MODELLING OF SUPPORT SYSTEMS FOR OFFSHORE WIND FARMS

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SUMMARY

With projected expansion of the offshore renewable energy sector, in terms of capacity (individual machine ratings and overall array size), depth and distance from shore, the development of effective support strategies that are appropriate to the array under consideration becomes more difficult. Recent research at UCL led to the production of a tool for modelling different Operation and Maintenance strategies for offshore windfarms. Developed in a 6 month MSc project, the Matlab model incorporated a range of input parameters such as array location, configuration and equipment reliability and developed a maintenance strategy utilising a choice of vessels. The model was validated by comparison with available data, with good correlation. Ongoing work is examining the use of the UCL developed Design Building Block approach to design Wind Farm Support Vessels, and to integrate the ship design models with the O&M model to allow an integrated analysis approach.

1. INTRODUCTION

The Marine Research Group (MRG) is a division of the University College London (UCL) Department of Mechanical Engineering [1]. In addition to providing postgraduate education in Naval Architecture and Marine Engineering, the group has a range of research activities, including; design methods and tools; multihulls and novel hullforms; electric propulsion; efficiency and emissions reduction; unmanned vehicles and their use in maritime systems; safety and risk based design; and CFD.

Although the majority of the work in the MRG is oriented towards naval vessels and submarines, there is particular interest in key areas of civilian vessel design, specifically emissions reduction, safety, novel designs and design methods for service vessels. This paper describes an ongoing research area incorporating several of these interests.

2. OVERVIEW OF THE OFFSHORE WIND FARM SECTOR AND FUTURE TRENDS

Offshore wind farms development started in 1990 and therefore is relatively young, rapidly growing, industry sector. As of the 30th June 2013, 1,939 offshore wind turbines, with a combined capacity of 6,040 MW, were grid connected in European waters in 58 wind farms across 10 countries. Currently, an additional 18 offshore wind farms are under development, planned to be fully integrated in the grid by the end of 2015 [2]. Significant capacities are developed around the word with recent initiative in United States on the rise.

The United Kingdom is the world’s sixth largest producer of wind power. In July 2009, the low carbon transition plan was decided by the British government to achieve targets of 40% low carbon fuels and 20% renewable energy in electricity generation by 2020. Since 2000, five development rounds have been agreed to increase the amount of wind energy in the UK energy mix. In June 2008, the Crown Estate launched the Round 3 of sites allocations. While sites allocated in Rounds 1&2 had a production capacity of 8 GW total, the Round 3 is planned to provide additional 25 GW. This step-change in find farm capacity presents a significant but welcomed challenge for this young industry sector.

The production costs will need to be lowered significantly for the offshore find farm sector to become competitive with other energy sectors. In order to reduce associated risks and electricity production costs, technical advances in technologies are required, not only for main components (turbine generators, foundations, grid) but along the entire supply chain requiring novel approaches to achieve the development target. This challenge has triggered significant research and development on the management and planning side, looking for new financial models, planning, logistics solutions and operations and maintenance.

The more reliable systems are required followed with well-planned and efficient operation and maintenance that will maximise wind farm operability. There is even higher level of uncertainty in trying to estimate future electricity production cost from offshore wind farms (see Figure 1).

As the offshore wind farm industry developed from on-shore wind farms, moving to coastal waters at first and consequently further offshore, the consequences of the shift from shore to sea were not fully anticipated and unexpected failures were experienced. In the early stages of the offshore wind farm sector the common practice was that when a failure occurred, an operation was launched to correct the failure (i.e. failure-based maintenance strategy).

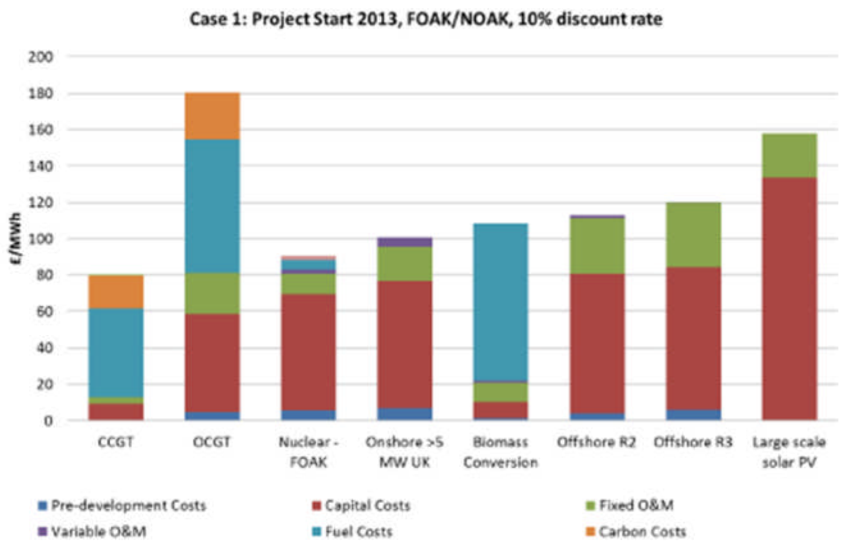

Figure 1 Comparison of the electricity production cost estimates from various sources with cost breakdown [3]

Offshore wind farm operation and maintenance (O&M) accounts for about 30% of the cost of electricity production, and is therefore potentially restricting further growth in the sector. The current focus is to reduce O&M costs and thus lower overall electricity production cost. That would allow the offshore find farm sector to be competitive with other energy sectors. UK Crown Estate suggests electricity production cost target of £100/MWh to be reached by 2020 [3]. In order to achieve this substantial cost reductions are required in all elements of the development and production with O&M having a significant impact.

The learning curve was, and still is, steep; the sector is continually improving but as most of the technologies are relatively new, planning is still burdened with a high level of uncertainty. As more experience and knowledge is accumulated management of the O&M activities will improve in efficiency and reduce in cost.

3. THE UCL O&M MODEL

3.1 O&M STRATEGIES FOR AN OFFSHORE WIND FARM

Rao [4] gave a definition of an ideal maintenance strategy: "An ideal maintenance strategy meets the requirements of machine availability and operational safety, at minimum cost". Two main types of O&M strategies can be distinguished: Corrective (failure-based) maintenance and proactive maintenance that can be further classified as time-based maintenance (TBM) or condition-based maintenance (CBM) as presented in Table 1.

Table 1: Overview of the Maintenance strategies

Failure-based maintenance	
Advantages	Disadvantages
Components are used for the entire lifetime During operation, the maintenance costs are low	No planning is possible Important downtime that can lead to heavy cost penalties Risks are high to have long delivery periods for some parts
Time-based maintenance	
Advantages	Disadvantages
Low downtime A scheduling is possible	Components are not used for the entire lifetime The overall cost is high.
Condition-based maintenance	
Advantages	Disadvantages
Components are used for a almost the entire lifetime A scheduling is possible The downtime is very low	Need for an expensive monitoring system to obtain reliable information Determine appropriate conditions

Failure-based maintenance: when a failure occurs, a maintenance operation is carried out. There is no need for an expensive monitoring system with this method and in addition, components will be used for their entire lifetime. However, planning of operations is impossible with this approach and the costs of the overall maintenance strategy are difficult to calculate in advance. This solution carries high risk: a failure can lead to significant downtime if the repair cannot be carried out due to weather conditions or a supplier shortage. [5]

Time-based maintenance: Maintenance operations are carried out at fixed time intervals, either age-based or clock-based. Usually, routine maintenance is performed at 2500hr and 5000hr internals [6]. Coordination of logistics and safe access are simplified thanks to the possibility of scheduling operations in advance.

Condition-based maintenance: Via an efficient monitoring system, when deterioration is detected or when a set of performance conditions is reached, maintenance is scheduled. This method requires an expensive monitoring system, but the downtime (time during which the wind turbine isn't working) is minimized. There is still no fully mature application of this strategy in the offshore wind sector [7].

Most of the existing offshore wind farms have adopted a failure based maintenance strategy with regular preventive maintenance tasks (once or twice a year, in July or in October & May). This reactive response is not cost-effective for large offshore wind farms located far away from the shore which will be the case for the majority of Round 3 wind farms. As O&M presents 30% of the total electricity production costs (versus 7% for onshore wind farms)[9], it is of high importance that cost-effective O&M strategy is selected early on and included in early feasibility analysis of the potential offshore wind farm development.

3.2 UCL TOOL

With this aim, an offshore wind farm O&Mtool was developed at UCL as a 6 month MSc individual project [8]. The purpose of the tool is to assess various O&M strategies and marine support strategies to find the most cost-effective solution for any specific offshore wind farm development. Furthermore the tool can be used to highlight early the possible beneficial offshore wind farm configuration parameters (size, layout etc.) that will lead to a significant reduction of the O&M costs.

The UCL model was based on condition-based maintenance (although failure based maintenance was also simulated for comparison) and the information used by the model is outlined in Figure 2, showing inputs, outputs and constraints considered. Based on the input parameters and within the given constraints, the code can give high level estimate of the O&M costs as well as estimate unplanned maintenance requirements and suggest preferable marine support strategy. A cost-effective maintenance strategy was built through three steps: The initial step was to assess a failure-based maintenance strategy, then the approach was improved by implementing both a grouping strategy and condition-based maintenance.

The input can allow for variation in wind farm type, size and shape, the distance from the shore, wind turbine reliability (the failure distribution was defined as an exponential distribution), the energy generated by a wind turbine over one year. The output parameters are the maintenance cost, the failure rates and types to be expected, suggested vessel types to be used and an estimate of the energy production for the given period. As limited data was available for existing and future offshore wind farm developments, they were modelled using approximations based on the available information. This is commensurate with the purpose of the tool to perform high-level evaluations of different scenarios for the early development phases of an offshore wind farm.

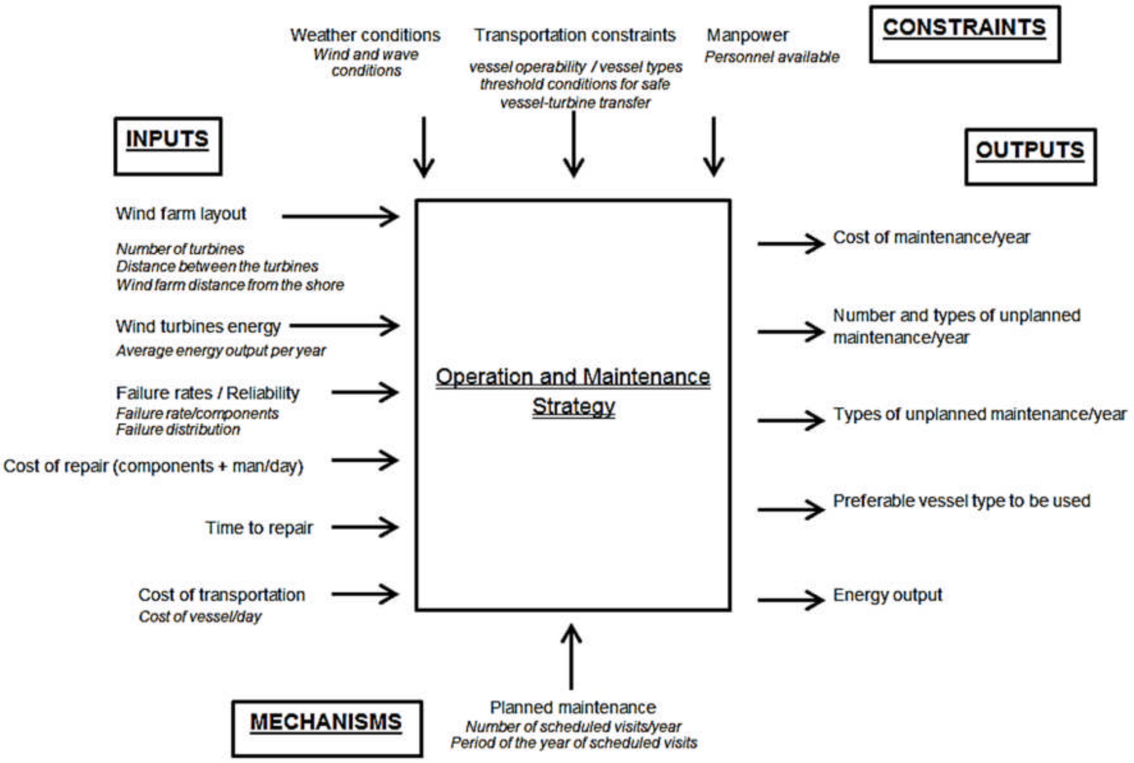

Figure 2: UCL Model SADT Diagram (after [8])

Weather is the main constraint: a maintenance operation cannot be launched outside a specified weather window. One of the main factors determining the high costs of energy production is the accessibility of the turbines. Even for UK Round 1, close to the shore with relatively mild environmental conditions, turbines were accessible on average for only 69% of the time [9]. Thus vessel motion characteristics and ability to access turbines in a range of sea states play a significant role in reducing the electricity production costs (Figure 3).

For the UCL MSc study, a Significant Wave Height (SWH) of 1.5m was assumed to be the limit for safe direct transfer from vessel to a turbine ('step over' onto the turbine ladder). However, in the most onerous region of the Southern North Sea (Dogger Bank and Hornsea), a transfer vessel (with or without a transfer system on board) operating in sea states up to a significant wave height of 2.5m may still deliver 90% accessibility. A system operating in significant wave heights of more than 2.5m would not be feasible as performance improvements would be minimal with significant cost increase [10].

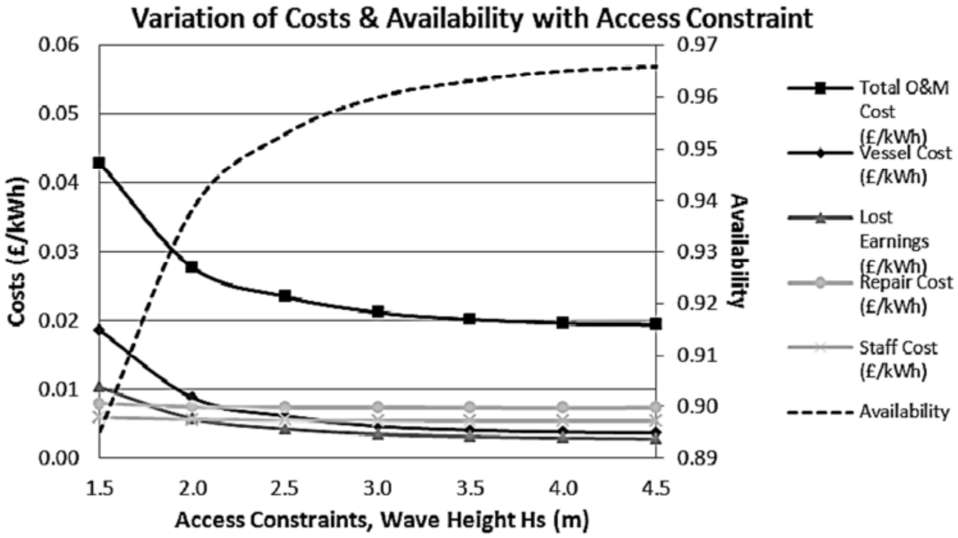

Figure 3: Influence of vessel access threshold on operational costs [9]

3.3 MARINE SUPPORT TO WINDFARMS

With currently operating wind farms, the trend is to use small boats, such as catamarans or SWATH vessels. However, as the distance from shore increases other approaches should be considered. An offshore substation is of interest for large wind farms situated at more than 75 km from the shore [11]. Table 2 summarises the three main marine support strategies under consideration.

Table 2 Marine Support Strategies overview [8]

Strategy	Relative Cost	Operability in Range of Weather Conditions	Transit Speeds	Distance From Port to Wind Farm
Work boats: Onshore-based marine access, with specialised work boats of some description, based at a coastal port	Low	Limited: Maximum wave height of 1.5m	Slow: ~20 knots	← 75km
Helicopter access, either as support to work boats or as the primary access	High	High: Insensitive to wave heights, though some visibility restrictions	Quick: ~135 knots	← 75km
Fixed or floating offshore base (offshore accommodation platforms, 'motherships' etc)	High	High: Assuming helicopters used with fixed base, and direct access system with floating base	Criterion is less relevant as close to site	→ 75km

Using a large ship as an O&M base provides more flexibility as the vessel can offer crew accommodations and can be equipped with a crane. Alternatively, a small ship can be used as an O&M base to support small offshore windfarms.

The different vessel types available for maintenance operations for offshore wind farms have been summarized in Table 3.

Table 3 Overview of existing O&M vessel types

Vessels	Types	Characteristics	Speed (kt)	Passenger capacity
Monohull service vessel	CTVs	Very high speed, small passenger and cargo capacity	26	12
Catamarans	CTVs	Medium speed. limited passenger and cargo capacity	25	12
Small Waterplane Area Twin Hull (SWATH)	CTVs	Moderate speed, limited passenger and cargo capacity	18	12
Jack-up barges	MPVs	Non self-propulsion. Slow, depend on other ships to tow them to the working area. Serve as feeder vessels or installation vessels	8	160
Jack-up vessels		Self-propulsion. Self-lifting and stabilization.	10	120
Crane Barge	MPVs	Heavy Maintenance and Construction	5	88
Crane Ships	MPVs	Lift heavy loads. Limited in speed and no deck space available for transporting the items to install	6.1	28
Semi-submersible platforms	MPVs	Good stability during cranes operation. Offers good deck pace and goof lifting capabilities. Cost a lot	6	736

Within the UCL O&M model all vessels are grouped into two types selected from Table 3, for high level modelling.

- For small scale repairs Crew Transfer Vessels (CTV); with speed of 25 to 30kt and relatively small, transporting 6 to 14 technicians and small tools or components.
- For large scale repairs: Multi-Purpose Vessels (MPV); Depending on the type of repair needed, different vessel types are used.

Due to the increasing number of offshore wind farms, the demand for O&M vessels is growing rapidly. A common assumption is to allocate one CTV per 35 turbines and one MPV per 140 turbines [12]. To validate the UCL O&M tool, the price and capability of each vessel type was based on the published data where available.

Two marine support strategies were incorporated in the model: A single type of large CTV; and a mothership with small CTV. They were represented in the UCL O&M tool and combined with the O&M strategies discussed earlier to assess their applicability to various offshore wind farm design projects and to identify the best solution.

The UCL modelling tool was tested on UK round 1 wind farms with available data [11, 12], and the correlation was satisfactory (Figure 4). Further tests were carried out for UK Round 3 sites at Morray Firth and Dogger Bank. Tests were also carried out to evaluate the influence of some key parameters on the cost or on the energy output.

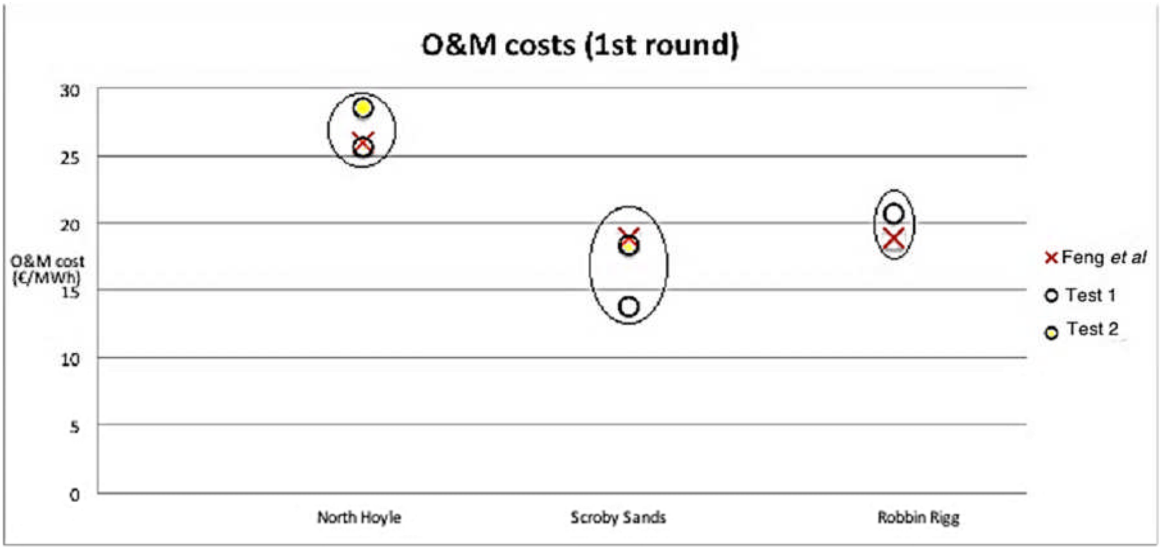

Figure 4: UCL Model Validation for UK Round 1 wind farms [8]

Considering the overall O&M strategy; in most simulations, a Condition Based Maintenance (CBM) strategy proved to be superior over failure based (with and without preventive maintenance). This was broadly expected as, despite higher direct O&M costs, CBM significantly decreases downtime and therefore increases annual electricity production.

In regard to the marine support strategy it was identified that a mothership / daughter vessel combination presents a preferable solution as it significantly increases flexibility (over a system based purely on large CTVs) and efficiency. The use of a small CTV again highlights the importance of the operability threshold for safe personnel transfer from the vessel to the turbine. As noted earlier, the operability threshold could be raised to a maximum of 2.5m SWH by using a personnel transfer device. This would significantly improve accessibility, decreasing downtime and therefore increasing overall electricity production rate. Section 5 describes the development of an illustrative design for such a CTV.

4. AN EXAMPLE TURBINE ACCESS VESSEL DESIGN

4.1 THE DESIGN BUILDING BLOCK APPROACH

The UCL Design Research Centre (DRC), part of the MRG, has expounded and developed a configurationally-centred approach to preliminary ship design, which adopts a flexible configurational model of the ship combined with naval architectural numerical analysis tools to ensure technical balance, while enabling innovative exploration during the formative design evolution. This is designated the Design Building Block approach [13]. The DRC instigated an alliance with Graphics Research Corporation Limited (GRC) (now part of Qinetiq) to incorporate the Design Building Block approach as the SURFCON facility in GRC's Paramarine Preliminary Ship Design System [14].

Paramarine is an object-based naval architectural design package utilising the commercial ParaSolid modeller as its core [15]. A screenshot of the system in use is shown in Figure 5. This shows the interactive graphical display of the design configuration (the "graphical pane" on the right, with a hierarchical navigation pane on the left and examples of numerical data and analysis (a resistance estimate).

Paramarine-SURFCON is not just a graphical layout tool, it also contains objects for the assessment of the performance of the design across a range of ship design capabilities, including resistance and propulsion, stability, manoeuvring and radar cross section signatures, in order that each design study is both numerically balanced and achieves the desired levels of ship performance. The interactive graphical interface enhances the use of these numerical analysis tools by placing the results in the context of the current ship configuration – for example, the results of a stability curve (GZ) calculation can be visualised to directly investigate the effect of geometric shape on the GZ curve, a particularly important issue for certain multi-hulled vessels.

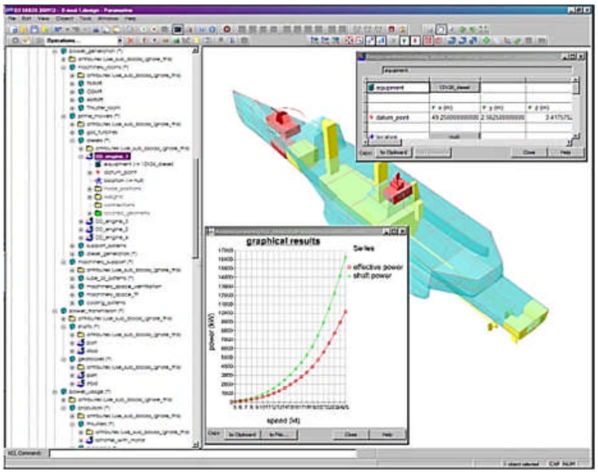

Figure 5: Screenshot of PARAMARINE showing interactive numerical, tabular and graphical information in the Design Building Block objects

The Design Building Block approach to early stage ship design seeks to encourage a more holistic approach to the development of the ship design solution. Instead of a set of numerical steps or a mechanistic approach, where each aspect of the performance of the design is examined separately and in turn, the integrated nature of the SURFCON implementation in PARMARINE allows aspects of the design's effectiveness to be assessed from the earliest stages of design. A further aspect of the DBBA is the use of a Functional Hierarchy to describe the ship. This features four main Functional Groups; FLOAT, MOVE, SERVICE and INFRASTRUCTURE. Individual Design Building Blocks have a position within this hierarchy and a classification under a more traditional weight group system for cost estimation.

The Design Building Block approach has been applied in a range of design studies including motherships for unmanned air [16], underwater [17] and surface vehicles [18], both monohull and multihull vessels and studies on the producability of merchant vessels [19].

4.1 OVERVIEW OF THE DESIGN

UCL developed an illustrative Wind Farm Support Vessel, both to demonstrate the application of the Design Building Block approach to the design of small craft, and to provide a baseline for future development of the integrated O&M and ship design method described above. This design was developed to meet the broad requirements for the small CTV identified in the analysis described in Section 3. As an illustrative design, the opportunity was taken to incorporate novel features such as the Trimaran Small Waterplane Central Hull (TriSWACH) hullform. Figure 6 shows the overall configuration of the illustrative design and Table 4 gives the principal particulars.

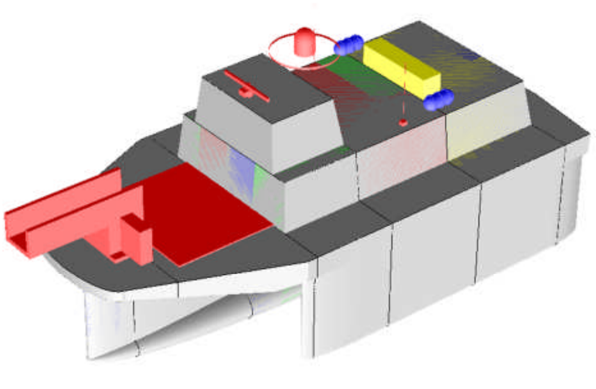

Figure 6: Illustrative WFSV design showing hullform and upperdeck equipment

Table 4: Principal particulars for the UCL WFSV design

Displacement (maximum)	159te
Length Overall	24.5m
Length Waterline (centre)	23m
Beam Waterline (centre)	1.5m
Bulb Diameter (Horizontal)	3.5m
Draught Overall	2.6m
Clearance Under Box	3.15m fwd / 1.65m aft
Length Waterline (side)	16m
Beam Waterline (side)	0.75m
Draught (side)	2m
Accommodation	12 technicians & 6 crew
Endurance	24 hours @ full speed
Propulsion Power	1600kW
Maximum Speed	22.5knots
Generating Power	72kW

4.2 Hullform and "FLOAT" Functional Group

Figure 7 illustrates the TriSWACH hullform and location of the azimuthing propulsors. The TriSWACH is a variant on the trimaran hullform, featuring a central hull consisting of a submerged bulb and a narrow surface piercing strut. Stability is provided by the long side hulls. Proposed by Dubrovsky [20] this hullform has a greater surface area than an equivalent displacement trimaran, but the very small waterplane area significantly reduces both wavemaking resistance and motions. The latter aspect is of particular interest for a WFSV as the reduced pitch and heave will increase the ability to transfer personnel to turbines, and provide greater flexibility in selection and location of the turbine access equipment to be fitted.

Like all small waterplane hullforms, the TriSWACH requires ballast tanks to maintain the draft within acceptable limits for seakeeping. For a small craft like a WFSV, there is ample volume in the submerged bulb to accommodate ballast tanks, as shown in Figure 8. As this virtually doubles the volume required for fuel tankage, the impact on the design can become significant as range increases.

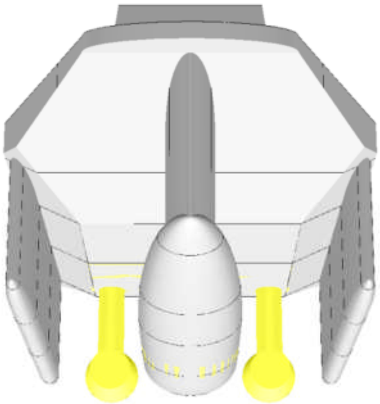

Figure 7: Bow view of the UCL WFSV showing the TriSWACH hullform and location of the azimuthing propulsors between the hulls.

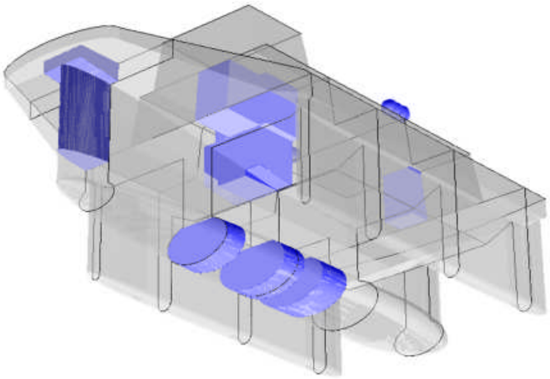

Figure 8: UCL WFSV design showing the "FLOAT" Functional Group, including ballast tanks in the hull

UCL has examined the application of the TriSWACH hull to a range of warships, including OPVs [21], destroyers [22] and small aircraft carriers [16]. A variant of this concept has been developed by Austal and used in the 27m turbine access vessel *Cable Bay* [23].

4.3 "MOVE" Functional Group

Figure 9 shows the MOVE Functional Group, primarily consisting of the propulsion machinery but including motion control (stabiliser machinery) and the cockpit.

The narrow strut makes installation of machinery in the lower hull difficult, unless delta shaped waterlines are used as in the Austal design. However, the large deck area available in multihulls allows an upperdeck machinery space to be incorporated. This has potential benefits in access for maintenance, but requires electrical propulsion or demanding shafting arrangements.

In the UCL design, mechanically driven azimuthing propulsors were fitted in between the hulls. The inboard machinery is in the main machinery space and this location provides an angular range of 25 degrees to port and starboard. In addition to improving manoeuvrability compared to fixed propellers, the propulsive efficiency in normal cruising should be improved by the propellers being located in the relatively favourable flow between the hulls.

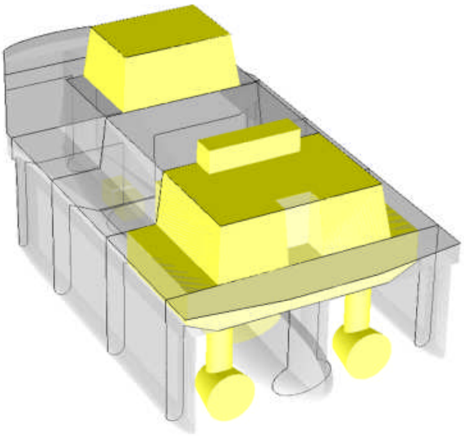

Figure 9: "MOVE" Functional Group, highlighting the upperdeck machinery space and azimuthing propulsors

4.4 "SERVICE" Functional Group

The SERVICE Functional Group primarily consists of the seating and stores for the turbine maintenance technicians, upper deck stowage for spare parts and turbine access equipment. As shown in Figure 10, these three occupy over half the length of the vessel.

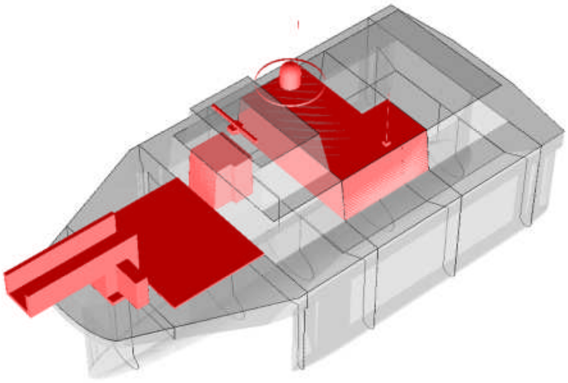

Figure 10: "SERVICE" Functional Group

The aft location of the upper deck machinery space leads to a linear arrangement for the SERVICE function; the seating space is amidships, with the forward deck used for stowage of up to two 10 foot ISO containers (to a maximum total weight of 2 tonnes) and the Houlder Marine Turbine Access System (TAS), shown in Figure 11 [24] is located forward.

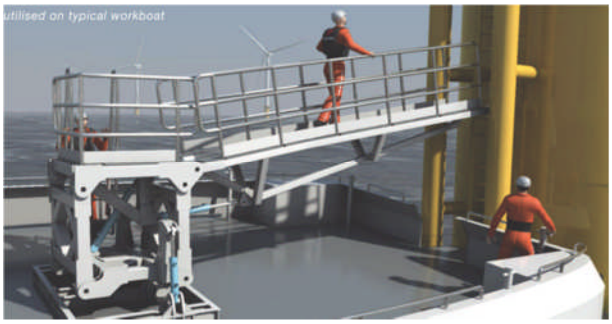

Figure 11: Houlder Marine Turbine Access System (TAS) [24]

4.5 "INFRASTRUCTURE" Functional Group

The final Functional Group is INFRASTRUCTURE. This includes the galley and dining area in the forward part of the superstructure, A/C and ventilation systems, fresh and black water tanks and systems; and two basic 3-berth cabins for the crew in the box structure.

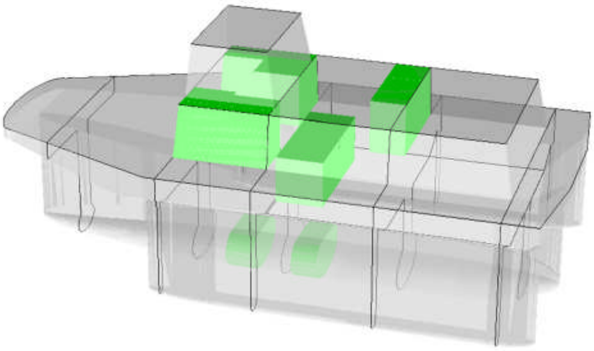

Figure 12: "INFRASTRUCTURE" Functional Group, showing galley and dining areas, ventilation and service tanks

4.6 USE OF THE DESIGN BUILDING BLOCK APPROACH IN THE DESIGN OF A WFSV

Although most research at UCL has focussed on the application of the DBBA to larger vessels, early PhD work using a prototype system examined the utility of having the early stage configurational model available in patrol boat design [25]. Specific features of the approach of particular interest in developing a WFSV design are:

- The flexible configurational model allows innovative concepts to be assessed without relying on previous designs.
- Having a configurational model increases certainty by permitted configuration-based, rather than interpolation-based estimates of weight etc.
- Interactive graphical displays of the layout can be used to elicit operator feedback on proposed designs.
- The model can be parameterised so that can be subjected to design space exploration or optimisation approaches. In the illustrative example, the hullform is fully parameterised and the internal spaces are

linked either to key features (such as bulkheads) or to each other (such as the overall superstructure arrangement).

5. A COMBINED APPROACH TO DESIGN DEVELOPMENT

The previous sections have described tools looking at two different levels or emphases of analysis of the vessels and the overall system needed to support offshore wind farms. The UCL O&M model operates at a high, strategic level, but is relatively fast to run and can incorporate a wide range of options through the various inputs and constraints. The Design Building Block approach allows the rapid development of early stage design models and can be used to develop single designs, or to generate parametric models for use in wider analysis.

The next stage of this research at UCL is planned to be the integration of the vessel design with the wider O&M system analysis. This draws upon the analysis performed by the Ministry of Defence (MoD) as part of the UK MoD Maritime Afloat, Replenishment and Support (MARS) programme, where a number of tools, including the Design Building Block approach were used to perform a wide-ranging analysis of options, both to select ship capabilities and size the vessel [26, 27]. UCL had some limited input in that project with regards to hullform modelling [28].

5.1 USES FOR AN INTEGRATED TOOL

The current O&M tool uses generic representations of the craft capabilities and performance, but there are several scenarios when it would be desirable to analyse specific vessel designs;

- Optimisation of vessel designs for a specific array;
- Development of flexible vessel designs that can be marketed to arrays using different O&M concepts;
- Development of designs for multi-purpose wind farms incorporating additional offshore infrastructure;
- Analysis and optimisation of an array, support plan and wind farm support fleet;
- Analysis and optimisation of a wind farm development for the likely available vessels.

5.2 CRAFT MODELS IN WIDER SYSTEM ANALYSIS

The development of WFSV models to feed into the O&M model uses the broad process shown in Figure 13. Some key points are; the use of baseline models of the craft to capture wider inputs; the development of topologically fixed, parametrically scaling models that are valid over the ranges of vessel capabilities of interest; the need to have numerical analysis tools that are valid over the size and capability ranges of interest; and the subsequent use of the “informed” parametric models within a wider O&M system analysis.

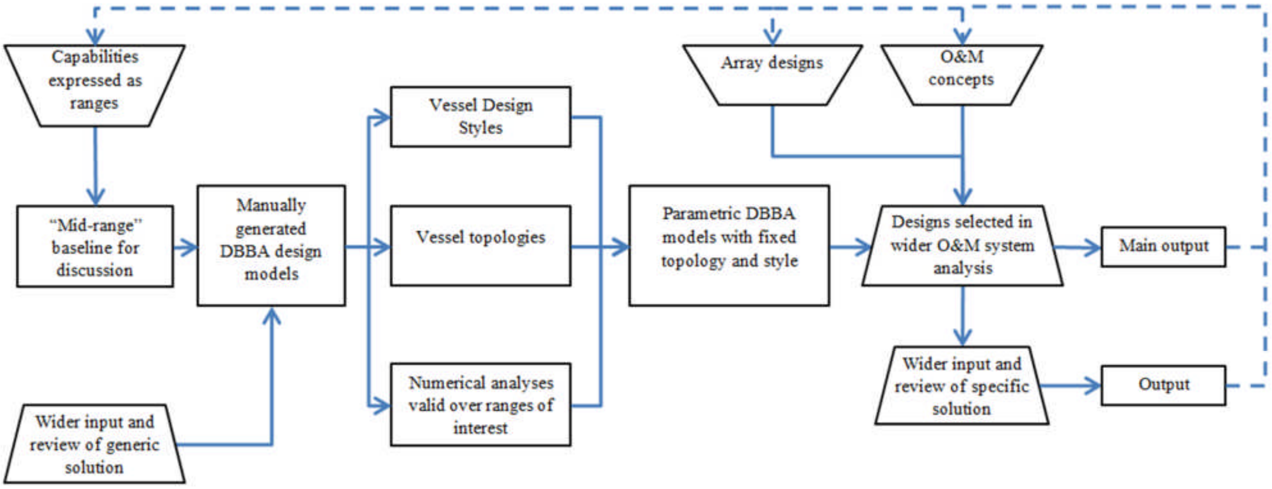

Figure 13: Overall process of WFSV model development and use in a wider O&M analysis

The parametric models can be structured in two ways. Either an iterative process can be developed to allow balanced designs to be produced for each combination of capabilities, or instead the models can size the vessels using a limited set of inputs (for example, the combination of O&M personnel size, stowage and TAS option capabilities), then explore a range of hullform parameters such as length and beam, in a non-iterative manner, retaining those combinations that meet the performance requirements. The latter method was used in the MARS modelling [27] and is conceptually much simpler as no automated decision making must be coded (e.g. if the design fails the intact stability, should the VCG be lowered or the beam widened, if both are possible?), so will be used in future UCL developments. An area for investigation is whether, for a vessel such as a WFSV, some decision-making can be coded into the model to reduce the time taken to search for an acceptable set of dimensions.

5.3 THE OVERALL ANALYSIS PROCESS

Considering the range of inputs to the O&M system shown in Figure 2, and the range of characteristics of the WFSV and other supporting craft shown in Table 3, the multi-dimensional "problem space" and "solution space" can be explored in different ways, depending on which of the use scenarios listed in Section 5.1 is of interest. Future UCL developments of the O&M tool and DBBA models will have to address this issue, as it is key to optimising the computing time required to run the models.

Selecting from the list of scenarios, some example usage concepts can be outlined:

Optimisation of vessel designs for a specific array;
The O&M model could be run for a range of plausible vessel costs and capabilities to develop a meta-model which could then be used to drive the optimisation of the parametric models. This could be used for a broader O&M vessel fleet consisting of different types.

Development of a flexible vessel design that can be marketed to arrays using different O&M concepts;
The vessel model could be run for a range of requirements to develop accurate meta-models for cost and capability. These could then be used in a wider O&M model exploration of different array concepts.

Both of these make use of "meta-models", these are simplified representations of results from more complex analysis, such as response surfaces, Artificial Neural Networks or even a look-up table of possible design variants. It may be the case that in some analysis scenarios, it is more desirable to run the vessel sizing model directly, however.

6. CONCLUSIONS AND FUTURE WORK

With projected expansion of the offshore renewable energy sector in terms of capacity, water depth and distance from shore, the development of effective support strategies more difficult. Operation and maintenance costs represent a high proportion of the cost of electrical power generated by wind turbines and so there is a current focus on reducing O&M costs and thus electricity production cost. Of particular interest is the improvement of availability, extending the range of sea states in which a turbine may be safely accessed. Three main options have been proposed for the marine support strategy for an offshore windfarm, and within these options there are a range of vessel types and capabilities that may be optimal for a given development.

Working from this general background, a 6 month UCL MSc project examined the issue of modelling different O&M strategies for offshore windfarms. A Matlab based tool was developed that utilised a range of inputs describing the wind farm arrangement and location, reliability of turbine components and individual costs for repair activities. Applying a selected maintenance strategy within external constraints such as weather conditions, the tool calculates the costs, energy production and support vessel requirements for the specified wind farm. The UCL O&M model was validated against published data for UK Round 1 windfarms.

To further develop this concept, a baseline CTV has been designed using the Design Building Block approach (DBBA). This exercise has demonstrated the applicability of the approach to this type of vessel, and will form the basis for continuing research to integrate the high level O&M modelling with parameterised vessel models to allow a more sophisticated analysis of the marine support strategy. Applying the configurationally centred DBBA to develop the vessel models will permit a wider range of innovative solutions to be assessed with higher confidence than a method employing a purely numerical model.

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