Force Partitioning Analysis of Vortex-Induced Vibrations of Wind Turbine Tower Sections

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The authors would like to thank you for reviewing our draft paper, and for your valuable feedback and comments. In the following sections, we try to address the reviewer's comments separately. The comments of the reviewer are marked in **bold** font, where the reply is written in *blue* and the changes in the manuscript as *red*. The line numbers are marked according to the updated manuscript.

Technical Comments

1. L31: the list of possible ViV is interesting, it will be better to illustrate the impact thanks to, ideally, a picture of it happening or at least a sketch

A figure is added in the introduction section showing the possible scenario when a wind turbine tower experiences VIV.

Line 33: Figure 1 shows a load case when a tower is standing on the foundation during installation at the site.

2. Fig3, why the cylinder not centred in the domain ? Was there any sensitivity study performed regarding the domain size and /or cylinder position ?

The cylinder is not placed in the centre but slightly toward the inlet, as is common in other literature [2, 5]. This further helps reduce the total number of cells required for the computation, thereby reducing costs.

A sensitivity study for the domain size was not performed for the current study but results are validated across a wide range of Reynolds numbers, further providing confidence on the domain size and cylinder placement.

3. L170: precise the FSI is performed using modal approximation (similar to OpenFAST). At first, it could be understood that a FE approach is done.

The sentence is modified as shown below:

Line 171: The structural properties of wind turbine towers must be calculated accurately to perform FSI simulations, which are carried out using modal approximation.

4. L174: illustrate the "stepped tower" used in your calculation

A figure is now added with edited text in line 174, as shown below.

Line 174: The wind turbine is considered as a stepped tower with n segments to calculate the natural frequency, as shown in Figure 5.

5. Eq10 and Eq15 use capitalised psi (Ψ), while Eq11,12,13,14 use the non-capitalised version (ψ)

The equations are corrected and ψ is used for consistency.

6. Eq11 and Eq12: consistency in writing the derivative. Either v'' and v' or $\dot{v}$ and $\ddot{v}$; here both are used

The variable v' represents the derivative of v in space, whereas $\dot{v}$ represents the derivative of v in time. Following sentence is added to line 185 for further clarity.

Line 185: , where $'$ represents space derivative and $\dot{}$ represents derivative in time.

7. L195 / Eq18, the phrasing "equivalent moment of inertia and mass" can be misleading as it looks like an average value, since it is the total sum divided by the length ? Moreover, saying "These equations are divided by the total length of the tower to ensure that both i_{eq} and m_{eq} have the right units of the moment of inertia and mass per unit length" feels like the i_{eq} and m_{eq} are build to satisfy your needs rather than the opposite. If it is not the case, could you please elaborate ?

Thank you so much for the comment. The term equivalent is used instead of average as I_{eq} and m_{eq} represent the moment of inertia and mass per unit length of a tower with varying dimensions along the length. As pointed out by the reviewer, line 199 may lead to confusion, and it is consequently removed.

Line 199: ~~These equations are divided by the total length of the tower to ensure that both I_{eq} and m_{eq} have the right units of the moment of inertia and mass per unit length.~~

8. L218: the mean error is calculated with respect to the Richardson extrapolation or previous results from Viré et al. ?

The mean error mentioned in line 220 is calculated with respect to the Richardson extrapolation. The error value is calculated between the medium and fine meshes. Furthermore, the meshes are compared to the literature, where an acceptable error in pressure curves and the separation point is found.

9. L223: the separation point is provided in degree, I suppose it is when the cross section of the cylinder is plotted on an r-theta coordinate system ? Here everything is provided in

cartesian or in x/c coordinate. Could you translate your results from degree to x/c system, so that it fits the plot in Fig4

The location at x/c coordinate is added to line 223, and the line is modified as shown below:

Line 223: Furthermore, the medium and fine mesh predict the separation point to be 112.2° ($x/c = 0.6889$) and 111.8° ($x/c = 0.6857$) respectively, in comparison to 111° ($x/c = 0.6792$) from the literature.

10. L269: The methodology to derive the natural frequency is detailed in section 3.1 and the numerical result is 0.48Hz. Using the methodology described in "aerodynamics of wind turbine" from Martin Hansen. Do you end up to that same frequency ?

The natural frequency of the tower is derived using the method to estimate the first flap-wise eigenmode, as described in the referenced literature. The frequency is calculated to be 0.56. The authors believe the reason for the difference in frequency could be twofold: (i) The natural frequency is calculated for the tower without including the waterline, but from where the tower actually starts. (ii) According to Structural Dynamics by Roy R. Craig [3], there can be a slight difference in the calculation of frequency between the Rayleigh method and other methods, depending on the Rayleigh Quotient calculated.

11. Table 2: Understood that the code needs a 3D structure, however a single cell of 1m seems prone to introduce edge effect ? Have you checked that ? Why not introducing either a small cell size (e.g. y+ dimension) ? Or using the same refinement in the z-direction than for x and y but on a smaller length (to limit the computational cost)

The single cell thickness is made to be in the similar order of the cell size near the inlet, outlet and far-field boundaries. The mesh is found to have sufficient quality when checked for aspect ratio, orthogonality and overall mesh parameters.

12. Section 4.2.1: It seems that GCS was performed only for Re = 3.6e6 ? I fear that for very high Re (e.g close to 18e6) the mesh may not be sufficient, have you performed analysis to verify that ? (even if it is not properly described in the paper)

The grid convergence study is indeed performed for $Re = 3.6 \times 10^6$, but the results are verified for $Re = 8 \times 10^6$ by comparison with the literature as shown in Table 1. The Reynolds numbers considered for this verification were up to $Re = 8 \times 10^6$. This seems reasonable as the wind turbine tower usually does not experience Re greater than 1×10^7 (corresponding to a wind speed of 25 m/s).

Study	Re	Strouhal Number	Mean Drag coefficient
Derksen [1]	8×10^6	0.34	0.36
Squires et. al [4]	8×10^6	0.37	0.37
Present study	8×10^6	0.34	0.397

Table 1: Comparison of results with the previous studies for $Re = 8 \times 10^6$.

13. Fig9: very interesting plots! For consistency can you use the same "time zones" in your zoomed in snippets ?

Thank you for your comment. The figures are updated with the same time limits on the x-axis.

14. L306: I was expecting to see vortex shedding behind a cylinder when reviewing the paper. When discussing about the "beating pattern" it would be interesting to see it by plotting the vorticity is Q-criteria. With a cylinder having Von Karman streets should be easy to see and correlates to the shedding frequency.

A new figure is added to the manuscript showing the vorticity behind the cylinder. The following lines are added to explain the figure.

Line 313: Figure 12 shows the vorticity formed behind the cylinder when the lift force develops a beating pattern. Figures 12a and 12b show the wake pattern at maximum positive displacements in a cycle, where Figure 12a depicts the time when the vortex-induced force is in phase with the kinematic force. However, Figure 12b illustrates the wake pattern when the two forces have a significant phase difference. It can be observed that vortices are shed from the bottom part of the cylinder when the forces are in phase. In contrast, vortices are shed from the top of the cylinder when the kinematic force and vortex-induced force are out of phase. The wake pattern development observed here is similar to that reported in previous studies by [6].

15. Fig11: it is a very important figure which introduce the core of the result. Can you add a zoomed in version next to it where you focus between $0 < U/U_{st} < 2$ and disregard the viscous component

A zoomed-in figure is added along with the existing figure.

16. L341, "vice versa" leads to confusion I don't think it is necessary here

The word is removed.

17. Fig12: I disagree with the interpretation of these plots. The energy transfer is analogous to the system's work and rather than the average the integral should be calculated. When applying the "work-energy principle" $W = \Delta E_K = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$ where v_2 and v_1 are the cylinder speed after and before the work is done, you realise that W is non zero. The reason being the cylinder does not finishes at rest. Therefore, I would say, that the same conclusions drawn for Fig13 and Fig14 apply here. The instantaneous values seems the most relevant in the case of the building up to the ViV state. Looking at Fig12b and 12c, I would say that the kinematic force contributes more than the vortex induced force. It is even more obvious in Fig13 and Fig14, where the red shaded area is driven by the green shaded area

Authors agree to the reviewer's comment, and changes are made to the manuscript as shown below. The mean energy transfer gives an idea about the nature of the force in general. Moreover, the instantaneous energy transfer (or energy transfer for a cycle) gives a better understanding of the development of VIV. As per Figure 12 (Figure 15 in the updated manuscript), the energy contribution from the vorticity-induced force is significant during onset, which is now added as shown in the text below. However, in all the cases, the contribution from the kinematic force drives the oscillation to be sustained, as shown in Figures 13 (Figure 16 in the updated manuscript) and 14 (Figure 17 in the updated manuscript).

Line 355: The major energy contributor to the lift force during the onset of VIV is the energy from the vortex-induced force.

Line 358: As the oscillations become significantly larger, the energy from the added mass contributes to the overall energy in the lift force.

18. The conclusion is well written and summarise nicely the work performed and outcomes. It is mentioned that tower designer should take care of cylinder size, taper, taper ratio. Will an second part of the current paper address in more details the relationships between those design parameters and the lock-in phenomena ?

Thank you so much for your comment. The next steps in the research will be to carry out numerical simulations for a three-dimensional tower and to study the effect of surface roughness, as explained in the conclusions section of the manuscript.

References

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