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# Wake dynamics study of a floating wind turbine model through phase-averaging

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Floating wind energy is a resource with a great potential: the absence of obstacle and stronger winds set its efficiency higher than the onshore one (new wind turbine models have capacity factor of 30-35% for onshore while offshore reach 42-55% [4]). This leads to an increase of the number of floating wind farm projects in Europe, while knowledge on the subject is still lacking. Indeed, in a wind farm it is important to understand the wake generated by an upstream wind turbine. It affects the wind of the downstream wind turbine by dropping its velocity and increasing the turbulence intensity, leading to wind farm energy losses and acceleration of the downstream wind turbine blades fatigue. Different studies have demonstrated that floater motions only slightly affect the wake in global-average [1, 10, 2]. However, the frequency domain shows their impact on wake parameters such as wake center, wake surface, potential downwind energy, etc. The objective here is to provide informations on the wake dynamics of a wind turbine model subjects to harmonic motions thanks to phase-averaging.

The experiments are carried out in the Atmospheric Boundary Layer (ABL) wind tunnel at LHEEA - Research Laboratory in Hydrodynamics, Energetics and Atmospheric Environment - in Centrale Nantes, France. It is a  $2m \times 2m$  cross-section and  $24m$  long facility, with a motor of  $45kW$  allowing a maximum speed of  $10m/s$ . Spires are installed at the entrance of the test section and performed metal plates are placed on the ground along  $26m$ . This configuration allows a 1:500 marine neutral ABL with a roughness length of  $z_0 = 5.5 \times 10^{-6}m$ , a power-law exponent of  $\alpha = 0.11$  and an integral length scale of  $L_u^x = 240m$  at hub at full scale [5, 11]. The model used is a porous disk of diameter  $D = 160mm$  and hub height  $z_{hub} = 120mm$  reproducing a 1:500 reduced-scale of FLOATGEN, the floating wind turbine installed on a barge at the SEM-REV test site. The porous disk motions are imposed by a 3DoF system, the studied cases are presented in Table 1 and are computed according to real FLOATGEN second order movements related to the interaction floater/mooring lines/wind - not interaction wave/wave. Finally, a Stereo PIV (S-PIV) system is placed at  $8.125D$  downstream the turbine model to measure the three-components of velocity of the plan normal to the flow.

Table 1: Imposed motion parameters on the porous disk

| Motion | Full-scale<br>amplitude [m/°] | Full-scale<br>Period [s] | Model<br>amplitude [mm/°] | Model<br>frequency [Hz] | Normalized<br>amplitude | Reduced<br>frequency |
|--------|-------------------------------|--------------------------|---------------------------|-------------------------|-------------------------|----------------------|
| fixed  | -                             | -                        | -                         | -                       | -                       | -                    |
| pitch  | 4°                            | 80                       | 4°                        | 2.5                     | 4°                      | 0.14                 |
| pitch  | 4°                            | 40                       | 4°                        | 5                       | 4°                      | 0.28                 |
| heave  | 2.5m                          | 133                      | 5mm                       | 1.5                     | 0.0313                  | 0.09                 |
| surge  | 5m                            | 100                      | 10mm                      | 2                       | 0.0625                  | 0.11                 |

A phase-averaging algorithm is processed based on the sinusoidal motion signal. Each S-PIV snapshots are associated with a time phase and a kernel smoothing - using Epanechnikov function - is performed all along the motion signal [12]. Because of the presence of meandering, the wake can artificially be widen and its velocity deficit be reduced. Two frames of reference can be defined: the Fixed Frame of Reference (FFoR) and the Meandering Frame of Reference (MFoR) - a modified Weighted Geometric-Center (WGC) algorithm is computed in order to obtain the MFoR [9, 6]. The former gives the influence of the disk on the downstream flow and therefore on a potential downstream wind turbine, while the latter follows the wake and its physics [3, 8, 7].

FFoR results are shown in Figure 1 and MFoR in Figure 2. Two main physics can be extracted from these figures: the pitch/heave one **(a)** **(b)** **(c)** and the surge one **(d)**. For the first one, Figure 1 shows that the wake surface increases and decreases at the same time as the y-coordinate of the wake center. The decrease is accompanied by a widening of the wake bottom, particularly visible at phase  $\frac{\pi}{3}$  and  $\frac{2\pi}{3}$ . The hypothesis is that these motions do not impact the wake surface but rather translate it vertically, the widening of the wake bottom related to a flattening of the wake on the ground. In the other hand, surge case seems to have less impact, its wake center and surface is only slightly modified along the phases. Nevertheless, in Figure 2 its wake radii along y and z - *i.e.* the distance between the wake center and the right and top edge of the wake - are correlated with each other, and are accompanied by an increase and decrease of the potential wake energy (not shown here). The hypothesis is that surge motion compresses and expands the wake without impacting the wake center, related to a wake 'pumping'.

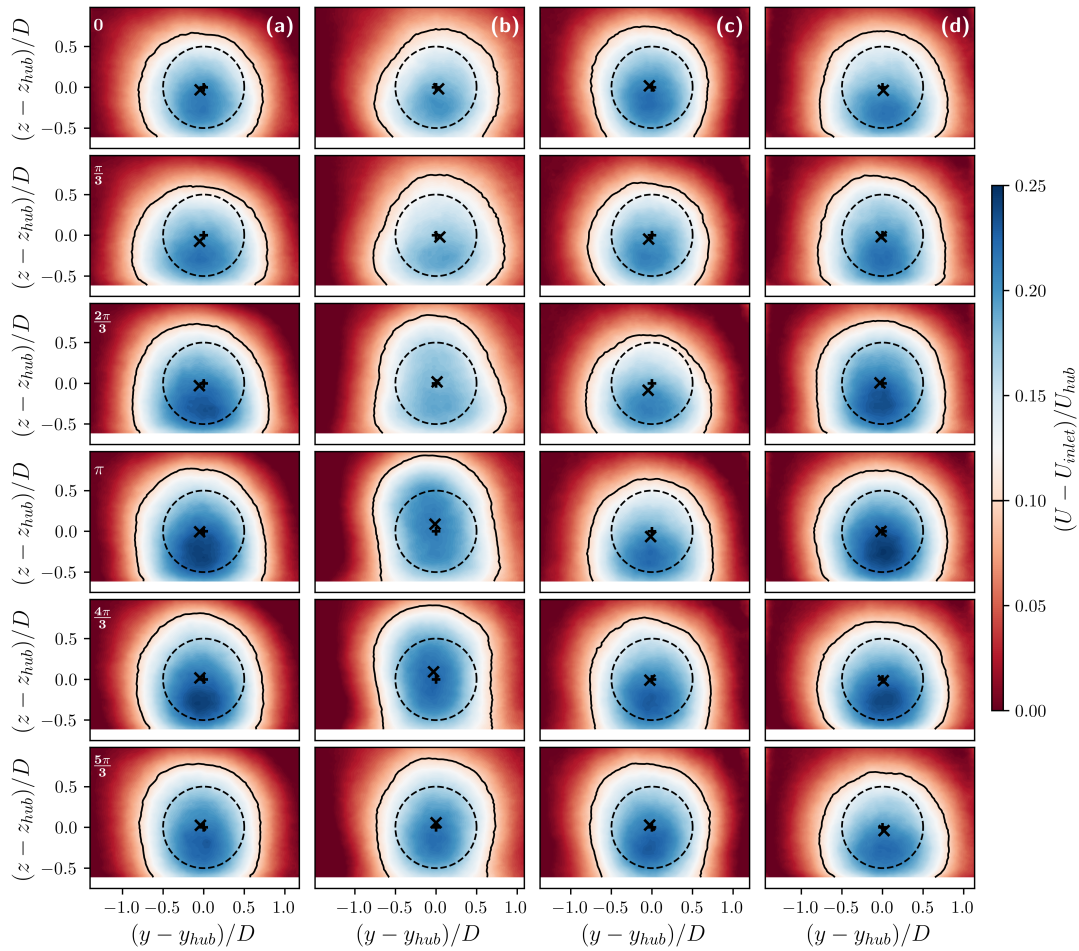


Figure 1: FFoR velocity deficit fields for different phases  $[0; \frac{\pi}{3}; \frac{2\pi}{3}; \pi; \frac{4\pi}{3}; \frac{5\pi}{3}]$  for: **(a)** pitch  $f_{red} = 0.14$ , **(b)** pitch  $f_{red} = 0.28$ , **(c)** heave  $f_{red} = 0.09$  and **(d)** surge  $f_{red} = 0.11$ . The dashed line circle and the black plus represent the porous disk emplacement, the full line and the cross are respectively the wake (0.1 velocity deficit contour) and its center.

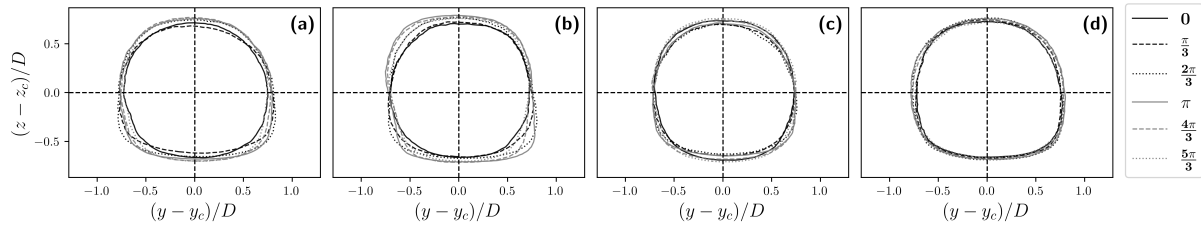


Figure 2: MFoR wake shape for different phases  $[0; \frac{\pi}{3}; \frac{2\pi}{3}; \pi; \frac{4\pi}{3}; \frac{5\pi}{3}]$  for: **(a)** pitch  $f_{red} = 0.14$ , **(b)** pitch  $f_{red} = 0.28$ , **(c)** heave  $f_{red} = 0.09$  and **(d)** surge  $f_{red} = 0.11$ .

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