Response to detailed comments of reviewer #2

Line 21: Missing citation.

#Response: This part is rewritten and now includes the missing citation.

Line 31: "These flight paths have been extensively studied in the context of AWE systems." Please, include the citations of the relevant studies.

#Response: This section is rewritten and does not include that sentence anymore.

Line 48: Predictable path shapes are not necessarily superior (see, for example, Makani Report No. 1). I suggest rephrasing this sentence.

#Response: The sentence is rephrased, as we indeed did not want convey it was more superior.

Section 1: The following reference is missing from the literature review: G. Licitra et al., Performance assessment of a rigid wing Airborne Wind Energy pumping system (doi: 10.1016/j.energy.2019.02.064).

#Response: This study is now included in the introduction section. Also, the differences to this study are mentioned.

Line 167: It's unclear whether CL and CD refer to the airfoil or the entire aircraft. If they refer to the airfoil, how are 3D effects accounted for? Including a figure showing the aircraft polars (perhaps with and without the tether) would be helpful.

#Response: We agree this paragraph lacks the proper explanation to be clear to the reader. As we think the next section clearly explains the effect of tether drag, and includes a reference to another work, this paper does not need this paragraph and we removed it altogether. The aerodynamic performance of the studied kite is explained in the cited work. This follows the comments of another reviewer requesting the methodology to be more concise.

Line 173: For aircraft, the lift-to-drag ratio is typically maximized well before stall. Is this also true for the tethered aircraft in this study?

#Response: In general, this is not the case, although we still like to stay away from stall for safety reasons. The tether drag lumped at the kite depends on the tether length, which is variable in the study as the kite flies pumping cycles. However, it is often true that the tether drag is larger than the kite drag. We did rephrase the paragraph, to fix a wrong statement (lift-to-drag-ratio should be the C_L^3/C_D^2 ratio instead, as power is proportional to this ratio instead, already concluded by Loyd). We look at large lift coefficients as the drag coefficient of the tether is generally larger than just the kite, increasing the importance of a high lift coefficient. The optimal angle of attack effectively shifts to a larger value for tethered aircraft than untethered ones. Figure 1 shows this effect. However, we think this figure does not fit within the content of the paper.

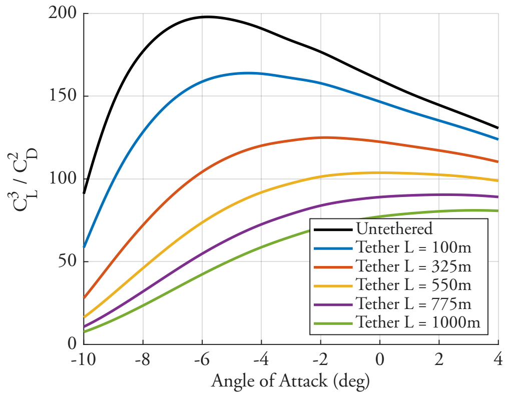

Figure 1: C_L^3/C_D^2 with different tether lengths for the MegAWES kite.

Line 177: If the polar plots were given, it would be clearer whether a 4-degree angle of attack is close to stall. What CL corresponds to 4 degrees?
#Response: As is mentioned above, the aerodynamic performance of the Kite is already published in the cited paper. In order to stay concise, this is chosen as the best compromise of including and referring to data. In that work, it is explained how the kite is kept in the linear region of the lift curve and how the maximum angle of attack for this region is determined. The CL corresponding to a 4-degree angle of attack would be 1.8, this is now added to the section as well. The aerodynamic method employed to obtain the lift curve had to stay in the linear region to ensure validity, as stall could not be predicted with the 3D panel method called Apame. The low 4 degrees angle of attack is somewhat misleading, though, as the wing has a structural twist of 5 degrees at the root. This makes the equivalent operational maximum angle of attack closer to 9 degrees.

Line 200: What is the kite position? Its center of mass?
#Response: This is rephrased; the position is indeed the centre of mass.

Line 213: Again, which reference point on the wing is used?
#Response: It is not fully clear to the authors what is meant here as this sentence does not refer to the wing. It is, however, clarified where the winch is positioned.

Line 222: What is the "equivalent wind speed"?
#Response: It means the wind speed in the direction of the tether. However, this quantity is not directly used in the framework; it is only part of the derivation. Therefore, we decided to rewrite the equation to simplify the definition.

Line 225: Please provide a brief definition of f*.
#Response: A sentence is added to define the reel-out factor f and its optimum f^*.

Line 233: Why was this optimization algorithm chosen? Please justify this choice. Also, the reference for the algorithm links to a presentation rather than a peer-reviewed paper.
#Response: The reference is changed to the actual published and peer-reviewed book chapter on the CMAES method. A justification is now provided in the text. This study built upon previous research that

had already employed the CMA-ES method successfully. Other methods, like the Matlab built-in FMINCON and GA method, were much less successful in providing a stable framework.

Line 243: I have concerns about the objective function. Why not use average power as the sole objective function and treat the other factors as constraints? If the chosen optimization algorithm does not support constraints (which I suspect), why not use a different algorithm? The choice of the objective function directly impacts the results, making this a multi-objective optimization problem where the five objectives have completely arbitrary weights. Please justify the weights selection. How could these weights be applied to other systems?

#Response: As this paper is not about optimisation, but rather a method to numerically explore parameter combinations, the weights are only there to work the optimiser towards a solution with zero penalty. As mentioned in the general response, the objective might have been misunderstood. If the mentioned values are not exceeded the penalties are zero. Therefore, a solution without penalties is what is aimed for and, thus, a constrained single objective optimisation. However, the applied weights were carefully selected to stabilise the process and fulfil the constraints. This exploration method proved to be the most successful in achieving this result, compared to the built-in Matlab GA and gradient-based methods. Especially, as we designed the framework to work with different kite designs where the initial condition is unknown. We have adapted the text to clarify this, emphasizing more this is not about finding an optimal flight path but rather to arrive at a path consistently obtained using the same objective to make the comparison more fair. We do acknowledge that changing the optimisation method and/or weight would maybe converge to a different, if not better solution, but this would require a comparison of different methods, tuning each and every one of them to work properly, which to the authors seems excessive and beyond the scope of this work. A future study could definitely focus on just the optimisation part, comparing the behaviour and convergence of different methods and their impact on the optimal trajectory for each pattern. The developed framework could function as the starting point of such a research project.

Additionally, some of these objectives may be insignificant (based on the figures, I suspect pVk = 0 and pFt = 0), while others may have large values (PAPR values in Table 3 exceed 2.5). However, these details are not explicitly provided in the results and should be included.

#Response: This is mostly answered in the previous response. We do not look at multiple objectives. Indeed, the PAPR values never manage to go below the 2.5, which is now also mentioned in the paper. There could be several reasons for this, one of which might be that we are stuck in a local optimum that in the current conditions does not manage to reduce the PAPR to 2.5, but at least tries to minimise it. Another reason could be that it is a limit of the longitudinal controller. In the paper we refer to another work, which explored minimising the power peaks by an additional tether force controller.

Section 2.5: The comparison criteria should align with the objectives. Two of the criteria are included in the objective function, but one is not—please elaborate on the reasons.

#Response: In general this would be true. However, this work intended to compare these criteria based on comparable flight paths, which are obtained by optimising the power.

Line 276: Why was 15 m/s chosen? Does this represent below-rated condition? Which wind shear is considered for the study? I cannot find this information.

#Response: The wind shear used was indeed not mentioned, this is added to the subsection system parameters. We use the measurement data from the Ijmuiden offshore measurement mast and after the maximum wind speed is reached the wind speed remains constant (at 250m altitude). The 15 m/s is indeed a below-rated condition. This allows the operation to be at maximum production capability as the kite should perform less optimally after rated power, which is beyond the scope of this work. Even though a rated power was never chosen for the MegAWES kite, during winch sizing (separate work), a 3MW limit was set, corresponding to about 20 m/s wind at operational altitude. The 15 m/s wind is the maximum wind speed in the simulation and thus constant from 250 meters altitude. Effectively, this means the tether only sees the wind shear, the kite experiences a constant wind speed of 15 m/s. Even though wind shear would add some variability in velocity throughout the pattern, we decided a study using a different wind shear model would be good for future analysis.

Line 285: Please provide citations for these statements. A low turning radius causes the aircraft to bank inward, reducing its projected area relative to the wind direction. As discussed in Makani's first report, this is one reason for avoiding low turning radii. Additionally, low turning radii experience greater wind speed reduction, though this effect does not appear to be considered in this study.

#Response: Indeed the first Makani report discusses the effect of banking on tether tension and thus finds the optimal path radius based on maximising power. This is included, as the forces and orientation of the kite influence the dynamics and thus time stepping. Which affects the force balance of the overall system and finally affects the power. We added this statement to the discussion. The explanation does not come from a reference, but is rather derived from the definition of centripetal acceleration and force, which are also mentioned in the Makani report. In order to make the patterns comparable, the cross-track error was set to a maximum of 75m. This way, we ensure the kite is always close to the prescribed path, and therefore, we can use the prescribed path as a comparative measure rather than the actual flown trajectory. A smaller radius and similar velocity would increase the centripetal force. To maintain control and prevent drifting outwards, either the velocity should increase or the aerodynamic performance. However, searching for power optimal solutions and assuming the wind speed is below rated, one can assume the kite operates around its aerodynamic maximum capabilities, leaving only the velocity to compensate. This is indirectly changed throughout the course of the parameter exploration as velocity cannot be directly controlled. That being said, the increased velocity also increases the aerodynamic forces. The upwind wind speed reduction for low turning radii is indeed not included, as there is no wake model. We believe a wake model would be too detailed for this work. The effect would further strengthen the statement that there is a limit on how small the turning radius would become.

Figures 8, 9, 10: These figures might be more appropriate for the appendix. Since this paper focuses on optimization results rather than the optimization process itself.

#Response: These three figures provide information on the relation between the power and the different pattern sizes. We do acknowledge that the paper might have focused too much on the word optimisation rather than constrained design space exploration towards a comparable path. Therefore, the images are modified to show the relations between the pattern dimension and performance criteria more clearly.