PO.56

ZephyCLOUD® Calculations
ZephyCFD® Model Validation in a Complex Site (Southern China)

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1. Abstract

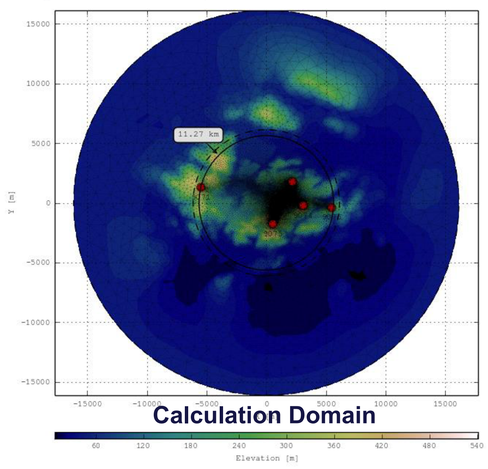
In China, commercial CFD codes are widely being used but due to long calculations and lack of transparency in the assessment process, wind engineers are not given the appropriate conditions to tune models in order to improve final outputs. As the economics of a project are crucially dependent on the site's wind resource, a very little change in wind speed estimates makes an enormous difference in terms of both debt and equity investment. Wind speeds extrapolations from measurement points to turbine locations in complex sites are highly challenging tasks and none of the traditional models (CFD or linear) have managed to prove themselves to be reference solutions. Guangdong Province Wind Power Generation Co., Ltd decided to start investigating ZephyCFD® as it offers unlimited scalability of the CFD runs with fully transparent processes so that the quality of any simulation relies on the efforts of fine-tuning that wind engineers can do by testing different meshing techniques, different turbulence models or different boundary conditions.

2. Site Description

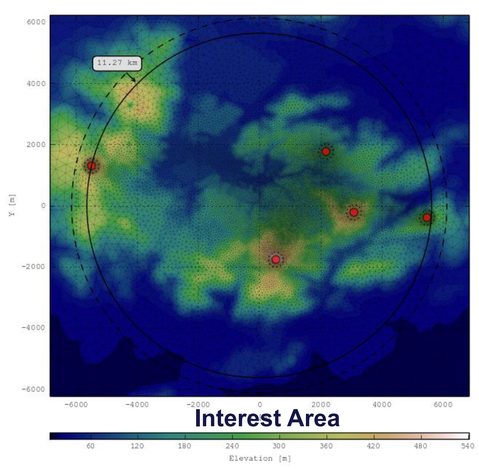
The studied project is a complex site located in Guangdong province (Southern China). Five 70-meter high met masts are installed on ridges with heterogeneous topographical features, among which 2 have concurrent wind monitoring periods (mast#1 & mast#2), with a distance of 11.27kms.

3. Mesh Generation

Five different meshes were generated using the M1 automatic mesh algorithm integrated in ZephyCFD®.
M1 generates prismatic cells to form a boundary-fitted unstructured mesh.
The interest area with a diameter equal to 11.27 km can be visualized in the figures below (black circle).
The whole calculation domain consists in a cylindrical volume covering a diameter which is 21 kilometers larger than the project area diameter, i.e. 32.27 kilometers.
The grid refinement area has a diameter which is one kilometer larger than the project area diameter, i.e. 12.27 km. The project area, the grid refinement area and the whole calculation areas can be visualized in the figures below (2D Ground Visualization).



Calculation Domain



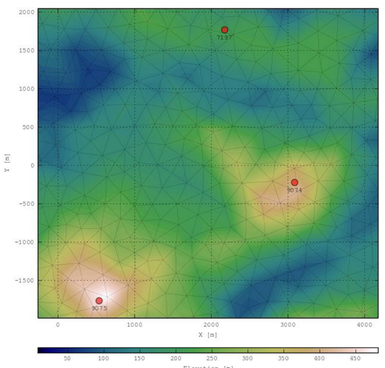
Interest Area

3.1 Horizontal Discretization

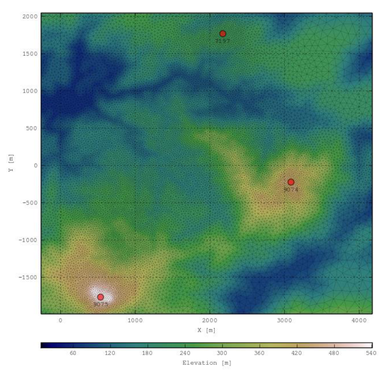
The mesh is refined around domain centre, and gets coarsened as we move away from the site center to the side boundary conditions. Fine mesh (30m resolution) and Coarse mesh (300m resolution) are visualized below with a zoom on the project area.
The coarse version of the mesh is generated to run a flow initialization calculation to speed-up convergence of the final calculation.

3.2 Vertical Discretization

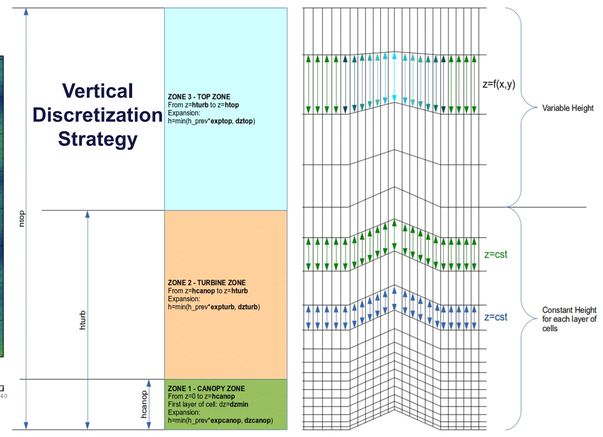
In the vertical direction, meshes are refined toward the ground boundary condition.
55 vertical layers of cells are used for the vertical discretization of the calculation domain.
For the first 33 layers of cells (in the Canopy and the Turbine zones), the cells height remains constant all over each of the layers.



Coarse Mesh for Model Initialization

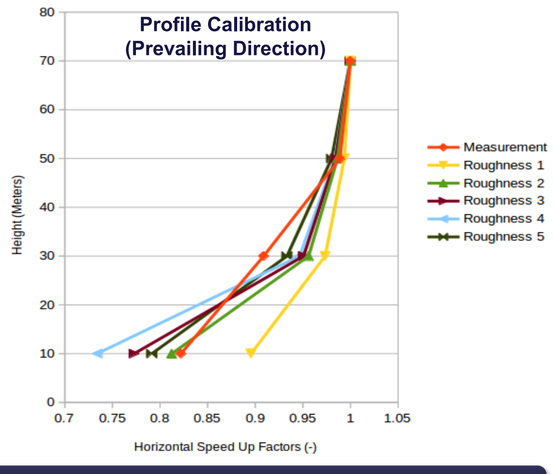


Fine Mesh for Final Calculation



4. Roughness Calibration

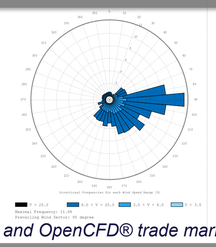
For the prevailing directions (80°), the measured wind profile is compared to the calculated wind profiles using different roughness values for the ground boundary condition.
The measured wind speeds and the calculated speed-ups are normalized at 70 meters height.
The 30m anemometer has several data quality issues and so this measurement height was not used.
The shear comparison shows that the roughness model 1 is the most appropriate as the related calculated profile reproduces the measured profile well.
This roughness model will be used for the CFD directional calculations.



5. CFD Calculations

5.1 Calculated Directions

Given the directional frequency distributions during the study period (cf. Wind rose figure), it has been decided to run 16 calculations every 10 degrees from 60° to 210° and run 3 other calculations to complete the wind rose (10° , 260° , 320°). Doing so, simulations efficiency is increased by allocating more resources to relevant directional sectors.


Measured Wind Rose

5.2 ZephyCLOUD® CFD calculations performance

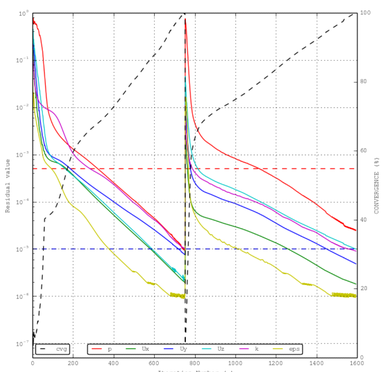
ZephyCLOUD® service allows ZephyCFD® user to run parallelized CFD simulations with the opensource OpenFOAM solver installed on cloud servers.
A total of 162 cloud configurations are designed going:

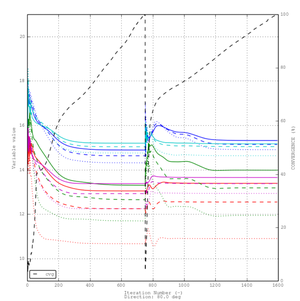
- from 12 simultaneous 8-CPU instances delivering 12 CFD directional results in one hour, 2 million cells for each run, 750 solver iterations for each run.
- to **72 simultaneous 36-CPU instances delivering 72 CFD directional results in 6 hours, 20 million cells each run, 2500 iterations.**

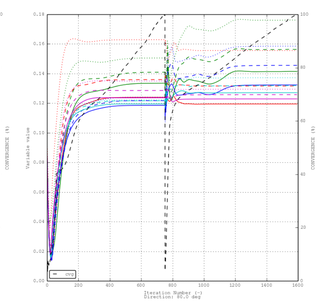
For this project, an intermediate user-defined ZephyCLOUD® configurations was used, with 3.5 million cells, 1250 iterations, delivering **19 CFD directional results in 1 hour.**

5.3 Iteration Process / Convergence

Lack of transparency can be a major issue when running CFD simulations with traditional software and so ZephyCFD has been designed to ensure the entire assessment process is perfectly auditable, transparent and with reproducible results. This has become a crucial differentiating factor to achieve increased project bankability.

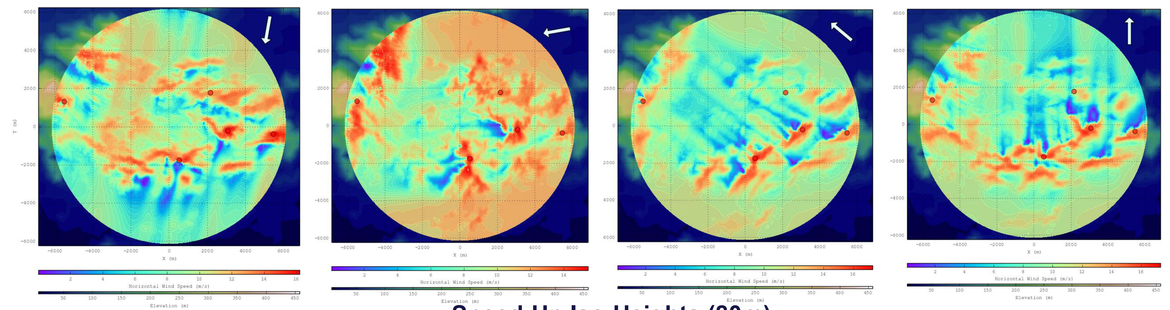

Residuals *(Left : Initialization, Right : Final Run)*


Velocity Results - Masts
(Left : Initialization, Right : Final Run)

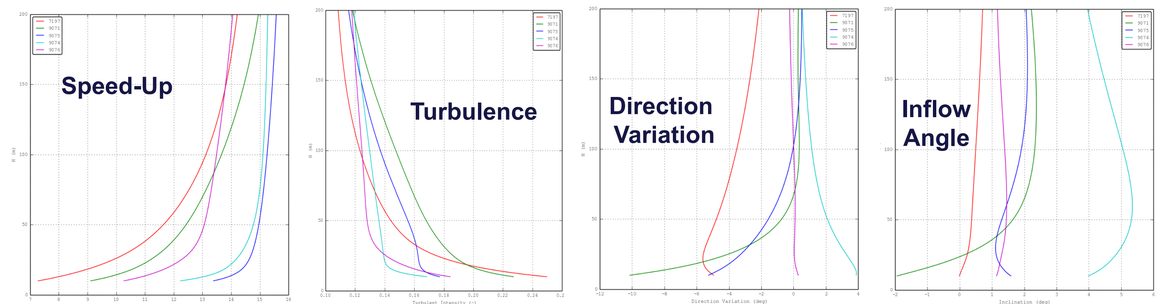

Turbulence Results - Masts
(Left : Initialization, Right : Final Run)

6. CFD Results

From the 19 calculated directions, 4 iso-height speed-up results at 80 meters are displayed in the figures below.
The iso-heights show that the flow recirculation and detachment zones are well simulated.
The white array shows the calculated directions.


Speed-Up Iso-Heights (80m)

Speed-up, turbulence, direction variation, flow inclination results profiles are plotted for the prevailing direction (80°) at the 5 mast locations.



7. Wind Extrapolations & Cross-Predictions

The table below shows the cross extrapolation table between mast#1 and mast#2 during the concurrent period.

Cross-Extrapolation Table

Relative Error = (Target – Reference) / Reference [%]	**Measured at Mast#1 (70m) 7.14 m/s**	**Measured at Mast#2 (60m) 5.21 m/s**
Calculated at Mast#1 (70m) from Mast#2 (60m) **7.19 m/s**	0.70%	
Calculated at Mast#2 (60m) from Mast#1 (70m) **5.50 m/s**		5.31%

- **Mesured Speed Variation from Reference** : 100*(7.14-5.50) / 7.14 = **-23%**
- **Calculated Speed Variation from Reference** : **:** 100*(7.14-5.21) / 7.14 = **-27%**

Comparisons between measured and modeled wind speed estimates have been made for a highly complex wind farm site in Guangdong province (South China). A number of conclusions can be drawn from the results of the wind speed and comparisons.
Based on these results, there is a clear evidence that ZephyCFD consistently and reliably captures the wind regime in between and around measurement towers.

References

1. ZephyCFD Marvelous Mistral, *Technical Note*
2. Comparison of two CFD tools against measurements on complex terrain, GDF-Suez, *SOWE Conference*
3. Validation of ZephyCFD in a Complex Site in India, CLP India, *ZephyTOOLS 1st User Meeting*