Wind Energy Science Conference
24 - 27 June 2025
Nantes, France

A Blind Test on Wind Turbine Wake Modelling: Benchmark Results and Next Steps

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Keywords: Wind Turbine Wake, Blind Test, Wind Tunnel Testing, Computational Fluid Dynamics

As the wind energy industry continues to grow, optimizing wind farm design and operation becomes increasingly important. Accurate modelling of wind turbine wakes is a key aspect, as these wakes and their interactions significantly influence energy production, turbine placement, and operational strategies. However, capturing the complexity of turbine wakes remains a challenging task due to the intricate interplay between wake dynamics, atmospheric boundary layer behaviour, and wind farm configurations [1]. Additionally, implementing effective wake control strategies can dramatically enhance a wind farm's energy output while reducing the levelized cost of energy, thereby improving the financial viability of wind energy projects. Achieving these outcomes relies on precise wake modelling to identify optimal control methods and operational practices [3].

Building on these challenges, this paper expands upon the foundation of our previous work [2], which lays the groundwork for a two-phase blind test study designed to advance the field of wake modelling and control in wind energy research. The study addresses the critical challenge of modelling wakes in wind farms, where turbine performance is significantly affected by wake interactions. To this end, a two-phase blind test initiative was designed to enhance wake modelling accuracy by benchmarking numerical models against open and experimental data, improving confidence in wake modelling methodologies. Initially introduced at the TORQUE 2024 conference, the blind test seeks to evaluate numerical approaches, quantify uncertainties, and foster transparency and collaboration within the wind energy community.

To support this initiative, two experimental campaigns were performed at Technische Universität München (TUM) and at the National Technical University of Athens (NTUA) to investigate wake flow control techniques. This document will briefly discuss the experimental set up and results and will present the relevant comparisons with the numerical predictions provided by the participants to blind test phase I. While both experimental set ups are detailed, only data from the TUM campaign are available at the time of writing, as the NTUA campaign results will form Phase II of an ongoing blind test campaign[1] and cannot be published.

The blind test is divided into two distinct phases:

- ✓ **Phase I: Benchmark Case**
  Announced during the TORQUE 2024 conference, this phase invites participants to simulate a baseline case involving two aligned turbines without active control. The objective is to establish a reference dataset for numerical model validation, ensuring participants can benchmark their approaches against experimental results. Open data for this phase are accessible at https://doi.org/10.5281/zenodo.10566400.
- ✓ **Phase II: Blind Test**
  This phase presents a more complex scenario, where the upstream turbine's wake is controlled using active individual blade pitch. While the case specifications (e.g., inflow conditions, turbine geometry, wake

[1] http://www.tweet-ie.eu/Blind_Test [last accessed 31 Jan 2025]

control strategy) are provided, the experimental results are withheld. The aim is to benchmark numerical techniques, assess solver reliability, and drive innovation in wake control modelling.

Phase I – Preliminary Results

The experiments of Phase I were conducted in the closed-loop, low-speed boundary layer wind tunnel at the Chair of Aerodynamics and Fluid Mechanics, Technische Universität München (TUM). The set up consists of two identically scaled wind turbine models, placed in line with a longitudinal distance of 5D, where D denotes the rotor's diameter. Fig 1 represents the experimental setup at TUM, with the precise placement of the static pressure taps located at the centre (y=0) of the wind tunnel ceiling, the location of the pitot tube as well as the wind turbine models.

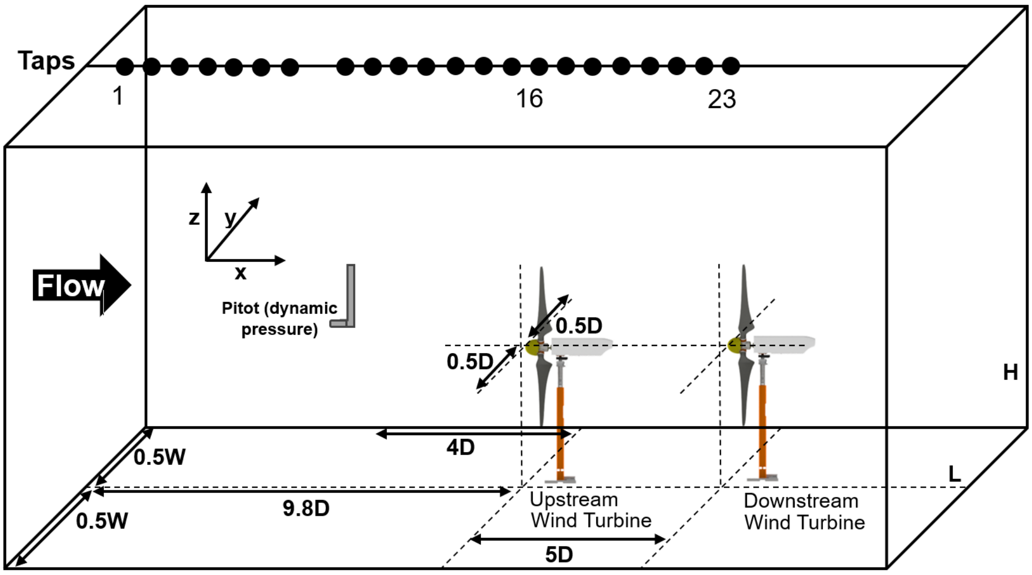

Figure 1: Sketch of the wind tunnel test section at TUM with the positioning of the pressure taps in the centre of the wind tunnel ceiling, the location of the pitot tube and the locations of the upstream and downstream wind turbine models.

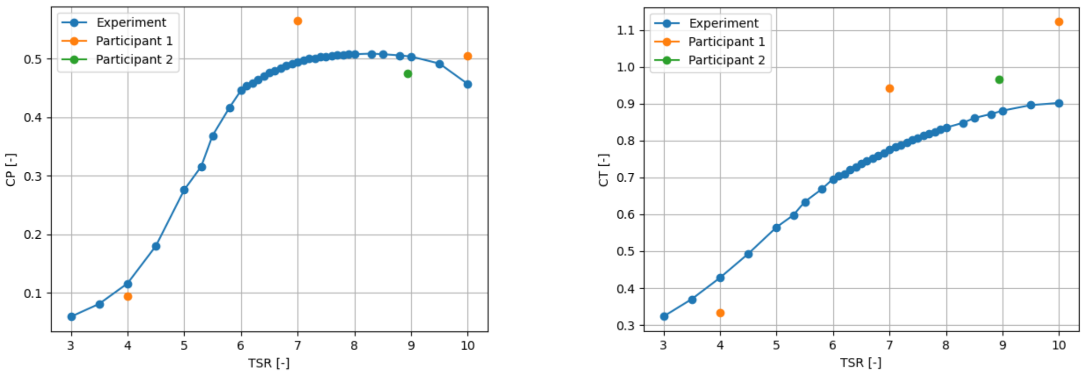

Figure 2: Comparison of preliminary Phase I results for the Power (left) and Thrust (right) coefficients as functions of the Tip Speed Ratio for the upstream wind turbine, with the downstream wind turbine operating at a constant rotational speed of $\omega = 574\ rpm$.

Since the Phase I deadline is still ongoing at the time of writing, the results presented here are preliminary. However, initial findings from *Participant 1*, utilizing the Reynolds-Averaged Navier-Stokes (RANS) equations with the k-ω SST turbulence model, indicate a promising start. This model successfully captured the relative trends of the upstream wind turbine in terms of power coefficient (C_P) and thrust coefficient (C_T), although it exhibited some deviation from the experimentally measured absolute values. The results reveal a maximum relative divergence of 14.1% in power and 21.6% in thrust compared to experimental measurements under conditions where the upstream turbine operates at variable rotational speeds, while the downstream turbine remains fixed at ω = 574 rpm. *Participant 2* also submitted a single case study employing a Large Eddy Simulation (LES) approach combined with the Actuator Line Method (ALM) for the same scenario, demonstrating improved correlation. The results indicate a relative difference of 6.3% in C_P and 9.2% in C_T, as illustrated in Fig 2.

Phase II – Test Cases

Experiments were carried-out in the large section $2.5 \times 3.5 \times 12\ m^3$ $(H \times W \times L)$ of the NTUA wind tunnel at NTUA. The set up consists of two identically scaled wind turbine models (G1 models [4]) which are placed in line with a longitudinal distance of 5D, see Fig 3. Both low turbulence ($T.I. \approx$ 1.5%) and high turbulence ($T.I. \approx$ 6%) inflow conditions were tested. Measurements include turbine loads and performance as well as Particle Tracking Velocimetry wake data for cases with and without wake flow control for the upstream turbine.

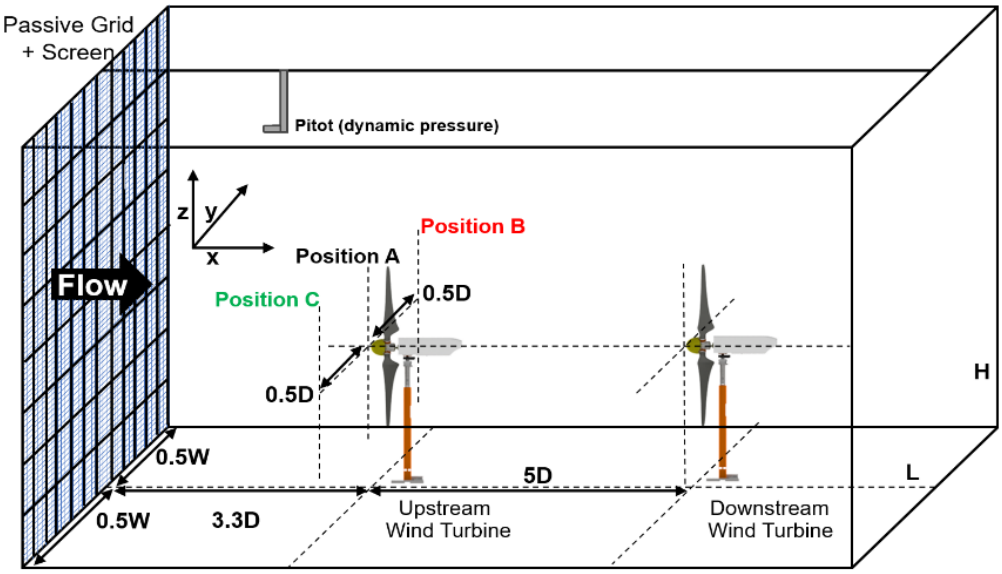

Figure 3: Sketch of the NTUA wind tunnel test section with the location of the pitot tube and the locations of the upstream and downstream wind turbine models.

Acknowledgements

The authors kindly acknowledge the financial support of the European project 'TWEET-IE' funded by the European Union's Horizon 2020 Research and Innovation Programme (Grant Agreement 101079125).

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