

COM02: FLOATING OFFSHORE WIND ACCESS STRATEGIES AND CONSIDERATIONS

Public Summary Report



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EXECUTIVE SUMMARY

Floating offshore wind (FOW) developers are anticipating a significant increase in floating offshore wind deployment over the next decade; the first commercial-scale floating wind farm is set to be built starting in 2029 [1] with a UK goal of 5 GW of floating wind by 2030 [2]. The influx of large turbines increases the demand on offshore construction and maintenance activities. A key aspect to ensure reliable maintenance is safe and effective transfer for technicians from shore onto turbines. However, there are concerns regarding transfer safety, optimal transfer method, and lack of standardisation.

This project aims to better understand different access methods, focusing on:

- Crew Transfer Vessels (CTV),
- Service Operational Vessels (SOV) with Daughter Crafts (DC),
- SOV with a Walk-to-Work (W2W) gangways,
- Helicopters.

The project began with a review of each method using currently available literature and stakeholder engagement. Next, different access methods were assessed using the OrcaFlex modelling software. Finally, logistical modelling measured impacts of various access limitations on key performance indicators (KPIs).

Work Package 2: Review of FOW Access Methods

Across all methods, priority was given to the distance from shore, the length of the maintenance campaign, and technicians' safety when determining which method to use to carry out transfers. SOV with W2W gangways have the highest expected use, despite the high cost, as the design has the highest accessibility limits and teams allowing for rotating shifts enable longer working hours. CTVs and DCs are similar in access design, and CTVs are expected to be limited by the distance of the turbines offshore, and used in farther distances for necessary individual repairs. Helicopters are expected to be rarely used, and restricted by the weather limits of the vessel used to prevent transferees being stranded. Exceptions for this include emergency transfer, especially in conditions of sea recovery, which is easier with helicopters than with SOVs. Most substructure designs are not expected to be able to winch onto the nacelle, further limiting helicopter use. Across all four methods, there were concerns regarding relative motion, maintaining contact, and lack of regulations. Several developers emphasised the importance of sharing findings across industries, including learning from fixed wind and oil and gas (O&G).

Increasing accessibility is an industry priority for ensuring consistent and reliable maintenance plans. Key universal methods for increasing access include:

- Increasing the number of landing points onto the turbine;
- Positioning the vessel into prevailing sea conditions;
- Minimising turbine motion, thereby limiting relative motion between turbine and vessel.

WP3: Analysis of FOW Turbine and Vessel Relative Motion

In this work package, access to FOWTs is investigated via numerical modelling in the software OrcaFlex. Methodologies to model access by: (a) Helicopter, (b) CTV, and (c) SOV with a W2W gangway were developed. These methods were then applied to models of a bottom fixed foundation, a FOWT on a semisubmersible foundation and a FOWT on a tension leg platform (TLP) foundation. The transfer method was then assessed in environmental conditions which are representative of the locations where FOWFs are likely to be deployed.

Broadly, the results show a reduction in access for the semisubmersible foundation compared to the TLP and bottom fixed foundations, which have very similar levels of accessibility. This is particularly true when considering access by helicopter, where a nacelle motion limit of 4m was applied based on hoist landing area standards. This motion limit was exceeded in all sea states with significant wave height (H_s) higher than 1.5m for the semisubmersible, and in lower H_s conditions with low wave peak period (T_p). By contrast, the nacelle on the TLP did not exceed this limit in any of the environmental conditions considered (H_s up to 2.5m, and T_p up to 14s).

Access via CTV was also more limited for the semisubmersible foundation. Figure i shows a comparison of CTV accessibility for the foundations and sea conditions considered, when the waves are from the direction of the foundation. The lower semisubmersible accessibility is likely due to the heave response of the foundation. This increases the relative vertical motion of the vessel and foundation, leading to increased slipping of the CTV fender against the landing area. As shown, the TLP has accessibility very similar to that of the fixed foundation, which is likely due to the limited heave motion of TLPs.

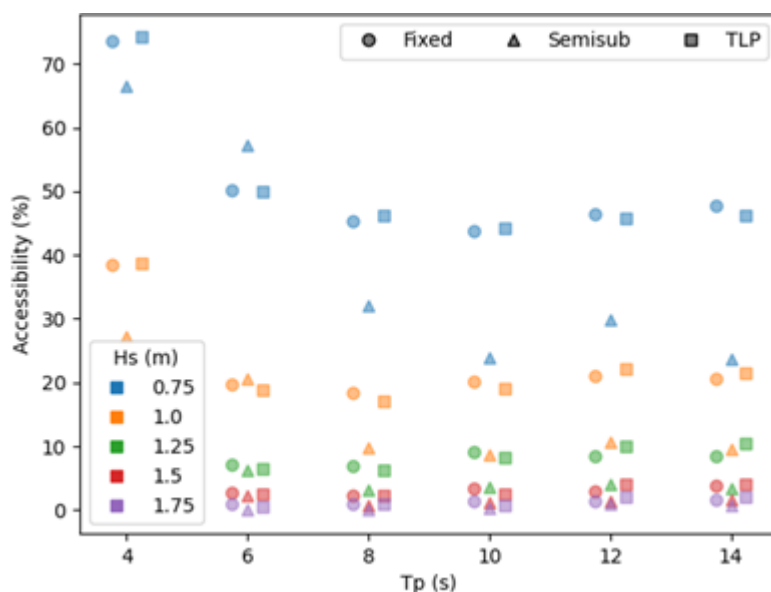


Figure i: comparison of accessibility by CTV for the three foundations considered, waves coming from the foundation.

Access by SOV is more similar across the foundation types considered, shown in Figure ii. With the correct wave orientation, all foundations can be accessed in seas up to 2.5m H_s , with contact between the gangway tip and the foundation maintained for 100% of the three hour simulation duration. This result suggests that the 2.5m upper limit usually stated for SOV access may be conservative, and access over this may be possible.

The wave conditions had a significant effect on access. If the vessel is not aligned during the wind and waves during the transfer process, there is a severe drop in accessibility: contact between the

gangway tip and landing area can drop from 100% to 0% if the vessel is not aligned. This result highlights the significance of a large number of access points, as even a change in wave heading of 45° can cause a reduction in accessibility by over 90%.

The wave period also affects access by SOV, particularly at higher H_s , where lower T_p sea states lead to lower access. This effect is especially pronounced for the semisubmersible foundation. This may be due to the increased demand that the lower T_p wave conditions create for the DP system: it is more challenging to maintain station when the vessel is pushed away more frequently. Maintaining station against the semisubmersible is an additional challenge, as both the vessel and the foundation are moving, potentially in opposite directions. This may be exacerbated by the DP control implemented here, which assumes that the vessel is reactive to the foundation position, and trying to catch up, whereas a DP control, which anticipates the foundation movement, may be able to perform better.

Overall, the analysis performed in this work package suggests that access to FOWTs may be reduced compared to fixed foundations, but will depend on the foundation design and the access method. For instance, the SOV with W2W (the most likely access method for FOWTs) is very similar for the FOWTs considered and the bottom fixed foundation, apart from at low T_p .

Additionally, the analysis has suggested that the industry would benefit from a standard way to assess access. The limits applied in this analysis are based on inspection of the physical nature of the transfer process but are not necessarily the limits which are applied in practice. Guidance on allowable nacelle motions for helicopter access would allow incorporation of access into the design process for floating wind turbines.

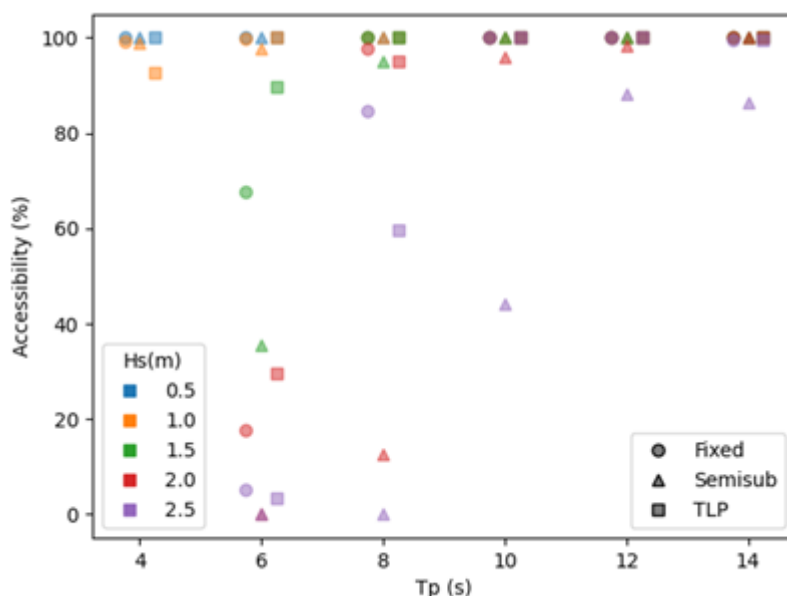


Figure ii: Access to foundations using SOV with W2W, waves from behind vessel.

WP4: Analysis of FOW Site Conditions and KPIs

This work package focused on modelling the impact of different weather limits at two different sites using the internal Combined Operations and Maintenance, People, Assets, and Systems Simulation (COMPASS) tool. Five different case studies were run for each site to illustrate the impact of turbine design and weather limits on access. These are shown in Table i.

Table 1: Case Studies

Case Study	Title	Weather Limits	Description
1	No Weather Limits	None	Transfer and transit were not limited in any weather conditions
2	Significant Wave Height Only	Hs Only	Transfer was limited to 2.5m Hs Transit was limited to 4m Hs
3	Fixed-Bottom Turbines	Hs and Tp	Hs and Tp access limits based on WP3 fixed-bottom modelling
4	Semisubmersible Turbines	Hs and Tp	Hs and Tp access limits based on WP3 semisubmersible modelling
5	Tension Leg Platform (TLP)	Hs and Tp	Hs and Tp access limits based on WP3 TLP modelling

Focusing on KPIs, including time-based availability and weather days, results pointed to the following weather planning and floater design recommendations:

Wave period should be considered when determining transferable weather windows.

Previous work for weather planning largely focuses on Hs as the limiting weather condition. Throughout the case studies, Tp was shown to further limit access, increasing weather days and decreasing annual transfers when considered alongside Hs.

Substructure motion negatively impacts accessibility.

Seen clearly in the differences between semisubmersible and TLP case studies, there is a direct correlation between turbine motion and decreased accessibility. Semisubmersible case studies consistently had more weather days, fewest transfers, and lowest accessibility of the case studies. However, TLP case studies had similar results to fixed-bottom turbines. These results suggest that designs that minimise motion will have greater accessibility, resulting in more working days and faster maintenance schedules.

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NOMENCLATURE

CAA	Civil Aviation Authority
CoE	Centre of Excellence
COMPASS	Combined Operations and Maintenance, People, Assets, and Systems Simulation
CTV	Crew Transfer Vessel
DC	Daughter Craft
DOF	Degrees of Freedom
DP	Dynamic Positioning
FOW	Floating Offshore Wind
FOWF	Floating Offshore Wind Farm
FOWT	Floating Offshore Wind Turbine
GUS	Get up Safe
Hs	Significant Wave Height
HV	High Voltage
KPI	Key Performance Indicator
LOLER	Lifting Operations and Lifting Equipment Regulations
MCGA	Maritime and Coastguard Agency
MSL	Mean Sea Level
NREL	National Renewable Energy Laboratory
O&G	Oil and Gas
O&M	Operations and Maintenance
PID	Proportional-Integral-Derivative

RAO	Response Amplitude Operator
SES	Surface Effect Ship
SOV	Service Operation Vessel
SWATH	Small Waterplane Area Twin Hull
TLP	Tension Leg Platform
Tp	Wave Peak Period
Uw	Wind Speed
VMC	Visual Meteorological Conditions
W2W	Walk-to-Work
WP	Work Package
WTG	Wind Turbine Generator

1 INTRODUCTION

The ability to access floating offshore wind turbines (FOWTs) is crucial for an effective operations and maintenance (O&M) phase of any future floating offshore wind farm (FOWF). It's suggested that 80% accessibility is required to achieve a wind farm availability above 90% [3]. This report is the collected work for COM02: Floating Offshore Wind Access Strategies and Considerations, which furthers understanding of access for FOWT and derisks specific methodologies.

Access for FOWTs is considered by operators to be more challenging than for fixed bottom turbines. Some of the reasons for this are:

- Lack of understanding of the effects of significant wave height and sea state, including direction and intensity for floating wind sites.
- Vessel / floater interface, and how landing location and are considered during design and construction phases.
- Number of components requiring maintenance: with floating wind, there are several designs that may require more maintenance activities.
- Proportion of planned and unplanned maintenance activities tending toward unplanned activities.
- Lack of industry standardisation for turbine access and the implications for training and new designs.
- Additional requirements and logistical challenges for emergency response activities.

This report is the collection of work split into three work packages (WP) and is split into sections by WP. First is a review of current access methodologies, covering crew transfer vessels (CTV), service operation vessels (SOV) with both daughter crafts (DC) and walk-to-work (W2W) gangways, and helicopter access. Section 3 covers OrcaFlex modelling including methodology, assessment of each access method, and a discussion around each. This information informs Section 4, which performs logistical modelling for 5 case studies to identify the impact of varying weather limits on key performance indicators (KPIs). Section 5 identifies key results from the study, including recommendations for further work.

2 REVIEW OF CURRENT ACCESS METHODOLOGIES

Stakeholder engagement and a literature review was performed to better understand concerns surrounding the four access methods.

Information from participants was gathered via semi-structured interviews. In addition to interviews, 2 companies also completed questionnaires on the same topics. ORE Catapult would like to acknowledge and thank all those who participated in individual interviews, recorded in Table 1.

Table 1: Interviewed Industry Stakeholders

Company	Representatives	Expertise Area
Health and Safety Executive	Paul Young, Jane Gordoio	Regulatory Body
Pict Offshore	Philip Taylor	Technology Developer
Ampelmann	Lorenz Nehring, Maichel VanNauta Lemke	Walk to Work Designer and Supplier
Deutsche Windtechnik	Sebastian Guse	Maintenance Service Provider
ORE Catapult	Katharine York	O&M Centre of Excellence manager
Total Energies	Guillaume Clement, Alexis Benhamou, Antoine Hillion	Offshore Wind Developer
Maritime and Coastguard Agency	Pete Lowson	Regulatory Body
SSE – Dogger Bank	Marcus Booth, Rachel Lawrence	Offshore Wind Developer
BP	Matt Bramwell	Offshore Wind Developer
Tidal Transit	Leo Hambro	CTV Operator and Supplier
Aventus Energy	Allan Mackenzie, Ross Thomson, Stuart Paterson	Maintenance Service Provider
Marine Power Systems	John Chapman, Graham Foster, Sebastian Merivale-Perry	Substructure Designers

2.1 Small Vessel Access (CTV and DC)

Crew transfer vessels (CTV) and daughter crafts (DC) are smaller vessels that provide faster transit compared to SOV access. CTVs transfer daily from port to site, while DCs transfer from an SOV ‘mothership.’

2.1.1 Method description

These vessels typically have a rubberised fender at their bow, and a stable connection with the foundation is created by “pushing on” – driving the vessel into a landing area consisting of two vertical steel tubes.



Figure 1: Crew Transfer Vessel Push on Process [3]

The thrust creates a friction force between the specialised fender, shown in Figure 2, and the landing bumper. Technicians can then step to the transition piece and climb the ladder to access the turbine. The connection only remains stable while the friction force is stronger than the shear forces caused by vessel motion due to irregular waves and wind. The window of fender stability, or when the friction force is stronger, allows for technicians to cross. The force used to push on typically ranges from 75% -80% of the maximum vessel power, and the vessel best maintains contact when the vessel is orientated perpendicular to the two landing bumpers. A review of publicly available videos suggests that the minimum window period is seven seconds [4]. Total transfer time for a team is about 10 minutes, not counting moving material or supplies.



Figure 2: CTV Fender Shape [5]

Due to difference in size between these vessels, there will be different landing area arrangements and requirements. Therefore, considering them as interchangeable on the same turbine without

considering vessel size may lead to difficulties in maintaining contact. There are also some concerns regarding DC use for floating wind, as DC have generally stricter weather restrictions and floating wind being located in harsher sea conditions.

2.1.2 Accessibility Considerations

The expected use of CTV and DC varies for floating offshore wind, largely determinant on the location of the wind farm. It's expected that closer to shore farms may still utilise CTVs, while far from shore turbines will minimise their use due to large transit time required. It is also assumed that CTVs are larger than their DC counterparts, so will have less strict weather limits for safe transfer.

While exact figures will vary based on vessel design, generic values for transfer operation parameters for CTV and DC are recorded in Table 2, and discussed in more detail below.

Table 2: CTV and DC parameters

Limitation	Crew Transfer Vessels	Daughter Craft Vessels	Comments
Significant wave height (Hs) for transfer (m)	1.2-1.5	1.2-1.3	
Max vessel speed (knots)	15-25 [6]	20+ [7]	
Time allowed offshore	1 shift	2-3 weeks	The DC allotted time is in relation to staying on an SOV
Distance allowed from O&M base (km)	30	110 (60 nm) from SOV or nearest port	The CTV allowable distance based on regulations is 60 nautical miles, or about 110 km. The value here is informed based on estimated actual-use limits.
Effective working hours (hours)	Location Dependent	10	
Personnel (#)	12-24	12	
Day Rate (£)	2,000 [8]	430	DC rate not inclusive of SOV costs

Sea Conditions

The significant wave height limit will vary for each vessel and angle to the waves. The direction of sea conditions impacts the vessel's ability to maintain contact, with environmental forces on the vessel beam making it more difficult to maintain the required push-on force at the landing area. Several stakeholders with in-field experience noted that there is often a discrepancy between stated wave limits and actual wave limits. As an example, for vessels where 1.5m was the accepted Hs limit, transfers were only able to be carried out in conditions closer to 1.1-1.2 m and was largely dependent on the location of the vessel landing. The highest transfer limit shared by respondents was a 2m significant wave height. Newer builds are expected to achieve higher transfer limits. There

is also anecdotal evidence suggesting transfer off a turbine back onto a vessel is slightly higher than transfer from the vessel onto the turbine.

There was little understanding or discussion regarding effects of sea conditions outside of significant wave height, such as wave period. The impact of wave period is discussed in depth in Sections 3 and 4.

The response of the floating wind turbine to the environment will introduce relative motion between the vessel and landing area, the effects of which on accessibility are not well understood. Stakeholders had a wide array of expectations. Some suggest the movement of the landing platform alongside the vessel will help minimise slip occurrences, though disconnection due to the wave period effects is still a risk. Others have noted that out of phase heave motion between the vessel and the turbine may further limit access.

Transit Time to Site

The time and operatable distance allowed from port is a limitation emphasised by operators for CTV use. While regulations allow CTVs to travel up to 60 nautical miles from port, stakeholder engagement suggested that in practice it is closer to 16 nautical miles (30 km) to avoid long transit times and fewer working hours. From stakeholder engagement, the maximum transit time for CTVs is 1.5 hours, up to 2 hours if absolutely necessary. Daughter crafts are able to work farther offshore, as they are launched from the SOV parent craft situated in the wind farm.

The longer the transit time, the fewer the working hours, or hours spent carrying out maintenance tasks. Assuming a 12 hour shift, DCs will consistently have about 10 hours of working hours due to their relative location to turbines. By comparison, the working hours provided by CTVs could be 8 hours or less, depending on the transit distance and vessel speed. Transit by CTVs may also lead to longer shifts for technicians if there is difficulty returning to port due to inclement weather or mechanical difficulty. An additional concern of long transit times is expediting technician burnout and exhaustion. Increased transit times directly correlate to sea sickness and fatigue.

Vessel Size and Design

DCs are smaller vessels and are expected to be used in calmer sea conditions than CTVs, though there will be variation in design. This results in a lower availability for DC, estimated by one respondent to be about half of CTV availability in harsh seas. Size also impacts the personnel and equipment that can be carried. DCs will likely be more limited in personnel and equipment that can be transferred.

CTVs are generally larger and able to transfer more personnel, allowing multiple teams to transfer during the same transit. However, there are safety-related limits on how many teams can be supported by one vessel. Specifically for floating wind, because of the distance between turbines, this is anticipated to be limited to 2-3 teams per CTV.

Vessel design will also impact accessibility and transit limitations. Modifications to hull design, such as surface effect ships (SES) or small waterplane area twin hull (SWATH), are known to have higher vessel speeds and limit the impact of swell waves and harsher sea states [9]. However, these vessels are untested in FOW, so there is a lack of current expertise on floating-specific use.

Regulation

Regulations currently in place for fixed wind are the baseline for forming regulations surrounding floating wind access. G+, the Global Offshore Wind Health and Safety Organisation, provides best

practice guides that outline the responsibilities of offshore personnel, safety concerns, and required training for CTV transfer. Guidance emphasises the importance of safety in transfer for all personnel, including their ability to refuse a transfer if they view the conditions as unsafe [10]. Each farm should have clear guidelines for transfer, with additional precautions in place to account for the lack of experience surrounding floating wind access.

2.2 Service Operation Vessel with Walk-to-Work System

SOVs are designed for long term offshore use. Fully equipped to house 50-100 people, SOVs are widely used to provide an offshore base for both offshore wind and O&G industries. SOVs can be used for technician transfer using either DCs or a W2W gangway. This method is the most likely option for widespread use in floating wind, especially for large scale farms situated farther from shore.

2.2.1 Method Description

The W2W system, shown in Figure 3, is secured onto an SOV, and is equipped with motion compensation to maintain connection (further details of motion compensation are discussed in Section 3.3.1). The gangway provides a secure walkway to allow technicians to walk from the vessel onto the turbine substructure. The vessel should be positioned in a drift off position from the wind turbine, and should face the wave direction as this allows for best control and stability. The dynamic positioning (DP) system applies directional thrust to the vessel at different points to correctly position the vessel.



Figure 3: Walk-to-Work Gangway reaching to a floating turbine, courtesy of Ampelmann

Once positioned, the gangway is then pushed out to the access point on the turbine substructure. Once attached, the gangway remains connected through friction force. The most common gangways employ the three DoF design where the gangway is made up of three moving parts: a slewing pedestal, a luffing hinge and an extending walkway, shown in Figure 4.

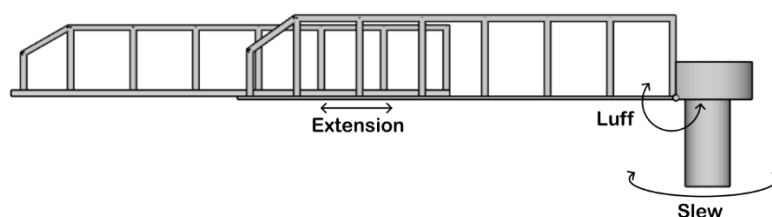


Figure 4: Most common W2W gangway design (compensating for three DoF)

Once a connection is made, the gangway attempts to maintain a 1-tonne push-on force against the foundation through the motion response systems.

2.2.2 Accessibility Considerations

Access by W2W is not possible if the gangway cannot be attached, or the relative motion between the vessel and landing area is too great to be compensated for, leading to automatic gangway disconnection. There is a wide variety in system design and limitations, and general assumptions for W2W accessibility limits are listed in Table 3.

Table 3: SOV with W2W Limitations

Limit	Value	Comments
Significant wave height (H_s) for transfer (m)	2.2-3.0	Will vary based on design and motion compensation capabilities
Max vessel speed (knots)	12-15	
Time allowed offshore (weeks)	2-4	
Effective working hours (hours)	10	Time for a single shift
Personnel (#)	50	Can be higher, but up to 50 wind farm workers
Day Rate (£)	30,000 [11]	Does not include fuel costs, from 2019 estimations

Sea Conditions

During engagement with external stakeholders, it was highlighted that for floating wind, long period swells will have a significant impact on accessibility, and may be a more limiting parameter than significant wave height in certain environments. This is due to a 10 metre separation requirement between vessel and turbine, meaning that the two moving bodies could be out of phase (they will be affected by waves at different timings) in heave. Out of phase heave motion has a significant impact on accessibility even in small significant wave heights, as the motion results in a larger total displacement between the foundation and vessel. This relative motion is a key issue when it comes to considering access for floating wind.

As well as the movement of the gangway connection point, vessels need to also compensate for the horizontal motion of the floating wind turbine. This is done by the DP system on the vessel, and station-holding is already required for fixed bottom transfer. However, stakeholders expressed concern that tracking the motion of a floating wind turbine may require substantial forces, at or

beyond the limits of many current DP systems. This will be particularly true for situations with high wind speed, with one operator stating they currently have a wind limit of 15 m/s for some headings. This concern was amplified in the push towards greener fuels and electric-based propulsion systems on future vessels which may reduce the available DP power.

The 3.5m significant wave height limit is the highest end of the estimations provided, and requires strong motion compensation capabilities. More conservative wave limitations reduce to 2.1-2.3 significant wave height. The highest significant wave height limit shared during engagement was 4m, though this was with the right current and low wind, and isn't expected to be a regular limitation. Anticipating sea conditions from forecasts is key to maintenance planning.

Time Offshore

SOV are also able to remain offshore for 2-4 weeks at a time. This allows them to work farther distances for longer periods of time, returning to port for a day to change crew, refuel, and restock every fortnight.

Regulation

A common concern is the lack of regulation and standardisation for gangway use in floating wind. As floating turbines begin to be built in large-scale farms, standard access designs would ease transfer and provide more consistency for technicians. This is true across all access methods, but is most necessary for W2W systems, as the gangway size and reach, and access point design require specific vessel and gangway design requirements. Lack of regulation is a safety risk for technicians and vessel workers.

As different companies develop internal standards and safety procedures, there is no industry standard method of sharing lessons learned to prevent accidents from reoccurring. In the same vein, lack of external oversight may lead to further issues, as standards introduced after manufacturing may limit health and safety implementations.

2.3 Helicopter Access

The expected use of helicopters for floating wind access varies most widely across the four considered access methods. When used in regular transfer, helicopters are limited to transfer only when an alternative transfer method, often W2W gangways, are also able to carry out transfers to prevent situations where technicians become stranded. While they are not expected for standard transfers, their use has been mostly been suggested for transferring personnel to SOV vessels and for emergency rescue.

2.3.1 Method description

The current method for helicopter transfer in fixed wind is to winch the technician down from the helicopter onto a landing area on the top of the turbine. Historically, this has allowed for access in otherwise inaccessible sea states and hasn't been used as a primary form of transfer due to the high costs associated with their use [12]. There are concerns regarding the use of an identical winching method for floating wind, due to the anticipated motion at the top of the turbine. Hywind, with SPAR floating turbines, has carried out winch transfers onto the nacelle in a test flight [13]. However, several developers suggest hoisting for floating wind to be carried out onto the substructure (for semi-submersible designs) or onto an SOV landing platform and technicians transferred via a DC or W2W gangway from there.

During heli-hoist operations, the nacelle is first rotated such that the blades are in-line with the wind direction [14]. The helicopter then approaches the nacelle from the downwind direction. This is to provide additional control to maintain position against the moving air. The helicopter must maintain a relative velocity and this is easiest in the forward direction. When in the hoist position, the helicopter must remain above the hoisting area. To mitigate the risk of collision between the turbine and the helicopter, a distance of at least 5m must be kept between the helicopter rotor and the turbine blades, see Figure 5 [14]. The technician is then safely lowered onto the hoisting area. This area should have a tilt of less than 2% (1.1°) and should have a minimum area of 4m x 4m [14]. A representation of the required landing area dimensions are provided in Figure 6.

As the guidance is based upon fixed wind turbines, no consideration of heli-hoist area motion is provided in the guidance. However, guidance does exist for heli-hoisting onto vessels [15]. The guidance suggests vessel motion limits of no more than 5° in roll and pitch, that the amplitude of the heave motion should not exceed 5m and 1.5 m/s velocity.

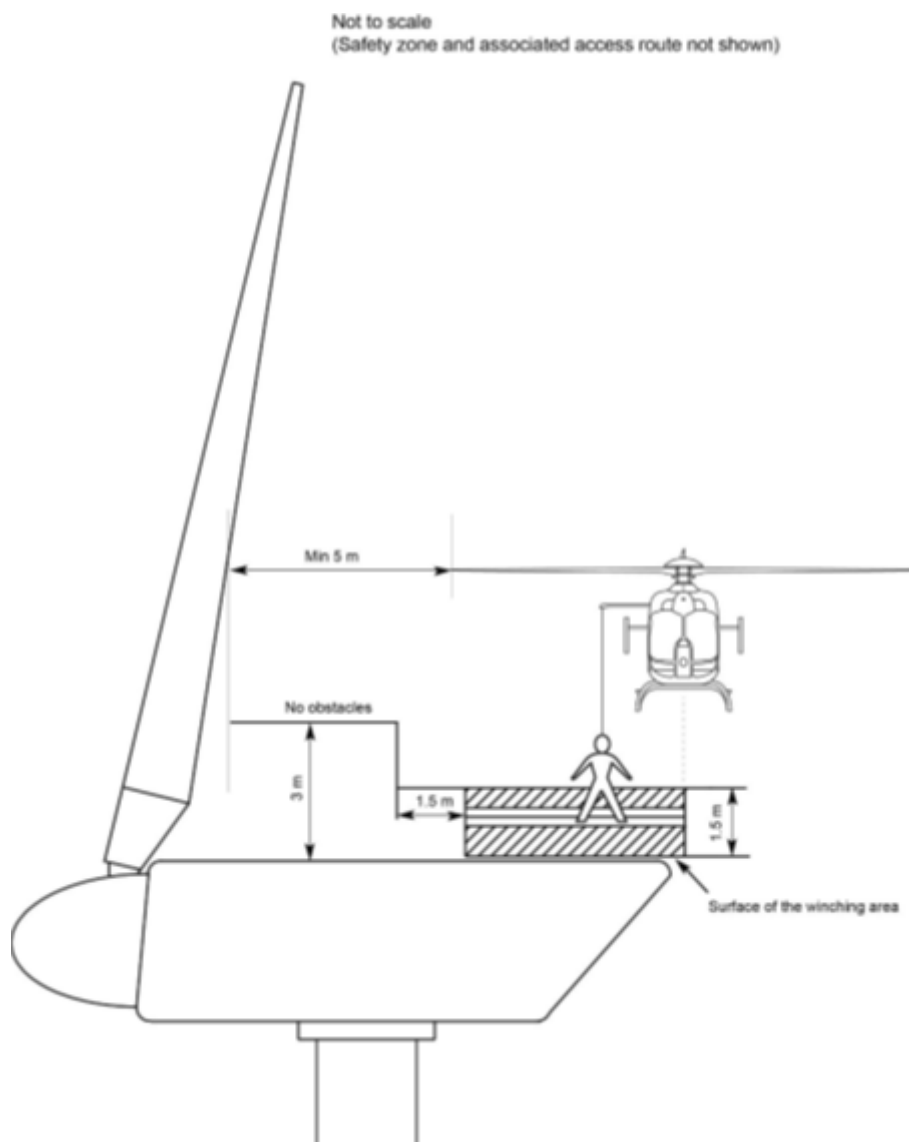


Figure 5: Orientation of wind turbine nacelle and helicopter [14]

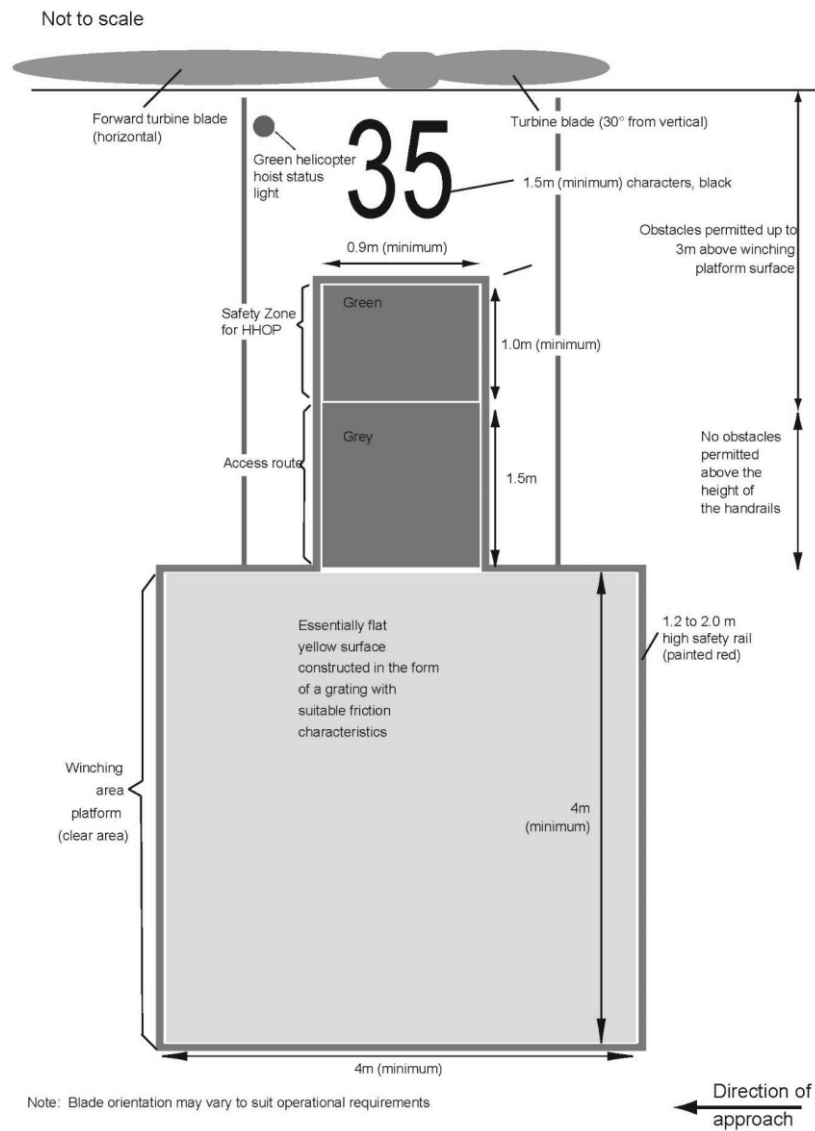


Figure 6: Design of heli-hoist area on top of nacelle [14]

2.3.2 Accessibility Considerations

The different character of helicopter access compared to vessels leads to different considerations for its use in technician transfer, as shown in Table 4.

Table 4: Accessibility Limits for Helicopters

Limit Type	Value	Comments
Wind Speed (knots)	30-50	Limit for transit, not hoisting
Helicopter Speed (km/h)	260	
Personnel (pax)	2-6	
Cost	£200,000 per annum for 450 MW wind farm [12]	Defined in ORE Guide to a Floating Offshore Wind Farm, 2019

Weather limits

Current transit weather limits for helicopters are solely wind based, with larger helicopters able to fly in stronger winds. The workable weather conditions are therefore higher than SOVs with W2W systems, and significantly higher than daughter crafts and CTVs. However, weather conditions such as fog or rain will significantly limit helicopter use. This is due to ICAO Annex 2 requirements for hoist operations. These specify that flights below 914 metres should only be conducted during daylight in Visual Meteorological Conditions (VMC) [16]. That is, clear visibility is necessary to carry out hoist operations.

For transfer onto floating wind turbines or SOVs in the field, wave conditions will affect landing area motion. This is likely to be different for different substructure and vessel designs. It is difficult to determine definitive wave conditions for technician transfer, as this will likely be determined on a wind farm and helicopter operator specific basis.

Transfer onto Substructure

To expand helicopter use, hoist systems onto the substructure of the turbine was suggested. This would work for semi-submersible designs, or designs with a large area that can be changed into a landing platform as per regulations.

A landing area on the substructure would allow for larger helicopters to be used, as the rotor size would not be limited to maintain a proper distance between the turbine rotors and helicopter rotors. This will be beneficial as turbines move farther from shore, requiring helicopters to be able to travel further.

Capacity

In contrast to CTVs and SOVs, helicopters are significantly limited in the payload that they can carry. As a result, stakeholders did not think that helicopters are a financially viable option for routine maintenance. However, the speed is situationally beneficial, such as when small teams or individuals need to be transferred from an SOV to shore faster than the next planned port return. These situations include the need for a technician with specific expertise for necessary maintenance, or for transporting back individuals for bereavement or similar family emergencies.

2.3.3 Regulations

Regulations play a large role in helicopter usage, from landings both on vessels and on turbines, to required safety procedures and planning. For winching onto turbine platforms, CAP 764 provides Civil

Aviation Authority (CAA) policy and guidelines, and chapter 10 of Standards for Offshore Helicopter Landing Areas by the UK CAA [14] outlines the necessary pieces of winching areas.

For transfer onto an SOV, either by landing the helicopter onto a helipad or through lowering technicians using the winch method, regulations such as CAP 427 [14] should be followed. These detail the requirements and best practices for the landing area, including size, markings, and necessary lighting.

Future consideration may include airspace restrictions, especially as seas become busier with larger farms and shared sea space. Health and safety training and certification should be updated, and accidents reported and adjusted for any additional risks and transfer issues.

2.4 Safety and Human Factors

The safety of technicians is at the forefront of access planning. This section reviews motion sickness and transfer safety for different methods, and emergency evacuation planning.

2.4.1 Motion Sickness and Offshore Conditions

It was widely noted that CTV transfers can be arduous, especially in inclement weather. This can result in fatigue and motion sickness, and are often exacerbated during long working periods. For short term effects, technicians are able to recover either onshore or on the turbine. To combat long term fatigue, an interviewee discussed changing to a 2 week rotation from a 3 week rotation.

The time of year also impacts fatigue, especially for CTV transfers. In the calmer summer months, transits are less tiring, but there are fewer weather days, increasing the likelihood of transiting every day during a shift. Alternatively, in the autumn and winter, there are likely to be more weather days, allowing for more rest. However, there will be marginal days when technicians will go to sea, but will be called off midway through the transit. These occurrences are particularly costly, as not only has no work been achieved, but also the technicians will be significantly fatigued.

For SOVs, there is concern regarding longer working hours. Working at or close to working limits may increase technician and tool exhaustion, leading to mistakes. Shift pattern also impacts productivity. With offshore campaigns lasting from 2-4 weeks with 12 hour shifts, there is anecdotal evidence that there is variation in productivity based on the time within the campaign. One developer explained that they aim to not have entire crew changeovers at once every 2 weeks, aiming instead for a 50/50 split to improve handovers and better maintain knowledge of current tasks and issues.

Additionally, there is a lack of technician training for offshore living. Most are unaccustomed to living and working offshore. Additional training would allow for better understanding of offshore living expectations.

Motion sickness is covered more in-depth in the report “The Technician’s Perspective,” published alongside this report.

2.4.2 Safety During Transfers

CTV and DC transfers require a step onto the ladder from the vessel, which inherently carries some risk. As such, each transfer relies (to some extent) on the technician’s confidence and ability. Each technician is also allowed to refuse a transfer they believe unsafe. Anecdotally, it was suggested that a technician will be less confident at the start of their career, but that competence is quickly gained over a dozen or so transfers. A reacquaintance with the method is also required at the start of the

summer season for technicians who have not worked on CTVs over the winter months, with some stakeholders suggesting there are more safety incidents in this transition period.

Similarly, engagement noted that technicians with different previous experience have different approaches to W2W access. New SOV and gangway designs have a learning curve that even experienced mariners require time to adjust to, requiring slightly longer times to connect and transfer during the learning period. However, there is anecdotal evidence suggesting that technicians may not be as actively aware of their surroundings, leading to accidents. This is likely from the feeling of safety provided from an enclosed, highly-engineered space.

2.4.3 Emergency Evacuation

Floating wind farms should have a clear plan of transferring off turbines in case of emergency evacuation, incoming weather, and for casualty movement to vessels. Two types of emergency responses should be prepared for in the planning phases: escape and evacuation. Escape is only done when evacuation is not possible and the technicians cannot safely wait on the turbine. Escape uses descenders and life rafts to leave the turbine, where search-and-rescue is then carried out. Search and rescue activities are easier to be carried out with helicopters rather than vessels.

Emergency evacuation should be first attempted using the vessel used for the initial transfer. To ensure timely transfers, vessels should remain within 30-60 minutes of transit time to any turbine with technicians. CTV and DC are able to transit at higher speeds, potentially allowing for faster response times. Transferring of casualties or those unable to descend the ladder requires a winch system to manually lower the worker onto the deck, in which case, stability of the vessel is key, where motion between vessel and turbine should be carefully monitored to ensure safe transfer and avoid collision with the deck.

Evacuation using W2W gangways, assuming that connection can occur, are easier for transferring casualties or people unable to transfer themselves, as it is a mostly horizontal transfer from the turbine substructure back to the vessel, especially true when the gangway is equipped with a lift. Additionally, SOVs have the distinct benefit of having med bays on the vessel, allowing for medical intervention on-site. There have been a small number of situations where the necessary medical intervention was more severe than the capabilities of the on-board medical team, in which case a helicopter was used to transfer from the SOV to an on-shore hospital.

Each farm operator should have a clear plan in case of emergency evacuation, incoming weather, and for casualty movement to vessels. Communication should be established with nearby offshore activities (such as nearby fixed wind or oil rigs) not run by the same operator in case of emergencies. It is also recommended for farm developers to have open communication with the Maritime and Coastguard Agency (MCGA) and helicopter providers early to discuss emergency processes.

Throughout all engagement, one stakeholder mentioned a situation where transfer off the foundation was not able to occur, and the turbine did not require evacuation. In this scenario, the technicians stayed on the turbine, using the 'blue barrels' equipped with necessary supplies to stay on the turbine overnight.

To further the safety of technicians, developing methods for sharing lessons learned across industry members should be prioritised. With no industry standard method, there is increased risk of reoccurring accidents. In the same vein, lack of external oversight may lead to further issues, as standards introduced after manufacturing may limit health and safety implementations.

2.5 Increasing Accessibility

Increasing accessibility is a vital part of ensuring consistent and reliable transferability. Methods for increasing accessibility for small vessels largely focus on securing the vessel, while W2W access focuses more on limiting the relative motion. While methods vary between access method, there are similarities, especially between small vessel and W2W access.

2.5.1 Vessel Specific Methods

Securing Small Vessels

To decrease the rate of disconnection between the landing platform and the small vessel, some developers have introduced a clamping mechanism to secure the vessel during transfers. This has currently only been implemented for fixed offshore wind use, increasing significant wave height limit to 2.7m [17]. This may be directly beneficial to floating wind in regards to counteracting the relative motion of the foundation and vessel, and maintaining contact in the harsher, far-from-shore sea states. In addition to increasing accessibility, technicians also report feeling safer during transfer when one is used. However, implementation in FOW may be more difficult because of the relative motion between the turbine and the vessel.

Electrification

As vessel designers push to reduce emissions, the switch to electric motors has unexpected benefits for CTV and DC accessibility. Electric motors have a faster response time due to the instant torque response compared to traditional diesel engines. This allows for electric systems to respond to forces faster and maintain contact in harsh conditions. As a result, automatic response systems are in development in order to minimise energy use during push-on. Such a system would track the grip of the fender, often in relation to the compression of the fender and vessel orientation, compensating for surge, sway, and yaw motions via automatic adjustments to thrust.

Motion Compensation and Dynamic Positioning (DP) Systems

The largest concern with increasing gangway capability is the increased safety risk if the telescoping velocity of the gangway is increased. There is a risk of technicians getting 'trapped' in the response, and the timing should be slow enough to minimise this risk, while fast enough to maintain contact. In current use for floating wind, there are no sensors 'seeing' turbine motion, meaning that all compensation of turbine motion is passive, while vessel motion is generally active.

Engagement has emphasised the importance of DP systems used in floating wind having a higher response capability than current offshore use, as there is an increase in severity in the case of DP failure and drift off scenarios for floating wind.

Development of W2W systems for floating wind are expected to require higher levels of motion compensation than systems currently in place for O&G and fixed wind. The current designs may not be able to be used because of different design and motion compensation requirements, especially in harsh conditions. Considerations for retrofitting SOV and older systems should include ensuring proper height requirements for access point reach, analysis of vessel use, and workability to optimise gangway positioning in relation to the vessel.

Technician Preference

Technicians will have a personal preference for transfer. This will vary based on experience, security, and experience offshore, as well as their onshore situation. Ultimately, the preference for CTV use

compared to SOV (either using a DC or W2W) will come down to individual technicians. Some are heavily opposed to long transit times, while others do not want to live offshore for long periods of time.

2.5.2 Shared Methods

Substructure Design

Substructure design directly impacts accessibility. Designs with less motion are preferred across all methods, especially for helicopter hoist methods.

Different substructure types have their typical motion responses to the ocean environment. Spar style substructures were noted by respondents as having low levels of heave motion, and stakeholders indicated that transfer onto a spar was similar to transfer onto a bottom fixed foundation. However, spar buoys were noted to yaw in certain conditions, meaning that there was a risk of the gangway tip slipping off due to this rotation.

Semisubmersible designs have higher levels of heave motion, particularly in long-period swell, complicating transfer due to the higher requirement for motion compensation. Additionally, some stakeholders expressed a view that workability (ability for technicians to carry out tasks) was the limiting factor, rather than access to the turbine itself.

Size also has an impact on accessibility across all substructure types. Larger turbines have a tendency for less movement due to their increased inertia, making the overall transfer more effective as less motion compensation is necessary. Larger sizes for semi-submersible designs will also potentially allow for more space for component transfer.

Multiple Access Points

Having multiple landing points was highlighted by several stakeholders to increase accessibility and allow for optimal vessel positioning in different sea headings. Adding multiple points is cheaper and requires significantly less steel for W2W access points compared to the landing platform and ladder required for CTV and DC use.

Landing location and Connector Shape

Developers and operators have pointed to the initial connection being the most difficult part of W2W access. Current standard practice for gangway connection is to have the vessel operator situate the SOV in position, then manually control the gangway to the 'push on' location, or to have the gangway push to a fixed point in space. Two methods have been introduced to minimise the risks associated with the status quo: target tracking and changing the connector shape from standard I-beams to increase grip retention. The latter would provide a guide at the connector point for easing the initial contact.

3 ASSESSING ACCESS THROUGH ORCAFLEX MODELLING

Three different access methods are explored using numerical modelling in the software OrcaFlex [18]. The study examines the impact of platform motion on the physical process of transferring human technicians and compares it with a stationary foundation. This provides quantitative estimates of accessibility for different FOW foundations.

3.1 Methodology

The approach uses OrcaFlex to model the different access methodologies described above. OrcaFlex is a leading software package used for the dynamic analysis of offshore marine systems [18]. For each access method, a recreation of the key structures is created within OrcaFlex and the motions of the structures due to different environmental loading conditions are compared against motion limits to assess the viability of transfer.

Three wind turbine foundation models were used: a bottom fixed turbine, the VolturnUS floating semisubmersible foundation, and a tension leg platform (TLP) provided by the TLP designer Marine Power Systems. Environmental conditions were determined through historical weather data analysis. To account for vessel responses, a Proportional-Integral-Derivative (PID) controller was written as a function within the simulation.

3.2 Assessment of helicopter access

For safe transfers, technicians must lower onto the nacelle landing area while the helicopter maintains a safe distance from turbine blades. The analysis for helicopter access focuses on nacelle motion to determine if a technician can safely be lowered onto the nacelle's landing area.

3.2.1 Accessibility assessment

To assess the accessibility of the nacelle from a helicopter, the motion of the nacelle is analysed. During the lowering operation, it is crucial to ensure that the landing area for the technician remains stable enough to prevent the technician from missing the landing area. Additionally, the helicopter must maintain a safe distance from the nacelle as defined by current standards [19].

Several key metrics are determined for each direction: X (horizontal in the direction of wind and waves), Y (horizontal perpendicular to wind and waves), and Z (vertical). These parameters are provided in Table 5.

Table 5: Key metrics for assessing the feasibility of Heli-hoist operations

Parameter	Description	Rationale
Max range	The maximum range in position that the nacelle reaches over the entire simulation	Indicates the footprint of the landing area
1 min rolling range	The difference between the maximum position and minimum position that the nacelle reaches during one minute	Indicates how much the nacelle landing area moves in a short time period – can indicate the likelihood of missing the landing area
Max Vel	The maximum velocity of the nacelle over the simulation period	Indicates how different from a stationary landing the operation will be.
RMS Vel	The root mean square velocity of the nacelle over the simulation period	Indicates how much the platform moves.

3.2.2 Effect of wave period on Floating Substructures

The results show that motion is predominantly in the X direction, with considerable movement in the Z direction for the semisubmersible foundation. The relationship between motion and significant wave height and peak wave period for these directions are explored in the following figures.

Semisubmersible

Semisubmersible nacelle motion was greatest in the X direction. At 2.5m Hs, the largest range of displacement in X is 8.16m, with a maximum velocity along X of 1.27m/s. There is also significant movement in the vertical direction, with a maximum range of 2.25m and a velocity of 0.54m/s.

Figure 7 shows the variation of the maximum nacelle displacement range in the X direction with different wave parameters. It can be seen that the greatest movement occurs at larger Hs and at Tp of 6s and 8s. A similar relationship is observed between the maximum nacelle velocity in the X direction and the wave parameters, see Figure 8, where there is a more pronounced peak of the X velocity at a wave peak period of 8s.

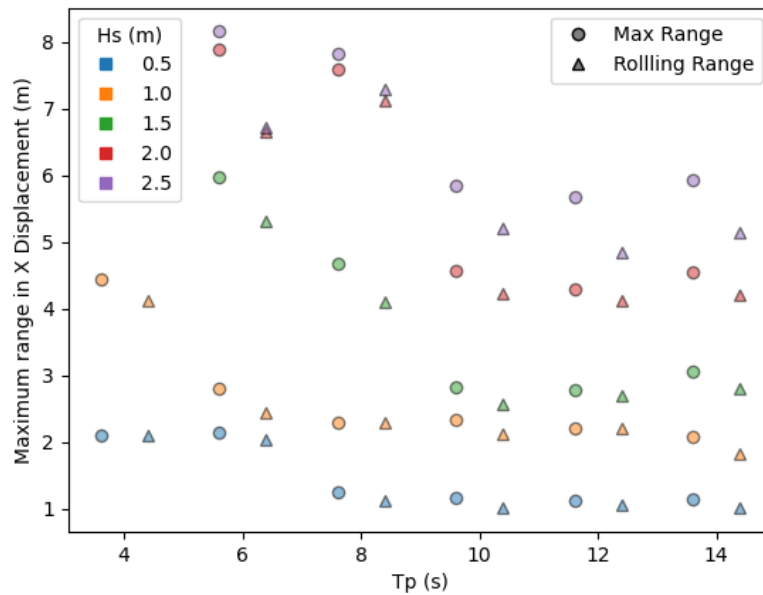


Figure 7: Maximum range and 1-min rolling range in X displacement of the nacelle for the semisubmersible

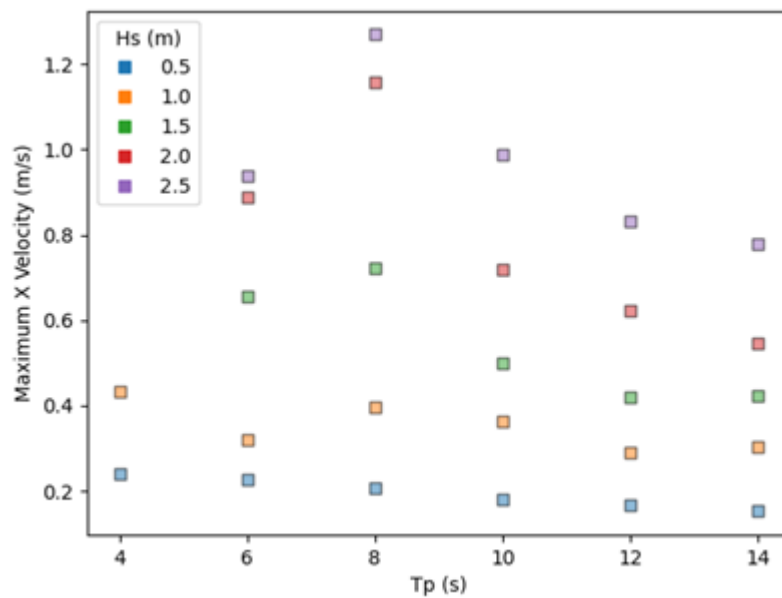


Figure 8: Maximum X velocity of the nacelle for the semisubmersible foundation

The summary statistics also indicate that the semisubmersible exhibits a significant motion in the vertical Z direction. The maximum Z displacement range for the wave characteristics is shown in Figure 9. Again, the Z range increases with increasing H_s but for this motion, there is also an increasing displacement range in Z with an increasing wave period. The relationship is also observed for the Z velocity of the nacelle.

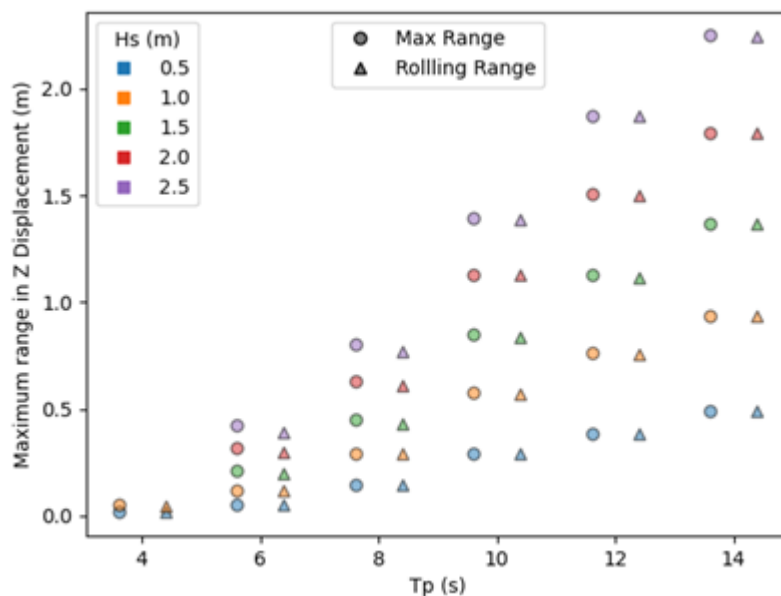


Figure 9: Maximum range and 1-min rolling range in Z displacement for the semisubmersible

TLP Foundation

TLP foundation motion was also greatest in the X direction, but is significantly more restrained than the semisubmersible, denoted by the maximum range of only 2.69m at HS 2.5m. Additionally, there is very little motion in the Z direction, with a maximum range of only 0.07m.

Figure 16 depicts the relationship of the wave characteristics with the maximum nacelle displacement in X for the TLP foundation. The range of motion increases as Hs and Tp increase, too.

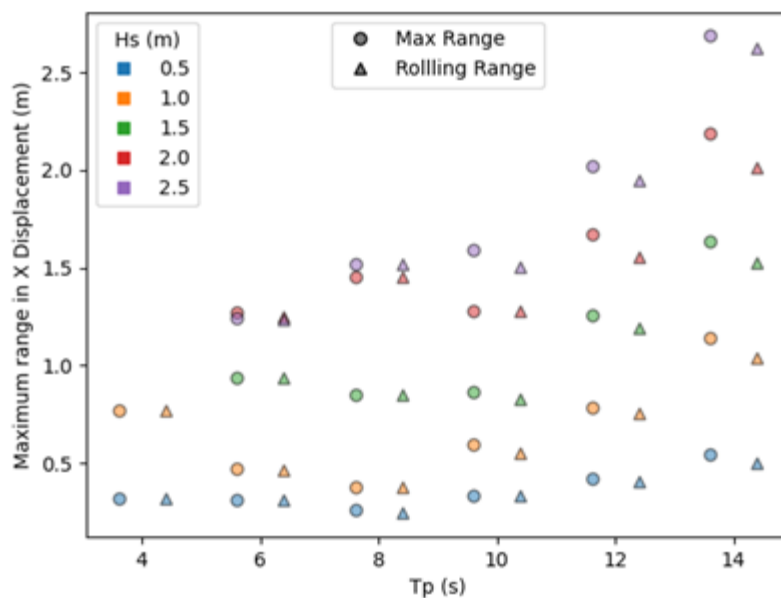


Figure 10: Maximum range and 1-min rolling range in X displacement of the nacelle for the TLP foundation

3.3 Assessment of CTV access

To assess CTV access, it is necessary to replicate the CTV push on process against a landing bumper. This is achieved in OrcaFlex using a combination of different objects and an external function (written in-house) which controls the propulsion and steering of the modelled vessel. A catamaran-hulled vessel with a specialised fender was used.

3.3.1 Calculation of the accessibility metric

A transfer can only occur when the bumper forms a stable connection with the landing area structure for longer than approximately seven seconds. To identify when this occurs, post processing of the fender motion is required. The time history of the vertical motion of the fender relative to the landing structure is extracted for each simulation. This time history is analysed to identify time windows when the fender remains within the pre-determined range for a period of longer than seven seconds. The cumulative duration of these windows is used to provide an approximation of accessibility.

3.3.2 Results

The CTV access results are presented in terms of average accessibility for a given H_s , T_p , wind speed and wind and wave direction relative to the vessel heading, where 0° is the waves approaching the vessel from the front, “a head sea”, and 180° is a “following sea”. The accessibility for each foundation is presented first, followed by a comparison of the three foundations for different H_s and T_p values.

Fixed Foundation

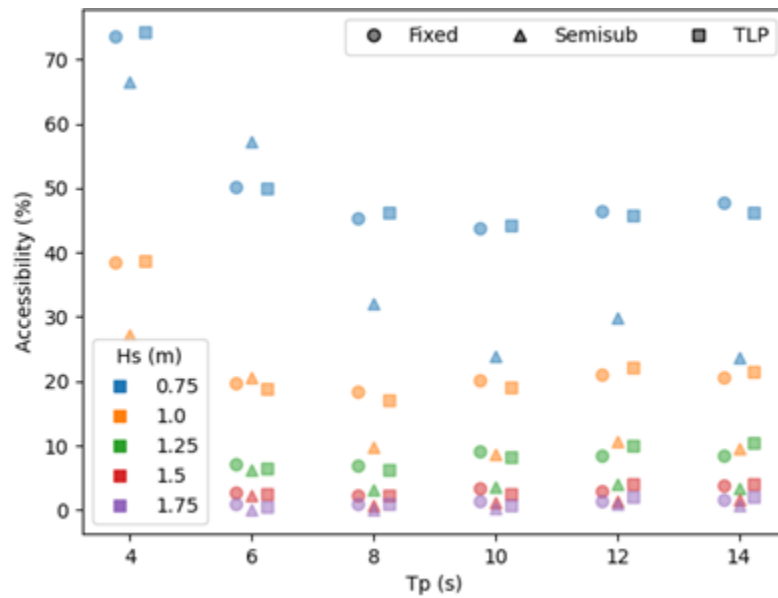
The accessibility for the fixed foundation displays a general decrease in accessibility as H_s increases and there is little variation with T_p .

Semisubmersible

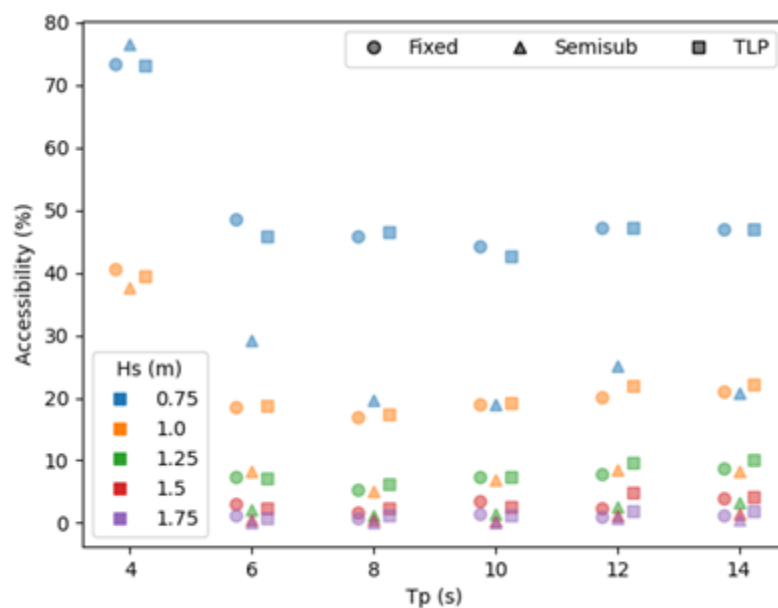
The average accessibility for the semisubmersible has a similar decrease in accessibility as for the fixed foundation. However, with the semisubmersible there is a significant variation with the T_p values – there is a noticeable reduction in access when moving from a T_p of 6s to a T_p of 8s and higher.

TLP

TLP foundations have a general reduction in accessibility can be observed with increasing T_p for wave directions which are not in line with the vessel heading (0° and 180°). A sharp drop in accessibility can be observed for a T_p of 14s at each H_s .



a) 0 ° wave direction



b) 180 ° wave direction

Figure 11: Comparison of the foundations average accessibility

3.4 Assessment of SOV & W2W Access

To model access from an SOV and a W2W gangway, it is necessary to capture the vessel response to the waves, the action of the vessel's DP system and the movement of the gangway as it connects the vessel to the turbine foundation. The vessel information, including W2W and DP capabilities, was supplied by a vessel owner.

In modelling, the DP system was implemented using a PID controller targeting the landing point on each foundation.

3.4.1 Accessibility Assessment

To assess the accessibility of the W2W gangway, the movement of the gangway is compared against the known limits. The time history of the 3 gangway elements – the slew, luff and extension – are extracted and analysed to identify time windows when all movements are within their limits. The minimum length of a required time window is assumed to be 30s. The cumulative duration of these windows is then compared against the total simulation time to provide an estimate of the accessibility for each simulation.

Additionally, for each simulation, the proportion of the different failure modes which contributes to the limits being exceeded can be compared. The length of time that the different limits are exceeded are summed over the simulation period, and a comparison between these lengths of time is provided by pie charts for each simulation.

3.4.2 Results

A comparison of accessibility across the three foundation types for wave directions at 0° and 180° are presented in Figure 12 and Figure 13, respectively. For each wave direction, the same general trend is observed of increasing accessibility with increasing T_p . Additionally, comparing the three foundations indicates that the semisubmersible foundation is consistently the least accessible. This is especially true when the wind and wave direction is 0° , where the TLP foundation is less accessible than the fixed one for several H_s and T_p combinations.

However, when the wave comes from behind the vessel, at 180° , there is less of a distinction between the accessibility of the TLP and fixed foundations. Instead, the accessibility of the TLP is in fact higher than of the fixed foundation at T_p of 6s and H_s over 1.5m, likely due to a shielding effect. The semisubmersible foundation remains less accessible than both the TLP and fixed ones in large H_s conditions.

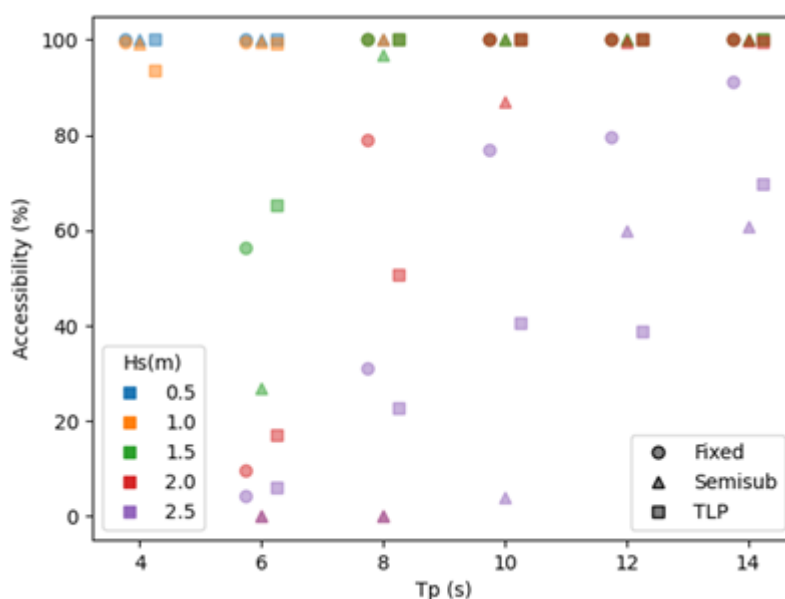


Figure 12: Comparison of accessibility across the three foundation types for wave directions at 0°

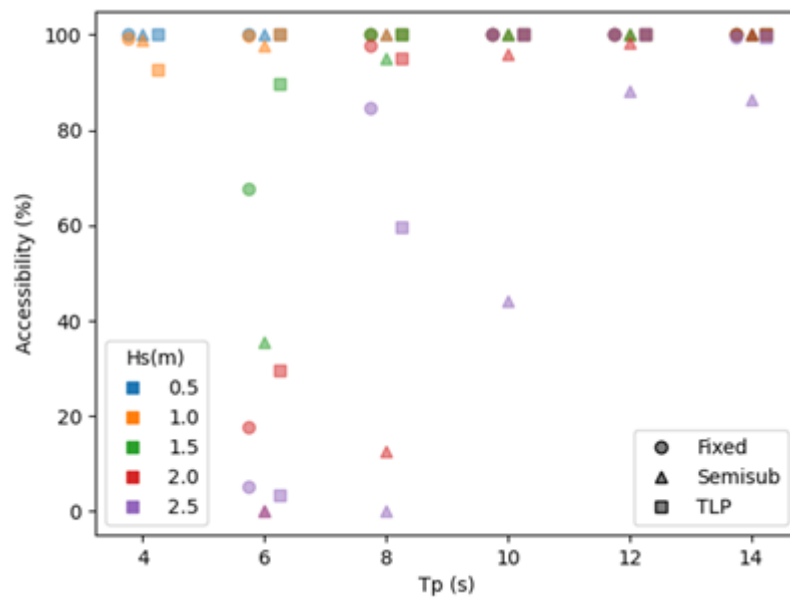


Figure 13: Comparison of accessibility across the three foundation types for wave directions at 180°

4 ANALYSIS OF FOW SITE CONDITIONS AND WIND FARM OPERATIONAL KPIS

To determine the impact on key performance indicators (KPIs) when T_p is considered, time-based logistical modelling was done for a variety of case studies. While previous work is often limited to significant wave height (H_s) to determine accessibility, modelling has shown the impacts of wave period (T_p) on accessibility.

4.1 Methodology

4.1.1 Setup

Logistical modelling utilised the Combined Operations and Maintenance, People, Assets, and Systems Simulation (COMPASS) internal tool. COMPASS uses the Monte-Carlo method to simulate turbine failures, and historic weather data to determine when maintenance can occur.

COMPASS utilises a defined wind farm, consisting of turbine locations, port, weather data, vessel data, and a maintenance task list to run simulations. For this study, each farm was made of 100 turbines, at two locations, shown in Figure 14.



Figure 14: Site and Port Location [20]

Broken into hourly time-steps, maintenance tasks are generated using the Monte-Carlo method, and completed when both a) the weather window is available for the entire task duration and b) a vessel is available for use. A single SOV vessel was used to carry out transfers. While running, the program then records key performance indicators including vessel usage and wind farm generation.

Maintenance activities consisted of 4.5 planned and 11.75 unplanned tasks per turbine per year.

4.1.2 Case Studies

Five case studies were performed for each site, described in Table 6. Each had identical farm layout and task lists, with only weather limit variation. The Hs and Tp limits were based on work described in Section 3, with paired limits rather than a set value for each.

Table 6: Case Studies

Case Study	Title	Weather Limits	Description
1	No Weather Limits	None	Transfer and transit were not limited in any weather conditions
2	Only Significant Wave Height	Hs Only	Transfer was limited to 2.5m Hs Transit was limited to 4m Hs
3	Fixed-Bottom Turbines	Hs and Tp	Hs and Tp access limits based on fixed-bottom lookup tables
4	Semisubmersible Turbines	Hs and Tp	Hs and Tp access limits based on semisubmersible lookup tables
5	Tension Leg Platform	Hs and Tp	Hs and Tp access limits based on TLP lookup tables

4.2 Results and Discussion

Each case study was run 50 times. Results were collected and analysed, focusing on 50th and 90th percentiles. The variation in weather delays, number of transfers, and availability between case studies is discussed here.

4.2.1 Wait on Weather

The wait on weather sums up all timesteps when transfer cannot occur. As the first case study (no weather limits) had no weather days, case study 2 (only Hs) was used for the baseline study. Compared to case study 2, a noticeable increase in delays can be found in case studies 3-5, as shown in Figure 15. North Scotland had more weather days for all case studies compared to the Celtic Sea.



Figure 15: Wait on Weather for North Scotland (top) and Celtic Sea (bottom)

For all three case studies using Tp, there is a noticeable increase in weather days. Case study 5 (TLP) has the lowest increase in weather days, between 47-51% for both sites. This was followed by case study 3 (fixed bottom), ranging from 53-54% for North Scotland and 63-64% for the Celtic Sea. Case study 5 (TLP) likely had the fewest weather days due to the slight motion allowing for accessibility in a different range of weather conditions compared to fixed and semisubmersible.

The two cases are still quite similar at the North Scotland site, likely due to the minimal motion TLP designs experience compared to other floating designs. However, the difference in the Celtic Sea, which has shorter average Tp, suggests that there is potential for TLP designs to be better equipped to handle access in conditions with a shorter average Tp.

Case study 4 (semisubmersible) had the most weather days, with an increase of 91% for North Scotland and 101% for the Celtic Sea compared to the baseline study. This increase in weather days at both sites indicates that the design of the platform will have a significant impact regardless of average sea conditions. This is due to the higher levels of motion semisubmersible designs have

compared to TLP. The added weather delays in relation to turbine motion point to an emphasis in motion mitigation for future designs to minimise weather delays.

Between the two sites, the increase in weather days compared to case study 2 is noticeably higher for Celtic Sea turbines compared to North Scotland. This was expected, as the Celtic Sea has a lower average wave period, and shorter wave periods limit transfer. Despite this, weather days were more frequent at the North Scotland site, largely attributed to the higher mean significant wave height.

4.2.2 Transfers

Illustrated in Figure 16, transfers mirror the weather days results. A transfer was counted for individuals, with teams of 2-4 based on task demand. Case study 4, focusing on semisubmersible FOWT, have the fewest transfers, and case studies 3 and 5 (fixed turbines and TLPs) have similar transfers. The horizontal lines indicate the transfers done in the 'no weather' conditions.

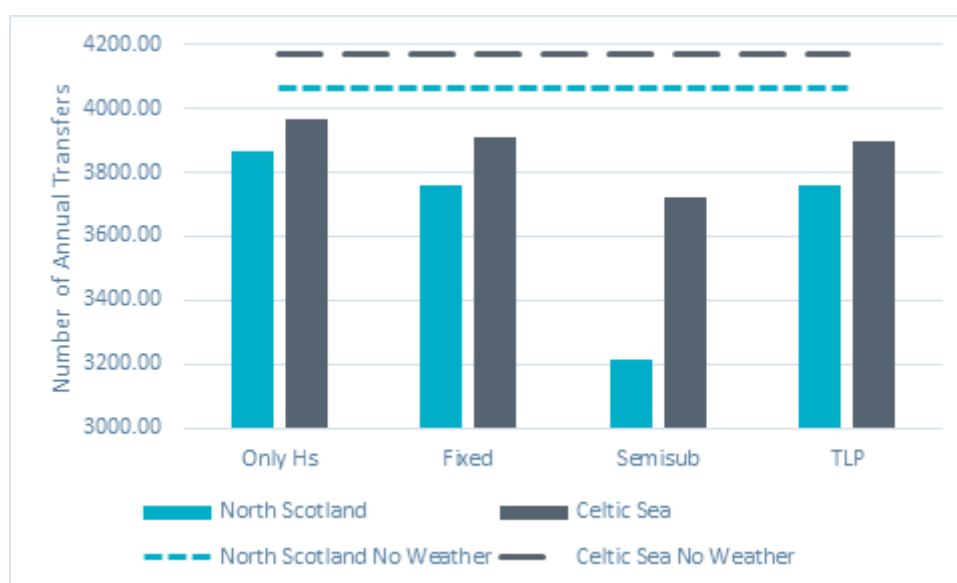


Figure 16: Transfers per year for North Scotland and Celtic Sea, 50th Percentile

Across all studies, North Scotland had noticeably fewer transfers than the Celtic sea. This is heavily impacted by the farther distance from port for the North Scotland site, which is about 100km farther than the Celtic Sea site. The transfers able to be completed highlights the impact of site location on access.

Patterns between the two sites were similar, with approximately the same drop in transfers for case studies 2, 3, and 5 compared to case study 1 (no weather limits). Case study 4 (semisubmersible) had the highest reduction in transfers at both sites, but the reduction at the North Scotland site was 21% compared to an 11% reduction at the Celtic Sea site. This is a significant difference from case study 2 (fixed bottom), which had a 5% reduction at both sites. The reduction in transfers, especially at the North Scotland site, again points to the importance of substructure design when considering access.

4.2.3 Time-Based Availability

Availability is a percentage of time that turbines are able to generate out of the lifetime of the turbine. This can be negatively impacted by failure to keep up with maintenance demands, leaving turbines unable to generate for significant periods of time.

Following a similar pattern to weather days and transfers, case study 4 (semisubmersible) at both sites had the lowest availability, and, with the exception of no weather limitations, North Scotland had lower availability than the Celtic Sea site. Availability for each study is shown in Figure 17.

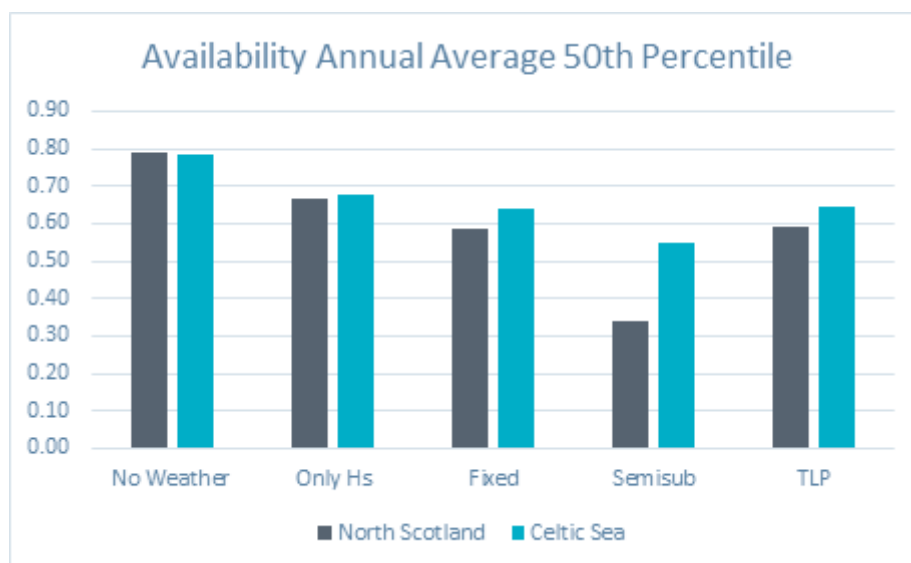


Figure 17: Annual Average Availability - 50th Percentile

Similar to weather days and transfers, case study 4 (semisubmersible) had the lowest availability at both sites. The North Scotland site had the largest reduction in availability compared to the base case, attributed to a combination of turbine design and site location.

Case Studies 2, 3, and 5 (Hs only, Bottom fixed, and TLP) have similar availability, especially at the Celtic Sea site. Here, they are within 5% of each other in the 50th percentile. This indicates that minimising turbine motion is beneficial to accessibility. To better plan maintenance scheduling, Tp should be considered when establishing realistic weather windows.

5 CONCLUSIONS

Safe, reliable, and efficient access of FOWTs is crucial to their maintenance and upkeep. This work focused on three different access methods:

- Small vessel access (CTV and DC),
- SOV with W2W gangways, and
- Helicopters.

Key takeaways from each section and suggestions for further work are discussed here.

5.1 Current Access Knowledge

Current industry knowledge, especially that from FOWT technicians, provides insight to concerns regarding floating access. Across all access methods, common concerns included:

- Relative motion between the turbine and the transfer vessel, complicating transfers;
- The lack of current regulation and standardisation for floating wind practice methods;
- The substructure design having a significant and direct impact on access methodologies and challenges;
- Harsher sea state conditions and farther from shore farm locations impacting workable hours; and
- Inconsistent technician training and knowledge gaps.

Overall, SOV with W2W gangways are generally considered the most likely and viable option. This is largely due to the far-from shore locations and harsher weather conditions of future floating wind farms, which SOVs are able to handle better than CTVs. The largest concerns with W2W use is gangway positioning and losing contact with the turbine. Contact is currently generally made by first positioning the vessel, then manually positioning the gangway to the push-on position. Development has been made for modifying the connector shape and implementing target tracking to assist with the positioning, expediting the process. In order to maintain contact, motion compensation and dynamic positioning are vital. Dynamic positioning is directly reliant on vessel design, though motion compensation generally comes from the W2W system itself. The largest concern with motion compensation is gangway movement during transfer, where technicians risk getting trapped between moving parts.

CTV use is expected for closer to shore or individual repairs, when an SOV is not currently active in the field. This is due to their stricter weather limitations and the long transfer times expected for floating wind farm locations. The cost and material requirements for landing platforms is also higher than that of W2W gangways. Methods for increasing CTV use include the addition of a clamping mechanism, use of a hoist system, and utilising electrification to reduce the response time and help maintain contact.

Transfer using helicopters has not been considered for standard transfers. Despite having the highest operable weather limits, they are generally reserved for use only during W2W weather limits and for emergency or specialised personnel transfer. Their high cost, including fuel use, limited space for

technician and materials make for an unlikely regular transfer method. Transfer generally occurs using a winch system, winching onto either an SOV or onto the nacelle, though it has been suggested that transfer could occur onto the substructure, due to the high movement of a FOWT nacelle making helicopter access improbable.

It is expected that for emergency evacuation, such as medical cases where the med bay on the SOV is incapable of handling the issue, helicopters would be used. It has also been suggested that they are used for taking individuals in need of compassionate leave or bringing to site specialised personnel, where moving the entire SOV to shore would not be plausible.

5.2 Modelling Access using OrcaFlex

To assess access methods, OrcaFlex was used to model access. Models of FOWTs were created, and their access by helicopter, CTV and SOV with a W2W gangway were analysed. These access methods were used for a fixed offshore wind turbine, a semisubmersible FOWT and a TLP FOWT. The time histories of access connections were examined to evaluate the relative accessibility of foundation types and the drivers of the differences.

The helicopter analysis focussed on the movement of the nacelle, which predominately moved in the horizontal plane in the direction of the wind and waves. There is no current guidance on assessing helicopter accessibility for a moving nacelle, so the heli-hoist area design was used to set motion limits for access. Using this limit the TLP foundation was accessible in almost all sea states considered, while the semisubmersible was accessible in only the most benign sea states. This difference was caused by the much greater movement of the nacelle of the semisubmersible. However, the limit for the range of motion was set by the minimum landing area; if the landing area's width and length increased, the limits would correspondingly increase, leading to a higher accessibility. It should be noted that the issue of velocity would persist, which was not considered in this analysis but was shown to be significant on the semisubmersible, with the nacelle reaching a maximum velocity of 1.2m/s in 2.5m Hs.

The results from the CTV analysis suggested that access would differ significantly across the different floating foundations. In the cases where the wind and waves were aligned with the access direction, the TLP foundation's access was very similar to the fixed foundation, but the access to the semisubmersible was significantly reduced. Consideration of the access process suggested that this was due to the comparatively increased surge and heave motion of the semisubmersible FOWT, as these motions would negatively affect the friction interaction set up between the fender and the landing bumper. Although the semisubmersible created an element of shielding when placed to weather of the CTV, this sheltering was only present for waves of certain wavelengths, and thus was only observed for modelled sea states with Tp of 6s.

While the general trends in relative accessibility were based on fundamental physical interactions, the exact numerical values of accessibility presented in the analysis appeared to be quite low. This might have been caused by an excessively conservative approach to defining successful access or because in reality technicians do not need many completely stable windows to complete a transfer. Additionally, the results in the certain wave directions suggested that the model was not accurately capturing some of the effects present in real scenarios. This might have been caused by the automatic control implemented in the model, which might have been modelled in a more reactive and attentive way than a human operator.

The SOV models suggested that access was possible up to 2.5m Hs for all foundations, but that access was contingent on the wave direction and heading. Direction in particular had a very significant impact on access, as the force of the wind and waves on the beam of the vessel and the roll response

severely reduced the time that the W2W gangway was able to maintain a connection. Additionally, shorter wave periods reduced access, as they presented an increased challenge to the station keeping of the DP system. This was particularly pronounced for the semisubmersible foundation, which was inaccessible in lower T_p values where access to the TLP and fixed foundations was possible. This was likely to be due to the surge motion of the semisubmersible foundation and the asynchronicity of its motion with the SOV. This could be compounded by the control approach used for the DP system. In this instance, a reactive control was used, where the SOV attempted to “catch up” with the foundation. A predictive control, which would move to the anticipated FOWT location, could potentially increase the accessibility.

Overall, the modelling suggested that access to floating wind turbines might be reduced depending on the foundation design and chosen method of access. In particular, if using a helicopter or CTV, the semisubmersible might be significantly less accessible than the current fixed foundations. If using an SOV, access for the semisubmersible would be more comparable to fixed foundations, except in low T_p wave states. The modelling suggests that access to the TLP foundation would be very similar to current bottom fixed offshore wind turbines when using an SOV.

The key factor in determining FOWT access are the surge and heave motions of the foundation. Therefore, the result that the semisubmersible foundation considered here was less accessible does not necessarily mean that all semisubmersible foundations will be as inaccessible. Designs which reduce these motions may be more favourable for access. The same is true for TLP designs, although by nature of their fundamental operation, these motions are likely to be small, suggesting that TLP access will in general be favourable.

5.3 Impact of Access using Logistical Modelling

As current maintenance planning focuses on H_s as the accessibility weather limit, there is a gap in understanding the effect of wave period on accessibility. Section 4 focused on the impact of access when T_p also limits access.

The internal modelling tool COMPASS was used to calculate weather days, number of transfers, and availability of varying model wind farms. This system uses the Monte-Carlo method to generate activities and historic weather data to determine when maintenance can occur. This project used two farms, the first located in the North Sea, and the second in the Celtic Sea. Both farms had 100 turbines and identical task lists. At each site, five case studies were run with varying weather limits on access. The first had no weather limits and the second only considered a 2.5m H_s .

For the remaining case studies, both H_s and T_p were considered. These used the results from previous work to establish H_s and T_p pairs, which were then used to determine weather limits for each of the listed turbine designs.

Results from modelling focused on annual wait on weather, transfers, and availability. The results of modelling pointed to three key findings:

Wave period has a noticeable impact on access when compared to only considering significant wave height

Most often, H_s is used as the limiting factor for transfers. It is used to determine when a vessel should attempt transfers, and in site weather analysis for planning maintenance campaigns. Historically, T_p is not often considered in maintenance planning.

Despite this, modelling from WP3 used both H_s and T_p to determine accessibility of different turbine designs. Modelling found that access was most impacted in conditions with high H_s and short T_p . The

limits there reflected an increase in weather days once T_p was used as a weather limit. Weather days rose significantly, with case studies 3 and 5 (fixed bottom and TLP) have about 50% increase and case study 4 (semisubmersible) about 100% increase in weather hours for each site.

The availability mirrored this effect, with the North Scotland case studies 3-5 dropping 11%, 49%, and 12% compared to case study 2 (H_s only) and the Celtic Sea case studies 3-5 dropping 5%, 19%, and 5%. This impact when T_p and H_s are considered points to a lower accessibility than expected when only considering H_s .

Impact of substructure design on accessibility will vary based on location.

Case study 4 (semisubmersible) had the highest reduction in transfers and availability. Additionally, compared to case study 2 (only H_s), the increase in weather days was at 91% and 102% for North Scotland and Celtic Sea sites respectively. This is significantly higher than case studies 3 and 5, where the increase ranged from 51-64%.

The reduction of availability and number of transfers compared to no weather conditions was also highest for case study 4. This suggests that transfers onto semisubmersible floating foundations will be more limited than TLP, which are similar to fixed bottom wind in availability and weather days.

The similarity between TLP and bottom fixed wind regarding weather days, number of transfers, and availability, are encouraging for maintenance expectations. The similarity in sea conditions on access allow for more direct planning to come from current bottom-fixed wind, adjusting for transit changes rather than additional weather limitations. This suggests that TLP maintenance planning can draw closely to current bottom fixed wind.

These impacts suggest a direct correlation between increased turbine motion and decreased accessibility. Designs to decrease motion, such as the use of heave plates could lessen the impact of T_p , especially in cases where one substructure type may not be suitable. Regardless of substructure type, designs should take into consideration stability and motion mitigation methods to increase accessibility.

T_p impact varies based on site location.

The turbine location and average sea state will directly impact access and transfers. Under no weather limitations, both sites had similar availability. However, for weather days and number of transfers, the Celtic Sea site had better results than the North Scotland site. This means more weather days, fewer transfers, and lower accessibility for every case study for the North Scotland site compared to the Celtic Sea.

The Celtic Sea, likely due to its lower average T_p , had a higher increase in weather days compared to the H_s only. While maintaining fewer annual weather days compared to North Scotland, the higher percentage indicates a higher susceptibility to T_p . Considering this, sites with lower average T_p should be more cautious about weather delays, taking into consideration both wave height and wave period during project planning.

These findings pointed to the importance of considering wave period in addition to wave height when planning for maintenance activities. The direct relationship between considering wave period and a loss of availability and increase in weather days highlights the potential for project interruption due to poor understanding of weather conditions.

6 REFERENCES

- [1] Green Volt, “The first commercial-scale floating offshore windfarm in Europe,” Green Volt, [Online]. Available: <https://greenvoltoffshorewind.com/>. [Accessed 10 July 2024].
- [2] UK Department for Business and Trade, “Offshore Wind,” UK Department for Business & Trade, 2024. [Online]. Available: <https://www.great.gov.uk/international/content/investment/sectors/offshore-wind/#:~:text=The%20British%20Energy%20Security%20Strategy%20%28BESS%29%2C%20published%20in,2030%2C%20including%205%20GW%20from%20innovative%20floating%20technology..> [Accessed 10 July 2024].
- [3] Atlantic Wind Transfers, “Atlantic Wind Transfers,” [Online]. Available: <https://www.atlanticwindtransfers.com/>.
- [4] YouTube, “Offshore CTV Video Search Results,” [Online]. Available: https://www.youtube.com/results?search_query=offshore+ctv+transfer.
- [5] Buoyant Works, “High Performance Adaptable Crew Transfer Vessel Bow Fendering,” 2024. [Online]. Available: <https://buoyantworks.com/wp-content/uploads/2024/01/FenderIT-CTV-FENDERING-Brochure.pdf>.
- [6] TGS Wind, “An Introduction to Crew Transfer Vessels,” TGS , 2024. [Online]. Available: <https://www.4coffshore.com/support/an-introduction-to-crew-transfer-vessels-aid2.html>. [Accessed 18 July 2024].
- [7] Chartwell Marine, “Daughter Craft,” Dhartwell Marine Ltd, 2022. [Online]. Available: <https://chartwellmarine.com/portfolio/daughter-craft/#:~:text=The%20daughter%20craft%20range%20have,excess%20of%201.5m%20Hs..> [Accessed 18 July 2024].
- [8] BVG Associates, “O.4.1 Crew Transfer Vessels,” 2019. [Online]. Available: <https://guidetofloatingoffshorewind.com/guide/o-operations-and-maintenance/o-4-offshore-vessels-and-logistics/o-4-1-crew-transfer-vessels/>. [Accessed 18 July 2024].
- [9] V. V. Dinghe, L. Pergod and C. Yung, “Offshore Wind Access Report 2022,” TNO, Petten, 2022.
- [10] G+ Global Offshore Wind, “G+ Offshore Wind Transfer,” Energy Institute, London, 2020.
- [11] BVG Associates, “O.4.2 Service operation vessels,” 2019. [Online]. Available: <https://guidetofloatingoffshorewind.com/guide/o-operations-and-maintenance/o-4-offshore-vessels-and-logistics/o-4-2-service-operation-vessels/>. [Accessed 18 July 2024].
- [12] BVG Associates, “Guide to a Floating Offshore Wind Farm O.4.4 Helicopters,” BVG Associates, 2019. [Online]. Available: <https://guidetofloatingoffshorewind.com/guide/o-operations-and-maintenance/o-4-offshore-vessels-and-logistics/o-4-4-helicopters/>. [Accessed 2 July 2024].

- [13] Offshore, “Partners Successfully Complete Hoist Mission for Floating Wind Turbines,” Offshore, 2023.
- [14] UK Civil Aviation Authority, “Standards for Offshore Helicopter Landing Areas,” Civil Aviation Authority, West Sussex, 2023.
- [15] HeliOffshore, “Wind Farm Recommended Practice,” 2023.
- [16] Skybrary, “Visual Meteorological Conditions (VMC),” SKYbrary, [Online]. Available: <https://skybrary.aero/articles/visual-meteorological-conditions-vmc>. [Accessed 25 June 2024].
- [17] Navingo, *Offshore Transfer Devices Seeks Partners to Bring TDD Transfer System to Market*, Offshore Wind.biz, 2017.
- [18] Orcina, “OrcaFlex - World-leading software that goes beyond expectation,” 2025. [Online]. Available: <https://www.orcina.com/orcaflex/>.
- [19] Civil Aviation Authority, “Standards for Offshore Helicopter Landing Areas CAP437,” Civil Aviation Authority, West Sussex, 2023.
- [20] Google, “Google Maps,” Google, 2009. [Online]. Available: https://www.google.com/maps/@54.0511433,-10.7812497,5z?entry=ttu&g_ep=EgoyMDI1MDExNS4wKXMDSoASAFQAw%3D%3D. [Accessed 21 January 2025].
- [21] Ørsted, “Ørsted partners with Pict Offshore to develop game-changing technology for offshore wind operations and maintenance,” 23 09 2019. [Online]. Available: <https://orsted.co.uk/media/newsroom/news/2019/09/orsted-partners-with-pict-offshore-to-develop-game-changing-technology-for-offshore-wind#:~:text=The%20Get%20Up%20Safe%20%28GUS%29%20system%20is%20a,the%20need%20for%20ladders%20and%20boat%20landings%20alto>. [Accessed 20 05 2024].
- [22] B. J. J. C. D. M. David Rowell, “How Does the Accessibility of Floating Wind Farm Sites Compare to Existing Fixed Bottom Sites?,” *Energies*, vol. 15, no. 8946, 24 November 2022.
- [23] L. P. C. Y. Vinit V. Dighe, “Offshore Wind Access Report 2022,” TNO, Petten, 2022.
- [24] BMT, “BMT 27m CTV hybrid design selected for expanding European offshore wind,” BMT, 2 March 2023. [Online]. Available: <https://www.bmt.org/news/2023/bmt-27m-ctv-hybrid-design-selected-for-expanding-european-offshore-wind/>. [Accessed 10 July 2024].
- [25] Carbon Trust, “Recommended Boat Landing Geometry for Public Release,” 2019. [Online]. Available: https://ctprodstorageaccountp.blob.core.windows.net/prod-drupal-files/documents/resource/public/Design_for_recommended_boat_landing_geometry.pdf.
- [26] ReNews, “Barge Master Bosch Go Walkabout,” [Online]. Available: <https://renews.biz/36462/barge-master-bosch-go-walkabout/>.

- [27] Copernicus Climate Change Service (C3S), “ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global climate,” [Online]. Available: <https://cds.climate.copernicus.eu/cdsapp#!/home>.
- [28] Norwegian Petroleum Directorate, “Regulations relating to loadbearing structures in the petroleum activities,” 1995.
- [29] DNV, “DNV-ST-0437 Loads and site conditions for wind turbines,” 2024.
- [30] PID Explained, “PID Controller Explained,” 2024. [Online]. Available: <https://pidexplained.com/pid-controller-explained/>.
- [31] Engineer's Edge, “Coefficient of Friction Equation and Table Chart,” 2025. [Online]. Available: https://www.engineersedge.com/coefficients_of_friction.htm.
- [32] Orcina, “Friction Theory,” 2025. [Online]. Available: <https://www.orcina.com/webhelp/OrcaFlex/>.

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