# Comparison of different approaches for simulating wakes in offshore wind farms

*University of Perugia - Department of Engineering*,

WindSim User Meeting - June 23-6-2021

Francesco Castellani

# Outline

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# INTRODUCING MYSELF ...

| | |
|---|---|
| Current position: | Associate Professor in Machine Engineering at the University of Perugia |
| Teaching: | Applied Mechanics (BD and MSc in Mechanical and Industrial Engineering) |
| Functions: | Scientific Director of the Wind Tunnel Laboratory "R. Balli" |

## RESEARCH TOPICS

| | |
|---|---|
| **Wind Energy** | Wind turbine operation; Wakes; Small Wind turbine dynamics; Fault Diagnosis; Structure and Gearbox vibrational analysis |
| **Mechanical Systems** | Hydraulic damping systems; rotational and linear actuators; Car and Motorcycle Aerodynamics; Wind Tunnel test experiments. |

# BACKGROUND IN WIND ENERGY

1999 → Resource Assessment and Wind Mapping for private companies and administrations

2003 → **First italian user of the WindSim**

2008 → Dealing with wakes (beta tester of the AD model in WindSim)

2010 → Start to analyse real operation data

2012 → Start developing small wind turbines

2014 → Dealing with TCM (Turbine Condition Monitoring) data

2015 → Studying loads and controls in small wind turbines

2017 → Analysing vibrations and aeroelastic numerical modeling

2018 → Studying power upgrade and early fault diagnosis

2019 → Experimental study of individual pitching using Windtunnel test

2020 → Experimental and numerical study of pitch unbalance

# Use of WindSim at University of Perugia


windsim
When the terrain gets rough

Certificate of Attendance

This certifies that

**Francesco Castellani**

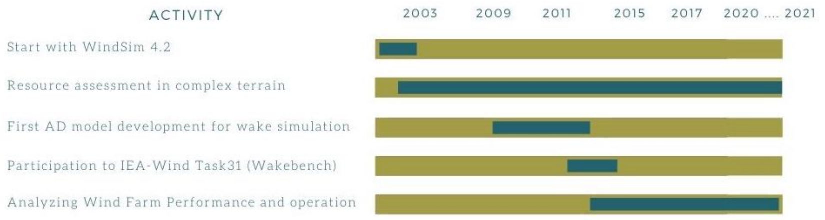
has attended the WindSim training course
in Rome 27-29 September 2004
covering the use of the modules:

| | |
|---|---|
| TERRAIN | Setting up the 3D terrain models. |
| WIND FIELDS | Establishing wind fields based on CFD, Computational Fluid Dynamics. |
| OBJECTS | Placement of turbines, processing climatology data. |
| RESULTS | Post-processing wind fields. |
| WIND RESOURCES | Generation of wind resource maps. |
| ENERGY | Calculation of the Annual Energy Production. |
| VISUALISATION | Full 3D interactive visualisation module, with flow field animations. |

Dr. Arne R. Gravdahl
VECTOR AS

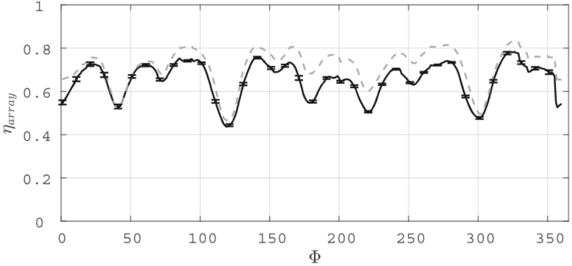
VECTOR AS • Industrigaten 9 3117 Tønsberg Norway • Phone: +47 33 38 18 00 • Fax: +47 33 38 18 08 • www.windsim.com

# Towards 20 years in using WindSim



# Wake simulation and Wind Farm performance

## The directional Farm "Efficiency"

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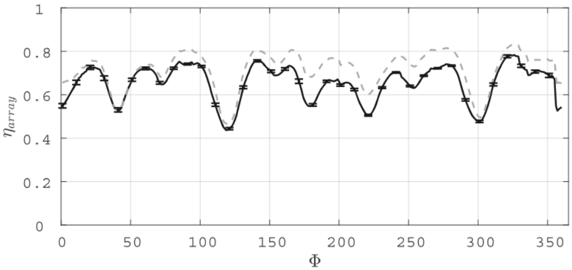


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⇒ Wake effect estimate is fundamental for efficiency

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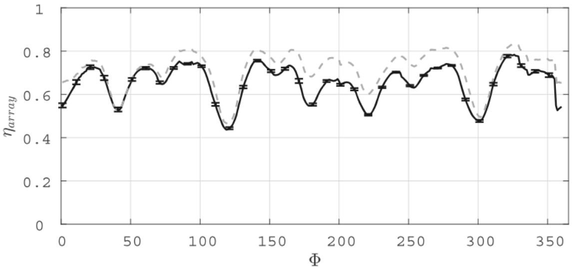


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⇒ Wake effect estimate is fundamental for efficiency

⇒ Terrain-Wake and Wake-Wake interactions can play an important role

# Wake modelling: different approaches.

Wake can be simulated with the "so called" **analytical (or engineering) models** (first of all the Jensen model) but they are not able to include the interactions of wakes with terrain or other wakes. Here we compare wake modelling with:

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- Engineering models
  - Jensen
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- Engineering models
  - Jensen
  - Ainslie
- Wake interaction models
  - WindSim Actuator disc (Version included up to WS9)
  - ORFEUS (spectral model)
  - OpenFoam Actuator disc
  - LES

# Published papers on this topic.

Wake Conference 2017 IOP Publishing
IOP Conf. Series: Journal of Physics: Conf. Series **854** (2017) 012042 doi:10.1088/1742-6596/854/1/012042

**Wind-farm simulation over moderately complex terrain**

**Antonio Segalini**[1] **and Francesco Castellani**[2]

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[2]Department of Engineering, University of Perugia, Perugia, Italy

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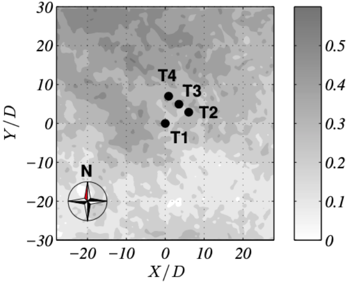
**RESEARCH ARTICLE** WILEY

**Data analysis and simulation of the Lillgrund wind farm**

**Alessandro Sebastiani**[1] | **Francesco Castellani**[2] | **Giorgio Crasto**[3] | **Antonio Segalini**[1]

# WindSim vs Orfeus comparison: first onshore testcase.

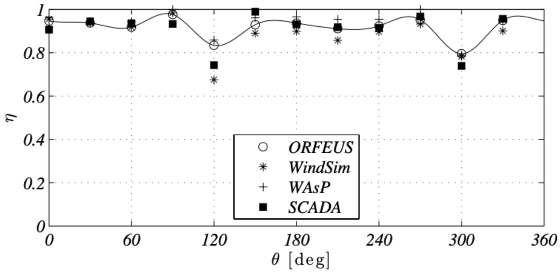


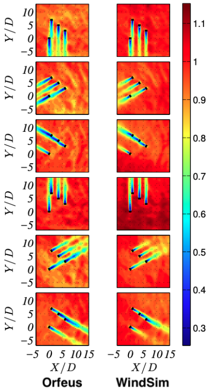

Defining the farm efficiency:

$$\eta(\theta) = \frac{1}{N_t P_{\max}} \sum_{i=1}^{N_t} P_i$$

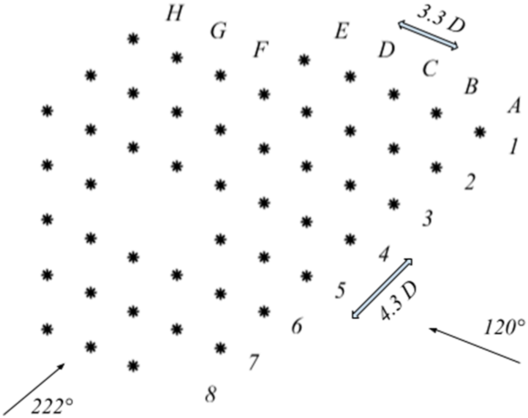

Francesco Castellani (francesco.castellani@unipg.it)

# WindSim vs Orfeus comparison: first onshore results.

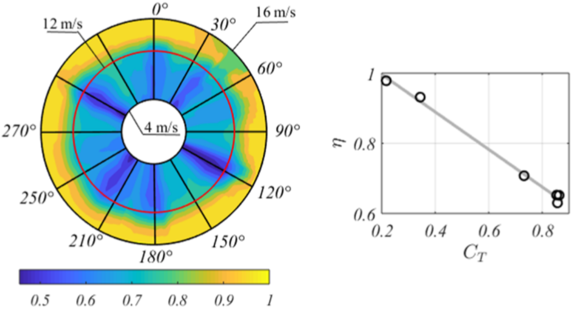


# The Lillgrund test-case

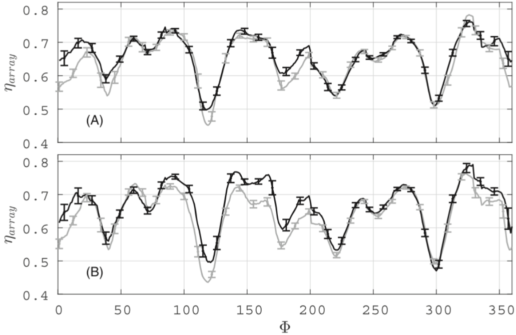


# The Lillgrund test-case:polar efficiency.




Contour plot (left) of $\eta_{\text{array}}$ for several $\Phi$ and $U_\infty$ between 4 and 16 $\mathrm{m/s}$. The rated speed value of 12 $\mathrm{m/s}$ is highlighted by the red circle. Linear relation (right) between efficiency and $C_T$ of the upwind turbines (grey line) based on SCADA data (black circles).

# The Lillgrund test-case: climatology effects.




(A) Diurnal and (B) seasonal variation of array efficiency as function of wind direction: grey lines = day/summer, black lines = night/winter.

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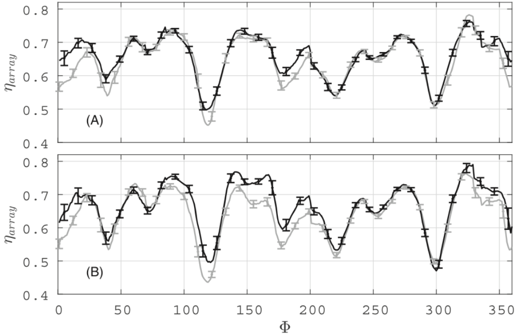
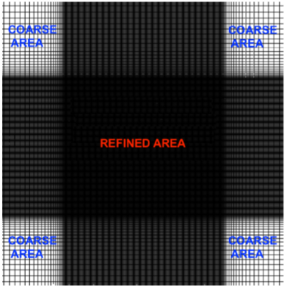



(A) Diurnal and (B) seasonal variation of array efficiency as function of wind direction:

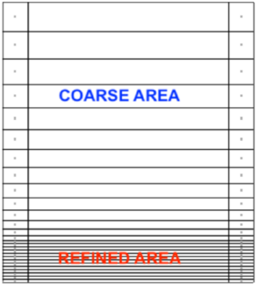
grey lines = day/summer, black lines = night/winter.

⇒ The stability cycle is **altered by water**.

# WindSim domain



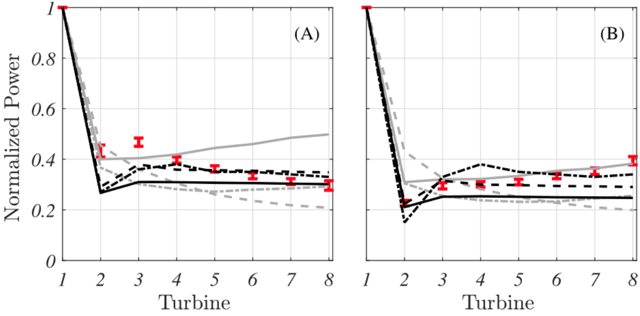
Horizontal distribution



Vertical distribution

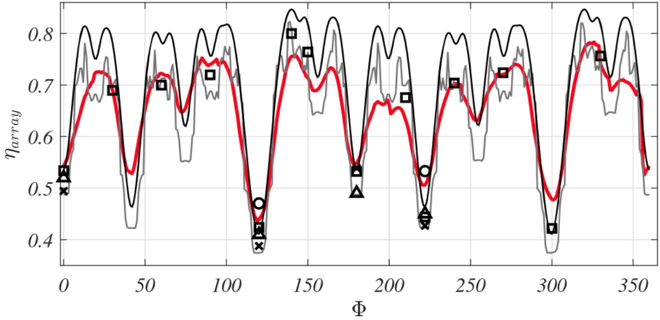
Distribution of the computational grid for the WindSim model: the spacing is approximately 120 m horizontally and 50 m vertically in the coarse region while in the refined area it is around 9 m in both directions. Different directions were simulated **rotating the layout** to adjust the cartesian grid.

# Results for the 222° direction sector.




LES (grey solid line), WindSim (grey dash-dotted line), OpenFOAM (black dash-dotted line), ORFEUS (grey dashed line), Jensen model (black solid line) and Ainslie model (black dashed line).

# Results for farm efficiency.




Array efficiency for 8m/s calculated with the Ainslie (black line) and Jensen (grey line) models, LES (black circles), WindSim (black crosses), OpenFOAM (black triangles) and ORFEUS (black squares) compared with array efficiency given by the SCADA between 6 and 12 m/s (red line).

# Estimating blockage effect.

$$\eta_b(\Phi) = \frac{\sum_{i=1}^{n(\Phi)} \left[U_{da_i}(\Phi)\right]^3}{\sum_{i=1}^{n(\Phi)} \left[U_{df_i}(\Phi)\right]^3}$$

where $n(\Phi)$ represents the number of turbines in the upstream row for the wind direction $\Phi$, while $U_{da_i}(\Phi)$ and $U_{df_i}(\Phi)$ are the velocities at the centre of the rotor for the ith upwind turbine in the cases with all the turbines and only the first row, respectively.

Power losses evaluated as $1 - \eta_b$ are:

| $\Phi$ | 0° | 120° | 180° | 222° |
|---|---|---|---|---|
| WindSim | 3.2% | 4.0% | 2.4% | 2.8% |
| OpenFOAM | 2.4% | 2.8% | 3.5% | 2.4% |
| ORFEUS | 2.5% | 3.3% | 1.6% | 2.2% |

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- WindSim, OpenFOAM and ORFEUS that estimated a blockage between 2% and 4% depending on the model and wind direction (i.e., changing with the frontal farm layout)

$\Rightarrow$ CFD-RANS with AD is a "strong" directional wake approach: ambient turbulence and wake meandering need to be included for offshore or flat terrain sites.

# Future work (wish-list)

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- Repeat calculations with the new AD model included in WS11


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- Repeat calculations with the new AD model included in WS11
- Run more and more direction sectors
- Exploring stability and turbulence effects
- Test the new AD in very complex terrains

# Thanks for your attention

.... see you next User Meeting