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Comment on wes-2021-154

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Referee comment on "The revised FLORIDyn model: implementation of heterogeneous flow and the Gaussian wake" by Marcus Becker et al., Wind Energ. Sci. Discuss., https://doi.org/10.5194/wes-2021-154-RC1, 2022

The authors present their manuscript on a novel dynamic wind farm simulator, FLORIDyn, with verifications against large-eddy simulations (LES). In this model, they extend past implementations of FLORIDyn to three-dimensional flow using propagating Observation Points to model the wake dynamics. The model is verified against LES simulations using SOWFA by comparing three and nine turbine cases under both homogeneous and heterogeneous flow conditions. The paper is of good quality and I enjoyed reading it. It clearly shows the need for computationally efficient mid-fidelity dynamic wind farm simulators. I believe this work is relevant to the community, particularly in the field of wind farm control.

I do have some remarks, which could improve the overall quality of the paper before publication. They are listed in the points below.

- Section 1: I think it is worth mentioning literature on the Dynamic Wake Meandering (DWM) model as it has been verified and used extensively in dynamic wind farm simulations in HAWC2, FAST.Farm and HAWC2Farm. The DWM model shares qualities with the presented FLORIDyn approach, particularly in the use of observation points (similar to passive tracers in DWM literature), and in the way it extends a static wake model to behave dynamically. See: **Larsen, G. C., Madsen, H. A., Thomsen, K., & Larsen, T. J. (2008). Wake meandering: A pragmatic approach. Wind Energy, 11(4), 377–395. https://doi.org/10.1002/we.267**, and **Madsen, H. A., Larsen, G. C., Larsen, T. J., Troldborg, N., & Mikkelsen, R. (2010). Calibration and validation of the dynamic wake meandering model for implementation in an aeroelastic code. Journal of Solar Energy Engineering, Transactions of the ASME, 132(4), 1–14. https://doi.org/10.1115/1.4002555**, etc

- Line 85 - The code which is cited here is a direct link to the GitHub page. For longevity, it is advised to register the code with an open-access repository with a DOI (such as Zenodo) and to cite the newly minted DOI.

- Line 98 - Please define the notation C_P and C_T.

- Section 2.1 - Please define the coordinate system used (x = longitudinal, y = lateral, z = vertical).

- Equation (2) and (3) - δ defines only a lateral deflection - could it be useful to define a vertical deflection? For example, when applying the helix approach?

- Line 171 - Is there a particular reason for choosing 1/4D?

- 180 to 189 - The authors mention the use of the mean ambient wind speed to propagate the OPs. This is a fair compromise and is supported by some literature. There is, however, other literature that provides different conclusions. See, for example, **Andersen, S. J., Sørensen, J. N., & Mikkelsen, R. F. (2017). Turbulence and entrainment length scales in large wind farms. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 375(2091). https://doi.org/10.1098/rsta.2016.0107**, Which measures a propagation speed of around 0.69 to 0.88 times U_∞.

- Equation 9 - This formulation assumes that the wind direction is uniform across space and is known a priori. Is this applicable to wind fields that have spatially non-uniform wind direction changes? What about wind fields where the wind direction is not clearly defined, or is gust-like?

- Line 231 - The authors use a blade pitch-TSR look-up table. These tables are typically generated using static turbine simulations. Is it reasonable to use static lookup tables in a dynamic simulation? What are the implications of doing so?

- Line 238 - Have the authors considered using an alternative relationship between C_T and a? For example, **Aagaard Madsen, H., Juul Larsen, T., Raimund Pirrung, G., Li, A., & Zahle, F. (2020). Implementation of the blade element momentum model on a polar grid and its aeroelastic load impact. Wind Energy Science, 5(1), 1–27. https://doi.org/10.5194/wes-5-1-2020,** which uses a cubic equation ($a = k_3C^3_T + k_2C^2_T + k_1C_T + k_0$), which extends into the high thrust region. It can also be inverted analytically using a cosh substitution.

- line 245 - The authors mention the use of a constant value of the power-yaw exponent P_p. It has been shown in literature and measurements that P_p can vary, especially for turbines in wake conditions. See: **Liew, J., Urbán, A. M., & Andersen, S. J. (2020). Analytical model for the power-yaw sensitivity of wind turbines operating in full wake. 1–18. https://doi.org/10.5194/wes-2019-65** and **Howland, M. F., González, C. M., Martínez, J. J. P., Quesada, J. B., Larrañaga, F. P., Yadav, N. K., Chawla, J. S., & Dabiri, J. O. (2020). Influence of atmospheric conditions on the power production of utility-scale wind turbines in yaw misalignment. Journal of Renewable and Sustainable Energy, 12(6). https://doi.org/10.1063/5.0023746**

Similar effects are expected for how C_T varies with yaw angle. As the presented model is intended for control purposes, it is important to consider how the power loss is modeled for yaw steering in future studies. Is a variable P_p a possibility in FLORIDyn?

- Figure 6 - The use of a low pass filter on the power signal is justified to replicate the delay in the turbine response. However, what is the motivation for using a zero-phase low pass filter on one signal and a causal filter on the other? Even with the same damping and cut-off frequency, I expect there to be a noticeable phase delay in the causal filter compared to the non-causal filter (which I believe is visible in Figure 11). So comparing the signals from different filters may be misleading. Would it make sense to use the same filter type on both the SOWFA and FLORIDyn results?

- Continuing from the previous point, have the authors considered using a causal filter in real-time instead of in post-processing? From the results, it appears that FLORIDyn responds quite quickly to changes in the wind field. In reality, there will be some delay due to the inertia in the turbine rotor.

- Section 3.2 - The nine turbine case is an interesting showcase of FLORIDyn's ability to respond to a wind direction change. The process of simulating a wind direction change is nuanced and often requires many physics-defying assumptions. It is worth mentioning these assumptions, for example:
  - The uniformly rotating wind field in the FLORIDyn simulations is a fair compromise to showcase the model and to test controllers. Could you please elaborate on how the wind direction change is performed in SOWFA? It is unclear if the wind field is also rotated uniformly in SOWFA, which will break continuity, or it is using a different method such as **Stieren, A., Gadde, S. N., & Stevens, R. J. A. M. (2021). Modeling dynamic wind direction changes in large-eddy simulations of wind farms. Renewable Energy, 170, 1342–1352. https://doi.org/10.1016/j.renene.2021.02.018** and **Andersen, S. J., S rensen, N. N., & Kelly, M. (2021). Les modelling of highly transient wind speed ramps in wind farms. Journal of Physics: Conference Series, 1934(1). https://doi.org/10.1088/1742-6596/1934/1/012015**
  - Continuing from the previous point, Stieren shows noticeable hysteresis effects on the power output of turbines during a wind direction change. It is unclear if the SOWFA simulation is set up in a way to capture these effects.
  - Both SOWFA and FLORIDyn simulations set the turbine yaw angle to match the changing wind direction. This is reasonable as a show-case of the flow model, however, it is idealistic and does not reflect the delay that a turbine experiences when changing its orientation.

- Line 397 - I don't understand the phrasing "from 164 to 6.5 simulation steps". Perhaps rephrase?

- Line 401 - Does the presented FLORIDyn simulation run on a single core? From my understanding, MATLAB will use parallel (or at least multithreaded) computing for certain operations by default.

- Table 2 - The computational time is quite impressive for so many OPs. To strengthen the argument, it would be nice to see a comparison with the iteration time for SOWFA. Additionally, it may be worth mentioning the required computational resources for both (CPU seconds per iteration, memory, etc).

- Line 403 - Does the simulation time increase exponentially? I would expect it to increase linearly with the number of turbines, or perhaps quadratically if the OPs interact with each other.

- line 431 - The authors mention adapting FLORIDyn for turbulent conditions. As the presented model propagates the OPs using the ambient wind speed, I am curious how FLORIDyn can be adapted for turbulent flows. Will the OPs propagate based on a turbulent wind field? Will there be issues with the untidy movement of so many OPs? How can the issues outlined in Section 2.3.3 be resolved?

- Line 437 - The authors suggest using FLORIDyn within the control loop. Out of curiosity, could you elaborate on how such a setup would work? How would measured observations be translated into a state in a FLORIDyn simulation?

Typographical Corrections

The paper is, overall, well written. I have listed some inconsistencies, spelling, and grammar mistakes below. I recommend reviewing the manuscript carefully for other small corrections.

- Stay consistent with the use of American or British English. For example (if you are sticking to American English):

- maximise -> maximize

- colour -> color

- modelling -> modeling

- behaviour/neighbour -> behavior/neighbor

- centred -> centered

- travelling -> traveling

or if you are sticking to British English:

- -ization -> -isation

- -ize -> -ise

- Remember to hyphenate certain word pairs:
- ever changing -> ever-changing
- real time -> real-time
- second order -> second-order
- start up -> start-up
- steady state -> steady-state
- state space -> state-space
- two dimensional/three dimensional -> two-dimensional/three-dimensional
- line 2 - In this paper a new... -> In this paper, a new...
- line 3 - at low computational cost -> at a low computational cost
- line 32 - question if -> question of whether
- line 35 - This could possibly lead -> this could lead
- line 43, 110, 112 - center line -> centerline
- line 70, 128 - down stream -> downstream
- line 72 - Changes of -> Changes in
- line 73 - six-turbine-simulation -> six-turbine simulation
- line 74 - large eddy simulation simulation -> large eddy simulation
- line 79 - In this paper we... -> In this paper, we...
- line 99 - Eventually a basic... -> Eventually, a basic
- line 202 - assumes an uniform -> assumes a uniform
- line 206 - wolrd -> world
- line 214 - at the cost calculating -> at the cost of calculating
- line 222 - orientation remains the same -> orientation remain the same
- line 307 - to give an idea, how... -> to give an idea how...
- Figure 8 (in the y-label) - differenece -> difference
- line 340 - an dynamic -> a dynamic
- line 351 - flow filed -> flow field
- Figure 10 (caption) - as indicator -> as an indicator

- line 373 - shows a similar behaviour -> shows similar behavio(u)r

- line 376 - too fast -> too-fast

- line 392 - Ghz -> GHz

- line 392 - a SSD -> an SSD

- line 396 - take away -> takeaway

- line 416 - computational lightweight -> computationally lightweight

- line 421 - shows a good performance -> shows good performance

- line 427-428 - (repetition of 'improvement'. Consider rephrasing)