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Analysis of Wind Turbine Wake Meandering Using the Actuator Disc Model

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ABSTRACT

The wind turbine wake, where the wind speed is reduced due to energy extraction by the turbine, is one of the essential factors for evaluating energy production in wind farms. The lateral and vertical low-frequency oscillation of the wake, called wake meandering, causes a fluctuating loading on the downstream turbines, leading to increased fatigue and uneven loadings (Larsen, 2022) and affects the overall wind farm performance by impacting the wake recovery (Hodgson et al., 2023). A key driving mechanism of wake meandering is the amplification of upstream disturbances (Gupta and Wan, 2019). The qualitative impact of disturbances, such as the thrust force (Medici and Alfredsson, 2008), turbine loading distribution (Dong et al., 2023), and inflow fluctuations (Mao and Sørensen, 2018) on the dynamic wake characteristics have been reported in the literature. However, quantifying the individual effects of these perturbations is challenging due to their complex interactions, such as the coupling between turbulent inflow and unsteady turbine loading.

This work aims to define and explore a well-defined parameter space to isolate and quantify the effects of the perturbations, such as turbine loading magnitude and distribution, on the wake instability, dynamic wake characteristics and wake meandering parameters. The study uses high-fidelity Large Eddy Simulations (LES) in OpenFOAM to capture the complex unsteady flow features within the wake shear layer. The wind turbine is modelled by an in-house actuator disc model (ADM), allowing for a simplified and controllable definition of parameters while preserving the essential wake dynamics, as shown in Fig. 1. The LES results are then analysed using the linear stability analysis method. This study provides insights into wake stability and its relationship to wake recovery and turbulence intensity, which are expected to advance our understanding of wake dynamics and contribute to more accurate models for wind turbine wakes and wind farm layout optimisation.

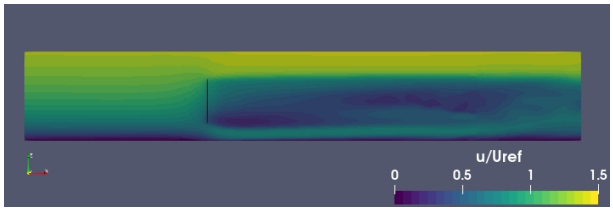

Figure 1: Normalised streamwise velocity on y=0 plane around the actuator disc under a sheared inflow.

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