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Supergen ORE Hub: ECR Forum
5th November 2019

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Control Design for Floating Offshore Wind Turbines

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Summary

The floating offshore wind turbine (FOWT) technology is emerging and attracting increased attention due to possibility of installing turbines far away from shore in deep water to get access to stronger and more consistent wind with less shear. In addition, in offshore environment there is a potential to install giant turbines to harness more energy, without worrying about limited-site and visual/ acoustic pollution, typically existing in onshore and near-shore locations. However, the FOWT technology has several challenges; among them is the requirement to have stable platform to carry the wind turbine systems components (tower, nacelle, blades … etc.). Stabilizing the platform with the lowest possible size and cost is a topic that researchers address using advanced control systems. The stable platform is directly linked with reduced fatigue on the turbine tower and other components.

In land based wind turbines, a control systems for 1) blade pitch angles and 2) generator torque is essential element that is used increase both efficiency and safety of the turbine during operation. However, the available literature shows that these fixed-based wind turbine control approaches cannot be directly used with FOWT; an instability can result. Hence, several modified/improved control techniques are tailored to cope with this problem. There are 3 categories that has been identified for FOWT control: 1) Basic PI/PID controllers with gain scheduling carefully modified to account for the platform instability problem, 2) Advanced control methods such as H_∞ , Model Predictive Control (MPC) and Disturbance Accommodation Control (DAC) that can address all FOWT control objectives in a simultaneous multi-objective way, and 3) Structural control which include addition of extra actuator in the FOWT, e.g. in the nacelle or platform, to help in reducing platform motion in such a way to avoid instability and reduce fatigues. Each of the three categories has its own pros and cons with a lack of comparative studies between them in terms of cost, reliability and performance. In our current research, two main point are to be investigated:

- Potential of using advanced control techniques combined with technique for rejecting the wave disturbance through the use of Unknown Input Estimation (UIE) methods. It is expected that UIE can improve the performance of FOWT, in terms of power and rooter speed regulation, structural fatigue reduction and platform stabilization.
- Rationale of multi-objective control with extra actuator(s) installed in FOWT platform.

CFD surface effects on flow conditions and tidal stream turbine performance.

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This work was undertaken as part of the DyLoTTA project – Dynamic Loading of Tidal Turbine Arrays. The project seeks to help understand the loading of horizontal axis tidal turbines subjected to a variety of operating scenarios. Within this work, as a pre-curser to the modelling of tidal arrays subjected to wave climates, the effect of modelling a single HATT subject to a regular wave, using two differing boundary setups was studied. A 'free surface' and a 'free slip' numerical model were created, to assess the differences between their surface boundary conditions and how this causes changes in the generated flow conditions and turbine performance under uniform current flow conditions. The 'free slip' model was a single phase, incompressible flow model with the 'top' boundary at the still water level using the 'free slip' boundary condition. The 'free surface' model was a homogenous, multiphase model with a distinct free surface interface between the water and air phases. The 'top' boundary was in the air region of the model and specified as an 'opening' allowing bidirectional flow across the boundary. Development of the model was split into 3 mains sections: Geometry, Mesh & Physics setup. The 2 different numerical models were compared to experimental data obtained at IFREMER, Boulogne Sur Mer, France [2]. The average performance characteristics show little difference between the numerical models. Therefore, the transient dynamic loadings were investigated (Figure 3). There was little difference in average individual blade torque and thrust between the models. The 'free surface' model estimated the average thrust on the hub to be over double that of the 'free slip' model, giving 20.1 N and 8.2 N respectively. This is due to the addition of hydrostatic forces in the 'free surface' model which affect the hub significantly. The fluctuation of the individual blade thrust results show good agreement between the 2 model types.

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MORPHING BLADES FOR LOAD ALLEVIATION OF TIDAL TURBINES

The use of passive unsteady load mitigation technology for wind and tidal turbines, such as bend-twist coupling, is typically limited to low frequency fluctuations and is not suitable to large blades, due to structural rigidity requirements. Active control systems, such as actuated flaps, can respond to higher frequencies than whole-blade passive devices due to their smaller size. However, active systems may reduce turbine reliability. Hence there is a need to develop a high-frequency passive technology if turbines are to survive in the harsh marine environment.

Here we show analytically and with CFD that the unsteady loads of a turbine can be completely cancelled with a chordwise flexible blade. Additionally, we demonstrate that when the blade is rigid near the leading edge and flexible only near the trailing edge, the unsteady load mitigation is proportional to the length of the flexible portion compared to the blade chord.

We verify this relationship between flexible portion length and load reduction experimentally with a blade that has a morphing trailing-edge. The morphing trailing-edge extends 25% of the chord of the blade and it allows unsteady load mitigation by about 25%, without any variation in the mean load - thus there is no penalty in terms of power extraction. The mechanism has been tested at low and high reduced frequencies showing satisfactory results at both regimes.

Developing a Coupled CFD Model for Evaluating Floating Tidal Stream Concepts

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ABSTRACT

Floating systems provide an opportunity to expand the available tidal stream energy resource and reduce the levelised cost of energy (LCOE) by increasing the number of viable deployment sites; simplifying the installation, maintenance and decommissioning, and; by accessing greater flow speeds near the free surface. However, the proximity of the free surface raises concerns over both the power delivery and the survivability of these systems, due to the presence of waves and the associated excitation of the floating structures. Without an accurate prediction of the power output and greater confidence in the resilience of these systems, the risk to investors is too high to gain significant support for the industry. This has led to the development of a coupled and fully-nonlinear numerical model within the open-source CFD environment, OpenFOAM, capable of evaluating the performance and behaviour of full floating tidal systems [1]. The model solves the incompressible Reynolds-Averaged Navier-Stokes equations for a two-phase fluid [2], tracks the motion of the system in six degrees of freedom, and uses expression-based boundary conditions for wave generation [3]; a two-way coupled, actuator method to represent the turbine [4]; and a static catenary formulation for the moorings [5]. The model has previously been shown to agree with industry standard codes in relatively benign conditions, but has demonstrated additional complexities are present in more realistic conditions and these are not captured by simpler approaches.

This work details the continuing development of the numerical model, and, in particular, focuses on validation against the Modular Tide Generator's (MTG) floating tidal platform concept, which consists of a catamaran style hull, catenary mooring system and a submerged horizontal axis tidal turbine. The simulation results are compared with a series of 1:12 scale physical experiments, conducted in the COAST laboratory's Ocean Basin at the University of Plymouth. The behaviour of the full system has been explored in a range of wave, current, and wave-current conditions, both with and without the turbine. In each case, the accuracy of the numerical model predictions has been assessed against multiple criteria, including the motion of the barge, tension in each of the mooring lines and the thrust on the turbine. The results imply that the model successfully captures some of the key coupled properties of the problem, including relative increases in turbine load due to the motion-thrust coupling. However, further work is required to improve turbine load calculations in reversing flows, and to introduce dynamic catenary mooring line functionality.

REFERENCES

[1] Brown, S., Ransley, E., Xie, N., Greaves, D., Johanning, L., Guerrini, E., "Validation of a coupled CFD model for evaluating floating tidal systems", in *Proceedings of the 29th Ocean and Polar Engineering Conference (ISOPE),* Honolulu, Hawaii, USA.

[2] Rusche, H. (2002). "Computational fluid dynamics of dispersed two-phase flows at high phase fractions" *Ph.D. Thesis,* Imperial College of Science, Technology & Medicine.

[3] Jacobsen, N., Fuhrman, D., Fredsøe, J. (2012). "A wave generation toolbox for open-source CFD library: OpenFOAM®", *Int. J. Numer. Meth. Fluids*, 70, 1073-1088.

[4] Brown, S., Ransley, E., Greaves, D. (2020). "Developing a coupled turbine thrust methodology for floating tidal stream concepts: verification under prescribed motion", *Renew. Energ.,* 147, 529-540.

[5] Bruinsma, N., Paulsen, B., Jacobsen, N. (2018). "Validation and application of a fully nonlinear numerical wave tank for simulating floating offshore wind turbines", *Ocean Eng.,* 147, 647-658.

Wind Energy O&M Research

Dr James Carroll, Lecturer and Chancellor's Fellow at the University of Strathclyde

Research Motivation:

Background and Motivation: The growth of offshore wind energy is a significant feature of the UKs present and future energy mix. Wind energy is now a mainstream energy generation method in the UK and globally. In the UK alone, the offshore wind energy industry has installed approximately 8GW or roughly 2,000 offshore turbines in recent years.

However, the impressive growth rate seen in the offshore wind energy industry has been partially driven by government policies and subsidies. For the offshore wind energy industry to be truly sustainable and meet the recent strike prices, the cost of generating electricity from offshore wind must continue to drop. One method of reducing the cost is to reduce operation and maintenance (O&M) costs. In an industrial context, this demand for O&M cost reduction is the motivating factor for my research. The motivation for my work in an academic context relates to a number of novel research opportunities unique to the wind energy operations and maintenance field.

Research Interests:

Interests: From my previous industrial experience and academic work, I have identified three research areas to assist in reducing the cost of offshore wind energy. In each of the three areas I have secured funding and started the process of building a research team. The 3 areas of offshore wind energy cost reduction research are:

1. Failure and remaining useful life prediction of wind turbine components

2. Turbine reliability and O&M cost modelling

3. X-Rotor novel turbine development and X-Rotor O&M cost modelling

My research is driven by a close collaboration with wind turbine OEMs and wind farm operators. That collaboration allows me to identify research gaps in the O&M area, obtain access to operational data and lean on the existing expertise of globally leading wind energy players. The combination of close industry collaboration with the relevant expertise located throughout the University of Strathclyde allows for the opportunity to carry out academically significant and industry applicable research in the wind energy O&M field.

Further details on each of the above three research areas can be seen in my ORE Supergen poster, presented at the annual assembly.

Multi-Scale Offshore Wind Farm Modelling

The research project is focused on CFD modelling of wind turbine wake evolution and merger in large-scale wind farms, and particularly in addressing the lack of understanding of wind turbine wake physics. The contemporary engineering models for big wind farms have been shown to neglect key physics, especially the wake evolution and interaction in large wind turbine arrays. This leads to limitations of the engineering models such that the accuracy of power prediction is scenario dependant and the low fidelity in lifetime yield, unsteady loading and fatigue damage rate prediction. For example, the Largest Wake Deficit (LWD) model gives a reasonable prediction downstream the 2nd turbine in a 2-turbine array when the turbines are in line with each other; meanwhile, the LWD shows a large deviation but the Linear Super-Position (LSP) model gives a close prediction in this scenario when the 2nd turbine is partially in the wake of the 1st turbine. Additionally, all those models become less accurate when the size of the array increases.

Hence this project is aiming to develop a more reliable wake evolution reduced-order model for large wind farms. To achieve this, a good understanding of the turbine wake physics, both the evolution of a single wake and the evolution & interaction of multi-turbine wakes, is essential. The project will be supported by the following detailed objectives;

A. The understanding of single wake evolution and turbine performance under different inflow conditions. This will be achieved by conducting blade resolved simulations of a wind turbine in uniform and non-uniform (shear profile or wake profile) inflow conditions over a range of turbine operating conditions and turbulence intensities.
B. The understanding of wake merger and interaction of small (2-4) turbine group with key array arrangements. This will be supported by CFD simulations with a combination of DES/LES and Actuator Line method.
C. The development of a wake evolution reduced-order analytic model for wake propagation through a wind farm that conserves momentum across scales, from the individual turbine scale to the wind farm scale.
D. Demonstration and validation of the reduced-order model through comparison with existing engineering wake models in predicting the power distribution, unsteady load, fatigue damage rate and lifetime yield uncertainty.

Dr. **Xiaosheng Chen** is a Post-Doc Research Assistant at the University of Oxford partially supported by the SUPERGEN ORE Hub through EPSRC project No. EP/S000747/1. He graduated with a Ph.D. degree from the Loughborough University and was part of the research team in the National Centre for Combustion and Aerothermal Technology (NCCAT) (previously and now still the Rolls-Royce University Technology Centre (UTC) in Combustion System Aerothermal Processes). Then he became a research assistant of the NCCAT and seconded to Rolls-Royce plc. He has successfully conducted a few research projects, from hybrid LES-RANS simulations of unsteady heat transfer and multi-row effusion cooling array to the aerodynamics of combustor and fuel injector with different configurations. His research interest is in exploring and understanding the detailed flow physics as well as their relations with heat transfer performance using CFD simulations, as well as helping the design and optimisation of fluid related machinery with his knowledge in fluid mechanics. He is also an expert in CFD code development, especially in Large Eddy Simulation (LES), Detached Eddy simulation (DES) and hybrid LES.

Micromechanical modelling of jacked piles in sands

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Driven piles provide the most common foundation system for fixed oil and gas production platforms (Jardine, 2019). They are also employed in deep-water applications including tension leg platforms. The design of such systems involves the determination of diameter, wall thickness and embedded length. Like for any other foundation type in sand, the capacity and deformability of the foundation depends on the stress state of the corresponding soil. Despite the improvements achieved by the most recent design codes the stress profile around the shaft is often based on empirical correlations (Randolph, 2003). these are more unreliable when dealing with complex soil profiles such as crushable calcareous sands.

Calibration chamber experiments (Yang et al., 2014) and centrifuge tests (Klotz and Coop, 2001) have highlighted the intense stress concentrations that develop below the pile tips, and also shown that pile geometry and driving cycles affect the final stress regime. Particle breakage, which is known to affect sands' mechanical behaviour significantly (Ciantia et al., 2019a) also occurs during driving. Physical tests with highly instrumented piles and calibration chambers have identified aspects of the evolution of ground displacements and stresses around penetrating piles (White and Lehane, 2004). These programmes have provided benchmarks to test numerical modelling approaches for penetration problems.

The discrete element model (DEM), which considers individual soil particles and their interactions explicitly, is a numerical tool which is very well suited to study large displacement contact problems such as pile penetration. Its discrete nature also provides fundamental insights into the mechanisms that underlie macroscopic behaviour (Ciantia et al., 2019b). In this work a 3D DEM is used to simulate highly instrumented calibration chamber experiments of a cone shaped tip pile penetrating into crushable granular media. Particle breakage is simulated by employing a rigorous failure criterion applied to elasto-brittle spheres. Particle scaling is used to limit the number of particles considered and it is shown that the penetration curves become scale independent above a threshold limit provided a scalable crushing model is used. The particle crushing model parameters are calibrated by matching triaxial and one-dimensional compression tests. Both monotonic and cyclic jacking are modelled and it is shown that the DEM model captures very well the experimental stress measurements during and after its penetration. The particle-scale mechanics that underlie the observed macroscopic responses are analysed, placing emphasis on the distribution of crushing events around the pile tip and distributions of particle stresses and forces around the shaft. By comparing simulations run with crushable and uncrushable grains the physical mechanisms for the well-known, yet not fully understood, marked shaft capacity increases developed over time by piles driven in sands is proposed.

References

Ciantia, M.O., Arroyo, M., O'Sullivan, C., Gens, A., Liu, T., 2019a. Grading evolution and critical state in a discrete numerical model of Fontainebleau sand. Géotechnique 1–15.

Ciantia, M.O., O'Sullivan, C., Jardine, R.J., 2019b. Pile penetration in crushable soils : Insights from micromechanical modelling. In: Proceedings of the XVII ECSMGE-2019. Reykjavík, pp. 298–317.

Jardine, R.J., 2019. Geotechnics, energy and climate change: the 56th Rankine Lecture. Géotechnique 1–57.

Klotz, E.U., Coop, M.R., 2001. An investigation of the effect of soil state on the capacity of driven piles in sands. Géotechnique 51, 733–751.

Randolph, M.F., 2003. Science and empiricism in pile foundation design. Géotechnique 53, 847–875.

White, D.J., Lehane, B.M., 2004. Friction fatigue on displacement piles in sand. Géotechnique 54, 645–658.

Yang, Z.X., Jardine, R.J., Zhu, B.T., Rimoy, S., 2014. Stresses Developed around Displacement Piles Penetration in Sand. J. Geotech. Geoenvironmental Eng. 140, 04013027.

Abstract: Assessing the economic benefit, technological innovation opportunity and ecological effects of the UK deployment of ORE technology

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Over the next two years, Supergen ORE will define and investigate the three ‘aspirational ORE deployment scenarios’ (AOSs) of offshore wind, wave and tidal electricity generating technology deployment required to meet carbon reduction targets coupled with changing demand to 2050. Each of these scenarios will be explored to enable quantification of the potential effect on the UK economy and the sector’s supply chain, particularly the benefit to fragile regions. Furthermore, technology innovation needs required to deliver each scenario will be identified, in addition to an ecological assessment.

The potential economic benefit, in terms of Gross Value Added (GVA) and jobs supported, offered to the UK by the production and deployment of wave and tidal electricity generation technology in domestic and international waters will be calculated. In addition to this, Supergen ORE will assess the UK supply chain for its capability to deliver this deployment and realise the resultant potential economic benefit. Coupled with ecological impact assessment and quantification by the University of Aberdeen, the range of GVA results produced by this study will inform policymaking at a UK level. Final results will be delivered in mid- 2021.

For each AOS, high-level characteristics of deployment scenarios are defined using cost-optimisation energy system models to project realistic deployment levels based on the Strategic Energy Technology Ocean Energy Implementation Plan (SET Plan) cost targets [2]. These deployment figures will serve as inputs in an Input-Output (IO) analytical model, where high and low leakage rates will be applied to measure result sensitivity to changes in supply chain capability. This is particularly relevant in the comparison of offshore wind’s economic offering to the UK – largely O&M-based – with the potential for the creation of a new wave and tidal technology industry in the UK. The economic and job creation implications of such developments will be therefore investigated, as well as how the ORE industries will engage with, reinvigorate and ultimately benefit economically marginalised coastal communities [1]. IO analysis will track the economic impact across the supply chain, throughout the UK economy. This will allow for identification of the highest-value activities to the UK economy, which in turn will indicate specific industries into which resource and effort would reap the largest future benefit.

The study will also identify the extent and nature of step-change technology innovation required to achieve each AOS. Pathways to technology development will be carved out, and will feed into design and modelling activity. The practicalities of expanding the range of deployment locations to achieve higher capacity targets will be investigated. The study will examine and present the implications of the increased complexity of operating deep-water, relative to shallow and intermediate water depths. Necessary innovation will be assessed in all components, from device to transmission methods [1].

[1] Supergen ORE Hub, *Case for Support*, 2018.

[2] SET-Plan, *Ocean Energy Implementation Plan*, 2018.

Machine learning for power system impedance estimation

Kamyab Gibaki

The increasing penetration of power electronic converter interfaced distributed energy sources into the power grid (e.g. Wind), introduced new challenges to the monitoring, protection and control of the system. The high amount of converter interfaced sources impacts the stability of the system, especially in a weak grid with high inductive impedance. The knowledge of the grid impedance at the connection point of the converter to the grid (PCC) is essential for improving the control strategy and overall grid stability by either changing the control action or re-tuning the controller. In micro-grids, a variation of impedance is an indication for islanding or grid connection mode operations. Furthermore, the knowledge of grid impedance will be useful to improve the power quality, detection of the fault location, ground faults and grid unbalanced operation.

Various methods are proposed to estimate impedance of power network, though all of the methods can be classified into passive and active methods or combination of these two. The passive methods are known to be 'non-invasive' and active methods are 'invasive'. Generally, the active methods are invasive as a disturbance signal is injected to the grid. Then the signal processing techniques are used to estimate the impedance of the grid. However, passive methods do not need any disturbance injection, and the available information of the non-characteristic current and voltage at the PCC is used to estimate the grid impedance. Hence, the performance of the power system is not degraded using passive methods. Both the passive and active impedance estimation methods have shortcomings for power system applications. The passive methods can become inaccurate, and the active methods impact power quality.

In this research project, to avoid the shortcomings of the other estimation methods, a passive machine learning based technique to estimate the impedance of the power grid at the point of common coupling of a converter interfaced distributed generation source is proposed. The proposed method is based on supervised learning and provides a fast and accurate estimation of the grid impedance without adversely impacting the power quality of the system. This method does not need an injection of additional signals to the grid and provides an accurate estimation of the grid impedance. Multi-objective NSGA-II algorithm is used for optimisation and tuning the random forest model for accurate estimation of both R and X The resistive and inductive reactance of grid is estimated using Random Forest model due to its capability in the prediction of multiple output values simultaneously.

Numerical Models of a Floating Hinged Raft Wave Energy Converter

Siya Jin, Deborah Greaves, Martyn Hann

University of Plymouth

This research aims at building proper numerical models for a floating hinged raft wave energy converter (WEC) to estimate its dynamic responses. Two methods are used: (1) a fully non-linear CFD model based on ANSYS/LS-DYNA; (2) a linear/ partial non-linear time-domain model based on WEC-Sim. The CFD model is firstly validated by comparing with the experimental data for a fixed raft. The numerical results fit well with the experimental data. A floating hinged WEC is then built in the CFD tank. The performance of the WEC is well predicted by CFD method and the pitch resonance is well captured. The results are compared with the linear results derived by engineers from MaRINET2. As expected, the WEC response is over-predicted by linear method. This concludes the importance in future work to carefully take consideration of the non-linear terms in models by WEC-Sim.

Near wake characteristics comparison of a tidal stream turbine with URANS-AL model

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Abstract: Wake development has a great impact on performance of downstream turbines and ecological change when tidal turbines are installed in arrays. In this paper, velocity deficit profile and turbulent characteristics are studied using URANS-Actuator Line (AL) model in comparison with experimental data in near-wake region. The results show that the URANS-AL model agrees well with experiment in wake velocity profile. However, there is great disparity for turbulent kinetic energy comparison in which tip vortex correction for turbulence should be considered in AL model.

Methods

Recent works have extensive studies on wake comparison and loading of tidal stream turbine but mostly in far wake region (x>8D). In this study, wake profile and turbulent characteristics in URANS-AL are compared with experimental data near wake (0<x<1D). The computation in this study is conducted using STREAM, an in-house finite-volume solver for (RANS) equations on multi-block, structured, curvilinear meshes using SIMPLE pressure-correction algorithm. k-ε turbulent model is used with standard wall function. The experiment is carried out in IFREMER flume (Payne, Stallard et al. 2017, Payne, Stallard et al. 2018)

Results

The computational model is derived from the X-MED turbine (Payne, Stallard et al. 2017, Payne, Stallard et al. 2018) with a rotor diameter D=1200mm and mean flow velocity is 0.8m/s. Figure 1 shows the wake profile from CFD agrees well with the experiment. The turbulent characteristics in near wake region in Fig 2 shows the turbulent development from ambient and cohere structures. It is seen from Fig.3 there exists a great disparity near wake where URANS-AL model can only capture the ambient turbulence development but fail to describe the tip vortex structure in turbulent mixing.

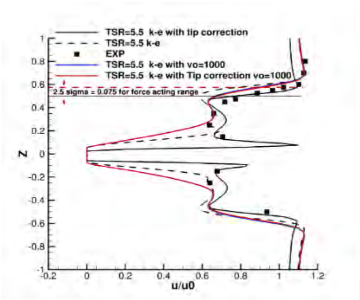

Fig.1 Comparison of velocity profile between CFD and experiment

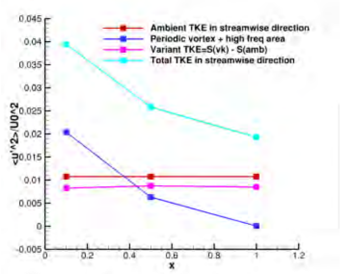

Fig.2 Near wake turbulent characteristics at TSR=5.5

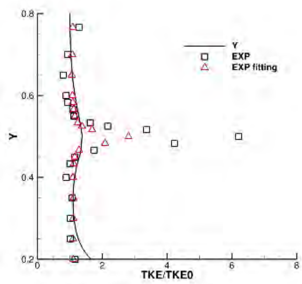

Fig.3 Comparison of *k* between CFD and experiment at *x=0.1D*

Conclusions

In this study, the velocity profile near wake agrees well with the experimental results, although the wake deficit with CFD method shows slightly wider. As for turbulent kinetic energy comparison, great disparity in near wake region shows URANS-AL model can only capture the ambient turbulence development but fail to describe the tip vortex structure in turbulent mixing. On-going work will focus on the tip vortex correction for turbulence prediction in AL model.

Acknowledgements:

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References:

[1]. Apsley, D. D., T. Stallard and P. K. Stansby (2018). "Actuator-line CFD modelling of tidal-stream turbines in arrays." Journal of Ocean Engineering and Marine Energy 4(4): 259-271.

[2]. Payne, G. S., T. Stallard and R. Martinez (2017). "Design and manufacture of a bed supported tidal turbine model for blade and shaft load measurement in turbulent flow and waves." *Renewable Energy* 107: 312-326.

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Plate anchors for offshore floating facilities: Soil-anchor-floating system interactions

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There are a variety of anchoring and mooring systems that can be embedded in the sea floor to hold offshore floating renewable energy facilities in place. These foundation systems are subjected to a sustained load in still water conditions and also need to withstand large numbers of variable cyclic loads due to wave and wind forces which act on the renewable energy structures. Previous research has shown that in soft soils, these foundations can strengthen as a result of the cyclic loading conditions, and this strengthening can result in some added capacity to the foundation. If these gains in capacity are harnessed, then more efficient and cost-effective anchoring and mooring systems can be designed and used for the foundations of offshore floating facilities.

This research project aims to improve the foundation design for embedded plate anchors, an anchoring system that is an efficient solution for the foundations for offshore floating facilities. Plate anchors are currently used in various offshore applications, and can be installed by a range of means. For example, the plate may be connected to a harness and installed by drag embedment or via a suction anchor. Alternatively, helical pile or screw anchors gain their capacity from a plate element located at the base.

The project investigates the soil behaviour around these plate anchors, particularly when the plate is subjected to sustained and cyclic loads based on different sea states that fluctuate in severity based on weather cycles and seasonal variations. The behaviour of the soil and its interaction with the plate anchor will also be integrated into existing models, such as WEC-Sim (Wave Energy Converter Simulator), which are currently being used by structural and fluid dynamics engineering researchers to understand the overall behaviour of floating offshore renewable energy structures.

Current work over the past three months has focused on using PLAXIS 2D, a finite element software that is designed for modelling deformation and stability in geotechnical engineering, to understand the soil behaviour around an embedded plate anchor.

Initially, the plate anchor was loaded monotonically to failure as a benchmarking exercise to check that the ultimate bearing capacity (V_{uu}) obtained from PLAXIS 2D agreed with the existing, well established, analytical solutions for the ultimate bearing capacities of surface and embedded footings. Once the monotonic solutions were validated, the embedded plate anchor was subjected to a preload, a force consisting of a fraction between 0.1 to 0.65 of the ultimate bearing capacity, before being consolidated and then being pushed to failure. The resulting gains in strength within the soil, and therefore gains in capacity of the plate anchor when pulled to failure, were elaborated by separating the overall failure mechanism around the plate, into the behaviour of the soil above and below the plate. The soil above the plate strengthened as the preload was increased. Conversely, the soil below the plate became weaker as the preload was increased. The net effect represented the global increase in strength within the soil and capacity of the plate anchor. The patterns of changing strength were affected by a gap opening beneath the plate under certain loading conditions and filling with water. The soil constitutive model adopted in the analysis is able to replicate the effect of a zone of free water forming beneath the plate, which is an improvement over previous modelling of this problem.

Future work will extend these numerical analyses to different cyclic loading conditions. Integration of the interaction between the soil and plate anchor into existing fluid dynamic and structural models such as WEC-sim is an ongoing collaborative task. The centrifuge is currently being prepared for testing and once ready, will be used to performing model tests to obtain the experimental data to further validate the finite element results obtained from PLAXIS 2D, and to observe and measure the soil behaviour and capacity of the plate anchor under different cyclic loading conditions.

Real-time wave energy control based on machine learning

Liang Li

A controller is usually used to increase the power extraction of wave energy converters. Despite the development of various control strategies, the practical implementation of wave energy control is still difficult since the control inputs are the future wave forces. In this work, the artificial intelligence technique is adopted to tackle this problem. A multi-layer artificial neural network is developed and trained by the machine learning algorithm to forecast the future wave forces. The receding horizon strategy is used to implement control online. Analysis results show that the power extraction is increased substantially with the smart controller. The prediction error is quantified, and its influence on power extraction is examined. The wave force phase error leads to a substantial reduction of power extraction, whereas the effect of wave force amplitude error is nearly negligible.

Title: Future offshore floating wind platform – challenge and opportunity

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Summary:

To date, all the demonstrated concepts for offshore floating wind development are still based on a simple “one turbine one platform” system, where each turbine will be mounted on a single floating platform. However, this system will cause lots of waste on manufacturing the floating platform, and increase the cost of transportations as well as onsite installations. Therefore, a question has been raised: “Could two or more turbines seat on one platform?” By doing so, the usage of one platform could serve for multi turbines which significantly decreases the cost of transportation and installation for a wind farm. Additionally, this could have a better performance on space utilization.

For future offshore wind developments, very large floating structure (VLFS) can be potentially considered as a promising alternative for their potential to maximize the power generating capacity and to drastically reduce some dangerous and costly offshore operations.

Development of novel low-cost methods to understand environmental processes in highly energetic ORE sites

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With a rapid expansion in offshore renewable energy (ORE), a broader perspective on their ecological implications is timely to predict environmental change. Effects of ORE structures on the marine environment are highly complex and range from physical changes, such as altered flow patterns around structures, to the settlement of benthic organisms, all the way to top predator behavioural change. Understanding such interactions is imperative when planning ORE installations and will eventually help accelerate the consent and implementation of structures in order to play a key role in decarbonising global energy supply.

The Atlantic-facing coastlines of the UK and Ireland have many geographic, economic and demographic characteristics that present a unique opportunity for the development of ORE technologies and could provide a distinctive competitive advantage in a global marketplace. This vision led to the recently founded Bryden Centre, a cross-border renewable energy research centre funded by the EU under the Interreg VA programme. Led by Queen's University Belfast, the Bryden Centre covers institutes in the Northern Ireland, Western Scotland and Irish border regions, engaging in a broad range of challenge- and industry-led projects. Apart from advancing the application of marine- and bio-energy, the Bryden centre also serves a stewardship role through environmental research activities.

Here, several novel methodologies are presented to give an overview of recent research approaches developed across the Bryden Centre that focus on tidally energetic environments. Due to their highly dynamic nature, tidal channels and inlets present a particular challenge to modelling high-resolution flow patterns as well as the fine-scale distribution patterns of marine fauna. Also, to assess potential environmental interactions between marine fauna and man-made structures in these habitats, a more thorough understanding of underlying hydrodynamics is required. Therefore, the presentation will draw from recent, low-cost methodological approaches developed to understand 1) tidal flow processes 2) marine fauna site usage and, 3) potential risks of animal collision with ORE structures. To better understand fine-scale flow processes, a combination of approaches is being developed, including the use of drones to map coherent structures (e.g. vortices, convergence/divergence), as well as the use of georectified oblique photography, validated through GPS drifters and vessel-mounted ADCP transects. Further, in order to quantify the fine-scale distribution of seabirds around man-made and natural wake structures, drones are used to both track bird trajectories and to map distribution patterns to be compared to vantage point survey designs which are currently being optimised for tidal sites. Finally, to increase predictive power in animal collision risk with the moving parts of tidal energy technology, simulation models including 3D animations are being developed in the game engine Blender.

Offshore Wind Turbine Multi-physics Modelling

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Operation and maintenance (O&M) account for a substantial part in wind turbine cost, mainly due to the assets' high cost and the harsh environment they are operating. Modern wind turbines often rely on advanced machine learning technologies for assisting fault detection & identification but having difficulty in understanding the cause of these faults. For better supporting wind turbine condition monitoring and robotic inspection, and to understand how the mechanical failure and electrical failure will have an influence on each other, this study aims at developing a holistic advanced model of dynamics for offshore wind turbines. A direct-drive wind turbine with a permanent magnet synchronous generator (PMSG) on a monopile foundation is introduced and the wind turbine mechanical components are modelled using the state-of-the-art aero-hydro-servo-elastic (AHSE) dynamic model. The electrical parts of the wind turbine model take account of a detailed representation of a PMSG and its fully rated voltage source converter (VSC). A comparison of the statistical values of the power distribution between steady wind and turbulent wind conditions shows that using a simplified model with steady winds fails to address the generous range of instantaneous power outputs.

Individual Pitch Actuator Monitoring for Offshore Wind Turbines

EPSRC Prosperity Partnership – "A New Partnership in Offshore Wind"

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Abstract

Offshore wind turbines have large rotor diameters and high towers for high energy capture. The significant development of offshore wind power in recent years has led to a significant decrease in the levelized cost of energy (LCoE) of this form of renewable energy. However, unexpected malfunction and failures of turbine components especially pitch system will result in expensive repairs and typically months of machine unavailability, thus increasing the operation and maintenance (O&M) costs and threatening to increase the LCoE.

Hydraulic pitch systems (actuators & sensors) are prone to faults, affecting the turbine power output and system stability, which contribute approximately 22% of the annual turbine downtime just after the electrical subsystem. Therefore, it is of fundamental importance to design appropriate pitch actuator monitoring strategy to obtain the fault information and compensate the fault effects. During my research work, the following pitch actuator monitoring strategies are studied. The effectiveness of the proposed strategies is verified in the FAST 5MW NREL wind turbine model.

(1) **Fault monitoring for pitch actuator stuck (PAS) faults**.

After PAS occurs, the pitch actuation output will stay constant no matter what the pitch reference is. Moreover, the pitch measurement will be a fixed value. A fault detection and isolation (FDI) strategy using a Kalman filter is proposed. The pitch system output estimates are generated from the Kalman filter and a residual is used to detect the faults.

(2) **Fault monitoring for pitch incipient dynamic changing faults**.

Hydraulic leakage due to improper management of oil, pump wear from continuous operation & high air content in oil will cause pitch actuator system has changed pitch system dynamics. This leads to slow pitching and unstable outputs. A step-by-step sliding mode observer is adopted obtain the pitch fault estimates.

(3) **Fault monitoring for pitch sensor faults**.

Pitch sensor faults lead to incorrect pitch position readings. Hence, the pitch control system cannot guarantee that each blade is in the reference position. 4 different sensor faults are considered including (i) biased sensor, (ii) stuck sensor output, (iii) total and (iv) partial sensor faults. A robust "unknown input observer" using H infinity optimization theory is used for accurate sensor fault estimation.

Programmable flexible materials for mooring and station keeping

Saeid Lotfian, University of Strathclyde

Renewable marine energy has emerged as a centrepiece of the new energy economy, because of its abundance, regularity and to be environmental - friendly. Floating offshore platforms could solve the problem of using high depth water to extract energy by using mooring systems. The moorings of wave devices, floating tidal turbines and ultimately floating offshore wind turbines will be subjected to the combined excitations of hydrostatic, hydrodynamic, aerodynamic and electromechanical forces driven by a combination of wave, tidal, wind and network interactions. The performance and structural responses of the energy converters are influenced by the behaviour of the moorings.

The required performance characteristics of dynamic mooring systems (Functional Specification) and the adaptive strain/stiffness requirements for a 10MW Taut Line Buoy (TLB) floating structure concept with four-anchor was defined. In this study, different mooring line diameters were considered and the maximum RAO (Response Amplitude Operator) motion amplitude achieved when the waves have an incident angle of 0 degrees (head sea). The following objectives were investigated during this research:

- Investigate the potential of programmable flexible materials to provide adaptive behaviour and improved sympathetic mooring response.
- Study the dynamic mooring systems to create a definition of adaptive strain/stiffness.
- A combination of smart materials and structure solutions would be investigated in tandem with mooring design analysis.

Motion damping of a TLP floating offshore wind turbine using porous materials

Ed Mackay – University of Exeter

A key challenge for developing cost-competitive floating offshore wind is the efficient design of stable platforms. Large platform motions lead to reduced energy yield and increased fatigue loads on the turbine. Adding a porous outer layer to a floating platform has the potential to reduce platform motions without significant increase in size and cost.

This poster presents the results of scaled model tests of a tension leg platform (TLP) for a floating wind turbine, comprising a central solid cylinder with a porous outer cylinder. Tests were conducted with outer cylinders with porosities of 0%, 15% and 30% and are compared to a base case with no outer cylinder. For each configuration, the total mass and centre of mass are kept constant to allow consistent comparison. It is shown that for the cases with a solid outer cylinder the surge motion resonance is shifted to a lower frequency due to the entrained mass of water inside and increased added mass of the outer cylinder. Increasing the porosity of the outer cylinder is shown to increase the frequency of the resonant response, bringing the resonant frequency closer to that of the base case with no outer cylinder. Increasing the porosity of the outer cylinder also reduces the amplitude of the resonant response, with a 20% reduction for the 15% porosity case and a 40% reduction for the 30% porosity case.

The scaled test results are compared to predictions from an iterative boundary element method (BEM) model and shown to give good agreement. The numerical model indicates that the inclusion of the porous outer layer increases the excitation forces at lower frequencies compared to the base case. However, the porous outer cylinder significantly increases the damping at low frequencies, where the radiation damping is low, leading to a lower motion response.

Keywords: Wind turbine aerodynamics, wind tunnel testing, RANS, DES, aeroelasticity, morphing wing, flutter control

Aerodynamic and Aeroelastic Research at the new Swansea University

Marinos Manolesos

Swansea University has undergone a very significant period of transformative growth and development over the past five years, which has included raising its research profile and expanding to a brand-new campus in 2015. The college of engineering, 10th in the UK for research quality (REF 2014), is housed at the newly built Bay Campus, a £450 million development project of the University. Part of this investment is the new, purpose-built low-speed wind tunnel. The facility was commissioned in 2016 and belongs to the pioneering Zienkiewicz Centre for Computational Engineering.

The focus of our Aerodynamics research is flow control and aeroelasticity for the Wind Energy and Aerospace industry, using experimental and numerical tools of variable fidelity in a complementary manner. Examples of ongoing research include 3D separation on airfoils [1], vortex generator flows [2], flatback airfoil flow control [3], morphing wingtips based on compliant structures [4]; Fish Bone Active Camber Morphing Concept [5]; Nonlinear Control for Flutter Suppression in Nonlinear Systems [6];. Current industrial collaborators in Research projects include Vestas and Airbus. This presentation will discuss the latest developments in wind energy and aerospace research at Swansea University.

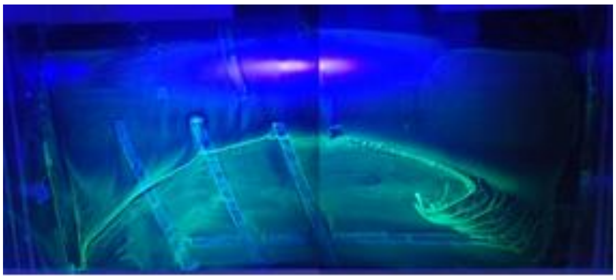
Figure 1. Stall cell trace on the suction side of a wing [1]


Figure 2. Nonlinear flap control for flutter suppression [6]

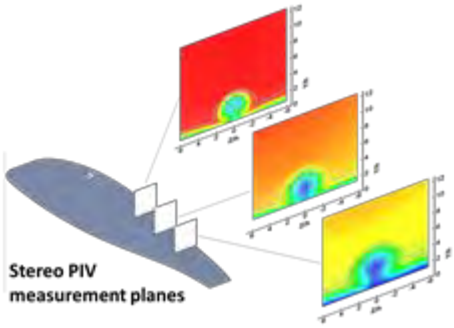

Figure 3. Vortex Generator flow control [2]

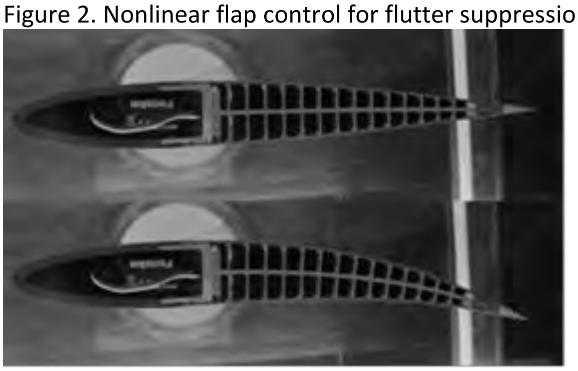
Figure 4. Active camber morphing concept [5]

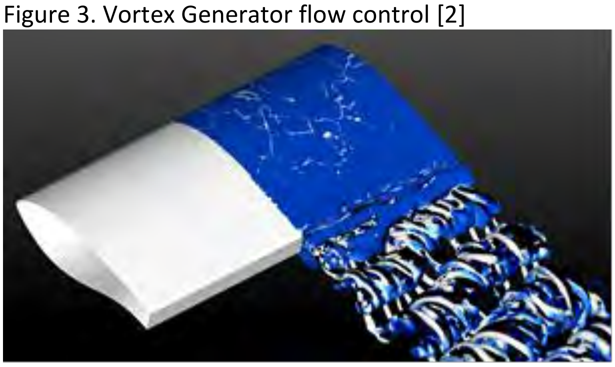
Figure 5. Detached Eddy Simulation on flatback airfoils [3]

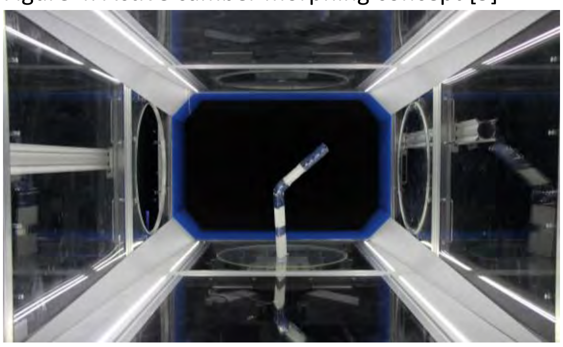
Figure 6. Morphing wingtip wind tunnel tests [4]

[1] Phys. Fluids. 26 (2014). doi:10.1063/1.4869726.
[2] Renew. Energy. 146 (2020) 1249–1261. doi:10.1016/j.renene.2019.07.063.
[3] Wind Energy Sci. Conf., Cork, 2019. doi:10.5281/ZENODO.3455217.
[4] J. Intell. Mater. Syst. Struct. 29 (2018) 3293–3304. doi:10.1177/1045389X18783076.
[5] J. Aircr. 52 (2015) 307–319. doi:10.2514/1.C032725.
[6] J. Guid. Control. Dyn. 40 (2017) 1925–1938. doi:10.2514/1.G002519.

Wake structure of tidal stream turbine arrays under increasing flow depth

Pablo Ouro

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At every tidal site the local environmental conditions regarding water depth or bathymetry are different. These can notably change the flow dynamics, e.g. velocity profile distribution, impacting on the energy generation capabilities of tidal stream turbine arrays, and hence there is a need to individually investigate the layout that maximises the energy generation of the array. Relatively low submergences, i.e. turbines occupy a great proportion of the water level, can have an immediate effect in the tidal turbine flow dynamics, restricting the wake structure whilst diminishing wake velocity recovery rate. Consequently, the energy generation capabilities from secondary rows are greatly reduced. Due to this obvious implication, it is necessary to identify and quantify the changes in wake recovery mechanisms depending on the relative water depth in order to better plan the location of the turbines within the array to maximise energy generation.

A Digital Offshore FArms Simulator (DOFAS) [1] is used to accurately predict the flow through a tidal turbine farm under four water depth conditions. DOFAS is based on the highly-accurate method of large-eddy simulation equipped with an actuator line model and immersed boundary method for the representation of tidal turbines and bathymetry, respectively [1-3]. Stallard et al. [4] experimentally tested laboratory-scale tidal turbine arrays, operated in shallow flow conditions with a relative water depth of less than two equivalent turbine diameters. This setup can be considered of very shallow nature and is used to validate DOFAS, both in terms of performance prediction and wake velocities.

Findings from previous wind turbine farm studies [5] with similar scope on the wake dynamics cannot be directly extrapolated to tidal turbines, due to the latter ones operating in flows constrained by two vertically bounded surfaces, i.e. water depth and bathymetry, and hence the wake's vertical expansion can be notably constrained. In this work, the flow mechanisms involved in the wake behind three turbines in one row with the four different depths are explored, quantifying those main mechanisms involved in the recovery of kinetic energy which has been linked to the available power for secondary row of turbines. Our results show that turbulence has a great influence on kinetic energy recovery with the transport of mean kinetic energy due to Reynolds stress being determinant both in their horizontal and vertical contributions. Results of production of turbulent kinetic energy can also be linked to study the fatigue loads that turbines to be placed in the wake will undergo during their operating life, and how these vary depending on the water depth.

REFERENCES

[1] Ouro P, Ramírez L, Harrold M. 2019. Analysis of array spacing on tidal stream turbine farm performance using Large-Eddy Simulation. *Journal of Fluids and Structures*. 91: 102732.

[2] Ouro P, Harrold M, Stoesser T, Bromley, P. 2017. Hydrodynamic loadings on a horizontal axis tidal turbine prototype, *Journal of Fluids and Structures*. 71: 78 – 95.

[3] Ouro P, Stoesser T. 2019. Impact of Environmental Turbulence on the Performance and Loadings of a Tidal Stream Turbine. *Flow, Turbulence and Combustion*. 102(3): 613 – 639.

[4] Stallard T, Collings R, Feng T, Whelan J. 2013. Interactions between tidal turbine wakes: experimental study of a group of three-bladed rotors. *Phil Trans R Soc A*. 371: 20120159.

[5] Cal B, Lebron J, Castillo L, Kang H, Meneveau C. 2010. Experimental study of the horizontally averaged flow structure in a model wind-turbine array boundary layer. *Journal of Renewable and Sustainable Energy*. 2: 013106.

Title: Datacube services for the Offshore Renewable Energy industry in the UK

Authors: Dr. Alberto S. Rabaneda, Dr. Rodney Forster

Abstract: Monitoring of the coastal zone is necessary in order to quantify human activities. Offshore wind farms, tidal and wave power stations need marine and atmospheric environmental information to select optimal sites and to forecast power production. The large-scale construction of offshore renewable energy sites may also have environmental impacts which are still unknown in the long term. These impacts might not be only produced by constructed power devices, but also by the following increase in marine traffic around the area. Some natural coastal processes have also an important impact such as the dragged sediments and organic matter by rivers. The collection of samples for analysis and *in situ* measurements at specific locations have been the most common conventional methods for environment and resource monitoring. They can provide accurate information with high temporal frequency, but just for particular points in terms of space.

Earth Observation satellites have the potential to help overcome these limitations, by greatly increasing the spatial coverage of samples. Satellites are a most cost-effective device for ocean observation, providing water quality and sea parameters related information over extensive spatial and temporal scales. The introduction of remote sensing into environmental monitoring provides a novel capability to evaluate, analyse and forecast changes of specific ocean products.

Examples of such value-added water quality products, which come from thematic processing of SAR and optical images are: remote sensing reflectance, turbidity, chlorophyll-a concentration, algal bloom detection products, man-made object detection, wave height and many others. These represent an important set of parameters to control the quality of the water in coastal and inland waters. Furthermore, ocean resource products can be also obtained from satellite remote sensing such as sea level, significant wave height, sea surface winds, currents, salinity or surface temperature among others.

Making the best use of the vast quantities of earth-observing data arising from the Sentinels and other satellites requires new methodologies to merge all the different environmental parameters. A solution in development by different teams for different locations is the Datacube. This new technique will allow time-series analysis and at the same time help find correlations between parameters which will lead to a better understanding of physical processes and the human impact on the environment.

The Humber region in UK has the highest density of neighbouring offshore wind farms in the world; with five sites fully commissioned, and others under construction or at the planning stage. Other maritime users in the regions are shipping, ports and harbours, tourism, fishing and aquaculture, all with their own impacts on the environment. Hence, a Datacube is being created to store and visualise processes along the Humber coastline and open North Sea. The first target of this Datacube is to support offshore wind farm activities and quantify possible impacts of a changed distribution of suspended sediments.

The Collaborative Computational Project in Wave Structure Interaction (CCP-WSI)

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ABSTRACT

The UK has an outstanding record of research in Wave Structure Interaction (WSI) and good reason to maintain this status, particularly in the light of its leading position in the development of modern offshore renewable energy (ORE) technologies. However, the challenges facing the WSI community in developing the necessary complex, multi-physics, multi-component suit of Computational Fluid Dynamics (CFD) software are significant and represent a goal that can only be achieved through a collaborative code development environment.

In response, a Collaborative Computing Project (CCP) has been established to serve the UK research community in the area of WSI. The project, which has been active for 4 years, brings together computational scientists, CFD specialists and experimentalists with the shared objective of developing a Numerical Wave Tank (NWT) facility that complements existing and future UK experimental laboratory facilities and supports leading-edge research in marine, coastal and offshore engineering.

The overarching aims of the CCP-WSI Project are to develop and maintain a robust and efficient computational WSI modelling tool, build the community of researchers and developers around WSI and provide a focus for software development and code rationalization.

The combined CCP-WSI and SIG-WSI network is a growing international group of over 115 researchers, spanning academia and industry in 5 continents. The group has identified a number of key WSI challenges/priorities and has co-created a roadmap for WSI code development through industry focus group workshops with 75 attendees.

The CCP-WSI has advanced understanding of the applicability and reliability of WSI through a set of internationally recognised Blind Test series' involving 50 participants. The CCP-WSI Blind Test activities have been presented in dedicated sessions at 3 international conferences with 25 papers published in 3 special issue journals. Over 80 journal publications have been generated by the CCP-WSI team and over 20 presentations have been given at national and international conferences. A number of pilot projects with industry, outreach activities with school children and public audiences have also been delivered.

Training has been provided to the community with 76 attendees, including training in software engineering, specific code development, the use of the CCP-WSI Code Repository and specific WSI developments and a week-long Hackathon for intense collaborative code development. The CCP-WSI Code Repository and clearing house provides a platform for co-creation and sharing of open-source WSI code for community use, and is maintained by the CCP-WSI Organisation on Github with over 45 users and more than 300 commits. The CCP-WSI Data Repository supports a growing database of benchmarking test cases for community use and validation practices.

Assessing Free Surface Effects in Tidal Turbine Simulations

Pál Schmitt, Milo Feinberg, Christian Windt, Josh Davidson

For tidal turbines operating in shallow water, interactions with the free surface can have a strong effect on performance and structural loading. Accounting for blockage and scaling effects alone is insufficient. Design tools that do not consider free surface effects will reliably fail to produce accurate results, and in many cases show large variation from collected data.

Especially cross-flow turbines, like the RivGen and TidGen devices developed by ORPC, operate close to the surface and any design tool which does not consider free surface effects, and the possibly dramatic effect on power output and loading, will yield useless results.

By far the most common way to take free surface effects into account, for example for wave propagation problems, are volume of fluid (VoF) methods. The **OpenFOAM C++** framework for computational fluid dynamics offers two useful VoF implementations, **interFoam** and **interIsoFoam**.

However, the additional computational burden when compared to a single phase fluid solver like pimpleFoam is signficant, since additional variable fields, equations for species transport, and high mesh resolution in the vicinity of the free surface are required.

potentialFreeSurfaceFOAM is essentially an extension of the classic incompressible, single phase flow solver pimpleFoam. A special boundary condition relates pressure **p** to surface elevation **zeta** using the hydrostatic condition. The variable **zeta** is only evaluated on the patch describing the free surface, allowing free surface effects to be accounted for with virtually no extra cost.

Comparison with field data from ORPC trials indicates that changes in power output, thrust and surface elevation, including the development of a bore above the turbine, are captured correctly. Detailed validation against experimental tests are still required as suitable data is not yet available.

The origin of potentialFreeSurfaceFOAM solver is unclear and the authors are not aware of any treatment in academic literature, but we suggest it as a useful and efficient tool for many marine and offshore engineering problems.

Learning-Based Robust Control for Offshore Wave Energy Converters

Mr Shuo Shi and Professor Ron Patton

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Abstract

Wave energy has the potential to contribute up to 2.1 TW power, particularly considering suitable high energy density locations worldwide. However, the high Levelized Cost of Energy (LCoE) of wave power impedes the development of commercial applications of Wave Energy Converter (WEC) devices due to the low energy conversion efficiency and high maintenance requirements. Optimal control of WEC can maximise the overall efficiency and guarantee the safety as well as reliability of WEC, hence reducing the LCoE.

This PhD research focuses on Data-driven and Robust learning control method for wave energy converters to maximize the power take-off from waves. Using this learning control algorithm the Hull University Control & Intelligent Systems research team has participated in the International Wave Energy Control Competition - WECCCOM, organised by a consortium of institutions in R&D of marine renewable energy systems. A novel wave excitation force prediction and estimation method has been developed due to the requirement for implementing a power efficiency maximisation control of wave energy converters (WECs). The Hull team is ranked among the top 3 competitors in the competition.

(1) Short-term Wave Forecasting using Gaussian Process for Optimal Control of WECs

The Gaussian Process (GP) model for short-term wave forecasting is developed and shows better or comparative performance with Neural Network (NN) and Autoregressive (AR) modelling methods. The GP strategy is not only capable of forecasting the mean value of wave elevations but also provides the uncertainty of forecasting, which is beneficial to the safe operation, robust and optimal control of the WEC device.

(2) **Robust Data-driven Estimation of Wave Excitation Force for WECs**

A data-driven technique has been developed to estimate the wave excitation force (WEF), which uses a robust Bayesian filter in WEC hydrodynamic system which is described by non-parametric Gaussian process (GP) models. This modern way of incorporating the first principle model into a probabilistic framework is more robust than calculating estimates of a parametric function representation. Unlike sample-based non-linear Kalman filters, the means and covariances of joint probabilities can be directly computed based on analytic moment matching.

(3) **Learning-based prediction-less resonating controller for WECs**

We developed a data-efficient learning approach for the complex-conjugate control of a wave energy point absorber. Particularly, the Bayesian Optimization algorithm is adopted for maximizing the extracted energy from sea waves subject to physical constraints. The algorithm learns the optimal coefficients of the causal controller. Less than 20 function evaluations are required to converge towards the optimal performance of each sea state. Additionally, this model-free controller can adapt to variations in the real sea state and be insensitive and robust to the WEC modeling bias.

One-fluid formulation for floating offshore renewable energy devices

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The overall scientific goal of this research is a step change in the numerical simulation of complex Multiphysics problem, involving multibody dynamics (MBD), solid mechanics and wave hydrodynamics, which lies well beyond the capacity of today's analytical solutions. From the modelling standpoint, the ideas pursued in this research will represent an original contribution in the numerical analysis of MBD and fluid mechanics coupling, with an efficient methodology to model connected structures as a continuum.

In the ‘one-fluid’ formulation, e.g. [1], the multiple connected rigid bodies are modelled as a different phase of non-viscous fluid, and their motions are linked by a unified equation by Lagrange Multipliers. The whole system is solved in a continuum and unified manner, and there is no explicit imposing the coupling boundary or condition or usage of MBD governing equations. The key ingredients of this methodology are: 1) the solution of the underlying Navier-Stokes equations and 2) the consideration of distributed Lagrange multipliers to enforce rigid body constraints. From the spatial discretisation point of view, we employ a Cartesian staggered Finite Volume scheme (Marker-and-Cell (MAC) grid) and a level set methodology to describe the evolution of the various interacting phases. Results suggest that the unified ‘one-fluid’ equation can predict the dynamic response of, e.g., WECs, and fixed and moving cylinders in the numerical wave tank [2] and [3].

[1] Yang, L. (2018). One-fluid formulation for fluid and structure interaction with free surface. Comput. Methods Appl. Mech. Eng., 332, 102-135.
[2] Yang, L., Yang, H., Yan, S., Ma, Q. and Bihnam, M. (2016). Comparative study on water impact problem. In Proc. 26th ISOPE.
[3] Yang, L., Stagonas, D., Chen, S. (2020). Comparative Study on Steep Focused Waves Interactions with Fixed and Moving Cylinder. ISOPE Shanghai, China, June 14 - June 19.In review.

Modelling Spatial and Temporal Species Dynamics in Response to Changes in Climate and Productivity in the North Sea

Neda Trifonova

Abstract

There is about to be an abrupt step-change in the use of our coastal seas, specifically by the addition of large-scale offshore renewable developments to combat climate change. New modelling frameworks are required to aid site determination and purpose and to estimate the effects of different uses on our natural resources. Being able to forecast the ecological benefits and trade-offs that will occur with the operation of offshore renewable devices and future climate change is vital for the sustainable management of all uses of our marine ecosystems. Understanding how usage of spatial habitat of marine species may change with climate change and offshore renewable devices is challenging but of key importance and essential for the sustainable management of their populations. In this study, computational Bayesian ecosystem models will be applied to provide indications of how ecosystems are likely to change. Bayesian networks are models that graphically and probabilistically represent dependency relationships among variables. They can integrate physical and biological variables presented at different scales. In addition, Bayesian networks integrate the uncertainty associated with species dynamics due to the action of multiple driving factors. In the initial stages of this study, optimization techniques ("search-score") have been applied to find the data-driven interactions among a set of physical and biological variables within three spatial areas of the North Sea: northern, southern North Sea and west of Scotland. These data-driven dependencies were found over different temporal and seasonal windows. Specifically, a hill-climb technique with random restart, was used to find the level of confidence of each relationship throughout space and time. In this way, we can identify significant relationships that shape species dynamics in both space and time. Using the identified relationships, ultimately Bayesian ecosystem models will be built to investigate the impact on the species dynamics, using outcomes of climate change on the physical habitats and productivity. Model scenarios will be investigated to examine the likely outcomes of alternative management and climate scenarios, and for evaluating trade-offs and benefits to aid site determination and purpose in the context of large-scale offshore renewable devices.

References

Trifonova, N., Kenny, A., Maxwell, D., Duplisea, D., Fernandes, J. and Tucker, A. (2015). Spatio-temporal Bayesian network models with latent variables for revealing trophic dynamics and functional networks in fisheries ecology. Ecological Informatics, 30, 142-158.

Sadykova, D., Scott, B., Dominicis, M., Wakelin, S., Sadykov, A., Wolf, J. (2017). Bayesian joint models with INLA exploring marine mobile predator-prey and competitor space habitat overlap. Ecology and Evolution, 7 (14), 5215-5226.

Scott, B., Sadykova, D., Sadykov, A., Dominicis, M., Wakelin, S., Wolf, J. (2017). Local vs global: How to assess the ecological cost and benefit of large-scale renewables? OCEANS 2017, 1-2.

Supergen ECR Forum Abstract
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Offshore wind turbines (OWTs) must be sufficiently resilient to withstand both storms and operational deterioration over a 20-25 year life in an aggressive marine environment. Extreme storms, such as Typhoon Rammasun in 2014 (a Category 5 super typhoon with winds of up to 259 km/h) caused failure of the structural components in onshore wind turbines. However, similar empirical observations do not yet exist for OWTs. In addition, OWTs are rapidly increasing in size: the 9MW OWT introduced last year by Vestas has a rotor diameter of 154 meters, more than twice the diameter of the earliest OWTs. This means that observed failure rates from previous generations of OWTs would not be suitable for the current, much larger, generation.

Current risk assessment procedures for OWTs often neglect structural failure and focus on the equipment only, which can be assessed using existing empirical databases. However, this is not enough: an OWT is a complex integrated system where failure of the structure may cause loss of all equipment. This project developed a catastrophe risk modelling framework, shown in Figure 1, to assess the risks associated with offshore wind infrastructure exposed to extreme wind and wave conditions, to ensure safe designs and to price insurance policies. A site-specific assessment of structural fragility is developed, to quantify the probability of structural failure at different environmental conditions using aero-elastic analysis. Separately, a hazard model defines the probability of different environmental conditions occurring. Combining the hazard and fragility enables the estimation of structural failure rates which can then combined with empirical mechanical and electrical component failure rates to assess financial losses of an entire OWT system.

Additionally, degradation in the form of small cracks that grow from weak points in the structure over many years of energy production and eventually threaten the integrity of the machine (fatigue) is modelled. However, numerical assessment of fatigue damage over the life of a structure is computationally expensive, due to the need for aero-elastic simulation of a large number of environmental conditions. This makes structural fragility for FLS a challenging task as it also requires numerical sampling of random variables to model uncertainty in the estimation of fatigue damage. This project proposed using Gaussian process regression to build surrogate models for fatigue damage caused by different environmental conditions. Ultimately, a structural reliability calculation using the surrogate model highlights the large scatter in fatigue life prediction due to parameter uncertainty, and enables the calculation of loss functions.

The results from a case-study application in Dutch waters indicate that failure of the structure plays a major role on the overall risk profile of an offshore wind farm, and that for an OWT located in European waters fatigue dominates the structural financial losses.

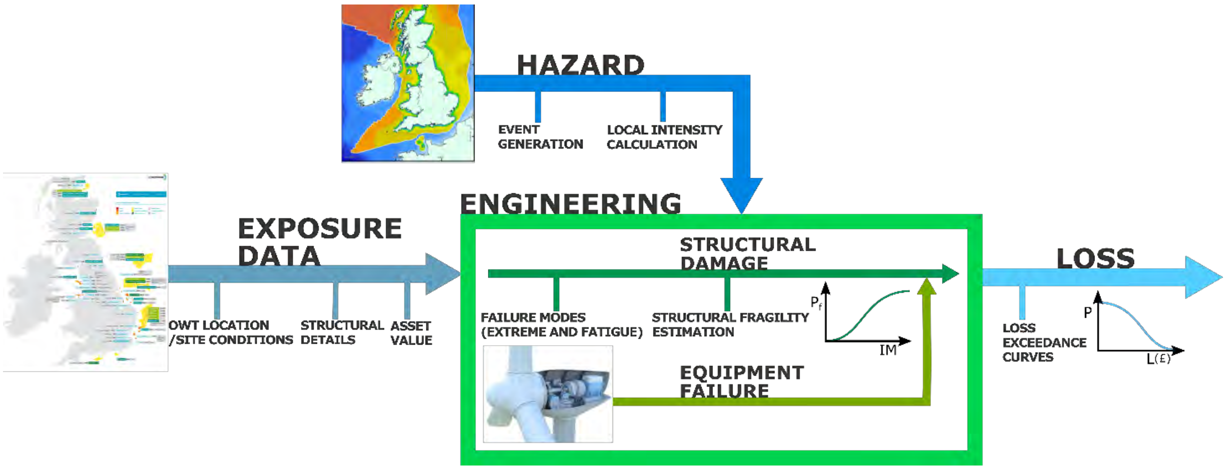

Figure 1: Proposed probabilistic risk modelling framework for offshore wind turbines