mass [ton]	80.6
Rotor Cone Angle [deg]	3.00
Nacelle Uptilt Angle [deg]	5.00
Blade Mass [kg]	16039
Tower Mass [ton]	513
Blade Cost [k$]	121.6
Tower Cost [k$]	769.6
Aerod. AEP static [GWh]	14.96
Electrical AEP static [GWh]	13.91
Aerod. AEP turbulent [GWh]	13.98
Electrical AEP turbulent [GWh]	13.00
NREL CoE [$/MWh]	43.76

Blade root t = 80 mm









Max tower D = 6.0 m

IEA Task 37 – Reference Wind Turbines

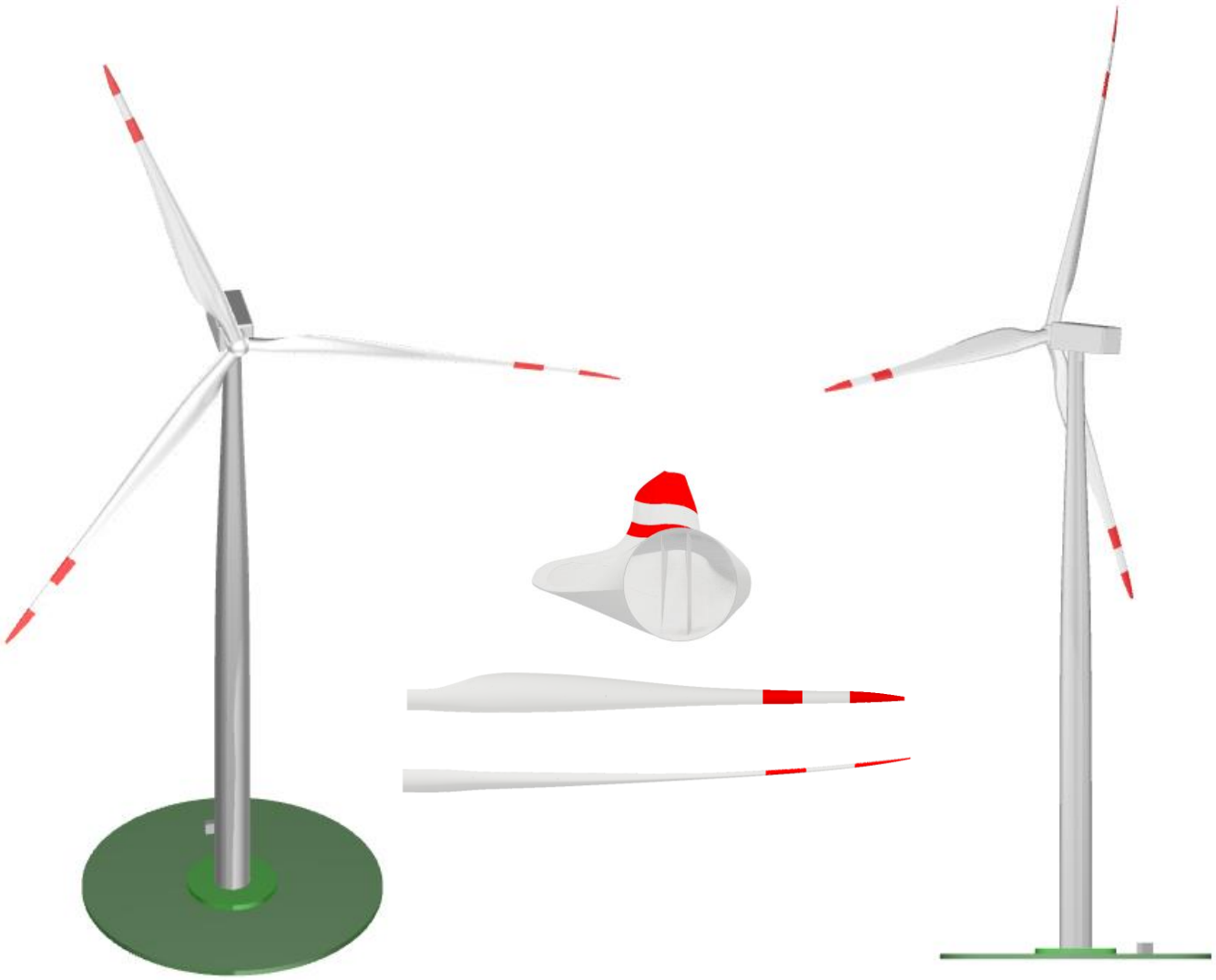
Wind Energy Institute

Assumed

Scaled from 2.0 MW design

Optimized by Cp-Max for min CoE

Onshore 3.35 MW – 3D CAD



Offshore 10 MW – Assumptions I

The **IEA Task 37 offshore 10 MW RWT** is a design based on the **DTU 10MW RWT** released in 2013

Data	Value
Wind Class	1A
Rated Electrical Power [MW]	10.00
Drivetrain	Direct drive
Substructure	Monopile
Specific rotor power [W/m²]	Approx 320
Maximum Tip Speed [m/s]	90.0

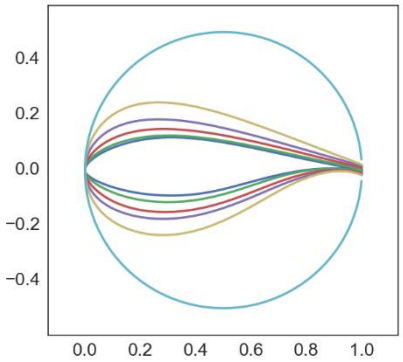
Set of values assumed by the partners through an industrial survey

The new design will feature:

- ✓ A complete aerostructural redesign of the rotor based on a GFRP layup
- • Redesigned direct drive configuration
- • Tower and foundation (monopole) design from SINTEF for a 30 m water depth

Offshore 10 MW – Assumptions II

FFA airfoil family



Airfoil	Thickness
Circle	100 %
FFA-W3-360	36.0 %
FFA-W3-301	30.1 %
FFA-W3-241	24.1 %
FFA-W3-211	21.1 %

Blade structural topology similar to the DTU 10MW RWT, composites from the DTU 10MW RWT blade

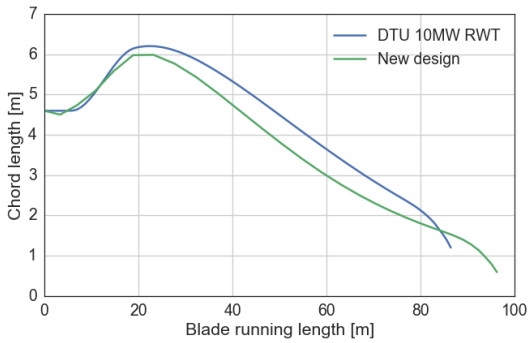
Blade Components	From (% span)	To (% span)	Material Type	E_{11} [MPa]	E_{22} [MPa]	G [MPa]
External shell	0	100	Triax glass	21790	14670	9413
Spar caps	5	98	UD glass	41630	14930	5047
Shear webs	5	98	Biax glass	13920	13920	11500
TE and LE reinf.	5	98	UD glass	41630	14930	5047
Sandwich core	5	98	Balsa	50	50	150

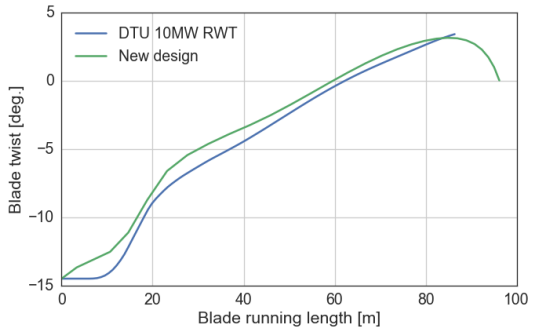
Steel tower

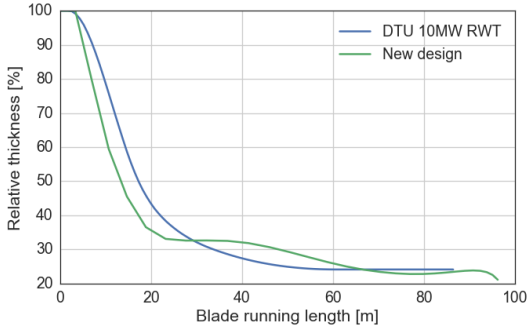
Tower	Young's modulus [MPa]	Density [kg/m³]	Yield strength [MPa]
Pile of steel truncated cones	210	8500	355

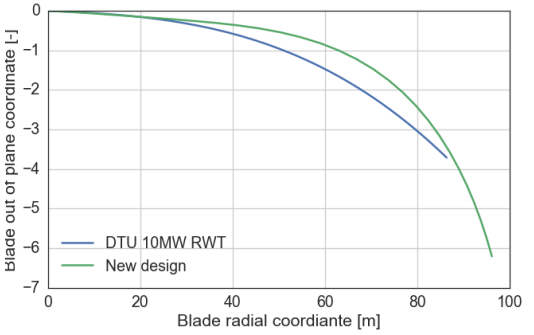
Offshore 10 MW – III

Data	Value
Wind Class	1A
Rated Electrical Power [MW]	10.00
Rated Aerodynamic Power [MW]	10.64
DT & Generator Efficiency	96 %
Hub Height [m]	119.00
Maximum Tip Speed [m/s]	90.0
Rotor Overhang [m]	7.10
Length Blade Root Flange [m]	2.80
Hub Mass [ton]	105.5
Nacelle Mass [ton]	446.0
Tower Mass [ton]	365
Rotor Cone Angle [deg]	4.00
Nacelle Uptilt Angle [deg]	6.00
Tip speed ratio	10.5
Rotor Diameter [m]	198.00
Blade prebend	6.2
Blade Mass [ton]	47.7
Aerod. AEP static [GWh]	51.4
Electrical AEP static [GWh]	48.3
Aerod. AEP turbulent [GWh]	-
Electrical AEP turbulent [GWh]	-









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Assumed Adapted from DTU 10.0 MW design Optimized by HAWTOpt2

DTU

Offshore 10 MW – IV

Data	Value
Wind Class	1A
Rated Electrical Power [MW]	10.00
Rated Aerodynamic Power [MW]	10.64
DT & Generator Efficiency	96 %
Hub Height [m]	119.00
Maximum Tip Speed [m/s]	90.0
Rotor Overhang [m]	7.10
Length Blade Root Flange [m]	2.80
Hub Mass [ton]	105.5
Nacelle Mass [ton]	446.0
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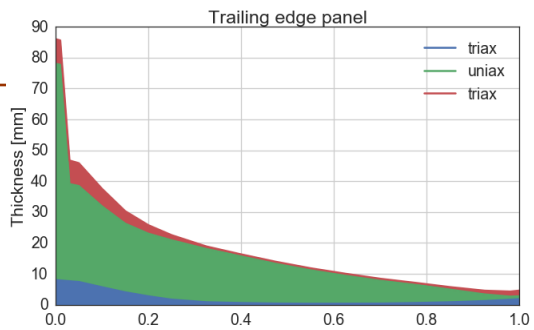
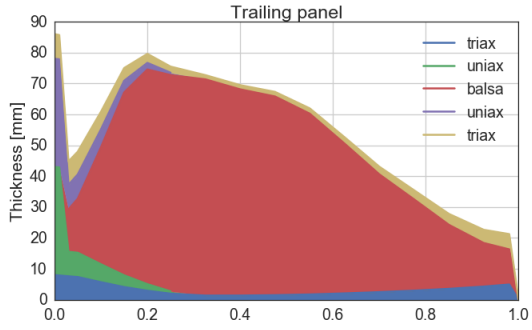
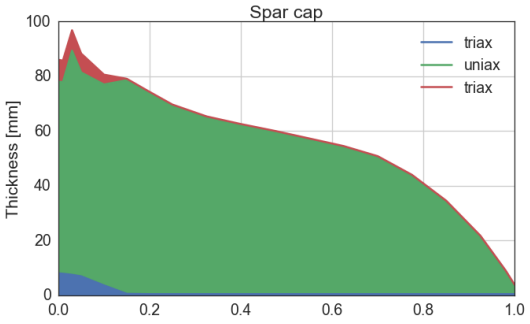
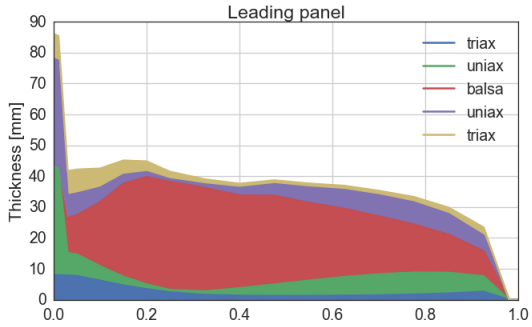
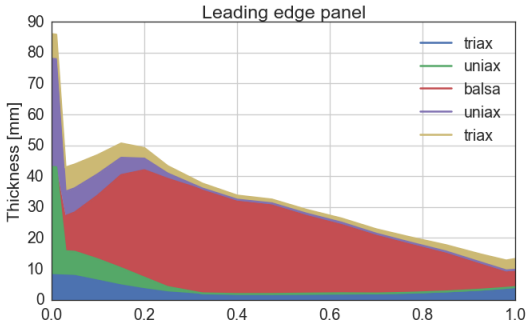
Aerod. AEP static [GWh]	51.4
Electrical AEP static [GWh]	48.3
Aerod. AEP turbulent [GWh]	-
Electrical AEP turbulent [GWh]	-











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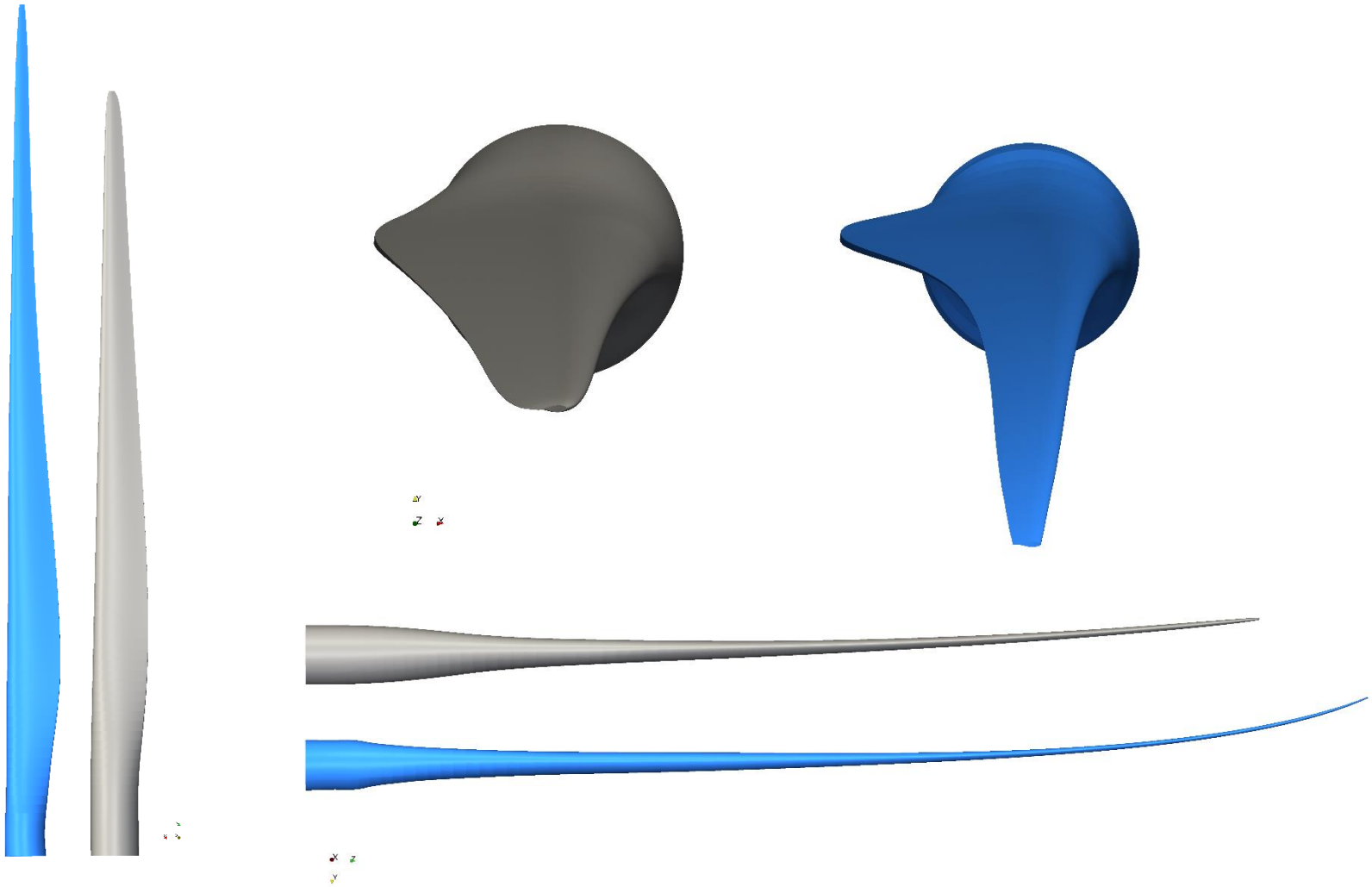
Assumed Adapted from DTU 10.0 MW design Optimized by HAWTOpt2

DTU

Offshore 10 MW – III



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DTU 10MW RWT

IEA Task 37 offshore 10 MW RWT

DTU

Conclusions

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Two reference wind turbine models are being finalized within IEA Task 37:

- 3.35 MW onshore wind turbine
- 10 MW offshore wind turbine
- Inputs are welcome both from academia and industry
- Final report with full designs soon released

SINTEF

DTU

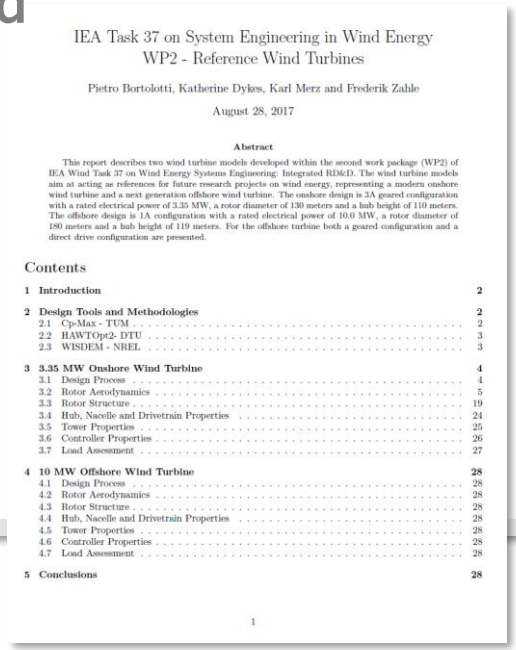
TUM

TU Delft

CENER

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Universität Stuttgart



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WP2 - Reference Wind Turbines

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August 28, 2017

Abstract

This report describes two wind turbine models developed within the second work package (WP2) of IEA Wind Task 37 on Wind Energy Systems Engineering: Integrated RD&D. The wind turbine models aim at acting as references for future research projects on wind energy, representing a modern onshore wind turbine and a next generation offshore wind turbine. The onshore design is 3A geared configuration with a rated electrical power of 3.35 MW, a rotor diameter of 130 meters and a hub height of 110 meters. The offshore design is 1A configuration with a rated electrical power of 10.0 MW, a rotor diameter of 180 meters and a hub height of 119 meters. For the offshore turbine both a geared configuration and a direct drive configuration are presented.

Contents

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References

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Thank you!