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Investigation of Controlled Airborne Wind Energy System Flying in Turbulent Atmospheric Conditions Using Large Eddy Simulation

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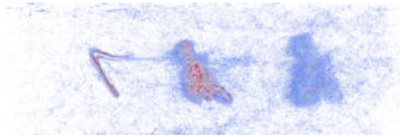
Rigid-wing ground-gen airborne wind energy systems (AWES) fly complex trajectories. This therefore calls for accurate modeling of the dynamics and for advanced control. Flying in atmospheric conditions also requires a high fidelity modeling of the turbulent scales. Such a framework was first developed by Haas et al. [1], where they used Large-Eddy Simulation (LES) to study AWES farms in realistic turbulent winds. 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 path-tracking non-linear model predictive controller from the optimal control toolbox AWEbox [2].

In the present work, we aim to develop a LES framework to study more accurate AWES models in turbulent winds and assess the robustness of the controller against flow perturbations. The toolbox AWEbox is also used for trajectory generation and control. Here the device is flown with a closed-loop controller using a 6-DOF aircraft model; the control surfaces are thus also modeled.

The reference rigid-wing AWES from [3] is considered and is modeled using an actuator line (AL) for the wing. The control surfaces cannot be discretized using an AL because the LES flow solver grid size is too coarse relatively to their span; they are thus modeled using their lift slope. The tail control surfaces (elevator and rudders) are each a lifting surface of small aspect ratio and they are modeled using their effective lift slope. The effect of the main wing ailerons is also modeled: the local lift is modified following the aileron deflection angle. The addition of the control surfaces allows for the evaluation of the aerodynamic moments; as is required by the 6-DOF aircraft model.

The AL-based model is used to study the behavior of controlled AWES when flying in turbulent atmospheric flows; also with shear as for the atmospheric boundary layer (ABL). The performances are then compared to those from the idealized conditions, evaluated with AWEbox. More complex scenarios will also be investigated, where the AWES encounters additional perturbations such as the wake from a wind turbine or from another AWES.



Volume rendering of the wake vorticity field produced by a rigid wing AWES flying a 4-loop trajectory in a turbulent inflow.

References:

[1] Haas T., De Schutter J., Diehl M., Meyers J. . Large-eddy simulation of airborne wind energy farms. Wind Energy Science, 2022.

[2] De Schutter J., Leuthold R., Bronnenmeyer T., Malz E., Gros S., Diehl M. . AWEbox: An Optimal Control Framework for Single- and Multi-Aircraft Airborne Wind Energy Systems. Energies. 2023.

[3] Eijkelhof D. and Schmehl R.. Six-degrees-of-freedom simulation model for future multi-megawatt airborne wind energy systems. Renewable Energy, 2022.