

Safe and Efficient Transfer Operations and Maintenance Strategy for UK Round 3 Offshore Wind Farms

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1. Introduction

Energy providers are under pressure to maintain supply with the increasing demand for energy and the ever increasing cost of fossil fuels. The UK government are looking towards green energy for the future thus offshore wind farms are a great source of renewable power. Since 2001 The Crown Estate in the United Kingdom has been granting permission for the building of offshore wind farms within its territory. Currently, offshore wind farms are operational up to 12 nautical miles for Round 1 and 40 nautical miles for Round 2 off the UK coastline. However, there is a trend for wind farms to be moved further offshore. For example, currently under development is Dogger Bank, which is 195km off of the Yorkshire coastline and constitutes a Round 3 wind farm. It is planned there will be more than 2000 turbines on this site, and it is due to be operational within the next 5 years.

Operation and maintenance vessels that will be dedicated to this huge area will need to transport not only technicians but equipment and spare parts to ensure that the turbines' uptime is kept to a maximum. The maintenance requirements for Rounds 1 and 2 wind farms are currently being met by small shore-based catamarans for minor maintenance and chartered offshore heavy lift vessels for major maintenance. The current maintenance strategy is not suitable for Round 3 wind farms. As Round 3 wind farms are up to 174 nm away from the nearest coast line the vessel will be unable to return to shore daily thus the vessel must have enough supplies and crew to maintain the turbines for a sustained period of time. The greater distance from land causes an issue with travel time and passenger discomfort (seasickness leading to loss of work time) which current vessels do not address. Volatile and hostile weather conditions mean that the minor maintenance repair vessels cannot achieve optimum operational capability. The current offloading method that is in use for round 1 and round 2 will not be acceptable due to the increased wave heights that occur further offshore.

There is a requirement for a suitable offshore wind farm support vessel and offloading system that meets the needs of a UK Round 3 Wind Farm. This project is aimed at creating an offshore support vessel with an offloading system in order to achieve maximum productivity and safety.

This project falls into the research area of waterborne transport, focussing on developing offshore wind farm support vehicle technology. The project will also encompass aspects of safety improvement, industry competitiveness and logistics innovation. The reason for selecting this area of research is that a real need for technological advancement in this industry was identified. As a team we had an interest in exploring this market and creating a new solution to overcome the challenges of offshore wind farm O&M vessels and offloading methods.

2. Literature Review

2.1. Current situation

One of the major problems with constructing wind farms further offshore is the access to the turbine for maintenance and regular surveying. The small workboats that currently service the Round 1 and 2 turbines on day visits from the shore do not have a long enough range and suitable sea-keeping functions. Current boats are mainly SWATH vessels (small water-plane area twin hull) capable of achieving up to 20 knots in waves of up to 2.5m and carrying up to 12 engineers [4]. However the winds and wave conditions are significantly greater further offshore therefore such a speed is unlikely. A further consideration is that the Round 3 wind farms are planned to be significantly larger, both in terms of turbine size and power output.

For example the largest of all the new developments is Dogger Bank in the North Sea, an area which has been licensed to Forewind (a collaboration of four UK energy companies) to develop. It is stated on their website that they will aim to achieve the agreed target of 9GW of power output, which is 10% of the projected UK energy demand, by 2020 by fully developing the site. They also claim that “if fully developed, it is likely to be the world’s largest offshore wind project” [5].

Of course it is not yet known the exact design for the turbines which will be built at Dogger Bank, and how turbine surveys and maintenance will be carried out there. What is known is the peak and average wind speed and wave height in that area of the North Sea. Information from 4COffshore [6], a worldwide database of wind farms and wind farm service vessels, lists the six specific project sites within Dogger Bank. However the meteorological surveys for the wind and wave height specifically for the Dogger Bank projects have not been completed by Forewind to date. Most maps show a significant wave height of 3-4m in that area of the North Sea, which would result in the current SWATH vessels being unsafe and unsuitable for a large proportion of days.

It is worth noting that for the first few years at least of a turbine life, the original equipment manufacturer (OEM) is liable for the O&M logistics as per the warranty, although this can be the case for the entire lifetime. Key OEM companies include Siemens, Samsung and AREVA. These are different to the wind farm project owners who have the ultimate responsibility and final decision on O&M logistics; these are namely the “big 6” energy companies in the UK: Centrica, EDF, E.ON, RWE, Scottish Power and SSE [3].

2.2. Current research and development

The current rationale for planning the O&M for the large Round 3 wind farms is vague. This is due to a lack of experience and useful data for turbines of such a size and distance from the coast in the UK and in the North Sea. This has been seen by the experiments done on predicting the power outputs of Round 3 wind farms [7]. Whilst wind speeds in the Dogger Bank zones are well documented, possible

fluctuations with a wind turbine layout, or the effect of one turbine on another is not. Furthermore, the exact locations of each of the separate projects and layouts of the turbines are yet to be decided. All of this culminates in a level of uncertainty, which can be extended to O&M predictions. By its nature, unscheduled maintenance is unpredictable, but scheduled maintenance may become unpredictable if access to the turbine cannot be guaranteed on a certain day, as previously mentioned.

One of the important areas of research which will impact on vessel design aspects is the reliability and availability of the wind turbines. It goes without saying that the wind farm operators aim for 100% availability, although this is almost always impossible. Several research papers have been published on measuring these parameters [8] [9] [10] [11]. Perhaps the most useful of these papers is the one published by Sandia National Laboratories [12] which provides some suggestions for technical maintenance cost reductions around technical changes to improve turbine reliability. However this report, along with the others referenced are more aimed at turbine design rather than turbine O&M, and are therefore only indirectly relevant to this project.

A key source of information has been from the Crown Estate themselves [3]. The Crown Estate publication, which has been produced in collaboration with Scottish Enterprise, is very useful in outlining and explaining not only the O&M requirements of an average wind turbine, but also the current industry practices and logistics. Importantly, a market forecast for future offshore wind turbine O&M in the UK shows a significant increase in turbine maintenance cost using an offshore-based (mother-ship) strategy. This market trend is driving the research into improved offshore O&M strategies and vessels, which “will gradually shift from strategies optimised for near-shore sites towards those that are most suited to very distance offshore wind sites” [3]. Thus the design problem for this project is introduced.

The Crown Estate publication is clear in detailing the issues surrounding offshore logistics and turbine access. It states that the main factors which will influence maintenance logistics and design decisions are “safety and regulatory factors, response time (a function of speed), flexibility, personnel carrying capacity, equipment payload, weather and sea-state dependency, and direct cost of retaining and using a service” [3]. Specifically for turbine access, the main problems are transit time (which impacts on the productivity of the technicians) and accessibility (as a direct result of sea conditions). These factors and specific problems highlight an area of research and development that the industry is in need of.

A competition held in 2010 by the Carbon Trust has begun to address this. The Offshore Wind Accelerator program has since been working with many collaborators to improve and reduce the cost of offshore wind power by 10% by 2015 [14]. The shortlisted entrants in this competition tackled three categories of design challenges: the vessels, the transfer systems and the launch and recovery systems. Of interest to this project is the transfer systems, which include ideas of mechanical and robotic platforms and bridges, put forward by leading companies such as BMT Nigel Gee Ltd. and Houlder Ltd [13]. However, with an industry that is developing as such a fast pace, these designs could be considered somewhat out of date, particularly with the extra demands for reliability and efficiency that are now expected.

Another key source of information of current vessels has been Germanischer Lloyd [4] who has been involved in developing and classifying purpose built wind turbine support vessels of various types. This

brochure has again emphasised the increased demand for such vessels and the complex challenges of offshore wind farm O&M. Their research and expertise has led to a set of new rules and tools specifically for offshore support vessels, which will be critical for optimising design. However much of their case studies and experience is with the SWATH workboats for the Rounds 1 and 2 wind farms. Nevertheless, various publications available through their website will prove useful for further offshore O&M vessel development.

Research from the 'Design & Operation of Wind Farm Support Vessels' conference organised by RINA in London, UK in January 2014 was gathered with the aim of gaining a global view and an industry perspective of the current situation. There are no limitations with respect to design of vessels or transfer systems. Thus far, vessels have been kept at a length less than 24 m to avoid class rules. Development in classification rules driven by DNV [15] is starting to take place, which removes the desire to design support vessels that are limited in length. To date, research and development has been made in all aspects of this subject, from the ergonomics of a high speed craft to the introduction of active suspension in catamarans. Still no viable solution has been suggested to address the challenges that the weather conditions and location of Round 3 windfarms present with respect to technicians and equipment transfer between support vessels and turbine.

To conclude, much of the O&M planning for UK Round 3 wind farms such as Dogger Bank is currently being undertaken by many of the main companies in the offshore wind turbine market. Specific maintenance vessel design and turbine access solutions are currently not known for two main reasons: firstly, the research into various methods and vessels is still ongoing, and secondly, market competition dictates a certain level of confidentiality at this stage.

2.3. References

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- [3] *A Guide to UK Offshore Wind Operations and Maintenance*, The Crown Estate, Scottish Enterprise and GL Garrad Hassan, 2013
- [4] *GL – Mapping the Future in Offshore Wind: Wind Turbine Installation Ships and Wind Farm Service Vessels*, Germanischer Lloyd, 2012
- [5] *Forewind*, available at: www.forewind.co.uk/about-forewind/background (accessed 05/01/14)
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- [11] *Reliability, Availability and Maintenance aspects of large-scale offshore wind farms, a concept study*, by G.J.W. van Bussel, M.B. Zaaijer, Marine Renewable Energies Conference, Vol. 113, No. 1., March 2001
- [12] *Wind Turbine Reliability: Understanding and Minimizing Wind Turbine Operation and Maintenance Costs*, by C.A. Walford, published by Sandia National Laboratories, March 2006
- [13] *Offshore Wind Accelerator Access Competition – shortlisted designs*, The Carbon Trust, available at: www.carbontrust.com/media/105306/owa-access-innovators.pdf (accessed 10/12/13)
- [14] *Offshore Wind Accelerator*, The Carbon Trust, available at: www.carbontrust.com/our-clients/o/offshore-wind-accelerator (accessed 25/01/14)
- [15] *Development of Rules for Classification of Wind Farm Service Craft*, by M Schei-Nilsson, DNV GL, Norway. Design & Operation of Wind Farm Support Vessels Conference 29-30 Jan 2014, RINA, London UK

3. Design Requirements

Any design must meet the requirements outlined by the problem.

The requirements of a vessel carrying out O & M on Round 3 Wind Farms need to address the challenges inherent to the offshore environment and wellbeing and safety of the technicians. These can be split into three categories:

3.1. Sea Keeping

The sea keeping requirements that must be addressed:

- Reduced motions to prevent sea sickness from land trained technicians
- Crew comfort to ensure an environment beneficial to productivity
- Good manoeuvring capabilities
- High speed to reduce travel time between turbines

3.2. Station Keeping

For the transfer of technicians to the turbine the vessel must have the ability to maintain position whilst providing a stable platform from which to work. This will include:

- Collision prevention between the vessel and turbine
- Controlled approach to the turbine

3.3. Transfer Operations

- The transfer system must produce a reliable and predictable movement to enable the technicians and equipment to move from the vessel to the turbine and back.
- The system must also supply a speedy method of transfer to increase productivity of the vessel and cost benefit inherent to the system costs.

All parts of the O & M operation must consider the safety of the technicians and crew as the predominant design requirement.

4. Concept Overview

In order to maximise safety and efficiency, our offshore wind farm technicians and equipment transfer strategy utilises a large Offshore Maintenance Vessel (OMV), with individual Crew Offloading and Transfer units (COTs) being transferred to the turbine via a motion compensating carriage system.

The OMV is an ocean going 3000 gross tonnage vessel and offers improved seakeeping over smaller Crew Transfer Vessels (CTVs). The OMV has accommodation for all crew and technicians required, with all associated hotel facilities as well as workshop and storage facilities. The COTs are stored on the loading bay located on the aft deck of the vessel.

The COTs are small individual units for the transfer of up to four technicians with all the tools and equipment required for the majority of maintenance tasks of a wind turbine. The technicians and tools are transferred from the OMV to the turbine within the COTs, and then the COT is left on the turbine platform whilst the maintenance tasks are being carried out. They are then transferred back to the OMV once the tasks have been completed.

The COTs are transferred from the OMV to the turbine and back via a motion compensating carriage system (see figure 1). This consists of a tower located on the aft deck of the OMV at amidships, to which a horizontal boom is attached. This boom then attaches to the turbine while the vessel is in position stern-to. Within the tower is a motion compensating system, so that when the boom is attached to the turbine, the boom, and therefore the COT being transferred, experiences very little motion, if any, even in heavy seas. The COT is lifted off the aft deck, onto the boom, transferred to the turbine and then placed on a platform on the turbine, where the technicians can then disembark.

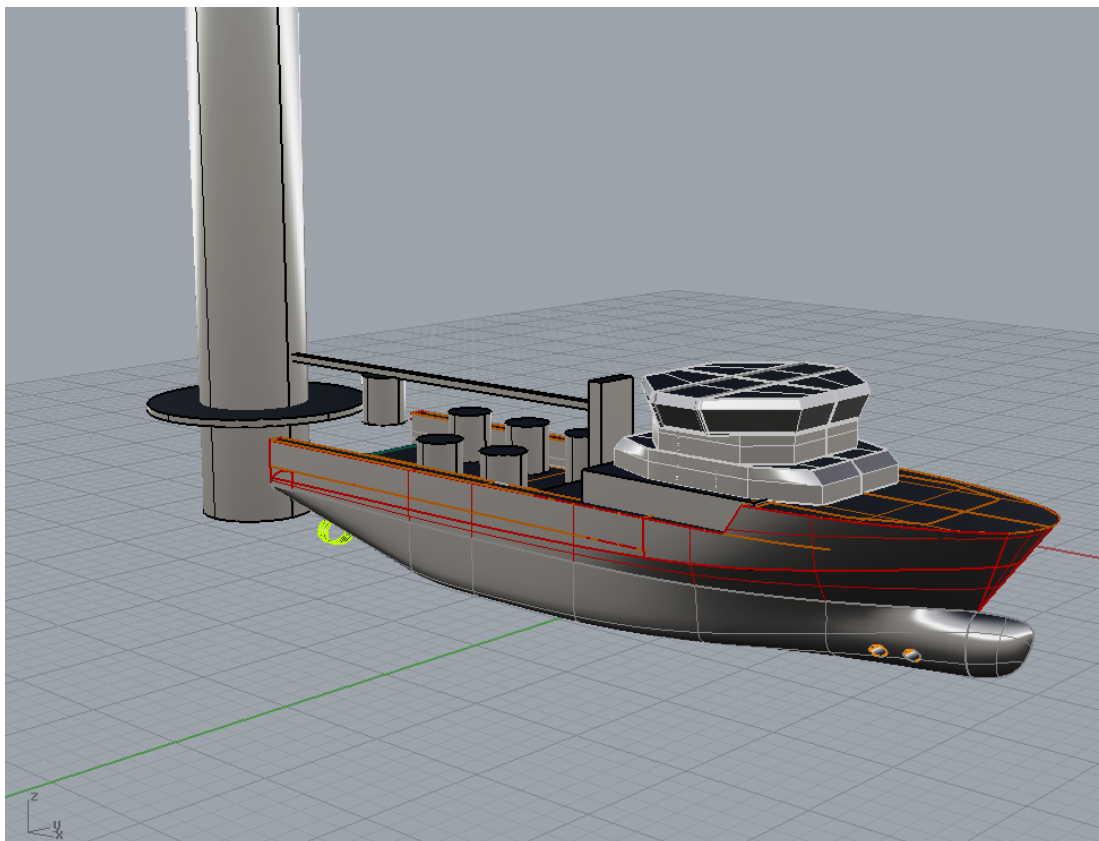


Figure 1: Rendered Diagram of Offloading System

4.1. Strategic Innovation

The logistical and management system using a vessel to deliver technicians and equipment within self-contained units to the turbine is a new approach to offshore wind farm Operation and Maintenance (O&M). Each OMV is able to provide service crews to several turbines successively, and is flexible to respond to both scheduled and unscheduled maintenance. The OMV carries all the technicians and equipment necessary for O&M, which means it can operate independently without the need for outside support for up to 13 days. This provides a unique selling point for this concept within the offshore wind farm industry, along with the technical advances described below.

4.2. Technical Innovation

The motion compensating carriage system is an innovative solution to ensure safe crew and equipment transfer. The system within the tower which provides the motion compensating capability will require further research and development. The response time of the hydraulic actuators and sensors within the system will need to be tailored for this application. There is also a requirement for the system to be able to analyse the current sea state and respond accordingly. State of the art motion compensating systems currently have to be reprogrammed when the vessel moves to a different area of operation, or the sea state changes considerably [1].

Another area of innovation is the connection between the boom and the turbine. It allows for a quick connection and transfer, and allows the boom to be connected at any point around the turbine tower, and gives reasonable versatility with respect to the height at which the boom can be connected, incorporating further state of the art technology.

4.3. References

- [1] *Performance evaluation of service vessels and access systems for offshore wind*, by Simon Mockler, DNV GL, UK. Design & Operation of Wind Farm Support Vessels Conference 29-30 Jan 2014, RINA, London UK

5. Concept Design

5.1. COT Capsule design

5.1.1. Capsule requirements: Personnel

The number of personnel required to visit the turbine for routine turbine maintenance depends heavily on nature of the problem. Any job that requires major component replacement will demand a greater number of personnel than routine maintenance such as painting, visual inspections, cleaning and bearing checks [1]. Some models for turbine maintenance regimes have suggested three technicians are required per turbine [2], others recommend two to five personnel [3]. From this, it has been decided that an allowance will be made for four personnel per capsule, as the aim is to have one capsule per turbine.

Assumptions on average weight of the personnel were made based on the design of Toshiba elevators [4]. In this report, comparisons were made between the number of passengers and weight. A weight of 630kg corresponded to 8 people, giving a rough average of 80 kg per person. We took into account the protective gear that is worn by personnel and subsequently added a safety factor; this resulted in an assumption of 100kg per person for our design. The total combined weight of the personnel is less of a concern from a limitation point of view, but rather from a distribution point of view. This is due to the stability of the lifting and transfer method, discussed later.

The equipment and tools for maintenance will be heavier than the personnel combined, as can be seen in table 1. Loading the capsule with tools and equipment and ease of access were considered in deciding seating arrangements. The scenario which is most appropriate is to have the tools and equipment centrally placed and the seats around the equipment. In this way, the equipment and tools won't be a hazard should emergency evacuation of the COT or turbine be needed.

Designs of racing car seats, rollercoaster seats and other alternatives were considered, but the design and size of seats are based on airline staff seats, collapsible with quick-release safety harnesses. All capsules will be equipped with a first aid kit. All personnel including the capsule itself are fitted with an Emergency Position-Indicating Radio Beacon (EPIRB).

5.1.2. Capsule requirements: Tools and Supplies

Given the space limitations within the capsule and the volume of tools and equipment required, only essential tools should be stored in each capsule with space for specialised equipment for individual repairs. The following is a list of services that will need to be provided in order to carry out routine maintenance [1]:

- External and internal tower cleaning
- Environmental cleaning e.g. oil/hydraulic spill
- Wind turbine blade cleaning via rope access or platform
- Gearbox inspection and oil changes
- Load testing, installation and certification of anchor/ eye bolts
- Installation and certification of full arrest equipment
- Installation and repair of wind monitoring systems
- Tower painting and surface inspection/ recoating
- Lightening conductor/ protection testing, installation and repair
- Rope access and cradle services
- Electrical inspection and light bulb changing
- Cable tray installation and cleaning
- Bolt torque testing
- Bearing replacements
- First Aid Kit

In order to carry out these services, it is assumed that the following equipment will be required:

Table 1: Masses on the COT

	Approximate mass (kg)	Approximate volume (m³)
Cleaning equipment- general	3	0.075
Oil spillages, oil/hydraulic Spill kit	2	0.075
Fall arrest equipment, Ropes, Harness	20	0.25
Oil	50	0.04
Spare nuts/bolts	30	0.25
Bolt torque meter	neg.	neg.
Electrical testing equipment	neg.	neg.
Paint	15	0.015
Lighting	neg.	neg.
General tools/ toolbox (x4)	60	0.18
Communication equipment	70	0.03
First Aid Kit	neg.	neg.
Emergency rations	neg.	neg.
Total	260 kg	1 m³

The total weight of the equipment needed in the capsule is approximately 260kg, requiring approximately 1 m³ for storage. This is based on the assumption that the daily maintenance requirements are fulfilled as per the description above.

5.1.3. COT communication

The personnel in the capsule and on the turbine will require constant communication with the vessel, not just for the offloading and return transfer operations, but also throughout the visit to the turbine for safety and scheduling reasons. A radio system is installed on the COT.

5.1.4. Final COT design

As well as the findings for personnel and tool requirements of the turbine, other factors are considered when defining the final shape and layout of the COT. These are:

- Sitting around the outside or in the middle
- Chairs fold to create more space
- For weight distribution – stores in the middle for ease of loading
- Volume for tools and supplies is a minimum of 1m³
- Shape of toolbox could be more than 1m tall but the height of 2.5m is seen as adequate for a person to stand up in
- Minimum weight of tools 260kg
- Personnel weigh 400kg approx.
- Open plan layout
- Floor space a minimum of 0.5m for sitting and 0.5m for leg room
- The COT must be Buoyant long enough for the crew to escape
- Collision of the COT into the turbine, although it should be minimal the COT should withstand impact and protect the crew and also minimise damage to the turbine.
- Lighting both for the crew on board and navigation/emergency lighting such as strobes
- Materials, light weight and withstand sea air conditions
- Structure rigid enough to be self-supporting and withstand impact loads and cargo loads
- Maintenance – easy to maintain either with painting and easy to fix on board the vessel
- Colour – bright colours to identify the COT should an accident mean it fell in the water
- Versatility – can it be used for other operations such as evacuating injured crew/technicians
- The position of the COT as it rests on the turbine platform i.e. Can the crew get off the COT onto the platform

Taking into consideration the above design requirements it has been decided that the COT should be circular; this reduces potential damage to the turbine if a collision occurred. The circular floor panel is surrounded with a fender to further prevent damage during a collision and also reduces impact forces. The fender is also buoyant allowing the COT to remain floating long enough for the crew to evacuate. The bulk of the weight is positioned in the middle where a compartment for stores is located. A central frame supports the weight of the COT and a non-structural canopy will provide some protection against

the elements. The seats attach to the central column and can be folded away to allow easy access. The dimensions, parts and final design are shown in Figures 2 and Appendix 1.

The Euler buckling calculations for all COT structural components can be found in Appendix 2. The base plate is made from grated aluminium, and is able to withstand an impact force of up to 3.3 tonnes. It has a weight of 593kg.

The circular fender around the base plate is constructed of nylon outer skin with closed cell foam filling. It is assumed that the entire fender will weigh 100kg, but further calculations of buoyancy and stability are required.

The side panels are not structural since they cannot support the weight of the seated crew. The structural frame is constructed from 50mm diameter aluminium hollow tubing with a 3mm wall thickness. The seats are made from composite material.



Figure 2: Image of COT

5.1.5. References

- [1] *A Guide to UK Offshore Wind Operations and Maintenance*, The Crown Estate, Scottish Enterprise and GL Garrad Hassan, 2013
- [2] *Accessing the far shore wind farm*, by C.L. Cockburn, S. Stevens, E. Dudson, BMT Nigel Gee, Published by The Royal Institute of Naval Architects
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5.2. Vessel design

5.2.1. Selection of vessel type and hull shape

The innovation in the crew transfer strategy comes from the COT units and their carriage system and not from the vessel hull on its own. Therefore in order to simplify the design process for the vessel, a pre-designed hull of an Offshore Support Vessel (OSV) was used. The size of OSV was selected in order to increase vessel stability in heavy seas, compared to the small day boats that are currently being used for offshore wind farm maintenance, and also to allow space for the COTs and COT transfer system. A stock 50m OSV hull design was selected, and used within the modelling program MaxSurf in order to obtain resistance curves and power requirements for the hull [2]. Using this hull, the superstructure (accommodation, bridge etc.) was designed in order to meet the requirements for our crew transfer strategy.

5.2.2. Propulsion

Three main propulsion methods were evaluated, and the following factors were considered when deciding on the most effective method of propulsion.

Azimuth Pods	
Advantages	- Better use of ship space as the engine can be placed in any location throughout the vessel - Ships can steer using the pods therefore they do not require assistance during dockings. - Lower vibration levels and emissions - Improved steering, manoeuvring and braking capabilities
Disadvantages	- Expensive compared to the direct drive counterpart - Losses through electrical wiring - 30MW power limitation per pod

Controllable Pitch Propeller (CPP)	
Advantages	- Constant RPM, varying pitch to control vessel speed. - Instantaneous reverse without reducing engine output power (decreased stopping distance) - Main engine does not need to be reversible
Disadvantages	- Expensive - Complex to integrate into vessel - Higher fuel consumption - Thicker hub required

Fixed Pitch Propeller (FPP)	
Advantages	- Smaller propeller hub leading to increased open water efficiency - Designed for service speed to have least amount of cavitation - Simple construction and less maintenance than CPPs
Disadvantages	- Potential cavitation, strength, & stability issues at highly loaded off-design conditions. - Only optimised for one speed

It was therefore decided that the vessel is to be propelled by 2 Azipods at the rear with 2 bow thrusters to maximise manoeuvrability of the vessel. This will also allow for dynamic positioning system, which contributes to improved station keeping.

The main engines will need to provide max power of 8.9MW at the propeller for a top speed of 18 knots, the service speed for this vessel will therefore be 16 knots at 4.4MW, and this data is taken from Maxsurf resistance [2]. Each engine will need to provide 5MW each and each thruster will need to be rated at 4.5MW. This information can be found in greater detail in Appendix 2. The engines need to output a greater amount of power to overcome resistance in the wires and switchboard. To provide enough thrust, 2 Azipod CZ 1400 will be used as they are rated at 4.5MW, each with a diameter of 3.6m [1].

5.2.3. General Arrangement and Accommodation

It is necessary to determine and specify the Offshore Maintenance Vessel layout, in particular:

- Arrangement of Accommodation
- Description of accommodation facilities
- Bridge location
- Position of stores/workshop
- Position of transfer tower
- A number of capsules to be carried on deck

The accommodation will be situated below the bridge in the forward part of the vessel, between amidships and the fore peak. The accommodation is spread over two decks, covering a total area of 560m². The facilities will include a galley and mess, cabins for ship's crew as well as wind turbine technicians, heads, laundry and offices etc. There will be accommodation for 24 technicians and the OMV will abide by MCA manning regulations. The crew and technicians will be accommodated in 35 cabins with 10m² of floor space including en suite heads and showers. This leaves a total of 210m² for corridors and stairs, the galley and mess, recreation facilities such as a gymnasium, laundry services and office space. A medical centre will be located below the bridge.

The bridge is located on Deck 4, above the accommodation block. It has a 360° view, including an aft facing operations control centre. The bridge is positioned between midships and the bow in order to allow for a better view for transfer operations.

Between the transfer tower and the accommodation a workshop is located as well as a tool and spare parts store. The transfer tower is located at amidships, and aft of this is the operations deck where the COTs are stored. A total of 6 COTs will be carried on the vessel, see figure 3.

5.2.4. References

- [1] *Azipod CZ gearless thruster: High-efficiency thruster solution for offshore vessels*, ABB Brochure, available at:
[www05.abb.com/global/scot/scot293.nsf/veritydisplay/ab3fd4cfa309a54dc1257b75003be8fa/\\$file/ABB%20Azipod%20CZ%20Brochure_2013_Lowres.pdf](http://www05.abb.com/global/scot/scot293.nsf/veritydisplay/ab3fd4cfa309a54dc1257b75003be8fa/$file/ABB%20Azipod%20CZ%20Brochure_2013_Lowres.pdf) (accessed 24/01/14)
- [2] MaxSurf (v8), Marine 3D Modelling Software

5.3. Lifting operation design

The vessel is fitted with a suspended boom that is coupled to a tower located at amidships. For the offloading operation, the vessel will reverse up to the wind turbine and connect the end of the boom to a linking point located above the platform on which the COT will be lowered. Once the vessels boom is connected to the turbine, the motion-compensating system is enabled. The COT is then transferred from the loading bay of the vessel to the platform on the turbine on the underside of the boom. Refer to figure 3.

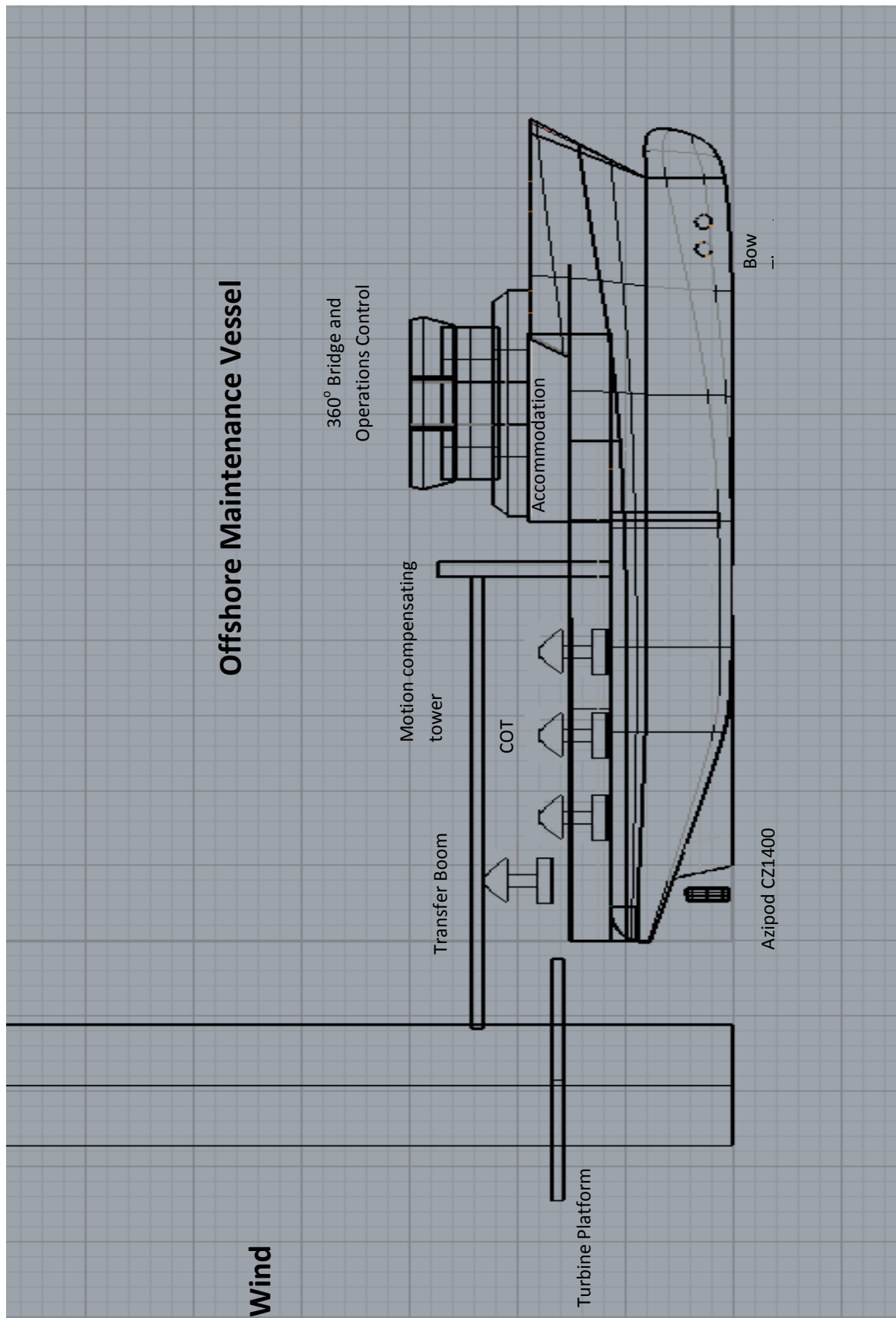


Figure 3: Offloading System Design

5.3.1. The Tower

The tower is placed at amidships and stands eight meters tall. The tower is designed to compensate for the heave movement of the vessel and is fixed to the weather deck. The end of the boom is able to move along the length of the tower. Within the tower, a heave reduction system dampens the wave movement transferred from the vessel, reducing the vertical movement of the boom. The link between the heave reduction system and the boom allows for sway and removes torsional stresses that would be caused by roll movement.

5.3.2. The Boom

The COT is transferred from the loading bay of the vessel to the wind turbine platform via the boom. Before the boom is connected to the turbine, it is supported by a frame located at the stern of the vessel to support its length during transit. This frame will be removed once the connection between the boom and the turbine is made. The boom has a railing system to which the COT is connected, this includes an extending capability for lowering down and lifting the COT off the loading bay, see figure 4 and 5. The method required to secure the COT to the boom must be a rigid connection to prevent pivoting and wave induced movement in the COT

5.3.3. Capsule connection device

The connection method for this will be a single pin with an automated mechanism (see below). There will be a guidance system consisting of a simple conical part to allow for easy connection when the vessel and boom are moving around a lot, ensuring the pick up from the turbine and deck is done quickly and safely. All of the lifting operations will be controlled from the operations control centre on the bridge.

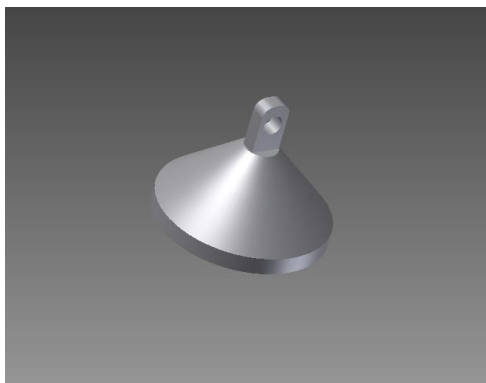


Figure 4: COT Connection Point

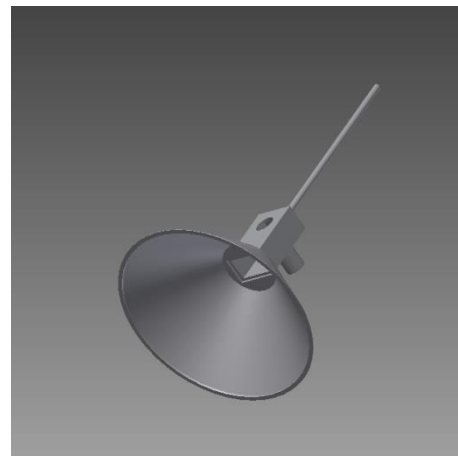


Figure 5: Boom Connection Point

5.3.4. Loading Bay Logistics

The vessel will be travelling between turbines, loading and offloading COTs (personnel and equipment) as needed. This will require the other COTs to be moved and positioned on the loading bay prior to transfer. This process will be done manually using deck equipment.

5.4. Turbine Modifications

5.4.1. Turbine platform

A platform will be required on the turbine that extends 360° around the tower. This is the platform that the COTs are placed on, and where the technicians will enter the tower from. The platform will be 5m above highest astronomical tide (the tidal range is 2m). A door will be located just above this platform to allow access into the tower. The platform has a width of 5m.

5.4.2. Boom connections

The connection points (vertical tubes) are placed around the circumference of the turbine from 3m to 7m above the platform. These enable the transfer boom to connect to the turbine at any point around the tower, and allows for the motions of the boom. There is an advantage of having these connection points around the entire turbine circumference as it allows for approach at almost any angle. This in turn reduces the time for manoeuvre of the OMV, and allows the vessel to position itself in response to the wave direction, i.e. head on to the waves.

5.5. Logistics Management

5.5.1. Assumptions of O & M requirements

- On average, each visit to a turbine is 10 hours and requires a team of 4 technicians to expedite quicker job completion, so each COT would service one turbine per day.
- There are 6 COTs and 24 technicians on each vessel
- For significant wave heights up to 2m, each lift operation takes less than 10 minutes and for significant wave heights up to 4m, each lift operation takes up to 15 minutes.
- Lifting operations can be carried out outside of daylight hours.
- Each turbine requires 6 visits per year in total, with the ratio of scheduled to unscheduled maintenance being 1:5 [1].
- Condition Monitoring Systems are sophisticated enough to determine the nature of unscheduled maintenance, and therefore if a COT and team is not sufficient to fix it.

5.5.2. Wind Farm Supporting infrastructure

It is suggested that there will be at least one permanent platform per project which would not only serve as the electrical distribution point, but also as a warehouse for spare parts and fresh supplies. This platform would act as a refuelling point for the vessels and a changeover place for new crew and technicians on the vessel, who would swap shift every two weeks. The transport to and from the shore would be either by helicopter or by large vessel. This takes 1 day out of the working period every 2 weeks leaving 13 days for maintenance of the turbines.

5.5.3. System Productivity

There are 334 working days of the year that the vessel will be able to maintain the wind turbines, this takes into account holiday periods, return trips to replenish stocks and maintenance periods for the vessel. Each vessel can hold a maximum of 6 COTs therefore the theoretical maximum amount of visits per year is 2004 solely scheduled visits. The added unpredictability of unscheduled maintenance would result in a realistic number of visits per year being fewer than 2004.

5.6. Cost Analysis

As data for Round 3 Wind Farms is unavailable and there is a non-linearity regarding their relationship to existing wind farms, cost benefit analysis of the O & M system becomes complicated to model. From the study by Seaspeed Marine Consulting Ltd Uk [1] there is a direct correlation between the increase in vessel investment and operational cost and the increased availability of the turbines, justifying a vessel with larger initial investment.

5.6.1. References

- [1] *Performance Evaluation Of Wind Farm Support Vessels*, S. Philips, Seaspeed Marine Consultants Ltd. RINA Conference 29-30 January 2014, Design & Operation of Wind Farm Support Vessels, London uk.

6. Areas for further development

Certain aspects of the overall system are not state-of-the-art but others are conceptual. This chapter will address potential technology gaps, describing these gaps and themes for further development in areas of technical feasibility, safety, environment, production, logistics etc.

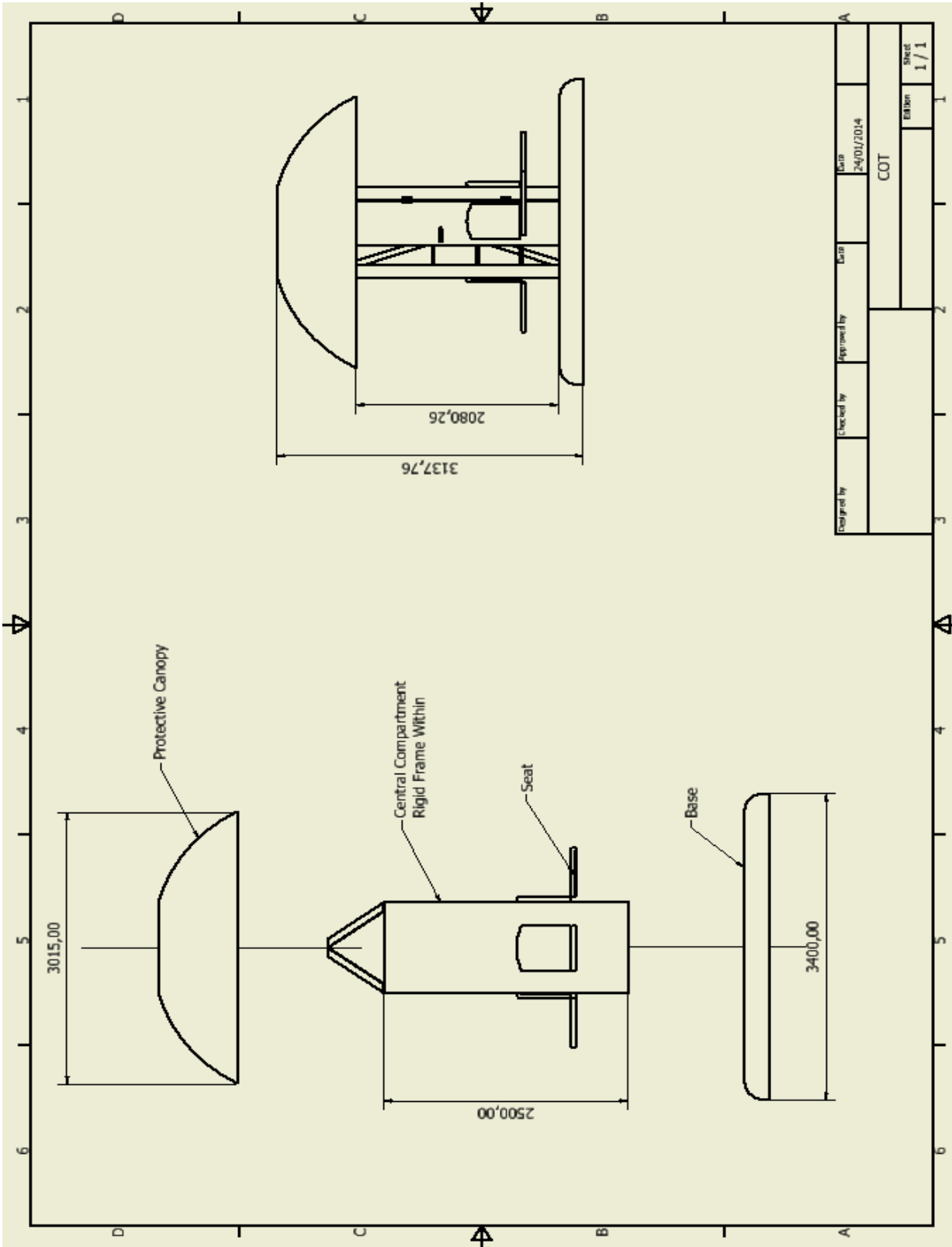
Technical Feasibility	Turbine connection point - Strength calculations needed, considering weight of boom, COT and transfer system. Angular movement needed joint between boom and connection point to be developed.
	Vertical Connection Tubes - Stress & strength calculations necessary to dictate requirements
	Boom - Wealth of technology from factory industry for design of transfer system in boom
	Connection Pod - The nature of the COT connection (magnetic, mechanical, hydraulic, electric etc) needs to be researched and developed. Research is needed to find solutions to loading issue with Cots close to tower
	Support Frame - Clear issue with moving COTs on loading bay, specifically COTs closer to the tower. The lateral movement of the support frame not sufficient for boom to hang above COTs close to tower
	Tower - The heave compensating system within tower is one of the big gaps. Technology can be taken from crane industry. (The current allowable lateral force is 200kN [1])
	Platform – Research is needed to investigate if securing measures are necessary in rough weather
Safety	Turbine connection point - clamp strength and joint strength paramount to safety of technicians. Independent certification will be implemented
	Vertical Connection Tubes - Quality and durability must be assessed to ensure safety of crew
	Boom - Bending resistance and strength needs to be of the highest order
	Lifting method - Rigorous inspection and testing needed
	Support frame - In transit the support frame protects the COTs and crew members from boom
	Vessel subject to SOLAS regulations
Environment	Decisions made on transport, manufacturing and decommissioning will be influenced by environmental impacts. Vessel subject to MARPOL regulations
Production	Material cost must be traded off with strength and quality, the latter being crucial. Contracts given to companies offering the best combination. Maintenance and support will be provided by manufacturers
Logistics	Production and manufacturing
	All components that directly involve the transport of technicians will be subject thorough routine inspection and maintenance plan needed. Replacement and installation location

References

- [1] *Performance Evaluation Of Wind Farm Support Vessels*, S. Philips, Seaspeed Marine Consultants Ltd. RINA Conference 29-30 January 2014, Design & Operation of Wind Farm Support Vessels, London uk.

7. Appendices

7.1. Appendix 1: Technical Drawing Of COT System



7.2. Appendix 2: Material Selection and Weight Calculation

Each component of the COT is specified with the appropriate material for strength and weight calculations. The CES Edupack is used to obtain the material specifications [1].

Bottom Plate: The bottom plate must be strong enough to withstand an impact if the COT is swinging around during heavy weather transfers. Aluminium is selected as the material for the COT, reducing the total weight of the structure and aluminium is also durable in sea conditions.

Aluminium	
Density	2900 kg/m ³
Price	1.64 GBP/kg
Young's Modulus	70 GPa
Yield strength	300 MPa

Impact Force

Based on 2000 kg capsule moving at 5mph (2.23 m/sec),

$$\frac{1}{2} m v^2 = Fd$$

With a 0.25 diameter fender,
a stopping distance of 0.2 m (d) is assumed.

The impact force is,

$$\frac{0.5 \times 2000 \times 2.23^2}{0.2 \times 9.81} = 2534 \text{ kg}$$

Safety factor of 1.3 gives 3300kg (32.4 kN).

Fixed – Free Euler buckling

$$P_e = \frac{\pi^2 E I}{4 L^2} \quad I = \frac{B D^3}{12}$$

It is assumed that any impact will act as a single point load due to the circular shape of the base. The breadth of the aluminium at that point is assumed to be 0.012m (B) and the length of the fixed-free column is 1m (L) .

$$D = \sqrt[3]{\frac{P_e 48 L^2}{\pi^2 E B}} = \sqrt[3]{\frac{3300 \times 9.81 \times 48}{\pi^2 \times 70 \times 10^9 \times 0.012}} = 0.057 \text{ m} = 60 \text{ mm}$$

$$\text{Total } m^3 \text{ of aluminum} = 0.06 \times \pi \times 1.5^2 = 0.43 \text{ m}^3$$

$$Total\ weight = 0.43 \times 2900 = 1229.9\ kg$$

An aluminium-grated floor is specified to reduce weight. From the brochure [1] using a concentrated load of 33kN over a 1metre span the weight of the product is 84 kg/m³. The total weight of the floor is,

$$84 \times \pi \times 1.5^2 = 593\ kg$$

A 50% reduction on the solid aluminium bottom plate

Storage Doors/side panels and shelves

$$Weight\ of\ side\ panels = 4 \times 1 \times 2.5 \times 0.003 \times 2900 = 87kg$$

Using Pined – Pined Euler buckling (the most severe case), the lateral load required to buckle the panel is,

$$P_e = \frac{\pi^2 EI}{L^2} \quad I = \frac{1 \times 0.003^3}{12} = 2.25 \times 10^{-9}$$

$$P_e = \frac{\pi^2 \times 70 \times 10^9 \times 2.25 \times 10^{-9}}{2.5^2} = 248\ N$$

The lateral load is applied in the strongest plan of the panel (lateral compression). The panel alone would not support the weight applied by the seated crew. Therefore, structural bracing is required to support the weight of the seats and crew (Figure 2).

Structural frame

The specification for the frame is 50mm diameter aluminum hollow tubing with a 3mm wall thickness.

The cross sectional area is,

$$(\pi \times 0.025^2) - (\pi \times 0.022^2) = 4.4296 \times 10^{-4} m^2$$

The maximum applies stress is,

$$\sigma = \frac{F}{A} = \frac{12.98 \times 10^3}{4.4296 \times 10^{-4}} = 29.3\ MPa$$

Therefore the yield stress is not the defining design criteria. Calculating the buckling stress for a pinned-pinned column,

$$I = \left(\frac{\pi \times 0.025^4}{4} \right) - \left(\frac{\pi \times 0.022^4}{4} \right) = 1.23 \times 10^{-7} m^4$$

$$P_e = \frac{\pi^2 \times 70 \times 10^9 \times 1.23 \times 10^{-7}}{2.5^2} = 13.575 kN = 1.384 tonnes$$

The total weight of the structural frame is,

$$(4 \times 2.5 \times 4.4296 \times 10^{-4}) + (8 \times 1 \times 4.4296 \times 10^{-4}) + (4 \times 0.71 \times 4.4296 \times 10^{-4})$$

$$= 9.23 \times 10^{-3} m^3$$

$$9.23 \times 10^{-3} \times 2900 = 26.77 kg$$

Using the same aluminium tubing for the bracing on the doors, the extra weight of the bracing is,

$$2.88 \times 8 \times 4.4296 \times 10^{-4} = 0.01 m^3$$

$$0.01 \times 2900 = 29 kg$$

The Total Weight of the capsule:

Bottom plate	600kg
Floor fender	100kg
Side panels	87kg
Structural frame	56kg
Seats	12kg
Crew weight	400kg
Tools and equipment	500kg
Total	1755 kg

References

- [1] CES EDUPAC, (2013), Material Selection Software

7.3. Appendix 3

Results from Maxsurf 3D Modelling programme for the OMV hull resistance:

Speed (kts)	Resistance (N)	Power (kW)
10.0	62688.43	322.4971
10.5	74627.65	403.1137
11.0	89724.85	507.743
11.5	107063.42	633.3991
12.0	127678.89	788.2043
12.5	156407.93	1005.79
13.0	199052.78	1331.221
13.5	257337.38	1787.208
14.0	324530.84	2337.343
14.5	388365.13	2896.988
15.0	441021.3	3403.214
15.5	484729.69	3865.181
16.0	528573.75	4350.749
16.5	583284.13	4951.11
17.0	659009.16	5763.401
17.5	765539.45	6891.982
18.0	965076.92	8936.612

