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WIND ENERGY SCIENCE DISCUSSIONS

Interactive comment on "Ground-generation airborne wind energy design space exploration" *by* Markus Sommerfeld et al.

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Response to referee 1 wes-2020-123

Markus Sommerfeld

December 31, 2021

1 Author response

Dear reviewer 1,
Thank you very much for your helpful comments to our manuscript, "Ground-generation airborne wind energy design space exploration", wes-2020-123. I am very sorry that I could not resubmit the revision sooner. My full-time work and family, together with a relocation to Japan, required my attention and time.
The manuscript underwent major revision. Several figures and sections have been replaced and new ones have been added.
Sincerely, Markus Sommerfeld

2 General Comments

Overall it is a good work. I appreciated reading the paper and I found interesting the results. I believe it needs some more physical explanations and interpretations to be a really high quality work. Here are my comments.

3 Specific comments

Table 1 It seems that all your results above rated power are directly influenced by the tether values because the power is the product of F^{max}_{tether} and $\dot{l}_{tether}$. This should be clearly stated in the text and in the conclusions. A design space exploration would investigate the effect of changing these constraints on the power output. Maybe, consider changing the title (I agree with the other Comment)

- Changed title
- Added clarification in sub-section Tether model.
- Varying tether diameter and thereby maximum tether force would vary rated power and rated wind speed. An interesting analysis would be to determine the optimal tether size for a given location to maximize AEP.
- At higher wind speeds, a higher max. reel-out speed could would increase instantaneous power. At low wind speeds ideal reel-out speed (according to Loyd with cosine losses) is within the current constraint. Choosing the right ground station design (drum diameter, motor, winch etc.) is an optimization problem beyond the scope of this paper.

Line 182 Have you tried to start from different initial conditions (i.e. different circular loops) to find the global optimum and avoid local optima?

- To determine the global optimum with certainty, using the current optimizer, is not possible due to the complexity of the problem. Varying the initial conditions to determine the global optimum would also drastically increase the computational cost as it would have to be adjusted for each of the 6 designs, 3 weights, 30 wind conditions, two locations and two sets of aerodynamic coefficients.

- The initial path is generated via several homotopy strategy which transform an initial circular path to a periodic path similar to a helix. The radius of the initial circle is determined from the tether length and estimated flight speed. We compared several initial tether lengths depending on system mass, size and wind speed to achieve convergence. We found that initial tether lengths needs to increase with system size and wind speed to converge to a feasible solution.
- Clarified in text

Line 278 It is not clear to me why higher lift coefficient results in higher rated power when the rated power is just the product between reel-out velocity and tether force, which are constrained. Please clarify it.

- Aerodynamic coefficients indirectly affect rated power because the tether diameter, and therefore tether force, is changed such that rated wind speed is kept constant. Tether reel-in and reel-out are kept constant for all designs.
- Clarified in text

Line 301 Does the path length include the reel-in part? Please specify it. Is there any physical reason why the flight path remains constant with wind speed? Is this true also after rated?

- This section has been re-written and c_p has been replaced with the power harvesting factor https://link.springer.com/chapter/10.1007%2F978-3-642-39965-7_1

Line 304 You mention the minimal turning radius without introducing it. Please do that. The minimal turning radius is quite important. Have you a constraint on this? Can you show/ comment how large is the turning radius compared with the wing span? A too small turning radius divided by wing span results in a big difference is tangential velocity between inner and outer part of the wing

- Paragraph removed.
- The minimal turning radius is the result of optimization and not a fixed constraint. Larger systems with higher inertia have a larger turning radius.
- Determining the turning radius is difficult as trajectories are so diverse and deteriorate at higher wind speeds.

Line 305 For conventional WTs, the evaluation of Cp always requires the evaluation of the axial induction at the wind turbine. In this work, I suppose, the induction is neglected. Please state it here. Since for AWESs the induction is typically neglected, the concept of swept area loses its typical meaning. Indeed, the reference area is the kite wing area in Loyd equation. This is why in AWE, the Power harvesting factor (see "Airborne Wind Energy: Basic Concepts and Physical Foundations",Moritz Diehl in "Airborne Wind Energy", Ahrens, Diehl, Schmehl (2013) - page 18) is defined and not the Cp you define in this paragraph. I believe that introducing this factor in your considerations and plots would make your conclusions more understandable. Moreover, the power losses associated to the path are typically associated to the cosine of the opening angle (angle defined by the tether length and the turning radius) powered by 3 (see section 4 of "The Influence of Tether Sag on Airborne Wind Energy Generation", Trevisi et al, (2020) for more details). It could be interesting to include this term in your considerations

- Removed the calculation of c_p and replaced with the power harvesting factor from Diehl et al.
- re-wrote this section

Line 390 Why half of the tether drag and the entire tether mass? I do not see the physical reason. Can you elaborate?

- Mentioning half the tether drag here was supposed to reference the previous description in Sub-section "Tether model". This Sub-section explains that

half of the tether drag at every element is equally divided between the two endpoints and finally transferred to either the aircraft or ground station.
- Clarified in the text.
- The entire tether mass is assigned to the aircraft node, because it is the only thing supporting it and keeping it in the air. As the tether can not support compressive forces, the ground station can not support it.

Line 405 Did you use include the tether drag in consistent way with literature for the evaluation of the system glide ratio ($\frac{L_{wing}}{D_{total}}$)? For instance see equation 4.8 in "Efficiency of Traction Power Conversion Based on Crosswind Motion",Ivan Argatov and Risto Silvennoinen in "Airborne Wind Energy", Ahrens, Diehl, Schmehl (2013). Using the mentioned equation can be a simple check for your results. ?

- The shown data is the result of the optimization. The tether model is described in section 3.5 'Tether model'
- I did not include a comparison to the simplified tether drag estimate used in the QQS model in section 3.2, equation 3.
- I believe including this requires the generation of another figure as including these data would overcrowd the plot?
- Do you believe the inclusion is necessary for the understanding of these results?

Line 242 Can you explain how you computed the tether drag power loss?

- Added a clarification in Sub-section Power losses
- A portion of the tether drag is attributed to the kite node ($F^{kite}_{tether-drag}$), which is as we know an underestimation of the actual tether drag. The kite moves at a speed of v_{kite}. Then the power loss is defined as $F^{kite}_{tether-drag} \cdot v_{kite}$.

Line 427 TYPING ERRORS SIM

- corrected