Wind Energ. Sci. Discuss.,
https://doi.org/10.5194/wes-2020-123-AC4, 2021

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

Markus Sommerfeld et al.

msommerf@uvic.ca

Received and published: 31 December 2021

article [utf8]inputenc [utf8]inputenc lmodern xcolor [normalem]ulem geometry float lipsum multirow hyperref tikz

Response to referee 2 wes-2020-123

Markus Sommerfeld

December 31, 2021

1 Author response

Dear referee 2,
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

;omment 1 In this paper, Sommerfeld et al present a good body of work combining realistic wind data with an optimal control based trajectory optimisation toolbox to explore the effects of multiple wing scale variants. However, I would advise rephrasing the title as the content is not a "Ground-generation airborne wind energy design space exploration" but rather a comparison of scaling effects based on a reference design that is derived from previous work on the Ampyx AP2 model. The current title promises much more, and as a minimum, a design space exploration should look at more than a single configuration that is just scaled.

- Changed title

Comment 2 The work presented here is a high level description of the optimisation results for the scaled variants of the AP2 reference model. However, the discussion of the results at times lack depth. The results are simply presented as optimisation results from the model as compared to an actual design/variant exploration which should try and correlate the design variations to the results. The discussions do not distinguish between model and physical/design driven artefacts. In a few instances, hypotheses for the results obtained are given but they are not fully explored and confirmed. This should be trivial given the capabilities of the model utilised.
In its current form, this manuscript is a macro description of the results of the power optimisation toolbox utilised, and lacks the exploration and discussion of results that would elevate this to a holistic scientific publication.

- Tried to address and added additional figures.

3 Specific comments

Line 59 Please clarify what these other studies refer to.

- Added citations

Line 91 Have the results between this higher ïňĄdelity time resolved model been compared to a simpler steady state model for power prediction?

- added a reference sub-section "Quasi-steady state reference model" and a comparison to optimized power in the results section.

Line 132 What are the actual constraints applied to the tether speeds? Is it $v_{out} = 10m/s$?

- Most of the constraint are mentioned Section 3.6 Constraints and Table 1, $v_{out} = -15 : 10\ m/s$

Line 140 The CL vs α curves shown depict the typical offset in lift from slats, while in the text ïňĆaps are also mentioned. Which one is it? If the coefïňĄcients are just adjusted in a representative manner please mention that, as the change in CD does not look like the typical change associated with slats. In fact,the CD looks simply offset as well, which would not be the case with slats. If this is strictly a theoretical exercise, it would be prudent to ensure that such a combination of resulting CL , CD , and Cm is actually possible from said high lift devices. If this has already been done (or not done), please mention it explicitly. Even simple literature references should sufïňĄce for this.

- added references
- yes, CD is just offset by adding to CD_0. CL_0 is offset as well and stall is delayed (see non-extending flaps Figure 8.1 and leading edge slot 8.3: https://www.fzt.haw-hamburg.de/pers/Scholz/HOOU/AircraftDesign_8_HighLift.pdf).
- I struggled finding a better refernce for the effect of HL on drag, can you please recommend one? In the end, the point of this investigation is to identify the effect of improved aerodynamic coefficients on AWES performance. Therefore, I could also remove mentioning high lift devices.

- The text mentions: 'Lift and drag at zero angle of attack are increased, stall is delayed, and pitch moment decreased.'

ıe 165-170 The actual constraints utilised for the results discussed is vital and missing. Are all the system constraints described in Section 3.6 in Table 1.? While implementation speciïňĄc constraints are also helpful, as a bare minimum, system constrains should be listed clearly. Interpreting optimisation results without the speciïňĄcs of the constraints can be quite futile.

- Added reference to Table 1, which summarizes the majority of the implemented constraints, earlier in the text
- Inequality constraints: angle of attack and side slip angle or tether speed, acceleration and operating altitude.
- Equality constraints: Tether diameter, density and aircraft size and weight
- Added a citation to the relevant awebox website and publications for further information
- Which other constraints do you see as necessary to be specifically mentioned / listed to improve understanding?

Line 202 It is not clear why the results should not be consistent if all the studies referenced to are utilising the same model. Describe the reasoning behind expecting different results if the path constraints are the same?

- Rewritten sentence. This sentence just signifies that the trajectories are not irregular, follow expected paths. I am not expecting different results. The fact that they are consistent with previous results just emphasizes that these are not exceptional or hand-picked examples.

ɜs 203-205 Please add a plot with the tether forces and speeds over the cycle, to show how the expected trajectory is changed in order to satisfy the constraints? This would make things much clearer.

- Broke up the figure into 2 figures and added additional sub-figures to compare the changes in trajectory and caused by changes in wind speed and aerodynamic coefficients.

Line 215 Why is total cycle time constant across all variants explored? This seems more like an artefact of how the problem is setup/constraints placed on it, rather than something stemming from the physics of the problem. Please clarify the reason for this constant cycle time.

- Very minor variation between aerodynamic coefficient and wind speed were observed in the previous awebox version. The updated awebox now result higher variation in cycle times depending on system configuration. The plots have been updated and commented in the text.

Line 216 Kindly cite the previous investigations - again if they all utilise the same model, it should be highlighted that this could be a model based artefact. While from these results it would seem that the cycle time has no impact on the power produced, the trickle down effect to more detail design drivers such as structural loads (as touched upon in 4.3) are highly impacted by loading frequency which would be a function of the cycle time. Hence it would be good to know if this result is something physical or just model based.

- Clarified in text: These were previous comparisons swiping over a number of loops.
- The investigation of load cycles is mentioned in the future work section

ɜs 219-222 Some more clarity on the aerodynamic forces periodicity would be helpful here. How does it correlate to only wind speed variations for the same scale of aircraft. Similarly, how does it correlate to aircraft scale for a given wind speed? What can be said about the inïňĆuence of cycle time on the periodicity? These kind of discussions are expected from such work rather than just a direct description of the results.

- Added additional figure describing the drops in tether tension (tension troughs)

Line 230 It would be good to clarify that the power factor ratio considered (CL^3/CD^2) does not contain the tether drag. Instead, it might be prudent to use the total system's power factor that includes the tether drag when interpreting these results.

- Clarified in text
- implement tether drag power estimate & tether drag estimate in QSS section

Figure 4 It would seem that the model always tries to maintain the same number of loops (5?). Please clarify why this might be? This ïňĄgure would be much more useful if the variant wing design shown in Appendix A1 was included in the comparison. Results from A1 are for a different (onshore) wind proïňĄle, that makes it meaningless to try and derive any conclusions b/w the two wing variants (reference AP2 and HL) In the current form, the ïňĄgure lacks clarity. Instead, a single ïňĄgure showing the trajectories for multiple variants followed by a more detailed ïňĄgure investigating the variations along the full trajectory would be much more interesting.

- Clarified in text
- Number of loops is fixed = constraint
- Split figure into 2 and added additional reference for to better contextualize the results.

Line 260 Are the forces from manoeuvre loads due to the loops also neglected in this section? Was an initial estimate made before neglecting these effects? Is this true for all scales of wings considered in this study? Given the nature of the study

(path optimisation and wing scaling), can anything be said about the signiïňĄcance of ignoring the loads arising directly from the path? Overall, the motivation for including this section is lacking. The results presented here are straight forward and well understood - forces and moments scale with the wing span and aerodynamic lift coefïňĄcient. Please consider dropping this section as it does not contribute any new insights.

- Removed this section

Line 283 How exactly is P_{rated} determined? Please clarify. Is it constrained by the model? The tether forces and speeds are constrained from my understanding.

- Clarified in text
- Rated power here is defined as the maximum, almost constant cycle average power, which is constrained by the limits on instantaneous tether force and speed. From this rated wind speed can be inferred.

Line 291 Do mention effects of mass and resulting cut-in wind speed on the AEP here as well.

- Section rewritten and figure replaced

Line 298 Please motivate the depowering hypothesis for the power variations. Taking the case of $A_{wing} = 50$, why does the system depower already around the rated wind speed? $U_{ref} = 10$? An additional plot of the constraint violations at such points would be very insightful.

- Section rewritten and figure replaced
- Variation in power are the result of wind speed profile shape and the AWES trajectory. Formulation was not clear. The AWES needs to depower to stay within tension constraints (adjust angle of attack) which result in constant rated power.

Line 301 The discussion on path length is quite lacking. From ïňĄgure 7, there seems to be quite some variation that is not explained. For example, what could be the reason for increase in L_{path} for the $A_{wing} = 50$ variant at wind speeds above 25? Is it the result of a depowering manoeuvre? Please explain these results better.

- Section removed and replaced with power harvest factor

Line 304 Another reason why system constraints utilised in the model should be explicitly mentioned in one place. How is the minimal turning radius deïňĄned? How does it scale with the wings aspect ratio? Is it constrained?

- Section removed and replaced with harvesting factor

Figure 7 Please add the conïňĄguration (HL?) utilised to the legend. Rated power plots seem to have quite some anomalies - do mention if/how the data is interpolated. For example $A_{wing} = 150$ seems to have data points that are not on the curve.

- Figure removed and replaced with harvesting factor

Line 305 The motivation for deïňĄning this C_p^{AWES} is missing. The swept area for AWES doesn't compare well to the swept area of traditional wind turbines.

- Section removed and replaced with harvesting factor

Line 312 Please motivate such hypothesis with more data, it should be trivial with the model utilised here to investigate the ratio of lift force to tether drag for the design variants considered.
A ïňĄgure plotting the aerodynamic forces, inertia forces and tether drag for a few wing variants considered in the study would greatly enhance the rather brusque discussion of these results.

- Section removed and replaced with harvesting factor

Line 336 Please consider adding another data point for either conïňĄguration with a different mass scaling factor in addition to the AEP variation for the reference vs HL conïňĄguration. Figure 10 does explore this aspect to some extent, but it could be combined here for a better discussion.

- Added another figure with quasi steady-state model for reference

Figure 8 What is the reason for the HL conïňĄguration not to follow the linear increase in rated power until $U_{ref} = 10$ as the AP2 conïňĄguration? There seems to be quite some perturbations at lower wind conditions?

- Clarified in text
- This is the result of the optimization for various wind profile shapes $\rightarrow$ different local optima

Line 344 Clarify what aspect of Figure 7 shows the infeasible solutions for lower wind speeds.

- Figure removed
- the missing data represents infeasible solutions

Line 390 Why is half the tether drag attributed to the ground station? How is the ground station affected by the tether drag?

- Clarified in text
- As descried in Sub-section 3.5, the total tether drag is divided up evenly between the top and bottom node at every tether segment, resulting in half the tether drag being attributed to the aircraft and the other half to the ground station.

Line 392 Doesn't the 6DOF model utilised here compensate for the reduction in apparent speed by increasing angle of attack to maintain the same aerodynamic force?

- Clarified in text. Yes, but this is not enough to maintain sufficient lift and tether tension. Compare time series figure 6 and figure 7.

Line 405 Again, why is half the drag assigned to the ground station? The total system drag is of importance here.

- clarified in text: As descried in Sub-section 3.5, the total tether drag is divided up evenly between the top and bottom node at every tether segment, resulting in half the tether drag being attributed to the aircraft and the other half to the ground station.
- The total system drag is compensated by both the aircraft and the ground station, while the system weight is compensated only by the aircraft, because the tether can not support compression. For simplification, half of the tether drag is assigned to both the aircraft and ground station. In reality this will be distributed differently.

Line 411 Please add additional data to back this hypothesis. Would this change if the cycle time changes? This seems again an artefact of the model implementation, and not a physical effect. If this is not the case, please motivate.

- Added a small sentence referencing tension trough analysis.
- What kind of data could back this up? Optimization runs at lower wind speeds did not converge and can not be used for this analysis. It might be possible that AWES with a lower load factor can operate, but power production would be extremely low.
- It is difficult to derive general weight limits because lift force varies so much along the trajectory which is why I used average lift force.

Line 440 This should include the system weight (including tether mass).

- Clarified in text

ıe 445,455 Some ambiguity in the nomenclature - high lift airfoil != high lift devices (as was described previously).

- That is correct. What is meant is that the high lift configuration or high lift airfoil is derived from adjusting the AP2 coefficients as if high lift devices were used.
- clarified in text

Line 460 Would this be different if tether speeds are varied instead of being ïňĄxed? Is this ïňĄxed tether speed assumption probably the reason why the model has ïňĄxed cycle times for all the design variants considered?

- Yes, without this constraint the results would look very different. With unconstrained tether speed the produced power would continue to increase with wind speed.
- This constraint was applied to reflect ground station motor and generator limitations.
- The design of the ground station needs to strike a compromise between maximum power, AEP or cf and cost. In the end it is another location and wind resource specific optimization.
- Reran optimization with an updated awebox version. Now cycle times vary more with wind speed and design.

4 Technical corrections

Line 11 Missing space

- implemented

Line 427 sim=>

- implemented