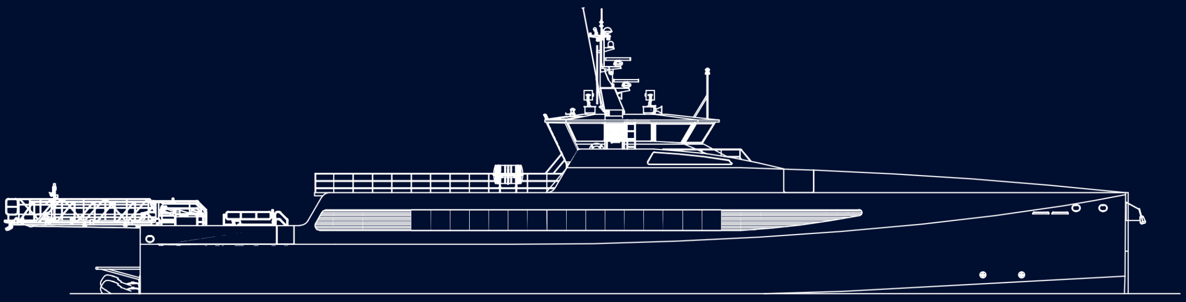
Concept Design of a Fast Crew Supply Vessel

Designing an attractive alternative to helicopters for long-distance crew transportation at mild conditions



MSc Thesis Marine Technology
Carolien Willemijn van Mens

TU Delft DAMEN

Concept Design of a Fast Crew Supply Vessel

Designing an attractive alternative to helicopters for long-distance crew transportation at mild conditions

by

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The cover image is the concept design which has been designed in this master thesis project.

Preface

This thesis marks the end of my Master study Marine Technology at Delft University of Technology. In 2013, I started at this university as a Bachelor student in Architecture since I had always dreamed to become an Architect. Although I enjoyed this study, the drive and satisfaction of my friends with other studies in Delft triggered me to challenge myself more. In combination with my passion for the technical dimension of sailing, I started the Bachelor Marine Technology after receiving by Propedeuse for Architecture. Throughout the years, I have always been satisfied with this change. Having visited many graduation speeches in this period, I have had a clear goal in mind for my own Master thesis: to execute a research which I liked so much that I would enjoy it (almost) every day. This has been a great success all the way and could not have been possible without the pleasant cooperation with my supervisors and Damen. Due to the focus of my research on ship design, I am happy that I could complete the circle of my study path by becoming a Marine Engineer and Naval Architect.

I am very thankful for the support I have received from the TU Delft during my research. Jaap Gelling, I would like to thank you for helping me to improve this project, your flexibility, enthusiasm and supportive attitude throughout the entire process. The fact that you were always ready to help, has been a great support to me. Your impressive stories have sparked my enthusiasm about the maritime industry. Also, I would like to thank Robert Hekkenberg for the critical and clear feedback during our progress meetings. It has always been useful and has helped me with the organisation of this thesis.

Additionally, I am very grateful for the opportunity provided by Damen Shipyards to conduct my research in a relevant and practical environment. Vincent de Leeuw, I would like to thank you so much for your support as daily supervisor and the countless of occasions you have helped me to understand the fundamentals of the subject matter. You have succeeded in making me feel a more complete marine engineer and I have enjoyed working together as a team very much. As part of Damen, I would also like to thank Geerten Poen, Nico van den Heuvel, David Stibbe, Olav Haga, John Nieboer and the rest of the team for the support to provide me with all information I needed.

Finally, my gratitude goes out to my family, boyfriend and friends. Mom and dad, thank you for providing me the opportunity to obtain my degree, and your support and faith in combining it with my student life as I did. Jelger, thank you for your patience, confidence, and improving my content and writing. Family and friends, your support and friendship have allowed me to enjoy my time as a student so much and we will definitely continue to do so together after my graduation as well. Thank you for everything.

Carolien Willemijn van Mens
Rotterdam, June 2021

Abstract

Crew transportation executed by vessels started as a result of the development of offshore platforms close to land. Due to the growing oil demand in combination with limited space for new installations in shallow water areas, these platforms have expanded to deepwater locations. To transport crew over these longer distances, helicopters are used nowadays.

Offshore crew transportation is driven by cost, safety, comfort, speed, workability, logistical solution, integrated solution, resilient solution and reputation. An assessment of these concludes that vessels can compete with helicopters for crew supply in the offshore market. Subsequently, an analysis to understand the performances of existing Crew Transfer Vessels competing with helicopters, results in the identification of a market gap: vessels that can operate in mild sea conditions and sail long distances at high speed.

This research aims to develop a concept design for a Fast Crew Supplier (FCS) that fits the market gap while scoring better relative to helicopters on the combination of cost, safety, comfort, and speed.

The selection of the vessel design requirements is based on detailed characteristics of West Africa, the Mexican Gulf of Mexico and the Middle-East. Main design requirements for the concept design are the significant wave height between 1.5 and 2 meters, speed between 35 and 40 knots, personnel capacity between 80 and 150 and a range of 1200nm. Since the vessel has to transfer and transport personnel, it should perform well at zero and at high speed.

In addition to the above described criteria, the hull design and its dimensions have the most influence on the goal of the concept design, according to the elaborated HoQ. Hull-types considered for the design are the mono-hull, catamaran, trimaran, SWATH, hydrofoil, WIG and ACV. With the use of literature research, the seakeeping analysis program (SHIPMO) and costs calculated, the most attractive hull design relative to the boundary conditions has been defined; the mono-hull.

Optimal dimensions are determined after an iterative process of the arrangements of the vessel in combination with stability characteristics. In this, the calculation and evaluation of the longitudinal centre of gravity (LCG) and the metacentric height (GM) have played a major role. The final length is 51m, and the final beam is 8.2m, which results in the concept design FCS 5108. According to the results of speed, range, significant wave height and cost, the FCS 5108 fits the market gap.

Comparing the FCS 5108 to a helicopter as crew transportation to an offshore field with three platforms in West Africa, the concept design is considered significantly more cost-effective, safer, more comfortable, and fast enough. To conclude, the FCS 5108 fits the market gap and scores better on the combination of the four design drivers relative to helicopters. For the further development of this concept design, it is recommended for Damen to continue in the Systems Engineering Approach and Design Spiral.

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Introduction

The shale revolution has created a competitive environment for new offshore oil and gas projects in the recent years. Despite the uncertain future, expectations are that the global demand for natural gas and oil consumption will grow until 2040 (Hendrikse, 2020). Furthermore, forecasts state that the deepwater offshore exploration and development activities grow between 2020 and 2025 (Mordor Intelligence, 2019). As a result, the number of offshore platforms will grow in the upcoming decade. This means that the transportation of crew to and from these installations will increase as well.

Crew transportation executed by vessels started as a result of the development of offshore platforms close to land. Due to the growing oil demand in combination with limited space for new installations in shallow water areas, these platforms have expanded to deepwater locations (Mordor Intelligence, 2019). Given the speed advantage, helicopters are preferred over vessels to transport crew over these longer distances. Additionally, rougher sea-state conditions in deepwater areas limit vessel operations as well. However, crew transfer vessels (CTV's), compared to helicopters, result in less fatal accidents and are more cost-effective (Brittan and Douglas, 2009). For this reason, Damen Shipyards has designed the Fast Crew Supplier (FCS) 7011 for the transit and transfer of crew at long distances in rough sea-state areas. For areas with mild conditions, this vessel is too expensive due to unnecessary features, e.g. high seakeeping performances and high installed power. Therefore, this research aims to design a more cost-effective FCS for these operational conditions.

The objective of this research is to develop a concept design for a vessel that matches market opportunities, while scoring better on the combination of design drivers relative to helicopters. This will be presented in this report in four parts. Part I creates an overview of the crew transportation in the offshore market. It starts with the research motivation in Chapter 2, whereafter more background information on vessels for crew transportation in the offshore market is given. Chapter 4 explains the project contribution and problem definition. The final chapter of this part is Chapter 5 and elaborates on the methodology of the research. Part II executes the design process and final concept design. It starts with the selection of operational areas in Chapter 6 and selection of design requirements in Chapter 7. Chapter 8 elaborates on the selection of the hull-type. The design is shown in Chapter 9 followed by a case study in Chapter 10. In Part III, the conclusion is given in Chapter 11 and a discussion on the research and recommendations are presented in Chapter 12. In Part IV the appendixes can be found.

I

Project Background and Research Objective

2

Motivation

This chapter describes the motivation of this research. As a first step, it introduces the offshore crew transportation drivers in Section 2.1. It explains the market and design requirements to give an understanding of the important focus points. Next, Section 2.2 elaborates on the existing ways of offshore crew transportation based on these drivers. It gives awareness of differences between helicopters and vessels to ensure which parts make vessels attractive relative to helicopters and which not. With this background information, Section 2.3 concludes on the motivation for this study.

2.1. Introduction to Offshore Crew Transportation Drivers

This section gives more information on the offshore crew transportation market by evaluating its drivers. It gives an understanding of the market needs. These will be used in Section 2.2 to compare vessels and helicopters and to conclude which drivers make one of them more attractive. Additionally, these will be used in a later stage, to make decisions concerning the goal of this project.

In the market of offshore crew transportation, two kinds of clients are of importance. First, the end-clients, which are the oil and gas companies. They need to periodically exchange personnel on their platforms, which requires crew transportation services. Therefore, they hire operators which are the second kind of clients. These operators own the vessels and arrange the entire logistical operations. End-clients are companies such as Shell, Total, BP, ExxonMobile, Petrobras, Pemex and Equinor. Their market drivers are essential since they set out the design requirements for the vessels owned by the operators. Based on the market drivers of the end-clients and the design requirements of the operators, nine offshore crew transportation drivers are:

1. *Cost*
   Lowering the logistical cost is a key driver for the end-clients. This has become more important due to the decreasing oil price, which generates less income. Consequently, lower operational cost is desired.

2. *Safety*
   Safety is an essential aspect for companies since this relates to their responsibility for their personnel.

3. *Comfort*
   Providing a comfortable ride for personnel increases the personnel's well-being and their efficiency.

4. *Travel time*
   Decreasing travel time results in better personnel experiences.

5. *Workability*
   Workability, or uptime, means the percentage of time the crew transportation method is able to transport crew. This is affected by the way it can handle environmental factors.

6. *Logistical solution*
   The offshore companies aim for an efficient and easy logistical solution for crew transportation. This means, a total efficient logistical solution, such as supplying more platforms with crew in one trip, and easy on-board logistics to improve crew comfort. By optimising these offshore and on-board logistics, the companies could increase their profit because of the higher efficiency.

7. *Integrated solution*
   Offshore companies prefer an integrated solution to exclude the need for third parties. The reason for this is that third parties typically increase the complexity of the total crew transportation operation. Furthermore, an integrated solution ensures that the crew transportation service fits the platforms capabilities at all times.

8. *Resilient solution*
   Resilient solutions concern the aim of companies to be independent of just one option for crew transportation. For instance, for some North Sea platforms, just one specific type of helicopter executes transportation services. If something goes wrong with this type, there is no resilience to fall back on another option of transportation. Consequently, this will lead to a shutdown of the production, which results in a loss of income for the end-client.

9. *Reputation*
   Public opinion influences the reputation of the client. For example, it can be affected by personnel safety and sustainable choices. Negative publicity leads to a damaging reputation of the company.

2.2. Review of Offshore Crew Transportation Drivers

Helicopters and vessels currently execute the supply of crew to and from offshore platforms. This section elaborates on these two options. First, Subsection 2.2.1 gives general information on both helicopters and vessels to provide insight into their implementation. Section 2.2.2 to Section 2.2.6 discusses the two options by analysing them based on the offshore crew transportation drivers given in Section 2.1. This review shows for each driver which option is most attractive. Based on this, Section 2.2.7 concludes which option is favourable over another and which drivers should be focused on to improve this option for offshore crew transportation.

2.2.1. General

Helicopter

Helicopters traditionally execute long-distance crew transportation due to their speed, flexibility and passenger comfort (Brittan and Douglas, 2009). This operation starts at the airport. Before taking-off, check-in procedures have to be handled which are time-consuming due to extensive safety policies. Subsequently, the flying transit to the offshore platform takes place. At arrival, landing procedure is critical. After this, the personnel can conveniently step out of the helicopter directly on the offshore platform. Figure 2.1 gives an illustration of the total transportation process.

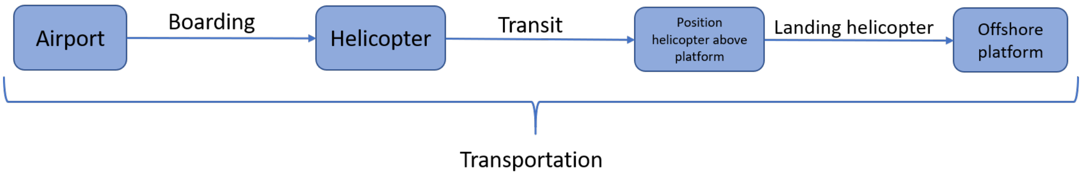


Figure 2.1: Transportation process of a helicopter from onshore to the platform

Examples of helicopter operators are Bristow, CHC, Bond, Era, Earoleo, NHV and PHI. Two commonly used helicopters for the long distance transportation are Augusta Westland 139 and Sikorsky S92. Table 2.1 shows their specifications and Figure 2.2 illustrates Augusta Westland 139.

Table 2.1: Overview commonly used helicopters for crew transportation in the offshore market

	Augusta Westland 139	**Sikorsky S92**
Personnel [-]	12	18
Range [nm]	550	540
Cruise Speed [knots]	140	130

Figure 2.2: Augusta Westland 139

Crew Transfer Vessel

The crew transportation via marine ways for long distances has always been regarded as slow, more hazardous and less comfortable than helicopters (Brittan and Douglas, 2009). However, in modern times this seems to be overcome by three specific technological advancements. These are high-speed hull design, DP2 automatic vessel station-keeping and innovations in crew transfer systems. This increases the level of passenger safety and comfort that exceed helicopter crew transportation.

The transportation with a CTV starts at the harbour, kicking-off with the handling of quick check-in procedures. Subsequently, the sailing transit to the offshore platform takes place. When arriving, the vessel locates next to the platform to transfer personnel using a crew transfer system. Therefore, vessels have to provide proper seakeeping performance at high speed (during transit) and at zero speed (during transfer). Figure 2.3 illustrates the total transportation process and Figure 2.4 shows the FCS 7011, which is an example of a crew transportation vessel.

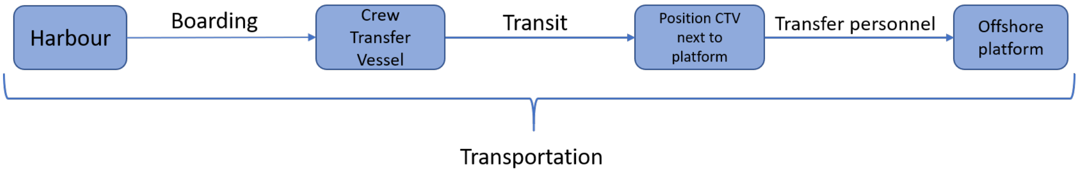


Figure 2.3: Transportation process of a vessel from onshore to the platform

Figure 2.4: FCS 7011

One of the differences between the transportation process of vessels and helicopters is their way of crew transfer. Marine transfer aims to bridge the dynamic gap between a vessel moving on the sea surface and the platform. This is in contrast with the helicopter, which position is already on the platform itself during crew transfer. Various transfer methods can be used to move the personnel between the offshore platforms and marine vessels. The list below describes systems executing this, based on reportings of IMCA (2014) and Strong (2008).

- *Gangways, bridge and accommodation ladders*
  These are the primary personnel transfer systems between a vessel and an offshore structure. An appropriate certification of the gangway or accommodation ladder is required.

- *Personnel transfer carrier*
  This method uses a crane on the platform to lift a carrier between the vessel's deck and the platform. Three main devices are the collapsible net, the rigid basket and the rigid capsule. Collapsible nets transfer passengers who are holding onto the outside. Rigid baskets move while the passengers are standing at the inside. By using rigid capsules, passengers are seated inside.

- *Swing-rope transfer*
  When the platform does not provide crane access, the swing-rope is a commonly used method. The personnel make a timed swing on a knotted rope between the vessel and the platform. It relies heavily on human responses and serious incidents are not uncommon.

- *Motion-compensated gangways*
  Motion-compensated gangways are mounted on a vessel and can connect with the platform to allow personnel to pass safely across. In this system, a hydraulic active heave compensation ensures the adjustment of the length and the angle of the gangway to compensate for the vessel's movement. Some gangways can compensate for all six degrees of motions of the vessel.

The personnel transportation executed by vessels involves various companies. These are yards, design companies, and operating companies. Leading designers are Incat Crowther, Piriou and Damen. Typical operators are CMS, SPO, SEACOR, ABC Maritime and Bourbon.

2.2.2. Safety

Significant data is available related to helicopter operations and incidents, whereas this information on marine transfers is rare. This could be the result of just few casualties in ship-based transportation. Nevertheless, it makes a reliable comparison between the safety performance of marine and helicopter transportation difficult (Strong, 2008). This chapter focuses on the conclusions of previous studies, despite the fact that more recent data would help to develop safer solutions and facilitate better decisions on crew supply arrangements.

Brittan and Douglas (2009) argue that marine crew transportation carries a significantly lower risk of fatal incidents than helicopters. Strong (2008) confirms this, but also claims that CTVs result in more (minor) injuries compared to helicopter transportation. Table 2.2 gives a generalised overview of these observations. Furthermore, Vinnem (2016) published an article with the title 'Helicopter safety can probably not be better, time to consider boat transport' in which he questions if improvements to helicopter safety are realistic. Vinnem and Røed (2020) stated that if vessels were to replace the use of helicopters, fatal accidents could be eliminated.

Table 2.2: Generalised comparison of accident types in offshore crew transportation

	Fatalities	Injuries
Helicopter	Yes	Rare
Vessel	Rare	Yes

Furthermore, by investigating the annual reports of BP (2019) and Shell (van Beurden, 2019), it can be observed that they give attention to fatal accidents. According to BP, safety has high importance for the company, especially the minimisation of fatal accidents. They want to emphasise their determination to eliminate these tragic incidents since loss of life is a matter of great regret to the company.

So, the principal aim of end-clients to prevent fatalities, results in the urge to transport crew by vessels. Although this leads to more (minor) injuries, focus should be given to lower the risks concerning marine crew transportation.

2.2.3. Travel Time

The travel time depends on three stages in the transportation process: boarding, transit and transfer. In the Gulf of Mexico, the Sikorsky S92 and FCS 7011 are compared on these three stages travelling to deep and shallow water. Figure 2.5 shows the results for shallow water and Figure 2.6 for deepwater.

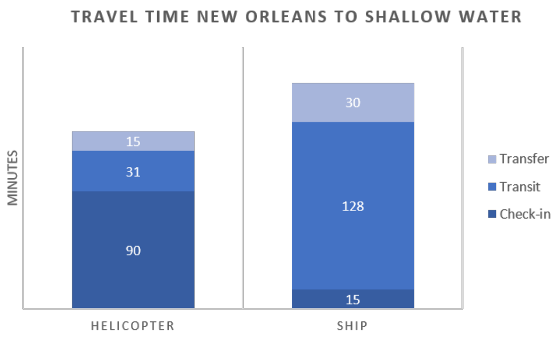


Figure 2.5: Travelling time Gulf of Mexico shallow water

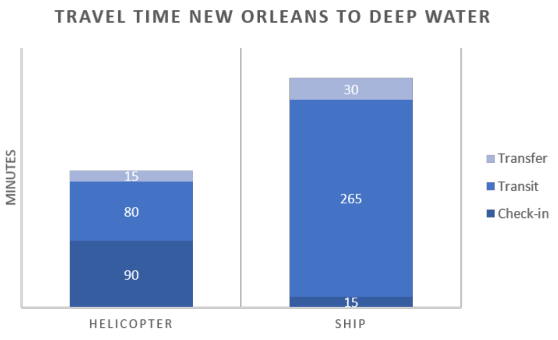


Figure 2.6: Travelling time Gulf of Mexico deepwater

The figures indicate that the helicopter's travelling time is shorter than for a vessel, due to its faster transit. Although, its boarding and arrival procedures take longer. Figure 2.7 shows a graph of the transporting time in comparison with the nautical miles to cover. At distances shorter than 50nm the total transportation process of a vessel takes less time. The longer the distance the bigger the difference, so the more important the speed becomes of a vessel to be an attractive alternative to helicopters. Therefore, for long-distance transportation speed is essential. It should be noted that these times are based on directly moving to and from the platform. In case of deploying the vessel to supply more platforms in one ride, this time will increase slightly.

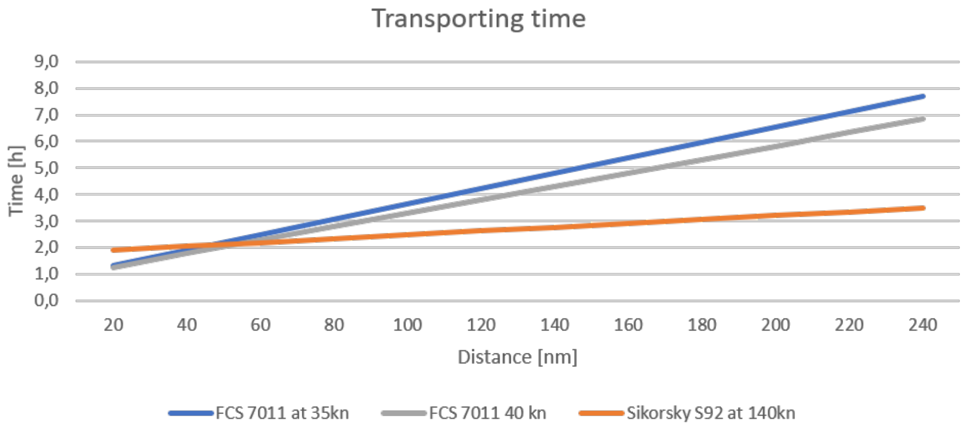


Figure 2.7: Comparison transporting time related to nautical miles

2.2.4. Cost

This part elaborates on the comparison of transportation cost per trip per person of vessels and helicopters, which are shown in Figure 2.8. This cost is based on the transporting time demonstrated in Figure 2.7 and a calculation of cost per hour per person of the FCS 7011 and the Sikorsky S92. It is executed using a standard cost rate per hour excl fuel cost and the cost of fuel per hour. This data is obtained from the sales department of Damen and the calculations are shown in Confidential Appendix 1. The FCS 7011 is used carrying 120 passengers with a cruise speed of 35 and 40 knots. The Sikorsky S92 is used with a cruise speed of 140 knots and a carriage of 18 passengers. Concerning the cost per person per trip, in combination with the number of passenger, an approximate occupation is estimated at 70% for vessels and 90% for helicopters. For the vessel this percentage is lower since a lot of variation is possible in a vessel of 120 persons. These percentages are processed in the calculation of cost per person per trip.

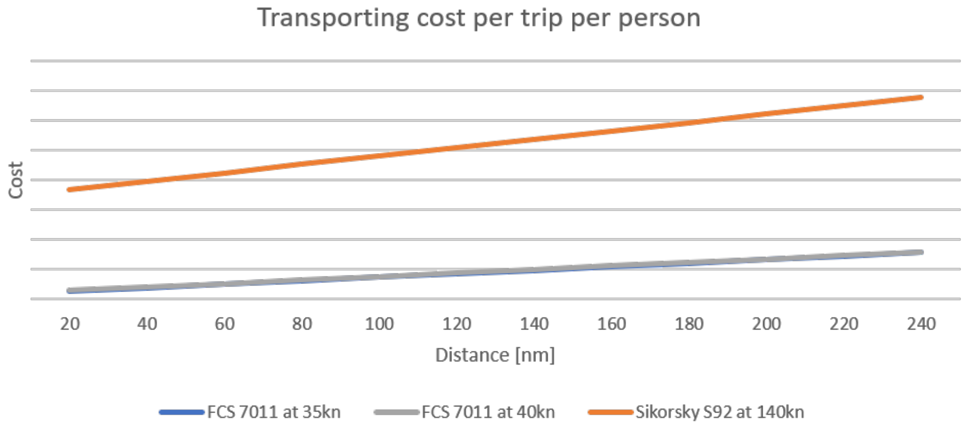


Figure 2.8: Comparison transporting cost related to nautical miles

This comparison concludes that the cost per trip per person with a Sikorsky S92 is significantly higher than for the FCS 7011. The further the distance, the higher the difference. Between 120 and 180nm the cost for Sikorsky S92 is approximately between 5 and 6 times higher. As can be seen this difference is mainly due to the starting fee. This is significantly higher than the vessel due to high insurance, maintenance, restoration and depreciation. At longer distances, this difference increases. Furthermore, relative to the high cost of the helicopter, the cost for the vessel at 35kn and 40kn are closely to each other. Sailing at 40kn leads to higher valuable cost, due to the higher fuel consumption. at which sailing at 40kn leads to higher cost. When the vessel is used to supply multiple platforms in one ride, the total cost difference will decrease slightly since this consumes more time.

2.2.5. Comfort

Since the vessel's transit time generally takes longer than a helicopter, its comfort is essential. Better comfort results in more efficient time use during the transit. Figure 2.9 and Figure 2.10 show the seating arrangement of the Sikorsky S92 and the FCS 7011.

Figure 2.9: Seating arrangement Sikorsky S92

Figure 2.10: Seating arrangement FCS 7011

As can be seen, the vessel has more available space. This leads to more tables and comfortable seats, a space to walk, additional rooms, and options for obtaining drinks and food. Figure 2.11 shows an example of a kiosk seating arrangement and Figure 2.12 of a meeting room. Furthermore, the personnel can take more luggage with them. The seakeeping of a vessel should be sufficient in order to use these advantages.

Figure 2.11: Kiosk seating arrangement FCS 7011

Figure 2.12: Meeting room FCS 7011

2.2.6. Other design requirements

Weather influences the workability of vessels and helicopters. As a result of too high wave heights, the vessel is not able to transport crew. Too much wind or fog results in the inability of helicopters to fly. However, the workability of a helicopter is higher than a vessel.

Concerning the offshore logistics, it is disadvantageous for helicopters that they can carry significantly less personnel. They have to fly back and forth when more than 18 passengers need to be transported. In addition, vessels could supply multiple platforms of crew during one trip. However, this results in a more complicated organisation for vessels. This also applies to on-board logistics. More space is available whereby carrying cargo and luggage is also an option, but more organisation is needed.

With regards to the integrated solution, nearly all offshore platforms have an helicopter deck. This means an integrated solution for helicopters is already available. For marine crew transfer, a different specific system is required. As a result, helicopters are currently a better integrated solution than vessels. In case, a new offshore platform is designed for marine crew transfer, the design requirements for the helicopter deck may be revised.

From a resilience perspective, it is attractive to have both helicopters and vessels available because they can back-up each other. Therefore, it is of interest to have vessels which can sail in certain areas where currently just helicopters are providing crew transportation services, and the other way around.

Flying with helicopters leads to a worse reputation than vessels since helicopters have a higher chance of fatalities and have an adverse appearance concerning sustainability.

2.2.7. Conclusion

This section evaluated crew transportation by helicopters and vessels based on the its drivers. Table 2.3 gives an overview of these findings.

Table 2.3: Comparison of offshore crew transportation drivers of helicopter and vessels

	Helicopter	Vessel
Cost	-	+
Safety	-	+
Comfort	-	+/-
Travel time	+	-
Workability	+	-
Logistical solution	+/-	+
Integrated solution	+	+/-
Resilient solution	+	+
Reputation	-	+

Overall, this table shows that, if weighting all factors equally, a vessel is more attractive than a helicopter for crew transportation. Drivers that ensure this are cost, safety, comfort, reputation and logistical solution. However, it should be noted that helicopters are still widely used nowadays. This can be explained by the findings that its speed, workability and integrated solution are better. In case a vessel is able to improve these design aspects, it can become even more attractive. On the other hand, if vessels do not succeed in having good seakeeping during transit and transfer, the comfort of a helicopter is better. This could lead to a preference for helicopters.

2.3. Research Motivation

Currently, helicopters are commonly used for long-distance crew transportation to and from offshore platforms. Based on the offshore crew transportation drivers, it is interesting to deploy vessels for these kind of operations. These vessels should have proper seakeeping capabilities during both transit (at high speed) and transfer (at zero speed). When this is met, vessels are an attractive option for long-distance crew transportation in comparison to helicopters. Therefore, in the next chapter, more research will be done on opportunities of vessels in the offshore market.

3

Background Information

This chapter provides background information on offshore crew transportation vessels. It gives a perspective on design considerations for such vessels to be competitive in a helicopter market which requires long-distance crew transportation. Section 3.1 elaborates on the design drivers based on the offshore crew transportation drivers discussed in the previous chapter. Next, Section 3.2 discusses the potential operational areas for CTVs. Furthermore, Section 3.3 and Section 3.4 present the current CTVs of Damen and its competitors respectively. As a final step, Section 3.5 provides the conclusion on the market gap and design considerations.

3.1. Design Drivers

This section zooms in on the design drivers for offshore crew transportation vessels. Based on the discussed drivers in Section 2.2, four design drivers are selected. These are cost, safety, comfort and speed, since they have a great impact on choices in the concept design phase and they are correlated with one another. The design drivers are discussed in more detail in Sections 3.1.1 to 3.1.4 respectively.

3.1.1. Cost

For the vessel operators, two types of cost are important to consider, which are investment cost and operational cost. Damen calculates the investment cost for ship operators using their integral direct cost (IDC) method plus a profit margin. In he IDC, the production cost and the product organisation cost are taken into account. In addition to the IDC, Watson (1998b) describes a way of cost estimating. The operational cost include all cost during transportation. Examples are the fuel per person transported, salaries and the cost of the crew.

Based on both investment and operational cost, two separate cost values can be selected with which a new vessel design has to comply to be an attractive alternative to helicopters.

3.1.2. Safety

The traditional method of ship safety is based on the philosophy that it is achieved by applying the rules and regulations of the governing bodies. This is a broad concept and understandings of the actual meaning of the term vary widely. According to Kuo (1997) results have shown that the most important features associated with safety are: training, injury, harm, management, design, reliability, human factors and attitude. For example, human factors are impacted by personnel's well-being, since fear or feeling sick could result in poor choices by humans.

In general, naval architects tend to handle safety as a matter of creating designs that comply with rules and regulations. Operators tend to believe that safety is achieved by following the required operational procedures. Scientists consider this by conducting a risk analysis or a reliability study. An adopted definition by several organisations worldwide is: "Safety is a perceived concept which determines to what extent the management, engineering and operation of a system are free from danger to life, property and the environment" (Kuo, 1990). It means that safety is a three-dimensional quality involving management, engineering and operation. Furthermore, all three aspects are closely associated with human factors.

In 1980, J.A. Keuning did research on the reaction of humans on accelerations. Discomfort reduces the ability to perform tasks, and reduces safety on board. The most dominant parameters are the amplitude and frequency of both the vertical and lateral accelerations. The effects can be tempered by the ability to see static points and good quality of air. Motion sickness on board of ships, for instance, is most likely to occur if passengers cannot see the horizon. Additional to this, Khattab (1999) found the following factors that could propagate seasickness: anxiety, fatigue, hunger, smell, greasy food, reading, carbonated or alcoholic drink and bad air quality.

Stapersma et al. (2012) value safety in terms of vertical and lateral acceleration. For RMS vertical accelerations the limiting motion criteria is 0.15g ($1.47 m/s^2$). Research findings of Keuning and van Walree (2006) are that typical values for the maximum accepted vertical accelerations at the wheelhouse are $8.0 m/s^2$. Stapersma et al. (2012) recommend lateral acceleration values between 0g and 0.04g for crew safety. According to Karpinnen and Aitta (1986) the lateral acceleration limit for passenger ships is 0.05g. However, for fast ships vertical accelerations are dominant which means lateral acceleration limits are insignificant.

Concluding, it is possible to value various safety factors. Since the vertical accelerations are dominant for fast ships, this value is taken as limiting value. For the safety of the vessel, the limiting motion criteria should at least be satisfied. These or other limiting criteria, are difficult to compare to the safety of helicopters. Therefore, to increase the safety, design choices should be made based on safety insights as much as possible besides the weighing up against a number.

3.1.3. Comfort

The level of comfort can be expressed in terms of human performance degradation. For this, various kinds of methods have been developed. Examples are the Motion Sickness Incidence (MSI) and the Motion Induced Interruptions (MII) calculations. All these methods are based on the significant value of the vertical accelerations. For ships with linear motion characteristics, like slow displacement vessels, this is a good and reliable way to assess seakeeping characteristics. However, conventional high speed vessels show a clear non-linear seakeeping behaviour, for which a comparison based on 'significant seakeeping behaviour values' is inadequate. This is clarified below.

Figure 3.1 presents the seakeeping characteristics of two different vessels. One conventional high speed vessel (red line) and a hypothetical ship with linear motion characteristics (black line). The graph shows the cumulative probability of exceeding certain vertical accelerations. Comparing these two ships based on “significant values” would yield a completely wrong conclusion. The “significant value” for both vessels is found at approximately 13%, so at the purple vertical line. Comparing these values of the red and black line, the conclusion is that the “red line ship” has a better seakeeping performance than the “black line ship”, as the significant value of vertical accelerations is lower. In real life however, the maximum vertical acceleration peaks of the “black line ship” are only half of those of the “red line ship”. This can be seen at the green vertical line. These high acceleration peaks can easily endanger the construction of high speed vessels and their crews.

Summarising, in real life, the "black line ship" will be completely superior in seakeeping to the "red line ship". Although, based on the "significant value", the conclusion would have been reversed. So, for the comparison of the seakeeping performance of high speed vessels, the focus should be on the highest acceleration peaks of the vessel's behaviour to be expected.

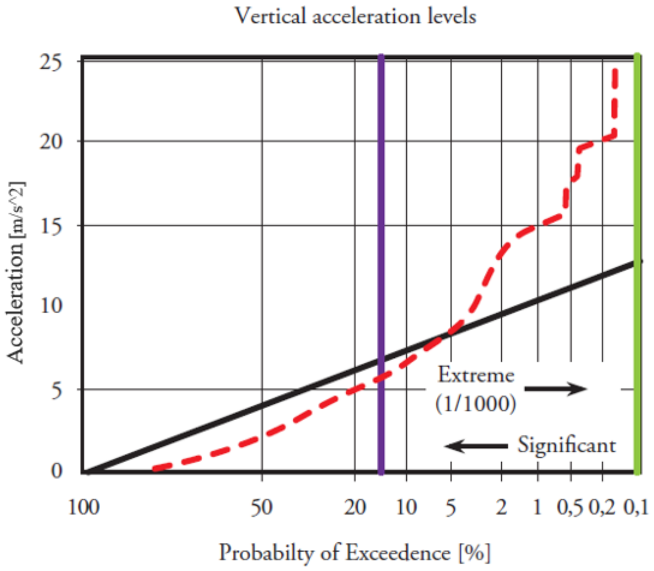


Figure 3.1: Distribution of peaks and troughs of an acceleration signal (Gelling and Keuning, 2011)

It is useful to find out where the vertical accelerations are minimal. Positioning the personnel around this location improves their comfort. Based on model tests of the FCS 7011 this is between 20% and 40% of the length. These could be assumed as general for axe bow vessels within the same range of speed and LCG.

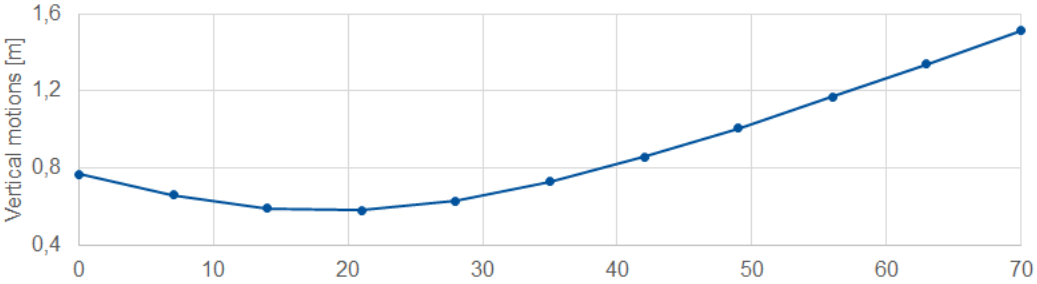


Figure 3.2: Distribution indication of vertical acceleration along ship length

Concluding, comfort is dependent on various aspects. Despite the existence of MSI and MII calculations, it is hard to value the level of comfort for fast crew supply vessels. Therefore, it is important to make design choices in order to, for instance, reduce the vertical accelerations, and improve comfort.

3.1.4. Speed

As explained in Section 2.2.3, the boarding and transfer time of a vessel are more attractive than a helicopter. For the transit time, on the other hand, this is not the case. To improve the attractiveness of vessels, their transit time could be decreased by increasing the speed. The speed can be defined and compared as the guaranteed service speed in knots. Besides, it is essential to state that the actual speed is subject to the state of the sea, draft, trim, the condition of the hull surface, and the propellers (Babicz, 2015). Although it is possible to make the transit more comfortable than with helicopters, there is still a maximum time that companies and personnel are willing to spend on crew transportation. Therefore, marine transportation has to comply with a maximum time value. Based on this, a required speed has to be chosen which at least can comply with this time value.

3.1.5. Conclusion

The four vessel design drivers are cost, safety, comfort and speed. These drivers are interdependent and conflicting, because, for instance, higher speed results in higher investment cost. This results in a multiple criteria decision problem which needs to be solved to find the best design solution. The drivers can be valued in various ways. By selecting limiting criteria concerning these values, trade-off decisions could be made to compare them. Figure 3.3 clarifies the inter-dependency of the four design drivers. Ultimately, this vessel design solution can be compared to helicopters in order to find the best offshore crew transportation option.

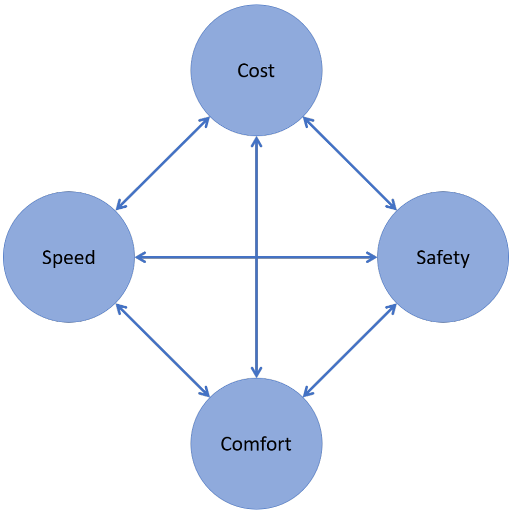


Figure 3.3: Clarification on inter-dependency of the design drivers

3.2. Operational Areas

This section executes research on the potential operational areas for long-distance crew transportation. To design vessels for these operations, the characteristics of these areas need to be known. Three type of areas are identified in which vessels could be an attractive alternative to helicopters:

- *Helicopter markets*
  These are areas where the crew transportation is currently executed by helicopters. Therefore, this is a potential market for CTVs since vessels could be an alternative to helicopters.

- *Greenfield projects*
  These are new projects which are planned to start. For these offshore platforms, a new kind of crew transportation has to be selected. The choice for clients between crew boats or helicopters is open.

- *Volume per run*
  Areas where the volume per run is high means that more offshore platforms are closely located to each other. Hence, personnel of various platforms could be transported by one vessel at the time, like a bus service. This results in lower cost due to a better occupancy rate.

Figure 3.4 shows potential areas for CTVs. These are Gulf of Mexico, North-East Latin America, South-East Latin America, West Africa, West Australia and West Europe.

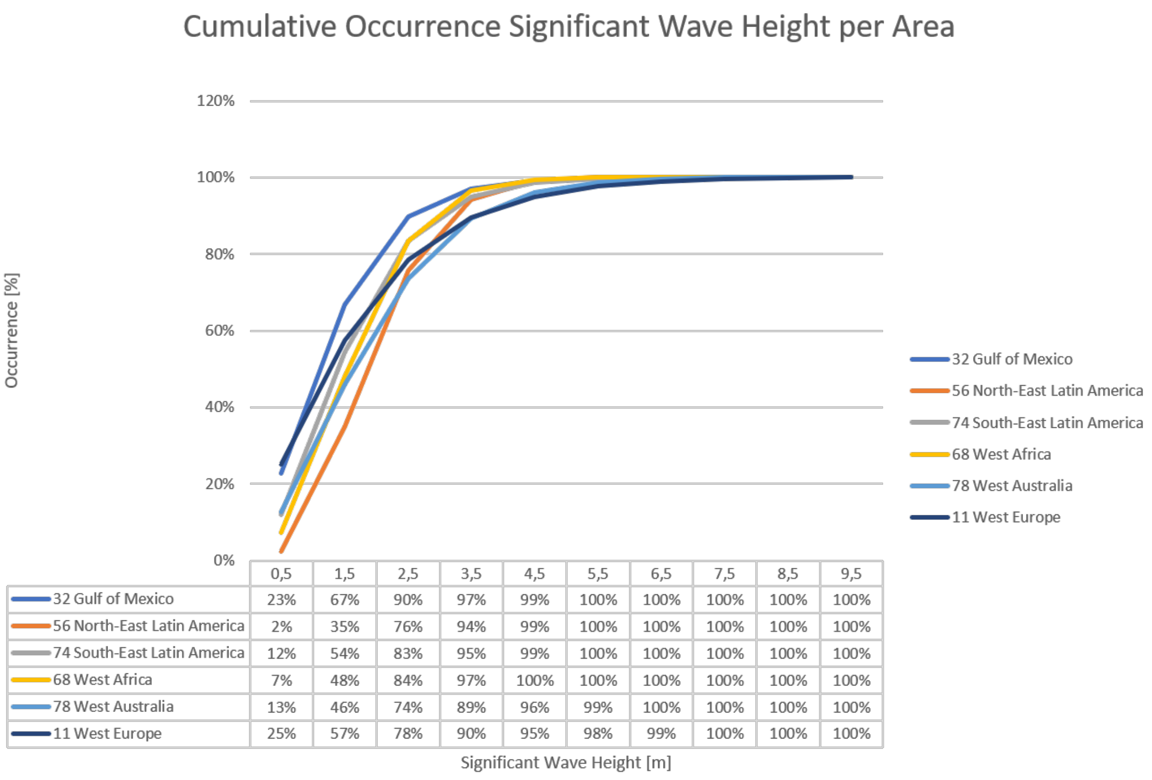
Figure 3.4: Global potential areas for marine crew transportation (Damen Shipyards, 2020)

In these areas, a vessel has to meet the design requirements which include significant wave height (H_s), wave period, range, number of personnel, and regulations. As a first step, it is interesting to know the significant wave heights and wave periods in these areas. A combination of these two affects the sea condition. Table 3.1 clarifies that for the ship behaviour, it is the best to have a low H_s and a long period. Therefore, a combination of these two is the best. However, a low H_s in combination with a short period also leads to acceptable ship behaviour. Likewise, for a high H_s and a long period. However, the ship behaviour in a high H_s together with a short period, is extremely undesirable.

Table 3.1: The effect of the combination of wave heights and wave periods on ship behaviour

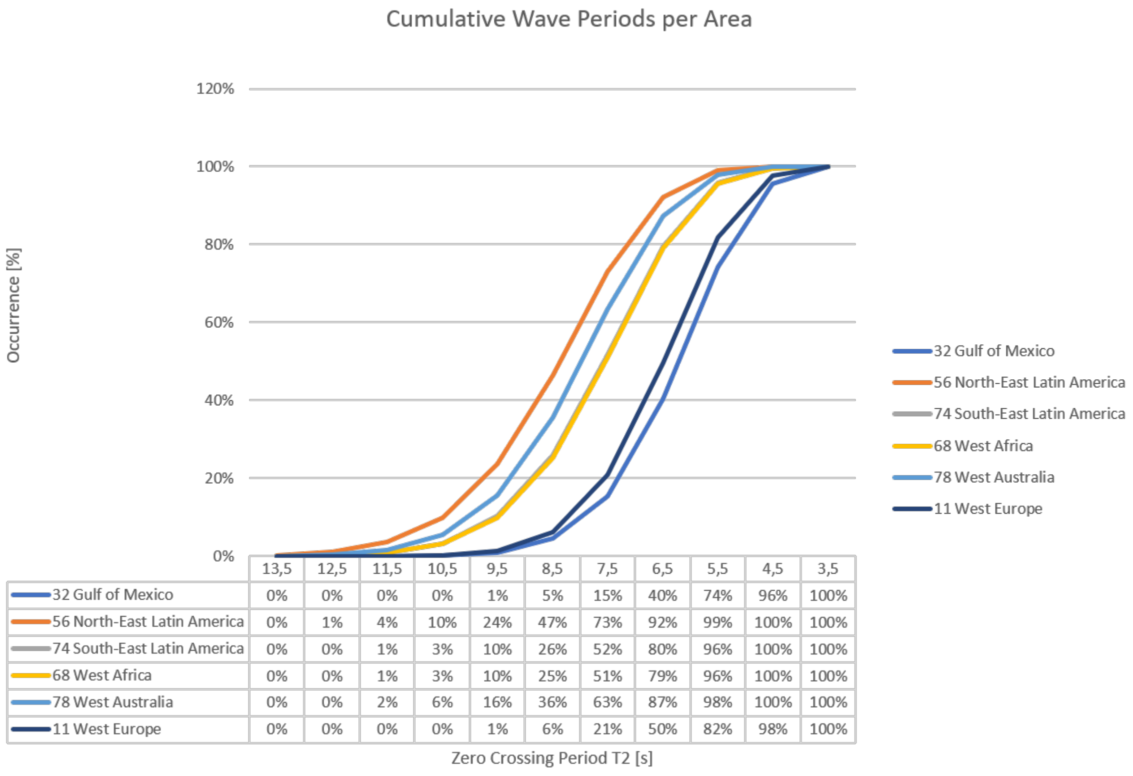
	Short Waves	Long Waves
Low H_s	+	++
High H_s	–	+

Figure 3.5 and Figure 3.6 show charts which give first impressions of significant wave heights and wave periods per area, based on scatter diagrams. These scatter diagrams are based on data of Britisch Maritime Technology Limited (2000) and are presented in Appendix A. Values become more relevant when the cumulative occurrence is high. Appendix B shows charts with the percentage of the occurrence given in percentage per significant wave height or wave period.



	0,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5
32 Gulf of Mexico	23%	67%	90%	97%	99%	100%	100%	100%	100%	100%
56 North-East Latin America	2%	35%	76%	94%	99%	100%	100%	100%	100%	100%
74 South-East Latin America	12%	54%	83%	95%	99%	100%	100%	100%	100%	100%
68 West Africa	7%	48%	84%	97%	100%	100%	100%	100%	100%	100%
78 West Australia	13%	46%	74%	89%	96%	99%	100%	100%	100%	100%
11 West Europe	25%	57%	78%	90%	95%	98%	99%	100%	100%	100%

Figure 3.5: Cumulative significant wave heights of areas



	13,5	12,5	11,5	10,5	9,5	8,5	7,5	6,5	5,5	4,5	3,5
32 Gulf of Mexico	0%	0%	0%	0%	1%	5%	15%	40%	74%	96%	100%
56 North-East Latin America	0%	1%	4%	10%	24%	47%	73%	92%	99%	100%	100%
74 South-East Latin America	0%	0%	1%	3%	10%	26%	52%	80%	96%	100%	100%
68 West Africa	0%	0%	1%	3%	10%	25%	51%	79%	96%	100%	100%
78 West Australia	0%	0%	2%	6%	16%	36%	63%	87%	98%	100%	100%
11 West Europe	0%	0%	0%	0%	1%	6%	21%	50%	82%	98%	100%

Figure 3.6: Cumulative wave periods of areas

Figure 3.5 displays that a significant wave height up to 2.5m has a high occurrence for all the areas since the cumulative percentages lie between the 70% and 90%. Besides, for North-East Latin America, West Australia and West Europe up to 3.5m also have a high occurrence.

Figure 3.6 shows that for West Africa, West Australia and North- and South-East Latin America a period up to 6.5s has a high occurrence. Their percentages are laying between 70% and 100%. For the Gulf of Mexico and West Europe, the period is shorter.

Table 3.2 gives an overview of the combination of these wave heights and wave periods. Findings based on these data are that West Europe is an area to avoid.

Table 3.2: Indication of significant wave height and period per area

Area	**Hs**	**Period**	**Rating**
Gulf of Mexico	Low	Short	+
North East Latin America	Medium	Long	+
Sout East Latin America	Low	Medium	+
West Africa	Low	Medium	+
West Australia	Medium	Short	+/-
West Europe	High	Short	–

3.2.1. Conclusion

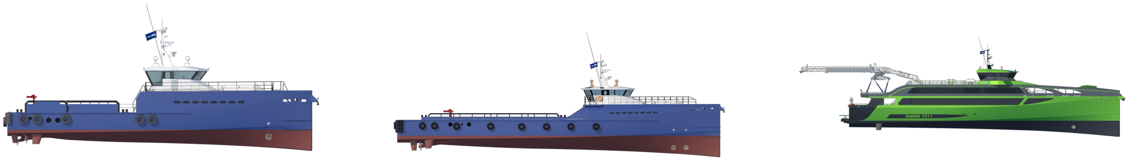
So, six attractive areas for the vessels to operate in are selected. Overall it is seen that the significant wave height up to 2.5m commonly occurs. Based on the combination of the wave height and wave period, West Europe is regarded as an area to avoid. It should be noted that the conclusions are based on widely spread areas. Therefore, more detailed research on these and additional regions is needed. By gaining more information about the distance to platforms, number of personnel, and regulations for relevant operational areas, complete area characteristics could be linked to the four design drivers.

3.3. Damen Vessels and Gap Analysis

This section executes an investigation on the Fast Crew Suppliers (FCS) of Damen. It discusses the existing crew transfer vessels and their specifications. Subsequently, Subsection 3.3.4 describes the market gap in the Fast Crew Suppliers of Damen.

Damen works with standardisation and series building to offer its customers state-of-art maritime solutions that are sustainable, future-proof, and have short delivery times. The standard hulls can be customised in alignment with the requirements of the client. This is also the case for Damen's Fast Crew Suppliers. Proven concepts of Damen are the FCS 3307 and the FCS 5009 since over fifty of each of them are in service. A new concept which is an attractive alternative to helicopters is the FCS 7011. These vessels will be discussed in detail since this research is executed in cooperation with Damen. Since the vessels are customised, the variant with the highest speed will be discussed because this is the most attractive for long-distance crew transfer. Figure 3.7 illustrates these three vessels.

Figure 3.7: Damen Fast Crew Suppliers, f.l.t.r. FCS 3307, FCS 5009 and FCS 7011



All these three vessels have a chined hull with a deep-V bottom and an Axe Bow. This Axe Bow Concept has advantages due to the characteristics of the hull form. First, it reduces the vertical accelerations significantly and eliminates bow slamming. Therefore, the persons on board will be less tired, which will reduce the operational risk. Second, it ensures ships to sail at and sustain a high speed in waves while having advanced seakeeping characteristics. Besides, up to medium-high speeds, it results in low resistance. Due to the seakeeping characteristics, the safety of the vessel, personnel and crew increase significantly. With this concept the ship ensures a combination of cost-effectiveness, comfort and safety.

3.3.1. FCS 3307

The Damen Fast Crew Supplier 3307 is a modern high-speed vessel for the transportation of personnel and limited cargo to short-distance offshore platforms. It has a maximum speed of 28 knots and is driven with three marine diesel engines, each driving a fixed-pitch propeller. A basket is available to execute the transfer of crew. However, the vessel does not have dynamic positioning capabilities. Relative to the FCS 7011, the cost of the FCS 3307 is 16/100, which is much more cost-effective. Table 3.3 shows an overview of its characteristics.

3.3.2. FCS 5009

The Damen Fast Crew Supplier 5009 is a modern high-speed vessel. It is meant for the transportation of personnel and of more serious cargo to medium-distance offshore platforms. The maximum speed is 29 knots. The FCS 5009 is traditionally not designed to transfer personnel with a motion-compensating gangway. Although on two FCS 5009s which were already in operation, an L-type Ampelmann motion-compensated gangway system has been fitted.

The vessel is driven with four fixed pitch propellers powered by diesel engines. It has no roll reduction devices like the gyroscope and ride-control system of the FCS 7011. The cost of the FCS 5009, relative to the FCS 7011 is 28/100, which is more cost-effective. Table 3.3 shows an overview of its characteristics.

3.3.3. FCS 7011

In order to reduce cost, increase safety, efficiency/flexibility and workable days on long distances compared to helicopters, the FCS 7011 is designed by Damen. This vessel is built and is planned to be in an extended trial period. It is a modern high-speed and lightweight vessel, which can sail long distances. The vessel is well suited for the transportation and transfer of personnel and light cargo. The ambitions of Damen concerning the transit are:

- Speed up to 40 knots
- Transit in sea state up to a significant wave heights of 3.0 meters
- Transit long distances up to 150-200 nautical miles
- Highest comfort level in the industry
- Personnel spending time on board useful

The ambitions concerning the transfer are:

- Landing height up to 18 meters
- Transfer in sea state up to a significant wave height of 3.0 meters
- Quick, easy and continuous access
- Luggage/tools transfer

The hull is manufactured from aluminium and has spray rails and a transom stern. Fixed fins are placed in the aft ship to improve intrinsic directional stability. The propulsion has four waterjets, which are driven by diesel engines. To process the vessel's ambitions, it needs significant integrated characteristics, which result in high cost for the vessel compared with other crew supply vessels.

A motion-compensated gangway can be fully integrated on the aft of the vessel. It means that preparations are executed to receive the S-type Ampelmann motion-compensating gangway system. Besides, a personnel transfer basket for 6 or 10 persons could be provided on the vessel. Retractable azimuthing bow thrusters are fitted for dynamic positioning operations.

A gyroscope is installed to reduce the roll of the vessel during marine access operations. As gyroscope a VEEM VG1000 is installed which ensures a rated torque of 1000kNm and an angular moment of 521kNms. Besides, active interceptors are fitted on the transom to improve the personnel's comfort for high-speed operations above 20 knots. This ride control system reduces wave-induced roll as well as pitch motions and is automatically controlled.

So, by using the FCS 7011 the current operations are improved, and a new market is opened. The current operation is improved by transferring personnel with a gangway instead of older options. This ensures an increase in workable days, safety, efficiency/flexibility. Despite the vessel's high price, it still ensures a significant cost reduction in crew change operations compared to helicopters. These features should be enough competition for the helicopters. Table 3.3 presents an overview of its characteristics.

3.3.4. Market Gap of Damen Fast Crew Suppliers

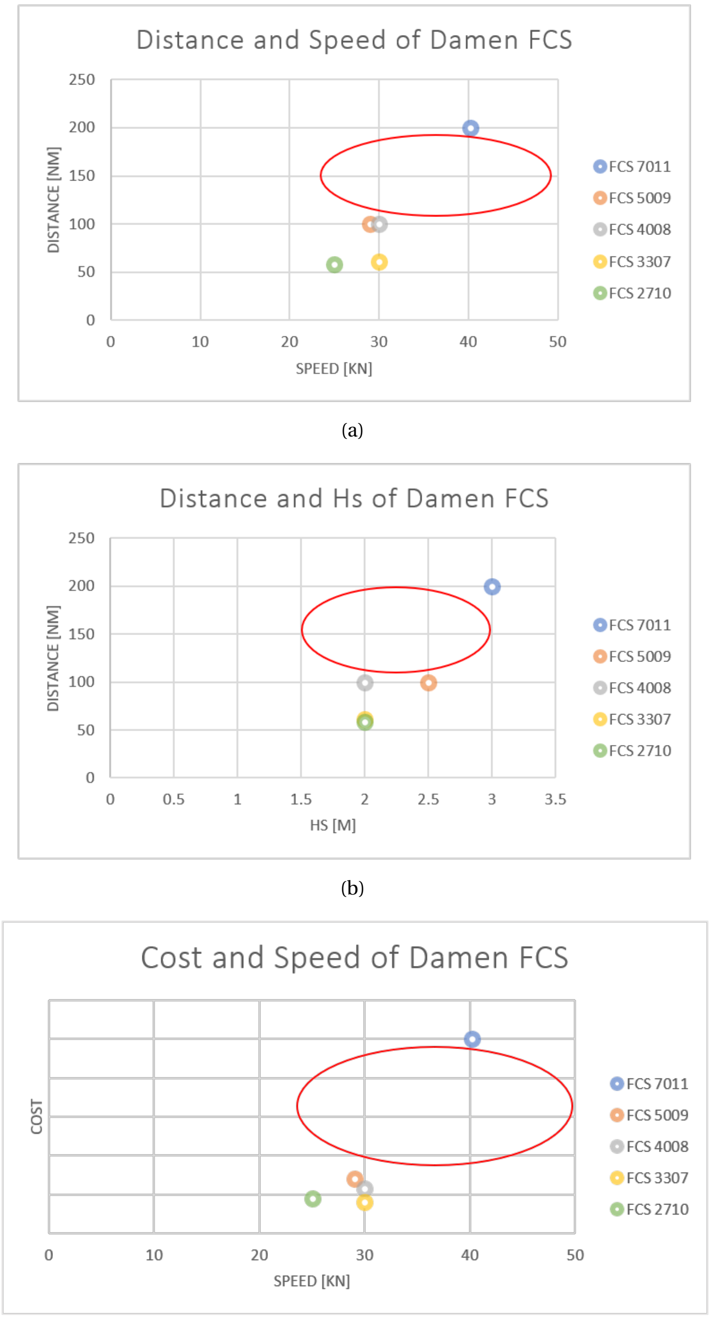
Table 3.3 shows an overview of the characteristics of the Damen Fast Crew Suppliers. By evaluating these, conclusions can be drawn.

Table 3.3: Overview of Characteristics Damen Fast Crew Suppliers

	FCS 3307	**FCS 5009**	**FCS 7011**
General			
Hull material	Aluminium	Steel	Aluminium
Superstructure	Aluminium	Aluminium	Aluminium
Mono or Twinhull	Mono	Mono	Mono
Dimensions			
Length overall [m]	34.2	53.2	73.6
Beam overall [m]	7.3	10.1	11.2
Deck space gross [m^2]	75	240	35
Capacities			
Personnel [persons]	50-75	50-80	120-250
Performance			
Max. speed [knots]	28	29	40
Max. distance to platform [nm]	60	100	200
DP performance [class]	0	2	2
Transfer system	Basket	Ampelmann L-type	Ampelmann S-type
Significant wave height [m]	2	2-2.5	3
Machinery			
Total power [kW]	3250	6750	14400
Propulsion	3x Fixed Pitch Propeller	4x Fixed Pitch Propeller	4x Waterjet
Cost			
Price [% wrt FCS 7011]	16	28	100
Fuel per hour at max speed [l]	813	1688	3600
Extra			
Additional role	Fifi option	Fifi option	-
Comfort	-	Gyro option	Gyro, Interceptor

The first conclusion that can be drawn is a gap between the three ships in speed. While the FCS 7011 can sail up to 40 knots, the FCS 5009 and FCS 3307 can reach 29 and 28 knots. Second, there is a significant difference in cost. The cost of the FCS 7011 is more than three times higher than the FCS 5009 and more than five times higher than the FCS 3307. Moreover, the FCS 7011 can transit and especially transfer personnel from the vessel to the platform in significant wave heights of 2.5m-3.0m. In comparison, the FCS 5009 has a maximum of 2.0m-2.5m and the FCS 3307 2.0m. Last, the FCS 3307 is the only vessel without dynamic positioning performances.

Figure 3.8 presents the described gaps by plotting the vessels against each other in terms of cost, speed, H_s and distance. These graphs also include the FCS 4008 and FCS 2710 of Damen to show a complete overview of their supply of Fast Crew Suppliers.



(a)

(b)

(c)

Figure 3.8: Graph indicating the gap of Damen's Fast Crew Suppliers

These graphs show apparent gaps between the FCS 7011 and the other Fast Crew Suppliers. Concerning the distance gap between 100nm and 200nm, it should be confirmed if this is an area of interest. Whether there is a market for a vessel able to sail distances up to 100 to 200nm is dependent of the locations of offshore platforms. Using the Copernicus Tool, which is further explained and used in Chapter 6, it is confirmed that platforms are located at these distances. Therefore, it could be confirmed that the distance gap relates to an area of interest. Concluding, it is attractive to add a vessel that fits into the gaps and helps Damen to provide a full range of market solutions. The exact characteristics of this vessel are still unknown and depend on the trade-off of design drivers as explained in Subsection 3.1.5.

3.4. Competitors Vessels and Gap Analysis

This section investigates existing vessel solutions of the competitors of Damen, to find out whether competitors have filled the explained market gap of Damen. Besides, by evaluating these competitors, lessons could be learned about their design choices and what clients require.

It is decided to include the vessels which have the possibility to have a motion-compensated gangway. This means that the vessels need sufficient deck space. Therefore, it is chosen to investigate vessels with a length of 50 metres and above. Two market-leading designers in these fast crew suppliers are Incat Crowther and Piriou. Design companies have more variants of each vessel type which are closely related to each other. Accordingly, it is decided to analyse the most relevant vessel for each yard. The five selected vessels are Muslim Magomayev, Pacific Kestrel, Seacor Puma, Alya MCcall and Kacey, shown in Figures 3.9 to 3.13. It should be noted that the Pacific Kestrel is out of service for a long time already due to damage.

Figure 3.9: Muslim Magomayev

Figure 3.10: Pacific Kestrel

Figure 3.11: Seacor Puma

Figure 3.12: Kacey

Figure 3.13: Alya McCall

Table 3.4 presents their information and specifications. When the fuel per hour at maximum speed could not be found, an estimation is made by using the total power multiplied with the specific fuel consumption of 210 g/kWh divided by the fuel density of 840 g/l. Not all the data is found for all the vessels. The maximum distance the vessels can sail to offshore platforms, and the H_s is estimated based on data the vessel has sailed the past year. Therefore, it is possible that the vessel can sail further and in higher significant wave heights than indicated.

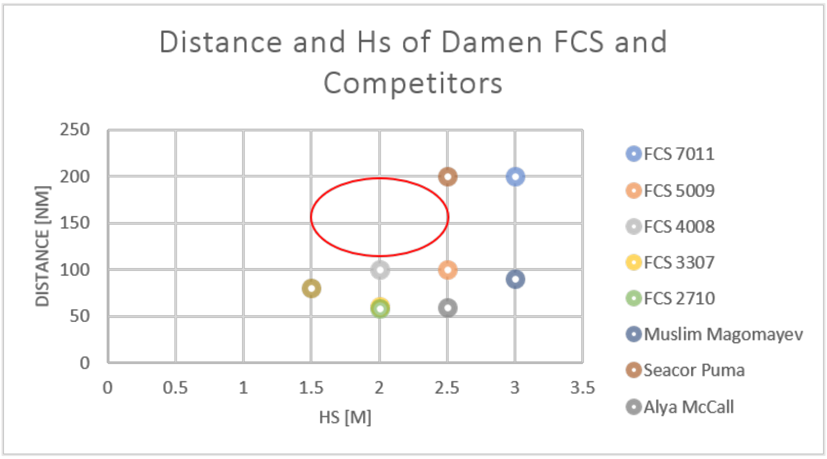
Table 3.4: Overview of Characteristics Damen's Competitors

	Muslim Magomayev	**Pacific Kestrel**	**Seacor Puma**	**Alya MCcall**	**Kacey**
General					
Building Yard	Incat Tasmania	Austal Philippins	Astilleros Armon, S.A.	Gulf Craft	SEAS - Vietnam
Design	Incat Crowther	Incat Crowther	Incat Crowther	Incat Crowther	Piriou
Operator	CMS	SPO	SEACOR	SEACOR	ABC Maritime
Build Year	2014	2016	2017	2015	2014
Sailing area	Middle East	Middle East	West Africa	Middle East	West Africa
Mono or Twinhull	Twin	Twin	Twin	Mono	Mono
Dimensions					
Length overall [m]	70	57.6	57.3	62.8	55.1
Beam overall [m]	16	12.5	12.5	9.8	10
Deck space gross [m^2]	274	230	286.5	327.5	240
Capacities					
Personnel [persons]	150	90	76	100	80
Performance					
Max. Speed [knots]	38.7	37	40	38	30
Max. distance to platform [nm]	90	-	200	60	80
DP Performance [class]	2	2	2	2	2
Transfer system	A-type Ampelmann	A-type Ampelmann	-	Basket	-
Significant Wave Height [m]	3	-	-	-	-
Machinery					
Main engines	MTU 16V4000 M73L	4x MTU 16V4000 M73L	4x Cummins QSK95	5 x Cummins QSK60	4 x Cummins KTA 50
Total power [kW]	11520	11520	11931	10071	5368
Waterjet	4x Hamilton HT900	4x Hamilton HT810	4x Hamilton Jet HM810	5x Hamilton HT810	4x Hamjet 811
Cost					
Price [% wrt FCS 7011]	-	-	-	-	-
Fuel per hour at max speed [l]	3020	2880	2983	2536	1342
Extra					
Additional role	-	FiFi 1	-	-	FiFi 1
Comfort	-	-	-	-	-

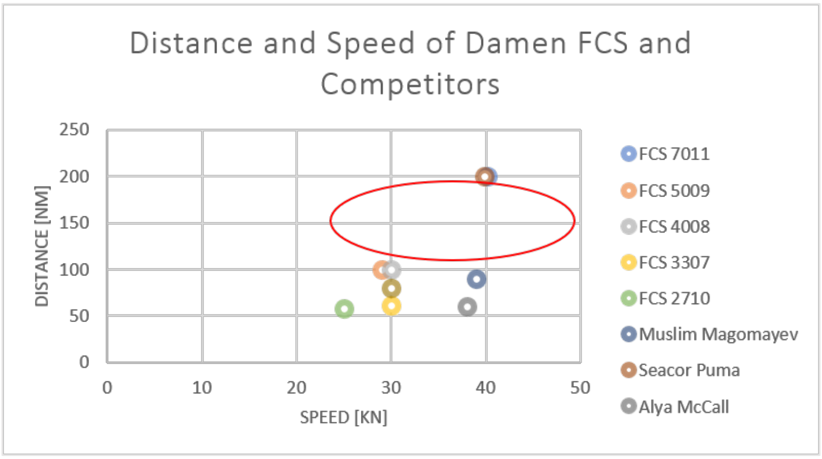
It is interesting to compare all the vessels which can compete with helicopters. Some vessels have mono-hulls, and some have twin-hulls. They are operating in the Middle East and West Africa, whereby the specifications of these ships could be assumed as sufficient for these areas' characteristics. There is a difference in the number of personnel that the vessels can transport, which is in line with the volume of the deckhouse. The longer and wider, the more personnel could be transported. Waterjets and transfer baskets are components that all vessel include. The Muslim Magomayev and Pacific Kestrel are equipped additionally with an Ampelmann A-type motion-compensated gangway. Others, for instance, like the FCS 5009, could be supplemented with an Ampelmann L-type. All the vessels can sail between 35 and 40 knots, except for Kacey. This can be explained by the difference in total power between Kacey and the other four vessels. Remarkable is that multiple vessels have Fire Fighting (FiFi) systems, which have a secondary role in helping other vessels or offshore platforms in case of fire. Regulations established by IMO about exhaust gas emissions are mentioned as Tier standards. Dependent on the sailing area, vessels have to comply with IMO Tier II or III. It is interesting to learn from when designing the new vessel. The cost, which plays a crucial role in this research, were not found.

3.4.1. Market Gap of Damen and Competitors

Figure 3.14 shows the graphs indicating the market gaps in Damen's Fast Crew Suppliers and its competitors. They base on the distance, H_s and speed since the competitors' vessels cost could not be determined.



(a)



(b)

Figure 3.14: Graph indicating the gap of Damen's FCS and its competitors

Concluding, the Seacor Puma partly fits into the market gap of Damen given in Section 3.3. Therefore, the market gap is reduced from a maximum H_s of 3m to 2.5m This means the actual market gap focuses on long-distances in mild sea conditions. In addition, the range of the competitors is estimated, whereby they have the potential to fill a part of the market gap as well. Therefore, it is essential to keep these competitors in mind while designing a new vessel, since these could be direct competitors. Improvements on these competitors vessels could be made by considering the offshore crew transportation drivers discussed in Section 2.1.

So, Damen has to design a Fast Crew Supplier which fits these gaps, is an attractive alternative to helicopters and outperforms competitive vessels. What the specific points in the gap will be, has to be researched, since speed, cost, comfort, safety, distance and H_s are all dependent on each other. This is because it is not possible to design a ship with the best options of all these characteristics.

3.5. Conclusion

The vessel's four design drivers are cost, safety, comfort, and speed. Concerning the vessel that could compete with the helicopter, a market gap for long-distances in mild sea conditions is found for CTVs. Therefore, Damen should design a vessel which fits this gap while meeting the four design drivers. The specific design is a multi criteria decision problem since the drivers are interdependent and conflicting. For example, higher speed invokes higher investment cost. The design of existing vessels can be used to support design decisions during the following research.

4

Project Contribution and Problem Definition

The research executed in Chapter 2 and Chapter 3 has led to a market gap for CTVs on long distances in mild conditions. In this gap, vessels have the potential to be an attractive alternative to helicopters. As a result, Section 4.1 discusses the importance and implementation of the study from a practical, scientific and societal perspective. It explains the goals of a new vessel. Based on this, Section 4.2 states the final problem definition, followed by the corresponding research questions in Section 4.3.

4.1. Importance and Implications of Research

This section acknowledges the importance and implications of the research from a practical, scientific and societal perspective.

4.1.1. Practical

A new type of Fast Crew Supplier needs to fit in the existing market gap, as described in Section 3.3 and 3.4, while meeting the four inter-dependent design drivers, given in Section 3.1. It has to be able to provide comfort and safety at top speed during transit and at zero speed during the transfer. It has to satisfy the following:

- Fits the market gap while meeting the four inter-dependent design requirements
- Provide comfort and safety at top speed (transit) and at zero speed (transfer)
- Sailing long distances in mild conditions
- More cost-effective than the FCS 7011 and helicopter
- Reach speed which is competitive enough to helicopters
- Outperforms competitive vessels on design requirements

This study is essential since a successful concept ship design, which can comply with these requirements, could be an attractive alternative to helicopters in a big offshore crew transportation market. Damen could contribute to a safer, more cost-effective and comfortable way of crew transportation in the offshore market by delivering such a design.

4.1.2. Scientific

This research aims to use the practical implementation of scientific material. Section 5.1 presents various papers and books of potential ship design methods and tools. Since a vessel's design is complex and has to do with inter-dependency, these will be used to answer the research question scientifically.

4.1.3. Societal

This research is executed in cooperation with the FCS department of Damen, which is responsible for the new generation of CTVs within the company. Therefore, it contributes to the development of new vessels which operate in the oil and gas market. From a societal perspective, the oil and gas market is often directly associated with environmental pollution and global warming. Although this widely-acknowledged impact of the oil and gas market is reprehensible in many ways, it should be kept in mind that the industry delivers energy on a world scale which creates prosperity for billions of people. For oil and gas companies that operate offshore platforms, the transportation of crew is a vital element. The design of new CTVs that can improve these transportation operations are beneficial for oil and gas exploitation activities and, hence, make a positive role in creating both local and global welfare.

Furthermore, it is important to consider responsibilities of a new-design CTV from a societal perspective. First of all, the vessel should provide safety for its passengers and crew. This means, the vessel's designer should adhere to the relevant safety regulations at all times in order to avoid any injuries or fatal accidents. Secondly, the vessel will operate very close to offshore installations which introduces the risk of collision. In case this happens, the platform can be damaged in such a way that it results in many on-board fatalities and / or environmental pollution (eg. oil spill). The impact of such an event has great societal consequences and, hence, there lays a major responsibility with the vessel's designer to create a safe ship with, for instance, sufficient power installed.

4.2. Problem Definition

The specific and most effective design of the new Fast Crew Supplier which fits the market gap and meets the design drivers is unknown. Various design approaches could be used in order to design this vessel. As a consequence, the following problem definition has been defined for this research project:

It is unclear what the design of a long-distance fast crew supply vessel sailing in mild conditions should be, in order to meet the design drivers to be an attractive alternative to helicopters in the offshore market.

4.3. Research Questions

The following main research question is formulated to follow up on the problem statement. It is divided into sub-questions which provide the basis for the project execution.

What should be the concept design of a Fast Crew Supply Vessel to become an attractive alternative to helicopters at long distances in areas with relatively mild conditions?

This research question is divided into six different sub-questions. These provide the structure of this research. In every chapter, at least one sub-questions will be covered. By combining all chapters, the aim is to answer the main research question. The sub-questions are as follows:

1. *What are design approaches and tools that could be used in order to design the vessel and make decisions?*
2. *Which mild sea condition areas are of interest and what are their characteristics?*
3. *What are the design requirements for a vessel operating in these areas?*
4. *Which hull-type suits these design requirements best?*
5. *What is the final concept design of this vessel and how does it score on the design drivers?*
6. *To what extend is the concept design more attractive than a helicopter?*

5

Methodology

As a basis for the follow-up project, this chapter describes the solution approach to answer the research question. It starts with an analysis of design methods applied in other studies in Section 5.1. Based on this, approaches and tools are selected to use for this research, which are described in Section 5.2. These two sections give answer on the first sub-question. This is needed to generate the solution approach of the project. Since the ship hull is an important decision concerning the four design drivers, section 5.3 gives a first analysis of this. Section 5.4 explains the method by focusing on each remaining sub-question individually. Finally, Section 5.5 discusses expected results.

5.1. Introduction to Ship Design Methods

This section will answer the first sub-question: *What are design approaches and tools that could be used in order to design the vessel and make decisions?* It elaborates on the relevant theory and concepts to design the new fast crew supplier, by presenting common approaches and tools. Different studies have been executed on ship design. In Subsection 5.1.1 approaches are explained, followed up by an elaboration on design tools in Subsection 5.1.2.

5.1.1. Design approaches

Various design approaches have been created for all types of design problems including vessels. It is commonly understood that the design process of a vessel has a strong iterative character. This iterative character mainly occurs once principal design choices are made. Since this research focuses on concept design, suitable approaches for the road leading to this have to be found. Evans (1959) first published a spiral form depiction of the iterative process. Hereafter, more approaches have been developed including Packing Approach, Concurrent Engineering, Set-Based Design and Systems Engineering. An overview of these design approaches and related literature is given in Figure 5.1. The goal is to find suitable design approaches for various stages in the research.

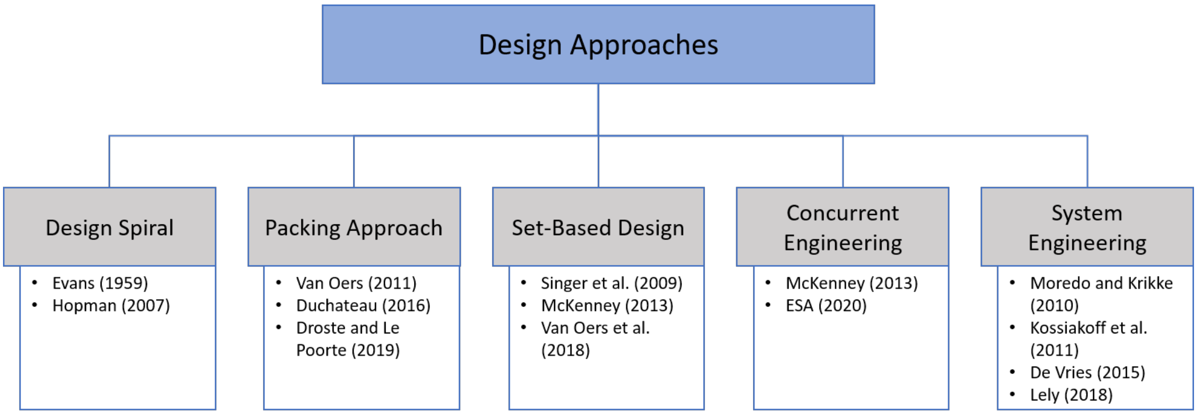


Figure 5.1: Overview design approaches and related literature

Design Spiral

Figure 5.2 shows an example of a design spiral. The process starts by generating a first idea of the ships' design and progresses down the spiral in sequence. Each step represents a particular synthesis or analysis of a particular design aspect. By going through the process once, there is a chance that the result will be out of balance. For instance, due to instability or weight. Therefore, all the steps have to be repeated again until the solution is found with sufficient accuracy and with all results in equilibrium to each other. The design spiral's weaknesses are that it just deals with how to design the ship, but not what is required. Besides, it only deals with synthesis and not with optimisation.

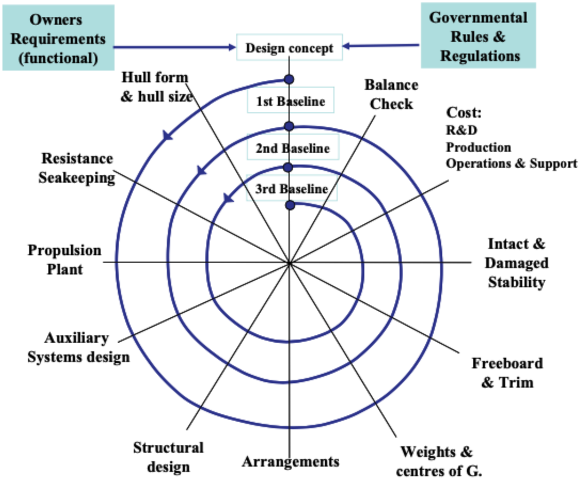


Figure 5.2: Ship Design Spiral (Hopman, 2007)

Packing Approach

The Packing Approach for ship design has been described by van Oers (2011) and Duchateau (2016). In his research, a work-flow of an interactive concept design approach for preliminary ship design was made. It integrates three basic steps of any concept design approach:

- Generating and assessing design concepts and their performance.
- Exploring and analysing design concepts and their criteria in the search for good performers and problem insight.
- Using the gained insight to select those high-performance concepts for further analysis.

These steps have to be performed iteratively in the process. Droste and le Poole (2019) improved the Packing Approach of Duchateau (2016). According to them, this concept design method is proven efficient for various ship-types and design problems. It is efficient in exploring a design problem by generating a large set of designs.

Concurrent Engineering

Concurrent Engineering (CE) is a systematic approach in which all design teams are simultaneously involved in the process. This way, conflicts are solved immediately by the various teams. It embodies team values of co-operation, trust and sharing in such a manner that decision making is by consensus, involving all perspectives in parallel, from the beginning of the design process (McKenney, 2013). The company European Space Agency, for instance, uses this approach in their design process (ESA, 2020).

Set-Based Design

Set-Based Design (SBD) is an approach in which a set of possible design options is created. Next, design decisions are made step by step to reduce the size of the set of solutions. Consequently, this design approach provides a high level of flexibility since more than one best design solution can exist at the same time. This means that trade-off decisions in the design process can be delayed until they are fully understood (Kana, 2018). In navel ship design, the SBD approach is commonly used (Singer et al., 2009, Van Oers et al., 2018).

Systems Engineering

Systems Engineering is a methodology that considers both the business and the technical needs of all customers. It aims to provide a quality product that meets the users' needs (TU Twente, 2020). According to Kossiakoff et al. (2011), it is most desirable to subdivide the life cycle into three broad stages, as shown in Figure 5.3. First, Concept Development is the initial stage of the formulation and definition of a systems' concept to satisfy a valid need the best. Second, the Engineering Development stage covers the translation of the system concept into a validated physical system design. This design meets the operational, cost, and schedule requirements. Finally, the Post-Development stage includes the production deployment operation and support of the system throughout its useful life.

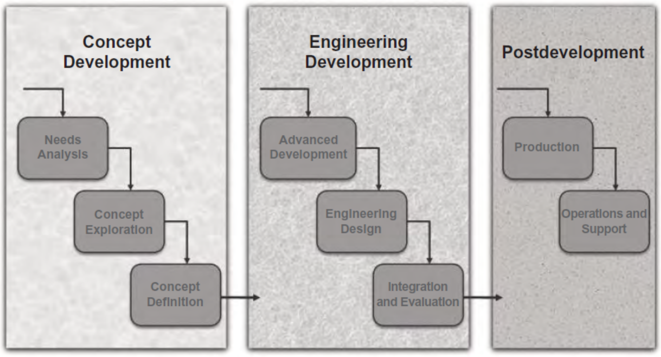


Figure 5.3: System life cycle model according to Kossiakoff et al. (2011)

According to Moredo and Krikke (2010), and de Vries (2015), the SE approach developed for naval vessels can be used for commercial vessels, despite no literature examples exist. In line with this, Lely (2018) suggests Systems Engineering (SE) as a relevant approach for high-speed craft (HSC).

Conclusion

In this research, the concept design and the first iteration are considered as important. The iterative character occurs once the concept design is made. Therefore the Packing Approach and the Concurrent Engineering method are found less attractive because of their prior focus on the complete design cycle. For instance, the Packing Approach requires multiple iterations before a proper concept design can be generated. Since the Design Spiral just deals with how to design the ship and not what is required, it will be used after the design requirements are chosen. At this stage the iterative process will start. For choosing the design requirements, the functional analysis, Set-Based Design and the System Engineering approaches are found most attractive. Set-Based Design is strong in evaluating trade-off decisions, but in contrast to System Engineering, requires explicit and measurable descriptions of design parameters in the early stage design phase. Such a design approach is not considered attractive when comparing various vessel concepts with different hull-types. Furthermore, Systems Engineering aims to meets the users' needs, which is considered as an important aspect for this research and design. For this reason, the combination of System Engineering and the Design Spiral is found to be the most suitable approach for the design problem in this research.

5.1.2. Design Tools

To support the design approaches, design tools can be used. These tools help to quantify and organise design characteristics. Especially, this is useful when more than one design requirements are in place. This is the case for a CTV which should comply with the four design requirements cost, safety, comfort and speed. These criteria are interdependent and could be conflicting since it would be impossible to maximise these four criteria simultaneously. Mckesson (2014) emphasises this in his book by titling a chapter as follows: "Fast, Comfortable, and Cheap: Pick any two". Consequently, trade-offs have to be made, which could be done by using a multiple criteria decision tools. Figure 5.4 gives an overview of several of these tools and related literature.

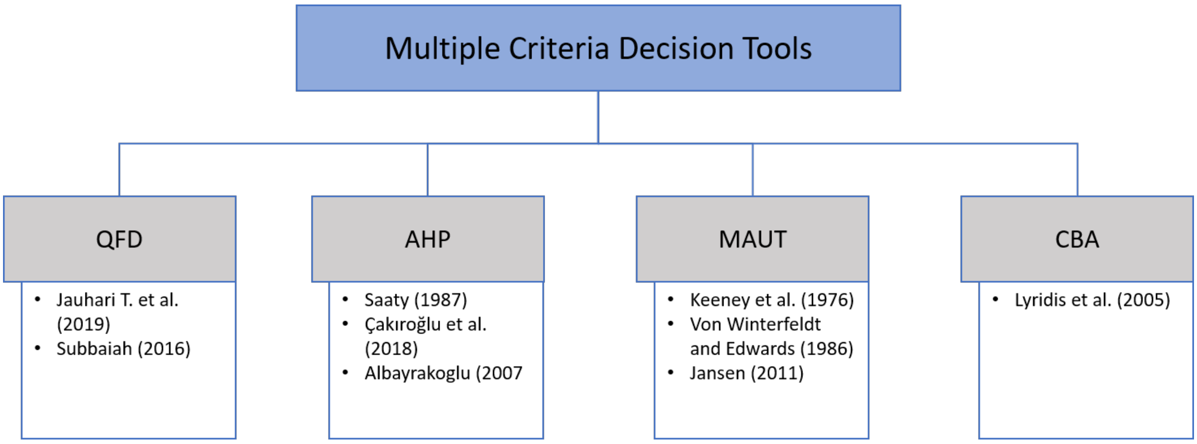


Figure 5.4: Overview multiple criteria decision tools and related literature

QFD

QFD stands for Quality Function Deployment. Its goal is to keep the design engineers, manufacturers, and marketers focused on the customer requirements and priorities during the design process. Thus, not only the feelings of the engineer or personal preferences are interesting. Using this tool can help in the following subjects (Kana, 2018):

- Decision making.
- Developing design objectives that satisfy key customer priorities.
- Trade-off studies as a method for developing selection criteria and its weightings.

- Strategic planning and documentation of design process.

QFD is typically used in conjunction with trade-off studies. QFD is an extensive process which has various kind of tools which could be executed. For instance, the Affinity diagram, Tree Diagram or the House of Quality. An example of the application of QFD is research of Jauhari T. et al. (2019). They have proposed a design model, in which the functional requirements and the design parameters can be assessed. It is performed with the use of QFD, which is their basis for a multi criteria decision analysis (MCDA).

AHP

The Analytic Hierarchy Process (AHP) is a tool which develops a priority ranking between various alternatives and which makes a single selection from a group of fixed alternatives (Saaty, 1987). It is a form of MCDA. It allows users to asses the relative weight of multiple criteria or multiple options against given criteria in an intuitive manner. When quantitative ratings are not available it is still possible to recognise whether one criterion is more important than another by using pairwise comparisons. Çakıroğlu et al. (2018) and Albayrakoglu (2007) used AHP in the ship design process.

MAUT

The basic concept of the multiple-attribute utility theory (MAUT) is to identify a set of evaluation criteria to select among a set of alternative candidates (Kossiakoff et al., 2011). The overall evaluation of an alternative is defined as a weighted addition of its values, with respect to its relevant attributes. This technique requires the decision-maker to evaluate the alternatives on each value dimension separately. It is needed to trade-off one attribute for another (Jansen, 2011). For the combination of the criteria into a single measure, MAUT uses the concept of utility functions. It translates the selection to a unitless measure of utility, which may be subjective or objective, depending on the data available. The utilities can be combined in different ways. For example, by a weighted sum, weighted product or sum of logarithms of the weighted utility. Contributors to this field of research are Keeney et al. (1976) and von Winterfeldt and Edwards (1986).

CBA

A more detailed type of trade-off study is the Cost-Benefit Analysis (CBA). It measures the effectiveness and estimates the cost of each design alternative. Hereafter a combination of these two metrics is created and cost-effectiveness analyses can be performed. Three of these analyses are equal cost-variable effectiveness, variable cost-equal effectiveness and variable cost-variable effectiveness. For this tool detailed models are needed. Lyridis et al. (2005) and MONALISA (n.d.) used this tool in vessel projects.

Conclusion

To support the selected design approach, design tools can be applied which help to quantify and organise design decisions. Since the design of a new CTV is considered a multiple criteria decision problem, tools that help in trade-off decisions are useful. CBA and AHP will not be used since CBA focuses too much on cost and the priority ranking of AHP is considered as less useful than the weighted values of MAUT. QFD is selected since it is particularly helpful in creating design objectives based on design requirements. Furthermore, it is decided to use the values of QFD as well in order to translate the design requirements into unitless measures. This is useful to compare different design characteristics effectively during the design process. For combining the interdependent design drivers into a single measure, MAUT is attractive to use. In the case of the hull comparison, this measure is useful to compare the multiple design criteria. For this reason, elements of MAUT will be applied in this study.

5.1.3. Approach and Tools Damen

Damen does not use specific design approaches. Overall, they make decisions based on the design spiral. At more complicated projects, they intend to use a V-diagram, which is a Systems Engineering performance which will be further explained in Section 5.2. An example of research executed by Lely (2018) describes the design approach of Damen. It looks at their initial design documents combined with interviews with project portfolio managers (PMM) and Design & Proposal engineers. The PPM followed the procedures of a new standard design, by starting with creating a document with a summary of deficiencies. Based on this, the initial design criteria are created by executing the design spiral. It contains objectives such as range, area of service, top speed, and capacity for a Fast Crew Supplier. This is a first document which contains ideas and objectives for the new design. At every update the content is more precise.

For the integration between the vessel and the motions compensated transfer system, Damen does have an approach and tool. When having the designed vessel's lines plan, the response amplitude operators (RAO's) could be defined. RAO's describe vessels motions in waves. Each displacement RAO defines the vessel response, for one Particular Degree of Freedom, to one particular wave direction and period. In cooperation with Ampelmann, the new RAO's can be defined with the motion-compensated gangway in operation. The lines plan can also be used to find the Root Mean Square (RMS) values of the vessel. RMS of a set of values is the square of the function that defines the continuous waveform. It can be used in order to assess comfort.

5.2. Selected Ship Design Method

This section gives more information on the selected design approach and design tools. Subsection 5.2.1 describes the concept development stage of Systems Engineering and Subsection 5.2.2 elaborates on QFD and MAUT.

5.2.1. Selected Design Approaches

Systems Engineering

Since in this research the concept selection and the first iteration are considered necessary, it is interesting to focus on the Concept Development stage of Systems Engineering. In this stage the systems need, explores feasible concepts, and selects a preferred system concept are established. The concept development stage divides three phases according to Kossiakoff et al. (2011):

- *Needs analysis*
  Defines and validates the need for a new system, demonstrates its feasibility and defines system operational requirements.

- *Concept exploration*
  Explores feasible concept and defines functional performance requirements.

- *Concept definition*
  Examines alternative concepts and selects the preferred concept based on performance, cost, schedule and risk and defines system functional specifications.

The operational objectives and functional requirements must be validated to quantify the effectiveness of a vessel. This can only be done after defining the measuring of effectiveness (MOE), and the measure of performances (MOP). According to Kossiakoff et al. (2011), the definitions are:

- *MOE*: A qualitative or quantitative metric of a system's overall performance that indicates the degree to which it achieves its objectives under specified conditions. An MOE always refers to the system as a whole.

- *MOP*: A quantitative metric of a system's characteristics or performance of a particular attribute or subsystem. An MOP typically measures a level of physical performance below that of the system as a whole.

Processing MOE and MOP could be done using an objectives tree structure. A combination of the MOE and MOP measurements, and this objectives tree structure could be used to generate a generic setup of Systems Engineering shown in Figure 5.5 (Lely, 2018).

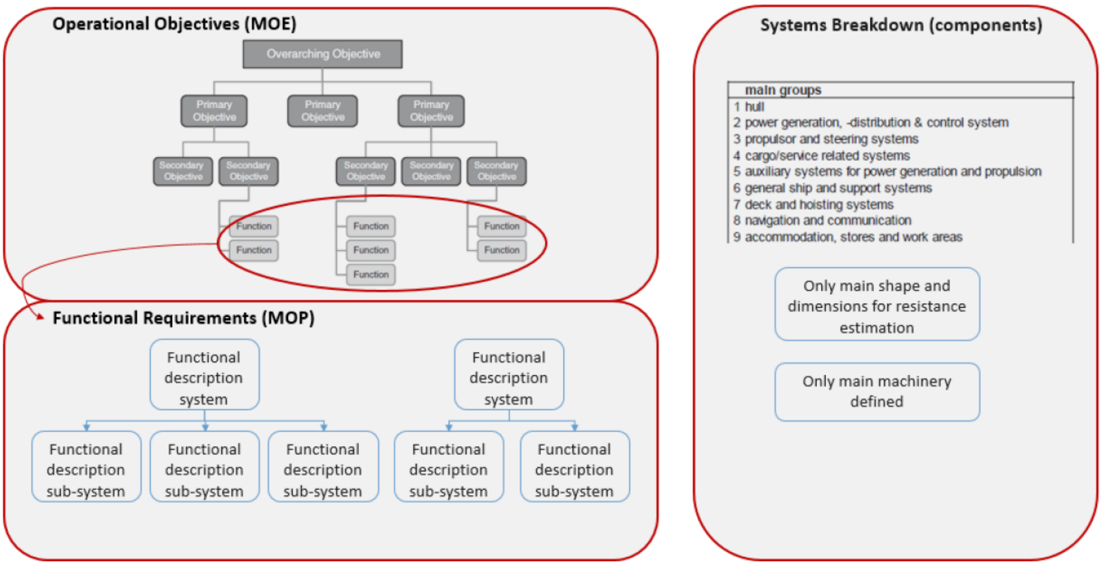


Figure 5.5: Generic setup of Systems Engineering executed by Lely (2018)

For Systems Engineering various models have been established. Lely (2018) concluded that the V-model and Kossiakoff model are preferred as a Systems Engineering model for Damen over the Dod-model, Waterfall model and the INCOSE V-model. Therefore, below the V-model is described additionally.

Figure 5.6 shows an example of the V-Diagram for ships. It emphasises on the verification during the development and validation during the execution. The functioning of the actual components and (sub)systems are validated with the original objectives and functional descriptions, per system level. Furthermore, the final description of the subsystems must be verified during the design. This is to ensure whether they meet the operational objectives. These verification and validation steps can only be done when the MOE and MOP have been defined.

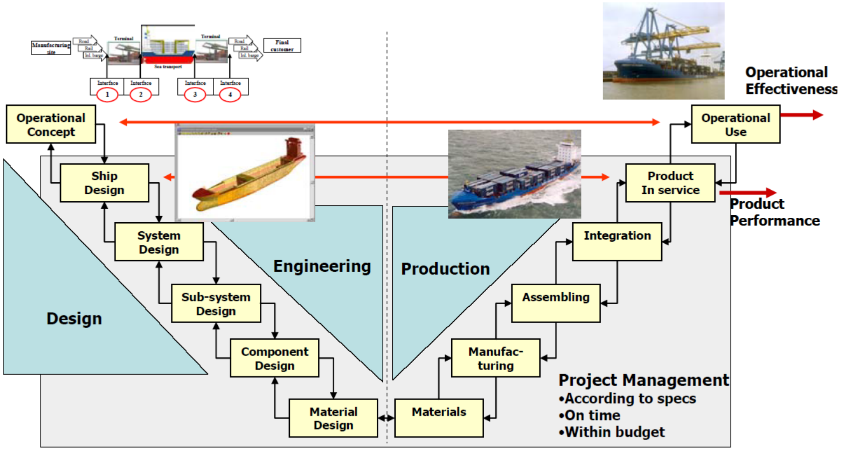


Figure 5.6: The generic production process for ships (Hopman, 2007)

Different models have been proposed in synthesising ship design observing the systems integration and interactions adopting the SE concept. For instance by Jafarzadeh et al. (2017), Vernengo and Rizzuto (2014) and Jauhari T. et al. (2019). Their models highlight the needs for the methods, tools and techniques. They observe detail and multi-disciplinary design considerations at the early design phase, assess the design cycle, and propose a structured collaborative environment. Moreover, the identified needs are considered to reduce design uncertainties and iteration to achieve effective design convergent and superior design quality.

A combination of the preferred Kossiakoff and V-model, according to Lely (2018), resulted in a proposed framework for HSC projects of Damen as illustrated in Figure 5.7. The Concept Development stage of Kossiakoff et al. (2011) is processed in the V-models' relevant concept development phase.

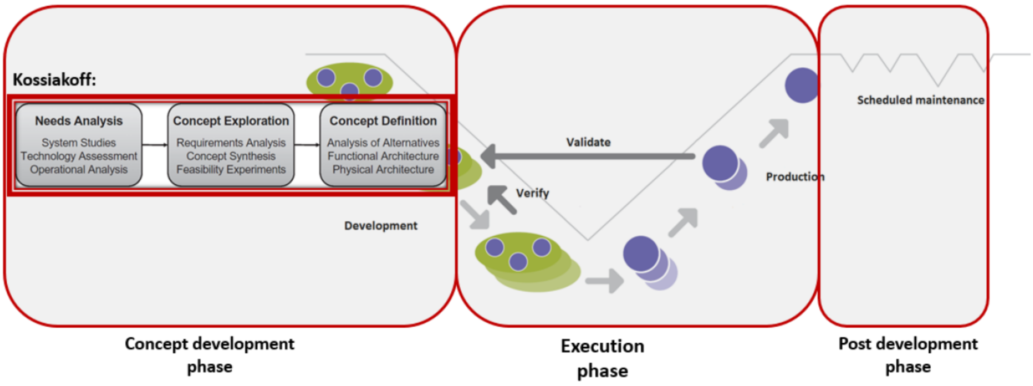


Figure 5.7: Proposed framework for HSC projects by Lely (2018)

Design Spiral

Finishing the elaboration of the concept development phase of systems engineering it is known what the concept should accomplish. Subsequently the design has to be formed, which will be executed using the design spiral. The iterative process will be run through, looking conceptual at various stages. Various stages that will be dealt with are:

- Hull form and hull size
- Resistance and seakeeping
- Propulsion plant

- Auxiliary systems
- Structural design
- Weights, centres of gravity, trim and stability
- Cost

5.2.2. Selected Design Tool

QFD

The QFD process which will be used is House of Quality. It is a product planning matrix which translates subjective and qualitative customer needs into technical engineering characteristics. It contains several elements which each show relationships between customer needs and engineering characteristics. Figure 5.8 presents a template example.

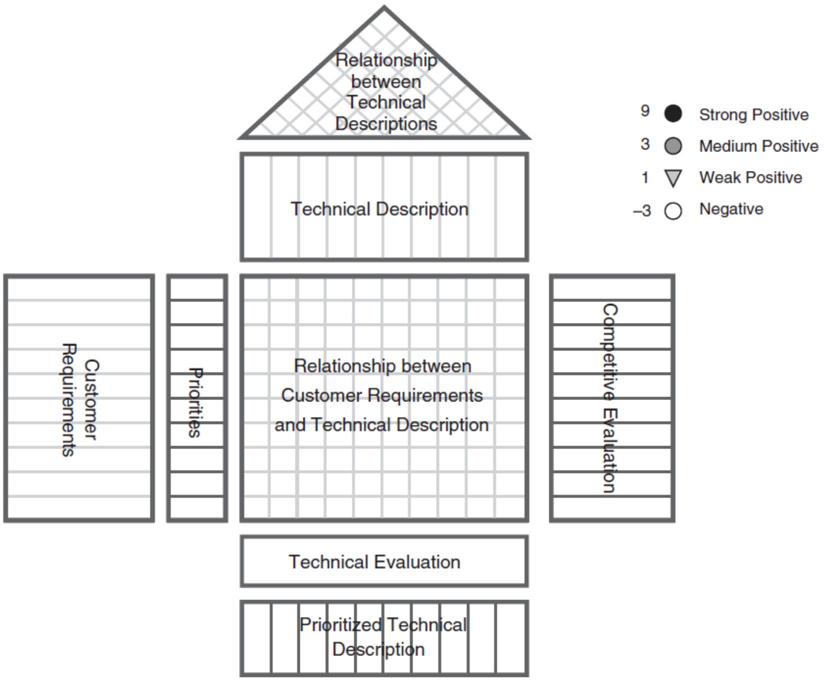


Figure 5.8: House of Quality

MAUT

Although the practical application of MAUT may vary, it emphasises that all procedures include the following steps (Jansen, 2011):

1. Defining alternatives and value-relevant attributes.
2. Evaluating each alternative separately on each attribute.
3. Assigning relative weights to the attributes.
4. Aggregating the weights of attributes and the single-attribute evaluations of alternatives to obtain an overall evaluation of alternatives.
5. Perform sensitivity analyses and make recommendations.

5.3. Introduction to Hull-Types

This section gives a first evaluation of ship hulls, since the hull plays a big part in the cost, safety, comfort and speed of the vessel. The range of possible ship-types that could be used in designing a CTV is wide. The hulls have various conflicting advantages and disadvantageous regarding the decision for the best ship-type for a specific design. Besides, choosing the material of the hull leads to different results in cost and speed. Furthermore, the hull structure design has become more critical technically and economically, which makes it an important part in the decision of the design (Okumoto et al., 2009). It is needed to consider the complete mission profile of a ship and to be prepared to meet the demands for compromises. Because of these reasons, this section studies ship-types at a global level.

Displacement mono-hulls have limits in resistance and seakeeping performance. They cannot sail at speeds higher than the hull speed due to the enormous increase of the wave-making resistance at that speed region. This can be overcome by making use of 'dynamic lift'. The pressure build-up below the bottom, lifts the ship partly out of the water, effectively decreasing the wetted surface and the displaced volume, thereby significantly decreasing the resistance. However, ships designed for dynamic lift, tend to have a lousy seakeeping performance, due to extreme vertical accelerations when slamming into waves. A solution to decrease slamming is developed by Damen, which are vessels with an Axe Bow, as explained in Section 3.3. From the beginning of the 'powered boat era', designers have been searching for solutions to go faster and improve seakeeping performance preventing the ship and crew for damage at high speed. These ships are called 'Advanced Marine Vehicles'. Five main categories are identified based on Stapersma et al. (2012), Mckesson (2014) and Papanikolaou (2014). Stapersma et al. (2012) identified five main categories in Advanced Marine Vehicles as follows:

- *Mono-hull*
  This is a single hull vessel. An advanced mono-hull has an underwater configuration which generates a hydrodynamic force at high speed. This acts on the ship's bottom, causing a partial lift of the ship (semi-planing) or almost fully (planing) above the water surface.
- *Multi-hull*
  This vessel consists of two or more hulls. An advanced multi-hull may show similar lift behaviour at high speeds as mono-hulls.
- *Hydrofoil*
  This vessel is equipped with a hydrofoil configuration below the hull, which lifts the ship's hull above the water surface when the speed increases.
- *Air lift types*
  Vessels supported by airlift which can be divided by power static lift vessels (hovercraft) or dynamic lift vessels (Wing in ground effect vehicles).
- *Hybrid vessels*
  Vessels which combine one or more of the categories mentioned above.

Apart from buoyancy, lift can be realised passively or actively. Passive lift (dynamic lift) means that lift generation is the result of speed and not of added power. Examples are dynamic lift of a high-speed planing craft or the lift of a hydrofoil. Active lift (powered lift) is generated by adding power to a device to produce lift. It is independent of the vessel's speed, since it is present even at zero speed, as long as the 'lift system' is switched on. Examples are the air cushions of hovercrafts and SES's. The suspension triangle in Figure 5.9 shows different ship-types in terms of these lift forces. They are scaled in a triangle with buoyancy, powered static lift and dynamic lift. The displaced water takes care of carrying the vessel in case of buoyancy. The cases of dynamic lift, are when the vessel's speed creates airlift or hydrodynamic lift. Extra power supply creates additional powered static lift.

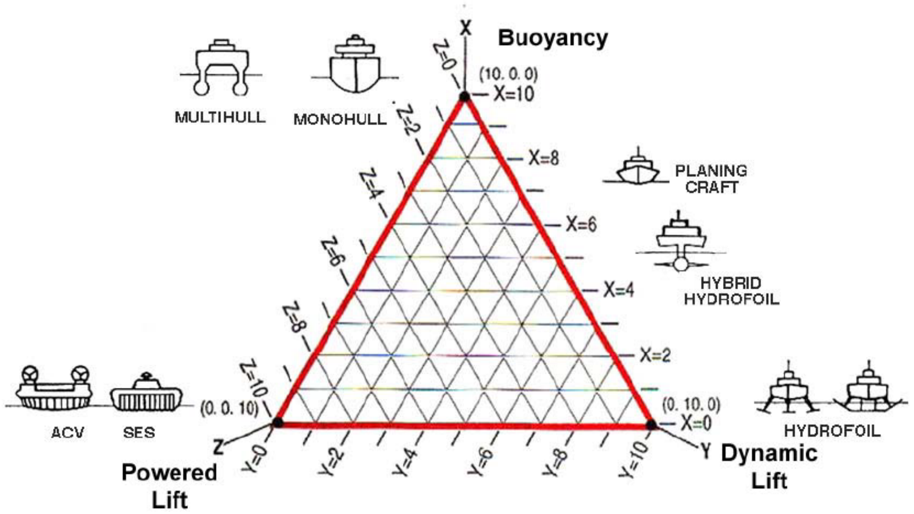


Figure 5.9: Suspension Triangle (Clark et al., 2004)

The ship evaluation in terms of the four design drivers can be executed using studies of Clark et al. (2004), Papanikolaou (2002) and Mckesson (2014). Findings of Mckesson (2014) are that a mono-hull gets into a problematical situation when it tries to go fast. The hull has to be made as slender as possible, to reduce drag for high speed. It reduces pressure and form drag. However, a slender mono-hull is difficult to stabilise. In contrast with that, a multi-hull is stable. Table 5.1 shows ratings according to the opinion of Mckesson (2014) of four hull shapes. A high number indicates a better performance. Shown is a multi-hull form: a Small Waterplane Area Twin Hull (SWATH), which speed/power ratio is lower than a mono-hull. However, it is also more expensive and not attractive for high-speeds. An improvement in speed/power ratio is the hydrofoil, which has a good sea-kindliness similar to the SWATH. However, the comfort of a hydrofoil has been rated as poor by Mckesson (2014). These findings show that it is hard to find a ship hull which performs the best at the four criteria. Consequently, it is needed to extensively investigate the ship-types and compare them to balance their competing requirements and desires.

Table 5.1: The subjective assessment of various Advanced Marine Vehicles against performance parameters of Mckesson (2014) (speed is addressed in terms of speed in a seaway)

	Sea-kindeliness	Speed/Power	Comfort & Space	Cost
Catamaran	2	1	3	3
Trimaran	2	2	2	3
SWATH	3	1	3	2
Hydrofoil	3	3	1	1

Besides the hull considerations, it is also important to make choices about the material of the hull. Decisions are made based on weight, price and fatigue. Typically used materials are aluminium, steel and Fibre Reinforced Plastics (FRP). Aluminium is more expensive but also has less weight (Yachting Pages, 2020). Light-weighted vessels have the advantage that less power is needed in order to reach the same speed. On the other side, steel has better fatigue characteristics aluminium. FRP is light weighted and could be less expensive than aluminium. For this type of material moulds have to be made. Damen has no experience with the use of FRP for ships above 30 meters. Therefore, for this concept it is expected that it takes high risks to design a vessel with an FRP hull.

5.3.1. Conclusion

Concluding, five primary choices of advanced marine vehicles are mono-hull, multi-hull, hydrofoil, airlift types and hybrid types. Mono-hulls are more attractive for high speeds than multi-hulls, but less for stability. The ship-types have distinct conflicting advantages and disadvantageous regarding the decision for the best ship-type for a specific design. The complete mission profile of a ship has to be considered, and demands for compromises have to be met. Therefore, more expanded research has to be executed of these ship types relating to the four design drivers.

5.4. Solution Approach

As a result of the research relative to sub-question one in this chapter, this section examines the suitable solution approach to execute this research in a structured manner, based on previous studies and investigations. It is explained by focusing on each remaining sub-question individually. Figure 5.10, gives an overview of the solution approach.

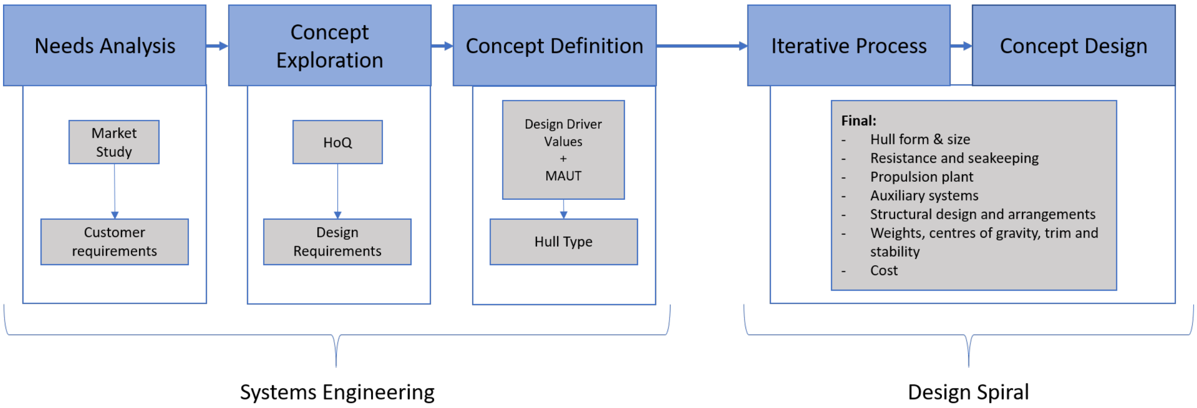


Figure 5.10: Solution Approach

As concluded in the first sub-question, the solution approach starts with executing a part of Systems Engineering and ends with partly executing the Design Spiral. First, the 'Needs Analysis' is elaborated on in sub-question two. Then, sub-question three gives answers relative to the 'Concept Exploration'. In the 'Concept Definition' phase, the hull-type will be selected, which corresponds with sub-question four. Next, the 'Iterative Process' and 'Concept Design' phases are elaborated in sub-question five. Finally, it will be compared with helicopters and the defined market gap. This way, a concept design of a Fast Crew Supplier will be accomplished.

2. Which mild sea condition areas are of interest and what are their characteristics?
This question is planned to be answered in Chapter 6, using and expanding the Copernicus tool of Damen. This tool is made based on data of Copernicus Marine Service (2020), and shows significant wave heights on the world map. It will be further elaborated on, whereby the locations of the offshore platforms can be seen related to these wave heights. By using this, it could be found what attractive areas are and what their characteristics are. An indication will be given for each area, in which H_s the vessel at least must be able to transit and transfer crew in, in order to reach the offshore platforms. Furthermore, it also has to be investigated at what distance the platforms are located.

3. What are the design requirements for a vessel operating in these areas?
By answering this question in Chapter 7, it is known for which areas the vessel will be designed. As a result, design requirements can be determined based on the regulations and wishes of clients in these areas. First, a House of Quality is executed, a design tool explained in Section 5.1. Conse-

quently, priorities are known and decisions regarding design objectives and selection criteria could be made better. The design requirements will be set based on the House of Quality outcomes and on trade-offs with regard to the research question. This will be done by using the generic setup of Lely (2018) as described in Subsection 5.1.1. In addition, Watson (1998a) could be used.

4. Which hull-type suits these design requirements best?
This answer will be answered in Chapter 8. As already explained in Section 5.3, vessels can be designed with various types of hulls. Five main categories are mono-hull, multi-hull, hydrofoil, airlift types and hybrid types. They have various conflicting advantages and disadvantageous. Therefore, it is needed to consider the complete mission profile and compromises. These trade-offs will be made first, by executing an assessment of various hull-types based on boundary conditions. Hull-types that satisfy these conditions, will be compared further based on literature and using the values of the House of Quality in combination with results of design drivers. Comfort results will be calculated by using a program evaluating seakeeping characteristics. This program will be chosen and explained in Chapter 8. The combination of these two results is a multi-criteria decision analysis. Therefore, elements of MAUT are used in order to select one of the hulls.

5. What is the final concept design of this vessel and how does it score on the design drivers?
By answering this question in Chapter 9, the final design will be shown and its cost will be calculated. The price based on the IDC and fuel consumption as described in Section 3.1 will be executed by using the approach of Damen. In addition, the method of (Watson, 1998b) could be used. Furthermore, the performances of the final concept design concerning speed, comfort ans safety will be presented.

6. To what extend is the concept design more attractive than a helicopter?
This question will be answered in Chapter 10 by executing a case study. The designed vessel will be compared with a helicopter. This can be done by using the criteria chosen relevant in this research based on the design drivers, described in Section 3.1. In this way it can be verified whether the design is an attractive alternative to helicopters or not.

By comparing the investment cost and the transportation cost per person of the vessel and the helicopter, a conclusion could be made which one is more cost-effective. In addition, the vessel should be more cost-effective than the FCS 7011.

Concerning the safety, the fact that a vessel is compared to a helicopter, it could already be said that it is safer. This is because Subsection 2.2.2 concluded that marine transfers carry a lower risk of fatal incident than helicopters. However, concerning the vessel, decisions have to be made to increase the safety. Especially for the transfer part, since this is a more risky operation than helicopters regarding injuries. Moreover, the vessel will be considered safe if it not exceeds the maximum vertical acceleration limit ($8.0\mathrm{m/s^2}$) as described in Subsection 3.1.2. As described in Subsection 3.1.3, the RMS vertical acceleration limit does not apply for fast ships due to their non-linear behaviour. However, if such vessels can be approached linearly, this limit ($1.47\mathrm{m/^2}$) could also be taken into account.

Compared to a helicopter, Subsection 2.2.5 showed that the comfort of a vessel is more attractive if meeting sufficient seakeeping characteristics. There are existing specific calculations to verify comfort. However, comparing these with helicopters is challenging, since these are related to the sea. Moreover, comfort is dependent on various qualities, whereby verification and comparisons are hard to do. However, distinctions could be made using the vessels' space and making decisions that increase its comfort. Moreover, if complying with same or better comfort values as similar vessels of Damen, it could be said that a vessel is more attractive than the helicopter.

Regarding the speed, conclusions drawn in Subsection 3.1.4 indicate that helicopters are less time consuming than vessels. However, on board a vessel it is possible to use time more efficiently. Since there is a maximum in time of this efficiency, a maximum transportation time of eight hours is chosen to be an attractive alternative to helicopters. This decision is based on an expected duration of a working day. So, the speed has to be such a value that it could comply with this. In addition, meeting the working time arrangement, which has a maximum of 12 hours for crew, will be checked.

Main research question: What should be the concept design of a Fast Crew Supply Vessel to become an attractive alternative to helicopters at long distances in areas with relatively mild conditions?

To give an answer on the main research question the concept design should compete with helicopters in mild condition areas at long distances in the offshore crew transportation market and should fit in the market gap of Fast Crew Suppliers. The answer of this question will be made based on the assessment of the criteria described in Table 5.2 and Table 5.3. The criteria of Table 5.2 are described above in the previous sub-question. The criteria of Table 5.3 are based on the market gap described in Sections 3.3.4 and 3.4.1.

Table 5.2: Overview of criteria to improve on helicopters

Design Driver	**Criteria to improve on helicopters**
Cost	Signficantly lower cost per person per trip
Safety	In addition to the proven improved safety in literature study: not exeed the limiting vertical acceleration value
Comfort	In addition to the proven improved comfort in literature study: not exceed the limiting value of comfort based on the FCS 7011
Speed	Supply multiple platforms of crew within the time range of eight hours

Table 5.3: Overview of criteria to fit in the market gap

Driver	**Criteria to fit in the market gap**
Cost	Significantly lower investment cost than the FCS 7011 (<70%)
Speed	Between 25 and 50 knots
Range	Distance between 100 and 200 nm
Significant wave height	Between 1.5 and 2.5 m

5.5. Expected Results

With this executed study, a new crew transfer vessel will be designed, which is an attractive alternative to helicopters in the offshore market. Based on the outcomes of Chapter 2, it is expected that the vessel will be an attractive alternative to helicopters in terms of cost, safety and comfort. To what extend the concept design is more attractive than a helicopter will be investigated. Furthermore, it is expected that the design fits in the discussed gap in Chapter 3, whereby Damen expands its market coverage. The new vessel will likely have a speed in the range of 30 to 40 knots and a cost at least lower than 70% relative to the FCS 7011. Further and final characteristics of the vessel in relation to the market gap will be determined in this study. The design decisions will be based on the four inter-dependent criteria. Concerning the hull-type, expectations are that innovative solutions are attractive but also expensive. This may lead to the selection of a conventional hull-type which is more cost-effective.

II

Design Process and Final Design

6

Selection of Operational Areas

The conclusions about areas drawn in Section 3.2 are based on widely spread areas. However, the selection of the vessel design requirements needs to be based on detailed characteristics of specific operational areas. Therefore, this chapter completes the insights on these operational areas. It will give an answer to the second sub-question: *Which mild sea condition areas are of interest and what are their characteristics?* First, a selection of areas with a high density of offshore platforms is made in Section 6.1. Based on this, the significant wave height the vessel should operate in is chosen in Section 6.2. As a result, the operational areas are determined in which the ship will be able to sail. However, not all these areas are interesting markets for Damen to sell their vessels. For instance, areas could be very traditional whereby they do not want to buy from other countries, or stick to their current vessels. Therefore, the operation areas are selected based on the market in Section 6.3. Figure 6.1 clarifies the above-mentioned approach.

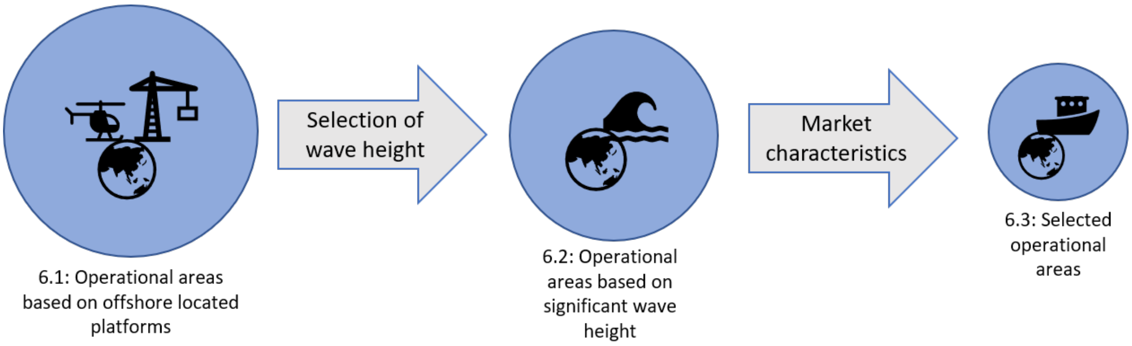


Figure 6.1: Approach of selection of operational areas

The decisions made in this section are executed by using the Copernicus Tool. It was launched by Damen and further developed together to support the purpose of this research. It is based on the data of CMS (2020) and has the data points of the first day of each month of three years. Accordingly, it is not assured that the tool gives fully realistic data. In this tool, two variables can be tuned: the maximum significant wave height and the occurrence of these significant wave heights. The tool uses a map with colour indications of which the legend is shown on the right-hand side of the window, as can be seen in Figure 6.2. For an improved usage of the tool, two adjustments have been made:

- *Implementation of offshore platforms*
  This ensures that decisions concerning areas and wave heights focus on locations of offshore platforms. The platforms which are shown are currently provided of crew by helicopters. The information about the offshore platforms is obtained from a database of 2018.

- *Implementation of the occurrence options 85%, 90% and 95%*
  The significant wave height occurrence corresponds with the workability of the vessel. In the initial tool, the maximum possible occurrence setting was 80%. Since it is of interest to design a vessel with as high as possible workability, the higher options are implemented.

6.1. Areas with Offshore Platforms

As a first step, the areas are investigated which have a significant number of offshore platforms. This is done because next to the selected areas in Section 3.2, other attractive areas could exist. These are identified by using the Copernicus Tool, including the offshore platforms, of which an impression is shown in Figure 6.2.

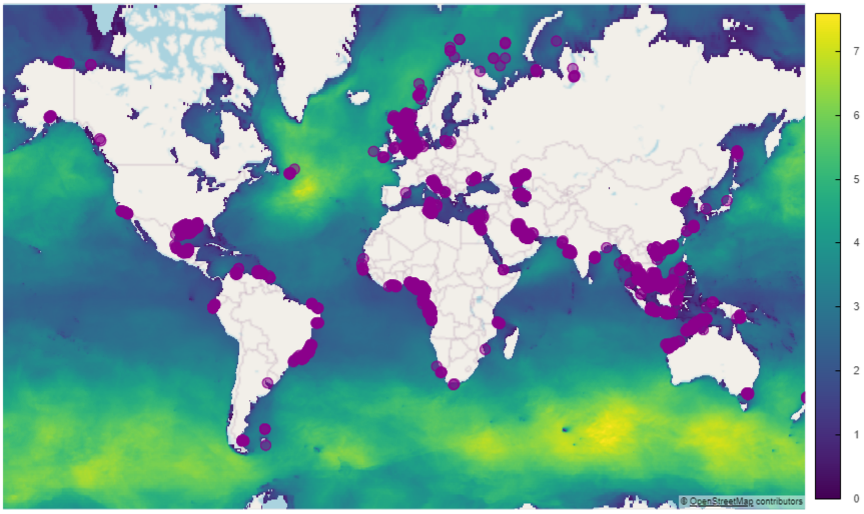


Figure 6.2: Copernicus map including offshore platforms (Settings: significant wave height of 2 meters and occurrence of 80%)

The figure shows that there are many areas of interest that could be selected. A shortlist of these areas is made and presented in Table 6.1. In this table the number of platforms per area are provided as well. It should be noted that the Gulf of Mexico is split up in an Mexican and American part which is done due to difference in regulations and wave heights.

Table 6.1: Attractive operational areas based on existing platforms.

Area	**Number of Platforms**
Australia	33
Bohai Bay	49
Europe	162
Gulf of Mexico, America	446
Gulf of Mexico, Mexico	128
Gulf of Thailand	348
Indonesia	77
Italy	23
Middle-East	298
North Latin America	47
South Latin America	160
Tunisia	32
West Africa	265

6.2. Significant Wave Height

The next step is to focus on the minimum significant wave height the vessel has to overcome to reach most offshore platforms at least 80% of the time. Therefore, specific research is conducted per area. The significant wave height values are chosen using the Copernicus Tool with the following boundary conditions:

- *Reach all platforms in a 100 to 200nm range*
  In the Copernicus Tool, the combined selection of significant wave height and occurrence gives a coverage in the map of the presence of that wave height and lower. This coverage is translated to the range of the vessel, whereby it will not exceeds its design limits. The selected wave height per area should enable the vessel to reach all platforms in a 100 to 200nm range, without exceeding its design criteria. Except if these platforms remain outside the boundaries in the Copernicus Tool when increasing the wave height.

- *Workability of 80% and 95%*
  The selected wave height is based on a percentage occurrence selection of 80% and 95%.

The combination of these two boundary conditions is chosen because they provide a high level of workability for the vessel and fills the existing gap in CTVs as described in Section 3.3. It is preferred to use the significant wave height occurrence rate of 95% since this yield the highest uptime, but the occurrence rate of 80% is also a workability which is acceptable. Next, within these boundary conditions, specific areas can be selected for which the vessel has to be designed. The characteristics of these areas help in creating the design requirements and making the design choices.

The selection of the significant wave height is based on the execution of the Copernicus Tool zooming in on the maximum significant wave height of each area. Table 6.2 shows the found values. Appendix C gives a detailed explanation of the decisions by illustrating the map and settings in the Copernicus Tool of each area.

Table 6.2: Significant wave heights of areas at workability of 80% and 95%, and the attractive area assessment based on a workability of 80% (* = based on 95%)

Area	**Number of Platforms**	**Hs [m] at 80%**	**Hs [m] at 95%**	**Attractive area for Hs up to 2m**
Australia	33	1.5	2.6	Yes
Bohai Bay	49	1	1.6	Yes*
Europe	162	2.1	3+	No
Gulf of Mexico, America	446	1.9	2.5	Yes
Gulf of Mexico, Mexico	128	1.4	2.3	Yes
Gulf of Thailand	348	1.9	2.6	Yes
Indonesia	77	1.1	1.6	Yes*
Italy	23	1	1.6	Yes*
Middle-East	298	1.4	2.2	Yes
North Latin America	47	2.2	2.6	No
South Latin America	160	2.3	2.9	No
Tunisia	32	1.4	2	Yes*
West Africa	265	1.8	2.3	Yes

Based on the selected significant wave height per area as shown in Table 6.2, a division of areas is made. This is done by selecting the areas possible to operate in, based on a vessel designed for the significant wave height combined with the needed workability. As a result, it is chosen to design a ship that can sail in significant wave heights up to 2 meters. Based on this boundary condition, the areas are rated as attractive or not attractive, shown in the last column of the table.

As a result of the selected significant wave height, the vessel will be able to reach all the platforms in ten areas for 80%. Additionally, all or a part of the platforms could be reached with an occurrence of 95%. Areas that drop out are North and South - East Latin America and, as also concluded in Section 3.2, Europe.

6.3. Market Characteristics

Each area selected in the previous section has its market specifications. For instance, whether an area has specific comfort aspects, what type of crew transportation is currently in use, or if it is a developing market. Therefore, this section elaborates on the market characteristics of the ten remaining areas. As a result, the final operational areas will be selected, upon which design choices can be made.

The market information is gathered at, and based on the experience of, the sales department of Damen. Appendix D gives an extensive explanation of each market. A summary of the essential considerations is shown in Table 6.3. The areas are ranked on the potential to access the market. For instance, areas could be very traditional whereby they do not want to buy from other countries, or stick to their current vessels. Another reason to rate an area as negative is due to significantly few offshore platforms. Additionally, they are rated on their platforms, which could be located too far or too close, or are too high.

Table 6.3: Rating of operational areas of interest

	Market Potential	Platform characteristics and location	Operational Areas of interest
Australia	+	-	No
Bohai Bay	-	+	No
Gulf of Mexico, America	+	-	No
Gulf of Mexico, Mexico	+	+	Yes
Gulf of Thailand	-	+	No
Indonesia	-	-	No
Italy	-	-	No
Middle-East	+	+	Yes
Tunisia	-	+	No
West Africa	+	+	Yes

Based on this ranking, West Africa, the Middle-East and the Mexican part of the Gulf of Mexico are the selected operation areas.

6.4. Conclusion

Based on the selected significant wave height and the market knowledge, three main areas are chosen: West Africa, the Mexican Gulf of Mexico and the Middle-East. These areas are the most attractive in terms of circumstances and marketing for Damen. Therefore, decisions concerning the concept design of the vessel will be made based on the characteristics of these areas. Nevertheless, the ship will be able to sail in the other selected areas appointed in Table 6.3.

7

Selection of Design Requirements

Based on the three selected areas in Chapter 6, the final design requirements are determined in this chapter. This will be done by setting up a House of Quality as explained in Subsection 5.2.2. For this tool, the customer requirements of the areas and the functional requirements of the vessel need to be known. Therefore, they are set up in Section 7.1. Subsequently, these two are linked with each other in a House of Quality in Section 7.2. This way, important aspects are determined, needed for designing the vessel. The final design requirements will be established in Section 7.3 which will induce the boundary conditions for the ship design. So, in the end of this chapter, an answer can be given on sub-question 3: *What are the design requirements for a vessel operating in these areas?*

Figure 7.1 shows the solution approach as explained in Chapter 5. This chapter will execute the first two phases, which are the 'Needs Analysis' and the 'Concept Exploration'. In the Needs Analysis, the design drivers given in Section 3.1 are studied, and in the Concept Exploration the possible combination of design characteristics are examined.

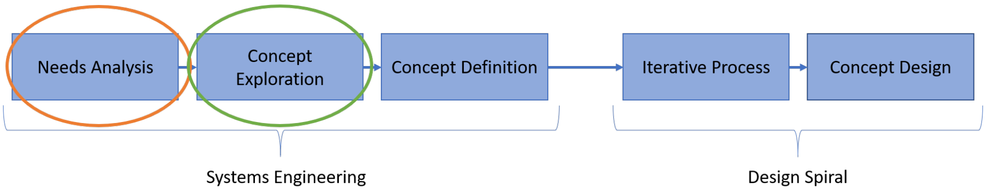


Figure 7.1: The indicated needs analysis (orange) and concept exploration (green) of the solution approach

7.1. Customer and Functional Requirements

The 'Concept Exploration phase' is investigated by first defining customer and functional requirements, using the Systems Engineering approach. Figure 7.2 shows the tree structure of the goal, the operational/customer requirements (MOE) and functional requirements which are related to the ship's systems (MOP). An enlarged version of this figure is presented in Appendix E.

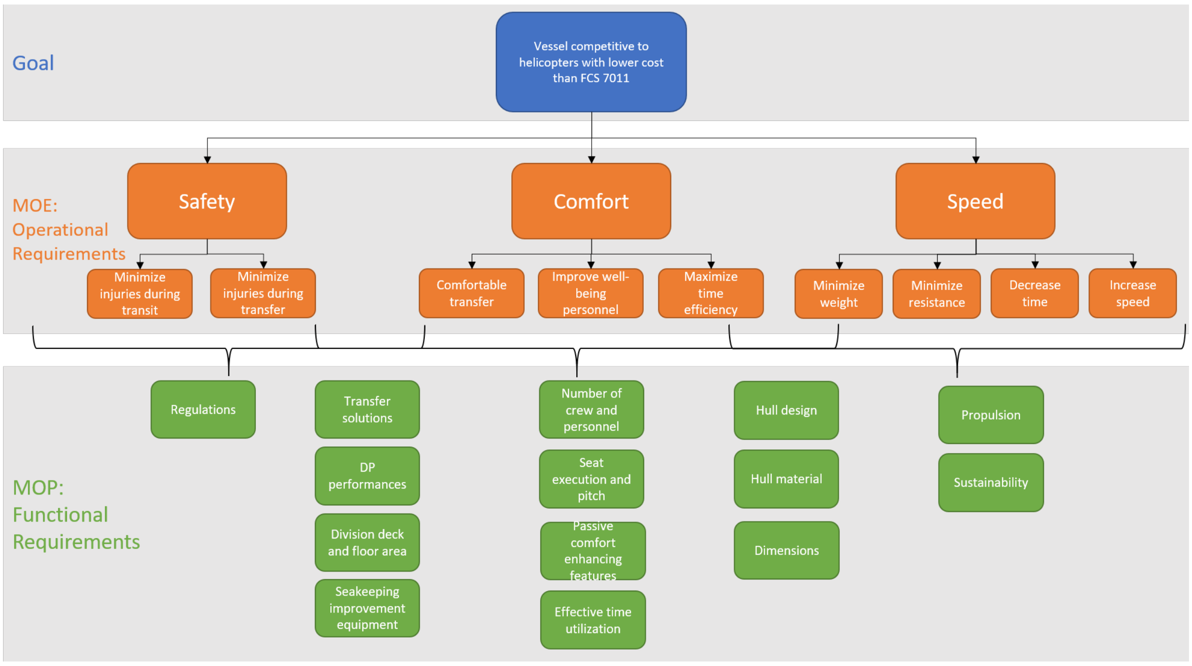


Figure 7.2: Tree structure of operational and functional requirements

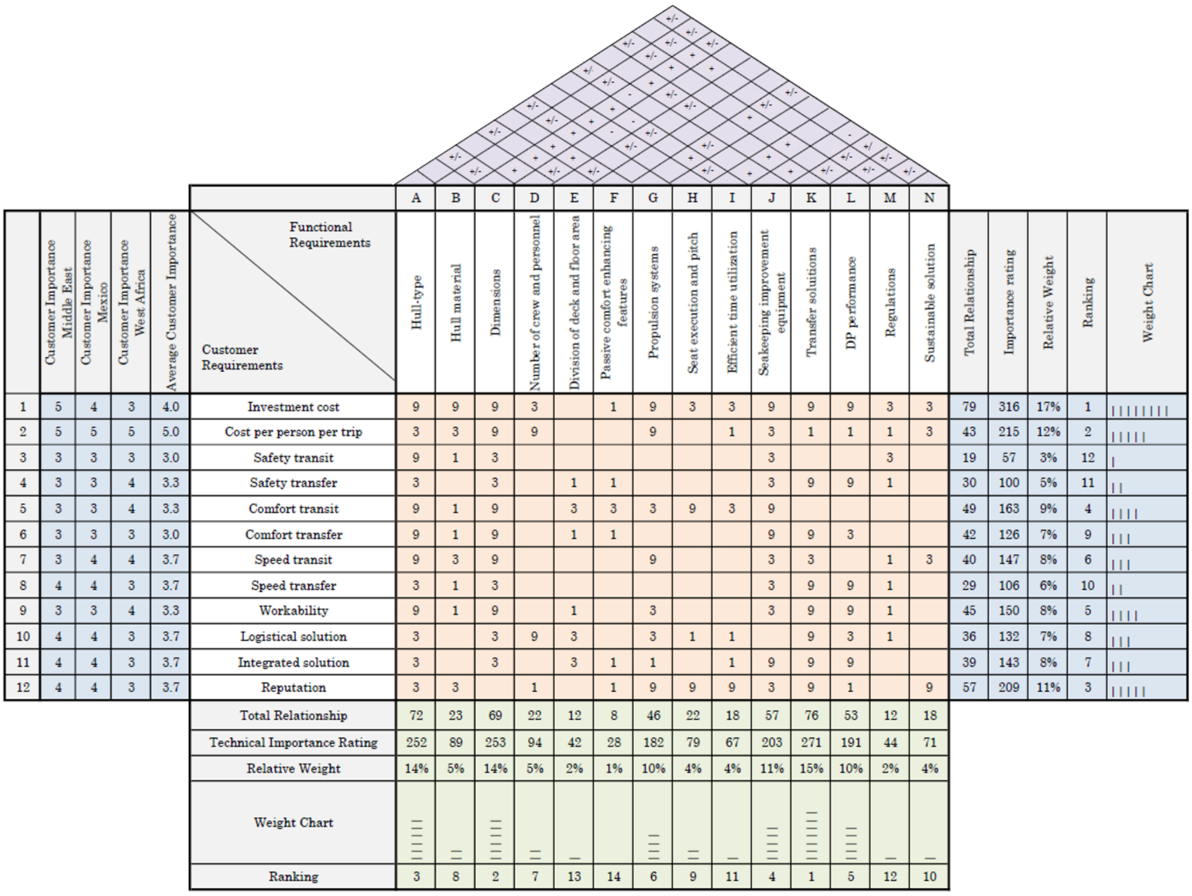
As explained before, the goal (blue) is to design the concept of a Fast Crew Supplier, for long distances and mild conditions, which is competitive to helicopters and more cost-effective than the FCS 7011. For the operational/customer requirements in the HoQ, the offshore crew transportation drivers, determined in Chapter 2, are used. In the tree structure, these are combined to the four design drivers. The design driver ’cost’ is processed in this goal. The operational requirements, ’safety’, ’comfort’ and ’speed’, have to be chosen and influence the cost. These are corresponding with the needs analysis. For the customer requirements in the HoQ, the offshore crew transportation drivers, determined in Chapter 2, are used. Additionally, the four defined design drivers are split up into ’transit’ and ’transfer’ part. The resilient solution will not be used further since a vessel itself is a resilient solution for the helicopter, and it does not impact the design choices of the vessel. From the division of these operational requirements, the functional requirements related to the ship’s systems are defined. The final customer and functional requirements are set out in Table 7.1 and further explained in Appendix E.

Table 7.1: Customer and functional requirements

Customer Requirements	Functional Requirements
Limited investment cost	Hull-type for low resistance in combination with good seakeeping
Competitive cost per person per trip	Hull material fit for intense use in offshore industry
Safe transit	Dimensions to fit high number of passengers
Safe transfer	Number of crew and personnel
Comfortable transit	Division of deck and floor area to fit cargo and personnel
Comfortable transfer	Passive comfort enhancing features
Fast transit	Propulsion systems fit to reach design speed
Fast transfer	Suitable seat execution and pitch
Competitive workability	Efficient time utilization for passengers
Efficient logistic solution	Sufficient seakeeping improvement equipment
Well integrated solution	Reliable transfer solutions
Good reputation	Excellent DP performance
	Compliant with regulations
	Sustainable solution

7.2. House of Quality

The House of Quality transforms qualitative user demands into quantitative parameters. In this research, it is used to determine the main aspects of the design of the vessel. Outcomes will be used to determine the design requirements in advance and during the design phase. Figure 7.3 shows the HoQ, which translates the subjective and qualitative customer needs into technical engineering characteristics. In this HoQ, the customer and functional requirements of Table 7.1 are abbreviated and processed. An enlarged version of this figure is presented in Appendix G. First, the customer importance is rated for the three selected operational areas, based on the knowledge of the sales information of Damen. It is ranked from one to five, where the number five has high importance and one a low priority. The relationships between the customer and functional requirements are elaborated as shown in the orange plane. In this field, the number 'nine' gives a strong, 'three' a moderate, and 'one' a weak relationship. This scale is non-linear since the strong relationship is considered as significantly more important than the moderate ones. The purple plane gives the relation within the functional requirements. This is indicated with pluses and/or minuses. The reasoning of these assessments is elaborated on in Appendix G.



	Customer Importance Middle East	Customer Importance Mexico	Customer Importance West Africa	Average Customer Importance	Functional Requirements / Customer Requirements	A Hull-type	B Hull material	C Dimensions	D Number of crew and personnel	E Division of deck and floor area	F Passive comfort enhancing features	G Propulsion systems	H Seat execution and pitch	I Efficient time utilization	J Seakeeping improvement equipment	K Transfer solutions	L DP performance	M Regulations	N Sustainable solution	Total Relationship	Importance rating	Relative Weight	Ranking	Weight Chart
1	5	4	3	4.0	Investment cost	9	9	9	3		1	9	3	3	9	9	9	3	3	79	316	17%	1	|||||||||
2	5	5	5	5.0	Cost per person per trip	3	3	9	9			9		1	3	1	1	1	3	43	215	12%	2	|||||
3	3	3	3	3.0	Safety transit	9	1	3							3			3		19	57	3%	12		
4	3	3	4	3.3	Safety transfer	3		3		1	1				3	9	9	1		30	100	5%	11	||
5	3	3	4	3.3	Comfort transit	9	1	9		3	3	3	9	3	9					49	163	9%	4	||||
6	3	3	3	3.0	Comfort transfer	9	1	9		1	1				9	9	3			42	126	7%	9	|||
7	3	4	4	3.7	Speed transit	9	3	9				9			3	3		1	3	40	147	8%	6	|||
8	4	4	3	3.7	Speed transfer	3	1	3							3	9	9	1		29	106	6%	10	||
9	3	3	4	3.3	Workability	9	1	9		1		3			3	9	9	1		45	150	8%	5	||||
10	4	4	3	3.7	Logistical solution	3		3	9	3		3	1	1		9	3	1		36	132	7%	8	|||
11	4	4	3	3.7	Integrated solution	3		3		3	1	1		1	9	9	9			39	143	8%	7	|||
12	4	4	3	3.7	Reputation	3	3		1		1	9	9	9	3	9	1		9	57	209	11%	3	|||||
					Total Relationship	72	23	69	22	12	8	46	22	18	57	76	53	12	18					
					Technical Importance Rating	252	89	253	94	42	28	182	79	67	203	271	191	44	71					
					Relative Weight	14%	5%	14%	5%	2%	1%	10%	4%	4%	11%	15%	10%	2%	4%					
					Weight Chart	——————	——	——————	——	—		————	——	—	—————	———————	—————	—	—					
					Ranking	3	8	2	7	13	14	6	9	11	4	1	5	12	10					

Figure 7.3: House of Quality

As a result, in the left blue plane, it can be seen in the ’Average Customer Importance’ column that the cost per person per trip is the highest rated, followed up by the investment cost. The customer requirement which has the most impact is the other way around, concluded from column ’Ranking’ in the right blue plane, which is based on the ’Relative Weight’ column. This is due to the customer importance and the total relationship with functional requirements. The green plane indicates that the transfer solution, dimensions and hull-type have a high technical importance rating. They have a relative weight of 15%, 14% and 14%.

7.3. Final Design Requirements

In order to meet the customer requirements ranked in the House of Quality, final design requirements of the ship and several systems are determined. This section elaborates on the highest rated customer and functional requirements. Multiple subjects for the design are considered, whereof a selection is made to determine. This means that various subjects have to be determined in the phase after the concept design. It does not mean that they are not included in decisions, but specific criteria are not determined. The extensive list of considered subjects is shown in Appendix F. Appendix M presents the list of criteria of the final design, of which some are determined later in this research. This section elaborates on the highest rated customer and functional requirements.

First of all, the cost per person per trip and investment cost are considered. For the combination of these customer requirements, the dimensions and propulsion are the most important functional requirements. Dimensions and propulsion are strongly related to number of passengers, amount of cargo, range and speed. These final requirements are discussed below. The dimensions and propulsion system to satisfy these requirements, will be determined in Chapter 9.

- *Personnel capacity between 80 and 150*
  This is based on the size and locations of the platforms, the customer wishes and rating in the HoQ of the logistical solution. To be flexible and be able to transport more personnel, the minimum is 80 persons and the maximum is 150 persons. This can be varied because the space can be arranged according to the wishes of the customer. For the concept design the number of 120 persons is taken with middle sized seats.

- *50t cargo capacity*
  Since the cargo is not one of the main goals, cargo capacity like the FCS 5009 would be too high. However, it is a competitive edge over helicopters, since they cannot transport cargo. Therefore, a cargo capacity is chosen which is more than the FCS 7011 but less than the FCS 5009, which resulted in 50t.

- *Speed between 35 and 40 knots*
  The speed is selected by investigating the locations of the platforms and the eight hours criterion of maximum transportation time of personnel, explained in Section 5.4. Based on the Copernicus Tool, it is observed that in these areas most platforms are located between 60 and 120nm from harbour and multiple further. Moreover, the speed of 29 knots of the FCS 5009 is assessed as too slow for long distance transportation in the Gulf of Mexico. Based on these reasons, it is decided to design a vessel that is able to reach a speed between 35 and 40 knots. Although this will lead to higher cost per person per trip, which is rated as most important for the customer, lower speed will come at the expense of the logistical solution competitive with helicopters.

- *Range of 1200nm*
  To answer the logistical solution demand of the customer, which is rated with 3.7, a range of 1200nm is chosen. For this range the best balance has to be found between refuelling and weight of the vessel. An advantage of a higher range is that the vessel has to refuel less. A disadvantages is the increase of the vessels weight due to a higher fuel capacity. A higher weight results in less efficiency concerning power and speed. The range of 1200nm complies with a speed of 37.5kn and the ability to sail 30 hours without refuelling. This time is chosen because, assuming sailing between the eight and twelve hours per day, the vessel is able to sail two to three days without refuelling. Based on this knowledge, a range of 1200nm is chosen, which ensures the vessel, with an appropriate weight, to refuel approximately once in three days.

Functional requirements that have a high technical importance rate are transfer solutions, hull-type, seakeeping improvement equipment, and DP performance. Due to it complexity, the hull-type is investigated and determined extensively in Chapter 8. The final design requirements of, and systems for, the transfer system, seakeeping improvement equipment and DP performance are described below.

- *Reliable Transfer Solution*
  In the House of Quality, the safety, comfort and speed of the transfer are average rated between 3 and 3.7. Moreover, the workability is rated at 3.3. Therefore it is decided to design the vessel

with the possibility to have both a motion-compensated gangway and a Frog. The concept will be designed with an Ampelmann L-type, which is able to compensate significant wave heights up to 2m. Relative to the Ampelmann S-type the gangway length is shorter which could result in an exclusion of various high offshore platforms. However, since the vessel will be smaller and needs to be less expensive and lighter, the L-type is chosen. Recommendations according the design with an S-type will be given.

- *Sufficient seakeeping improvement equipment*
  In case of a mono-hull, a gyroscope will be used as seakeeping improvement equipment. The specific type will be determined based on the dimensions of the vessel.

- *Excellent DP performance*
  For the use of a motion-compensated gangway, a dynamic positioning system is necessary. The vessel will be provided with a redundant system, DP2. A control system is fitted which allows the following modes:

  - Manual control of Vessel position and heading, using a single joystick
  - Automatic control of the Vessel positioning and heading: Station keeping

Based on the further outcomes of the HoQ the following design requirements are also determined.

- *Hull Material fit for intense use in offshore industry*
  Section 5.3 described three possible hull materials for vessels: steel, aluminium and FRP. First of all, FRP is not chosen to use since it is not a logistical choice for this concept size. Overall, aluminium has less attractive fatigue characteristics than steel. However, the personnel will be placed around the aft and middle of the ship, which means that the hull construction is high where bending moment is the highest. This results in a stiff aluminium vessel. Moreover, the hull investment cost will be higher using aluminium than using steel. However, since aluminium is light weighted, using this material results in lower engine cost and cost per person per trip. Since the cost per person per trip are rated higher than the investment cost in the HoQ, aluminium is chosen.

- *Division of deck and floor area to fit cargo and personnel*

  - The decision of space and sleeping facilities for crew will be made in the design phase since it should be based on the dimensions of the vessel. This will be chosen based on the crew number of related Damen vessels. This number correlates with the length of the ship.
  - A Fifi system is a competitive feature, compared to helicopters and improves the logistics, so it is attractive to offer this. Furthermore, for several clients this is a requirement. However, this will not be a strict requirement for the vessel, so it will be offered as an option. Therefore, in the design, space on the deck and in the engine room will be reserved to implement equipment required for a Fifi system.

- *Sustainable solution*
  It is chosen not to invest in sustainability options. Currently, it is unclear what the best sustainable future fuel will be, whereby it is too risky to design the vessel for one specific sustainable fuel. Furthermore, in the HoQ, sustainability has a relative weight of 4%, which makes this subject subordinated.

- *Compliant with regulations*
    - To comply with regulations in certain areas, the vessel will be designed to be able to implement up to IMO Tier III regulations. Space is needed in the engine room and tank room for equipment required to comply with these regulations.
    - Due to regulations, it is attractive to design a vessel with a GT value lower than 500. It results in a more cost effective vessel for the client since less crew and lower educated crew is required. This is something that will be taken into account while designing the ship. However, for this concept, this will not be a strict requirement.

8

Hull Selection

Building on the conclusion of Chapter 7 that the hull design and its dimensions are the most important functional requirements, this chapter investigates the hull-type of the concept design. It will give an answer to the fourth sub-question: *Which hull-type suits these design requirements best?* First, Section 8.1 assesses various hull-types relative to established boundary conditions. Next, the hull-types which are considered effective will be investigated based on literature in Section 8.2. Subsequently, Section 8.3 compares these hull-types by using SHIPMO. As a result, the most suitable hull-type will be selected for the ship design.

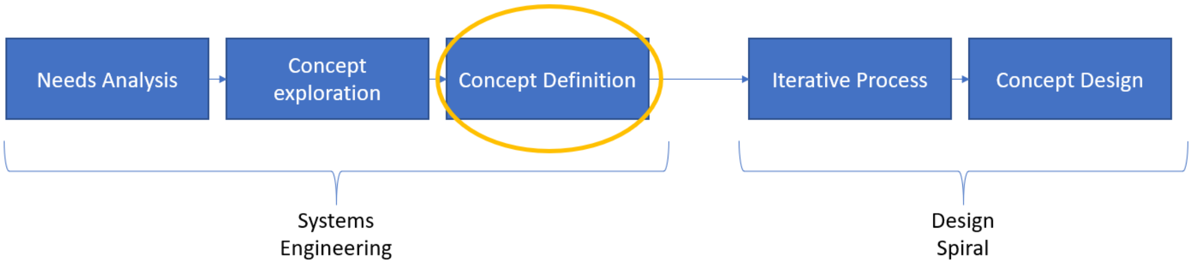


Figure 8.1: The indicated concept definition of the solution approach

8.1. Initial Hull Assessment

To decide which hull-type suits best for this concept, the options have to be evaluated thoroughly. An attractive hull-type at least has to meet all the boundary conditions. In order to know whether it is valuable to evaluate a certain hull-type extensively, this section assesses them based on the boundary conditions. The boundary conditions are:

- The speed / power of the hull-type has to be fit for a ship speed between 35 and 40 knots.
- At zero speed, the hull-type needs to have attractive seakeeping performance in significant wave heights from 1.5 to 2 meters.
- At high speeds (35-40 knots), the hull-type needs to have attractive seakeeping performance in significant wave heights from 1.5 to 2 meters.
- The hull-type has to be cost-effective for this concept.

This section elaborates on Monohull, Catamaran, Trimaran, SWATH, Hydrofoil, WIG and ACV, because these are proven concepts in the maritime world. Figure 8.2 illustrates these hull-types. New concepts like A2V are not taken into account. In addition to these hull-types, hybrid solutions exist. These will be further analysed, depending on the conclusions of the hull-types mentioned above. Appendix H gives an elaborate explanation of the hull-types.

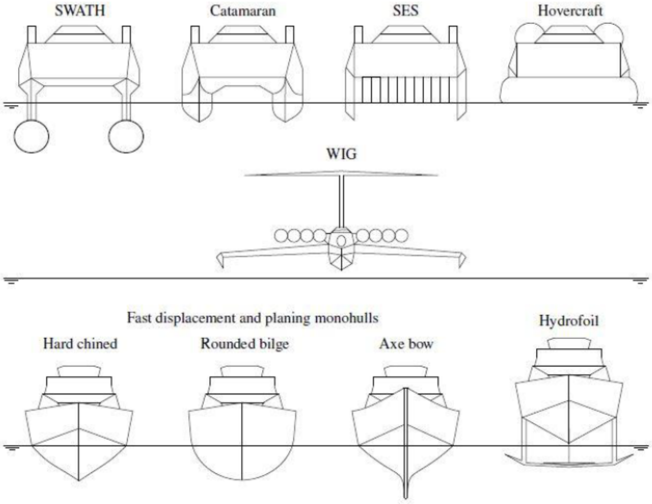


Figure 8.2: Various Hull-Types de Jong (2011)

An assessment overview of the hull findings explained in Appendix H is shown in Table 8.1. It concludes that the mono-hull, catamaran and trimaran are ship-types that are attractive to use for the concept design, according to the boundary conditions. For the decision which one fits best, more extensive research will be done. Since the SWATH, hydrofoil, WIG, and ACV are not rated as attractive, hybrid solutions will not be investigated further.

Table 8.1: Assessment overview of the hull findings

Boundary Conditions	**Monohull**	**Catamaran**	**Trimaran**	**SWATH**	**Hydrofoil**	**WIG**	**ACV**
Speed / power at around 35 knots	+	+	+	-	+	+	-
Seakindliness at zero speed in Hs around 1.5-2m	+/-	+	+	+	-	-	?
Seakindliness at high speed in Hs around 1.5-2m	+	+	+	+	++	++	-
Cost	+	+	+	+	+/-	-	-
	v	v	v	x	x	x	x

8.2. Literature-Based Review

As a result of the hull assessment relative to the boundary conditions in the previous chapter, the mono-hull, catamaran, and trimaran are three hull-types considered for the concept ship design. To be able to choose the best-suited hull-type they will be compared based on the four design drivers. Therefore, first literature is investigated. Overall, a lot of public literature can be found about the cost and seakeeping characteristics of mono-hulls. However, for catamarans and trimarans this is rare. This is because catamarans and trimarans originated later than the mono-hull, and by companies which did not published their research.

Davis and Holloway (2007) state that, for their configurations in head seas, passenger accelerations for a short catamaran can be twice the accelerations of a longer trimaran design. Figure 8.3 shows these results, such as that the vertical accelerations of a round bilge mono-hull are in between the trimaran and catamaran. In quartering and beam seas, it was observed that the trimaran loses its advantage and has a rolling motion that can be twice that of the catamaran depending on frequency. Results of mono-hulls are not available in these seas. These conclusions are based on the same speed as the concept design. However, it is also based on ships with lengths above 100 meters. Therefore, it is hard to establish the decision of the hull-type for lower than 70 meters on this literature study.

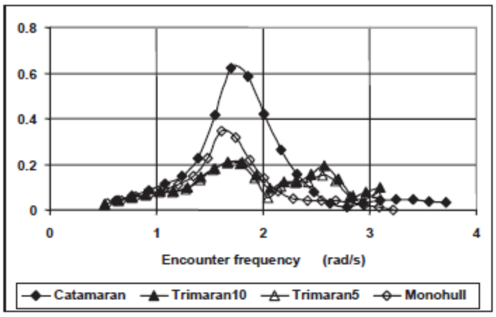


Figure 8.3: Vertical accelerations at LCG per unit wave height (g/m) in head seas at 40 knots (Davis and Holloway, 2007)

In line with this, Luhulima et al. (2014) also compared the round bilge mono-hull, catamaran, and trimaran. A seakeeping analysis was executed using Maxsurf and SNSYS AQWA. For the configurations in this research, it is concluded that multi-hull vessels demonstrate better characteristics on heave, pitch and roll motions in terms of seakeeping than mono-hulls. Figure 8.4 shows the results on heave. However, this is based on ships with low Froude numbers, which means low speeds because the ship lengths are around 70 meters. Since the needed speed between 35 and 40 knots results in higher Froude numbers, it neither possible to base decisions on this research.

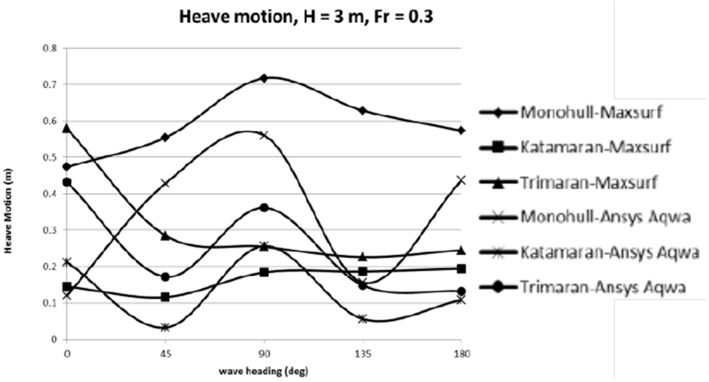


Figure 8.4: Heave motions at sea state 5 and Froude number 0.3 (Luhulima et al., 2014)

8.2.1. Conclusion

The literature which could be found never has the same characteristics as needed for the concept ship design. The conclusions were based on at least a significant difference in ship speed, ship length, significant wave height or incoming waves. Because the ship will be designed for the specific formulated circumstances and the four design criteria, the decision must be made on those. Therefore, it is not possible to base the conclusion on available literature.

8.3. Program-Based Review

As explained in the previous section, in this research, a goal is to draw conclusions for the best suiting ship-type based on the characteristics in specific circumstances. These are:

- Speed between 35 and 40 knots
- Significant wave height between 1.5 and 2 meters
- Plausible ship lengths, which is at least expected between 40 and 70 meters.

To be able to do this, a program based assessment is executed to justify the decision which hull-type should be used in these circumstances. This is done by drawing conclusions based on seakeeping and cost values. First, Subsection 8.3.1 explains the selection of the seakeeping analysis program SHIPMO. Subsection 8.3.2 verifies the program. Subsequently, the final hull analysis, using SHIPMO and cost calculations, is explained in Subsection 8.3.3. Finally, Subsection 8.3.4 gives the results of SHIPMO and the cost calculations, and draws conclusions for the best suiting hull-type.

8.3.1. Selection of SHIPMO

Various programs exist for seakeeping analyses of vessels. 'Maxsurf' and 'SNSYS AQWA' are two examples which are used by Davis and Holloway (2007). At Damen, the program 'SHIPMO' is available and, therefore, commonly used. This program is created by Marin and calculates ship behaviour using the frequency domain. It is based on 2D linear diffraction theory ('strip theory') and theoretical empirical formulations. Due to the linear approach, the maximum vertical accelerations are not taken into account which is needed for the seakeeping assessment of fast ships as explained in Subsection sec:comfort. A program that does take into account such vertical accelerations is 'Fastship'. However, this program is complex to use and, additionally, fast ships with an axe bow, which are considered in this study, can be approach with a linear motion model as well. Hence, it is decided that SHIPMO satisfies the modelling requirements of the seakeeping analysis and, therefore, will be used.

By using SHIPMO, the following responses can be calculated:

- Motions, velocities and accelerations in the ship's centre of gravity (surge, sway, heave, roll, pitch and yaw).
- Absolute and relative motions, velocities and accelerations (x-y-z) in reference points.
- MSI, MII and MIR values.

The seakeeping characteristics that are investigated for the comparison are MSI and the RMS vertical accelerations. The lower the MSI and vertical accelerations, the better the comfort. These two values are correlated with each other. The MSI is a simple and concise statistically-based measure for predicting the incidence of motion sickness by exposure to vertical accelerations. Equation 8.1 gives the equation of MSI, followed by equations 8.2 to 8.5 used for the MSI calculation.

$$\mathrm{MSI} = 100\Phi\left(\mathrm{z_a}\right)\Phi\left(\mathrm{z}'_\mathrm{t}\right) \quad \text{in } [\%] \tag{8.1}$$

Where:

$$\mathrm{z_a} = 2.128\log\left(\mathrm{a/g}\right) - 9.277\log(\mathrm{f}) - 5.809(\log(\mathrm{f}))^2 - 1.851 \tag{8.2}$$

$$z'_\mathrm{t} = 1.134\mathrm{z_a} + 1.989\log(\mathrm{t}) - 2.904 \tag{8.3}$$

$$\Phi(\mathrm{z}) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{z} \mathrm{e}^{\frac{-\chi^2}{2}}\,\mathrm{d}\chi \tag{8.4}$$

Where:

a = RMS value of generalised vertical acceleration estimator Gav in [m/s^2]
g = acceleration of gravity (g = 9.81) in [m/s^2]
t = duration of exposure in [min]
f = peak frequency of the generalised vertical acceleration spectrum S_{Gav} in [Hz]

Where:

$$S_{\mathrm{Gav}} = S_{\mathrm{av}} + p^2\, S_{\mathrm{aT}} + q^2\, S_{\mathrm{g}}{}^{*}\varphi \tag{8.5}$$

Where:

S_{av}= spectrum of vertical acceleration
S_{aT}= spectrum of transverse acceleration
$S_{\mathrm{g}}{}^{*}\varphi$= spectrum of roll (in radians) times
p,q = multiplication factors

8.3.2. Verification of SHIPMO

SHIPMO is a reliable program to obtain first impressions of the motions of a ship. Significant validations are available for Froude numbers up to 0.8. For Froude numbers above one, less validation material exists. The high speed of the concept design combined with different lengths leads to Froude numbers between 0.75 and 1. Moreover, for catamarans, this program is neither validated significantly, and the interaction between the hulls is not taken into account. Therefore, a verification is executed of SHIPMO. Eventual corrections will be processed in the results.

To verify SHIPMO, executed experiments by Damen and the TU Delft are compared with the SHIPMO results. The experiments were carried out with a model of the FCS 7011 and the catamaran FCS 4612. Both experiments are executed in head waves with a significant wave height of 2 meters and a spectral peak period of 7 seconds. For the FCS 4612 the speed is 35 knots, and for the FCS 7011 40 knots.

Linear Behaviour

Figure 8.5 shows the RMS and maximum value of heave motion, pitch motion, vertical acceleration at LCG and vertical acceleration at the bow. These experiments confirm the linear behaviour of an axe bow. Despite the small exponential increase of the crests of the catamaran, the ship can be approximated linearly. This small exponential increase can be declared by wet deck slamming. This is something SHIPMO does not take into account. However, this is a phenomenon that can be solved by increasing the ship cavity. So, SHIPMO, which is based on linear characteristics, can be used in order to compare fast mono-hulls, catamarans and trimarans in this research.

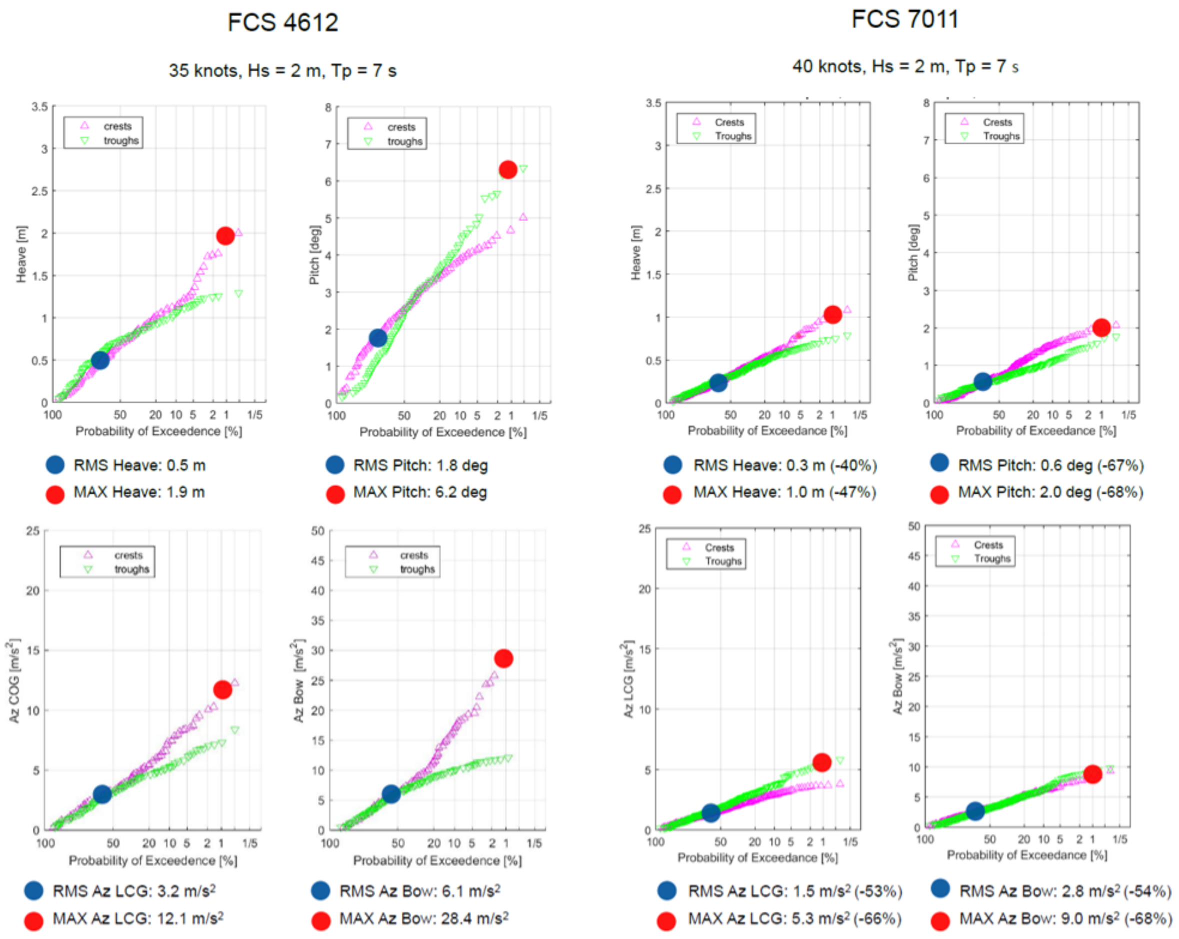


Figure 8.5: Results of model tests executed by Damen at the Delft University of Technology of a catamaran and mono-hull comparison

Corrections

In SHIPMO, RMS values of heave, pitch, vertical acceleration at LCG and vertical acceleration are found with the same conditions as the experiments. Table 8.2 shows results of the experiments and SHIPMO. A correction for SHIPMO, which leads to the same values of the experiments, is also shown.

Table 8.2: Comparison results experiment and SHIPMO

	FCS 7011 (vs=40kn)			FCS 4612 (vs=35kn)		
	SHIPMO	Experiment	Correction	SHIPMO	Experiment	Correction
RMS heave motion	0.3	0.3	1.12	0.9	0.5	0.54
RMS pitch motion	0.8	0.6	0.80	3.4	1.8	0.52
RMS vertical acceleration Bow	3.4	2.8	0.82	9.2	6.1	0.66
RMS vertical acceleration LCG	1.4	1.5	1.10	4.5	3.2	0.70

In addition, Table 8.3 gives values concerning the maximum value. This is done because despite that it is assumed that the linear approach of SHIPMO is valuable for this research, the experiments clearly show higher differences between the maximum and RMS values for the catamaran than the mono-hull. Therefore, these values are compared in order to develop a correction factor of the RMS value. This way, it is possible to approximate the maximum values of SHIPMO.

Table 8.3: Comparison RMS and maximum values experiment

	FCS 7011 (vs=40kn)			FCS 4612 (vs=35kn)		
	RMS	MAX	Correction	RMS	MAX	Correction
Heave motion	0.3	1.0	3.33	0.5	1.9	3.80
Pitch motion	0.6	2.0	3.33	1.8	6.2	3.44
Vertical acceleration Bow	1.5	5.3	3.53	3.2	12.1	3.78
Vertical acceleration LCG	2.8	9.0	3.21	6.1	28.4	4.66

From these values can be concluded that for a catamaran, the correction for RMS values to the maximum acceleration values is higher than for the mono-hull. These and the correction values of Table 8.2 can be used at the assessment of the SHIPMO results.

8.3.3. Final Hull Analysis

This subsection executes the comparison of the mono-hull, catamaran, and trimaran using SHIPMO. This will be done by a comparison in two ways and in the following order:

1. Comparison 1: dimensions based on same seakeeping characteristics
   (a) Compute the seakeeping values of the three ship-types with each three dimension variations in SHIPMO.
   (b) Find the dimensions with the same seakeeping values and calculate the corresponding cost.
   (c) Convert the results in unitless values and process the customer requirements.
   (d) Draw conclusions as a result of the highest total score on the final unitless measures.

2. Comparison 2: dimensions based on minimal dimensions needed for this concept.
   (a) Determine minimal dimensions for the mono-hull and catamaran needed for this concept.
   (b) Compute the seakeeping values of these dimensions in SHIPMO.
   (c) Calculate the cost of these vessels.
   (d) Calculate the revenue based on the workability of the vessels.
   (e) Convert the results in unitless values and process the customer requirements.
   (f) Draw conclusions as a result of the highest total score on the final unitless measures.

For this approach various assumptions and choices have been made. First, general assumptions will be explained, followed by assumptions concerning the cost analysis. Subsequently, additional assumptions for comparison 1 and 2 will be described.

Assumptions

General assumptions

- Calculations are made in the following circumstances
  - v_s = 37.5kn. This value is chosen because it is in between 35 and 40 knots.
  - H_s = 1.75m. This value is again chosen because it is in between 1.5 and 2 meters.
  - T_z = 6s (T_p = 7.7s). This value is based on wave data of the three operational areas, partly shown in Figure 3.6. During the calculation, the natural period of each vessel is checked. In addition, longer and shorter periods are investigated to exclude to make conclusions on the results of a ship that is in resonance.

- The displacement of the vessels is based on the ratio of length, beam and depth of the standard lines plan. This ratio is calculated with Equation 8.6, which Damen frequently uses.

$$\text{Ratio} = \frac{\text{Displacement}}{\text{L}^{1.5} * (\text{B} + \text{D})} \tag{8.6}$$

- For every ship-type, the seakeeping characteristics are calculated at the same location relative to the dimensions. During the calculation, also other locations are investigated to ensure conclusions would be the same on different locations.
  - x-axis: 40% of the vessel from aft deck
  - y-axis: 10% from the side deck
  - z-axis: at deck height (D)

- The mono-hulls are equipped with two fixed fins, two rudders and a gyroscope. The catamaran and trimaran without.

- Values are investigated from head, beam and quartering incoming seas. These are evaluated at starboard and port-side since the characteristics are calculated at the side of the ship. This location ensures an arm relative to the centre line, which causes an amplitude of roll. At one side of the ship this roll contributes to the heave motion, and at the opposite side this roll counteracts to the heave motion. Due to the combination of heave and roll, different RMS values can occur at the side locations of starboard and port-side. This results in different MSI and vertical acceleration values. Following waves are not taken into account since SHIPMO does not give reliable results in this situation on surge, sway and yaw motions. These motions do not have a spring term which results in an infinite encounter frequency at speeds. As a result, they have a natural frequency of zero. Since SHIPMO cannot handle this, it gives unreliable results at speeds. By disregarding these following waves, broaching is a phenomenon that is not taken into account. Findings of van Walree and Visser (2005) are that, for an axe-bow hull form featuring an enlarged hull form, no broach-like behaviour is observed for waves below 2.5m. Therefore, the chance that this phenomenon will occur at the concept design is negligible. The degrees of the incoming waves are set at:
  - 90 degrees
  - 135 degrees
  - 180 degrees
  - 225 degrees
  - 270 degrees

- For comparing the various configurations, the average MSI and vertical acceleration are taken of the five incoming waves of zero and 37.5m/s speed. Thus, for calculating these averages, it is assumed that all wave directions and speeds occur equally often.

Cost assumptions

The calculation of the cost and income for each vessel is based on their investment cost and operational cost. These calculations are shown in Confidential Appendix 2. An overview and assumptions of the cost calculation is given below.

- Investment cost
  The investment cost is calculated using the cost of the propulsion machinery, hull and superstructure. Based on existing Damen vessels it is assumed that this covers 1/3 of the total cost excluding an Ampelmann and Gyroscope. This way, the total investment cost could be calculated.

  - *Cost hull and superstructure*
    These cost are based on weight, which is approximated based on the inter and extrapolation of weights of existing Damen vessels. For the conversion from weight to cost, the market price per kilogram for aluminium is used.
  - *Cost propulsion machinery*
    This is based on the total installed power needed for the vessel. The needed power is calculated as a result of resistance with an efficiency of 63%. This is based on the efficiency of waterjets at a speed of 37.5 knots. The cost is predicated upon MTU price list of Marine Engines. For the catamaran, the resistance is calculated using executed model tests of Damen Fast Ferries and using data of Molland et al. (1994). However, these related ships have conventional hulls instead of axe-bow hulls. In experiments executed by Damen is concluded that a pure axe-bow hull has a higher resistance than a conventional fast ferry hull. Therefore, a correction of 10% is calculated on the results. For the mono-hull, the 'high-speed craft resistance program' provided by Damen is used. It should be noted that a standard axe bow hull is used and scaled in this program. Therefore, no differences are processed in these values as a result of various beams.
- Operational cost
  - *Fuel cost*
    The operational cost is based on the fuel cost which covers 1/4 of the total cost. The approximated total installed power is used to calculate the fuel cost. This is executed the same way as in Section 3.4. Namely, by multiplying the total power with the specific fuel consumption of 210 g/kWh and dividing by the fuel density of 840 g/l.
- Revenue
  The revenue is based on an average yearly rate in combination with the workability of the vessel. Since this vessel has the goal to replace helicopter transportation, it is insightful to base the revenue on helicopters than on the day rate of Fast Crew Suppliers. Profit could be made with at least 50% of the helicopter rates. Therefore, the average yearly revenue is based on 50% of the revenue of helicopters per trip. The workability is calculated using the up-time percentage of the FCS 5108 and FCS 4211 in West Africa, the Gulf of Mexico and the Middle-East. Appendix I shows these values. It should be noted that, in reality, the workability is dependent on more than only vertical accelerations in combination with the scatter diagram. It is known that the FCS 7011 has a workability of 80% in West Africa. The corresponding maximum vertical acceleration is used as the maximum value for the scatter diagram plots for the FCS 5108 and FCS 4211.

Additional assumptions for Comparison 1: based on same seakeeping characteristics

- For each ship-type, three variations are calculated, which can be seen in Table 8.4.

- For each ship-type, one lines plan is used and scaled to a 10 meter longer and 10 meter shorter lines plan. The catamaran and mono-hull lines plan already existed. The lines plan for the trimaran is made developed for this research. The beam of these vessels is based on the average ratio of existing vessels. For the catamaran and trimaran, the beam is 1/4 of the length. The beam of the demi-hulls of the catamaran and trimaran are scaled in the same ratio as the length. This is also based on existing vessels. The beam of the mono-hulls are based on the existing fast crew suppliers of Damen. The standard lines plans are:

  - Mono-hull: FCS 5209
  - Catamaran: FCS 4612
  - Trimaran: FCS 5013

Table 8.4 gives detailed information about the input used in SHIPMO of each configuration.

Table 8.4: Input information hull-types

		L [m]	B [m]	D [m]	B mid-hull [m]	B side-hull [m]	Displacement [t]
Mono	FCS 4208	42	8	4.3	-	-	256
	FCS 5209	52	9	4.3	-	-	343
	FCS 6210	62	10	4.3	-	-	455
Cat	FCS 3609	36	9	5.3	-	2.8	249
	FCS 4612	46	12	5.3	-	2.8	385
	FCS 5615	56	15	5.3	-	3.4	538
Tri	FCS 4011	40	11	4.8	4.8	2.1	291
	FCS 5013	50	13	4.8	6	2.6	411
	FCS 6015	60	15	4.8	7.2	3.1	569

Additional assumption for Comparison 2: based on minimal dimensions

- To determine the minimal dimensions of the vessels, first the area is calculated needed for the personnel. As explained in Section 7.3 the vessel should carry between 80 and 150 persons. The area is based on a minimal space per person of 1.1m^2 in combination with the maximal number of personnel of 150. While carrying 80 persons, in this case, the vessel has 2.1m^2 per person. Because of general seakeeping characteristics as explained in subsection 3.1.3, the personnel is placed as close as possible to the aft. Since the vessel will have an Ampelmann on board which needs 10m of length, the personnel is placed in front of it. Subsequently, the length is chosen by setting the front of the personnel space at 60% of the total length. This yields enough space at the bow of the vessel and attractive seakeeping characteristics for personnel according to Figure 3.2. The beam of the ship is chosen based on the ratios between the length and beam of existing vessels.

8.3.4. Results

This subsection elaborates on the results of the approaches mentioned above. Appendix I gives an overview of detailed SHIPMO results.

Limited Value

To ensure the results are at least acceptable, first, Figure 8.6 shows the MSI results of the FCS 7011 in significant wave heights of 2.75m. The MSI values of the FCS 7011 in significant wave heights of 2.75m are assumed as acceptable since this vessel is designed for these circumstances. In addition, the corresponding vertical accelerations are checked based on the criterion RMS value of 1.47m/s^2 and criterion maximum value of 8m/s^2 as explained in Chapter 3.

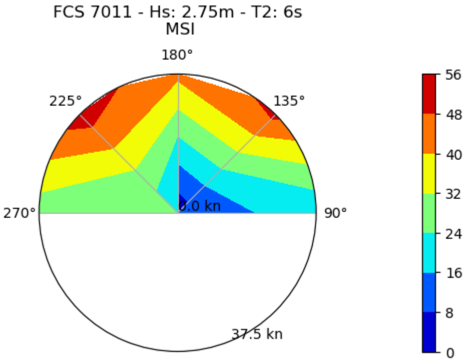


Figure 8.6: MSI FCS 7011 in H_s 2.75m

The limited MSI value that is assumed to compare the various ship-types with is 25.4%. The corresponding corrected RMS vertical acceleration is 1.1m/s^2 and the maximum is 3.5m/s^2, which implies it is accepted. An overview is shown in Table 8.5

Table 8.5: Overview of limiting factors based on the FCS 7011 in significant wave heights of 2.75m

	Limiting value
MSI [%]	25.4
Corrected RMS vertical acceleration [m/s^2]	1.1
Corrected MAX vertical acceleration [m/s^2]	3.5

Results of Comparison 1: based on same seakeeping characteristics

For the first comparison, ten configurations are calculated in SHIPMO. The results will be shown and discussed in this subsection. Figures 8.7, 8.8 and 8.9 show charts with the MSI results of the three hull-types, illustrating the three configurations. Attention: the legends of the nine charts relate to the corresponding chart and are all different from each other.

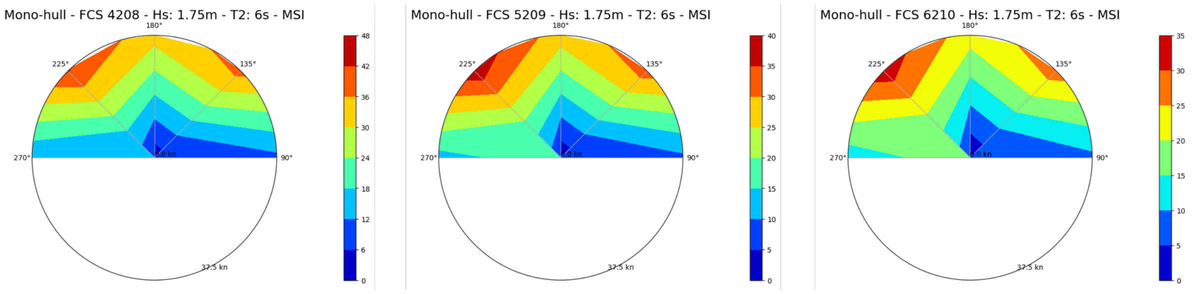


Figure 8.7: MSI results of mono-hulls

The MSI results of the three mono-hull configurations give accountable results. First of all, because the longer the vessel, the better the MSI values become. This is in line with the 'Enlarged Ship Concept' (Keuning, 2000). The values are lower than the the limiting values. This indicates that the mono-hull has better seakeeping characteristics than accepted.

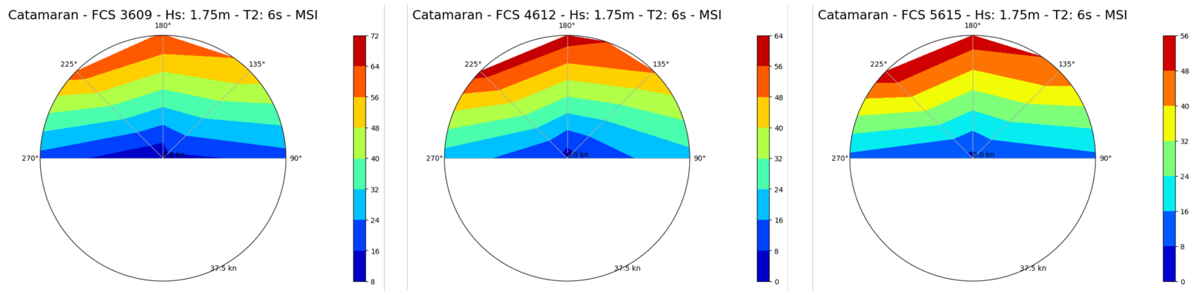


Figure 8.8: MSI results of catamarans

The MSI results of the catamaran FCS 3609 configuration gives higher values than the limiting value. These values indicate that this catamaran has worse seakeeping characteristics than accepted. The two other configurations give lower values than the limiting value. Similar to the results of the mono-hull configurations, the larger the catamaran, the better / lower the MSI values.

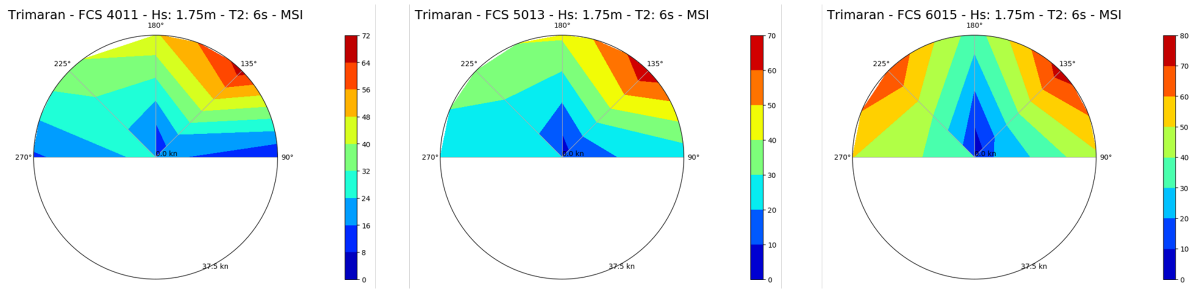


Figure 8.9: MSI results of trimarans

In contrast with the results of the mono-hull and catamaran configurations, for the trimarans unrealistic correlations are observed between the length and the MSI results. As can be seen in Figure 8.9, the longer the ship, the higher the MSI values become. This is conversely with the expectations. So by analysing the results, unusual correlations occur. Moreover, the MSI values are higher than the limiting value and than the values of the catamaran. Therefore, these results are further investigated.

Table 8.6 shows the average of the numerical results of MSI and vertical acceleration (Az) of the eleven configurations without correction.

Table 8.6: Average MSI and vertical accelerations results of SHIPMO

Configuration	**MSI [%]**	**Az [m/s^2]**
Limiting value	25.4	0.99
Mono-hull - FCS 4208	17.4	0.76
Mono-hull - FCS 5209	15.4	0.67
Mono-hull - FCS 6210	13.5	0.59
Catamaran - FCS 3609	27.0	1.58
Catamaran - FCS 4612	24.2	1.37
Catamaran - FCS 5615	22.6	1.13
Trimaran - FCS 4011	25.0	1.04
Trimaran - FCS 5013	25.9	1.19
Trimaran - FCS 6015	34.1	0.77

These values of the mono-hull and catamaran show that the vertical acceleration is correlated with the MSI at all the configurations. This means that the higher the vertical acceleration, the higher the MSI, or reversed. Again for the trimaran, unusual results are observed. It is decided that the trimaran will not be taken into account as a possible hull-type for this research, based on the reasons below.It should be noted that it is not concluded that a trimaran is not a suiting hull-type for these circumstances, but only left out consideration in this research.

- It was found that the heave and pitch results are as expected. However, the longer the ship, the higher the roll, which is not as expected. Moreover, in SHIPMO various errors occurred in the damping. For instance, the roll damping resulted in negative values, which should always be positive. It is concluded that results are unreliable, whereby decisions could not be made for trimarans based on SHIPMO.
- If using a trimaran for the concept design, further design choices cannot be made using SHIPMO.
- As explained in Section 8.2 minimal public literature is available for trimarans. Neither Damen has significant information about these kinds of vessels. They did experience with concept designs and performed seakeeping tests. A conclusion drawn as a result of these experiences is, for instance, that the seasickness levels of a trimaran are high but somewhat lower than on a catamaran. In combination with the SHIPMO results of the mono-hull and catamaran, it is expected that a mono-hull will be better than a trimaran.
- Many recommendations have been written for an improved concept design of a trimaran. It has not been developed further. Due to this lack of knowledge about this ship-type within Damen, designing a trimaran concept would result in plenty of research for Damen.

In addition to the results of SHIPMO, correction values will be processed, whereby more realistic vertical acceleration values are calculated. These are shown in Table 8.7. The correction value at LCG position is used (give in Table 8.2 and 8.3) since the reference points used in SHIPMO are closely to that position.

Table 8.7: Corrected vertical accelerations

Configuration	**MSI uncorrected [%]**	**Corrected RMS Az [m/s^2]**	**Corrected MAX Az [m/s^2]**
Limiting value	25.4	1.09	3.5
Mono-hull - FCS 4208	17.4	0.84	2.7
Mono-hull - FCS 5209	15.4	0.74	2.4
Mono-hull - FCS 6210	13.5	0.65	2.1
Catamaran - FCS 3609	27.0	1.10	5.1
Catamaran - FCS 4612	24.2	0.96	4.5
Catamaran - FCS 5615	22.6	0.79	3.7

These results indicate that in between the mono-hull FCS 4208 and FCS 5209 the vertical acceleration will be similar to the catamaran FCS 5612. The dimensions of the mono-hull are interpolated and checked, which results in a mono-hull FCS 4708.5 for the comparison. Figure 8.10 shows the cost comparison based on the similar seakeeping.

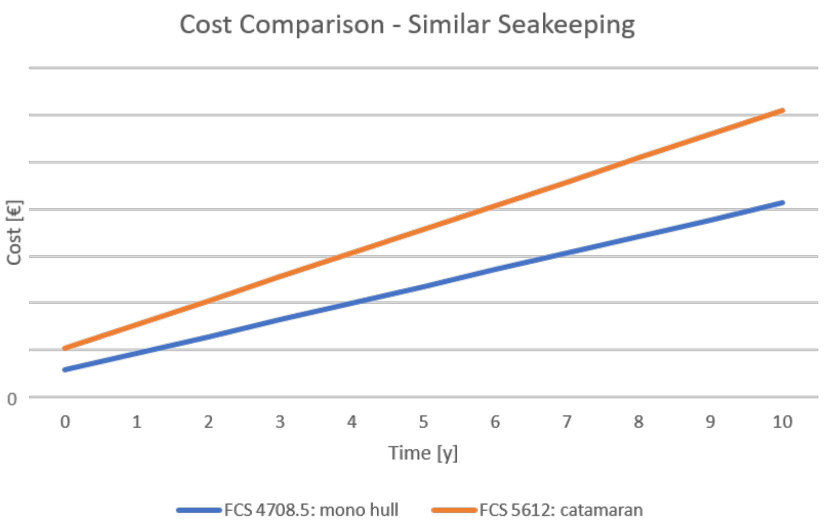


Figure 8.10: Comparison cost of FCS 4708.5 and FCS 5612

This figure indicates that the cost of the catamaran FCS 5612 is more than twice as high compared to the mono-hull FCS 4708.5. This difference can be declared because the FCS 5612 is significantly larger than the FCS 4708.5. Moreover, the catamaran should need such power at high speeds, resulting in highly rated engines, which increase significantly in cost. This required power also results in higher variable cost than for the mono-hull.

To be able to compare the results they are converted into unitless measures, based on the MAUT tool. First, the cost, comfort and workability are compared with each other by giving them a rating relative to the most attractive value of the FCS 4708.5 and FCS 5615. To improve this multiple-criteria decision, the customer requirements are processed using the values of the House of Quality (Section 7.2). This way the compared results are adjusted to the wishes of the customers. The vessel with the highest total customer rating is concluded as most attractive for these area and circumstances, based on comparison 1. Table 8.8 shows the values and results. The table including the values with units are shown in Confidential Appendix 3.

Table 8.8: Unitless values of the FCS 4708.5 and FCS 5612

	Rating FCS 4708.5	**Rating FCS 5615**	**Customer Rating HoQ**	**Customer Rating FCS 4708.5**	**Customer Rating FCS 5615**
Investment Cost	1.00	0.58	4.0	4.00	2.31
Variable Cost	1.00	0.70	5.0	5.00	3.51
Comfort Transit	1.00	0.93	3.3	3.30	3.06
Comfort Transfer	0.74	1.00	3.0	2.23	3.00
Workability	0.94	1.00	3.3	3.10	3.30
Total Customer Rating				17.6	15.2

Table 8.8 shows that the mono-hull FCS 4708.5 has the highest total customer rating, which indicates that in this case, the mono-hull is the most attractive ship-type. Thus, based on equalised speed and seakeeping characteristics and the resulting cost, in combination with the customer rating, it is concluded from the unitless values that, in this case, the mono-hull is the most attractive hull-type for the concept design.

Results of Comparison 2: based on minimal dimensions
In addition to previous conclusions, a comparison is made based on the minimum length needed for this concept. For the catamaran, the FCS 4211 is needed and for the mono-hull the FCS 5108 is needed. This is executed as described in the assumptions above. First, Table 8.9 gives an overview of the seakeeping results. Appendix I gives detailed results of SHIPMO.

Table 8.9: Results of mono-hull and catamaran with minimal dimensions

Configuration	**MSI uncorrected [%]**	**Corrected RMS Az [m/s^2]**	**Corrected MAX Az [m/s^2]**
Limiting value	25.4	1.09	3.5
Mono-hull - FCS 5108	16.6	0.79	2.5
Catamaran - FCS 4211	24.5	0.99	4.6

The MSI and vertical accelerations of the mono-hull are lower than of the catamaran. So, according to the seakeeping results, the mono-hull is more attractive. In addition, Figure 8.11 gives the cost of these configurations.

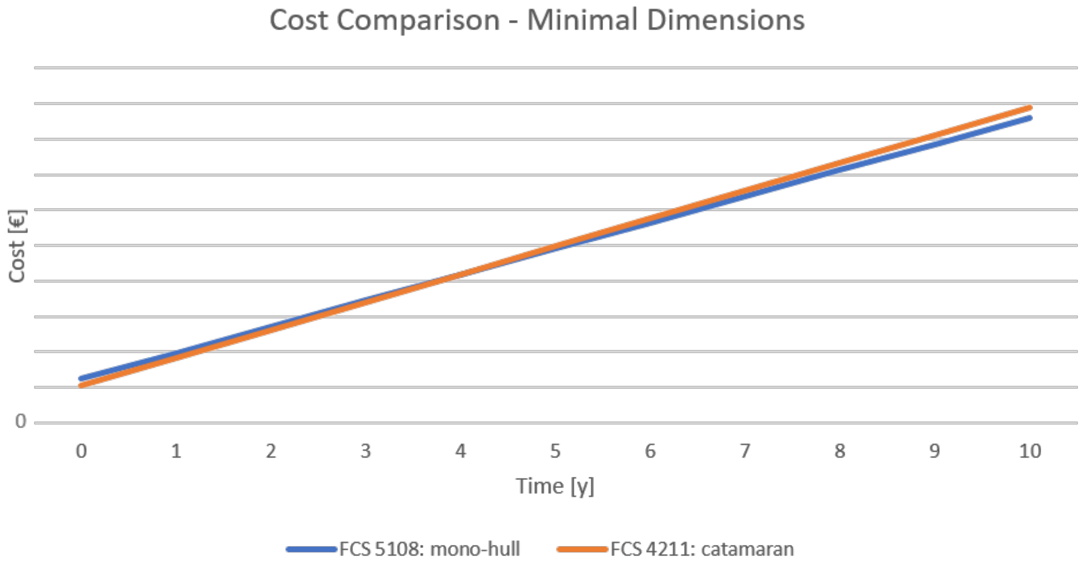


Figure 8.11: Comparison cost of the mono-hull and catamaran based on the minimal dimensions

What can be concluded from the figure is that the investment cost for the catamaran is lower than for the mono-hull. The cost of the FCS 5108 is 46/100 and of the FCS 4211 is 39/100 relative to the FCS 7011. On the other hand, the variable cost of the mono-hull is lower than the catamaran in this case, as a result of higher resistance results for the catamaran. This results in lower cost for the mono-hull after four years.

The seakeeping characteristics of a vessel also influence its workability, which in turn provides revenue. Therefore, Figure 8.12 gives the cost and revenue as a result of the workability. This calculation has been explained in Subsection 8.3.3. Workability values and corresponding scatter diagrams are presented in Appendix I.

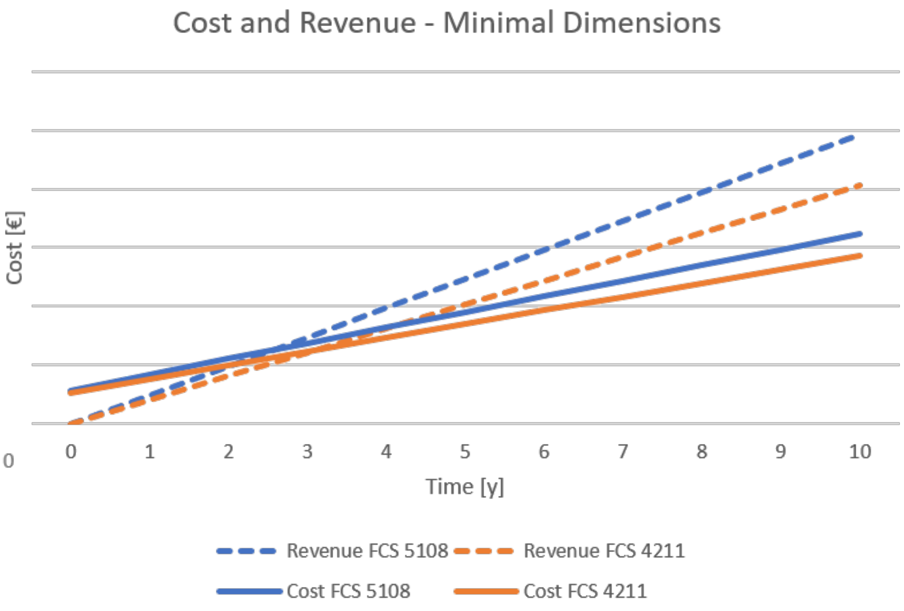


Figure 8.12: Comparison cost and revenue of the mono-hull and catamaran based on the minimal dimensions

From the figure, it can be concluded that after a period of 2.5 years, the mono-hull will have more profit than the catamaran. To compare the results processed with the customer requirements, Table 8.10 shows the unitless values of cost, comfort and workability. This is executed the same way as described in comparison 1.

Table 8.10: Unitless values of the FCS 5108 and FCS 4211

	Rating FCS 5108	**Rating FCS 4211**	**Customer Rating HoQ**	**Customer Rating FCS 5108**	**Customer Rating FCS 4211**
Investment Cost	0.92	1.00	4.0	3.44	4.00
Variable Cost	1.00	0.94	5.0	5.00	4.71
Comfort Transit	1.00	0.74	3.3	3.30	2.44
Comfort Transfer	0.84	1.00	3.0	2.53	3.00
Workability	1.00	0.83	3.3	3.30	2.72
Total Customer Rating				17.6	16.9

As can be seen in the figure, the mono-hull FCS 5108 has te highest total customer rating. Therefore, it is concluded that for the minimal needed dimensions for this concept, the mono-hull is the most attractive hull-type.

Analyses of different variables

Conclusions are drawn as a result of the choices made concerning speed, significant wave height and period. For extra reliability, some variations are checked and shown in Appendix I. Regarding the periods, calculations are also executed at T_z=4 and T_z=8. This resulted in the same conclusions. Furthermore, various speeds are calculated in steps of 10 knots. At speeds of 0 and 10 knots, the catamaran gives more attractive results than the mono-hull. At 20 knots and higher, this is reversed. So, at lower speeds, a catamaran is more attractive. Since SHIPMO has a linear approach, other significant wave heights with, in combination with the same T_z, leads the same results.

8.4. Conclusion

This chapter has compared different hull-types possible to use for the concept ship design. First, hull-types as the SWATH, hydrofoil, WIG, and ACV were rated unattractive since they do not meet one or more boundary conditions. On the other hand, the mono-hull, catamaran and trimaran are ship-types that did meet the boundary conditions, whereby they were considered for the concept design. Second, literature has been reviewed concerning these three ship-types. However, the literature which could be found never had the same characteristics as needed for the concept design. Therefore, it is not possible to base the conclusion on available literature. Last, the mono-hull, catamaran and trimaran have been compared based on speed, comfort and cost and revenue in two comparisons. This was assessed using the seakeeping analysis program SHIPMO and cost calculations. As a result, the trimaran was left out the comparison, due to unreliable results of SHIPMO and the lack of data. Based on the analysis, it is decided to use a mono-hull for the concept design.

9

Design

This chapter will give an answer sub-question 5: *What is the final concept design of this vessel and how does it score on the design drivers?* It elaborates on the final concept design of the Fast Crew Supplier. Section 9.1 examines the optimal dimensions by executing an iterative process of the arrangement of the vessel in combination with its corresponding centre gravity location. Next, Section 9.2 shows, and gives comments on, the final concept design. In addition, it elaborates on the performances of the four design drivers of the final design. Finally, Section 9.3 illustrates if the concept design fits in the formulated market gap.

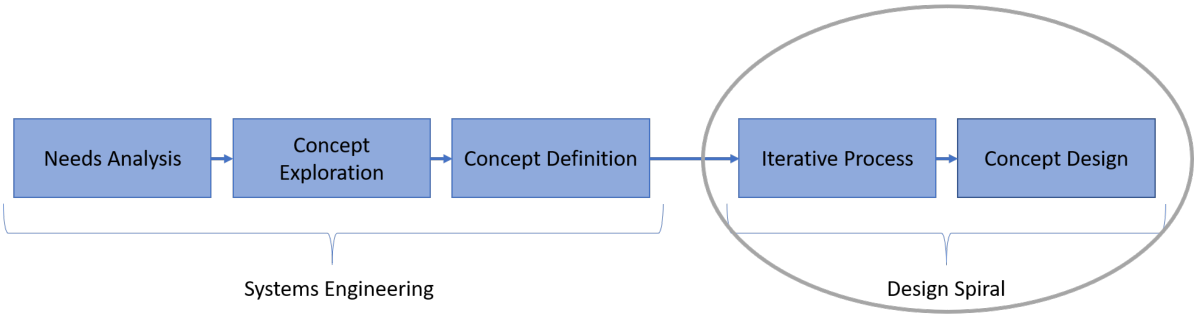


Figure 9.1: The indicated design spiral of the solution approach

9.1. Dimensions

This section establishes the final dimensions of the vessel. It elaborates further on the minimal dimensions of the mono-hull determined in previous chapter: the FCS 5108. These dimensions will be reviewed by assessing the longitudinal centre of gravity (LCG), vertical centre of gravity (VCG) and metacentric height (GM). The length will be determined by developing the arrangement in combination with the LCG. The beam will be established by the arrangement in combination with the VCG and its corresponding GM.

The determination of length and beam will be based on three loading conditions: lightweight, half fuel half cargo, and half fuel. The following iterative approach is used:

1. *Dividing the FCS 7011 and concept design in variable blocks*
   The ships are divided into various blocks, which are: hull, superstructure, wheelhouse, waterjets, engines + gearbox, crew accommodation, Ampelmann, personnel space, gyroscope, cargo and tanks. Appendix J gives an extensive explanation of these components. As a result,

the total lightweight without variable blocks is calculated of the FCS 7011. This is used for the concept design by scaling the weight and centre of gravity.

2. *Make an arrangement of the vessel*
   Subsequently, an arrangement for the concept design is made. Its LCG, VCG and weight are calculated based on suiting components or on the scaling of other existing Damen Fast Crew Suppliers. Appendix J gives detailed information on the finally used values.
3. *Calculate and check the LCG / GM*
   From this arrangement, the LCG and VCG of the concept design are calculated using the described blocks and their corresponding LCG and VCG. The relative location of LCG to the length of the concept design should be in the same range as the FCS 7011. For stability, the GM should be in the same range as the FCS 7011 in this situation. This way, it will be examined if the arrangement of the concept design could be accepted. Steps regarding the calculation and check are further explained in the following subsections.

9.1.1. Length

This subsection elaborates on the ship length by elaborating on the arrangement and its LCG. The location of its LCG determines the arrangement of the ship and vice versa. Since the location of LCG decides whether the ship trims, this location has to be checked. For this concept, the verification of an acceptable LCG is adjusted by using the data of the FCS 7011. The final arrangement and its length are found by executing the approach described above and the successive approach below.

1. Calculate the LCG of the FCS 7011 and the concept design.
2. Calculate the ’relative LCG’ (LCG/L) of the FCS 7011 and the concept design.
3. Check if the ’relative LCG’ of the concept design is in the same range of the FCS 7011 and start the iterative process.

As a result of the iterative process, the final arrangement and length are chosen. It is possible to arrange the vessel with a length of 51m while having an acceptable LCG. A schematic overview of the final arrangement corresponding with the table is shown in Section 9.2. Table 9.1 gives the corresponding values of the LCG of the FCS 7011 and FCS 5108 of three different loading conditions.

Table 9.1: LCG values of the FCS 7011 and FCS 5108

Loading Condition	**LCG FCS 7011 [m]**	**LCG FCS 5108 [m]**	**LCG/L FCS 7011 [-]**	**LCG/L FCS 5108 [-]**	**Difference [-]**
Lightweight	25.87	19.39	0.370	0.380	0.011
Half Cargo - Half Fuel	26.15	20.59	0.374	0.404	0.030
Half fuel	25.75	19.40	0.368	0.380	0.012

From the table, it can be observed that the final LCG relative to the length of the FCS 5108 is higher than of the FCS 7011. This means the LCG of the FCS 5108 is laying further from the aft. It is known that the LCG of the FCS 7011 is laying too much to the aft. The LCG/L of the FCS 4208 is around 0.42 and of the FCS 5009 around 0.39. Since these values of the FCS 5108 are higher than the FCS 7011 and do not exceed the values of the FCS 4208, the arrangement corresponding with the values in the table is assumed as acceptable.

9.1.2. Beam

This subsection elaborates on the beam of the vessel by determining its stability. Essential values for this stability are the VCG and corresponding GM. For a mono-hull, it is the trick to design a vessel that has an as low as possible GM, which satisfies the stability requirements. A low GM results in lower 'stiffness', which leads to less effort for a gyroscope to counteract roll motions and better comfort. The wider the vessel, the higher the GM becomes and reversed. Therefore, the final beam of the vessel is chosen as a result of the VCG and corresponding GM. This is done by executing the approach described above and the successive approach below.

1. Calculate the VCG of the FCS 7011
2. Calculate the corresponding GM using SHIPMO. This GM is taken as an accepted value and used for the stability check of the concept design.
3. Calculate the VCG of the concept design.
4. Calculate the corresponding GM of the concept design using SHIPMO.
5. Check the GM corresponding to the accepted value and start the iterative process of finding the beam.

The 50t of cargo that the concept design will be able to carry, leads to a significant variation in VCG and GM. Therefore, a decision has to be made on which loading condition the design choices will be based. For this concept, the decision is made that difference in GM had to be smaller than 0.3 in all loading conditions. Moreover, the condition with half fuel was leading, since the main purpose for this concept design is to transport crew and not cargo. The final dimensions of the three loading conditions are shown in Table 9.2.

Table 9.2: Results of VCG and GM of the FCS 7011 and FCS 5108

Loading Condition	**VCG FCS 7011 [m]**	**VCG FCS 5108 [m]**	**GM FCS 7011 [m]**	**GM FCS 5108 [m]**	**Difference [m]**
Lightweight	4.81	3.94	1.702	1.892	0.190
Half Cargo - Half Fuel	4.70	4.09	1.570	1.386	-0.184
Half fuel	4.68	3.83	1.694	1.798	0.104

As a result of the iterative process, the final beam is found for the concept design, which is 8.2m. Since the half fuel condition was leading in this decision, the half cargo - half fuel condition is lower than accepted. This means that it is less stable. During the extensive weight calculation, needed to execute by Damen if willing to continue with the concept design, it should be determined if ballast tanks are needed. These tanks could decrease the variation of VCG and GM as the result of tanks and cargo. This will be discussed further in Chapter 12.

This beam is chosen as a result of the VCG calculation with an Ampelmann L-type. Since an Ampelmann S-type could increase the workability of the vessel, Damen could execute an extensive weight calculation with this gangway. In that case, the beam of the vessel should be 8.5m, according to the explained calculations. These also can be seen in Appendix J.

9.1.3. Depth

The depth for the FCS 5108 is determined based on the engine height. The height of the engine is 2.07m, which is supplemented with half a meter down and up. The engines are located 1.6 meters above the keel. This results in a depth of 4.7m.

9.1.4. Final Dimensions

As a result of the iterative process to investigate the length and beam of the vessel, the final dimensions are 51x8.2m. These dimensions are measured as acceptable based on the assessment of LCG and GM. Further stability criteria are not taken into account. Stability criteria that has to be checked if further developing this concept design are for instance: weather criterion (the severe wind criterion), heel due to pax crowding, maximum statical angle, top of the GZ curve and area under the GZ curve.

9.2. Final Design

As a result of the previous research and iterative process of the design spiral, the final concept design is the FCS 5108. To ensure the design and corresponding decisions could be used in the future by Damen, a General Arrangement (GA) is made in cooperation with them. Figure 9.2 shows the views of the profile, bridge deck, main deck and lower deck.

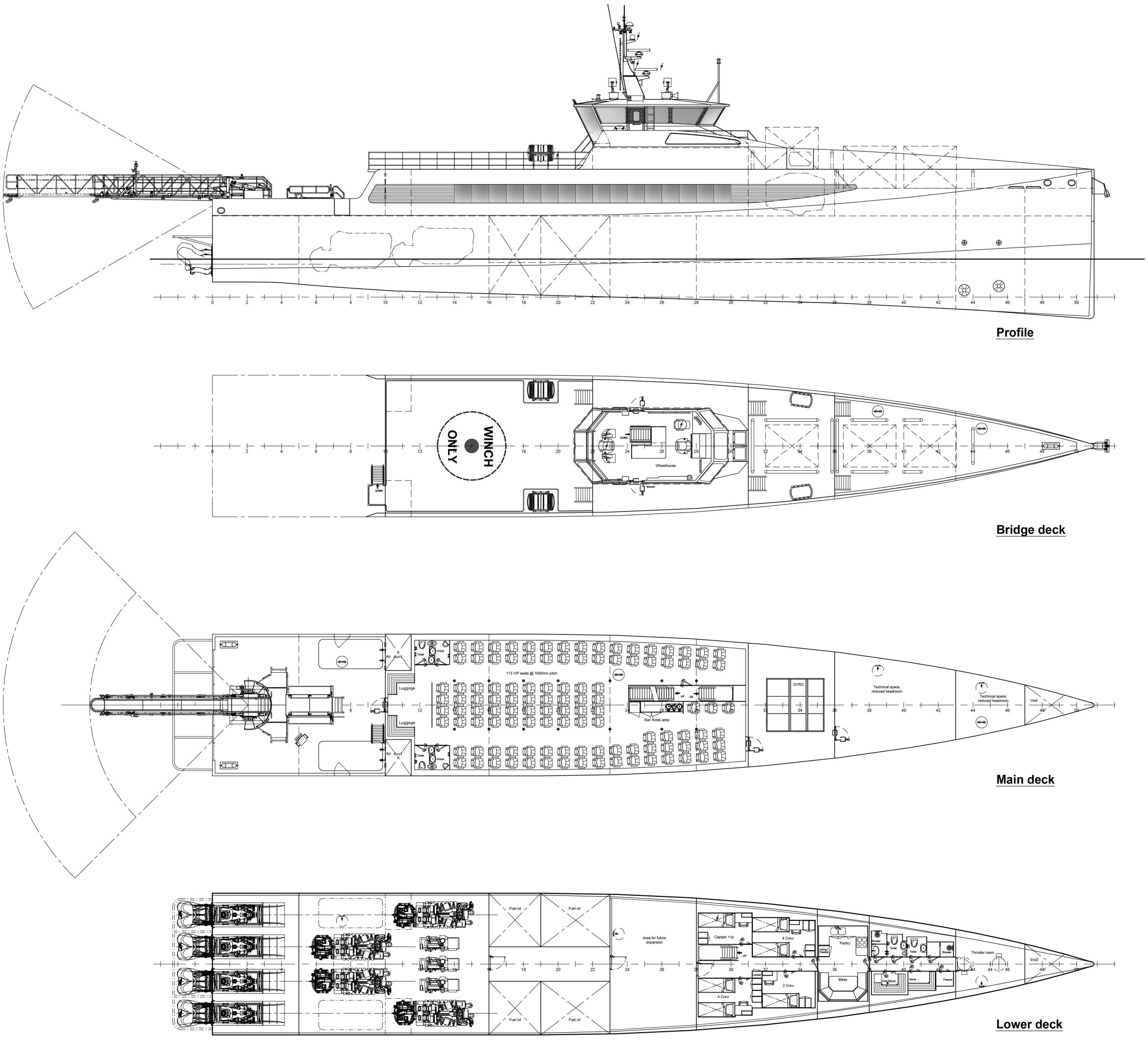


Figure 9.2: Four views FCS 5108 of the General Arrangement

An explanation of the arrangement of the vessel, which is a result of the iterative process, is described per item below:

- *Personnel*
  What can be seen is that the personnel is placed between 20% and 58%, which is attractive for the comfort. Finally, it is chosen to place 113 VIP seats with a pitch of 1m. The area is arranged with four lavatories and a small kiosk area.
- *Wheelhouse*
  The location of personnel results in a wheelhouse more to the aft of the ship compared with similar Damen vessels. From this location of the vessel, a line of sight is needed, which ensures seeing the water surface further than two times the ship length. Therefore, the wheelhouse is placed higher. This results in extra space, which is used for technical usage.
- *Ampelmann*
  As explained in Appendix J, the Ampelmann L-type is placed at the aft of the ship.
- *Gyroscope*
  Because the gyroscope could be placed at various locations, it is used to tune the VCG. Finally, it is placed on the main deck. If final stability calculations require, the area aft of the crew accommodation could also be used for fitting the gyroscope.
- Waterjets, Engine, Gearbox
  The beam of the vessel was dependent on the fitting of the four Hamilton HT810 waterjets. After extensive research, it was concluded that they could fit in the most attractive beam of 8.2m (as explained in this chapter). However, the fitting of the gearboxes and engines was not possible next to each other. Therefore, the two outer engines and gearboxes are placed forward.
- *Crew accommodation*
  The crew accommodation is located at the forward part, aft of the bow thruster room.
- *Tanks*
  As explained in Appendix J, the volume of the tanks is based on the needed power, 30 hours of sailing, the fuel density and consumption. The location of the tanks is located close to the LCG of the ship. This way, the vessel does experiences minimal consequences as a result of variable filled tanks.
- *Cargo*
  The cargo is placed on various heights. Two 10ft containers (3x2.4x2.4m) could be placed on the deck above the gyroscope. Space for another four 10ft containers could be placed one meter lower. These are located at this height because of the characteristics of the Axe Bow. This type of bow dives deeper into the waves, which results in the need of a relatively high bow. If reserving space for cargo at the main deck this hole could be filled with water. To resolve this, large freeing ports are required which ensures the effect of the high bow disappears. While designing a hole of 1m, the effect of the high bow is sufficient in combination with the corresponding freeing ports. This results in a space with a length of 11m and a height of 1.7m, which is reserved for technical space.
- *Area for future expansion*
  As can be seen, five meters in the lower deck is not filled. This area is for possible future expansions or extra needed space.

9.2.1. Cost

For the calculation of the cost of the FCS 5108, the same approach is used as explained in Subsection 8.3.3. In addition, it is expanded by processing more specific cost. Confidential Appendix 4 shows the calculation. For similar existing vessels of Damen, the ratio between the cost of specific systems and the total cost is calculated. This total cost is without the Ampelmann and the gyroscope. The specific systems taken into account are hull and superstructure, propulsion, waterjets, gearbox, seats and dynamic positioning system. These are chosen since they cover a high percentage of the total cost. This is also calculated for the FCS 5108. Subsequently, the total cost could be calculated using the ratio and adding the cost of the gyroscope and Ampelmann. As shown in Table 9.3, the investment cost of the FCS 5108 significantly lower relative to the FCS 7011. Due to the less weight and needed power of the FCS 5108 relative to the FCS 7011, the variable cost are also lower.

Table 9.3: Relative cost comparison FCS 5108 with FCS 7011

	FCS 5108	**FCS 7011**
Cost	43	100

9.2.2. Comfort

Concerning the comfort of the FCS 5108, calculations are executed in SHIPMO. Figure 9.3 illustrates, and Table 9.4 shows, the MSI results of the vessel. The average is compared with the average of the FCS 7011, which results in a lower MSI.

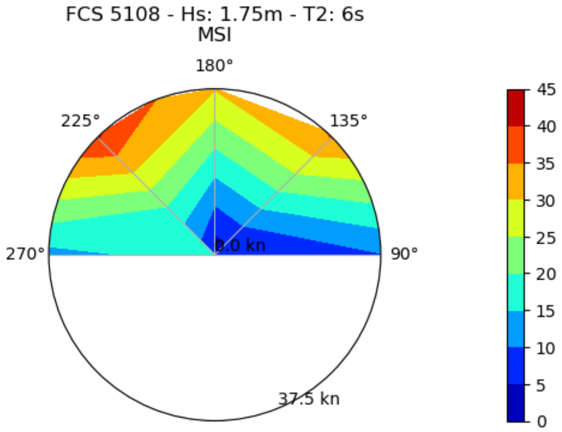


Figure 9.3: MSI results of the FCS 5108

Table 9.4: MSI results of the FCS 5108 and relation compared to the limiting value

Head [°]	**MSI [%]** **at Speed = 0kn**	**MSI [m/s^2]** **at Speed = 37.5kn**
90	7.9	9.7
135	1.7	35.3
180	1.3	30.2
225	5.7	40.5
270	17.3	13.3
Average	16.3	
Relation compared to the limiting value	0.64	

Table 9.5 shows the vertical acceleration results of the vessel. The corrected average RMS and corrected average maximum value are also calculated. These values are compared with the values of the FCS 7011. The vertical accelerations of the FCS 5108 are lower than the FCS 7011.

Table 9.5: Corrected vertical acceleration values of the FCS 5108 and the relation compared to the limiting value

Head [°]	**Corrected RMS Az [m/s^2] at Speed = 0kn**	**Corrected RMS Az [m/s^2] at Speed = 37.5kn**
90	0.38	0.42
135	0.20	1.58
180	0.18	1.79
225	0.32	1.82
270	0.60	0.51
Average	0.34	1.22
Average RMS	0.78	
Average MAX	2.50	
Relation compared to the limiting value	0.72	

Due to the lower MSI and vertical accelerations of the FCS 5108 compared to the limiting values, it is concluded that: regarding the vertical accelerations and MSI, the FCS 5108 complies on comfort. In addition, sailing in H_s of 1.75m, it even improves on the comfort of the FCS 7011 sailing in H_s of 2.75m, which is both in their designed significant wave heights. For clarification, the FCS 5108 does not improve on the FCS 7011 sailing in H_s of 1.75m.

9.2.3. Safety

As explained in Section 3.1, the limiting motion criteria for maximum vertical accelerations at the wheelhouse is 8.0m/s^2 and for RMS vertical accelerations is 1.47m/s^2. It is assumed that if the average of the accelerations at a speed of 37.5kn does not exceed these limiting criteria, the vessel is safe. When calculating these averages, it is assumed that all wave directions occur equally often. Appendix K shows the maximum vertical accelerations of the FCS 5108 at the wheelhouse. The corrected average maximum vertical acceleration at this location at 37.5kn is 4.24m/s^2. Using Table 9.5, it can be found that the corrected RMS vertical acceleration of the FCS 5108 at 37.5kn is 1.22m/s^2. Table 9.6 gives an overview. Since both values do not exceed the limiting motion criteria, it is concluded that the vessel is safe regarding the vertical accelerations.

Table 9.6: Overview results and limiting criteria concerning safety

	RMS Az [m/s^2] at Speed = 37.5kn	**MAX Az [m/s^2] at Speed = 37.5kn**
Average	1.22	4.24
Limiting value	1.47	8
Relation	0.83	0.53

9.2.4. Speed

The engines of the FCS 5108 are chosen as explained in Subsection 8.3.3. Figure 9.4 shows the final resistance chart of the FCS 5108, calculated in HSC Resistance Program. This is based on a fully loaded condition and with the standard Axebow 2014 dimensions using a length of 51m. It is ensured that the vessel can sail 37.5 knots. Since the total power of the engines is 10240 kW, which is higher than needed for 37.5 knots and is calculated on a loaded condition, it is expected that the ship can sail 40 knots.

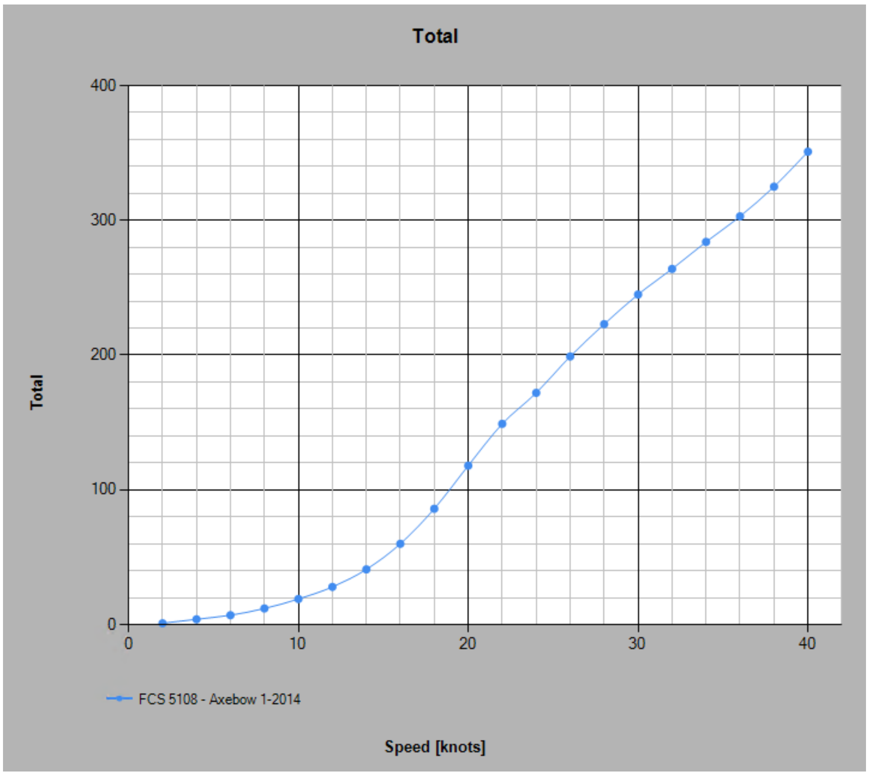


Figure 9.4: Resistance chart FCS 5108

9.2.5. Other

As explained in Chapter 7, it is attractive to design a vessel with a GT value lower than 500. This value is determined by calculating the enclosed areas. This way, an idea is sketched of magnitude and the possible feasibility of the lower GT than 500. The calculated GT is 560, which makes it hard to design this vessel with these corresponding goals with a lower than 500GT.

9.3. Design Relative to the Market Gap

One of the goals of this research was to design a vessel which fits in the market gap. Chapter 3 has formulated these gaps and indicated them in graphs. Figure 9.5 shows those graphs including the indication of the position of the FCS 5108, illustrated with the black star. As can be seen and concluded from the graphs is that the FCS 5108 fits in the formulated market gap.

(a)

(b)

(c)

Figure 9.5: Graph indicating the gap of Damen's Fast Crew Suppliers

10

Case Study

To be able to compare the FCS 5108 with a helicopter, this chapter executes a case study. After this case study an answer can be given on the sixth sub-question: *To what extend is the concept design more attractive than a helicopter?* The case is about three platforms in West Africa named Bonga, Bonga North, and Bonga Southwest. Similar to Chapter 2, the Sikorsky S92 is used as helicopter for the comparison. Figure 10.1 shows the current situation executed by helicopters. In this case the personnel first arrives at Porto Novo, whereafter it is transported to Lagos. From Lagos, the helicopter transports the personnel to one of the three platforms.

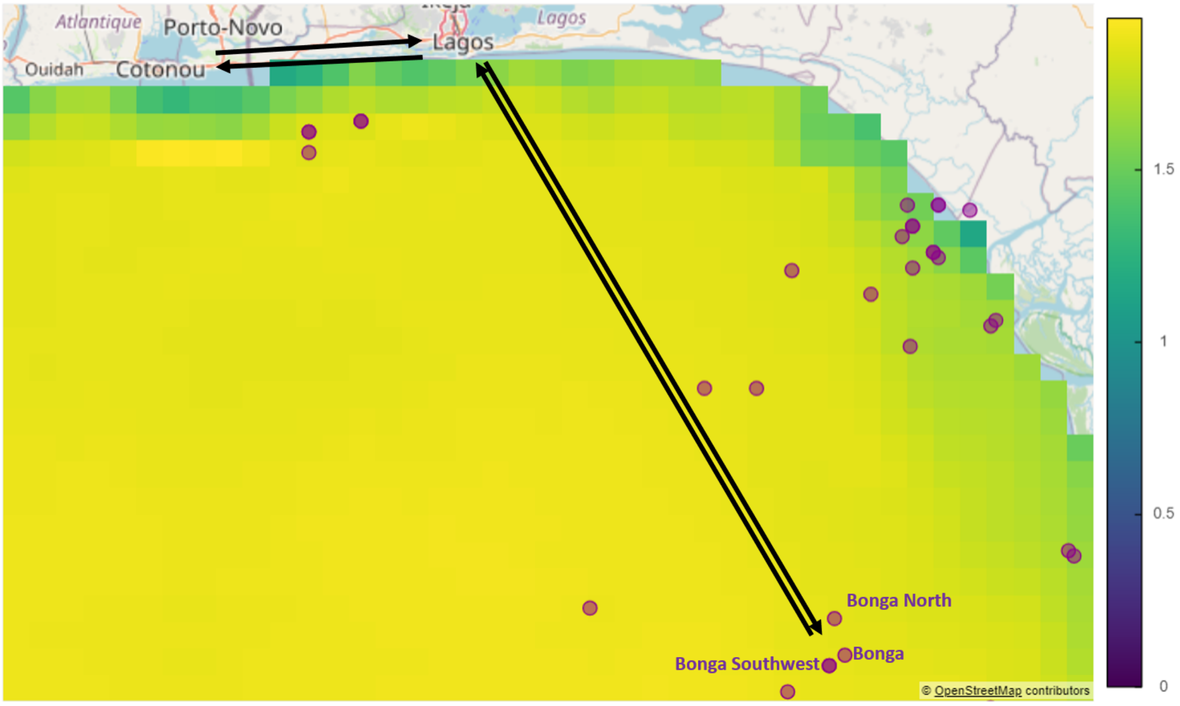


Figure 10.1: Current situation of crew transportation executed by helicopters (Copernicus tools settings: H_s=2m, occurrence=95%)

In case of using the FCS 5108 for the crew transportation, the situation will be as shown in Figure 10.2.

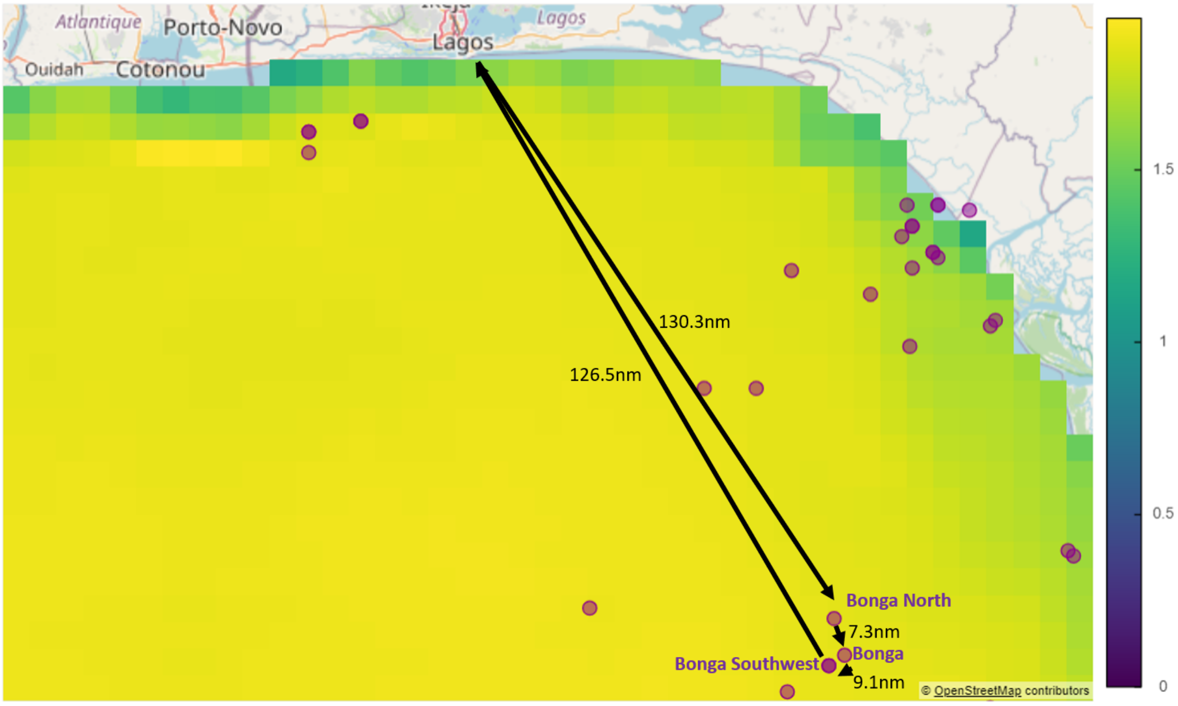


Figure 10.2: Assumed situation of crew transportation executed by the FCS 5108 (Copernicus tools settings: H_s=2m, occurrence=95%)

The comparison is between the FCS 5108 and the helicopter is made in two ways. First, relative to the current situation of the helicopter. Second, relative to the case where the crew transportation starts at Lagos, which has same travelling distance as a vessel. This second comparison is added because this more efficient logistical solution is assumed as more common in other situations. Table 10.1 gives the time needed for the transportation of personnel. For the vessel, these will be reached during one trip. For the helicopter, three separate trips are required. The transit time is calculated using the speed and distance, the check-in and transfer time are used the same way as in Subsection 2.2.3. For the helicopters the check-in takes 90 minutes and the transfer takes 15 minutes. For the vessel the check-in takes 15 minutes and the transfer 30 minutes.

Table 10.1: Time indication needed to reach the Bonga platforms by vessel and helicopter

	FCS 5108	**Sikorsky S92 current situation**	**Sikorsky S92 same travelling distance**
Total time to Bonga North [h]	4.0	4.7	2.6
Total time to Bonga [h]	4.9	4.8	2.7
Total time to Bonga Southwest [h]	5.9	4.8	2.7
Total time back to start [h]	10.3	9.5	5.3

As explained in Section 5.4, the maximum time duration of the crew transportation per person of eight hours is selected. If this is the case, the vessel will be rated as more attractive than helicopters in case of better cost. As can be seen in the table, the time duration to Bonga Southwest of the FCS 5108 does not exceed eight hours. In addition, in the case of the current situation of helicopters, the transportation of personnel to platform Bonga North takes less time than the helicopter. Furthermore, according to the regulations, the maximum time the crew of the vessel to be on board is 12 hours. As shown in the figure, the total time the crew has to be on board is 10.3 hours, which satisfies the regulations.

The cost of the helicopter and vessel is calculated the same way as executed in Chapter 2. For the FCS 5108, the fuel cost are based on the selected engine. Table 10.2 shows the cost comparison, which execution is shown in Confidential Appendix 5.

Table 10.2: Cost comparison of the FCS 5108 relative to the Sikorsky S92 in this case study

	FCS 5108	**Sikorsky S92**
Investment Cost [%]	Significantly lower	100
Cost per trip per person [%] related to current situation	10	100
Cost per trip per person [%] related to same travelling distance	18	100

Based on the cost and time comparison, in combination with the comfort and safety conclusions made in the previous chapter, it is concluded that, in this case and the corresponding assumptions, the FCS 5108 is a more attractive way of crew transportation than helicopters.

III

Conclusion and Discussion

11

Conclusion

This chapter provides the conclusion to this research. Based on the assessment of the offshore crew transportation drivers executed in Chapter 2, it has been concluded that vessels can compete with helicopters for crew supply in the offshore market. From these drivers, four interdependent and conflicting design drivers for vessels have been formulated, which are: cost, safety, comfort and speed. Through an analysis of existing Crew Transfer Vessels competing with helicopters, it has been found that there is a market gap for vessels that can operate in mild sea conditions and sail long distances. Therefore, the goal of this research has been to develop a concept design for a vessel that fits this market opportunity, while scoring better on the combination of the four design drivers relative to helicopters. This chapter answers the main- and sub-questions defined in Chapter 4. The sub-questions are discussed first, and after that, the main research question is answered.

1. What are design approaches and tools that could be used in order to design the vessel and make decisions?

An extensive study on applied design approaches and tools has been executed in in Chapter 5. In this research, the concept design and the first conceptual iterations are considered important. For the concept design, it has to be found out what was required for a vessel fitting in the market gap. The early-stage concept design phase of the Systems Engineering approach has been chosen as most attractive for this first phase. Subsequently, once the concept design was made, the iterative character occurred. The Design Spiral approach was the most attractive for this phase. To support the selected design approach, design tools can be applied which help to quantify and organise design decisions. Since the design of a new CTV is considered a multiple criteria decision problem, tools that help in trade-off decisions are useful. QFD is selected to use for this research to help in various choices that had to be made. This is because it helps create design objectives based on design drivers and could be used to translate results into unitless measures. This is useful to compare different design characteristics effectively during the design process. For the combined assessment of the values of the interdependent design drivers for the hull comparison, elements of MAUT were considered as attractive.

2. Which mild sea condition areas are of interest and what are their characteristics?

This question is answered in Chapter 6, using and expanding the Copernicus tool of Damen. First, a selection of thirteen areas with a high density of offshore platforms is made. Based on this, the significant wave height of a maximum of 2m, the vessel should operate in for at least 80% of the time, is chosen. As a result, ten operational areas are determined in which the ship could sail. Since not all these areas are interesting markets for Damen to sell their vessels, the final operation areas are selected based on the market access, and platform characteristics and location. These operational areas of interest are: West Africa, the Mexican Gulf of Mexico and the Middle East. These have significant platforms in the range of 60-120nm from a harbour and further. Decisions concerning the concept design of the vessel have been made based on the characteristics of these areas.

3. What are the design requirements for a vessel operating in these areas?

Based on the three selected areas, the final design requirements have been determined in Chapter 7. This is done by setting up a House of Quality. For this tool, the customer requirements of the selected areas and functional requirements of the vessel were set up and linked with each other. This way, important aspects were determined, used during the design phase of the vessel. Concerning the customer requirements, cost per person per trip is the highest rated, followed by the investment cost. The hull-type and its dimensions are rated as the most important functional requirements. The final design requirements and several systems have been established. For example, a significant wave height between 1.5 and 2 meters, speed between 35 and 40 knots, personnel capacity between 80 and 150 and a range of 1200nm. These induce the boundary conditions of the designed vessel.

4. Which hull-type suits these design requirements best?

This question has been researched and answered in Chapter 8. First, an assessment of various hull-types is executed relative to the boundary conditions. Hull-types as the SWATH, hydrofoil, WIG, and ACV were rated as unattractive since they do not meet one or more boundary conditions. The mono-hull, catamaran and trimaran are ship-types which did meet the boundary conditions, whereby they have been considered for the concept design.

Second, literature has been reviewed concerning these three ship-types. However, the literature which could be found never had the same characteristics as needed for the concept design. Therefore, it is not possible to base the conclusion on available literature.

Last, the mono-hull, catamaran and trimaran have been compared based on speed, comfort, safety, cost and revenue in two ways. The comfort was assessed using SHIPMO, which gives impressions of the motions of a particular ship. The first comparison is based on the three ship-types with dimensions resulting in the same seakeeping characteristics. For the second, the ship-types are compared with measurements corresponding with the minimum dimensions required for this concept. For both of the comparisons, the results of comfort and cost results are converted to unitless measures using the values of the House of Quality and elements of MAUT. Based on these values, the determination of the best suitable hull-type, which is a multi-criteria decision, could have been made. In the first comparison, it has been concluded that the trimaran could not be taken into account as a possible hull-type for this research. This is due to unreliable results of SHIPMO and the lack of data within Damen. Comparison 1 resulted in an FCS 5615 catamaran and an FCS 4708.5 mono-hull. Based on the processed unitless measures on the results of comfort and cost, the mono-hull was rated as most attractive. Comparison 2 resulted in a FCS 4211 catamaran and an FCS 5108 mono-hull. Based on the processed unitless measures of comfort, cost and workability, the mono-hull was rated as most attractive. So, based on the use of SHIPMO, cost estimation, and corresponding made assumptions, it has been decided to use a mono-hull for the concept design.

5. What is the final concept design of this vessel and how does it score on the design drivers?

Chapter 9 elaborates on the final concept and its corresponding cost as a result of an iterative design process. The optimal dimensions have been examined as a result of the iterative process of this in combination with the propulsion plant, arrangement, weights and centres of gravity. The final concept elaborates further on the minimal dimensions of the mono-hull determined in the previous sub-question: the FCS 5108. By evaluating the LCG, VCG and arrangements, the final dimensions have been set on a length of 51m, a beam of 8.2m and a depth of 4.7m. Relative to the FCS 7011, the cost of the FCS 5108 is 43/100. Concerning comfort relative to the FCS 7011, the vertical accelerations ratio, in both their own designed significant wave height, is 72/100. Since the FCS 5108 does not expand limiting vertical accelerations as found in literature, it is also assessed as a safe vessel.

6. To what extend is the concept design more attractive than a helicopter?

A case study has been executed in Chapter 10 to evaluate how the FCS 5108 compares to helicopters. It is executed based on a situation in West Africa and compared with the Sikorsky S92. The investment cost of the FCS 5108 is significantly lower than the Sikorsky S92. Relative to the Sikorsky S92 with the same travelling distance as the vessel, the cost per trip per person of the FCS 5108 is 17/100. Concerning the speed, the vessel is able to supply three platforms of crew within the selected limited time of eight hours.

As a final step, the conclusion to the main research question is provided:

What should be the concept design of a Fast Crew Supply Vessel to become an attractive alternative to helicopters at long distances in areas with relatively mild conditions?

The concept design of a Fast Crew Supply Vessel, which is an attractive alternative to helicopters at long distances in areas with relatively mild conditions, is the Fast Crew Supplier 5108, shown in Figure 11.1.

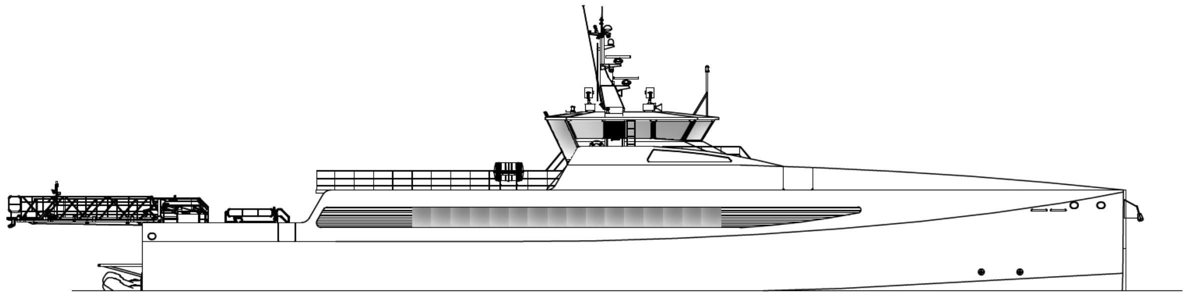


Figure 11.1: The Fast Crew Supplier 5108

Table 11.1 gives an overview of the criteria to improve on helicopters and the related results of the FCS 5108. Table 11.2 provides an overview of the requirements to fit in the market gap and the associated results of the FCS 5108.

Table 11.1: Overview of criteria to improve on helicopters and the corresponding score of the FCS 5108

Design Driver	**Criteria to improve on helicopters**	**Result of the FCS 5108 regarding to the criterion**
Cost	Significantly lower cost per person per trip	18/100
Safety	In addition to the proven improved safety in literature study: not exceed the limiting vertical acceleration value	83/100
Comfort	In addition to the proven improved comfort in literature study: not exceed the limiting value of comfort based on the FCS 7011	72/100
Speed	Supply multiple platforms of crew within the time range of eight hours	74/100

Table 11.2: Overview of criteria to fit in the market gap and the corresponding score of the FCS 5108

Driver	**Criteria to fit in the market gap**	**Results of the FCS 5108 regarding to the criterion**
Cost	Significantly lower investment cost than the FCS 7011	43/100
Speed	Between 20 and 50 knots	Up to 35-40 knots
Range	Distance between 100 and 200 nm	Up to 200 nm
Significant wave height	Between 1.5 and 2.5 m	Up to 2 m

According to the set criteria to improve on helicopters and to fit in the market gap, in combination with the made assumptions, it can be concluded that the FCS 5108 can compete with helicopters in mild condition areas at long distances in the offshore crew transportation market and fits in the market gap of Fast Crew Suppliers.

Figure 11.2 and 11.3 give a first impressions of the FCS 5108.

Figure 11.2: The Fast Crew Supplier 5108

Figure 11.3: The Fast Crew Supplier 5108

12

Discussion / Recommendations

This chapter provides a discussion on the research process and the research outcome. Additionally, recommendations for further research will be made. As first step, Section 12.1 presents the discussion. Next, Section 12.2 gives the recommendations.

12.1. Discussion

The discussion will reflect on the assumptions, results and conclusions. For this reason, the multi-criteria decisions, the established design requirements, hull-type comparison and final design are discussed in Sections 12.1.1 to 12.1.4.

12.1.1. Multiple-criteria decisions

This subsection discusses the customer requirements and House of Quality which concerns the multiple-criteria decisions.

Customer Requirements

The customer requirements have been used as a foundation for multiple criteria decision analyses. These were based on the average customer requirements of West Africa, the Middle East and the Mexican part of the Gulf of Mexico, as shown in Section 7.2. Moreover, these values are determined by the sales department of Damen based on their market knowledge. To give more realistic results, the customer requirement values should be based on the customer requirements indicated by the customers themselves and per area separately. In case of major changes, this, for instance, could lead to different dimensions and systems on board of the ship.

House of Quality

The ratings between customer requirements and functional requirements of in the House of Quality are, per definition, based on subjective assumptions. Appendix G explains the various ratings. However, these ratings could be discussed and could vary based on different insights. Again, in case of major changes this could lead to the same results as explained above.

12.1.2. Design Requirements

For the design requirements determined in this research, the cargo and motion-compensated gangway are discussed.

Cargo
The GM of a vessel varies as a result of the distribution of weight on board. The FCS 5108 is designed with a cargo capacity of 50t, which is relatively high compared to the deadweight of the vessel. In addition, the cargo is placed on deck, which is relatively high in the vessel. These two elements result in a low GM if cargo is on board, but a high GM if not. For the design of a vessel, a minimum GM is required to meet safety requirements. A higher GM results in less attractive seakeeping characteristics. Since the main goal of the vessel is the transportation of personnel to offshore platforms and the cargo is a minor aspect, the ship will sail mainly with personnel and without cargo. Therefore, a design specified on 50t deck cargo will not result in the best solution for crew transportation. To improve the seakeeping performance, ballast tanks could be implemented, or less cargo could be transported. In case of implementing ballast tanks, these installations should be placed aft and low to compensate for the LCG and VCG. In the design, extra space is made available to implement, for example, such ballast tanks. However, the locations of systems have to be shifted in this case. In case it is decided to transport no or less cargo, the beam can be reduced. This results in reduced hull cost and a reduced resistance which has a positive impact on fuel consumption.

Motion-Compensated Gangway
Regarding the motion-compensated gangway, only Ampelmann gangways have been investigated due to the current cooperation between Ampelmann and Damen. It is of interest to investigate motion-compensated gangways from other companies as well. This might create better fitting solutions that allow a broader range of design possibilities.

On the FCS 5108, the Ampelmann L-type is placed. The choice to select this type of gangway has been based on the fact that the Ampelmann S-type is significantly heavier than the L-type. In tests executed by Damen, an Ampelmann A-type managed to bring a 50m long Fast Crew Supplier in resonance due to its weight. This type has the same operation as the S-type but has more weight. However, the advantage of the S-type over the L-type is its long reach. This means that there is a chance that several offshore platforms fall outside the scope of the FCS 5108 equipped with the L-type. To solve this in the concept design, it is an exciting thought to install a future Ampelmann type with the weight of the L-type and the reach of an S-type.

12.1.3. Hull-type comparison

Concerning the hull-type determined in this research, the seakeeping analysis program and assumptions are discussed.

Seakeeping Analysis Program
For this research, it has been chosen to execute the seakeeping analysis in SHIPMO. As explained, this program is based on a linear diffraction theory and does not consider maximum vertical accelerations. In principle, this is not a correct approach for high-speed vessels, as these show non-linear behaviour. This, however, is compensated by the fact that the Axe Bow Concept almost behaves linearly. Although the results of SHIPMO in combination with processed correction factors have been evaluated, programs that can program maximum vertical accelerations are expected to be more precise. For this reason, ’Fastship’ could give more realistic results, which might improve this research. Moreover, as explained in Subsection 8.3.2, for catamarans and high Froude numbers SHIPMO has not been validated enough, and the interaction of hulls of the catamarans is not taken into account. Although corrections are processed on the results of SHIPMO, more proven programs could improve the reliability of the results. A program that can be used is ’PanShip’. This program uses a time-domain code and is validated at higher speeds / Froude numbers. Furthermore, it is also suitable for catamarans and trimarans. Since this is a Computational Fluid Dynamics (CFD) program,

and takes a lot of time, it is not attractive assess for preliminary designs. For this reason, it fell out of the scope of this research. For calculations at zero speed, 'PRECAL' is a program that uses a panel code and also gives more realistic results. As described in Subsection 8.3.4, trimarans had to be left out of this research because of the unreliable results in SHIPMO. To assess the trimaran compared with the catamaran and mono-hull, the program 'PanShip' could also be used.

Assumptions Assessment Hull-types
For the assessment of the hull-type comparison, various assumptions have been made. For instance, concerning the weight of the vessel and the form of the hull. In addition, it is assumed that the values of the FCS 7011 at significant wave heights of 2.75m are acceptable. Moreover, the workability is based on the vertical accelerations combined with the scatter diagrams of the areas. These scatter diagrams were only available of widely spread areas. It is expected that the scatter diagrams of the areas in a range of only 200nm from land are different. In these areas, the significant wave heights are typically smaller, and the wave periods are shorter. This impacts the seakeeping performance of both a mono-hull and a catamaran. However, 8.3.4 has shown that in these circumstances, the mono-hull still outperforms the catamaran. Hence, this would not have changed the hull-type design decision.

12.1.4. Final Design

As explained in Chapter 9, the acceptable dimensions are measured based on the assessment of LCG and GM. This means that further stability criteria are not taken into account. Stability criteria that could have been checked to increase the reliability of the concept design are, for instance: weather criterion (the severe wind criterion), heel due to pax crowding, maximum statical angle, top of the GZ curve and area under the GZ curve. These stability criteria are considered more relevant in the next phase of the design process. If, in this phase, the design will not satisfy one of the criteria, it is possible to increase the beam. This will contribute to the stability of the ship. However, a disadvantage will be that its weight increases, which will be at the expense of its speed.

12.2. Recommendations

Based on the conclusions and discussion, several recommendations for further research are:

- The final ship length of the vessel is based on the minimal needed dimensions in combination with the ability to fit all systems in the vessel. This is done since the investment cost is rated higher by the customer than comfort. However, based on the outcome of the Enlarged Ship Concept research program, it is expected that a lengthened concept has a slightly higher cost, but increases the seakeeping performance significantly. For this reason, it is of interest to evaluate this ship with bigger lengths as well. The perfect balance should be found between comfort and cost.

- A conclusion of this research has been that comfort could be rated in various ways. In this study, this is done using the MSI and vertical accelerations. Besides these technical elements, subjective aspects also play a role, such as happiness on board and quality to work during travel time. For further research, it is recommended to consider a comfort index which takes both technical and subjective elements into account. This index should then be easily comparable with cost. This way, a good balance for the vessel design between comfort and cost can also be found.

- As explained, the FCS 5108 has the Ampelmann L-type as motion-compensated gangway. With this gangway system, it is possible that not all platforms can be supplied of crew due to its reach. In this research, no data was available on the landing heights of the platforms.

To better understand the number of platforms that can and cannot be reached, it is recommended to investigate the landing heights of the platforms in the three operational areas. Next, apart from a more extended gangway system, it might be considered to install systems to lower the landing height. Possibilities and results of these are recommended to research.

- Literature indicated that the trimaran results in better seakeeping characteristics than catamarans. In this research, no conclusions could be drawn concerning the trimaran as a suitable hull-type for this concept design. However, in literature it has been demonstrated that, in certain circumstances, the trimaran has better seakeeping performances than the mono-hulls. Therefore, it is recommended to investigate the characteristics of the trimaran in more detail. This could be done using ’Panship’, as explained in the discussion.
- It is concluded that this concept design is an attractive alternative to helicopters in mild condition areas at long distances. Therefore, it is recommended to continue the design process and start the next ’Engineering Development’ phase, continued with the further steps of the Systems Engineering approach and Design Spiral.

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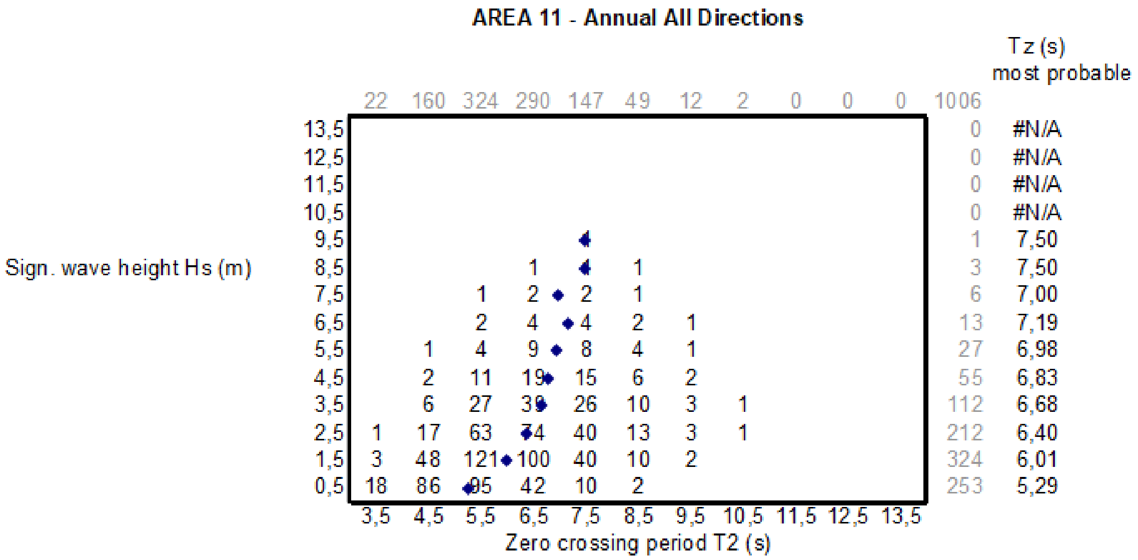
IV

Appendixes

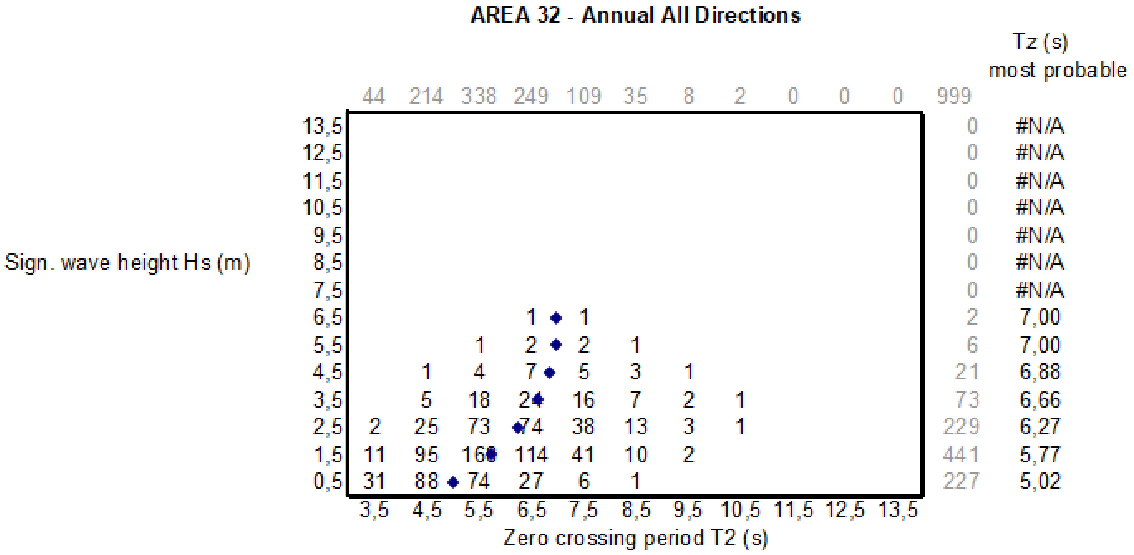
A

Scatter Diagrams



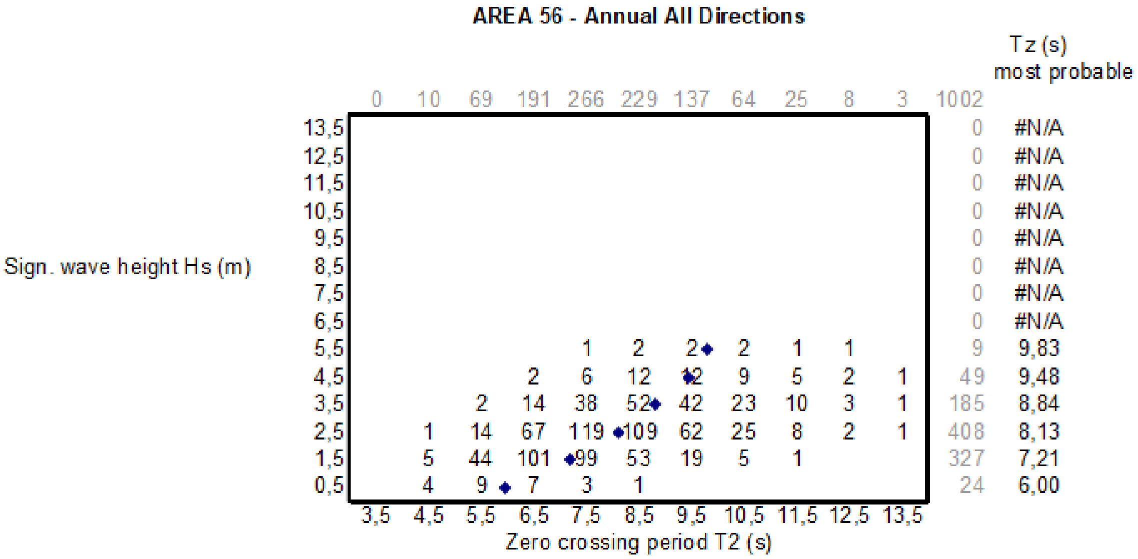
	22	160	324	290	147	49	12	2	0	0	0	1006	Tz (s) most probable
13,5												0	#N/A
12,5												0	#N/A
11,5												0	#N/A
10,5												0	#N/A
9,5					1							1	7,50
8,5				1	1	1						3	7,50
7,5			1	2	2	1						6	7,00
6,5			2	4	4	2	1					13	7,19
5,5		1	4	9	8	4	1					27	6,98
4,5		2	11	19	15	6	2					55	6,83
3,5		6	27	39	26	10	3	1				112	6,68
2,5	1	17	63	74	40	13	3	1				212	6,40
1,5	3	48	121	100	40	10	2					324	6,01
0,5	18	86	95	42	10	2						253	5,29
	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5	11,5	12,5	13,5		

Figure A.1: Scatter diagram West Europe



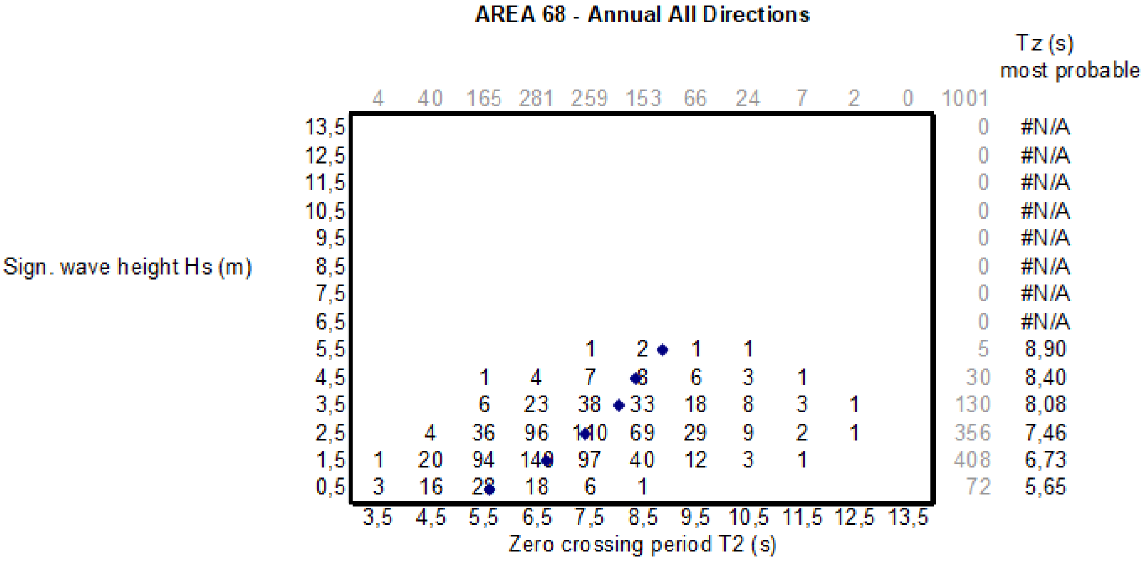
	44	214	338	249	109	35	8	2	0	0	0	999	Tz (s) most probable
13,5												0	#N/A
12,5												0	#N/A
11,5												0	#N/A
10,5												0	#N/A
9,5												0	#N/A
8,5												0	#N/A
7,5												0	#N/A
6,5				1	1							2	7,00
5,5			1	2	2	1						6	7,00
4,5		1	4	7	5	3	1					21	6,88
3,5		5	18	24	16	7	2	1				73	6,66
2,5	2	25	73	74	38	13	3	1				229	6,27
1,5	11	95	168	114	41	10	2					441	5,77
0,5	31	88	74	27	6	1						227	5,02
	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5	11,5	12,5	13,5		

Figure A.2: Scatter diagram Gulf of Mexico



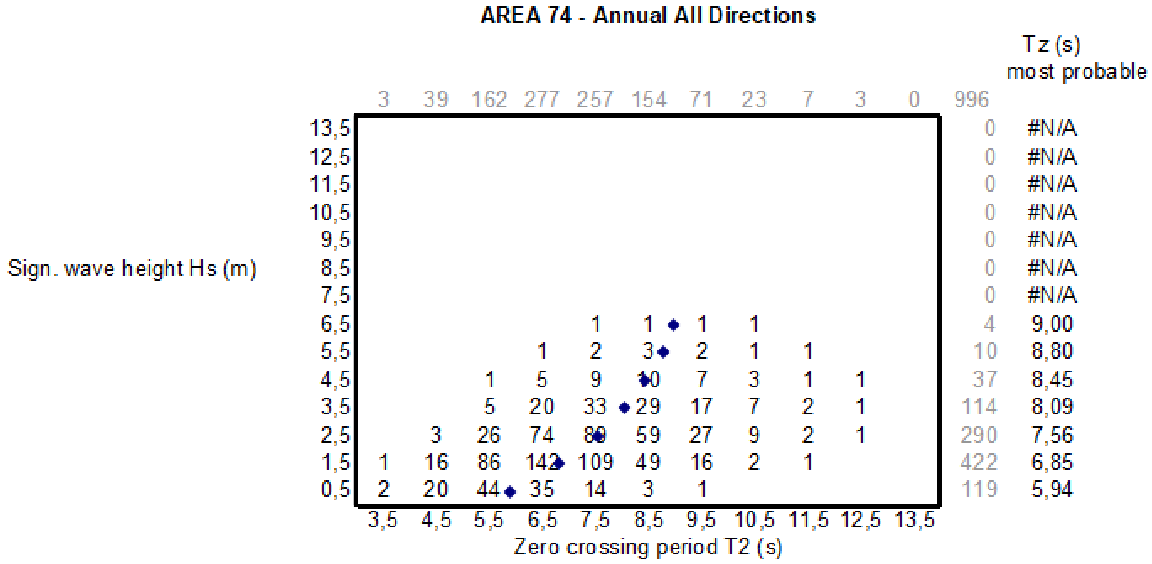
Sign. wave height Hs (m)	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5	11,5	12,5	13,5		Tz (s) most probable
	0	10	69	191	266	229	137	64	25	8	3	1002	
13,5												0	#N/A
12,5												0	#N/A
11,5												0	#N/A
10,5												0	#N/A
9,5												0	#N/A
8,5												0	#N/A
7,5												0	#N/A
6,5												0	#N/A
5,5					1	2	2	2	1	1		9	9,83
4,5				2	6	12	12	9	5	2	1	49	9,48
3,5			2	14	38	52	42	23	10	3	1	185	8,84
2,5		1	14	67	119	109	62	25	8	2	1	408	8,13
1,5		5	44	101	99	53	19	5	1			327	7,21
0,5		4	9	7	3	1						24	6,00

Figure A.3: Scatter diagram North East Latin America



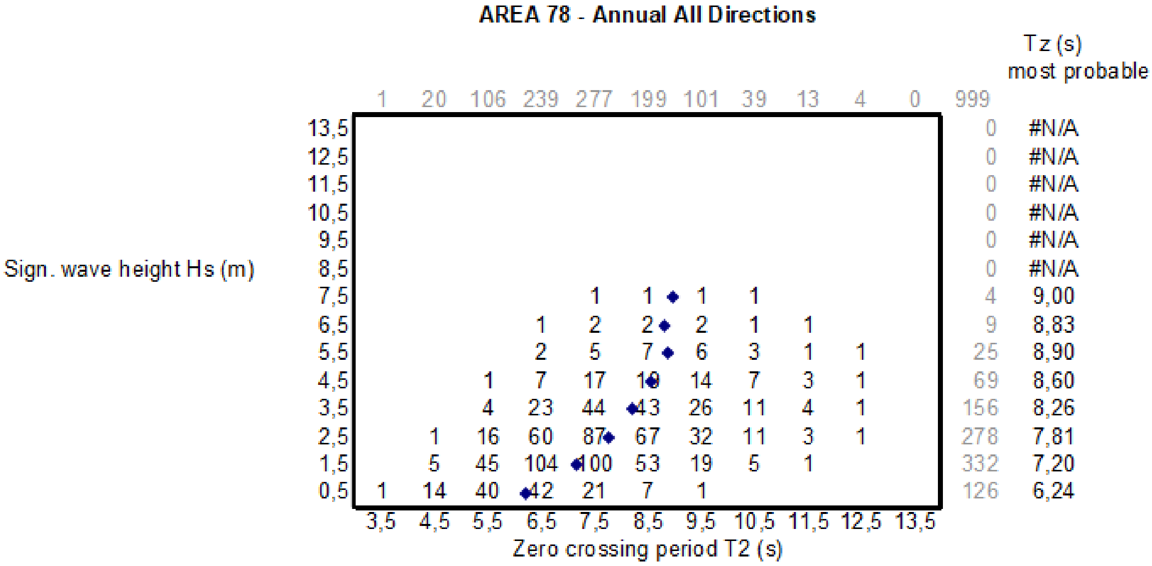
Sign. wave height Hs (m)	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5	11,5	12,5	13,5		Tz (s) most probable
	4	40	165	281	259	153	66	24	7	2	0	1001	
13,5												0	#N/A
12,5												0	#N/A
11,5												0	#N/A
10,5												0	#N/A
9,5												0	#N/A
8,5												0	#N/A
7,5												0	#N/A
6,5												0	#N/A
5,5					1	2	1	1				5	8,90
4,5			1	4	7	8	6	3	1			30	8,40
3,5			6	23	38	33	18	8	3	1		130	8,08
2,5		4	36	96	110	69	29	9	2	1		356	7,46
1,5	1	20	94	140	97	40	12	3	1			408	6,73
0,5	3	16	28	18	6	1						72	5,65

Figure A.4: Scatter diagram West Africa



Hs (m) \ T2 (s)	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5	11,5	12,5	13,5		Tz (s) most probable
	3	39	162	277	257	154	71	23	7	3	0	996	
13,5												0	#N/A
12,5												0	#N/A
11,5												0	#N/A
10,5												0	#N/A
9,5												0	#N/A
8,5												0	#N/A
7,5												0	#N/A
6,5					1	1	1	1				4	9,00
5,5				1	2	3	2	1	1			10	8,80
4,5			1	5	9	10	7	3	1	1		37	8,45
3,5			5	20	33	29	17	7	2	1		114	8,09
2,5		3	26	74	89	59	27	9	2	1		290	7,56
1,5	1	16	86	142	109	49	16	2	1			422	6,85
0,5	2	20	44	35	14	3	1					119	5,94

Figure A.5: Scatter diagram South East Latin America

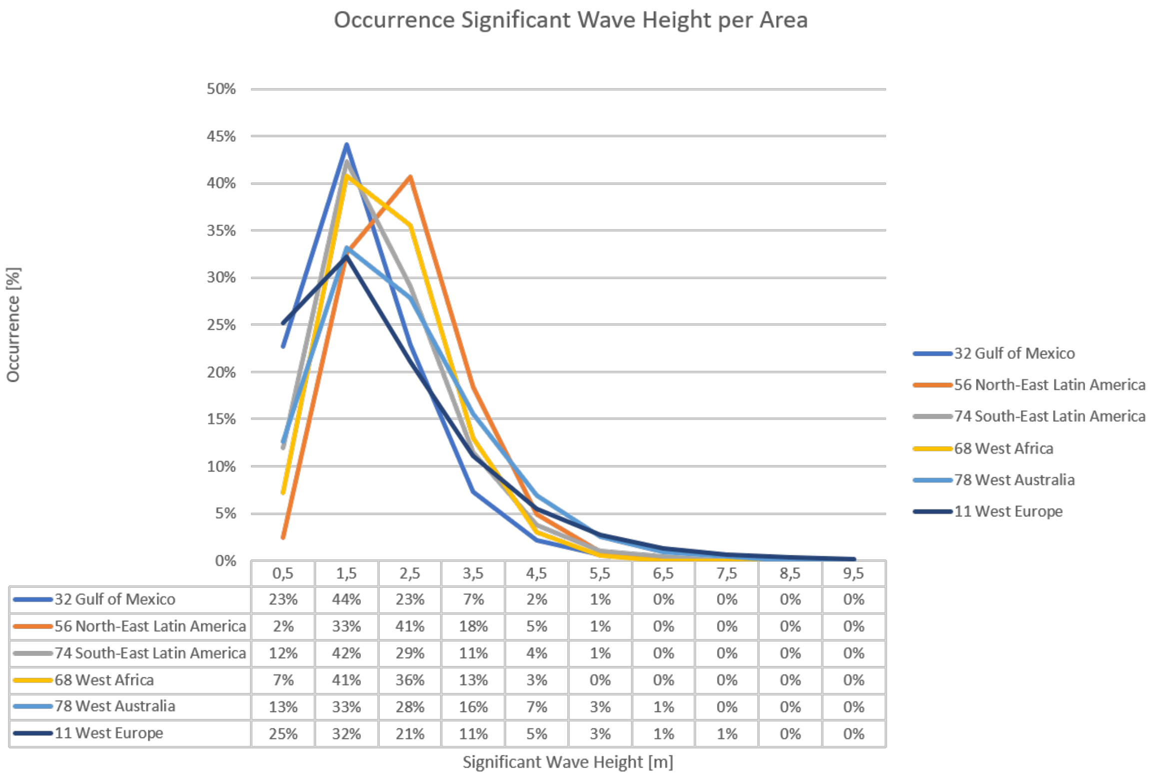


Hs (m) \ T2 (s)	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5	11,5	12,5	13,5		Tz (s) most probable
	1	20	106	239	277	199	101	39	13	4	0	999	
13,5												0	#N/A
12,5												0	#N/A
11,5												0	#N/A
10,5												0	#N/A
9,5												0	#N/A
8,5												0	#N/A
7,5					1	1	1	1				4	9,00
6,5				1	2	2	2	1	1			9	8,83
5,5				2	5	7	6	3	1	1		25	8,90
4,5			1	7	17	19	14	7	3	1		69	8,60
3,5			4	23	44	43	26	11	4	1		156	8,26
2,5		1	16	60	87	67	32	11	3	1		278	7,81
1,5		5	45	104	100	53	19	5	1			332	7,20
0,5	1	14	40	42	21	7	1					126	6,24

Figure A.6: Scatter diagram West Australia

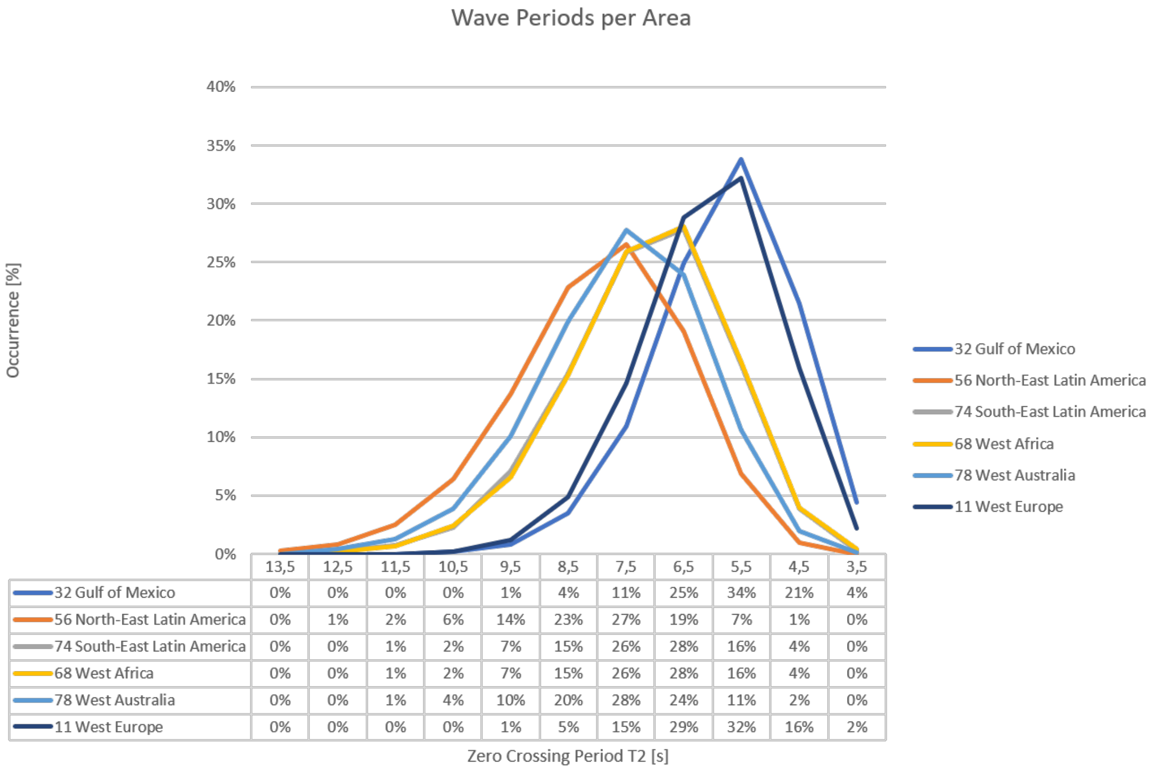
B

Charts Significant Wave Heights and Periods



	0,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5
32 Gulf of Mexico	23%	44%	23%	7%	2%	1%	0%	0%	0%	0%
56 North-East Latin America	2%	33%	41%	18%	5%	1%	0%	0%	0%	0%
74 South-East Latin America	12%	42%	29%	11%	4%	1%	0%	0%	0%	0%
68 West Africa	7%	41%	36%	13%	3%	0%	0%	0%	0%	0%
78 West Australia	13%	33%	28%	16%	7%	3%	1%	0%	0%	0%
11 West Europe	25%	32%	21%	11%	5%	3%	1%	1%	0%	0%

Figure B.1: Significant Wave Heights

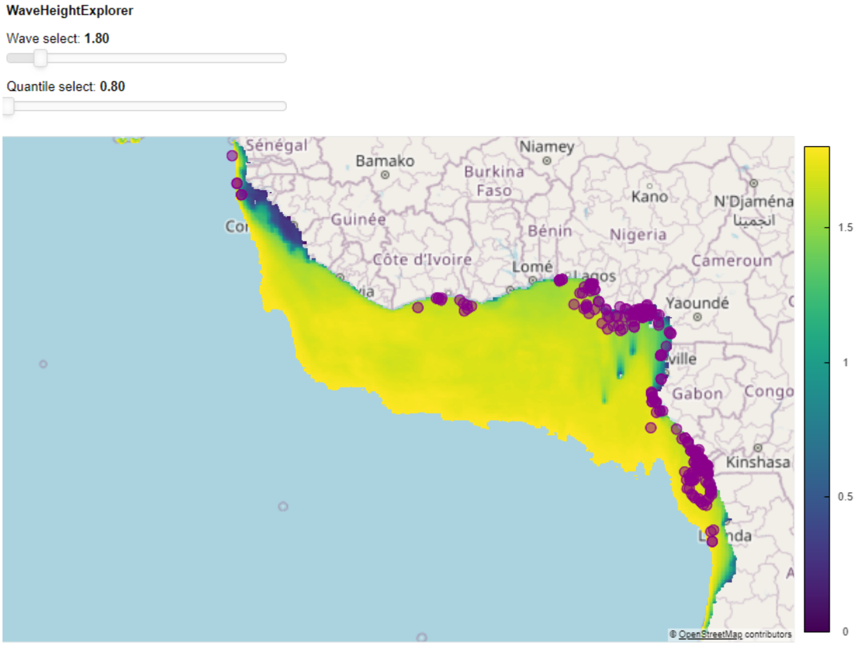


	13,5	12,5	11,5	10,5	9,5	8,5	7,5	6,5	5,5	4,5	3,5
32 Gulf of Mexico	0%	0%	0%	0%	1%	4%	11%	25%	34%	21%	4%
56 North-East Latin America	0%	1%	2%	6%	14%	23%	27%	19%	7%	1%	0%
74 South-East Latin America	0%	0%	1%	2%	7%	15%	26%	28%	16%	4%	0%
68 West Africa	0%	0%	1%	2%	7%	15%	26%	28%	16%	4%	0%
78 West Australia	0%	0%	1%	4%	10%	20%	28%	24%	11%	2%	0%
11 West Europe	0%	0%	0%	0%	1%	5%	15%	29%	32%	16%	2%

Figure B.2: Periods

C

Selection Significant Wave Heights per Area in the Copernicus Tool

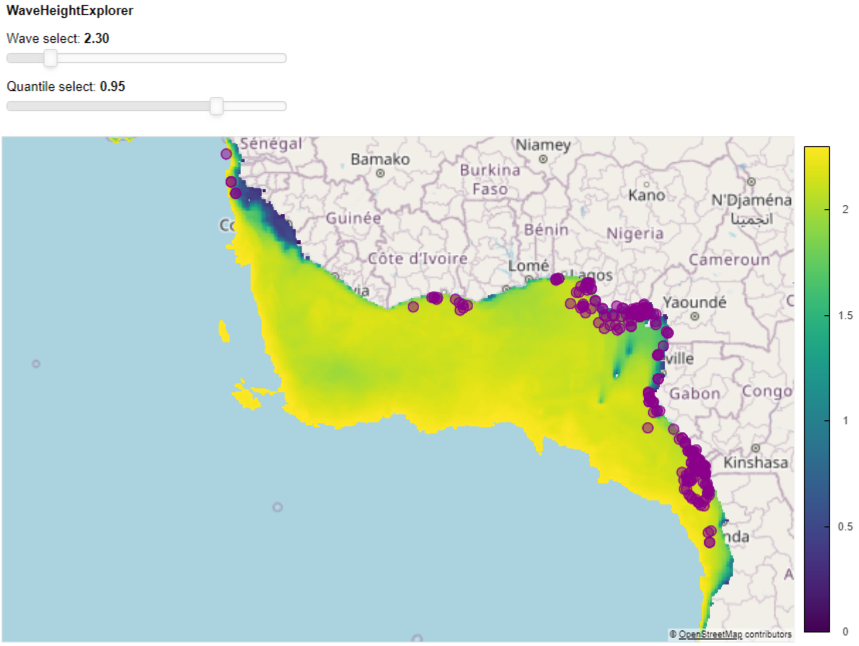


WaveHeightExplorer

Wave select: **1.80**

Quantile select: **0.80**

Figure C.1: Choice Significant Wave Height ability to reach platforms West Africa at quantile select 0.8

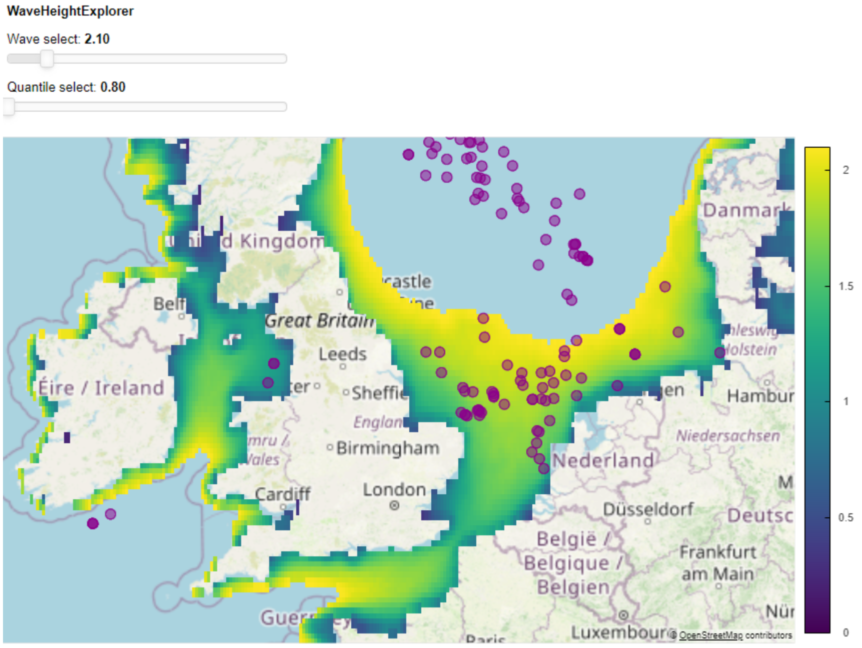


WaveHeightExplorer

Wave select: **2.30**

Quantile select: **0.95**

Figure C.2: Choice Significant Wave Height ability to reach platforms West Africa at quantile select 0.95

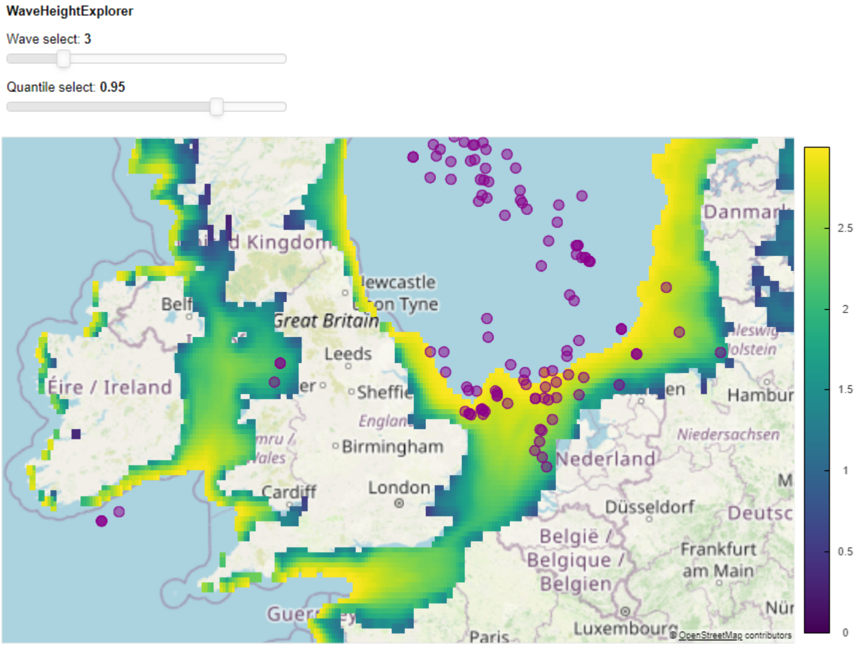


WaveHeightExplorer

Wave select: **2.10**

Quantile select: **0.80**

Figure C.3: Choice Significant Wave Height ability to reach platforms Europe at quantile select 0.8

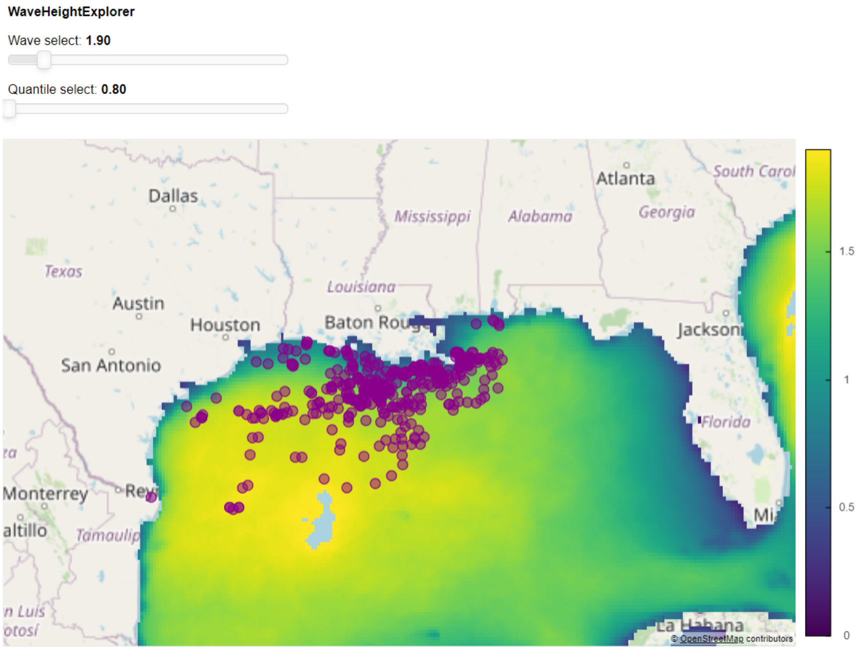


WaveHeightExplorer

Wave select: **3**

Quantile select: **0.95**

Figure C.4: Choice Significant Wave Height ability to reach platforms Europe at quantile select 0.95

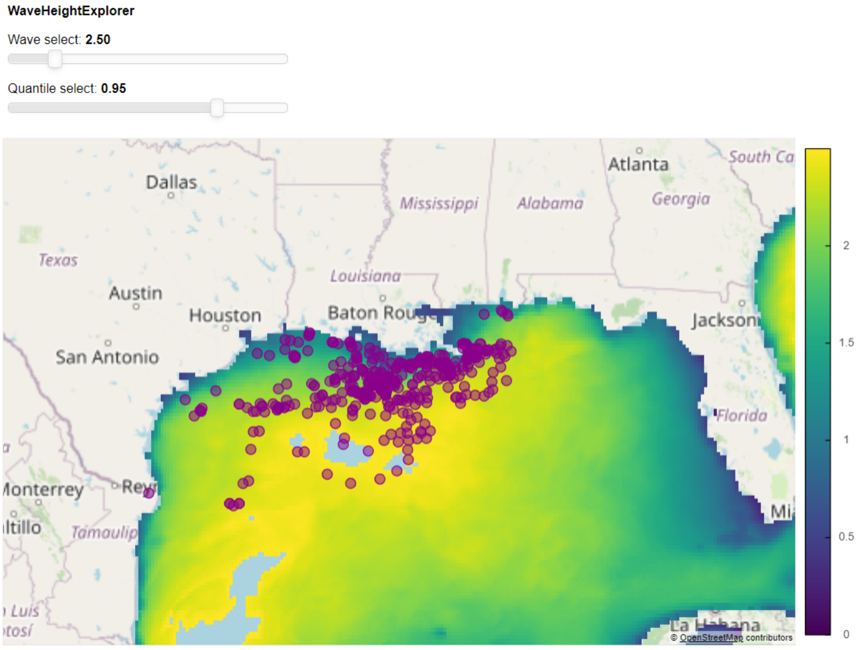


WaveHeightExplorer

Wave select: **1.90**

Quantile select: **0.80**

Figure C.5: Choice Significant Wave Height ability to reach platforms American part Gulf of Mexico at quantile select 0.8

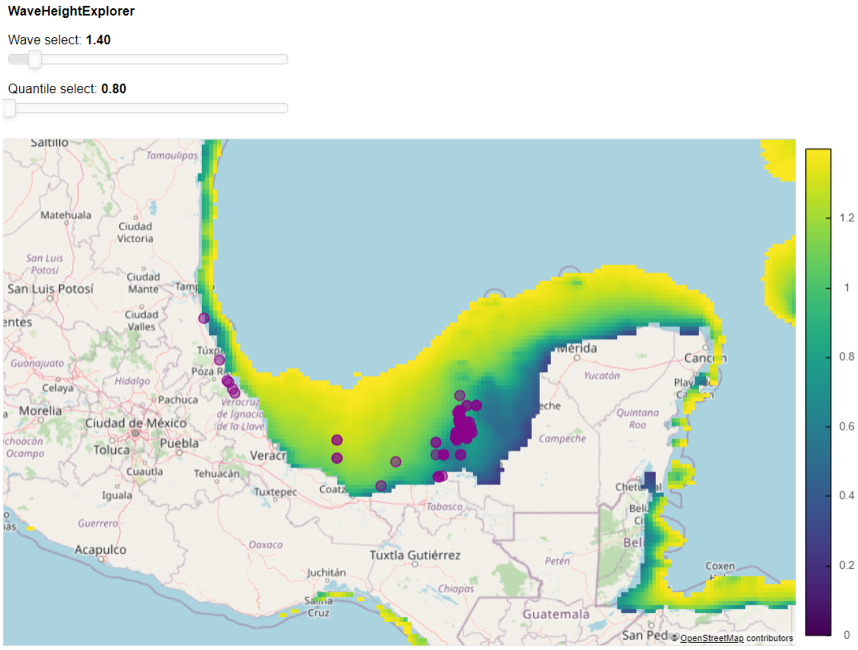


WaveHeightExplorer

Wave select: **2.50**

Quantile select: **0.95**

Figure C.6: Choice Significant Wave Height ability to reach platforms American part Gulf of Mexico at quantile select 0.95

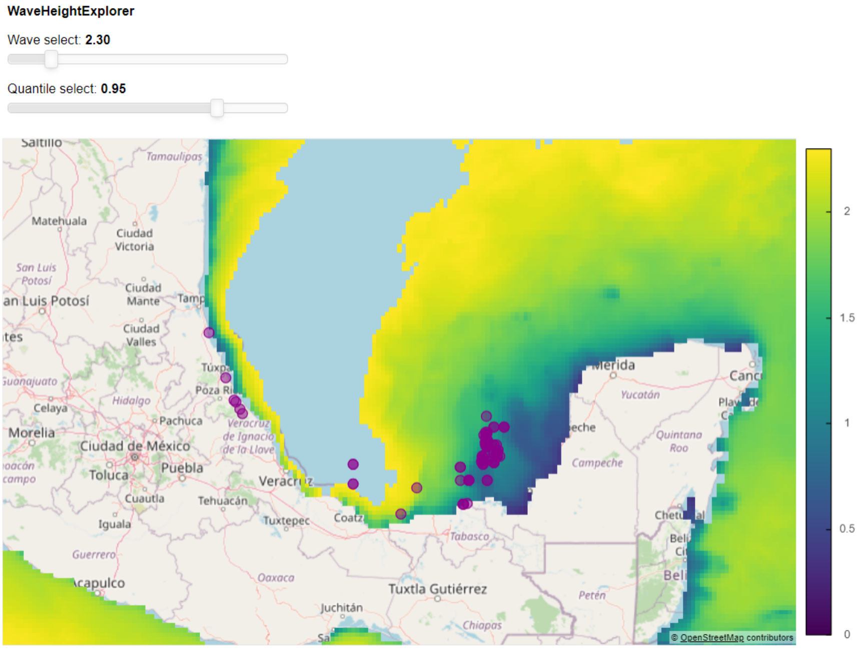


WaveHeightExplorer

Wave select: **1.40**

Quantile select: **0.80**

Figure C.7: Choice Significant Wave Height ability to reach platforms Mexican part Gulf of Mexico at quantile select 0.8

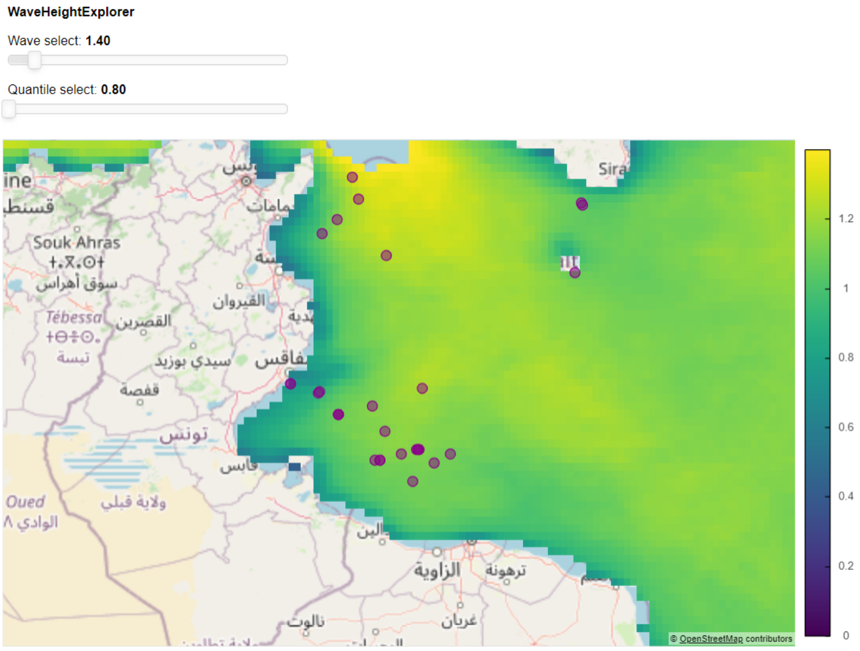


WaveHeightExplorer

Wave select: **2.30**

Quantile select: **0.95**

Figure C.8: Choice Significant Wave Height ability to reach platforms Mexican part Gulf of Mexico at quantile select 0.95

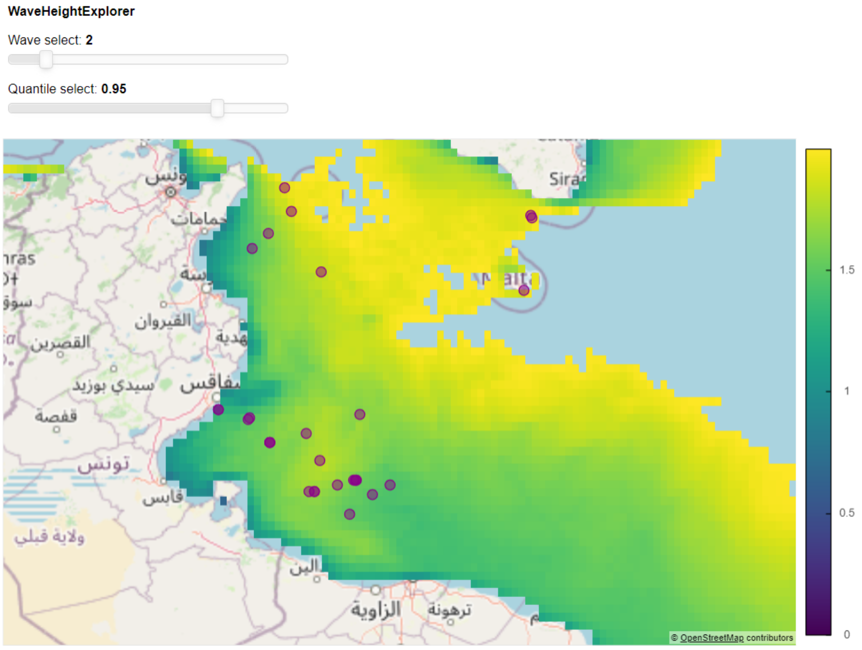


WaveHeightExplorer

Wave select: **1.40**

Quantile select: **0.80**

Figure C.9: Choice Significant Wave Height ability to reach platforms Tunisia at quantile select 0.8

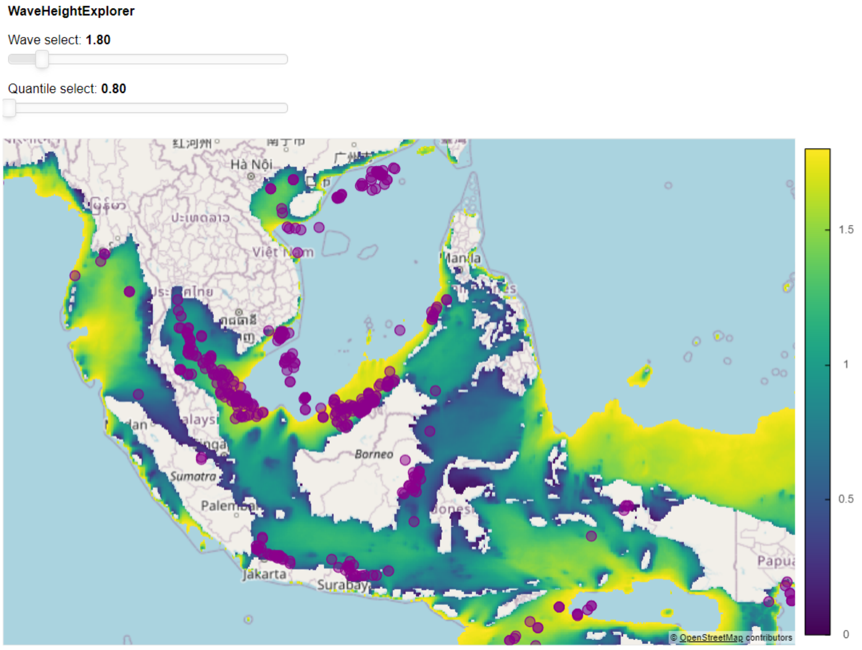


WaveHeightExplorer

Wave select: **2**

Quantile select: **0.95**

Figure C.10: Choice Significant Wave Height ability to reach platforms Tunisia at quantile select 0.95

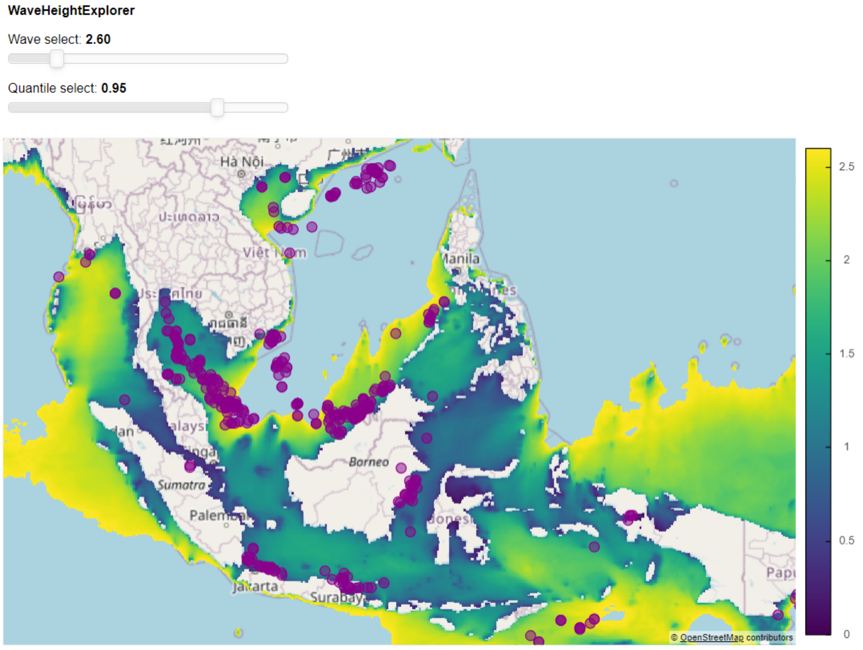


WaveHeightExplorer

Wave select: **1.80**

Quantile select: **0.80**

Figure C.11: Choice Significant Wave Height ability to reach platforms Indonesia at quantile select 0.8

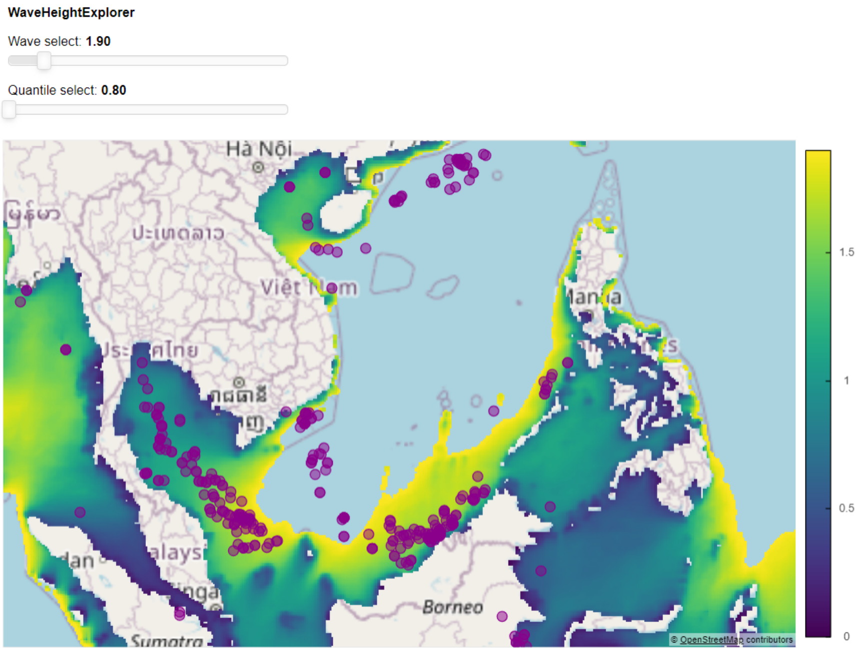


WaveHeightExplorer

Wave select: **2.60**

Quantile select: **0.95**

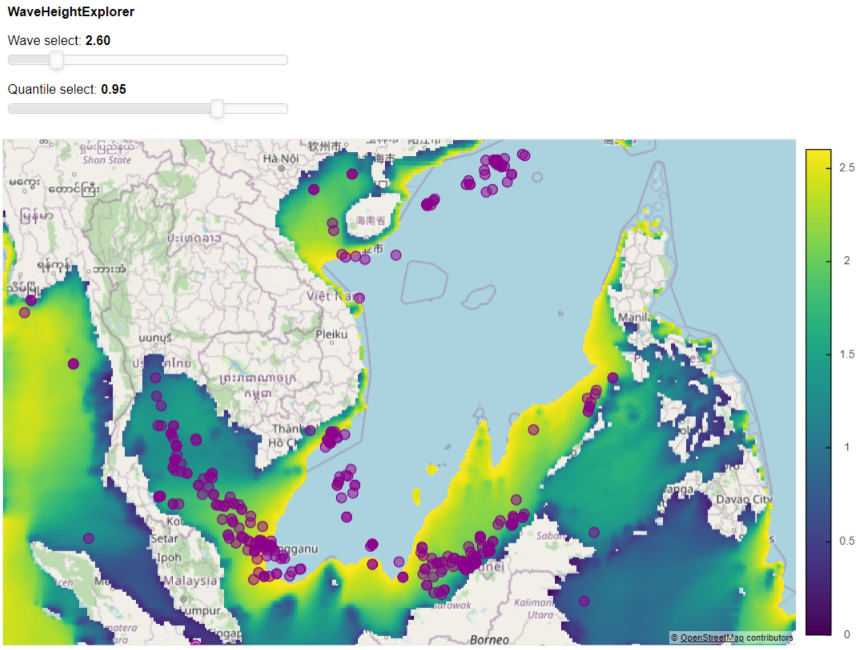
Figure C.12: Choice Significant Wave Height ability to reach platforms Indonesia at quantile select 0.95


WaveHeightExplorer

Wave select: **1.90**

Quantile select: **0.80**

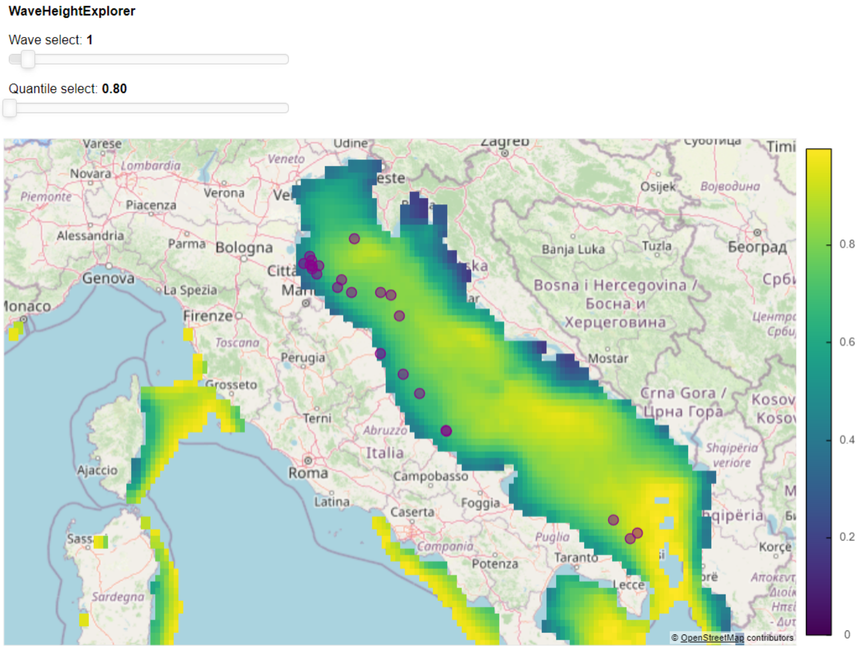
Figure C.13: Choice Significant Wave Height ability to reach platforms Gulf of Thailand at quantile select 0.8


WaveHeightExplorer

Wave select: **2.60**

Quantile select: **0.95**

Figure C.14: Choice Significant Wave Height ability to reach platforms Gulf of Thailand at quantile select 0.95

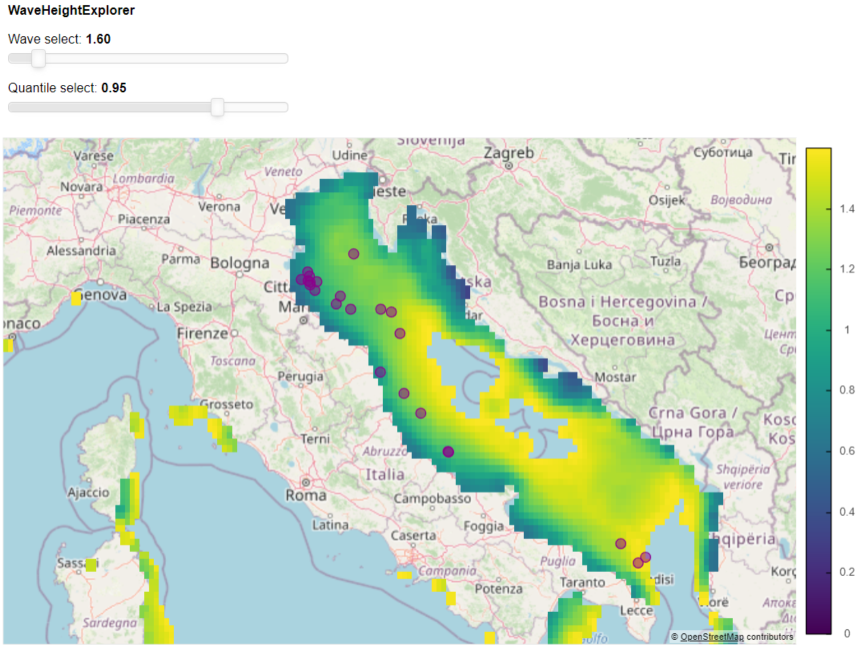


WaveHeightExplorer

Wave select: **1**

Quantile select: **0.80**

Figure C.15: Choice Significant Wave Height ability to reach platforms Italy at quantile select 0.8

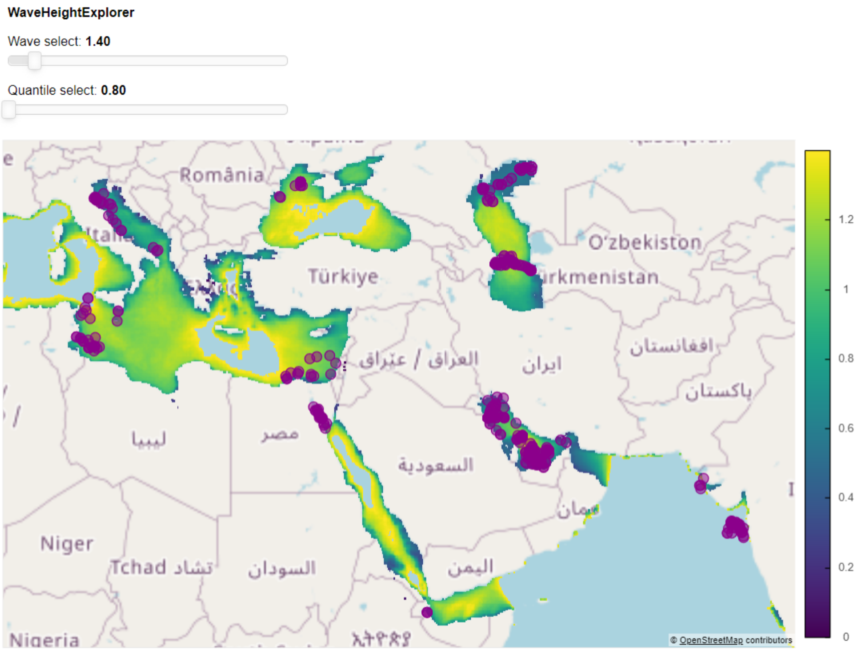


WaveHeightExplorer

Wave select: **1.60**

Quantile select: **0.95**

Figure C.16: Choice Significant Wave Height ability to reach platforms Italy at quantile select 0.95

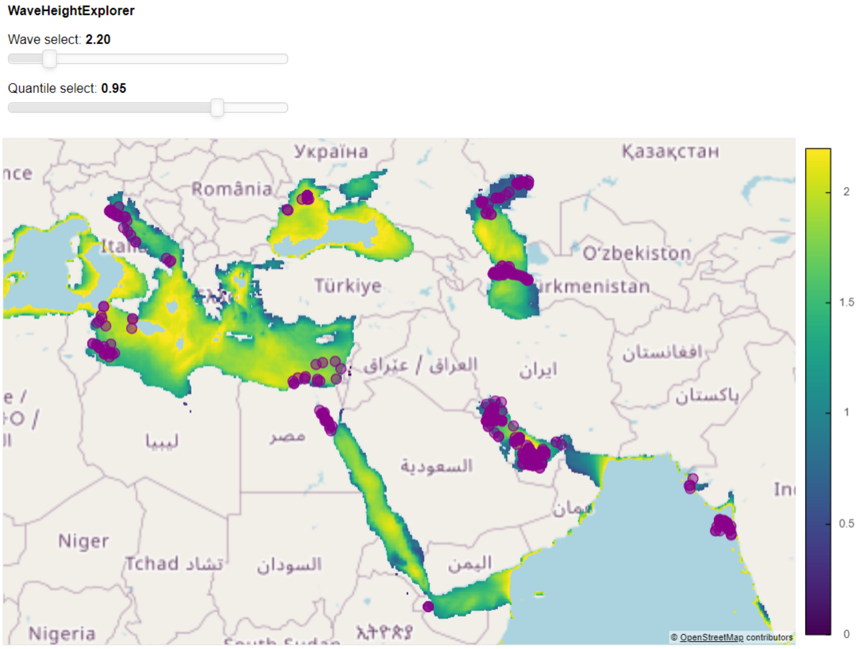


WaveHeightExplorer

Wave select: **1.40**

Quantile select: **0.80**

Figure C.17: Choice Significant Wave Height ability to reach platforms Middle-East at quantile select 0.8

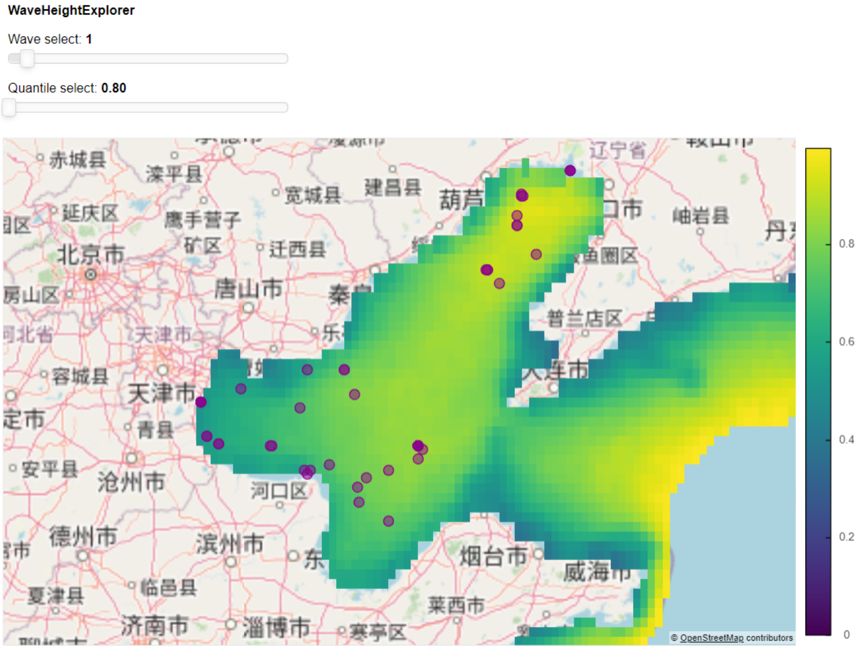


WaveHeightExplorer

Wave select: **2.20**

Quantile select: **0.95**

Figure C.18: Choice Significant Wave Height ability to reach platforms Middle-East at quantile select 0.95

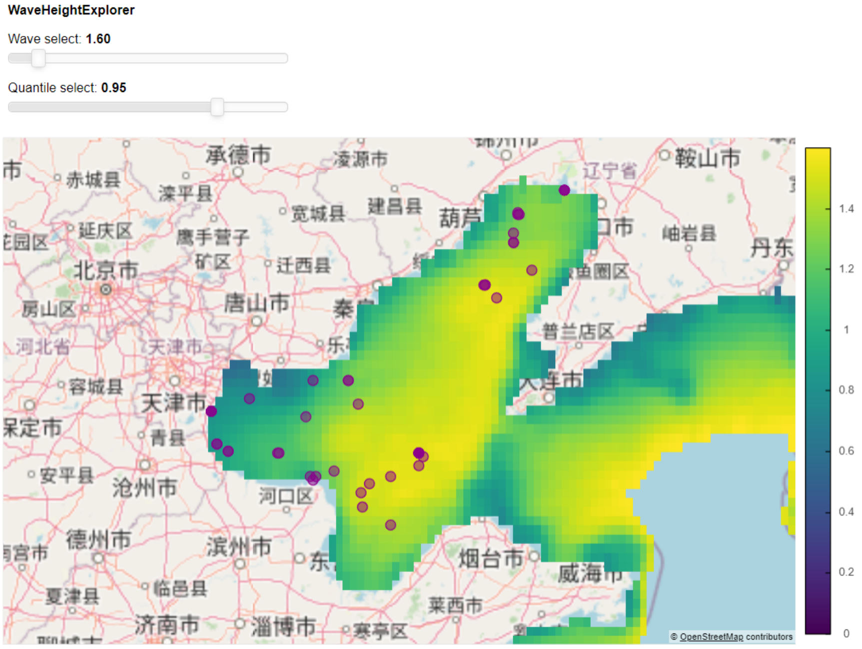


WaveHeightExplorer

Wave select: **1**

Quantile select: **0.80**

Figure C.19: Choice Significant Wave Height ability to reach platforms Bohai Bay at quantile select 0.8

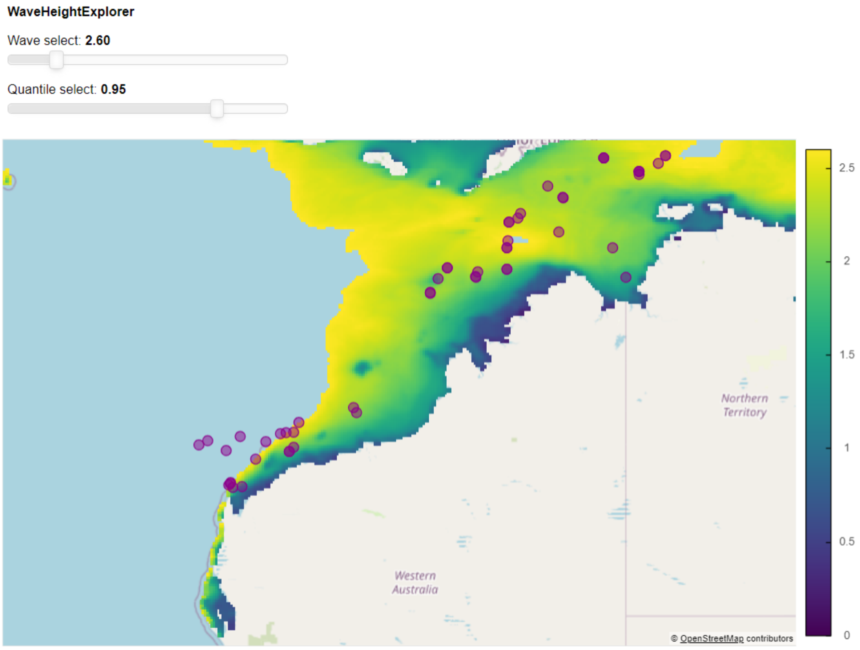


WaveHeightExplorer

Wave select: **1.60**

Quantile select: **0.95**

Figure C.20: Choice Significant Wave Height ability to reach platforms Bohai Bay at quantile select 0.95

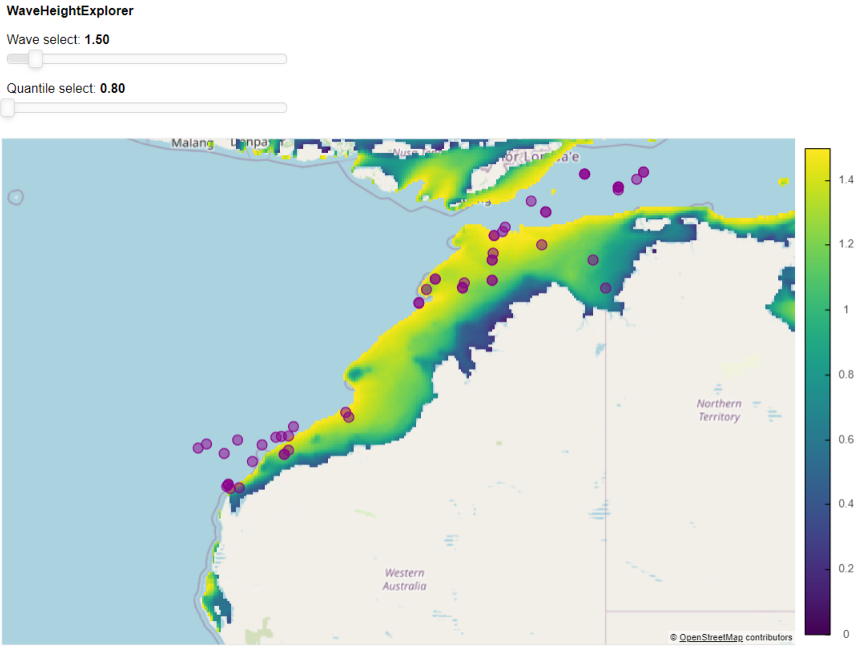


WaveHeightExplorer

Wave select: **2.60**

Quantile select: **0.95**

Figure C.21: Choice Significant Wave Height ability to reach platforms Australia at quantile select 0.8



WaveHeightExplorer

Wave select: **1.50**

Quantile select: **0.80**

Figure C.22: Choice Significant Wave Height ability to reach platforms Australia at quantile select 0.95

D

Market Information Potential Operational Areas

- *Gulf of Mexico, Mexico (446)*
  This area has a lot of FPSO's which are located far from land. The Mexican part of the Gulf of Mexico has high requirements for speed and comfort. It is known that the FCS 7011 is too expensive for this area, but the FCS 5009 is to slow.
- *Middle East (298)*
  In the Middle-East already a lot of crewboats arrang the transport of crew to offshore platforms. Due to the surplus of vessels it is a cost driven market. Comfort is subordinated to the cost.
- *Indonesia (77)*
  Indonesia is a hard market for Damen to sell their vessels. This is because of the enormous supply of their own traditional crew boats and their extremely cost driven market. The crew supply is executed by small vessels, since the offshore platforms are small and are located close to land.
- *Tunisia (32)*
  Tunesia is a traditional market. Damen has less information about this market.
- *Bohai bay (49)*
  the Bohai Bay is not an area Damen sells its vessels to, since everything is arranged and controlled by themselves. This chinese competition is hard to compete with and there is a limited market knowledge.
- *Italy (23)*
  This area sails with traditional crewboats and the platforms are located closely to land. Moreover the investments are relatively low.
- *West Africa (265)*
  In West Africa at the moment a lot of helicopters supply the crew transport to offshore platforms. This could lead to a high saving potential when transporting crew with vessels.Interesting areas are Nigeria Ghana and Angola since new offshore platforms will be developed. In this area a Damen Service hub is needed, since the ships are hard to maintain by the locals. Therefore, it is important that the vessels are easy to maintain, which is more important than the comfort.
- *Gulf of Mexico, America (128)*
  The American part of the Gulf of Mexico is a helicopter market at the moment. With the supply of crewboats, cost could be saved. However, in this area the platform heights are over the 30 meters due to the prevention of hurricanes. This makes it hard for the crewboats to transport

crew by motion compensated gangways, which results in the transportation by frogs. Moreover, America requires to build the ships in America itself, which results in approximately two times higher building cost. In this area also IMO tier and IPA 4 is required.

- *Australia (33)*
  This market is conservative and unions are dominant. This results in high comfort requirements. They currently execute the crew transport by helicopters. The distances from the ports are long which results in complex logistics.
- G*ulf of Thailand (348)*
  This area has the same characteristics as Indonesia, which makes it a hard market for Damen to sell its vessels to.

E

Explanation Functional Requirements

- *Hull design*
  This contains the design of the hull, for instance a mono-hull, twin-hull, or a hydrofoil. The influence of the use of an axebow (as explained in section 3.3) or not is also taken into account. The decision of hull design result in different response to waves and different resistance.
- *Hull material*
  The material of the hull could be for instance aluminium, steel and fibre reinforced polymers. Their weight for instance influences design choices.
- *Dimensions*
  This contains dimensions of the hull and structure. The length, beam, draft and dept for instance influence the quantity of material and for instance their seakeeping.
- *Number of crew and personnel*
  The number of personnel the vessel can transport and the needed crew are taken into account in this functional requirement. It can influence the ship decisions in a positive and negative way simultaneously. The more personnel will be transported to more crew will be needed, which increases crew space. However, more personnel decreases the cost per person per trip and could realise a more complete logistical solution.
- *Division of deck and floor area*
  The dimensions result in the total deck and floor area. How much of this needs to be used for the floor area and / or deck area influences the division of the total area. The floor area includes the inner space for personnel to sit, relax, use the restaurant or meeting rooms. The deck area consist of the outer space which can be used for cargo and the transfer system.
- *Passive comfort enhancing features*
  These are features which enhance comfort passively. Features that influence the design that are taken into account are for instance, the window area, HVAC (heating, ventilating and air conditioning), location of personnel on deck and non active systems. They are important for the well being of personnel.
- *Propulsion*
  Propulsion is needed for speed, but is also needed for dynamic positioning of the ship. This functional requirement contains the type of propulsion, engine type, needed power and fuel consumption.
- *Seat execution and pitch*
  Various executions of chairs are possible to implement in the ship. This could be basic and small, but also luxury and with bigger dimensions. The pitch relates to the space around each seating and improves for instance the comfort.
- *Effective time utilization*

This is the time which could be used effective during the transportation. This could be ensured for instance by the possibilities to sleep, work or execute entertaining activities.

- *Sea-keeping improvement equipment*
  To improve the sea-keeping of a ship, equipment could be used. Examples are gyroscopes, interceptors and stabilising fins as explained in section 3.3. They for instance have influence on the weight of the ship which has a relation with various customer requirements.
- *Transfer solutions*
  Various types of transfer solutions could be used to transfer personnel from the vessel to the platform. This requirements comprises the influence of the decision of these various types.
- *DP performance*
  During the transfer at zero speed it is important that the vessel moves as least as possible. Dynamic positioning performances could minimise the movements in x-y plane and could ensure the vessel stays on position. This could improve the safety, comfort and speed of the vessel and its operations.
- *Regulations*
  It contains the governmental regulations which could lead to specific design requirements and influences the design choices. Specific regulations of various companies itself are neglected.
- *Sustainability*
  This is influenced by sustainable solutions like like battery, the use of other fuels or the implementation of solar panels on the roof of the deck-house. This requirements also includes the way the ship is sustainable for instance as a result the amount of emissions.

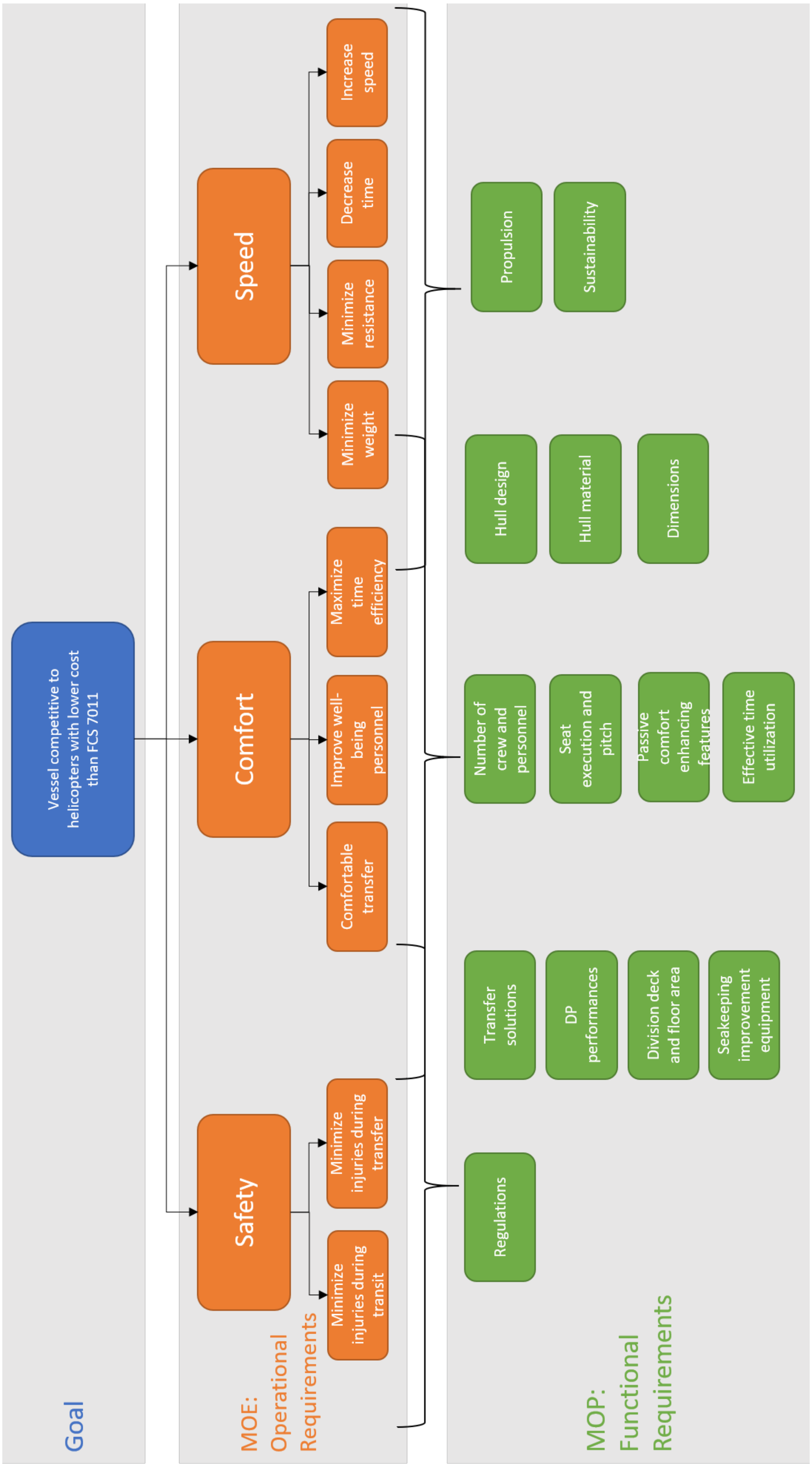


Figure E.1: Enlarged tree structure of operational and functional requirements

F

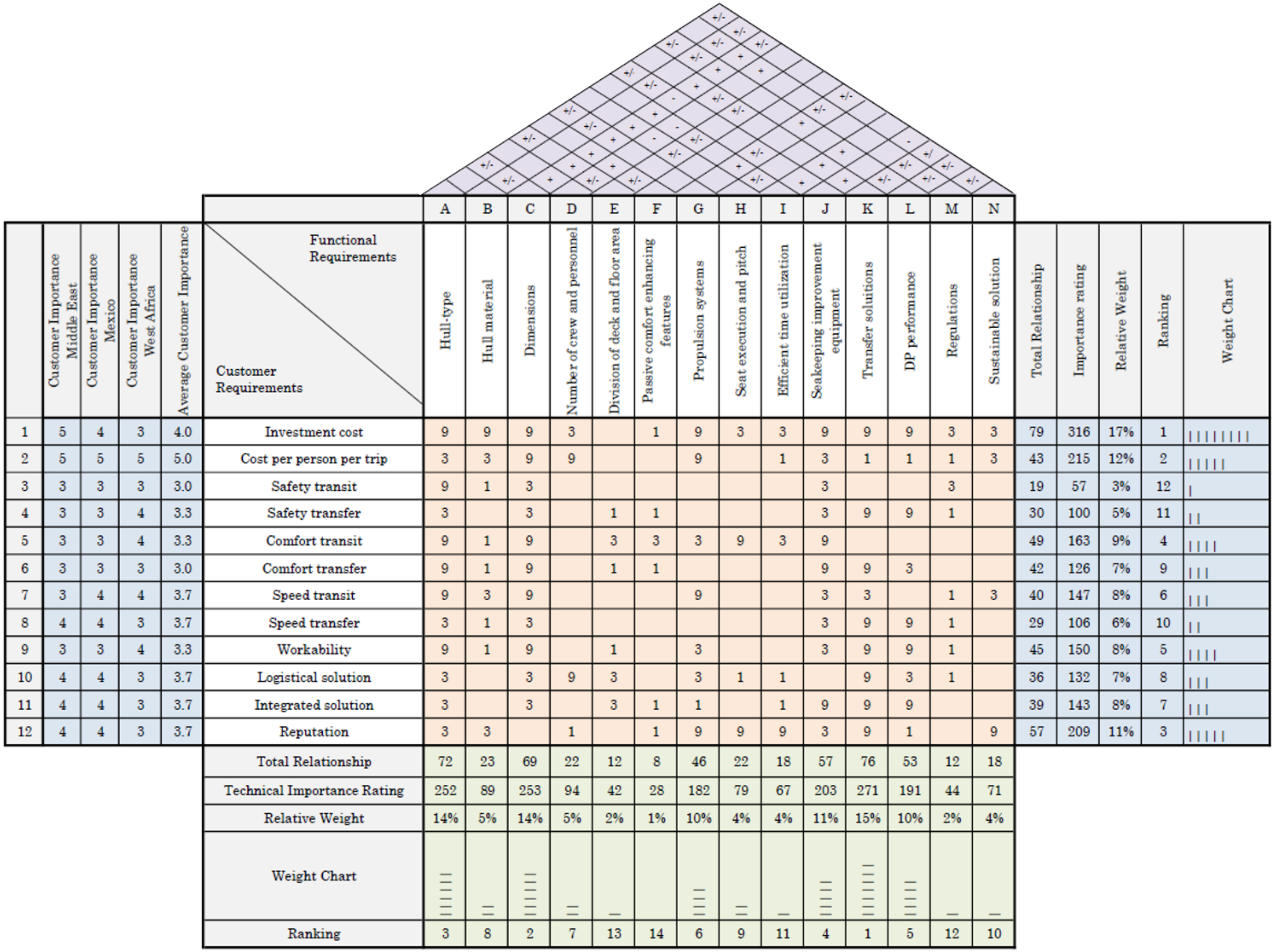
Extensive Design Subjects

Extensive List of Design Subjects

Hull Design
Length (L)
Beam (B)
Draft (D)
Draught (T)
Fuel oil
Fresh water
Waste water
Lube oil
Sludge / Dirty oil tank
Hyd oil
Dipsersant
Foam
Crew
Industrial Personnel
Personnel cabins
Deck load
Deck strength
Deck area
Number of containers
Max DWT
Design draught
Operational areas
Operating profile
Life time
Class
Flag
Regulations
Water, air and inside temperature
Max Hs
Max wind speed
Vertical accelerations
Noise levels
Stability
Min GM
Max GM
Weight
Construction
Fatigue life
Lines plan
Spray rail
Fixed fins
Wheelhouse
Deck Camber
Wheelhouse
Deck hatches
ER hatches
Windows
(Cargo) Railing
Fendering
Bollards
Lashin points
Container fitting
Mast
Deck covering
ICAF
PSD
Engine mounting
Gearbox
Propulsion
Shafting arrangmenent
Rudders
Bow thrusters
Piping
Skids
Bilge system
Fuel tank
Cooling water main engines
Fresh water
Black/grey water
Sewage treatment
Lubrication oil
ER ventilation
Air conditioning
Heating
Exhaust
Electircal system
Reefer sockets
Anchor
Deck crane
MOB
Rescue boat
Cargo pumps
Fire Fighting
Accommodation
Noise levels
Fire insulation
Wheelhouse
Hospital
Laundry
Passengers accommodation
Minimal pitch and width seats
Navigation
Search light
CCTV
Entertainment
Comfort

G

Reasoning House of Quality Assessment



	Customer Importance Middle East	Customer Importance Mexico	Customer Importance West Africa	Average Customer Importance	Functional Requirements / Customer Requirements	A Hull-type	B Hull material	C Dimensions	D Number of crew and personnel	E Division of deck and floor area	F Passive comfort enhancing features	G Propulsion systems	H Seat execution and pitch	I Efficient time utilization	J Seakeeping improvement equipment	K Transfer solutions	L DP performance	M Regulations	N Sustainable solution	Total Relationship	Importance rating	Relative Weight	Ranking	Weight Chart
1	5	4	3	4.0	Investment cost	9	9	9	3		1	9	3	3	9	9	9	3	3	79	316	17%	1	||||||||
2	5	5	5	5.0	Cost per person per trip	3	3	9	9			9		1	3	1	1	1	3	43	215	12%	2	|||||
3	3	3	3	3.0	Safety transit	9	1	3							3			3		19	57	3%	12	|
4	3	3	4	3.3	Safety transfer	3		3		1	1				3	9	9	1		30	100	5%	11	||
5	3	3	4	3.3	Comfort transit	9	1	9		3	3	3	9	3	9					49	163	9%	4	||||
6	3	3	3	3.0	Comfort transfer	9	1	9		1	1				9	9	3			42	126	7%	9	|||
7	3	4	4	3.7	Speed transit	9	3	9				9			3	3		1	3	40	147	8%	6	|||
8	4	4	3	3.7	Speed transfer	3	1	3							3	9	9	1		29	106	6%	10	||
9	3	3	4	3.3	Workability	9	1	9		1		3			3	9	9	1		45	150	8%	5	||||
10	4	4	3	3.7	Logistical solution	3		3	9	3		3	1	1		9	3	1		36	132	7%	8	|||
11	4	4	3	3.7	Integrated solution	3		3		3	1	1		1	9	9	9			39	143	8%	7	|||
12	4	4	3	3.7	Reputation	3	3		1		1	9	9	9	3	9	1		9	57	209	11%	3	|||||
					Total Relationship	72	23	69	22	12	8	46	22	18	57	76	53	12	18					
					Technical Importance Rating	252	89	253	94	42	28	182	79	67	203	271	191	44	71					
					Relative Weight	14%	5%	14%	5%	2%	1%	10%	4%	4%	11%	15%	10%	2%	4%					
					Weight Chart	||||||	||	||||||	||	|		||||	||	|	|||||	|||||||	|||||	|	|					
					Ranking	3	8	2	7	13	14	6	9	11	4	1	5	12	10					

Figure G.1: Enlarged tree structure of operational and functional requirements

Customer Requirements - Functional Requirements

Customer Requirement	Functional Requirement	Rate	Opmerking
Investment cost	Hull Type	9	Big part of the cost
	Hull Material	9	Big part of the cost
	Dimensions	9	The bigger, the more material needed, the higher cost
	Number of Crew and Personnel	3	More seats and sleeping places etc.
	Division deck and floor area		Has to do with the choice how many for crew and for cargo. Dimensions are dependent of cost, not division. At most extra woot for deck coating.
	Passive comfort enhancing features	1	More expensive to built more windows. Big windows more expensive than small windows. Degree of investment makes rating 1.
	Propulsion	9	Big part of the cost
	Seat execution and pitch	3	Difference in price seats. Degree of investment makes rating 3.
	Effective time utilization	3	Investment degree makes rating 3
	Seakeeping improvement equipment	9	Equipment to improve could be expensive which makes it 9.
	Transfer Solutions	9	Big part of the cost
	DP Performance	9	Cost DP system: computer, software. Dependent of bow thruster, waterjets, engines.
	Regulations	3	Cost to comply, volume not taken into account
	Sustainable solution	3	Cost to implement
Operational cost per person per trip	Hull Type	3	Could result in less or more fuel consumption
	Hull Material	3	Could result in less or more fuel consumption
	Dimensions	9	Could result in less or more fuel consumption. Maintenance cost.
	Number of Crew and Personnel	9	The more personnel, the lower the cost per person. More personnel could also lead to more crew.
	Division deck and floor area		Number of personnel dependent on this, but cost not directly dependent on this
	Passive comfort enhancing features		No result in cost per person per trip
	Propulsion	9	Type, quantity and speed results in consumption cost.
	Seat execution and pitch		More or less processed in rate number of personnel
	Effective time utilization	1	Entertainment during trip could lead to less salary for the personnel during the trip. Small influence.
	Seakeeping improvement equipment	3	More or less fuel/slamming/constant speed/accelerations. Equipment needed is heavy.
	Transfer Solutions	1	Faster transfer results in less cost. Small influence.
	DP Performance	1	Influences transfer speed. Small influence

	Regulations	1	For instance, how much crew, maintenance, safety instructions, security vessel.
	Sustainable solution	3	For instance batteries heavier which results in more cost for fuel
Safety Transit	Hull Type	9	Vertical accelerations
	Hull Material	1	Weight influences ship motions. Fatigue materials not taken into account because happens slowly, whereby not an influence on safety transit.
	Dimensions	3	Wider ship improves stability (higher GM. Longer ship decreases vertical accelerations. So dimensions influence safety transit.
	Number of Crew and Personnel		
	Division deck and floor area		
	Passive comfort enhancing features		Seasickness not assessed as relevant for safety during transit
	Propulsion		Faster, slower, accelerations processed in hull design. Danger collision not taken into account, because on sea.
	Seat execution and pitch		
	Effective time utilization		
	Seakeeping improvement equipment	3	Equipment has influence in ship motions as a result of waves. During transit interceptor influence aft.
	Transfer Solutions		
	DP Performance		Not relevant when having speed
	Regulations	3	Which equipment needed as a result of regulations. For instance rescue boat.
	Sustainable solution		
Safety Transfer	Hull Design	3	Ship behaviour. Not very much impact on safety, more on comfort.
	Hull Material		Aluminium light so more motions, but negligible.
	Dimensions	3	Influence on stability
	Number of Crew and Personnel		Negligible relation
	Division deck and floor area	1	Small relation. For example big deck results in longer walks which is less safe. To small is unsafe for basket.
	Passive comfort enhancing features	1	Influence on seasickness. Which has influence on choics which could lead to unsafe situations during transfer.
	Propulsion		
	Seat execution and pitch		
	Effective time utilization		
	Seakeeping improvement equipment	3	Equipment can improve on safety. For instance less motions which prevents people of falling overboard.
	Transfer Solutions	9	

	DP Performance	9	Minimal motions important for transfer. Risk bask high if a lot of motions. Ampelmann should disconnect.
	Regulations	1	Stability criteria during transfer exist
	Sustainable solution		
Comfort Transit	Hull Type	9	How does hull-type behave as a result of waves
	Hull Material	1	Aluminium light, can result in more motions. Small influence
	Dimensions	9	Location seatings personnel. Dimensions influences GM which influences comfort. Enlarged Ship Concept ensures lower vertical accelerations.
	Number of Crew and Personnel		Result less area less luxury seats not taken into account. Results in less seats.
	Division deck and floor area	3	Space to move, for luggage dependent of division. Deck area not important for comfort.
	Passive comfort enhancing features	3	For instance possibilities to look outside
	Propulsion	3	Speed results in less duration which improves comfort
	Seat execution and pitch	9	Comfort seats and space around
	Effective time utilization	3	Results in efficient time to work and entertainment
	Seakeeping improvement equipment	9	Can decrease motions ship a lot and thus improves comfort
	Transfer Solutions		No influence on transit
	DP Performance		No influence on transit
	Regulations		Dependent of client not of government. Maybe requirements minimal needed seats, is ignored.
	Sustainable solution		
Comfort Transfer	Hull Type	9	How does hull-type behave as a result of waves
	Hull Material	1	Aluminium light, can result in more motions. Small influence
	Dimensions	9	Dimensions influence natural frequency of hull. Influences comfort a lot
	Number of Crew and Personnel		
	Division deck and floor area	1	For instance more space to move
	Passive comfort enhancing features	1	For instance: seeing the window during waiting for transfer
	Propulsion		
	Seat execution and pitch		
	Effective time utilization		Not taken into account: personnel waiting during transfer for further transportation.
	Seakeeping improvement equipment	9	Gyroscope
	Transfer Solutions	9	
	DP Performance	3	
	Regulations		

	Sustainable solution		
Speed Transit	Hull Type	9	Hull with certain speed comfortable or not through waves.
	Hull Material	3	For instance aluminium light, so faster
	Dimensions	9	Hulls influence resistance and therefore speed.
	Number of Crew and Personnel		dependent because more platforms if more personnel, but nothing to do with design of ship
	Division deck and floor area		
	Passive comfort enhancing features		
	Propulsion	9	
	Seat execution and pitch		
	Effective time utilization		
	Seakeeping improvement equipment	3	For instance gyro negative for speed because of weight. Negative or positive influence
	Transfer Solutions	3	Gewicht beinvloed snelheid
	DP Performance		
	Regulations	1	Regulation exist of relation speed and construction strength.
	Sustainable solution	3	Weight or power cost speed
Speed Transfer	Hull Type	3	Takes longer if ship reacts a lot on waves
	Hull Material	1	Less or more motions a a result of material
	Dimensions	3	Locating relative to platform
	Number of Crew and Personnel		Negligible, because overall the same amount of transfer persons.
	Division deck and floor area		
	Passive comfort enhancing features		
	Propulsion		
	Seat execution and pitch		
	Effective time utilization		
	Seakeeping improvement equipment	3	Equipment can decrease motions and therefore speed transfer
	Transfer Solutions	9	
	DP Performance	9	Level of DP influences time.
	Regulations	1	As a result of regulations ampelmann has to disconnect for example which cost time
	Sustainable solution		
Workability	Hull Type	9	Possibility to sail in various wheater circumstances
	Hull Material	1	Reaction on waves
	Dimensions	9	Reaction on waves
	Number of Crew and Personnel		

	Division deck and floor area	1	Deck area bigger is easier for basket and workability
	Passive comfort enhancing features		Dependent seasickness but negigible for workability
	Propulsion	3	High enough power for various waves, ability to sial
	Seat execution and pitch		
	Effective time utilization		
	Seakeeping improvement equipment	3	Could improve behaviour in certain wheater circumstances which can improve workability
	Transfer Solutions	9	Needs to transfer in wheater circumstances
	DP Performance	9	Worse DP performance result in low workability
	Regulations	1	Not satisfying regulation results in no ability to sail
	Sustainable solution		
Logistical Solution	Hull Type	3	How fast able to be somewhere
	Hull Material		
	Dimensions	3	Bigger is more logistical solutions. For instance cargo, shower.
	Number of Crew and Personnel	9	More personnel could result in more platforms to reach. The other way around more logistics needed on board
	Division deck and floor area	3	Luggage, personnel, cargo needed for solution
	Passive comfort enhancing features		
	Propulsion	3	Speed important, needs to be fast enough to reach various platforms
	Seat execution and pitch	1	Personnel stays longer on board, comfort of higher interest.
	Effective time utilization	1	Longer on board so of interest to use time efficiently
	Seakeeping improvement equipment		
	Transfer Solutions	9	Type of transfer solution important, because every platform is different. Crane, landing height.
	DP Performance	3	
	Regulations	1	For instance data needed of people on board
	Sustainable solution		
Integrated Solution	Hull Type	3	Has to perform well at speed and zero speed
	Hull Material		
	Dimensions	3	Transfer system has to fit.
	Number of Crew and Personnel		
	Division deck and floor area	3	Transfer system has to fit.
	Passive comfort enhancing features	1	
	Propulsion	1	

	Seat execution and pitch		
	Effective time utilization	1	Increases integrated solution since it could be able to work during transportation.
	Seakeeping improvement equipment	9	Equipment should be integrated. Should work at speed and zero speed.
	Transfer Solutions	9	
	DP Performance	9	
	Regulations		
	Sustainable solution		
Reputation Damen	Hull Type	9	Influence on image. Sea axe or not.
	Hull Material	3	Light is less emmissions, more sustainable, reputation.
	Dimensions		
	Number of Crew and Personnel	1	
	Division deck and floor area	1	
	Passive comfort enhancing features	9	Care personnel
	Propulsion	9	Kan je eel erg tegen zitten en heel erg uitbuiten
	Seat execution and pitch	3	Care personnel
	Effective time utilization	3	Care personnel
	Seakeeping improvement equipment	9	
	Transfer Solutions	9	
	DP Performance	9	
	Regulations	3	Classes
	Sustainable solution	9	
Reputation Customer	Hull Type	3	Influence on image
	Hull Material	3	Light is less emmissions, more sustainable, reputation.
	Dimensions		
	Number of Crew and Personnel	1	More platforms and crew supply in one ride.
	Division deck and floor area		
	Passive comfort enhancing features	1	Care personnel. Not much in the eye
	Propulsion	9	Kan je eel erg tegen zitten en heel erg uitbuiten
	Seat execution and pitch	9	Care personnel.
	Effective time utilization	9	Care personnel
	Seakeeping improvement equipment	3	Gyroscope for instance
	Transfer Solutions	9	Difference comfort an safety personnel
	DP Performance	1	Care personnel. Not much in the eye

Regulations		No much difference
Sustainable solution	9	

Functional Requirements - Functional Requirements

Hull Type	Hull Material		
	Dimensions	+/-	Mono longer for stability and speed relative to dimensions. Dimensions cat different.
	Number of Crew and Personnel		
	Division deck and floor area	+/-	Catamaran and of mono-hull have various possibilites for deck area.
	Passive comfort enhancing features		
	Propulsion	+/-	Dependent of design: more or less propulsion for certain speed. Does it fit: catamaran hard.
	Seat execution and pitch		
	Effective time utilization		
	Seakeeping improvement equipment	+/-	Hull type results in different behaviour en thus other systems (levels) needed.
	Transfer Solutions		
	DP Performance	+/-	More or less power needed per hull-type. For instance axe bow needs a lot of power in the front.
	Regulations		
	Sustainable solution	+/-	Less resistance is more sustainable
Hull Material	Dimensions	+/-	Deck strength per material various per size. For instance FRP strong at big dimensions.
	Number of Crew and Personnel		
	Division deck and floor area		
	Passive comfort enhancing features		
	Propulsion	+/-	Light is less propulsion needed
	Seat execution and pitch		
	Effective time utilization		
	Seakeeping improvement equipment	+/-	Light is more motions, is easier to demp. Degree of side effects.
	Transfer Solutions		Decision transfer solution not dependent on material. Deck strength however should be strong enough.
	DP Performance	+/-	Light is more motions but also easier to counter. Influences forces needed for DP.
	Regulations	+/-	For instance for FRP other regulations about fire and strength.
	Sustainable solution	+/-	Sustainable material. Steel and aluminium relatively easy to process after lifesplan.
Dimensions	Number of Crew and Personnel	+	More space more personnel
	Division deck and floor area	+	If certain space needed for personnel, it influences residual space for deck
	Passive comfort enhancing features	+	Space
	Propulsion	+	Bigger is heavier so more propulsion needed
	Seat execution and pitch	+	If the same amount of personnel, more pitch
	Effective time utilization	+	More space for effective time utilization. For instance douche, changing room, meeting room.

	Seakeeping improvement equipment	-	How much needed dependent of dimensions. Natural frequency. Large: less equipment needed, but stronger.
	Transfer Solutions	+	Space for ampelmann of frog to land. Has to be able to handle the forces.
	DP Performance	+	Bigger ship, more DP needed
	Regulations	+	Overall: bigger ship, stricter rules. For instance if >500GT.
	Sustainable solution	+/-	Bigger is more material and power, more emmisions. Bigger is more possibilities for for instance batteries and IMO TIER etc.
Number of Crew and Personnel	Division deck and floor area	+/-	
	Passive comfort enhancing features	+	Influence number of personnel. For instance how many Windows.
	Propulsion		
	Seat execution and pitch	-	
	Effective time utilization	-	More crew is less space for changing room, restaurant etc
	Seakeeping improvement equipment		
	Transfer Solutions	+/-	Dependent on amount of personnel per transfer. Average 20.
	DP Performance		
	Regulations	+	Rules for amount of personnel, crew
	Sustainable solution		
Division deck and floor area	Passive comfort enhancing features	+/-	For instance more floor area, hvac, windows
	Propulsion		
	Seat execution and pitch	+/-	
	Effective time utilization	+/-	More space for restaurant, sleeping seats, work spaces
	Seakeeping improvement equipment		
	Transfer Solutions	+	More space needed for big transfer system
	DP Performance		
	Regulations		
	Sustainable solution		not taken into account. Negligible for instance: more solar pannels if more roof.
Passive comfort enhancing features	Propulsion		
	Seat execution and pitch		Not taken into account: maybe more windows more seats.
	Effective time utilization		
	Seakeeping improvement equipment		
	Transfer Solutions		
	DP Performance		
	Regulations		No minimam needed
	Sustainable solution		
Propulsion	Seat execution and pitch		
	Effective time utilization	+	faster is more time effiecient.

	Seakeeping improvement equipment	+/-	Faster is less equipment needed, but stronger.
	Transfer Solutions		
	DP Performance	+	Engines needed for DP
	Regulations	+/-	Propulsion has to do with regulations. For instance speed, IMO Tier. The faster sailing, the more forces the ship has to handle: thicker plates.
	Sustainable solution	+/-	More power is less sustainable.
Seat execution and pitch	Effective time utilization	+/-	More space for sleep, watching movie, work. Results in pros and cons. One excludes the other
	Seakeeping improvement equipment		
	Transfer Solutions		
	DP Performance		
	Regulations		Assume seats accepted
	Sustainable solution		Not taken into account: less pitch, more personnel, more sustainable.
Effective time utilization	Seakeeping improvement equipment	+	Better seakeeping, better pasttime due to better comfort.
	Transfer Solutions	+	
	DP Performance	+	
	Regulations		
	Sustainable solution		
Seakeeping improvement equipment	Transfer Solutions	+	ship has to be stable during transfer. Equipment ca nensure that.
	DP Performance		No because DP is in xy
	Regulations		
	Sustainable solution	-	For instance gyroscope heavy, thus results in les sustainability.
Transfer Solutions	DP Performance	+/-	
	Regulations	+/-	requirements for transfer and transit. Ampelmann results in more regulations due to sidestroke.
	Sustainable solution	+/-	Influences weight
DP Performance	Regulations	+/-	For instance some areas has to satisfy minimum dp classes.
	Sustainable solution	+/-	voegt zware boegschroef toe, brandstof verbrandne om op plek te blijven.
Regulations	Sustainable solution	+/-	Some areas enforce sustainability, for instance IMO Tier

H

Assessment Overview of First Hull Findings

H.0.1. Mono-hull

A mono-hull is a ship type with one hull. It is supported by buoyancy, whereby the seakeeping is dominated by buoyancy. Since the GM is lower than twin-hulls it has lower stability but it results in less jerky movements. The speed / power characteristics of are attractive. The cost are generally conventional. As can be seen in Figure 8.2, a mono-hull can be carried out in various forms of hulls, for instance hard chined, rounded bilge and the in Chapter 3 explained Axe Bow.

H.0.2. Catamaran

A catamaran has the aim to make a slender hull given stability by using two identical hulls side by side. It is supported by buoyancy, whereby the seakeeping is dominated by buoyancy and has the same physics as a displacement mono-hull. The speed / power characteristics of a catamaran are attractive because of the reducing wave-making resistance. The ship is desirable for high speed hydrodynamics and low speed applications. The divisible area is large per tonne of displacement, whereby a lot of deck and floor area can be arranged at a low density. Therefore a catamaran is well suited to payloads or missions with a low density, such as the transportation of people. The cost are generally conventional. Alternate configurations of the catamaran are the SWATH, semi-SWATH, a Wave-Piercing vessel and a foil assisted vessel. Also like the mono-hull, a catamaran can also be provided with the Axe Bow Concept, which means two axe bow hulls (twin axe design). The speed/power ratio, seakindlness at zero and high speeds around 1.5-2m and the cost of the catamaran are found as attractive. Therefore the catamaran is a hull type that could be used for this circumstances.

H.0.3. Trimaran

A trimaran has the aim to make a slender hull given stability by using small outrigger hulls. It is supported by buoyancy, which results in buoyancy-dominated physics. Long for its displacement yields good seakeeping. Since it is a ship with high slenderness it has good speed / power characteristics. The comfort, space and load carrying characteristics of the trimaran are somewhere between the mono-hull and catamaran. It could be a challenge to fit the machinery into the vessel as a result of the slender hulls. The cost are generally conventional. The speed/power ratio, seakindlness at zero and high speeds around 1.5-2m and the cost of the trimaran are found as attractive. Therefore the trimaran is a hull type that could be used for this circumstances.

H.0.4. SWATH

SWATH stands for Small Waterplane Area Twin Hull, which has two torpedo-like lower hulls which are positioned some depth below the free surface by a set of surface-piercing struts. It is supported by buoyancy and is a type of catamaran designed for minimum motions or maximum sea-kindliness. This is because the small waterplane area the excitation forces, caused by surface wave action, are low. Concerning the speed / power it is possible to have low wave-making resistance. Although the high wetted surface of a SWATH generally means that it is not a high-speed hull form. Therefore a SWATH is not attractive to use at demand for high speed. Comfort, space and load carrying capability is like the catamaran. Except that carrying load could change the draft or trim. Maintaining the desired attitude is usually executed by ballast systems. The cost are generally conventional. Because a SWATH is not attractive to use at demand for high speeds, it will not meet the boundary condition to sail at 35 knots. Therefore this ship type could not be used for the concept design to fit in the gap.

H.0.5. Hydrofoil

A hydrofoil is a vessel supported by a wing structure which is submerged in the water. The lift generated by these wings lifts the ship out of the water, which reduces the drag of the hull. It is supported by passive hydrodynamic lift, since the forward motion of the vessel is needed to generate lift. At high speeds, a hydrofoil is well detached from the sea surface excitations whereby it can deliver excellent seakeeping performances. However at zero speed the sea-kindliness is not favourable since it is is a very light-weighted hull. This ship type can attain substantially higher speeds for a given thrust than a competing buoyant ship type. Overall a hydrofoil is optimal only across a quite narrow band of operating speeds, since a small variation in speed can cause a substantial change in the amount of reliance that is placed upon the hull buoyancy. In general, a hydrofoil is only optimal across a narrow band of operating speeds, since a small variation in speed can cause a significant change in the amount of reliance on the hull buoyancy and thus the introduced amount of hull drag. The comfort and space is flexible since it can be a mono-hull or a multi-hull. Load carrying ability is mono-hull like. This ship type is quite expensive.

Since this ship type has excellent speed/power and seakeeping characteristics it is valuable to use in very rough seas. Because of the high cost for the vessel is is worth it in these circumstances. However, at mild conditions the advantageous are overspected and therefore too expensive. In contrast, a hydrofoil could have less length as a result of its good seakeeping which results in less cost. Moreover, the seakeeping performances of the hydrofoil are not attractive during transfer. Because of these two reasons, the hydrofoil is not a ship type which will be used for the concept design.

H.0.6. WIG

A WIG (Wing In Ground) is a wing which flies close to the water or ground surface to benefit from reduced drag of the wing. This ship type does not operate in extreme conditions and is aerodynamically driven passively generated by the shape of the wing. If the chord length between the surface and WIG is large enough it then isolates from the roughness of the sea, which results in a advantageous ride quality. Since it is a sort of airplane it can have speeds in the order of several hundred knots. There is not a lot ability of transporting bulk cargo is, since it is an airplane like configuration. The cost are intermediate between ships and aircrafts, which results in high expenses. Because of the high cost and the bad seakeeping at zero speed the WIG is not attractive.

H.0.7. ACV

An ACV (Air cushion Vehicle) is also known as a hovercraft. It displaces its weight of water in the form of an air bubble depressed into the sea surface. This air cushion eliminates friction. This means that it still floats by displacing water, but the water is displaced by a fan machine. Therefore it is supported by active hydrostatics. It has the capability of amphibious operation, which means it can operate at sea but also for instance on land, ice or swamp. An ACV has little response to the sea surface. However when the wet deck slams, or a wave comes trough the cushion this results unpleasant impulsive events and is disadvantageous sea-kindliness. The zero wetted surface of the ACV results in the lowest drag of any of the AMVs. However, at speeds lower than 50 knots the efficiency is low because of the use of air screw propellers instead of marine propellers. Moreover, noise and vibration are associated with air propulsion. It is easy to arrange space due to the rectangular platform. The carriage of load is limited by the maximum air cushion pressure that can be sustained by the skirts. The cost for an ACV are high partly because of the lift machinery and its associated control systems. The ACV meets none of the four boundary conditions.

I

Results SHIPMO

Table I.1: MSI and Vertical Accelerations results SHIPMO

	MSI				**SDA vertical accelerations**		
FCS 7011 @ 2.75	head,speed	0	37.5		head,speed	0	37.5
	90	15	17		90	2.0	2.1
	135	3	50		135	0.9	8.4
	180	1	42		180	0.7	8.2
	225	16	53		225	2.1	9.0
	270	31	27		270	3.4	3.1
Mono-hull - FCS 4208	head,speed	0	37.5		head,speed	0	37.5
	90	9	10		90	1.5	1.6
	135	3	38		135	0.9	6.2
	180	2	33		180	0.8	7.3
	225	7	43		225	1.3	7.0
	270	17	13		270	2.1	1.8
Mono-hull - FCS 5209	head,speed	0	37.5		head,speed	0	37.5
	90	6	9		90	1.2	1.5
	135	1	32		135	0.7	5.3
	180	1	27		180	0.6	6.0
	225	6	38		225	1.2	6.2
	270	18	13		270	2.3	1.8
Mono-hull - FCS 6210	head,speed	0	37.5		head,speed	0	37.5
	90	5	9		90	1.1	1.5
	135	1	28		135	0.6	4.6
	180	1	22		180	0.5	4.8
	225	7	33		225	1.3	5.4
	270	18	12		270	2.3	1.7

Catamaran - FCS 3609	head,speed	0	37.5		head,speed	0	37.5
	90	11	21		90	2.8	2.5
	135	13	54		135	1.9	14.1
	180	9	64		180	1.5	18.2
	225	8	61		225	1.4	15.8
	270	8	21		270	2.6	2.5
Catamaran - FCS 4612	head,speed	0	37.5		head,speed	0	37.5
	90	10	21		90	2.6	2.5
	135	5	49		135	1.1	11.3
	180	2	61		180	0.8	15.1
	225	5	60		225	1.1	15.4
	270	10	20		270	2.6	2.4
Catamaran - FCS 5615	head,speed	0	37.5		head,speed	0	37.5
	90	13	14		90	1.8	1.9
	135	8	46		135	1.4	10.6
	180	5	53		180	1.1	12.2
	225	5	54		225	1.1	11.3
	270	14	14		270	1.9	1.9
Trimaran - FCS 4011	head,speed	0	37.5		head,speed	0	37.5
	90	19	8		90	2.1	2.0
	135	9	67		135	1.3	9.5
	180	4	47		180	1.0	10.9
	225	17	38		225	1.2	9.7
	270	27	15		270	2.1	1.9
Trimaran - FCS 5013	head,speed	0	37.5		head,speed	0	37.5
	90	17	24		90	2.1	3.7
	135	5	67		135	1.1	12.9
	180	2	42		180	0.8	9.0
	225	13	38		225	1.8	8.5
	270	30	21		270	3.9	4.0
Trimaran - FCS 6015	head,speed	0	37.5		head,speed	0	37.5
	90	15	48		90	1.8	1.8
	135	3	75		135	0.9	7.1
	180	1	35		180	0.6	7.1
	225	12	70		225	0.9	7.0
	270	32	50		270	1.9	1.8
Mono-hull - FCS 4708.5					head,speed	0	37.5
					90	1.2	1.4
					135	0.7	5.7

					180	0.7	6.7
					225	1.3	6.7
					270	2.3	1.9
Mono-hull - FCS 5108	head,speed	0	37.5		head,speed	0.0	37.5
	90	8.0	9.5		90	1.4	1.5
	135	1.7	35.8		135	0.7	5.8
	180	1.3	31.0		180	0.7	6.7
	225	5.6	41.2		225	1.2	6.8
	270	17.7	13.9		270	2.2	1.9
Catamaran - FCS 4211	head,speed	0	37.5		head,speed	0	37.5
	90	9.7	19.7		90	2.5	2.4
	135	5.4	50.3		135	1.1	11.9
	180	2.9	63.1		180	0.9	16.0
	225	5.3	60.3		225	1.1	15.6
	270	9.5	19.0		270	2.5	2.3

Table I.2: Comparison locations ship

	FCS 5709				**FCS 4813**		
MSI 40	head,speed	0	37.5		head,speed	0	37.5
	90	6	9		90	12	15
	135	1	31		135	5	47
	180	1	25		180	2	59
	225	6	37		225	4	58
	270	19	13		270	11	15
MSI 60	head,speed	0	37.5		head,speed	0	37.5
	90	7	9		90	12	15
	135	4	39		135	4	53
	180	3	33		180	5	67
	225	7	43		225	9	66
	270	20	14		270	12	15
aza 40	head,speed	0	37.5		head,speed	0	37.5
	90	1.2	1.4		90	2.7	2.6
	135	0.6	5.1		135	1.1	10.9
	180	0.6	5.6		180	0.8	14.2
	225	1.2	6.0		225	1.0	14.8
	270	2.3	1.9		270	2.7	2.5
aza60	head,speed	0	37.5		head,speed	0	37.5
	90	1.3	1.5		90	2.8	2.6
	135	1.0	6.5		135	1.1	12.9
	180	0.8	7.2		180	1.1	18.1
	225	1.3	7.2		225	1.5	18.4

	270	2.4	1.9		270	2.7	2.5

Table I.3: Comparison Speed

	CAT - 4612			**MONO - 4208**		
0	heading	MSI_Perso		heading	MSI_Perso	
	90	10.4		90	14.2	
	135	4.6		135	17.6	
	180	1.9		180	2.0	
	225	4.5		225	26.0	
	270	10.3		270	30.4	
			6.3			18.0
10	heading	MSI_Perso		heading	MSI_Perso	
	90	10.1		90	5.5	
	135	14.8		135	11.5	
	180	6.1		180	13.3	
	225	11.6		225	21.9	
	270	10.7		270	20.5	
			10.7			14.5
20	heading	MSI_Perso		heading	MSI_Perso	
	90	10.0		90	7.6	
	135	20.6		135	20.0	
	180	35.4		180	23.2	
	225	36.7		225	28.3	
	270	10.3		270	18.0	
			22.6			19.4
30	heading	MSI_Perso		heading	MSI_Perso	
	90	9.9		90	8.9	
	135	39.4		135	25.0	
	180	49.9		180	28.7	
	225	52.6		225	30.1	
	270	10.7		270	16.1	
			32.5			21.8

Table I.4: Workability ahv comfort obtained from scatter diagram (SDAaza=8.4m/s^2)

	FCS 5108	**FCS 4211**
West Africa 1 (North)	79.2	29.3
West Africa 2 (Middle)	68.4	19.0
Mexico	75.8	38.1
Middle-East 1 (Red Sea)	81.9	49.9
Middle-East 2 (Persian Gulf)	91.9	72.4
Average	79.4	41.7
Corrected Average	72.2	59.6

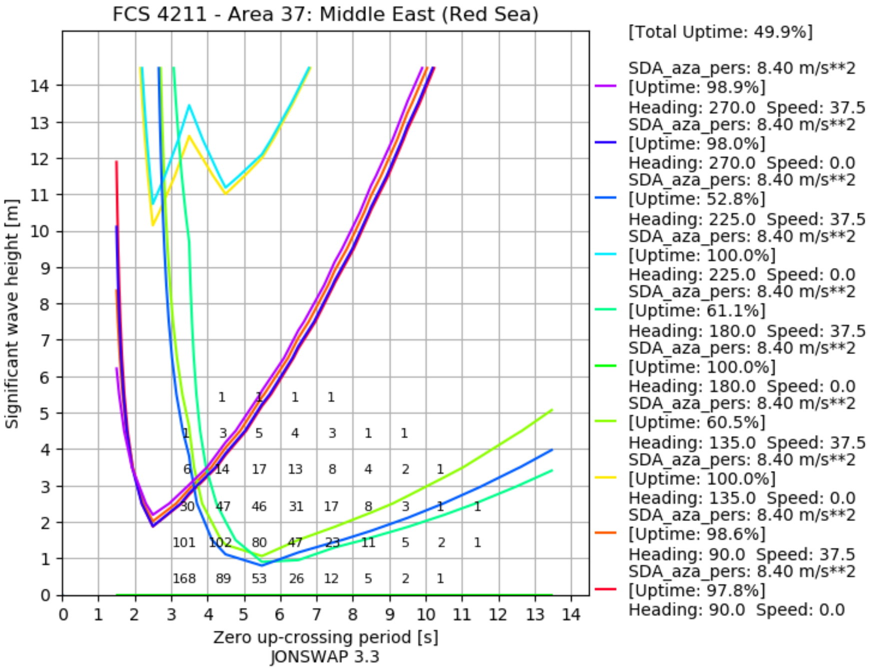


Figure I.1: Scatter Diagram FCS 5108 Gulf of Mexico

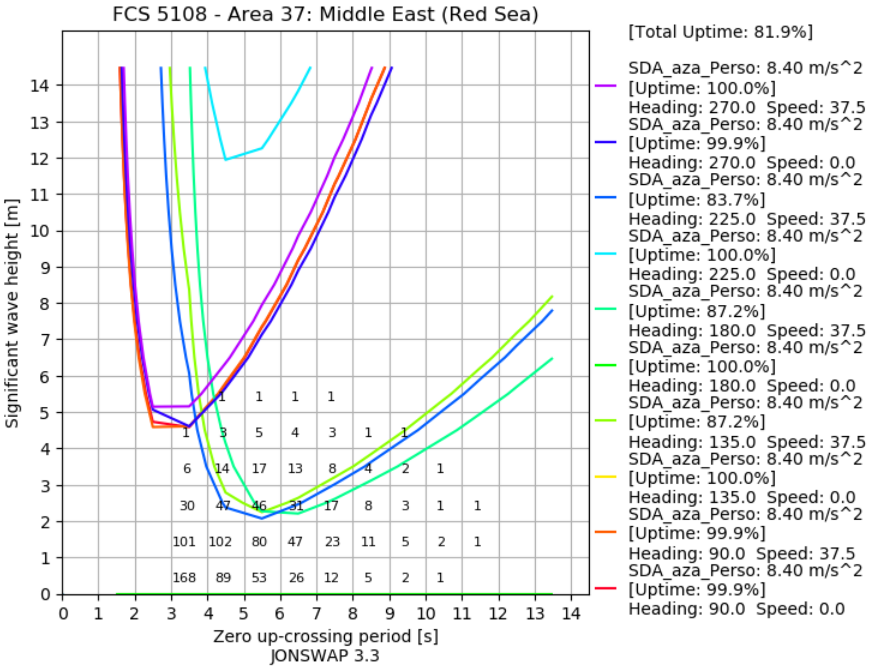


Figure I.2: Scatter Diagram FCS 5108 Gulf of Mexico

Table I.5: Maximum vertical acceleration values of the FCS 5108 at the wheelhouse

Head [°]	**MAX Az [m/s^2] at Speed = 0kn**	**MAX Az [m/s^2] at Speed = 37.5kn**
90	1.25	1.36
135	0.75	5.58
180	0.63	6.34
225	1.05	6.29
270	1.97	1.65
Average	5.65	4.24

J

Design Results and Considerations

LCG

Table J.1: Block calculation LCG

Block Calculation LCG										
Part	**FCS 5108.2**					**FCS 7011**				
	Weight [kg]	LCG [m]	Weight *LCG	Final LCG [m]	LCG/L	Weight [kg]	LCG [m]	Weight *LCG	Final LCG [m]	LCG/L
Total Lightweight without variables	81091	20.22	1639347			173609	27.75	4817222		
Waterjets	14400	0.50	7200			18880	0.50	9440		
Ampelmann	8000	6.00	48000			26291	8.90	233990		
Engine + Gearbox	42900	11.30	484770			57484	11.30	649715		
Interior personnel	10000	20.00	200000			28006	31.00	868186		
Interior crew	6000	35.00	210000							
Hull	64154	22.44	1439625			131951	31.50	4156457		
Superstructure	16572	23.00	381156			29566	29.00	857414		
Wheelhouse	3322	25.00	83050			3322	38.30	127233		
Gyro	19820	33.75	668925			19820	46.90	929558		
Tanks	35831	19.50	698709			76180	25.00	1904500		
Cargo	25000	35.00	875000			7500	56.00	420000		
Total Lightweight	266260		5162073	19.39	0.380	488929		12649213	25.87	0.370
Total lightweight with 1/2 cargo 1/2 fuel	327091		6735782	20.59	0.404	572609		14973713	26.15	0.374
Total lightweight with 1/2 fuel	302091		5860782	19.40	0.380	565109		14553713	25.75	0.368

VCG

Table J.2: Block calculation VCG

Block Calculation VCG										
Block	FCS 5108.2					FCS 7011				
	Weight [kg]	VCG [m]	Weight *VCG	Final VCG [m]	Final GM [m]	Weight [kg]	VCG [m]	Weight *VCG	Final VCG [m]	Final GM [m]
Total Lightweight without variables	81091	3.70	300314			173609	4.333777	752383		
Waterjets	14400	1.85	26640			18880	1.85	34928		
Ampelmann	8000	5.20	41600			26291	11.41	299980		
Engine + Gearbox	42900	2.47	105963			57484	2.474304	142233		
Interior personnel	10000	6.26	62600			28006	6.78	189881		
Interior crew	6000	3.53	21180							
Hull	64154	4.18	268084			131951	4.89	645240		
Superstructure	16572	4.83	80068			29566	6.128	181180		
Wheelhouse	3322	11.58	38478			3322	13.72	45578		
Gyro	19820	5.19	102866			19820	3.02	59856		
Tanks	35831	3.08	110360			38090	3.08	117317		
Cargo	25000	7.15	178750			750	12.45	9338		
Total Lightweight	266260		1047793	3.94	1.892	488929		2351260	4.81	1.702
Total lightweight with 1/2 cargo 1/2 fuel	327091		1336904	4.09	1.386	527769		2477914	4.70	1.570
Total lightweight with 1/2 fuel	302091		1158154	3.83	1.798	527019		2468577	4.68	1.694

Explanation blocks

An explanation of the blocks is given below:

- Total lightweight without variables
  The lightweight without the variables is calculated for the FCS 7011 including its related LCG and VCG. The weight is calculated using the same ratio as Equation 8.6. The bow thrusters of the FCS 7011 are within this weight, whereby these are counted off and the bow thrusters of the FCS 5108 are counted on. The LCG and VCG is calculated at the same percentage of the length.

- Waterjets
  The waterjets type that are used are the Hamilton HT810. This is one type smaller than used for the FCS 7011. The length needed is 7 meters, from -2 to 5 is needed for the waterjets.

- Ampelmann
  The FCS 7011 is equiped with an Ampelman S-type with a weight of 18 tonnes. It is able to compensate for a significant wave height of 3 meters. Since the concept design in this research is designed for significant wave heights between 1.5 and 2 meters, an Ampelmann L-type suits better. This type compensates up to 2 meters and has a weight of 8 tonnes. Moreover, this type has a smaller footprint, which is 4.4x6.6m. Since the gangway needs to locate on the ship itself 10 meters in length are designed for the gangway. The gangway length relative to the FCS 7011, however is two times as small.

- Engine + Gearbox
  For the waterjets, engine and gearbox two grouping location options are possible. It is possible to combine the waterjets with the gearbox or the engine with the gearbox. The second option is chosen since this way it is possible to influence the LCG more since the weight is higher of the component which could be shifted at the longitudinal axis. This causes lower revs an higher torque of the engine. Moreover, a thicker shaft is needed. For the waterjet gearbox combination higher revs, lower torque and a thinner shaft is needed. This results in earlier emerging vibrations since it is less stiff. It is calculated that the FCS 5108 needs a power of

9555kW which results in the MTU 16V 4000 M65L* engine. The engines together with the gearbox need a length of 10 meters.

- Interior personnel
  The interior of personnel for the FCS 7011 is calculated together with the crew accommodation. For the FCS 5108 it is calculated separately. Based on the FCS 5009.
- Crew accommodation
  The weight and dimensions of the crew accommodation are based on the FCS 5009 and FCS 7011.
- Hull
  The hull is calculated using values of the FCS 7011 and the same ratio as Equation 8.6.
- Superstructure
  The superstructure is calculated using values of the FCS 7011 and Equation 8.6.
- Gyro
  The same gyroscope is used as the FCS 7011. The LCG and VCG of the gyroscope itself is calculated using the data of the FCS 7011. The gyroscope itself is placed at a different location.
- Tanks
  The FCS 7011 is equipped with fuel tanks which result in 18 hours of sailing at full speed. The FCS 5009 for 85. Based on the needed power, 30 hours of sailing, the fuel density of 840 g/l and the fuel consumption of 210 g/kWh, the weight and tank dimensions are calculated. The height of the tanks is chosen as identical as the FCS 5009 since the structure of the lower deck is the same. This results in a fuel tank length of 4.7 meters. In addition space and weight is calculated for water and extra tanks which results in a total length of 9 meters.
- Cargo
  The vessel will also be able to transport 50t of cargo. A surface of 1.5m^2 per tonnage of cargo is used for the total surface.

K

SHIPMO Results FCS 5108

Table K.1: Results FCS 5108 Surge, Sway, Heave, Roll, Pitch and Yaw

SDA Surge	head,speed	0	37.5	
	90	0.00	0.00	
	135	0.81	0.18	
	180	0.92	0.14	
	225	0.81	0.18	
	270	0.00	0.00	
				0.3
SDA Sway	head,speed	0	37.5	
	90	1.45	1.57	
	135	0.73	0.25	
	180	0.00	0.00	
	225	0.73	0.25	
	270	1.45	1.57	
				0.8
SDA Heave	head,speed	0	37.5	
	90	1.72	1.64	
	135	1.24	1.77	
	180	0.98	1.52	
	225	1.24	1.77	
	270	1.72	1.64	
				1.5
SDA Roll	head,speed	0	37.5	
	90	5.96	2.63	
	135	5.60	2.20	
	180	0.00	0.00	
	225	5.60	2.20	
	270	5.96	2.63	
				3.3
SDA Pitch	head,speed	0	37.5	
	90	0.42	0.26	
	135	4.75	3.55	
	180	5.14	3.63	
	225	4.75	3.55	
	270	0.42	0.26	
				2.7
SDA Yaw	head,speed	0	37.5	
	90	0.62	0.82	
	135	2.99	0.72	
	180	0.00	0.00	
	225	2.99	0.72	
	270	0.62	0.82	
				1.0

Table K.2: Workability based on scatter diagram

Workability based on comfort - scatter diagram	
Area	FCS 5108.2
West Africa 1 (North)	79.5
West Africa 2 (Middle)	69.4
Mexico	75.9
Middle-East (Red Sea)	81.6
Middle-East (Persian Gulf)	91.5
Average	79.6
Corrected Average	72.3

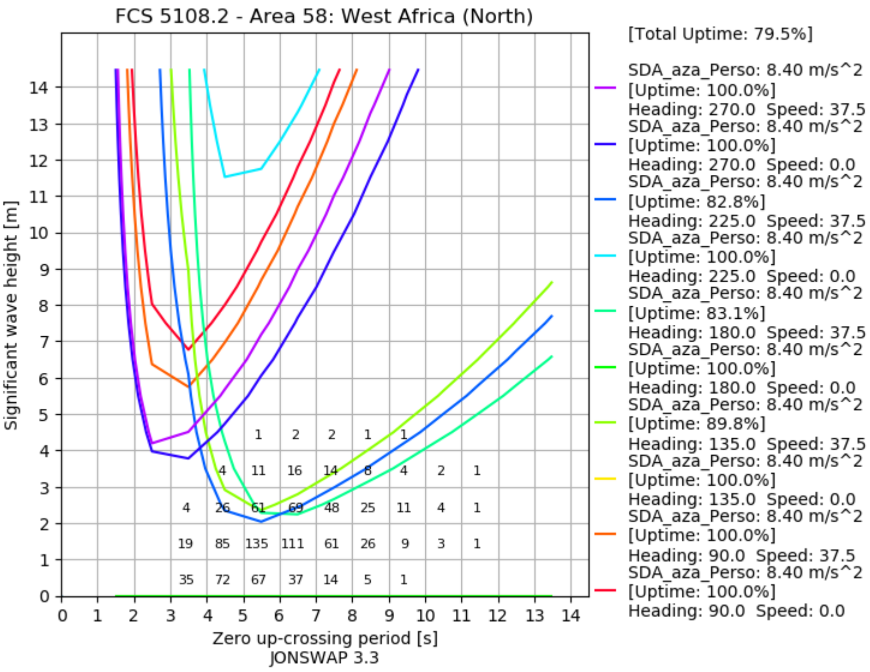


Figure K.1: Scatter Diagram FCS 5108 West Africa North

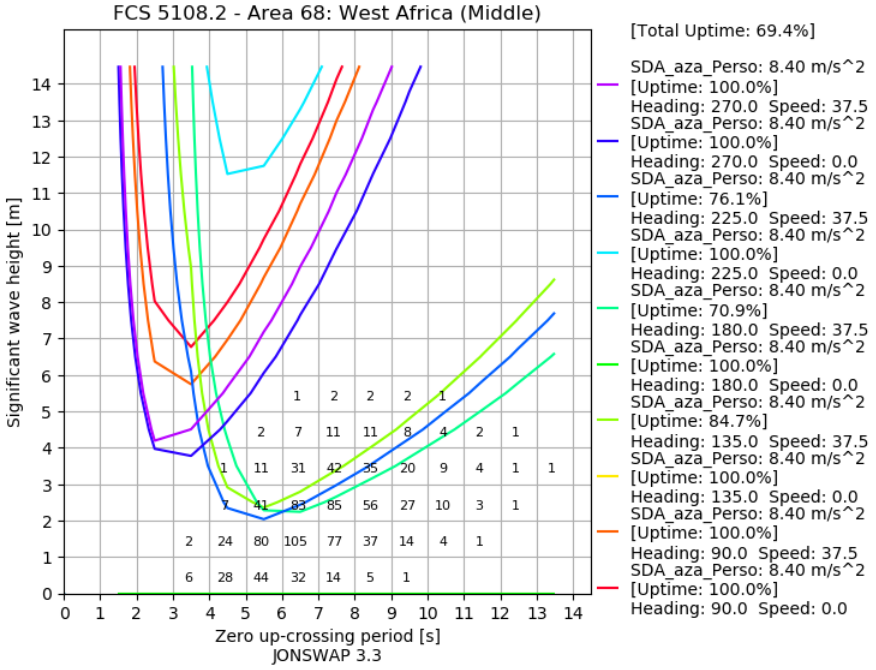


Figure K.2: Scatter Diagram FCS 5108 West Africa Middle

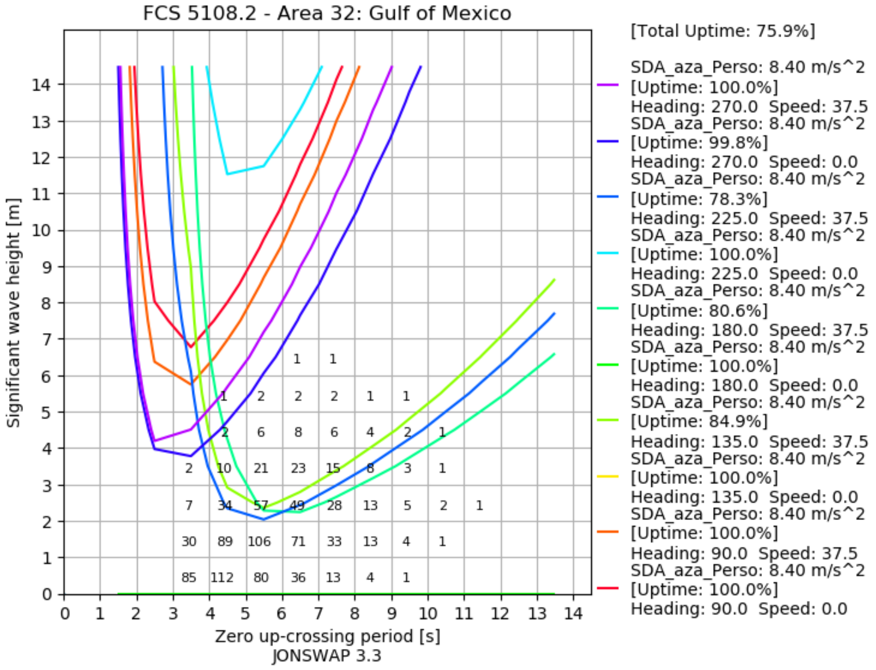


Figure K.3: Scatter Diagram FCS 5108 Gulf of Mexico

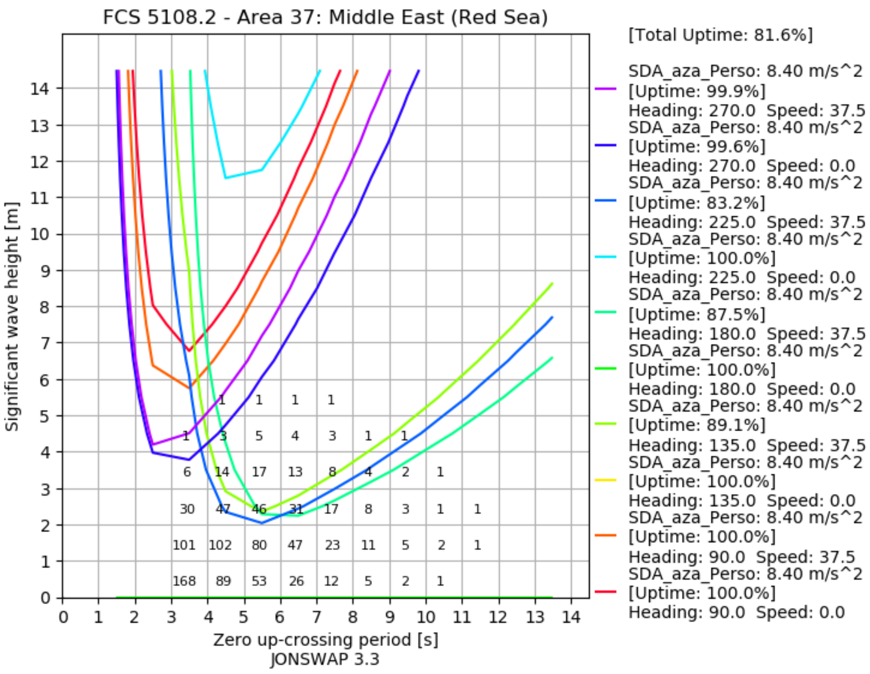


Figure K.4: Scatter Diagram FCS 5108 Middle East Red Sea

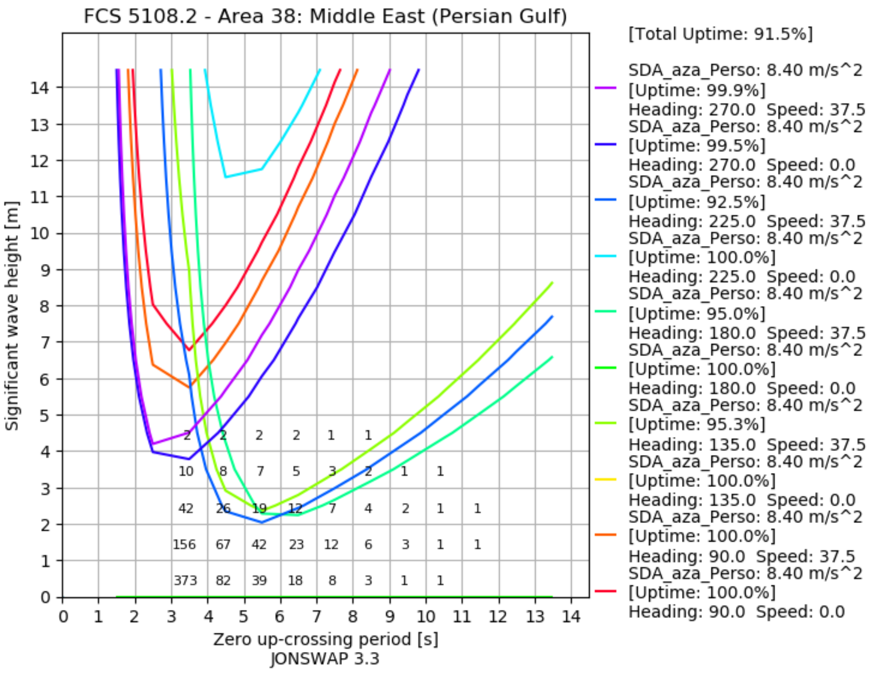


Figure K.5: Scatter Diagram FCS 5108 Middle East Persian Gulf

L

General Arrangement FCS 5108

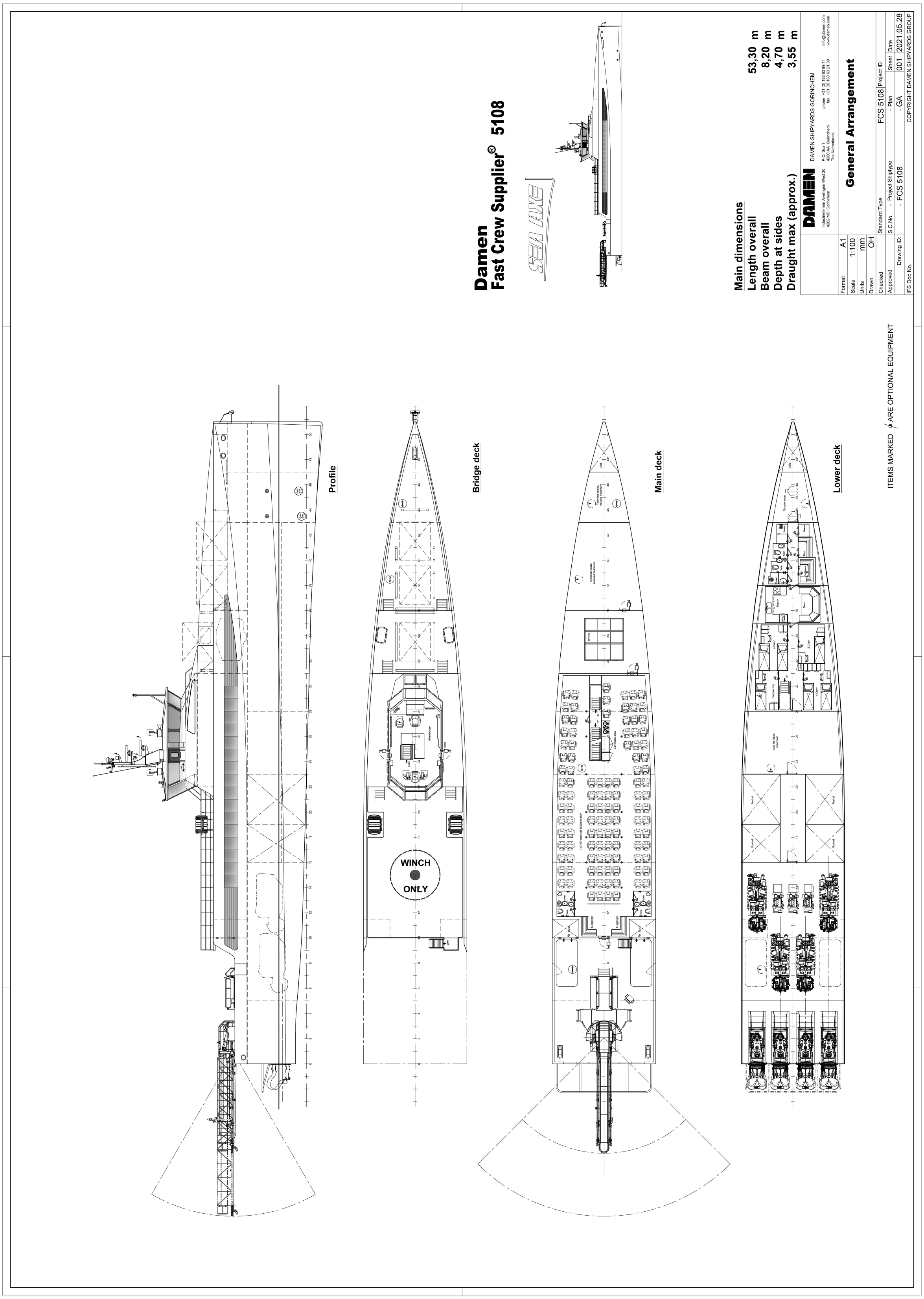


Figure L.1: General Arrangement FCS 5108

M

Final Design Criteria FCS 5108

Design criteria FCS 5108

Code	Catogory	Subject	Description	Reqd	Actual	Units	Execution and motivation
000	Information	General	The FCS 5108 is specially designed to compete in the Middle East, West African and Mexican market				
000	Required	Hull design	The hull shape will be optimised for personnel comfort, keeping in mind performance and sea keeping in the areas mentioned above. The Sea Axe design must be used.				
000	Required	Dimensions	Length around 51m, optimise for low price/high performance		51.00	m	
000	Required	Dimensions	Beam, optimise for low price/high performance		8.20	m	
000	Required	Dimensions	D, optimise for low price/high performance		4.70	m	
000	Required	Dimensions	Draught, no special requirements				
000	Required	Capacities	Fuel oil		85.3	m3	Range at 37.5kn (93% MCR ~9555 kw, ~2389l/hr) 1125 nm
000	Required	Capacities	Crew	10	11	pers	6 cabins on lower deck
000	Required	Capacities	Industrial personnel	80	113	pers	Normal 130 pax, extendable less or more pax
000	Required	Capacities	Deck load		50	ton	
000	Required	Capacities	10' containers				4 containers can be placed
000	Information	Operational areas	Designed for limited significant wave height		2	m	
000	Information	Operating profile	Engine: 1A rating. For FCS logical decision because significantly sailing at high speed				
000	Required	Life time	Construction not determined				
031	Required	Class	The vessel will be classed by Bureau Veritas for the following notation: I + Hull ● MACH crew boat sea area 3 DP2				
070	Required	Design conditions	Maximum wave height Hs		2		At higher wave height, speed reductions are expected.
076	Required	Stability	GM with half fuel and half cargo	1.69	1.80	m	150 ton dwt, including 80 ton deck load
076	Required	Weight	Light Ship weigth		226	ton	
110	Required	Construction	Aluminium				
110	Required	Lines plan	100% - Sea Axe lines plan				
210	Required	PSD					4x MTU MTU 16V 4000 M65L* / 10240kW 4x Reintjes VLJ 1930 4x Hamilton waterjets HT 810
223	Required	Bow thrusters	Thruster power, DP2				
650	Required	Fire fighting	Optional, capcity equal or better compared to competition				
722	Required	Accommodation	Based on 10-12 crew, 4 cabins				Sanitair spaces at same longitudinal position for easy pipe
738	Required	Seats	VIP seats, Minimal pitch	750	1000	mm	
738	Required	Seats	VIP seats, Minimal width	450	650	mm	
		Transfer system	Ampelmann L-type				
		Transfer system	Frog				
			Gyroscope				

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