Author's response to Anonymous Reviewer #1

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Dear Reviewer,

thank you for taking the time and effort in providing us with your detailed feedback and diligent comments. We feel that they have contributed significantly to the strength of the manuscript. In this document, we address these comments point by point including pointers to the changes made in the manuscript. When referring to Figure and Table numbers, we use the numbering in the updated manuscript.

Kind regards,
Jochem De Schutter on behalf of the authors

Comment 1.
I was not familiar with the concept of wake regeneration above conventional wind farms, so perhaps this could be explained a bit in more detail: How does this work? What is the advantage? .

Response:
In this concept, kite systems (without own generation capability and thus with low complexity) could be installed strategically between wind turbines in an offshore wind farm, possibly only using existing infrastructure. By flying above the wind farm, they would be able to redirect airflow from the unaffected boundary layer into the wake of wind farms to enhance their overall efficiency through wake re-energizing. The initial simulation studies referenced in the text indicate that a wind farm performance boost of several percentage points could be attainable. We have added more explanation in the text, but removed the reference from the abstract so as to not distract the reader at that point.

Comment 2.
Line 15: "The solution of the original no-wake problem deviates with 145 % compared to this reference solution." Specify what solution you are looking at; is it power, trajectory? I only find out later that it is the force. Furthermore, what is the reference solution? The one that includes the wake? Please clarify. .

Response:
Thank you for pointing out this inclarity. We have elaborated as follows: "In a numerical case study based on a dual-kite system, we examine the sensitivity of the OCP optimal cost (average tether force) and design to the key transcription parameters. Based on this sensitivity analysis, we find an efficient transcription that solves the problem at three times the computational cost of the OCP without any wake model, while still retaining accuracy (in terms of combined error of optimal cost and design) within 5 % compared to a highly resolved transcription of the wake-aware problem. The solution of the no-wake problem deviates with 145 % compared to this highly-resolved reference solution."

Comment 3.
Introduction: The writer could refer to the following papers:

- T. Haas, J. De Schutter, M. Diehl, and J. Meyers, "Large-eddy simulations of airborne wind energy farms", Wind Energy Science, 2022.
- J.-B. Crismer, T. Haas, M. Duponcheel, and G. Winckelmans, "Large eddy simulation of airborne wind energy systems flying in turbulent wind using model predictive control", Wind Energy Science Discussions, 2026, Preprint discussion started: 09 Jan 2026; under review for Wind Energy Science (WES).
- Pynaert N., Haas T., Wauters J., Crevecoeur G., Degroote J. (2025). Aero servo simulations of an airborne wind energy system using geometry-resolved computational fluid dynamics. Wind Energy Science (WES). https://doi.org/10.5194/wes-10-2663-2025.

In these studies, the wake is simulated by coupling AWEbox to a virtual wind environment (LES-RANS) that includes the wake implicitly. The trajectories that are flown are, however, based on simplified models that do not include the wake. The aforementioned studies could benefit from your work. It could also be interesting to compare the wake and induction with these studies (perhaps in future work).

Response:
Thank you for the suggestion. We agree and have integrated this research branch into the introduction narrative.

Comment 4.
Line 55: "In conclusion, the accurate performance assessment of utility-scale kite systems requires the development of optimization-friendly engineering wake models capable of capturing self-induction effects." It could be beneficial to stress that the high controllability of airborne wind energy systems enables them to avoid wake and induction effects, potentially increasing power output, provided that this information is incorporated into the controller, further highlighting the significance of this study.

Response:
Thank you for this suggestion. We have added the sentence: "Moreover, kite systems possess many degrees of freedom and their high controllability allows them to adjust their flight path so as to avoid wake effects in consecutive flight loops, thereby boosting performance, provided that this information is incorporated in the optimization model."

Comment 5.
Line 80 "To limit the scope of this paper, we consider a kite system with fixed tether length, thereby excluding pumping-style AWE systems, which rely on tether reeling." Also specify that no power generators are involved; e.g. fly-gen systems, but purely act as actuators.

Response:
We have added this information in the paragraph.

Comment 6.
Line 94: You introduce y as a parameter for the wake state; is it possible to give a physical meaning to the "wake state" to help the reader? Also sometimes it is denoted as y(t,.), something y(t,tau); is there a (mathematical) difference? Please explain.

Response:
The full wake state $y(t, \cdot)$ represents the full spatial vorticity distribution (structure, orientation, strength, ...) that has resulted from the flight trajectory up until the current physical time t. The wake state $y(t, \tau)$ then represents an infinitesimal segment of this distribution, which has an age (or convection time) $\tau \in \mathbb{R}^+$, which represents the time elapsed since that portion of the wake was generated at the boundary $\tau = 0$. We have added this explanation to the text.

Comment 7.
Line 109: A figure would be helpful for the reader to visualize the states of the system.

Response:
We have added an illustrative figure of the system including the states.

Comment 2.
Line 131: "Incorporating more realistic wind and density profiles as a function of flight altitude is considered straightforward and omitted here for simplicity." I would argue that wind shear has a big influence on the wake development, so I am not so sure this is straightforward.

Response:
Thank you for this comment. We have changed the formulation to be more precise. Within the proposed framework, one would need to just insert any

wind shear profile $u_\infty(z)$ into the model, and it would be taken into account automatically in the wake development (different convection speeds at different altitudes). That is the "straightforward" part. However, we admit that in this case further validation simulations would be necessary.

Comment 8.
Line 156: "properly distributed"; do you mean uniformly distributed?

Response:
We have clarified: For each tether, these forces are computed for the boundary nodes such that they produce resultant forces and moments equivalent to those obtained by numerically integrating the drag distribution along the tether.

Comment 9.
Line 171: "For each wing, we ignore the induction of its own trailing wake less than a time T away, since this part is taken into account by the induced drag term." Can you discuss what would be the effect of not including the induced drag instead?

Response:
Accurately resolving this region would require a significantly finer representation of the vortex distribution close to the wing, increasing model complexity and computational cost. We have made a clarification in the text.

Comment 10.
I find "u^f" not so intuitive to indicate the induced velocity, but perhaps this is the standard notation in the literature.

Response:
The "f" superscript refers to "far"-wake induction as opposed to the "near"-wake induction included in the induced drag term. Here, we follow the notation of [Trevisi et al., 2023]. We have added this relationship in the text.

Comment 11.
Figure 1: Indicate both methods using (a), (b), or (left),(right).

Response:
Thank you for the correction.

Comment 12.
Figure 3: The legends in panels (b) and (c) are difficult to read; using black instead of white would likely improve their readability. In addition, including the system trajectory in these figures would provide valuable additional context.

Response:
Thank you for this comment, we have changed the figures accordingly.

Comment 13.
Line 250: "One problem is that the optimal orientation trajectory by construction assumes zero angle-of-attack"; I would rather state that the angle of attack is not included or represented in the model, zero angle of attack would mean zero lift (or zero angle-of-attack lift).

Response:
Thank you for the suggestion, which we have implemented in the text.

Comment 14.
Figure 4: I had some difficulties understanding the figure. Clearly indicate in the figure what is part of the DUST simulation (I assume the thin black line) and the vortex loop wake (I assume the red dots, and blue arrow?).
Response:
We have added the kite trajectory to the plot, added more information to the legend and the caption so that all visual information is clearly defined.

Comment 15.
Line 323 "For the atmospheric airborne actuator case, as well as for the ship towing case, the tether pulling force is to be maximized." Please provide additional explanation and justification for why this metric is the most appropriate or meaningful choice for the atmospheric actuator case.
Response:
The rationale behind this metric is that it is used as a simple proxy for the amount of momentum that can potentially be redirected into the wind farm. We have added this explanation to the text.

Comment 16.
Figure 6: Indicating the system trajectory in the figure would improve clarity. Additionally, including an error contour plot could further enhance the informative value of the results.
Response:
We have added the full flight trajectories as well as the wing position and orientation at the time of the snapshot. While we do not disagree that an error plot would provide additional information, we have chosen to not include it in this text and we hope the reviewer agrees that, given the added orientation by the kite trajectories, sufficient information is available to compare the two results.

Comment 17.
Combine figure 6,7,8 to enhance the readability.
Response:
We have implemented your suggestion.

Comment 18.
Table 1 describes the system variable bounds (both tether and wing properties),

and Table 2 describes the kite system model parameters (both tether and wing properties). Why are they not presented in the same table? Furthermore, how are these system parameters determined?

Response:

The tables are separate because they provide different types of information (fixed parameter values vs. min-max variable bounds). While both tables address properties of both wing and tether, there is no parameter/variable that is present in both tables. So merging both tables would lead to many empty entries. However, we have moved Table 1 further backwards in the paper, closer to Table 2, since the numerical values are only relevant in the numerical example. In short, the parameters are chosen so as to represent a very high-load utility-scale example, using typical values from the AWE literature. We have provided more specific justifications in the text (beginning of Section 6.1).

Comment 19.

I wonder if it would be valuable to also compare the discretized wake with the DUST simulations.

Response:

We have added a comparison of the aerodynamic loads for the reference OCP transcription with the analytic vortex-loop solution and the DUST simulation using the exact same boundary condition, showing very good agreement.

Comment 20.

Line 418: "The transcription includes a time transformation approach to deal with the variable time grid." This appears to be an important step and would benefit from a more detailed explanation.

Response:

This is a standard technical trick since many years, not specific to the new developments. We have added a reference should the reader want to learn about the technical details.

Comment 21.

The optimal flight trajectory obtained using the no-induction model appears physically unrealistic. For a flight speed of 190 m/s and a turning radius of 50 m, the required centripetal acceleration would be approximately 73 g, which is far beyond feasible operational limits. Please clarify this point and discuss the physical realism and practical implications of the resulting trajectory.

Response:

We agree that the concrete presented trajectory is outside the range of practical relevance. Nevertheless, induction (and tether drag) effects are roughly independent of the chosen wind speed (see [Trevisi et al, 2023], where a simplified model is derived and the induction factor only depends on the gliding ratio), and similar validation and design trade-off results are therefore expected for lower design wind speeds with lower flight speeds and therefore a more reasonable flight envelope. The main modeling error here is that the mass of the wing does not scale appropriately with the very high observed wing loading, leading to an underestimation of the gravity-induced variations in the flight speed. However, in the dual-kite set-up, such variations are exptected to be low anyway. Since the goal of the example was to generate an extreme scenario for the validation rather than to examine practical design trade-offs, we decided to not repeat the simulations at lower wind speeds. We have added this explanation in the text.

Comment 22.
Line 488: "The model is also very well able to capture the induced velocity field around the wing trajectory flown, suggesting that it is well-suited for optimization purposes." I believe this sentence is a bit misformulated: The system model, including the wake model, increases the accuracy; on the other hand, the speed will determine if it is well-suited for optimization purposes. E.g., High-fidelity LES would not be well-suited for optimization purposes, but captures induced velocity very well.
Response:
We agree and have removed this part of the sentence.

Comment 23.
Line 493: Specify the original OCP (with or without wake model?)
Response:
We have changed the text accordingly.

Comment 24.
Line 495: Specify the reference solution (with or without wake model?)
Response:
We have changed the text accordingly.

Technical corrections

Comment 25.
At the end of the introduction, the conclusion is not included in the discussion of the structure of the paper.
Response:
We have adjusted the text accordingly.

Comment 26.
To be checked with the editor, but if I remember correctly, vectors should be defined in bold.
Response:
This is indeed the guideline, and we have changed the text accordingly.

Comment 27.
Section 4.4 has almost the same title as Section 4.3.
Response:

We made the titles more precise.

Comment 28.
Figure 9: Please explain N, M, N, to make the figure self-explanatory.
Response:
We have added more explanation to the caption.

Comment 29.
Figure 9: Punctuation mark forgotten.
Response:
Thank you, we have made the correction.

Comment 30.
Line 418: "four RadauIIa collocation points" → Typo?
Response:
This is not a typo, RadauIIa is a Runge-Kutta integration method.

Comment 31.
An introduction to the sections is missing in Chapter 6.
Response:
We have added an introduction.

Comment 32.
Eq. 10: is "u_t, i" defined somewhere?
Response:
This is in essence just a helper variable to build up the formulas more slowly, but to be sure we have added a definition in the text.