Experimental and numerical analysis of a semisubmersible floating wind turbine under waves and wind

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ABSTRACT

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1. Introduction

Floating offshore wind turbines (FOWTs) have been the subject of numerous studies due to the possibility of exploiting the vast wind resources located in deep waters. As an emerging technology, the growth of the wind energy industry depends on FOWTs achieving more competitive costs, which has pushed for larger rotors and new designs for both floaters and moorings.

Since FOWTs are complex structures, their design requires the evaluation of performance and structural integrity for a myriad of environmental conditions (wind, wave, current, among others) and operating conditions (power production, normal shut down, fault conditions, etc.). Due to their intricate dynamics, this procedure requires modelling software capable of accounting for the couplings between aerodynamics, hydrodynamics, controls, moorings and structural behavior of the FOWT (the so-called aero-hydro-servo-elastic software). A substantial effort has been made to validate these tools, as exemplified by the OC3 (Jonkman and Musial, 2010), OC4 (Robertson et al., 2014) and OC5 (Robertson et al., 2017) projects, but this is still an ongoing development.

In fact, the experiments required to validate the numerical tools, usually performed in model scale, are far from an easy task, for it is impossible to keep all the dimensionless parameters that describe the different physical aspects of the problem. For instance, while the scaling of the waves requires that the Froude number ($\mathrm{Fr} = U^2/(gL)$, with U a characteristic speed, L a characteristic length and g the gravitational acceleration) be conserved, the aerodynamic loads are governed by the Reynolds number ($\mathrm{Re} = UL/\nu$, with ν the kinematic viscosity).

They are, however,

The growing importance of offshore wind turbines to the global energy mix has made it clear that this technology will contribute significantly to the transition to a greener future. Since they are fairly complex systems, which is specially true for Floating Offshore Wind Turbines (FOWTs), their design is an intricate task that requires a large amount of numerical simulations to assess their performance and structural integrity under the action of environmental loads.

Vittori et al, 2022: SIL c/ thruster Thys et al, 2021: Cabos

Ensaio com SIL com algumas limitações

Na primeira parte, a ideia é verificar aspectos importantes da hidrodinâmica (que é a parte que é fisicamente capturada no ensaio) que o modelo numérico tem que levar em conta. Mais especificamente, é avaliada a importância de elementos de Morison retangulares p/ modelagem do pontoon; a importância de forças de segunda-ordem tanto na

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horizontal quanto vertical (conforme já sabido na literatura); e mostra-se que levar em conta a inclinação média do casco devido ao vento não é mto importante.

Na segunda parte, o objetivo é avaliar o quão importante são aspectos que foram deixados de lado na modelagem aerodinâmica do ensaio, o que é feito numericamente comparando o modelo que é fiel às condições de ensaio (apenas thrust e pás consideradas rígidas) com um modelo numérico em que as forças aerodinâmicas são calculadas nos seis graus de liberdade e a flexibilidade das pás é considerada (embora de forma simples com o elastodyn. Preciso estudar em que situações seria necessário usar o beamdyn).

2. Description of the prototype and the experimental setup

Falar que foi feito no TPN e dar as principais dimensoes do tanque.

2.1. Main properties of the FOWT

- Caracteristicas da FOWT, RNA, ancoragem

2.2. Software-in-the-loop approach for aerodynamic loads

Tem que incluir o controle. Adicionar alguns resultados de teste de bancada

2.3. Limitations of the experiment

2.4. Environmental conditions

- Condições de onda e vento

3. Numerical models

The wave forces are considered in OpenFAST by a combination of radiation/diffraction forces, taken into account using Cummins' approach (Cummins, 1962; Ogilvie, 1964) with frequency-domain coefficients computed with WAMIT (version 7.0.1), and the quadratic drag from Morison's equation. Concerning the former, one of the main questions about the numerical modeling of the experiments was wether the mean hull inclination caused by the wind should be considered when solving the radiation/diffraction problem. Indeed, one of the main hypothesis of the Boundary Element Method behind WAMIT is that the body oscillates around a mean position, but it is not clear at first how important the few degrees of inclination induced by the wind are.

For that reason, a different set of radiation/diffraction coefficients (i.e. first- and second-order wave forces, added mass and potential damping) was computed for each wind condition, using low order meshes with different inclinations that were determined by experimentally measuring the inclination of the model under the action of constant wind in calm waters. Since this is a somewhat cumbersome procedure, it is important to assess whether it is worth the cost, so all the OpenFAST simulations were performed twice: once with radiation/diffraction coefficients obtained using the inclined mesh, and once with coefficients from an even keel mesh. One of the inclined meshes (ESPECIFICAR) and the even keel mesh are illustrated in Figures XX, while the differences between the results obtained with them are discussed in Section 4.4.

4. Reproducing the experiments with numerical models

Explicar aqui como é organizada a seção e a metodologia usada p/ mostrar o resultado. O foco é em apresentar três aspectos físicos que tiveram maior atenção na modelagem do problema, e não tanto nos resultados da comparação entre o experimento e o ensaio.

4.1. The need for drag forces on the pontoons

Fazer figuras ilustrativas p/ mostrar o pontoon e a nomenclatura, junto com uma tabela com os diâmetros e coeficientes de arrasto adotados nas colunas/pontoons p/ cada um.

Mostrar os decaimentos com três curvas: experimental, C_D pro caso de um pontoon circular (o errado, tipo heave only p/ surge e surge only p/ heave) e C_D pro pontoon retangular. Daí, mostrar que consegue pegar bem o heave e o surge simultaneamente quando tá retangular, o que não é possível no caso circular.

Resultados a gerar: - Gráfico do Decaimento de heave com (lado a lado com o de surge): — Experimental — OpenFAST - Rect. pontoon — OpenFAST - Circ. pontoon S - Gráfico do Decaimento de surge com (lado a lado com o de heave): — Experimental — OpenFAST - Rect. pontoon — OpenFAST - Circ. pontoon H

- Heave p/ APR01-IDLE-IRR-I1 – Série temporal e espectro na esquerda – RAO na direita — Experimental — OpenFAST - Rect. pontoon — OpenFAST - Circ. pontoon S — WAMIT no RAO

- Mesma coisa p/ surge

4.2. The importance of second-order forces on both horizontal and vertical motions

Mostrar o offset e o pitch

4.3. Main results

Explicar o procedimento adotado para processar a grande quantidade de ondas, que é baseado nas estatísticas. Mostrar tabela com períodos naturais e níveis de amortecimentos + tabela de resumo das estatísticas p/ ondas irregulares.

Ilustrar c/ gráficos de séries temporais e espectros de casos selecionados (tem que ter a aerodinâmica p/ mostrar que o rotor tá funcionando) + gráfico do máximo e média

4.4. The impact of mean hull inclination when computing radiation/diffraction coefficients

As mentioned in Section 3, one of the objectives of this work is to assess the impact of considering the mean hull inclination caused by the wind when solving the radiation/diffraction problem. Figure X, which summarizes in a boxplot the differences in the maxima obtained for each of the quantities analyzed in the previous sections for all the irregular waves, shows that this is not the case: in fact, the differences are .... (falar também que a diferença é ainda mais irrelevante quando se pensa na tabela de extremos)

Mostrar um gráfico comparando as estatísticas calculadas c/ inclinação e sem.

As a more in-depth example, Figure X presents the time series and PSD's of roll and pitch motion obtained for the FOWT under the combined action of the IRR12 sea ($H_S = 4.44$ m, $T_P = 11.34$ s and incidence of -10°) and the turbulent wind condition (mean wind speed 10.59 s and TI = 12%) with an incidence of 47°, which is schematized in the same figure. This case was chosen for being the one that presented the largest difference in the horiontal acceleration at the nacelle, with the model considering an inclined mesh (denoted by IC) predicting a maximum horizontal acceleration of $0.85\,\mathrm{m/s^2}$ and the one with an even keel mesh (denoted by EK) providing $0.74\,\mathrm{m/s^2}$, which is actually closer to the experimental value of $0.64\,\mathrm{m/s^2}$.

Mostrar gráfico de série temporal do que deu a maior diferença e explicar usando RAO e o .3

In fact, this could be anticipated by looking directly at the radiation/diffraction coefficients that are imported by OpenFAST. These are illustrated by Figure X (first-order diffraction forces), Figure X (mean drift force) and Figure X (added mass and potential damping). For conciseness, only the mesh with the largest inclination (dizer qual é aqui, i.e. p/ qual vento, e qual é a inclinação) and only one wave incidence (45°) is plotted, and the results for sway and roll are omitted because they are qualitatively the same as surge and pitch.

Mostrar gráficos das forças

It is worth pointing out that only the impact on the radiation/diffraction coefficients was assessed, and it is possible that hull inclination may be important to effects related to real flow phenomena, such as drag forces.

5. The impact of rotor simplifications adopted in the model tests

- Comparar resultados das simulações nas condições reais e identificar diferenças pro modelo que é mais próximo do ensaio.

- Usar simulações intermediárias p/ explicar essas diferenças

6. Conclusions

CRediT authorship contribution statement

Lucas H. S. Carmo: Conceptualization, Methodology, Software, Validation, Formal analysis, Writing – original draft. **Alexandre N. Simos:** Conceptualization, Formal analysis, Writing – review, Supervision. **Pedro C. de Mello:** Experiments.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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