PERFORMANCE EVALUATION OF WIND-FARM SUPPORT VESSELS

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SUMMARY

This paper summarises the experience gained by Seaspeed in the evaluation of performance of wind-farm support vessels through extensive programmes of sea trials and model tests. This has been extended here to the development of a techno-economic methodology to assist in the selection of the most appropriate size and type of vessel for particular wind-farm applications.

1. INTRODUCTION

The first offshore wind-farms in Europe were installed in the 1990's and the subsequent development of this industry has been particularly rapid since that time. The London Array, completed in 2013, is currently the largest offshore wind-farm in the world with a peak rated power of 630 MW. At this time the UK has about 20 offshore wind-farms with nearly 800 turbines operational.

Access to these turbines is largely provided for by fast wind-farm support vessels (WFSV), generally less than 24 metres in waterline length with speeds of between about 15 and 30 knots. There are approximately 250 of these vessels in the UK and this fleet comprises a diverse range of vessels in terms of size, shape, hull form, propulsion system and operational speed. Whilst they almost all have a capacity for 12 technicians and are predominantly of a catamaran configuration, their operational performance is also quite varied.

2. VESSEL CONSTRAINTS

The thresholds relating to vessel size (24 metres) and technician capacity (12 passengers) are largely regulatory driven, although the latter issue is, at the time of writing, under review.

Vessel speed is a compromise between cost (initial and operating) and the need to operate to, within and back from the wind-farms generally within a day. Of course speed is not the only important factor in this regard – the transit time can be minimised by operation from local ports which, by their nature, tend to be shallow and have tidal restrictions, thus influencing the choice of vessel size. However, too small a vessel is likely to unacceptably compromise seakeeping ability.

Another constraint for these small relatively fast craft is the need to approach and link with the wind turbine towers in order to provide a safe access passage for the maintenance technicians. The towers themselves have been designed to accept certain lateral thrust forces (many rated at about 200 kN) and this limit would typically be reached by the approach in rough weather of vessels with displacements of about 100 tonnes, depending on the nature of their fendering system.

The environmental conditions in which these vessels often operate are also worthy of note. Local tidal current effects can dominate vessel performance with respect to the transfer of technicians to the wind turbine towers and the nature of coastal conditions means that not only can the fetch and persistence of given sea conditions be short (implying only partially developed sea spectra) but also the directional spread of wave energy can be significant.

WFSV are multimodal in the sense that they need to provide acceptable performance across a number of operational modes – in particular high speed for transit, precise manoeuvrability and rapid response for approach to the towers, safe transfer of persons between vessel and the tower and comfort at low speed loiter. This increases the complexity of the vessel design and inevitably involves some technical compromises.

Financing considerations are also important with respect to vessel design and selection. As with most ships, the need to maintain an acceptable future residual value has an impact on their design, generally involving hedging against changes in local market conditions. Thus, for example, a larger than normal vessel might provide beneficial characteristics for a certain specific operation, but such an investment will only be made if the investor can be reasonably confident that the market for its services can be sustained for an acceptable period – if the specific operation ceased then the vessel (and its charter rate) may be unsuitable for other operations, making it a less valuable asset.

3. PERFORMANCE ASSESSMENT METHOD

It can be seen, even from the limited discussion above, that selection of the most appropriate WFSV is far from straightforward, hence the need for a logical and transparent method for assessing different vessel designs.

The concept used here is based on the assessment of vessel characteristics across all modes of operation with respect to a range of performance thresholds, and the combination of that data with statistical information relating to environmental conditions and operational schedules. This is used to provide an evaluation of vessel 'availability', which is taken here to mean the percentage time that the vessel is actually available to undertake its required tasks at the wind-farm.

If such assessments are made as a function of vessel size, or more specifically, cost, this provides the opportunity to assess the cost of attaining a given availability – or conversely the availability possible for a given budget. Most importantly it can be used to assess the likely performance of a given vessel if used on a specific wind-farm from a specific port.

It is assumed that the vessel is available if it can carry the required payload, is operational and is capable of providing satisfactory transit and transfer operations to the wind-turbine tower. This availability is influenced by a number of factors such as those indicated schematically in the influence diagram in Figure 1.

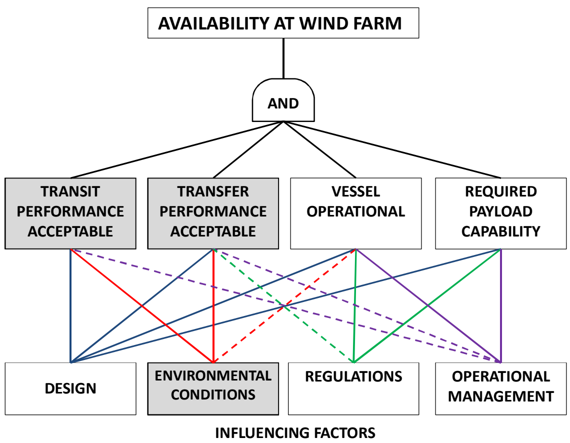

Figure 1: *Availability Influence Diagram*

The objective of the methodology presented here is to provide a means to compare the cost benefit of different designs, taking account of the impact of environmental conditions on the transit and transfer operations (highlighted in Figure 1 above).

If the availability calculation is undertaken for a number of different vessel sizes for say three different wind-farms (say a very sheltered site close to the shore, a partially protected site further from the shore and an exposed site still further from the shore) it is possible for a diagram such as that shown in Figure 2 to be generated (where cost, which could be purchase or operating cost, has been substituted for vessel size).

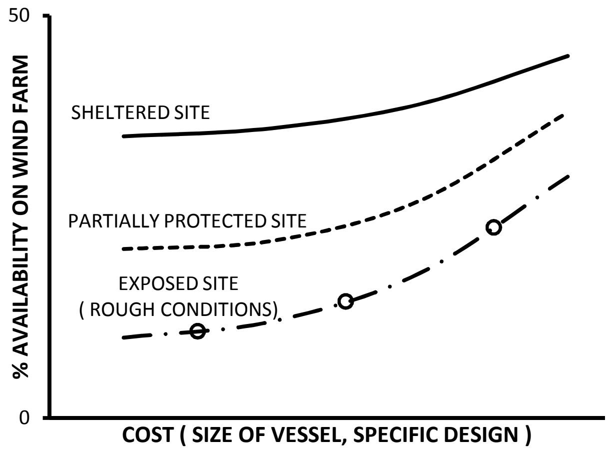

Figure 2: *Availability vs Cost Diagram*

The steps involved in producing such a diagram are described in paragraphs a. to f. as follows:

a. Assessment of the involuntary and voluntary reduction in vessel speed with increasing significant wave height on the basis of powering, motion, slamming and other limitations. Typical thresholds used are 85% MCR for powering, pitch rms 3 degrees and roll rms 4 degrees, vertical acceleration in the superstructure rms 0.15g, slamming or green-water over the bow once in every 100 waves and avoidance of deck-diving in following seas. These parameters are assessed for each heading (head, bow, beam, stern and following seas) and graphs of operational speed vs significant wave height produced as per Figure 3.

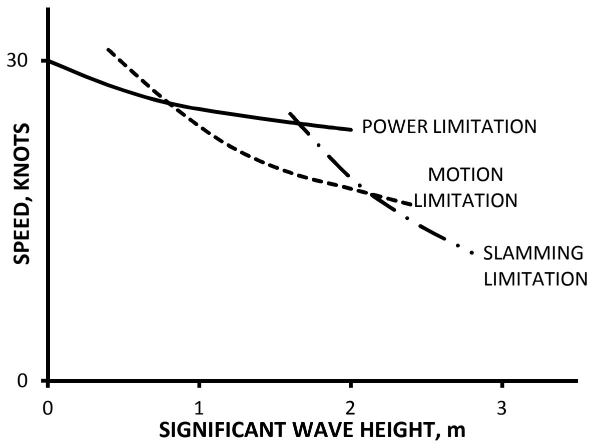

Figure 3: *Operational speed vs significant wave height (one such graph required for each heading).*

b. With knowledge of the distance and direction of the transit between the departure port and the wind-farm, the time of transit to and from the wind-farm is calculated using the data from Figure 3 for each of say twelve wave direction sectors (e.g. 0°, 30 °, 60 °, 90 ° etc) on the basis of significant wave height. For the given number of hours in a day that the vessel is operational, the actual time that the craft is available for operation on the wind-farm itself, can thus be calculated (as a percentage of 24 hours). This allows the type of data presented in Figure 4 (transit limit line – on primary vertical axis) to be developed.

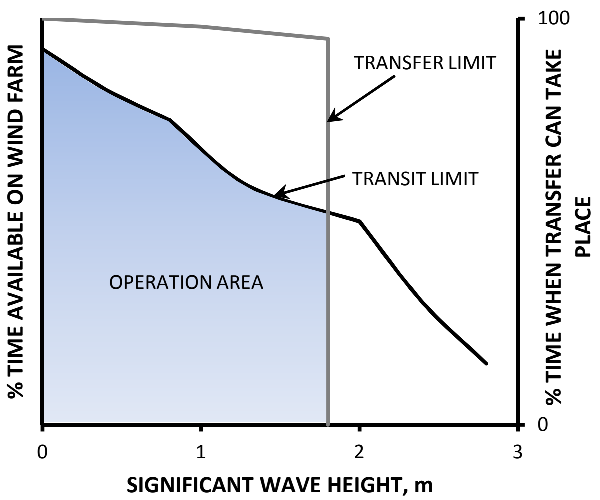

Figure 4: *The primary vertical axis indicates the percentage time the vessel is available due to transit time limitations. The secondary axis indicates the transfer limitation line based on a 95% confidence level of the fender not slipping. The shaded area indicates the percentage time the vessel is fully operational at the wind-farm. (One such graph is required for each wave direction sector).*

c. A similar calculation is also performed with respect to the ability of the vessel to undertake a safe transfer at the tower. This calculation is currently based on experimental data relating to the vertical, lateral and longitudinal forces experienced by a vessel attached to the tower over a full range of headings and sea conditions. If the mean and standard deviation of the forces are known from these tests, and the capability of an access system (such as the friction coefficient of the fender) is known, then it is possible to calculate, for example, the significant wave height at which there is a 95% confidence level of the fender system not slipping. This calculation is undertaken at the aforementioned twelve wave direction sectors with knowledge of the heading of the transfer pillars on the towers in the specific wind-farm, thus providing an assessment of the limiting sea conditions relevant to the transfer process and access system selected. The above calculations allow the transfer limit line to be added to Figure 4 (on secondary vertical axis).

d. The data from the transit and transfer limit lines in Figure 4 can then be combined to give the time that the vessel is fully operational on the wind farm, shown shaded in Figure 4. This then takes account of the effect voluntary and involuntary speed reductions due to weather on the time it takes to get to the wind farm and the likelihood of making a safe transfer once there.

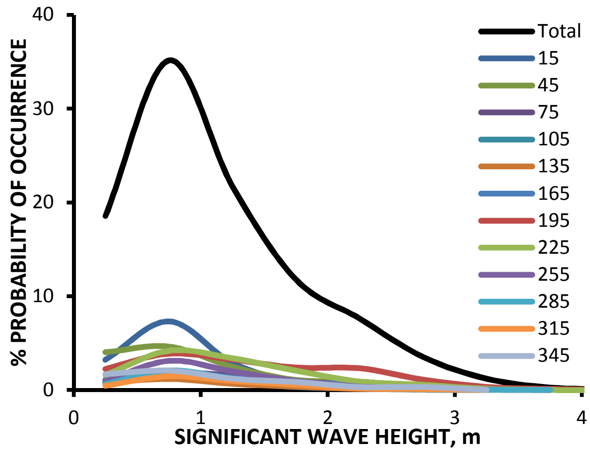

Figure 5: *Wave statistics (annual occurrence of significant wave heights)*

e. If the occurrence statistics for the sea conditions (significant wave height) in each wave direction sector are known (as per Figure 5), then these can be simply combined with the percentage time when the vessel is fully operational on the wind-farm (as per Figure 4) to arrive at a figure of 'availability' which is relevant to the period of the wave statistics data (e.g. monthly, seasonally or annually).

f. If this calculation is repeated for a number of different vessels sizes, then the availability data generated can be used to populate the graph in Figure 2 above for a given wind-farm site.

It should be noted that there are other important parameters (omitted here for the sake of clarity) that can be accounted for in this assessment procedure, and these are discussed below.

Tidal current – this can be a particularly significant issue with respect to transfer capability due to its effect on both the longitudinal and lateral drag on the vessel when on the tower and the extent to which the propulsion thrust is required to be diverted to maintain the correct heading. Should the effect of tide on the transfer process be known then this can be incorporated in a straightforward manner by modification of the transfer limit line in Figure 4, and thus accounted for in this assessment process.

Wave period – this can affect the motion characteristics of the vessel when in transit and also when on the tower, although its influence is largely secondary to wave height. During recent model tests, it was found that wave period appears to have little influence on the forces experienced on the tower (see Figure 7) but does have a more noticeable influence on motions during transit. This affect can be accounted for by introducing another step in the analysis process and requires knowledge of the effect of wave period on motions and its statistical distribution for each significant wave height group in each wave direction sector.

Sea Spectra – the nature of a sea spectrum can have a significant effect on vessel performance, and with many wind-farms situated in coastal areas, limited fetch, shallow water and complex energy spreading are common influencing factors. These issues can be accounted for in the availability model but are generally not that important when comparing the performance of one vessel size with another.

Personnel performance – there is some limited data available outlining the detrimental effect of motion on the ability of personnel to undertake typical ship-board tasks. There could be some benefit in incorporating this in the availability model, but this is not considered to be worthwhile until more reliable data is forthcoming.

Approach mode limitations – it is well known that approaching and coming into contact with the tower in order to undertake a transfer can be a challenging process. The particular issues that limit this process are largely undefined, apart from the slightly vague notions of operator skill and vessel manoeuvrability. Until such time as this aspect can be better predicted, it is considered relevant to assume that should a transfer be possible once in position, then the approach is also likely to be possible. It is acknowledged, however, that this is not always the case.

4. SUPPORTING INFORMATION

The cost-benefit assessment described above relies on the provision of relevant and reliable data. A database of such information has been developed based on computer simulations, scaled model tanks tests, open water tests and full scale trials on a wide range of WFSVs.

In terms of motion prediction in a transit or loiter situation, existing seakeeping software can provide reasonably reliable estimates at most speeds and headings. This can be extended to cover motion sickness incidence and some other whole body vibration quantities should they be required. However there are some events that are difficult to predict in this way such as directional stability, deck diving, propulsor ventilation and cross-deck slamming, where validation by open water model tests or full scale experience is beneficial. To this end a number of WFSV designs have been tested using self propelled models in open water conditions. See Figures 6 for one example.

Data from such tests over a range of designs, sea-conditions and speeds has proven particularly useful in terms of confirmation of operational limitations such as slamming thresholds, occurrence of green water over the bow (and the influence of bow freeboard), directional control in stern seas and lateral accelerations in bow and beam seas. This testing technique has also provided a much appreciated exposure to the general handling and behaviour of these vessels in realistic conditions, particularly by the developers of novel craft arrangements.

Figure 6: *Self propelled 1/12 scale model of SWATH craft tested at 25 knots at all headings in a 2.8m significant wave height sea-state. Motions recorded in all six degrees of freedom along with speed, propeller rpm, rudder angle and video data on and off the model.*

Performance prediction of the vessel when attached or thrusting up against wind turbine towers is less well catered for although there are relevant simulation programs in existence. The parameters of interest tend to be vessel motions, triaxial forces imposed on the tower by the vessel, slamming occurrence, propulsor emergence and stern swamping. Recent scaled hydrodynamic tests of self propelled models thrusting up against a turbine tower over a full range of headings has provided an indication of sea-state limitations for all these parameters. The added impact of tidal current has also been established in these tests but only at tidal directions along the same axis as the wave direction (due to limitations of the towing tank used in the experiments).

An example of results from these tests is provided in Figure 7 which shows the effect of wave period and heading on the vertical forces experienced at the bow fender of a 24 metre multihull craft in a 2 metre significant wave height sea state. It was notable that on a number of vessels the performance was limited more by stern swamping in stern seas and severe roll in beam seas than by exceedence of performance thresholds relevant to access systems.

Also of crucial importance to fender based access systems is the variation in longitudinal thrust when thrusting against the tower, since fender friction is proportional to this thrust. Such variation occurs due to changes in drag on the hull by wave orbital flow, inertial forces due to vessel motion, changes in steering angle, thrust variations due to propulsor performance in varying flow conditions and ultimately their ventilation due to emergence. Knowledge of not only the mean thrust but also the rms variation of thrust provides the ability to predict with some confidence the frequency of bow slippage due to loss of friction.

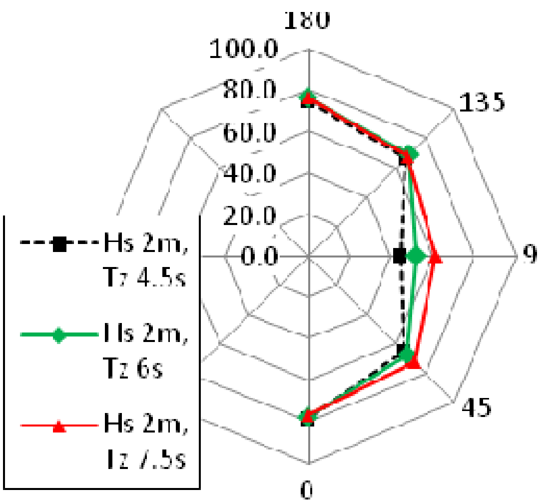

Figure 7: *Vertical forces (rms kN) experienced on a 24 metre hull design with the bow attached to a turbine tower, in 2 metre significant wave heights.*

The effect on transfer availability of other types of access systems, such a motion compensated brows (see Figure 8) and bow clamping devices as well as fender based systems has been investigated in some detail. Whilst most systems show benefits in particular situations, the cost-benefit model described above allows this to be put in perspective, in particular to assess whether the cost of fitting such a system may, if relevant, be better allocated to the procurement of a larger or more capable vessel.

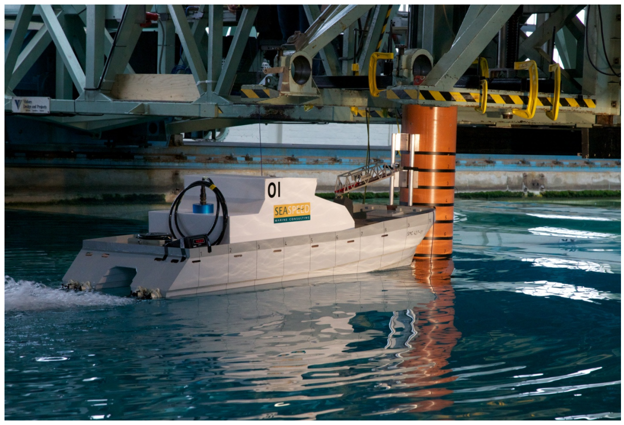

Figure 8: *Self propelled scale model test of active motion compensated brow on a 24 metre WFSV hull whilst thrusting up against a turbine tower in head seas.*

5. CONCLUSIONS

This paper describes an approach to performance evaluation of WFSV using a cost-benefit approach. This brings together a holistic appreciation of vessel performance and the occurrence statistics of environmental conditions to provide an estimate of availability of the WFSV, which can then be directly related to the associated procurement or operational costs.

Based on feedback from operational experience and full scale trials, the data required for such an approach has been outlined as have methods for the procurement of such information. Whilst existing performance prediction software can provide much of what is required, the important contribution of hydrodynamic scale model tests for verification, refinement and extension of this information, particularly for conditions adjacent to the towers, is highlighted.

It is proposed that this method provides for a flexible approach to realistic performance evaluation in that it can provide a cost benefit assessment based on a set of relatively simple parameters, which can also then be refined to include as much relevant information as is available.

6. AUTHORS BIOGRAPHY

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