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Large Eddy Simulation of two Airborne Wind Energy Systems with wake interaction

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1 Introduction

Airborne wind energy (AWE) has recently gained much interest due to its significant potential as a green energy source. Until now, most studies have investigated single AWE systems, as the existing systems are so far operated as a single unit. However, AWES wind farms will be essential for the large-scale development of the technology. Existing studies investigating farm configurations mainly focus on farm layout [1, 2], performances [3] or on techno-economic studies [4], and use lower-fidelity models. In those studies, simple aerodynamic models are employed and wakes are not taken into account. The study by Haas et al. [5] is the only one that considered an AWES wind farm using a sufficient fidelity, i.e. using computational fluid dynamics, to assess more precisely the performance of an AWES farm. In their work, each AWES was represented by its main wing, modeled as an actuator sector. The system dynamics were computed using a 3-DOF point-mass model coupled to a closed-loop nonlinear model predictive controller (NMPC) from the optimal control toolbox AWEbox [6]. In the present study, we also develop a Large-Eddy Simulation (LES) framework to investigate AWES, also in farm configurations. However, the AWES main wing is modeled using an Actuator Line (AL) and the 6-DOF dynamics model of AWEbox [6]. Therefore, it requires the implementation of control surface models in addition to the AL.

In this work, we investigate a two-kite configuration where the second kite flies in the wake of the first one. As shown previously, the NMPC controller can handle quite well high turbulence intensity [7]. Here, we investigate its ability to remain on the desired trajectory when subjected to stronger perturbations (i.e., from the leading kite's wake). We also assess the impact on the power production and the wing loading. The methodology is described in the next section. Section 3 shows early results from this investigation and the last section draws the first conclusions.

2 Methodology

Flow solver The Large-Eddy simulations are performed using a fourth-order finite difference solver for incompressible flows, developed at UCLouvain [8, 9]. The domain is discretized using a Cartesian staggered grid, and the temporal integration is handled using a second-order Adams-Bashforth scheme. Synthetic turbulence is added at the inflow in the form of Mann synthetic turbulence boxes [10].

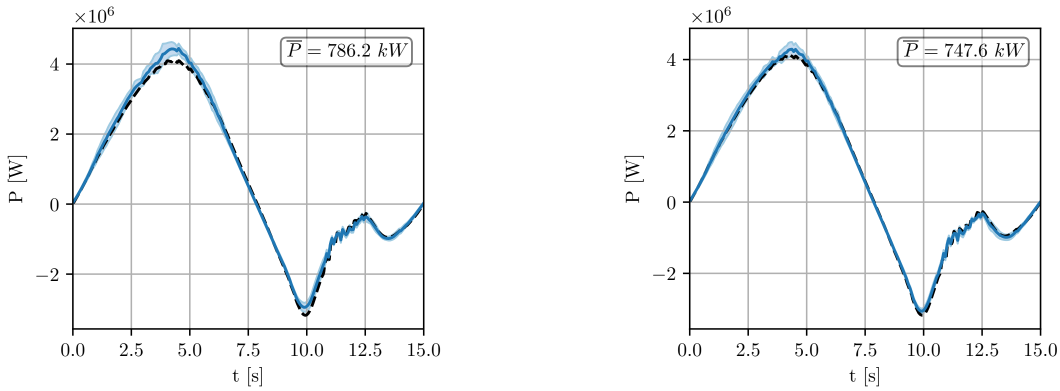
Aircraft model The AWES considered here is the rigid-wing reference AWES called MegAWES [11]. It has a wing span b of 42.5 m and an aspect ratio of 12. Within the flow solver, the main wing is modeled using an improved actuator line (AL) method based on 2D (i.e., cross-plane) regularization kernels and near tip corrections, see Trigaux et al. [12]. The effect of the elevator and the two rudders is modeled using their lift slope coefficient and the velocity measured at the location of their aerodynamic center. Because these forces are small, they are not added to the flow. The effect of the ailerons deflection is added to the AL by modifying the local airfoil aerodynamic properties of the affected wing sections.

Optimal trajectories and control In the present work, each AWES flies a precomputed trajectory generated using `AWEbox` [6] which is a modeling and optimization toolbox that generates power-optimal flight paths. It also provides NMPC control for flight path tracking. The reference flight paths are precomputed for specific mean wind conditions and a given set of operating constraints. Then, the AWES is flown using the NMPC controller in the LES framework. The toolbox is integrated with the flow solver in a two-way coupling, using the forces evaluated by the AL-based aircraft model as input to the dynamics model and the controller.

3 Preliminary results

Based on the work already achieved in [7], a second kite is added to the simulation. The simulation domain is $9D \times 3D \times 3D$ and with about 17 grid cell points of the LES solver per wing span. The ground station of the first kite is located at $3D$, and the second kite at $6D$ downstream of the domain entrance. The two kites fly the same trajectory: here a single-loop trajectory of effective diameter $D \simeq 5b$, in a 10 m/s inflow with a turbulence intensity (TI) of 6 %.

The results in terms of power output are reported in Figure 1. As demonstrated in [7], the kites are able to follow their flight paths very well, even in a highly turbulent inflow. This is translated here by the fact that the two kites give a power very close to that of the reference, as computed with `AWEbox`. As the inflow turbulence is already quite high, the second kite is not perturbed much by the first kite's wake. However, it produces about 5 % less power because of the wake velocity deficit from the first kite; as can be observed in Figure 2. We also see that the wake of the kites remains quite straight despite the trajectory plane being tilted.



(a) **(b)**

Figure 1: 14-cycles averaged power production with their standard deviation (shaded area) for the first (a) and second (b) devices flying in LES with AL (—); `AWEbox` reference (– –).

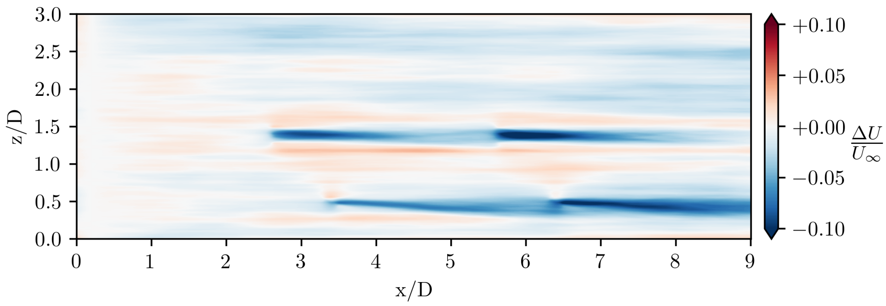


Figure 2: 14-cycles averaged in plane streamwise velocity deficit for the considered two-kite configuration.

4 Conclusion and perspectives

We emphasized the importance of conducting research on AWES wind farms, and we presented the framework developed to study such farms using LES combined with an AL model for the main wing. The preliminary results show that, in such high TI inflow, the second kite also flies its trajectory very well, despite its interaction with the wake from the first kite, at least for the configuration investigated so far. The wake losses result in about 5 % less power, which is comparable to the findings obtained in [5].

The above results will be further detailed and different kite spacings and trajectories (e.g. 4-loops trajectory) will be investigated. Other cases of wake interaction such an AWES flying in the wake from a conventional wind turbine will also be studied in following work.

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