# Review of “High-fidelity aeroelastic analyses of wind turbines in complex terrain: FSI and aerodynamic modelling“

Christian Grinderslev, Postdoc, DTU Wind Energy

**General comments:**

The paper presents results from a set of fluid-structure interaction simulations of a small wind turbine with increasing complexity in both structural representation and wind flow. The most complex case considers a fully resolved wind turbine including tower, set in complex terrain with forest elements upstream creating a highly turbulent inflow. All this with the wind turbine structurally represented as shell FEM elements for the most complex case. The step wise increase of complexity allows the authors to assess the impact of various choices such as the impact of structurally using shell elements rather than beam elements, along with the impact of even considering flexibility in such simulations.
The study concludes that for simple uniform inflow, the choice of structural representation has little impact on the response, whereas a higher dependency is found when considering more complex wind flow. The impact of including flexibility is investigated by looking at velocity deficits in the near wakes along with computations of the damage equivalent loading (DEL) with and without flexibility. It is found that for simple inflow the DEL increases when including flexibility, while the opposite happens in the turbulent inflow.

The paper is well written and easy to follow. The simulations are the most complex I have experienced, considering both high complexity in flow, terrain and structural representation. The step wise increase in complexity allows to easily follow its impacts.

I do have some requests of minor corrections/clarifications as stated below. I especially have many questions to the CFD setups, which could be clarified for the sake of reproducibility. Don’t be fooled by the amount of comments. I am very happy about the work, but I think there are low hanging fruits to harvest.

All in all, I recommend publication of the article after the minor adjustments.

A big thanks to the authors for an excellent contribution to the field, showing how far we have come in the world of blade resolved fluid-structure interaction. I’m looking forward to following the continuation of the work and the validation with experiments.

**Specific comments/questions:**

## Section 2.1.1 - CFD setup:

The **domains** of the various CFD setups are depicted in figure 2.

- It would be nice with an explanation of the abbreviations (FMC, FMT and so on.) I guess FMC is “full model complex” and so on, but it would be nice for the reader to see it more explicitly written out in order to remember it easily later on.

- It would be nice with some dimensions of the domains on the figure, as they seem to be quite different. Also state the position of the turbine in the domain.
- For the FMC case, the domain seems extremely wide, while quite short. First of all, why so wide? Secondly, is the distance from rotor to outlet only 3D as suggested in Figure 11? It might be due to the ratio, that it seems short, but have you conducted a tests of the sensitivity of this? In my experience having the outlet of the domain too close to the turbine can have a big effect on results.

The **grids** are presented here as well:

- How are the cell sizes of the upstream cells which transport the turbulent inflow? What kind of resolution can be captured?
- For the NS-walls at the ground, do you really resolve the boundary layer close to the surface to a y+=1? Or do you use a wall function?
- You write that the sensitivity of the mesh resolution has been investigated in Guma et al, 2018 and Shäffler, 2019. However, in the work by Guma, the flow is simple and steady, while the flow here is much different. The work of Shäffler does not seem to be available but more an internal work?
  Could you state some more about how and to what degree the mesh sensitivity have been investigated? I agree that it's nice that you can use the same mesh for the turbine itself in all the setups, but this might vary from inflow and turbulence model how well suited it is.
- You use a time step of 1 degree rotation. This is quite high compared to my own experience (using another solver), however this of course also depends on the number of sub iterations etc. Did you do a sensitivity study on the time steps? I guess the Chimera grids will jump a few cell sizes for each time step.

**Turbulence** is described in this section as well:

- You write that the FLOWer solver is a URANS/DES solver, however you only state that you use the Shear-Stress-Transport (SST) k-omega model in this work. Does that mean that you use URANS to transport the turbulent fluctuations? I'd think that to be way too dissipative. Could you comment some more on this choice if you really are using URANS?
- How does the turbulence behave over the travelled distance? Does the TI for instance change a lot? And how does the spectrum look?
- You write that you superimpose the turbulence measured from a met mast to the sheared inflow. How did you distribute the turbulence? Did you use tools like PyConTurb to constrain it, or is it more in relation to the spectra and TI you mean it's similar to measurements?
- What is the stratification of the measured/imposed turbulence?
- You describe that you have used different mean velocity and shear for cases FMT and FMC to keep them consistent despite the terrain. However, Table 2 shows the same exponent and velocity for the two cases. Also, you later state that you have ensured the same hub velocity close to the rotor for these two cases, but how large are the differences between bottom and top position of the blade tip if you impose different shears?

## Section 3 - Results

Your simulations are run for 60 seconds simulation time, which is quite limited, but also understandable with the massive setups that you run here.

- How about transients? Do you for all cases start from a converged state of the stiff rotor?

- Do you turn on the flexibility instantly, and does this give rise to some transient motions, that should have some time to damp out?
    - The reason I ask is for instance Figure 6. Why is the shell response so “wiggly” in such a steady flow? Is this actually physical?

- Any thoughts on the limited time signals, on for instance FFTs and calculations of DEL?
    - Is it enough data to resolve the FFTs sufficiently? Maybe for comparison purposes as they are both the same length.
    - Is it enough data for a good DEL estimate? (I don’t have much experience here)

For uniform inflow, you state that the choice of structural representation has very little impact on the response, whereas the shell representation is needed in more complex flows. What is that statement based on? Only the given RMS?

- Would it perhaps be enough to instead use a beam model which could model bend-twist coupling like HAWC2 for instance?
- When I look at the responses shown in figure 8, I agree that there are differences, but I’m not sure I think it justifies the ≈70% increase in computational effort of using a shell model.
- Could you compare the DEL of the two setups (beam vs shell) and see if that justifies the use of more heavy computations?
- In your previous paper on the DanAero turbine, flexibility increased DEL (however much less than the turbulence in itself). What could be the reason for the opposite effect here?

For the near wake investigation, you compare flexible and stiff configurations and see close to no effect.

- It’s a little hard to assess how big the differences of deficits really are as there’s no scale to compare to.
- Could you add a profile upstream of the turbine? At least for the FMC case it’s hard to guess how the incoming flow looks, and therefor hard to evaluate the deficit.

## Minor corrections/suggestions:

- Avoid abbreviations in the title. FSI sort of excludes the unfamiliar readers.
- Line 43-45. You give the impression that the work by Li, Y et al. was a continuation of Heinz’, with the same solvers etc. This is not the case.
- Deformation plots are related to blade radius, but I guess the unit is % not [-]?
- Fig 10, has no quantification on the velocity profiles. Also avoid the use of terms like x-y slices, as the reader is not necessarily familiar with the coordinate system.
- Fig 11. The colorbar makes it look like there is very little shear for FMT, which is not the case. You might reconsider the colorbar limits.
- Fig 14. The figure text is really small.