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NTNU
Norwegian University of
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Faculty of Engineering
Department of Marine Technology

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Salmon Emergency Response Vessel

Design of a new vessel type using system based ship design with added insight through discrete event simulation

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Design of a new vessel type using system based ship design with added insight through discrete event simulation

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Marine Technology - Marine Systems Design
Submission date: June 2021
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MASTER THESIS IN MARINE TECHNOLOGY

SPRING 2020

For stud.techn.

Vincent Rabben

Topic:
Salmon Emergency Response Vessel
Design of a new vessel type using system based ship design, with added insight through discrete event simulation

Background

The Norwegian salmon aquaculture industry has a need of improving its preparedness for emergency situations. This became apparent during the spring of 2019 when a large scale toxic algae bloom affected the region of Northern Norway. The results were mass mortality of salmon, meaning a large loss of potential food for the society, as well as a large economic loss to the farmers. This thesis seeks to improve the emergency preparedness of the industry by designing a response vessel. The focus for the thesis and design will be directed towards the fish, where the goal is to maximize the value of the threatened fish during a crisis, both to the society and economically to the farmers.

Objective

Increase the preparedness of the Norwegian salmon aquaculture industry, through the design of a vessel that contribute to secure the welfare and value of the biomass assets at risk during crisis situations.

Tasks
The candidate is recommended to cover the following parts in the master's thesis:

a. Review state of art within the topic. That means to document what others have done and published previously.
b. Document the problem and the system in which the problem is located.
c. Document the method used for solving the problem.
d. Document the needs and suggest functions to handle these.
e. Develop a concept of design.
f. Provide additional insight through analysis.
g. Develop a detailed design.
h. Discuss strengths and improvement potential in one's approach and work – with respect to conclusions.
i. Suggestions for further work.

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General
In the thesis the candidate shall present his personal contribution to the resolution of a problem within the scope of the thesis work.

Theories and conclusions should be based on a relevant methodological foundation that through mathematical derivations and/or logical reasoning identify the various steps in the deduction.

The candidate should utilize the existing possibilities for obtaining relevant literature.

The thesis should be organized in a rational manner to give a clear statement of assumptions, data, results, assessments, and conclusions. The text should be brief and to the point, with a clear language. Telegraphic language should be avoided.

The thesis shall contain the following elements: A text defining the scope, preface, list of contents, summary, main body of thesis, conclusions with recommendations for further work, list of symbols and acronyms, reference and (optional) appendices. All figures, tables and equations shall be numerated.

The supervisor may require that the candidate, in an early stage of the work, present a written plan for the completion of the work.
The original contribution of the candidate and material taken from other sources shall be clearly defined. Work from other sources shall be properly referenced using an acknowledged referencing system.

Supervision:
Main supervisor:
Professor Bjørn Egil Asbjørnslett

Sub-supervisor:
Svein Aanond Aanondsen

Company contact:

Deadline: 10.06.2020

Preface

This master thesis is the concluding work of a Masters's degree at the Department of Marine Technology at the Norwegian University of Technology and Science with a specialisation in Marine Systems Design. The work was done during the spring of 2021 and the workload corresponds to 30 ETCS. The work builds on a project thesis written in the autumn of 2020, where the focus was on carrying out a literature study as well as some identification of the needs to be covered in the design. The scope of the project thesis and the subsequent master's thesis will be the development of an emergency response vessel for increased preparedness in the Norwegian aquaculture industry.

The project was in part done cooperating with the research project of Sintef on coastal preparedness, although the cooperation has been limited. Thanks go to Ingunn Marie Holmen and Ørjan Selvik for helpful input and involvement in the project. I would also like to thank Frode Tenfjord and Hans Owen Thunem from Optimar who have provided valuable insight into the fish processing equipment.

I would like to thank my parents Karianne and Hans Christian for their endless support in all aspects of life. I would also like to thank my great colleagues and friends for their great company throughout the final part of our time as students. I wish you all the best, Andreas, Benjamin, Dani, Ingvild, and Malin.

Thanks to my supervisor, Bjørn Egil Asbjørnslett, for the guidance of my work and also the guidance in finding an exciting project. Thanks to Svein Aanondsen for good discussions and feedback and for guiding me through the jungle of ship design. Finally, thanks are handed to the Ph.D. candidate Hans Tobias Slette for input on the simulation.

TRONDHEIM, JUNE 10, 2021

VINCENT RABBEN

Summary

The Norwegian salmon aquaculture industry has a need of improving its preparedness for emergency situations. This has become apparent due to events such as the large-scale toxic algae bloom that affected the whole region of Northern Norway during the spring of 2019. The results were mass mortality of salmon and a large loss of potential food for the society, as well as a large economic loss to the fish farmers. This thesis seeks to improve the emergency preparedness of the industry by designing a response vessel. The focus for the thesis and design is directed towards the fish, where the goal is to secure fish welfare as well as the value of the threatened biomass asset during a crisis, both to the society and to the farmers.

The vessel design is developed through a task clarification phase where a short *accelerated business development* is used to identify the expectations of the industry. Further, the needs are identified for different emergency scenarios. A set of functional requirements for the main function is selected based on the stated goal of maximizing the value of the fish. The main result from this phase is the selection of a concept of a vessel with a buffer tank capacity and the possibility to transfer the fish to support vessels. Stunning and bleeding fish and cooling it down in RSW tanks is selected as the method of handling fish for consumption while cooling whole fish is selected as the preferred method of handling the all ready dead fish, which will be used in production of fish meal and fish oil.

Further, a phase of concept design is carried out. System based ship design is used as the method for identifying the spaces needed for the different functions and further establishing the main dimensions of the ship as well as an outline of the design. The result is a length of 60,8 meters and a beam of 12 meters, a cargo capacity of 400 m^3 for fish to consumption, and 200 m^3 for the already dead fish.

An analysis of the outline using a discrete-event simulation is then done to assure a good dimensioning of the main function of the ship. The results show that the design outperforms already established design types such as a dedicated stun and bleed vessel, by a good margin.

Finally, a detailed design is developed in the embodiment phase. This to show how the functions could be arranged. The resulting arrangement is designed with a good workflow for the main function, with clear segregation between the handling of dead fish and fish for consumption. The support functions are also placed in a satisfying manner, for example accommodation which is situated in a way that ensures good rest for the workers. Furthermore, the tank arrangement and stability test show that the design is stable and with satisfying trim in all conditions. The result is a final design that satisfies the objective of increased preparedness through contributing to securing fish welfare and the value of the threatened biomass asset.

Samandrag

Den norske lakseoppdrettsnæringa har eit behov for å forbetre beredskapen for krisesituasjonar. Dette blei tydeleg mellom anna våren 2019 då ein storskala algeoppblomstring råka Nord-Noreg. Resultatet var massedødelegheit av laks og eit stort tap av potensiell mat for samfunnet, samt økonomisk tap for oppdrettarar. Med denne masteroppgåva blir det ønskja å betre beredskapen i næringa ved å designe eit beredskapsfartøy. Fokuset for avhandlinga og designet vil bli retta mot fisken, der målet er å sikre god fiskevelferd, samt verdiane til den truga ressursen som biomassen er. Dette sett frå både samfunnet og fiskeoppdrettaren sin ståstad.

Skipsdesignet er utvikla gjennom ein designprosess beståande av ein fase for avklaring av oppgåve der dei første modulane frå metoden 'accelerated business development' blir brukt for å identifisere forventningane til designet frå næringa. Vidare blir behova identifisert for forskjellege ulykkesscenario. Eit sett med funksjonskriterier som vil bli fokusert på blir valt basert på det uttalte målet om å få mest mogleg verdi ut av fisken. Hovudresultatet frå denne delen er eit designkonsept for eit skip med buffertankkapasitet og moglegheit for å sende lasta vidare til støttefartøy. Å bløgge og nedkjøle fisken i RSW blir valt som handteringsmetode for fisken som går til konsum, mens nedkjøling av heil fisk blir valt som handteringsmetode for den allereie døde fisken, som vil bli brukt i produksjon av fiskemjøl og fiskeolje.

Vidare blir det gjort ein konseptfase av designet. I denne fasen blir 'system based ship design' brukt som metode for å identifisere plassen ein treng til dei ulike funksjonane og blir deretter brukt til å finne fram til hovuddimensjonane til skipet, samt eit første utkast av designet. Resultatet er eit skip med lengde 60,8 meter og ei bredde på 12 meter, ein lastekapasitet på 400 m^3 for fisk til konsum, samt 200 m^3 for den allereie døde fisken.

Ein analyse blir gjort for designutkastet ved hjelp av ein diskret-hendelses simulering. Resultatet viser at designet utkonkurerer allereie etablerte skipstypar i akvakultur med god margin.

Til slutt blir eit detaljert design utvikla for å vise korleis hovudfunksjonane kan arrangerast. Det resulterande arrangementet er designa med god arbeidsflyt i hovudfunksjonane, med ei klar segregering mellom handteringa av den døde fisken og fisken til konsum. Støttefunksjonane er også plassert på ein god måte, som til dømes innkvartering av mannskapet som er ordna slik at kvile for arbeidarane er sikra. Vidare viser tankarrangementet og stabilitetstestar at designet er stabilt og har tilfredsstillande trim i alle kondisjonar. Resultatet av det endelege designet er eit design som tilfredsstiller målet med å auke beredskapen gjennom å bidra til sikring av fiskevelferd og verdiane av den truga biomassen. Vidare viser tankarrangementet og stabilitetstestar at designet er stabilt og har tilfredsstillande trim i alle kondisjonar. Resultatet av det endelege designet er eit design som tilfredsstiller målet med å auke beredskapen gjennom å bidra til sikring av fiskevelferd og verdiane av den truga biomassen.

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Nomenclature

ΔT	Temperature Difference
Δ	Displacement
A_C	Admiralty Coefficient
C_p	Specific Heat Constant
m	Mass
P_B	Propulsion power
Q	Cooling Capacity
t	time
V	Ship velocity

Acronyms

ABD Accelerated Business Development.

CAD Computer-Aided Design.

ERRV Emergency Response and Rescue Vessel.

FAO Food and Agriculture Organization.

MDO Marine diesel oil.

NPD Naphthalene, Phenanthrene, Dibenzothiophene.

PAH Polyaromatic Hydrocarbons.

SBSD System Based Ship Design.

SFI Research-Based Innovation.

SWOT Strengths, Weaknesses, Opportunities, Threats.

UN United Nations.

Chapter 1

Introduction

Background and Motivation

Only in recent years have systematic work of risk assessment seen in other industries been done in aquaculture. Although the industry actors are good at helping each other out in emergencies, there has not been done much work on preparedness plans for the industry, and especially on regional emergencies.

This became apparent during the algae blooming that occurred in the northern region of Norway during the spring of 2019. A toxic algae blooming of large scale led to mass mortality of salmon. Efforts were made by the fish farmers to save as much salmon as possible by either relocating it or sending it to the slaughterhouse. At the same time they struggled with handling the accumulation of dead fish. It is estimated that about 14 500 tonnes of fish died and was made to ensilage and that a slaughter potential of about 36 000 tonnes was lost due to emergency slaughtering. In total, the losses have been estimated to be over two billion NOK [1]. This is a large loss of potential food as well as a large economic loss that potentially could have been lower if the industry had been better prepared. The fish farmers use the commons to produce the fish and so they have a responsibility to ensure that as much as possible of the fish is utilized, even in emergencies.

The question of response plans and capabilities was raised following the algae blooming. The ongoing Sintef research project on coastal preparedness is one of the projects addressing this [2]. Part of the project on coastal preparedness looks into the design of a response vessel. This thesis will have the same focus. There has not yet been designed a response vessel for the aquaculture industry or been published any scientific papers on the development of one. While only initial work has been done on this up until this point, vessels with similar roles have been created for other sectors such as the oil and gas sector and can serve as inspiration. Their regulations could possibly serve as a guideline for the criteria for a response vessel in aquaculture [3].

Objective and Scope

This thesis seeks to improve the emergency preparedness in Norwegian aquaculture through the design of an emergency response vessel. The thesis will provide background information on unwanted hazardous events that the industry should be prepared for and identify the needs in these. Functional requirements needed for a ship to handle the situations will be identified. A design will then be developed using the methodology presented in the thesis. The design concept will be analyzed using a simulation tool before the detailed design is developed. The final design of the response vessel and its arrangement will be presented and discussed.

The scope of the emergency response vessel will be limited to handling biomass. The objective of the vessel is to maintain good fish welfare and try to maximize the value from the fish, both for the society and, economically for the farmer, given a crisis scenario. This does also mean that focus has been hazardous scenarios where the loss of biomass and economic value is one of the possible consequences. Further, the scope has been narrowed down by focusing on a few sets of possible scenarios. The hazardous scenarios in focus are algae blooming, collision and/or grounding accidents of fish farms that contain fish, and fire on fish farms or vessels. Of the needs in these scenarios, the need for handling of live and dead fish has been of extra focus due to the need being a common denominator across the different scenarios as well as the added value in operation outside of crisis situations.

Structure Overview
The second chapter, *Literature Review*, will look into and give an overview of existing, relevant, literature for the project. The most important literature that is used in the thesis will be presented and a brief overview given. The literature review includes design theory, previous work done in the field of study, as well as present current projects.
Further, the third chapter, *Problem Analysis*, will give a detailed description of the problem. The background of the problem will be described in detail as well.

The fourth chapter is the *Method* chapter. It describes how the theory presented in the literary study (ref. chapter 2) and mainly the part that covers design methodology (ref. section 2.4) is going to be used in a design procedure that will be utilized in the process of designing an emergency response vessel for the aquaculture industry. A schematic of the procedure will be presented, followed by a detailed description.

In chapter five, *Task Clarification*, the first part of the design phase will be presented. Here, the needs of the industry will be identified as well as identifying some fitting functional requirements. This will be done by carrying out a short 'Accelerated Business Development' process.

The second part of the design process will be covered in chapter six. This chapter will present the results from the 'System Based Ship Design' process as well as discuss the pros and cons of this method. An outline of the design will be established in this chapter.

Chapter seven will cover the benchmarking of the design outline by using a tool developed for initial analysis of the design. In this case, a simulation tool. The simulation tool will be used to compare the designs' response capability to already established designs in aquaculture. The analysis will be used for confirmation of the design concept before proceeding with the detailed design.

Finally, the development of the detailed design will be covered in chapter eight. The phase of sketching will be presented first before the detailed design is shown through a general arrangement with a presentation of the design, and the logistics concerning the main function. Furthermore, the tank arrangements and stability checks will be presented.

In nine the results of the design phase will be discussed. The discussion will try to assess whether the design answers the questions raised when assessing the needs of the industry and to what extent the design does this. The process of developing the design will also be discussed. Additionally, the assessment of the design through analysis will be discussed. Finally, concluding remarks on the design and process will be made in chapter ten.

Chapter 2

Literature Review

This chapter will look into and give an overview of existing, relevant literature for the project. The literature study was done as part of the candidate's project thesis, the autumn of 2020 [4]. The needs that are highlighted are general needs, not specific to the goal of maximizing the value from the salmon.

2.1 Emergency Preparedness & Vessel Response

In this section, the focus will be on emergency preparedness and the work done on response vessels within different areas.

Emergency preparedness can be defined as being prepared for action to meet unexpected, unwanted critical situations and accidents [5]. Critical situations in the context of fish farming are situations that in various ways can lead to large losses and animal welfare crises if not acted on quickly. Situations where personnel is damaged and potentially in danger of losing their lives are of course also covered by the emergency preparedness term, but will not be focused on in this project. These types of accidents are covered by governmental health emergency preparedness such as the Norwegian rescue services.

Seen in the context of risk research, emergency preparedness is planning on what actions to take after an emergency has happened. In a bow-tie diagram, this is the right side of the "knot". The bow-tie model is a model for illustrating the relationship between identified hazardous events, the causes of the event, its consequences as well as barriers to reduce probabilities and barriers to mitigate the consequences [6]. An example of a bow-tie diagram using relevant examples is presented below. The study of preparedness is here the study of how well the reactive initiatives are, such as a response vessel. A response vessel can be looked upon as a mitigating barrier in a bow-tie model.

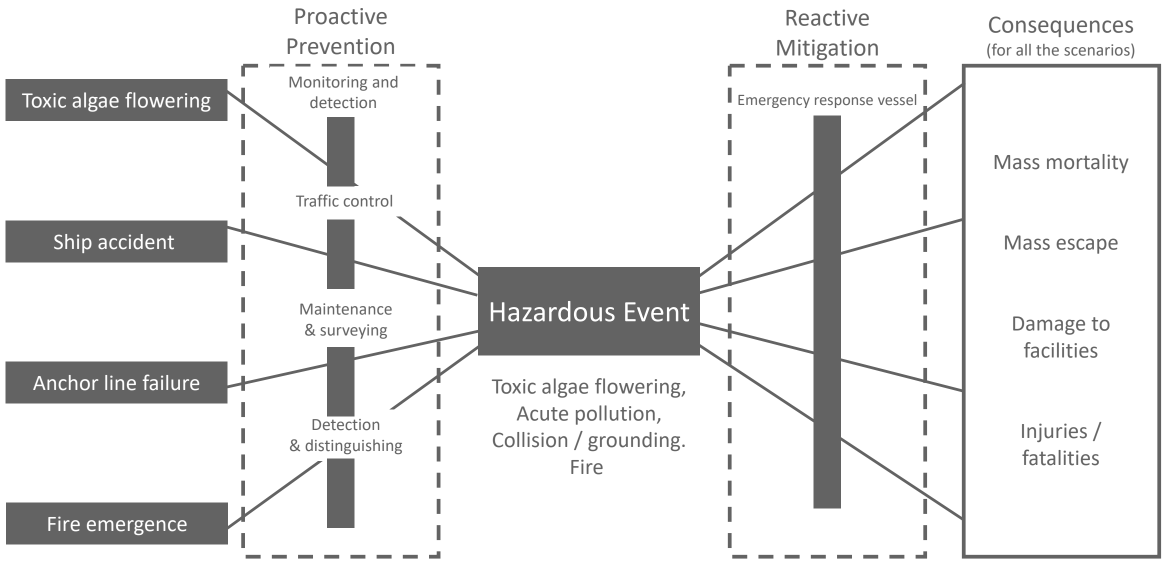


Figure 2.1: Bow-tie diagram for aquaculture with a response vessel shown as a reactive measure

2.1.1 Vessel Response

According to the Wärtsilä Encyclopedia of Ship Technology, emergency response is defined as *all actions through alarm, escape, muster, communications and control, evacuation and rescue* [7]. Furthermore, Emergency Response and Rescue Vessel (ERRV) is defined as *A purpose-built rescue vessel attending offshore installations. An ERRV should combine good maneuverability, enhanced survivor reception and medical after-care facilities, state of art navigational/communications equipment, and rescue craft capable of operating in severe weather.* The encyclopedia goes further into describing such vessels, stating that they often are fitted with both daughter crafts and fast rescue crafts as well as equipment for retrieving casualties in bad weather. Although the capability of handling personnel damages and casualties is not a focus in this project, a large part of the definition is fitting. In addition, some level of medical response ability should be required and kept in mind in the design process of a vessel.

Although there are no rules and regulations for emergency response in the aquaculture industry, the regulations for emergency response vessels in the Norwegian petroleum sector (Forskrift om beredskapsfartøy, 1991) can serve as a basis for the development of similar vessels in service of aquaculture [3]. The regulation covers requirements for new and existing emergency response vessels registered in Norway. There are special requirements to the building of the ship, including special requirements of load line and propulsion system (Forskrift om berededskapsfartøy, 1991, §§ 10 and 11). The regulation further covers how the vessel should be equipped and what extra criteria emergency response equipment and other equipment on board needs to meet (Forskrift om berededskapsfartøy, 1991, §§ 12-14 and §23-27). Additionally, the regulation has particular requirements for ships that have the role of rescuing people. Worth mentioning is § 14 on towing and pushing, a function that can be very relevant for a response vessel in aquaculture (Forskrift om berededskapsfartøy, 1991, § 14). In addition, the section of the regulation on managing this type of ship, including the staffing, training of personnel, and the development and implementation of preparedness plans and instruction can be said to be relevant (Forskrift om berededskapsfartøy, 1991, §§ 25-27).

Among scientific papers on emergency response vessels, the paper from Pettersen et al. (2020) on latent capabilities in ships with regards to support in marine emergency response should be mentioned [8]. This paper suggests that latent capabilities can support existing emergency response when the capability of the current infrastructure is exceeded. Latent capabilities here being defined as capabilities that were neither intended nor recognized during the design phase. The paper further proposes a method for identifying latent capabilities for use in contingency planning. The authors also suggest there are economical benefits of highlighting such capabilities. The paper points to the large oil spill in the Gulf of Mexico in April 2010, when Deepwater Horizon exploded and sank, as an example and proof of method. Here, advanced offshore vessels were used to support the work of stopping the blowout and mitigating the environmental consequences. One can from this draw parallels to the aquaculture industry and the recent algae blooming in 2019. Reports on how the crisis was handled show how all resources available were shared and used creatively. Fishing vessels and their pumps were for example used to handle dead fish accumulation in pens [9]. Latent capabilities are, therefore, as illustrated by the example, very much relevant to the aquaculture industry. Whether this should be considered and accounted for when assessing the preparedness, could be discussed.

The recent master's theses of Håkonsen (2017) and Thunes (2018) can serve as sources of information [10, 11]. Both theses look at preparedness and response in aquaculture with focus on the use of discrete-event simulation as an analysis tool. Their use of discrete-event simulation will be further discussed in chapter 2.5.

Apart from the aforementioned papers, the author has struggled to find scientific papers on the design of response vessels and their functional requirements. However, the author finds that there are relevant reference ships from other segments than aquaculture that can serve as inspiration and guidance in the design process.

2.2 Hazardous Scenarios

In this section different incidents that can cause a need for swift response will be identified and investigated.

2.2.1 Algae Blooming

Algae blooming is a phenomenon that happens several times each season and is in itself not harmful, but a necessary and natural phenomenon. The blooming is a natural part of the life cycle of algae and an important part of the energy transport in the sea [12]. On occasions, the algae that bloom are toxic to the salmon and can cause it to suffocate. This is of course a very severe situation that can lead to mass mortality and extreme losses if not acted on quickly. The algae blooming that happened in the spring of 2019 in the northern part of Norway is an example of this. This case has led to an increased focus on the response to the threat of toxic algae blooms.

The algae blooming in the spring of 2019 led to large losses. It is estimated that about 14 500 tonnes of fish died and was made to ensilage while about 36 000 tonnes of slaughter potential was lost due to emergency slaughtering. In total, the losses have been estimated to be over two billion NOK [1]. This loss has made a large economic impact locally and the industry will feel the effect of the crisis for several years. To prevent a similar crisis in the future the work has started on how to better be prepared if similar events arise in the future.

Sintef is among one of the research centers in Norway working on this issue [2]. The work includes research on how to monitor and predict toxic algae. The research is still in its early stages, with the challenge being to identify when toxic algae are blooming. This research could have a very large effect on what the response to a toxic algae bloom should be. A good tool for monitoring algae levels and predicting toxic blooming could drastically increase the time window to act within. If the tool is very good the preferred means of action could for example be to move fish while a shorter notification could call for emergency slaughter to salvage the most economic value. The response vessels for these two scenarios would look very different. However, how good this monitoring tool will be is hard to tell, hence one should assume that the response time will be low.

The other aspect of the work is how to respond to the situation if it arises. Part of the work done on this has been studying what happened during the crisis, highlighting challenges, shortcomings and experiences gathered from the crisis. A report mapping the chain of events and response during the toxic algae blooming has been written by Nofima on demand from the Norwegian Seafood Federation [9]. The report states that the cooperation of the different firms was very good and that collectively sharing resources and distributing them where they were needed the most helped reduce the consequences.

Amongst the areas with potential for improvement, the report mentions a need of upscaling the response plans on how to handle large quanta of dead fish and suggests establishing contracts with purse seiners [9]. This ship type proved very helpful during the crisis, but the report mentions that the dispensations needed to carry dead fish should be given beforehand to improve the response time. The report also highlights that the regional capacity to receive ensilage should be increased. The capacity to grind dead fish was highlighted as a bottleneck and the farmers have suggested mobile grinding capacity as an alternative solution. The low capacity of grinding has also led to a new vessel concept. Scanbio has recently built a ship with increased grinding capacity [13]. The vessel, which started operating in September 2020, has a capacity of 750 cubic meters and can grind 60 to 80 tonnes of dead fish per hour. The ship will be registered as a chemical tanker. This is a large contribution to the preparedness with regards to the capacity of handling dead fish.

Important functional requirements with regards to algae blooming can be summed up as quick handling of fish that is alive and needs to be either relocated or processed, in addition to swift handling of dead fish to ensure the stability of the fish farm.

2.2.2 Acute Pollution

An emergency scenario that could occur is a case of acute pollution. An example of this is if there is a large ship accident, either a collision or grounding. This could mean large oil spills. If the ship additionally carries cargo that could be harmful to the environment, the consequences could be severe.

There are several examples of accidents leading to oil spills along the coast of Norway. Thankfully, these types of accidents have yet to lead to increased fish mortality and or loss to whole farms. The most recent event was the collision between the Norwegian frigate HNoMS Helge Ingstad and the oil tanker Sola TS. The collision led to Helge Ingstad taking in water and later capsizing and sinking. Marine diesel oil leaked in to the ocean and drifted from the wreck. Local fish farmers paid close attention to the situation and luckily it did not become a serious disaster. Further, the Norwegian Institute of Marine Research has stated that the effect of the pollution on the marine environment was little [14]. The accident could however have become an environmental disaster had Sola TS, fully loaded with crude oil, taken larger damage. This type of scenario is therefore very important to consider, despite no damage to fish farms in recent times.

Figure 2.2: Picture of the oil spill from Helge Ingstad captured from the Norwegian Coastal Administration's observation plane [15]

The Norwegian Coastal Administration is today responsible for the governmental preparedness against acute oil spills. This includes nationwide administrative authority. The Norwegian Coastal administration works with preventive measures as well as training and preparing for acute pollution. In case of pollution they are assessing the situation, mobilizing different stakeholders and coordinating the response. The resources consist of 27 oil spill depots a long the Norwegian coastal line, of which 16 are main depots. These depots are stocked with oil spill equipment such as different booms, recovery units (skimmers) and off-loading units. In addition, the Norwegian Clean Seas Association for Operating Companies (NOFO) has available resources and municipalities have resources, typically managed by fire brigades [16].

The larger extent of use of finer refined fuel oils such as for example Marine diesel oil (MDO), which is becoming a requirement in many close shore areas, means that this type of oil spill has a larger relevance than before. A study carried out by Sintef Ocean on behalf of the Norwegian Coastal Administration uncovers that these types of fuels will spread quickly in a fine film, restricting the possibilities of mechanical removal, use of dispersants as well as in-situ burning [17]. The lighter oils will however both evaporate and disperse more quikly but are also more toxic for marine organisms [18]. The experience from earlier reports on the four largest oil spills in Norwegian coastal waters, has been that that the effects on wild fish and crustaceans are small. The fish farms that were affected during the four largest spills were not affected hard and the tests showed detectable, but small increases in NPD/PAH levels. These are levels that are found in the bile of fish and crustaceans that indicate toxicity. The effect on fish is however hard to quantify, since the fish seem to move when they sense oil in the water [19]. This is not possible for farmed salmon since it is contained. Contamination may then lead to stress and mortality. Pollution from oil spills is therefore a scenario that should be considered when assessing the preparedness of the Norwegian aquaculture industry.

An aspect that needs to be considered is the availability of gear for oil spill response. As mentioned above, there are both governmental, municipal and private resources available. However, there is an order of priority in the case of oil spills. The resources will then be prioritized on protecting natural resources that are priceless. This means that wild life will be prioritized ahead of fish farms. In the case of a large oil spill this could mean that all available resources are used to try to protect wildlife. The aquaculture industry should therefore plan for these cases as well and consider organizing its own depots in addition to the ones already existing. This type of depots could also be in combination with storage of other types of equipment needed in different scenarios.

To sum up, the important functional requirements for an oil spill scenario can be said to be quick deployment of oil spill gear to protect the fish. In addition, quick response in the form of either relocation or processing can be needed.

2.2.3 Collision and/or Grounding Accident of Operating Fish Farms

A hazardous scenario to be considered is the scenario of collision, or grounding of fish farms. This could be a scenario where for example a ship loses power for a period of time and drifts in to the fish farm, or a collision due to other reasons, or it could be that the pen starts drifting due to failure on anchor lines, and ends up grounding. In these cases there could be damages to the construction and net, and potentially danger to people and large escapes of fish.

An event where an anchor line has failed could lead to a complex situation. The bag could collapse, leading to crowding of the fish and potentially mass mortality. The accumulation of dead fish in the bottom of the cage would lead to an increase in draft, potentially leading to a submerged cage edge and escaping fish. In such a scenario one would have the following needs: Towing capacity to stretch out the fish cage, acting as the broken anchor line. Diving support and/or capacity to fix the broken anchoring. Pump and storage capacity to remove the dead fish. Resources for the recapturing process. This is a very complex situation potentially requiring the response of several vessels and good coordination of the resources.

According to the Norwegian aquaculture law (Akvakulturloven, 2005, § 13) the fish farmer has a responsibility to recapture as much fish as possible in the case of an escape [20]. In addition, the regulation of the operation of aquaculture facilities states that the farmer has a responsibility to both proactively and reactively limit the escape (Akvakulturdriftsforskriften, 2008, § 37) [21]. A guidance document for preparedness in the case of fish escape has been developed by the Norwegian Seafood federation in cooperation with the Norwegian Directorate of Fisheries and Safetec [22]. The document provides clarification on the roles of different stakeholders during the event of a fish escape, as well as instructions on how fish farmers should create emergency response plans.

The fish farmer is responsible for providing gear for recapture [22]. Today, farmers typically own this type of gear together and has it at local depots. The role of a response vessel could be to transport the gear from the depot to the location where it is needed, similar to how oil spill response gear is distributed. Here the gear is loaded on to a fast towed barge.

The effect of recapture was studied by Skilbreid and Jørgensen in 2010 [23]. In their experiment they released 1031 salmon in to a fjord, all tagged were of 48 tagged with acoustic transmitters. The fish was then tried recaptured through trawling and fishing with gill-nets. The results showed that the trawl was unsuccessfully (possibly due to sub-optimal towing speed and or trawl size) while the gill-nets proved to be effective. The recapture rate was reportedly 40% for the tagged fish and 60% for the acoustically tagged fish, indicating that the total recapture rate was higher than 40%. More than 80% of the salmon was captured within 40 kilometers of the release site. The report concludes that a significant portion of escaped salmon can be recaptured if the effort is widespread and lasts for at least four weeks. One should keep in mind that these results were obtained in a fjord and might not be representative for other locations where the fish might disperse more widely. This can be seen as an incentive for quick and large response in form of recapture fishing when there has been a large escape.

The functional requirements for preparedness for a scenario of collision or grounding are complex, but can be summed up as: Towing capacity, diving and capacity to handle broken anchor lines, handling of dead fish and quick deployment of recapture gear. In the situation of a collision, the requirements for acute pollution may also apply.

2.2.4 Fire On Fish Farm or Vessel

Fires are a hazard to be considered in preparedness for the aquaculture industry in Norway. Fires could occur on feed barges or vessels in close vicinity to the fish farm. These fires can spread to the flotation ring of the farm, causing it to lose buoyancy and submerging the net causing fish to escape. Fires will also be a potential hazard for personnel.

The use of batteries in the aquaculture industry and the coastal fleet is an element to take in to consideration when assessing the preparedness in terms of fires. A report from ABB and Bellona on the potential reduction of emissions from the aquaculture industry, states that about half the feed barges in Norwegian aquaculture uses electric power from shore [24]. The report states that a hybrid solution is a good way to reduce emissions at locations where electric power from shore is not available. A hybrid solution means that a battery package is installed in addition to a different power source, most commonly a diesel generator. For feed barges this configuration means that the diesel generators only run when the battery needs charging. This means minimal run time of the diesel generator with it running at optimal utilization. Battery packs can also be used in combination with an electrical power supply from shore. Here, the dimensions of the power supply can be reduced as an effect of the battery pack. This is similar to peak shaving effects that ships experience with installed battery packs. The report states that when battery prices decrease, the use of full electric vessels at fish farms will be a viable option, while hybrid solutions are more used today. In conclusion the use of batteries is increasing in the aquaculture sector.

The introduction of large battery packs on feed barges and on ships also represents an increased fire hazard. Fires in lithium batteries can be aggressive and are hard to put out, and so the consequences of fires could be more severe.

Most service vessels today are equipped with sea water pumps and can contribute extinguishing fires using these. An example is vessels equipped to do washing of nets. These vessels are often equipped with high pressure pumps. The equipment is however not designed to put out fires. One should therefore consider the effectiveness of this equipment. A possibility is installing gear for fire response, such as water cannons, that can utilize the same pumps that the vessel already needs for other operations.

The most important function to consider when assessing preparedness towards scenarios with fire is the ability to extinguish the fire quickly. In addition there might be a need of other supporting roles in such cases, such as towing, diving, recapture of fish, etc. Finally, there might also be a need of medical services, but as stated previously this function will not be covered here. Needles to say though, it is of course something to keep in mind.

2.3 Ship Design In Aquaculture

This section will look at the research that is done on design of vessels within aquaculture.

Sintef has since 2015 had an ongoing research program on exposed aquaculture [25]. The program follows the scheme of research-based innovation (SFI), meaning that it involves stakeholders from the industry and has a goal of enhancing the technology transfer from the research. One part of the research program focuses on the design of service vessels in exposed aquaculture. In this process, a ground work for design methodology has been developed, with the intention of designing service vessels for exposed aquaculture.

In cooperation with the vessel design module of the exposed research program, Nekstad (2017) wrote a Master's thesis on the subject of modularization of aquaculture service vessels [26]. In his thesis, Nekstad tries to uncover how modularization can be used to implement operational flexibility in this vessel type. The thesis identifies all the different operations and the functions and systems needed to carry them out. These are then assessed using design structure matrices to discover what functions should be part of the permanent infrastructure and what could be part of different equipment packages. A framework is created for the design of flexible aquaculture service vessels. This is finally applied in a case study where a service vessel is designed. The thesis can serve as a very good source in several ways, as it is a good example of how one can structure the problem. In addition, the work of mapping the different operations of a service vessel and the corresponding gear can be very useful. Many of the tasks of a response vessel will be similar to that of a service vessel and the framework may also be used to map additional operations and gear. The use of change matrices to study the change between vessel configurations is also carried out and an aspect that should be considered when designing an emergency response vessel.

Functional requirements of aquaculture service vessels are described by Nekstad. He refers to the functional requirements for fishing vessels presented by Ellingsen and Endal (2007) that can be applied to service vessels, in addition to adding some himself. The requirements are as follows:

- A safe working platform and living quarters for the crew
- A stable platform from which one or multiple types of missions can be performed in an efficient manner.
- Ability to operate and maneuver in the required manner at the farm sites, and in the waters where the farm sites are located.
- Ability to sail to and from the aquaculture facility, perform its mission(s) and either sail back to port or to the next location, with minimum expenditures, in the weather conditions that the vessel is required to operate in.

2.4 Design Methodology

This section will cover important literature on design methodology in general as well as design methodology specific to ship design.

2.4.1 Needs, Function, Form

When designing, one is mapping between the needs, functional and physical domain. This is done using synthesis and analysis. Synthesis being to come up with suggested solutions and analysis the testing of the suggested solutions. The performance of a solution can be said to be the deviation from the functional requirements, where a well performing design is close to the functional criteria in its solution. This is illustrated in the figure below.

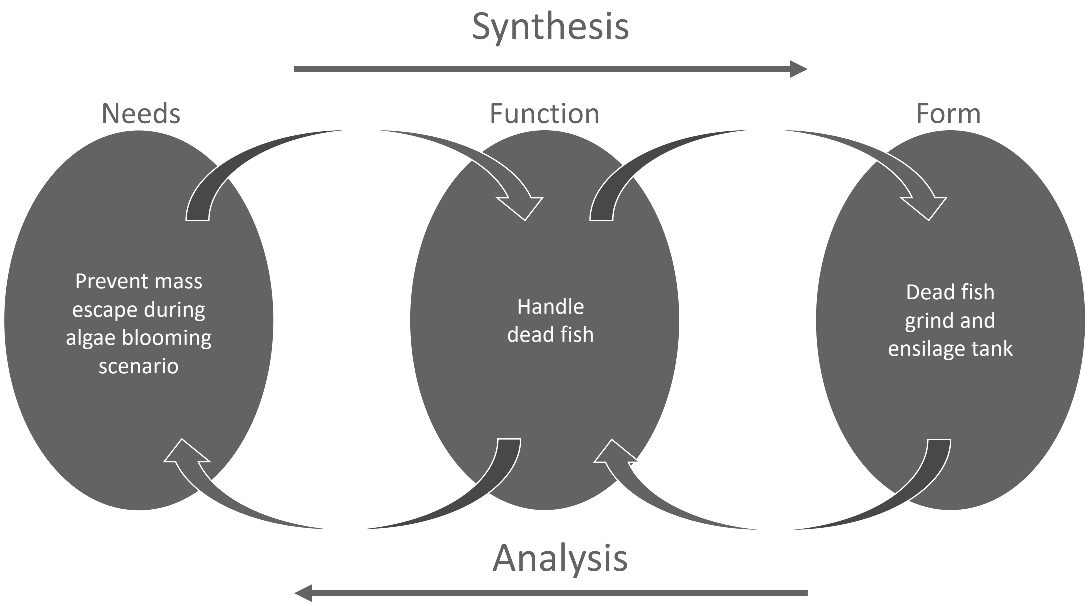


Figure 2.3: Illustration of needs, function, form mapping using an example from algae blooming. The illustration is based on a similar figure presented in a lecture on engineering design theory in the course *TMR4135 - Design Methods 2: Special Vessels* [27]

Function can be defined in a variation of ways. In mathematics it is defined as relation between an input and an output, where each input is related to exactly one output. A similar definition is used by Pahl and Beitz (2013) [28]. They state that a function is *the intended input/output relationship of a system whose purpose is to perform a task.* An additional definition provided by Pahl and Beitz is the definition of a function as one that can be defined as a statement consisting of a verb and a noun. These should be generic process and operands, such as "transform energy" or "transport matter" to keep the physical solution as open as possible. This definition and way of approaching the function term is also being used by Jakobsen (1990) in the book *Produktutvikling* [29] and is central in systematic design. Finally, de Weck et. al (2011) defines the function as *the action for which a thing is specially fitted or used, or the reason for which a thing exists* [30].

Needs is the stakeholders requirements, while **form** is the physical solution.

2.4.2 Systematic Design / Catalogue Design

Systematic design is a design method presented by Pahl and Beitz (2013) in their book *Design Engineer - a systematic approach* [28]. This design method builds on the German school of engineering. The method is devided in to four phases:

- Task clarification: Clarification of the designs task. In ship design this means identifying the stakeholders requirements.
- Conceptual design: The main function to form mapping happens during this stage
- Embodiment design: Developing the layout
- Detail design: Developing the documentation needed to produce the design

The method has its basis in the fundamentals of technical systems, where functional, working, constructional and system interrelationships are central. Pahl and Beitz also provide guidelines on how to identify the different interrelationships.

The functional interrelationship describe the functional structure and the relationship between different functions. It can be seen as the functional domain, as stated above. According to Pahl and Beitz it can be described through:

1. Ensure task-specific description (for example using the process operand definition)
2. Make sure descriptions are valid in general. On the low level of the system- and function hierarchy
3. Make sure there is a logical relationship and sequence of subfunctions

The working interrelationship describes how the functions are realized with concern to physical laws. This is corresponding to the mapping between function and form mentioned earlier. The working interrelationship can according to Pahl and Beitz be described as follows:

1. The physical effects are important, in other word to describe quantitatively the effects of the physical laws. The laws of physics as a relation between functions and form are also important.
2. Ensure the geometrics and materials are so that the physical effect can be utilized. Proven solutions to functions are found in design catalogue.

The use of design catalogues is an important aspect of the design method and the reason why it is often also referred to as catalogue design. It is a principle that has been adopted by others. System based ship design does for example build on catalogue design.

The constructional interrelationship describes the working structure and enables the physical realization of the designed system. This is related to the form domain described earlier. **The system interrelationship** describes the interaction between the designed system and the environment it is operating in, including the interaction with the user.

2.4.3 Axiomatic Design

The axiomatic design method is a method developed by Nam-Pyo Suh from the end of the 70's. The method was first presented in 1978 in *On an Axiomatic Approach to Manufacturing and Manufacturing Systems* [31]. Nam-Pyo Suh with his experience in mechanical engineering and manufacturing developed the method with an intention of improving the scientific rigor of design [32]. The theory has been applied to larger scale systems design in more recent time. A good presentation of the theory is presented in the first chapter of *Axiomatic Design in Large Systems: Complex Products, Buildings and Manufacturing Systems* by Farid and Suh (2016) and is the basis for the theory presented on axiomatic design here [32]. The theory gets it name from the two axioms of the theory:

The independence axiom states that the different functional requirements should be independent of each other. Changing one design parameter should then only affect one functional requirement. This is a very powerful axiom, but very hard to carry out in practice. Coupled designs should be tried to be uncoupled. This is hard to achieve in ship design where different parameters often have an effect on each other. An example in ship design is that an increase in lifting capacity will mean a larger hull due to need of stability. This will again have an affect on resistance and the needed propulsion.

The information axiom states that the information content of the design should be minimized to reduce the complexity. This will increase the probability of making a design that fulfils the functional requirements. The more difficult a system is to describe, that is the more complex it is, the more difficult it is to predict its performance. Both axioms should be valid on all the levels of the function- and system hierarchy.

The axiomatic design is a good design principle, but hard to achieve for functional coupled systems such as design of special vessels, as illustrated by the example. However, the theory is something to strive for to keep the design process as simple as possible, to reduce the complexity. The principles are used in modularity and the use of design structure matrices.

2.4.4 Parametric Design

In parametric design a database of relevant reference vessels is used to establish some relationships between parameters. This is a method used by Papanikolaou (2014) [33]. Relationships between parameters can for example establish volume based on length beam and depth, estimate the building cost etc. This is done through regression analysis. The best results come from specialized databases where you have full control of the vessels included, but regressional analysis are also available. This method is best for novel ship types such as tankers, container vessels and bulk ships, where there is a lot of data available and empirical results available. For special vessels the method should be used with caution. First of all, reference data may be hard to come by and there might not be many or any reference vessels if the segment is new. For innovative designs this method can be used to get insight from similar markets and operations. The danger of this is ending up with designs based on previous designs when the optimal solution may be a completely different approach. This is on the other hand a quick way to estimate the main dimensions and costs and is a method used by many design offices.

2.4.5 System Based Ship Design

System based ship design SBSD is a design method developed by Kai Levander (2012), specifically for the design of ships [34]. The method is based on the principles of systematic design of Pahl Beitz. In this method all the functions are defined, similarly to the systematic design method. Areas and volumes needed for these functions are then established based on similar ships, this in accordance with the principles of parametric design. This way of establishing the volumes and areas is similar to the use of catalogue design in the systematic design method. The method of system based ship design is used to establish a good estimation of the main dimensions of the ship as well as the cost. The functions are later placed when the arrangement is created. Also worth mentioning is that the concepts of modularity quite easily can be applied here.

2.4.6 Modularity

Modularity is the decomposition of a larger system into smaller parts. These parts should be relatively self-sufficient. The modules can then be assembled to multiple end products. This is typical for car manufacturing. Modularization is a way of handling complexity as suggested by Herbert Simon [35]. The pros of modularization is that one can design a product that can be customized and have variety, be produced more efficiently, have reduced risk, outsource parts of the design and production and have greater flexibility and changeability. On the other hand, modularity can lead to less optimized architecture, less optimized performance and product similarity.

2.4.7 Accelerated Business Development

Accelerated Business Development (ABD) is a design method develop by the ship design company Ulstein to be used to provide structure in the design process [36]. The goal is to turn a vessel business idea in to a business idea, then a vessel specification and finally a general arrangement [37]. The method consists of several modules where the first four are of interest for this thesis and the methodology described later. In these modules the focus is gathering information by developing a business concept, assessing expectations as well as looking at the competitiveness and uncertainties [37].

2.5 Simulation

The course on ocean space simulation provided by NTNU the fall of 2020 and its corresponding compendium has served as literature on the topic of simulation [38]. The course covers theoretical background on simulation and application of the theory. The course taught application of the theory using the Simulink extension of MATLAB [39].

In the past years there has been written three master's theses that can serve as good sources on discrete event simulation with regards to emergency response in aquaculture. Two of the theses have also been mentioned in chapter 2.1.1 as providing some background on vessel response. These theses can provide inspiration on how to define the problem when simulating, and how a response case can be modelled. The thesis of Josefsen (2016) looks at response time for acute pollution in arctic areas [40]. The thesis looks at fleet composition and how fitting several ships with oil response gear can reduce the response time.

Håkonsen (2017) looks at emergency preparedness and response in aquaculture [10]. The thesis looks at the use of wellboats and light diving vessels, as well as slaughter vessel, to evaluate emergency escape and emergency slaughter of fish. The simulation model does not model the cause of the accidents, but has these two modes of emergency. The thesis further compares a sheltered and exposed location and concludes that the same response time is possible to obtain for an exposed location if the availability of response vessels is increased. Furthermore, the thesis concludes that the capacity need for emergency slaughter is much higher for exposed areas.

Thunes (2018) looks at emergency response to acute pollution in aquaculture [11]. This thesis looks at how different fleet compositions of wellboats can respond to an emergency need of transport due to a acute pollution, and how the same fleet performs in normal conditions. The conclusion reached is that a smaller fleet with a standby response vessel performs best during normal operations and provides sufficient capacity during an emergency. Both Thunes (2018) and Håkonsen (2017) states that further research on preparedness in Norwegian aquaculture is needed.

Chapter 3

Problem Analysis & Problem Description

The world population is increasing and with it, the demand for food production to feed it. At the same time, the world society faces the problem of climate change. The challenge of achieving this development sustainably, reducing the strain on our planet, is a focus area of the United Nations (UN). It has developed 17 sustainable development goals to achieve a better, more sustainable future for all [41].

A part of the solution is an increased utilization of marine resources. In the Food and Agriculture Organization's (FAO) report on the state of global fisheries and aquaculture from 2020, the development, as well as predictions for the future, are presented [42]. This report predicts that the utilization of wild resources will remain the same, while the aquaculture segment will increase drastically and surpass the amount of catch from fisheries by 2030. Goal number two, *zero hunger*, and goal number 14, *life below water*, are two goals to keep in mind in the work with aquaculture. They are respectively to "end hunger, achieve food security and improved nutrition and promote sustainable agriculture" and "conserve and sustainably use the oceans, seas and marine resources for sustainable development" [41].

The salmon aquaculture industry in Norway has in the last years grown and quickly become a large export industry. It is said to have large growth potential and is Norway's leading alternative in providing more food from marine resources.

The increasing size of the salmon aquaculture industry in Norway has meant that there at all times are large values swimming around in pens all along the coast of Norway. These values account for the largest asset of most fish farming companies. In addition to being an asset to the farmers, it is an asset to society as a food source. The asset takes its form as live biomass, a vulnerable asset. It is therefore important to consider how to protect the fish, both considering the value to society, the welfare of the animals as well as the economical aspect.

The vulnerability of the fish was proven in the spring of 2019 when a large algae blooming occurred along parts of the Norwegian coast. During this crisis, it is estimated that about 14 500 tonnes of fish died and was made to ensilage while about 36 000 tonnes of slaughter potential was lost due to emergency slaughtering. In total, the losses have been estimated to be over two billion NOK [1].

Following the algae blooming of 2019 questions of response plans and capabilities were raised. One of the projects addressing this is the Sintef research project on coastal readiness [2]. The project is divided into four research areas:

- Environmental and algae surveillance on operational vessels for early detection and surveillance during emergency preparedness situations.
- Development of operational assistance service in danger and accident situations, for example, an emergency operations center
- Simulator based training and emergency drills
- Emergency response vessel designed to handle hazardous situations and accidents in coastal areas

The final point will be the focus of this thesis. The questions then become: What is emergency response? What is emergency response in Norwegian aquaculture? What critical situations should the industry be prepared for? What is an emergency response vessel? What needs are there to be covered? What needs can be covered by a response vessel? What are the functional requirements for such a ship and what could the design be like?

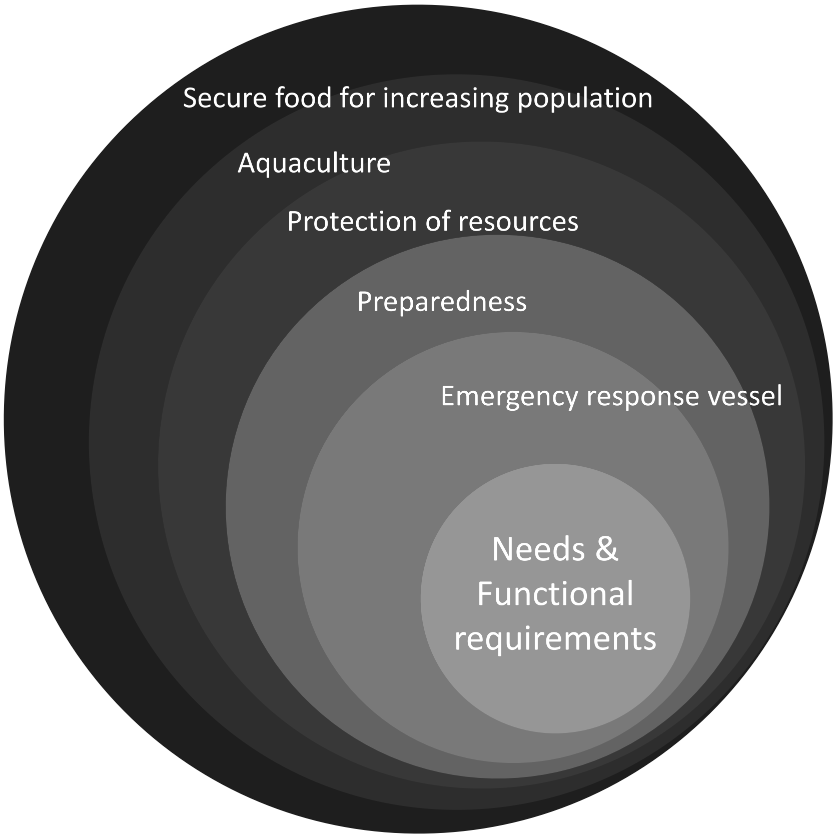


Figure 3.1: Overview of the project focus area

Answering the questions above becomes an important part of the thesis, asking them is a part of doing so. The needs of the aquaculture industry have to be assessed. This to truly understand what should be improved and how it can be done. Further, the questions on what needs should be covered are an important part of narrowing down the scope of a response vessel.

The preparedness of the industry should cover people, the environment, and assets. Since the people are already covered by rules and regulations, as well as the national rescue services, the focus for this thesis will be on the fish and the needs that the industry has regarding fish in crises situations. This is also a need that is seen across all the emergency scenarios studied and can therefore be said to be an important area of study. The focus will in part cover the protection of the environment through caring for the resources of the society as well as potentially avoiding mass escapes that can threaten the wild salmon stock.

The industry will need to be better prepared to handle crises where the biomass is put in danger. The goal will be to gain the most economic value from the fish stock given a crisis. With this goal set for the industry and the design, the scope is further reduced by excluding a key aspect of preventive work. Preventive here in the sense that the design will not have a role in reducing the chances of a crisis situation but can still prevent larger crises by acting swiftly.

The current fleet that handles fish in today's aquaculture industry is mainly wellboats with a small, but increasing amount being stun and bleed vessels, that process the fish at the pen by bleeding the fish and cooling it down. While most of the wellboats have large capacities, they are also large vessels with low operating speeds. For the salmon, a wellboat may not be the most suitable solution in a crisis. The fish may already be stressed due to the crises at hand and possibly weak due to the crisis situation. The stress levels will be raised further if transported in a wellboat. Large mortality may be a consequence. Here, the stun and bleed vessel has an advantage in that it bleeds the fish right away, eliminating the possibility of the fish dying onboard on the way to the slaughterhouse due to sickness or stress. At the same time the challenge of maintaining the quality of the bled fish. Furthermore, one of the challenges faced in a crisis situation could be large mortality and the quick accumulation of dead fish as experienced during the 2019 algae bloom [9]. None of the vessel types discussed have this capability. With the discussed ship types not being optimal the development of a dedicated design is needed to improve the preparedness.

With the goal above set, the question is how the yield from the fish stock can be maximized. This will be done by assessing all needs and possible functions of the different hazardous scenarios keeping the goal of maximizing the economic yield in mind. The choices in the design phase will be taken with this goal in mind. The method that will be used to develop the design will be presented in the next chapter.

Chapter 4

Method

This chapter describes how the theory presented in the literature study (ref. chapter 2) and mainly the part that covers design methodology (ref. section 2.4) is going to be used in a design procedure that will be utilized in the process of designing the emergency response vessel for the aquaculture industry.

A schematic of the procedure is presented on the next page. The process will follow the three first phases of systematic design: Task clarification, concept design, and embodiment design. All three phases will be covered in the thesis.

The first part will be the task clarification phase. In this phase, the expectations of the industry will be identified, as well as the concept of the project stated using the first modules of Ulstein's *Accelerated Business Development* (ABD). Furthermore, the needs of the vessel in the different crisis scenarios will be mapped and a selection of functional requirements needed to meet these selected using the principles of catalogue design to make selections based on established solutions. Preferably, the solution space would have been kept open longer in the design process, but this has not been done in this thesis due to the limited time available.

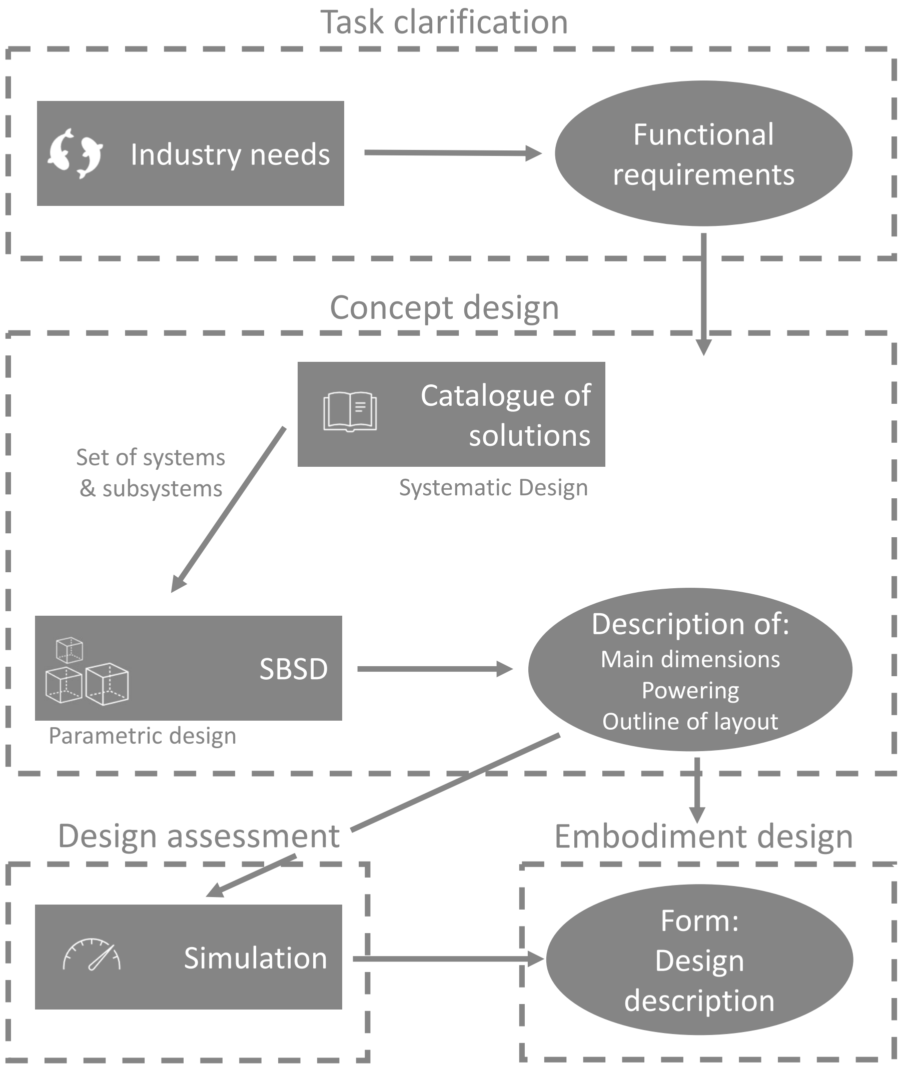


Figure 4.1: Design procedure

Having established the functions of focus the next phase of the design is the concept phase. In this phase, the method of system based ship design (SBSD) will be used. The concepts of modularity described earlier are used when dividing the different functions of the ship into systems. The principles of parametric design are applied when calculating factors for the ship type, using data from reference vessels and/or a database of a similar ship type. Initially, the main functions will be dimensioned, before the method will be used to establish the size of the different functions in the ship. These will be used to establish the main dimensions, the propulsion, as well as a rough outline of the vessel. The results of spaces for the different functions will also be used in the design of the arrangement.

The next phase is an analysis phase where the results from the concept design phase are assessed and compared to established designs from aquaculture. A discrete-event simulation tool will be used to compare response capabilities by simulating the time needed to carry out missions of varying sizes in different weather scenarios. This will be done to gain confidence in the design concept before continuing the development of the detailed design.

This will be done in the final phase of the process, the embodiment design. Here, the layout of the vessel will be developed with initial sketching of the placement of the volumes and areas established in the concept phase being done before the level of detail is increased and the detailed design developed. A general arrangement is the goal of this phase and the conclusion of all the design work done throughout the process.

Chapter 5

Task Clarification

The design phase of the thesis has been presented in chronological order. In reality, the process has been iterative, jumping between the different phases with no clear transition from one phase to another. The interrelationships and the most important cases where discoveries later in the design phase have led to new iterations being needed have been tried illustrated throughout the thesis. For a little extra insight into the design phase the reader is referred to the design log in Appendix A.

In this chapter, the needs of the ship will be identified and some functional requirements set for the design. This will be done by first carrying out a short ABD process to identify the stakeholders' expectations as well as do a SWOT analysis in order to better understand the needs of the different stakeholders and identify aspects that strengthen the projects and aspects that should be given extra attention due to being potential showstoppers.

5.1 Brief ABD

5.1.1 The Concept

The need: *Maximizing yield from the fish given emergency situations.*

The mission of the design is to contribute to salvage of biomass and good fish welfare in crisis and accident scenarios, as well as acting as a high functioning vessel in normal conditions. The ship should be one of the first at the site and act fast to save as much fish as possible.

5.1.2 Economics

The economic viability of the project was demonstrated by the consequences of the algae bloom of 2019, where huge values were lost. The project could reduce the risk of large economic losses, and without very large costs if spread on a region. Who the project owner should be and how the service will be paid for is a question of interest with no obvious solution. One suggestion could be that a shipowner that already operates in the same business segment, either service vessels, processing vessels, wellboats, or a combination could own and operate the boat. The ship could then be on hire for a region of fish farmers with a premium being paid if the services are needed. The fee would cover that the ship obliges to only take on missions in said region and that it terminates the current mission if a quick response is of need. It could also be a clause to the contract that the region that has paid for the services needs to use the normal services of the ship.

An issue arises if the need for the ship is larger than its capacity. This could very easily happen for example in a toxic algae bloom. The conundrum then of course becomes how the resources should be prioritized.

5.1.3 Performance expectations

The performance expectations vary with the stakeholders and the expectations of the most important stakeholders should be given more consideration. The main expectation is that the design is expected to have excellent performance in both ordinary operation and response mode and to be part of a profitable business. This is to a large extent the performance expectations of the ship owners. In addition, the expectations of other stakeholders should also be taken into consideration. A list of expectations of different stakeholders is presented in Figure 5.2.

Higher Influence	Stakeholders	Expectations	Interest	Influence	Type of influence
	Ship owner / operator	Wants the design to excel in both ordinary and response mode. Should be profitable.	High	High	Project owner. Has the last word in most matters and has the ability to make the project happen or not.
	Charterer(s) / Fish farmer	Wants to get the maximum yield from the fish stock in crisis situation for a reasonable price. Wants to feel safe and insured.	High	Medium	Will not buy the service if it does not meet expectations. Need to link up with existing infrastructure.
	Shareholders	Profitable project that leads to dividends and or increased stock price.	High	Medium	Can vote on decisions
	Classification society	A safe design that is up to protocol.	Medium	High	Will approve the vessel design.
	Government		Medium	Medium	Can change
	Crew	Functional design that makes work easier and good crew areas and facilities.	Medium	Medium	A good workplace can increase interest for work leading to better candidates.
	Environmental / Animal Organizations	A design with low emissions that does not harm the environment or fish.	Medium	Low	Can cause negative attention harming the company reputation.
Lower Influence	Shipyard	Wants to win the contract and earn as much money as possible. Does also want the ship to be a good reference.	Medium	Low	Can delay the design, has influence on the final result. Will select the cheapest solutions that fit the spec.

Figure 5.1: Stakeholders Expectations

5.1.4 SWOT

The SWOT analysis is an analysis looking into the competitiveness of a business concept, product, or similar. A scheme for a SWOT analysis for the design and business concept is presented below. Important takeaways are that the design needs to focus on not becoming multi useless as well as ensuring that the strengths of the concept are excelling. Of the external factors, the opportunities can be said to outweigh the threats. The threat of fish farmers making deals with wellboats rather than going for a special vessel design should however be monitored. The deals with fish farmers should however in a design process be clarified early in the process.

Figure 5.2: Strengths, Weaknesses, Opportunities and Threats

5.2 Needs To Be Covered and Supporting Functions

Further, the needs and functions that could fulfill these were identified for the hazardous scenarios in focus for the thesis. This list can be found in Appendix B. The functions were then rated as strictly needed, could be needed, and not needed keeping the stated goal of maximizing the economic yield of the fish. Based on the rating of the functions a selection of functions to be focused on in the further design of the vessel was done and are listed below. During this process, a sketch for a concept with a buffer tank capacity was done. The sketch is presented below in Figure 5.3. This vessel would be fast sailing, first at the crisis site taking control of the situation and commencing operations quickly. The quick commencement of work is thought to possibly reduce the rate of death in salmon.

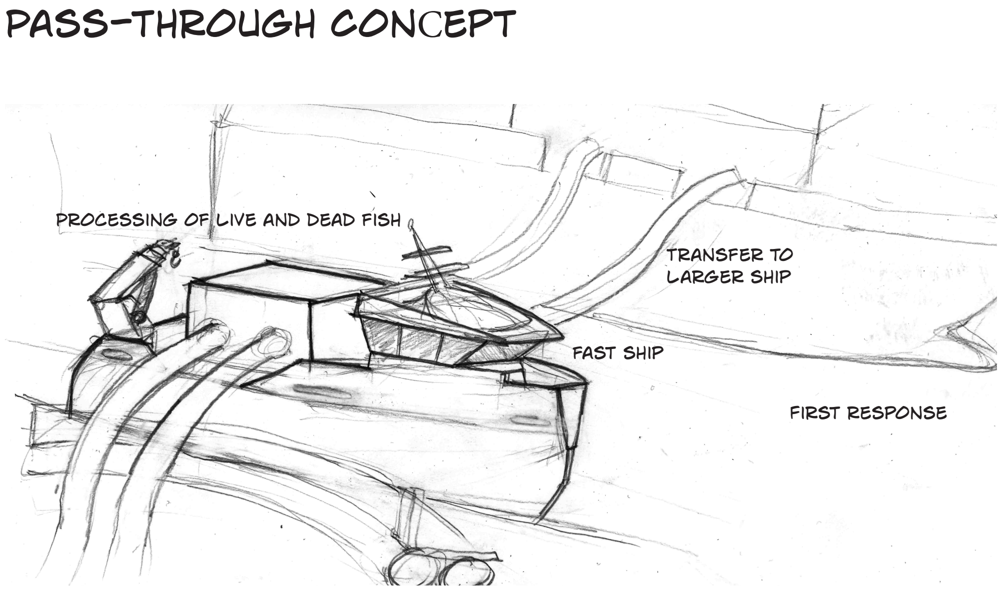


Figure 5.3: Sketch of the concept of a ship that can do ship to ship transfers of processed fish

The aspect of the buffer tank capacity was seen as a good way to increase the presence of the ship in the crisis area and increasing the utilization of all the gear installed. This was aspect was included in the functions of the design. The other selected functions are listed below.

Emergency stun and bleed

There is a need for stun and bleed capacity. The needed rate should be tried assessed. The number should be calculated based on how long time is available. This would perhaps vary for the different scenarios. Additionally, the response time should be included in the assessment.

RSW tank capacity

There is a need for tank capacity in combination with a stun and bleed plant. This to chill down and ensure the quality of the salmon. The size of storage should be considered. In a first response scenario, where the ship is first at the site and commences and takes control of the situation before support arrives, the time window and rate will be factors dimensioning the needed storage size. It should be considered if this size is large enough for the normal operation, and what value RSW storage provides in normal operation.

Cranes

The normal crane capacity for pumping is needed. Additionally, the need of keeping the pen afloat if buoyancy is lost due to fire is mentioned. This is perhaps too large a load. The ship would also need additional stability. This need is considered to perhaps be too complicated to be handled by the response vessel being designed. An option could be a system of adding buoyancy to the flotation ring. This would probably only be an option if the fire is put out.

Pumps

Pump capacity is needed to match both the emergency slaughter need and the needed rate of dead fish pumping. If the dead fish is needed to be pumped simultaneous to the fish being stun and bled, thus should be taken into account. The pump capacity may also need to be sized to handle ship-to-ship transfer of fish if this is needed in the design solution. Finally, the pump capacity should be assessed to see if it is large enough to service firefighting equipment.

Later in the design process, the focus was switched from grinding the dead fish and producing ensilage to keeping the dead fish chilled whole chilled in RSW. This is due to the strict regulations on ensilage in ships as well as the stated goal of maximizing the economic yield. Whole dead fish can be sorted into two gradings where the best one can be used in fish meal and oil while the other one is made to ensilage. This results in a better price and a higher grade of the end product for the dead fish. Ideally, the ship should be able to sort the different categories of dead fish. There is no good, automatic, solution to this today, and so it would have to be done manually. The cost-benefit should be studied if to be implemented. With the rapid development of gear that utilizes machine learning to recognize species, among other things, the idea of a machine that can grade the fish automatically is not far-fetched.

Tubes

In combination with the pumping system of fish, there is a need for tubes and or similar systems to guide the flow of fish in the ship. This system must be dimensioned to fit the flow rate and should be designed to best treat live fish and maintain the quality of dead fish.

Lights

The need for good lighting to be able to carry out operations in conditions with low light levels is needed.

Hotel

The vessel needs to be equipped with hotel functions for the crew. The size will in part be determined by the size of the crew. The functions should include a galley, mess, day room, and cabins. Some of these functions might overlap.

Quite late in the concept design phase awareness was made of the need for two shifts of workers in crisis situations where the ship will be processing around the clock. This led to an increase of the crew size quite late in the design process.

Design Speed

The ship needs a high design speed in order to quickly arrive at the crisis site and gain control of the situation. A design speed of 19 knots was decided on in this phase. Due to the ship size not being known at the time the quite hefty consequences of introducing such a high design speed were not discovered until later in the concept design phase. This will be discussed further later.

The selected functions to be focused on will then be brought into the concept design phase where the method of system based design will be used to establish the spaces needed for the different functions. Both the functions stated above and functions more generally needed for ships, such as engine spaces. This will be covered in the next part of the thesis.

Chapter 6

Concept Design

This chapter will present the results from the System Based Ship Design process as well as discuss the pros and cons of the method. An outline of the design will be established in the chapter.

6.1 Dimensioning of The Main Function

An important part of the design is the parameters surrounding the main task of stunning and bleeding the fish. This should be given extra attention since it is the main activity and focus of the ship, and it could also quickly be the parameters that to a large extent dimensions the ship due to it being a voluminous activity in what very likely will be a volume critical design.

To determine the needed size of the different components of the main functions, the approach will be to settle on a good estimation of the time window where the ship will be without the support. The rate of the stun and bleed plant and the RSW tank capacity will then be scaled to achieve the goal within the time window. The goal for the ship is to process a high enough amount of fish for the fish pens to sustain a crisis situation long enough for support to arrive. By processing the fish, the rate of death is decreased and the probability of a system collapse lowered while the process of handling the fish is started. How much fish needs to be processed is uncertain. The assumption that 35% of a fish pen, equal to 54, 600 fishes (or about 275 tonnes) is sufficient is made for this thesis. Further investigations should be made into what the limit could be and what factors and external parameters contribute to this number. To accommodate some flexibility, the storage capacity is rounded up to 300 tonnes. This size is the same size as some of the stun and bleed vessels operating today, such as Taupo and Taupiri of the shipping company Napier [43]. This is a good indicator that the ship can be highly functional in normal operation.

The estimation of the time window is done by investigating the ship traffic in a region. For this study, the geographical focus area that is selected is the area defined as *production area 7 - Northern Trøndelag with Bindal* by the Norwegian Directorate of Fisheries. The same area will be used for the simulation presented later in the report and the geographical area will be described in further detail in chapter 7.1.2. AIS data showing the traffic of ships related to the aquaculture industry for a week, found at the Barentswatch website is analyzed [44]. All ships of relevance are logged with the amount of time spent in the region and the number of visits to fish farm locations, slaughterhouses, or if they are only passing through the area. The focus in the study is put on the availability of wellboats, while data for other ship types are presented and suggested for use in further work. A summary of the data obtained for the wellboats can be found in the table below, while the complete set of data and study can be found in Appendix C.1.

Table 6.1: Data and calculations of available wellboats in the region

Number of ships observed	17
Ship Days per week	30,3
Ship days per day [days]	4,3
Ship Hours per day [hours]	103,7
Avg amount of ships available at any hour of the day	4,3
Prob. of one ship ready	0,3
Expected number of ships ready at any hour of the day	1,30

In addition to listing the number of ship observations of wellboats, the expected number of ships available at any time is estimated to be 1,3. A time of 2 hours to prepare for response is assumed leading to two hours being the minimum possible response time. Time to prepare for response is the time from the first notification to the ship is underway. Furthermore, the mean distance in the region, of 43 nm together with an assumed speed of 12 kn is used to calculate a mean response time of 3,6 hours. Here, a geographical uniform distribution is assumed. Looking at the geographical area and how the fish farm locations are spread as well as how the traffic situation is, this can be said to be a fair assumption for this use. To account for the availability of ships and how the probability that the nearest ship is closer than the mean distance increases when there are more ships available, this has been modeled quite simple by dividing the sailing time by the number of ships available. In practice, this means that the sailing time for the nearest available ship is halved if the number of available ships is doubled. This model returns reasonable numbers for this ship type, in the given geographical area. A better way to model the impact of ship density on response time is something that would be interesting to study in itself, especially when developing a response plan for a larger area, for example for the Norwegian aquaculture industry as a whole. Using this method, a mean sailing time of 2,8 hours is calculated. Combined with a response time of two hours the mean total response time is 4,77 hours. Plotted below, is the probabilistic distribution and cumulative probability using the mean total response time and a standard deviation of 1,5 hours. From the plot, we can see that for a cumulative probability of 90%, the response time is about 7 hours. While the plot starts at 0 hours response time, 2 hours will be used as the lower end of the time window. A response time between 2 and 7 hours is the time that will be used in further calculations of time windows, although the extreme cases might be an even longer response time.

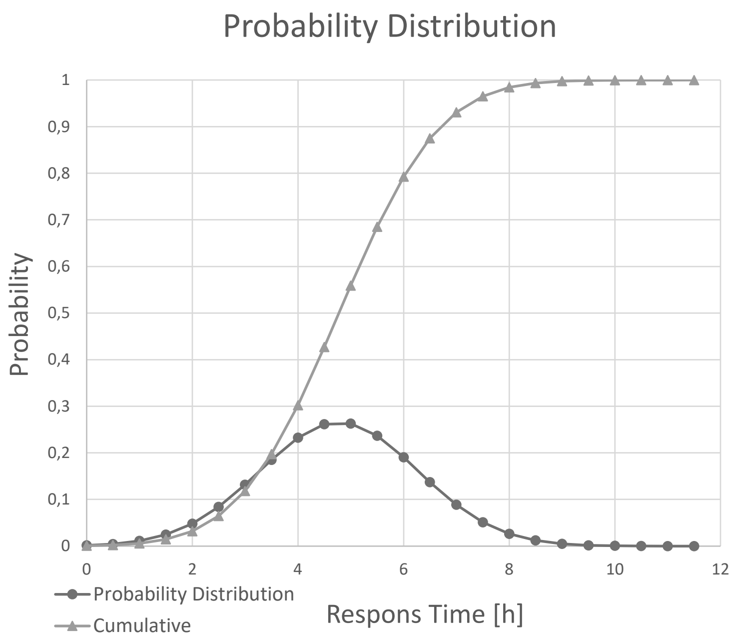


Figure 6.1: Probabilistic distribution of response time for wellboats in the region

An element that should be taken into the consideration is the hesitation of contacting wellboats at the first signs of a crisis. This will mean an increased time regardless of whether there is a free wellboat in the area at the time of crisis or not. The threshold for contacting the response vessel should on the other hand be low. This could be ensured through the type of contract the vessel is on. Although not taken into account here, it is a strong argument for the use of a dedicated response vessel for early action in potential crises.

The response of the designed vessel also needs to be estimated to calculate the window of time where the vessel will be the lone vessel at the location, apart from smaller working vessels. This time has simply been calculated using the design speed of 19 kn and an average distance of 43 nm. The design speed was established earlier on in the section on task clarification. The result is a response time of 2,3 hours and a time window of 6,7 hours. A scenario of 10% mortality in a pen with 780 tonnes of salmon, 156 000 individuals averaging at 5kg is assumed, with a constant mortality rate of 1% of the original volume dying per hour. The input data for the scenario is presented in table 6.2 below.

Table 6.2: Scenario input for dimensioning fish handling equipment

Support response	9	[h]
Vessel Speed	19	[kn]
Avg. Distance	43	[nm]
Response time	2,3	[h]
Time window	6,7	[h]
Live fish		
# of pens	[tonnes]	Number of fish (5 kg)
1	780	156000
Dead fish at Arrival		
% Dead 10 %	Tonnes 78	Number of fish (5 kg) 15600
Fish death rate		
% per hour 1,0 %	Tonnes per hour 7,8	Number of fish per hour (5 kg) 1560

To dimension, the fish handling gear, as well as tank capacities needed in the ship, some targets had to be set for how much fish the ship should be able to process during the time window where the vessel is first at site. It should again be made clear that this is the buffer capacity of the ship. Some assumptions had to be made as to what could be considered the target value. The goal of the vessel is to arrive and gain control over the situation before support arrives. In situations where there is large fish mortality, this would mean removing live fish from the pen to reduce the crowding and resulting stress of the live fish, as well as removing dead fish to reduce congestion of dead fish and reduce the mortality rate. Detailed studies and collaboration with biologists would be interesting to better understand what happens in a fish pen during a crisis and how the intervention of a response ship can better the situation. This could lead to target values. For this thesis, however, an assumption is made and goals set for the ship. For live fish handling the goal is set to process 35% of a full pen, that is 273 tonnes. For the dead fish, the goal was set to process all the fish dead at arrival as well as the fish dying during the rest of the time window. The targets and resulting rates needed are presented in table 6.3. The result of the study is a need for a processing rate of 135 fish/min and an RSW tank capacity of 366 m^3 for the live fish and a processing rate of 65 fish/min and RSW tank capacity of 175 m^3 for the dead fish. To provide some extra buffer as well as capacity in normal operation an RSW capacity of 400 m^3 for live fish and 200 m^3 for dead fish.

Table 6.3: Target values and needed rates for fish processing

Live fish		
Goal:		Unit
Percentage of 1 pen	35 %	[%]
Number of fishes	54600	[Count]
Tonns of fish	273	[Tonns]

Need:		
Rate	135	[fish/min]
Fish (5kg avg.)	273	[tonnes]
Fish volume	256	[m3]
RSW needed (70% fish)	366	[m3]
RSW Selected	400	[m3]

Dead fish		
Goal:		Unit
Percentage of the dead fish	100 %	[%]
Number of fishes	26109	[Count]
Tonns of fish	131	[Tonns]

Need:		
Rate	64,6	[fish/min]
Fish (5kg avg.)	130,5	[tonnes]
Fish volume	123	[m3]
RSW needed (70% fish)	175	[m3]
RSW Selected	200	[m3]

Further on the resulting rates of the above study are used to try to equip the ship with suitable gear for handling the fish. This was done in collaboration with representatives from Optimar, a manufacturer of fish handling gear. Valuable insight and information were provided on how to equip a ship to meet the requirements uncovered by the study were provided in meetings. The equipment list is presented in table 6.4. Some values were provided in fish per minute while others were established from experience from ships of similar size. The needed size of the RSW plant was established with its own study presented later on.

Table 6.4: Equipment list

Name	Producer	# Units	Fish/min	Tot. fish/min
Feeder/stun/bleed	Optimar	2,0	90	180
Bleeding tube	Optimar	1,0	200	200
Pumps Live fish	SeaQuest	1,0	200	200
Pumps for discharging fish for consumption	Cflow	1,0	150	150
Pumps deadfish	Cflow	1,0	150	150
RSW Plant	Frio Nordica	2,0	-	-
Washing system	Skjong	1,0	-	-
UV & partikkel -fiklter	-	2,0	-	-
Ozone-plant	-	1,0	-	-
Min. Live / Dead				180/150

6.1.1 RSW Plant

The dimensioning of the plant was done by studying the cooling capacity needed in order to both cool seawater before the processing commences and salmon to the target temperature in a satisfying manner. To calculate the needed cooling capacity the formula for cooling capacity presented below is used [45].

$$Q = \frac{m \cdot C_p \cdot \Delta T}{t} \tag{6.1}$$

Calculations were made for both cases and the cooling of salmon turned out to be the most power-consuming process and hence became dimensioning for both the live and dead fish. The calculations and resulting choices are presented in Table 6.5 on the next page. The total needed cooling capacity was calculated to be about 1340 kW. In talks with Optimar, a choice was made to equip the ship with two RSW plants of 640 kW each and a total cooling capacity of 1280 kw. While the cooling capacity of the RSW plant is 1280kW the needed electrical input can be estimated to a quarter of this, 320 kW. This combination of plants was thought to be the most suitable despite being a little lower than the calculated need. This is due to the increased redundancy of having two equal and quite large plants compared to the combination of one large and one smaller plant (that would fit the needed cooling capacity better) in the case of failure in one of the systems. With the installed plant it would take 5 hours to cool down the live salmon and 7,5 hours to cool down the dead salmon. Although there is a significant difference in the target value the result can be said to be acceptable. The variations of processing rates mean that the cooling power could be diverted where it is needed the most. This is especially the case for the dead fish, where the needed rate of processing drops once the accumulated dead fish has been handled. In this case, a larger part of the RSW plant's capacity could be used for the cooling of fish for human consumption.

Table 6.5: Calculation of needed RSW plant cooling capacity

LIVE			DEAD		
Input					
Tank capacity	[m3]	400	Tank capacity	[m3]	200
Filling needed to start in two tanks	[%]	40 %	Filling needed to start	[%]	40 %
RSW	[t]	49,2	RSW	[t]	24,6
Salmon	[t]	273	Salmon	[t]	130,5
Temp RSW	[C]	0,5	Temp RSW	[C]	3
Temp Sea	[C]	17	Temp Sea	[C]	17
Temp Salmon	[C]	17	Temp Salmon	[C]	17
Time to cool sea water	[h]	2,5	Time to cool sea water	[h]	2,5
Time to cool salmon	[h]	4	Time to cool salmon	[h]	6
Cp_sea	[J/kg K]	4020	Cp_sea	[J/kg K]	4020
Cp_salmon	[J/kg K]	3368	Cp_salmon	[J/kg K]	3368
Result					
Cooling Sea Water			**Cooling Sea Water**		
Cooling capacity needed	[kW]	362,6	Cooling capacity needed	[kW]	153,8
Time to cool fish	[h]	13,9	Time to cool fish	[h]	13,3
Cooling Salmon			**Cooling Salmon**		
Cooling capacity needed	[kW]	1053,6	Cooling capacity needed	[kW]	285,0
Time to cool seawater	[h]	0,9	Time to cool seawater	[h]	1,3
Selected					
Cooling Capacity		1054	Cooling capacity		285
Total					
Calculated max capacity	[kW]	1339			
Installed	[kW]	**1280**			
Time to cool seawater	[h]	1,1			
Energy needed for initial cooling	[kWh]	340			
		Live			Dead
Time to cool salmon	[h]	5,0		[h]	7,5

6.2 Machinery Dimensioning

6.2.1 Propulsion Power

For the machinery, a method for early estimation is used for the estimation of the needed propulsion power of the ship. This is due to hydrodynamics not being a focus of the design process. The method chosen was the use of an admiralty coefficient based on vessels in the same segment as the new proposed design. Through the admiralty formula, the power needed on the propeller can be estimated with the displacement and the speed of the vessel. The formula can be seen below. The process was also selected because the machinery could be scaled to the size of the ship without a time-consuming iterative process.

$$P_B = \frac{\Delta^{2/3} \cdot V^3}{A_C} \tag{6.2}$$

An average admiralty coefficient was calculated based on reference vessels. All these vessels are stun and bleed vessels, one larger, two moderate ones, and two small ones. The results of the process are presented in the table below while the calculations can be found in Appendix C.2. Due to some small calculation errors, 3330 kW was used for the calculations of areas, volumes, and weights.

Table 6.6: Admiralty Coefficient

Ship Name	Speed	Displacement	Power	Admirality Coefficient
Average	12,7	1012	790	251,0
Design	19	1312	3300	251,0

There are some uncertainties regarding the coefficient since the displacements of the reference vessels are not disclosed to the public and hence had to be estimated. This was done by using the main dimensions and design speed found in the ship database of *Shipping Publications*, estimating a rough block coefficient from the ship type as well as based on pictures of the hull shapes (as illustrated in Figure 6.2 [46]) and by reading the draft off pictures of the ships found on the internet where the draft is marked on the hull [47].

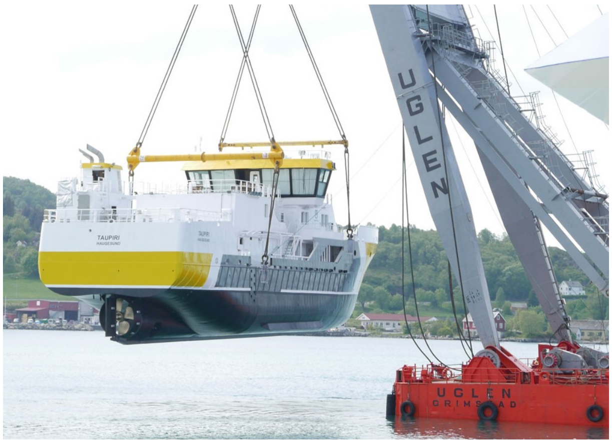


Figure 6.2: Picture showing the hull shape of Taupiri [46]

In addition to this, there was uncertainty in the numbers found on the propulsion power with the values varying between different sources. Apart from the uncertainties in the input variables, the selected method may not be optimal due to the large difference in design speed. The formula is an empirical formula that works well scaling between similar values. It scales the power with the vessel speed to the power of three and this scaling factor might not be the case for such high vessel speeds. Overall the process can however be said to have provided the needed first estimates, but should also be treated as just that, estimates. More attention should be given to the hydrodynamics with regard to the propulsion and needed machinery in further development of the design and further thought be given to the possibility of reducing the design speed some, due to the large power need at such a high velocity. Reflection on this was done at a too late stage in the design process to do large changes and so the proceeding design will have a design speed of 19 knots.

In addition to the power needed for propulsion, there is an additional need for power for other loads such as hotels and equipment such as cranes, pumps, fish handling equipment, etc. Most of these loads being relatively small compared to the power needed for propulsion and not in use during full steam. The largest of these loads will be from the RSW cooling system. To try and keep the size of the main engine as low as possible, power has been set to the propulsion power needed. While the power capacity might be stretched a bit this will be solved by adding a battery pack for peak shaving and that can act as a booster for shorter amounts of time. This will be covered in the following section.

For the propulsion, a pod powered by an electrical engine was selected. This to have good maneuverability without the need for a stern tunnel thruster. Due to the selection of a battery as well as a pod for propulsion the engine system has been chosen to be diesel-electric with a single generator set.

6.2.2 Battery Pack

A battery pack will be selected for the ship. The battery pack will be used for peak shaving to take on larger loads for smaller amounts of time. This is done to ensure a more even load on the generator, operating the generator at optimal conditions and could also mean a reduced need of maximum power of the generator. Due to the large difference of load during sailing and processing, the generator set can be operated in a way where it is turned on and operated at optimal conditions to charge the battery while the battery is used to provide the needed power to the processing gear.

For the selection of a battery, a parametric approach was made due to the fact that the propulsion system and assisting battery pack has not been a main focus in this thesis. A ratio of how large the energy storage systems of the reference ships are compared to the size of the main engine is calculated, and the average value used for the design of the response vessel. All the reference vessels are vessels installed with battery packs from the manufacturer *Corvus*, and the data, as well as the size of the needed pack, was obtained at their websites [48]. The data on the engine size was found in the ship database of *Shipping Publications* [47]. All the ships are either operating in the fishing or aquaculture segment. The ships are respectively two purse seiners, a processing vessel, a wellboat, and a long line fishing vessel. The result was a ratio of 0,122 kWh per kW of main engine power, resulting in a battery size of 400 kWh for the designed response vessel. The calculations and results can be found below in Table 6.7. This study can be said to be a simple one and the large variations in the ratio of the reference vessels suggest that the ships use the battery packs in different ways and that more time should be used to study what solution fits the response vessel best. However, the study gives a good indication and quick indication of the battery pack needed in a vessel of this size.

Table 6.7: Battery Study

Ship Name	Main Engine Size [kW]	Battery Size [kWh]	Ratio
Libas	6000	508	0,085
Hardhaus	4880	1000	0,205
Norwegian Gannet	5300	305	0,058
Hordagut	5529	994	0,180
Atlantic	2500	203	0,081
Avg			0,122
Response vessel	3300	403	
Result:		400	

Looking at the load of 320 kW from the RSW plant and the needed time of 1,1 hours the energy need would be about 340kWh. The conclusion is that the battery pack selected from the parametric study is large enough to take on the cooling of the RSW needed for the initial filling of the tanks and commencement of processing.

6.2.3 Machinery Space

For the machinery space, the ratios for offshore vessels quickly proved to return values on an over-dimensioned machinery. To gain some better indications of the size of the machine room a study was carried out using the general arrangement of a trawler with freezing storage of the fish. The ship is the trawler named *Doggi* owned by Lerøy Havfisk [49]. The arrangement of the ship was an attachment to a Master's thesis from 2018, written at NTNU [50]. This ship was more of the same size and has a compact arrangement as well as parallels between the spaces needed for the freezing plant and RSW plant of the response vessel. An aquaculture vessel would of course be preferred, but no general arrangements were obtained. The machinery space was measured and compared to the installed engine power. Using the same ratio of space to engine power, an estimation of a needed machine room of 188 m^2 was made. Details on the measurements from the arrangements and calculations of the ratio can be found in Appendix C.3.

6.3 Tank Spaces

The tank spaces are estimated. The fuel and lubricants are based on the size of the main engine, the specific fuel consumption, and a decided range of 3000 nm, meaning an endurance of 6.6 days with the ship sailing at 19 knots. The fresh water and sewage tanks are estimated based on usage per crew and a 14 day endurance for the freshwater (essentially 24 days with a crew of 14 in normal operations). An endurance of 3 days has was set for the sewage, meaning it has to be dumped every 3 days. The needed tanks for live fish, dead fish, and blood water are based on the calculations of the main function's dimension. The results are presented briefly in the table below, while calculations can be found in Appendix C.4.

Table 6.8: Tank Spaces

Tank type	Volume[m3]
Fuel	118
Lubricant	3
Fresh Water	81
Suage & Greywater	17
RSW - Live fish	400
Chemicals for cleaning	25
RSW - Dead fish	175
Blood water	40
Ballast, side tanks	100
Ballast, duble bottom	100
Voids	50
Total	1109

6.4 Space For Equipment

The spaces needed to fit the equipment of the ship were estimated. Included in this category is are deck equipment such as cranes and mooring equipment, open decks, The calculations were in part done based on the discussions held with Optimar with regards to the fish handling and processing related equipment, and by using established ratios from the compendium as well as data found on the web for specific equipment. To account for the additional space needed around some of the equipment the covered area was estimated by adding a percentage to the footprint of the equipment. The volume was estimated by multiplying the area needed with the deck height for equipment that was to be placed in enclosed decks while the volume of the equipment placed on deck is not of importance other than the height not being in conflict with operations or line of sight from the bridge. The result of the calculations was a needed area of 464 m^2 and a volume of 741 m^3. The full list of equipment and their calculated contribution to the needed area can be found in Appendix C.5.

6.5 Crew & Service Areas

For the crew areas, most of the spaces needed are calculated based on the size of the crew which as stated earlier has been set to be 24 at maximum. The number has however been set to 14 for some of the areas such as the mess. This is due to the fact that the ship normally will be operated with a crew of 12 - 14 persons. In the instances where the ship is operated with two shifts processing around the clock, the need for crew recreational spaces will not be twice as large as in normal operations since everyone will not be using these areas at the same time. To solve the high demand of cabin spaces, 10 of the cabins have been designed to be two-person cabins. This solution reduces the accommodation space drastically. The two shifts will also not be using the cabin at the same time. In addition to the accommodation spaces the bridge, office spaces, and assisting spaces such as galley, washing rooms, stores, and AC plant have been estimated. The result is a needed area of 350 m^2 and volume of 990 m^3 for the accommodation spaces and 270 m^2 and volume of 770 m^3 for the service areas. The calculations and results are presented in Appendix C.6.

6.5.1 Summary of Spaces

When the needed space for all the functions had been found they were summed up together to get a better overview of the needed areas, volumes, and the resulting gross volume and gross tonnage. The summary is presented below. The summary of the spaces will be used to estimate the displacement of the ship. This will be discussed in the following section.

Table 6.9: Summary of the needed spaces

	m2/DWT	m3/DWT	Area [m2]	Volume [m3]
Total Main Function	0,73	0,26	293	104
Total Ship Equipment	1,03	1,78	414	720
Total Accommadation	0,86	2,45	349	989
Total Service	0,67	1,90	270	768
Total Machine Room	0,36	3,19	145	1287
Total Tanks	-	2,75	-	1109
Gross Area & Gross Volume			1470,5	4977,5
Gross Tonnage				1363,5

6.6 Weight Estimation

The summarized spaces are then used to estimate the weight of the ship using different ratios on weight per volume established in the compendium on system based ship design [34]. Some of the weights are established based on the size of the spaces while others are calculated based on certain values, such as for example the weight of the fish. The weight of the hull structure was estimated from the volume of the hull, how this was established is explained in the next section. The calculations are presented in Appendix C.7. The result is a total displacement of 1312 tonnes, with 869 being allocated to deadweight and the remaining 443 being the lightship weight.

6.7 Hull Size & Shape

With all the needed spaces and the weights estimated the process of designing a hull that could fit all the different functions was started. The first part of this process was designing a numerical hull in a spreadsheet. The hull shape was estimated based on established curves on the change in waterplane area coefficient and block coefficient as a function of the height above the baseline per draft (h/T). This returned how the deck areas and volumes vary for each deck due to the hull shape. The superstructure was also modeled. The total area and volume was then controlled to be suitable for the needed spaces established from the earlier studies. The length and beam of the ship were changed to get the needed areas and volumes while keeping an eye on the ratios of length to beam as well as depth to beam and controlling that the ratios were within the same range as the reference vessels. Finally, to obtain the wanted block coefficient the draft was changed while the length and beam were fixed and the displacement established in the weight estimation used. In order to have the displacement estimated the numerical hull was needed. The numerical hull is presented in Appendix C.8. The next step was to model the hull.

Since hull modeling is not an area of focus for this thesis a hull provided by the co-supervisor was used as a baseline for the hull design. A picture of the hull shape displaying the lines on the hull is presented below in Figure 6.3. This hull has a length of 100 meters, a beam of 20 meters, and a molded depth of 12 meters. The block coefficient of the hull was 0,70.

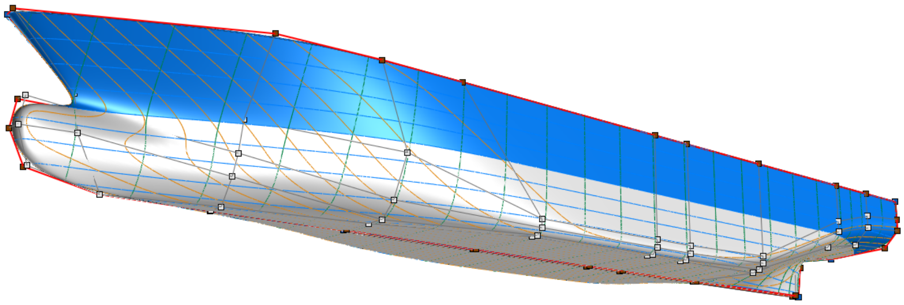


Figure 6.3: The starting point for modelling the hull shape

The base hull was then first scaled in the x, y, and z-direction in order to obtain the intended waterline length, beam, and depth to the main deck. Furthermore, adjustments had to be made to the lines to take the block coefficient down from 0,7 towards the target of 0,55. This was done by reducing the amount of flat ship side moving the control points that define the ship side towards the longitudinal center of the ship. Moving this to the center of the ship reduced the block coefficient to a satisfying level, but left the ship without any flat ship side. The design needs a flat shipside when mooring at a fish pen during processing. Hence other measures had to be taken. The control points were moved to an intermediate position leaving enough flat ship side. To further reduce the block coefficient adjustments were done to the midsection of the ship. A rounder bilge was modeled and the block coefficient further reduced. At this point, a block coefficient of 0,58 was obtained. The coefficient could have been reduced further by either increasing the radius of the rounding of the bilge or by doing a deadrise. This is however believed to not have a great effect on the resistance. The deadrise would decrease the block coefficient, but also increase the wetted area and so it is uncertain what the effect would be on the resistance. Since the hydrodynamics are not the main focus of the thesis the block coefficient was said to be satisfying with regards to the original objective of a ship with lines for relatively fast transit. The resulting hull shape used for the rest of the design phase can be seen in the figure below, while a lines plan is included in Appendix D.3 for a more detailed description. The main dimensions ended up being the same as established for the numerical hull, while the increase in block coefficient led to a new and lower draft of 3,5 meters.

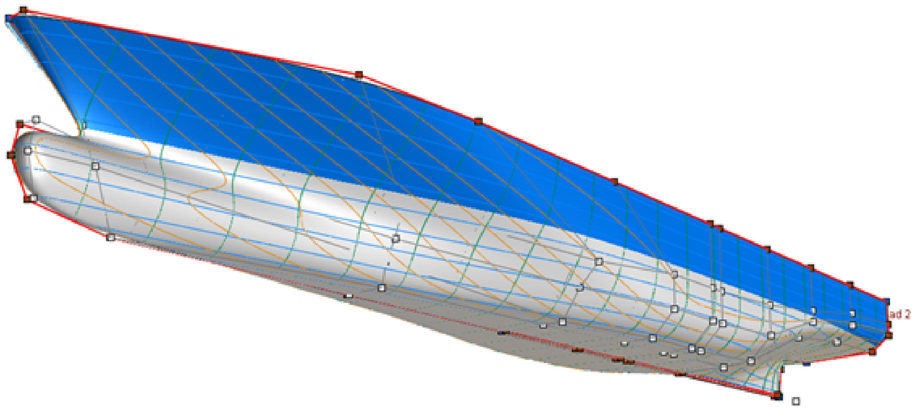


Figure 6.4: Hull Shape

6.8 Stability Check

A stability check was performed to ensure that the estimated stability of the ship was satisfying before proceeding with the design. This to uncover any stability issues early in the design phase so that measures could be taken to either move heavy functions down in the ship or make adjustments to the hull to increase the stability. This was not needed in this case where the metacentric height was estimated to be about 3,5 meters based on the weights from the weight estimation and their rough vertical placement in the ship. This indicates that the ship is stable and with a good margin. Hence one could move on in the design process with confidence in the stability of the design. The stability will in addition be assessed in greater detail later in the design process when the tanks have been modeled. This will be presented in section 8.4.1. The stability check can be found in Appendix C.9.

6.9 Summary

From the system based ship design method the spaces needed as well as the weight of different systems have been established. In addition to this, the main dimensions of a hull were established and the hull designed as well. The next step of the design process is using these data to try and create a good arrangement for the design. This will first be done by placing the volumes of the systems before developing a more detailed arrangement through several revisions.

6.10 Discussion of System Based Ship Design as Method

The system based method has its pros and cons. It is a powerful tool as a parametric method when the data that lays to ground is good. When the database of ships that are being used does not quite fit the vessel type that is being designed it takes some tweaking to get reasonable results and so the time spent in this phase also increases. Although most of the ratios are from the section on offshore vessels in the system based ship design compendium some studies had to be done for parts of the design such as the machinery space. This is due to the fact that the ship is smaller and more compact and has more functions that are overlapping both in use of space and the needs they cover. This can be said to be a weakness of the system based method when using it for smaller ships where it is harder to define the space used for different functions for the reference vessels. The quality of solving this by looking at one solution and scaling this one to fit the new design could be discussed. While it does not have the advantage of being based on several reference vessels and gaining the rigor of a proper parametric method it does have the advantage that the designer does know exactly what is included of functions in the spaces covered, where one would have to trust a database blindly.

Chapter 7

Design Analysis

Added insight through discrete event simulation

This chapter will cover the work of developing a tool for initial analysis of the design concept. In this case, a simulation tool. The simulation tool presented in this thesis has its basis in a tool developed in the project thesis of the candidate [4]. Some of the descriptions of how the simulation is built up and works were also written as part of the project thesis. This simulation tool was developed to assess how well the response capability of the developed design is compared to different design concepts. This was done by testing different designs for the same missions and comparing how much time the designs use on the different parts of the mission. For this thesis, small changes will be made to the tool in order to be able to apply it to the new design developed in the thesis, and gain insight into the performance of the vessel in response compared to already established design types. The tool was developed before handling of dead fish was identified as an important measure of merit. The simulation, therefore, focuses on the handling of fish for human consumption and the dead fish handling has to be seen as an additional attribute of the designed response vessel. This will be discussed further in the chapter.

7.1 Simulation Description

7.1.1 Simulation method

As stated, the goal of the simulation is to assess the response capabilities of different designs. This will be done by constructing a set of missions that need to be carried out by the designs. The missions will vary in size, distance, and inertial conditions. The designs will do the same set of missions three times, with the sea state varying for each set. The performances will then be compared. The components and architecture of the simulation model is described in Appendix E.2

7.1.2 Location

The geographical focus area of the project is the area defined by the Norwegian Directorate of Fisheries as *production area 7 - Northern Trøndelag with Bindal.* The area is shown in the map below, gathered from the map and information service Barentswatch [44]. The sailing distances and weather will be based on this area.

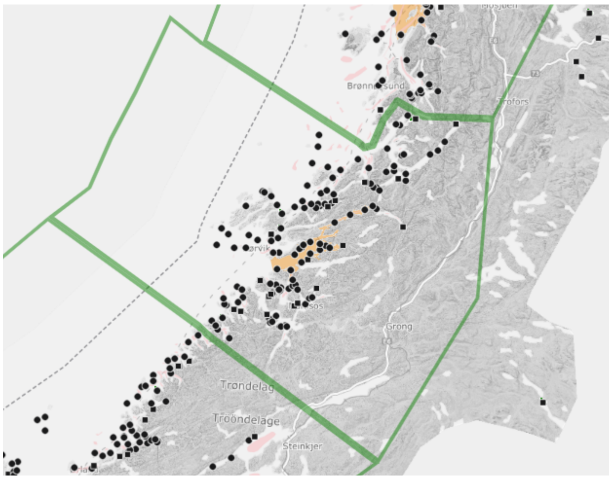


Figure 7.1: Production Area 7 - Northern Trøndelag with Bindal [44]

7.1.3 Weather

In order to simulate how the different designs perform in the geographical area, weather data and specifically wave height for the selected area were used. A data set of 6 geographical points was obtained. Rather than modeling a simulation where the geographical point being used changes with the location of the ship, an average of all the points was created in order to get a weather situation that represents the whole region. Although a simplification, this can be considered a fair one, considering the rather small geographical area. The largest inaccuracy of the weather simulation could be that the natural change in wave heights due to sheltered waters is not represented. It can however be assumed that this does not have an impact on the validity of the results given the level of detail that this simulation covering. The weather data was then processed using the Markov chain method. This was in part done to create sufficiently long data sets, but mainly to create data sets that start at predetermined sea states. This is done to test the designs in different environmental conditions without having to simulate for a whole year. The ships will be run through a weather scenario starting at a low medium and high sea state. The sea states are presented in the table below.

Table 7.1: Defined sea states for the simulation

Sea State number	1	2	3	4	5	6
Wave height [m]	0,77	1,53	2,30	3,06	3,83	4,59

Sea State number	7	8	9	10	11	12
Wave height [m]	5,36	6,12	6,89	7,65	8,42	9,18

The sea states will affect the performance of the vessels in two ways. If the sea state is larger than the operational limit of the vessel, the ship will have to wait for better weather. To solve this in the simulation, a perfect weather forecast has been assumed. This means that the ship knows when a long enough weather window opens, at the time it opens. This will in reality mean a shorter waiting time than in a real situation. The second way the sea states will have an effect on ship performance is the sailing time. Here, the ship speed has been modeled with a reduction factor that increases exponentially with the increasing sea states.

7.1.4 Designs

Four different designs are tested in the simulation. The first design is a concept established in the early sketching and idea phase of the project. This was the design that was used to test the feasibility of the concept in the project thesis. The second and third designs are based on existing ship types in aquaculture shipping, while the fourth design is the vessel design developed in this thesis. The four different ships and their respective design parameters will be presented in this section. A summary of the design parameters are presented below:

Table 7.2: Design description of different ships to be simulated

No.	Speed [kn]	Storage [tonnes]	S&B [t/h]	Op. Lim [sea state]	Mobilize [-]
1	14	inf	25	3	1
2	16	150	50	5	0.75
3	12	400	100	4	0.5
4	19	inf	54	4	1

The first design, the early concept for the thesis, is a smaller vessel that is similar to typical service vessels in size. This vessel will normally operate as a service vessel with the ability to do small stun and bleed operations as well. This typically in association with service operations where there might be increased mortality in the fish stock. The storage capacity is therefore low in the ship. Despite this, the capacity of the design has been set to infinite for this design. This is because the ship will process the fish and transfer it to larger ships that will bring the fish to the slaughterhouse. This will in essence mean an infinite storage capacity. The downside to this is that the vessel is depending on available transfer ships. This is for the sake of simplicity taken into account by assigning a low processing rate. Due to the need for ship-to-ship transfer, the operational limit is low compared to the other designs. A reference vessel for design number one could be the combined service and stun and bleed vessel *Csaver* [51].

Figure 7.2: Reference ship for design 1 - Csaver [51] to the left and
Reference ship for design 3 - Aqua Merdø [52] to the right

The second design is similar to the first one. This design is a larger vessel with combination of service and stun and bleed with a higher focus on stun and bleed functionality. This vessel has a larger stun and bleed plant and a mid-range storage capacity. The vessel has the highest operational limit of the three designs. This because it is a smaller, wider vessel with no need of ship to ship transfer. A specific reference vessel has not been selected for this ship.

The third design is a larger stun and bleed vessel. This vessel has the highest processing speed and storage capacity, but is also the vessel with the lowest service speed of the four designs. Its operation limit is lower than for the second design due to a larger size and lower stability. A reference ship for the third design is the stun and bleed vessel Aqua Merdø [52].

The fourth design is the response vessel developed in this thesis. The outline of the design has been described in throughout the previous chapter. For the simulation it will be described with the design parameters presented above in Table 7.2. While the first design has had its processing rate dialed back to account for the dependence of other ships, this has not been done for the response vessel due to the large buffer tank capacity. The storage capacity has been set to infinite due to ship-to-ship transfers. The operational limit has been set to the same as design number three due to their similarity in size and has not been reduced despite the planned ship-to-ship transfer, this again due to the large buffer tank capacity. Furthermore, the ability to mobilize is set to the maximum value, the same as for the first concept.

7.1.5 Scenarios

The designs are run through different scenarios. The sailing distance to the mission, the amount of salmon that needs to be slaughtered and the current task of the ship are the input variables of the scenarios that were set. Based on the geographical area a maximum distance of 70 nm was decided. A range of distances has then been selected based on this. For the mission size, the designs were tested for a range from 500 to 950 tonnes. The unit of tonnes was decided.

Number of individuals would perhaps be a better way to model the time carrying out a stun and bleed operation, but weight is a better way to consider the storage ability of the ships. The current task of the ship has three options; not currently doing any mission, doing a mission that easily can be aborted or doing a mission that takes longer to abort. The ability to abort current missions is one of the design parameters. The scenarios are presented in Appendix E.1.

7.2 Simulation Results

The results from the simulation will be presented below and discussed in further detail in Section 7.3. Larger plots can be found in Appendix E.3.

Table 7.3: Average time spent by each design

Design Nr.	Average mission time [hours]	Percentage
1	50,3	112 %
2	57,1	141 %
3	37,3	57 %
Response Vessel	23,7	-

From the table, we can see that the response vessel has the lowest average mission time across all combinations of mission size, sailing distance, initial mission, and weather situation. It outperforms the other designs with a good margin, with design number three (the large stun and bleed vessel) being the closest one with 57% more time spent, and design number one and two following with 112% and 141% more time spent, respectively.

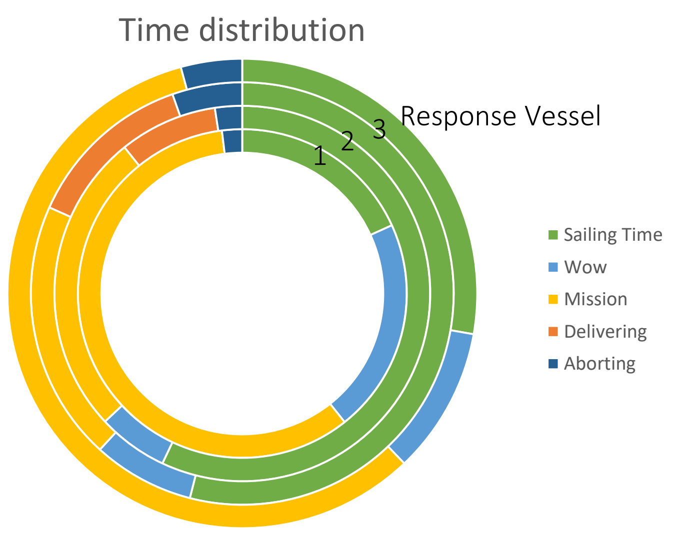


Figure 7.3: Time composition for all the designs

Figure 7.3 shows how the different designs spend their time. The plot shows that there is a similarity in the time distribution of design number one and the response vessel, and between design number two and three. This can be explained by the similarity in method of operation of the respective pairs. Design number one and the response vessel spend a larger part of the time on processing, a smaller part on sailing, and no time delivering. Design number two and three are quite similar, but design two uses a larger part of its time processing than design number three.

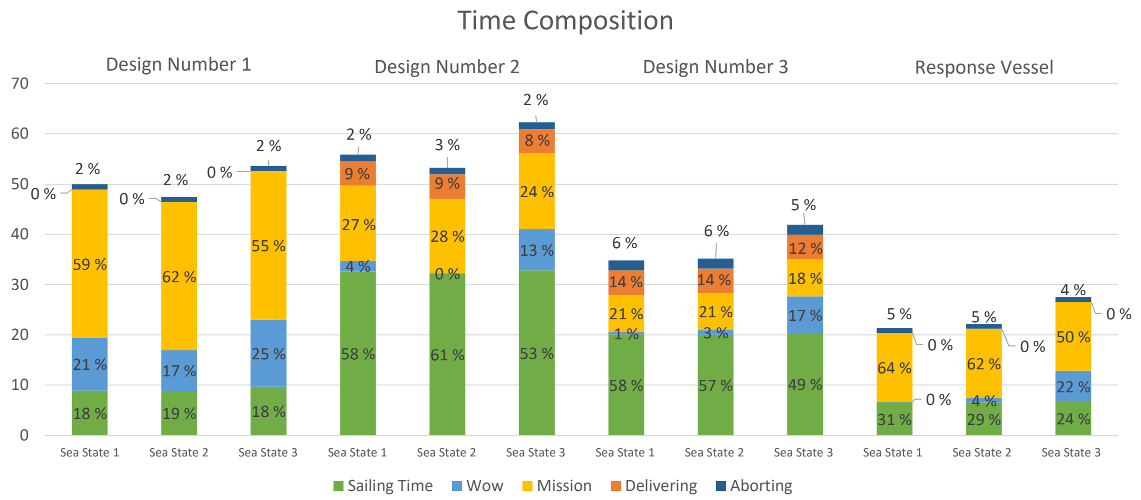


Figure 7.4: Time composition across the three weather scenarios for all the designs

The figure above shows how the composition and time spent changes with the changing weather situation. Absolute values on the time spent are provided. It is apparent that all the ships spend more total time on a mission and a larger portion of the time waiting on weather for the harshest weather. Design number 1 spends the most time waiting on weather with large values across all sea states, but outperforms the second design due to the large portion of time spent processing. Design number two waits the least on weather both in terms of time spent and portion of time. The sailing time stays relatively stable for all vessels across the sea states. The same goes for processing and delivering, while the percentage has some changes due to the additional time spent waiting on weather during sea state number three.

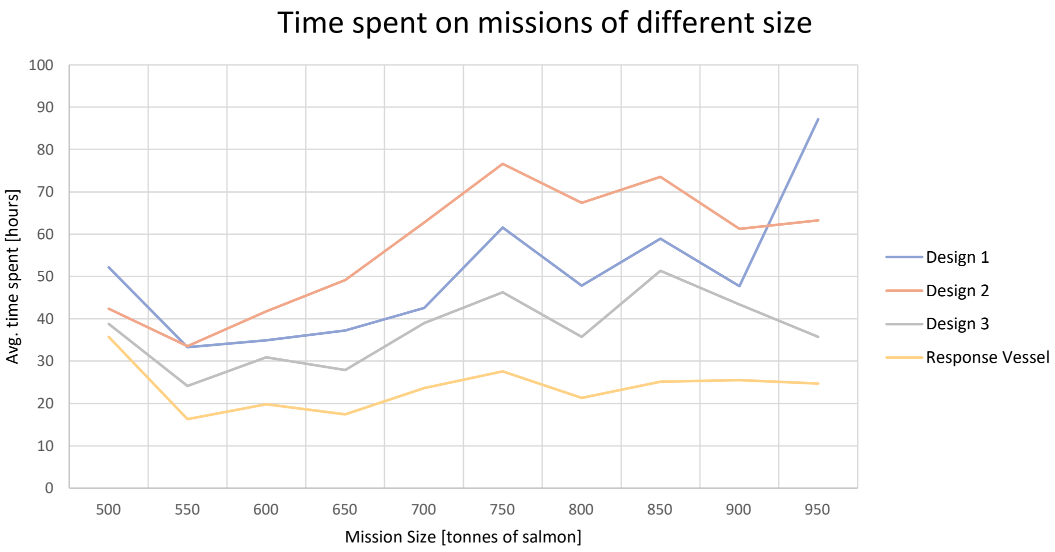


Figure 7.5: Average time spent on missions of different size

The figure shows how the average mission time across all the weather states changes with the mission size. The high value for the smallest mission, as well as the spike for design number one at 950 tonnes, are worth noting. Apart from this, the same ranking as seen earlier is represented in the graph with a few exceptions where the time of design one is longer than that of design two.

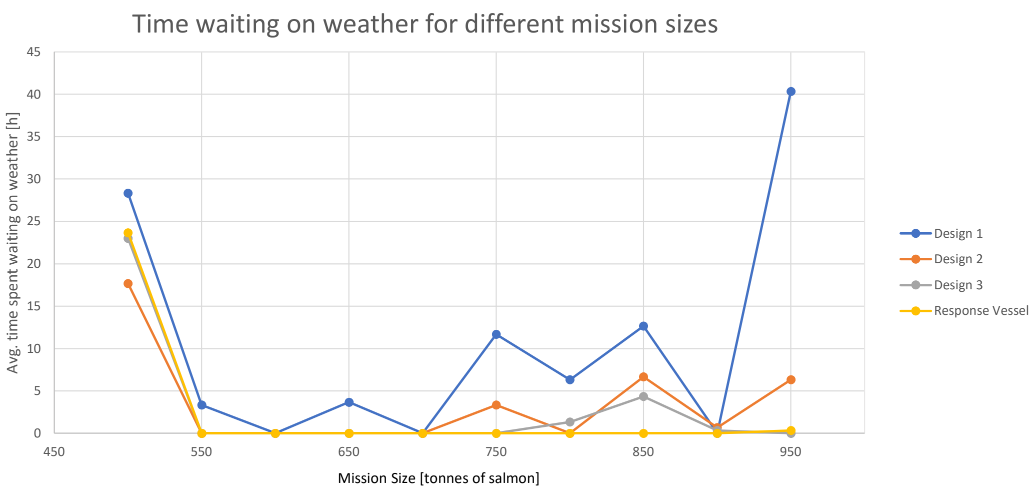


Figure 7.6: Average time spent waiting on weather for different mission sizes

The figure shows the average time spent waiting on weather for different mission sizes. Notice is made of the large value for all designs for the mission size of 500 tonnes and also the large amount of time spent waiting on weather for design one on the largest mission.

7.3 Discussion of Simulation Results

The results show that the response vessel uses the least time, shown both in Table 7.3 and Figure 7.4. Based on this one may conclude that the design developed in this thesis is the best response vessel for an emergency slaughter case. However, there are some shortcomings to the model that will be discussed and the results need to be considered accordingly. Despite the shortcomings the response vessel design performs best by a good margin, hence one can be quite confident that the design is the best one.

The design concepts and their attributes become apparent in the results. For example, the low sailing time of design number one and the response vessel can be explained by the fact that these designs do not have to sail to port to deliver the fish. Consequently, a larger portion of the time is spent processing, also apparent in the results. For the first design, one could say that the ship is better at response than the second design that has a very similar performance in terms of total time spent. This due to carrying out the main part of its mission, processing, for the largest portion of time. The results show that maximizing the utilization in that the first design outperforms the second design with double the processing speed. Combining this with an increased processing speed yields a highly efficient ship as shown for the results of the response vessel. In addition to the argument of increased utilization of the installed processing equipment, another argument for the concept of the response vessel and design number one is that the ships are present at the location for a larger period of the time. This can be very advantageous in the case of unforeseen changes to the situation.

The simplification of not modeling the availability and arrival of ships for transfer of the processed fish to shore could be a source of error and provides uncertainty to the results presented. Rather than trying to model this, the dependency was accounted for with a reduced rate of processing for the first design. The assumption in itself may not have been the worst, but the reduced rate may not be accurate. For the response vessel, however, the buffer tank is thought to eliminate the need of modeling this dependency. In reality, it is reduced while not eliminated. As stated earlier in the thesis the capacity of the buffer tank is about 300 tonnes of salmon, meaning a dependency for all the scenarios of the simulation.

For all the designs we see a large increase in the time waiting on weather for the harshest weather situation. Although this does make sense, the increase may be too high. This is due to the fact that the simulation is modeled so that the weather window needs to cover for the whole operation in order for the vessel to proceed. This would not be the case in a real-life scenario. Here, the vessel would use smaller weather windows and rather sail to shore half-full if the weather stays bad for a longer period. The implications of this simplification are especially large for the first design as well as for the response vessel. This due to an operation being defined as processing the whole quantity of fish in one go, regardless of the size, for the designs with an infinite capacity. Consequently, these designs have to wait for a very long weather window due to their capacity being infinite. This reduces the efficiency of the response vessel and the first design, and so the performance relative to the other ships could be better due to this. Additionally, the weather window is calculated using a 100% efficiency meaning that the weather window may be smaller than needed. Although a small inaccuracy, it is not on the conservative side. Positively, all ships are affected equally by this inaccuracy.

Looking at Figure 7.5, there are some abnormalities in the relationship between the mission size and the average mission time. One would expect to see that the mission time increases with the size of the mission and this is the overall trend. There are however as stated earlier some abnormalities for the smallest mission size for all the designs, and the largest mission for design number one. A possible explanation to this is provided in Figure 7.6. There seems to be a clear relation between the abnormal results of the mission time and the time spent waiting on weather. The explanation to this is harder to pinpoint. One explanation could be that the extra waiting is caused by a weather spike that all the ships encounter in the same mission. For the largest mission and design number one, the explanation could be the need of a large weather window combined with a lower operational limit than the other designs.

Another possible source of uncertainty is the variation shift in time and corresponding sea state due to the designs using different amounts of time on each mission. Hence, the weather situation will only be identical for the first mission and later on shifted more and more. This means that the ships could encounter the same weather in different missions and/or at different times of a mission, where it could be more or less crucial.

The main takeaway from the simulation when looking at the assessment of the response vessel design is that the response vessel outperforms the other designs. While the absolute numbers of hours spent perhaps only can be seen as indications of the expected time to handle crisis situations, the results can be used to see the performance relative to each other. An aspect that should be discussed is the added value that the response vessel brings apart from processing the fish that will be used for human consumption. When the response vessel is present at the location for such a large part of the crisis it will also handle a lot of dead fish that can be utilized for production of fish meal and oil. For the concepts the response vessel is compared to in the simulation, an additional ship is needed to handle the same functions. It is therefore a bit hard to assess the goodness of the response vessel looking at all the functions. The concluding remark is however that the response vessel will be processing dead fish at the same time as it is performing better in emergency slaughter response.

Chapter 8

Embodiment Design

In this chapter the detailed design will be presented. The process of developing the detailed design based on the concept phase will be presented first, before the final design and its features will be presented and discussed.

8.1 Sketching phase

When the system based ship design process was nearing the end and the hull had been modeled a phase of sketching outlines for the design started. During this phase a method of combining hand sketching and CAD was used. Quick sketches were made by hand outlining the different functions. The broad strokes of the logistics were done with extra focus given to the main function. An example of a sketch like this is presented in Appendix D.2.

Based on the sketches done by hand boxes were drawn inside the outline of the hull as shown in Figure 8.1 on the next page. The areas were then measured and compared to the areas obtained from system based ship design. Notes were made to what changes that had to be made in accordance with the results from the system based ship design method.

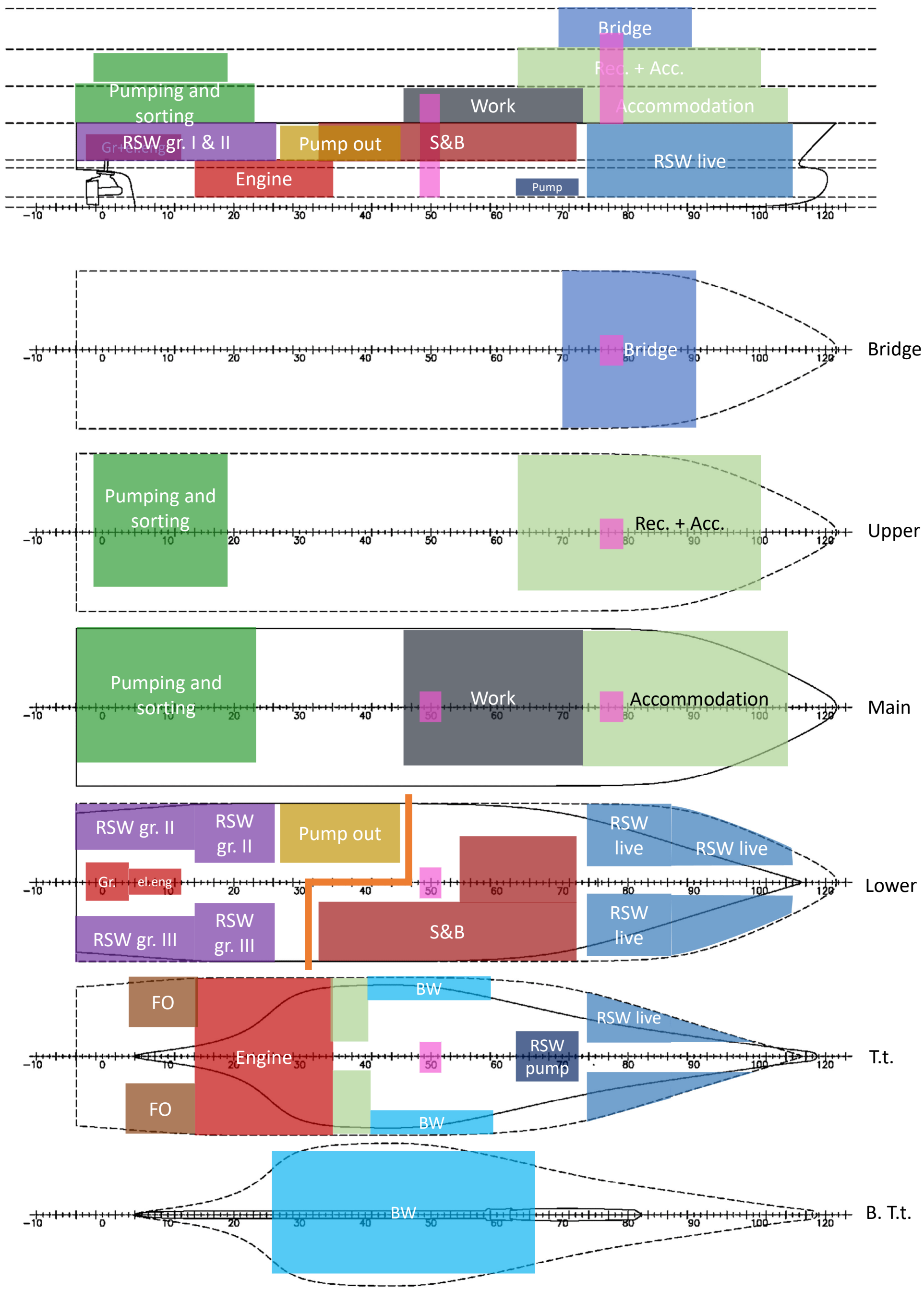
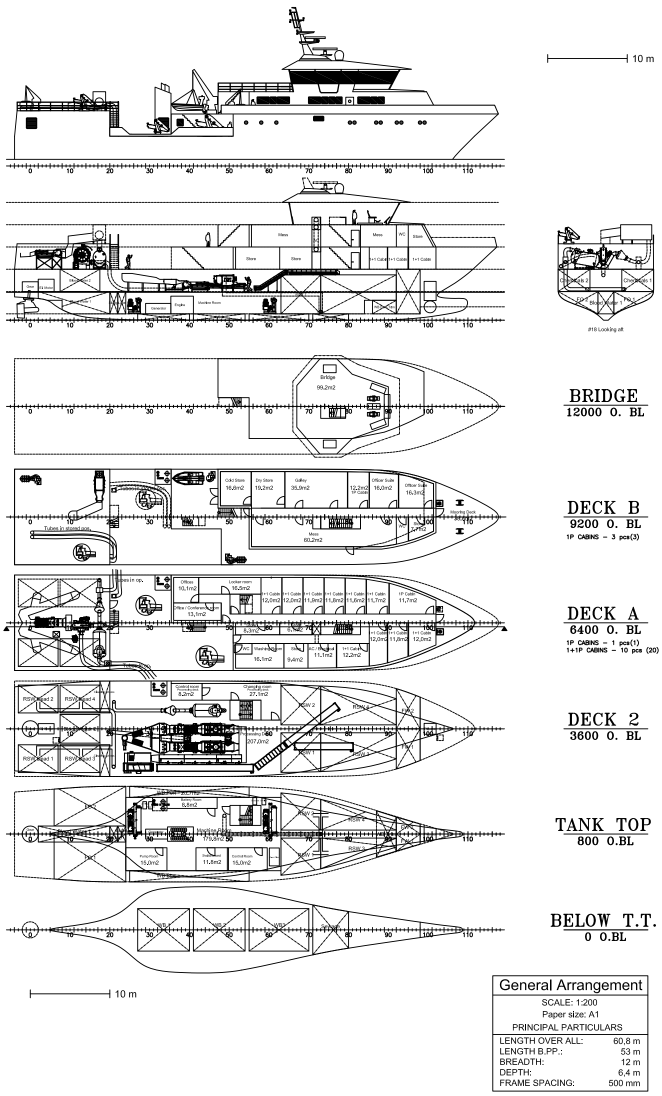


Figure 8.1: Sketch exploring the placement of the different spaces including the needed space

8.2 General Arrangement

The general arrangement was further developed through several iterations of sketching on paper and using CAD. Iterations were done with feedback from Optimar on the arrangement of the processing equipment. The general arrangement can be found in Appendix D.1 with an overview like the one below and larger plots of the decks. None of the drawings provided in the appendix are plotted to scale, but with the inclusion of a measuring staff. For a complete drawing plotted to scale, the reader is referred to the digital appendix of the thesis. The final design and its functions will further be explained in the next section.



8.3 Functional Explanation

8.3.1 Main function

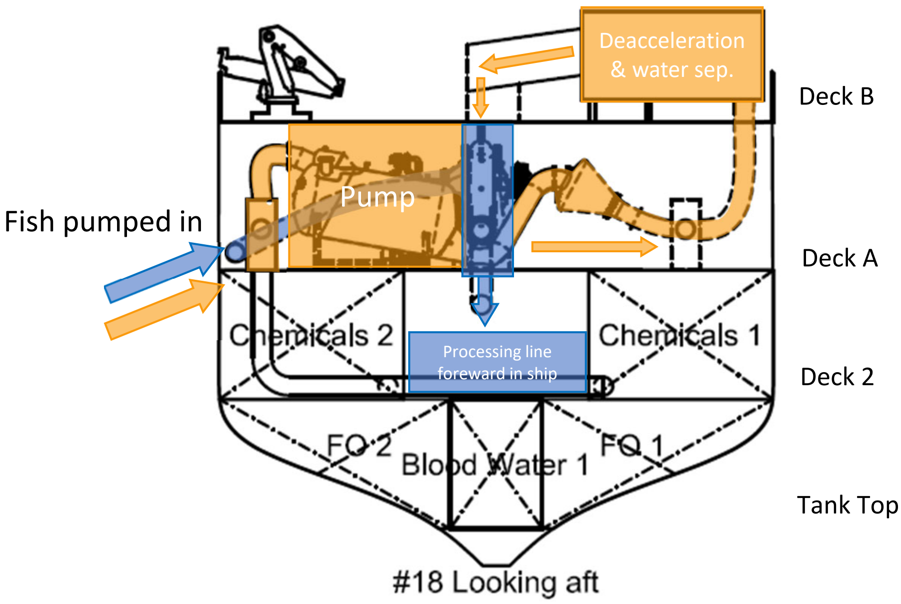


Figure 8.2: Cross section with explanation of the fish flow and functions

The flow of the fish into the ship is shown in the cross-section above. The flow of the live fish going to human consumption is highlighted with the blue color, while the flow of the dead fish that will be used for fish meal and oil is shown in orange. The fish is pumped in at the main deck. The dead fish is pumped up into a deaccelerator and water separator that is placed on the deck above. This gear reduces the speed of the fish while also separating the water that is pumped together with it and sending this back to the sea. From this point, the dead fish is passed on through the process using only gravity. The dead fish further enters the processing room of the dead fish. This is better seen in the longitudinal section below. Here the dead fish enters a destruction stunner where the dead fish is given an electrical shock with a very high voltage to ensure that it is dead. Afterward, it is distributed to the different RSW tanks for dead fish using a chute.

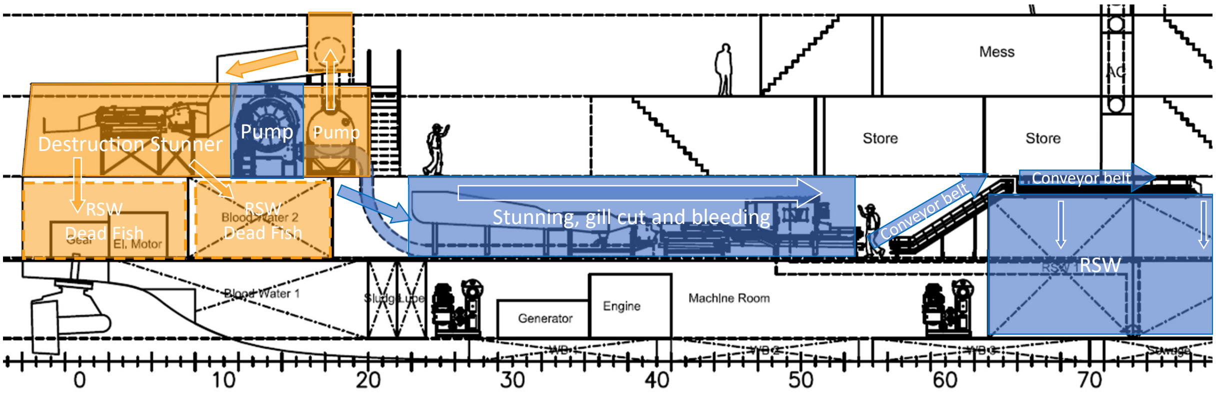


Figure 8.3: Longitudinal section with explanation of the fish flow and functions

The live fish is also pumped in on the main deck from the starboard side. Here it passes through the pump and proceeds down a deck to the processing plant. This is better seen in the longitudinal section. The fish is processed before it is distributed in the RSW tanks for fish for human consumption using a system of conveyor belts. The process plant for the live fish is shown in further detail in Figure 8.4 below.

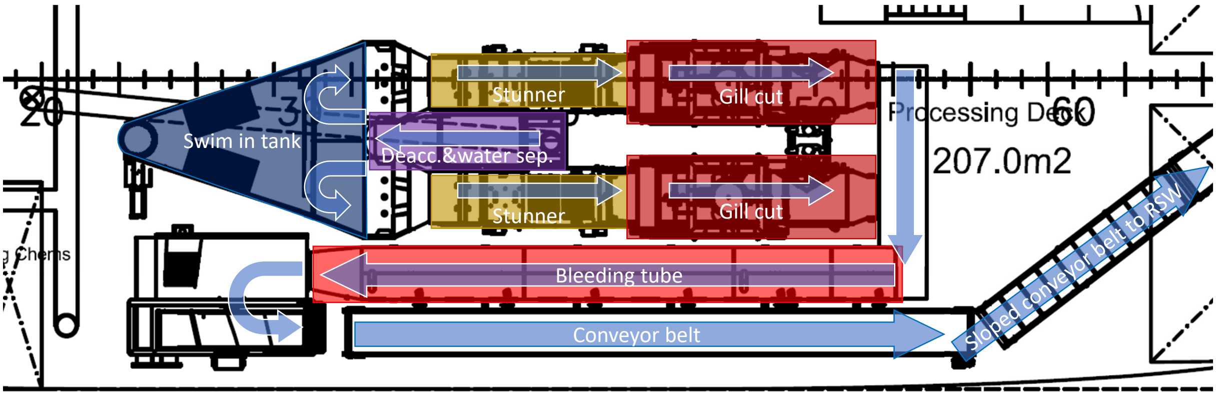


Figure 8.4: The processing deck with explanation of the fish flow and functions

When the live fish enters the processing plant it first enters a deaccelerator and water separator the same way the dead fish does. Further, the fish is passed on to a tank where there is a current in the water. The salmon will, following its instincts, swim against the current leading it into the next phase of the processing with its head coming first. In this phase, the salmon is stunned with an electrical shock. The gear used for this is the same as the stunner for dead fish but is operated at a lower voltage, only stunning the fish. In the next step of the process, the salmon is given a cut through the gills by a robot, cutting the main artery of the fish. Further, the salmon is passed to a bleeding tube where it spends approximately three minutes passing through. During this process, the salmon bleeds out. The blood water is passed to a storage tank. The bled-out salmon is then passed on to a system of conveyor belts that transports the fish forward in the ship above the RSW tanks where the salmon is distributed to the four different tanks.

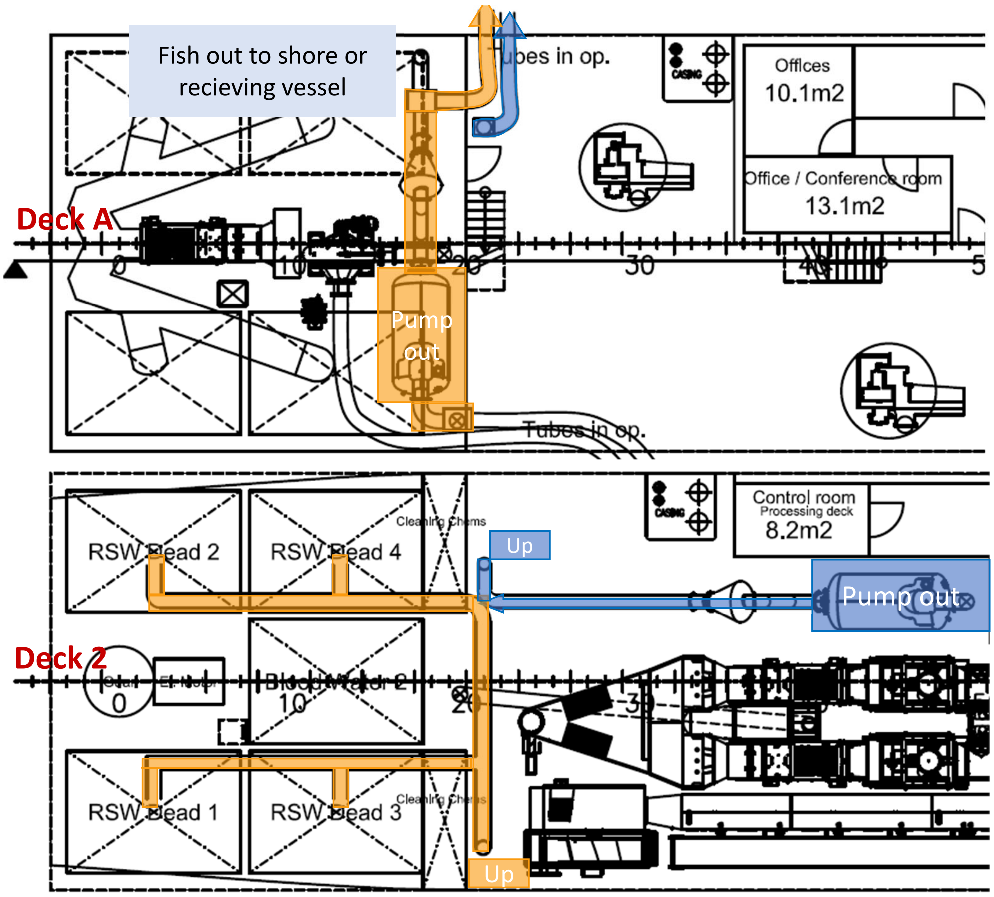


Figure 8.5: The flow of fish out from the vessel

The flow of fish out of the vessel for either unloading to shore or to other vessels will happen out the port side. An overview of this logistic is provided in Figure 8.5 above. The dead fish will be transferred out using the same vacuum pump that is being used for the loading. This is made possible by using valves. The dead fish is pumped from the bottom of the RSW tanks up through the vacuum pump and out on the port side. For the fish for human consumption, a separate pump placed on the processing deck is used. In the same way as the dead fish, the live fish is pumped from the bottom of the tank, up to the pump on the processing deck, through the pump, up through the next deck, and out on the port side. The installation of an extra pump for the fish for human consumption means that the ship can process fish continuously while at the same time unloading. This is not possible with a single pump for dead fish, but not seen as needed either.

8.3.2 Areas for work

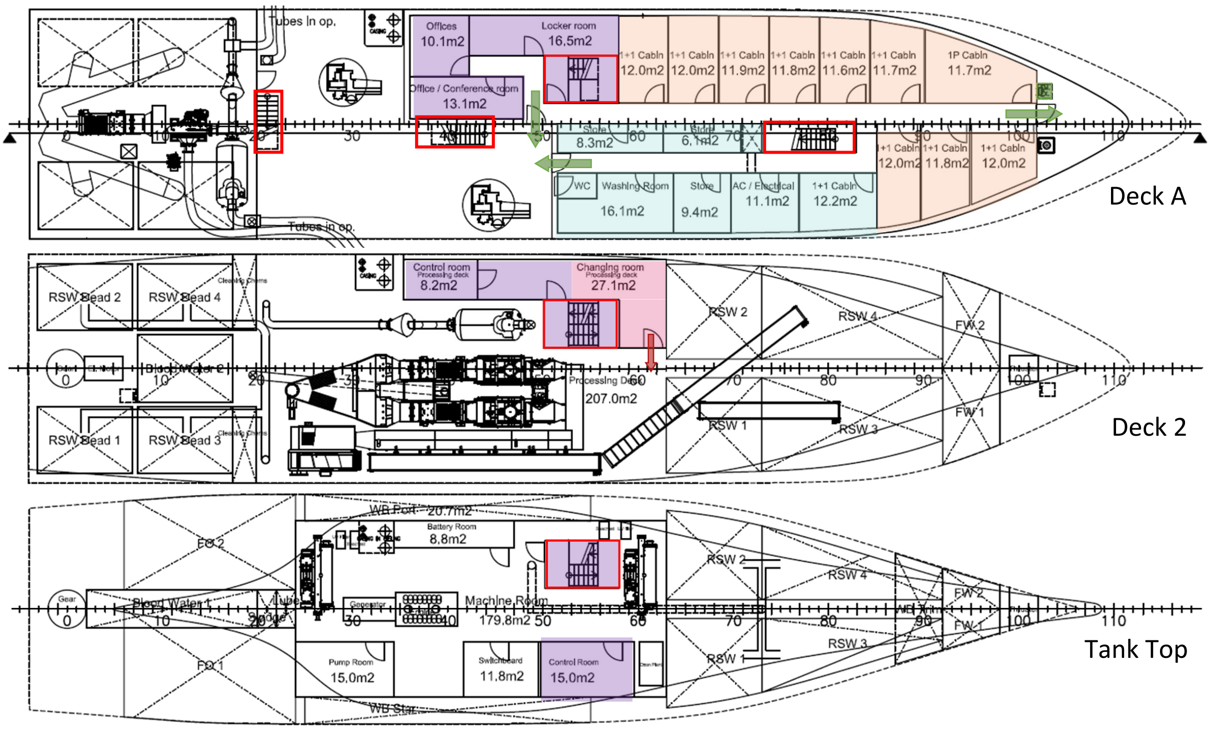


Figure 8.6: Explanation of the logistics of the areas used for work

Above in Figure 8.6 an overview of the logistics of the areas used for work is presented. The arrangement has been developed to obtain an optimal workflow not being in conflict with the accommodation areas. This is especially important in the emergency scenarios where two shifts will be working continuously and the ship must be run smooth as a clock. Therefore the two functions have been tried separated as well as possible. When a crew member of the ship starts their shift the person will start by moving from the cabin area and to the wardrobe on deck A. After changing into the needed work attire, the person does not need to enter the hallway of the accommodation area again before the shift is done or the mess is to be used. Hence this hallway will be a clean zone. The workers will then either use the office area, exit to work on deck A, or use the internal staircase moving down in the ship. On deck 2 the worker can exit the staircase to enter either the control room of the processing equipment or the processing deck itself. In order to enter the processing room, the worker needs to enter a new wardrobe where needed attire for hygiene is put on. This wardrobe acts as a buffer between the processing deck and the rest of the ship since the criteria for the hygiene are that of a slaughterhouse. To access the engine room and its control room the internal staircase is used to descend another deck.

8.3.3 Accommodation areas

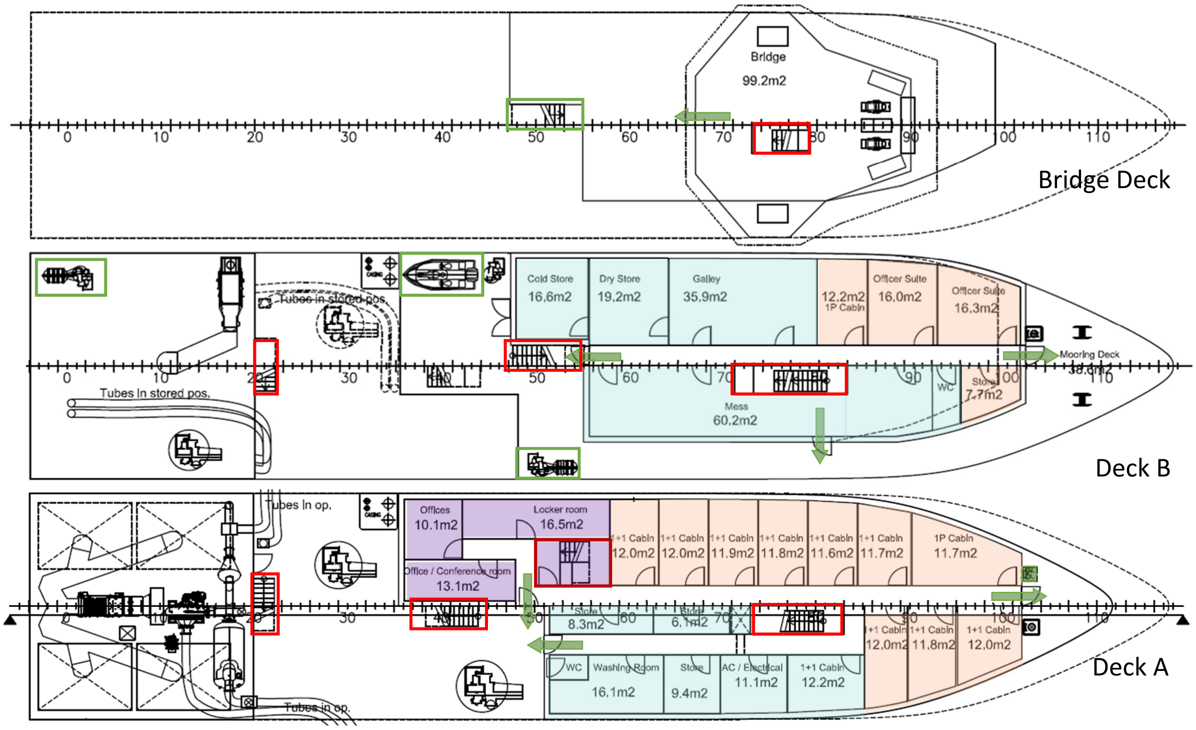


Figure 8.7: Explanation of the logistics of the areas used for accommodation

The figure above provides an overview of the logistics of the accommodation areas. Highlighted with the green arrows are the exits that will act as emergency exits and the emergency rafts and MOB boat are marked with green boxes. The staircases of the ship are marked with red boxes. As stated previously the goal has been to create a clear distinction between the work-related functions and the accommodation functions. A goal of the arrangement has been to place the cabins as far away from where the work is being done as possible. This is why the majority of the cabins have been placed on the port side of the ship and why the cabins of the officers are placed as far forward in the ship as possible. This is to ensure crew comfort in emergency scenarios where the ship will be operating around the clock. The crew is one of the most important assets in an emergency and hence their rest is of high importance. The galley and mess are placed on deck B. This to get a nice mess with a lot of natural light. The galley and attached stores are placed aft in the superstructure on the port side adjacent to the deck that will act as a provision landing as well as housing the MOB boat. The deck is fitted with a crane that can both launch the MOB boat and be used to load and unload provision. There is a large exit from the stores to ensure a good logistics of provisions. The bridge can be accessed either through the staircase placed in the middle of the accommodation area or through an external staircase. The bridge has been shaped with wings with consoles for taking control of the ship maneuvering. These will be used during berthing at the fish farms and general berthing of the vessel. In addition, the wings provide the crew at the bridge extra overview of the work being done at the main deck.

8.4 Tank Arrangement

The tanks were modeled in Delftship according to the needed tank volumes identified in the system based phase. The tank arrangement is presented in Appendix D.4. The tanks were modeled to try and obtain good stability, as well as trim. This will be commented on further in the next section on stability calculations. There are some small deviations between how the tanks were modeled in Delftship and how they are placed in the general arrangement. In order to be able to model the tanks so that they follow the shape of the hull, the tanks had to be modeled all the way out to the hull. For some of the tanks, service space was needed between the hull and the tanks. These tanks are placed this way in the arrangement by moving them in towards the centerline of the ship. In Delftship however, the tanks are modeled all the way out to the hull for the tanks. This solution to the problem ensures that the vertical center of gravity for the tanks stays the same, and the same for free surface effects. There will be some changes from Delftship to the final design when it comes to mass inertia, but this will not be assessed for the ship in this thesis. The conclusion is that the solution is satisfying.

8.4.1 Stability Calculation

The stability of the design was checked in Delftship. Different loading conditions were made in order to see that the vessel has satisfying stability in all the different conditions of its operation. The reports from the stability check can be found in Appendix D.6. The most critical loading condition is the loading condition named *all tanks half laden*. For this condition, all the tanks have been set with a filling of 50%. For this condition all the criteria are satisfied and within a good margin. This can therefore be said for all the conditions with the exception of the lightship condition. For this condition, the criteria related to rolling due to wind are not satisfied. The ship is however floating with a good GM and a satisfying GZ curve. So the lightship condition should be avoided and the ship not sailed in this condition if the weather does not allow it. This is however not an issue since this condition is not needed in the normal operation of the vessel. The trim is also the worst for the lightship condition with a trim of 15 centimeters. When it comes to the trim for the remaining conditions, the arrangement of the tanks has returned satisfying trim in all conditions with the largest trim, apart from the lightship, occurring in the half laden condition with a trim of 9,3 centimeters. To summarize, the tank arrangement satisfies the stability criteria and has the ship operating at a good trim for all the conditions.

Chapter 9

Discussion

The needs of the industry were investigated in the task clarification. Here all the needs were tried identified with corresponding functions. For the ideal design process, the solution of the design would preferably be held open for a longer period of time with the functions being set later. Due to the extent of this thesis and its stated goal of developing an arrangement, a shorter period of time was allotted to this phase and so the work of looking at established functions started early. Further, the scope of the needs to be handled by the vessel was narrowed in and a list of functions for further focus in the design process was selected. The list had to be quite concise due to limited time and so one can discuss if potentially important design areas were left out from the focus area when the scope of the needs to be covered was narrowed down. For example, recatch nets have not been a focus of the design due to these functions not being essential in maximizing the profit of salmon given a crisis. They are however important in order to protect the stock of wild salmon.

Further, the design concept was developed using the method of system based ship design. As discussed earlier in the thesis this method has its pros and cons. The method works best for similar ship types and so alternative approaches were needed to some aspects of the design. The method provided a good overview of the spaces needed for the different functions and was the basis for selecting the main dimensions. Looking at the final arrangement most of the functions seem to be of reasonable size when drawn in the arrangement and the ship is not larger than it has to be nor too cramped. Hence one can say that the used method of system based ship design ended up returning the desired results.

The design process is iterative and while it, as stated earlier, is tried presented in a systematic order to best provide oversight of the process to the reader there has been work done between the different phases. The implications of some of the decisions done during the early phase and their effects on other parts of the design were not discovered until later, in the later phases. An example of this is the design speed. For these cases, it would be interesting to go back to the task clarification and question the importance of the needs, such as, for example, the design speed, to assess the trade-off between increased design speed and its effects on the end design. In addition, the aspect of cost becomes important when asking these questions and would be interesting to include in further work on this type of design. Due to the limited time, not all of these iterations could be done and the concept phase had to be concluded so that the development of a detailed design could go on.

Before the detailed design was developed the concept was analyzed using a simulation tool. The results gained from this simulation showed that the concept performed very well in emergency slaughter response of live salmon compared to already established ship types. As discussed earlier there are some inaccuracies in the simulation model and potential for improvement. In addition, it would be interesting to develop a simulation tool that tries to assess the processes at the location in further detail. While the absolute number of hours spent for the response vessel only could be seen as an indication of the time it will spend, the performance relative to the other designs can be used to establish that the concept certainly improves the preparedness of the industry, and with a good margin.

With the concept analyzed and its validity verified by the simulation tool, the detailed design was developed. The final arrangement of the project is satisfying, looking at the scope of the thesis as well as the workload. The arrangement could always be improved in level of detail, but the time was limited and so a reasonable level of detail had to be selected. The main functions are arranged in a matter that causes a good flow of the fish through the main functions. Clear segregation of the dead fish and the fish for human consumption has been established. Further, the needed hygiene in the processing deck has been assured by separating it from the rest of the ship with a wardrobe. The recreational areas are placed in a manner that ensures crew rest and with the recreational areas with lots of natural light.

Further, the tanks are arranged in a very satisfying matter such that the ship obtains good trim and is stable in all loading conditions, but for the lightship. In this condition, the ship can not be sailed in stormy weather, but the ship will not be sailed in this condition since the ballast tanks will be used to ensure the needed stability.

A good outline for the new vessel type is laid to ground in this thesis. A name should be provided for the new vessel type to be used in further studies on this type of vessel and a few possibilities and suggestions will be discussed. One suggestion is that the name should be general enough to be an umbrella covering different types of response vessels focusing on salmon, where further development of such design might also include other functions such as treatment of fish. While this vessel is designed with salmon in mind it will function the same for sea trout. The suggested name for the vessel type designed in this thesis is *Salmon Emergency Response Vessel* or *SERV* abbreviated. In the future, the cultivation of other fish species might be at larger quanta in Norway than seen today and there might also be an increase of crustacean and mollusc species. This is also the case for the rest of the world and so a different suggestion for a name for this type of vessel could be neutral to species, and also include several groups of organisms. A second suggestion for this ship type, regardless of species is, therefore, *Aquaculture Biomass Emergency Response Vessel* or *ABER-Vessel* for short.

The author believes a different term should be used for response vessels in aquaculture that may have a larger focus on saving people, protecting the environment, and saving structures. This type of vessel will probably become more relevant and possibly a requirement as the aquaculture industry moves further away from shore into exposed waters in the near future. The term for this type of vessel could be *Aquaculture Emergency Response and Rescue Vessel*, or *AERRV* abbreviated.

Chapter 10

Conclusion

The work done and presented in this master's thesis delivers on the objective. A vessel design that improves the preparedness of the Norwegian salmon aquaculture industry has been designed. The preparedness is improved by securing the welfare and biomass assets at risk in crises.

As stated earlier in the discussion the design phase is iterative and several rounds of iteration could always be done to improve the design. While the final design of the SERV is not a complete design it is a good outline for what such a design should do and how it can be arranged to do so. Considering that this has been work done by a single person on a new ship type, the result is satisfactory.

Suggestions for further work would be to improve some of the aspects of the thesis that have been discussed earlier. Among the most interesting areas is the link between the task clarification phase and the concept phase where it would be interesting to investigate the importance of different functional requirements and the impact of their scale on the performance of the final design. For such a design, the cost could be included to be able to include a trade-off study. Furthermore, the use of a simulation tool provided good insight in the design phase. The inaccuracies pointed out in earlier discussions could be improved to obtain better comparisons and more accurate absolute values.

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Appendix

A Design Log

Date: 17.02	Keyword: Needs for scenarios
Started gaining overview of the different needs that are relevant for the different scenarios. Try to fill out these for all scenarios.	

Date: 25.02	Keyword: Needs, rating
Finished needs list (but might be updated) Tried to highlight the needs I though was the most important ones, seen from a fish health / biomass salvaging point of view. Green highlighting. Needs of importance, but not a clear priority was highlighted in yellow.	

Date: 26.02	Keyword:
Thought: In the scenario of a fire, the priority should be controlling the fire. I do not think there should be started any processes of moving or slaughtering fish during a fire. The question becomes what role the preparedness ship has? Perhaps it is part of the first response of putting out the fire and doing small tows and when the situation is more under control, it is at the site and can process fish, if needed. In this case, larger ships for transport may have been called upon and arrive quicker than in a normal case. If fitted with diving / ROV gear. It can also carry out some of the first damage assessments under water.	

Date: 03.03	Keyword: Needs, shortlist
Started making short list of the needs that should be covered and making some notes on what the functions and functional requirements for covering the different needs could be.	

Date: 08.03	Keyword: Guidance, needs shortlist, ABD
After guidance session with BEA I became aware that the short list I have been working on is a good mix between needs and functions. Should perhaps take a separate round on needs, but feel that this has been covered, if not in a list format, then at least in the pre study done in the autumn. Conclude that I should do tougher choices, cutting in the focus area of the ship, to make it easier to develop the design. Should perhaps do the first stages of the ABD process to define the 'business concept'. Try and find out what the concept is and who the stakeholders are.	
Date: 10.03	Keyword: ABD
Started ABD study.	

Date: 11.03	Keyword:

Spoke to a friend working as an engineer in aquaculture classification with background working at fish farms. Got some feedback and new ideas. Positive to first response vessel to get started on situation before the larger ships arrive. To keep the process going and prevent the whole pen from "collapse". Need to establish how large the window as first response vessel will be.

Date: 15.03	Keyword:

Idea: If the ship is already a quick platform for first response. Could it be fitted with treatment gear as well? Could this be part of the normal operation? The buffer tanks thought of in the original concept might not be large enough. The combination of stun and bleed and treatment can however be of interest since treatment operations often lead to increased mortality. The urgency of treatments and what type of treatments are more urgent than others should be investigated.
Con: Was supposed to decrease the design window. This is introducing a new possible function…

Date: 19.03	Keyword:

Meeting with Svein Aa.

Date: 07.04	Keyword:

There is an ongoing situation of toxic algae in Chile with 3850 tons lost so far (Flere store lakseoppdrettere rapporterer inn tap på grunn av giftige alger i Chile (ilaks.no)
There also has been a cases in Chile in 2020 (Algae blamed for death of 861,000 salmon in Chile - FishFarmingExpert.com). The question then is if this issue is more relevant on a global scale or at least if it is more relevant to other waters than the Norwegian.

Date: 13.04	Keyword:

Started processing the data from the traffic study in the Rørvik region. Struggling to figure out how to go from a probability of there being ships available / expected ships available to an expected response time and a distribution of probability when it comes to response time.

I think I have settled on trying to achieve a min, median and max response time. The ship should then probably be designed to handle a response time of somewhere between median and max.

Date: 14.04	Keyword: Ensilage, Pumps

Working on defining the time window:

Should perhaps use the probabilities to estimate the expected time for response and then use distance and speed to determine the distribution of travel time. Combine these two somehow for a distribution of time window.

Date: 16.04	Keyword: Ensilage, Pumps
Decisions made in SBSD: Ensilage tank should be placed close to systems with heat (such as engine room) to increase the speed of the autolysis. Ensilage collection could be part of the normal operation. Need to determine if there is a need for separate pumps for ship-to-ship transfer, if the same pumps as for loading can be used or if the pumps of the other ships (or slaughterhouse) can be used.	

Date: 23.04	Keyword: Sketch, GA
Sketching placement of functions	

Date: 26.04	Keyword: RSW
Had a chat with Dimitar who is writing a master on dimensioning RSW plants. Got input from him on what will be the dimensioning factor. It will most likely be the time to chill down the water before commencing operation. At first glance these parameters seem to be good for my design: 400m3 divided on 6 tanks. A flow rate of 1 (changes all the water once every hour) Will lead to about 5 hours time needed to prepare and 13 hours to reach 2 degrees temperature of the fish.	

Date: 27.04	Keyword: Ship size and shape
Decided that the L/B ratio rad to be changed to a larger one to make sure the ship is slender and can obtain the needed speed.	
Date: 03.05	Keyword:
Agreed meeting with Optimar within the week. Initial comments: Ensilage not optimal. Better to salvage whole fish if you can deliver them within 24 hours to shore. Can then be used for higher quality products such as fish meal and fish oil. Questions regarding the meeting with Optimar that were raised during meeting with supervisor: What a response vessel in salmon aquaculture should be and how it should cooperate with other resources? What type of equipment should be used?	

Started modelling the hull.

Date: 05.05	Keyword:
Should investigate the possibility of using existing s&b ships for ship-to-ship transfer in crisis situations.	

Date: 10.05	Keyword:
Important with the functionality of sorting out the dead fish from the stun and bleed line. Is it possible to this the same way for the other way around (try to sort out the live fish from the presumed dead, when pumping from deep down in the pen)? How will the logistics be then? Should all fish enter at about the same spot (in the middle) and then be guided to the correct spot? Or should there be larger distance by placing the core of the ship at the middle? This means it would be harder to send fish between stations, if that is necessary.	

Date: 11.05	Keyword: Sketching, areas, volumes, Optimar, meeting

Continuous sketching. Trying to place rough areas and volumes in the hull. Doing rough calculations of tank volumes, will need to model the tanks where they follow the hull.

Meeting with Optimar:
Optimar presented their stun and bleed line. Are going to send .dwg files for me to use in the design.

There is no automatic way of sorting out dead fish right now, but this will surely be an automated process in the near future.

Discussed the Elax patent on sorting out dead fish during stunning. Sorts them out right after stunning. A camera detects that the fish does not tighten its muscles when being stunned and hence is dead.

Back breaking is no longer an issue in the stunning process according to Optimar.

Highlights that I have not included washing time in my calculations. For a ship that never empties its RSW tanks fully, they declare that they think there is a need to wash them at least once a day. Furthermore, they highlight that the blood water capacity may be a limiting factor for how long the ship can process continuously.

Water from an ILA location can only be dumped in the same area. Must sail back if the slaughterhouse is in the same region. Can send the water ashore if the amount is small enough. Speaks in favor of ships with RSW rather than wellboats.

In addition to cleaning of the tanks they also need to be ozonated. This process takes about three hours. Ozon can be dumped anywhere.

Another perspective provided by Optimar was one regarding the crew size. If the ship is to process for longer times, there will be a need for two shifts. How this will affect the need for crew spaces is uncertain. Perhaps there could be 2 person cabins. Need to investigate the possibility of sailing with one shift in normal operation and having the second shift sent to the boat if there is an emergency (else, the ship might be very expensive in normal operations). Declared that they think that gutting vessels are the future, even more so than stun and bleed. This due to the quality increase when there is no gut that can decompose. This is however more space consuming and not ideal for a response vessel.

Date: 12.05	Keyword:
Continued sketching and compared the sketched areas and volumes to the SBSD to see what changes needs to be made to a new revision.	

Date: 14.05	Keyword:
Supervision with Svein Aa: Discovered some issues with tanks: How should the structure be fixed for tanks that need a smooth inside, such as RSW tanks? Have decided to model them as all the way to the skin in Delftship, but move them in 500mm in the GA. This way the stability check in Delftship is nearly the same. And the tank sizes and shapes are correct in the GA.	

Date: 16.05	Keyword:
Finished modelling the tanks and drew the tank arrangement in to the GA in AutoCAD with the correct distance to the skin.	

Date: 18.05	Keyword:
Carried out initial stability test with a rough wind profile.	

Date: 20.05	Keyword: GA
Decided to move the fore mooring deck one deck up to increase the internal area of the fore super structure on the main deck.	
Date: 21.05	Keyword: GA, Gear
Reviewed the stability test of the ship in Delftship. Concluded that the stability is satisfactory. Only the light ship condition does not meet all the criteria. Here the GM and max GZ is sufficient, but the ability to take dynamic loads is not sufficient. So the ship can not be sailed in storms in the light ship conditions.	

Received the first drawings from Optimar. Some of the drawing need to be modified to fit my need.

Date: 22.05	Keyword: GA, Gear

Started drawing in the gear from Optimar.
Noticed I might have underestimated how much space I need on top of the RSW tanks. Need to consider how to solve the transportation of bled salmon in to the tanks.

Date: 24.05	Keyword: GA, Gear

Frode Tenfjord got back with some comments on the first draft of the production plant:
Had understood the overall flow of the fish and placed the gear correctly. Informed me on the difference between two types of stun and bleed lines he had sent, where the newest one was optimal for the use in the response vessel with a deacceleration tube and water separation included in the line.

Furthermore, the flow was explained in further detail.

There is a need for destruction stunning for the (presumed) dead fish to ensure that it is dead before entering the RSW compartment.

Comments that the RSW tanks should ideally not be deeper than 4 meters, due to the pressure that the fish.

The tube into the ship needs to be a minimum of 1,5 meters above the water line. Placing it on the main deck (about 3 meters above) is not an issue. However, the fish does “prefer” the pressure rather than vacuum, so one should strive to make the portion before the pump as short as possible.

Further sketching/ drawing was done:
Outlines of the accommodation decks were made as well as the bridge

B Task Clarification

	Algae blooming	Acute pollution
Commanding officer at location	Needed	Needed
Command central	Needed	Needed
Cargo capacity	Capacity needed is larges for live fish (30/70 fish water) Needed capacity for stun and bled fish smaller (70/30 fish water) Ensilage storage needed in case of dead fish	
Towing capacity	Towing of pen with fish could be alternative to wellboat	Towing capacity to handle ship accident may be needed.
Recatch net	Needed if there is risk of a submerged net (due to large amounts of dead fish)	
Oil spill gear	Gear similar to oil spill gear could be used to create a barrier around the fish pens. Does this type of gear exsist? Would i work?	Yes, needed. Should be mobilize as quickly as possible.
Well capacity	Yes, for early relocation of fish that are not of slaughter size and fish is not at risk of dying in well	Yes, if relocating fish is the best option.
Emergency slaughter	Yes, for salvaging biomass that is at risk of being lost	Could be the best option
Cranes	Normal crane capacity for pumping activities. Remove mooring of pen in case of pen towing activity	Cranes needed to handle oil spill gear + wellboat and or stun and bleed operation.
Gear to cut mooring	Could be needed in emergency case where pen needs to be moved quickly. Does there exist gear for this purpose?	
Winches	To remove mooring (for towing)	

	Algae blooming	Acute pollution
Algae detecting sensors	A preventive measures. All aquaculture vessels could be equipped with this type of gear, collectively gathering data for estimation in different areas, and forecasts of toxic bloomings to increase preparedness level. Part of the sintef project, talks of "fairy boxes" on vessels.	
Algae gear / tests	Future gear might be able to protect pens from algae (similarly to oil protective gear)	
Pump capacity	Pumps for live fish (100k fish) and dead fish.	
Ensilage capacity	There might be a large need for ensilage capacity in case of large fish mortality.	
Grind capacity	In case of dead fish, grind capacity is needed in addition to ensilage tank capacity	
Diving gear		
ROV		
Fire fighting canon		
First aid		
Rescue zone / leider		
Reception room		
Hospital (Sick bay)		
Rescue line		
Lights	Overview in operations in the dark. Handy in all scenarios	Overview in operations in the dark. Handy in all scenarios
Heatseeking cameras		

	Algae blooming	Acute pollution
Drones (flying)	May provide overview of algae blooming extent and priority of resources. Aviation and satelite photography might also be used	May provide overview of oil spill extent, drift and provide valuable information in the planning stage

	Collision / Grounding	Fire
Commanding officer at location	Needed	Needed
Command central	Needed	Needed
Cargo capacity	Storage space for rope	
Towing capacity	Towing of pen (with or without fish depending on distance and damage)	Tow away burning object to prevent spreading of fire. (For example boat moored at feed barge)
Recatch net	Needs to be deployed quickly in surrounding area to minimize escaped fish	May be needed, but not a high priority
Oil spill gear	In the case of collision with ship oil spill gear might be needed. In this case the gear will be used to contain the spill, and hence, the protection of the fish farm may be difficult and not prioritized	Could be needed if fuel from feed barge starts leaking, but not a priority in case of fire
Well capacity	Relocating fish may be an option for damaged / unsatble construcitons. The level of urgency is probably not the highest for these cases	Not likely time for relocation of fish with wellboat during fire, but there might be a need if fire is under control and fish needs to be moved due to damages. But, this will not be an imminent need.
Emergency slaughter	Can be the best option in cases where there might be an increased mortality (due to many possible factors, such as a collapsed bag) and restoration of normal operation may take some time	Could be the best option
Cranes	Needed for wellboat / stun and bleed + assitance in setting up towing	Keep the fish pen afloat if buoyancy is lost due to fire
Gear to cut mooring	Could be needed in emergency case where pen needs to be moved quickly. Does there exist gear for this purpose?	Might be needed if parts of a plant is to be moved.
Winches	Needed	Possibly (To remove mooring for towing)

	Collision / Grounding	Fire
Algae detecting sensors		
Algae gear / tests		
Pump capacity		Seapumps to be used to put out fire. Specialized equipment preferred
Ensilage capacity	Removal of deadfish could be needed before towing operation in the case of a grounded fish pen	Needed in case of dead fish. Large escape more likely than large amounts of deadfish.
Grind capacity	Yes, if ensilage is needed	Needed in case of ensilage
Diving gear	Needed to inspect potential damages to the pen and fix these at the accident site if possible.	Needed to inspect potential damages to the pen and fix these at the accident site if possible.
ROV	Might be an alternative to divers.	Might be an alternative to divers. Can be used during fire without putting lives in danger
Fire fighting canon		Preferred to just seawater pumps and normal hoses. Could be used in combination with existing pump capacity.
First aid		Might be needed. (Other than minimum req.?)
Rescue zone / leider		Can come in handy, but not a necessity.
Reception room		Handy in case of injured persons, but not a priority for this project
Hospital (Sick bay)		Handy in case of injured persons, but not a priority for this project
Rescue line	Small equipment that should be included to simplify retrival of MOB	Small equipment that should be included to simplify retrival of MOB
Lights	Overview in operations in the dark. Handy in all scenarios	Overview in operations in the dark. Handy in all scenarios
Heatseeking cameras		Might be used to identify critical areas of the fire as well as locating potential MOB

	Collision / Grounding	Fire
Drones (flying)	May provide overview	May provide overview. Especially if equipped with IR camera

C Concept Design

C.1 Response Time Study

Table 1: Ships observed in the studied area

Row Labels	Count of Type	Sum of Ship Days per week	Sum of Ship days per day [days]	Sum of Ship Hours per day [hours]	Sum of Avg amount of ships available at any hour of the day	Prob. of one ship ready	Expected number of ships ready at any hour of the day
Dive	2	6,5	0,93	22,29	0,93	0,5	0,46
Ensilage	2	0,5	0,07	1,71	0,07	0,5	0,04
Fast Personell	1	3	0,43	10,29	0,43	0,6	0,26
Resque	1	3,25	0,46	11,14	0,46	0,9	0,42
ROV	1	3,5	0,50	12,00	0,50	0,3	0,15
Service	3	5	0,71	17,14	0,71	0,4	0,29
Service	2	3,75	0,54	12,86	0,54	0,4	0,21
Service Kat	12	35	5,00	120,00	5,00	0,4	2,00
Service Kat	2	5,25	0,75	18,00	0,75	0,4	0,30
Stun and bleed	1	1	0,14	3,43	0,14	0,4	0,06
Wellboat	17	30,25	4,32	103,71	4,32	0,3	1,30
Grand Total	44	97	13,86	332,57	13,86		

Table 2: Max, Median and Min Total response time

	Distances [km]	[nm]	Sailing Time @12kn [h]	Tot. Response time (2h from call to sail) [h]
Max	150	81,0	6,75	8,75
Meadian	80	43,2	2,78	4,78
Min	10	5,4	0,45	2,45

Table 3: Probability distribution of response time

Time to respond [hours]		Probability	Cumulative Prob.
0	2	0,0017	0,0007
0,5	2,5	0,0046	0,0022
1	3	0,0112	0,0059
1,5	3,5	0,0245	0,0145
2	4	0,0479	0,0321
2,5	4,5	0,0841	0,0645
3	5	0,1319	0,1181
3,5	5,5	0,1852	0,1974
4	6	0,2326	0,3023
4,5	6,5	0,2615	0,4268
5	7	0,2630	0,5592
5,5	7,5	0,2368	0,6852
6	8	0,1907	0,7926
6,5	8,5	0,1375	0,8747
7	9	0,0887	0,9309
7,5	9,5	0,0512	0,9653
8	10	0,0264	0,9842
8,5	10,5	0,0122	0,9935
9	11	0,0051	0,9976
9,5	11,5	0,0019	0,9992
10	12	0,0006	0,9998
10,5	12,5	0,0002	0,9999
11	13	0,0000	1,0000
11,5	13,5	0,0000	1,0000

C.2 Propulsion Power

Ship Name	Speed	L	B	D	CB	Displace ment	Power	Admirality Coefficient
Taupo	13	37,9	11	3	0,65	833	750	259,4
Aqua Merdø	12,5	59,2	13,6	4	0,65	2146	900	361,0
Csaver	12	19	9,4	4	0,7	513	800	138,3
Taumar	13	28,5	10,2	3	0,7	626	750	214,3
Taupiri	13	42,9	11	3	0,65	943	750	281,7
Average	12,7	37,5	11,04	3,4	0,67	1012	790	251,0
Design	19	57	12	3,65		1311	**3274,2**	251,0

C.3 Machinery Space

Reference	Engine Power [kw]	2000
	A engine [m2]	95
	A freeze [m2]	18
	A tot [m2]	113
	H [m]	4,8
	V tot [m3]	542,4
	[m2/ kW]	0,1
	[m3/kW]	0,3
Design	Area [m2]	188,0
	Volume [m3]	902,5

C.4 Tank Spaces

Table 4: Calculation of tank spaces

Tank type	Usage [g/kWh]	Usage [tonn/day]	Range [nm]	Endurance [days]	Margin-factor	Volume [m3]
Fuel	190	15,0	3000	6,6	1,2	118,1
Lubricant	1	0,08	3000	6,6	6	3,1
Crew Number	24 l/crew/day					
Fresh Water	200	4,8		14	1,2	80,6
Suage & Grey-water	200	4,8		3	1,2	17,3
RSW - Live fish						400
Chemicals for cleaning						25
RSW - Dead fish						175,1
Blood water						40
Ballast, side tanks						100
Ballast, duble bottom						100
Voids						50
Total Tanks & Voids						1109,3

C.5 Ship Equipment

Name / Use of deck area	#	Area [m2]	Covered [%]	Height [m]	Covered area [m2]	Covered Volume [m3]
Tunnel thrusters	1	35	10,0 %	6	38,5	231
Steering gear	1	5	10,0 %	2,8	5,5	15,4
Mooring deck forward	1	10	15,0 %	0	11,5	0
Mooring deck aft	1	10	15,0 %	0	11,5	0
Cranes	3	3	0,0 %	0	3	0
Crew outdoor deck	1	50	0,0 %	0	50	0
Other open decks	1	200	0,0 %	0	200	0
Total ship equipment spaces					320	246,4

Name	Producer	# Units	Fish/ min	Tot. fish/ min	Surplus [%]	Weight Estimate [tonn]	Tot. Weight [tonn]	L [m]	B [m]	H [m]	Area [m2]	Covered [%]	Covered area m2	Covered Volume m3
Feeder/stun/bleed	Optimar	2,0	90	180	33 %	7,5	15	14,5	1,7	2,8	49,3	10,0 %	54,2	162,7
Bleeding tube	Optimar	1,0	200	200	48 %	5	5	14,5	1,2	2,8	17,4	10,0 %	19,1	57,4
Pumps Live fish	SeaQuest	1,0	200	200	48 %	3	3	2,5	2	3	5	5,0 %	5,3	15,8
Pumps for discharging fish for consumption	Cflow	1,0	150	150	-	1,5	1,5	5	2	2,8	10	5,0 %	10,5	31,5
Pumps deadfish	Cflow	1,0	150	150	132 %	1,5	1,5	5	2	2,8	10	5,0 %	10,5	31,5
RSW Plant	Frio Nordica	2,0	-	-	-	2	4	-	-	-	-	-	-	-
Washing system	Skjong	1,0	-	-	-	2	2	-	-	-	-	-	-	-
UV & partikkel -fiklter	-	2,0	-	-	-	1	2	-	-	-	-	-	-	-
Ozone-plant	-	1,0	-	-	-	3	3	-	-	-	-	-	-	-
Total				150			37						99,6	298,9

Name	#	Area [m2/unit]	Area [m2]	Covered [%]	Height [m]	Covered area [m2]	Covered Volume [m3]
MOB Boat	1	25	25	100 %	6	25	150
Life boats	2	2	4	100 %	1	4	4
Life saving appliances	30	0,5	15	100 %	2,8	15	42
Fire surveillance	2	4	8	0 %	3	0	0
Total rescue and fire fighting spaces						44	196

Total all equipment:	463,62	741,26

C.6 Crew & Service Areas

Crew Number	24

Crew lodging						
Cabin category	# Cabins	Bunks pr/cabin	Size [m2]	Height [m]	Area [m2]	Volume [m3]
Officer Large Suite	1	1	16	2,8	16	44,8
Officer	2	1	12	2,8	24	67,2
Other Crew	10	2	12	2,8	120	336
Chief	1	1	16	2,8	16	44,8
Total crew	**14**	**24**	**14**	**m2/crew**	**176**	**492,8**
Cabin corridor	30 %	of cabin area		2,8	52,8	147,84
Crew cabin area					**229**	**641**

Crew Recreational areas						
Name / space usage	Seat(s)	[m2 /seat]	[m2 / crew]	Height [m]	Area [m2]	Volume [m3]
Dayroom / Mess	14	4	2,33	2,8	56	156,8
Locker room / Changing	24	-	1,5	2,8	36	100,8
Toilet	2	-	3	2,8	6	16,8
Crew Recreational areas			**2,33**	**m2/crew**	**56**	**157**

Stairs and emergency exits						
Name / space usage	Decks	[m2 / deck]	[m2 / crew]	D-height [m]	Area [m2]	Volume [m3]
Stairs	2	16	1	2,8	32	89,6
Stairs to machine	2	15	1	3,2	30	96
Hallway	2	1	0,1	2,8	2	5,6
Stairs and emergency exits			**2,7**	**m2/crew**	**64**	**191,2**

Total crew fasiliteter			**5,00**	**m2/crew**	**349**	**989**

Ship service				
Name / Use of space	m2/crew	Høyde	Area m2	Volume m3
Bridge	2,5	2,8	60	168
Office	1	2,8	24	67,2
Ship service area	3,5		84	235,2

Catering Space				
Name / Use of space	m2/crew	Høyde	Area m2	Volume m3
Galley	1,5	3	36	108
Provision store	1	3	24	72
Waste	1	2,8	24	67,2
Total Catering Space	3,5		84	247,2

Hotel service				
Name / Use of space	m2/crew	Høyde	Area m2	Volume m3
Linen store, Washing	1	2,8	24	67,2
Hotel Store	1	2,8	24	67,2
Other stores	0,5	2,8	12	33,6
Cleaning Store	0,5	2,8	12	33,6
Total hotel service	3		72	201,6

Technical area for hotel				
Name / Use of space	m2/crew	Høyde m	Area m2	Volume m3
AC rom	1	2,8	24	67,2
Electrical room	0,25	2,8	6	16,8
Total Technical area	1,25	m^2/crew	30	84

Total Service Spaces	11,25	m^2/crew	270	768

C.7 Weight Estimation

Lightweight				
Weight group:	**Unit**	**Value**	**Coefficient [ton/unit]**	**Weight[tonn]**
Hull structure	Volum [m^3]	2767	0,075	207
Deck House	Volum [m^3]	168	0,05	8,4
Ship equipment and gear	GV [m^3]	442,4	0,004	1,8
Hotel	Areal [m^2]	348,8	0,19	66,3
Machinery	Effekt [kW]	3328	0,01	33
Ship Systems	GV [m^3]	4894,5	0,004	19,6
Fish handling gear	Vekt [tonn]	37,0	1	37,0
Fush handling deck	Areal [m^2]	100	0,4	39,8
Totalt	GV [m^3]	4894,5	0,085	414
Reserve	%	6		29
Lightweight				**443**

Deadweight				
Weight group:	**Unit**	**Value**	**Coefficient [ton/unit]**	**Weight[tonn]**
Fish	Capacity [tonnes]	273	1	273
Dead Fish	Capacity [tonnes]	131	1	131
Crew	PAX	24	0,09	2,2
Provision and store	Personer	24	0,2	5
Fuel Oil	Volume [m^3]	98,4	1,2	118,1
Lub Oil	Volume [m^3]	3,1	0,9	2,8
Fresh Water	Volume [m^3]	80,6	1	80,6
Sewage & Grey Water	Volume [m^3]	17,3	1,1	19,0
RSW	Volume [m^3]	400	0,3	120,0
RSW Dead Fish	Volume [m^3]	175	0,3	52,5
Chemicals for cleaning	Volume [m^3]	25	1	25,0
Blood water	Volume [m^3]	40	1	40,0
Deadweight				**869**

Displacement [tonnes]		**1311**
	Deadweight / Displacement	**0,662**

C.8 Numerical Hull

Weight from weight estimation:		
Displacement	1311	tonn
Density Seawater	1,025	tonn/m3
Nabla, Displaced volume	1279,2	m3

Geometric definition

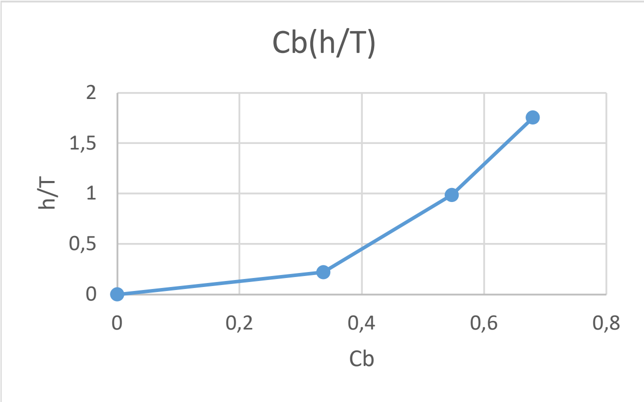
Main dimensions	Value	Unit	Ratios	Value
LOA	57	m	LWL/(nabla^1/3)	5,07
LWL	55	m	LWL/LPP	1,04
LPP	53	m	Lpp/B	4,42
Beam	12	m	B/T	3,29
Draft	3,65	m	Fn	0,4208
Watertight deck	6,40	m	CB, Wanted	0,55
Freeboard	2,75	m	CB, Calculated	0,55
			CW	0,79
			CM	0,99
			CP	0,56

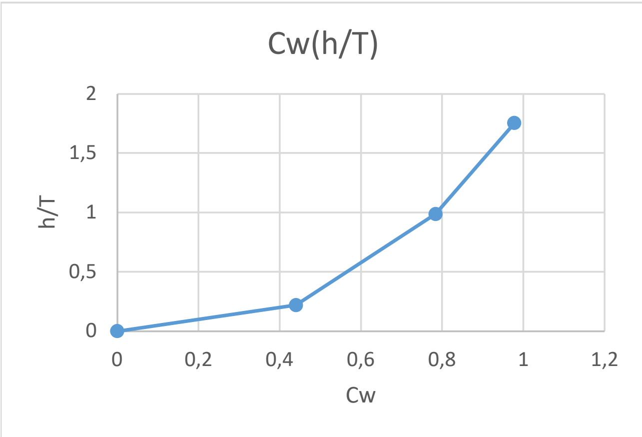
Deck areas and volumes in hull

Dekksnavn	Høyde over BL [m]	Dekk høyde [m]	Dekk areal [m2]	Areal koef	System areal [m2]	System volum [m3]
Dobbel bunn (baseline)	0	0,8	0	-	-	172
Dekk 3	0,8	2,8	280	0,3	84	1081
Dekk 2	3,6	2,8	498	0,6	299	1514
A-Deck	6,4					
Total hull					**383**	**2767**

Dekknavn	Høyde over BL [m]	Dekk høyde [m]	Dekk areal [m2]	Areal koef	System areal [m2]	System volum [m3]
A-deck	6,4	2,8	669	0,8	535	1498
B-deck	9,2	2,8	669	0,6	401	1123
Bridge	12	3,1	669	0,15	100	311
Top of bridge	15,1	0,5				
Total Superstructure	15,6				1036	2932
Total Hull + Superstructure					**1419**	**5699**

h/T	Cw(h)	Cb(h)
0	0	0
0,219178082	0,43976892	0,33726584
0,98630137	0,78374607	0,54725083
1,753424658	0,97762698	0,67966777





C.9 Stability Check

Lightweight				
Weight group	**Weight [tonn]**	**Gravitasional Center KG/D**	**KG [m]**	**Moment [tonn * m]**
Hull Structure	207	0,6	3,84	796,8
Deckhouse	8,4	1,3	8,32	69,9
Ship equipment	1,8	1	6,4	11,3
Hotel	66,3	1,25	8	530,2
Machiney	33,3	0,4	2,56	85,2
Ship systems	19,6	0,6	3,84	75,2
Processing Gear	37,0	0,85	5,44	201,3
Processing Deck	39,8	0,85	5,44	216,8
Totalt	414	0,75	4,80	1986,6
Reserve	29	1	6,4	185,3
Lightweight	**443**	**0,77**	**4,9**	**2171,9**

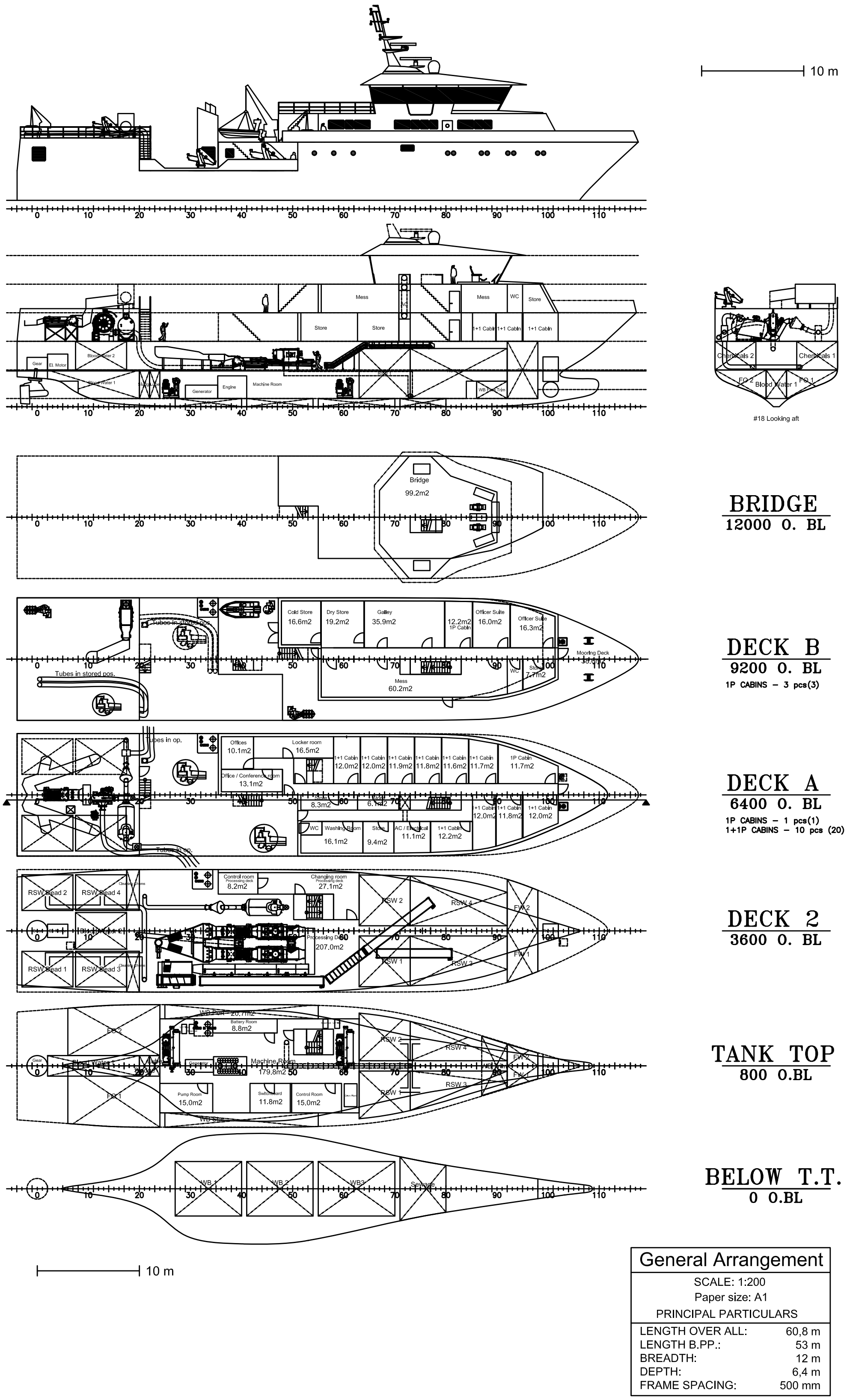
Deadweight				
Item	**Weight [tonnes]**	**Center of gravity KG/D**	**KG [m]**	**Moment [ton * m]**
Fish	273	0,85	5,44	1485,12
Crew	2,16	1,25	8	17,3
Provition and store	4,8	1,05	6,72	32
Fuel Oil	118,1	0,4	2,56	302,4
Lub. Oil	2,8	0,4	2,56	7,2
Fresh Water	80,64	0,4	2,56	206,4
Sewage and grey water	19,0	0,05	0,32	6,1
Blood water	40	0,15	0,96	38,4
Deadweight	**869**	**0,38**	**2,4**	**2095,1155**

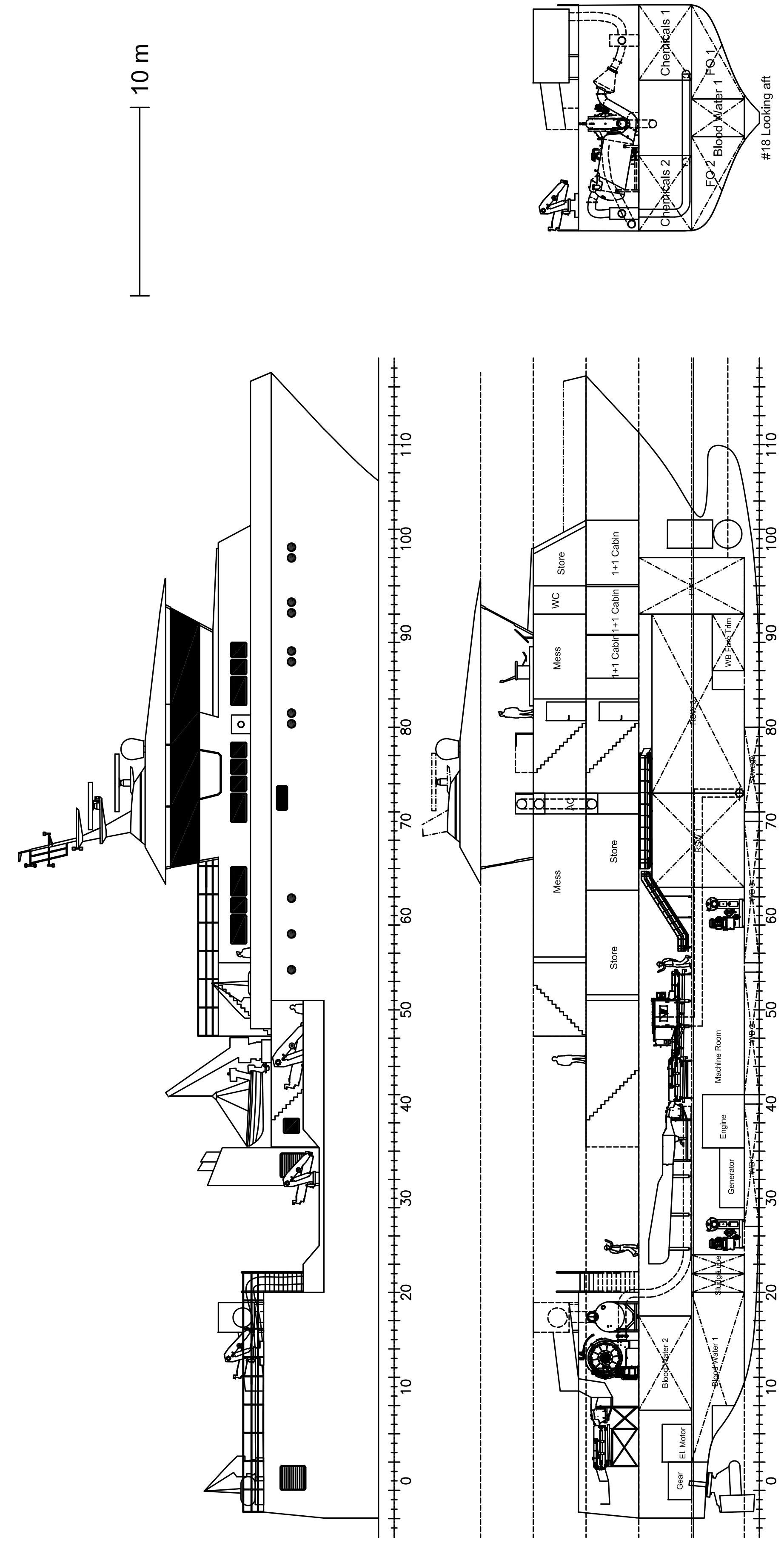
Lightweight + deadweight	**1311**	**0,5**	**3,25**	**4267,0**

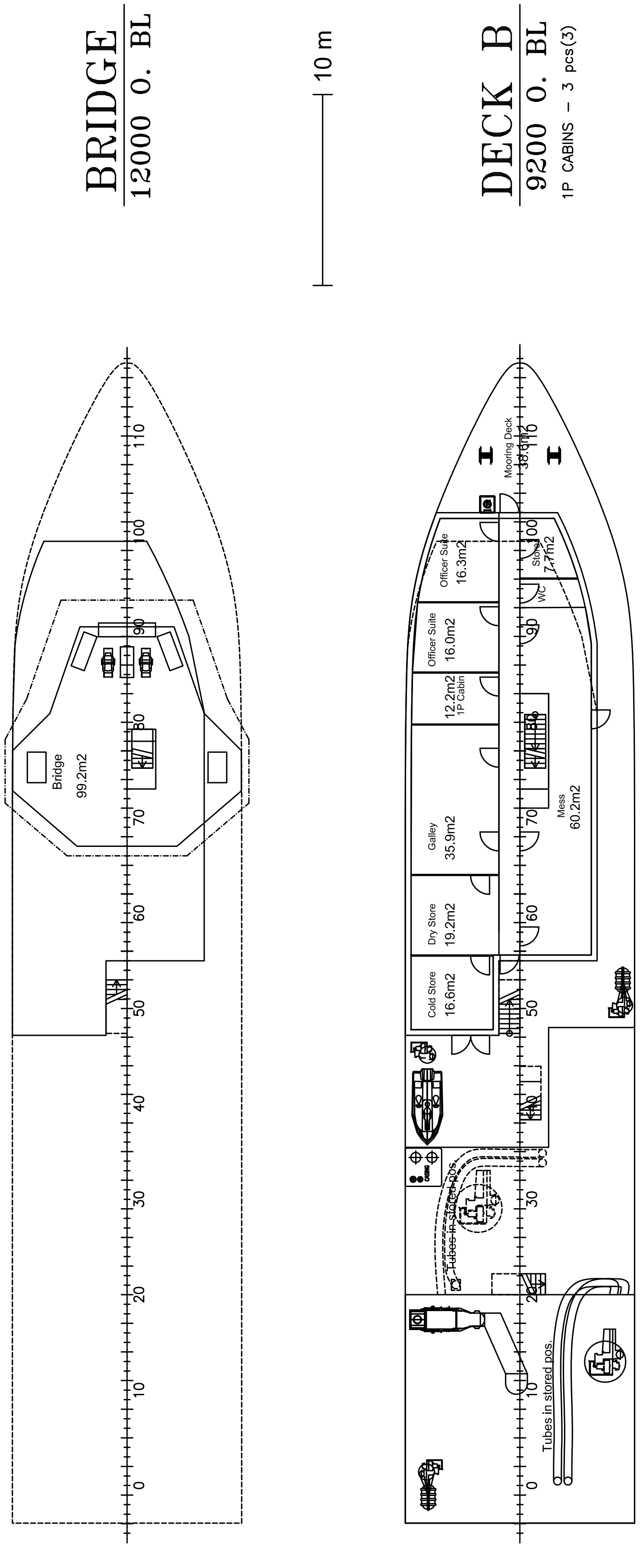
Ship Stability		
Center of floatation	KB [m]	3,04
Transverse metacenter	BM [m]	3,79
Metacenter above keel	KM [m]	7
Metacentric height	**GM [m]**	**3,58**

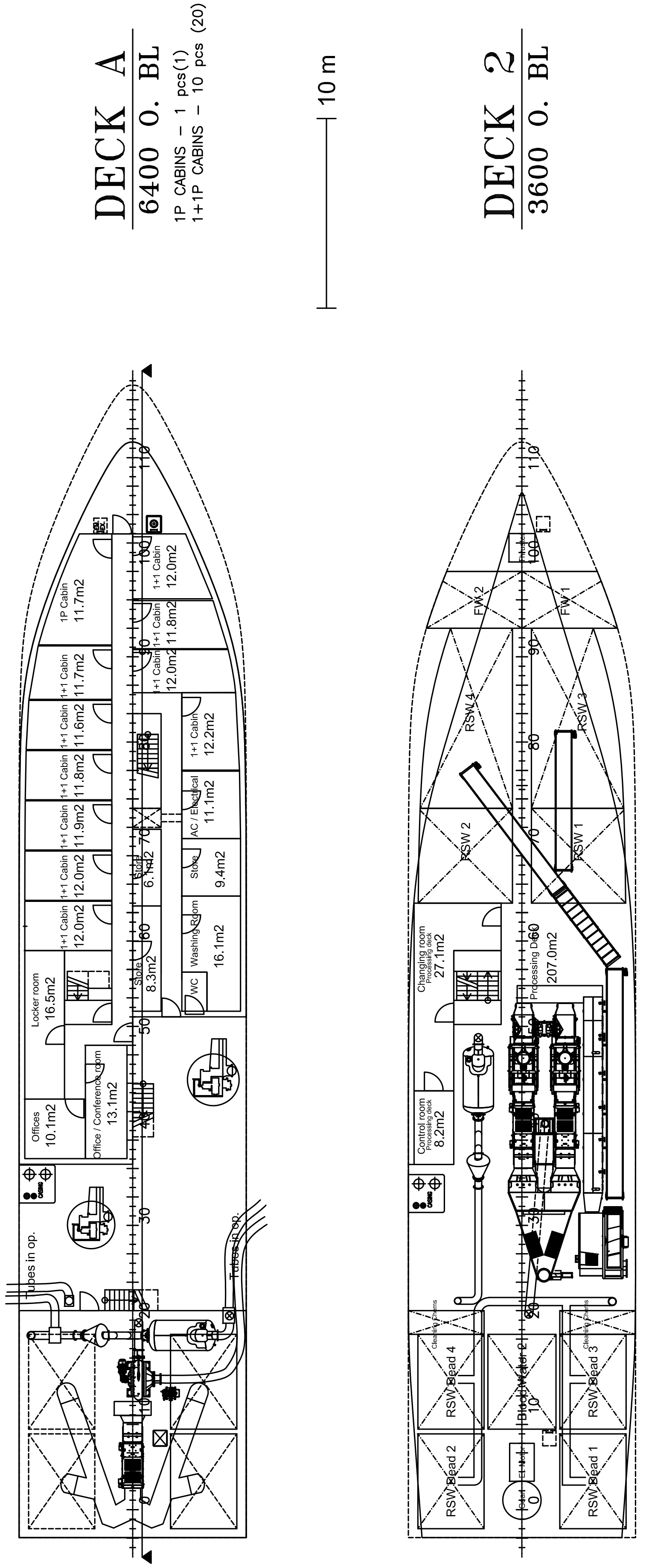
D Embodiment Design

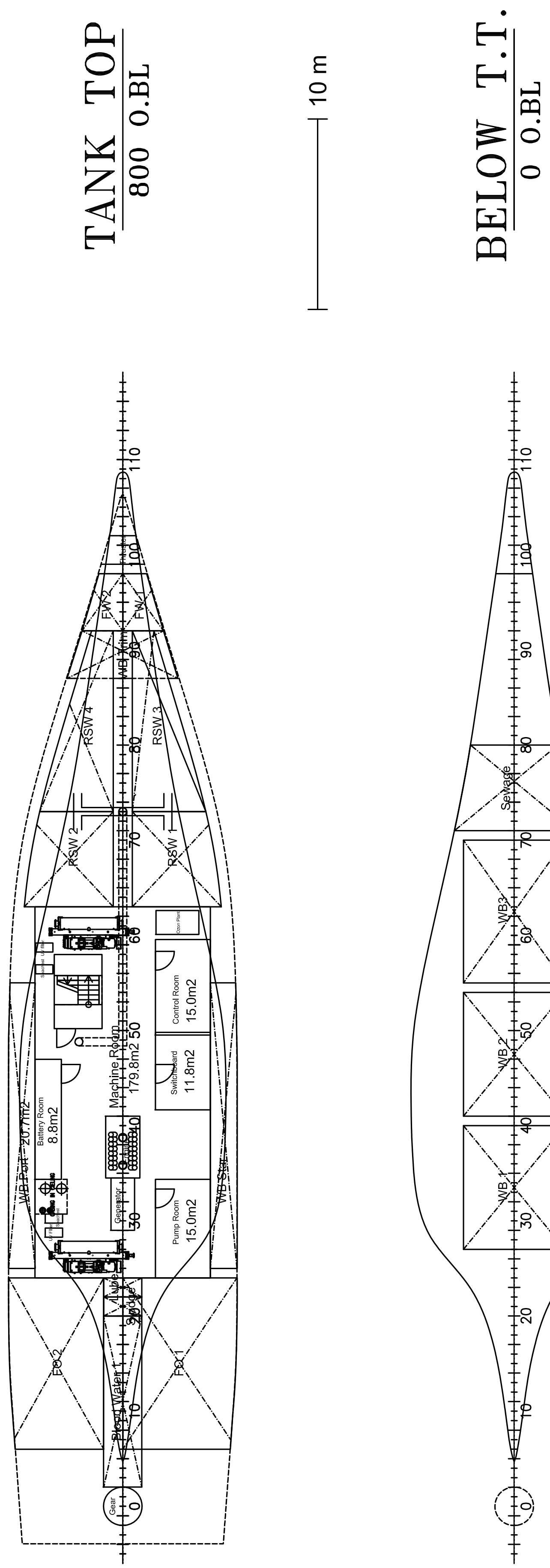
D.1 General Arrangement



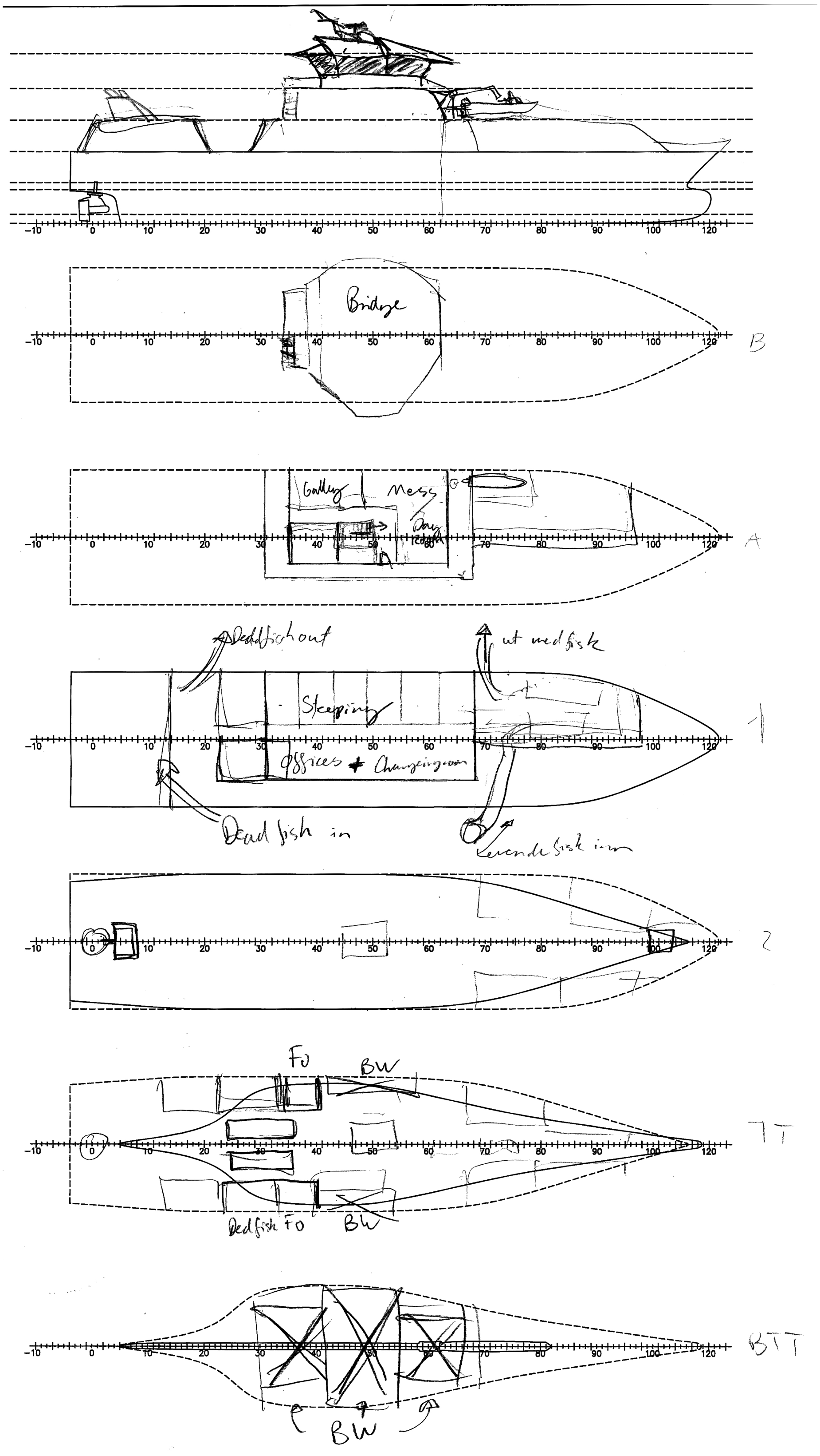

10 m
Chemicals 1
FO 1
Blood Water 1
FO 2
Chemicals 2
#18 Looking aft
Store
WC
Mess
1+1 Cabin
Store
Machine Room
Engine
Generator
Blood Water 2
Blood Water 1
El. Motor
Gear
WB Fore Trim
0
10
20
30
40
50
60
70
80
90
100
110


BRIDGE
12000 O. BL
10 m
DECK B
9200 O. BL
1P CABINS – 3 pcs(3)
Bridge
99.2m2
Mooring Deck
Officer Suite
16.3m2
Store
7.7m2
WC
Officer Suite
16.0m2
12.2m2
1P Cabin
Galley
35.9m2
Mess
60.2m2
Dry Store
19.2m2
Cold Store
16.6m2
Tubes in stored pos.
Tubes in stored pos.

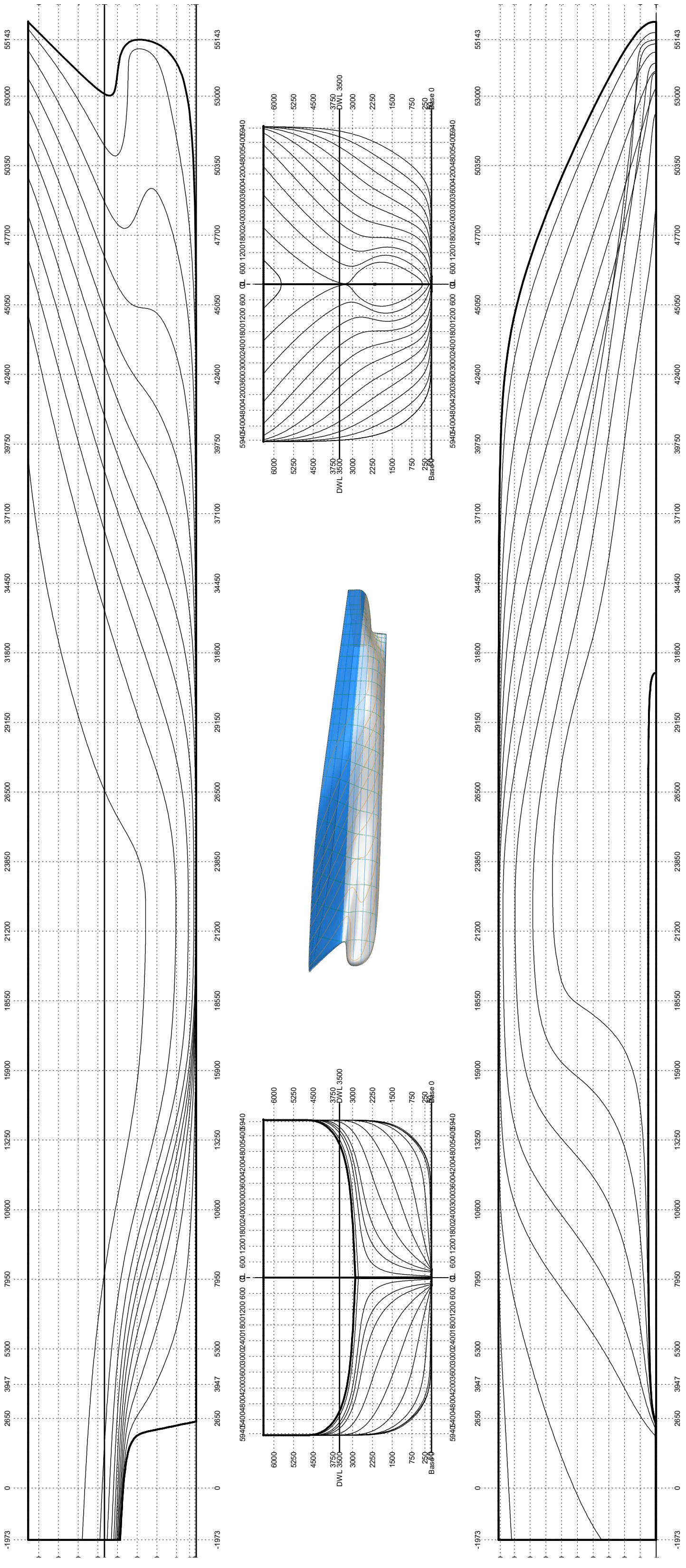

DECK A
6400 O. BL
1P CABINS – 1 pcs(1)
1+1P CABINS – 10 pcs (20)
10 m
DECK 2
3600 O. BL
1P Cabin 11.7m2
1+1 Cabin 12.0m2
1+1 Cabin 11.8m2
1+1 Cabin 11.7m2
1+1 Cabin 11.6m2
1+1 Cabin 11.9m2
1+1 Cabin 12.2m2
AC / Electrical 11.1m2
Store 6.1m2
Store 9.4m2
Store 8.3m2
Washing Room 16.1m2
WC
Locker room 16.5m2
Offices 10.1m2
Office / Conference room 13.1m2
Tubes in op.
FW 1
FW 2
RSW 1
RSW 2
RSW 3
RSW 4
Changing room Processing deck 27.1m2
Processing Deck 207.0m2
Control room Processing deck 8.2m2
RSW Bead 1
RSW Bead 2
RSW Bead 3
RSW Bead 4
BloodWater 2


TANK TOP
800 0.BL
10 m
BELOW T.T.
0 0.BL
Machine Room
179.8m2
Control Room
15.0m2
Switchboard
11.8m2
Pump Room
15.0m2
Battery Room
8.8m2
Generator
RSW 1
RSW 2
RSW 3
RSW 4
FW 1
FW 2
FO 1
FO 2
Gear
Sewage
WB 1
WB 2
WB3

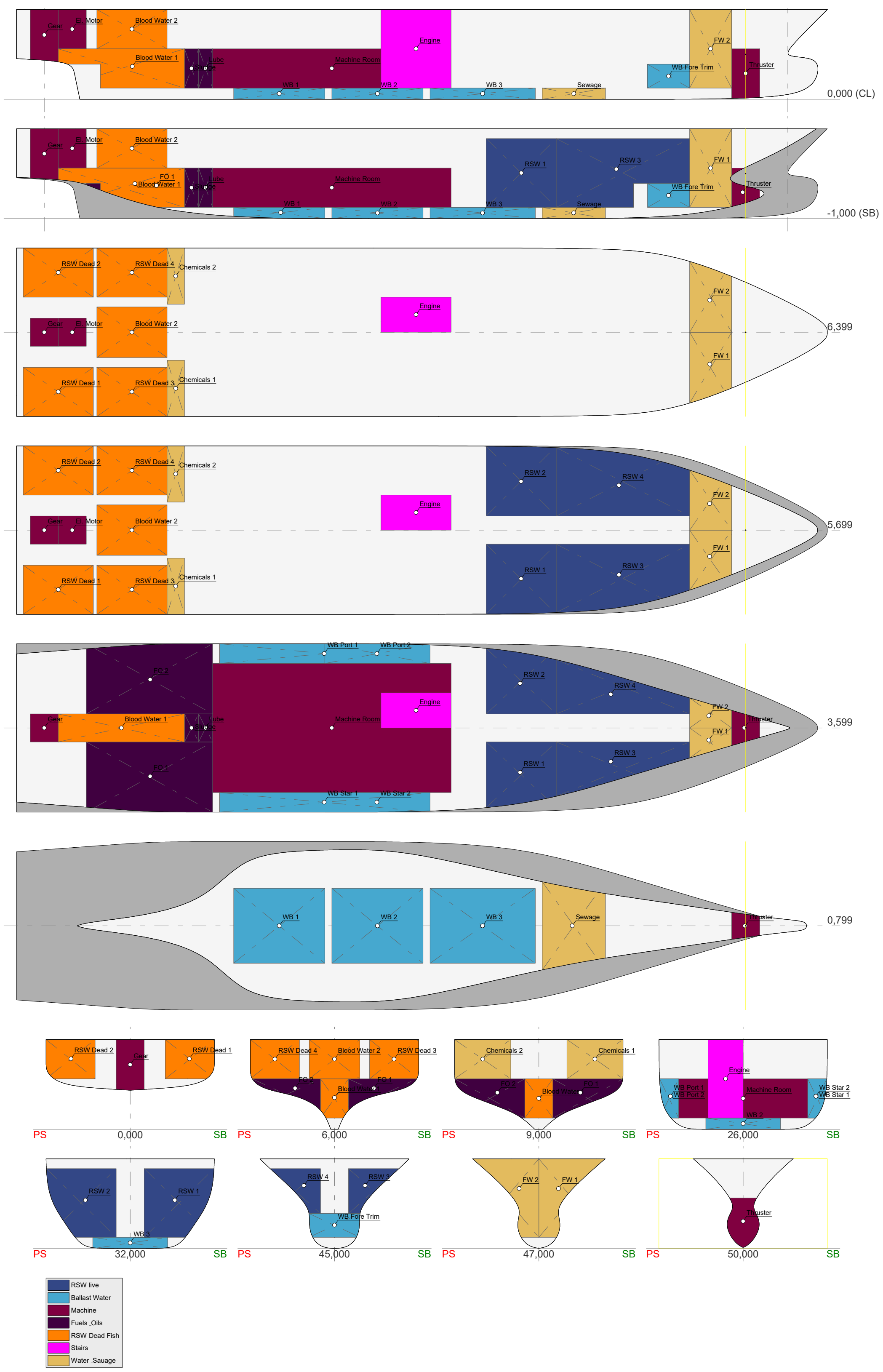
D.2 Sketches


Bridge
B
Galley
Mess
A
Dead fish out
ut med fisk
Sleeping
Offices + Changingroom
Dead fish in
1
2
FO
BW
TT
Dedfish FO
BW
BTT
BW

D.3 Lines Plan



D.4 Tank Arrangement



D.5 Hydrostatics

Design hydrostatics report

Design hydrostatics report

Designer			
Created by			
Comment			
Filename	rev13_Skip_53x12x6.fbm		
Design length	53,000 (m)	Midship location	26,500 (m)
Length over all	57,793 (m)	Relative water density	1,0250
Design beam	12,000 (m)	Mean shell thickness	0,0000 (m)
Maximum beam	12,000 (m)	Appendage coefficient	1,0000
Design draft	3,500 (m)		

Volume properties		Waterplane properties	
Moulded volume	1283,66 (m^3)	Length on waterline	55,056 (m)
Total displaced volume	1283,66 (m^3)	Beam on waterline	12,000 (m)
Displacement	1315,76 (tonnes)	Entrance angle	40,970 (Degr.)
Block coefficient	0,5767	Waterplane area	523,45 (m^2)
Prismatic coefficient	0,6396	Waterplane coefficient	0,8230
Vert. prismatic coefficient	0,7007	Waterplane center of floatation	21,082 (m)
Wetted surface area	758,70 (m^2)	Transverse moment of inertia	5247,6 (m^4)
Longitudinal center of buoyancy	24,304 (m)	Longitudinal moment of inertia	95173 (m^4)
Longitudinal center of buoyancy	-3,989 %		
Vertical center of buoyancy	2,000 (m)		

Midship properties		Initial stability	
Midship section area	37,87 (m^2)	Transverse metacentric height	6,088 (m)
Midship coefficient	0,9017	Longitudinal metacentric height	76,142 (m)

Lateral plane	
Lateral area	184,75 (m^2)
Longitudinal center of effort	27,713 (m)
Vertical center of effort	1,784 (m)

The following layer properties are calculated for both sides of the ship

Location	Area (m^2)	Thickness (m)	Weight (tonnes)	LCG (m)	TCG (m)	VCG (m)
Layer 0	1793,51	0,000	0,00	24,518	0,000 (CL)	3,940

Sectional areas

Location (m)	Area (m^2)	Location (m)	Area (m^2)	Location (m)	Area (m^2)	Location (m)	Area (m^2)	Location (m)	Area (m^2)
-1,973	4,29	7,950	20,28	21,200	39,44	34,450	27,80	47,700	8,44
0,000	5,23	10,600	26,91	23,850	39,29	37,100	23,54	50,350	5,55
2,650	8,48	13,250	32,93	26,500	37,87	39,750	19,37	53,000	3,28
3,947	11,46	15,900	37,11	29,150	35,26	42,400	15,43	55,143	0,01
5,300	14,24	18,550	39,02	31,800	31,82	45,050	11,77		

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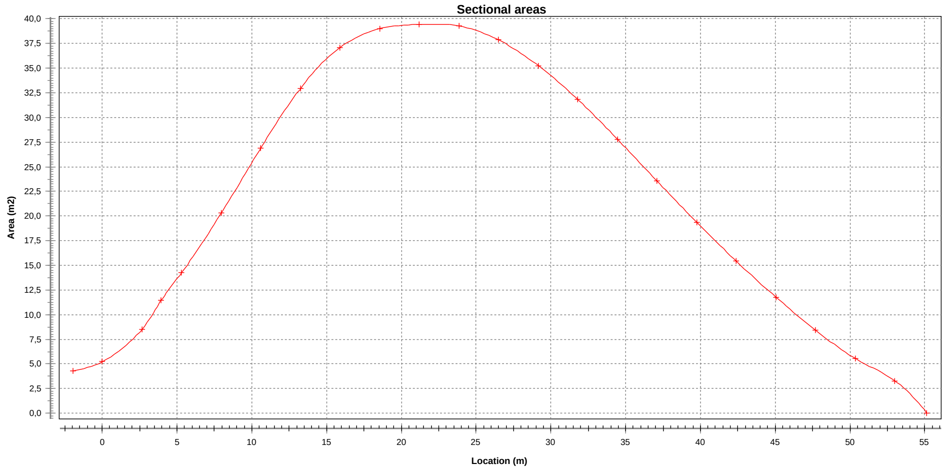
Design hydrostatics report



NOTE 1: Draft (and all other vertical heights) is measured from base Z=0,000
NOTE 2: All calculated coefficients based on project length, draft and beam.

D.6 Intact Stability

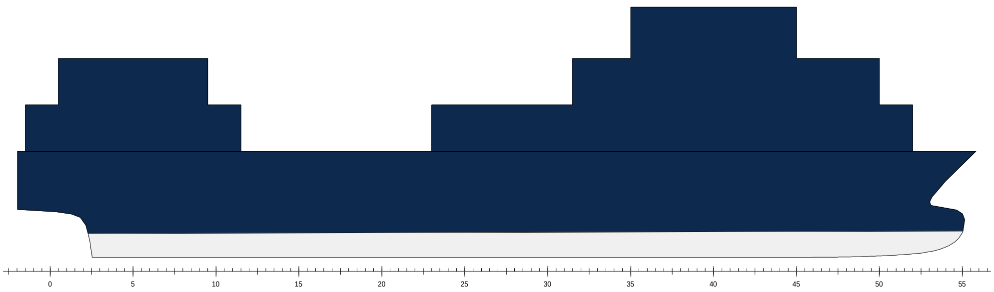
D.6.1 Lightship

Intact stability

Lightship

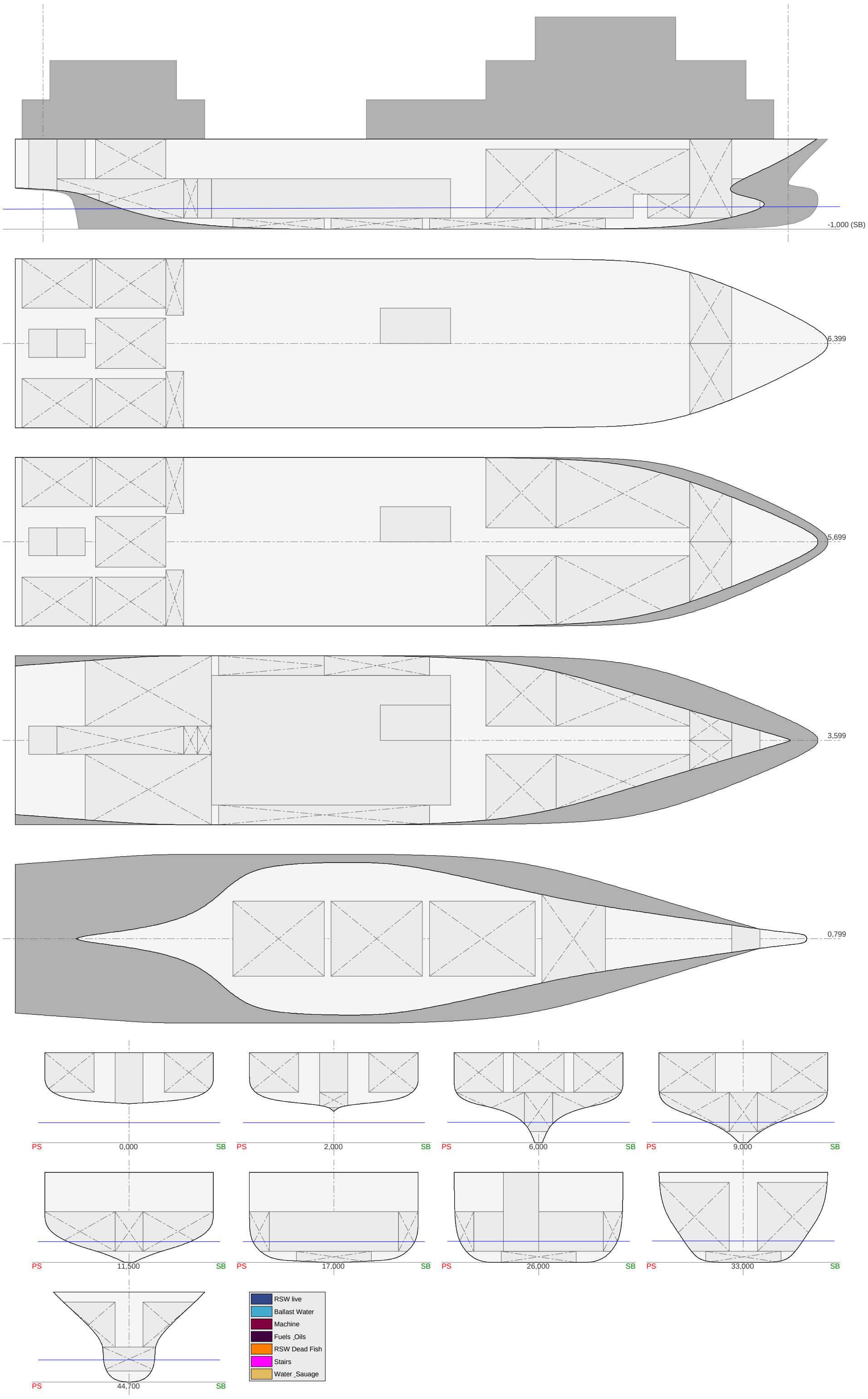
Designer			
Created by			
Comment			
Filename		rev13_Skip_53x12x6.fbm	
Design length	53,000 (m)	Midship location	26,500 (m)
Length over all	57,793 (m)	Relative water density	1,0250
Design beam	12,000 (m)	Mean shell thickness	0,0000 (m)
Maximum beam	12,000 (m)	Appendage coefficient	1,0000
Design draft	3,500 (m)		

Silhouette 1



30.05.2021 DELFTship 12.10 (320)

1


-1,000 (SB)
6,399
5,699
3,599
0,799
PS
0,000
SB
2,000
6,000
9,000
11,500
17,000
26,000
33,000
44,700
RSW live
Ballast Water
Machine
Fuels ,Oils
RSW Dead Fish
Stairs
Water ,Sauage

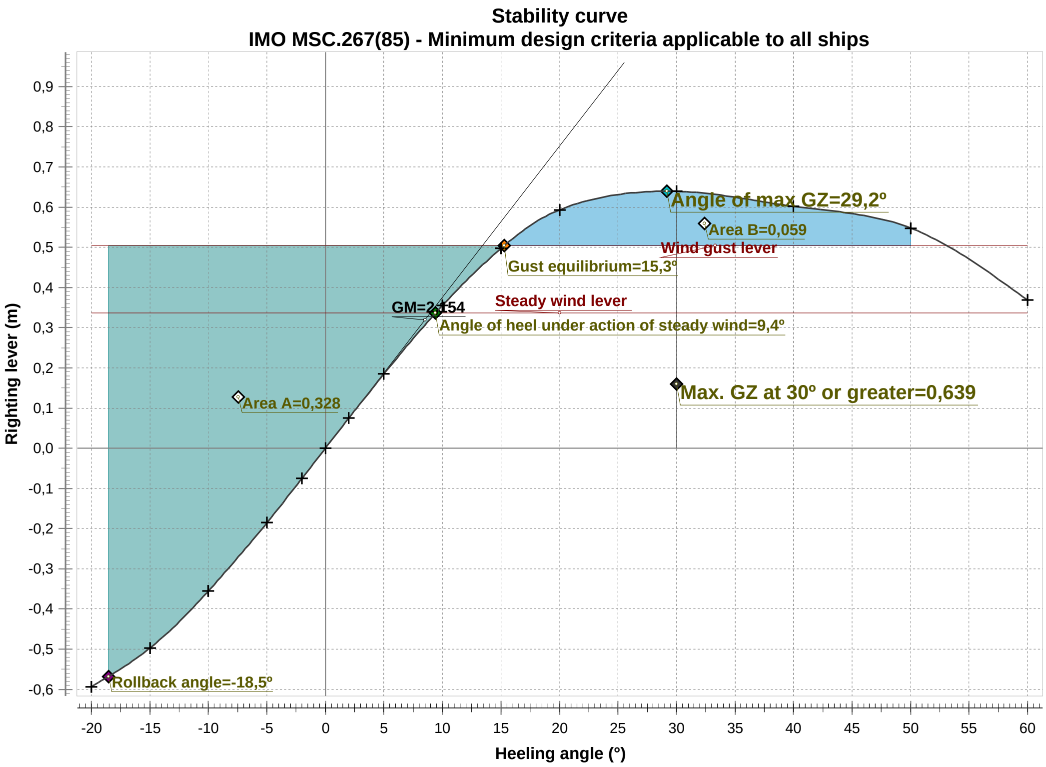
Hydrostatic particulars

List	0,0 (CL) (Degr.)	GG'	0,000 (m)
Draft aft pp	1,433 (m)	VCG'	4,900 (m)
Mean moulded draft	1,512 (m)	Max VCG'	3,884 (m)
Draft forward pp	1,591 (m)	GM solid	2,154 (m)
Trim	0,158 (m)	G'M liquid	2,154 (m)
KM	7,054 (m)	Immersion rate	3,652 (t/cm)
VCG	4,900 (m)	MCT	8,35 (t*m/cm)

Description	Density (t/m³)	Fill%	Weight (tonnes)	LCG (m)	TCG (m)	VCG (m)	FSM (t*m)
Lightship			435,00	26,500	0,000 (CL)	4,900	
Deadweight			0,00	0,000	0,000 (CL)	0,000	0,00
Displacement			435,00	26,500	0,000 (CL)	4,900	0,00

Righting levers

Heeling angle (Degr.)	Draft (m)	Trim (m)	Displacement (tonnes)	KN sin(ø) (m)	VCG sin(ø) (m)	GG' sin(ø) (m)	TCG cos(ø) (m)	GZ (m)	Area (mrad)
0,0º (CL)	1,512	0,158	435,00	0,000	0,000	0,000	0,000	0,000	0,000
2,0º (PS)	1,510	0,163	435,00	0,246	0,171	0,000	0,000	0,075	0,001
5,0º (PS)	1,501	0,186	435,00	0,612	0,427	0,000	0,000	0,185	0,008
10,0º (PS)	1,467	0,270	435,00	1,206	0,851	0,000	0,000	0,355	0,032
15,0º (PS)	1,405	0,415	435,00	1,765	1,268	0,000	0,000	0,497	0,069
20,0º (PS)	1,307	0,633	435,00	2,269	1,676	0,000	0,000	0,593	0,117
30,0º (PS)	0,963	1,287	435,00	3,089	2,450	0,000	0,000	0,639	0,227
40,0º (PS)	0,351	2,257	435,00	3,752	3,150	0,000	0,000	0,602	0,336
50,0º (PS)	-0,712	3,636	435,00	4,302	3,754	0,000	0,000	0,548	0,437
60,0º (PS)	-2,483	5,896	435,00	4,612	4,244	0,000	0,000	0,368	0,518



Evaluation of criteria

IMO MSC.267(85) - Minimum design criteria applicable to all ships

International Code on Intact Stability (2008), Part A, §2.2 - §2.3

Description	Attained value	Criterion	Required value	Complies
Area 0º - 30º	0,2267 (mrad)	>=	0,0550 (mrad)	YES
Area 0º - 40º	0,3355 (mrad)	>=	0,0900 (mrad)	YES
Area 30º - 40º	0,1088 (mrad)	>=	0,0300 (mrad)	YES
Max. GZ at 30º or greater	0,639 (m)	>=	0,200 (m)	YES
Lower angle	30,0 (Degr.)			
Upper angle	90,0 (Degr.)			
Angle of max GZ	29,2 (Degr.)	>=	25,0 (Degr.)	YES
Initial metacentric height	2,154 (m)	>=	0,150 (m)	YES
Severe wind and rolling criterion (weather criterion)				NO
Wind silhouette:	Silhouette 1			
Windspeed	50,54 (kn.)			
Wind pressure	51,4 (kg/m^2)			
Wind area	495,99 (m^2)			
Steady wind lever	0,337 (m)			
Deck immersion angle	44,28 (Degr.)			
Wind gust lever	0,505 (m)			
Ratio of areaA/areaB	5,544	<=	1,000	NO
Maximum allowed static heeling angle	9,4 (Degr.)	<=	16,0 (Degr.)	YES
Max allowed ratio static angle/deck immersion angle	0,213	<=	0,800	YES

The condition does NOT comply with the stability criteria

D.6.2 Ballast

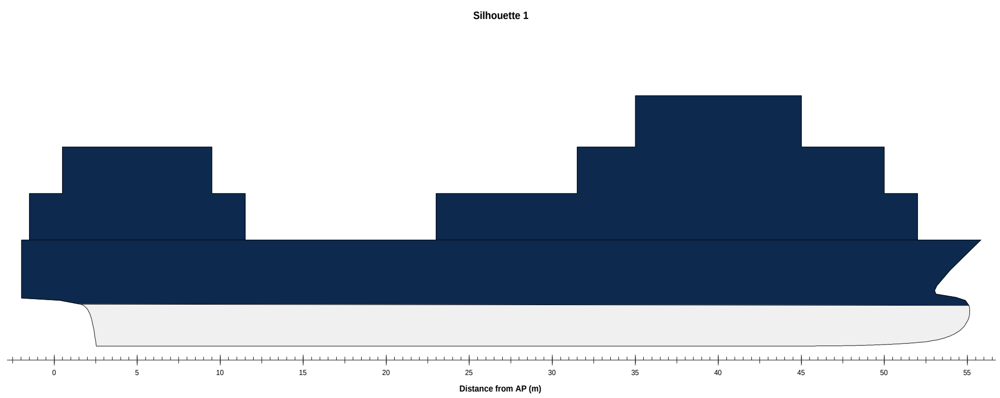
Intact stability

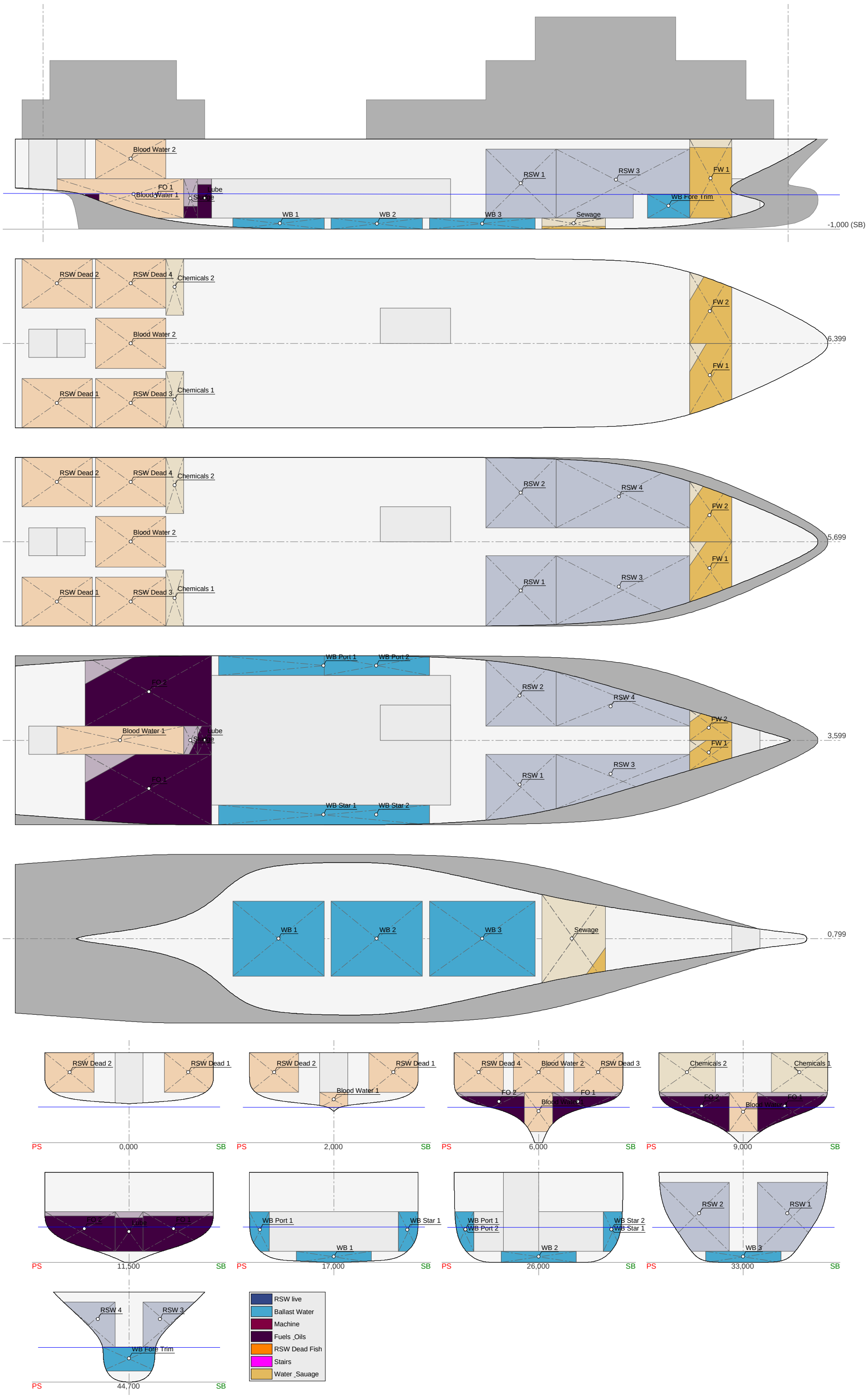
Ballast

Designer			
Created by			
Comment			
Filename		rev13_Skip_53x12x6.fbm	
Design length	53,000 (m)	Midship location	26,500 (m)
Length over all	57,793 (m)	Relative water density	1,0250
Design beam	12,000 (m)	Mean shell thickness	0,0000 (m)
Maximum beam	12,000 (m)	Appendage coefficient	1,0000
Design draft	3,500 (m)		

Calculation settings

Center of gravity of tanks containing liquids	:	Actual COG





-1,000 (SB)
6,399
5,699
3,599
0,799
PS
SB
0,000
2,000
6,000
9,000
11,500
17,000
26,000
33,000
44,700
RSW live
Ballast Water
Machine
Fuels ,Oils
RSW Dead Fish
Stairs
Water ,Sauage

Hydrostatic particulars

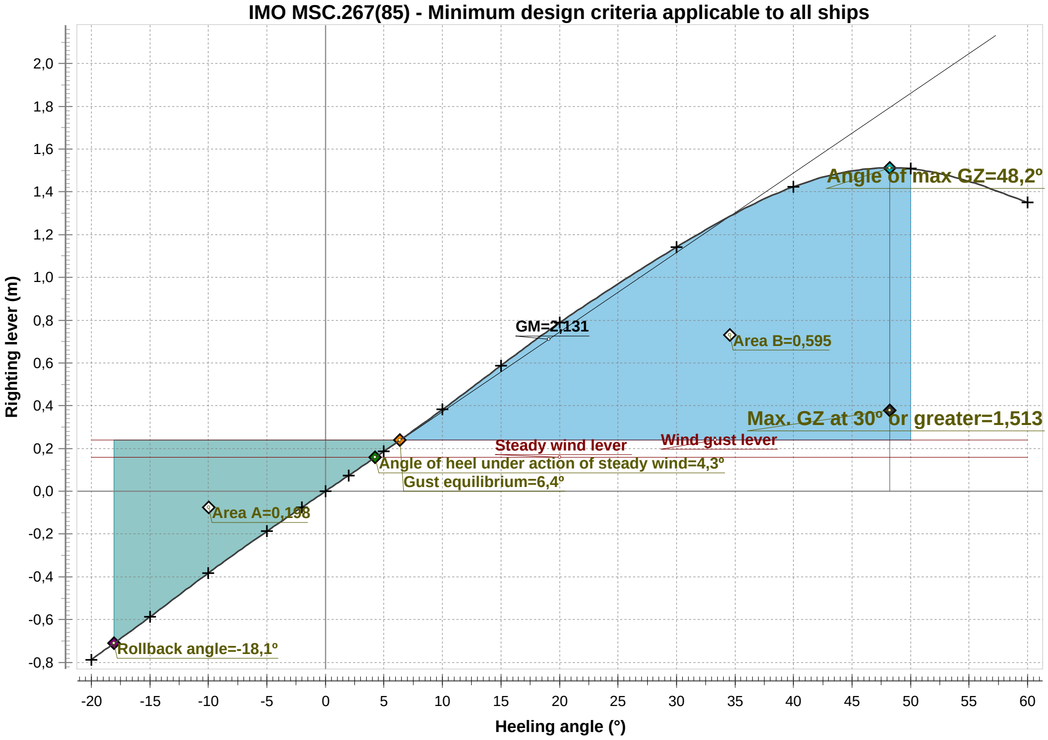
List	0,0 (CL) (Degr.)	GG'	0,222 (m)
Draft aft pp	2,537 (m)	VCG'	3,805 (m)
Mean moulded draft	2,495 (m)	Max VCG'	5,179 (m)
Draft forward pp	2,453 (m)	GM solid	2,353 (m)
Trim	-0,083 (m)	G'M liquid	2,131 (m)
KM	5,936 (m)	Immersion rate	4,305 (t/cm)
VCG	3,583 (m)	MCT	11,01 (t*m/cm)

Description	Density (t/m³)	Fill%	Weight (tonnes)	LCG (m)	TCG (m)	VCG (m)	FSM (t*m)
RSW live							
RSW 1	1,0530	0,0	0,00	33,915	-3,070 (SB)	3,518	0,00
RSW 2	1,0530	0,0	0,00	33,915	3,070 (PS)	3,518	0,00
RSW 3	1,0530	0,0	0,00	40,341	-2,578 (SB)	3,923	0,00
RSW 4	1,0530	0,0	0,00	40,341	2,578 (PS)	3,923	0,00
Totals for RSW live			0,00	0,000	0,000 (CL)	0,000	0,00
Ballast Water							
WB 1	1,0000	100,0	24,52	16,913	0,000 (CL)	0,433	0,00
WB 2	1,0000	100,0	27,01	23,758	0,000 (CL)	0,403	0,00
WB 3	1,0000	100,0	30,85	31,218	0,000 (CL)	0,406	0,00
WB Star 2	1,0000	100,0	25,04	23,601	-5,227 (SB)	2,310	0,00
WB Star 1	1,0000	100,0	49,18	20,092	-5,230 (SB)	2,342	0,00
WB Port 1	1,0000	100,0	49,18	20,092	5,230 (PS)	2,342	0,00
WB Port 2	1,0000	100,0	25,04	23,601	5,227 (PS)	2,310	0,00
WB Fore Trim	1,0000	100,0	18,28	44,432	0,000 (CL)	1,670	0,00
Totals for Ballast Water			249,08	24,046	0,000 (CL)	1,648	0,00
Fuels & Oils							
FO 1	0,8000	80,0	40,51	8,657	-2,852 (SB)	2,487	62,88
FO 2	0,8000	80,0	40,51	8,657	2,852 (PS)	2,487	62,88
Lube	0,2000	85,0	0,93	11,500	0,000 (CL)	1,990	0,13
Sludge	0,8000	30,0	1,32	10,500	0,000 (CL)	1,220	0,52
Totals for Fuels & Oils			83,27	8,718	0,000 (CL)	2,461	126,42
RSW Dead Fish							
RSW Dead 1	1,0530	0,0	0,00	1,006	-4,226 (SB)	5,018	0,00
RSW Dead 3	1,0530	0,0	0,00	6,253	-4,245 (SB)	5,004	0,00
RSW Dead 2	1,0530	0,0	0,00	1,006	4,226 (PS)	5,018	0,00
RSW Dead 4	1,0530	0,0	0,00	6,253	4,245 (PS)	5,004	0,00
Blood Water 1	1,0000	0,0	0,00	6,343	0,000 (CL)	2,378	0,00
Blood Water 2	1,0000	0,0	0,00	6,250	0,000 (CL)	5,000	0,00
Totals for RSW Dead Fish			0,00	0,000	0,000 (CL)	0,000	0,00
Water & Sauage							
FW 1	1,0000	80,0	29,07	47,404	-1,155 (SB)	3,820	14,74
FW 2	1,0000	80,0	29,07	47,404	1,155 (PS)	3,820	14,74
Sewage	1,0000	20,0	3,18	37,610	0,000 (CL)	0,118	27,95
Chemicals 1	1,0000	0,0	0,00	9,375	-4,000 (SB)	5,000	0,00
Chemicals 2	1,0000	0,0	0,00	9,375	4,000 (PS)	5,000	0,00
Totals for Water & Sauage			61,33	46,896	0,000 (CL)	3,628	57,44
Lightship			435,00	26,500	0,000 (CL)	4,900	
Deadweight			393,68	24,363	0,000 (CL)	2,129	183,86
Displacement			828,68	25,485	0,000 (CL)	3,583	183,86

Righting levers

Heeling angle (Degr.)	Draft (m)	Trim (m)	Displacement (tonnes)	KN sin(ø) (m)	VCG sin(ø) (m)	GG' sin(ø) (m)	TCG cos(ø) (m)	GZ (m)	Area (mrad)
0,0º (CL)	2,495	-0,083	828,68	0,000	0,000	0,000	0,000	0,000	0,000
2,0º (PS)	2,494	-0,079	828,68	0,207	0,125	0,008	0,000	0,074	0,001
5,0º (PS)	2,486	-0,052	828,68	0,519	0,312	0,019	0,000	0,187	0,008
10,0º (PS)	2,457	0,056	828,68	1,040	0,622	0,036	0,000	0,382	0,033
15,0º (PS)	2,406	0,252	828,68	1,561	0,927	0,046	0,000	0,588	0,075
20,0º (PS)	2,329	0,491	828,68	2,065	1,226	0,052	0,000	0,788	0,135
30,0º (PS)	2,070	1,042	828,68	2,991	1,792	0,058	0,000	1,141	0,304
40,0º (PS)	1,591	1,696	828,68	3,787	2,303	0,059	0,000	1,424	0,530
50,0º (PS)	0,874	2,720	828,68	4,311	2,745	0,058	0,000	1,508	0,790
60,0º (PS)	-0,251	4,457	828,68	4,507	3,103	0,054	0,000	1,350	1,041

Stability curve
IMO MSC.267(85) - Minimum design criteria applicable to all ships



Evaluation of criteria

IMO MSC.267(85) - Minimum design criteria applicable to all ships

International Code on Intact Stability (2008), Part A, §2.2 - §2.3

Description	Attained value	Criterion	Required value	Complies
Area 0º - 30º	0,3043 (mrad)	>=	0,0550 (mrad)	YES
Area 0º - 40º	0,5300 (mrad)	>=	0,0900 (mrad)	YES
Area 30º - 40º	0,2258 (mrad)	>=	0,0300 (mrad)	YES
Max. GZ at 30º or greater	1,513 (m)	>=	0,200 (m)	YES
Lower angle	30,0 (Degr.)			
Upper angle	90,0 (Degr.)			
Angle of max GZ	48,2 (Degr.)	>=	25,0 (Degr.)	YES
Initial metacentric height	2,131 (m)	>=	0,150 (m)	YES
Severe wind and rolling criterion (weather criterion)				YES
Wind silhouette:	Silhouette 1			
Windspeed	50,54 (kn.)			
Wind pressure	51,4 (kg/m^2)			
Wind area	444,38 (m^2)			
Steady wind lever	0,159 (m)			
Deck immersion angle	35,60 (Degr.)			
Wind gust lever	0,239 (m)			
Ratio of areaA/areaB	0,334	<=	1,000	YES
Maximum allowed static heeling angle	4,3 (Degr.)	<=	16,0 (Degr.)	YES
Max allowed ratio static angle/deck immersion angle	0,120	<=	0,800	YES

The condition complies with the stability criteria

D.6.3 Processing

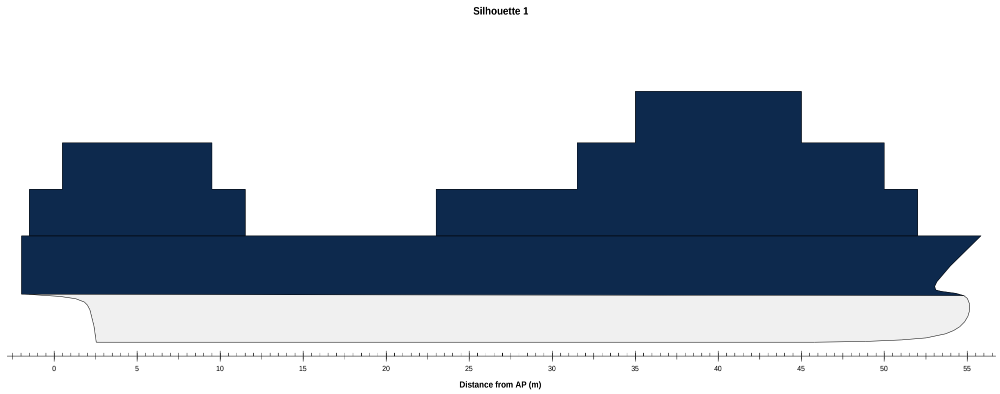
Intact stability

Processing

Designer			
Created by			
Comment			
Filename		rev13_Skip_53x12x6.fbm	
Design length	53,000 (m)	Midship location	26,500 (m)
Length over all	57,793 (m)	Relative water density	1,0250
Design beam	12,000 (m)	Mean shell thickness	0,0000 (m)
Maximum beam	12,000 (m)	Appendage coefficient	1,0000
Design draft	3,500 (m)		

Calculation settings

Center of gravity of tanks containing liquids	:	Actual COG



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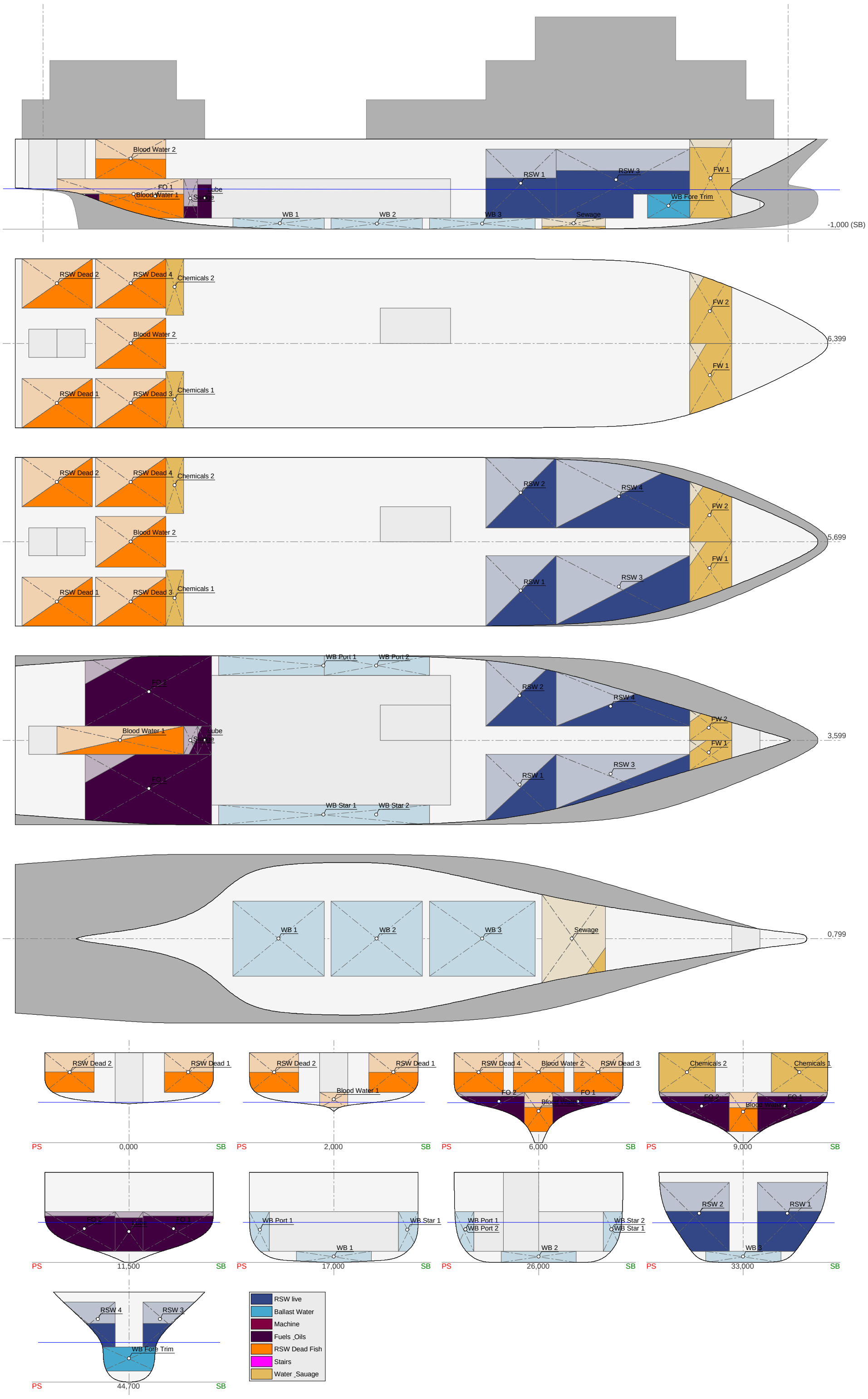

Blood Water 2
FO 1
Blood Water 1
Lube
Sewage
RSW 1
RSW 3
FW 1
WB Fore Trim
WB 1
WB 2
WB 3
-1,000 (SB)
RSW Dead 2
RSW Dead 4
Chemicals 2
FW 2
6,399
RSW Dead 1
RSW Dead 3
Chemicals 1
RSW 2
RSW 4
5,699
WB Port 1
WB Port 2
FO 2
WB Star 1
WB Star 2
3,599
0,799
PS
SB
0,000
2,000
6,000
9,000
11,500
17,000
26,000
33,000
44,700
RSW live
Ballast Water
Machine
Fuels ,Oils
RSW Dead Fish
Stairs
Water ,Sauage

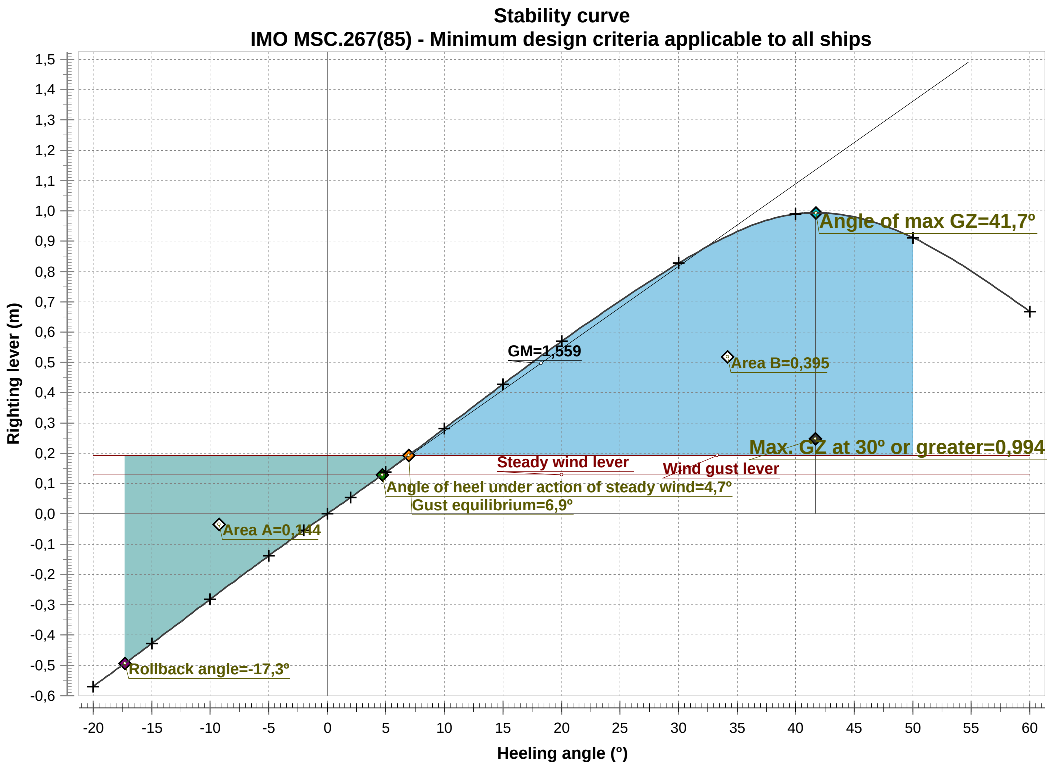
Hydrostatic particulars

List	0,0 (CL) (Degr.)	GG'	0,425 (m)
Draft aft pp	2,871 (m)	VCG'	4,351 (m)
Mean moulded draft	2,839 (m)	Max VCG'	5,291 (m)
Draft forward pp	2,807 (m)	GM solid	1,984 (m)
Trim	-0,064 (m)	G'M liquid	1,559 (m)
KM	5,910 (m)	Immersion rate	4,692 (t/cm)
VCG	3,926 (m)	MCT	13,24 (t*m/cm)

Description	Density (t/m3)	Fill%	Weight (tonnes)	LCG (m)	TCG (m)	VCG (m)	FSM (t*m)
RSW live							
RSW 1	1,0530	50,0	50,28	33,865	-2,777 (SB)	2,347	35,92
RSW 2	1,0530	50,0	50,28	33,865	2,777 (PS)	2,347	35,92
RSW 3	1,0530	50,0	56,12	39,902	-2,218 (SB)	2,871	31,81
RSW 4	1,0530	50,0	56,12	39,902	2,218 (PS)	2,871	31,81
Totals for RSW live			212,79	37,049	0,000 (CL)	2,623	135,45
Ballast Water							
WB 1	1,0000	0,0	0,00	16,913	0,000 (CL)	0,433	0,00
WB 2	1,0000	0,0	0,00	23,758	0,000 (CL)	0,403	0,00
WB 3	1,0000	0,0	0,00	31,218	0,000 (CL)	0,406	0,00
WB Star 2	1,0000	0,0	0,00	23,601	-5,227 (SB)	2,310	0,00
WB Star 1	1,0000	0,0	0,00	20,092	-5,230 (SB)	2,342	0,00
WB Port 1	1,0000	0,0	0,00	20,092	5,230 (PS)	2,342	0,00
WB Port 2	1,0000	0,0	0,00	23,601	5,227 (PS)	2,310	0,00
WB Fore Trim	1,0000	100,0	18,28	44,432	0,000 (CL)	1,670	0,00
Totals for Ballast Water			18,28	44,432	0,000 (CL)	1,670	0,00
Fuels & Oils							
FO 1	0,8000	80,0	40,51	8,657	-2,852 (SB)	2,487	62,88
FO 2	0,8000	80,0	40,51	8,657	2,852 (PS)	2,487	62,88
Lube	0,2000	85,0	0,93	11,500	0,000 (CL)	1,990	0,13
Sludge	0,8000	30,0	1,32	10,500	0,000 (CL)	1,220	0,52
Totals for Fuels & Oils			83,27	8,718	0,000 (CL)	2,461	126,42
RSW Dead Fish							
RSW Dead 1	1,0530	50,0	24,90	1,012	-4,201 (SB)	4,325	18,44
RSW Dead 3	1,0530	50,0	25,21	6,256	-4,240 (SB)	4,305	18,44
RSW Dead 2	1,0530	50,0	24,90	1,012	4,201 (PS)	4,325	18,44
RSW Dead 4	1,0530	50,0	25,21	6,256	4,240 (PS)	4,305	18,44
Blood Water 1	1,0000	50,0	18,91	7,126	0,000 (CL)	1,694	4,99
Blood Water 2	1,0000	50,0	24,70	6,250	0,000 (CL)	4,300	19,05
Totals for RSW Dead Fish			143,83	4,554	0,000 (CL)	3,968	97,78
Water & Sauage							
FW 1	1,0000	80,0	29,07	47,404	-1,155 (SB)	3,820	14,74
FW 2	1,0000	80,0	29,07	47,404	1,155 (PS)	3,820	14,74
Sewage	1,0000	20,0	3,18	37,610	0,000 (CL)	0,118	27,95
Chemicals 1	1,0000	100,0	13,72	9,375	-4,000 (SB)	5,000	0,00
Chemicals 2	1,0000	100,0	13,72	9,375	4,000 (PS)	5,000	0,00
Totals for Water & Sauage			88,76	35,298	0,000 (CL)	4,052	57,44
Lightship			435,00	26,500	0,000 (CL)	4,900	
Deadweight			546,94	24,152	0,000 (CL)	3,152	417,08
Displacement			981,94	25,192	0,000 (CL)	3,926	417,08

Righting levers

Heeling angle (Degr.)	Draft (m)	Trim (m)	Displacement (tonnes)	KN sin(ø) (m)	VCG sin(ø) (m)	GG' sin(ø) (m)	TCG cos(ø) (m)	GZ (m)	Area (mrad)
0,0º (CL)	2,839	-0,064	981,93	0,000	0,000	0,000	0,000	0,000	0,000
2,0º (PS)	2,837	-0,055	981,93	0,206	0,137	0,015	0,000	0,055	0,001
5,0º (PS)	2,829	-0,005	981,93	0,517	0,342	0,037	0,000	0,138	0,006
10,0º (PS)	2,799	0,141	981,94	1,036	0,682	0,072	0,000	0,282	0,024
15,0º (PS)	2,750	0,325	981,94	1,547	1,016	0,103	0,000	0,428	0,055
20,0º (PS)	2,679	0,527	981,93	2,044	1,343	0,131	0,000	0,569	0,099
30,0º (PS)	2,437	0,971	981,93	2,981	1,963	0,191	0,000	0,827	0,221
40,0º (PS)	2,014	1,558	981,94	3,771	2,524	0,258	0,000	0,989	0,382
50,0º (PS)	1,440	2,454	981,94	4,236	3,008	0,316	0,000	0,912	0,552
60,0º (PS)	0,573	3,862	981,94	4,424	3,400	0,356	0,000	0,668	0,691



Evaluation of criteria

IMO MSC.267(85) - Minimum design criteria applicable to all ships

International Code on Intact Stability (2008), Part A, §2.2 - §2.3

Description	Attained value	Criterion	Required value	Complies
Area 0° - 30°	0,2212 (mrad)	>=	0,0550 (mrad)	YES
Area 0° - 40°	0,3825 (mrad)	>=	0,0900 (mrad)	YES
Area 30° - 40°	0,1612 (mrad)	>=	0,0300 (mrad)	YES
Max. GZ at 30° or greater	0,994 (m)	>=	0,200 (m)	YES
Lower angle	30,0 (Degr.)			
Upper angle	90,0 (Degr.)			
Angle of max GZ	41,7 (Degr.)	>=	25,0 (Degr.)	YES
Initial metacentric height	1,559 (m)	>=	0,150 (m)	YES
Severe wind and rolling criterion (weather criterion)				YES
Wind silhouette:	Silhouette 1			
Windspeed	50,54 (kn.)			
Wind pressure	51,4 (kg/m^2)			
Wind area	425,61 (m^2)			
Steady wind lever	0,129 (m)			
Deck immersion angle	32,59 (Degr.)			
Wind gust lever	0,194 (m)			
Ratio of areaA/areaB	0,365	<=	1,000	YES
Maximum allowed static heeling angle	4,7 (Degr.)	<=	16,0 (Degr.)	YES
Max allowed ratio static angle/deck immersion angle	0,144	<=	0,800	YES

The condition complies with the stability criteria

D.6.4 Fully laden

Intact stability

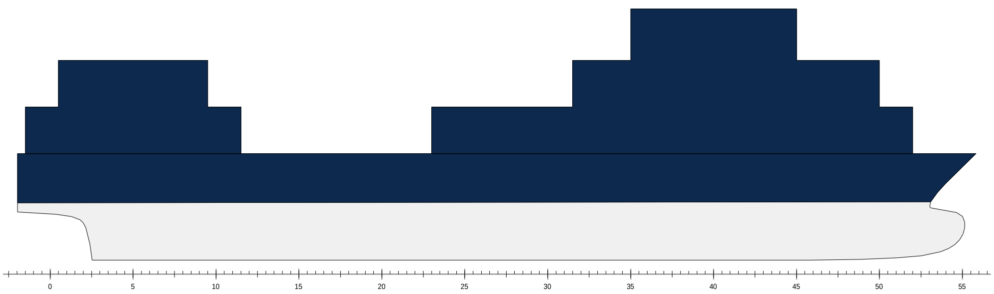
Fully laden

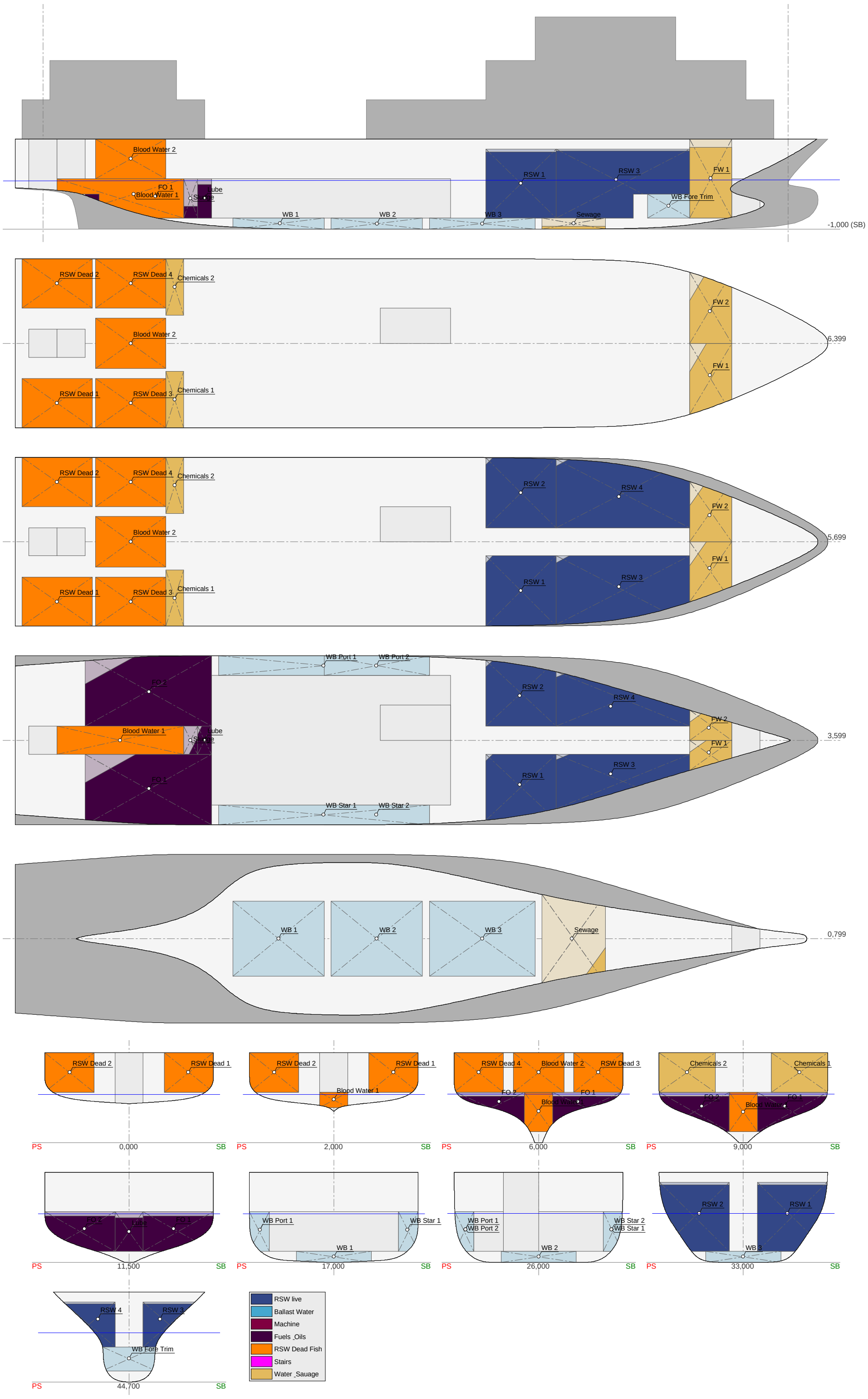
Designer			
Created by			
Comment			
Filename		rev13_Skip_53x12x6.fbm	
Design length	53,000 (m)	Midship location	26,500 (m)
Length over all	57,793 (m)	Relative water density	1,0250
Design beam	12,000 (m)	Mean shell thickness	0,0000 (m)
Maximum beam	12,000 (m)	Appendage coefficient	1,0000
Design draft	3,500 (m)		

Calculation settings

Center of gravity of tanks containing liquids	:	Actual COG

Silhouette 1




Blood Water 2
FO 1
Blood Water 1
WB 1
WB 2
WB 3
RSW 1
RSW 3
FW 1
WB Fore Trim
Sewage
-1,000 (SB)
RSW Dead 2
RSW Dead 4
Chemicals 2
FW 2
6,399
RSW Dead 1
RSW Dead 3
Chemicals 1
RSW 2
RSW 4
5,699
WB Port 1
WB Port 2
WB Star 1
WB Star 2
3,599
0,799
PS
SB
0,000
2,000
6,000
9,000
11,500
17,000
26,000
33,000
44,700
RSW live
Ballast Water
Machine
Fuels ,Oils
RSW Dead Fish
Stairs
Water ,Sauage

Hydrostatic particulars

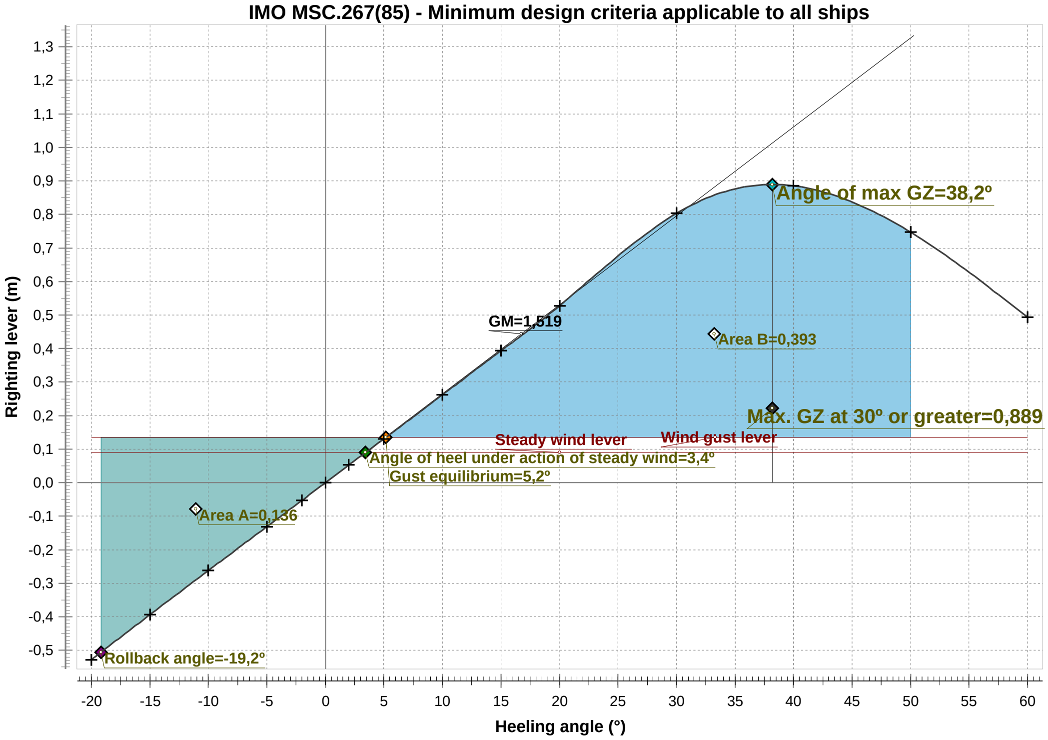
List	0,0 (CL) (Degr.)	GG'	0,324 (m)
Draft aft pp	3,442 (m)	VCG'	4,562 (m)
Mean moulded draft	3,475 (m)	Max VCG'	5,320 (m)
Draft forward pp	3,508 (m)	GM solid	1,843 (m)
Trim	0,066 (m)	G'M liquid	1,519 (m)
KM	6,081 (m)	Immersion rate	5,347 (t/cm)
VCG	4,239 (m)	MCT	17,73 (t*m/cm)

Description	Density (t/m³)	Fill%	Weight (tonnes)	LCG (m)	TCG (m)	VCG (m)	FSM (t*m)
RSW live							
RSW 1	1,0530	95,0	95,53	33,911	-3,050 (SB)	3,408	51,14
RSW 2	1,0530	95,0	95,53	33,911	3,050 (PS)	3,408	51,14
RSW 3	1,0530	95,0	106,62	40,309	-2,547 (SB)	3,833	67,22
RSW 4	1,0530	95,0	106,62	40,309	2,547 (PS)	3,833	67,22
Totals for RSW live			404,30	37,286	0,000 (CL)	3,632	236,73
Ballast Water							
WB 1	1,0000	0,0	0,00	16,913	0,000 (CL)	0,433	0,00
WB 2	1,0000	0,0	0,00	23,758	0,000 (CL)	0,403	0,00
WB 3	1,0000	0,0	0,00	31,218	0,000 (CL)	0,406	0,00
WB Star 2	1,0000	0,0	0,00	23,601	-5,227 (SB)	2,310	0,00
WB Star 1	1,0000	0,0	0,00	20,092	-5,230 (SB)	2,342	0,00
WB Port 1	1,0000	0,0	0,00	20,092	5,230 (PS)	2,342	0,00
WB Port 2	1,0000	0,0	0,00	23,601	5,227 (PS)	2,310	0,00
WB Fore Trim	1,0000	0,0	0,00	44,432	0,000 (CL)	1,670	0,00
Totals for Ballast Water			0,00	0,000	0,000 (CL)	0,000	0,00
Fuels & Oils							
FO 1	0,8000	80,0	40,51	8,657	-2,852 (SB)	2,487	62,88
FO 2	0,8000	80,0	40,51	8,657	2,852 (PS)	2,487	62,88
Lube	0,2000	85,0	0,93	11,500	0,000 (CL)	1,990	0,13
Sludge	0,8000	30,0	1,32	10,500	0,000 (CL)	1,220	0,52
Totals for Fuels & Oils			83,27	8,718	0,000 (CL)	2,461	126,42
RSW Dead Fish							
RSW Dead 1	1,0530	100,0	49,81	1,006	-4,226 (SB)	5,018	0,00
RSW Dead 3	1,0530	100,0	50,42	6,253	-4,245 (SB)	5,004	0,00
RSW Dead 2	1,0530	100,0	49,81	1,006	4,226 (PS)	5,018	0,00
RSW Dead 4	1,0530	100,0	50,42	6,253	4,245 (PS)	5,004	0,00
Blood Water 1	1,0000	100,0	37,82	6,343	0,000 (CL)	2,378	0,00
Blood Water 2	1,0000	100,0	49,39	6,250	0,000 (CL)	5,000	0,00
Totals for RSW Dead Fish			287,66	4,447	0,000 (CL)	4,663	0,00
Water & Sauage							
FW 1	1,0000	80,0	29,07	47,404	-1,155 (SB)	3,820	14,74
FW 2	1,0000	80,0	29,07	47,404	1,155 (PS)	3,820	14,74
Sewage	1,0000	20,0	3,18	37,610	0,000 (CL)	0,118	27,95
Chemicals 1	1,0000	100,0	13,72	9,375	-4,000 (SB)	5,000	0,00
Chemicals 2	1,0000	100,0	13,72	9,375	4,000 (PS)	5,000	0,00
Totals for Water & Sauage			88,76	35,298	0,000 (CL)	4,052	57,44
Lightship			435,00	26,500	0,000 (CL)	4,900	
Deadweight			864,00	23,395	0,000 (CL)	3,906	420,59
Displacement			1299,00	24,435	0,000 (CL)	4,239	420,59

Righting levers

Heeling angle	Draft	Trim	Displacement	KN sin(ø)	VCG sin(ø)	GG' sin(ø)	TCG cos(ø)	GZ	Area
(Degr.)	(m)	(m)	(tonnes)	(m)	(m)	(m)	(m)	(m)	(mrad)
0,0º (CL)	3,475	0,066	1299,00	0,000	0,000	0,000	0,000	0,000	0,000
2,0º (PS)	3,474	0,069	1299,00	0,212	0,148	0,011	0,000	0,053	0,001
5,0º (PS)	3,468	0,088	1299,00	0,528	0,369	0,027	0,000	0,131	0,006
10,0º (PS)	3,444	0,152	1298,99	1,043	0,736	0,045	0,000	0,262	0,023
15,0º (PS)	3,403	0,243	1299,00	1,545	1,097	0,054	0,000	0,394	0,052
20,0º (PS)	3,340	0,348	1299,00	2,037	1,450	0,059	0,000	0,528	0,092
30,0º (PS)	3,133	0,586	1299,00	2,986	2,119	0,064	0,000	0,803	0,209
40,0º (PS)	2,883	0,934	1299,00	3,674	2,725	0,064	0,000	0,885	0,360
50,0º (PS)	2,602	1,414	1299,01	4,055	3,247	0,061	0,000	0,747	0,505
60,0º (PS)	2,217	2,165	1299,00	4,221	3,671	0,057	0,000	0,493	0,614

Stability curve
IMO MSC.267(85) - Minimum design criteria applicable to all ships



Evaluation of criteria

IMO MSC.267(85) - Minimum design criteria applicable to all ships

International Code on Intact Stability (2008), Part A, §2.2 - §2.3

Description	Attained value	Criterion	Required value	Complies
Area 0º - 30º	0,2090 (mrad)	>=	0,0550 (mrad)	YES
Area 0º - 40º	0,3600 (mrad)	>=	0,0900 (mrad)	YES
Area 30º - 40º	0,1510 (mrad)	>=	0,0300 (mrad)	YES
Max. GZ at 30º or greater	0,889 (m)	>=	0,200 (m)	YES
Lower angle	30,0 (Degr.)			
Upper angle	90,0 (Degr.)			
Angle of max GZ	38,2 (Degr.)	>=	25,0 (Degr.)	YES
Initial metacentric height	1,519 (m)	>=	0,150 (m)	YES
Severe wind and rolling criterion (weather criterion)				YES
Wind silhouette:	Silhouette 1			
Windspeed	50,54 (kn.)			
Wind pressure	51,4 (kg/m^2)			
Wind area	390,41 (m^2)			
Steady wind lever	0,090 (m)			
Deck immersion angle	27,46 (Degr.)			
Wind gust lever	0,135 (m)			
Ratio of areaA/areaB	0,345	<=	1,000	YES
Maximum allowed static heeling angle	3,4 (Degr.)	<=	16,0 (Degr.)	YES
Max allowed ratio static angle/deck immersion angle	0,125	<=	0,800	YES

The condition complies with the stability criteria

D.6.5 All tanks half laden

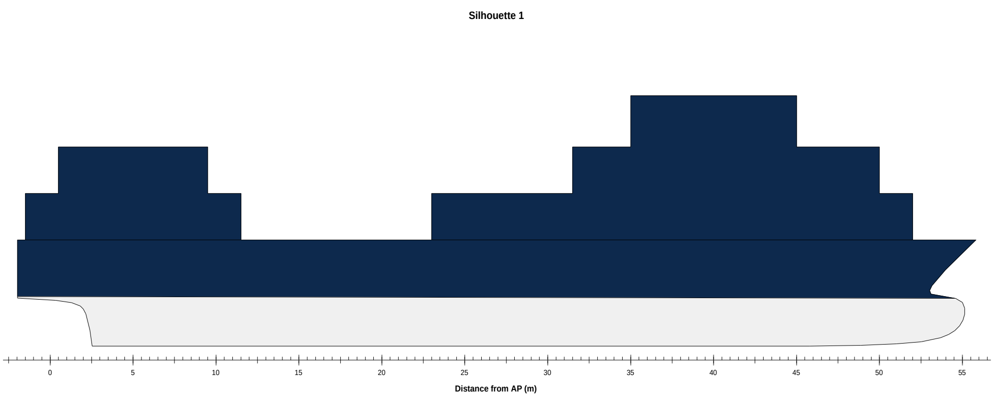
Intact stability

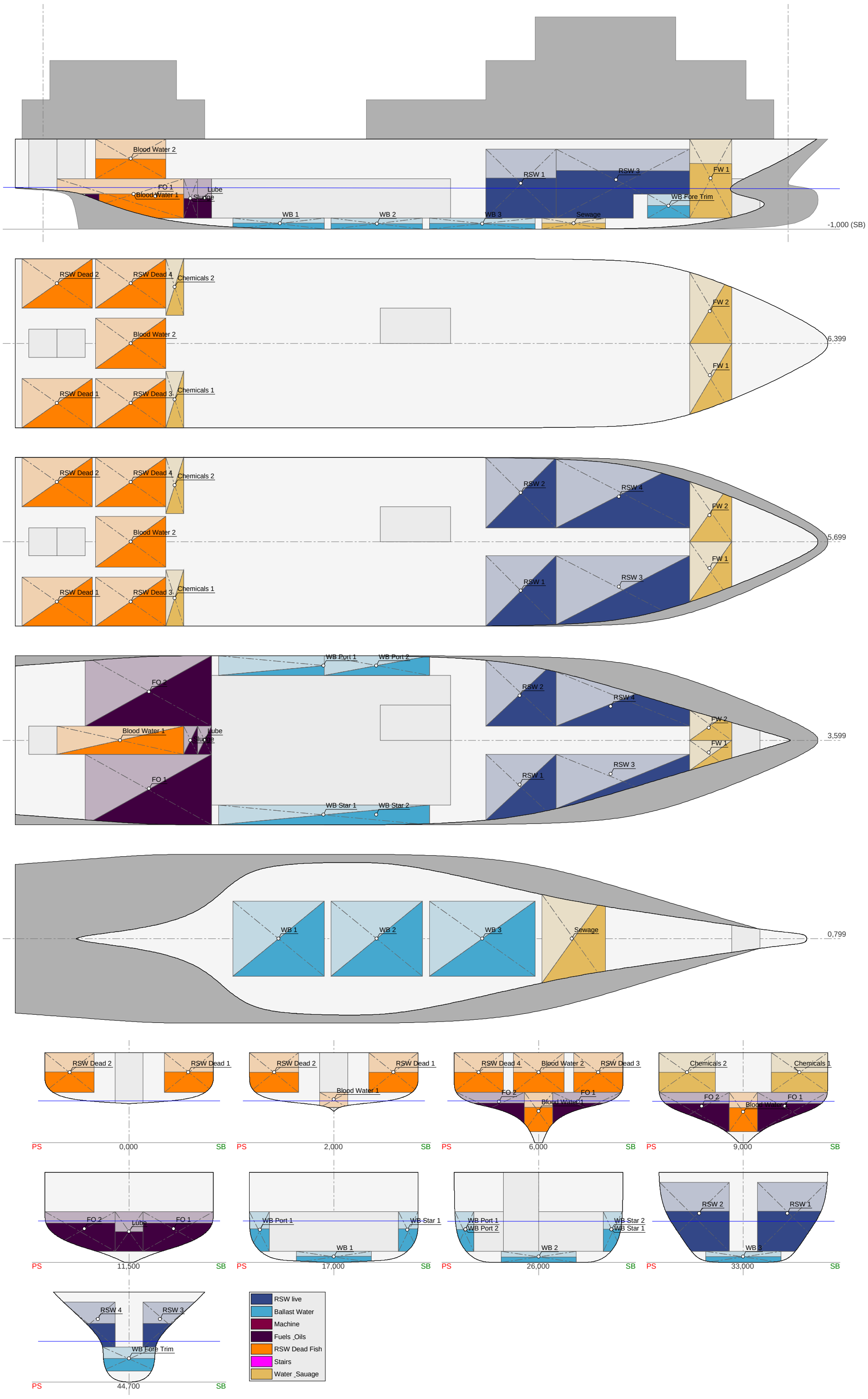
All tanks half laden

Designer			
Created by			
Comment			
Filename		rev13_Skip_53x12x6.fbm	
Design length	53,000 (m)	Midship location	26,500 (m)
Length over all	57,793 (m)	Relative water density	1,0250
Design beam	12,000 (m)	Mean shell thickness	0,0000 (m)
Maximum beam	12,000 (m)	Appendage coefficient	1,0000
Design draft	3,500 (m)		

Calculation settings

Center of gravity of tanks containing liquids : Actual COG





Blood Water 2
FO 1
Blood Water 1
Lube
Sludge
WB 1
WB 2
WB 3
RSW 1
RSW 2
FW 1
WB Fore Trim
Sewage
-1,000 (SB)
RSW Dead 2
RSW Dead 4
Chemicals 2
FW 2
6,399
RSW Dead 1
RSW Dead 3
Chemicals 1
RSW 4
RSW 3
5,699
FO 2
WB Port 1
WB Port 2
WB Star 1
WB Star 2
3,599
0,799
PS
SB
0,000
2,000
6,000
9,000
11,500
17,000
26,000
33,000
44,700
RSW live
Ballast Water
Machine
Fuels ,Oils
RSW Dead Fish
Stairs
Water ,Sauage

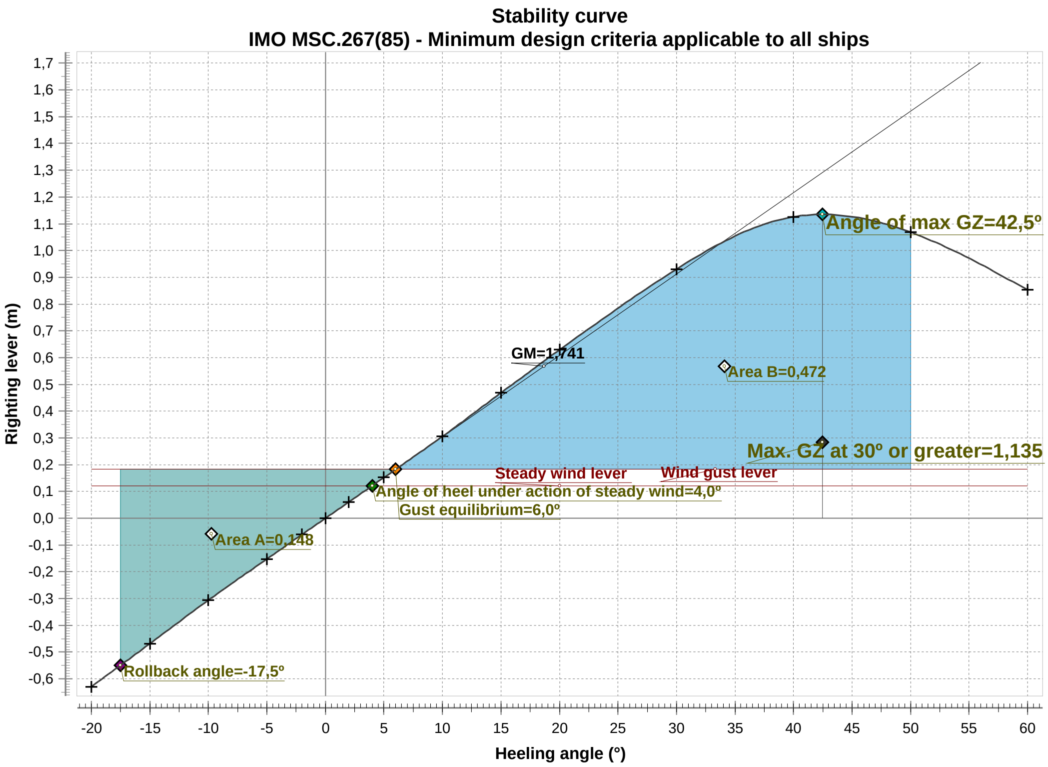
Hydrostatic particulars

List	0,0 (CL) (Degr.)	GG'	0,647 (m)
Draft aft pp	2,978 (m)	VCG'	4,233 (m)
Mean moulded draft	2,932 (m)	Max VCG'	5,295 (m)
Draft forward pp	2,886 (m)	GM solid	2,387 (m)
Trim	-0,093 (m)	G'M liquid	1,741 (m)
KM	5,974 (m)	Immersion rate	4,883 (t/cm)
VCG	3,587 (m)	MCT	14,75 (t*m/cm)

Description	Density (t/m³)	Fill%	Weight (tonnes)	LCG (m)	TCG (m)	VCG (m)	FSM (t*m)
RSW live							
RSW 1	1,0530	50,0	50,28	33,865	-2,777 (SB)	2,347	35,92
RSW 2	1,0530	50,0	50,28	33,865	2,777 (PS)	2,347	35,92
RSW 3	1,0530	50,0	56,12	39,902	-2,218 (SB)	2,871	31,81
RSW 4	1,0530	50,0	56,12	39,902	2,218 (PS)	2,871	31,81
Totals for RSW live			212,79	37,049	0,000 (CL)	2,623	135,45
Ballast Water							
WB 1	1,0000	50,0	12,26	17,076	0,000 (CL)	0,246	79,52
WB 2	1,0000	50,0	13,50	23,766	0,000 (CL)	0,204	80,56
WB 3	1,0000	50,0	15,42	31,186	0,000 (CL)	0,209	92,95
WB Star 2	1,0000	50,0	12,52	23,522	-5,173 (SB)	1,643	1,43
WB Star 1	1,0000	50,0	24,59	20,253	-5,173 (SB)	1,689	2,96
WB Port 1	1,0000	50,0	24,59	20,253	5,173 (PS)	1,689	2,96
WB Port 2	1,0000	50,0	12,52	23,522	5,173 (PS)	1,643	1,43
WB Fore Trim	1,0000	50,0	9,14	44,439	0,000 (CL)	1,249	12,78
Totals for Ballast Water			124,54	24,107	0,000 (CL)	1,161	274,61
Fuels & Oils							
FO 1	0,8000	50,0	25,32	9,182	-2,619 (SB)	2,140	44,99
FO 2	0,8000	50,0	25,32	9,182	2,619 (PS)	2,140	44,99
Lube	0,2000	50,0	0,55	11,500	0,000 (CL)	1,500	0,13
Sludge	0,8000	50,0	2,20	10,500	0,000 (CL)	1,500	0,52
Totals for Fuels & Oils			53,38	9,260	0,000 (CL)	2,107	90,62
RSW Dead Fish							
RSW Dead 1	1,0530	50,0	24,90	1,012	-4,201 (SB)	4,325	18,44
RSW Dead 3	1,0530	50,0	25,21	6,256	-4,240 (SB)	4,305	18,44
RSW Dead 2	1,0530	50,0	24,90	1,012	4,201 (PS)	4,325	18,44
RSW Dead 4	1,0530	50,0	25,21	6,256	4,240 (PS)	4,305	18,44
Blood Water 1	1,0000	50,0	18,91	7,126	0,000 (CL)	1,694	4,99
Blood Water 2	1,0000	50,0	24,70	6,250	0,000 (CL)	4,300	19,05
Totals for RSW Dead Fish			143,83	4,554	0,000 (CL)	3,968	97,78
Water & Sauage							
FW 1	1,0000	50,0	18,17	47,396	-0,856 (SB)	2,947	4,82
FW 2	1,0000	50,0	18,17	47,396	0,856 (PS)	2,947	4,82
Sewage	1,0000	50,0	7,96	37,621	0,000 (CL)	0,248	43,27
Chemicals 1	1,0000	50,0	6,86	9,375	-3,999 (SB)	4,300	6,53
Chemicals 2	1,0000	50,0	6,86	9,375	3,999 (PS)	4,300	6,53
Totals for Water & Sauage			58,01	37,065	0,000 (CL)	2,897	65,98
Lightship			435,00	26,500	0,000 (CL)	4,900	
Deadweight			592,56	23,939	0,000 (CL)	2,622	664,43
Displacement			1027,56	25,023	0,000 (CL)	3,587	664,43

Righting levers

Heeling angle (Degr.)	Draft (m)	Trim (m)	Displacement (tonnes)	KN sin(ø) (m)	VCG sin(ø) (m)	GG' sin(ø) (m)	TCG cos(ø) (m)	GZ (m)	Area (mrad)
0,0º (CL)	2,932	-0,093	1027,56	0,000	0,000	0,000	0,000	0,000	0,000
2,0º (PS)	2,930	-0,081	1027,55	0,209	0,125	0,023	0,000	0,061	0,001
5,0º (PS)	2,922	-0,029	1027,56	0,521	0,313	0,056	0,000	0,152	0,007
10,0º (PS)	2,893	0,112	1027,56	1,039	0,623	0,110	0,000	0,306	0,027
15,0º (PS)	2,846	0,285	1027,56	1,548	0,928	0,151	0,000	0,468	0,060
20,0º (PS)	2,776	0,472	1027,56	2,043	1,227	0,187	0,000	0,629	0,108
30,0º (PS)	2,540	0,882	1027,56	2,983	1,793	0,259	0,000	0,931	0,245
40,0º (PS)	2,137	1,447	1027,56	3,766	2,305	0,335	0,000	1,126	0,427
50,0º (PS)	1,605	2,285	1027,56	4,214	2,747	0,397	0,000	1,069	0,622
60,0º (PS)	0,815	3,579	1027,55	4,399	3,106	0,440	0,000	0,853	0,791



Evaluation of criteria

IMO MSC.267(85) - Minimum design criteria applicable to all ships

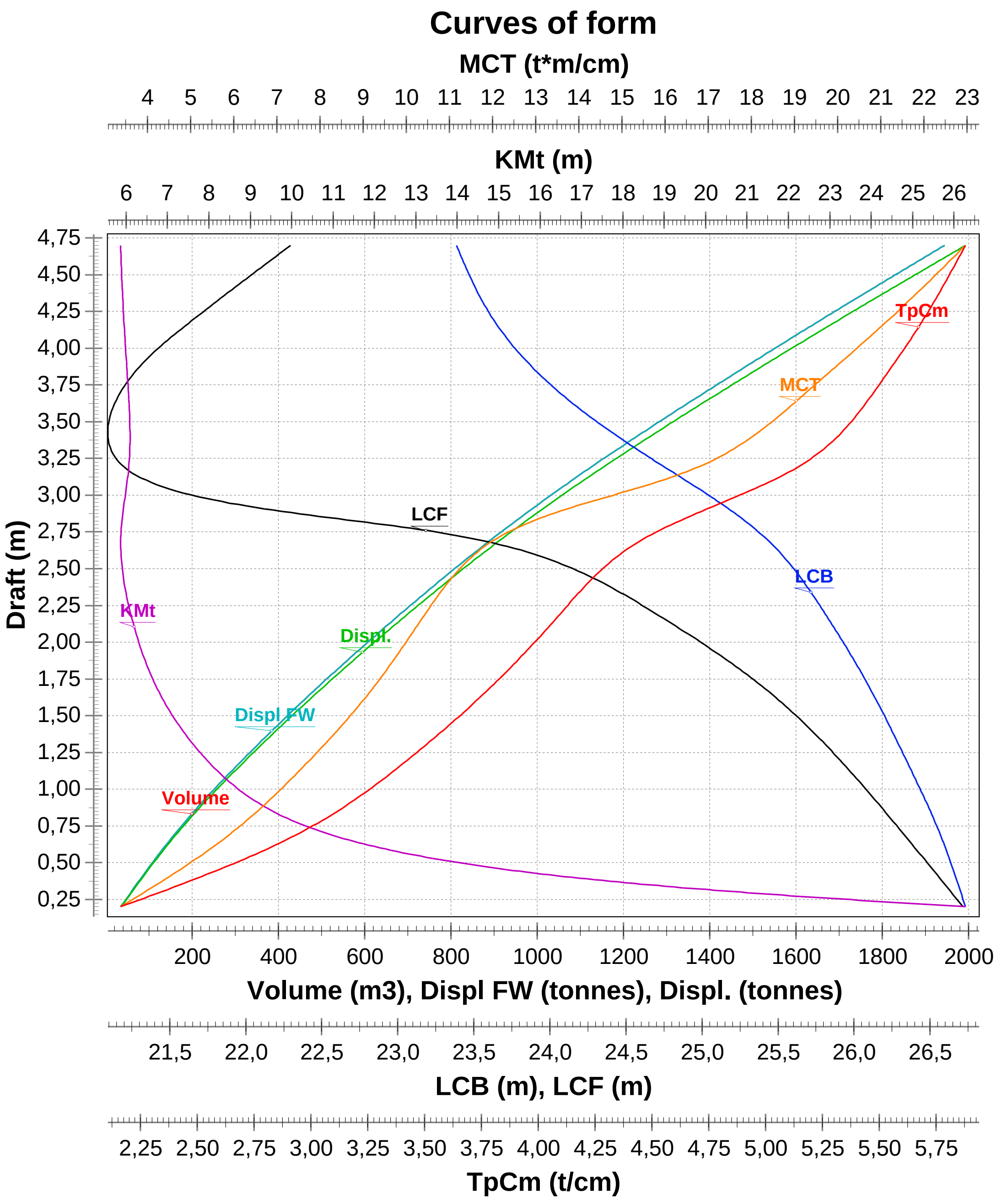
International Code on Intact Stability (2008), Part A, §2.2 - §2.3

Description	Attained value	Criterion	Required value	Complies
Area 0º - 30º	0,2450 (mrad)	>=	0,0550 (mrad)	YES
Area 0º - 40º	0,4274 (mrad)	>=	0,0900 (mrad)	YES
Area 30º - 40º	0,1825 (mrad)	>=	0,0300 (mrad)	YES
Max. GZ at 30º or greater	1,135 (m)	>=	0,200 (m)	YES
Lower angle	30,0 (Degr.)			
Upper angle	90,0 (Degr.)			
Angle of max GZ	42,5 (Degr.)	>=	25,0 (Degr.)	YES
Initial metacentric height	1,741 (m)	>=	0,150 (m)	YES
Severe wind and rolling criterion (weather criterion)				YES
Wind silhouette:	Silhouette 1			
Windspeed	50,54 (kn.)			
Wind pressure	51,4 (kg/m^2)			
Wind area	420,35 (m^2)			
Steady wind lever	0,122 (m)			
Deck immersion angle	31,89 (Degr.)			
Wind gust lever	0,183 (m)			
Ratio of areaA/areaB	0,314	<=	1,000	YES
Maximum allowed static heeling angle	4,0 (Degr.)	<=	16,0 (Degr.)	YES
Max allowed ratio static angle/deck immersion angle	0,125	<=	0,800	YES

The condition complies with the stability criteria

D.7 Curves of form

Hydrostatics report



E Simulation

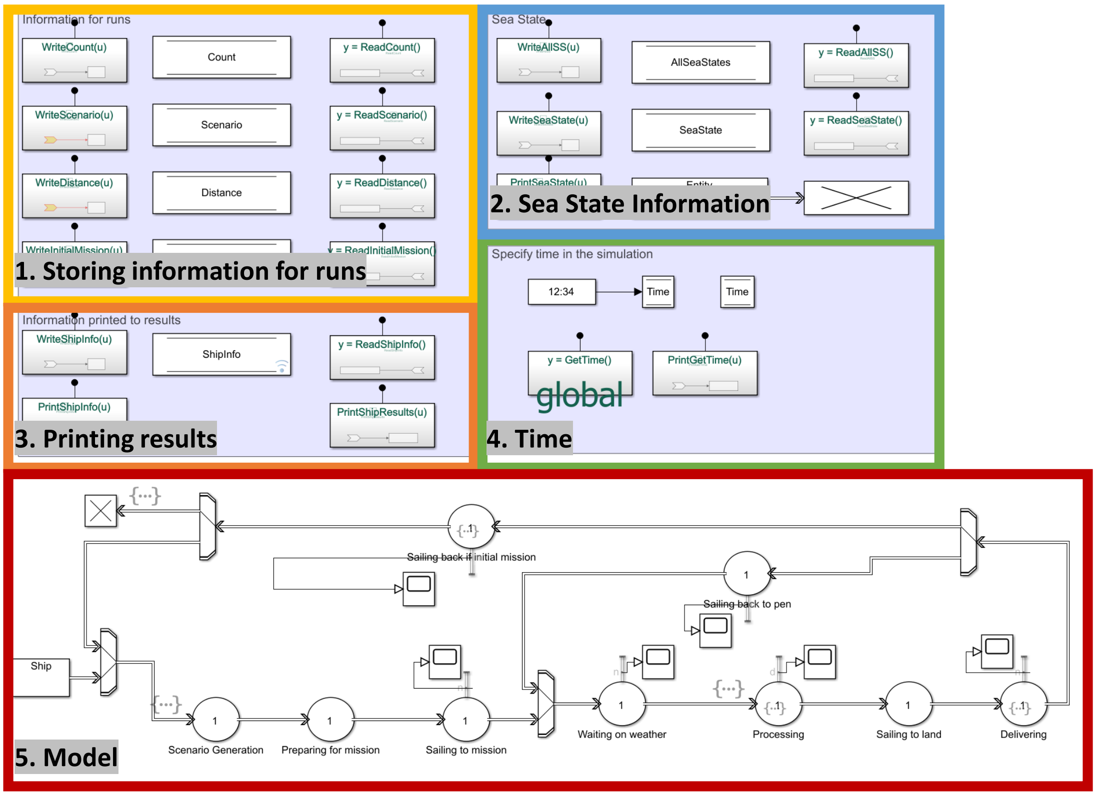
E.1 Scanario Description

Table 5: Scenarios for the ships will be tested for

No.	A mount of fish [tonnes]	Distance [nm]	Start scenario [-]
1	500	20	0
2	550	30	1
3	600	40	2
4	650	50	0
5	700	60	1
6	750	70	2
7	800	60	0
8	850	50	1
9	900	40	2
10	950	30	1

E.2 Explanation of the model

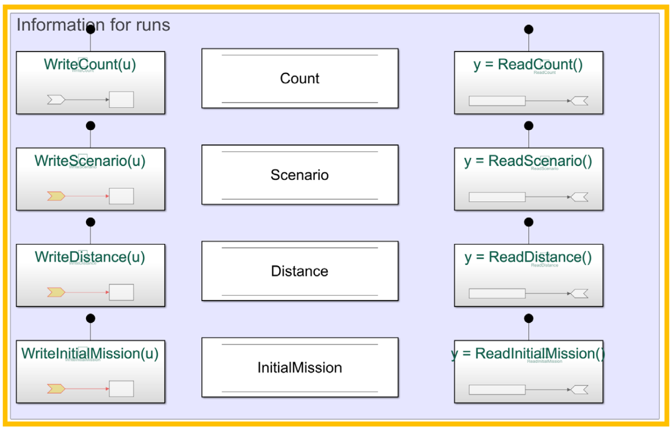
Simulation Model overview



A brief explenation of the simulation will be provided in this document.

Above, the whole simulink model is depicted. Each seaction will be commented on.

1. Storing information for runs

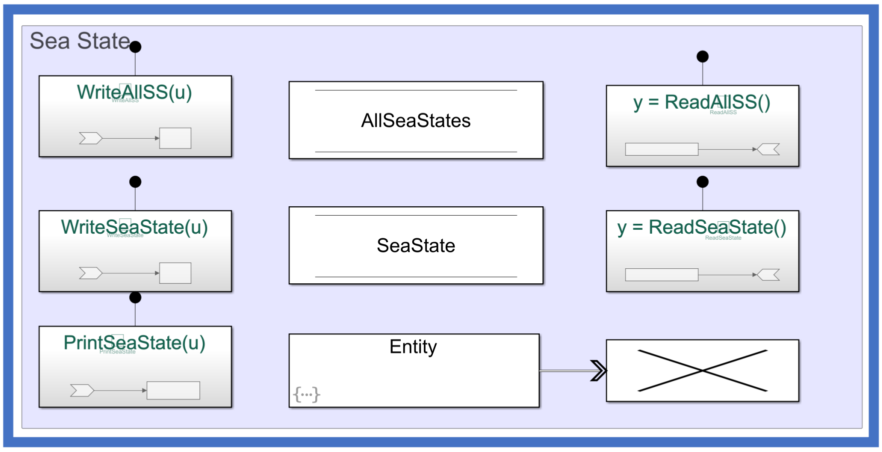


This part of the simulation consists of data memory stores with corresponding functions to write and read information to them.

There is one store for each of the parameters of the mission and in addition a store that stores the count of what mission the ship is currently on.

I

2. Sea state information

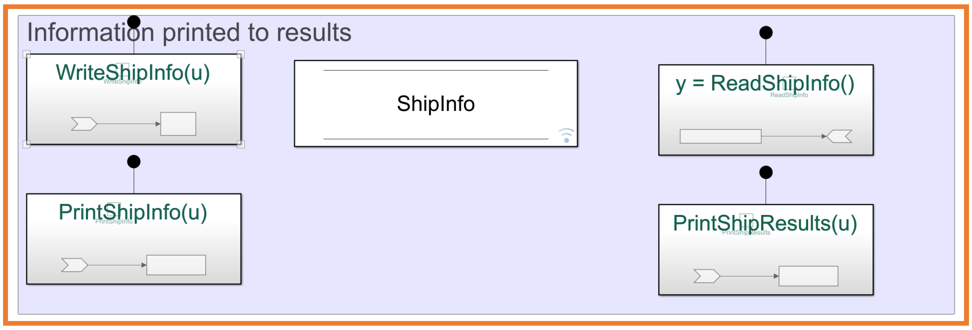


This section of the model determines the sea states of the simulation. There is an entity generator that for every whole time instant runs a code. The first time it runs, all the sea states are loaded from an excel-file (The sea states where processed in MatLAB by first “cleaning” the imported nc file and then using a Marcov chain).

All the seastates are saved to «AllSeaStates». The code in the entity generator reads the sea states and writes the sea state at the current time instance to the store called «SeaState»

«AllSeaStates» is needed to access more than just the current sea state at the same time. This is needed for the servers where a for loop is used to calculate the sailing time with varying sailing speed due to seastates, as well as calculating the WoW.

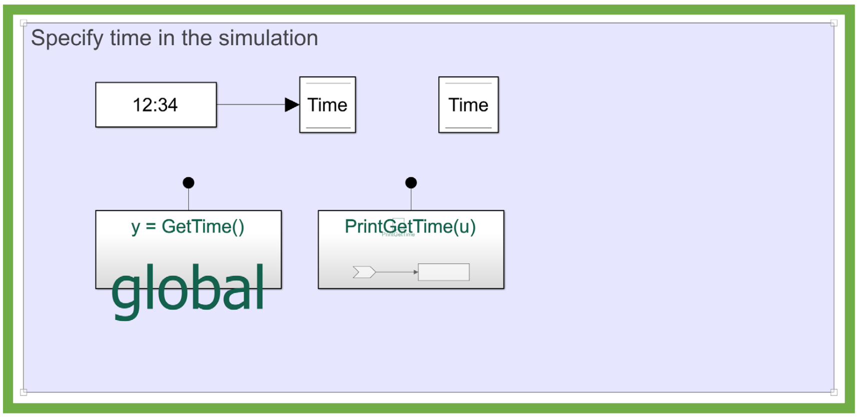
3. Printing results



This section of the code stores information that follows the ship, such as time spent sailing, time waited for weather, etc. This info is then printed to the workspace of MatLAB both as a vector that is printed each time it is changed, and as a vector that is printed at the end of each run.

This data is the resuts of the simulation.

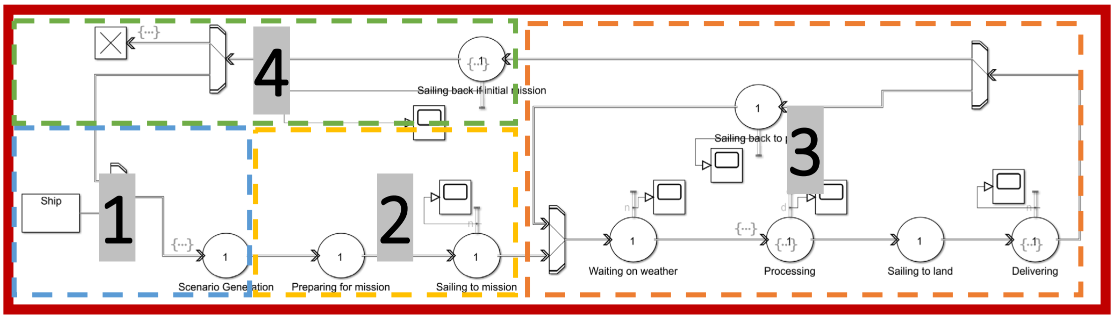
4. Time



This section of the model writes the time of the simulation (from a digital clock) to a data store memory. So that the current time can be used in other parts in the simulation (for example as when the sea state is determined, as mentioned earlier)

The section includes a read function to read the current time, and also a print function to be able to print the current time to the workspace if needed.

5. Model



Part 1:
The vessel is generated with input from MatLAB
The vessel reaches the first server where the scenario is read from excel. Updates for each loop.

Part 2:
The vessel aborts its current mission if it has one. The time used to determine the time spent aborting is based on the scenario and the designs ability to abort.

The next server models the vessel sailing to the mission. The distance is determined by the scenario (and is for simplicity the same for all sailing legs). The sailing speed is affected by the sea state.

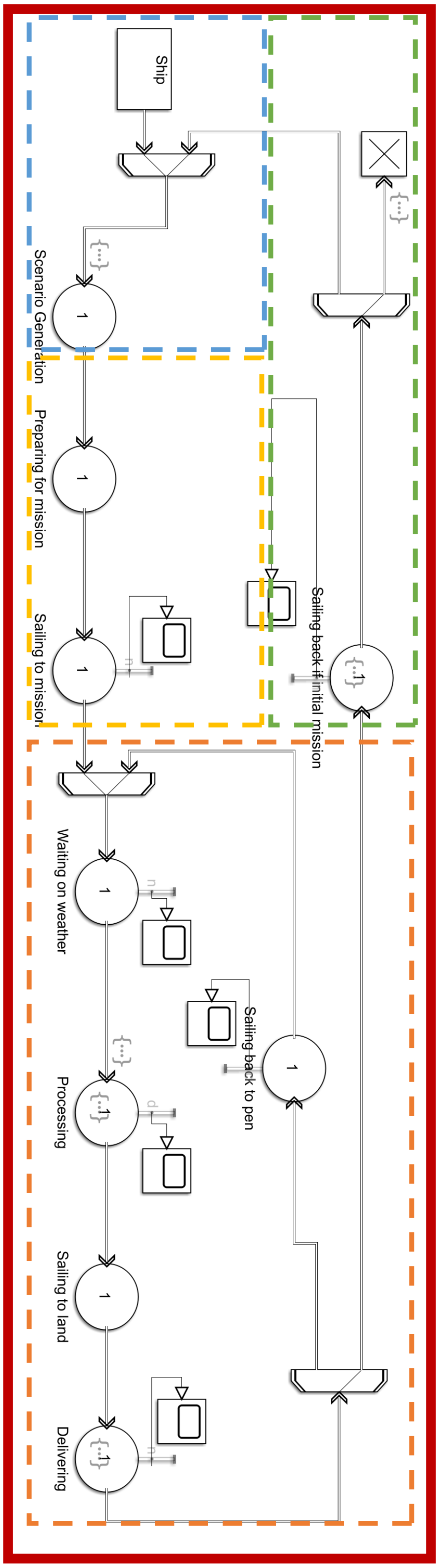
Part 3:
The vessel reaches the "mission loop" where it enters a loop of processing and sailing. The vessel first reaches the waiting for weather server. Here it waits for a weather window long enough to carry out the whole mission.

The ship processes as much salmon as possible, either the vessel capacity or what is left in the fish pen (vessel 1 has an infinite capacity due to ship to ship transfer). The processing speed is reduced when the sea states increases.

The vessel (except design 1) sails to land. Then delivers the salmon. Sails back to the fish pen if there is more fish left, exits the loop if not.

Part 4:
The vessel sails back to the initial mission if it had one.

The vessel exits the whole simulation through the entity terminator when all the predetermined missions are carried out.


Ship
Scenario Generation
Preparing for mission
Sailing to mission
Sailing back if initial mission
Waiting on weather
Processing
Sailing back to pen
Sailing to land
Delivering

How to run the simulation

To run the simulation:
1) Run “RunSim.m”

This script also prints the results to the folder.

The plots in the excel file “Plots” uses data from the resultfiles. The origin file might need updating due to it being in a zipped folder. This is done in the data tab of excel.

Optional:
The weather file that the simulation uses is already saved in the folder. However, if you want to reproduce them or create a new set with a different seed you must:
1) Run “WeatherImport.m” (to import the nc data and clean them)
2) Run “MarcovChain.m” (to create a longer set of data that starts at different sea states)

E.3 Plots

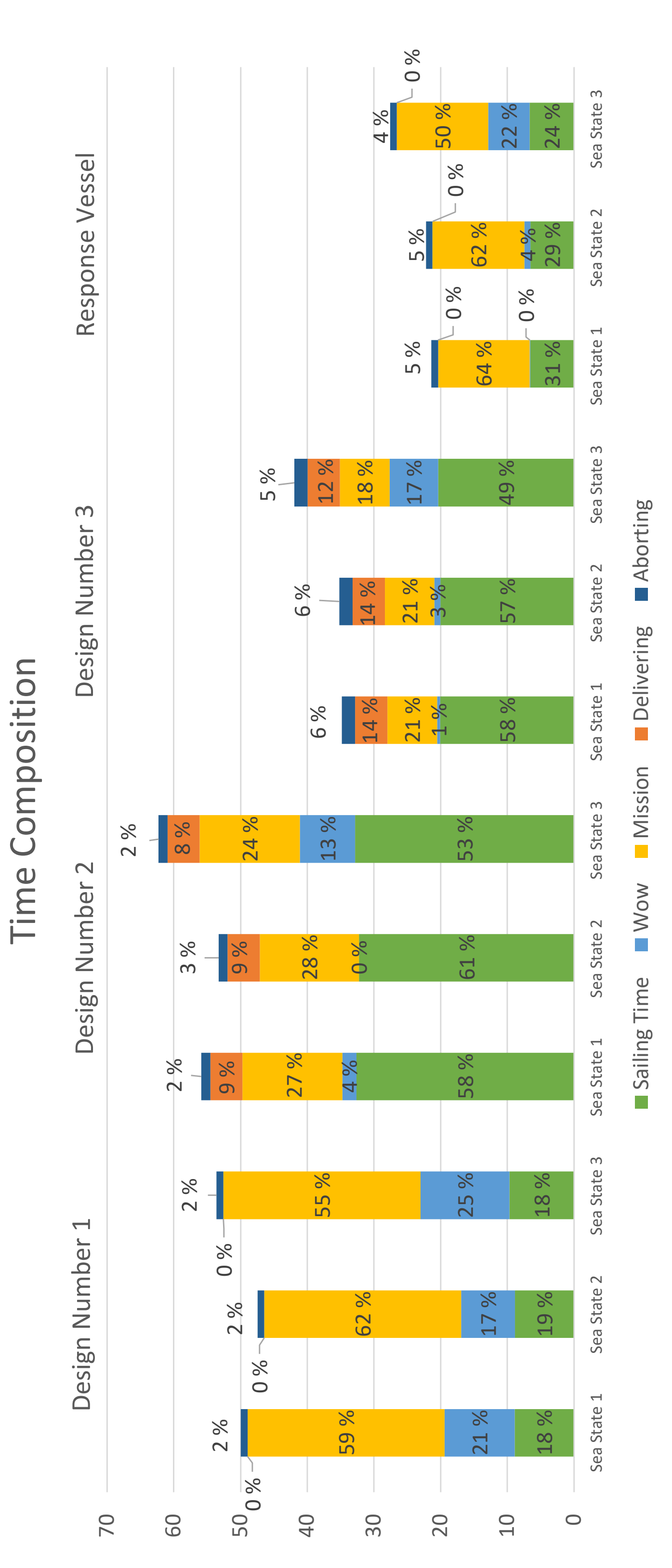


Figure 1

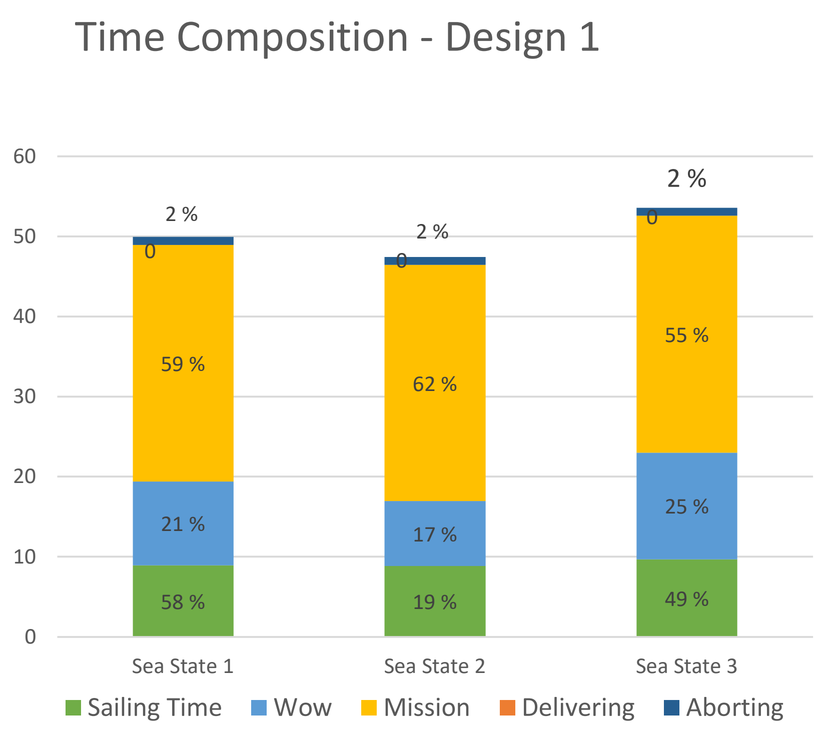


Figure 2

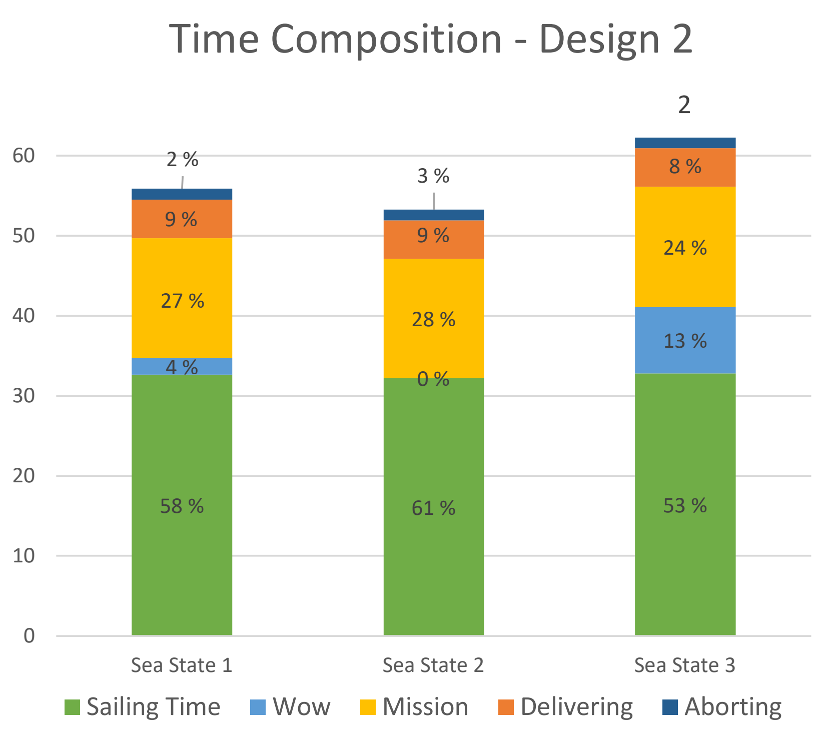


Figure 3

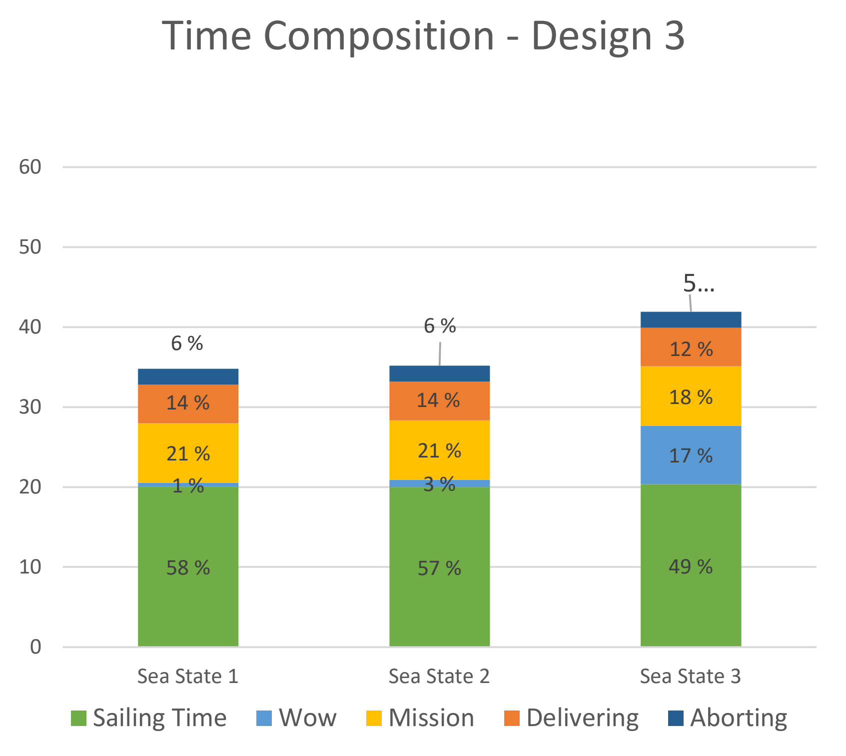


Figure 4

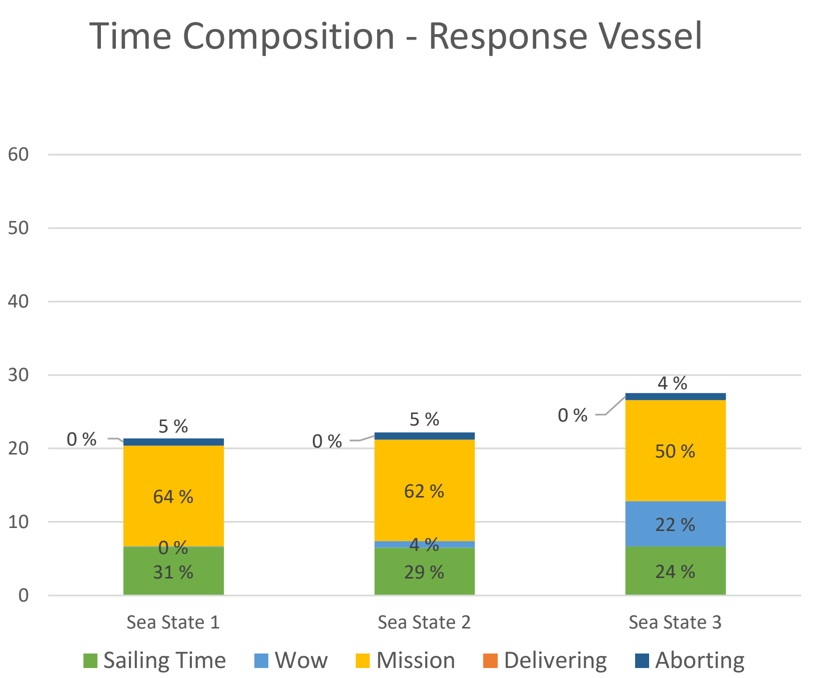


Figure 5

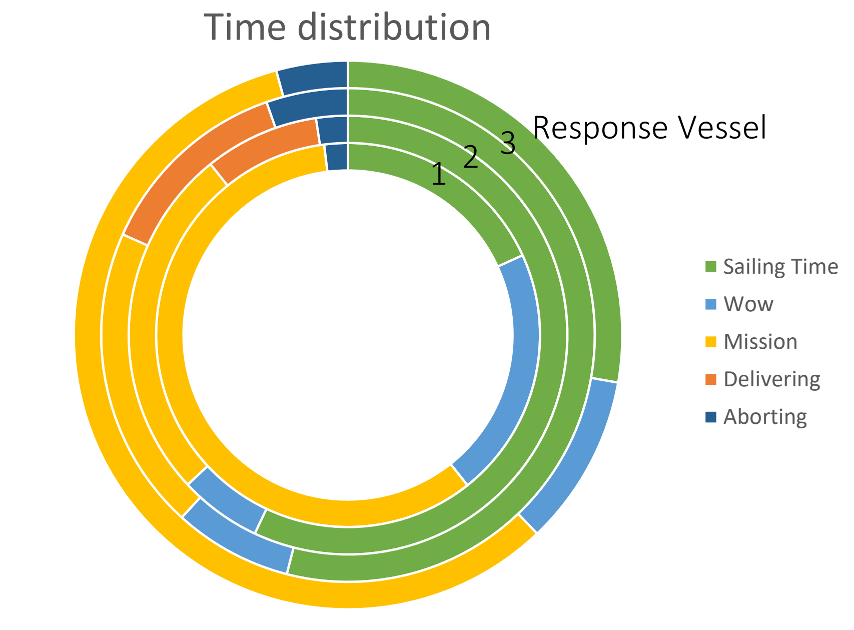


Figure 6

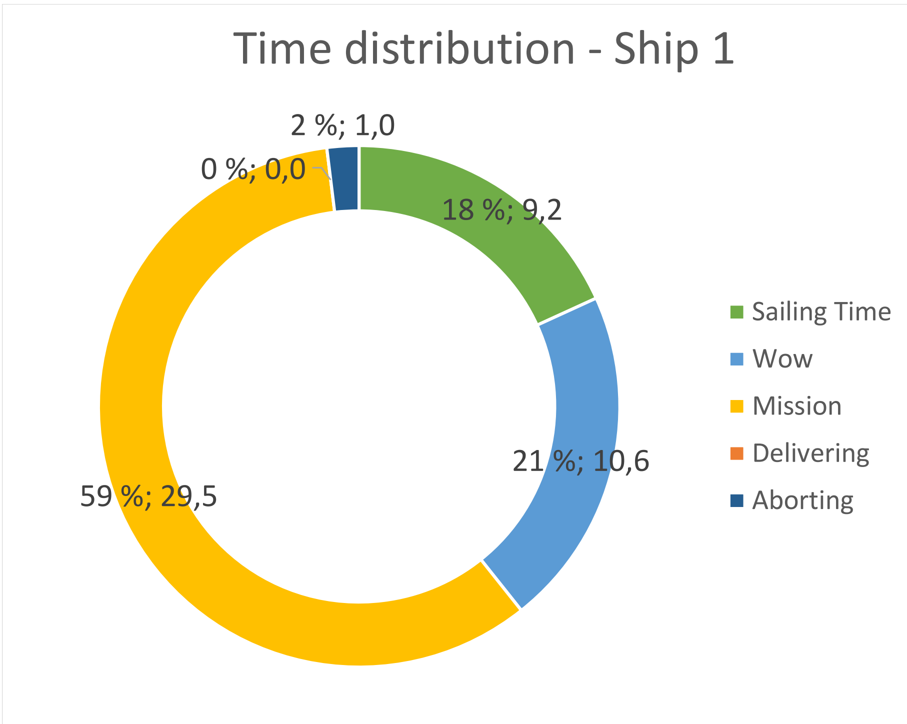


Figure 7

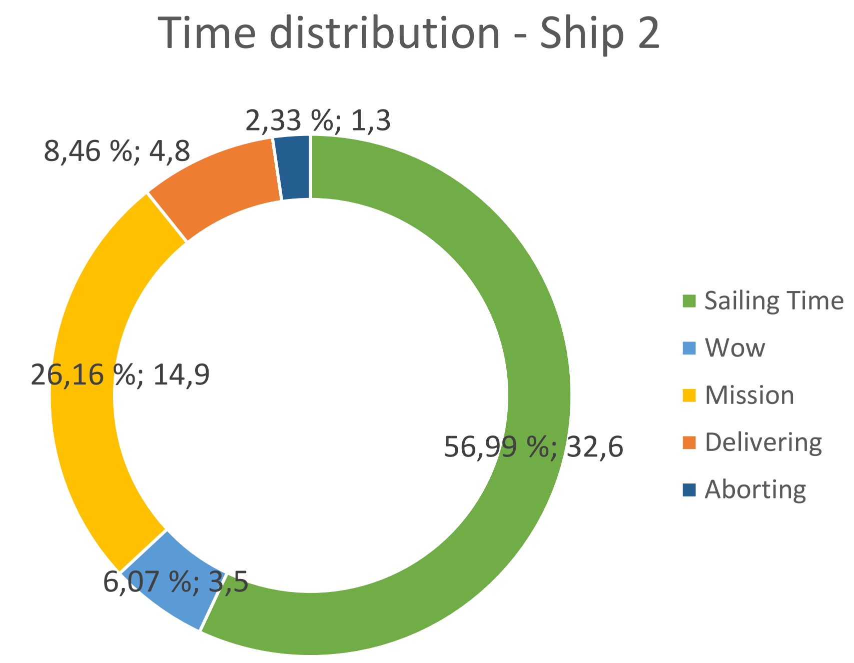


Figure 8

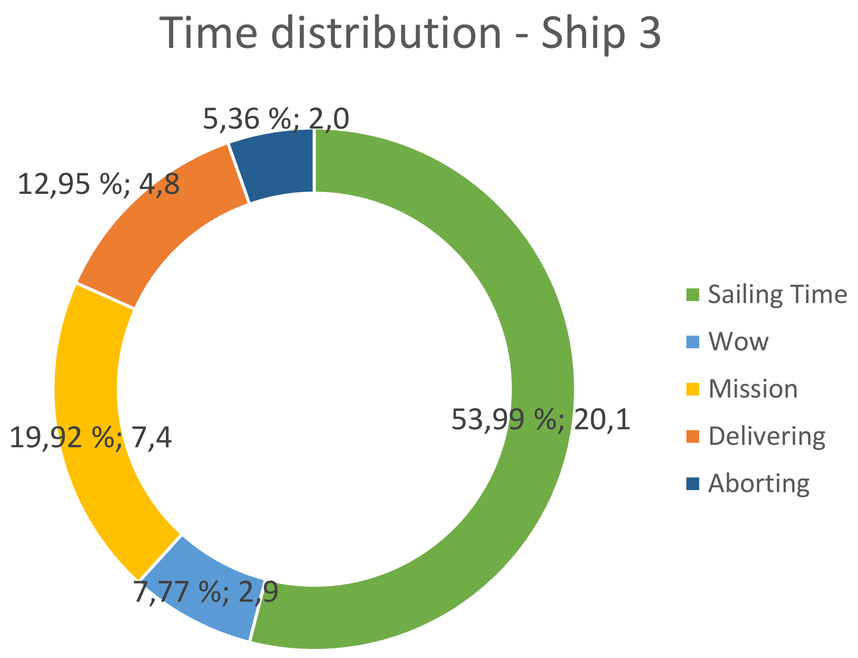


Figure 9

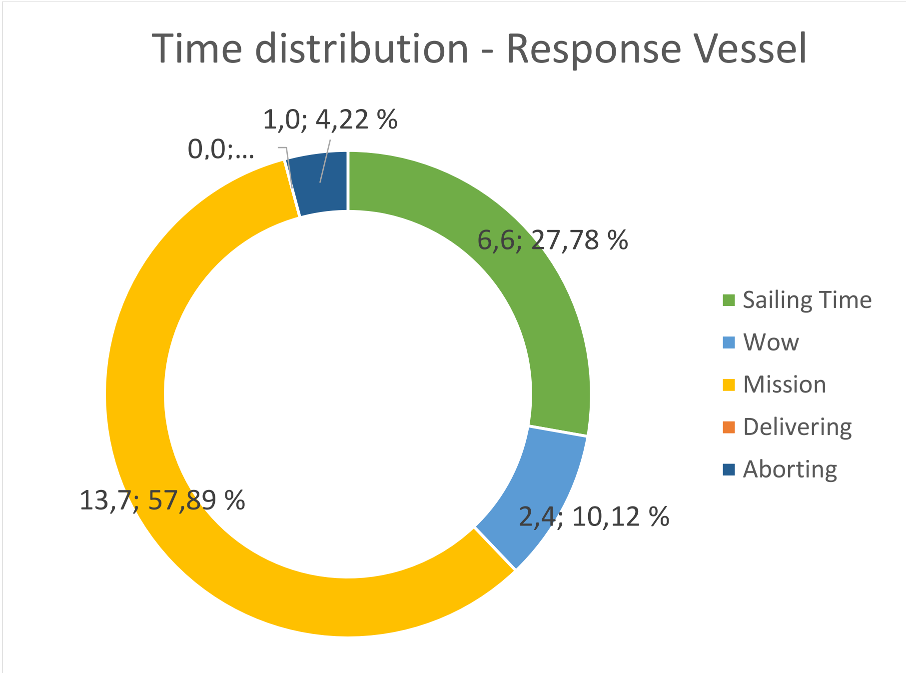

Time distribution - Response Vessel
1,0; 4,22 %
0,0;...
6,6; 27,78 %
13,7; 57,89 %
2,4; 10,12 %
Sailing Time
Wow
Mission
Delivering
Aborting

Figure 10

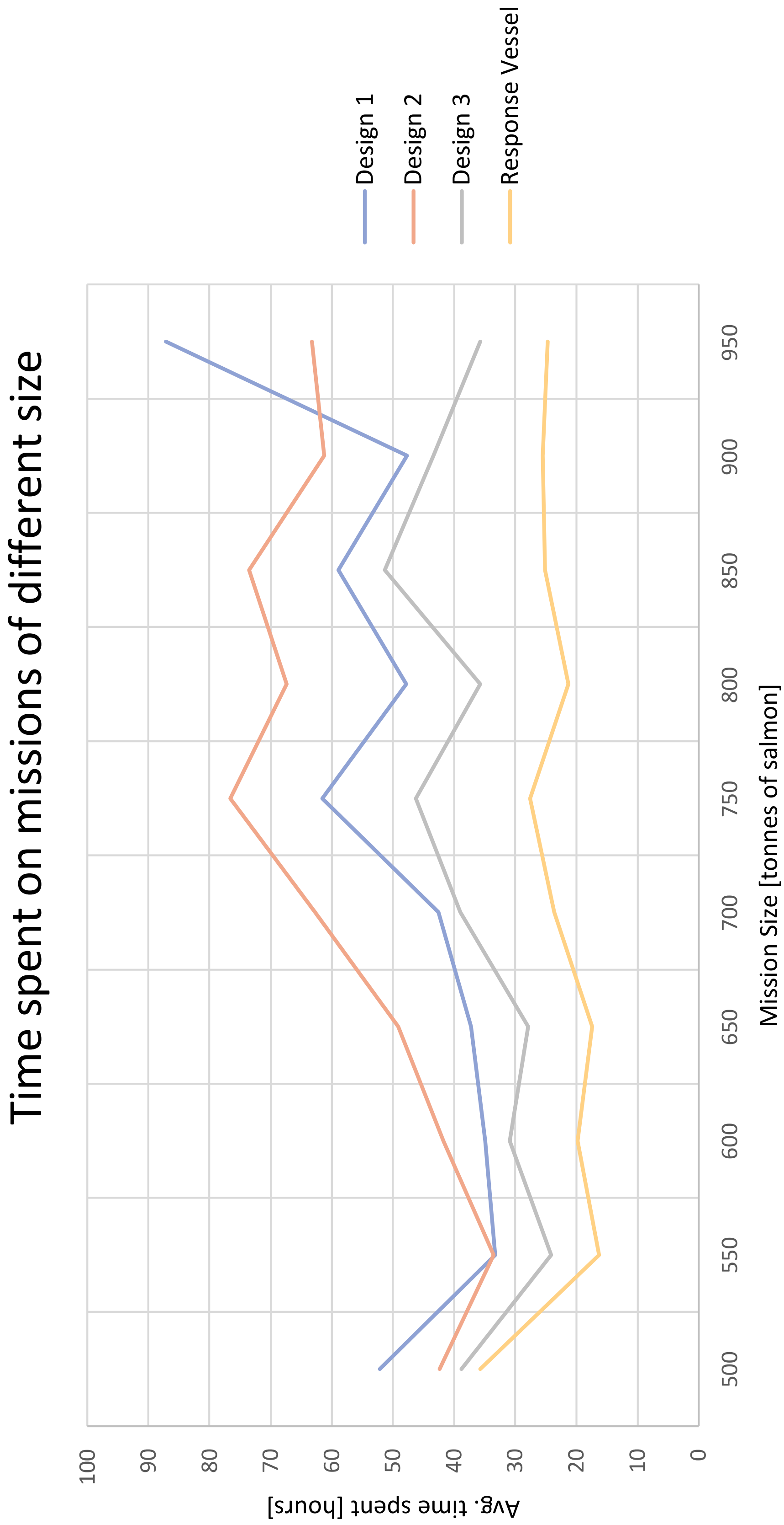

Time spent on missions of different size
Avg. time spent [hours]
100
90
80
70
60
50
40
30
20
10
0
500
550
600
650
700
750
800
850
900
950
Mission Size [tonnes of salmon]
Design 1
Design 2
Design 3
Response Vessel

Figure 11

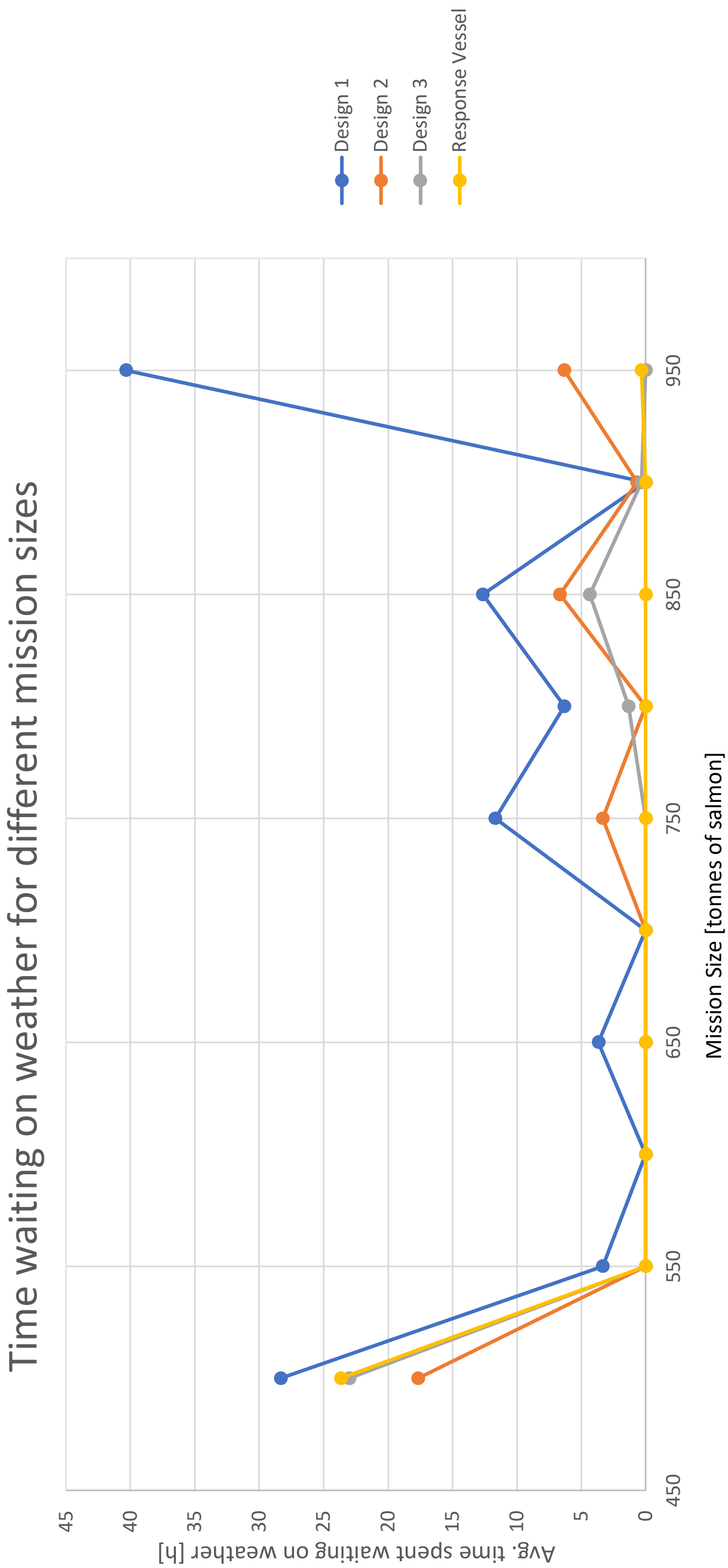

Time waiting on weather for different mission sizes
Avg. time spent waiting on weather [h]
45
40
35
30
25
20
15
10
5
0
450
550
650
750
850
950
Mission Size [tonnes of salmon]
Design 1
Design 2
Design 3
Response Vessel

Figure 12