Response to Anonymous Referee #3

Authors' responses to reviewer comments appear in blue text. Line numbers referenced in the authors' responses refer to the revised document. Figures with Arabic numerals (e.g., Figure 10) correspond to the revised manuscript; figures with Roman numerals (e.g., Figure iv) only appear in response to the reviewer's comments.

We sincerely thank the reviewer for their valuable comments, which have greatly improved our manuscript.

The present studies are intended at investigating the wake characteristics of a balloon wind turbine using an actuator disk theory solved through an LES solver. Although the topic itself is of interest, I do feel the authors need to improve the paper for publication. The following aspects are some comments from my side:

1. The authors provide too detailed formulations on the LES and actuator disk theories while they do not attempt to improve them. These can be omitted.

   Thank you for your feedback. We have carefully considered your comment and made revisions to reduce the extent of this section while still ensuring clarity and comprehension. The governing equations of LES and sub-grid stress model for turbulence modeling were removed from section 2. General descriptions of Momentum and Balde element theories were eliminated from sections 3.1 and 3.2. Moreover, primary equations in these theories, i.e., equations 1, 2, 13, 14, and 15, and their descriptions were eliminated from the sections. Nevertheless, the secondary equations resulting from the substitution of various variables in these equations were retained to convey the fundamental principles of the BEM theory.

2. Numerical description is too weak. The authors shall provide more information about the approaches used to solve the sets of flow equations, e.g., time integration? discretization? convergence acceleration?

We added more information about the simulation set up in Line (210) of the manuscript as follows:

Line (210): The PISO scheme was utilized for pressure-velocity coupling. This scheme is well-suited for unsteady and highly transient flows, which are characteristic of wind turbine wake simulations. For spatial discretization of pressure and momentum, the second-order form and the time integration, the second-order implicit, were employed to improve the stability and convergence of the simulations. Simulations ran for a maximum of 20 iterations per time step, using a convergence criterion of 1×10^{-4} for the residuals in all cases.

3. Temporal discretization studies are not performed. How can we sure the solutions are accurate with respect to time size?

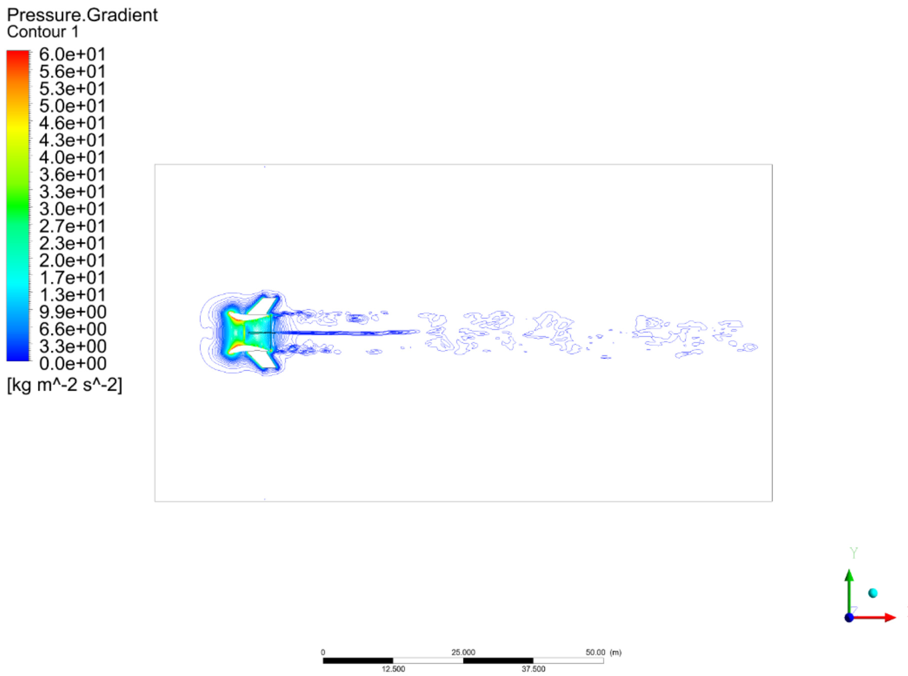
Due to the inherent complexity and computational demands of LES, conducting a comprehensive investigation into the accuracy with respect to time size would have imposed significant limitations on our computational resources. However, we would like to emphasize that we took steps to ensure the accuracy and convergence of our simulations in terms of the time step size. Sensitivity studies were conducted to assess the impact of the time step size on the convergence of the simulations. After careful consideration, we selected a minimum time step that led to the convergence of the simulations, which was approximately close to the rotor rotation of 2.5° ($\Delta t = 0.0016$ s).

The criterion used for the computation of the time step was added to Line (215) of the manuscript as follows:

Line (215): The size of the time step was selected after sensitivity studies to assess the impact of the time step size on the convergence. The minimum time step leading to the convergence of the simulations was selected, which was approximately close to the rotor rotation of 2.5° ($\Delta t = 0.0016$ s). LES calculations were run sufficiently to reach stable statistics of the flow.

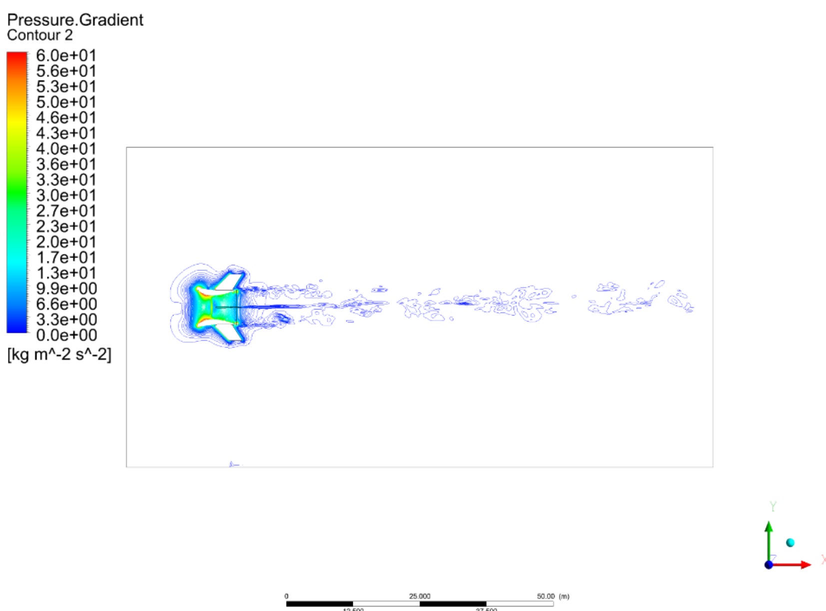
4. Upstream domain looks a bit too small.

To complete the determination of the domain dimensions, it was solved separately by different domain sizes and observing the variable flow gradients at the boundaries. The computational domain was chosen as the minimum size that exhibited zero gradients at the boundaries. Figure i illustrates the pressure gradients for $U_{ref} = 7$ m s^{-1} and $\theta_{tilt} = 0^{\circ}, 5^{\circ}$ and 10° on a symmetry plane of the balloon in the finalized domain. The pressure contours provide an evident indication that there is no pressure gradient present at the boundary of the domain with the determined dimensions.



Pressure.Gradient
Contour 1
6.0e+01
5.6e+01
5.3e+01
5.0e+01
4.6e+01
4.3e+01
4.0e+01
3.6e+01
3.3e+01
3.0e+01
2.7e+01
2.3e+01
2.0e+01
1.7e+01
1.3e+01
9.9e+00
6.6e+00
3.3e+00
0.0e+00
[kg m^-2 s^-2]
Y
X
0
25.000
50.00 (m)
12.500
37.500

(a)



Pressure.Gradient
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5.3e+01
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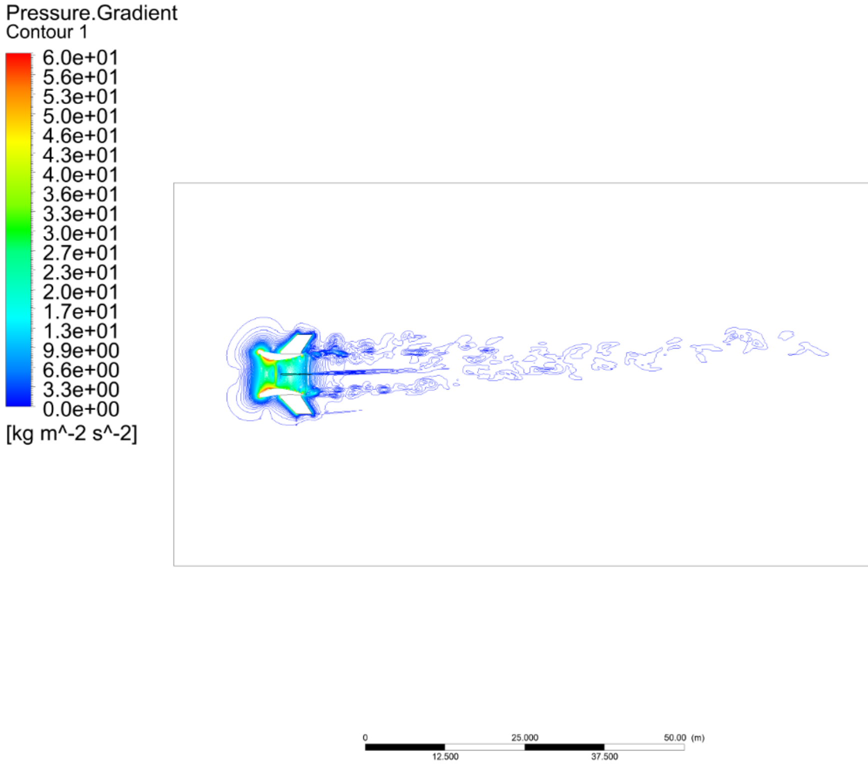
4.3e+01
4.0e+01
3.6e+01
3.3e+01
3.0e+01
2.7e+01
2.3e+01
2.0e+01
1.7e+01
1.3e+01
9.9e+00
6.6e+00
3.3e+00
0.0e+00
[kg m^-2 s^-2]
Y
X
0
25.000
50.00 (m)
12.500
37.500

(b)



(c)

Figure i. Pressure gradient contour for U_{ref} = 7 m s^{-1} and(a) $\theta_{tilt} = 0^{\circ}$, (b) $\theta_{tilt} = 5^{\circ}$ (c) $\theta_{tilt} = 10^{\circ}$on the symmetry plane of the balloon (z=0).

5. Validation studies use conventional wind turbines, while the case being studied is much more complex.

Due to the novelty of balloon wind turbines, there is a lack of experimental data in the literature to validate the numerical results pertaining to their aerodynamics and wake flow. Nevertheless, it is possible to assess the methodology employed in this study to characterize the wake flow of these turbines. To this end, we employed the same methodology to investigate the wake behavior of a smaller turbine that had been previously studied experimentally.

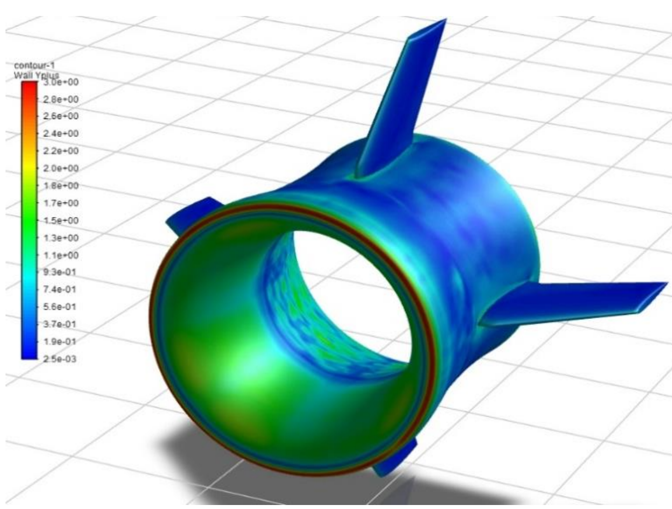
There are two key differences between the balloon wind turbine and the smaller turbine: the diameter of their rotors and the presence of the balloon in the main model. Based on the results obtained from the balloon wind turbine, it is evident that the effective length of the rotor wake is considerably longer than that of the balloon, and they do not interact under various inflow conditions considered in this study. Hence, the wake flow behavior of the rotor is independent of the balloon.

Although the turbine being studied differs in diameter from the smaller turbine used for validation, it is still significant to validate our methodology using a smaller turbine with available experimental data. The purpose of this validation was to demonstrate the accuracy and reliability of the numerical approach, irrespective of the specific turbine size or complexity.

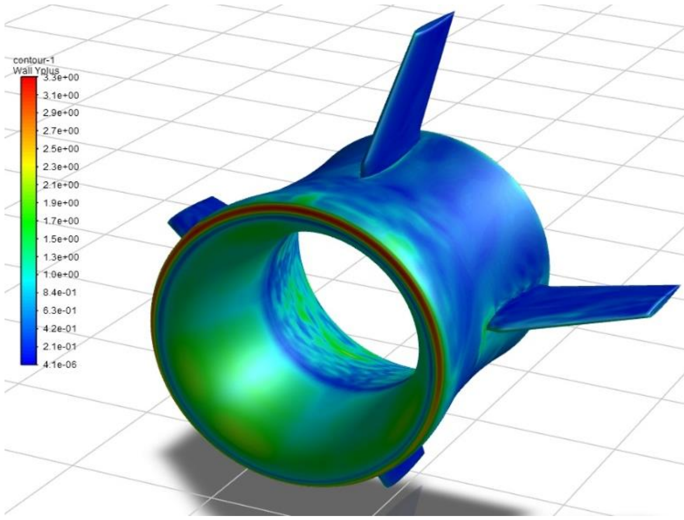
Furthermore, the utilization of LES enables high-resolution analysis of the turbulent flow structures within the turbine wake. By adequately resolving the flow features, our model captures the intricate complexities associated with different turbine sizes. The results obtained from the validation study showcased a satisfactory agreement between the LES-ADM method and experimental measurements. Therefore, in the absence of experimental data for the balloon wind turbine, we argue that validating the robustness of our methodology through promising outcomes obtained using the same approach serves as a reliable indicator of the accuracy of the main model's findings.

6. If the authors claim to use LES, is the energy in the proximity of the balloon wall resolved well?

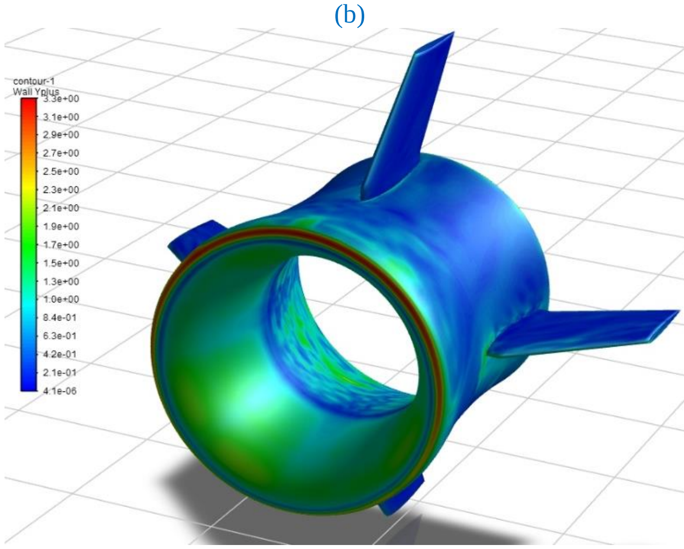
In LES, the y^+ values should be lower than 5 for wall-resolved LES simulations. Moreover, the Dynamic Smagorinsky model tends to perform better in capturing near-wall turbulence compared to traditional static SGS models, as it adapts the SGS model coefficients dynamically based on the local flow characteristics. When using this model, a lower y Plus value (closer to 1) is often recommended for accurate resolution of the near-wall turbulent structures. This is because the model is designed to capture small-scale motions more effectively, and a finer resolution near the wall helps to capture the important energy-containing turbulent eddies. When the y^+ value falls within this range, it generally indicates that the energy near the wall is resolved well. To reach these values near the balloon wall in the simulations, the mesh size and its spacing near the wall were adjusted accordingly. Figure ii illustrates y^+ contours for $U_{ref} = 7$ m s^{-1} and $\theta_{tilt} = 0^{\circ}, 5^{\circ}$ and 10° on the balloon wall. According to the figure, the value of this parameter is close to 1 in most regions on the wall and does not exceed 3.5 in any region for different wind scenarios.



(a)



(b)

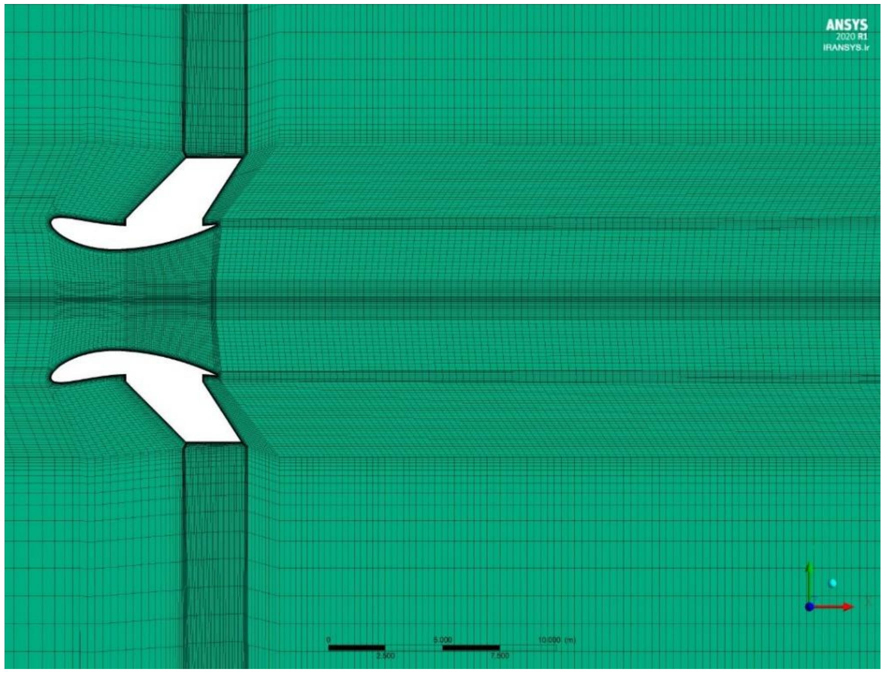


(c)

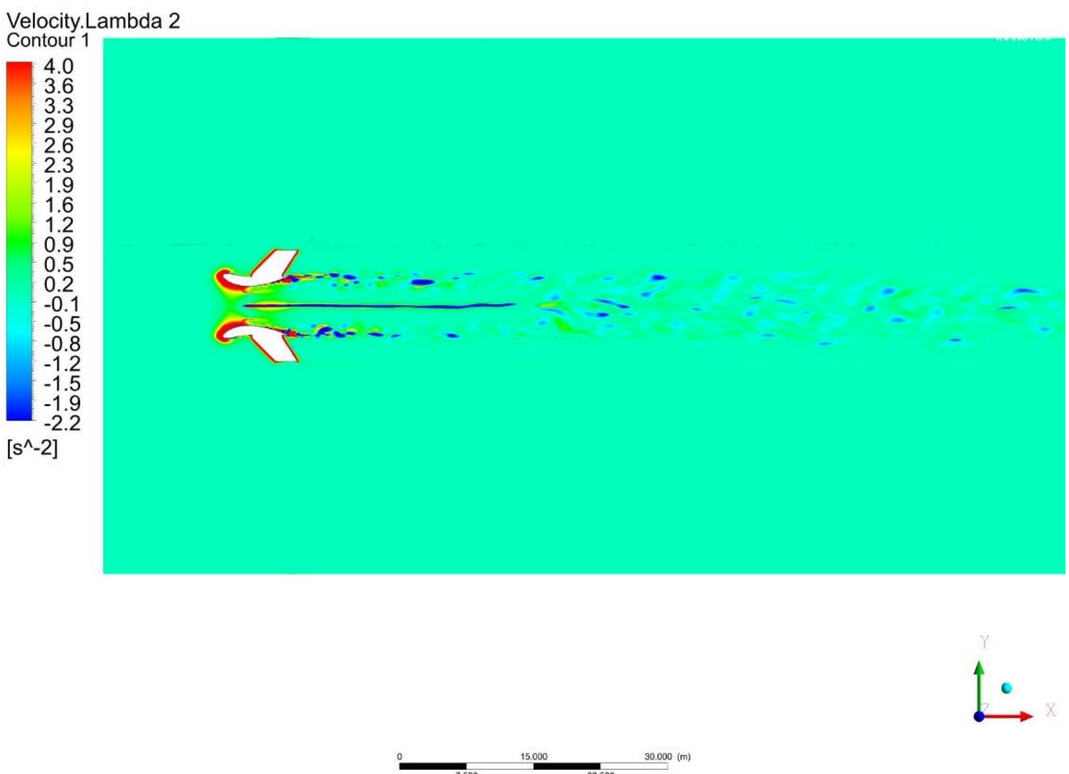
Figure ii. Wall Yplus contours for U_{ref} = 7 m s^{-1} and (a) $\theta_{tilt} = 0^{\circ}$, (b) $\theta_{tilt} = 5^{\circ}$ (c) $\theta_{tilt} = 10^{\circ}$ on the balloon's wall.

7. The authors focus the studies on the wake, but the mesh behind the balloon does not seem to be well refined such that it can well resolve small eddies. Perhaps plot the Q or Lambda2 criterion?

To determine the mesh distribution in the wake region, LES mesh criterion, which is presented in section 5.1, was adopted. The mesh size in the near-wake is illustrated in Figure iii (a). To resolve smaller eddies behind the turbine and balloon's separation region, the mesh sizing in these areas were refined to be smaller, which is evident in the figure. The magnitude of Lambda 2 is clipped for smaller eddies, and the corresponding contour is depicted in Figure iii (b). It is evident that the small eddies in the separation zone of the balloon and the wake of the turbine are properly resolved.



(a)



(b)

Figure iii. (a) Mesh distribution (b) Lambda 2 contour on the symmetry plane of the balloon

8. Last minor aspect: remove the 6th point in Conclusion as nothing is written there.

Thank you for pointing out this error; we have removed it.