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Dynamic response of a wind turbine wake subjected to surge and heave step motions under different inflow conditions

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INTRODUCTION

A basic assumption for dynamic wake modelling is that flow structures are passively transported in the atmospheric flow, governed by an advection velocity U_a , in accordance with the Taylor's frozen hypothesis. This measure holds significant importance in unsteady wind farm modelling in general, as FLORIDyn or FAST.Farm.

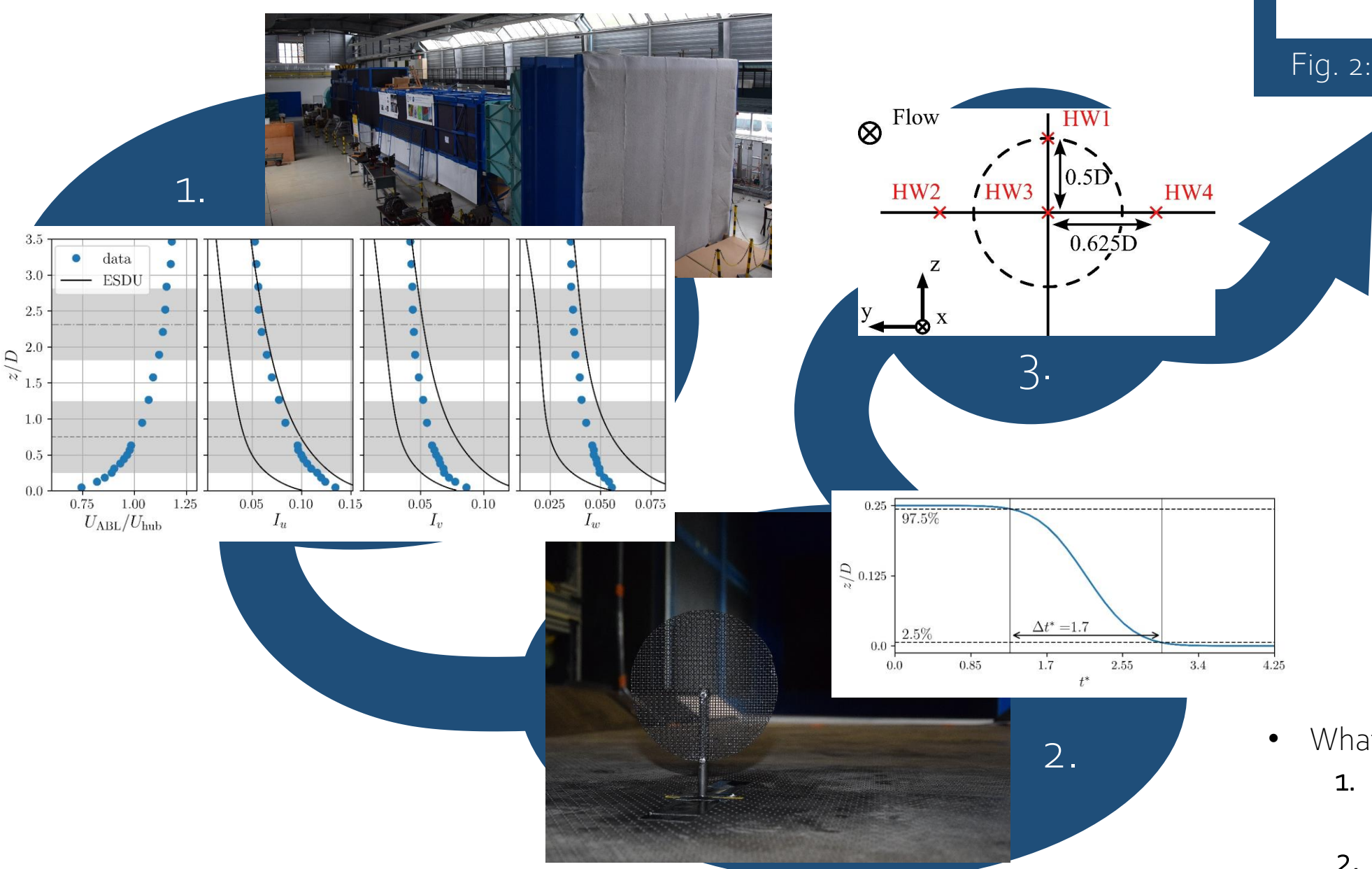
In this study, a realistic Atmospheric Boundary Layer (ABL) is developed in the wind tunnel of the LHEEA, and experiments on a turbine model subjected to heave and surge (up-down and fore-aft translations) step motions are performed with two different hub height. The purpose is to retrieve and analyse the transient times according to the experimental conditions.

MAIN OBJECTIVES

- Retrieve the advection times related to heave and surge step motions.
- Study the impact of the inflow conditions on the transient times.

METHODOLOGY

1. A neutral marine ABL is developed in the wind tunnel.
2. A porous disc of diameter D (wind turbine far-wake generator) is installed with two hub height and subjected to heave and surge step motions. U_{hub} is the velocity at hub.
3. Four Hot-Wires measure the u -velocity component at $x = 8.125D$ downstream of the model.



The resulting inflow conditions for both configurations are summarised in the following table, with ΔU_{ABL} the ABL velocity difference at the limits of the porous disc, I_u, I_v, I_w the turbulence intensity at hub height, and xL_u the full-scale integral length-scale at hub height:

Parameters	ABL configuration	Low shear configuration
z_{hub}	$0.75D$	$2.31D$
U_{hub}	3.0 m/s	3.4 m/s
ΔU_{ABL}	$0.42U_{hub}$	$0.11U_{hub}$
$[I_u, I_v, I_w]$	$[0.09, 0.06, 0.05]$	$[0.06, 0.05, 0.04]$
xL_u	240 m	260 m

METRICS

The metrics used are:

- the aerodynamic timescale $\tau_0 = \frac{D}{U_{hub}}$
- the first and last times when the velocity curve cross the velocity difference of $0.07U_{hub}$, respectively τ_{start} and τ_{end}
- the step motion effect duration $\Delta\tau_i = \tau_{start} - \tau_{end}$
- and the advection velocity $U_a = \frac{8.125D}{\tau_{start}}$.

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SCAN ME

RESULTS

A phase-averaging method synchronised with the step motions is performed. The resulting phase-averaged velocities and x and z disc positions are noted \tilde{u} , \tilde{x} , and \tilde{z} , respectively.

Here, only the HW1 velocities are shown, the other curves are available in the article.

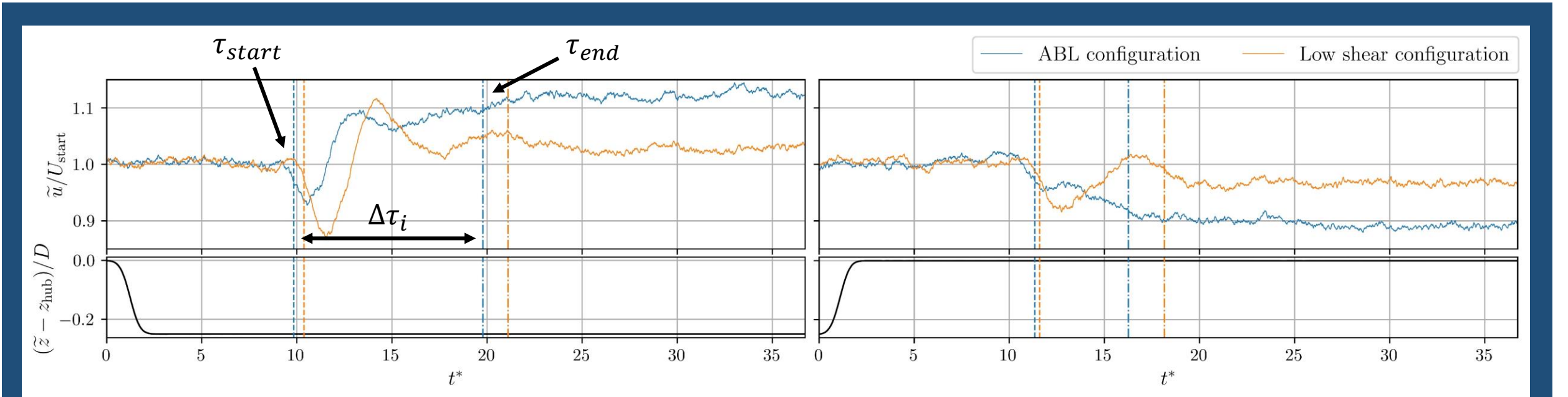


Fig. 1: Phase-averaged velocities of HW1 in the wake of a porous disc subjected to heave descent (left) and ascent (right) step motions in both configurations. The dashed and dashed-dotted lines are the start times (τ_{start}) and end times (τ_{end}), respectively, and $t^* = t/\tau_0$ is the normalised time

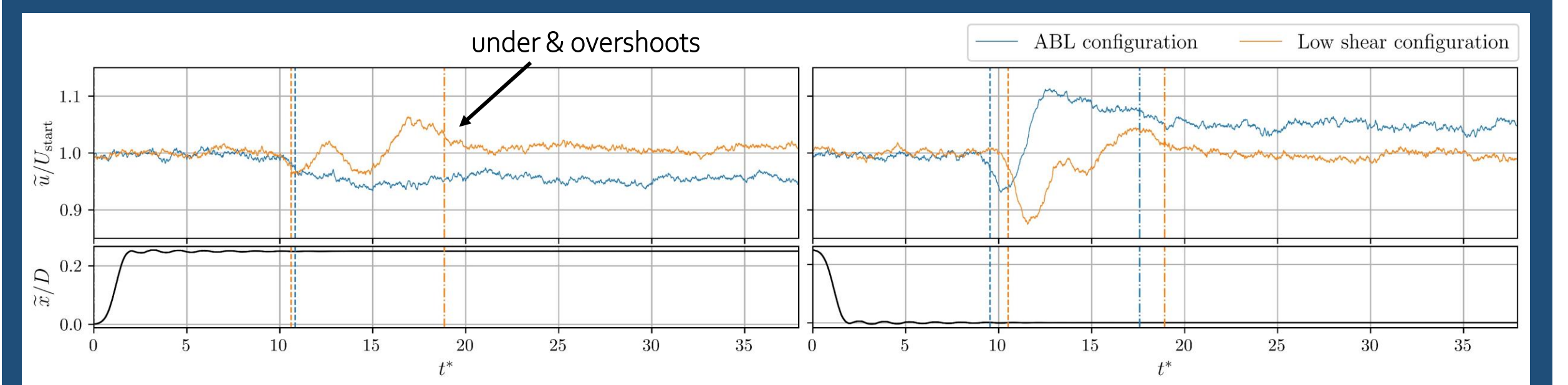


Fig. 2: Same as Fig. 1 but for surge backward (left) and forward (right) step motions.

For the ABL : Low shear configuration, the HW1 results are:

	τ_{start}/τ_0	τ_{end}/τ_0	$\Delta\tau_i/\tau_0$	U_a/U_{hub}
Heave descent	9,92 : 10,37	19,83 : 21,17	9,92 : 10,80	0,82 : 0,78
Heave ascent	11,38 : 11,64	16,34 : 18,21	4,96 : 6,56	0,71 : 0,70
Surge backward	10,80 : 10,68	– : 18,79	– : 8,12	0,75 : 0,76
Surge forward	9,48 : 10,46	17,62 : 19,01	8,15 : 8,54	0,86 : 0,78

- What is seen:
 1. Under/overshoots in all HW velocities for heave step motions in low shear configuration.
 2. Under/overshoots in all HW velocities for surge step motions in low shear configuration.
 3. Less clear responses in ABL configuration.
 4. Time start difference between the ascent and descent step motions.
- What is hypothesised:
 1. May be associated to the passage of a ring vortex – seen in [1] with the formation of a growing ring vortex in a porous disc wake under transient loads.
 2. May be associated to wake deflection – the brief motion time during which the porous disc exhibits a relative angle with the inflow can be similar to a pitch angle case. A previous study have reported that, at $x = 8D$, wake deflection can reach $y = 0.35D$ for a yaw angle of 10° [2], here heave step motions induce a relative angle between the inflow and the porous disc reaches 10° and 8.5° for ABL and low shear configurations, respectively.
 3. Attributed to reduced mixing effects in the low shear configuration – lower shear, lower turbulence levels in the inflow and less ground effect.
 4. Could not be attributed to the velocity shear – in ABL configuration, the corrected τ_0 would result in a ascent step motion start time of $10.2\tau_0$, slightly higher than those in a descent step motion.. However, in the other configuration the shear is almost null, and the corrected τ_0 would present negligible modifications.

CONCLUSIONS

- In case of low shear, step motion responses correspond to a second-order dynamic system – with under/overshoots.
- In case of realistic ABL, step motion responses mostly correspond to a damped system – without under/overshoot.
- Inflow conditions barely change the transient times and the advection velocities.
- Advection velocities are similar to those found in previous studies [3, 4].
- For heave step motions: $U_a \approx 0.7U_{hub}$ for ascent and $U_a \approx 0.8U_{hub}$ for descent – not due to the local velocity change.
- Step motion effects persist for a duration 3 to 6 times longer than the manoeuvre.

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