Simulation et Optimisation pour les Énergies Marines Renouvelables

May 30 to June 2, 2022 - Roscoff Marine Station

Monday, 30.5: Numerics

14:00 - 15:00 *Welcome*

15:00 - 16:00 **Axelle Viré**: *TBA*

TBA

16:00 - 16:30 **Mikael Grondeau**: *Study of the spatial positioning of a vertical axis tidal turbine farm of type HYDROQUEST : Simulation by a LBM-LES approach*

Marine turbines are an alternative in the future energy mix. Several technologies are being tested. Thus, the HYDROQUEST vertical twin axis tidal turbine has been tested at scale 1 on the site of Paimpol Bréhat between 2029 and 2021 as part of the OCEANQUEST project. In parallel, modelling studies have been conducted on the positioning at scale 1. The purpose of the communication is to present a study of positioning of turbines of a marine turbines HYDROQUEST pilot farm by the development of a LBM-LES (Lattice Boltzmann Method -Large Eddy simulation) model and the representation of the blades by Actuator Lines. This study is carried out with ambient turbulence conditions representative of a tidal turbine site in the Raz-Blanchard. Several configurations are studied.

16:30 - 17:00 *Coffee break*

17:00 - 17:30 **Hugo Carrillo**: *MOPINNs for PDE simulations*

We present a study in Multi-Objective Physics-Informed Neural Networks (MOPINNs) for meshless simulation of PDEs. MOPINNs use an EMO algorithm to find the set of trade-offs between the data and physical losses of PINNs (boundary conditions and PDE in residual form, respectively) and therefore allow practitioners to correctly identify which of these trade-offs better represent the solution they want to reach. We discuss how MOPINNs overcome the complexity of weighting the different loss functions. We provide an exploratory analysis of this technique in order to determine its feasibility by applying MOPINNs on PDEs of particular interest: the heat, waves, and Burgers equations. Finally, we present some preliminary results in applications to tidal turbine simulations.

17:30 - 18:00 **Elise Grosjean**: *Non-Intrusive Reduced Basis two-grid method: Application to offshore wind farm simulations*

This talk is concerned with a low-cost numerical tool which is the NIRB two-grid method [1], and its application to simulations of offshore wind farm. It is part of Reduced Basis Methods (RBM) which are used to solve parametric problems for a large number of parameter values, and aim at reducing the computational costs of high fidelity (HF) codes while preserving the accuracy of classical simulation tools (e.g. finite element). Its advantage is its non-intrusiveness, which means that the industrial code does not need to be modified. It is very convenient when dealing with complex simulations. I will present 2D and 3D results on the application. An EDF solver (code_saturne) is used to solve the Reynolds Averaged Navier-Stokes equations representing the wind around the turbines.

[1] R. Chakir and Y. Maday, Une méthode combinée d'éléments finis à deux grilles/bases réduites pour l'approximation des solutions d'une E.D.P. paramétrique, C. R. Acad. Sci. Paris, Ser. I Vol 347, p435-440, 2009.

20:00 *Dinner at Hotel Gulf Stream*

9:00 - 10:00 **Yann Michel**: *An introduction to Data Assimilation in Numerical Weather Prediction as practised at Météo France*

Data assimilation is the theory and practice on how we estimate an analysis, e.g. an initial state for the prediction of a numerical model. In operational Numerical Weather Prediction, this is achieved several times a day for the atmosphere - and possibly the surface and ocean in a coupled prediction model in a computationally efficient way. The basic objective information that can be used to produce the analysis is i) the observation and ii) a recent forecast, both of which are affected by systematic and random errors. We will first introduce the fundamental data assimilation concepts : how the problem is cast in a Bayesian framework, the variational approach and the Kalman Filter. We will then describe the Ensemble Kalman Filter methods; Ensemble of Data Assimilations and uncertainty estimation; Hybrid variational/ensemble based methods. On the observation side, we will also describe the latest developments in the modelling of observation error covariances and handling of non-Gaussian errors. Illustrations will be based on operational practice at Météo-France and ECMWF, including a description of the global observing system, with emphasis on how to use satellite observations.

10:00 - 10:30 **Geoffrey Beck**: *Time domain waves-floating structure interactions in Boussinesq regime*

This work deals with the interaction of waves with a floating structure immersed in a 2D fluid in coastal area. The horizontal plane is decomposed into two regions: the exterior region where the surface of the fluid is in contact with the air, and the interior region where it is in contact with the bottom of the object. In the exterior region, we have the standard equations, where the surface is free but the pressure is constrained (equal to the atmospheric pressure). In the interior region, this is the reverse: the pressure is free but the surface is constrained, which changes the structure of the equations. Finally, coupling conditions between both regions are needed. We show how to implement this program in the case where the waves are described by the nonlinear dispersive Boussinesq equations. We also show an efficient numerical method that exploits the added-mass effect and the dispersive boundary layer.

10:30 - 11:00 *Coffee break*

11:00 - 11:30 **Umberto Bosi**: *A unified nonlinear Boussinesq approach for wave/floating body interaction*

This work is concerned with the development of an efficient and accurate nonlinear tool for floating Wave Energy Converter (WEC) analysis, such as point absorbers. We have considered depth-integrated Boussinesq wave equations. These are well-known, efficient tools for simulating nonlinear wave propagation. The study is based on the work of Jiang and Lannes on a unified Boussinesq model. The domain is decomposed into a free-surface and a body sub-domain and they are both modelled with the same depthintegrated approach. We have reproduced published results for fixed pontoon, heaving box in forced motion and in free movement when subjected to a train of waves. Preliminary works to expand the framework are presented: the effect of latching control to a single body and the expansion to two horizontal dimensions. The final aspiration of this work is to bridge these fundamental developments to applications of engineering relevance.

11:30 - 12:00 **Cristian Brutto**: *A semi-implicit finite volume scheme for a simplified hydrostatic model for fluid-structure interaction*

In this talk, a novel semi-implicit finite volume scheme (SIFSI) is presented for the coupled solution of the water flow and the movement of one or more floating structures. The model is based on the hydrostatic pressure assumption and the shallow water equations. The coupling is achieved via a nonlinear volume function in the mass conservation equation that depends on the coordinates of the floating structures. The resulting mildly nonlinear pressure system is solved using a nested Newton method. The accuracy of the volume computation is improved by using a subgrid. The model is able to treat fluid-structure interaction in the context of geophysical free surface flows in an efficient and flexible way, and the employed nested Newton method rapidly converges to a solution.

12:00 - 14:00 *Lunch at Hotel Gulf Stream*

14:00 - 15:00 **Daniel Coles**: *The roles of optimisation in establishing tidal stream power potential*

In this presentation the role of optimisation in the design of (a) tidal stream turbine arrays, and (b) hybrid energy systems is explored. Results are presented from a gradient-based optimisation study that considers tidal stream turbine array design (i.e. the number of tidal stream turbines and their locations) that minimises levelised cost of energy (LCoE) within the Alderney Race. LCoE is a common metric used to assess the viability of renewable energy projects, which describes the ratio of the total lifetime cost of a project to the energy output over its lifetime. From an energy systems perspective, LCoE fails to consider the whole-system cost of energy. This is demonstrated using a brute force approach to hybrid energy system design. Results show that diversification of the renewable energy mix through the adoption of solar PV, offshore wind and tidal stream energy results in improvements to energy system performance and security, whilst maintaining low wholesystem cost of energy.

15:00 - 15:30 **Mathieu Dubois**: *Modeling and validating dynamic wake meandering for wind turbine*

A validation procedure for modelling dynamic wake meandering (DWM) for a wind turbine is presented. The meandering phenomenon is modelled according to Taylor theory [1] for the diffusion of a passive scalar and the validation method makes use of results from Large Eddy Simulations (LES) of a single-turbine in different conditions of atmospheric boundary layer. To do so, a tracking algorithm applied to the LES simulations determines the wake center position in real time for different downstream locations behind the turbine. These wake center positions are compared to the outputs obtained from the application of Taylor theory. Results show an effective capture of the low frequencies of the wake center position spectrum at every downstream positions. High frequencies are well captured for close wake positions but results deteriorate with far wake positions.

15:30 - 16:00 *Coffee break*

16:00 - 17:00 **John Ringwood**: *Numerical transparency for wave energy device co-design*

The design of wave energy converters (WECs) has revealed itself to be somewhat ad-hoc and diverse, with over 200 prototypes proposed. This diversity, due to a wide variety of inspirations and range of researcher backgrounds, presents a richness to the original brainstorming activity of developing a new product. However, a major difficulty is to achieve convergence on a technically and economically viable device, through a process of reduction and optimisation. While a number of structured development processes have been proposed, none has yet shown proven success.

A key component in the development, simulation and optimisation of wave energy devices is a suitable hydrodynamic model. This provides a platform for power production estimation, control design and, ideally, geometric optimisation, among other uses. Recently, control co-design has been suggested as an integrated framework within which control and geometric optimisation, which are interdependent, can be performed. However, one of the limiting factors is the ?opaqueness? of the vast bulk of hydrodynamic solvers, with an exponential increase in the degree of opaqueness with an increase in model fidelity. Specifically, there is a very poor transparency from the hydrodynamic models and parameter back to the original geometric and other physical parameters describing the fundamental WEC construction.

This talk considers this issue of opaqueness in the context of a broader discussion about control co-design and examines if there are any alternative approaches, or post-processing techniques, that might be used to improve the efficacy of the control co-design process for WECs. Two case studies are used to illustrate the use of hydrodynamic models within a control co-design framework, which look at the interplay between the energy maximising control system and aspects of the overall system design, including optimisation of the WEC geometry and optimisation of power take-off stroke and force constraints.

Dinner on your own

9:00 - 10:00 **Jørgen Hals Todalshaug**: *Control of wave energy converters ? some governing theoretical and practical aspects.*

One obstacle to making economically viable wave energy converters has been the strong dynamic coupling between system components along the energy conversion chain. This coupling is reviewed, focusing first on the need to control the motion response, and on the challenges involved in optimising this response. A closer look is then taken at the hydrodynamic and mechanical properties of wave energy converters. The former dictate how much power can be extracted from the waves while the latter dictate how much is lost on the route to electric power or other useful output. But there is also a connection between these two processes: The optimal power to be converted in the primary step are limitied by the losses in the conversion chain. Furthermore, there is a link between the machinery losses and the need to predict incoming waves. What are the practical implications of these insights?

10:00 - 10:30 **Gastón Vergara Hermosilla**: *From Water-waves to Cummins-type equations*

In this talk we will present some recent formulations of integral differential equations that generalize the well-known Cummins equation. Being more precise, we will deal with some recent formulations of the water wave equations in asymptotic regimes, to then take advantage of them and establish some explicit transmission problems that describe fluid-structure interactions. Thus, we will study how, under certain restrictions, it is possible to obtain some generalizations of the Cummins equation. Next, we will show methods by which the wave-energy community uses these integral differential equations to control and optimize this type of energy production.

10:30 - 11:00 *Coffee break*

11:00 - 11:30 **Martin Parisot**: *Floating body simulations using large scale modeling*

The resilience of floating wave energy converters in a real-world setting and the optimization of a farm of them require the simulation of the flow around them on large time and space scales. These simulations required the use of reduced models taking into account the main properties of the flow and the fluid-structure interactions in particular in terms of transferred energy. We proposed a congested shallow water-type model able and a ImEx Finit-Volume scheme able to treat the fluid-structure interactions [1,2]. Recent work on this project has focused on taking into account the dispersive effect, the impact of the vertical velocity profile and the air pockets trapped under the structure.

[1] E. Godlewski, M. Parisot, J. Sainte-Marie and F. Wahl, Congested shallow water model: roof modeling in free surface flow, ESAIM: Mathematical Modelling and Numerical Analysis (2018) DOI: 10.1051/m2an/2018032

[2] E. Godlewski, M. Parisot, J. Sainte-Marie and F. Wahl, Congested shallow water model: on floating body, The SMAI journal of computational mathematics (2020) DOI: 10.5802/smai-jcm.67

11:30 - 12:00 **Laurent Barthelemy**: *Optimizing Berthing of Crew Transfer Vessels against Floating Wind Turbines – A Comparative Study of Various Floater Geometries*

Securing the return on investment for commercial floating wind farms by a proper estimate of the operation and maintenance downtime is a key issue to triggering final investment decisions. That is why crew transfer vessel wheather stand-by issues should be assessed together with new floating wind floater concepts, in an attempt to boost their cost attractivity. However, such issues as the numerical investigation of the landing maoeuvre of a service ship against a floating wind turbine reveal complex to calculate. Based on similarities with seakeeping, the proposed paper investigates both various ship hull and floater geometries, in an attempt to estimate the weather limitations associated to each configuration. Most recent works find that calculation compares with 5% accuracy to an experiment from a test tank at model scale. Therefore, after 3 years work, we are now in the position to be able to propose weather access criteria guidelines for various cases and to compare them with other publications.
METHOD DESCRIPTION
Vessel seakeeping:

- Assess vessel responses (amplitude and phase angles).
- Compare them with vessel responses from available publications, as a benchmark.

Vessel berthing

- Model the friction between the vessel fender and the floater boat landing analytically, then with a software and compare.
- Model both vessel and floater with a software.
- Compare resulting wave masking effects of existing floater shapes.

MAIN RESULTS AND FINDINGS The wave masking effect calculation for a square floater has already been cross-checked with an existing demonstrator. For other floaters, the present paper proposes an estimate by calculation. The present calculation method also shows potential developments for the following reasons :

- Possibility to compare berthing performances between catamarans and monohulls.
- Ability to accommodate more realistic sea-states if data is available: bidirectional waves, etc.
- Option to move the berthing calculation from a deterministic to a stochastic approach.

12:00 - 14:00 *Lunch at Hotel Gulf Stream*

14:00 - 15:00 **Jeffrey Harris**: *TBA*

TBA

15:00 - 15:30 **Matthieu Ancellin**: *Roadmap for the open source BEM solver Capytaine*

The linear potential flow model is key in the engineering of most floating bodies, including wave energy converters and floating wind turbines. Many numerical solvers are available, most of them being costly closed-source commercial codes. The development and maintenance of an open-source alternative can greatly benefit education and research in this field.

The open-source Python+Fortran code Capytaine, based on Nemoh, has been first released in 2019 and got the attention of a part of the marine energy community. In this talk, we will discuss the strengths and shortfalls of the code. The development of the code is continuing and some of the on-going and future works will be presented.

15:30 - 16:00 *Coffee break*

16:00 - 17:00 **Yanlin Shao**: *A complete and consistent second-order hydrodynamic model in the time domain for floating structures with large horizontal motions*

Floating offshore structures often exhibit low-frequency oscillatory motions in the horizontal plane, with amplitudes in the same order as their characteristic dimensions and larger than the corresponding wave-frequency responses, making the traditional formulations in an inertial coordinate system inconsistent and less applicable. To address this issue, we extend and explore an alternative formulation completely based on a non-inertial body-fixed coordinate system. Unlike the traditional seakeeping models, this formulation consistently allows for large-amplitude horizontal motions. A numerical model based on a higher-order boundary element is applied to solve the resulting boundary-value problems in the time domain. A new set of explicit time-integration methods, which do not necessitate the use of upwind schemes for spatial derivatives, are adopted to deal with the convective-type free-surface conditions. To suppress the weak saw-tooth instabilities on the free surface in time marching, novel low-pass filters based on optimized weighted-least-squares are also developed, which are applicable for both structured and unstructured meshes.

For ship seakeeping and added resistance analyses, we show that the present computational model does not need to use soft-springs for surge and sway, in contrast to the traditional models. The present model is considered as a complete 2nd order wave-load model, as all the 2nd order wave loads, including the sum-frequency and difference-frequency components, are solved simultaneously. Some more details on the model can be found in two recent paper by Zheng et al. (2020) and Shao et al. (2022).

At the end of the lecture, two examples, including a floating monopile and the OC5 floating offshore wind turbine, both exposed to irregular waves, will be studied using the new solver for demonstration purposes.

[1] Shao, Y.*, Zheng, Z., Liang, H., Chen, J. (2022) A consistent second-order hydrodynamic model in the time domain for floating structures with large horizontal motions, Computer-Aided Civil and Infrastructure Engineering, https://doi.org/10.1111/mice.12782.

[2] Zheng, Z., Chen, J., Liang, H., Zhao, Y., Shao, Y.* (2020) Hydrodynamic responses of a 6MW spar-type floating offshore wind turbine in regular waves and uniform current, Fluids, 5(4), 187.

17:00 - 17:30 **Marco Gambarini**: *A scalable numerical approach for the simulation of large arrays of floating objects*

Modeling large arrays of floating objects interacting with sea waves is a classical problem in ocean engineering, with applications such as WECs and ice floes. A common approach is to solve the equations of Stokes wave theory up to first or second order using the boundary element method. The latter requires the solution of large dense systems of linear equations. A new preconditioner for such systems based on the method of reflections, with a novel coarse correction, is proposed. Numerical experiments show that the number of iterations is independent of the number of objects for general array layouts. The behavior of the coarse matrix is also analyzed, reviewing efficient solution techniques for regular and quasi-regular arrays. This is joint work with Edie Miglio and Gabriele Ciaramella.

17:30 - 18:00 **Lucas Perrin**: *Time parallelization, observers and data assimilation*

Assimilation and identification problems related to hyperbolic systems arise in many fields of applications, e.g. weather forecasting, seismology or reconstruction of ocean surface [2, 8, 1, 7]. Despite the growing importance of computational issues in these fields, to the best of our knowledge, time parallelization of the assimilation procedures has never been investigated either from a practical or from a mathematical point of view. On the other hand, the use of such parallelization techniques for optimal control problems is now well documented. The processing of data arriving as a continuous stream adds a new level of difficulty, both for the assimilation method, which can no longer be based on adjoint computation, and for time parallelization, which usually applies to simulations on bounded, predefined time intervals. The problem of adjoint-free assimilation is usually dealt with by observers, also called nudging techniques [3], but other methods based on probabilities can also be use [5]. Adapting parallelization techniques in time is the core of this presentation. Our aim is to present a coupling between a time parallelization method and an observer, in order to accelerate the data assimilation procedure over unbounded time intervals. We will mainly focus on the algorithm ParaExp [4] for the first part, and the Luenberger observer [6] for the second one. We will present both problems individually, and then our solution for applying the ParaExp algorithm onto the Luenberger observer over and unbounded time interval. We will then illustrate the performance of this technique with some numerical examples over systems governed by evolution partial differential equations (PDEs), specifically parabolic and hyperbolic problems. Finally, we aim to apply those parallelization methods to data-assimilation problems over a system arising from Linear Wave Theory (LWT).

[1] Reconstruction of Ocean Surfaces From Randomly Distributed Measurements Using a Grid-Based Method, vol. Volume 6 : Ocean Engineering of International Conference on Offshore Mechanics and Arctic Engineering, 2021. doi :10.1115/OMAE2021-62409. V006T06A059.

[2] M. Asch, M. Bocquet, M. Nodet. Data assimilation : methods, algorithms, and applications. Fundamentals of Algorithms. SIAM, 2016.

[3] D. Auroux, J. Blum, G. Ruggiero. Data assimilation for geophysical fluids : the Diffusive Back and Forth Nudging, vol. 15 of INdAM Series, pp. 139–174. Springer, 2016.

[4] M. J. Gander, S. Güttel. Paraexp : A parallel integrator for linear initial-value problems. SIAM Journal on Scientific Computing, 35(2), C123–C142, 2013. doi :10.1137/110856137.

[5] J. M. Lewis, S. Lakshmivarahan, S. Dhall. Dynamic data assimilation : a least squares approach, vol. 13. Cambridge University Press, 2006.

[6] D. Luenberger. An introduction to observers. Automatic Control, IEEE Transactions on, 16, 596–602, 1972. doi :10.1109/TAC.1971.1099826.

[7] A. Simpson, M. Haller, D. Walker, P. Lynett, D. Honegger. Wave-by-wave forecasting via assimilation of marine radar data. Journal of Atmospheric and Oceanic Technology, 37(7), 1269 – 1288, 2020. doi :10.1175/JTECH-D-19-0127.1.

[8] C. K. Wikle. Atmospheric modeling, data assimilation, and predictability. Technometrics, 47(4), 521–521, 2005. doi :10.1198/tech.2005.s326.

20:00 *Gala Dinner*

8:30 - 9:30 **Grégory Pinon**: *TBA*

TBA

9:30 - 10:00 **Laurie Jego**: *Optimisation of Parc Arrangement for a 4 Bi-Vertical Axis Turbines Tidal Farm using the Actuator Cylinder Method*

Vertical axis turbines produce electricity from currents independently from their direction, which is a great asset for harvesting energy from tidal currents which direction can present large variations during a tide. The Actuator Cylinder model is an accurate method for representing such turbines in an acceptable computing time. The model is implemented in a 2D stationary resolution and applied on a bi-level of two counter-rotating rotors marine turbine designed by Hydroquest for different current magnitudes and directions. Finally, two parc configurations are tested under several current conditions in order to determine the more suitable arrangement for a maximum power production according to flow velocity and direction.

10:00 - 10:30 *Coffee break*

10:30 - 11:00 **Kabir Shariff**: *An improved empirical model of a tidal turbine wake*

The wake behind turbine affects the performance of turbines in a park. Accurate estimation of the wake effect is paramount to optimize the placement of turbines in tidal turbine parks. A simple empirical model is developed from numerical simulation using the non-rotational actuator disc model estimate the velocity deficit and added turbulence behind a tidal turbine in realistic flow condition (ambient turbulence 5% to 20%). The study shows a self-similar Gaussian shape streamwise turbulent intensity in a lateral direction similar to the velocity deficit profile. The turbulent wake radius expands according to a power law depending on the ambient turbulent intensity. This is a first step towards a generalized model for tidal turbine park.

11:00 - 11:30 **Laura Mayol**: *Uncertainty evaluation of BEM approaches for offshore wind turbine design*

A better understanding of the complex physics influencing large offshore wind farms can deliver significant cost savings. This is one of the main goals of the Hiperwind project [1]. The present study focuses on the uncertainty evaluation of the Blade Element Momentum (BEM) aerodynamic approach, widely used for aero-servo-hydro-elastic models during design studies. A comparison between BEM and vortex-based model is conducted for two different offshore technologies: a fixed 2.3 MW installed on a monopile and a future generation IEA-15MW mounted on a modified UMaine floater. As a result, a well-fitted uncertainty metamodel is obtained, and it is found that the uncertainties of the BEM are higher for the floating wind turbine case.

[1] HIghly advanced Probabilistic design and Enhanced Reliability methods for high-value, cost-efficient offshore WIND (HIPERWIND) Project: European Commission, https://cordis.europa.eu/project/id/101006689, 2021.