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RAPID DEVELOPMENT IN OFFSHORE WIND AND THE NEED FOR JACKUP INSTALLATION VESSEL EVOLUTION

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ABSTRACT

Since the first turbines were installed off the coast of Denmark in 1991, the offshore wind industry has grown steadily, particularly in Europe, to become a key part of the energy mix. The industry has matured and in recent times, exploded, as the race for greater efficiencies has led to bigger and bigger turbine designs. In the early days, installations were carried out in any way possible, with specialized vessels emerging as the size of turbines and volume of work expanded. In this paper the rapid growth of the industry is reflected upon, with the corresponding impact on the installation methods employed and the need for larger, more capable vessels. Finally a new installation concept, representing a possible future direction for Jackup installation vessels is introduced.

KEY WORDS: Wind Turbine Installation Vessel, WTIV, Wind Energy, Jackup, Crane

INTRODUCTION

Offshore wind farms consist of massive generators mounted on specialized support structures. The vast majority of turbines today are horizontal axis, upwind turbines, meaning that the hub points into the wind during operation. While floating solutions are emerging in some areas, bottom supported options are much more common and will continue to dominate the market in the near future. The terminology commonly used to describe the various components are described in figure 1. The wind turbine generator itself consists of long blades attached at a hub to the main body called the nacelle; the entire package sometimes referred to as the rotor-nacelle assembly. The generator is supported on a tall cylindrical tower section which is in turn supported by the substructure. In the most common case, the foundation is provided as a large diameter monopile, on which a transition piece is installed. The transition piece provides a platform for accommodating boat landings, and access to the tower as well as housing supporting equipment. At the top of the transition piece, a flanged connection is typically provided for connection to the tower. Common alternatives to the monopile solution are gravity base structures, which are typically large concrete bases primarily used in shallow water, and jackets, which use a truss structure to provide increased strength and stiffness in deeper water applications.

While there are variations, installation of wind turbines is typically carried out in two stages, with the substructure installed first and the tower, nacelle and blades installed later. Installation of the substructure depends heavily on the type of foundation employed. As the size and weight of foundations continues to grow, there is ongoing debate on whether floating or jackup vessels are best suited to foundation installation. For the tower, nacelle and blade installation the consensus however is that large specialized jackup vessels are the preferred option, providing the stable base required for these high precision installations. As there are alternative options for installation of the foundations, the discussion in this paper is therefore focused on the issue of tower, nacelle and blade installation using specialized jackup vessels, commonly referred to as wind turbine installation vessels (WTIV).

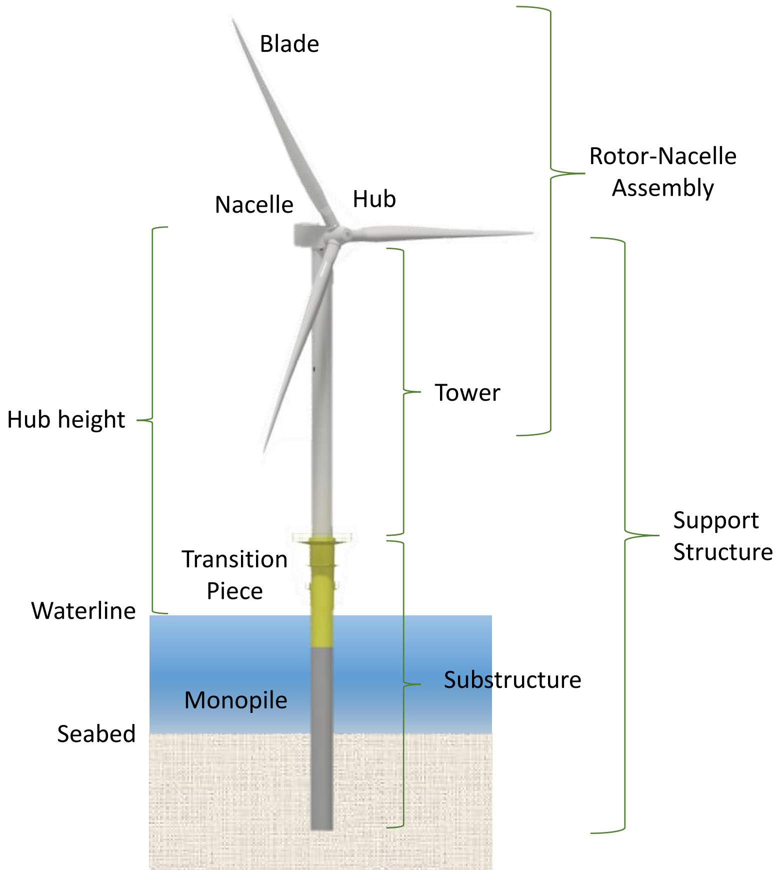


Figure 1. Typical components for offshore wind (monopile example)

WIND TURBINE EVOLUTION

The evolution of the offshore wind industry has been driven by the rapid development of the wind turbines themselves. The first offshore wind farm, Vindeby, installed in 1991, consisted of 11 turbines with a rated capacity of 450KW each for a total of 4.95MW. By 2007 individual turbines of 5MW were exceeding this total and today turbines with more than 8MW capacity are installed while turbines with 10 to 12 MW capacity are being rolled out. This rapid evolution is illustrated in figure 2, where the height and diameter of the rotor are illustrated for key examples over the years. The GE Haliade-X turbine with 12MW capacity and 220m diameter rotor represents the current "future" turbine, but what will be developed in a further 5-10 years is yet to be seen.

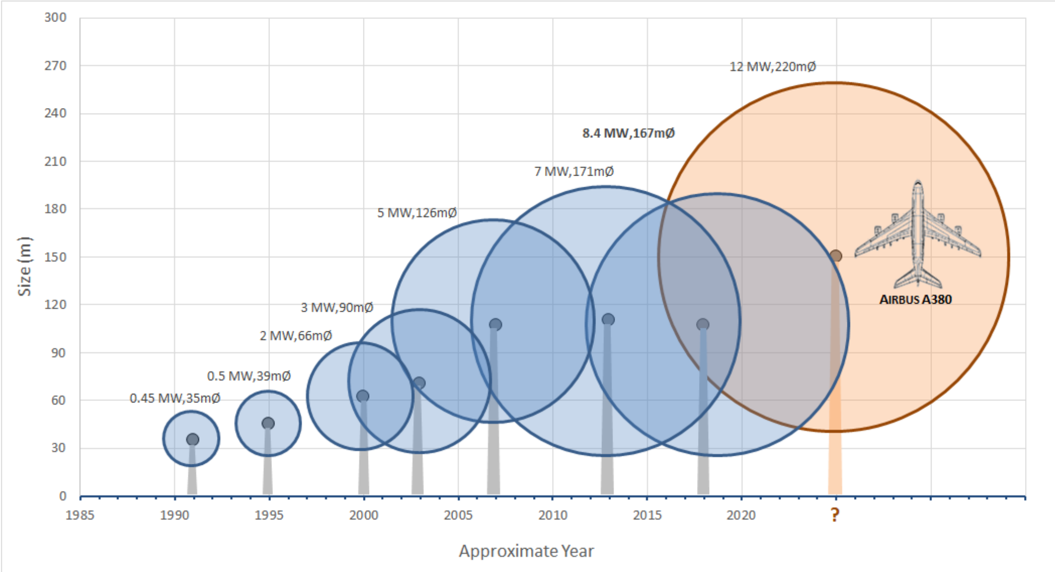


Figure 2. Evolution of Offshore Wind Turbines
(Blue represents turbines already installed, Orange represents the new GE Haliade-X turbine)

WIND TURBINE INSTALLATION VESSELS

In the early days of offshore wind, installation works were typically carried out from available coastal construction vessels, sometimes modified with additional cranes and equipment to carry out the job at hand. Figure 3 and 4 show installation being carried out in 1991 and 2001 respectively.

Figure 3. Installation work being carried out on the first wind farm at Vindeby (*source:Windeurope* [1])

Figure 4. Installation work being carried out Vattenfall's Yttre Stengrund project (*source:Wind Power Monthly* [2])

Figure 5. Seafox 5 (now Blue Tern) carrying out installation work

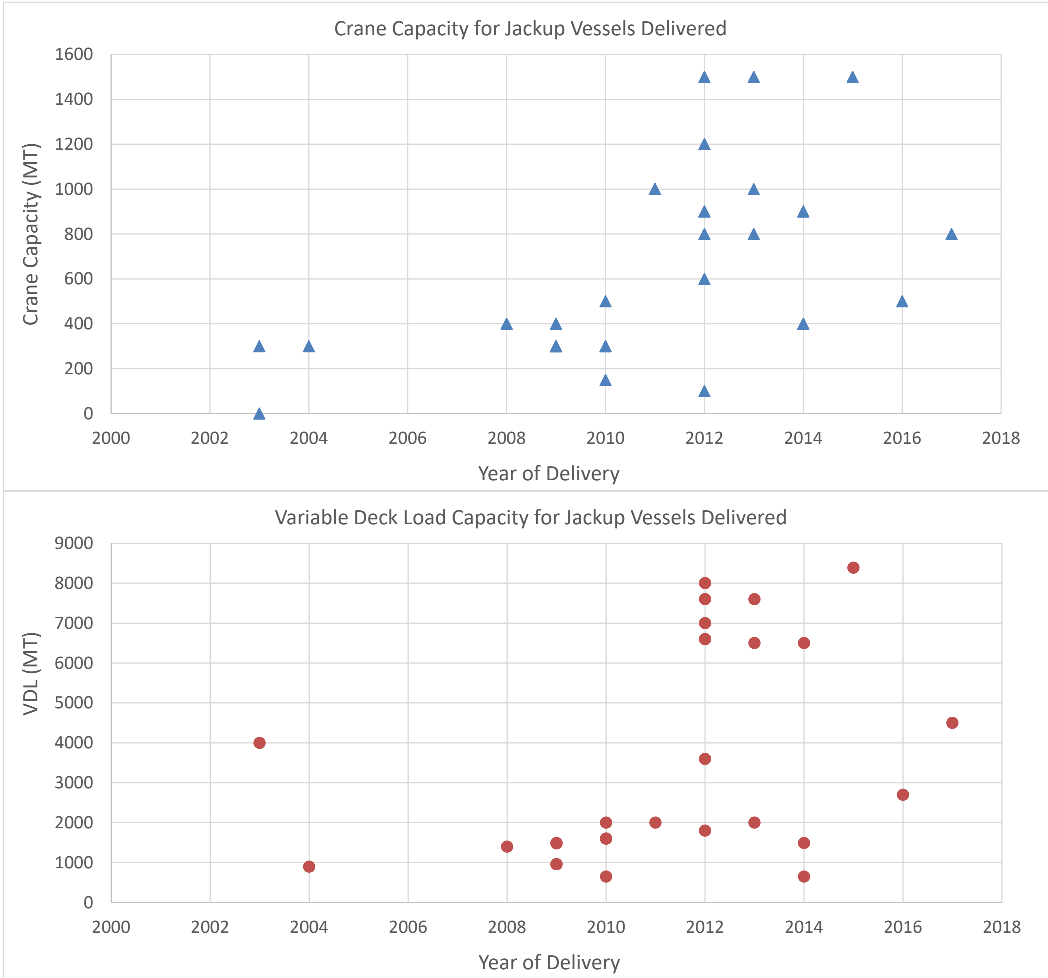


Figure 6. Evolution of Jackup vessels used for wind turbine installation work
(Crane capacity above, VDL below. Note, data incomplete and some points overlap)

As the industry has grown however the volume of work and increased size of the turbines to be installed has led to the adoption of more and more specialized vessels. The first purpose built vessel, the Mayflower Resolution (later MPI Resolution), delivered in 2003, was self-propelled, provided capacity to carry complete turbines and was equipped with a 300MT crane. Referring to figure 6, which shows a collection of available WTIV data, such vessels with cranes of 300-400 MT continued as standard until a step change occurred around 2011-2012 where several vessels entered the market with much larger cranes and cargo carrying capacity. This jump, towards much larger custom wind installation vessels, allowed transport and installation of several units in each trip. Vessels such as the Seafox 5 (now Blue Tern), shown in figure 5, designed and built by Keppel in 2012, is illustrative of the jump that was made. Vessels such as this were designed to install foundations as well as wind turbine components and could also work in other industries if the wind installation work was low.

The evolution of such designs, in many ways was accompanied with a change of mentality, with more alignment towards offshore oil and gas standards and jackup design thinking. Jackup designers however had to adopt to the different needs of the WTIV market. One key area where this is seen is in the frequency of jacking. While a drilling jackup may make a few rig moves a year, WTIV jackups can move every day, resulting in very different demands on the jacking systems, legs and guides. For example, in the course of designing the Seafox 5, OTD developed a wind specific jacking system to provide higher speed and longer life performance, and incorporated a patented guide system to improve installation performance while reducing the wear on rack teeth. On its first job the vessel completed 106 jacking operations, successfully jacking and installing in sea states in the range of 2m without issues.

"106 jacking cycles up & down is equivalent to what a normal drilling rig is doing in a 20 year lifespan. To do this during this project within only a year and with almost zero down time rating of the duration, proves the robustness of the design and equipment built by Keppel." - *Operations Director of Seafox 5.*

WTIV OF THE FUTURE

With the steps being made at present in wind turbine designs, the next step change in WTIV designs will follow. The recently announced Jan De Nul vessel, Voltaire, reported to be equipped with a 3000MT crane and 14000MT VDL may be the first of these new generation vessels. The challenges to be overcome to install next generation turbines vessels raises several questions and there is scope for some new innovations. For example, ass discussed earlier, while some designs will continue to strive for an all in one solution capable of installing both turbines and foundations, others are choosing to prioritize on turbine installation, with the assumption that the foundations can be installed using floaters. This approach allows WTIV cranes to be optimized for higher lifting (vs heavier lifting for foundations) while the jackup vessels are then optimized to support the operations of such cranes while carrying cargo in a way that allows maximum number of turbines to be accommodated in each trip.

A possible solution for the next generation WTIV is illustrated in figure 7. This concept, referred to as the T2500X, combines a 2500MT crane with an innovative leg arrangement and other design features to provide a range of benefits over more traditional designs. The elegant and well balanced design, with favorable center of gravity under both loaded and unloaded conditions, helps to reduce CAPEX. The arrangement of a single forward leg allows for efficient ship-shaped hull bow form, and the single leg aft allows for narrowing of the stern and reduces wave making resistance. In combination, these effects reduce total resistance resulting in competitive transit speed which can be achieved with smaller propulsion and powering, leading to greater fuel efficiencies.

Figure 7. OTD T2500X Wind Turbine Installation Vessel

While the design is optimized for wind turbine installation operations, the large available deck and 2500MT main hook capacity still enable effective use for other offshore heavy lifting operations including installation of foundations, and decommissioning activities.

A key focus of the design is the innovative leg arrangement and crane position which provides benefits to cargo arrangement and operations. As larger jackup installation vessels are developed, it has become apparent that the ability to lift and position cargo on deck is an important limiting factor in obtaining favorable deck arrangements. Most designs today have a leg encircling crane positioned on one of the aft legs, lets say the starboard-aft leg for the sake of discussion. With the weight of the crane aft and starboard, positioning weight forward and towards port on the vessel is important in obtaining balanced load conditions. Positioning the vessels own components forward and port can help to achieve this, however as the weight of cargo is significant, positioning of the cargo itself is key in being able to manage weights and minimize ballast to be carried.

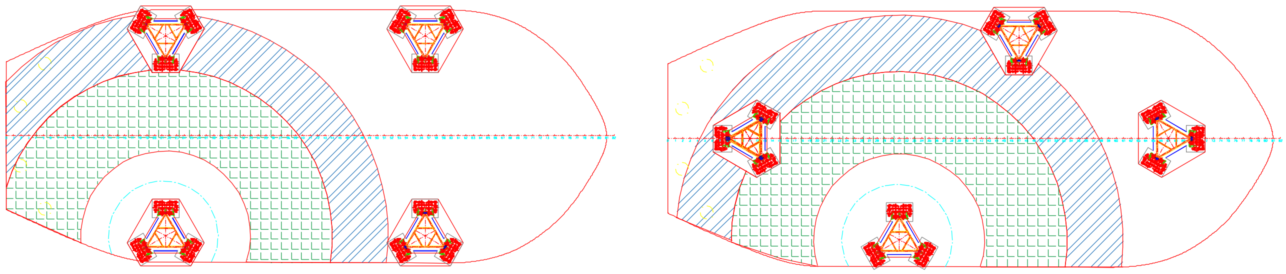
A typical crane load chart provides a limited region of maximum lifting close to the crane, with load capacity (and lifting height) reducing at larger radius. This means that the ability to reach areas far forward of the crane, with heavy items such as towers and nacelles, is typically limited. Referring to figure 8(a), for the case of a large WTIV, this can result in a dead spot behind the forward port leg and a crane coverage which is concentrated towards the aft. In order to avoid specifying larger and larger cranes to help keep up with the increasing vessel dimensions a change of approach is needed.

One solution to reach further forward is to use a pedestal crane installed in front of the aft leg. This approach was employed in the Seafox 5 design and provides a workable solution. Current preference in the industry however is to employ leg encircling cranes which, although more costly, provide greater unobstructed operations around the leg allowing access to greater regions of the deck and flexibility in cargo arrangements.

The T2500X design provides an innovative solution to this problem as the crane, and leg, is positioned further forward on the hull. This leg position is complemented by the arrangement of the other 3 legs which further open up the accessible deck areas, making best use of the available load chart. Additional details such as the port side wrap-around of the living quarters further enhances the load balance while maximizing useful access to the main deck spaces.

Figure 8 provides an illustration of the T2500X deck outline, with legs arranged in a traditional rectangular arrangement and in the proposed arrangement. In both cases, for better comparison, the exact same deck size and shape is used and the leg centroid is identical. A load chart with “heavy” and “medium” capacity zones is then overlaid on these layouts and the accessible area shaded. In this case the “medium” capacity would correspond roughly to the weight of future towers and nacelles. The improvement in the accessible areas is clearly seen and can be quantified by looking at the total areas as well as the center of the area, which is essential in allowing balanced load arrangements. The improvement of the T2500X over the traditional arrangement is:

- 11% greater accessible area.
- 14m forward shift of center of accessible area.



(a) Traditional (b) T2500X

Figure 8. Comparison of effective load chart on deck

The greater access to deck areas opens up several options for cargo arrangements, as shown in figure 9. While carrying blades aft is likely to be the preferred arrangement for many, the unique leg arrangement also provides the ability to carry blades diagonally along the aft-port side. This option may be attractive as blades become longer as the extent of overhang and "effective width" of the vessel and cargo can be limited. Regardless of the arrangement preferred, the figure illustrates that there is ample accessible deck space available for carrying either 5 sets of future turbines or 10 sets of today's 8MW turbines. There is also space remaining to accommodate handling tools and various installation equipment which are excluded in the figures for better clarity. The layouts illustrate that sufficient deck cargo space is available facilitating efficient, safe and comfortable operation for the crew.

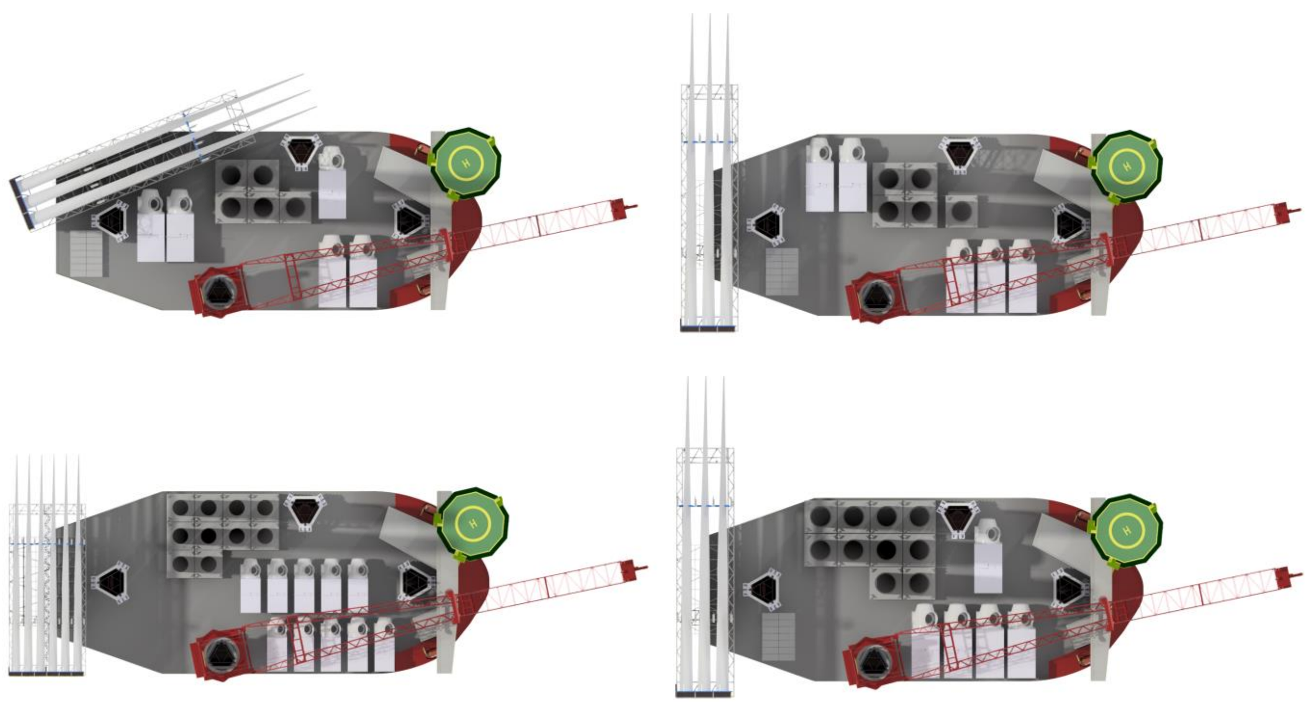


Figure 9. Illustrative example cargo arrangements

(clockwise from top – 5 x 12 MW turbines with blades on side, 5 x 12 MW turbines with blades aft, 5 x 12 MW turbines with blades aft and 2 piece towers, 10 x 8 MW turbines with blades aft)

After investing in such an asset, with quality transit and elevated capabilities, the last thing an owner wants is to be held up waiting for favorable weather. With this in mind, the T2500X is designed for enhanced going on and off location capability and is equipped with the latest version of OTDs Rig Move Assist^{TM}. An example showing the going on and off location screen from the system is given in figure 10. The system integrates onboard monitoring devices and vessel information for transit, going on and off location and preloading operations, in an intuitive display capturing real time conditions against the relevant operating limits.

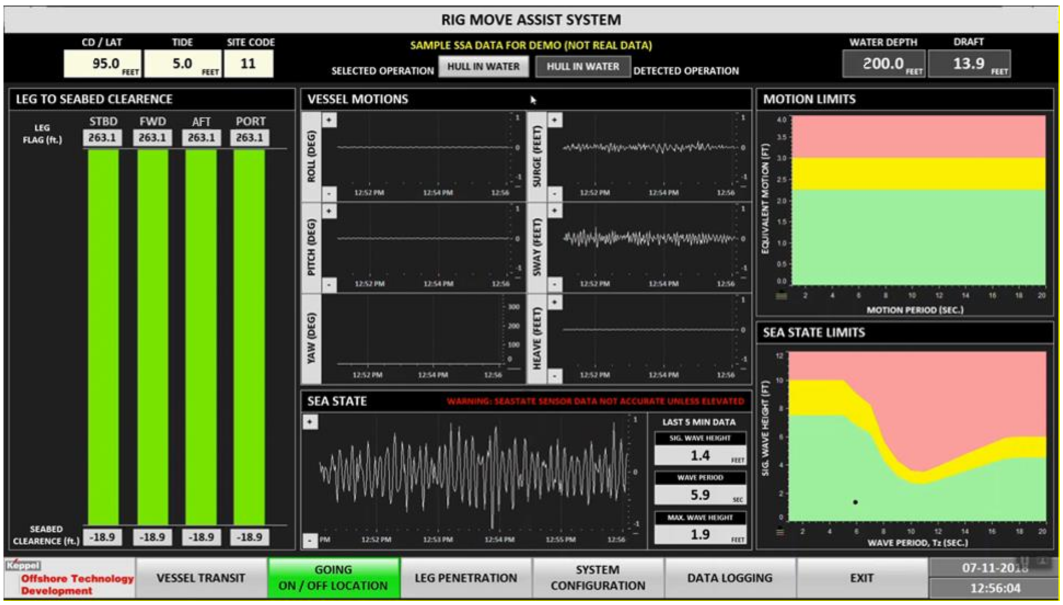


Figure 10. Example Rig Move Assist^{TM} Screen

CONCLUSIONS

The offshore wind industry has grown quickly, particularly in Europe, to become an established part of the energy mix and an essential energy source as the planet moves toward a lower carbon future. As the race for greater efficiencies leads to bigger and bigger turbine designs, the vessels used for installation must evolve. While 4 legged, rectangular jackup vessels are currently the go to solution, in this paper we have introduced an alternative approach. The T2500X is presented and some of the benefits are highlighted, particularly in terms of maximizing use of the crane load chart. The benefit of a larger and more forward accessible cargo area allows for larger effective vessel cargo capacity, without the need to employ oversized cranes or to move components on deck. In addition, the innovative approach leads to several other key benefits including an improved hull form providing reduced resistance, high transit speed and fuel efficiency. The T2500X provides a new direction for the next generation of wind turbine installation jackups and represents a key enabler in driving offshore wind even more strongly into the future.

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