Table 1. Parameters of the motions imposed on the wind turbine model.

Motion	Full-scale amplitude	Full-scale period [s]	Model-scale amplitude	Model-scale frequency [Hz]	Normalized amplitude	Strouhal number
Fixed	–	–	–	–	–	–
Heave **H**	2.5 m	133	5 mm	1.5	0.03	0.09
Surge **S**	5 m	100	10 mm	2	0.06	0.11
Pitch $\mathbf{P_{0.14}}$	4°	80	4°	2.5	4°	0.14
Pitch $\mathbf{P_{0.28}}$	4°	40	4°	5	4°	0.28

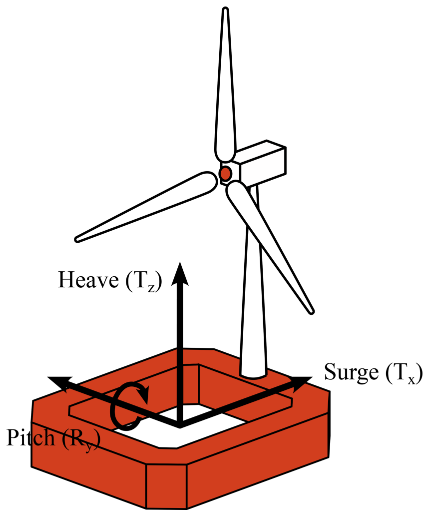

Figure 3. Degrees of freedom of a floating wind turbine platform. Surge (T_x) and heave (T_z) are the translation motions studied, and pitch (R_y) is the rotation motion studied.

A binarization process is then performed using a threshold velocity deficit set to $U_{\text{thresh}} = 0.1U_{\text{hub}}$ to determine the points that are part of the wake (Fig. 5c). This process consists of pixel detection, inspired by watershed processing (Beucher, 2004) where each pixel verifies if its neighboring pixels belong to the wake by comparing the local velocity deficit value to the threshold one. As in España et al. (2011), the wake is unified to decrease pixel noise (Fig. 5d), and the final field provides the integration surface S_{wk} to be used in the WGC to find the wake center coordinates y_c and z_c:

$$\left(y_c(t) = \frac{\iint\limits_{S_{\text{wk}}} y e^{\Delta u(t,y,z)} \mathrm{d}y\mathrm{d}z}{\iint\limits_{S_{\text{wk}}} e^{\Delta u(t,y,z)} \mathrm{d}y\mathrm{d}z}; \quad z_c(t) = \frac{\iint\limits_{S_{\text{wk}}} z e^{\Delta u(t,y,z)} \mathrm{d}y\mathrm{d}z}{\iint\limits_{S_{\text{wk}}} e^{\Delta u(t,y,z)} \mathrm{d}y\mathrm{d}z} \right), \quad (3)$$

where $\Delta u(t,y,z) = U_{\text{ABL}}(y,z) - u(t,y,z)$, $u(t,y,z)$ is the instantaneous velocity, and $U_{\text{ABL}}(y,z)$ is the mean inflow velocity at point (y,z). U_{ABL} is calculated for each case as the average of the velocity profiles of the mean field at the S-PIV measurement plane limits, which present the lowest porous disk impact.

The results show that the lower part of the wake is truncated, as in Fig. 5, due to the S-PIV measurement plane definition. This truncation could potentially misrepresent the wake surface but also the wake center coordinates, especially for z_c. As the wake descends, a new portion of the wake disappears under the S-PIV measurement plane, which leads to an "artificial" decrease in the wake surface and an increase in the wake center z coordinate. Tests with an ideal Gaussian wake showed a difference of $0.1D$ between the WGC result and the real one when 20 % of the wake is cut off, representative of the worst case here – i.e., when the porous disk is at the bottom. Thus, considering the up–down motions (mainly pitch motion cases), the amplitudes of the wake statistics in MFoR are misrepresented. The consequences for the analysis of the curve trends are limited, however.

In order to reduce this effect for the phase-averaged wake centers, a Gaussian fit approach is used. In this method, a least-squared error method is computed between the S-PIV u-component velocity field and a 2D Gaussian function defined by

$$f_{\text{Gf}}(y,z) = A \exp\left[-\frac{1}{2} \left(\frac{(y-y_c)^2}{\sigma_y^2} + \frac{(z-z_c)^2}{\sigma_z^2} \right) \right], \quad (4)$$

where A is the amplitude, and σ_y^2 and σ_z^2 are the variances of the Gaussian function in the y and z directions, respectively. The wake center (y_c, z_c) found is the location of the center of the 2D Gaussian function closest to the velocity field.

With a high level of turbulence, the instantaneous fields cannot be assimilated to a Gaussian distribution, and Gaussian fitting results in incoherent wake center values. Thus, the WGC method is applied to the instantaneous velocity fields and Gaussian fitting to the phase-averaged ones (the processes are detailed in Fig. 8).

2.2.2 Phase-averaging and kernel smoothing

The phase-averaging method is applied to the S-PIV velocity fields according to the harmonic motion imposed on the porous disk in FFoR and in MFoR. A kernel smoothing, defined by an Epanechnikov function (Wand and Jones, 1995; Hastie et al., 2009), is used to smooth the velocity deficit fields over phases. The Epanechnikov kernel smoother is defined as

$$K_h(t_\phi, t) = \frac{3}{4h} \left(1 - \left(\frac{t_\phi - t}{h\lambda} \right)^2 \right), \quad (5)$$