Review of "Controlling rigid-wing airborne wind energy systems during circular flight without exact path following"

WES

1 Outline of the paper

This paper proposes flight controls for rigid wing, ground-gen airborne wind energy systems during the traction (production) phase. The control inputs are classical control surface angles (ailerons, elevators, rudder). The objective is to drive the kite along trajectories that generate the maximum power. The authors step away from the classical idea of defining a trajectory and controllers to follow it. Instead, they shape the naturally occurring oscillations towards desirable trajectories. This approach seems to lead to robust behaviours to realistic wind profiles, allow for multi-kite farm synchronisation and both figure of eight and circle trajectories.

2 Contributions of the paper

- The proposed control approach – although based on PI controllers – is novel and well engineered.
- This controller can be tuned easily and tuning procedures are proposed.
- The results are assessed through detailed simulation based on experimental data
- A Lyapunov proof is given for the input-to-state stability of the angle of attack dynamics

Overall, the paper is well written, pedagogical and pleasant to read. The control design is quite empirical - except for the angle of attack - but well engineered nonetheless. The idea underlying the control design shows great understanding of these complex system dynamics, and is very relevant to the field.

3 Questions and suggestions for improving the paper

- l 36 : "Equilibrium solutions exist only when gravity is ignored and the circular trajectory is perpendicular to the wind" don't (static) equilibria also exist higher in the wind window, with the kite pointing to the north of the sphere? Please be more precise.
- l 57 : "However, they require specialist knowledge to implement" this is not an argument to disqualify control laws from the literature. It may simply mean that they require more work to ease the practical implementation. But it is an argument to compare your proposed solution to the literature.
- l 133 : what the reference plane is and how it is defined is unclear throughout most of the paper. Please clarify how it is defined and what is its relation to the kite's periodic trajectories or transient behaviour. This is the main issue with the paper, and this core concept should be clarified.
- l 139, 146 and Fig 3b : it is unclear if Z_R should align with the earth's up or down vector when $\lambda_R = \zeta_R = 0$.
- Fig 3. Adding the kite may (?) help to clarify the impact of the reference plane's orientation
- The control inputs are the control surface angles. How is their saturation taken into account? Are anti-windup methods implemented, and how does the kite behave during saturation?
- l 162 : "implies that the reference plane's orientation $[\lambda_R, \zeta_R]$ is known"? This seems like an assumption, but isn't it always true in practice? If so why phrase it this way?

- l 179 : "circle centre overlapping the winch when viewed from the wind-facing direction" ⇒ "circle center on the ground"
- Fig 8 & l 249 : X_P are drawn as vectors, but the considered as "coordinates". Pleas correct. l 249 do you mean instead the elevation angle of point P? (same for Y_P).
- l 267 : how is the climb angle defined and tracked? (explain more than "via λ_P")
- l 275 : what is "control travel saturation"?
- l 281 : "both ζ_P and λ_R are 0" ⇒ "both ζ_P and λ_P are 0"
- Fig 13 : what is the color gradient? turbulence? what is the unit?
- l 307 : "the turbulence box is convected downstream with the mean wind speed" please clarify
- Please clarify if the control gains are kept identical throughout the paper
- l 365 : has noted
- l 378 : "The kite with highest altitude experiences more control difficulty, but notably produces 46% less power" "The kite with highest altitude experiences more control difficulty, **and** notably produces 46% less power"
- l 383 : how does it compare using the realistic wind profile from Fig 13?
- l 470 : "Appendix C presents the stability proof of the controller" ⇒ "Appendix C presents the stability proof of the α dynamics in closed-loop with the proposed controller"
- l 489 : it is preferable to stick to a realistic scenario (i.e. the two ground stations are separated)
- l 511 : "this method does not provide full navigation capabilities as seen in circular-flight analysis" what is limited if one follows F8 trajectories? Please be more specific

Also, a recap of all the (state-space) equations that should be implemented on the onboard computer would be appreciated to ease the further control implementation.