Reviewer comments

Stefano Macrì, Sandrine Aubrun, Annie Leroy, Nicolas Girard

Co-authors thank the reviewers for their fruitful comments and will give point by point answers below. In this response to the reviewers the response of the authors not included in the revised manuscript will be written in blue while the part included in the revised manuscript will be written in red.

1 Response to reviewer 2

The paper provides an experimental study of certain aspects of yaw dynamics. The experimental approach seems fine and the writing is generally clear. My main concerns lie in the contribution of the work in terms of knowledge about what the authors call wake deviation dynamics and the loading on downstream turbines, which does not seem to be reported (discussed). The conclusions and discussion of the results lack a connection to the physics, which would potentially yield the insights that the paper aims to provide.

I was confused by the term wake deviation (dynamics) as it is not precise and was not really clarified in the paper.

The term *wake deviation* is used to describe the fact that, when a wind turbine is misaligned, its overall wake deviates from its normal position. Its normal position is given for a yaw angle equal to zero (rotor normal to the wind direction and so, wake centerline aligned with the wind direction). In this study, a wake deviation angle is considered to measure the wake deflection. *Finally, wake deviation dynamics* refers to the fact that one wants to study the dynamics of this phenomenon, through the analysis of the transient aspects of this wake deviation process during yaw manoeuver. More particularly, in order to clarify the term wake deviation, the following sentences have been added or rephrased to the revised paper :

in the abstract

This article investigates the far wake response of a yawing upstream wind turbine and its impact on the global load variation of a downstream wind turbine. In order to represent misalignment and realignment scenarios, the upstream wind turbine was subjected to positive and negative yaw manoeuvres.

While wake flow and wind turbine load modifications during yaw manoeuvres are usually described by quasi-static approaches, the present study aims at quantifying the main transient characteristics of these phenomena.

and in the introduction

deviate its wake from its nominal position

response during the yaw manoeuvre of a wind turbine

PIV fields aim at measuring the profile for the far-wake velocity distribution and permit to deduce the wake deflection. The latter can be described by a wake skew angle that depends on the yaw angle and the downwind distance in particular (Bastankhah and Porté-Agel (2016)). In this study, a wake deviation angle, computed from the estimation of the wake center displacement will be considered. In addition, a wake deviation duration will be introduced to analyse the transient aspects of this wake deviation process during yaw manoeuvre.

It was not clear that the balance would detect asymmetric loading on the disk, which might be important in this context. In general little discussion of the downstream turbine was affected is provided.

The aerodynamic balance is a 6DoF balance and so, can measure the asymmetric loading (see Muller et al. (2015) in which this asymmetric loading measurement was used to characterise the wake meandering). The objective in the present study was to use the loading of the second wind turbine as an indirect indicator of the upstream WT wake deviation and of the induced downstream WT thrust increase. The analysis was focused on the thrust measurement because that is the only loading that can be related to a notion of WT performance. This second WT model is considered here as a sensor of the global WT performance variations. Additionally, the streamwise force (thrust here) has a much higher value than the crosswise forces; measurement accuracy is therefore higher in the streamwise direction. In order to clarify this statement, the following sentences have been added to the revised paper in section 2.3.

It should be noted that the aerodynamic balance can detect the asymmetric loading on the downstream WT. Nevertheless the analysis will be focused on the thrust measurement because that is the only loading that can be related to a notion of WT performance.

There are some additional yaw models not discussed in the literature review that should be included, particularly in terms of computing the behavior of the wake centerline and in capturing the yaw dynamics (which the authors claim has never been done). Given those works it is unclear that the wake deviation angle is a meaningful metric since the centerline is not a straight line due to the curled wake etc., discussed even in some of the papers cited.

The reference suggested by the reviewer has been added in the introduction and the following sentences have been rephrased to take the reviewer's remark into account.

Some studies on the effects of yaw misalignment on wind turbine wakes, mainly based on quasi-static approaches, have already been carried out describing the effect of WT yaw on the wake position, in wind tunnel conditions (e.g. Bastankhah and Porté-Agel (2016); Grant et al. (1997); Howland et al. (2016); Schottler et al. (2018)) and at full scale (e.g Howland et al. (2020)). However, analyzing yaw manoeuvre dynamics, by studying the transient process between the non-yawed and yawed conditions, affords new insights into wake interactions.

As concerns the second part of the reviewer comment, it is right. Indeed, one underlying conclusion of the present work is that the wake deviation is particularly difficult to quantify because (i) the wake deviation angle is one angle of magnitude smaller than the yaw angle and because (ii) the definition of the wake center is not clear for an asymmetric wake distribution as encountered for skewed wakes. Therefore, the wake center position is not the best candidate to characterise the consequences of the wake modification during yaw manoeuvre. The more global indicators, as the available wind power for a downstream wind turbine or the thrust applied to downstream wind turbine, give better and less ambiguous results.

I was somewhat confused by the choice of metrics in general, particularly in section 5.1. There was little discussion given as to why these are the correct metrics to consider in practice. The chosen ones for example do not provide information about what the downstream turbine might see in terms of velocity, wake or loading (although these things were alluded to in the abstract). These issues are of great importance and of far greater interest than the effect of cyclic yawing behaviour, which is not clear is common in practice.

The chosen metrics actually provide information on the yaw angle of the upstream WT, the wake deviation angle at the location of a downstream WT and the loading applied to the downstream WT. The present paper is focused on the determination of the transients (dynamical part of the processes), which are generally described, as a first approach, by their duration and the time delay between the action (yaw manoeuvre) and reaction (wake skewing for instance). Consequently, it has been decided to use normalised metrics to restrain the attention to these transient parameters. The reviewer refers to the cyclic yawing. This principle is indeed not used in practice. This is more a "trick" that is used in the present wind tunnel study to be able to reproduce automatically 500 times the same yaw manoeuvre and then to obtain converged statistics by phase-averaging velocity and load measurements. Each cycle is composed of a yaw increase from 0° to 30°, a still period, a yaw decrease from 30° to 0°, a still period. During the result analysis, yaw increase transients and yaw decrease transients are studied separately.

The choice of configuration was also strange since the streamwise spacing was short for all cases (in practical wind farms spacings are often at least 5-7D) and there was little justification for these choices.

The reviewer is right when saying that the spacing is quite small compared to real wind farms. But, since the present work falls within a set of previous and ongoing studies for which the layout of the Ablaincourt-Pressoir wind farm operated by Engie Green was already used as reference, the same spacing as for this wind farm had been chosen. The wake interactions of two specific wind turbines were particularly investigated (Garcia et al. (2019); Macrì et al. (2020)) and some yaw control strategies have been tested on these both WT. In order to justify these choices, the following sentence has been added in the revised paper in section 2.1.

The fixed downstream distance was chosen according to the data set from a working wind farm studied in Garcia et al. (2019) & Macrì et al. (2020).

The list of results in bullet form was rather superficial and were merely observations of the data rather than an analysis.
The presentation of the results as a list has been modified (see green part).

Why are equations (7) and (8) the appropriate choice; they just empirical fits to a chosen shape but the significance of this shape or choice is not mentioned.

The reviewer raises a relevant question that could be investigated in another future study. A parametric study on the type of fit functions was performed before ending-up with the chosen ones. Exponential laws were used because first, they fit well to the measured data and also because they provide tunable parameters that can be physically interpreted : c can be straightforwardly associated to the transient speed and τ_{lag} to the time delay. A section (5.4) dealing with the fitting coefficient results interpretation has been added (see response to reviewer 1).

A few minor comments

Using S for area is unnecessarily confusing.
S_D is replaced with A_D in the revised paper.

Figure 1 should be larger (there is a lot of white space so it should be easy to make it easier to read and see all of the detail within the sketch).
The figure 1 has been reworked following this comment.

References

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