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AN INNOVATIVE HULL DESIGN FOR AN OFFSHORE WIND FARM SUPPORT VESSEL

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SUMMARY

A crucial issue for the maintenance of an offshore wind farm is safe access to the wind turbine by the service crew. Current transfer limits are not suited to sites located in more exposed locations further from shore, which are continually being explored by new projects. Weather downtime will increase in these sites if current vessels are utilised. A vessel that can operate safely for a greater percentage of the year is required.

This study discusses a new vessel design to meet the changing demand of the offshore wind sector. Optimised hydrodynamic characteristics allow the innovative vessel to access wind turbines significantly above current limits of 1.5m Hs, thus addressing crew health and safety, and comfort. It utilises narrow catamaran hulls to minimise waves load and has a heaveplate at a deep draught to restrict heave and pitch motions. The design was numerically modelled in ANSYS AQWA and experimental trials to evaluate the operational aspects of the design were carried out in Lir National Ocean Test Facility at 1:25 scale. It was demonstrated that the design can access wind turbines up to a Hs of 3.5m at an estimated cost that is less than that of a SWATH.

NOMENCLATURE

[Symbol]	[Definition] [(Unit)]
Hs	Significant wave height (m)
P	Pressure (N m^{-2})
M	Mass (kg)
LCG	Longitudinal Centre of Gravity (m)
VCG	Vertical Centre of Gravity (m)
C_B	Block Coefficient
C_{RW}	Service Range Coefficient
C_o	Wave Coefficient
C_L	Length Coefficient
I_{xx}	Moment of Inertia ($kg.m^2$)

1. MODEL DESIGN

1.1 DESIGN METHODOLOGY

When accessing offshore wind turbines, vessels must keep their motion minimised in order to operate safely. The wave-induced accelerations on the vessels hinder the transfer of personnel from vessel to wind turbine as well as the operation of a crane for the transfer of replacement parts. In addition, when operating a wind farm it is costly to have wind turbines broken down so i. Increasing the weather window that a vessel can get service personnel on and off the wind turbine directly increases the wind farms output.

Generally catamarans are used as support vessels, these, are mostly small and fast vessel s of a length up to 30m mainly developed for the transfer of service technicians and materials from shore to the wind farm. These vessels are for the most part restricted to a maximum significant wave height of 1.5m.

For current wind farms it is possible to carry out day return journeys to the offshore wind farm but as the wind farms are constructed further offshore this will become a major issue. When the outgoing time is longer than a normal working day there will be a requirement to operate in conjunction with offshore accommodation platforms and mother-ships to house service crew. For this scenario, a new type of transport vessel could be of benefit, one that is able to stay at the wind farm for long periods and carry out transfers in high seastates.

1.2 DESIGN INNOVATION

With technical and design innovations is it possible to minimise the amount of weather downtime experienced and expand the times where a safety access is possible to an offshore structure. The Grand Draught Catamaran (GDC) as developed in this study and shown in Figure 1 is designed to minimise wave load at time of transfer and to reduce the vessels response to waves.

Narrow hulls reduce the wave force impact to the hull. With the narrow hulls, the catamaran is more stable in waves and the hulls receive a smaller wave load than a wider hull. A large heaveplate set at a deep draught primarily reduces the vessels heave motion and secondarily it reduces pitch motion.

The GDC has a wide breath in relation to its length and is designed to maximise the stability curve, which is compromised by the small water plane area generated by the narrow hulls. The heaveplate is fabricated from steel and the hull from aluminium to ensure a low centre of gravity. It is ballasted with water at a draught of 12m and is connected to the hull by 8 columns.

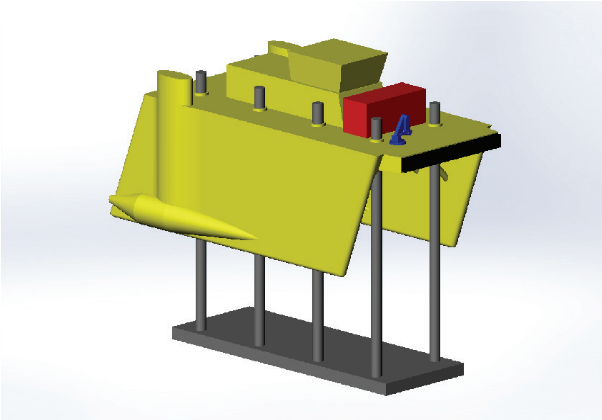

Figure 1: Isometric Design Rendering of the GDC

Due to the narrow hulls, there is a tube constructed at the aft of both hulls for engine rooms for the engine service, fresh air supply and the exhaust. A vertical access chamber is installed from the deck to the engine room.

To prevent any contact between the hulls and the monopile the bow tapers. In addition, there is a large horizontal distance between the front of the heaveplate and the forward perpendicular. The freeboard of the GDC is also large to prevent slamming of the tunnel and minimise water on deck due to large waves and the models reduced heave and pitch transfer functions. Structurally the GDC included struts that braced the slender demihulls to the deck structure of the catamaran, though above the waterline they add to the waveload on the GDC for larger waves.

1.3 MODEL CHARACTERISTICS

The design is based on a catamaran, but with deep narrow hulls and a large heaveplate set at a draught of 12m. The guidelines from the DNV-GL and Lloyds Register were consulted to prepare the pre-dimensioning.[1, 2, 3, 4] The main characteristics of the GDC are presented in Table 1.

The narrow demi-hulls of the vessel are 0.63m wide with a draught of 3.2m. This is too small for a normal engine, hence there is a special compartment at the lower aft end of the hulls, used as an engine room, the start, and the ends of these compartments are cone shaped to reduce resistance.

The lower deckhouse accommodates the service crew area, the first aid ward and the luggage store, and the the bridge and the technical control centre are located in the upper deckhouse. From the technical control centre it is possible to monitor the engine, and use of the crane.

The main engines are two MTU 12V 396 TE74L one of these engines has a rated power max of 1500kW at 1900rpm. In the front of each demi-hull a bow thruster (Sleipner SH 550/386 TC) is installed. The bow thruster enables the vessel to turn in a small area or to stay clear of an offshore structure, which is very important for the safety of the service crew. On the foredeck, a crane is installed to lift parts or equipment to the offshore wind turbine.[5, 6]

Table 1: Main Characteristics of the GDC

Vessel Property	GDC Value
Length Overall	24m
Beam Overall	13.87m
Draught	12m
Vessel Depth	19.65m
Demi-hull Beam	0.63m
Demi-hull Draught	3.2m
Displacement	359m^3
Freeboard	7.65m
LCG aft of midship	1.84m
VCG from underside of heaveplate	7.54m
Block Coefficient, C_B	0.52
Service Range Coefficient, C_{RW}	1
Wave Coefficient, C_o	4.10
Length Coefficient, C_L	0.52
Heave Natural Period	12.1s
Pitch Natural Period	20.8s
Roll Natural Period	38.5s
Metacentric Height	0.095m
Centre of Buoyancy	5.2m
I_{xx}	2 x 10^7 kg.m^2
I_{yy}	3.6 x 10^7 kg.m^2
I_{zz}	1.5 x 10^7 kg.m^2

2. NUMERICAL ANALYSIS

The numerical modelling of the GDC was carried out in ANSYS AQWA in the frequency domain.[7] There was no damping employed in the model simulated, therefore the RAO amplitude at peak frequency tended to infinity. The distribution of volume and mass was estimated from a detailed structural design.

The model was setup so that the structure was free to move in all directions. A point mass for the geometry of the model was defined explicitly along with the Ixx, Iyy and Izz moments of inertia. The draught was set in the geometry file, and the mass was dependent on the mesh generated. A mesh was created comprising of quadrilateral and triangular panels was utilised with a defeaturing tolerance of 0.3m and a maximum element size of 1m. This allowed frequencies up to 0.51 Hz to be modelled. The Hydrodynamic diffraction and radiation problem was then solved for the desired heading angles and frequencies. The mesh setup and pressure distribution for a H_{max} of 6m is shown in Figure 2. The heave, pitch and roll RAO results for five different headings are plotted in Figure 3.

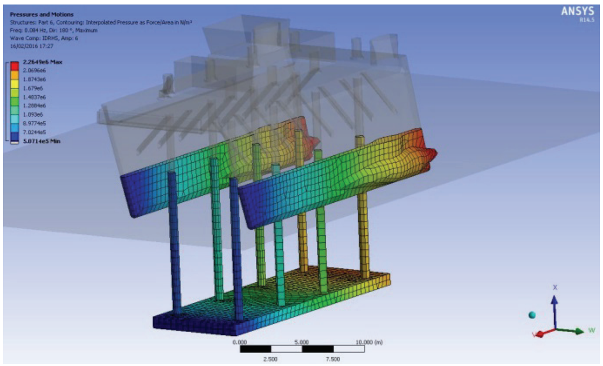

Figure 2: Pressure variation on the GDC Hull

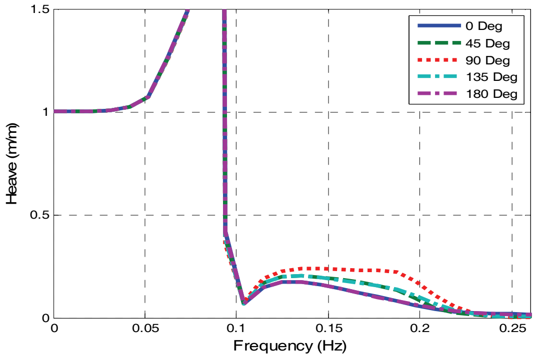

Figure 3(a) Numerical Model RAO - Heave

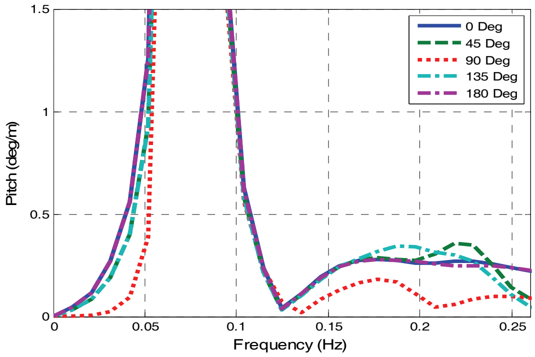

Figure 3(b): Numerical Model RAO - Pitch

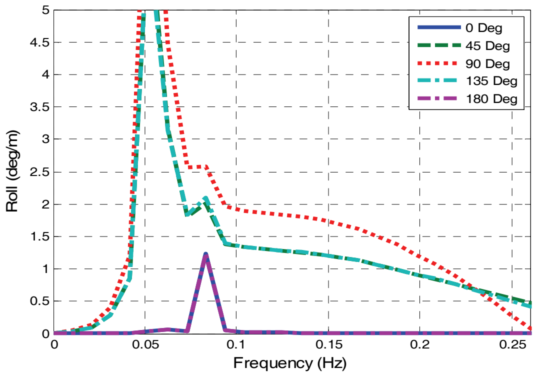

Figure 3(c): Numerical Model RAO - Roll

3. PHYSICAL MODELLING

The physical model testing was carried out at 1:25 scale in Lir. The ocean basin is 25m long 18m wide and has a depth of 1m. The waves are created with a wavemaker comprising of forty bottom hinged flap-type paddles. To minimise reflection in the wavetank there is a beach at the opposite end of the tank to the wavemaker, where wave absorption material is placed. Any waves that return through the tank are accounted for with Funke and Mansard method and are actively absorbed by the wavemaker.

The motions of the system undergoing testing are determined using a Qualysis ProReflex. This system enables accurate motion measurement using a set of reflective markers attached to the device and a camera system which uses infrared LEDs mounted around each lens to track the markers. Wave heights were recorded with wave probes provided using National Instruments LabVIEW Real-Time embedded controllers. All instrumentation was recorded concurrently at a frequency of 32Hz.

The model was tested in three different situations; firstly, a decay test to determine the natural periods shown in Figure 4, secondly, the free RAOs were determined in irregular waves, see Figures 5 and 6, thirdly, the interaction with a monopile was investigated, see Figures 7, and 8.

The free decay of the GDC is shown in Figure 4. The model free floating in a calm tank was initially displaced in heave, pitch, or roll and then allowed to oscillate. The natural period of heave, pitch and roll was recorded as 12.1, 20.8, and 38.5s respectively. The range suggested by the numerical modelling was 10.7 – 13.7s for heave and pitch and 16.0 – 24.0s for roll. The forced oscillation tests presented in Figure 6 found the natural period for heave to be 12.2s and pitch to be 12.0s. These natural periods are generally larger than the peak frequency of most seastates encountered in the North Sea. The damping coefficients of the hydrodynamic forces may be obtained from the free decay tests and then applied to the numerical model.

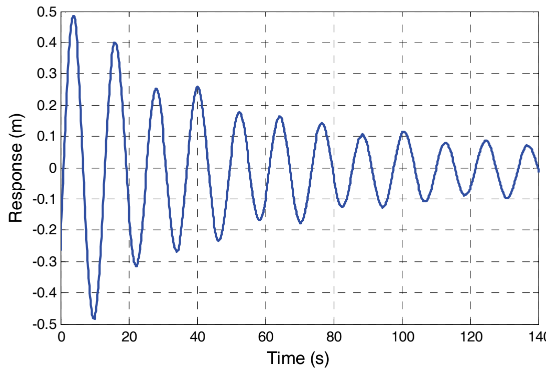

Figure 4: Sample Decay Test, Heave Decay – Natural Period 12.1s

Figure 6: shows the heave and pitch RAO results of 1:25 scale model tests of the GDC and a catamaran at 0 degree heading. The RAO graphs were compiled based on the response of the model to panchromatic waves with peak periods from 4 to 12.5 seconds with a significant wave height from 1 – 3.75m. The model performs well with very little motion being experienced above 0.12Hz. The physical modelling results correlate well with the numerical model for the same heading in both heave and pitch. Comparing the GDC to the catamaran (the catamaran was a 24m long vessel approximating a generic windfarm support vessel) it can be seen that the GDCs heave RAO is smaller than the catamaran for frequencies above 0.12Hz and significantly lager for lower frequencies. In pitch, the GDC is comparable to the catamaran for frequencies below 0.08Hz and gradually reduces as the frequency increases, above 0.12Hz there is very little motion compared to the catamaran.

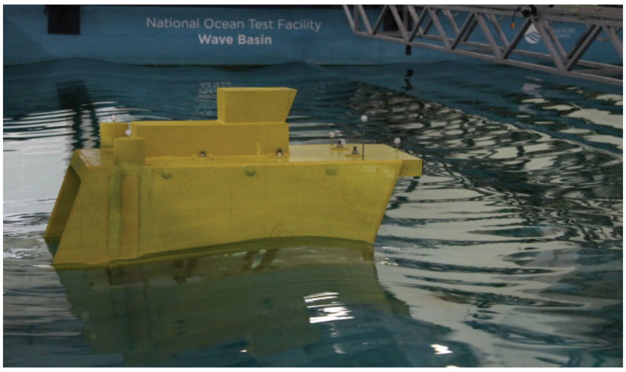

Figure 5: Physical RAO Testing

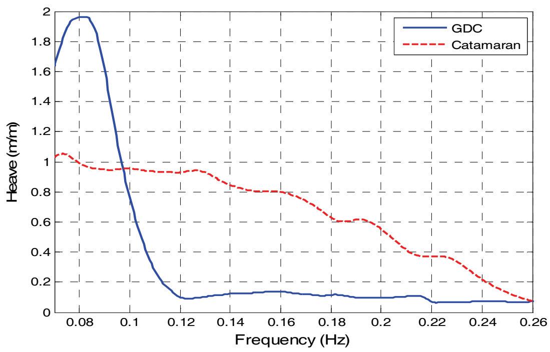

Figure 6(a): Physical Model RAO – Heave

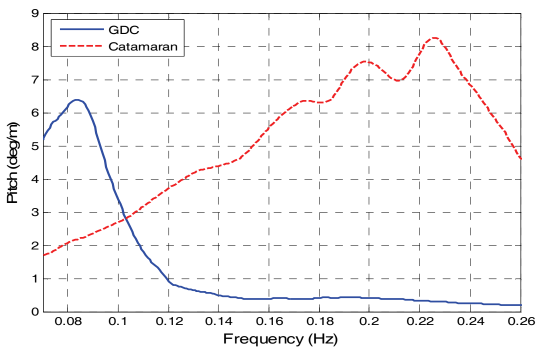

Figure 6(b): Physical Model RAO – Pitch

The interaction with a monopile was tested for five headings 0, 45, 90, 135, and 180 degrees. A monopile was simulated by a low friction pvc pile of about unplasticised polyvinyl chloride (PVC-U) pipe that was bolted to an internal steel box section, that was itself supported on a large diameter galvanised steel frame, see Figure 7. This was then weighed down with approximately 150kg of lead to prevent motions. The top of the monopile was braced to the wave tank bridge to prevent vibrations. To create the bollard pull a small section of the monopile was cut out to allow a line to be run from the model to a series of pulleys in the monopile, a known lead weight were then placed at the end of the line in such a way that it would not be immersed in water.

In Figure 8: the performance plots for the GDC and catamaran are presented, showing the significant wave height at varying angles that they can transfer personnel safety. The method outlined by Seaspeed is used to quantify a confidence limit based on the number of slips per unit time, where a slip is defined as when the frictional contact between the vessel and monopile is broken.[8] For the model testing carried out in this paper that was defined as 0.01m at model scale. Both the GDC and catamaran had a similar setup, with the same bollard pull and fender material. A sensitivity analysis was carried out examining the confidence limit of a slip not occurring, 80%, 75%, and 70% confidence limits are presented in Figures 8(a), 8(b), and 8(c) respectively.

The performance limits that the GDC can provide a safe access is dependent on wave heading, ranging from 1.5m Hs to 3.5m Hs. The GDC performance excels in seas with a heading from 0 - 90 degrees. Though its performance is limited in stern and stern quartering seas, these conditions are rarely encountered.

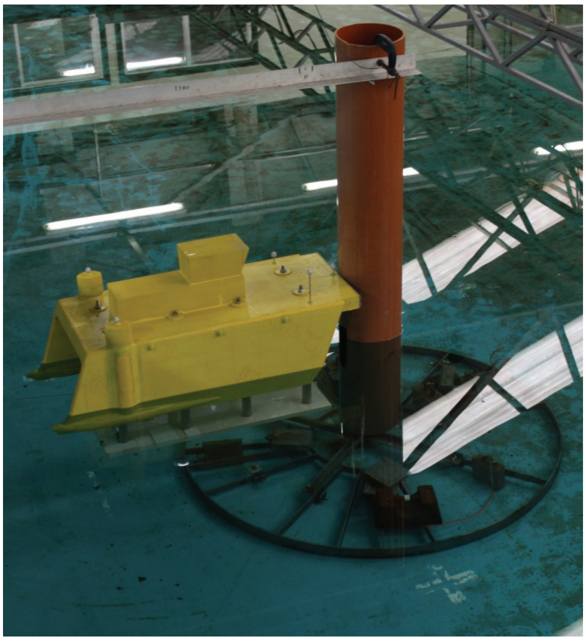

Figure 7(a): GDC and Monopile Foundation Setup

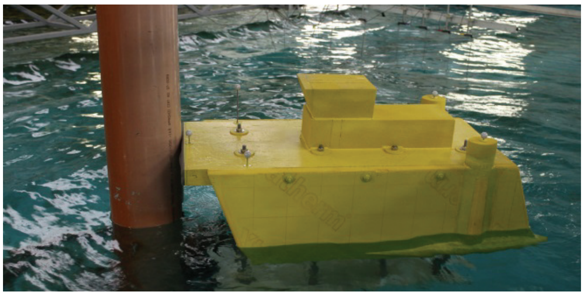

Figure 7(b): GDC and Monopile Foundation Testing

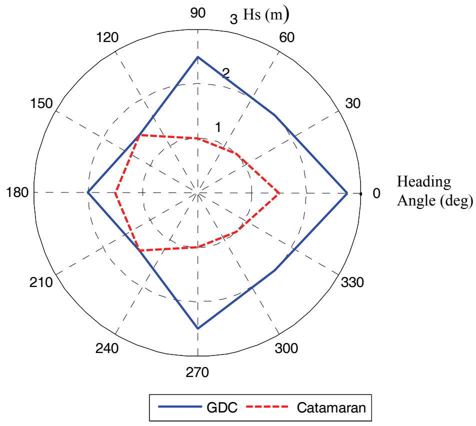

Figure 8(a): 80% Confidence Limit Performance Plot

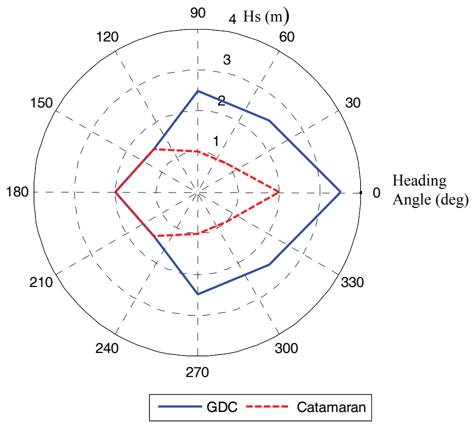

Figure 8(b): 75% Confidence Limit Performance Plot

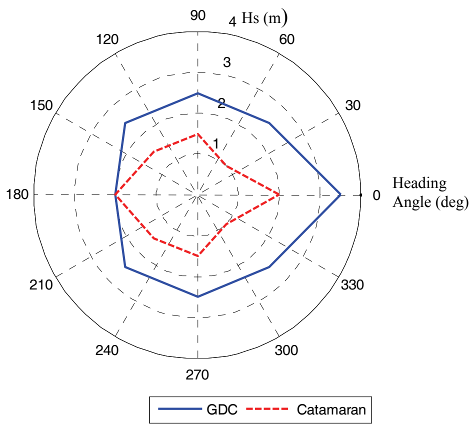

Figure 8(c): 70% Confidence Limit Performance Plot

In Figure 9(a) the towing set up is shown. The ITTC standards were consulted for the towing tests.[9,10] The GDC was towed at speeds of 0.2 – 12.8kn over a 20m distance. The standard displacement hulled catamaran was towed at speeds of 0.1 – 22.6kn over 20m. The length of the tank is not suitable for a precise estimation of resistance, as the top speeds were maintained for a small amount of time. However, they do provide a general impression of the vessels resistance. In Figure 9(b), it can be seen that the GDC has a substantially larger resistance than the standard catamaran. Presently it is possible to run the GDC up to 12.8 knots, as is shown in the resistance test in Figure 9(b). A commercial catamaran runs with double the speed at around 22kn.

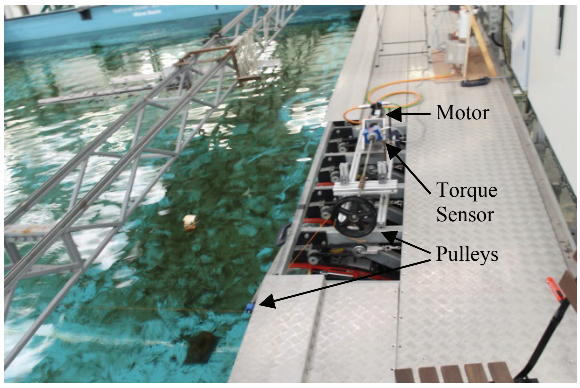

Figure 9(a): Towing Setup, Showing Pulley Setup, Motor, and Torque Sensor

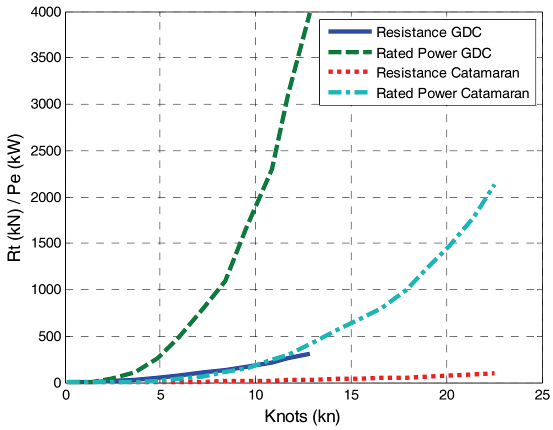

Figure 9(b): Resistance Test Comparison of the GDC and Catamaran

4. COST ANALYSIS

The construction costs of a catamaran with heaveplate are greater than that of a catamaran, but less than that of a SWATH. Nevertheless, this is a preliminary calculation and the cost is dependent on the equipment utilised. At the first calculation, the cost of the hull is the same as the cost of a commercial catamaran. An additional cost for the GDC is the cost for the heaveplate construction and fitting it to the main hull extra and added to the cost of the main catamaran hull.

The order cost of each vessel was calculated from the summation of the relevant components, the additional expenses required for construction, profit etc. were factored from shipyard percentage estimates. Based on this method the GDC was determined to be €5.4M which is more than a commercial catamaran (€3.3M), but it is much cheaper than a SWATH (€11.3M) as is shown in Table 2.

The operational expenses are outlined in Table 3, however they are not entirely measureable, mainly due to an uncertainty at present regarding which main engine, is most suitable for the vessel. Presently the running costs are split between the salary for the employers, the insurance, and the engine operation costs. The salary and the insurance cost are depended by the country where the vessel is operated. The engine that is currently specified has a fuel consumption of 384.5 l/h at full power.

Table 2: Cost Calculation

	SWATH	Catamaran	GDC
Order Cost	€3,928,900	€1,660,000	€2,558,494
Working Hours/Cost	€757,200	€241,500	€290,240
	€4,686,100	€1,901,500	€2,848,734
Engineering Cost	60%	25%	35%
	€7,497,760	€2,376,875	€3,845,791
Running Cost	30%	25%	25%
	€9,747,088	€2,971,094	€4,807,238
Profit	10%	7%	7%
	€10,721,797	€3,179,070	€5,143,745
Margin of Risk	5%	5%	5%
Total	€11,257,887	€3,338,024	€5,400,932

Table 3: Operational Expense

	SWATH	Catamaran	GDC
100% MCR Speed (kn)	18	22	10
Fuel per hour (100% MCR)	400	300	770
Crew members (min.)	2	2	2
Passengers (max.)	12	12	12
Tank capacity (litre)	12200	8400	25000
Service ratio (NM)	274.50	308.00	162.34

5. DISCUSSION

This work shows that the GDC is a catamaran that can perform well in a high seastates, potentially accessing wind turbines at a Hs of up to 3.5m. Although no survivability testing was carried out, the vessel was interacting comfortably with a seastate of Hs 3.75m.

The RAO graphs show the GDC generally performs much better than the catamaran, particularly for frequencies above 0.12Hz.

The GDC provides improved access on a catamaran as can be seen in Figure 8. The performance limits that the GDC can provide a safe access for is dependent on wave heading and the safe working limits, ranging from 1.5m Hs to 3.5m Hs. The GDC performance excels in seas with a heading from 0 - 90 degrees.

However, the drawback of the GDC is the fuel efficiency as can be seen in Figure 9(b). With the current engine, the GDC is currently limited to 10kn and requires about 8 times the power of a catamaran to travel at this speed. For this reason, it is designed to stay at the wind farm as much as possible.

Following on from the current work the next design methodology steps are to optimise the GDC and reduce the resistance. Further numerical modelling and a larger scale model are required to optimise the design. An investigation into the design of the heaveplate and the columns may provide options to reduce the resistance.

6. ACKNOWLEDGEMENTS

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8. AUTHORS BIOGRAPHY

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