HOW CAN CFD MODELS COMPLEMENT MEASUREMENTS?

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DATA FROM ADVANCED FLOW MODELS

- Turbulence Intensity assessed
- Inflow angle assessed
- Shear modelling in forested terrain
- Possibility of time-dependent computations

This information could be used with multidimensional power curves for Energy Yield Assessment.
IS CFD UP TO THE JOB? – TURBULENCE

Predicted average TI is 1% off (on average on a selection of sites)

Typical modeled and measured turbulence intensity comparison in forested terrain
IS CFD UP TO THE JOB? – WIND SHEAR

Predicted average shear is 0.04 off (on average on a selection of sites)

Forest ed sites should be handled appropriately:

- garbage in garbage out

- canopy model typically significantly enhances results

Typical modeled and measured wind shear comparison with an accurate forest dataset
IS CFD UP TO THE JOB? – INFLOW ANGLE

Typical plot of measured (blue) and CFD-modeled (red) inflow angle (°) vs. wind direction
CASE STUDY 1 – IS CFD UP TO THE JOB? – RECIRCULATIONS

Highly complex topography:

– RIX of 12.8% on average
– 30% in sectors 30 and 150
– 5% in sectors 90 and 270

No trees

1 mast with 1Hz measurements

3 planned turbines

CASE STUDY 1 – SPECTRAL ANALYSES

Measured time-series are analyzed using power spectral analyses.

Preferred time scales are found in the flow, i.e. phenomena come back in time with a specific periodicity.

Time-dependent simulations are carried out.
Simulations are shown to be able to reproduce preferred frequencies measured at the mast.

Simulations can help us understand the reason for these peaks.

(1) The utilisation of the computer code called VENTOS® was made under the agreement between Natural Power Consultants Ltd. and CEsA-Centre for Wind Energy and Atmospheric Flows of FEUP-Faculty of Engineering of the University of Porto.
CASE STUDY 1 – CONCLUSIONS

VENTOS® was shown to be able to reproduce time-dependent phenomena

Mast data and time-dependant CFD analysis enable:
- understanding of flow behavior on site
- characterize complex flow structures

Time-dependant simulations can be required/useful in complex terrain for proper decisions to be made regarding:
- site suitability
- appropriate operating restrictions
Wind flow depends on temperature and heat fluxes.

Many common models do not properly model thermally-driven flows.
Example of the VENTOS/M\(^{(1)}\) coupled CFD model:
- Solve the time-dependant RANS equations
- Solve the transport equation for potential temperature
- Initial and boundary conditions are obtained from WRF

We expect:
- More precise EYA, especially for unstable & stable atmospheres
- Less need for site measurements

\(^{(1)}\) Developed by the Centre for Wind Energy and Atmospheric Flows, University of Porto under a joint venture with RES and Natural Power
Stability taken into account

- TI and shear are a function of Vh
- Diurnal/seasonal variations of TI, shear, IA are modelled

Absolute modelling

- PDFs are not bound to resemble PDFs measured at masts

Time-dependant modelling

- Time-series based EYA/Stress analysis can be performed
- Extreme values at each turbine location
EXAMPLE OUTPUT – TI(VH)

Picture by courtesy of the University of Porto
EXAMPLE OUTPUT – ERROR ON WIND SPEED ON A SITE SHOWING STRONG THERMAL VARIATIONS
EXAMPLE OUTPUT – NEGATIVE SHEAR

(Note that measurements are over a year, while computations are meant to represent one full year)
The model is able to reproduce diurnal patterns observed for thermally-driven flow.
EXAMPLE OUTPUT – TIME SERIES

3% difference in energy flux
CONCLUSIONS

1. CFD enables detailed flow characterization
   - Additional outputs are merely used for site suitability
   - Time-dependant simulations could be used further
   - Multidimensional power curves should improve accuracy of EYA

2. Coupled CFD generate virtual mast time series
   - More accurate analyses (stability, mast independent)
   - Next level EYA, with PC(Time, Vh, TI, Shear, IA, Density)
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CASE STUDY 1 – SITE CHARACTERISTICS

- Complex, forested site
- Underproduction

Site topography and forestry map

On site wind rose
CASE STUDY 1 – OBSERVED UNDERPERFORMANCE

Most turbines showing low capacity factors are located next to the forest.

- **Capacity factor per turbine**
- **Site topography and forestry map**
Underperforming turbines are shown to be performing properly in some wind directions (300), but not in other (150).

Wind turbine performance for a given wind direction
CASE STUDY 1 – ADDED VALUE OF CFD

- Underperformance is due to high turbulence/shear
- Impact on yield could be assessed through multidimensional power curves

Wind direction

Turbulence (TI) map for 300 wind sector

Wind direction

Turbulence (TI) map for 150 wind sector
CASE STUDY 1 – FUTURE FOREST SCENARIOS

- Impact of tree growth/felling on flow can be assessed
- Impact on yield could be assessed through multidimensional power curves

Turbulence (TI) map with the actual forestry

Turbulence (TI) map after forestry cuts (hypothetical scenario)