WIND RESOURCE ASSESSMENT BEST PRACTICES

Calibration of a New Actuator Disk CFD Wake Model
Picowind Validation Project (France)

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WHITE PAPER - PUBLIC REPORT

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Introduction

Accurate wake modeling is important to reduce project uncertainties before financial closure, especially when developing offshore wind farms. Wake modeling can also be used to optimize sector management during project operation. Due to hardware limitations and huge simulation durations, empirical wake models such as the ones included in traditional CFD (Computational Fluid Dynamics) software are based on linear equations. Simplifying the physics of turbine to turbine interactions can lead to high level of modeling errors for both waked wind speed and turbulence level estimates.

But now, cloud computing offers unlimited, scalable and elastic calculation power through ZephyCLOUD service and advantages of unstructured meshing techniques included in ZephyCFD software can be leveraged to define new approaches taking into consideration wake modeling within the CFD simulations.

The PICOWIND research project is funded by La Compagnie du Vent to deeply evaluate and improve the power production of a 22MW wind farm in operation and to benchmark traditional wake models and calibrate the new ZephyCFD wake model. La Picoterie wind farm (11 turbines Gamesa ; G90 2 MW ; 78m at hub height) is located in Charly-sur-Marne (France) and is instrumented with one nacelle-mounted LiDAR and three ground-based vertical profilers (two SoDAR units -Sound Detection and Ranging- and one LiDAR unit -Light Detection and Ranging). Remote sensors measurements of free stream wind speeds along with both upwind and downwind vertical wind profiles are collected in order to first calibrate a new CFD (Computational Fluid Dynamics) actuator disk wake model and then validate it against available measurements of the PicoWind project. The proposed wake model leverages the advantages of unstructured meshing techniques by running a first wind flow model to take into consideration the horizontal flow deviation at each turbine locations before generating an actuator disk mesh for the final simulation.

Site Description

La Picoterie operating wind farm data are used to benchmark traditional wake models and calibrate new wake models in the frame of the PICOWIND research project.

Figure 1: **La Picoterie Operating Wind Farm**

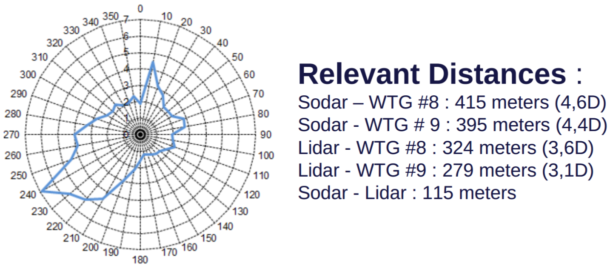

Figure 2: **Wind Rose during Study Period**

Benchmarking Empirical Wake Models

Objectives

- Comparing measured wake against simulated wake using two empirical wake models (PARK and Fast EVM) included in a traditional CFD software.

- For freestream wind directional sectors, calculate the alpha ratio at six different heights between waked wind speeds and freestream wind speeds measured by two sodars and simulated.

Methodology

Measured Wake :

- Measured wind data from East Sodar and West Sodar are considered;

- Data sets are filtered and only freestream wind data are kept from both Sodars for six different freestream wind directional sectors;

- Alpha ratio (downstream Sodar wind speed / upstream Sodar wind speed) is calculated for six different heights.

Simulated Wake :

- For six different freestream directional sectors, Freestream Sodar data at 80m height are used as reference wind data in the traditional CFD software;

- Two empirical wake models are considered : PARK and Fast EVM wake models;

- For six different freestream directional sectors, Waked wind speeds are calculated for six different heights;

- For six different freestream directional sectors, Alpha ratio is calculated for six different heights.

Results

The table below(in appendix as well) compares the simulated alpha ratio against the calculated ratio for six different freestream wind sectors, six different heights and two different empirical models of a traditional CFD software.
Alpha = downstream Sodar wind speed / upstream Sodar wind speed

Table 1: **Simulated Alpha Ratio Against the Calculated Ratio for Six Different Freestream Wind Sectors**

Directional Sector	Height (m)	Measurements			PARK Wake Model				Fast EVM Wake Model			
		Sodar East (m/s)	Sodar West (m/s)	Alpha	Sodar East (m/s)	Sodar West (m/s)	Alpha	Relative Error (%)	Sodar East (m/s)	Sodar West (m/s)	Alpha	Relative Error (%)
Freestream Wind East 61-101	40	4,204	4,594	**1.093**	4.4	3.88	**0.882**	24%	4.4	4	**0.909**	20%
	50	4,532	4,662	**1.029**	4.69	4.06	**0.866**	19%	4.69	4.14	**0.883**	17%
	60	4,805	4,743	**0.987**	4.93	4.27	**0.866**	14%	4.93	4.25	**0.862**	15%
	80	5,292	5,079	**0.960**	5.31	4.54	**0.855**	12%	5.31	4.49	**0.846**	13%
	100	5,717	5,625	**0.984**	5.67	4.91	**0.866**	14%	5.67	4.92	**0.868**	13%
	120	6,116	6,215	**1.016**	5.98	5.27	**0.881**	15%	5.98	5.47	**0.915**	11%
Freestream Wind East 66-96	40	4,353	4,577	**1.052**	4.54	3.84	**0.846**	24%	4.54	3.98	**0.877**	20%
	50	4,663	4,599	**0.986**	4.82	4.02	**0.834**	18%	4.82	4.08	**0.846**	17%
	60	4,950	4,660	**0.942**	5.08	4.23	**0.833**	13%	5.08	4.15	**0.817**	15%
	80	5,444	5,046	**0.927**	5.46	4.5	**0.824**	13%	5.46	4.37	**0.8**	16%
	100	5,871	5,658	**0.964**	5.84	4.89	**0.837**	15%	5.84	4.86	**0.832**	16%
	120	6,249	6,271	**1.004**	6.16	5.28	**0.857**	17%	6.16	5.52	**0.896**	12%
Freestream Wind East 71-91	40	4,515	4,519	**1.001**	4.11	3.34	**0.813**	23%	4.11	3.52	**0.856**	17%
	50	4,793	4,517	**0.942**	4.38	3.51	**0.801**	18%	4.38	3.59	**0.82**	15%
	60	5,011	4,553	**0.909**	4.6	3.7	**0.804**	13%	4.6	3.63	**0.789**	15%
	80	5,420	4,946	**0.913**	4.94	3.95	**0.8**	14%	4.94	3.79	**0.767**	19%
	100	5,759	5,535	**0.961**	5.28	4.23	**0.801**	20%	5.28	4.23	**0.801**	20%
	120	6,049	6,088	**1.006**	5.59	4.54	**0.812**	24%	5.59	4.86	**0.869**	16%
Freestream Wind West 221-241	40	6,224	6,448	**0.965**	5.32	6.46	**0.824**	17%	5.64	6.46	**0.873**	11%
	50	6,289	6,806	**0.924**	5.64	6.84	**0.825**	12%	5.82	6.84	**0.851**	9%
	60	6,384	7,114	**0.897**	5.96	7.17	**0.831**	8%	5.94	7.17	**0.828**	8%
	80	6,762	7,653	**0.884**	6.47	7.72	**0.838**	5%	6.28	7.72	**0.813**	9%
	100	7,428	8,131	**0.914**	6.96	8.17	**0.852**	7%	6.85	8.17	**0.838**	9%
	120	8,163	8,554	**0.954**	7.43	8.56	**0.868**	10%	7.65	8.56	**0.894**	7%
Freestream Wind West 216-246	40	5,992	6,047	**0.991**	5.18	6.1	**0.849**	17%	5.45	6.1	**0.893**	11%
	50	6,096	6,405	**0.952**	5.47	6.46	**0.847**	12%	5.64	6.46	**0.873**	9%
	60	6,204	6,714	**0.924**	5.76	6.77	**0.851**	9%	5.79	6.77	**0.855**	8%
	80	6,570	7,241	**0.907**	6.22	7.29	**0.853**	6%	6.13	7.29	**0.841**	8%
	100	7,171	7,714	**0.930**	6.68	7.72	**0.865**	8%	6.65	7.72	**0.861**	8%
	120	7,845	8,131	**0.965**	7.13	8.1	**0.88**	10%	7.34	8.1	**0.906**	7%
Freestream Wind West 211-251	40	6,033	5,839	**1.033**	5.22	5.92	**0.882**	17%	5.44	5.92	**0.919**	12%
	50	6,211	6,207	**1.001**	5.5	6.27	**0.877**	14%	5.66	6.27	**0.903**	11%
	60	6,351	6,507	**0.976**	5.76	6.58	**0.875**	12%	5.84	6.58	**0.888**	10%
	80	6,705	7,036	**0.953**	6.22	7.08	**0.879**	8%	6.21	7.08	**0.877**	9%
	100	7,230	7,517	**0.962**	6.66	7.51	**0.887**	8%	6.7	7.51	**0.892**	8%
	120	7,800	7,931	**0.983**	7.12	7.88	**0.904**	9%	7.3	7.88	**0.926**	6%

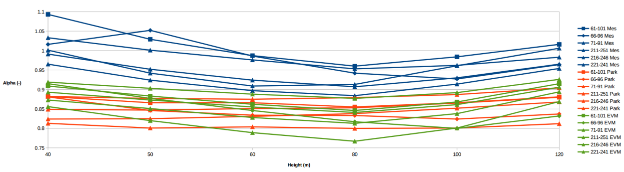

Figure 3: **Simulated Alpha Ratio Against the Calculated Ratio for Six Different Freestream Wind Sectors(graph)**

Benchmarking Conclusions

- The simulated wake is higher than the measured wake for both the empirical models.
- As expected, the measured wake is higher at hub height.
- Simulated wake is not higher at hub height for one empirical model
- Such results show that a new approach for wake modeling is required in order to reduce wake modeling uncertainties in complex sites.

Toward ZephyCFD actuator disk wake model

Objectives

- Define a workflow allowing automatic and optimized cloud computations through actuator disk CFD wake model.
- Define the validation methodology to be followed.

Methodology

- Free of wake calculations are run for 36 ten-degrees wind sectors based on standard Zephy-CFD calculation process, and resulting wind directions are extracted at each hub location.
- 36 actuator disk meshes are generated, taking into account the exact orientation for each of the rotors (based on the previously evaluated wind directions).
- Flow is automatically initialized, remapping from previously evaluated free of wake calculations results, considering a high wind condition thrust coefficient.
- 10 consecutive CFD runs are processed ; between each process, the thurst coefficient is varied to evaluate the wakes for 10 different bins of wind speed
- All the wind speed bins and directions sectors are statistically processed with the measurements to evaluate the wake effects at each hub.
- Total of 38 meshes, 432 CFD computations, 37 remapping process ; can be considered as an **expensive numerical process** and **cannot be processed easily by any standard hardware**.

Results

Free of wake calculations:

- Standard ZephyCLOUD service is used ; a 6.5 millions of cells mesh is generated on the cloud, and 36 wind directions are then evaluated.
- The mesh accuracy in the viscinity of the project is equal to 25.2 meters

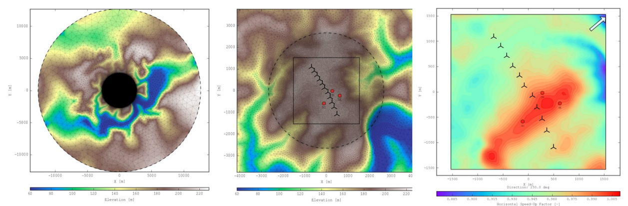

Figure 4: **The 36 calculations are run simultaneously on 36 virtual machines ; each machine has 36 cores.**
The complete duration for the whole process is 1h32.

Actuator Disk Meshes:

- Position, size, and rotor orientation are controled.
- Refinement in the rotor volume and downwind each rotor should be investigated and benchmarked thanks to the soldar measurements.
- Mesh generation should be distributed on virtual instances to make possible simulteneous mesh generations and optimized computation durations.

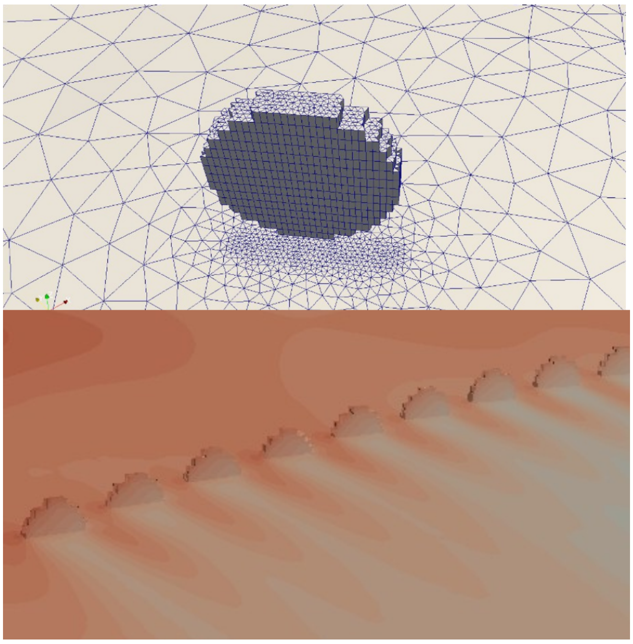

Figure 5: **Refined Rotors in Actuator Disk Mesh and Their Wake Shapes**

Actuator Disk Computations:

- The number of iterations is highly reduced, due to the initialization strategy, using remapped results from free of wake calculations ; the initial thrust coefficient calculation converges in a few hundred of iterations.
- A few tens of iterations allows to evaluate each new thrust coefficient configuration, so that the global process can be evaluated in a few hours.

Conclusion

- The modeling strategy for optimized wake calculations through Actuator Disk model has been defined.
- Thanks to ZephyCLOUD scalability, the whole process is expected to last a few hours with high refinement criterions.
- The measurements from PICOWIND research project will allow to benchmark and to calibrate the mesh refinements in both rotor volume and wake zone.

Appendix

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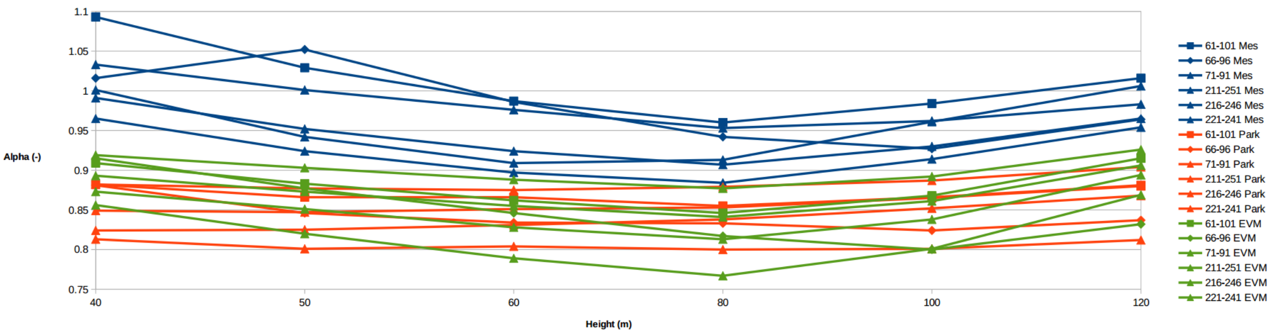

Figure: vSimulated Alpha Ratio Against the Calculated Ratio for Six Different Freestream Wind Sectors(graph)