How cloud-computing is unlocking accurate wake modelling

Recent discussions, about offshore wind resource estimation, demonstrated the need for more sophisticated wake models to reduce the risk of overestimating power production. In this context, ZephyScience developed a new computation methodology, empowered by its cloud-computing services.

This topic emerged over the past few months: wake models used up until now by the wind resource community are ignoring the so-called 'blockage effect', resulting from the two-way coupling between wind turbines and the atmosphere.

According to DNV-GL, unaccounted losses from the blockage effect can represent up to 4% of the mean annual energy yield. Therefore, an accurate modeling of wake and blockage effects should be implemented, in order to perform correct estimations of future production.

Why did the industry neglect blockage effect?

To perform wake losses evaluation, many engineering models have been introduced over the past decades. While all aiming at accurately describing the flow field downwind a single rotor, these have been regularly enhanced or completed with new ones.

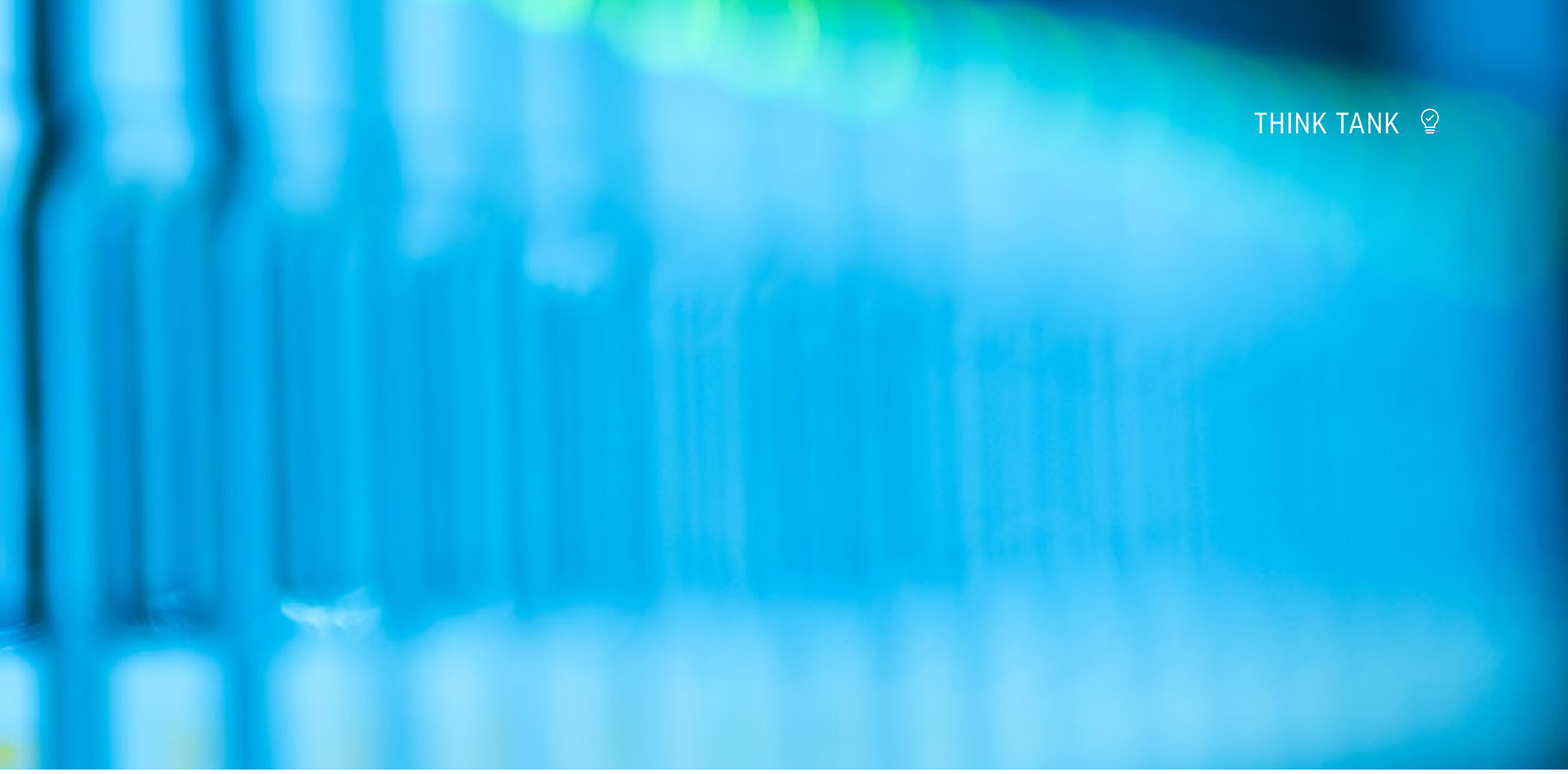
It is worth noting that:

- such models were able to accurately describe the flow field downwind of a rotor
- if taking into account the individual effect of the wake from one turbine to another, wake combination models need to be used to evaluate the combined effect of individual wakes

However, for both wake and wake combination models, such engineering solutions don't take into account the general effect on the whole farm, commonly known as the blockage effect.

During the first decades of wind farm development, the number of machines within a farm remained low enough to keep the uncertainties related to wake combination models and blockage effect low, especially if compared with uncertainty levels related to the wake model itself.

With larger arrays of turbines, especially since the industry started developing offshore wind farms, the relative importance of these two uncertainties naturally tends to increase… and so it is



becoming more and more important to perform a more accurate modeling of the wake interactions.

Why make the blockage effect a separate matter?

The Wind industry now focuses on the blockage effect, with, as the trending requirement for wake effect assessors: 'your wake model needs to capture the blockage effect, please provide for an evaluation of the specific loss due to the blockage effect'.

At ZephyScience we strongly believe the wind industry should focus its efforts on wake models where the blockage effect is inherently taken into account, rather than making it a problem in and of itself. Once a truly holistic model is available, estimations of specific losses due to the blockage effect would become pointless and bring no added value to the project.

To that end we undertook to develop such a model using advanced CFD methodologies.

Wake effects computations with CFD

Year after year, flow models, using three-dimensional Computational Fluid Dynamics, were introduced in the industry.

Including the turbine rotors within the CFD model allows the model, following the actuator disk technique, to directly solve the wake interactions, so that these types of flow model intrinsically take into account any blockage effect, and would avoid using any wake combination model.

Nevertheless, a few challenges need to be overcome, so that this technology is used with a sufficient level of confidence for evaluating the wake effects:

- by including the rotor within the model, there is no direct possibility to access the unperturbed free wind (as if the turbine was not there); this unperturbed free wind is a key result, since it is required to evaluate the machine characteristics: thrust and power coefficients
- model inputs for each machine are the machine characteristics: thrust and power coefficient; these are heterogeneous over the farm and need to be evaluated from results including the wakes. In this vicious circle, the main model inputs should be deduced from its own results, and each modification on a given machine will propagate downwind
- when using RANS solver, a large number of flow situations, directions, wind velocities, air densities, thermal stratifications, should be solved to represent the project accurately.

Additionally, due to the computing requirements for running large CFD models including rotors, massive investments in expensive hardware configuration were required and so this became only affordable to a few major consultants and turbine manufacturers.

ZephyWakes

ZephyScience is a French firm created in 2012, and specializes in CFD modeling for the wind energy industry. We created and developed ZephyTOOLS, a module toolbox for wind developers, including climatology data screening, MCP long-term extrapolation and CFD simulations for yield assessments.

We are open-science believers, and our success is mainly based on our two pillars: open-source and cloud-computing.

Within an ambitious project that has received funding from the European Union's Horizon 2020 research and innovation program, we are now introducing our new wake model to the industry.

ZephyWakes leverages the full potential of open-source and cloud-computing to ensure the highest reliability of the results. It aims in setting a fully automatic modeling chain, which will enable the evaluation of the most accurate wake losses. It should allow any wind

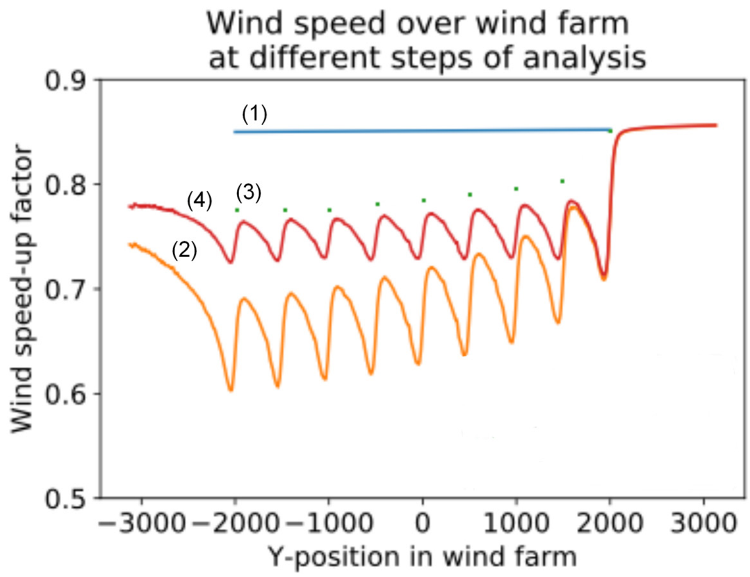


Fig 1 Results of the CFD flow modeling at different steps of analysis

resource consultant to produce reference solutions at decent costs, removing doubts and precisely quantifying how simplified wake combination models introduce extra uncertainties in the resource assessments.

How do we deal with the main challenges?

High computing requirement?

ZephyCloud, the cloud-computing service that can be activated from our current solutions already allows, almost instantly, the use of cloud computing configurations, with up to 96 processors and 192 Gb or RAM.

On top of that, clustering options easily allow such configurations to be combined, so that the largest models can be run.

With ZephyWakes, we are now targeting 5 metre resolution models near the rotors and 20 metres within the wakes.

High number of flow situations?

With traditional solutions running on local hardware, increasing the number of flow situations always means longer calculation queues. Whatever hardware configuration is considered, an increase in the number of projects can only be compensated by either, an increase in the delays, or by decreasing the number of flow situations to be solved, which in turn directly affect the accuracy or even for the validity of the results.

Again, cloud-computing allows us to address the problem with a no-compromise approach, with up to hundreds of computing configurations that can be run all-together: it allows running an important number of flow situations, without affecting the total duration of the modeling chain.

Several sensitive analyses will allow the definition of the degree of accuracy of each criterion, to ensure the reliability of the final results whilst remaining cost efficient.

Thrust and power coefficients evaluation?

The process behind ZephyWakes is divided into 3 main steps, the preparation, the CFD flow modeling and the energy capture, presented in the graph Fig 1.

The preparation step defines the project configuration and runs free flow wind simulations without including the rotors (1). From the direction results at each hub, rotors are reconstructed with the appropriate orientation. CFD results are then averaged over each rotor surface to evaluate for the free-of-wake results. These free-of wake results are then used to build and initialize the main CFD computations, which take into account the rotors and the wakes (2).

During the main CFD computations, the operating turbines modify the free-stream-flow from which the thrust and power coefficients should be evaluated. ZephyScience's method determines the free wind at the location of the turbine while keeping the wake effect of the surrounding turbines (3).

Turbines are deactivated one by one along the flow direction, to properly evaluate thrust and power coefficients for each turbine, averaging results over the disk. Each new coefficient is transferred to the whole farm calculation to propagate the real thrust over the results, before switching to the next machine Fig 2.

Once this iterative process is finished and the final results are available (4), an energy capture can be performed by evaluating speed-up factors between the waked wind speeds at the rotors and the free wind speeds at measurement locations, for each flow situation.

The benefits of the iterative method, on the turbine thrust coefficients, are seen when analyzing wake effects over several rows of turbines. To that end, the calculations are first run in free-stream, then repeated with activated turbines, with an initial thrust coefficient based on free-stream wind velocity, and lastly these results are compared to the final output, after the turbine-wise iterative update of thrust coefficients.

What appears at the end of the calculations, is the final results clearly show higher speed-ups at rotor height and a smaller spread in wind velocities over the rows. Moreover, the velocity loss is the highest between the first row and the second row of turbines.

For real-case sites, such as CREYAP, a relatively hilly terrain, with 22 units of 2MW turbines, Fig 3, losses of up to 6% can occur for down-stream turbines.

What next?

ZephyScience is now reaching the final development stages of the ZephyWakes model. Our teams are currently working with several leading companies to validate the model on several real test sites.

The aim now is for ZephyScience to optimize the model, to reduce the costs of simulation, with a clear ambition of creating an efficient tool for all wind farm developers from onshore to offshore and helping our partners to economise on expensive model prediction costs.

This technology can represent the future of wind modeling. With the development of wind farm projects in terrains with higher complexity and given the need for more accuracy in the results, cloud-computing is the keystone of reliable wind power estimations.

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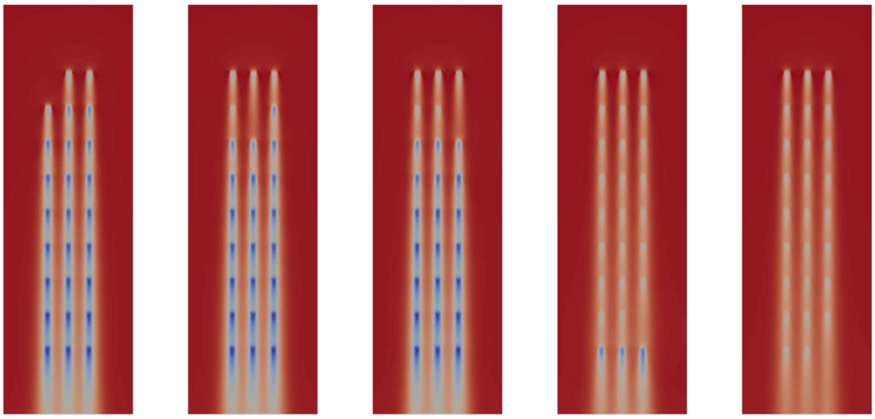

Fig 2 Appropriate wind input propagation over the wind farm

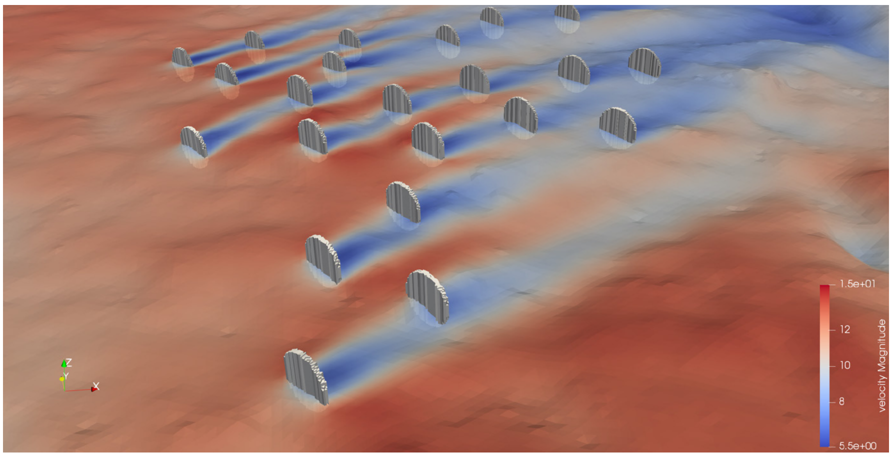

Fig 3 Flow field visualization for the CREYAP test case