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Conceptual design of windplanes

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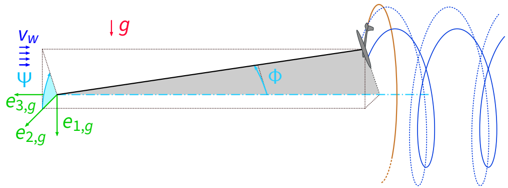
This abstract summarizes the main findings of the Ph.D. thesis *Conceptual design of windplanes* [1]. The thesis focuses on the design of windplanes (i.e. Fly-Gen AWESs), and the methods can be later applied to other AWE topologies (Ground-Gen and rotational).

The first part addresses the research question: "**Given a wingspan, which design maximizes power?**". In this part, the plane is modelled as a point mass flying circular crosswind trajectories and a periodic solution to the tangential equation of motion is found. Since the design problem is formulated for a given wingspan, the optimal aspect ratio is finite and airfoils with high lift-to-drag ratio are optimal. Large radii trajectories decrease the generated power because of the gravitational potential energy exchange. Small radii trajectories decrease the generated power because of the aerodynamic induction. It exists then an optimal mass, as this is the main parameter determining the trajectory radius.

The second part investigates the research question: "**Can windplanes fly stable orbits?**". In this part, the plane is modelled as a rigid body, the non-linear equations of motion are solved with a harmonic balance method and the aerodynamics model is linearized about non-linear operating points. The design framework *T-GliDe* (Tethered Gliding systems Design) is developed with an "all-at-once" formulation, allowing the use of automatic differentiation. If the gravity is removed from the model, the problem has a steady solution. The windplane is trimmed in the circular crosswind trajectory which maximizes the projected area. If the gravity is included in the model, the simplest control strategy is to trim the horizontal stabilizer, the vertical stabilizer and the turbine thrust coefficient to constant values, to actuate the ailerons cyclically and to control the vertical stabilizer in closed loop. The cyclic control of the ailerons rolls the plane and redirects the lift to compensate gravity and to stay airborne. The vertical stabilizer is controlled in closed loop to increase directional stability and damp the precession mode. A moderate reduction in power coefficient between the steady case and the dynamic case with this simple control is found at low wind speed. A complete stability analysis is carried out, showing that the pendulum mode is lightly damped and the precession mode needs feed-back control.



Schematic view of the windplane flying circular trajectories.

References:

[1] Trevisi, F.: Conceptual design of windplanes. Ph.D. thesis, Department of Aerospace Science and Technology, Politecnico di Milano, 2023 https://doi.org/10589/216694.