

#### F&U som støtte for innovation og konkurrencedygtighed

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# F&U som støtte for innovation og konkurrencedygtighed

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Offshoreenergy.dk's årsmøde 23. og 24. oktober 2014 i Odense



**DTU Vindenergi** Institut for Vindenergi

#### **DTU's Mission**

DTU skal udvikle og nyttiggøre naturvidenskab og teknisk videnskab til gavn for samfundet.





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8 DTU Wind Energy, Technical University of Denmark

23 October 2014



![](_page_10_Picture_0.jpeg)

## **FP7 project** – Design Tool for Offshore Wind Farm Clusters

![](_page_10_Picture_2.jpeg)

Progress is to achieve a robust design tool for planning of offshore wind farms. The progress include benchmark analysis of several wake models using production data, investigation on some uncertainties on annual energy production and study of inter- and intra-array grid possibilities for the offshore.

![](_page_10_Picture_4.jpeg)

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### **EERA DTOC concept**

![](_page_11_Figure_2.jpeg)

#### Main Components

- Use and bring together existing models from the partners
- Develop open interfaces between them
- Implement a shell to integrate
- Fine-tune the wake models using dedicated measurements
- Validate final tool

# Fuga – wake model for large offshore windfarms

- Solves linearized RANS equations
- Latest version incorporates: atmospheric stability, meandering, effects of nonstationarity and spatial de-correlation of the flow field.
- No computational grid, no numerical diffusion, no spurious pressure gradients
- Integration with WAsP: import of wind climate and turbine data.
- Fast, mixed-spectral solver:
  - 10<sup>6</sup> times faster than conventional RANS!
  - $-10^8$  to  $10^{10}$  times faster than LES!

![](_page_12_Figure_8.jpeg)

![](_page_12_Figure_9.jpeg)

Hornsrev validation

\* Søren Ott, Jacob Berg and Morten Nielsen: 'Linearised CFD Models for Wakes', Risoe-R-1772(EN), 2011

![](_page_12_Picture_12.jpeg)

## **EERA DTOC portfolio of models**

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Name	Partner	Status	Programs	Input/ output	Script/ GUI	Database interface	IPR	Com
CFDWake	CENER		Fluent, C++, OpenFOAM	ASCII	script	Yes		
CorWind	Risoe DTU	Ope	DOS exe Delphi	CSV files	no	no	+	+
CRES-farm	CRES	Ope	Linux/ Fortran77	ASCII	no	no	+	
CRESflowNS	CRES	Ope	Linux/ Fortran77	ASCII	no	no		
DWM	Risoe DTU	Ope	Fortran, pc, pc- cluster	ASCII	script		+	
ECNS	ECN	Beta	Linux/ Fortran90	ASCII	No	No	+	
EeFarm	ECN	Alpha	Matlab	Matlab scripts	Script/ GUI	yes	+	+
Farm-farm interaction	ECN	Ope	Fortran	ASCII	No	no	+	
FarmFlow	ECN	Оре	Delphi	ASCII/ binary	GUI	Yes	+	+
FlowARSM	CRES	Alpha	Linux/ Fortran77	ASCII	no	no		
FUGA	Risoe DTU	Ope	Fortran, C, Delphi, pc	ASCII	Script/ GUI	No	+	
NET-OP	SINTEF	Proto type	Matlab	ASCII	script	No	+	
Skiron/WAM	CENER	Ope	Unix/ Fortran	GRIB	script	yes		
TOPFARM	Risoe DTU	Beta	Matlab/C/ Fortran	ASCII	script		+	
UAEP	Risoe DTU		Matlab, pc	ASCII/ binary	no	yes		
VENTOS	UPorto	Beta	Unix/ Fortran	ASCII	no	yes	+	+
WAsP	Risoe DTU	Ope	Windows pc	ASCII	Script/ GUI	No	+	+
WCMS	Fraunhofer	Ope	Matlab/JAVA	OracleDB		yes	+	
WRF	Risoe DTU	Ope	Unix, Linux, Fortran90	netCDF	Shell script	yes		
WRF/ROMS	CIEMAT	Ope	Linux/ Fortran	netCDF	script	yes	+	

### TOPFARM

![](_page_14_Picture_1.jpeg)

TOPFARM is a fundamentally new approach to layout optimization of wind farms. From the investor's perspective the TOPFARM platform answers the fundamental question:

"What kind of layout results in the optimal economical performance of the wind farm throughout its lifetime".

The balance between power, loads and costs

![](_page_14_Figure_5.jpeg)

Middelgrunden layout as of now and as results of the TOPFARM optimization. Measurement of deficit in atm. boundary layer wind tunnel

![](_page_14_Figure_8.jpeg)

Wake meandering assumption in DWM

![](_page_15_Picture_0.jpeg)

# Wind-wave loads and response for offshore wind turbines

![](_page_15_Picture_2.jpeg)

Load models for highly nonlinear waves

Linea Wind turbine Aero-elastic response to waves and wind Dynamics of floating wind turbines CFD for detailed loads

## Offshore wind turbine control system

![](_page_16_Picture_1.jpeg)

#### Power production

Generator torque controlCollective pitch control

![](_page_16_Figure_4.jpeg)

![](_page_16_Figure_5.jpeg)

#### Extreme and fatigue load reduction

- o Drive train damper (T<sub>G</sub>)
- Exclusion zone  $(T_G)$
- Tower for-aft mode damper (CPC)
- o Thrust peak shaver (CPC)

![](_page_16_Picture_11.jpeg)

## **Collective pitch control**

![](_page_17_Picture_1.jpeg)

#### • Thrust peak shaving

![](_page_17_Figure_3.jpeg)

### JacketOpt

#### **Topologies**

- Classical four legged jackets
- Classical three legged jackets
- Pod-like structures (three or four legs)

20

10

0

-10

-20

-30

-40

10

- Full-lattice towers (three or four legs)
- Monopiles
- User defined structures

![](_page_18_Figure_8.jpeg)

#### JacketOpt

#### Design variables (outer)

- Overall dimensions within bounds
- Placement of X-braces within bounds

#### Design variables (inner)

- Member diameters within bounds
- Member thickness within bounds

![](_page_19_Figure_8.jpeg)

## JacketOpt GUI

![](_page_20_Picture_1.jpeg)

Optimization Module (Static Loads)			
uter problem definition	Inner problem definition	ī ( <b></b>	
General data	Objective function: Minimize mass	V Figure 1	
Jacket height [m]: 76.00	Constraints	File Edit View Insert Tools Desktop Window Help	<u>۲</u>
Mud brace height [m]: 1.50	Local von Mises constraints (static)		
Water depth [m]: 50.00	Yield strength [MPa]: 355.00		
Number of legs: 3	Material factor: 1.15		
Number of brace levels: 4	Frequency constraint(s)		
Vax finite element size [m]: 1.00	0.27 <= First [Hz] <= 0.31	20	
ower inner radius [m]: 3.800	0.27 <= Second [Hz] <= 0.31		
/ariable linking: Symmetry+legs+braces 🔻	1.00 <= Third [Hz] <= 1.10	10-1	
Structure type: Classical jacket 🔹	1.00 <= Fourth [Hz] <= 10.00		
/ariables	Mass constraint		
8.00 <= Half base width [m] <= 20.00	Mass [tonnes] <= 1000	-10	
8.00 <= Half top width [m] <= 16.00	Max top displ. [m]<= 2.00		
5.00 <= Transition height [m] <= 10.00	30.00 <= D/t ratio <= 120.00	-20	
	Design variables for legs	-30.	
	0.25 <= Inner radius [m] <= 1.50		
	0.02 <= Thickness [m] <= 0.12	-40	
	Design variables for braces etc		
	0.10 <= Inner radius [m] <= 1.00	-50 -51 -51 -51 -51 -51 -51 -51 -51 -51 -51	
	0.01 <= Thickness [m] <= 0.05		
	Design variables for transition jacket	-10 -10 5 10	
	0.25 <= Inner radius [m] <= 1.50		
	0.01 <= Inickness [m] <= 0.12		
lver options (outer problem)	Solver options (inner problem)	Files	
iolver: GPS 🔻	Solver:	Mass file: JacketData\InnWindtowerOffshoreRambolitt.mass	
Optimality tolerance: 1.0e-03	Optimality tolerance: 1.0e-03	Loads file: JacketData\InnWindtowerOffshoreRambolitt.loads	Ontinica
easibility tolerance: 1.0e-06	Feasibility tolerance: 1.0e-05	BC file: JacketData\InnWindtowerOffshoreRambolitt.bc	Opumize
fax. iterations: 500	Max. iterations: 500	Tower geometry file: JacketData\InnWindtowerOffshoreRambolitt.geo	
Tax. function evals.: 500	Max. function evals.: 500	Tower sections file: JacketData\InnWindtowerOffshoreRambolitt.sec	Export results
ime limit [h]: 24	Verbosity One line 💌	Tower dimensions file: JacketData\InnWindtowerOffshoreRambolitt.dim	
/erbosity One line 💌		Results files: JacketData\jacket_opt	

![](_page_21_Picture_0.jpeg)

#### A preliminary example for INNWIND.EU

- DTU 10 MW reference turbine
  - Hub height 119 m
  - Rotor mass 229 tons
  - Nacelle mass 446 tons
  - Tower mass 505 tons

#### Four legs and four levels of X-braces

Minimum mass design Max tower top displacement 2.25 m First and second frequency between 1P and 3P Third and fourth frequency above 6P

Static loads only! No fatigue constraints!

![](_page_21_Figure_10.jpeg)

10

-10

Best found design. Mass: 1.09151 [ktonnes].

10

0

-10

![](_page_22_Picture_0.jpeg)

#### A preliminary example for INNWIND.EU

- DTU 10 MW reference turbine
  - Hub height 119 m
  - Rotor mass 229 tons
  - Nacelle mass 446 tons
  - Tower mass 505 tons

#### Four legs and three levels of X-braces

Minimum mass design Max tower top displacement 2.25 m First and second frequency between 1P and 3P Third and fourth frequency above 6P

Static loads only! No fatigue constraints! Best found design. Mass: 1.0419 [ktonnes].

![](_page_22_Figure_11.jpeg)

#### Validering og Test

![](_page_23_Picture_2.jpeg)

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#### Østerild Test Centre – Prototype Wind Turbines

7 Wind Turbines – Max. 16 MW each – Max. height 250 m

**5** Envision

![](_page_25_Picture_0.jpeg)

#### Long range windscanner – Kassel campaign

![](_page_25_Picture_2.jpeg)

Metmast

- Measured for 6 weeks with 6 windscanners, full synchronisation over a 3G network
- Alignment accuracy of about 0.05° (1m over 1km)
- Excellent measurement results in scanning mode – within 1% accuracy at > 3km

![](_page_25_Figure_7.jpeg)

## Lidar ways of measuring the offshore resource

2. Windscanner(s) on the coast

![](_page_26_Figure_2.jpeg)

## Spørgsmål