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Wind tunnel study of the wake meandering of a floating wind turbines by a porous disk

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Over the years, offshore wind farms are becoming an efficient energy solution thanks to the absence of obstacles, which allows a greater efficiency due to stronger and more constant winds. Indeed, the capacity factor is 23% on average for an onshore wind turbine and 35% for an offshore wind turbine (new models reach 30-35% for onshore and 42-55% for offshore [8]). Also, the development of floating wind turbines allows placement further from the coast, where the water depth is too important for bottom-fixed wind turbines, allowing even greater power. Moreover, in a wind farm, it is important to know the wake generated by a wind turbine upstream in order to better understand its consequences on the one placed downstream. Indeed, the upstream wind turbine affects the wind by a velocity deficit and by an increase of the turbulence intensity which drops the energy efficiency and accelerates the fatigue of the blades of the downstream wind turbine. Thus, different studies have shown that in addition to these stationary mean wake characteristics, an unsteady component is responsible for the motion of the whole far wake at low frequency: the wake meandering [6, 9, 10, 14]. During their experiments on a floating wind turbine model, *Schliffke et al.* [13] presented the different characteristics of the velocity and turbulence intensity profiles downstream of a moving porous disk. The results show the possibility that the signature of the motion imposed on the wind turbine model can be detected in its far wake, implying that the motions of the floating wind turbine directly influence the dynamics of its far wake (at $4.6D$ distance from the porous disk in this case). Therefore, the objective here is to provide informations concerning the wake meandering of a floating wind turbine and to characterize different parameters of the wake according to the platform motion, such as the wake center position, the wake surface or the velocity deficit.

The various experiments are carried out in the atmospheric boundary layer wind tunnel of the Laboratoire de recherche en Hydrodynamique, Énergétique et Environnement Atmosphérique in Centrale Nantes (LHEEA). This wind tunnel has a $26m$ long and a $2 \times 2m$ surface test section. It has a centrifugal fan coupled to a $45kW$ electric motor which allows to reach speeds up to $10m/s$. A grid and spikes are installed at the entrance of the wind tunnel and perforated metal sheets are placed on the ground, over the $15m$ of the test section, to reproduce the model of a marine atmospheric boundary layer [5, 15]. The model used in the experiments represents the $2MW$ floating wind turbine of the FLOATGEN project installed at the Centrale Nantes SEM-REV offshore test site [4]. Using a geometric reduction scale of $1/500$, the model is a $160mm$ diameter porous disk with a hub height of $120mm$ and a strength of 57%, which gives a drag coefficient $C_T \approx 0.65$ and a blockage ratio of 2% in the test section [1, 13]. Several studies have shown that the porous disk is an efficient tool that can represent very simply the physics of the far wake of a wind turbine ($x/D > 3 - 5$, with D the diameter of the wind turbine or its model) [2, 3, 12]. The model is placed in the wind tunnel test section and the three components of the velocity are measured in the plane normal to the mean flow at $x/D = 8$ using a SPIV system. In order to study the effects of the meandering of the wind turbine wake, several cases of float motion were tested: 1D motions with a single frequency (heave, surge and pitch), a realistic 1D surge motion with a range of amplitude and frequency and a real 3D motion with a multi-frequency heave-surge-pitch combination. The algorithm utilised to recover the different parameters of the wake and of the meandering phenomenon is a modified method Weighted Geometric-Center (WGC) already used in literature [6, 7, 11] and defined by the formula:

$$\forall \Delta u_i > \Delta u_{thresh} : \begin{cases} y_c = \frac{\sum_i e^{\Delta u_i} y_i}{\sum_i e^{\Delta u_i}} \\ z_c = \frac{\sum_i e^{\Delta u_i} z_i}{\sum_i e^{\Delta u_i}} \end{cases}$$

where (y_i, z_i) are the coordinates of the point, u_i the velocity and u_{thresh} the thresh value (here $u_{thresh} = 0.9u_{inlet}$).

As seen by *Schliffke et al.* [13], the results show that the motions of the floater do not modify mean fields. Figure 1 present the wake center distributions for the fixed case, a heave case ($A = 10mm$ and $f = 6Hz$) and a pitch case ($A = 8deg$ and $f = 2.5Hz$). The different distributions are very similar and have globally the same characteristics with a flattening along the y -axis and a concentration of wake centers inside the dashed line circle, which represent the position of the porous disk, where the density can reach its highest values. The observation of similarities can be carried out for other mean fields like mean velocities, standard deviations, turbulent kinetic energy or Reynolds normal and shear stresses, not shown here. However, statistical graphics show responses of the mouvement on the wake, such as power spectral density on figure 2 where the PSD of the Z positions of the wake center in function of the Strouhal number are plotted for the different cases. The figure is separated into four graphics: the heave, the pitch, the surge and the 'realistic' motions. The black line represent the fixed case and the dashed vertical black line indicate the Nyquist limit of the SPIV. Thus, the link between the heave and pitch motions and their respective far wake responses are clearly visible while the surge movements do not seem to impose any response in the wake, or at least a smaller one than in the other studied cases, and the 'realistics' cases with a range of combinaisons amplitude/frequency show no specific response frequency.

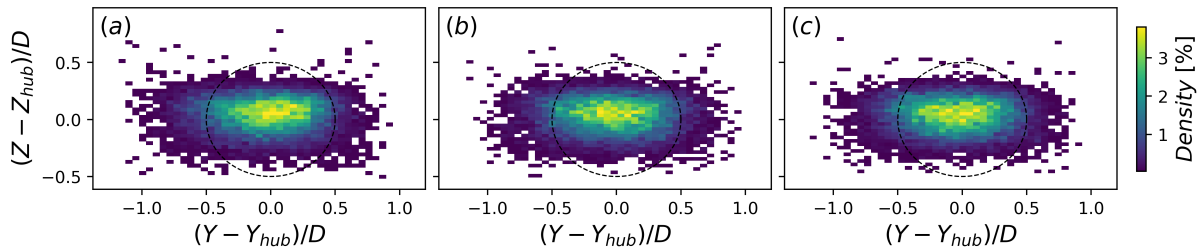


Figure 1: Wake center distribution for (a) fixed case, (b) heave [$A = 10mm, f = 2.5Hz$] and (c) pitch [$A = 8, f = 2.5Hz$]. The dashed line circle represent the porous disk.

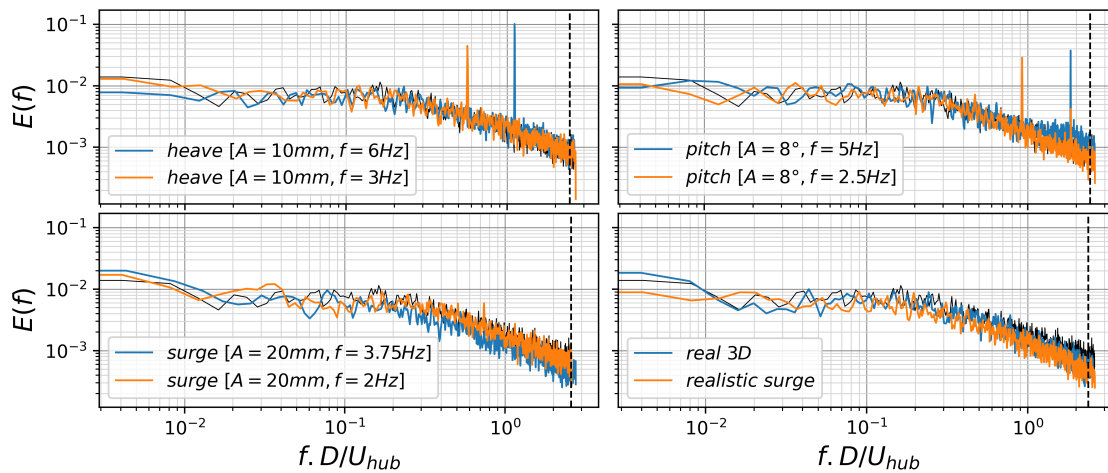


Figure 2: Z-wake center PSD for the different tested cases. The black line represent the fixed case and the dashed vertical line is the Nyquist limit of the system.

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