Wake Dynamics Of Floating Offshore Wind Turbines

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Introduction

The Problem:

- Floating turbines can harness the vast wind resource located in deep water regions estimated to make up 80% of all practical wind resource[1].
- In low turbulence environments, platform motions have been shown to elicit a strong relative wake response, generating large scale coherent structures[2]. It is unclear how these structures interact with the sheared turbulent offshore flow conditions.

Aim:

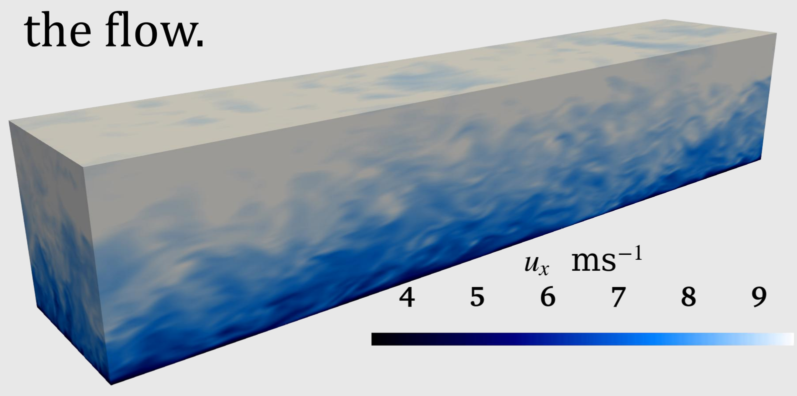
- Investigate the coherent wake dynamics of floating turbines subject to sheared turbulent flows.

Methods

1

Precursor:

- OpenFOAM[3] large eddy simulation.
- Turbulent sheared inflow generated in a periodic recycling region.
- Stress lower boundary condition creates shear.
- A uniform body force is applied to drive the flow.



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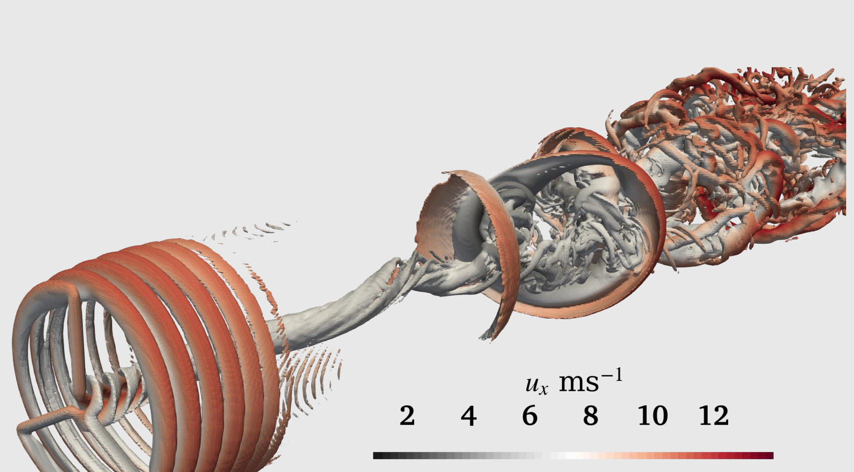


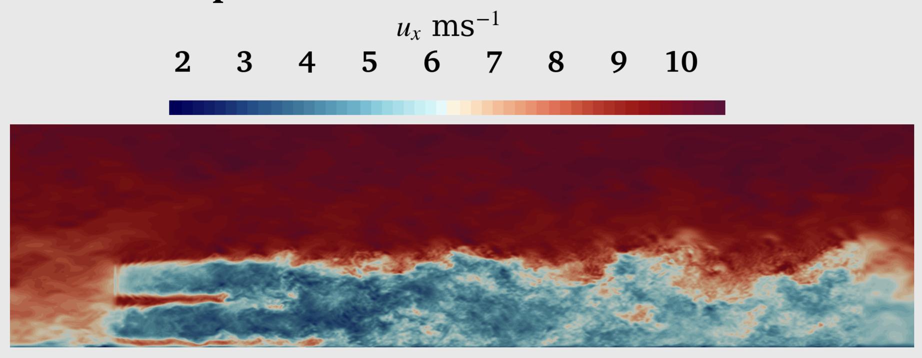
Turbine Representation:

- An actuator line method[4] is used to virtually represent the turbine.
- This negates the need to resolve the small length scales required for accurate lift and drag calculation.

3

Successor:

- The outflow of the precursor is used as an inflow to the successor simulation.
- Platform motions are assumed to be sinusoidal, removing the aero-hydro coupling and producing highly interpretable results.



Results

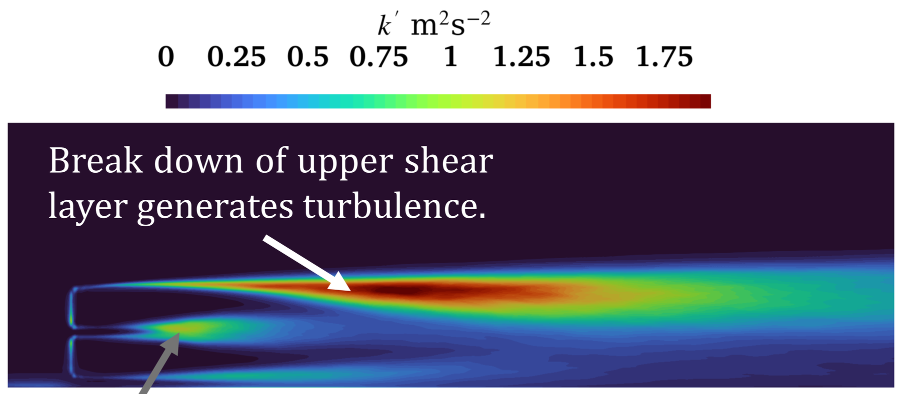
Triple Decomposition & Phase Averaging:

- The velocity field is decomposed into the triplet $(\overline{\boldsymbol{u}}, \tilde{\boldsymbol{u}}, \boldsymbol{u}'')$ where $\overline{\boldsymbol{u}}$, $\tilde{\boldsymbol{u}}$, and $\boldsymbol{u}''$ represent the mean, coherent, and incoherent components.
- The coherent component is defined to be the fluctuation of the phase averaged velocity, $\tilde{\boldsymbol{u}}(\boldsymbol{x},\tau) \equiv \langle \boldsymbol{u}(\boldsymbol{x},t)\rangle_\tau - \overline{\boldsymbol{u}}(\boldsymbol{x})$.
- The incoherent component is defined as $\boldsymbol{u}''(\boldsymbol{x},t) \equiv \boldsymbol{u}(\boldsymbol{x},t) - \langle \boldsymbol{u}(\boldsymbol{x},t)\rangle_\tau = \boldsymbol{u}(\boldsymbol{x},t) - \tilde{\boldsymbol{u}}(\boldsymbol{x},\tau(t)) - \overline{\boldsymbol{u}}(\boldsymbol{x})$.
- From this, the coherent kinetic energy $\tilde{k} \equiv \frac{1}{2}\tilde{u}_i\tilde{u}_i$ and turbulent kinetic energy $k' \equiv \frac{1}{2}\overline{(u_i u_i)}$ energy can be calculated[5].

Platform Motion Settings:

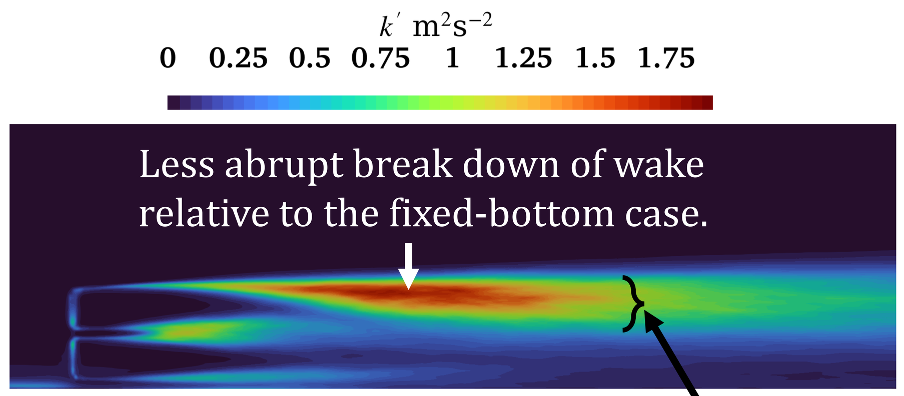
- Motions are characterised by a non-dimensional frequency $f_p^\star \equiv \frac{f_p D}{U_\infty}$ and amplitude A_p, where D is the rotor diameter and U_∞ is the mean hub height velocity.
- Pitching case: $f_p^\star = 0.72, A_p = 2.5°$
- Rolling case: $f_p^\star = 0.32, A_p = 2.5°$

Turbulent Kinetic Energy (side view):



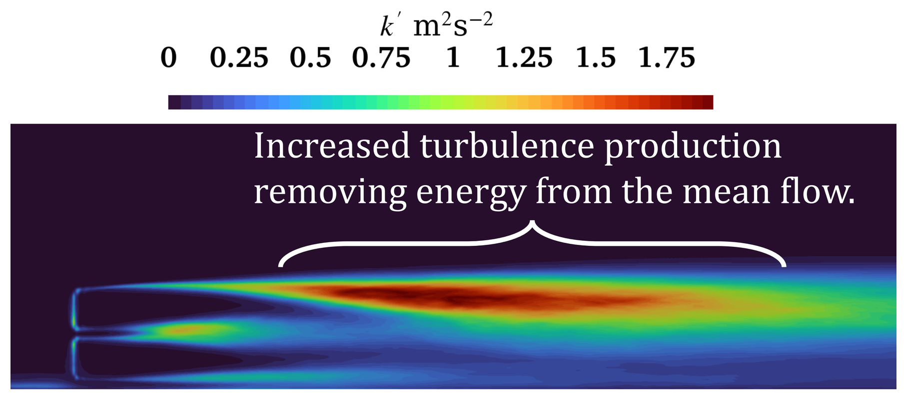
1a. Fixed-Bottom Turbine

High energy nacelle jet created by low thrust sections and lack of nacelle model creates high shear.



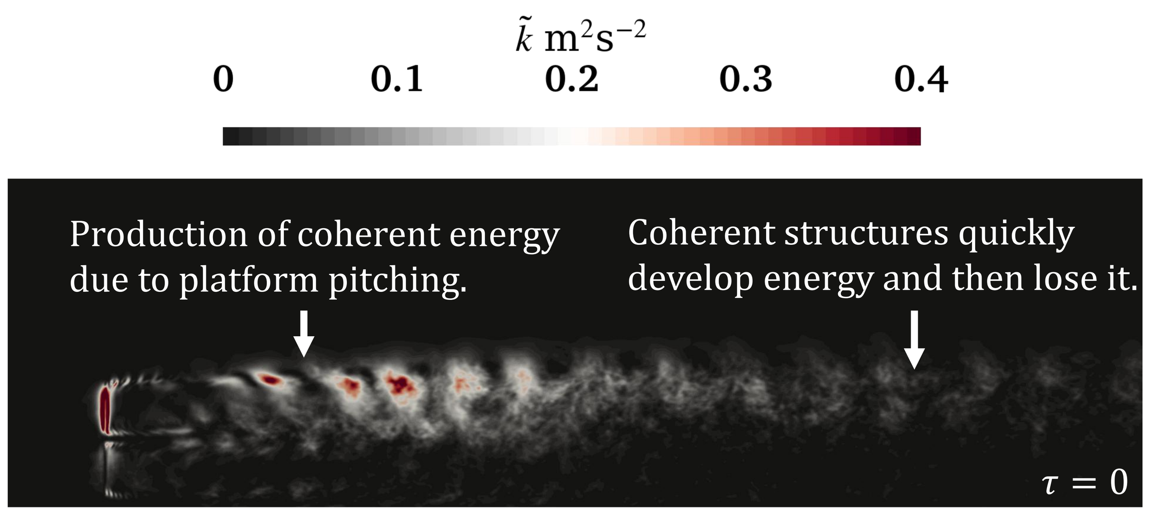
1b. Pitching Turbine

Turbulence produced over a taller region due to platform pitching generating vertical wake deviation.

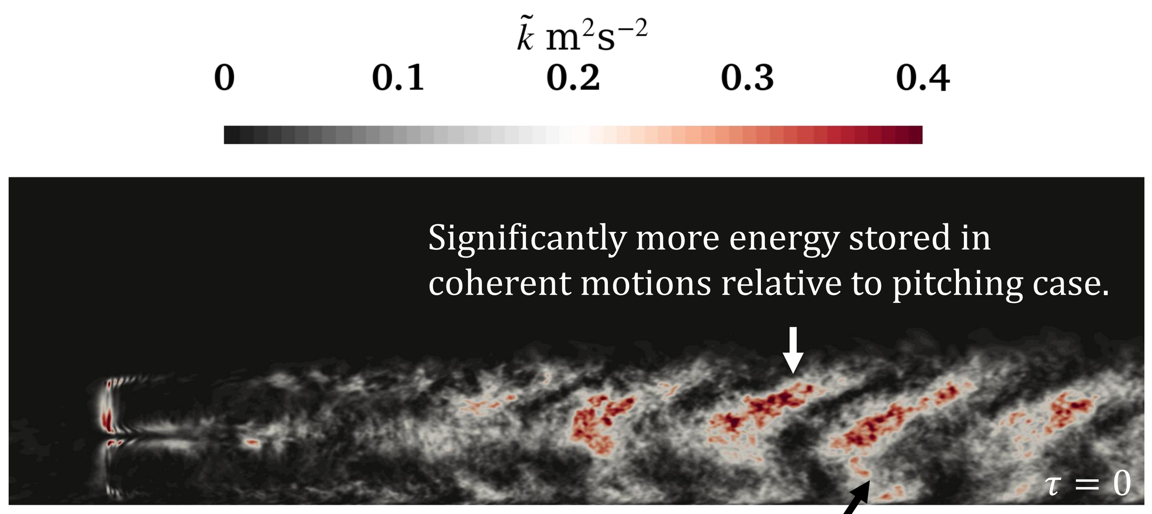


1c. Rolling Turbine

Coherent Kinetic Energy (side view):



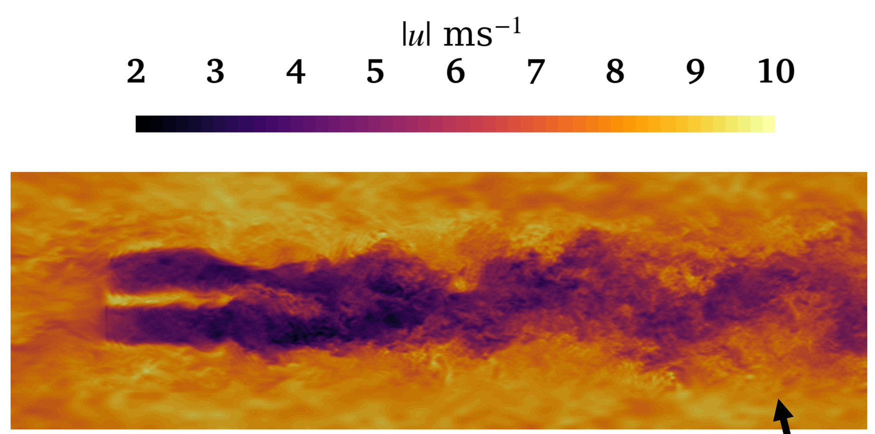
2a. Pitching Turbine



2b. Rolling Turbine

Increase in coherent kinetic energy with increasing streamwise distance, suggesting growth of an unstable mode.

Induced Wake Meandering (top view):



3. Rolling Turbine

Rolling motions act as a path to wake meandering, side-to-side motion of the wake, spreading the wake in the lateral direction.

Discussion

- Figures 1a, 1b and 1c depict the turbulent kinetic energy within the wake for different platform motion cases. A pronounced peak is observed at the top of the wake for all three cases and is associated with the breakdown of the upper shear layer. **The addition of pitching motions does not significantly impact the production of turbulence** but extends the vertical region over which turbulence is generated. In contrast, the **rolling motions appear to produce significantly more turbulent kinetic energy**, indicating that significant amounts of energy are being removed from the mean flow and injected into unsteady fluctuations.
- Figures 2a and 2b show the decomposition of the kinetic energy into its coherent component. **Pitching motions generate energetic modes that quickly diminish with streamwise distance**. Most of the energy is concentrated near the top of the wake, consistent with the asymmetric platform motion induced velocity. **Rolling motions produce significantly more coherent kinetic energy**. Furthermore, the energy content associated with these coherent structures increases with downstream distance, **suggesting the growth of an unstable meandering mode,** consistent with recent literature[2].
- Figure 3 is an example of the wake meandering mode generated by rolling motions. This can be seen by the side-to-side periodic deviation of the wake centreline.

Conclusions

1. Decomposition of the flow field into mean, coherent, and incoherent components reveals **a clear signature of platform motions within the turbine wake**.
2. **The strength of this signature depends on the platform motion degree of freedom** suggesting platform motions play a complex role in shaping wake dynamics, even under turbulent, sheared inflow conditions.
3. Understanding the intricate mechanisms governing wake evolution and recovery remains a significant challenge, with important **implications for both power production and downstream rotor loading**.

References

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Acknowledgement

This work used the ARCHER2 UK National Supercomputing Service through the EPSRC Access to HPC project, Wake Aerodynamics of Offshore Wind Turbines. The authors acknowledge support from DG's EPSRC studentship (no. EP/S023801/1) and CRV's UKRI Future Leaders Fellowship (no. MR/V02504X/1). TR acknowledges support from his Thatcher Scholarship.

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