Damping the heave motion of floating wind turbines

Keywords: floating wind, waves, heave, fluid-structure interaction, fluid mechanics, experiments, designs

Context, positioning and goals:

Wind power is emerging as the most promising renewable energy source. By 2019, 417TWh of wind power was generated in Europe, representing 15% of electricity demand [1]. To accelerate the energy transition, the European Union has set a target of increasing installed offshore wind power capacity to 300GW by 2050 (from 12GW in 2020), making wind power the marine renewable energy with the greatest potential in the European Green Pact.

The appeal of installing larger wind turbines (i.e. with greater capacity, see figure 1) farther from the coast is to take advantage of the stronger, more regular and therefore more predictable winds. However, far from the coast in deeper water depths, it is no longer possible to mount wind turbines on the seabed (as is the case near the coast) without increasing significantly the installation costs. To remain competitive, floating wind turbines are the optimal alternative. However, there are still a number of technological challenges to overcome before the technology can be deployed to guarantee its survival in extreme wind, wave and current conditions. One major problem is the heave motion, or vertical movement of the floating structures around its buoyancy equilibrium, which cannot be prevented by anchoring alone [2,3]. Current solutions consist of placing wind turbines on floating platforms that dampen the heave motion by design, using energy dissipators. However, it is not yet possible to predict the dissipation of a particular structure: a great deal of experimental testing is still needed in laboratories. Our aim is to make progress on the design of stable floats, by validating our understanding of the physical mechanisms involved.

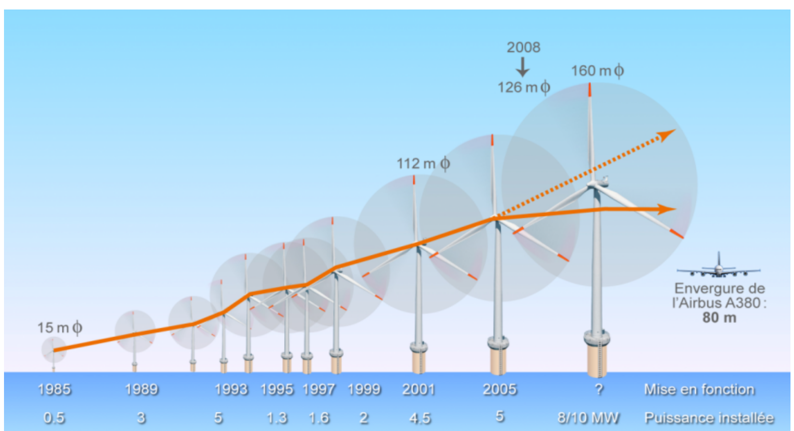

Figure 1 : Evolution of the size and power of offshore wind turbines (©Connaissance des Énergies)

Today's floats are typically cylindrical, semi-submersible steel structures, interconnected by rods (see figure 2: semi-submersible and spar). The wind turbine rests on one of the columns or on the bars, depending on the prototype. This structure must enable the wind turbine to extract energy from the wind while remaining sufficiently stable in a potentially very strong wave field in the open sea, with strong currents and winds.The technologies currently being studied are based on the knowledge acquired from offshore oil platforms, as the sea conditions are similar. However, the dimensions of these structures are very different: typically 300 m versus 50 m wide, and 100 ktonnes versus 1 ktonne for a wind turbine! Heave damping technological solutions have been validated at large scales with a significant empirical component, which are not able to be transfered directly to the new scales considered (by dimensional analysis and numerical calculation [3]).

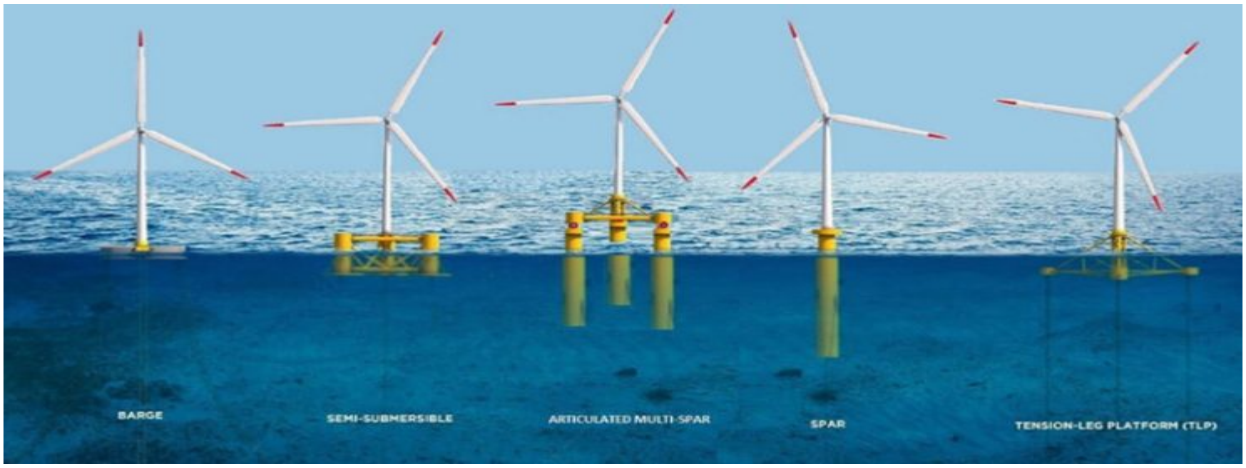

Figure 2 : Floating wind turbine prototypes (source: windpowerengineering.com)

One of the aims of the study is to design a structure with a natural resonance frequency outside the frequency range of the wave field at the installation site. The next step is to maximize the dissipation of vertical movements of the floating structure. In other words, the structure's natural period of oscillation needs to be increased and the generation of vortices from the oscillation needs to be amplified. One solution is to use heave plates (see figure 3).
The shape (circular, hexagonal with or without skirt...), porosity (solid, perforated), number and various dimensions of these plates vary greatly from one prototype to another, further underlining the empirical nature of knowledge on the subject. Studies are also often limited to measurements with oscillation forcing [2-4], and therefore without direct coupling to waves. More recently, Thiagarajan and Moreno (2020) [5] showed that waves greatly influence the dissipation coefficients, and that existing studies are not directly transferable to conditions with waves. The few studies investigating wave coupling are limited to very small-scale models of floating wind turbines, with poor multi-scale conditions [5,6] (there are too many dimensionless numbers to preserve). Wave and current coupling does not appear to have been explored. It's a difficult problem, and a risky one for industry! Solving it requires the improving fundamental knowledge. Moreover, it's also a key competitive issue, and the subject has received little attention in academic studies.

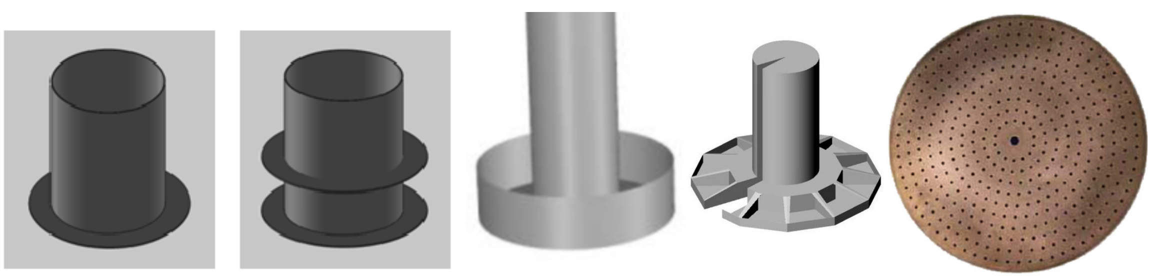

Figure 3 : Examples of different heave plate technologies. From left to right: single disk, double disk, single disk with skirt, disk with skirt and reinforcement, porous disk.

Thus, our project aims to identify heave damping technologies by first improving knowledge of the physics of coupling structures in a wave field. We aim to answer the following question: how can the oscillations of one or more floats in a wave and current field be damped, with the goal of identifying new, stable offshore wind turbine concepts? By analyzing in successive steps the various coupling elements between floating structures and the surrounding fluid, we aim to revisit current studies for floating wind turbines and explore new damper concepts, possibly without direct links to the conventional technologies currently being studied. Our fundamental studies of fluid-floating-structure interactions in the marine context will also serve other applications in marine engineering: floating structures with anchorages, that are smaller than oil platforms, also remain to be designed for multiple new uses in the open sea, for example for wave energy extraction.

Scientific challenges:
The project's starting point is the identification of a technological barrier (damping the heave of floating wind turbines currently under development) that is in fact also a scientific barrier: understanding the fluid-structure interactions that would make it possible to link empirical knowledge about oil platforms (large scales) to the knowledge currently being developed for floating wind turbines (smaller scales).

Models exist for large scales, which today describe oil platforms well, but at the cost of empiricism when it comes to coupling with smaller scales. However, current knowledge of eddy generation does not allow models to be adapted directly to small scales: we must either resort to numerous additional observations, or make progress in our understanding of dissipative mechanisms, in order to select only a well-chosen subset. We are making this second choice, in order to remove a scientific challenge (vortex creation) which would also remove a technological challenge (opening up new horizons for the damping of heave in offshore wind turbines currently under development).

The subject is a difficult one, as many parameters are interrelated at small scales. However, the risk of not arriving at a satisfactory theory is tempered by the acquisition of new, less risky and clearly publishable experimental knowledge.

Scientific and technical program:

The study will focus on a simplified quasi-two-dimensional case forced into heaving motion, producing refracted waves. This will enable us to establish simple laws on the impact of heave plates in a uni-directional wave section, and then identify levers for amplifying dissipation. We will study the impact of different heave plate technologies on float dynamics. We'll also look at the vorticity generated by this device.
To quantify the impact of the heave plates and the source of the forces leading to this motion , velocity field measurements will be made using particle image velocimetry (PIV), synchronized with measurements of the resultant forces acting on the floater and its vertical displacement
The parameters to be varied are: the linear mass of the float, the stiffness of the system (simulating mooring lines), its size, the type of heave plate (see figure 2), and the frequency and amplitude of waves in the case of regular waves.

We will seek to establish a theoretical model explaining the dissipation of uplift plates. This work could also involve the use of numerical tools if necessary, taking advantage of the codes developed and used within the host Laboratories.

The result of this work will be a theoretical formulation (analytical or pseudo-analytical) of the physical phenomenon studied, leading to publications in fluid mechanics and/or ocean engineering journals.

Information about the laboratories
The work will be carried out in the Unité de Mécanique (UME) of ENSTA Paris, in collaboration with the Laboratoire d'Hydraulique Saint-Venant (LHSV) at Ecole des Ponts ParisTech.

The UME has a wave channel (8m long, 50cm wide) and a free-surface racecourse (test section 50cm x 80cm) in which the project experiments will take place.

Desired candidate profile :
Fluid mechanics experimenter with expertise in fluid/structure interactions and potential wave theory.

Contract start date:
Between October and December 2023.

Net wage :
Based on past research experience.

Contact :
Send CV, cover letter and transcript to luc.pastur@ensta-paris.fr and remi.carmigniani@enpc.fr.
Letter(s) of recommendation would be appreciated.

References :
[1] Wind Europe. Wind Energy in Europe in 2019. 2020. Available online: https://windeurope.org/about-wind/statistics/european/wind-energy-in-europe-in-2019/ (accessed on 10 October 2020).
[2] Bezunartea-Barrio *et al.* (2019), Scale effects on heave plates for semi-submersible floating offshore wind turbines: case study with a solid plain plate, Journal of Offshore Mechanics and Arctic Engineering
[3] Lopez-Pavon et Souto-Iglesias (2015), Hydrodynamic coefficients and pressure loads on heave plates for semi-submersible floating offshore wind turbines: A comparative analysis using large scale models
[4] Tao et Dray (2008), Hydrodynamic performance of solid and porous heave plates
[5] Thiagarajan & Moreno (2020) Wave Induced Effects on the Hydrodynamic Coefficients of an Oscillating Heave Plate in Offshore Wind Turbines, Journal of Marine Science and Engineering
[6] Mello *et al.* (2021) Influence of heave plates on the dynamics of a floating offshore wind turbine in waves, Journal of Marine Science and Technology