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Two in-line wind turbines interaction with a Vortex Particle Method code

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1 Introduction

Interaction of wind turbines wakes in farms affects the energy production and blade loads [1, 2]. The ability to correctly predict wakes interaction between turbines and its effects is essential and also necessary to develop control strategies. It requires extensive experimental resources or high-fidelity numerical codes to capture these wide range of flow scales involving multi-physics phenomena.

Numerous wind tunnel wake interaction study have been conducted the past decades [3, 4, 5]. A recent one, called TWEET-IE [6] and performed by the National Technical University of Athens (NTUA), aims to provide a recent and extensive experimental results database to benchmark numerical codes. The experimental set-up consists in two aligned laboratory scale three-bladed wind turbines under uniform low-turbulent inflow, as shown in Figure 1. These two turbines are operated at different TSR to test different wake interaction conditions. This TWEET-IE experimental set-up will be the basis of our numerical study in order to validate our numerical tool, a Vortex Particle software, before going to real size wind turbines and possibly moving to the scale of small wind farms.

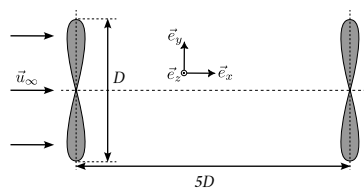


Figure 1: TWEET-IE experimental set-up reproduced numerically.

2 Numerical method

The present numerical simulations are performed using a three-dimensional unsteady Lagrangian Vortex Particle Method (VPM) [7]. This method is based on the discretisation of the fluid into vorticity carrying particles. The governing equations for this model are the filtered Navier-Stokes equations in their velocity-vorticity formulation for Large-Eddy Simulation [8]. A recently developed lifting line (LL) approach provides radial loads along the turbine blades, circulations, angle of attack and integrated power and thrust coefficients [9, 10]. A tip correction [11] is applied on the loads to circumvent the limited influence of tip vortex on the true velocity due to particles velocity smoothing [12, 10].

Table 1: Turbines definition

D [m]	R_h [m]	L_b [m]	z_h [m]	N_s	dr [m]
1.1	0.054	0.496	0.82	30	0.033

Table 2: Cases parameter

Case	ω_{T1} [rad · s ⁻¹]	ω_{T1} [rad · s ⁻¹]	dt [s]
1	41.68	60.11	$1.5 \cdot 10^{-3}$
2	62.52	60.11	$1.4 \cdot 10^{-3}$
3	72.88	60.11	$1.2 \cdot 10^{-3}$
4	83.36	60.11	$1 \cdot 10^{-3}$
5	104.41	60.11	$8 \cdot 10^{-4}$
6	89.01	25.97	$1 \cdot 10^{-3}$
7	89.01	36.34	$1 \cdot 10^{-3}$
8	89.01	41.47	$1 \cdot 10^{-3}$
9	89.01	50.68	$1 \cdot 10^{-3}$
10	89.01	61.05	$1 \cdot 10^{-3}$

3 Set-up

Table 1 presents the turbine model geometrical and numerical properties: rotor diameter (D), hub radius (R_h), blade length (L_b), as well as the chosen space discretisation defined by the number of blade sections (N_s) and associated section width ($dr = L_b/N_s$). Numerically, turbines are submitted to an uniform laminar inflow of velocity $U_\infty = 6.3 \text{ m} \cdot \text{s}^{-1}$. This value is chosen based on the mean velocity at the turbine position [6]. VPM is unmeshed, so no boundary is applied in the simulation. A limitation of the software will be the high experimental wind tunnel blockage of almost 20%, which cannot be reproduced by our numerical code. Following [12, 10], the time-step (dt) is chosen so that the maximum angular step ($d\theta$) between the two turbines is 5.0° per time-step.

4 Results

Power and thrust coefficients, both for the upstream and downstream turbines, will be presented for all configuration presented in Table 2. Turbines interactions will also be analysed via velocity maps as it is presented in Figure 2. Finally, fluctuations of power and thrust coefficients will also be presented to analyse the physical phenomena at stake.

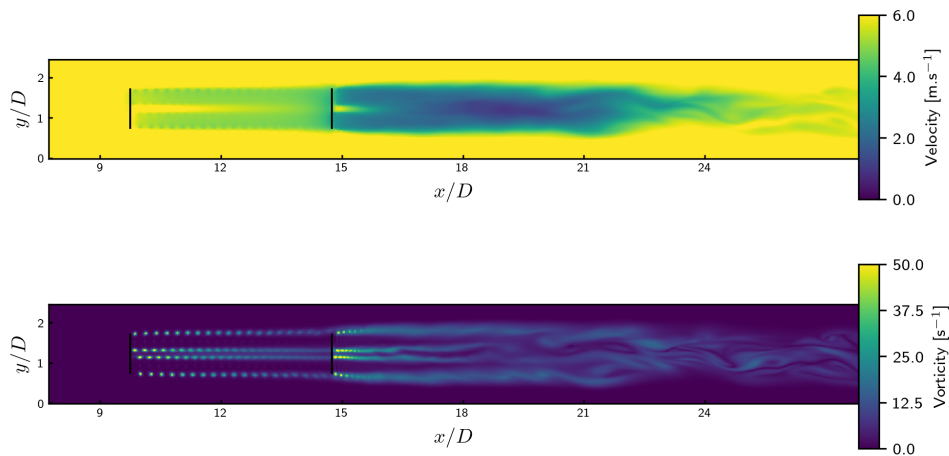


Figure 2: Instantaneous velocity and vorticity map for *Case 1* of Table 2.

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