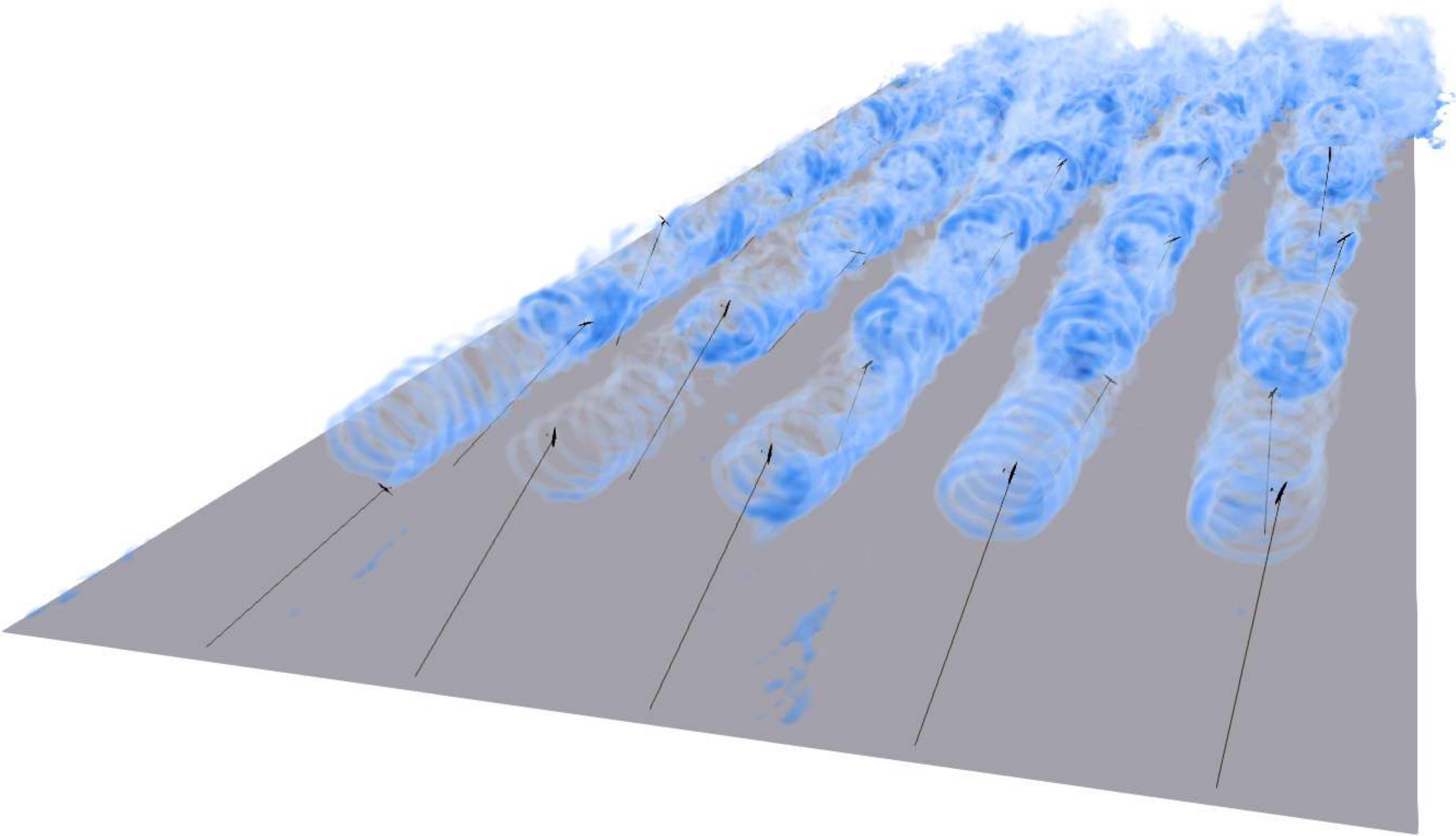
Visualisation of flow structures in the wake of on-board power generation AWE systems (D1) by means of iso-volumes of the wake velocity deficit coloured by axial wind speed component (PhD dissertation Thomas Haas, KU Leuven, 2022).



Performance Investigation of Utility-Scale Airborne Wind Energy Farms using Large-Eddy Simulations

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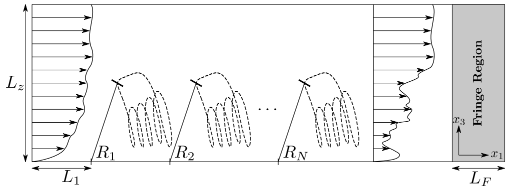
The utility-scale deployment of airborne wind energy (AWE) requires the development of large-scale AWE systems in the multi-megawatt range targeting farm operation [1]. We propose a virtual AWE farm simulator combining large-eddy simulations and optimal control techniques to investigate the performance of AWE farm configurations [2]. The wind field in which the AWE farms operate is an unsteady three-dimensional turbulent boundary layer and the tracking of individual flight path in the presence of these turbulent fluctuations is tackled using a nonlinear model predictive controller (NMPC). The complex dynamics of wind and AWE systems are subsequently coupled using an actuator sector method. The considered AWE systems operate in both on-board and ground-based pumping generation modes (drag and lift modes) and are scaled to harvest up to 5 MW of power at a rated wind speed of 12 m/s. We investigate three farm configurations comprising of 25 systems arranged in 5 columns and 5 rows using two different farm layouts: Two drag-mode AWE farms with moderate and high system densities of respectively 10 MW/km2 and 28 MW/km2 (D1 and D2) and one lift-mode AWE farm with the identical moderate system density (L1) are considered.

The AWE farms operate in below-rated wind conditions with a mean background flow speed of 10 m/s measured at 100 m. During operation, the individual systems adapt their flight path to the encountered large-scale boundary layer wind speed variations and local wake effects. The wake effects significantly impact the power performance of downstream rows, resulting in power losses of up to 17% (L1), 25% (D1), and 45% (D2) relative to the front row of the farm configurations. Although the employed NMPC successfully accomplishes flight path tracking, for lift-mode systems however, it fails to adequately track the power profiles. Hence, over one hour of operation, the combined wake and tracking losses result in farm efficiencies of 82.5% (L1), 89.2% (D1), and 75.6% (D2).



Side view of the computational domain used for co-simulation of turbulent boundary layers and AWE parks. The dimensions in streamwise, spanwise and vertical directions are L_x = 10 km, L_y = 4 km, and L_z = 1 km, respectively. The downstream position of the first row of AWES systems is L_1 = 1 km [3].

References:

[1] Kruijff M., Ruiterkamp R. A Roadmap Towards Airborne Wind Energy in the Utility Sector. In: Schmehl R. (eds) Airborne Wind Energy. Springer, Singapore, 2018. doi:10.1007/978-981-10-1947-0_26

[2] Haas T., De Schutter J., Diehl M., Meyers J. Large-eddy simulation of airborne wind energy farms. Wind Energy Science, Vol. 7, pp. 1093–1135, 2022. doi:10.5194/wes-7-1093-2022

[3] Haas T. Simulation of Airborne Wind Energy Systems in the Atmospheric Boundary Layer, PhD dissertation, KU Leuven, 2022. https://lirias.kuleuven.be/handle/20.500.12942/693167