

Optimizing for Operability and Safety

Offshore Wind Farm Operations & Maintenance Vessels and Workboats

By: Guido F. Perla, PE, Chairman | Guido Perla & Associates, Inc.
Stefan T. Wolczko, Naval Architect | Guido Perla & Associates, Inc.

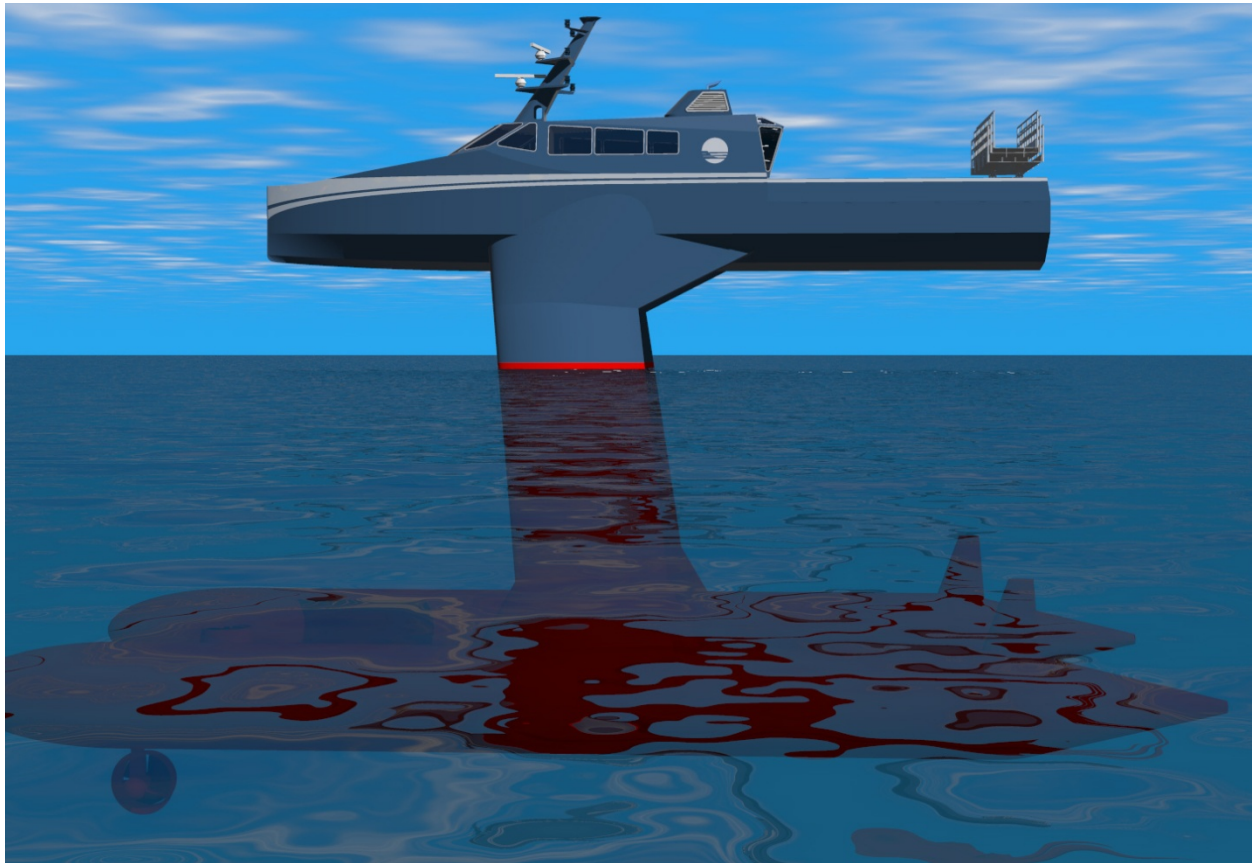


Figure 1 - Karenamar at operating draft

Introduction

Guido Perla & Associates – Company Profile

Guido Perla and Associates, Inc. (GPA) is a full service naval architecture and marine engineering firm in Seattle, Washington, United States, with subsidiaries in China, Germany, Chile and Brazil. GPA has 31 years of experience in continuous service to the international marine community, and is well known for its practical and cost-effective design philosophy. The company has worked primarily in commercial vessels and work boats, most notably including offshore support vessels, passenger vessels, tugs, research vessels, and fishing vessels. GPA's services range from concept and preliminary design work to production engineering and shipyard support engineering. The company's extensive knowledge of and experience with the offshore industry enables GPA to transition into offshore wind support and crew transport vessels as these

two industries are very similar in many regards. The following paper details the vessel that GPA has adapted to provide the optimum combination of safety, functionality and performance for the next generation of offshore wind operations and maintenance vessels.

Project Background

In 1972, GPA Founder and Chairman Guido F. Perla was studying naval architecture at the University of Michigan. It was at this time that Mr. Perla had a realization—that the basic fundamentals of surface ship design are flawed. Ships are the only vehicle designed by man that operates at the interface of two fluids, and essentially, this is the cause of almost every difficulty in naval architecture. Trying to find a solution to this dilemma, Mr. Perla started to work to address this issue, and thus, the *Karenamar* concept was born. *Karenamar* is a vessel with an advanced hull form designed to absolutely minimize vessel motions. The idea was somewhat before its time, however, as it is a complex design and the microcomputer technology needed to control it was nonexistent at the time of its conception. The challenges of the operations and maintenance needs of the offshore wind industry demand advanced vessel capabilities such as those offered by *Karenamar*; fortunately the technology needed to successfully implement this concept is now readily available. The GPA team firmly believes that this concept is both feasible and the ideal solution for the challenges facing far-offshore wind operators.

The offshore wind industry is rapidly growing. All over the world, notably in the UK, industry and government are working to create a reality in which wind energy is a commodity harvested as efficiently as possible. Improvements in operations strategy and planning are being made, new technology is being developed, and changes to political policy are being enacted to achieve this goal. The number of wind turbines in operation is constantly growing. Several factors, including the need for greater turbine availability and the progression toward wind farms that are larger and considerably farther offshore than present practices permit are creating a demand for offshore wind farm Operations and Maintenance Vessels (OMVs) that are more adaptable and able to operate safely in rougher conditions.

The UK, which has been increasingly dedicated to renewable energy over the past decade, has assumed a role as one of the primary leaders in the drive forward for offshore wind power. The UK has committed itself to provide for a significant amount of its own power demand—as much as 40% of its total electricity consumption by 2020—with renewable energy sources.¹ This is a radical increase over current UK renewable power generation, which is roughly one tenth of that figure, and will require significant development in the offshore wind energy sector.

Offshore wind power development in the UK began in 2000, when The Crown Estate, owner of the UK coastal seabed out to a distance of 12 nautical miles (22.2 km), announced what is referred to as Round 1 of UK offshore wind farm development. This was a pilot program of leasing offshore territory under which areas of seabed were made available to offshore wind farm developers. The limits were set to 10 square km in size with a maximum of 30 turbines. The total capacity of awarded leases was 1.5 GW.²

¹ The Carbon Trust “Offshore Wind Power: Big Challenge, Big Opportunity”, 2008

² The Crown Estate; http://www.thecrownestate.co.uk/offshore_wind_energy, retrieved 14 Jan 2011

Following the success of Round 1, in 2003, The Crown Estate announced the results of the competitive tender process for Round 2 wind farms. The awarded leases were located farther offshore than Round 1 projects, and included significantly greater power generating capacity, at a total of 7.2 GW. In 2008, the Crown Estate announced Round 3, granting wind farm developers leasing contracts totaling 25 GW of power generating capacity, with wind farms located even further from shore, split into nine areas, with some of the areas reaching the UK continental shelf limits. Round 3 wind farms are expected to be completely installed by 2020.³ Data have shown potential for development of new wind farms in the UK and around Europe following Round 3 as well. The creation of a long-standing and sustainable offshore wind industry is underway. Industry research, while recommending new policy and significant investment, is optimistic about the opportunities for growth now and in the future.⁴

The drive further offshore and toward greater offshore wind power output in the UK is not unchallenged, however. In addition to political and permitting obstacles that offshore wind developments must overcome, the environmental and engineering problems inherent in offshore installations in locations such as the North Sea are formidable.

Environmental obstacles to the development of offshore wind farms come about largely due to the potential impact of large wind turbine installations on native animal life. As a result of these concerns in the UK, The Crown Estate performs Environmental Impact Assessments (EIAs) to determine which sites will be suitable for development.⁵ The large scale wind farms planned for Round 3 have been located based on constraints imposed by these EIAs, and as a result, much of the installed power generation for Round 3 will be placed in far-offshore in locations such as Dogger Bank.⁶

Wind farms such as Dogger Bank will be roughly 200 km offshore, which makes them both difficult to reach and exposed to more consistently rough conditions than Round 1 or 2 wind farms. Additionally, these wind farms are projected to have up to 9 GW per installation, which translates to a range of several hundred to well over one thousand turbines per development. This quantity of turbines is unprecedented in any installment globally.⁷ Large distances from shore and exposed offshore conditions can complicate construction—limited weather windows when turbines can be safely installed can impede development efforts—and they can also complicate the issue of operations & maintenance. Maintenance and repair missions will inevitably be required during all seasons with so many turbines in operation, and this will require the ability to perform these missions in adverse conditions.

Given these concerns, it is arguable that the present state of the art in wind farm operations and maintenance, which often involves the use of small, high-speed catamaran Personnel Transport Vessels (PTVs), exhibits a technology gap in the context of Round 3 wind farms. The preferred methodology with these vessels to interface between a PTV and a wind turbine structure is simply to power the PTV up against the foundation while personnel disembark onto a ladder.

³ The Crown Estate; www.thecrownestate.co.uk, retrieved 14 Jan 2011

⁴ RenewableUK; “UK Offshore Wind: Building an Industry”, 2010

⁵ The Crown Estate; www.thecrownestate.co.uk/environmental_considerations retrieved 13 Jan 2011

⁶ The Carbon Trust “Offshore Wind Power: Big Challenge, Big Opportunity”, 2008

⁷ The Crown Estate; http://www.thecrownestate.co.uk/our_portfolio/marine/offshore_wind_energy/round3/r3developers.htm, retrieved 13 Jan 2011

While the simplicity of this method is appealing, the level of risk associated with such a maneuver quickly becomes unacceptable as sea state increases. Other options include the use of significantly heavier displacement vessels fitted with motions-compensated gangways, but even this solution has limits that will make it impractical for operation in a Round 3 wind farm. The environment requires a solution uniquely suited to the obstacles associated with these new wind farms.

Karenamar is well suited as a solution to this engineering problem. In the recent past, GPA has invested a significant amount of research and development (R&D) work into this concept for use in transporting crew to far-offshore oil rigs, which is shown below in Figure 2. Much of this work is applicable for the design’s adaptation into the offshore wind operations and maintenance market.



Figure 2 - The Karenamar concept in use as an offshore oil industry crew boat

Design Details

Dimensions

The characteristic dimensions of this vessel can be seen below in Table 1.

Table 1 - Principal Characteristics

Principal Characteristics	
Length, Overall	41.5 m
Breadth, Overall	18.5 m
Operating Draft	12.7 m
Operating Air Draft	12.4 m
Displacement	665 MT
Installed Power	1100 kW
Cruising Speed	12 knots

Capacities

The *Karenamar* concept carries 15 operations and maintenance personnel, is operated by 4 crew members, and carries 1 metric tonne of cargo (tools/parts). With these capacities, this vessel can effectively accomplish a variety of missions and meet all of the maintenance and repair needs of a Round 3 wind farm:

1. A single major repair mission (*up to 1 MT of equipment, 5 crew required*)
2. Several (up to 7) simultaneous minor repair missions, depending on turbine vicinity (*up to 100 kg of equipment, 2 crew required per mission*)
3. Several (up to 7) simultaneous manual restart missions, depending on turbine vicinity (*up to 25 kg of equipment, 2 crew required per mission*)
4. At least 3 simultaneous planned maintenance missions, depending on maintenance crew and tools/parts requirements (*up to 300 kg of equipment, 2 – 5 crew required per mission*)

The vessel's cargo is carried on an open aft deck measuring 7.5m in length and 4.5m in breadth. This deck is protected by plate bulwarks and a plate bulkhead on all sides. These measurements do not include the stowage area for a crew transfer system, which is mounted near the transom, but do include three escape hatches from the below-deck spaces (which must be kept clear). The design places the cargo deck aft so that it can be positioned as near to the turbine foundation as possible, making crew transfers and nacelle crane cargo transfers simple and safe.

The vessel carries enough fuel to make a round trip at cruising speed from shore to a wind farm that is 300 km offshore, though it is not intended to do so in normal operations.

Design Characteristics

Hull Form

The hull form employed in this design is of the ultra-small waterplane area type. Utilizing advanced technology over the conventional Small Waterplane Area, Twin-Hull (SWATH) concept, this design minimizes the waterplane area of the hull form—far more than any existing displacement vessel—in order to achieve the absolute smallest seaway-induced motions possible. Effectively, the concept abandons the idea of using waterplane area for stability, which allows this area to be minimized to the structural limits of the hull strut material, which is steel, along with the rest of the hull.

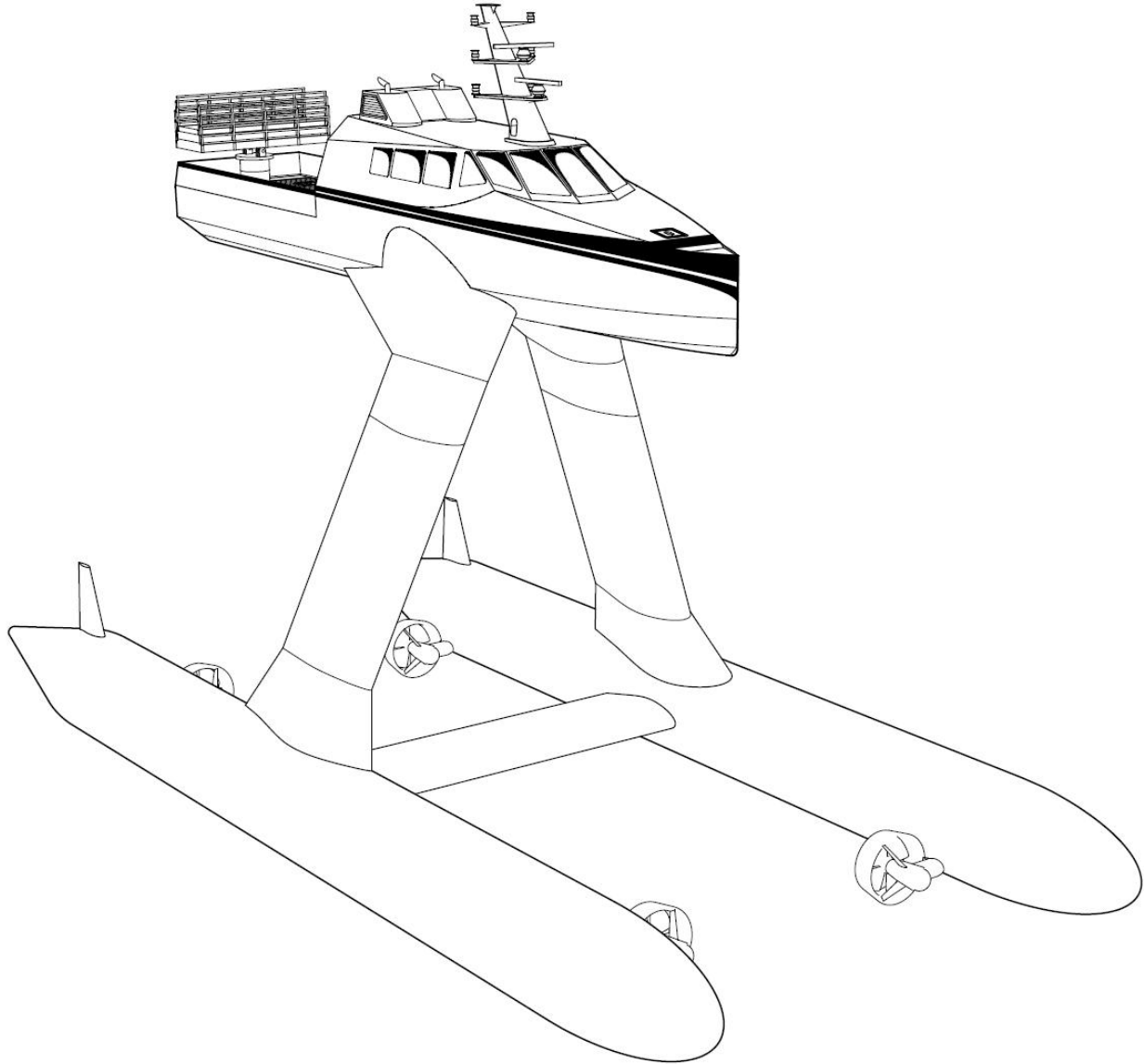


Figure 3 - Perspective design sketch

This scalable concept provides a stable and virtually motionless platform in considerably rough conditions. It is highly maneuverable and inherently adept at station-keeping with little input from the vessel's thrusters. The hull form is optimized to provide a safe platform to conduct operations interfacing between itself and fixed structures.

As shown in Figure 3, the hull form employs two deeply submerged, sub-surface demihulls, connected by a triangular strut arrangement. The two upper struts connect to the main central hull, which houses the personnel and accommodations, power plant, a number of auxiliary systems, the cargo deck, and the bridge. The main central hull always remains above the surface of the water. The demihulls are connected to each other with a horizontal hydrofoil strut. This hydrofoil is fitted with control surfaces to adjust—in concert with an azimuth thruster system—elevation and transverse attitude of the hull during transit. The depth of these demihulls below the surface is determined by weather conditions and to minimize surface wave

making while in transit. In calm weather situations, the vessel can rest on the main central hull to save fuel normally consumed by maintaining altitude.

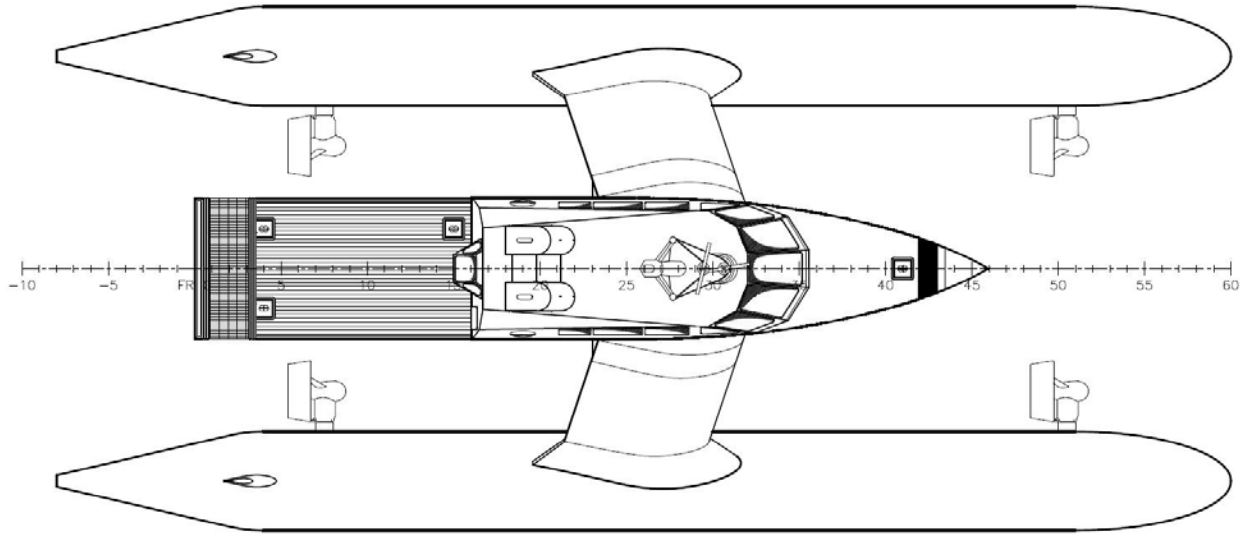


Figure 4 - Thruster arrangement

Propulsion, Dynamic Positioning and Dynamic Stability

The demihulls are fitted with two pairs of transversally-oriented “swing-up” type, external electric drive azimuth thruster units—one pair forward and one pair aft—as can be seen in Figure 4. These drives, which are in the up position (horizontal azimuth axis) by default, can be swung down any amount up to 90°, to the vertical position (see Figure 5). This allows the azimuth drives to provide thrust in all directions (vertically, longitudinally, and transversally). These thrusters, in conjunction with the mid-body hydrofoil and the ballast tanks, control the direction of travel of the vessel, the vessel’s attitude, and its altitude. This arrangement allows for 3-dimensional dynamic positioning (DP) system to be achieved with a total of four thrusters.

The demihulls house the support equipment for these electric thrusters, as well as tankage for ballast, diesel fuel, and other miscellaneous fluids. Also contained in the demihulls are ducts for a high-flow rate air system, which replaces the use of multiple pumps for moving ballast (as well as other fluids needed for vessel operation). High-volume, low-pressure screw compressors use these ducts to move air into tanks open to the sea, and utilize hydraulic action to displace large amounts of ballast out of the vessel at a high rate. This allows the ballast system to aid in maintaining the vessel at a steady upright position on a desired waterline without absolute dependence on the thrusters.

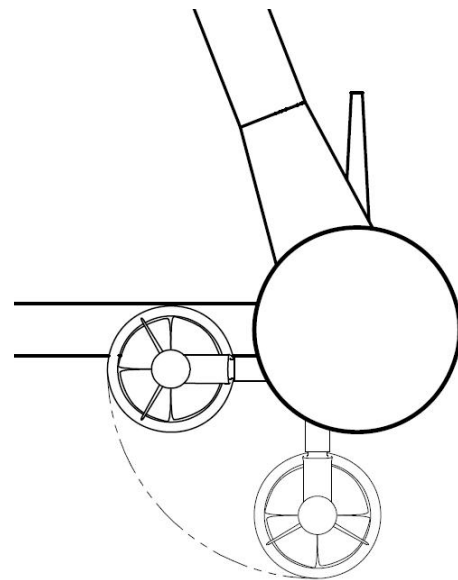


Figure 5 - Section view of swing-down thruster

It should be noted that while this vessel is stable in the dynamic condition, like a bicycle or a person walking, it is not statically stable (at the operating draft). The vessel is engineered to be stable while not moving with the use of the propulsion/DP thrusters as well as the ballast system. This system of thrusters and ballast tanks, however, are too complex to be controlled directly by user input, and therefore the propulsion, stability and DP controls must use a computer program as an intermediary between the thrusters and the user interface, similar to a flying wing or other advanced fly-by-wire aircraft.

Unlike these aircraft, however, this design has been engineered to safely handle mechanical failures, including a worst-case total failure of these systems. In a case where the vessel loses all power, the design of the hull, the loading condition of the vessel, and the default ballast configuration at any given time will be such that the vessel will be slightly negatively buoyant at the operating draft. This will result in the vessel settling onto a safe waterline on the main central hull, on which the vessel will become inherently statically stable and allow the crew to affect repairs to the vessel.

Operational Capabilities

The primary driving requirement for designs in this field is the need for an operating platform that exhibits minimal motions in considerably rougher conditions than those seen in present-day wind farms. The movement of offshore wind farms to locations farther offshore, namely to the order of hundreds of kilometers away from land, has placed these wind farms in an environment where wind turbines and their operators will need to reckon with the full force of bluewater meteorological and ocean (met-ocean) conditions.

Barring fluke minor equipment malfunctions, the most likely time for a turbine component to fail is when it is under stress in the higher end of the range of tolerable met-ocean conditions that the turbine will experience. Therefore, repairs and maintenance work that can be done in adverse met-ocean conditions will be at a high premium as wind farms move into less protected waters.

Motions

Karenamar was specifically designed to naturally exhibit strictly limited motions in a seaway. Judging by the measure of waterplane area, or the area of the intersection between the enclosed volume of the hull and the surface of the water, the excitation forces exerted by the sea to cause motions will be very small. This is largely due to the fact that this vessel has a small fraction of the area exhibited by a typical vessel of similar displacement. Generally speaking for a given displacement, a vessel's seaway motion excitation forces are proportional to the area of the waterplane, which is the theoretical background behind vessel types such as SWATHs. Unlike the SWATH hull form, however, *Karenamar* is a design that takes advantage of this quality as far as contemporary technology permits.

Karenamar has many advantages over her closest conventional cousin, the SWATH. The side area on the struts piercing the surface (which is considerably smaller than that found on a SWATH of similar displacement), as well as the lower foil section, greatly diminish the transverse forces experienced by SWATHs in heavy weather, which have been known to cause racking, and subsequently, structural problems in SWATHs. Additionally, the chronic issue of resonance in SWATH motions in a seaway is eliminated with a *Karenamar*-style hull form, as these vessels do not rely on waterplane area for stability as a SWATH does.

Hindcasted wave data reflecting the probability density for the occurrence of a given sea state indicate that a design for future offshore wind farm OMVs should be able to safely operate in seas of at least 3m significant wave height in order to increase effectiveness over the current state of the art. The unique hull form and thruster arrangement of this design will result in motion amplitudes on the order of a few centimeters in seas exceeding 3m of significant wave height. Assuming that a competing vessel (such as a smaller offshore vessel) would be limited to operations in 1.5m of significant wave height, *Karenamar* would be operable at least 55% more frequently than the conventional vessel.⁸

Speed

An important consideration in the design of an offshore wind farm OMV is its operating profile. In large wind farms, such as those planned in the UK Round 3 wind farms, careful attention will need to be paid to the logistics of maintaining the large numbers of wind turbines that will be in service. Included in these considerations will be the number of OMVs needed, which will be dependent on the speed and payload of these vessels. *Karenamar* has been optimized for an operating profile designed by the GPA R&D department, which involves multiple OMVs based from a mother ship or fixed platform located at the wind farm.

This operating profile primarily consists of multiple planned maintenance missions (normally three) being carried out by one OMV at any given time during a day shift. The vessel will leave the mother ship at the beginning of each shift and return at the end of the shift, with all primary hotel facilities contained by the mother ship. This profile, which is characterized by short-distance passages, allows for the vessel to move at lower speed than a vessel required to make long-distance passages. This is specifically an advantage over vessels that work from shore or other distant base points, as it permits less displacement in the design than a larger power plant—for a faster vessel—would require.

Based on the projected size of the large Round 3 wind farms and, more specifically, the likely size of the service areas that one of these vessels would operate in (roughly 200 turbines per service area), 12 knots was chosen as the cruising speed for this type of vessel. This speed allows both expedient trips (on the order of one half hour, one way) and excellent fuel economy, which is enhanced by the deep submergence of the demihulls. This design element eliminates wave making resistance from the demihulls. This quality, along with the difference in hull pressures between submerged and surfaced hulls, eliminates the large changes in trim generally associated with SWATH designs at different speeds, in addition to lowering total resistance.

According to regression-based and theoretical resistance calculations performed by GPA, a power plant of 1,100 kW will be adequate to make this cruising speed. At peak consumption, this power plant will consume 234 L of diesel fuel per hour. It is anticipated that the average hourly fuel consumption will be considerably less than this figure, however, as a significant amount of the vessel's working day will likely be spent in the DP or loitering modes while supporting maintenance crews, which will require much less power than the peak condition.

⁸ Source: NATO STANAG 4194, 1983

Turbine Operations and Personnel Safety

The design of any OMV will require the ability to carry cargo in such a manner as to allow simple loading and unloading with a nacelle crane. As can be seen in Figure 6, this design utilizes an open and unobstructed aft cargo deck to store equipment needed for maintenance and repair missions. Figure 6 also shows the use of an aft-facing DP control station, which grants the

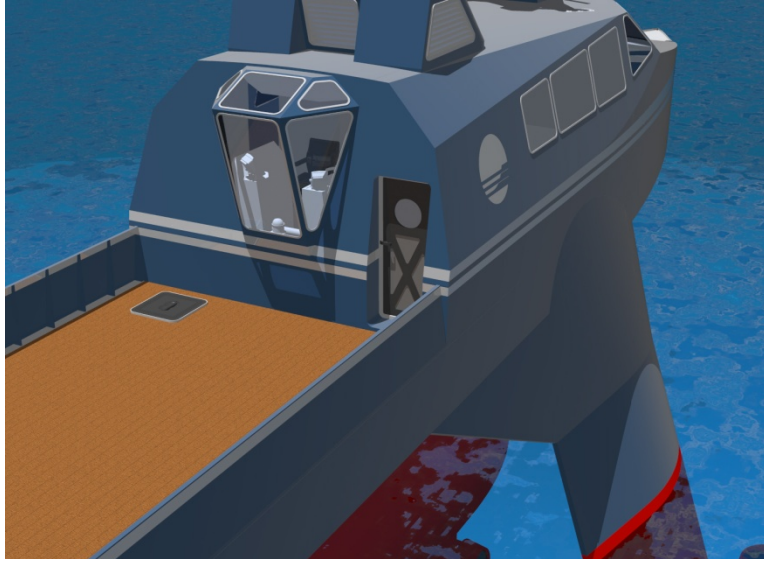


Figure 6 - Cargo deck and DP control station

operator ease of supervision and control over all of the vessel's maneuvers. With this aft control station, operators will be able to effectively evaluate and react appropriately to situations developing while interfacing with the turbine structures.

Crew safety and comfort are of paramount importance to any design of OMVs, but those intended to operate far offshore place particularly high value on these qualities. While the importance of safety is obvious, in locations where weather can be harsh and seas accordingly rough, the ability of the crew to function properly can be seriously impeded by a lack of comfort. Seasickness can be a seriously debilitating condition, as many offshore oil drilling operators have learned in their drive further offshore. Drilling crews have been significantly delayed in beginning a shift due to seasickness resulting from a crew boat trip, and there is risk that this could be replicated in offshore wind crews as their work moves farther into the North Sea and elsewhere.

Crew comfort and safety are primary strengths of the *Karenamar* design. While decreases in motion amplitudes and accelerations offer an increase in personnel comfort and safety on any vessel, in the case of an offshore wind farm OMV, these decreases provide many advantages. In addition to preventing decreased productivity, this design's hull form and its elimination of motions provides a viable solution to the problem of interfacing a vessel with a fixed structure in a seaway. A steady platform on a DP-capable vessel allows operators to maneuver close to a turbine foundation, deploy a crew gangway or other transfer system, safely disembark personnel to the turbine structure, and then offload any cargo. This can be done with a conventional vessel, but the motions of these vessels cause these operations to be prone to accidents and they are restrictive in terms of operable sea states. A vessel with the *Karenamar* hull form can accomplish the same tasks, with low risk of incident, in significantly higher sea states than presently possible with any conventional hull form.

Cost Estimation

Design Development and Construction

The design discussed in this paper is presently at an advanced concept stage, and will require further development to become commercially available. By the estimate of Guido Perla & Associates, roughly US\$1.3 to \$2.0 million will be required to complete the engineering of the vessel prior to the beginning of the prototyping process. Once this has been accomplished, it is estimated that the price of the first prototype will be roughly US\$18 million, if constructed in the United States.

Risk Management

The *Karenamar* design is the first of its kind to be proposed for commercial service. As such, special consideration will be required to permit its use by classification societies and regulatory bodies within national governments. This design will require approval from both parties in the case of a commercial deployment, and special ground work regarding the nature of the safety and risk inherent in this design will be necessary in order to obtain this approval.

Project Status

Funding

Currently, this project has been solely funded as a research and development project at Guido Perla & Associates. GPA will continue to develop this concept internally as it always has done with original ideas, but it should be clear that cooperation with interested parties could be welcome.

Planned Future Development

The plan for development of the concept proposed in this paper includes work in all aspects of the design. One key task will be the development of a DP control system that can operate thrusters arranged as shown in this design and perform accurate station-keeping in three dimensions. Additional to this will be a towed and self-propelled model test series as well as finite-element analysis to optimize the structural arrangement of the vessel. Following this and GPA's other standard ship design practices will be the development of a prototype and eventual commercialization of the concept in an offshore wind farm.

Operability and Safety – Wind Farm Efficiency

The offshore wind industry is a hotbed of innovation and new ideas put into practice. Guido Perla & Associates has determined that OMVs are no exception to this rule. Generally, conventional vessel types cannot transfer crew safely in an appreciable sea state without significant tonnage, and even then, vessel motions present potential hazards. For operations and maintenance work, specialized vessels must be utilized to efficiently address the needs of the maintenance and repair scheme. Additionally, these specialized vessels need to be capable of operating safely in adverse conditions. A conventional vessel newbuild, redesign or retrofit will not be capable of withstanding the operating environment necessary to maintain respectable turbine availability in these far-offshore wind farms.

Karenamar is capable of safely and efficiently maintaining offshore wind farms in conditions that cannot be withstood by present-day operations & maintenance vessels. Wind farms are making the leap to harsher conditions, and the vessels that maintain these wind turbines must keep up with them. Failing to adequately address this need could result in unpreparedness and poor wind farm performance due to low availability. This design provides a viable solution to this challenge, and can contribute significantly to the cost effectiveness of a Round 3 or other wind farm.