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Design of an Offshore Drilling Fluid Maintenance Vessel

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Marine Technology
Submission date: June 2017
Supervisor: Svein Aanond Aanondsen, IMT

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Preface

This thesis has been written by Yngve Windsland and is a part of the Master of Science degree in Marine Technology with specialization in Marine Systems Design and Logistics at the Norwegian University of Science and Technology in Trondheim. The thesis work has been distributed over the entire spring semester 2017, and the work done in this thesis represents the equivalence of 30 ECTS. The focus in this thesis is ship design in practice by use of the system based ship design methodology.

The author would like to thank several persons for their guidance and help during the thesis work. First, supervisor Assistant Professor Svein Aanond Aanondsen for helpful guidance through weekly meetings throughout the semester. The system based ship design process was unfamiliar to the author in the beginning of this thesis and without guidance throughout the semester, the thesis work would have been much more troublesome to finish. Much time has been used interpreting the methodology and thus parts of the steps in the methodology has been remained unanswered. Mud engineer Torgeir Kjøstvedt has also been a great resource and has provided the author with valuable information regarding offshore drilling operations. Also a thank to Principal Consultant Bjørn Olav Gullberg and Operation Manager Terje Skram at Statoil for introducing the problem and providing the author with statistical data of vessel movements and bulk cargo after helpful skype meetings.

Yngve Windsland

Yngve Windsland
Trondheim, June 11th 2017

Summary

This thesis aims to design an offshore drilling fluid maintenance vessel to increase reuse and recycling of drilling fluids. Large quantities of drilling fluids are used during drilling operations and both transport and procurement of drilling fluids are expensive. By performing maintenance of drilling fluids offshore, less transportation and procurement of the highly valuable fluid are needed and thus a potential of overall cost reduction emerges.

In this thesis, offshore drilling operations are studied in the light of drilling fluid maintenance and bulk shipments. A vessel design able to perform drilling fluid maintenance offshore is developed and principal particulars for the vessel is presented. Economic benefits of introducing such vessel design, and current rules and regulations for reuse and recycling of drilling fluids, are not discussed in this thesis.

In this thesis a vessel concept develops by using the system based ship design methodology. Drilling operations, drilling fluid maintenance, and platform supply vessels used to assist drilling operations as dedicated storage vessels, are analyzed to investigate the potential of implementing a drilling fluid maintenance vessel. Based on these analyses a concept design emerges. To aid in the development process of designing a vessel, a three-dimensional model and general arrangement drawings are created to visualize and validate the vessel design. An outline specification of the vessel is presented as a solution to the objective of performing drilling fluid maintenance offshore.

This thesis proposes a vessel design able to perform drilling fluid maintenance offshore. Contaminated drilling fluid, used in a drilling operation, is treated onboard the vessel by a drilling fluid maintenance system. The drilling fluid maintenance system consists of; three solids control units and one centrifuge to clean the contaminated drilling fluid, one mud-mixer to mix additives into the drilling fluid, and storage tanks to store the drilling fluids and components. These systems are connected to a pump and piping system to move the drilling fluid around in the vessel.

Total installed machinery in the vessel is 8700 kW. This power is distributed on three main generators of 2600 kW, one auxiliary generator of 700 kW, and one emergency generator of 200 kW. The main propulsion system consists of two azipull thrusters. In addition, there are two tunnel thrusters and one retractable azimuth thruster in the bow. Accommodation capacity for the vessel is 25 persons distributed on 19 cabins, where 13 of them are single cabins intended for the crew and 12 double cabins intended for clients.

The vessel length over all is 91,5 meters and the breadth is 20,5 meters. Total displacement for the vessel is 9670 tonnes and the deadweight tonnage is 6295 tonnes. Total drilling fluid tank capacity is 1612 m^3 and a total of 1690 m^3 water ballast tanks are placed in the hull to adjust vessel trim and heeling when loaded. The vessel design complies with the International Maritime Organization requirements for intact stability for the loading conditions presented. However, more loading conditions should be tested to ensure that the vessel is sufficiently safe.

Large uncertainties regarding the quality of the contaminated drilling fluid makes it difficult to determine the performance of the drilling fluid maintenance system and is therefore not identified in this thesis. Methods based on simulation could be utilized to address these issues in further development of the concept. However, experience from a similar concept, Safe Scandinavia, shows that drilling fluid maintenance performed offshore, significantly reduce transport of contaminated drilling fluids to shore for maintenance. Similar results may therefore apply for this vessel design, but should be further analyzed.

The vessel design presented is similar to a large platform supply vessel and designed to operate on a fourteen-days long roundtrip. This is due to directions given by Statoil Marine early in the design process. This reduce the overall design space early in the design process. Exploration of the entire design space could drastically change the design and ought to be done to not exclude better designs. To verify the financial feasibility of the vessel concept, an assessment of building cost, operating cost, required freight rate, and profitability should be done. This could be used to guide the design towards better solutions. The vessel design presented can however be used as a template or reference vessel for further development of the drilling fluid maintenance vessel concept. As traditionally done in the ship design industry an outline specification report of the vessel is presented in Table 1 in “Outline Specification” (after the summary in Norwegian), introducing the principal particulars and systems decided for the vessel.

Sammendrag

I denne avhandlingen er målet å designe et offshore borevæske-vedlikeholds fartøy for å øke gjenbruk og resirkulering av borevæsker. Store mengder borevæske blir brukt under boreoperasjoner og bade transport og innkjøp av borevæske er kostbart. Ved å utføre vedlikehold av borevæske offshore vil man trenge mindre transport og innkjøp av denne meget kostbare væsken og dermed finnes et overordnet potensial for å spare store kostnader.

I denne avhandlingen er offshore boreoperasjoner studert i lys av vedlikehold av borevæske, og bulk leveranser. Et skipsdesign som er i stand til å utføre vedlikehold av borevæske offshore utvikles og hoveddimensjonene for dette fartøyet blir presentert. Økonomiske fordeler ved å innføre et slikt design, samt regler angående gjenbruk og resirkulering av borevæsker er ikke diskutert i denne avhandlingen.

Utviklingen av et fartøy utvikles i denne avhandlingen ved bruk av system basert skipsdesign metodikken. Boreoperasjoner, vedlikehold av borevæsker og forsyningsskip brukt til å assistere under boreoperasjoner som dedikerte lagerfartøy er analysert for å undersøke potensialet ved å innføre et borevæske-vedlikeholds fartøy. Basert på disse analysene er et fartøy konsept foreslått. Som hjelpemiddel i skipsdesign prosessen er en tredimensjonal modell og general arrangement tegninger laget for å verifisere og validere designet underveis. En spesifikasjonsoversikt av fartøyet er presentert som en mulig løsning til målsettingen om å designe et offshore borevæske-vedlikeholds fartøy.

Denne avhandlingen foreslår et skipsdesign som er i stand til å utføre vedlikehold av borevæske offshore. Brukt/skitten borevæske, brukt i en boreoperasjon, behandles ombord av et vedlikeholdssystem. Vedlikeholdssystemet består av tre ”partikkel kontroll” enheter og en sentrifuge som renser den brukte borevæsken. En miksestasjon blir deretter brukt til å tilsette tilsetningsstoffer og lagertanker blir så brukt til å lagre borevæsken. Alle disse systemene henger sammen i et rør og pumpesystem som gjør at borevæsken kan flyttes rundt i systemet.

Total installert maskin ytelse i skipet er 8700 kW og er fordelt på tre hovedgeneratorer på 2600 kW samt en hjelpegenerator på 700 kW og en nødgenerator på 200 kW. Fremdriftssystemet består av to azipull thrustere bak, samt to tunnel thrustere og en nedsenkbar thruster i baugen. Sengekapasiteten ombord er på 25 personer hvorav 13 av disse er fordelt på enkeltmannslugarer og de resterende 12 er fordelt på dobbel lugarer. Enkeltmannslugarene er hovedsakelig tiltenkt mannskapet og dobbeltlugarene er tiltenkt klienter.

Skipets totale lengde er på 91,5 meter og er 20,5 meter bredt. Total vektdeplasement for skipet er på 9670 ton og har en dødvekt på 6295 ton. Total borevæske kapasitet er på 1612 kubikk og det er totalt rom for 1690 kubikk med ballastvann for å justere trim og krengning av skipet når det er lastet. Designet er i henhold til regler satt av International Maritime Organization for intakt stabilitet, basert på fire testede lastekondisjoner. Flere lastkondisjoner bør undersøkes for å fastslå at skipet er tilstrekkelig sikkert.

Stor usikkerhet relatert til kvaliteten på den brukte borevæsken gjør det vanskelig å vurdere ytelsen til vedlikeholdssystemet og er dermed ikke identifisert i denne avhandlingen. Metoder som baserer seg på simulering kan utnyttes for å løse disse problemene i en videre utvikling av konseptet. Men erfaringer fra et lignende konsept, Safe Scandinavia, viser at vedlikehold av borevæske offshore signifikant reduserer transport av brukt/skitten borevæske inn til land for vedlikehold. Lignende resultater er derfor ikke usannsynlige å få til for fartøyet i denne avhandlingen, men videre analyser bør gjøres for å validere disse antagelsene.

Skipsdesignet som presenteres i denne avhandlingen har mange likheter med allerede bygde større forsyningsskip (PSV) og er designet for å operere i en fjorten dager lag rundtur. Dette er en antatt operasjons profil som er gitt på bakgrunn av ønsker fra Statoil Marine i starten av design prosessen. Disse styringene av designet er med på å minke mulighetsområdet til forskjellige design tidlig i design prosessen. Å undersøke hele mulighetsområdet kan drastisk endre designet og burde gjøres for å ikke avskrive bedre design muligheter. For å vurdere de økonomiske rammene til fartøyskonseptet burde en vurdering av bygge kostnader, operasjonskostnader, nødvendig frakt rate og lønnsomheten vurderes. Dette kan deretter bli brukt til å lede design prosessen i riktig retning. Designet utviklet i denne avhandlingen kan senere bli brukt som referanse eller mal for videre utvikling av borevæske-vedlikeholds fartøy konseptet. Som vanlig i skipsdesign industrien er en spesifikasjonsoversikt av skipet presentert, denne kan finnes i Tabell 1 i kapittel ”Outline Specification” på neste side (kun engelsk versjon). Denne introduserer hoved-dimensjonene og -systemene til skipet.

Outline Specification

Table 1: Outline specification

Mission Description					
Operation area	North Sea				
Description	Drilling operation support vessel, drilling fluid maintenance.				
Target market	Offshore support				

Main Characteristics					
Length OA	91,5	m	Gross volume	17215	m3
Length PP	85,6	m	Gross tonnage	4901	GT
Beam	20,5	m	Lightweight	3375	tonnes
Draft max	6,9	m	Deadweight	6295	tonnes
Depth to main deck	8,5	m	Displacement	9670	tonnes
Crew and client	25	Beds (13single cabins)	DWT/displacement	0,65	
Cargo deck	945	m2	LWT/GV	0,19	

Machinery and Rough Power Demand					
Machinery type	Diesel electric generators and azipull propulsion				
Propulsion power	6630	kW	Main machinery	3 x 2600	kW
No. of propellers	2	units	Auxiliary power	700	kW
Diameter propellers	3,06	m	Emergency power	200	kW
			Total installed power	8700	kW

Tank Types and Capacities					
Water ballast	1690	m3	Liquid mud/multi use	1612	m3
Fuel oil	700	m3	Base oil / LFL*	910	m3
Fresh water	1120	m3	Void and cofferdams	485	m3

Drilling Fluid Maintenance System					
Solids control	3	units	Operators	2-3	persons
Centrifuge	1	unit	Drilling fluid mixing	1	unit

*Low Flashpoint Liquid

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Abbreviations

Δ	Weight displacement
$\bigtriangledown$	Volume displacement
1 µm	One micrometer. Equals $1 \cdot 10^{-6}\ meter$
BL	Base Line
CB	Block coefficient
CP	Prismatic coefficient
CW	Waterplane area coefficient
DWT	Deadweight tonnage
Fn	Froude’s number
FO	Fuel Oil
GA	General Arrangement
GH	Guldhammer/Harvalds method
GT	Gross tonnage
GV	Gross Volume = 4,5*GT^0,971
HPU	Hydraulic Power Unit
HTHP	High Temperature High Pressure (related to wells)
Kn	Knots
LFL	Low Flashpoint Liquids
LGS	Low gravity solid
LM	Liquid Mud (Drilling fluid)
Loa	Length over all
Lpp	Length per perpendicular
Lwl	Length waterline
LWT	Lightweight ship
MGO	Marine Gas Oil (fuel)
NCS	Norwegian Continental Shelf
Nm	Nautical miles
NOK	Norwegian Krone
NPD	Norwegian Petroleum Directorate
OBM	Oil based mud/drilling fluid
OSB	Oseberg B (platform)
OSC	Oseberg C (platform)
OSO	Oseberg Øst (platform)
OSS	Oseberg Sør (platform)
OSV	Offshore Support Vessel

PSV	Platform Supply Vessel
Ro	Density [kg/m3]
RPM	Rotations per minute
SBM	Synthetic based mud/drilling fluid
SBSD	System Based Ship Design
SG	Specific Gravity
w	Wake (coefficient)
WB	Water Ballast
WBM	Water based mud/drilling fluid
WT	Water Tight Bulkhead

1. Introduction

The oil and gas industry has been the main engine in the Norwegian economy and the basis for the Norwegian prosperity for over 40 years. Since the startup in the early 70's, the oil and gas industry has produced values equivalent of 12 000 billion NOK to Norway's gross domestic product (NPD, 2017). Even with a considerable lower oil price in recent years, the oil and gas industry is still and will be the backbone of the Norwegian economy.

High oil prices lead to an international economic upturn in the petroleum industry with high capacity utilization and a significant cost growth as consequence (Moen, 2016). Now, with a significant drop in oil price, reduced income have been a real concern in the industry. It is therefore important to develop new systems and optimize operations on the shelf to maintain a competitive advantage as Norwegian oil and gas will still be an important energy source in years to come especially as transport demand increases (L. Kristoffersen, 2017).

Field-development is an important part of maintaining production levels on the Norwegian Continental Shelf (NCS). As seen in Figure 1, development wells represents the largest share of the investments on the NCS. Drilling operations are therefore subject to great savings if optimized with smarter and more efficient solutions (NEA, 2016b).

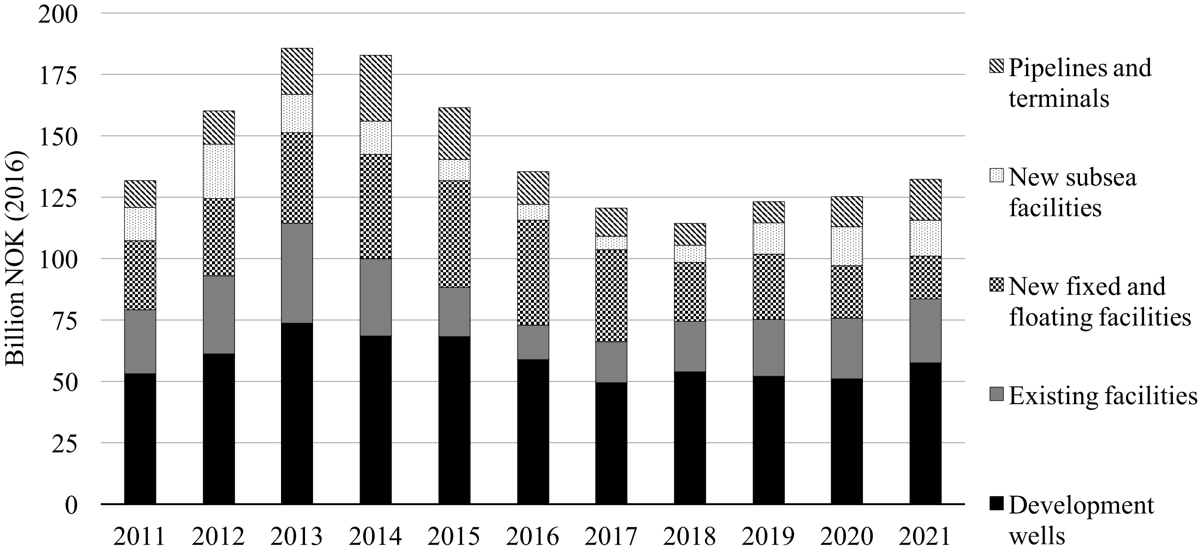

Figure 1: Investments by main category. Historical figures for 2011-2016 and forecast for 2017-2021. Source: (NEA, 2016b)

Despite rough times in the industry, there are still strong value creation on the NCS. In 2016, five plans for development and operations (PODs) were submitted with a total investment value of NOK 23 billion. These are in addition to the seven already started field development projects with a total estimated investment cost of NOK 233 billion (NPD, 2017). The Norwegian Petroleum Directorate (NPD) reports that in 2016 the activity level, with respect to development wells, has remained stable. The number of drilled development wells was in 2016 the same as in 2013/2014 when the oil price was at its highest (NPD, 2017).

Drilling activity is one of the most expensive operations on the NCS, therefore cost reduction measurements have great potential of increasing profitability. According to Petoros annual report from 2013, offshore drilling operations were twice as expensive in 2012 as in 1992 (Petoro, 2013). Since 2014 the industry has managed to increase the efficiency of drilling operations, leading to a 50% cost reduction per well. Still, there are potential of even further cost reductions by thinking outside the box and utilize potential in new technology and changes in systems already in place (Moen, 2016).

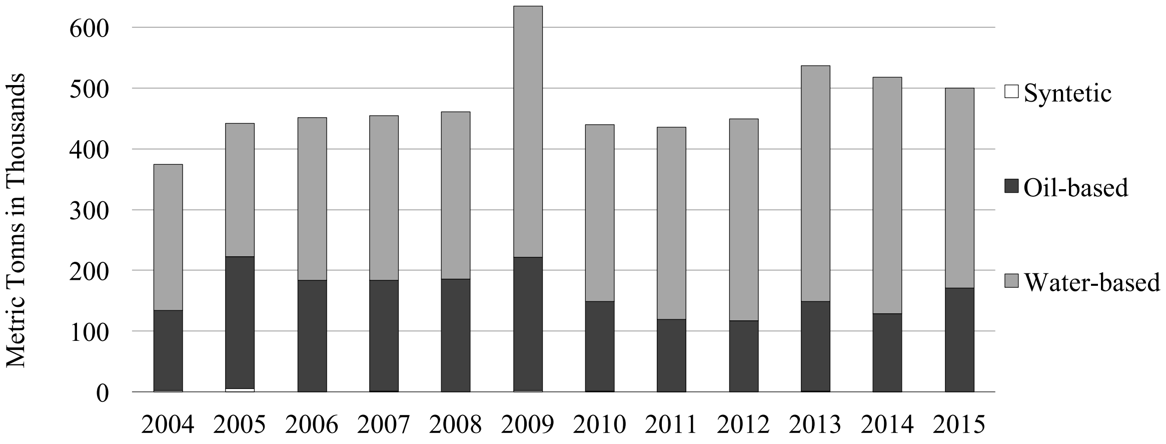

Figure 2: Drilling fluids used on the NCS from 2004-2015. Source:(NEA, 2016a)

As illustrated in Figure 2, water- and oil-based drilling fluids represents the majority of used drilling fluids at the NCS. Synthetic-based drilling fluid (SBM) has been used in a much smaller extent and thus barely visible in the figure. Oil-based drilling fluid (OBM) is used when water-based (WBM) no longer fulfills the required performance during drilling operations. There are much higher costs involved when drilling with oil-based drilling fluids due to logistics- and product cost. On average, one cubic meter of OBM is ten times more expensive as WBM. Average OBM cost is approximately 15 000 NOK/m3, while average WBM cost approximately 1500 NOK/m3 (Lindland, 2006).

Today platform supply vessels (PSVs) are used to transport drilling fluids in liquid bulk tanks from onshore storages to offshore drilling platforms. On the return trip (from the drilling platform and back to shore), wastes and used/contaminated drilling fluids are transported to shore for disposal or storage. Although drilling operations are carefully planned, drilling operations almost never progress according to the drilling plan. Therefore, planning the logistics are difficult for the operators. Due to high uncertainty in drilling fluid demand, additional vessels are needed in addition to original routed vessels, thus increasing overall cost and logistics work (Vik & Gullberg, 2016).

The overall objective in this thesis is to design an offshore drilling fluid maintenance vessel that increase reuse and recycling of drilling fluids. The vessel intends to reduce the overall need for transport and procurement of new drilling fluids. Due to the large differences related to cost, OBM is the focus in this thesis. This thesis shall present a vessel design by use of a suitable ship design methodology. The design is based on a concept where used drilling fluids from drilling platforms are loaded, maintained, and stored on a vessel for later to be reused in a new drilling operation, without the need to be treated and stored onshore. A 3D model and general arrangement drawings of the vessel design shall be presented and the vessel performance shall be estimated.

This thesis will not discuss rules and regulations regarding issues with shared drilling fluids during drilling operations. However, this issue has been mentioned by almost every person that have been contacted and could be an interesting subject to further investigate.

Drilling fluids are a complete study in itself and in this thesis design of different types of drilling fluids are not discussed in depth. However, the main components and functions are listed and explained. Drilling fluid content and cost are also highly protected and difficult to receive good information about as this is competitive information that drilling fluid suppliers wish to withheld from public. However, understanding the properties and limitations of reusing drilling fluids is important to design a good vessel.

The remainder of this thesis is structured as follows. In Chapter 2, a literature review of offshore drilling operations is done to investigate the potential of designing a drilling fluid maintenance vessel. The focus is on drilling fluids and drilling fluid maintenance systems. In Chapter 3, different ship design methodologies are presented and discussed. A suitable design methodology for the design issue emerge from this chapter. In Chapter 4, the system based ship design methodology, selected to solve the design issue, is presented. An outline of how it is used in this thesis is also done. In Chapter 5, the system based ship design methodology is put into practice and a vessel design develops. In this design process it is practical to discuss results as they appear during the process, therefore results and discussion is also done in this chapter. However, in Chapter 6 an outline specification report/main results of the vessel design are presented, and in Chapter 7 the most important findings are discussed in an extended discussion chapter. Conclusions and recommendations are presented in Chapter8, while recommended expansions of the work is presented in Chapter 9.

2. Offshore Drilling Operations

In this chapter, a literature review of offshore drilling operations is presented. In addition, vessel movements and bulk cargo shipments during drilling operations are analyzed. This chapter is used to investigate and outline a potential of designing an offshore drilling fluid maintenance vessel.

2.1 Drilling Fluid System

Drilling fluids are often referred to as drilling mud due to the history of drilling, as regular mud was primary used as drilling fluid in the past (Mitchell & Miska, 2011). To avoid any misunderstandings or confusions regarding the terms used in the remains of this thesis, drilling muds and drilling fluids refers to the same product. Drilling fluids are being used in a drilling fluid cycle, as illustrated in Figure 3.

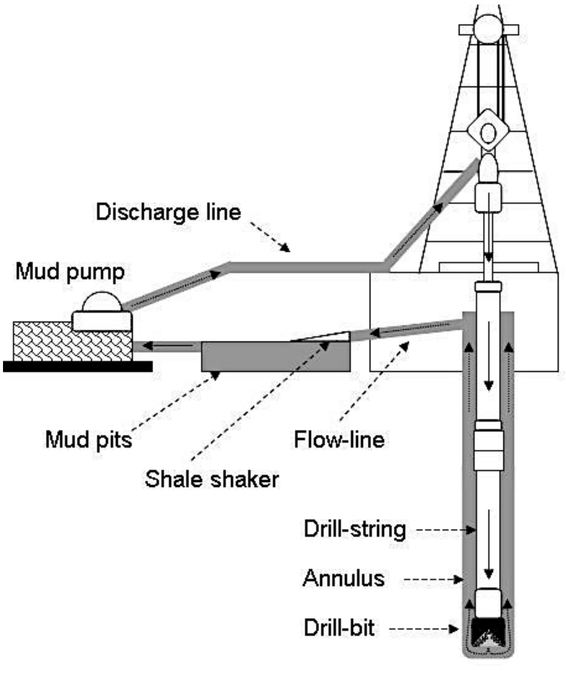

Figure 3: Drilling fluid cycle. Source: (Pettersen, 2007)

The figure illustrates how the drilling fluid circulates during drilling operations. The illustration is based on the most common and widely used “rotary drilling” technique, used both in on- and offshore drilling operations (Bourgoyne et al., 1986). The drilling fluid is pumped down the drill string where it lubricates the drill-bit, which are mounted at the end of the drill string. The drilling fluid then transports cuttings from the bottom of the well to the surface through annuls. At the surface the drilling fluid is gathered in mud pits at the drilling deck. Before the drilling fluid enters the mud pit, drill cuttings are removed from the fluid by use of solids control equipment like shale shakers (explained in detail later). Shale shakers roughly separates drill cuttings from the drilling fluid and store cuttings in containers for later treatment and disposal onshore (Pettersen, 2007). There are different stages during drilling operations deciding what type of drilling fluid being used. Wells are most commonly drilled in five main sections, as illustrated in Figure 4.

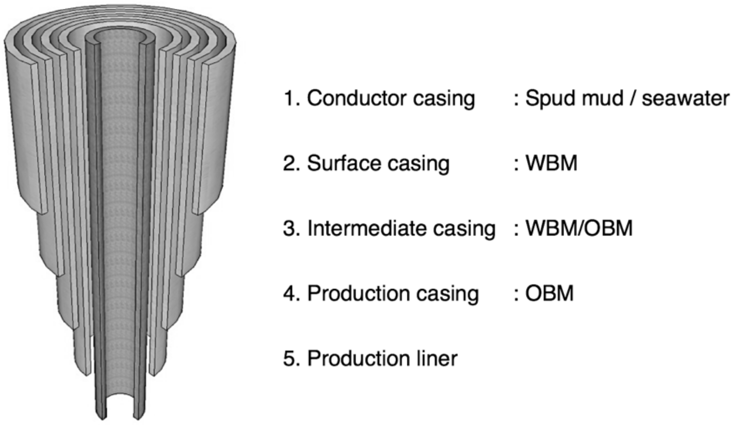

Figure 4: Typical well casing diagram and related mud types used in drilling operations.

When drilling the upper part of a well it is called the spudding phase. This part is most commonly drilled by use of a sea-water or a seawater-bentonite based drilling fluid (bentonite is explained below) (Growcock & Harvey, 2005). During this drilling phase the drilling fluid is not connected to the drilling fluid cycle, as presented Figure 3. The fluid will not return to the drilling deck for reuse and the wastes get spread out at the seabed. Drilling a hole for the conductor casing (spudding phase) is typically done for the first couple hundred meters of the well and then steel casings are cemented into position to ensure well stability. When the steel casings are properly installed in the upper part of the well, a riser system can be installed to connect the drilling fluid cycle between the well and drilling unit at sea surface, as shown in Figure 3 (Mitchell & Miska, 2011).

As the well depth increase, the mud system complexity also increases. This is due to increased hostile conditions and other technical difficulties that emerges downhole. There are several different ways to design a well. The most commonly used well design is illustrated in Figure 4 (Devold, 2013). The conductor casing is installed to prevent formation cave-ins at the seafloor. Surface casings prevents fresh water contamination from the ground water zone. Intermediate casing sections are drilled with complex drilling fluid properties due to increasingly troublesome formations downhole. In deeper wells there are often drilled more than one intermediate section and these are often the longest sections in a well (Growcock & Harvey, 2005). The production casing section penetrates the producing zone and protect the production liner that are used to produce from the well (Neff, 2010). Drilling fluids are usually replaced for each section drilled. In addition, due to constant changes in technical requirements of the drilling fluid, additives are also constantly added to the present drilling fluid during the drilling operation. This is done to adjust the drilling fluid characteristics to address changes in formation and pressure downhole (Neff, 2010).

A drilling operation typically starts with a relative simple water based drilling fluid at the top and ends with a complex oil-based fluid at the end. For each section drilled, the diameter of the well hole decreases, starting with a typical 30-42" diameter and ending up with an 7" production diameter (Devold, 2013). The drilling operators cannot drill one single borehole with one specific drill-bit diameter, due to friction- and pressure issues. After spudding the upper parts of the surface, creating a hole for the conductor casing and installing a riser system, the rest of the drilling operation continues following a repetitive pattern: Drilling, insert casing, displacing the drilling fluid with cement, cementing the casings in position, displacing the cement with new drilling fluid, and then continue drilling with a smaller drill-bit to insert smaller casings. All this is done until the well is near the oil reservoir and the well is soon ready to drill through the last layer of the reservoir and for the production liner to be installed (Mitchell & Miska, 2011). In Figure 5, a more detailed figure of a traditional drilling fluid cycle system is presented.

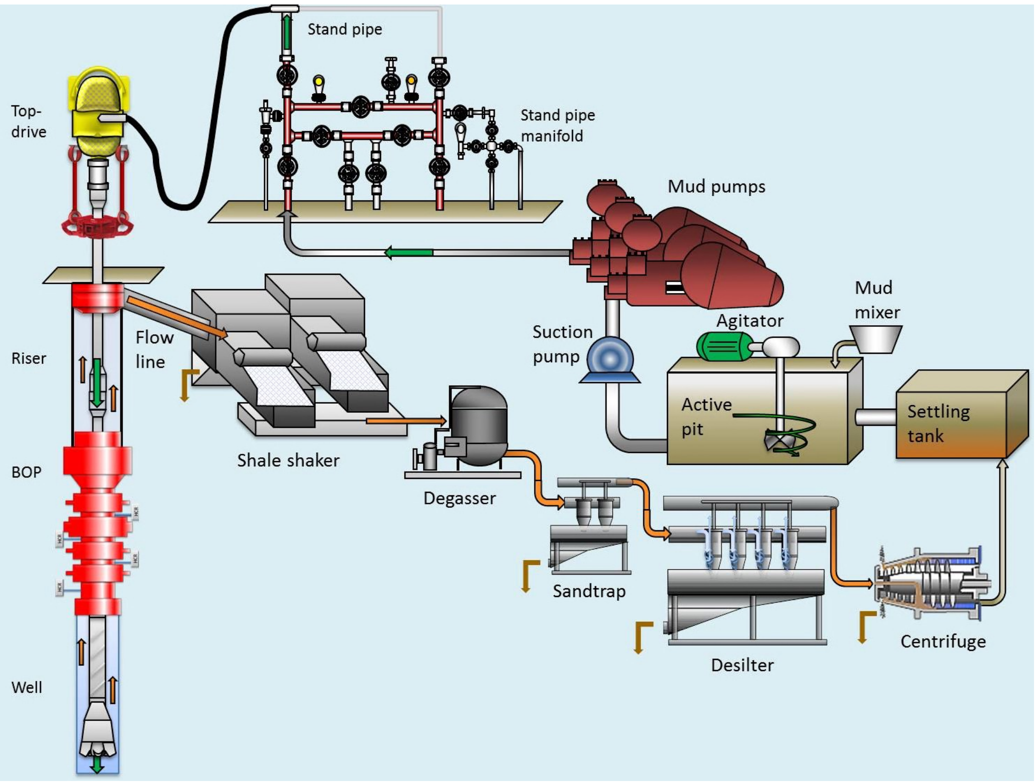

Figure 5: Drilling fluid system on a conventional drilling unit. Source:(Keneth Ludvigsen, 2017b)

The drilling fluid is pumped from the active pit through the riser system down to the drill-bit. A drilling unit can have several storage tanks with drilling fluids, but the one used in the drilling process called active pit. “Contaminated”/used drilling fluid, coming up from the borehole, is then passed through solids control equipment (shale shaker, degasser, sandtrap, desilter, and centrifuge) to remove unwanted particles. Contaminated drilling fluid is the condition of the drilling fluid after being used downhole. Then the drilling fluid is stored in a settling tank, where small particles accumulates near the bottom, and removed. The drilling fluid then enter the active pit again where a mud mixer is used to add lost drilling fluid or additives due to loss through the solids control equipment, or down hole (Keneth Ludvigsen, 2017b).

Drilling fluid must be brought offshore to enter the drilling fluid cycle. This drilling fluid can either be newly produced on an onshore factory or recycled from other drilling operations. New drilling fluid is produced onshore in batches and transported by platform supply vessels (PSVs) to the drilling unit. Used drilling fluid is sent back to shore for recycling after being used in a drilling operation. Recycled drilling fluid is treated onshore by a maintenance system before transported out to a new drilling operation (Hestad, 2017).

2.2 Drilling Fluid Design

Briefly explained, a drilling fluid is a blend of fine grained solids, organic and inorganic compounds dissolved or distributed in a so called continuous phase, which are either water or an organic liquid (AECOM, 2016). The main tasks for the drilling mud is 1) to transport drill cuttings, produced by the drill bit, away from the borehole, 2) ensure balanced pressure inside the well, and 3) make a filter cake between the formations and borehole to reduce fluid loss. A filter cake is a term for when the drilling fluid creates a membrane between the borehole and formations. This prevents fluid loss to the formation during drilling. The drilling fluid also performs important additional functions such as ensuring cooling and lubrication of the drill bit, keep drill cuttings floating, reduce stuck pipe (friction), and transfer hydraulic power to the drilling equipment (Growcock & Harvey, 2005).

There are mainly three different types of different drilling fluids and they are classified depending on their base: Oil-based mud (OBM), synthetic-based mud (SBM), and water-based mud (WBM). The usage of SBM on the NCS is negligible, as showed in Figure 2, and will not be further discussed. In WBM water or brine (high salinity water solution) is the base fluid in which solids are blended into. Water/brine is therefore termed the “continuous phase”. In OBM oil is the base fluid in which solids are blended into. Here the oil is termed the continuous phase. Figure 6 shows the most commonly used composition of WBM and OBM in the industry today.

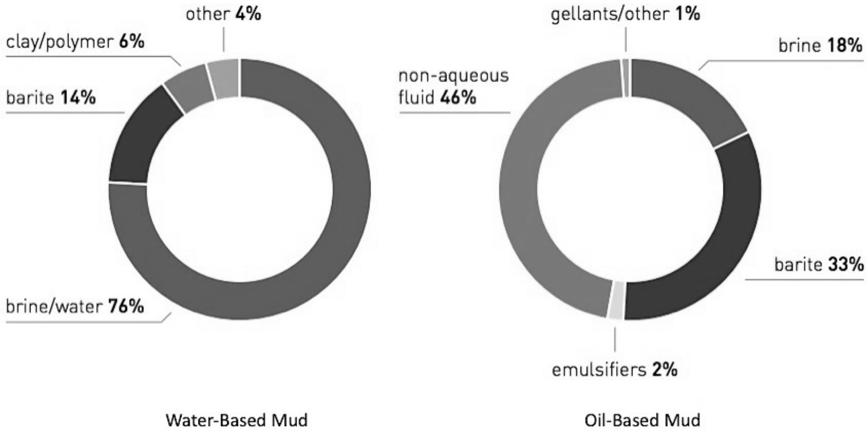

Figure 6: Drilling fluid composition in weight percent of most common WBM and OBM (Bentonite is also called clay/polymer). Source:(IPIECA/OGP, 2009)

WBMs are mostly made up of brine/water, barite, polymers and other additives such as chlorine. Brine is a mixture of water and salt, which is much saltier than seawater (above 5% salinity). OBMs are made of a non-aqueous fluid, barite, brine, emulsifiers and other additives such as gellants (IPIECA/OGP, 2009).

Bentonite, also referred to as gel, is used to make a filter cake so that the drilling fluid does not flow through the wall of the borehole and lost to the formation. In addition, certain polymers are used to increase the tightness of the filter cake so that less drill fluid are lost during drilling. Polymers has the ability of give the drill fluid high viscosity, but not carrying capacity, i.e. it is not suitable of carrying cuttings away from the hole. Bentonite on the other hand adds viscosity and carrying capacity to the fluid, making it possible to carry drill cuttings away from the borehole. Stops often occurs during drilling operations (IPIECA/OGP, 2009). The properties of bentonite make the drilling fluid gellant so that when the pumping of drilling fluid stops, the bentonite helps the drill cuttings stay afloat in the drill fluid. This prevents accumulating of the cuttings downhole. Too much bentonite on the other hand is abrasive on the drilling equipment (Growcock & Harvey, 2005).

Barite is the most common weighting agent used to ensure proper formation pressure in the well. This is important to prevent uncontrolled influx of formation fluids leading to a blowout. Barite is one of the most used additives in both WBM and OBM on the NCS and added to the drilling fluid to increase the density of the system to ensure borehole stability (SPE, 2015).

OBMs are non-aqueous drilling fluids based on mineral oils, diesel or refined linear paraffin's. In recent time diesel has been banned from being used in most areas due to high toxicity. OBMs are typically built up with either an oil-or synthetic-base fluid, a detailed description of different non-aqueous fluids (OBM) are listed in Table 2 (Growcock & Harvey, 2005).

Table 2: Non-aqueous drilling fluids used in the North Sea. Source: Growcock and Harvey (2005)

Oil-based fluids	**Main components**	**Application area**
Oil	Weathered (oxidized) crude oil; asphaltic crude, soap, water 2–5%.	Moderate cost, low-press well completions and workovers, low-press shallow reservoirs; water used to increase density and cuttings-carrying capacity; strong environmental restrictions may apply.
Asphaltic	Diesel oil; asphalt, emulsifiers, water 2–5%.	Moderate cost, any applications to 315°C; strong environmental restrictions may apply.
Invert emulsion	Diesel, mineral, or low-toxicity mineral oil; emulsifiers, organophilic clay, modified resins, and soaps, 5–40% brine.	High cost, any applications to at least 230°C; low maintenance, environmental restrictions.
Synthetic	Synthetic hydrocarbons or esters; other products same as invert emulsion.	Highest cost, any applications to at least 450°C; low maintenance.

As can be seen in Table 2 OBMs are used to address the most challenging high pressure high temperature (HPHT) wells, and the cost of using this type of drilling fluid is significantly higher than simple WBMs. In addition, the most expensive fluid types require less maintenance than the moderate priced OBMs, making these a suited target for drilling fluid reuse/recycling. As OBMs are based on oil and synthetic products they cannot be discharged into the sea without treatment due to the environmental impact.

2.3 Drilling Fluid Supply Chain

Drilling fluids sent to a drilling platform come from different origins. The drilling fluid is either brand new or recycled. If the drilling fluid is new, it has been produced onshore or built on the platform from raw material by mud engineers. If the drilling fluid is recycled, three origins are normal. As shown in Figure 7, the origin of recycled drilling fluid can be, 1) an onshore base where it has been sent from another drilling operation, 2) from a previous drilled section at the same rig, or 3) from another drilling platform, where they have drilled a well with the same characteristics. Where the drilling fluid comes from depends heavily on the drilling fluid condition and the required characteristics for the well to be drilled (Lindland, 2006).

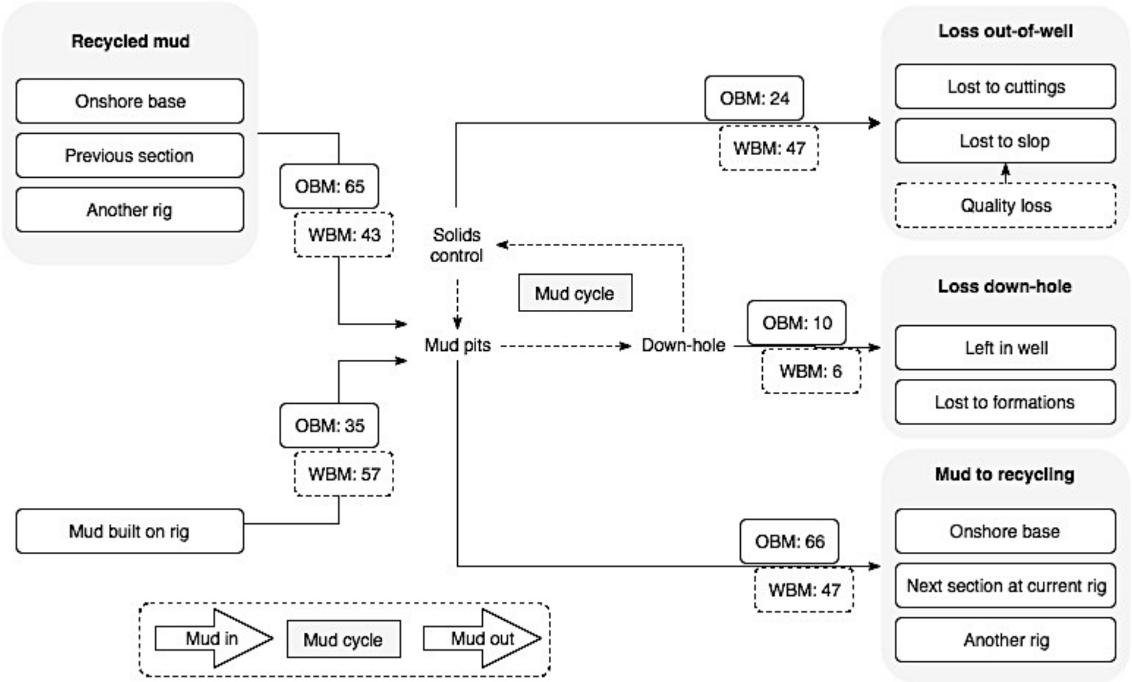

Figure 7: Drilling fluid flow during drilling operations performed: 1999-2005 on the NCS. Source and consumption of OBM and WBM, in percentage. Source: (Lindland, 2006)

As illustrated in the lower left corner in Figure 7, the overall drilling fluid flow during a drilling fluid lifetime can be explained fairly simple; drilling fluid enters the drilling cycle where it performs its functions, and then the drilling fluid exit the drilling fluid cycle for disposal or recycling. During drilling operations, loss of drilling fluid occurs throughout the operation due to various reasons. These are listed in Table 3.

Table 3: Loss of drilling fluid during drilling operations on the NCS.

Type of drilling fluid loss	Percentage of total loss	Cause/explanation
Loss out-of-well	OBM: 24% WBM: 47%	Cuttings adhesion of drilling fluids Spillage on the rig and from different equipments Expired drilling fluid that no longer is able to perform
Loss down-hole	OBM: 10% WBM: 6%	Loss to formations Leftovers in the well after drilling
Mud to recycling	OBM: 66% WBM: 47%	Change of drilling fluid to be used in next section Sent to recycling on present rig for reuse in new section Sent to onshore base for treatment and storage Sent to another rig on offshore field for treatment and reuse

The amount of losses of drilling fluids are dependent on the formations, performance of the solids control equipment, and what type of drilling fluid used (Pettersen, 2007). As shown in Figure 7 and listed in Table 3, the drilling fluid typically leaves the drilling fluid cycle due to three reasons: 1) loss out-of-well, 2) loss down-hole, or 3) mud sent to recycling for reuse.

Loss out-of-well refers to loss of drilling fluids due to; mud stuck on the cuttings that is not recovered by solids control equipment, spillage on the drilling deck during operations, and expired drilling fluid due to reduced quality. Loss down-hole is due to changes in formations where the filter cake is not good enough and leftovers in the well after the drilling process is done. In addition, drilling fluids are sent to recycling after use. Based on reported numbers in Lindland (2006), it is a continuous demand for refilling of drilling fluids throughout a drilling operation. Due to loss out-of-well and loss down-hole, mud has to be built on the rig to ensure sufficient amounts of drilling fluid in the circulation system at all time. When performing drilling operations, loss of drilling fluids is inevitable, but can be significantly reduced with proper solids control and by drilling with optimized drilling fluids, tailor made for each section of a well.

After completion of a section, the drilling fluid pits on deck will contain all the drilling fluid used in that section. This drilling fluid are denoted “mud to recycling” and will normally be sent back to the drilling fluid supplier for maintenance (Kjøstvedt, 2017). It is up to the mud engineers to determine whether or not the drilling fluid further can be reused, or simply destructed. Drilling fluids that are in good enough condition and does not need maintenance can further be used in in a new well, either in same rig or transported to a new rig for similar operation there.

2.4 Drilling Fluid Maintenance

As presented in Table 3 and Figure 7, there are large volumes of used drilling fluids that are sent to shore for recycling, and thus subject to more efficient handling. Most important are OBMs. OBMs are far more expensive than WBMs and due to environmental concerns, prone to much more troublesome handling. Due to environmental aspects and economics, OBMs are reused in several wells but are subject to comprehensive transport and handling requirements when transported to shore (Neff, 2010). When performing drilling operations, OBMs are stored in separate tanks on the drilling platform and connected to the drilling fluid cycle when needed. Space limitations on the drilling platform makes it necessary to also order drilling fluid from shore. Some installations do not have the ability to process drilling fluids properly and are heavily dependent on vessel shipments (Skram, 2017). Dedicated storage vessels (PSVs) are also heavily used during drilling operations to store drilling fluids and equipment instead of transporting it to shore (Kjøstvedt, 2017). Performing maintenance offshore on these vessels is therefore desirable but equipment is needed to perform drilling fluid maintenance, most important is the solids control equipment.

2.4.1 Solids control in drilling fluids

Solids/particles in the drilling fluid is an integral part of the function of the drilling fluid and important to manage properly during drilling operations. In Table 4, definition of common particles/solids in drilling fluids, and the size of these, are presented.

Table 4: Classification of solids in drilling fluids.(µm = 10^{-6} *m) Source:(Growcock & Harvey, 2005)*

Category/term	**Size (µm)**	**Types of particles**
Colloidal	<2	Bentonite, clays, ultra-fine drilled solids
Silt	2-74	Barite, silt, fine drilled solids
Sand	74-2000	Sand, drilled solids
Gravel	>2000	Drilled solids, gravel, cobble

Different equipment types are necessary to decrease particle content in the drilling fluid. There is a strong and dynamic relationship between the drilling fluid, solids dispersed in the drilling fluid, and the equipment (solids control equipment) used to reduce solids in the drilling fluid. A change in one of these will affect the other two (Growcock & Harvey, 2005). This relationship is intricate and beyond the scope of this thesis. Therefore, only a brief review of the equipment types and what solids they remove is done. This is done to discover the potential of installing such equipment to be used for maintenance of drilling fluids onboard a vessel.

Additives are used to give drilling fluids the required performance mainly in terms of viscosity, density and filtration control (filter cake). Other solids become part of the drilling fluid during the drilling operation. When drilling, the formations becomes part of the drilling fluid. This is because the drill-bit crushes the rocks in smaller pieces for each time they get in contact with the drill-bit. These solids are then mixed into the drilling fluid. In moderate concentrations these solids may strengthen the drilling fluid but in most cases these solids are in excessive concentrations and are detrimental to the performance of the drilling fluid and needs to be removed (Growcock & Harvey, 2005).

Larger solids are relative simple to separate from the drilling fluid by use of shale shakers, and do not cause further problems to the drilling operation. Colloidal solids on the other hand are much harder to separate. Too much drilled solids in the drilling fluid cause problems such as;

high friction to the drill string, poor cementing, or high pressure when running drill string in and out of the wellbore, resulting in well problems. The tolerance of drilled solids in the drilling fluid is unique for each well and for each type of drilling fluid used (Mitchell & Miska, 2011). Therefore, solids control is hard to manage. Smaller solids are harder to filter out of the drilling fluid compared to larger ones. It is therefore important to remove larger particles early so they do not degenerate into smaller, hard to remove, particles. In Figure 8, traditional solids control equipment is presented, and the particle size they can remove.

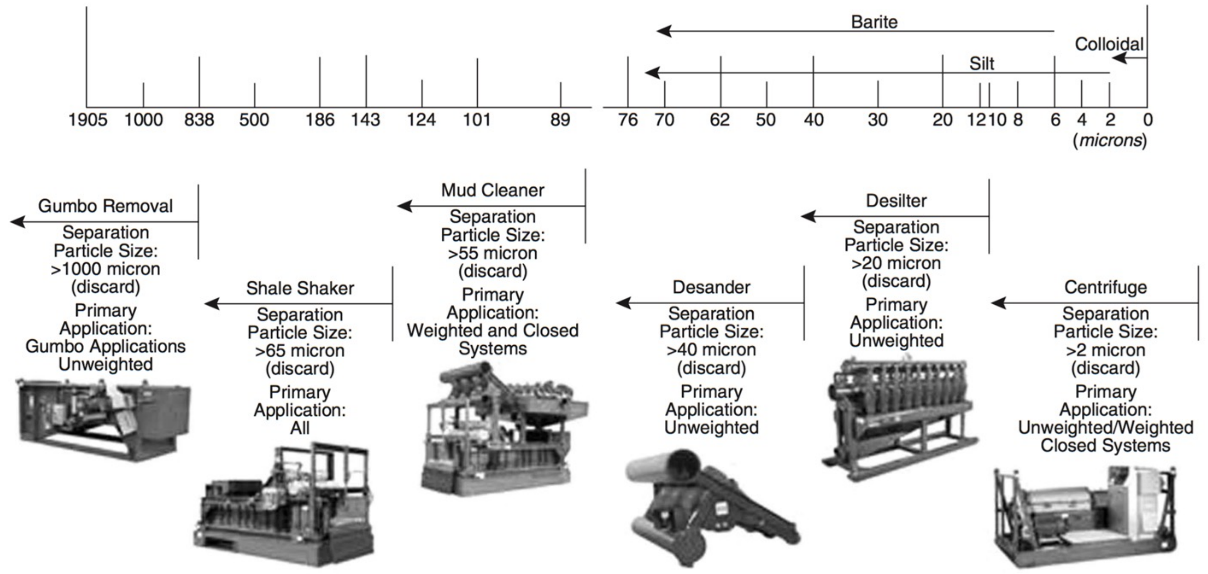

Figure 8: General solids control equipment and their removal capabilities. Source: (Growcock and Harvey, 2005)

Drilled solids are removed from the drilling fluid based on the size of the particle. Larger particles are removed before smaller particles. Traditionally used equipment for solid removal are presented in Figure 8, ordered by large particle size remover from the left, to smaller sized particles remover to the right. As the figure states, some of the equipment are used only for unweighted drilling fluid systems. These systems are not mixed with weighting agents. An unweighted drilling fluid does not contain any commercial weighting agents such as barite.

Solids control equipment shown in Figure 8 are installed on a platform relative to each other arranged from left to right, as shown in the figure. Gumbo removal is used when drilling through clay zones and used to filter out junks of clay, preventing clogging of the pipes. If not using gumbo removal equipment, shale shakers are normally the first stage of solids control. Here the drilling fluid (with cuttings/solids) enter the top of the shaker and get filtered through two or more vertically divided filters/shaker screens made of metal threads. Each floor with screens have different mesh size and vibrates to filter out solids. Depending on the mesh size and numbers of shaker screens, cuttings down to about 65µm are discarded from the drilling fluid. Further, mud cleaner, desander, and desilter equipment can be installed in series and typically ending up with a centrifuge at the end (Kenneth Ludvigsen, 2015).

2.4.2 Use of centrifuge to remove colloidal solids

In case of poor solids control of a drilling fluid, dilution is the main method to reduce solids content in the drilling fluid. A simple example: reducing solids in a drilling fluid with 50% would require that half of the drilling fluid is replaced with new/clean drilling fluid (Growcock & Harvey, 2005). Dilution is a costly process that is used to control the contents of colloidal solids to a required level. These solids have accumulated due to poor solids control. The consequence of excessive use of dilution is that too much drilling fluid goes to waste and corresponds to significant increased cost of the well. According to ISO standards, a centrifuge exploits rotation from an external force (electricity or hydraulics) to separate materials of various specific gravity and particle sizes from a drilling fluid (ISO, 2011). In weighted drilling fluids, a centrifuge is used to remove colloidal solids and recover barite from the drilling fluid. This is done to avoid colloidal solids accumulation that can cause problems and reduced ratio of drilling penetration (SLB, 2017). A centrifuge is used to maintain proper drilling fluid viscosity and weight without excessive use of dilution, saving rebuild- and disposal costs.

2.4.3 State of the art solids control equipment

New practice in the solids control industry is now to combine more of the traditional equipment into one compact flexible unit with the ability to remove solids of various size more efficiently. This relative light and compact solids control equipment use airflow, filters, and vacuum instead of shaking/vibration to separate drilled solids from the drilling fluid. Noise, vibration, oil-vapor and oil-mist are efficiently reduced using this equipment instead of traditional shale shakers. The result is lower environment impact, increased health and safety concerns for the workers, and up to 80% reduction of energy consumption (Cubility, 2017). Primarily the compact unit replace the traditional shale-shaker; however, it can also replace other solids control equipment downstream, as illustrated in Figure 9.

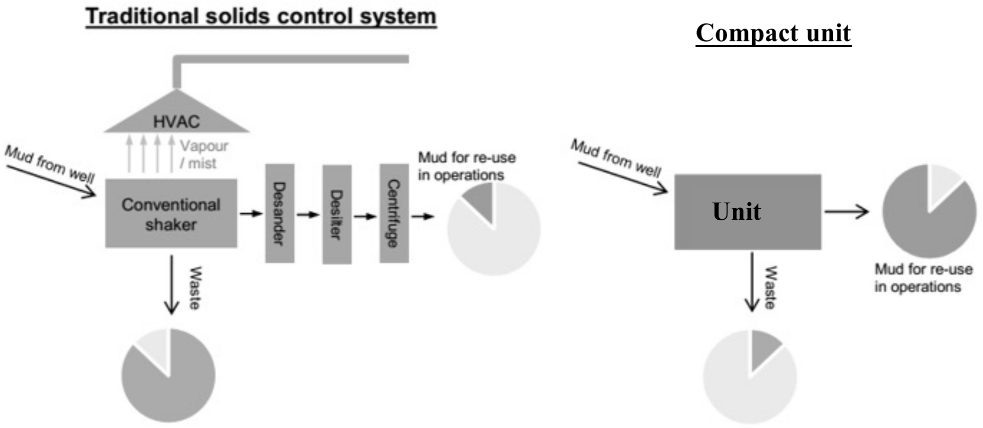

Figure 9: Traditional solids control system vs MudCube system. Equipment replaced by the "compact unit" also called MudCube. Source: (Cubility, 2017)

The compact unit separates coarser and fine solids from the drilling fluid with the same (or better) result as the shaker, desander, and desilter combined (Paaske, 2016). However, it is not capable of removing low gravity solids (LGS) and colloidal solids. Thus it does not replace the centrifuge. Shale shakers are prone to error due to high levels of vibrations and it is a messy process where drilling fluids and cuttings are soiling the equipment and platform deck. Errors cause downtime and inefficient drilling, leading to economic loss (Osmundsen et al., 2010).

2.4.4 Drilling fluid mixing and preparation

Drilling fluids are mixed in various ways. Some mixing equipment is sophisticated and some are rather primitive where the mixing is done manually. On drilling platforms there are installed mixing equipment that is used to mix all the wanted additives into the drilling fluid during operation. These additives are used to adjust among other; viscosity and density of the drilling fluid. The mixing equipment setup is relative simple. At the mixing unit, there is usually a sack cutter and a big bag cutter. These cutting machines cut bags, filled with powder/additives, and the powder can then be added to the fluid regulated by a mud engineer (Keneth Ludvigsen, 2017b). Frequently used dry bulk additives are also stored in separate tanks in the mixing unit ready to be blended with the fluid. In addition, fluid based additives are usually stored in $1000\ liter$ replaceable tanks (Kjøstvedt, 2017). Additives that are required in the drilling fluid, are then connected to a piping system that are connected to the drilling fluid tanks. Due to the need for dilution of the drilling fluid, there are normally base oil tanks placed nearby that can be used to dilute the drilling fluid. The drilling fluid tanks are equipped with agitators or circulation pumps that constantly circulate the fluid so that particles do not accumulate at the bottom (Kjøstvedt, 2017).

2.5 Drilling Fluid Cost

Common practice in the industry is that drilling fluid suppliers sell or lease drilling fluid to the drilling operators. When the drilling operators no longer need the drilling fluid, they sell it back to the supplier. The cost of drilling fluids is kept to a secret by drilling fluid suppliers much because of the rivalry between different suppliers. In Lindland (2006) drilling fluid prices from 2005 from three major suppliers in the North Sea market is presented. One can see that drilling fluids represents a significant cost in drilling operations. Some of the OBMs with a specific gravity (SG) above 2, cost more than $20\,000 NOK/m3$, OBM with SG 1,4 cost $12\,500\ NOK/m3$. If we adjust these values till todays value, assuming an average yearly inflation rate of 2 % this will approximately be $25\,365\ NOK/m3$ and $15\,853\ NOK/m3$. In 2015, over 170 thousand tonnes OBM were used on the NCS. Assuming a SG of 1,4, this equals approximately drilling fluid cost of NOK 2 Billion.

2.6 Vessel Logistics and Bulk Cargo Shipments

At the Oseberg field, storage vessels are frequently present during drilling operations. At this field there are recorded large amounts of drilling fluids used, due to many drilling operations. In addition, there has been recorded large quantities of drilling fluids returned to shore for maintenance. Therefore, vessel movement and bulk cargo shipments on this field is further analyzed. Statoil Marine in Bergen, who make sure that supplies arrive at their platforms, recorded delivered and retrieved amounts of OBM on all of their platforms from 01.01.16 – 01.03.17 (14 months), this data is investigated further, see Appendix A for the data provided.

Four platforms on the Oseberg field perform drilling operations: Oseberg Sør (OSS), Oseberg Øst (OSO), Oseberg B (OSB), and Oseberg C (OSC). These platforms were designed in the 80's and represents an older generation of platforms with more primitive solids control equipment installed and limited space for installment of new technology (Skram, 2017). According to mud engineers, and discovered in the vessel movement recordings, it is common to have a stand by storage vessel next to the platform. These vessels are intended to store equipment and drilling fluids during drilling operations. Such storage vessels are frequently used to manage limited space problems for drilling fluids by pumping drilling fluids back and forth between the platform and vessel (Kjøstvedt, 2017). In addition, scheduled PSVs arrives to deliver and pick up cargo at the platform. Instead of only store equipment and drilling fluids, these storage vessels could utilize their stay-time to perform drilling fluid maintenance in this operation mode. By performing drilling fluid maintenance offshore, one can reduce overall drilling fluid consumption, transportation, and cost of buying new fluid.

2.6.1 Vessel movements at the Oseberg field during drilling operations

It is of interest to study vessel movements and bulk cargo shipments to a platform during drilling operations to highlight a potential of a drilling fluid maintenance vessel. A dataset of when vessels arrived and departed from installations has been provided by Statoil Marine. A section of this dataset can be seen in Appendix A. The dataset from Statoil Marine has been analyzed focusing on the presence of dedicated storage vessels. During 2016, at OSS, OSO, OSC, and OSB, dedicated storage vessels have been frequently used, as shown in Figure 10.

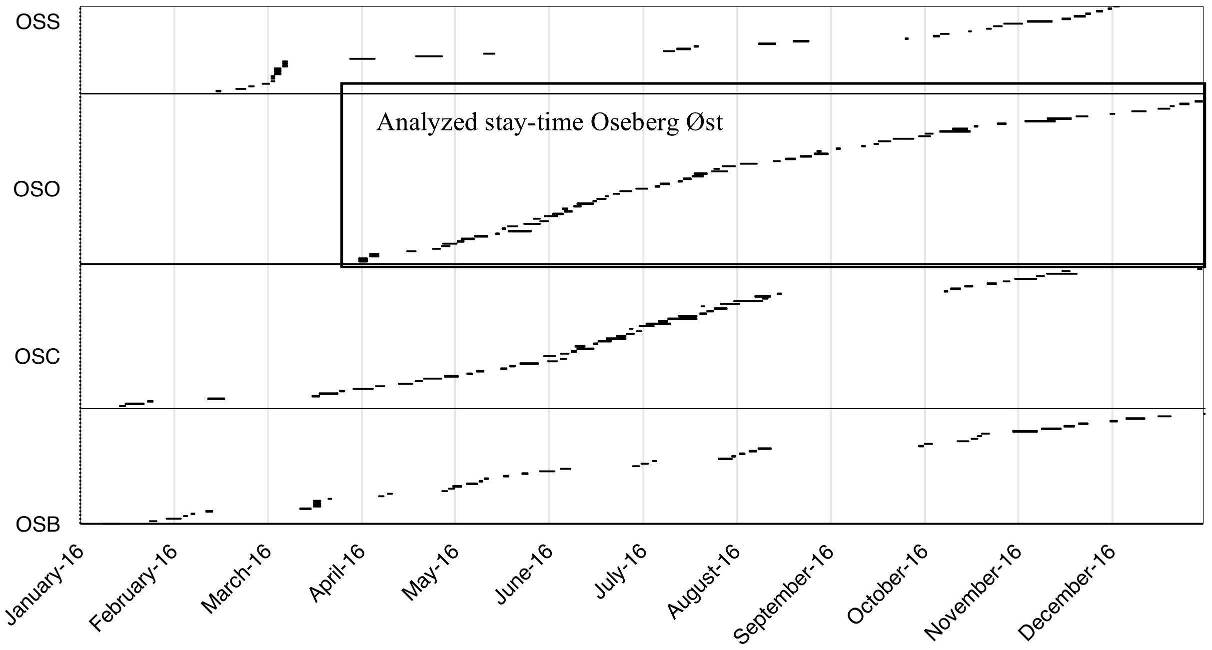

Figure 10: Dedicated storage vessel occurrence at OSS, OSO, OSC, and OSB during 2016. Each string represents vessel stay time at one platform. Minimum stay time is 24 hours.

Each horizontal-stretched line in the figure represents a vessel and the length of each line represents the stay-time. In this plot, vessels that have been located next to a platform for more than 24 hours are included. In total, for 2016, multiple vessels have been used simultaneously at the field. Table 5 describes the total time a storage vessel has been present at each of the platforms on the Oseberg field.

Table 5: Total stay time at each platform based on 14 months recordings.

Platform	Total number of days storage vessel present	Total time presence of storage vessel
OSS	126 days	31 %
OSO	243 days	60 % (92% from 01.04 to 31.12)
OSC	230 days	57 %
OSB	135 days	33 %

At Oseberg Øst (OSO), where there is performed most drilling activity, a storage vessel has been present next to the platform in 60 % of the time, based on the 14-month period. However, as can be seen in Figure 10, there were no vessel present at OSO until the end of March.

Public data from the NPD shows that there was no drilling activity at OSO at the start of 2016 and that drilling activity started in the end of March. Analyzing data from end of March (illustrated in figure) and forward in time, a storage vessel has been present at OSO in 92% of the time throughout the period. Drilling operations at OSO were constantly performed with only short interruptions, as illustrated in Figure 11.

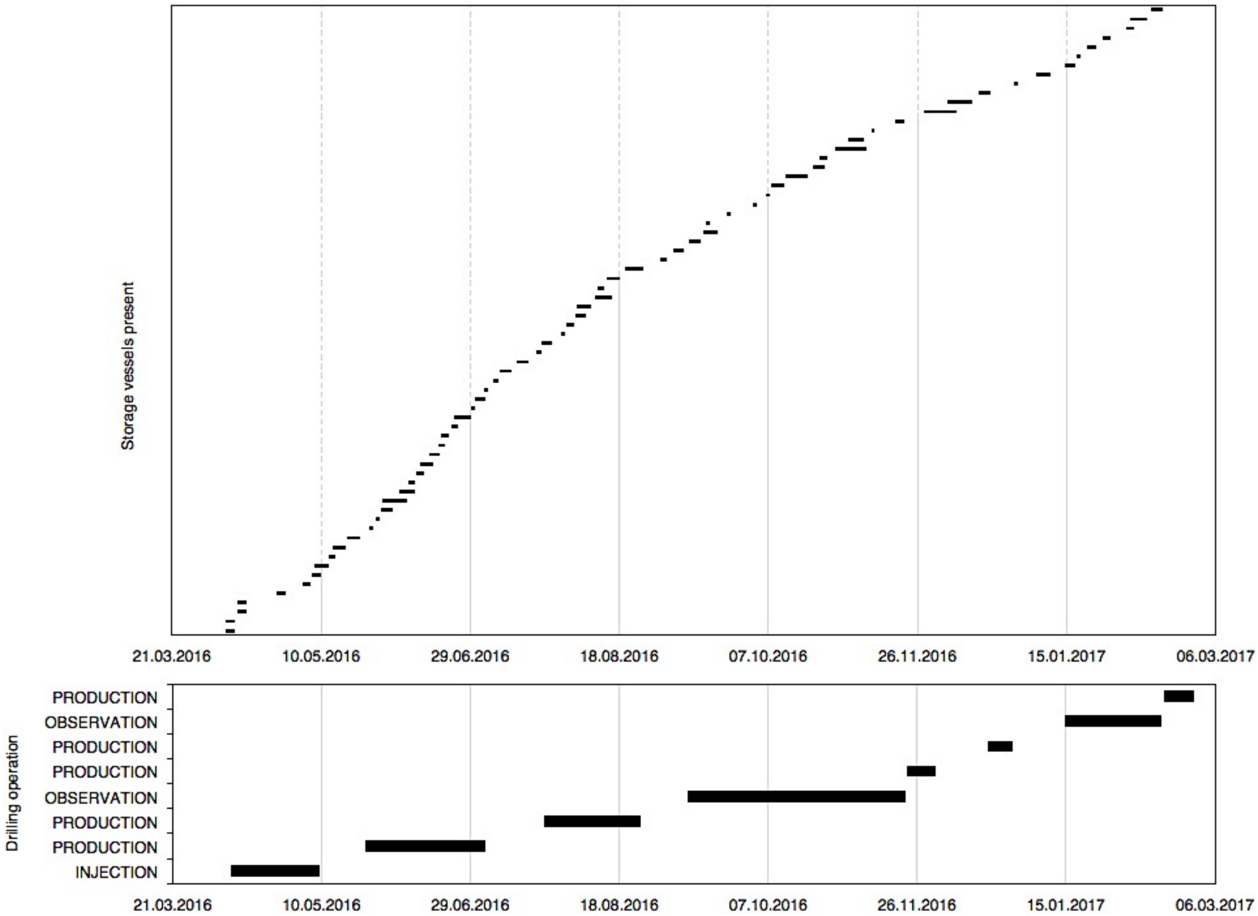

Figure 11: Drilling operations and storage vessels present on OSO. March.2016 - March 2017.

The majority of the assigned storage vessels operate on standby for up to four days. Recordings shows that some of the vessels have stayed for up to eleven days (at OSO). The total distribution of all storage vessels, with a stay time above 24 hours at Oseberg in the 14-month period, can be seen in Appendix B. As can be seen from these vessel movements, there is a direct connection between drilling operations and storage vessels present next to the drilling operation, regardless of the type of drilling operation. This can be seen in Figure 11, where a storage vessel is present during all drilling operations at OSO.

2.6.2 Drilling fluid shipments at the Oseberg field during drilling operations

The drilling fluid quality is of major importance regarding productivity at a drilling platform. Therefore, it is important for the drilling operators to drill with the best drilling fluid possible. When hitting new formations down hole, a new type of drilling fluid may be requested. Due to this, transportation of drilling fluid is needed. A significant number of such transportations are recorded and the amounts of drilling fluid being transported at the Oseberg field is large. As shown in Figure 12, there are large quantities of delivered OBM at Oseberg and large quantities sent back to shore for maintenance.

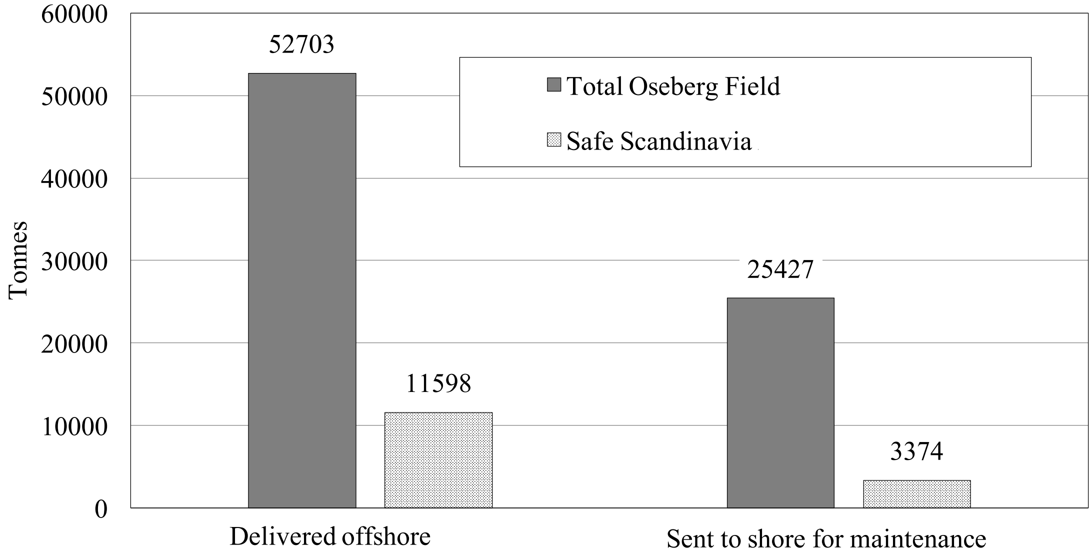

Figure 12: Recorded OBM shipments on the Oseberg Field. Grey columns represent the whole field. The dotted columns represent Safe Scandinavia. Values in tonnes.

As can be seen in Figure 12, in 2016, 52 703 metric ton OBM where delivered at platforms on the Oseberg field (delivered offshore). In addition, 25 427 tons of used OBM where sent to shore for maintenance. This means that over 48% of the OBM sent out to a platform at the Oseberg field were returned to shore for maintenance after being used.

Safe Scandinavia is a recently retrofitted semisubmersible mobile accommodation platform (TSV). This TSV is ordered to support Oseberg Øst during drilling operations. This vessel is equipped with a drilling fluid maintenance system. As can be seen in Figure 12, the rate of OBM sent back to shore for maintenance is significantly reduced compared to the entire Oseberg field. Only 29% of the OBM is now sent back to shore, 19 percentage points better than the Oseberg field in total. This vessel was discovered by the author late in the thesis period and has not been analyzed in depth. However, the maintenance system used at this TSV reduce overall transport of drilling fluids. In Figure 13, a summary of delivered and picked up bulk cargo shipments at Safe Scandinavia in 2016, is presented.

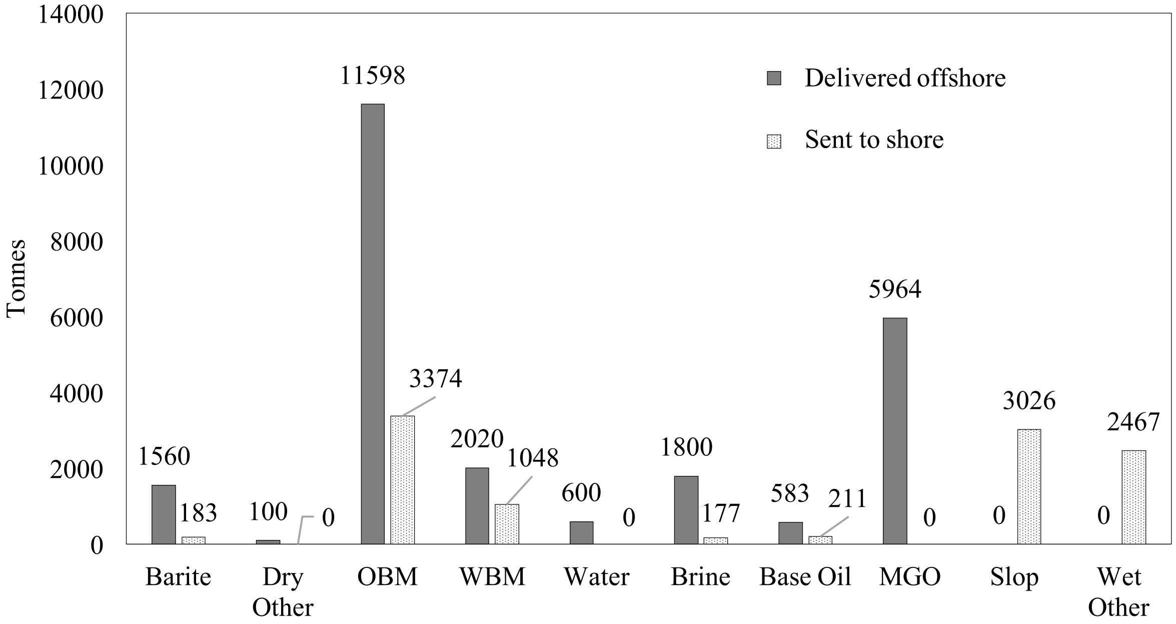

Figure 13: Delivered and picked up bulk cargo at Safe Scandinavia by dedicated storage vessels during drilling operations at Oseberg Øst.

As can be seen in Figure 13, OBM and fuel (MGO) are the most common bulk material transported. In addition, slop and other wet wastes are transported. These shipments indicate the amount of bulk materials needed during drilling fluid maintenance operations and can be used to determine the tank capacity relationship required in a drilling fluid maintenance vessel. Barite, brine, base oil, and fuel are important commodities to have available during drilling fluid maintenance. These bulk type are typical needed additives to change the characteristic of drilling fluids, as seen Chapter 2.2. In addition, there are large quantities of slop (drainage water and mixtures of liquid wastes on a platform) and other wet wastes that are returned.

Vessels are needed to ship all these bulk quantities back and forth. Looking further into the OBM shipments on the Oseberg field: In total during the 2016, there were 163 vessel trips with OBM delivered at the platforms performing drilling operations. There were also 79 trips of OBM picked up at the platforms to be shipped to shore for maintenance. The maximum recorded bulk load of OBM transported out to a platform was 967 tonnes. Maximum picked up OBM load was 813 tonnes. The average load weight delivered and picked up at the field were 252 tonnes and 278 tonnes, with standard deviation of 200 tonnes and 179 tonnes, respectively. The specific gravity SG of the OBM varies but an average of 1,4 is rater normal according to (Vik & Gullberg, 2016). OBM SG normally varies between 0,8 and 2,8. These numbers are extracted from the data provided by Vik & Gullberg (2016), Appendix A.

2.6.3 Proposed vessel route and operational profile

As presented, a common practice is to have a storage vessel (large PSV) present during drilling operations, supporting the platform with storage space. These vessels do not perform any other function other than storing drilling fluids and equipment for the platform. In order to utilize these vessels better, needed maintenance of OBM could be done when the vessel is present standby. Equipment presented in Chapter 2.4 could be installed on a vessel and perform drilling fluid maintenance. This would increase reuse and utilization of the expensive drilling fluid. Drilling fluid mixing equipment can be installed to adjust the drilling fluid characteristics so that the fluid meet required functionalities. Solids control equipment can be installed to reduce solids in the drilling fluid. Having a storage vessel with the ability to store and mix drilling fluids will reduce the need to buy new expensive drilling fluid from an onshore supplier. Vessels already being used as storage vessels handles large quantities of drilling fluids during standby operations at Oseberg, thus a potential of adding a maintenance system is present. Based on information retrieved from this chapter, a proposed vessel route at the Oseberg field for an offshore drilling fluid maintenance vessel is presented in Figure 14.

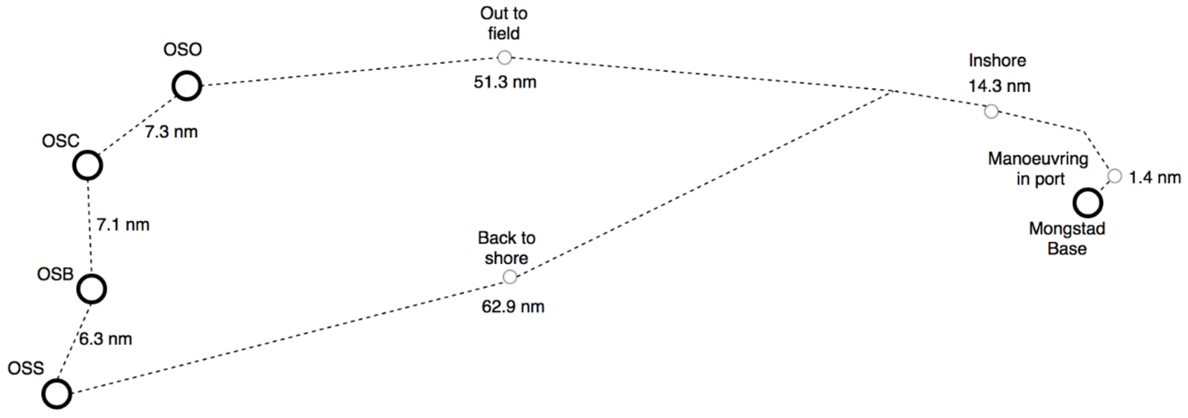

Figure 14: Sailing route and destinations at Oseberg for the vessel. Distances in nautical miles.

Mongstad onshore base is the nearest support base and is therefore the natural departure and destination port for vessels supplying platforms located in the Oseberg area. As illustrated, it is 14.3 nautical miles (nm) inshore transit plus 1.4 nm close to port maneuvering before approaching open sea and clear transit out to the field. A complete roundtrip, sailing via each platform and back to port, is approximately 166 nm long. This route is later used as basis for estimating an operational profile.

Based on meetings with Statoil Marine it is requested that the drilling fluid maintenance vessel shall operate on the field based on a 14-days roundtrip. This assumption limits the design space, as the vessel will need sufficient hydrodynamic characteristics and equipment setup. As crewmembers usually work four weeks at a time they will complete two roundtrips before a new crew takes over the operation, a 14-day long roundtrip is therefore suitable with respect to crew changes. Based on the vessel route presented in Figure 14, a preliminary operational profile can be made and later used in energy consumption estimations for the vessel. Based on the locations and distances presented in Figure 14, and the shipments of drilling fluids at the Oseberg field, an operational profile of the vessel is estimated and presented in Figure 15.

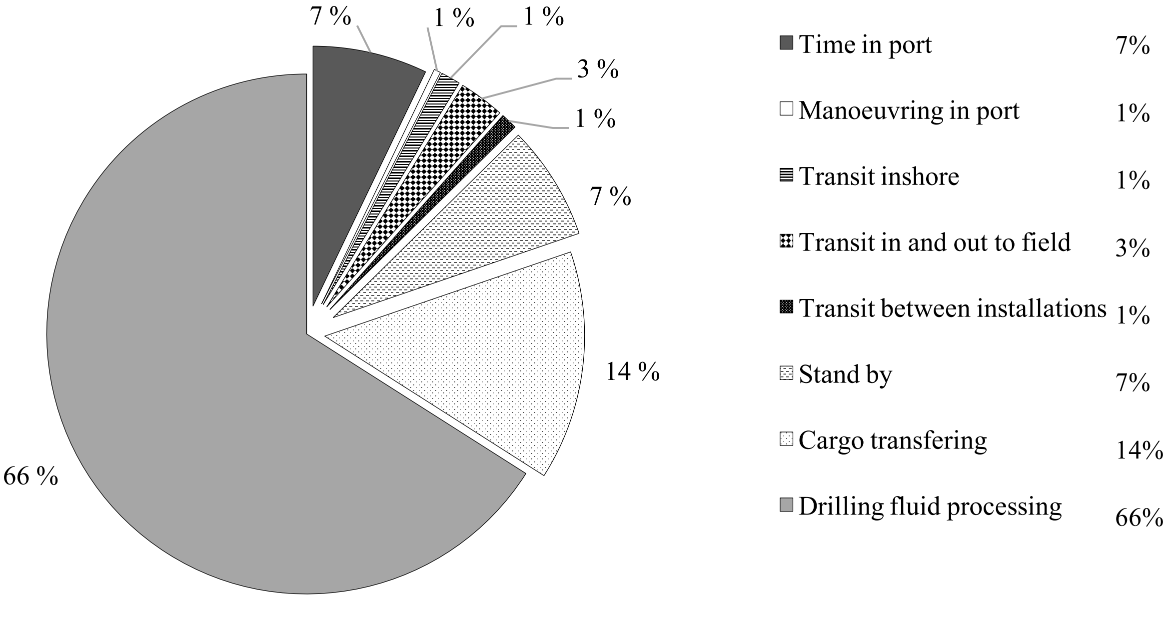

Figure 15: preliminary operational profile for the vessel design, based on the route presented above.

These percentages are based on a service speed of 12 knots (kn) in open sea transit, 7 kn when sailing inshore, and 2 kn maneuvering near port as an average. As can be seen in the figure, the vessel will operate mostly in a standby-drilling fluid processing/maintenance context and transferring cargo/drilling fluids back and forth to platforms. Time spent on drilling fluid maintenance operation is difficult to estimate due to uncertainties and is therefore assumed to be approximately 9 days. Assumed 24-hour stay each time the vessel is returning to port for cargo loading/unloading, crew change, food provisions, load fuel, cleaning of tanks and equipment, etc.

3. Design Methodologies

Looking back in history, shipbuilding and ship design has evolved from being more an art to become a science (Papanikolaou, 2014). Ships have historically been built by shipbuilders and naval architects with experience and proud traditions. The industry has developed over decades, mostly by a trial and error approach based on heuristics. As knowledge increased, the trial and error approach were gradually replaced with methods that are more practical, such as exploiting statistical data and empirical measurements from already successful designs. The ship design spiral developed by Evans (1959), presented in Figure 16, is perhaps the most known ship design methodology and the foundation for many other design methodologies.

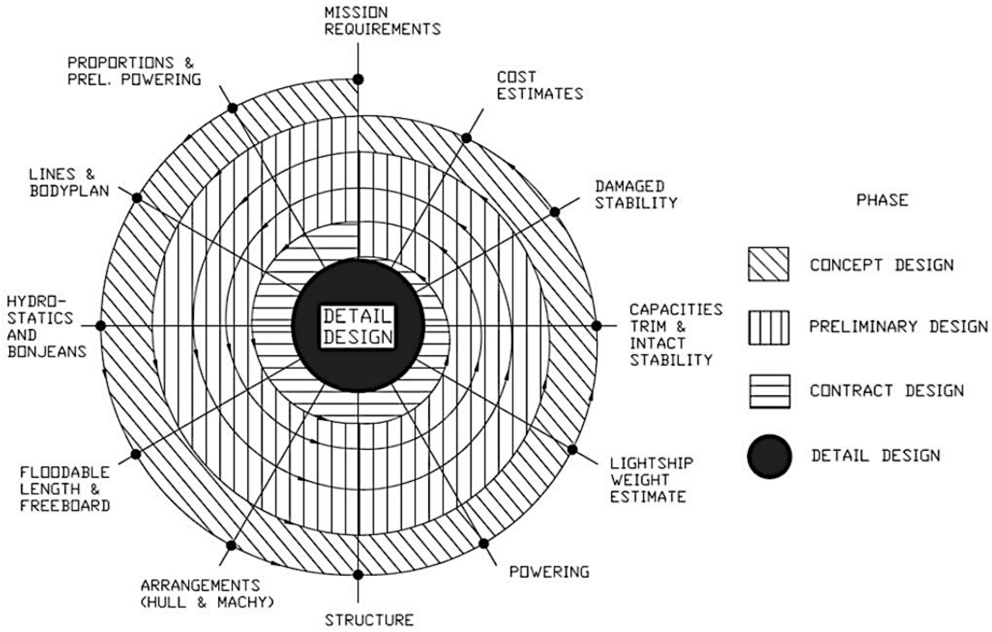

Figure 16: The ship design spiral by Evans (1959)

Evans developed this spiral to systematize the design process. It is an iterative process where the design space is limited for each step and cycle. This way you can move systematically from a vessel concept to a final vessel design. It is a well-known method but the downside of this method is that it is structured in a “design-evaluate-redesign” manner (Levander, 2012). This is problematic as the starting point of the iteration process is crucial (Erikstad & Levander, 2012). The successfulness of the design process is highly dependent on the starting point. If the designer is unlucky and start the iteration process far away from the optimal design, too much time is spent on checking and redesigning. The experience of the designer is therefore important to the successfulness of the design process (Erikstad, 2015).

It is preferred to reduce the design space early in the design process while still have enough flexibility to develop novel designs. Design methods are constantly evolving due to increased knowledge and new available technology. Much work has been done to optimize the starting point for the iteration process, so that less time is spent on unrealistic designs. Design methodologies such as set-based design, presented by Singer et al. (2009) and the system based ship design presented by Levander (2012) limits the design space early by utilizing early known information regarding the required vessel performance, and parameters from other vessels. In the set-based design methodology a set of vessel dimensions such as length, beam, and draft, are used to create all possible designs. The performance of each design is then evaluated. One can then select the best design based on wanted/required vessel performance. This method is however expensive if many dimensions are being tested (Erikstad, 2015).

The system based design, also termed system based ship design (SBSD), utilize early known information about the vessel mission, and required functions, and use this as basis for the vessel development (Levander, 2012). Here the systems required in the vessel are determined before the form of the vessel has been determined. Each system has a space demand and a specific weight that must fit inside the vessel. When these are known a hull can be built around the systems rather than designing a hull and check whether or not the systems fit inside the hull (S. S. Kristoffersen, 2014). Erikstad and Levander (2012) discuss the use of SBSD methodology used in designing offshore support vessels. The conclusion states that the method is well suitable and that a high degree of detail regarding the systems and performance of the vessel can be determined prior to the hull and general arrangement development.

State of the art research on ship design focus on shorten the time between idea and production by use of simulation, such as the VISTA project, presented in (Erikstad et al., 2015b). VISTA is a virtual sea trial tool intended to test the vessel design in different operation modes in a dynamic context, early in the design stage. This will help increasing energy efficiency, reducing risk, and increase safety of the vessel design. Current ship design methodologies such as SBSD, lack the ability to account for the complete spectrum of possible dynamic affected operation conditions. Dynamic aspects such as vessel routing, logistics, sea states, weather etc. are not considered in a realistic way. The vessel design is therefore not optimized for the real world. However, Erikstad et al. (2015b) concludes that the level of detail, simulation time, and programming skills needed in such simulation tool is substantial, making it hard to develop and use such system.

4. System Based Ship Design

SBSD is a modern design methodology that is built upon the already known design spiral by Evans (1959). The SBSD differ from Evans by reducing the number of iterations in the early design stages. Instead of shaping a hull and check whether or not the required systems fit into the hull, SBSD utilize early known information about the mission to define the systems first. When the systems required for the mission is stated, in terms of space and weight, one can start forming the hull around the systems instead. By doing this, one can limit the design space earlier in the design stage and thus save time and money. In addition, instead of creating designs from scratch, the method utilizes information about already built vessels to faster determine the principal particulars of the design. The SBSD approach can be illustrated as in Figure 17.

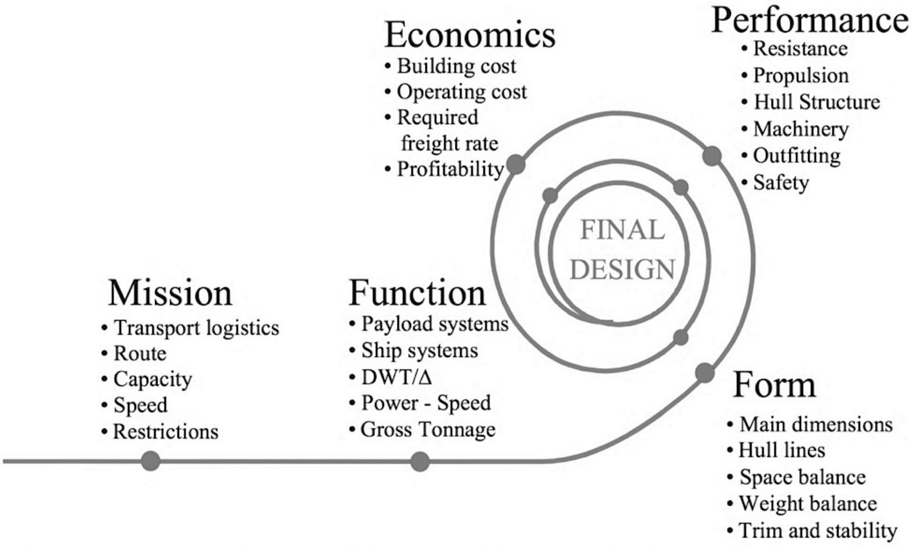

Figure 17: The system based ship design process. Source: Levander (2012)

The method is easy to understand and follow. In this thesis, the mission/logistic is first evaluated. The vessel logistics are one of the most important factors when designing a vessel as this will influence the main systems onboard. The vessel route, capacity, speed, and restrictions are stated based on the stakeholders need. The vessel logistics/mission serves as an input to upcoming steps in the design process and will, in this thesis, determine what kind of functions/systems required by the vessel.

Vessel movement and bulk cargo shipments on the Oseberg field are analyzed to discover potential areas to increase utilization of drilling fluids on the field. In addition, drilling fluid maintenance equipment is instigated to identify equipment that increase the quality of drilling fluids. The vessel mission is stated based on these findings.

Based on the vessel mission, a set of required functions are determined and a functional breakdown structure is made. The functional breakdown structure display all systems required in the vessel and based on this, a system summary of all required systems is made. These systems are found by utilizing information on similar vessels already built and the stated mission for the vessel. The space requirements and weight of each system defines the required volume and displacement on the vessel.

When all systems are found, volumes and weights are estimated, the vessel take form by building a hull around the systems. Some of the systems are required to fit into the hull, other systems can be placed in the deckhouse. The hull form is made based on coefficients found in already built vessels. When the hull and deckhouse are developed, the main dimensions for the vessel are found and further used to develop a 3D model of the vessel in DELFTship. The hull lines are then exported from DELFTship and imported in AutoCAD to draw the general arrangement of the vessel.

When knowing the form and weight balance in the vessel, performance of the vessel is estimated. Vessel stability estimations are done using the loading condition tool in DELFTship, resistance and propulsion calculations are done by hand using Guldhammer/Harvalds method and Bp −diagrams respectively. Installed power are estimated based on propulsion requirements and operational profiles based on the vessel mission.

5. Design of an Offshore Drilling Fluid Maintenance Vessel

From the literature study, a vessel concept idea emerges. The vessel is intended to assist or replace current dedicated storage PSVs during drilling operations. Large quantities of bulk supplies are needed during drilling operations. Often, delivery of these bulk supplies deviates from the originally planned supplies, due to change orders from drilling operators. In addition, deck space is limited on most drilling platforms. Hence, there is a need for a vessel that can operate at site during drilling operations with the ability to perform drilling fluid maintenance, especially OBM, and storage. About 50% of the delivered OBM to a drilling operation are sent back to shore for maintenance. Performing more of this maintenance offshore saves transportation, maintenance cost onshore, and procurement of new drilling fluid. Based on experience from Safe Scandinavia, it is believed that this vessel will contribute to a reduction of overall use of vessel transport during drilling operations, thus contributing to an overall cost reduction of offshore drilling operations.

5.1 Vessel Concept

Today the normal supply chain of OBM is relative simple. The OBM is premade onshore and transported out to a platform for usage. At the platform, additives and solids control equipment are used to keep the OBM in right condition. After use, the OBM is transported back to shore where it is processed and rebuilt to a new OBM that can be used in a new drilling operation, as illustrated in the upper part of Figure 18. A vessel can be used to perform OBM maintenance instead of transporting the OBM to shore for the same treatment, as illustrated in the lower part of the same figure. Dedicated storage vessels (presented in Chapter 2.6) can be used to perform these functions if installed with the appropriate equipment and tank design.

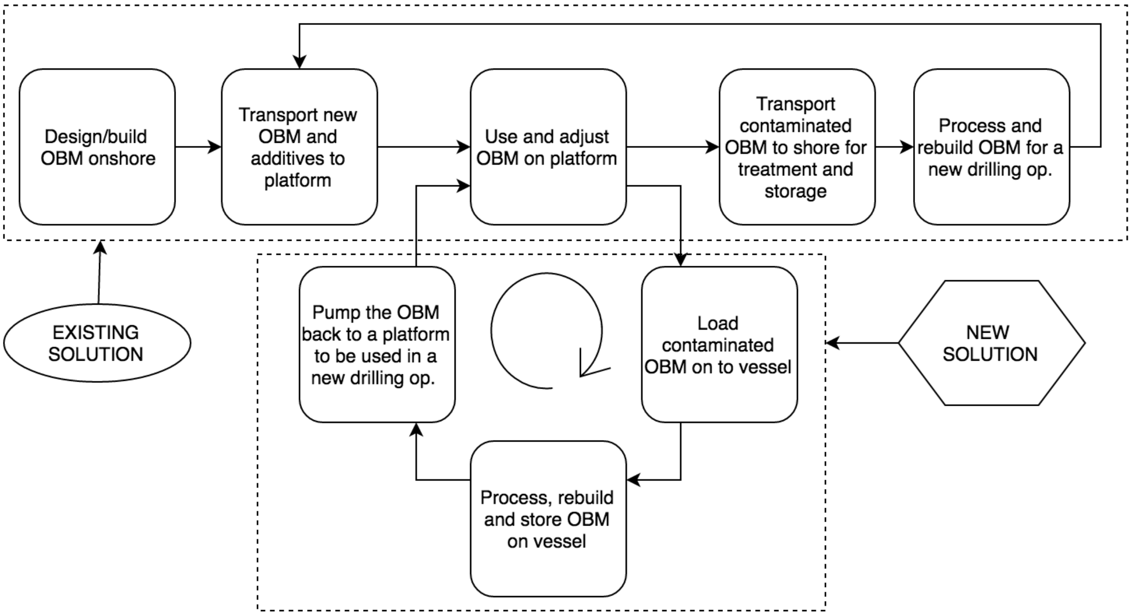

Figure 18: Drilling fluid maintenance vessel concept. The existing solution is illustrated on top and the new concept on bottom.

The vessel concept is as follows: After the drilling fluid is used on a platform, the drilling fluid is pumped over to the vessel where a drilling fluid maintenance system is used to increase the quality of the drilling fluid. The maintenance system must therefore consist of equipment that can separate out unwanted particles, and equipment that can add additives to the drilling fluid to meet required functions. In addition, dedicated storage tanks for the drilling fluid must be available onboard. This system is further explained in the following chapter.

5.2 Vessel Functions

The main function to be done onboard the vessel is to perform drilling fluid maintenance in a more efficient way and is based on the simple concept presented in Figure 19. The concept is to receive contaminated drilling fluid, perform a maintenance process and then deliver "new" drilling fluid to a new drilling operation.

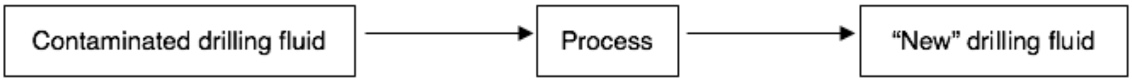

Figure 19: The main function to be performed offshore by the vessel.

Instead of transporting the drilling fluid all the way back to shore for maintenance, the maintenance can be done offshore. The drilling fluid maintenance system is a system that is supported by several under functions that supports the overall goal of reusing drilling fluids more efficiently. A complete list of needed functions and systems in the vessel is presented in Figure 20.

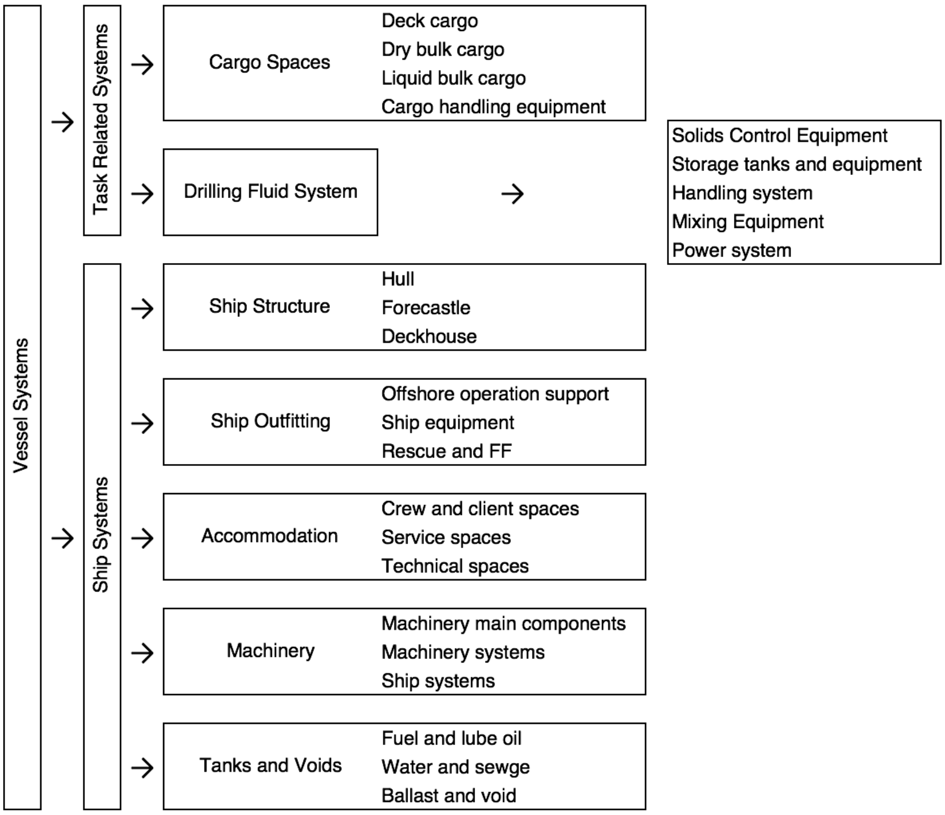

Figure 20: Vessel systems and functions required to perform the mission task of performing drilling fluid maintenance. Source: (Windsland, 2016)

Presumably, this is how the vessel appears to look like when it is done, but this is not necessary true. Depending on the size of the primary function for the vessel, additional functions may be included in the design. Relevant functions such as slop water treatment could have been highly relevant to install on the vessel, but is not allocated time to investigate in this thesis. Based on form, performance and economic feasibility of the vessel, some functions may be discarded or some may be added in the final design. However, the main function of the vessel is to be able to perform drilling fluid maintenance, thus proper equipment must be installed. This main function is therefore explained in more depth. As illustrated in Figure 20, the vessel shall be able to handle, clean, store and mix additives into drilling fluids. This "maintenance" system is better explained in the schematic drawing presented in Figure 21.

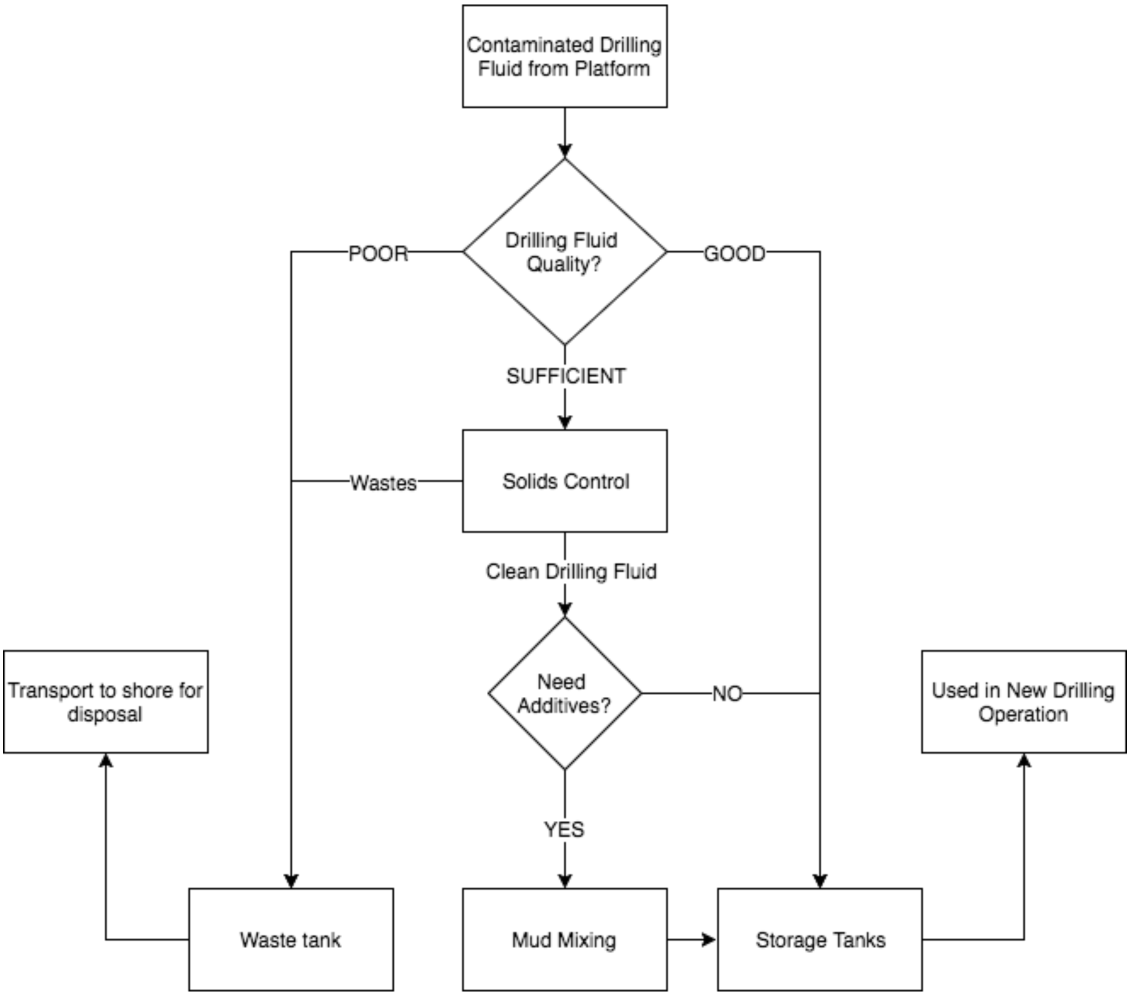

Figure 21: Schematic drawing of the drilling fluid maintenance system

As can be seen in Figure 21, contaminated drilling fluid from a platform has to be handled onboard the vessel. When the contaminated drilling fluid enters the vessel the quality of the drilling fluid determines what is happening. If the drilling fluid is too damaged and quality is poor, the drilling fluid is sent straight to the waste tanks. If the quality is good and need no maintenance, the fluid is sent straight to a storing tank. If the drilling fluid quality is sufficiently good, it is sent to the solids control equipment for maintenance. Wastes generated from the solids control equipment are sent to the waste tank. The cleaned drilling fluid is then sent to a mud-mixing unit were additives are mixed into the drilling fluid, if needed. If not, the drilling fluid is sent to a storage tank. After being treated by the mud-mixing unit, the drilling fluid is sent to storage tanks as well. Drilling fluids stored in the storage tanks are further used in new drilling operations, and wastes are sent back to shore for disposal.

It is necessary to install piping and pumping systems so that the drilling fluid can move from point A to B inside the vessel. Drilling fluids are stored in dedicated multiuse tanks. These tanks must be equipped with a system that keeps drilling fluid additives from settling on the bottom of the tank. When the drilling fluid is transferred back to a drilling platform, pumps must be used in order to move the fluid from the tanks and up to the drilling platform deck/tanks. The entire handling system require much space, support, and power, in addition to the ship systems onboard the vessel.

5.3 Vessel Form and Main Dimensions Development

The vessel operator (Statoil Marine) requested a vessel that has similar size as the largest PSVs operating in the North Sea supply vessel market today. This is because such vessels already operate as dedicated storage vessels. Parametric analysis done in Windsland (2016) shows that these vessels are typically 88-95 meters long (Lpp) and are relatively newly built, under 10 years old. These vessels are therefore used as guidelines (reference vessels) for the new vessel design. And is used for comparison throughout the entire design process. Vessel parameters with upper and lower bounds for the reference vessels are presented in Table 6. The complete list of vessels used in this analysis is presented in Appendix C.

Table 6: Output from the parametric analysis of main dimensions for larger sized PSVs in the market done in (Windsland, 2016).

Parameter	Lower bound		Upper bound	SI-unit
GT	4500	-	5500	-
GV	15900	-	19300	m^3
DWT at max draught	4800	-	6400	[mt]
Deck area	900	-	1175	[m^2]
Deck cargo weight	2500	-	3500	[mt]
LOA	88	-	95	[m]
Breadth	19	-	22	[m]
Draught max	6,5	-	7,3	[m]
Displacement at max draught	8500	-	10000	[mt]
LWT/GV	0,18	-	0,20	[mt/m^3]

5.3.1 Space and weight balance

From the functional breakdown of the vessel presented in Figure 20, a system summary can be developed and used to define the space needed inside the vessel. Five major systems are needed inside the vessel; machinery, tanks, cargo spaces, ship outfitting (including drilling fluid maintenance) and accommodation. Through use of the SBSD compendium, required space for each system is calculated and a system summary presented. Each of these systems are calculated in detail in and presented in Appendix D. During this process checking against the mission requirements and reference vessels are essential to develop a good design. The vessel system summary is presented in Figure 22. A more detailed presentation of the calculations done is presented in Appendix E.

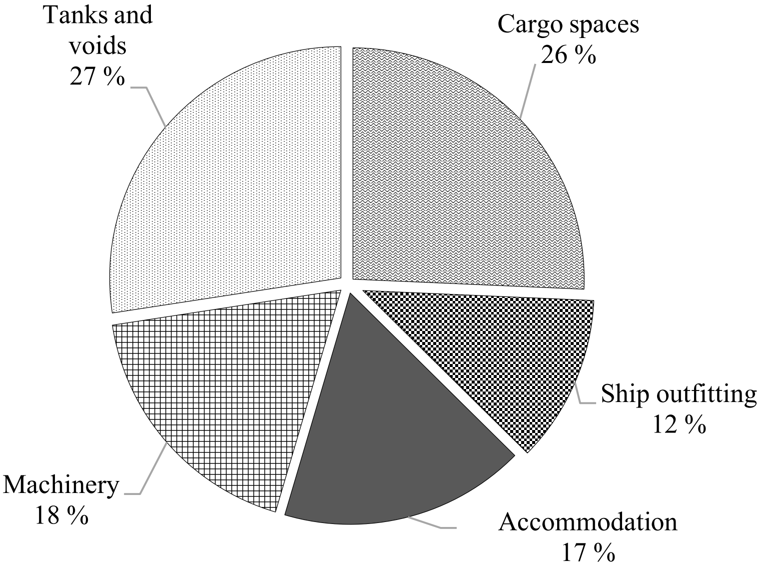

Figure 22: System summary, volume distribution in the vessel based on each system.

The system summary shows that each system require space in the vessel, and here the distribution of each system compared to the vessel in total is within normal values. An important factor used to guide the vessel design development is the number of passenger/crew capacity. The vessel is assumed to be operated much like a PSV and therefore the vessel is designed for the same number of persons as in a PSV of similar size (length between 88-95 meter). These PSVs normally have 25 beds where 13 of these are in single cabins for the crew, and additional 12 beds in double cabins for clients. Thus there are plenty of capacity to accommodate drilling fluid engineers to ensure proper operation of the maintenance system. Based on interview with a mud engineer, no more than 2-3 mud engineers working on shifts, are needed for this type of operation. Accommodation capacity determine required space for common spaces such as day rooms, gym, change room, mess room, service facilities, and cabin space etc. In addition, to accommodation capacity, the operational profile and energy demand determine the required space for machinery, tank capacities, and ship outfitting in the vessel. The cargo spaces (payload) are determined based on the mission to be performed and the most important parameter to design against as this is the "moneymaker" system onboard. Early in the process, assumptions are usually made and then later changed if not correct.

The sum of the volumes in the system summary defines the vessel gross tonnage and used to create a geometric definition of the vessel. By comparing the gross tonnage of the vessel with already built OSVs, weight groups of the vessel can be estimated. Estimated weight groups for the vessel are presented in Figure 23. The weight group calculations are presented in Appendix F, in more detail.

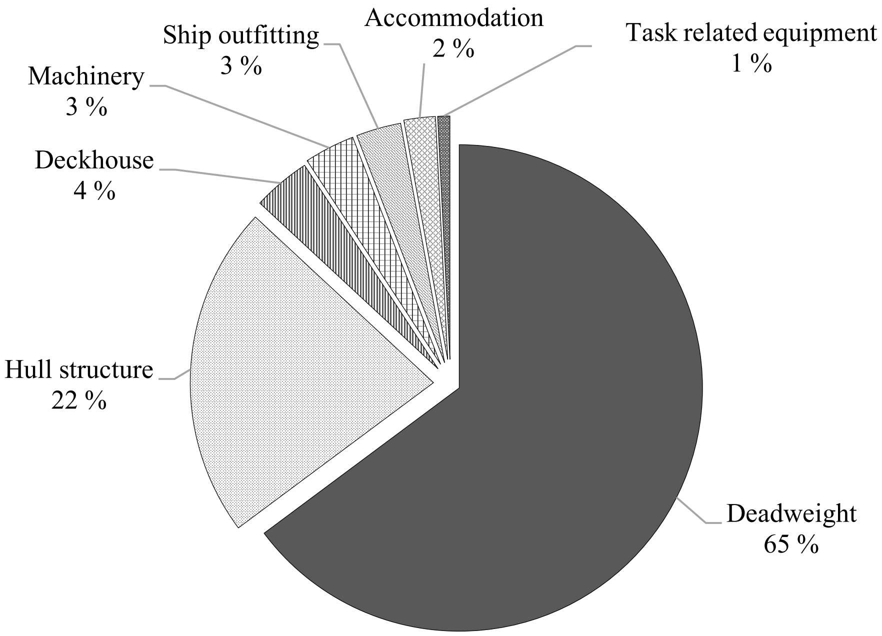

Figure 23: Vessel weight group estimations. LWT = 3349 tonnes. DWT = 6170 tonnes.

The combination of system summary and vessel weight groups now gives an estimation of the vessel lightweight and deadweight tonnage, which is $3349\,tonnes$ and $6170\,tonnes$ respectively. Important design criteria's for OSVs are the $DWT/displacement$ and $LWT\ /\ GV$ ratio. Here the ratio is: $DWT/Displacement\ = 0{,}65$ and $LWT/GV = 0{,}19$. These are within the recommended range for these type of vessels and the design process can proceed. Further discussion of these ratios are presented in the Chapter 7. The weight and internal volume of the vessel are now estimated and now we basically have all we need to make a hull. At this stage, one can also estimate the vessel intact stability. This is however done later in Chapter 5.5.3. Following, a building cost estimate should be done to check financial feasibility of the design. This is not done in this thesis due to time limitation.

5.3.2 Hull form approximation

The hull development is based on vessel coefficients displayed on the right hand side in Table 7, and has been developed by utilizing the SBSD compendium procedure and parameters from previously built OSVs, the system summary from Figure 22, and weight estimations from Figure 23.

Table 7: Selected vessel main dimensions. Based on service speed (12kn) and draught = 6,9m

Selected main dimensions			**Coeffisients**		
Length OA :	91,5	m	Slenderness:	LWL / ▽^(1/3) :	4,17
Length WL :	88,2	m			at Tmax
Length PP :	85,6	m		LPP/B :	4,18
Breadth Hull :	20,5	m		B/T :	2,97
Breadth WL :	20,5	m	Froudes no	Fn :	0,21
Draught Max	6,9	m		CB :	0,77
Depth to Main Deck	8,5	m			
Freeboard :	2,8	m	Waterplane c.	CW :	0,90
Depth to Upper Deck :	11,5	m	Midship c.	CM :	0,99
Weight Displacement max:	9560	ton	Prismatic c.	CP :	0,78
Volume Displacement max:	9327	m3			

The main dimensions (left-hand side in Table 7) are found based on gross tonnage from the system summary and weights/displacement from the weight estimation. The geometric definition (volume and areas in each deck of the vessel) takes form by evaluating the block (C_B) and waterplane area coefficient (C_W) at different drafts of the vessel. C_B is found by evaluating Froude's number and compare with other designs, and C_W is a function of C_B. C_W is useful for when developing deck area for each deck and C_B is useful for when developing the volume contained in each deck. What can be difficult during this hull approximation is to determine what systems that are going to take place in the vessel hull and what systems to take place in the deckhouse. This can be solved by comparing already built vessels, and has been done in this thesis. Exploited vessels have mainly been Far Solitaire, Far Searcher and Juanita, due to their tank arrangement and drilling fluid capacity. The complete geometric definition of the vessel is presented in Table 8.

Table 8: Geometric definition of each deck in the vessel. Used to define the main dimensions presented in the table above.

DECK AREAS AND VOLUMES IN THE HULL							
Deck Name:	Height above BL [m]	Deck height [m]	Deck area [m2]	Open Area [m2]	System Area %	System Area [m2]	System volume [m3]
Double Bottom	0	1,4	633	-	-	-	1342
Tank Top	1,4	4	1051	-	0,3	347	5208
2nd Deck	5,4	3,1	1529	-	0,5	818	4577
Main Deck	8,5			-			
TOTAL HULL	8,5	-	-	-		1164	11127

DECK AREAS AND VOLUMES ABOVE MAIN DECK							
Deck Name:	Height above BL [m]	Deck height [m]	Deck area [m2]	Open Area [m2]	System Area %	System Area [m2]	System volume [m3]
Main Deck	8,5	3	1678	945	1	733	2200
A-Deck	11,5	2,9	638	165	0,7	331	960
B-Deck	14,4	2,9	615	10	0,7	424	1228
C-Deck	17,3	2,9	446	134	1	312	905
D-Deck	20,2	2,9	308	100	1	208	602
Bridge	23,1	3,15	240	0	1	240	756
Top of Bridge	26,25	2	42	0	0	0	0
Funnel	26,25						0
TOTAL Deckhouses				1354		2248	6651

TOTAL HULL AND DECKHOUSE	Geometric Definition	4766	17778
	System Summary	4681	17215

The “Geometric Definition and “System Summary” should be equal to each other. In this case, there is a difference of 563 m3. This error is made because of adjustments made in the system summary during the thesis period after the 3D model and general arrangement (GA) drawings were made. Due to lack of time these corrections has not been adjusted for in the “Geometric Definition”. This will result in a source of error and should been adjusted in later iteration steps. The geometric definition of the vessel serves as input for development of a 3D model of the vessel.

5.3.3 Development of a 3D-model in DELFTship

A 3D model is useful when developing a vessel design. In the model, one can test different layout proposals relatively quickly and test whether or not a design is satisfying. In this thesis, a 3D-model is made in DELFTship and the hull lines created here are later imported into AutoCAD for creating GA drawings. The 3D model of the vessel design is presented in Figure 24. This design is later used for performance estimations in Chapter 5.5

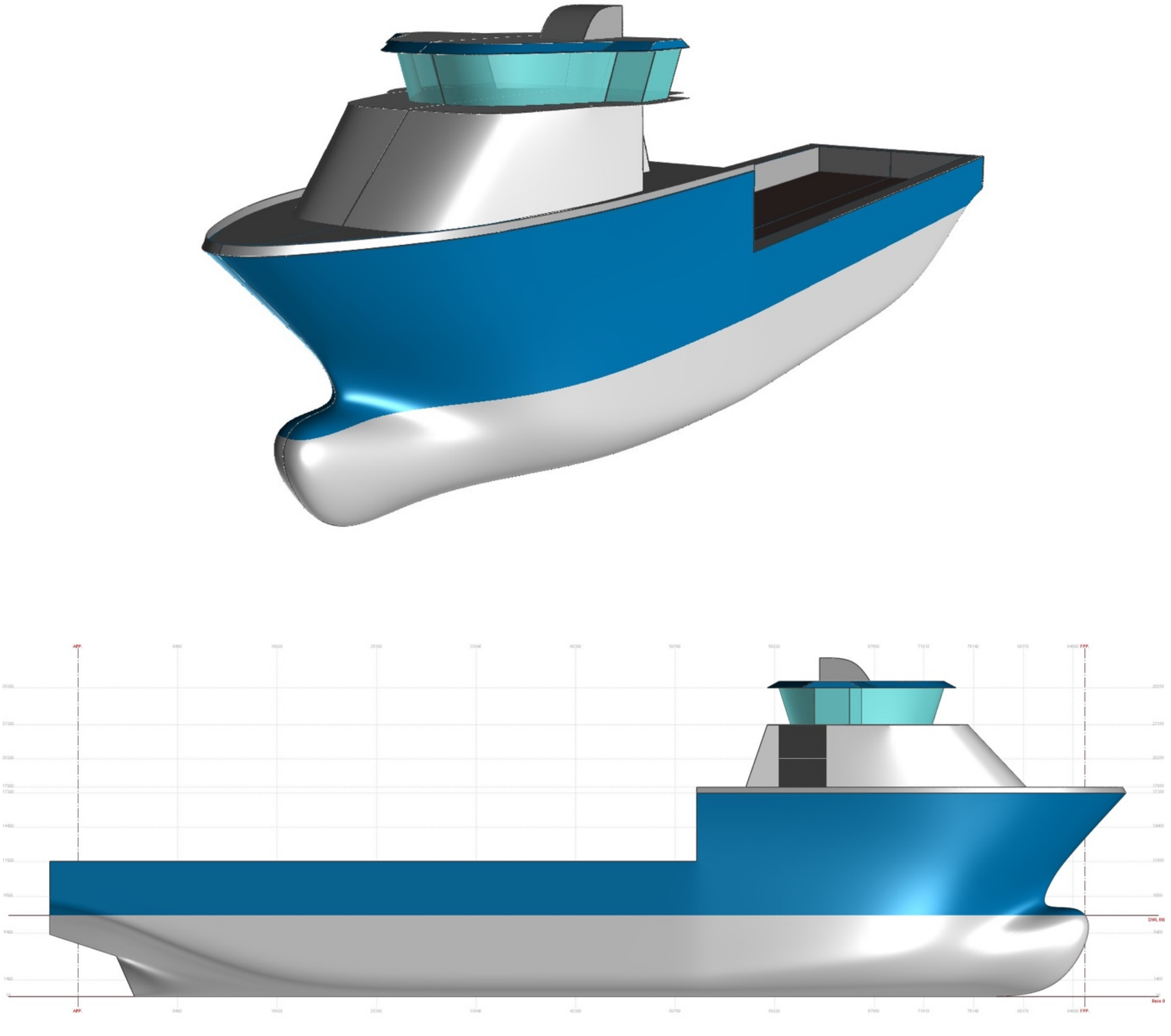

Figure 24: 3D model of the vessel made in DELFTship.

This 3D-model is made based on results presented in Table 7 and Table 8. The hull form is made by iterating between the C_B, C_P, and C_W, coefficients and vessel displacement presented in the vessel main dimensions. A bulbous bow is selected for this design due to the extent use in the industry. The bulbous bow reduce pitch in rough sea and improves the water inflow angle.

No hydrodynamic analysis regarding destructive wave pattern is done and should be done to ensure that the bulbous bow does not increase the hull resistance. As for now, it is only an extension of the hull, increasing the Froude's number and slenderness ratio.

It is time consuming to iterate between the coefficients and displacement. To save time, the iteration process is stopped before finding exactly the same coefficients values in the main dimensions. Optimally, more time should be used finding equal values. Main dimension coefficients from the iteration process in DELFTship versus the originally developed coefficient values, are presented in Table 9.

Table 9: Main dimension coefficients originally vs. DELFTship.

	Volumedepl. [m3]	**Weightdepl. [ton]**	**C_B**	**C_P**	**C_W**
Originally	9327	9560	0,77	0,78	0,90
DELFTship	9391	9626	0,75	0,76	0,89

The difference between originally developed values and DELFTship values result in marginal changes in the design and assumed to be sufficiently good in order to continue. However, the weight and volume displacement are larger in the DELFTship estimates but the coefficients are smaller, and this does not add up. The originally estimated values are based on Lpp and further investigation of the calculations done in DELFTship shows that DELFTship uses length at waterline (Lwl) as basis for displacement calculations. Thus the values in DELFTship are higher than one could expect compared to using Lpp. This was found late in the thesis process and thus not assessed any further.

5.4 General Arrangement

All systems required to perform the mission must be placed inside the vessel. The GA drawings illustrates how the vessel looks like inside and are therefore developed. The GA presents the location of main bulkheads, main equipment, deck, rooms within each deck etc. The GA is the most used vessel drawing and used as a reference for the other drawings. As stated above, the hull lines from the 3D-model are imported to AutoCAD to make the GA drawings. Due to the size (A0 format) and level of details in the GA drawings it is inconvenient to present the complete drawing in this chapter, some parts of the drawings are, on the other hand, presented. A complete collection of GA drawings for the vessel is presented in Appendix G. A full scale A0 drawing is attached in the back of this thesis.

5.4.1 Drilling fluid maintenance and tank arrangement

The primary function for the vessel is to perform drilling fluid maintenance. Contaminated drilling fluid enters the vessel through cargo hoses from the drilling platform. These hoses are connected to the vessel by hose connectors located in the cargo coamings between the Main Deck and A-Deck, right above the multiuse liquid mud (LM) tanks, which are located on 2nd Deck. The LM tanks are where drilling fluids are stored. From the hose connectors, piping inside the vessel ensures that the contaminated drilling fluid ends up in the preferred tank or entering the drilling fluid maintenance system. A section of the Tank Top Deck is presented in Figure 25 to illustrate location of the solids control equipment and LM tanks.

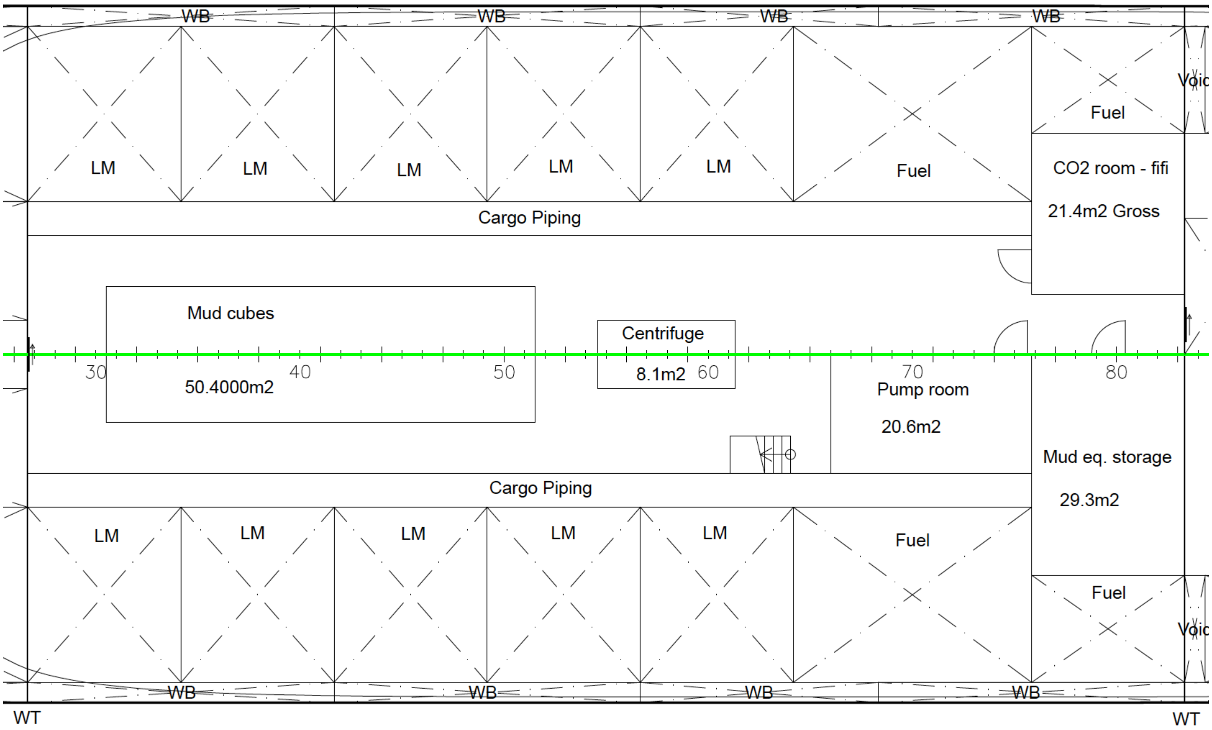

Figure 25 : Section of the Tank Top Deck on the vessel, showing the solids control system layout.

Several LM tanks are placed in the vessel to better control the free surface effect of the liquid cargo, and to increase flexibility when performing drilling fluid maintenance. The drilling fluids delivered to the vessel have various density and there is large variation in the volumes handled. Therefore, several water ballast tanks are installed in the vessel to adjust the trim and heeling angle. The total water ballast capacity is $1690\ m^3$. The total capacity of the LM tanks are $1612\ m^3$ and the intension of the tank design is to be able to use the same tanks for storing clean- and contaminated drilling fluids at the same time. Wastes from the treatment process are intended to be stored in the same tanks. All separated from each other of course. When using the same tanks for multiple products, cleaning is needed. Thus cleaning of the LM tanks is planned when the vessel is in port.

The LM tank capacity is selected by comparing tank design with the specialized drilling fluid supply vessel, “Far Solitaire”. In addition, an assumption that the vessel should be able to handle two average delivered loads and two average picked up loads of drilling fluids (based on numbers from Oseberg presented in chapter 2.6.2). This equals a capacity of 1325 m3 with a SG of 0,8. Further, 275 m3 additional space for wastes is added and thus total capacity is $1600\ m^3$. In DELFTship, this volume is found to be $1612\ m^3$ for simplicity during modelling. With a total of ten tanks, each tank has a capacity of approximately $161{,}3m^3$.

The area labeled “Mud cubes” denotes the compact solids control units, explained previously. Inside this area three compact solids control units are placed. Three units are assumed enough to make sure that the drilling fluid is sufficiently treated. This assumption is based on inputs from solids control equipment manufacturers. Additionally, it is installed a centrifuge to filter out low gravity solids that the three compact units does not manage to filter out. The distances between mixing unit, solids control (mud cubes and centrifuge) equipment, and the tanks are short so that the energy needed to move the fluid can be minimized. Further, a section of the 2nd Deck on the vessel is presented in Figure 26, showing the mud mixing system and LM tanks.

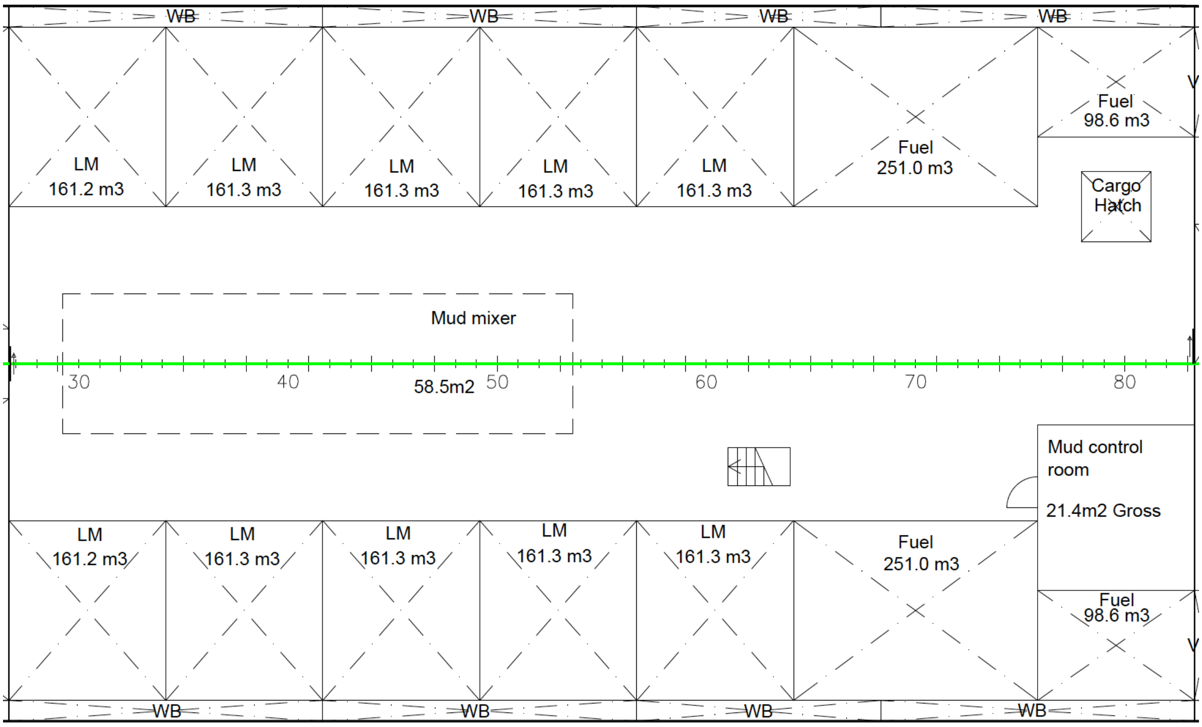

Figure 26: Section of the 2nd Deck on the vessel, showing the mud mixing system layout.

The mud-mixing unit is placed right above the solids control system. Adding substances to the drilling fluid is much easier from the top and down, instead of adding substances to the bottom of the tank for then to circulate them up in the fluid. Solids control equipment is placed below the mud-mixing unit because solids accumulate at the bottom of the tanks. And therefore easier to remove. Inside the marked area for mud-mixing equipment there are dedicated storage space for drilling fluid additives such as bentonite and barite. Due to the frequent need of diluting drilling fluids, base oil tanks are installed aft in the vessel near the mixing unit with a total capacity of $910\, m^3$, these tanks can also be used to store fuel oil and low flashpoint liquids (LFL). Base oil is used to dilute drilling fluids. Fresh water tanks and fuel oil tanks have a capacity of $1120\, m^3$ and $700\, m^3$ respectively. In addition, there are $485\, m^3$ in void spaces and cofferdams. The tank capacities here are based on delivered bulk cargo at Safe Scandinavia and reference vessel parameters from (Windsland, 2016). Se Appendix M and N for detailed tank arrangement and capacities in the vessel. A 3D overview of the tank arrangement is presented in Figure 27.

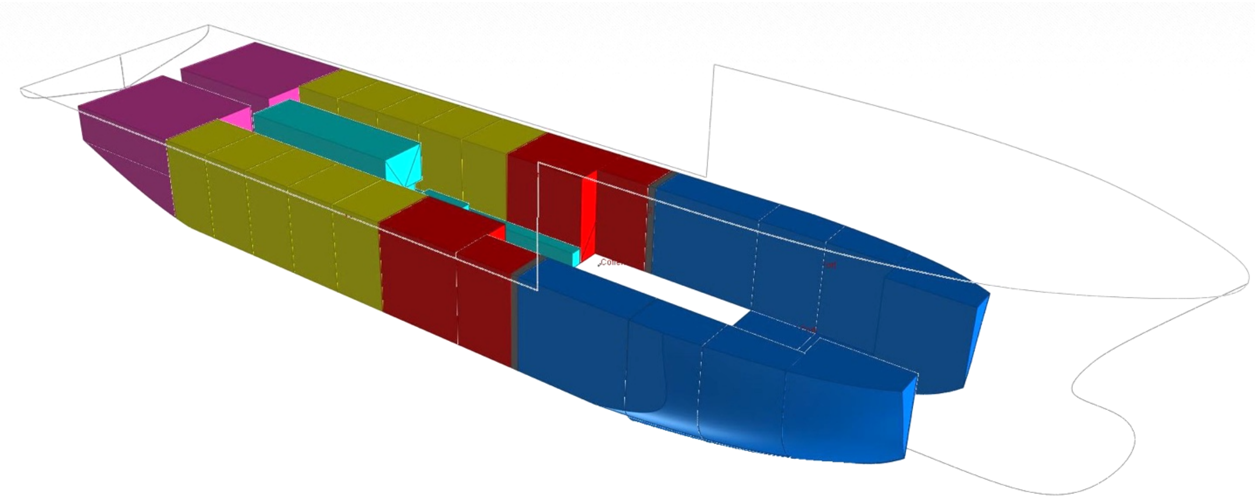

Figure 27: 3D overview of the tank arrangement, excluding water ballast tanks. (Pink = base oil, yellow = liquid mud, red = fuel oil, blue = fresh water, green = drilling fluid handling system).

A 3D model of the tank system better illustrates how the tank layout turns out during the design process. In this thesis, a 3D model has been of great importance when allocating required tank capacities in the vessel. Compared to a 2D drawing, a 3D model better illustrates curved faces and areas and thus faster to use in allocating volumes in the vessel.

5.4.2 Vertical distribution of deck areas

In total, the vessel consists of eight decks plus a deck on top of the bridge. The deck areas are organized roughly as follows: The main machinery, solids control equipment, and thrusters are located at the Tank Top Deck. The 2nd Deck is where the mud-mixing unit, engine shop, and mud control room are located. The mud control room is used to monitor the drilling fluid maintenance system and to control the drilling fluid mixing. On the Main Deck, ship service facilities such as hospital, laundry, gym and incinerator plant is located to free up space for cabins higher up in the ship. Engine control room is also located here. A-Deck is used for client cabins, which are installed with two beds per cabin. Paint shop, emergency generator, and auxiliary/harbor generator are also located here. Day room, mess and galley are located at the B-Deck. This is the deck best suitable for comfort as it is larger than the other decks in the deckhouse and still located relatively high above the sea level. Comfort is important to the crew and clients living onboard the vessel for several weeks. The vessel crew cabins are located on the C-Deck and officer cabins are located at D-Deck. All cabins are placed such that each has a window. Between the D-Deck and Bridge-Deck, a technical floor is installed for better access to cables. Vertical distribution of deck areas are presented in Figure 28. See complete attached GA for more details.

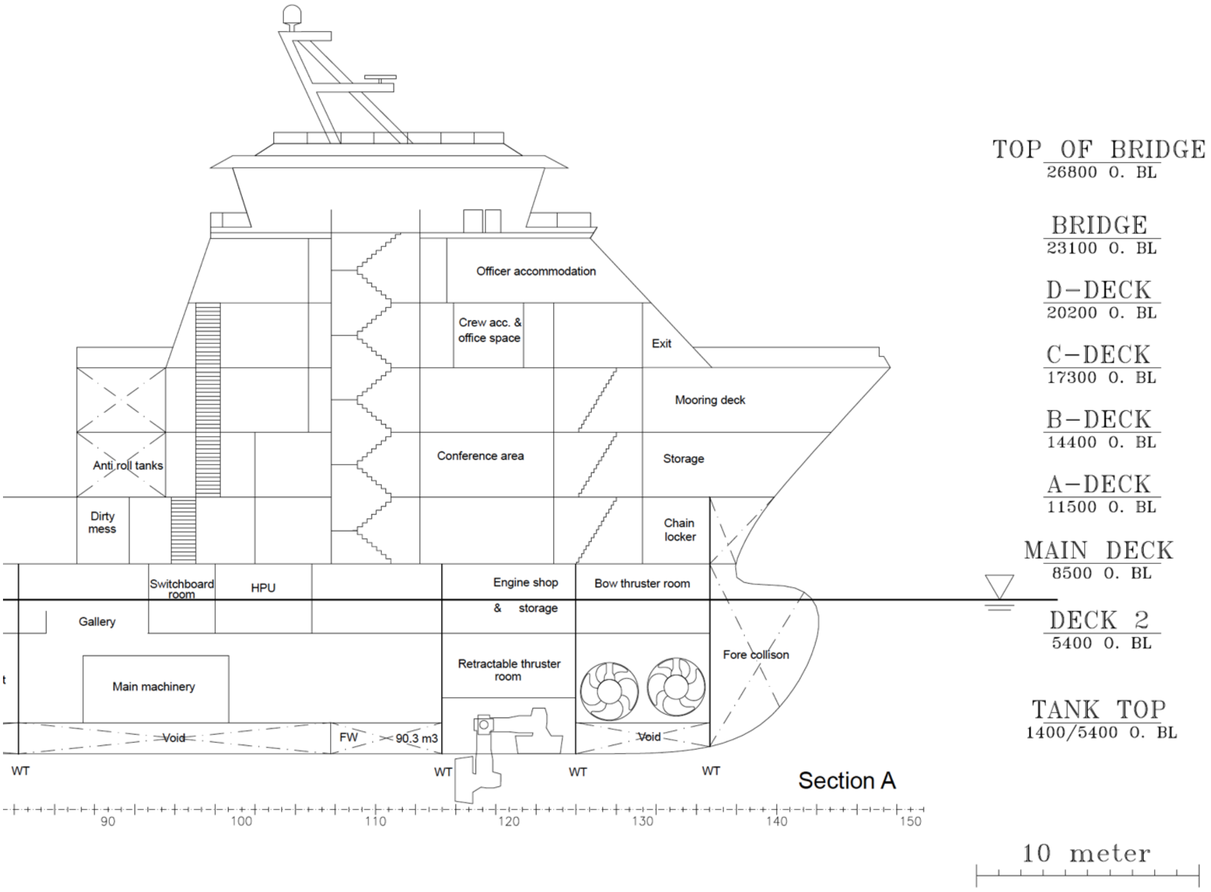

Figure 28: Section view of the vessel deckhouse. Vertical distribution of decks.

5.5 Vessel Performance Prediction

In this chapter the main performance indicators of the vessel is presented and discussed. According to the SBSD approach, there should be an evaluation of the performance of the vessel in terms of resistance and propulsion calculations, which will help deciding the needed machinery installed. The operational profile of the vessel should also be evaluated, and from there, a total list of power demand will determine the total installed machinery. In addition, there should have been an evaluation of the vessel damage stability and safety, outfitting, and structure analysis; this however, has not been carried out in this thesis due to time limitations. First, the resistance and propulsion characteristics are evaluated; later the operational profile is discussed. In addition, four loading conditions are tested to determine the intact stability of the vessel when loaded with cargo.

5.5.1 Resistance

It is necessary to ensure sufficient propulsion power compared to the total resistance of the vessel moving forward in the water. Simple calculations regarding resistance and propulsion are done using the Guldhammer/Harvalds (GH) method from the compendium used in "Marin Teknikk Grunnlag" (Amdahl et al., 2013). DELFTship, used to "form" the vessel, also provide resistance estimations of the vessel but the method used is not familiar to the author and therefore GH is used to predict the resistance. The resistance calculation is further explained in Appendix H. Results from the resistance calculations are presented in Table 10.

Table 10: Resistance from GH method and required breaking power/ engine size.

Vessel speed, V	**Total resistance of the hull, R_T**	**Azipull thruster resistance, $R_{azipull}$**
12 knots	200,6 kN	36,0 kN
14 knots	371,5 kN	48,9 kN

By using the GH method, the total resistance (R_T) values can normally be considered pessimistic. This means that the resistance of the hull may be too high. The calculations show that in 12 knots (service speed) and 14 knots the required thrust for the vessel is $200{,}6\ kN$ and $371{,}5\ kN$ respectively. These values are based on the vessel hull. Increased resistance due to the azipull thrusters must also be taken into consideration.

The vessel is assumed equipped with two azipull propellers powered by a diesel electric generator set. Diesel electric (DE) system provides more flexibility in the arrangement. The vessel has to be efficient in several operating modes and the flexibility of using DE system makes it possible to split the power between different equipment in different operating conditions. For instance, the system can split power when operating at dynamic positioning and perform drilling fluid maintenance. When the vessel is at transit between locations, the same system can be used for propulsion. By combining azipull thrusters and DE system more space in the aft of the hull can be used to ensure a better design on the drilling fluid maintenance system, as there will be no shaft-lines running through the large parts of the hull.

Azipull thrusters are more frequently used by PSVs. The azipull system combines good maneuverability (especially in low speed) and station keeping abilities with more simplified geometry in the aft of the vessel, resulting in a potential more optimized hull geometry and lower steel building cost (Rolls-Royce, 2017).

As can be seen in Table 10, resistance due to the presence of the azipull bodies when traveling in 12 and 14 knots are $36{,}0\ kN$ and $48{,}9\ kN$ respectively. The calculation of these values are rather intricate. As the complexity of the flow behind the vessel is highly unknown at this stage of design these values is highly uncertain and based on several assumptions. A detailed procedure of the azipull resistance calculations is done and can be found in Appendix H.

Azimuthing thrusters are in general less effective than conventional propeller setup. This is mainly due to the introduced drag from the propeller housing (body). This will also effect the propeller itself but neglected since it usually is small, according to Steen (2014). Drag forces introduced by the azipull body/housing are dependent on several parameters, especially wake (w) differences around the housing, struts and propellers, and at this design stage, are unknown. So, to adjust for increased resistance due to the azipull housing, simplifications are made. The total azipull resistance is a product of several hydrodynamic aspects and these are dependent on the wake. Since water-flow behind the vessel is unknown, it is assumed a constant wake (w). The added resistance due to the azipull thrusters are calculated by following a procedure available in the compendium used in “TMR4220 Naval Hydrodynamics” by Steen (2014). It must be made clear to the reader that bold assumptions are made and that more accurate calculations should be done later. The flow pattern behind a vessel is complex, and CFD-analysis could be done generate better results. However, the results give a basis for propeller determination. When the propulsion calculations are carried out, diameter of the propellers are determined, and installed engine effect found, a comparison with other vessels can be done to validate the results. The total resistance of the vessel, including azipull thrusters, in service speed (12kn) is $236{,}6\ kN$.

5.5.2 Propulsion

Traditionally the main challenge regarding propulsion systems design is to find the optimal combination of hull form, engine setup, and propeller dimensions. Propellers with few revolutions per minute (RPM) and large diameter are usually the most efficient way to move a vessel forward, compared to high RPM and small diameter. The vessel hull form in the aft part of the vessel gives a limit on how large the propeller can be. Therefore, a large diameter is set as the initial design parameter when selecting propellers for this design. Based on measurements of the hull done in the AutoCAD and DELFTship; the max space available for propellers is 4 meter, measured from the keel to the hull, at the aft perpendicular. DNV GL has requirements regarding clearance between the hull and the propeller tip. The propeller diameter suitable for the vessel will therefore be approximately 3 meters, see Appendix H for how the clearance were estimated.

Results from resistance calculations done in Chapter 5.5.1 are used as a basis for propeller and installed engine effect determination. The total resistance is assumed to be the sum of hull resistance and azipull resistance and gives $R_{tot}(12kn) = 236{,}6\ kN$ and $R_{tot}(14kn) = 420{,}4\ kN$. This gives $P_E(12kn) = 1460{,}5kW$ and $P_E(14) = \ 3027{,}6\ kW$ as required effect.

Calculations are further provided for 12 knots since this is the vessel service speed. Traditional iteration process using Bp-diagrams has been used in determining the propeller diameter and required installed effect. This may be a potential error source as the azipull propulsion system is used. This method is assumed well known to the reader and thus not all of the iteration steps is included in the main text, however the method calculations are included in Appendix H.

Assuming an open water efficiency $\eta_0 = 0{,}6$ and mechanical efficiency $\eta_M = 0{,}95$ the required delivered power P_D is $1221{,}4\ kW$ to each propeller. By comparing already operating OSVs in the North Sea, it is assumed four blades on each of the two propellers. Further, the blade area ratio, A_e/A_o, is assumed to be 0,85 (and later checked for cavitation). The flexibility of using DE propulsion system gives the possibility to choose optimal RPM given by the propulsion motors. Here 180 RPM is assumed and this gives a $Bp = 0{,}75$. By reading the Bp-diagram for $Z = 4\ and\ A_e/A_o = 0{,}85$ we get a $\eta_o = 0{,}605 \approx 0{,}600$. The assumed η_0 is close to the one found in the $Bp -$ diagram, we can therefore proceed. The optimal propeller diameter is then 3,06 meters. This is slightly larger than what was found to be the maximum diameter, but this limit is rather uncertain at this point. Therefore, a diameter for $3{,}06\ m$ is assumed to fit. The pitch ratio (P/D) is found to be 0,90.

Further, an evaluation of the blade area ratio is evaluated using a Burrill-diagram. This method is used to ensure sufficient blade area to avoid cavitation. This is a simple empirical method based on old model tests. The method is old and therefore uncertain; however, it gives an early prediction of cavitation. Results from the method shows that the propeller blade area is sufficient, as the results from the propeller test is lower than the 2,5 % line for cavitation, see Appendix H for detailed calculations.

The propeller diameter is set and when there is no risk of cavitation, the required installed engine effect can then be determined. The total efficiency η_T is found to be 0,561. The required installed effect per propeller is then $P_B = 1460{,}5\ kW/0{,}605 = 2550\ kWper\ propeller$. The total installed effect is then $P_B = 5100\ kW$.

Normally one should add a sea margin to ensure sufficient power in rough sea and increased resistance due to degradation, corrosion, dents etc. Here a sea margin is set to 30% due to the rough sea in the North Sea (Amdahl et al., 2013). Total installed machinery required for propulsion is then $P_B = 6630\ kW$. Compared with other OSVs with $GT\ =\ 4800$ (presented in Levander (2012)), this assumption is slightly below average ($7200\ kW$) but within the overall range of the vessels presented.

5.5.3 Early intact stability prediction

The true center of gravity (COG) is only found when the vessel has been launched and there has been performed an inclining test. However, one can perform some estimations of the COG and thus predict the stability of the vessel early in the design process. Stability calculations of the vessel are important and can be found in the output documents from DELFTship. Additional stability estimations are carried out manually based on parameters from the SBSD method early in the design stage. Here the intact stability is calculated based on the max draft condition and the same weights used to calculate the lightweight and deadweight for the vessel. KB and BM values for the vessel are estimated based on typical values found in other similar OSVs. The stability check calculations is presented in detail in Appendix I. These estimations are performed early in the design process and based on an assumed general arrangement solution. This is done before the arrangement drawings were done to make sure that the design is somewhat within the required limits regarding stability. When the general arrangement drawings are worked through, a review of the stability calculations should be done to so that the assumed stability can be adjusted for changes made in the true general arrangement. Intact stability estimates are presented in Table 11.

Table 11: Intact stability estimations based on SBSD compendium method, at max draft (6,9 m).

Center of buoyancy (KB)	Transverse metacenter (BM)	Metacentric height from b.l. (KM)	Vertical Center of gravity (KG)	Metacentric height (GM)
3,78 m	5,39 m	9,18 m	6,17 m	3,01 m

A rule of thumb for a vessel is to have positive initial metacentric height (GM). Due to possible damages that can happen to the vessel, a higher GM is often needed. Table 11 presents the results from intact stability calculations and shows that the GM is $3{,}01\ m$ and well above the requirement. The vertical center of gravity (VCG) is estimated to $6{,}17\ m$.

The longitudinal center of gravity (LCG) is also important to estimate, as it together with center of buoyancy (COB), will determine the trim of the vessel in lightweight condition and affect the stability of the vessel in other loading conditions. When the vessel is loaded with cargo, it is important to have control over the trim of the vessel to ensure sufficient stability. The trim of the vessel also affects the total resistance when sailing. Controlling the trim is therefore important. Water ballast tanks are therefore placed practical into the vessel to adjust the trim of the vessel in different cargo/loading (or lightweight) conditions.

The LCG is estimated by use of the tank arrangement function in DELFTship. By adding tanks in the hull and from there add a fluid or a point load to each tank, the LCG is estimated. The sum of all the tanks are put together to give the LCG (and VCG). The LCG for the vessel in lightship condition is found to be $47{,}1\ m$, with no water ballast to adjust for trim. The trim of the vessel is found to be $2{,}94\ m$ forward. See Loading Condition 1 in Appendix L for more details.

5.5.4 Loading conditions

The stability of the vessel must be checked in multiple loading conditions to ensure sufficient stability when the vessel is loaded with cargo. Stability in lightweight (LWT) condition is also needed to be evaluated. This is done by testing four loading conditions in DELFTship after the GA is completed. Loading Condition 1 is lightship condition with no water ballast to adjust trim. Loading Condition 2 is lightship with water ballast to adjust for trim. Loading Condition 3 is maximum loading of the vessel where the cargo tanks are fully loaded and water ballast used to adjust trim. Loading Condition 4 is a hypothetical normal operation with miscellaneous filling of cargo tanks and water ballast tanks to adjust the trim. The results from the loading condition stability tests are presented in Table 12, and the full reports from DELFTship are presented in Appendix L.

Table 12: Results from the four loading condition tests done in DELFTship.

Loading Cond.	**Displacement**	**VCG**	**LCG**	**GM**	**Trim**	**Mean moulded draft**
LWT	3375 t	6,9 m	47,1 m	6,8 m	2,9 m	2,8 m
LWT + Ballast	4438 t	5,8 m	41,7 m	6,2 m	0,1 m	3,5 m
Max loaded	9670 t	5,4 m	39,9 m	3,7 m	-0,1 m	6,9 m
Normal/average	7991 t	5,3 m	40,2 m	4,1 m	-0,3 m	5,9 m

Here in max loaded condition, the VCG is much lower than previously estimated VCG. This is because the cargo tanks below deck are filled, in the earlier estimated VCG, cargo was placed on the cargo deck and therefore a higher VCG was found. As can be seen in the Table 12, and in Figure 29, the trim in LWT condition is large and not favorable. This is due to the heavy drilling fluid that the vessel is transporting. When the vessel is loaded with heavy drilling fluid the vessel will have much better trim condition as the tanks are positioned aft of the LCG. Ballast tanks are therefore used to adjust trim (and heeling) both in LWT condition and in other loading conditions when needed. In Figure 29 the trim of the vessel in LWT condition is illustrated. In Figure 30, the trim of the vessel in ballasted condition is illustrated. In Figure 31, the trim of the vessel in max loading condition is illustrated. In Figure 32, the trim of the vessel in normal/average condition is illustrated.

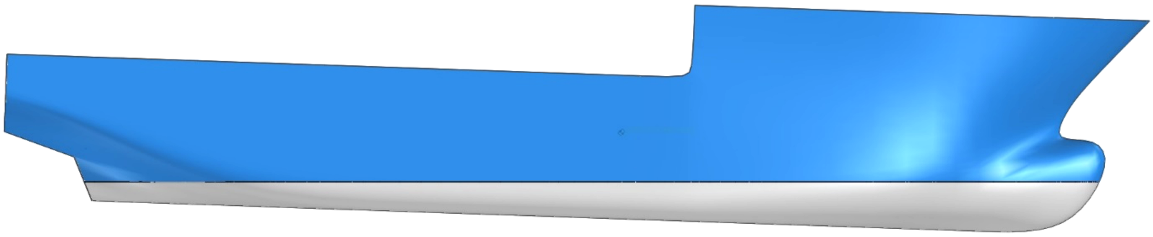

Figure 29: Vessel trim in LWT condition, from the 3D model made in DELFTship.

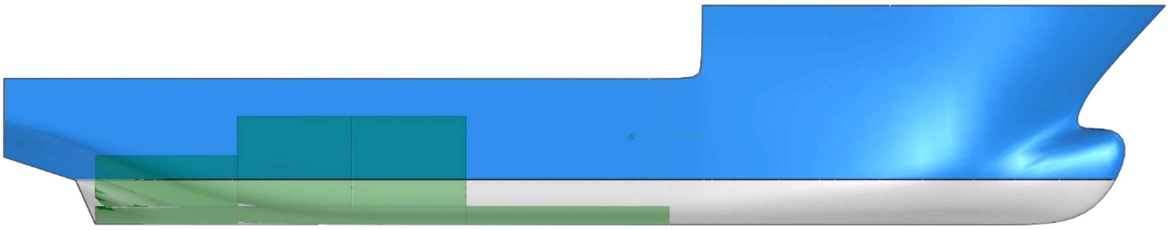

Figure 30: Vessel trim in LWT with ballast condition.

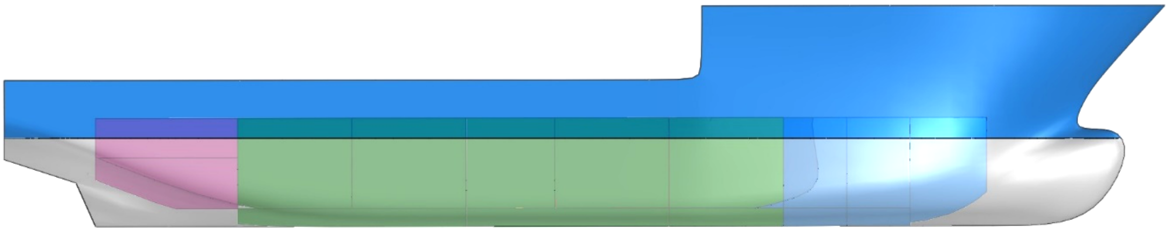

Figure 31: Vessel trim in max loading condition.

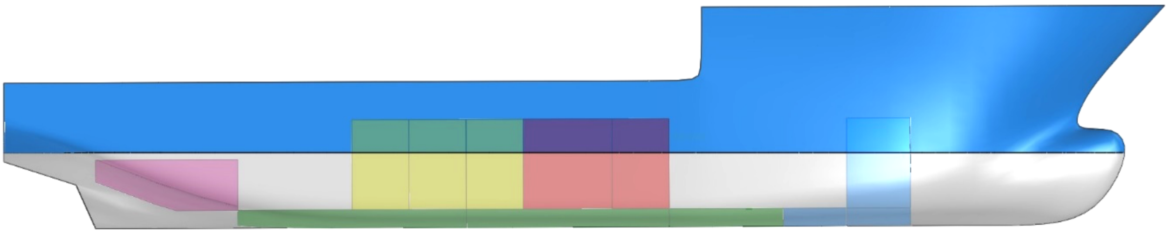

Figure 32: Vessel trim in normal/average condition.

LWT with ballasting shows that the trim is close to zero. Here, 1063 tonnes of water is used to balance the vessel. Max loaded condition is when all the tanks in the vessel are in use and fully loaded and the normal/average condition represents a typical operation were the tanks are filled miscellaneously. All stability evaluation criteria are approved in the four loading conditions. However, a review of the LWT condition (and LCG) should be done to reduce the initial trim in this condition. In addition, unsymmetrical loading conditions could be interesting to test to further evaluate the vessel stability.

5.5.5 Operational profiles and energy consumption

The main mission for the vessel is to sail from a port with bulk cargo related to drilling operations. Then at the offshore field, the vessel shall perform drilling fluid maintenance of contaminated drilling fluid used in a drilling operation. The optimal condition for the vessel with respect hull design and sailing speed, is to have an even load on each trip. Meaning that the vessel can sail from shore with a load of commodities and exchange this load with a relative equal amount of wastes coming from the drilling platform. The vessel will transport "new" cargo out to the platform and "used" cargo back to shore. To estimate the required machinery needed for this vessel the vessel route and operational profile presented Chapter 2.6.3 are evaluated with some simplifications. The same route is used but the operational profile is simplified and presented in Figure 33.

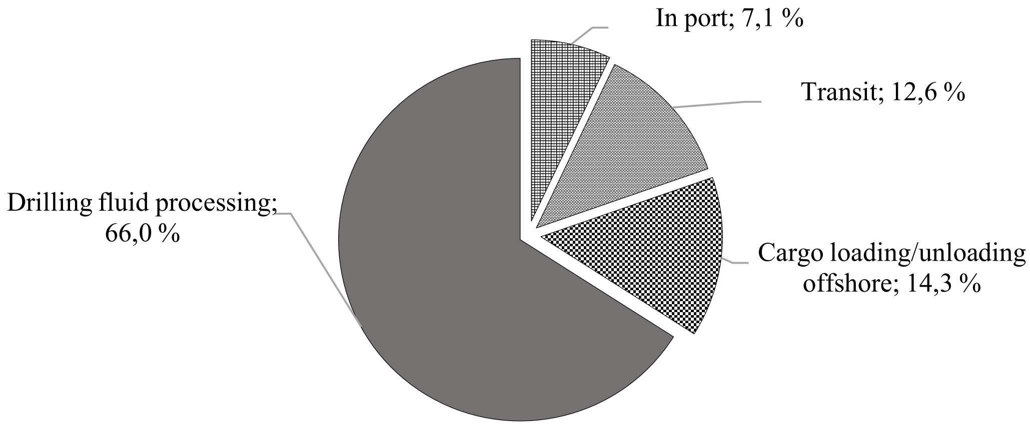

Figure 33: Operational profile for the vessel.

The vessel will, as stated before, sail in a 14-days roundtrip due to the request from Statoil Marine. This will therefore limit the vessel design and influence the energy consumption. If the vessel were to stay at the field at longer periods, the design could have been less optimized against resistance and propulsion. In an operation mode, e.g. cargo loading/unloading offshore, several factors influence the energy consumption. Further, these will also determine the required installed effect to make sure that the vessel can operate under these conditions when requested.

During transit, the main energy consumption is the propulsion system that is estimated in Chapter 5.5.2. There will also be energy needed to supply the living quarters with enough power (hotel load). This hotel load will somewhat be present during all operation modes as there will be people onboard the vessel most of the time. The hotel load can be difficult to determine and in this thesis, the hotel load is based on an educated guess. Also during transit, mud tank circulation is needed to avoid particle settlement.

During drilling fluid processing/maintenance, the main energy consumers are dynamic positioning by use of thrusters, solids control equipment, mud mixing equipment, circulation pumps and miscellaneous equipment such as hydraulics. When the vessel is transferring cargo (loading/unloading) offshore, i.e. pumping drilling fluid (or other bulk cargo) up to a platform, or receiving cargo from a platform, it is extremely important that the vessel can operate on dynamic positioning. The pump system needed to carry bulk cargo up to the platform also need sufficient power. In port, the energy consumption is rather small, but some systems have to be operative such as hotel load running the heat/air condition and service rooms. In Figure 34, energy consumption for each operation mode in normal/average operating condition is presented based on calculations presented in Appendix J.

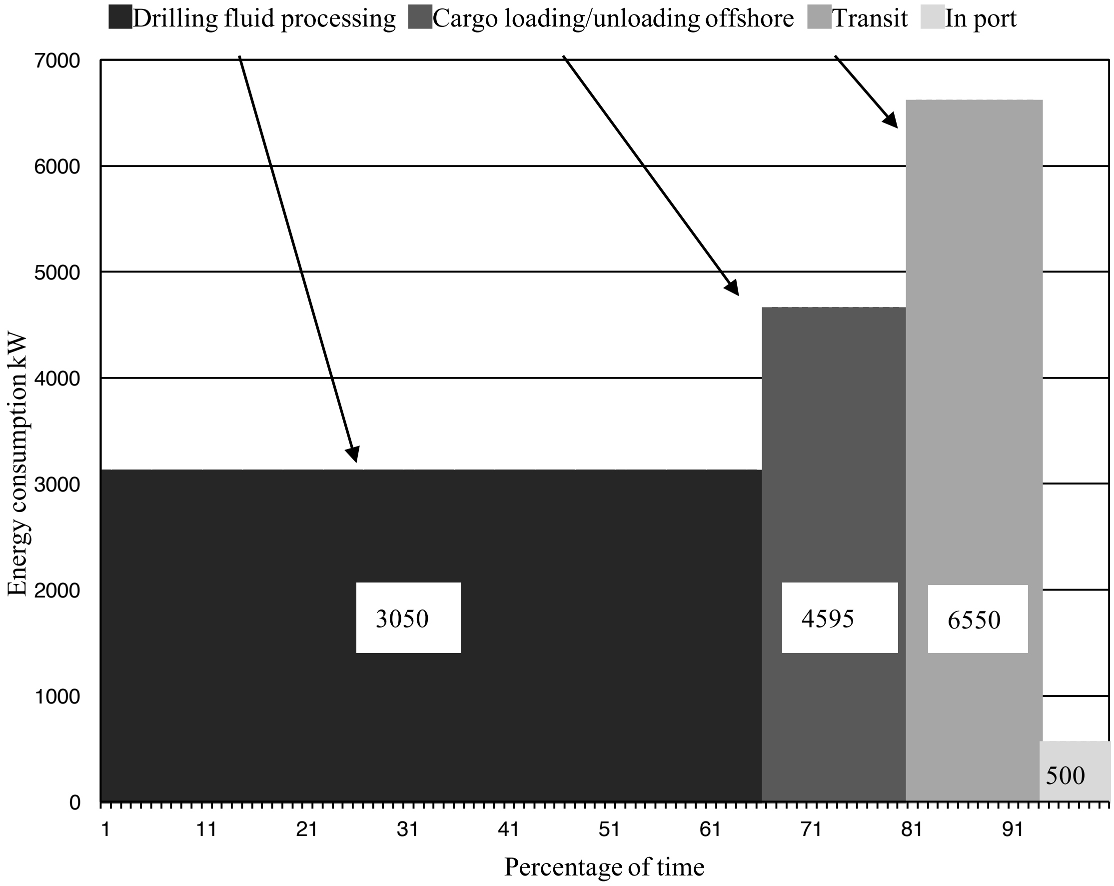

Figure 34: Estimated energy consumption in normal operation.

The operation mode that is assumed to consume most energy is when the vessel is at transit out to the field, and returning to shore (6550 kW). When in transit, the vessel will use most of its energy to supply power to the propulsion system. In addition, circulation pumps are used to circulate the fluid to prevent accumulation of high-density particles at the bottom of each tank and therefore electricity to each pump is needed. In addition, there must also be provided enough energy to support the daily operation of the vessel itself such as the galley, air condition, ventilation, and electricity i.e. hotel load. Hotel load must be provided in all operation modes. This is also the case for drilling fluid circulation, when the vessel has drilling fluids onboard.

The second largest consumer is drilling fluid transferring between vessel and platform (4595 kW). When the vessel approaches a platform to unload/load cargo, control of the vessel is extremely important. Dynamic positioning systems are used and these systems require sufficient power to make sure that the vessel will stay in position and not run into the platform. Here the thruster system with two bow thrusters, one retractable bow thruster and two azipull thrusters aft is useful. A 360-degree station-keeping capability map should be made for the vessel to assess the vessel's ability to stay in position when loading/unloading cargo. In this thesis, there has not been estimated station-keeping capability of the vessel and the power needed to stay in position. Therefore, assumptions regarding energy consumption in this operation mode is made. When loading/unloading cargo at a platform the largest energy consumption is due to the dynamic positioning as all propulsion units are operative and require power in case of unforeseen events. In addition, pump capacity to pump drilling fluid up to the platform is required.

When processing drilling fluids offshore the vessel require energy to run the solids control equipment, mud mixing equipment, circulation pumps, station keeping, and hotel load. The vessel will operate in this condition the most of the time and therefore one of the most important conditions to optimize power production (3050 kW). When the vessel is at port there is assumed an average power consumption of $500\ kW$.

In emergency operations, there must be enough power to handle critical situations, especially when the vessel is operating near an offshore oil and gas facility. To make sure that the vessel has enough capacity to avoid incidents an estimation regarding the station-keeping capacity should be analyzed further. A presentation of the required power for the vessel in high energy consumption operations is presented in Figure 35.

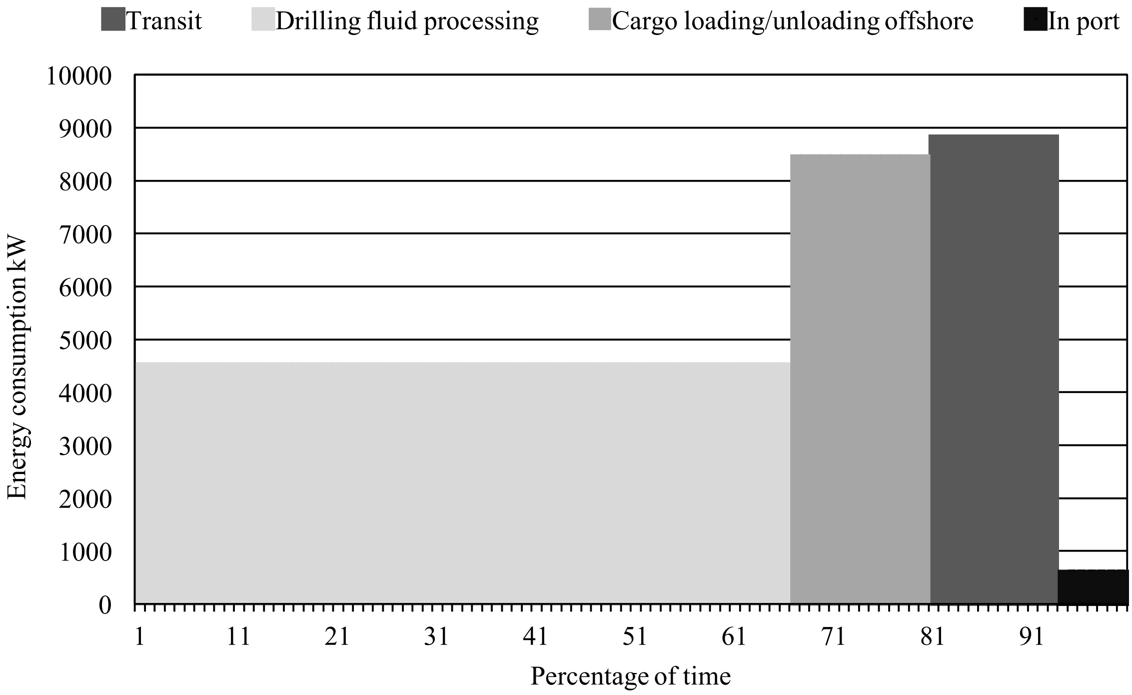

Figure 35: Estimated power consumption during high energy operations.

An assumption of the required machinery capacity is made for when emergencies and when high power consumption is needed, presented in Figure 35. These estimations can be seen in detail in Appendix K. The Results shows that the vessel should be able to generate about $8700\ kW$ in the most severe condition and therefore set as the minimum required installed effect on the vessel. Checking with the OSV database provided in Levander (2012), $8700\ kW$ is below the average installed power on similar vessels. However, according to the parametric analysis done in Windsland (2016), this value is higher than most other similar PSVs, but almost identical to another vessel; "Far Solitaire", which is a specialized drilling fluid supply vessel. Total installed power is therefore selected to $8700 kW$. When the SBSD spreadsheet was made an assumption of $10\ 000\ kW$ installed machinery was made, this value should therefore now be adjusted. These adjustments are not done in this thesis due to time limitations. The energy consumption estimate done in this thesis may not be sufficiently provided with details and can therefore be an error source.

When selecting generators for the vessel, the total installed power should be divided between several generators. The flexible arrangement makes sure that one can run each generator in optimal condition in periods with both high and low energy consumption. However, it is more economically to invest in large engines, so one should not have too many generators. Based on a parametric analysis of OSVs done in Windsland (2016) (and presented in Appendix C), newly built vessels tend to have 3-4 main generators installed, plus emergency generator and may additionally have an auxiliary generator.

Drilling fluid maintenance is the operation mode that the vessel will spend most of its time doing, so it is best if the generators can make electricity for the equipment used in this operation mode as optimal as possible. In addition, main propulsion has to be efficiently provided with power, as this is the largest single consumer. The selected generator set is therefore set to; $3\ x\ 2600\ kW$ main generators, $1\ x\ 700\ kW$ auxiliary generator, and $1\ x\ 200\ kW$ emergency generator (emergency generator is based on comparing existing designs). During drilling fluid maintenance one main and the auxiliary generator provide power for the maintenance operation. This is more than the demand for drilling fluid maintenance, but there will always be deviations whether there is low or high demand for processing power. When the vessel is at transit, two main generators ($2\ x\ 2600\ kW\ =\ 5200\ kW$) are used to generate propulsion power during service speed. If more power is needed all three generators are used to generate power ($3\ x\ 2600\ kW\ =\ 7800\ kW$). This is typically required when sailing in rough sea and when arriving at scheduled time is critical. During severe conditions, the auxiliary generator can be used in addition to all three main generators. In emergency conditions, the emergency generator can be utilized.

6. Main Results

Results obtained through this thesis are originally presented throughout the design process in Chapter 5. In this chapter, a summary of the main and most important results are presented in Table 13, called the "Outline Specifications" for the vessel design.

Table 13: Outline specification of the vessel design.

Mission Description					
Operation area	North Sea				
Description	Drilling operation support vessel, drilling fluid maintenance.				
Target market	Offshore support				
Main Characteristics					
Length OA	91,5	m	Gross volume	17215	m3
Length PP	85,6	m	Gross tonnage	4901	GT
Beam	20,5	m	Lightweight	3375	tonnes
Draft max	6,9	m	Deadweight	6295	tonnes
Depth to main deck	8,5	m	Displacement	9670	tonnes
Crew and client	25	Beds (13single cabins)	DWT/displacement	0,65	
Cargo deck	945	m2	LWT/GV	0,19	
Machinery and Rough Power Demand					
Machinery type	Diesel electric generators and azipull propulsion				
Propulsion power	6630	kW	Main machinery	3 x 2600	kW
No. of propellers	2	units	Auxiliary power	700	kW
Diameter propellers	3,06	m	Emergency power	200	kW
			Total installed power	8700	kW
Tank Types and Capacities					
Water ballast	1690	m3	Liquid mud/multi use	1612	m3
Fuel oil	700	m3	Base oil / LFL	910	m3
Fresh water	1120	m3	Void and cofferdams	485	m3
Drilling Fluid Maintenance System					
Solids control	3	units	Operators	2-3	persons
Centrifuge	1	unit	Drilling fluid mixing	1	unit

The main dimensions are found by analyzing the vessel mission and use of the SBSD methodology spreadsheets. Mission statement emerges from the literature review of drilling operations and analyzing vessel movements and bulk cargo shipments during drilling operations. The installed machinery is based upon the required propulsion thrust due to vessel resistance and analyzing the vessel in different operational profiles. Tank design emerges from comparing Safe Scandinavia bulk deliveries, PSV tank arrangements, and vessel fuel and water consumption. The drilling fluid maintenance system arrangement is based on literature review of drilling operations and guidance from solids control manufacturers and mud engineer perspective.

7. Extended Discussion

The extensive cost of drilling fluids confirms a potential of increasing reuse and recycling of drilling fluids. More specific: to perform more of the drilling fluid maintenance offshore. By doing this offshore, less loads of drilling fluids needs to be transported in total, i.e. less fluid need to be transported out to the field, and less fluid need to be transported back to shore. Due to time limitations in this thesis, potential economic benefits of implementing such vessel concept is not done. This should preferably be done to demonstrate financial benefits of the proposed concept. If there are no financial benefits, no further vessel concept development is needed.

The vessel movement on the Oseberg field analyzed in the literature review shows that dedicated storage vessels are present during drilling operations. According to mud engineers and drilling operators, these vessels only store drilling equipment and drilling fluids. Instead of only operating standby as storage, they could be replaced with a vessel with ability to perform drilling fluid maintenance as well. By implementing such vessel, drilling fluid providers will lose parts of their core business, as drilling fluid maintenance is an integral part of their business. A cooperation with drilling fluid providers seems unavoidable because only they know the exact drilling fluid content, which is critical information needed to achieve good drilling fluid maintenance. A future cooperation between drilling fluid provider and vessel logistics operator is therefore suggested to further develop the concept.

When developing this vessel concept, bold and design limiting assumptions are made. The one with most implications is that the vessel is to operate in a 14-days roundtrip between port and the offshore oil and gas field. The second is that the vessel design should be based on a large PSV design. These assumptions were made early in the design phase due to directions given by Statoil Marine. Without these assumptions, the vessel design would presumably be different in terms of form and size. Based on knowledge gained through this thesis, the vessel could have been larger and permanently stationed at the field. This concept could be designed more optimal against drilling fluid maintenance and storing, instead of hydrodynamic and propulsion abilities. Safe Scandinavia, presented in the literature study, is a similar concept only here the vessel is a converted semi-submersible flotel. Further analysis of Safe Scandinavia would be of interest to evaluate. Knowledge and experience data gained from Safe Scandinavia would also help optimizing the vessel design presented in this thesis. The author has not received/found enough information about Safe Scandinavia to analyze this concept in depth. However, statistics from the operation of Safe Scandinavia shows that by performing drilling fluid maintenance offshore, a significant reduction of transport of contaminated drilling fluids back to shore for maintenance were discovered.

Drilling fluid design, content, logistics, solids control, and mixing have an intricate relationship. Therefore, simplifications and assumptions are made throughout this thesis to be able to advance in the design process. The choice of tank design, solids control equipment, and mixing equipment are heavily based on assumptions made by interpreting inputs and guidance from interviews, equipment specifications and case studies. Three solids control units are assumed as sufficient to treat most of the drilling fluid delivered to the vessel. In addition, a centrifuge is used to filter out smaller particles. This assumption is based on inputs from solids control equipment manufacturers (Nag, 2017). The need for a mud-mixing unit emerged through interviewing an experienced mud engineer (Kjøstvedt, 2017).

An assessment of the interactions between the drilling fluid maintenance system, tank design, and the operational profile of the vessel should be evaluated more closely. However, assumptions had to be made, as there are large uncertainties regarding; the condition of the contaminated drilling fluid, the extent of how much the drilling fluid has to be treated, and how well the maintenance system can perform.

When determining the required systems and the space needed for each system in the vessel, three factors are mainly guiding the design process: the accommodation capacity, payload capacity, and power demand. Factors from the SBDS compendium are used to determine space for each system. The vessel is assumed operated much like a PSV, therefore accommodation capacity of 25 persons are used as basis for designing common spaces and cabins in the vessel. This accommodation capacity is more or less standard in the PSV segment. Accommodation capacity for 25 persons is more than enough to accommodate the crew, the drilling fluid operators and potential clients.

An assumption of 10 000 kW installed effect is made early in the design process based on parametric analysis of vessels with similar dimensions, presented in the SBSD compendium. This assumption turned out to be too high. Resistance and propulsion estimates using Guldhammer/Harvalds method and Bp-diagrams for determining propeller dimensions, shows that the vessel need 6630 kW effect for propulsion. Guldhammer/Harvalds method is also known for giving a pessimistic resistance estimate. In addition, evaluation the operational profile results show that 8700 kW is sufficient to be installed in the vessel. Meaning that less space for machinery is actually needed. Compared to the estimate of 10 000 kW, 1300 kW is in surplus. The equivalent space corresponding to the surplus of 1300kW is 390 m^3, according to the factor presented in the SBSD compendium. However, this estimation should be further investigated as several assumptions were made when finding the required effect, especially power consumption during transit and drilling fluid maintenance.

The payload capacity is the most important factor to design against, as this is the “moneymaker” system. Here an estimation of $1612\ m^3$ total storage capacity for drilling fluids is done. The system is able to store and treat four average loads of drilling fluids. These estimations are based on analyzing the bulk cargo shipment at Safe Scandinavia and the tank capacity of the vessel “Far Solitaire”, which is a specialized drilling fluid supply vessel. The whole system should be further analyzed to get better indication of required capacity, and performance.

The geometric definition of the vessel outlines how much space there is allocated for systems to take place on each deck. The geometric definition is supposed to be equal to the system summary because it is here the “building a hull around the systems” is done, and is the main feature of SBDS methodology. Two major errors in the spreadsheet was found late in the design process after the 3D-model was made and hull lines exported to AutoCAD for GA development. When using factors from the SBSD compendium, the factor for required engine casings is $40\ m2$ per deck. In reality only $25\ m2$ is needed for this design. In addition, some of the machinery systems were counted twice and thus too much volume is generated in the system summary. Results shows that the geometric definition is $563\ m3$ (about 3%) larger than what is required for the vessel. This surplus volume is because of these errors made. The errors are easily fixed in the system summary, but not in the geometric definition as the 3D model and hull lines has already been created and due to time limitations, could not be changed. This resulted in too much space in the hull. This became obvious when the general arrangement process began. Some of the decks in the vessel thus has too much space compared to the actual need and this can be seen in the GA drawings. When the hull lines are imported to AutoCAD, much work has to be redone if changes in the 3D model must be made. Preferably there should be a software that one can do the 3D modelling and GA drawings simultaneously. A solution to the volume surplus problem could be to compress the whole deckhouse more forward in the vessel. In the presented GA an additional stairwell is placed in the deckhouse to make use of the surplus volume. The stairwell improves escape-route options in the deckhouse.

Early in the hull development process, the internal volume and weight estimations shows healthy signs of a promising design based on typical design criteria’s for OSVs. The lightweight density, an indication of vessel complexity and building cost, shows that the vessel is relative simple and at the lower end of the complexity scale. Indicating that the vessel is relatively simple to build, pushing the building cost down. The deadweight/displacement ratio, an indication of payload capacity, indicates that the vessel is in the lower end of the scale for PSVs, but above the normal ratio for anchor handlers and construction vessels. This is as expected, as the vessel is equipped with a drilling fluid maintenance system that takes up the space normally used for payload on a normal PSV. Compared to anchor handlers and construction vessels, the drilling fluid maintenance system is smaller, lighter, and less complex.

Stability calculations shows that the vessel has proper intact stability as the GM was found to be positive and over $3{,}7\ m$ in all tested loading conditions presented. The stability reports from DELFTship also shows that the vessel pass all stability requirements according to offshore supply vessels IMO MSC.267 (85) code on intact stability. Here only four loading conditions are tested. Further validation of the vessel intact stability should be done by testing other loading conditions. In addition, vessel safety should be evaluated by performing deterministic or probabilistic damage stability analysis.

Required propulsion power is estimated based on Guldhammer/Harvalds method. More modern and accurate methods exist and should be evaluated to generate more accurate results. The resistance due to the azipull system is however more uncertain and this is due to the unknown actual position and geometry of the propulsion bodies. However, comparing the propulsion requirement with other similar vessels, the power demand is normal. Uncertainty regarding the wake behind the vessel is high. To retrieve accurate results CFD analysis of the system could be done to verify the resistance estimate. The installed effect and propulsion setup is however similar to other vessels in the industry and therefore considered as acceptable this early in design stage.

8. Conclusions

An offshore drilling fluid maintenance vessel used to reuse and recycle drilling fluids offshore is developed by use of the system based ship design methodology. By installing a drilling fluid maintenance system on a vessel, drilling fluid quality can be increased offshore. This will reduce overall drilling fluid transport and procurement of new drilling fluid. The vessel is equipped with a drilling fluid solids control system on the Tank Top Deck. This system consists of three compact units removing the majority of the solids dispersed in the contaminated drilling fluid by use of vacuum and filters. In addition, a centrifuge is used to filter out smaller solids. To adjust the drilling fluid characteristics, a mud-mixing unit, with storage for drilling fluid additives, are installed on the 2nd Deck. The entire maintenance system is connected to liquid mud/drilling fluid tanks and base oil tanks. The base oil tanks are filled with base oil used to dilute the drilling fluid. They can also store fuel or low flashpoint liquids if needed. The liquid mud tanks are used for both clean and contaminated drilling fluids. In addition, wastes generated from drilling fluid maintenance are also stored in one of the liquid mud tanks, as these tanks are multi-use compatible. Cleaning of the tanks is done when the vessel is in port. The drilling fluid maintenance system onboard is not tested and optimized in this thesis, due to time limitations.

Large uncertainties regarding the quality of the contaminated drilling fluid makes it difficult to determine the performance of the drilling fluid maintenance system and is therefore not identified in this thesis. Methods based on simulation could be utilized to address these issues in further development of the concept. However, experience from a similar concept, Safe Scandinavia, shows that drilling fluid maintenance performed offshore, significantly reduces transport of contaminated drilling fluids to shore for maintenance. Similar results may therefore apply for this vessel design, but should be further analyzed.

Regarding the technical aspects of the vessel presented. The vessel is equipped with a total installed machinery effect of 8700 kW. This power is distributed on three main generators of 2600 kW, one auxiliary generator of 700 kW, and one emergency generator of 200 kW. The main propulsion system consists of two azipull thrusters for better maneuverability in slow speed. In addition, there are two tunnel thrusters and one retractable azimuth thruster in the bow, primarily used when approaching a platform. The accommodation capacity for the vessel is 25 persons distributed on 19 cabins, where 13 of them are single cabins intended for the crew and 12 double cabins intended for clients.

The vessel main dimensions are as follows. Length over all is 91,5 meters and the breadth is 20,5 meters. Total displacement for the vessel is 9670 tonnes and the deadweight tonnage is

6295 tonnes. Total drilling fluid (liquid mud) tank capacity is 1612 m^3 and a total of 1690 m^3 water ballast tanks are placed in the hull to adjust vessel trim and heeling when loaded. Based on loading condition tests performed for the vessel, the design has sufficient intact stability, as it complies with the IMO requirements. However, only four loading conditions are tested and more loading conditions should be tested to ensure that the vessel is sufficiently safe.

The vessel design presented is similar to large platform supply vessels and designed to operate on a fourteen-days long roundtrip. This is due to directions given by Statoil Marine. This reduce the overall design space early in the design process. Exploration of the entire design space could drastically change the design and ought to be done to not exclude better designs. The vessel is designed based on static assumptions regarding sailing distance, weather, sea state, loading conditions, etc. which in real life are dynamic. Simulation tools such as presented in Erikstad et al. (2015b) has the opportunity to document the performance of the vessel while taking dynamic aspects into consideration and could be exploited in the design process to receive more accurate results.

To summarize. This thesis proposes a vessel design able to perform drilling fluid maintenance offshore. The utilization and performance of the maintenance system are not tested but could be further analyzed using tools such as simulation. The vessel design presented can further be used as a template or reference vessel for further development of the concept.

9. Further Work

Ship design is an iterative process where all system more or less are connected to each other. In this thesis only parts of the design are developed and presented and of course much work remains before the design is finished. To further develop this design, the following work is proposed.

9.1 Drilling Fluid Maintenance

- Evaluation of the drilling fluid maintenance system- and setup on the vessel should be reviewed and preferably tested in real life (or simulated) to better understand the need and performance of such system.
- The exact contents of the drilling fluid are kept secret by the drilling fluid suppliers. Further cooperation with them could result in better utilization of drilling fluids, as they know best how to optimize the quality of the fluid by performing drilling fluid maintenance.
- Drilling fluids content are held secret by the drilling fluid suppliers, making maintenance more difficult. Standardization of the drilling fluids makes it easier to keep track of content and easier to treat larger amounts of fluids. Such concept could be beneficial to introduce to increase the potential for a drilling fluid maintenance vessel. However, standardization may reduce the drilling fluid quality and ratio of penetration in a drilling operation.
- Cost estimates and financial opportunities regarding the concept should be developed to display economical potential. In addition, future demand for drilling fluids should be assessed.

9.2 Vessel Concept

The vessel concept vessel has similarities to normal PSVs. The main difference between this concept and a PSV is that the PSV usually have installed dry bulk tanks, for transport of cement, barite, and bentonite. Instead of installing dry bulk tanks on the concept vessel, a drilling fluid maintenance system is installed. In further work, a module based concept may be relevant to investigate. A suitable PSV could potentially be rebuilt by removing the dry bulk tanks and install drilling fluid system instead. Or, even more flexible, the vessel could be modularized. One module with a dry bulk tank system and one module with a drilling maintenance system. Thus having the flexibility of change system based on market need.

9.3 General Arrangement

The vessel drawings and 3D-model bear signs of that the design process is far from done. Several modifications are therefore proposed to investigate in further work regarding developing the concept. These proposals emerged throughout the designing process, and are not changed in the design due to lack of time.

- Compared to other vessels, the form on the hull is rater blunt. For better entrance angle and for the vessel to sail smoother in the sea, the hull form should be reviewed.
- In the aft part of the hull the outlet angle is steep and space for propulsion systems in the propulsion room is tight. A less steep outlet angle and more space for the propulsion system should be evaluated.
- The bulbous bow is not analyzed. To avoid added resistance, analysis of the bow should be done and optimized for the purpose of reduce slamming motion, increase vessel length, and reduce wave resistance.
- The vessel is to carry used drilling fluids. Due to hazardous gases that can develop when carrying used drilling fluids, a nitrogen system to surround toxic gasses should be investigated to install in the vessel.
- Some errors were made in the SBSD spreadsheet and could not be changed after the hull lines were imported to AutoCAD for general arrangement development. A review of the required space for machinery and casings should be done to adjust the volume required in the hull. Due to the space surplus, an additional stairwell was put into the ship and some of the service areas were made larger.

9.4 Performance

Performance analysis of the most important system onboard the vessel, the drilling fluid maintenance system has not been done. In further assessment of the vessel concept, an evaluation of the performance of this system could lead the design in other directions and is therefore important to explore. The maintenance system could be analyzed further with use of simulation.

Regarding the performance analysis already done in this thesis: The methods used for estimating the resistance and propulsion for the vessel are rather old. More modern and accurate methods should be explored to receive better estimates.

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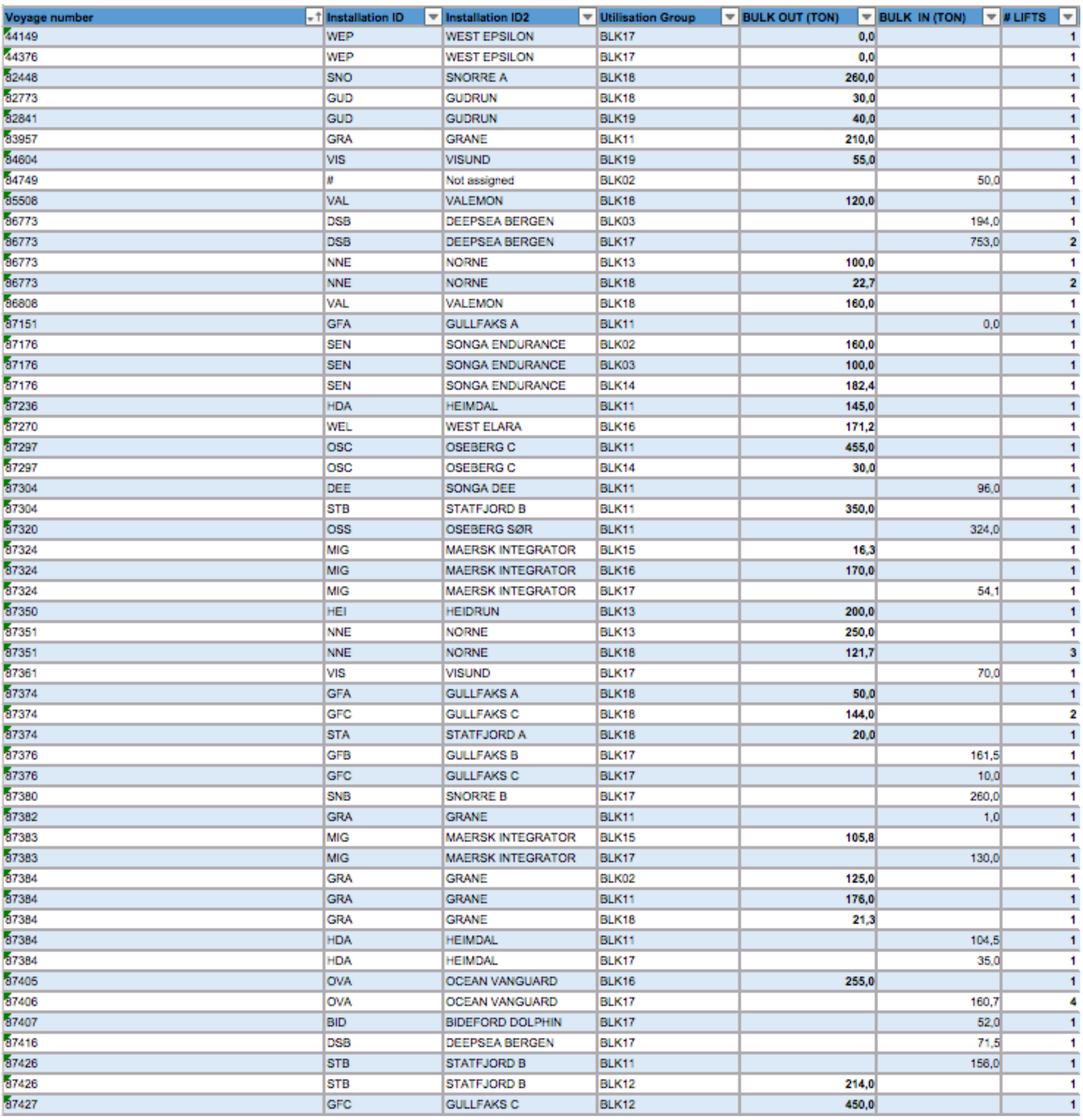
Appendices

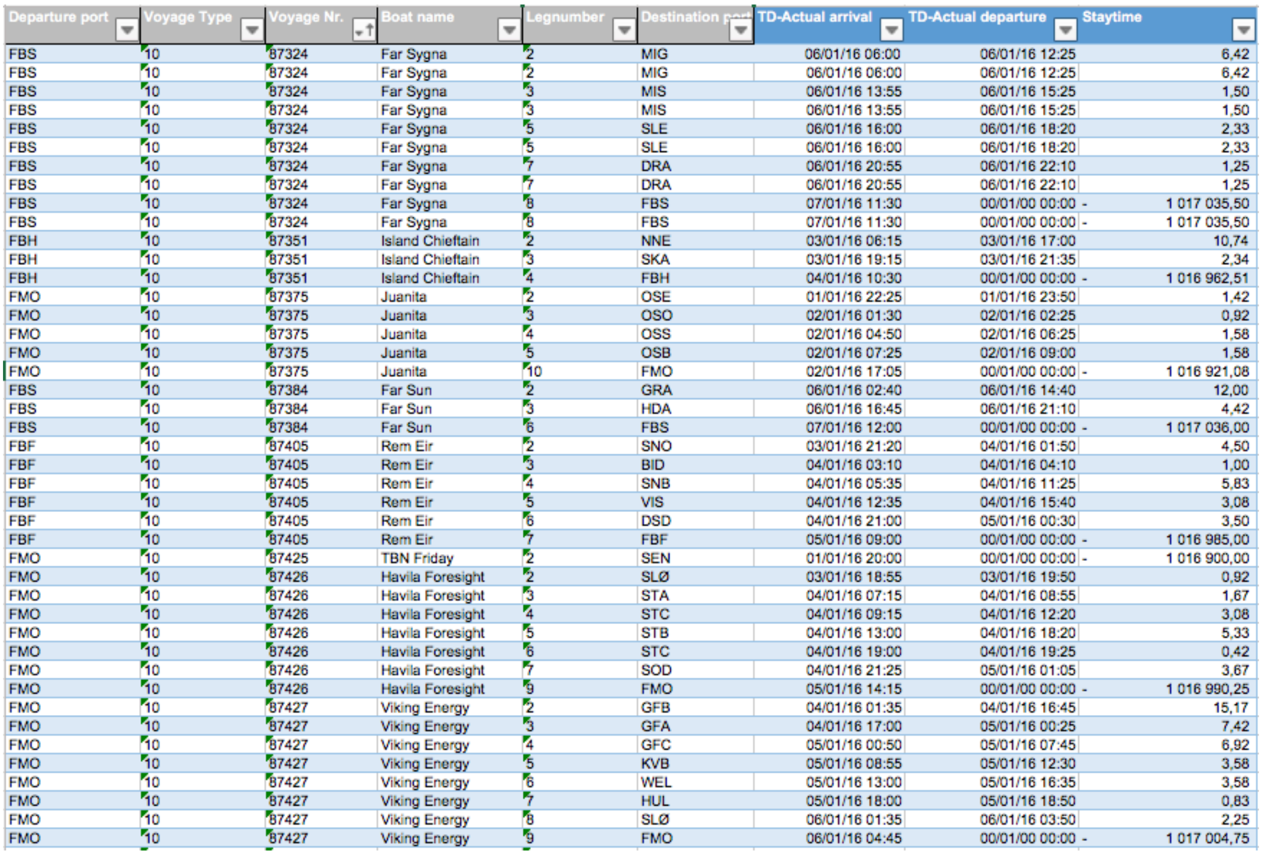
Appendix A: Data used for analyzing vessel movements and bulk supplies

Table 14A: Offshore installation bulk cargo shipments, data provided by Statoil Marine.



Voyage number	Installation ID	Installation ID2	Utilisation Group	BULK OUT (TON)	BULK IN (TON)	# LIFTS
44149	WEP	WEST EPSILON	BLK17	0,0		1
44376	WEP	WEST EPSILON	BLK17	0,0		1
82448	SNO	SNORRE A	BLK18	260,0		1
82773	GUD	GUDRUN	BLK18	30,0		1
82841	GUD	GUDRUN	BLK19	40,0		1
83957	GRA	GRANE	BLK11	210,0		1
84604	VIS	VISUND	BLK19	55,0		1
84749	#	Not assigned	BLK02		50,0	1
85508	VAL	VALEMON	BLK18	120,0		1
86773	DSB	DEEPSEA BERGEN	BLK03		194,0	1
86773	DSB	DEEPSEA BERGEN	BLK17		753,0	2
86773	NNE	NORNE	BLK13	100,0		1
86773	NNE	NORNE	BLK18	22,7		2
86808	VAL	VALEMON	BLK18	160,0		1
87151	GFA	GULLFAKS A	BLK11		0,0	1
87176	SEN	SONGA ENDURANCE	BLK02	160,0		1
87176	SEN	SONGA ENDURANCE	BLK03	100,0		1
87176	SEN	SONGA ENDURANCE	BLK14	182,4		1
87236	HDA	HEIMDAL	BLK11	145,0		1
87270	WEL	WEST ELARA	BLK16	171,2		1
87297	OSC	OSEBERG C	BLK11	455,0		1
87297	OSC	OSEBERG C	BLK14	30,0		1
87304	DEE	SONGA DEE	BLK11		96,0	1
87304	STB	STATFJORD B	BLK11	350,0		1
87320	OSS	OSEBERG SØR	BLK11		324,0	1
87324	MIG	MAERSK INTEGRATOR	BLK15	16,3		1
87324	MIG	MAERSK INTEGRATOR	BLK16	170,0		1
87324	MIG	MAERSK INTEGRATOR	BLK17		54,1	1
87350	HEI	HEIDRUN	BLK13	200,0		1
87351	NNE	NORNE	BLK13	250,0		1
87351	NNE	NORNE	BLK18	121,7		3
87361	VIS	VISUND	BLK17		70,0	1
87374	GFA	GULLFAKS A	BLK18	50,0		1
87374	GFC	GULLFAKS C	BLK18	144,0		2
87374	STA	STATFJORD A	BLK18	20,0		1
87376	GFB	GULLFAKS B	BLK17		161,5	1
87376	GFC	GULLFAKS C	BLK17		10,0	1
87380	SNB	SNORRE B	BLK17		260,0	1
87382	GRA	GRANE	BLK11		1,0	1
87383	MIG	MAERSK INTEGRATOR	BLK15	105,8		1
87383	MIG	MAERSK INTEGRATOR	BLK17		130,0	1
87384	GRA	GRANE	BLK02	125,0		1
87384	GRA	GRANE	BLK11	176,0		1
87384	GRA	GRANE	BLK18	21,3		1
87384	HDA	HEIMDAL	BLK11		104,5	1
87384	HDA	HEIMDAL	BLK17		35,0	1
87405	OVA	OCEAN VANGUARD	BLK16	255,0		1
87406	OVA	OCEAN VANGUARD	BLK17		160,7	4
87407	BID	BIDEFORD DOLPHIN	BLK17		52,0	1
87416	DSB	DEEPSEA BERGEN	BLK17		71,5	1
87426	STB	STATFJORD B	BLK11		156,0	1
87426	STB	STATFJORD B	BLK12	214,0		1
87427	GFC	GULLFAKS C	BLK12	450,0		1

Table 15A: Vessel voyage/movement information, provided by Statoil Marine



Departure port	Voyage Type	Voyage Nr.	Boat name	Legnumber	Destination port	TD-Actual arrival	TD-Actual departure	Staytime
FBS	10	87324	Far Sygna	2	MIG	06/01/16 06:00	06/01/16 12:25	6,42
FBS	10	87324	Far Sygna	2	MIG	06/01/16 06:00	06/01/16 12:25	6,42
FBS	10	87324	Far Sygna	3	MIS	06/01/16 13:55	06/01/16 15:25	1,50
FBS	10	87324	Far Sygna	3	MIS	06/01/16 13:55	06/01/16 15:25	1,50
FBS	10	87324	Far Sygna	5	SLE	06/01/16 16:00	06/01/16 18:20	2,33
FBS	10	87324	Far Sygna	5	SLE	06/01/16 16:00	06/01/16 18:20	2,33
FBS	10	87324	Far Sygna	7	DRA	06/01/16 20:55	06/01/16 22:10	1,25
FBS	10	87324	Far Sygna	7	DRA	06/01/16 20:55	06/01/16 22:10	1,25
FBS	10	87324	Far Sygna	8	FBS	07/01/16 11:30	00/01/00 00:00	- 1 017 035,50
FBS	10	87324	Far Sygna	8	FBS	07/01/16 11:30	00/01/00 00:00	- 1 017 035,50
FBH	10	87351	Island Chieftain	2	NNE	03/01/16 06:15	03/01/16 17:00	10,74
FBH	10	87351	Island Chieftain	3	SKA	03/01/16 19:15	03/01/16 21:35	2,34
FBH	10	87351	Island Chieftain	4	FBH	04/01/16 10:30	00/01/00 00:00	- 1 016 962,51
FMO	10	87375	Juanita	2	OSE	01/01/16 22:25	01/01/16 23:50	1,42
FMO	10	87375	Juanita	3	OSO	02/01/16 01:30	02/01/16 02:25	0,92
FMO	10	87375	Juanita	4	OSS	02/01/16 04:50	02/01/16 06:25	1,58
FMO	10	87375	Juanita	5	OSB	02/01/16 07:25	02/01/16 09:00	1,58
FMO	10	87375	Juanita	10	FMO	02/01/16 17:05	00/01/00 00:00	- 1 016 921,08
FBS	10	87384	Far Sun	2	GRA	06/01/16 02:40	06/01/16 14:40	12,00
FBS	10	87384	Far Sun	3	HDA	06/01/16 16:45	06/01/16 21:10	4,42
FBS	10	87384	Far Sun	6	FBS	07/01/16 12:00	00/01/00 00:00	- 1 017 036,00
FBF	10	87405	Rem Eir	2	SNO	03/01/16 21:20	04/01/16 01:50	4,50
FBF	10	87405	Rem Eir	3	BID	04/01/16 03:10	04/01/16 04:10	1,00
FBF	10	87405	Rem Eir	4	SNB	04/01/16 05:35	04/01/16 11:25	5,83
FBF	10	87405	Rem Eir	5	VIS	04/01/16 12:35	04/01/16 15:40	3,08
FBF	10	87405	Rem Eir	6	DSD	04/01/16 21:00	05/01/16 00:30	3,50
FBF	10	87405	Rem Eir	7	FBF	05/01/16 09:00	00/01/00 00:00	- 1 016 985,00
FMO	10	87425	TBN Friday	2	SEN	01/01/16 20:00	00/01/00 00:00	- 1 016 900,00
FMO	10	87426	Havila Foresight	2	SLØ	03/01/16 18:55	03/01/16 19:50	0,92
FMO	10	87426	Havila Foresight	3	STA	04/01/16 07:15	04/01/16 08:55	1,67
FMO	10	87426	Havila Foresight	4	STC	04/01/16 09:15	04/01/16 12:20	3,08
FMO	10	87426	Havila Foresight	5	STB	04/01/16 13:00	04/01/16 18:20	5,33
FMO	10	87426	Havila Foresight	6	STC	04/01/16 19:00	04/01/16 19:25	0,42
FMO	10	87426	Havila Foresight	7	SOD	04/01/16 21:25	05/01/16 01:05	3,67
FMO	10	87426	Havila Foresight	9	FMO	05/01/16 14:15	00/01/00 00:00	- 1 016 990,25
FMO	10	87427	Viking Energy	2	GFB	04/01/16 01:35	04/01/16 16:45	15,17
FMO	10	87427	Viking Energy	3	GFA	04/01/16 17:00	05/01/16 00:25	7,42
FMO	10	87427	Viking Energy	4	GFC	05/01/16 00:50	05/01/16 07:45	6,92
FMO	10	87427	Viking Energy	5	KVB	05/01/16 08:55	05/01/16 12:30	3,58
FMO	10	87427	Viking Energy	6	WEL	05/01/16 13:00	05/01/16 16:35	3,58
FMO	10	87427	Viking Energy	7	HUL	05/01/16 18:00	05/01/16 18:50	0,83
FMO	10	87427	Viking Energy	8	SLØ	06/01/16 01:35	06/01/16 03:50	2,25
FMO	10	87427	Viking Energy	9	FMO	06/01/16 04:45	00/01/00 00:00	- 1 017 004,75

Appendix B: Standby time for storage vessels at the Oseberg field.

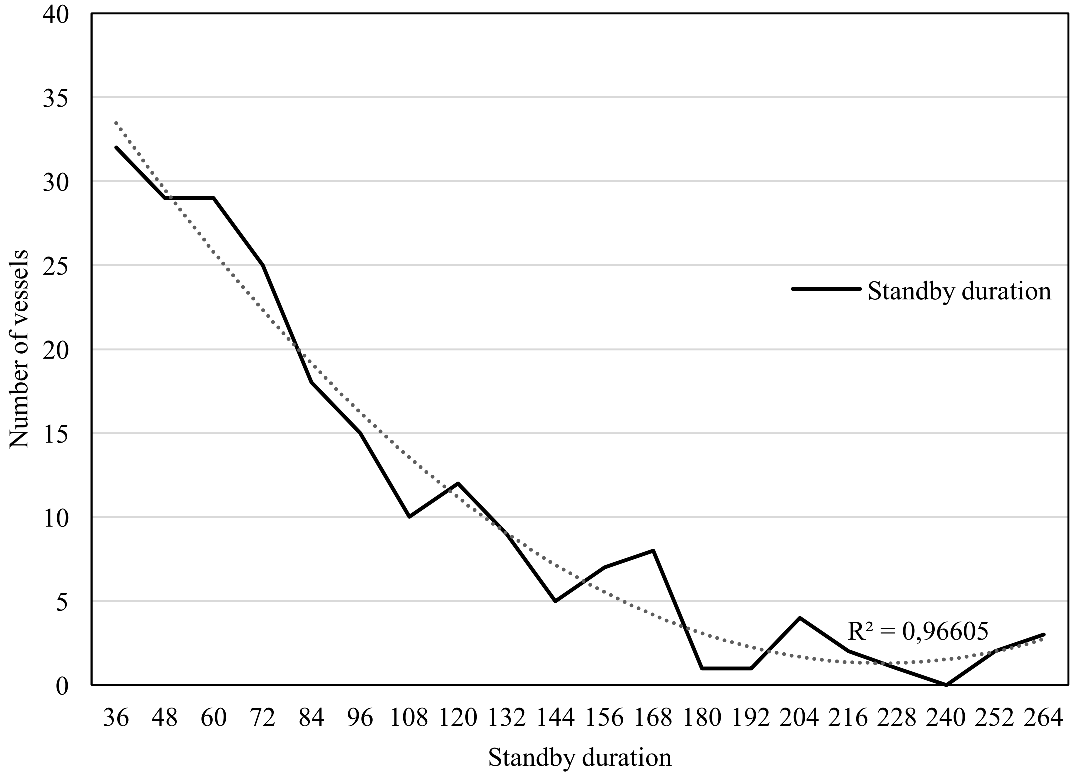
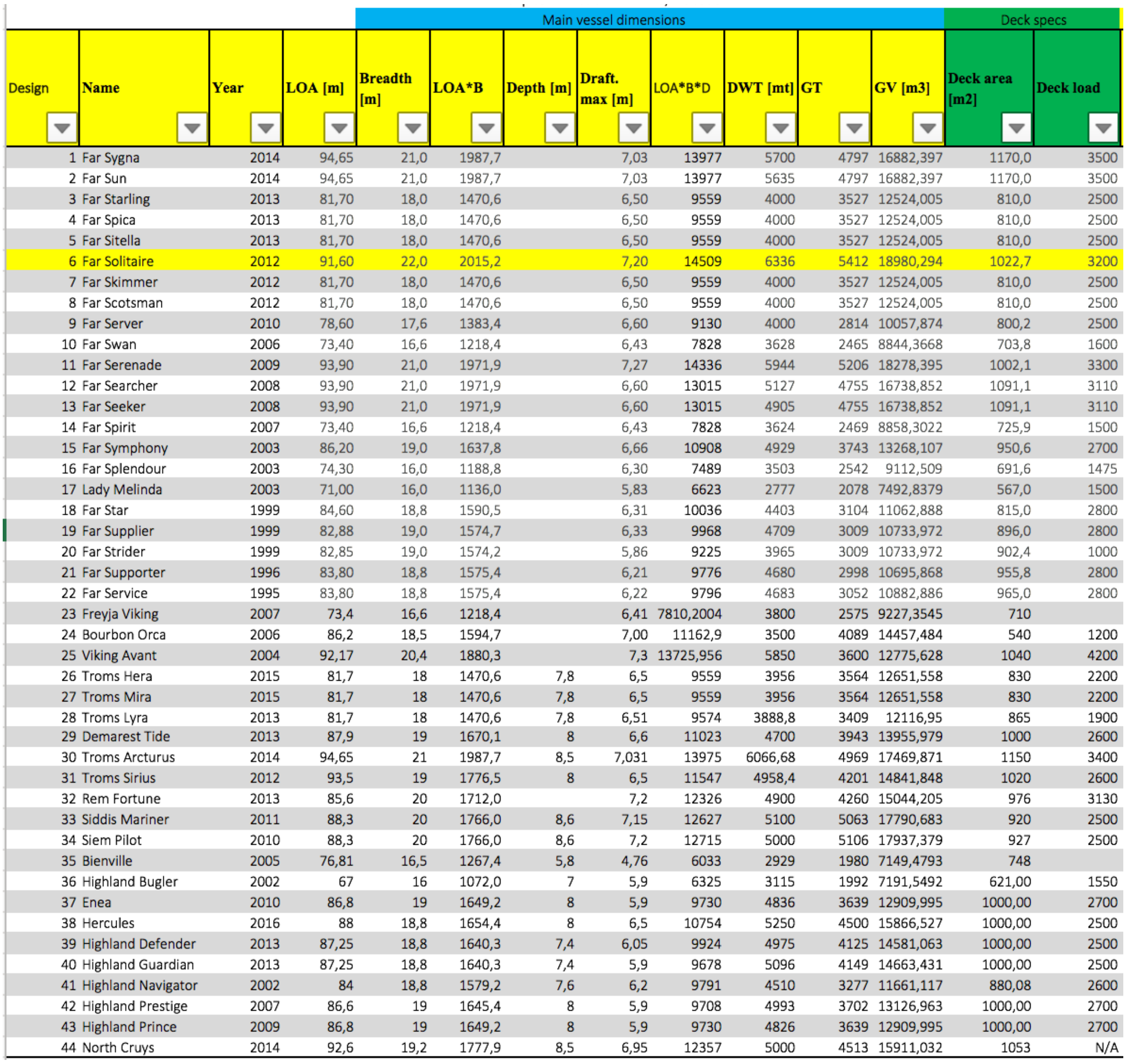


Figure 36A: Standby duration for all dedicated storage vessels at Oseberg field March 2016 - March 2017

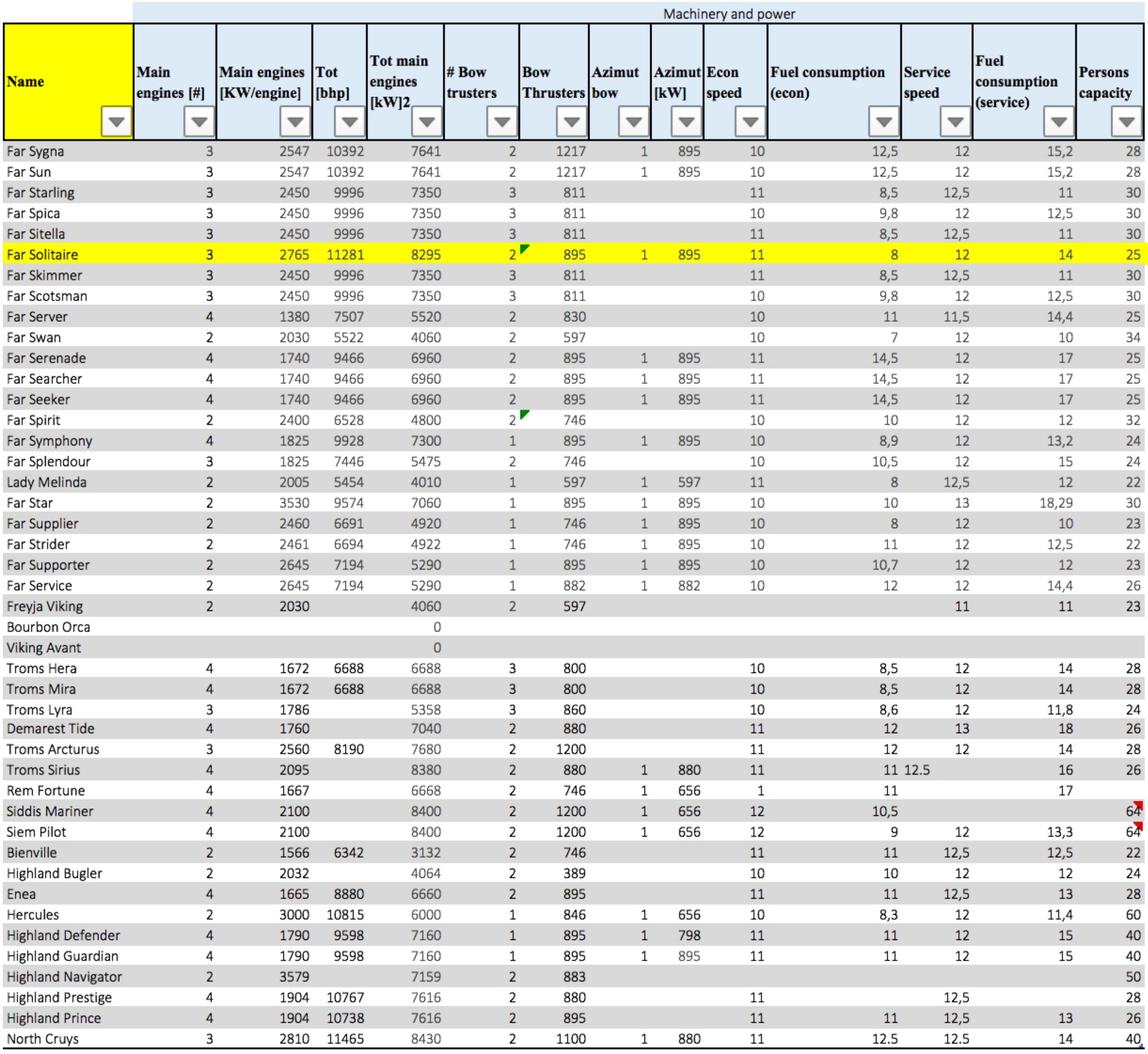
Appendix C: Parametric analysis of PSVs (Windsland, 2016)

This work is done in its entirety in the authors project thesis fall 2016, however, the vessel data here are used to verify and guide the final design presented in this thesis.



				Main vessel dimensions								Deck specs	
Design	Name	Year	LOA [m]	Breadth [m]	LOA*B	Depth [m]	Draft. max [m]	LOA*B*D	DWT [mt]	GT	GV [m3]	Deck area [m2]	Deck load
1	Far Sygna	2014	94,65	21,0	1987,7		7,03	13977	5700	4797	16882,397	1170,0	3500
2	Far Sun	2014	94,65	21,0	1987,7		7,03	13977	5635	4797	16882,397	1170,0	3500
3	Far Starling	2013	81,70	18,0	1470,6		6,50	9559	4000	3527	12524,005	810,0	2500
4	Far Spica	2013	81,70	18,0	1470,6		6,50	9559	4000	3527	12524,005	810,0	2500
5	Far Sitella	2013	81,70	18,0	1470,6		6,50	9559	4000	3527	12524,005	810,0	2500
6	Far Solitaire	2012	91,60	22,0	2015,2		7,20	14509	6336	5412	18980,294	1022,7	3200
7	Far Skimmer	2012	81,70	18,0	1470,6		6,50	9559	4000	3527	12524,005	810,0	2500
8	Far Scotsman	2012	81,70	18,0	1470,6		6,50	9559	4000	3527	12524,005	810,0	2500
9	Far Server	2010	78,60	17,6	1383,4		6,60	9130	4000	2814	10057,874	800,2	2500
10	Far Swan	2006	73,40	16,6	1218,4		6,43	7828	3628	2465	8844,3668	703,8	1600
11	Far Serenade	2009	93,90	21,0	1971,9		7,27	14336	5944	5206	18278,395	1002,1	3300
12	Far Searcher	2008	93,90	21,0	1971,9		6,60	13015	5127	4755	16738,852	1091,1	3110
13	Far Seeker	2008	93,90	21,0	1971,9		6,60	13015	4905	4755	16738,852	1091,1	3110
14	Far Spirit	2007	73,40	16,6	1218,4		6,43	7828	3624	2469	8858,3022	725,9	1500
15	Far Symphony	2003	86,20	19,0	1637,8		6,66	10908	4929	3743	13268,107	950,6	2700
16	Far Splendour	2003	74,30	16,0	1188,8		6,30	7489	3503	2542	9112,509	691,6	1475
17	Lady Melinda	2003	71,00	16,0	1136,0		5,83	6623	2777	2078	7492,8379	567,0	1500
18	Far Star	1999	84,60	18,8	1590,5		6,31	10036	4403	3104	11062,888	815,0	2800
19	Far Supplier	1999	82,88	19,0	1574,7		6,33	9968	4709	3009	10733,972	896,0	2800
20	Far Strider	1999	82,85	19,0	1574,2		5,86	9225	3965	3009	10733,972	902,4	1000
21	Far Supporter	1996	83,80	18,8	1575,4		6,21	9776	4680	2998	10695,868	955,8	2800
22	Far Service	1995	83,80	18,8	1575,4		6,22	9796	4683	3052	10882,886	965,0	2800
23	Freyja Viking	2007	73,4	16,6	1218,4		6,41	7810,2004	3800	2575	9227,3545	710	
24	Bourbon Orca	2006	86,2	18,5	1594,7		7,00	11162,9	3500	4089	14457,484	540	1200
25	Viking Avant	2004	92,17	20,4	1880,3		7,3	13725,956	5850	3600	12775,628	1040	4200
26	Troms Hera	2015	81,7	18	1470,6	7,8	6,5	9559	3956	3564	12651,558	830	2200
27	Troms Mira	2015	81,7	18	1470,6	7,8	6,5	9559	3956	3564	12651,558	830	2200
28	Troms Lyra	2013	81,7	18	1470,6	7,8	6,51	9574	3888,8	3409	12116,95	865	1900
29	Demarest Tide	2013	87,9	19	1670,1	8	6,6	11023	4700	3943	13955,979	1000	2600
30	Troms Arcturus	2014	94,65	21	1987,7	8,5	7,031	13975	6066,68	4969	17469,871	1150	3400
31	Troms Sirius	2012	93,5	19	1776,5	8	6,5	11547	4958,4	4201	14841,848	1020	2600
32	Rem Fortune	2013	85,6	20	1712,0		7,2	12326	4900	4260	15044,205	976	3130
33	Siddis Mariner	2011	88,3	20	1766,0	8,6	7,15	12627	5100	5063	17790,683	920	2500
34	Siem Pilot	2010	88,3	20	1766,0	8,6	7,2	12715	5000	5106	17937,379	927	2500
35	Bienville	2005	76,81	16,5	1267,4	5,8	4,76	6033	2929	1980	7149,4793	748	
36	Highland Bugler	2002	67	16	1072,0	7	5,9	6325	3115	1992	7191,5492	621,00	1550
37	Enea	2010	86,8	19	1649,2	8	5,9	9730	4836	3639	12909,995	1000,00	2700
38	Hercules	2016	88	18,8	1654,4	8	6,5	10754	5250	4500	15866,527	1000,00	2500
39	Highland Defender	2013	87,25	18,8	1640,3	7,4	6,05	9924	4975	4125	14581,063	1000,00	2500
40	Highland Guardian	2013	87,25	18,8	1640,3	7,4	5,9	9678	5096	4149	14663,431	1000,00	2500
41	Highland Navigator	2002	84	18,8	1579,2	7,6	6,2	9791	4510	3277	11661,117	880,08	2600
42	Highland Prestige	2007	86,6	19	1645,4	8	5,9	9708	4993	3702	13126,963	1000,00	2700
43	Highland Prince	2009	86,8	19	1649,2	8	5,9	9730	4826	3639	12909,995	1000,00	2700
44	North Cruys	2014	92,6	19,2	1777,9	8,5	6,95	12357	5000	4513	15911,032	1053	N/A

	Tank specification and arrangement																
Name	Fuel oil [m3]	# Fuel oil tanks	Pot water [m3]	# Pot water tanks	Drill water/WB [m3]	# Drill/WB tanks	Liquid mud [m3]	# Mud tanks	Brine [m3]	# Brine tanks	ORO [m3]	Base oil [m3]	# Base oil tanks	Methanol [m3]	# Methanol tanks	Dry bulk [m3] (Barite?)	# Dry bulk tanks
Far Sygna	1334		828		2806		1005		787			152		151		301	6
Far Sun	1331		813		2751		1003		785			152		151		301	6
Far Starling	917		730		1915		1270		1270			319		100		251	4
Far Spica	917		730		1915		1270		1270			319		100		251	4
Far Sitella	917		730		1915		1270		1270			319		100		251	4
Far Solitaire	1146		739		2447		1316		1559			403		403		229	4
Far Skimmer	917		730		1915		1270		1270			319		100		251	4
Far Scotsman	917		730		1915		1270		1270			319		100		251	4
Far Server	877		823		1257		975		975			155		178		296	5
Far Swan	1095		775		714		1072		859			214		179		340	4
Far Serenade	1260		1158		2522		1137		388			276		218		201	4
Far Searcher	1319	7	989	8	1457	7	911	6	404	4		240	2	206	2	353	8
Far Seeker	1319		989		1457		911		404			240		206		308	7
Far Spirit	1048		776		716		1072		856			214		191		340	4
Far Symphony	1678		736		550		837		804			305		163		288	6
Far Splendour	749		502		1281		785		417			190		211		253	4
Lady Melinda	1047		572		946		775		387			0		169		269	4
Far Star	1502,4		1684		1063		695		306			260		0		400	8
Far Supplier	1245		1017		894		680		352			221		108		400	8
Far Strider	3086		973		1057		0		0			0		0		400	8
Far Supporter	1668		1735		832		532		740			196		0		300	6
Far Service	1518		1399		894		503		377			198		0		300	6
Freyja Viking	1109		912		816		1071		1071			214				340	8
Bourbon Orca	1485		505		2480				560			445				255	
Viking Avant	1440		1040		2300		740		810			263		160		410	
Troms Hera	933	16	766	11	1821	24	1273	8	1273	8		305	3	221	2	305	4
Troms Mira	933	16	766	11	1821	24	1273	8	1273	8		305	3	221	2	305	4
Troms Lyra	1035	16	600	12	1840	24	1230	8	1230	8		310	2	100	2	250	4
Demarest Tide	1180	12	773	12	2650	22	967	8	967	8	1550	240	4	162	2	322	8
Troms Arcturus	1664	18	828	11	2690	22	1003	8	700	8	combo	152	2	150	2	300	6
Troms Sirius	1250	9	719	10	2747	27	1300	10	1300	10	1808	189	2	160	2	324	6
Rem Fortune	950		1007		2500		700	<=>	700			210		150		330	
Siddis Mariner	904		985		2289		703		539		1800	204		146		432	
Siem Pilot	904		985		2289		703		539		1800	204		146		432	
Bienville	541		801		478		1306									202	
Highland Bugler	861	9	810	8	889	10	772	8	<<<	8		208	2			255	
Enea	1038		1175		3476		959		1458			423		167		260	
Hercules	1100		1025		1650		2403				706			374		324	
Highland Defender	910	6	947	13	1843	19	2060	4+4	<<<<	4+4		231	2	335	2	425	5
Highland Guardian	911	6	947	13	1843	19	2060	4+4	<<<<	4+4		231	2	336	2	425	5
Highland Navigator	1189	14	1105	6	1383	6	693	8	919	7		232	2			396	
Highland Prestige	1593	16	1346	10	2720	15	1043	8	1869	12		319	3	130	2	365	8
Highland Prince	1038	12	1175	12	4225	17+10	962	6+2	1487	2+3+6		222	2+2 (167m3	167	2	265	6
North Cruys	1172	12	1097	13	1820	6+11	1203	10+4	1203	4+10	1963	535	2+2	330		365	



	Machinery and power												
Name	**Main engines [#]**	**Main engines [KW/engine]**	**Tot [bhp]**	**Tot main engines [kW]2**	**# Bow trusters**	**Bow Thrusters**	**Azimut bow**	**Azimut [kW]**	**Econ speed**	**Fuel consumption (econ)**	**Service speed**	**Fuel consumption (service)**	**Persons capacity**
Far Sygna	3	2547	10392	7641	2	1217	1	895	10	12,5	12	15,2	28
Far Sun	3	2547	10392	7641	2	1217	1	895	10	12,5	12	15,2	28
Far Starling	3	2450	9996	7350	3	811			11	8,5	12,5	11	30
Far Spica	3	2450	9996	7350	3	811			10	9,8	12	12,5	30
Far Sitella	3	2450	9996	7350	3	811			11	8,5	12,5	11	30
Far Solitaire	3	2765	11281	8295	2	895	1	895	11	8	12	14	25
Far Skimmer	3	2450	9996	7350	3	811			11	8,5	12,5	11	30
Far Scotsman	3	2450	9996	7350	3	811			10	9,8	12	12,5	30
Far Server	4	1380	7507	5520	2	830			10	11	11,5	14,4	25
Far Swan	2	2030	5522	4060	2	597			10	7	12	10	34
Far Serenade	4	1740	9466	6960	2	895	1	895	11	14,5	12	17	25
Far Searcher	4	1740	9466	6960	2	895	1	895	11	14,5	12	17	25
Far Seeker	4	1740	9466	6960	2	895	1	895	11	14,5	12	17	25
Far Spirit	2	2400	6528	4800	2	746			10	10	12	12	32
Far Symphony	4	1825	9928	7300	1	895	1	895	10	8,9	12	13,2	24
Far Splendour	3	1825	7446	5475	2	746			10	10,5	12	15	24
Lady Melinda	2	2005	5454	4010	1	597	1	597	11	8	12,5	12	22
Far Star	2	3530	9574	7060	1	895	1	895	10	10	13	18,29	30
Far Supplier	2	2460	6691	4920	1	746	1	895	10	8	12	10	23
Far Strider	2	2461	6694	4922	1	746	1	895	10	11	12	12,5	22
Far Supporter	2	2645	7194	5290	1	895	1	895	10	10,7	12	12	23
Far Service	2	2645	7194	5290	1	882	1	882	10	12	12	14,4	26
Freyja Viking	2	2030		4060	2	597					11	11	23
Bourbon Orca				0									
Viking Avant				0									
Troms Hera	4	1672	6688	6688	3	800			10	8,5	12	14	28
Troms Mira	4	1672	6688	6688	3	800			10	8,5	12	14	28
Troms Lyra	3	1786		5358	3	860			10	8,6	12	11,8	24
Demarest Tide	4	1760		7040	2	880			11	12	13	18	26
Troms Arcturus	3	2560	8190	7680	2	1200			11	12	12	14	28
Troms Sirius	4	2095		8380	2	880	1	880	11	11	12.5	16	26
Rem Fortune	4	1667		6668	2	746	1	656	1	11		17	
Siddis Mariner	4	2100		8400	2	1200	1	656	12	10,5			64
Siem Pilot	4	2100		8400	2	1200	1	656	12	9	12	13,3	64
Bienville	2	1566	6342	3132	2	746			11	11	12,5	12,5	22
Highland Bugler	2	2032		4064	2	389			10	10	12	12	24
Enea	4	1665	8880	6660	2	895			11	11	12,5	13	28
Hercules	2	3000	10815	6000	1	846	1	656	10	8,3	12	11,4	60
Highland Defender	4	1790	9598	7160	1	895	1	798	11	11	12	15	40
Highland Guardian	4	1790	9598	7160	1	895	1	895	11	11	12	15	40
Highland Navigator	2	3579		7159	2	883							50
Highland Prestige	4	1904	10767	7616	2	880			11		12,5		28
Highland Prince	4	1904	10738	7616	2	895			11	11	12,5	13	26
North Cruys	3	2810	11465	8430	2	1100	1	880	11	12.5	12.5	14	40

Appendix D: System Based Ship Design Spreadsheets

Mission description and design concept

Ship Identification	
Project	Offshore Liquid Bulk Support Vessel
Name	Yngve Windsland

Mission Description	
Operation Area:	North Sea
Description:	Year round support vessel
Target Market:	Support Offshore Drilling Operations

Payload Capacity and Performance	
Cargo Capacity	Drilling fluids and additives
Endurance:	14 days
Range:	166 nautical miles
Trial Speed	14 knots

Machinery and Rough Power Demand	
Machinery Type:	Diesel electric main propulsion
Auxiliary Power:	Generators
Generators:	
Propulsion	Twin azimuth stern
Tunnel thrusters	Two forward
Azimuth bow	One retractable forward

Rules and Regulations	
Class:	DNV
Flag:	Norwegian
Crew:	25 persons

Restrictions to Main Dimensions	
On Routes:	
At Platforms:	Height/length/dwt
In Ports:	Depth

OPERATION, ROUTE, AND SCHEDULE

Ship Performance	Service Speed	12	kn
	Power	75	% MCR
	Sea Margin	25	% MCR
	OBM Processing	20	m3/hour

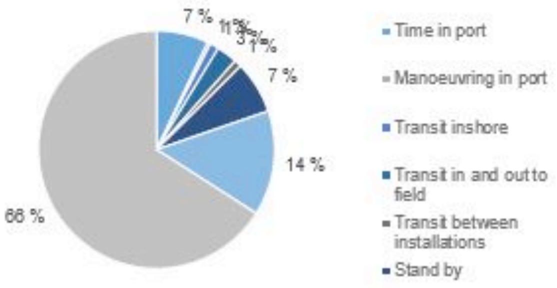
Transit Route	Mongstad onshore base	-	Oseberg oil and gas field
Distance roundtrip	166 nm		

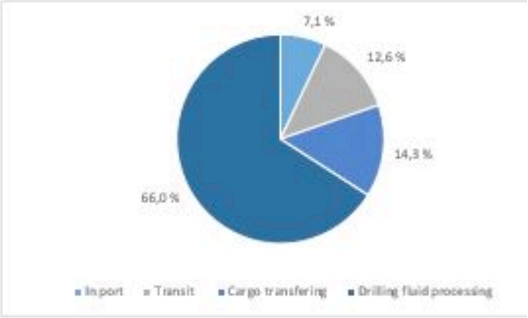
Transit Schedule	Out	In	Transfer Trip
Time in port	12 hours	12 hours	24 hours
Manoeuvring in port	0,7 hours	0,7 hours	1,41 hours
Transit inshore	2,0 hours	2,0 hours	4,1 hours
Transit in and out to field	4,8 hours	4,8 hours	9,5175 hours
Transit between installations	1,7 hours	1,7 hours	3,45 hours
Average speed	9,9 kn	9,9 kn	9,9 kn
Propulsion power	26 %	26 %	26 %

	Field service	Stand by	Cargo transfering	Drilling fluid processing
	Time per trip			
Usikker	Propulsion power			
Usikker	Shaft generators			
Usikker	Auxiliary power			

		Total roundtrip
Time per trip	14 Days	336 hours
Number of trips		25 per year
Operating days		350 per year

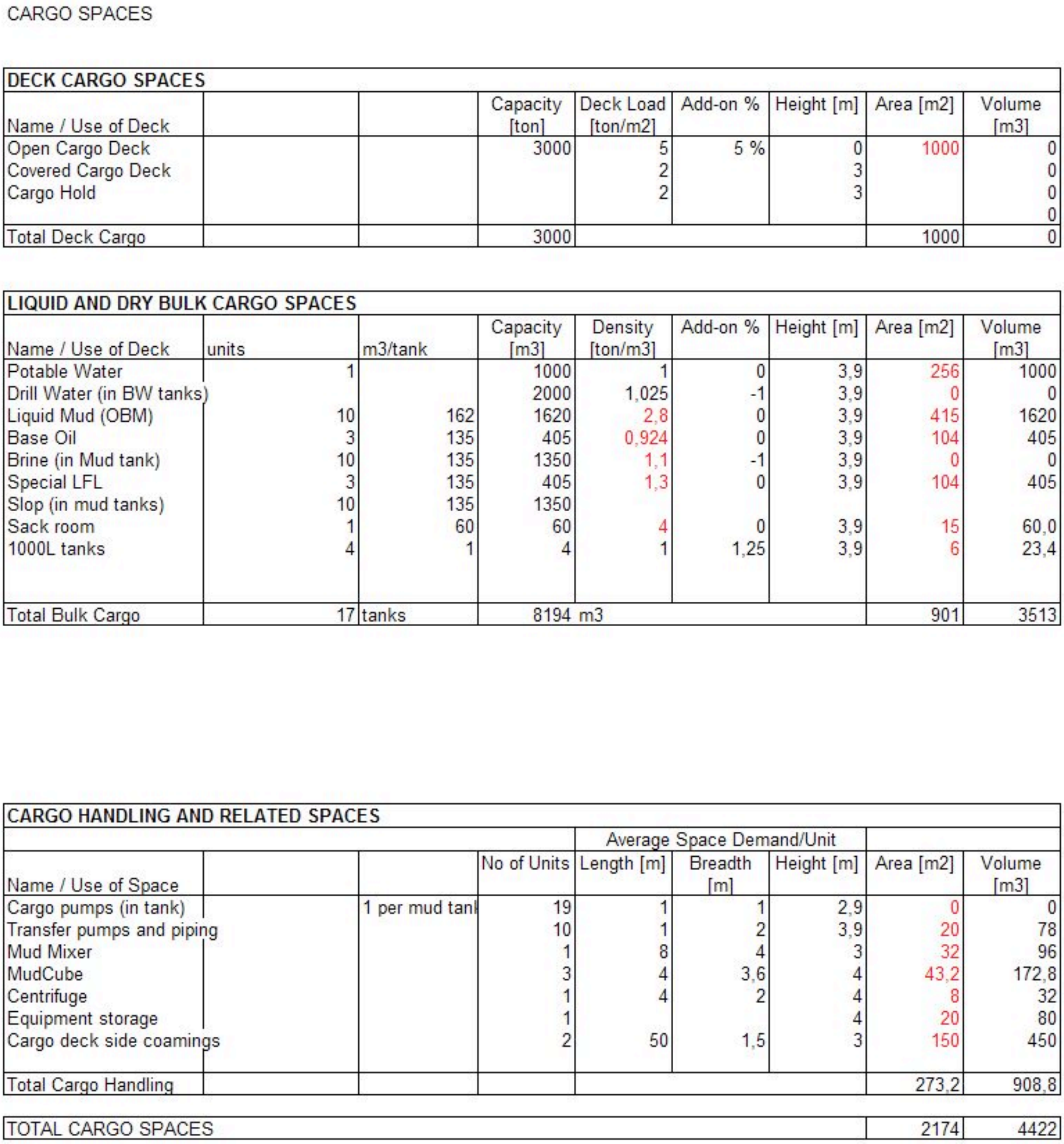
Time in port	24,0	7 %	Simplified =>	In port	24,0	7,1 %
Manoeuvring in port	1,4	0 %		Transit	42,5	12,6 %
Transit inshore	4,1	1 %		Cargo transfe	48,0	14,3 %
Transit in and out to field	9,5	3 %		Drilling fluid pı	222,0	66,0 %
Transit between installatio	3,5	1 %			336,5	
Stand by	24,0	7 %				
Cargo transfering	48,0	14 %				
Drilling fluid processing	222,0	66 %				





Operation	Distance	Speed	Time
Maneuvering in port	1,4 nm	2 nm/hr	0,7 hours
Transit inshore	14,3 nm	7 nm/hr	2,0 hours
Transit out to field	51,3 nm	12 nm/hr	4,3 hours
Transit OSO - OSC	7,3 nm	12 nm/hr	0,6 hours
Transit OSC - OSB	7,1 nm	12 nm/hr	0,6 hours
Transit OSB - OSS	6,3 nm	12 nm/hr	0,5 hours
Transit back to shore	62,9 nm	12 nm/hr	5,2 hours
Transit inshore	14,3 nm	7 nm/hr	2,0 hours
Manoeuverun in port	1,4 nm	2 nm/hr	0,7 hours
SUM Distance	166,3 nm	SUM Time	16,7 hours

NB! The pie diagrams presented above are the same as presented in main text, if not readable.



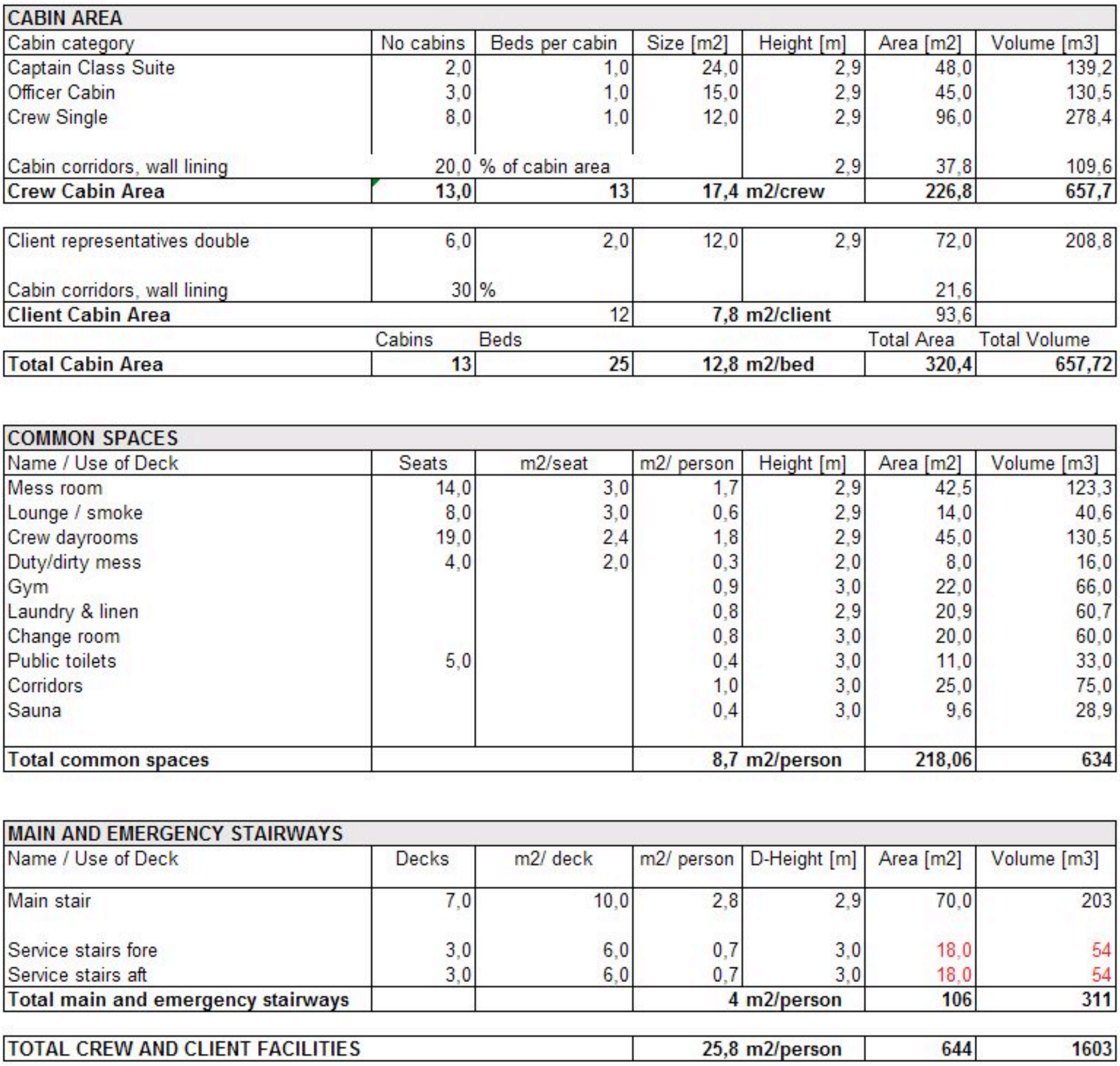
CARGO SPACES

DECK CARGO SPACES								
Name / Use of Deck			Capacity [ton]	Deck Load [ton/m2]	Add-on %	Height [m]	Area [m2]	Volume [m3]
Open Cargo Deck			3000	5	5 %	0	1000	0
Covered Cargo Deck				2		3		0
Cargo Hold				2		3		0
								0
Total Deck Cargo			3000				1000	0

LIQUID AND DRY BULK CARGO SPACES								
Name / Use of Deck	units	m3/tank	Capacity [m3]	Density [ton/m3]	Add-on %	Height [m]	Area [m2]	Volume [m3]
Potable Water	1		1000	1	0	3,9	256	1000
Drill Water (in BW tanks)			2000	1,025	-1	3,9	0	0
Liquid Mud (OBM)	10	162	1620	2,8	0	3,9	415	1620
Base Oil	3	135	405	0,924	0	3,9	104	405
Brine (in Mud tank)	10	135	1350	1,1	-1	3,9	0	0
Special LFL	3	135	405	1,3	0	3,9	104	405
Slop (in mud tanks)	10	135	1350					
Sack room	1	60	60	4	0	3,9	15	60,0
1000L tanks	4	1	4	1	1,25	3,9	6	23,4
Total Bulk Cargo	17	tanks	8194	m3			901	3513

CARGO HANDLING AND RELATED SPACES								
				Average Space Demand/Unit				
Name / Use of Space			No of Units	Length [m]	Breadth [m]	Height [m]	Area [m2]	Volume [m3]
Cargo pumps (in tank)		1 per mud tan	19	1	1	2,9	0	0
Transfer pumps and piping			10	1	2	3,9	20	78
Mud Mixer			1	8	4	3	32	96
MudCube			3	4	3,6	4	43,2	172,8
Centrifuge			1	4	2	4	8	32
Equipment storage			1			4	20	80
Cargo deck side coamings			2	50	1,5	3	150	450
Total Cargo Handling							273,2	908,8

TOTAL CARGO SPACES	Area [m2]	Volume [m3]
	2174	4422



CABIN AREA

Cabin category	No cabins	Beds per cabin	Size [m2]	Height [m]	Area [m2]	Volume [m3]
Captain Class Suite	2,0	1,0	24,0	2,9	48,0	139,2
Officer Cabin	3,0	1,0	15,0	2,9	45,0	130,5
Crew Single	8,0	1,0	12,0	2,9	96,0	278,4
Cabin corridors, wall lining	20,0	% of cabin area		2,9	37,8	109,6
Crew Cabin Area	**13,0**	**13**	**17,4**	**m2/crew**	**226,8**	**657,7**
Client representatives double	6,0	2,0	12,0	2,9	72,0	208,8
Cabin corridors, wall lining	30	%			21,6	
Client Cabin Area		**12**	**7,8**	**m2/client**	**93,6**	
	Cabins	Beds			Total Area	Total Volume
Total Cabin Area	**13**	**25**	**12,8**	**m2/bed**	**320,4**	**657,72**

COMMON SPACES

Name / Use of Deck	Seats	m2/seat	m2/ person	Height [m]	Area [m2]	Volume [m3]
Mess room	14,0	3,0	1,7	2,9	42,5	123,3
Lounge / smoke	8,0	3,0	0,6	2,9	14,0	40,6
Crew dayrooms	19,0	2,4	1,8	2,9	45,0	130,5
Duty/dirty mess	4,0	2,0	0,3	2,0	8,0	16,0
Gym			0,9	3,0	22,0	66,0
Laundry & linen			0,8	2,9	20,9	60,7
Change room			0,8	3,0	20,0	60,0
Public toilets	5,0		0,4	3,0	11,0	33,0
Corridors			1,0	3,0	25,0	75,0
Sauna			0,4	3,0	9,6	28,9
Total common spaces			**8,7**	**m2/person**	**218,06**	**634**

MAIN AND EMERGENCY STAIRWAYS

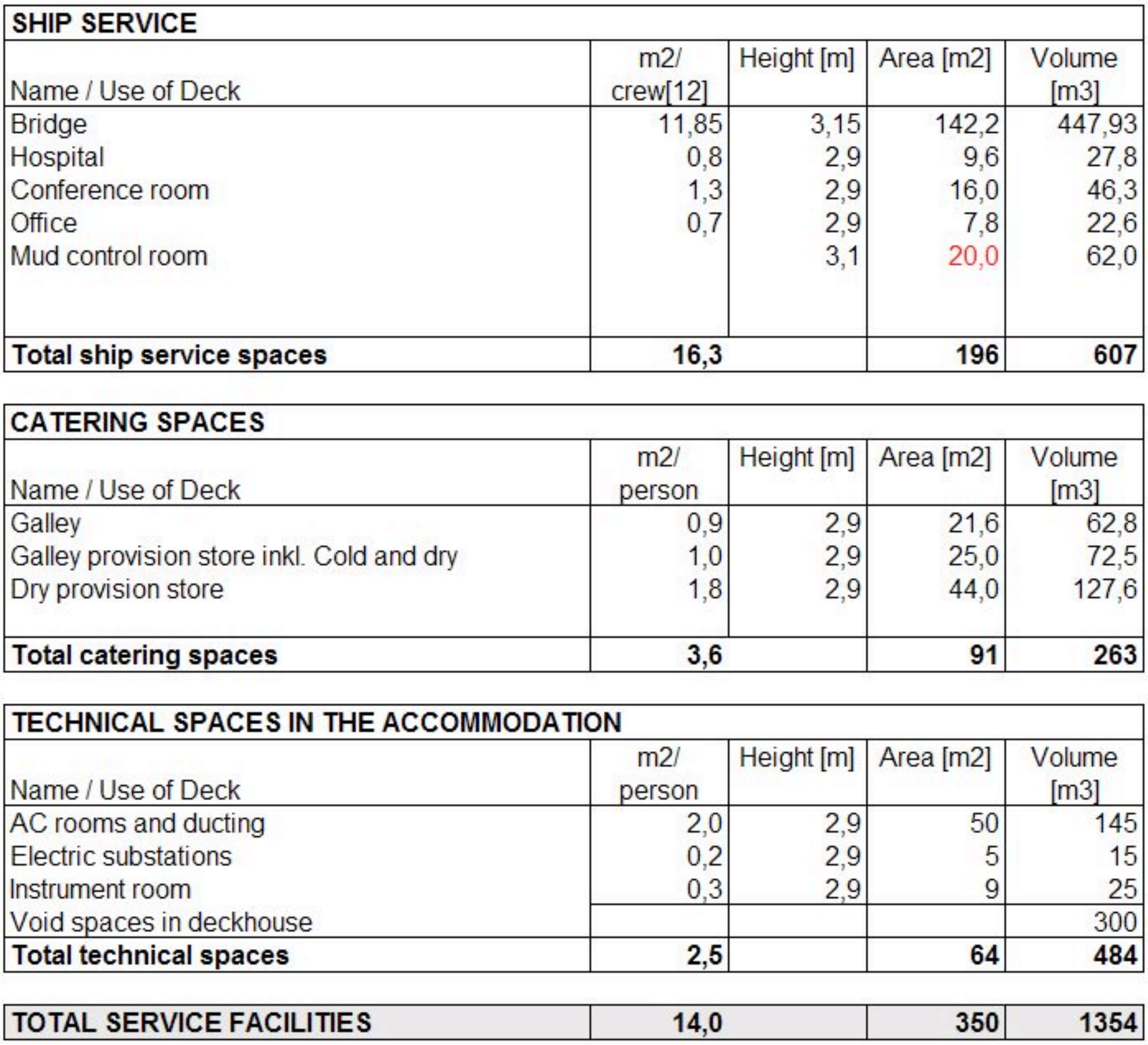
Name / Use of Deck	Decks	m2/ deck	m2/ person	D-Height [m]	Area [m2]	Volume [m3]
Main stair	7,0	10,0	2,8	2,9	70,0	203
Service stairs fore	3,0	6,0	0,7	3,0	18,0	54
Service stairs aft	3,0	6,0	0,7	3,0	18,0	54
Total main and emergency stairways			**4**	**m2/person**	**106**	**311**
TOTAL CREW AND CLIENT FACILITIES			**25,8**	**m2/person**	**644**	**1603**

MACHINERY, SPEED AND POWER		
Machinery type	Diesel Electric	
No of propellers	2	
Propeller diameter	3,05 m	Propeller load
Bollard pull	125 ton	assumed
	Trial Condition	Endurance Condition
Speed	14 kn	12 kn
Propulsion power	6630 kW	5100 kW
Load factor	100 %	70 %
Sea margin	0 %	30 %
Generators	10000 kW	2500 kW
Load factor	0 %	25 %
Auxiliary	0 kW	0 kW
Load factor	100 %	0 %
Total installed power	10000 kW	

Asssumed 10000 kW due to the reccomendations in the compendium made by Levander

MACHINERY SPACES							
Name / Use of Space		m2/kW	m3/kW	Height [m]	Area [m2]	Volume [m3]	
Main and auxiliary engine rooms		0,035	0,15	4	350	1400	Error source
Shaftlines, propellers, propulsion thrusters		0,01	0,04	4	100	400	Error source
Emergency generator, battery room		0,002	0,01	3,1	20	62	
SUM					470	1862	
Pump rooms and equipment spaces		0,003	0,01	4	30	120	
Workshops and stores		0,003721	0,01	4	37	149	
ECR and switchborad room		0,003	0,01	4	30	120	
Firefighting system, CO2 room		0,002	0,01	4	20	80	
SUM					117	469	
	Decks	m2/deck					
Engine casing	6,0	25,0	-	3,0	150,0	450	
Air intakes	6,0	15,0		3,0	90,0	270	
Funnel	1,0	10,0	-	5,0		50	
SUM					**240**	770	

Total machinery spaces	**0,31 m3/kW**	**827**	**3101**



SHIP SERVICE				
Name / Use of Deck	m2/ crew[12]	Height [m]	Area [m2]	Volume [m3]
Bridge	11,85	3,15	142,2	447,93
Hospital	0,8	2,9	9,6	27,8
Conference room	1,3	2,9	16,0	46,3
Office	0,7	2,9	7,8	22,6
Mud control room		3,1	20,0	62,0
Total ship service spaces	**16,3**		**196**	**607**

CATERING SPACES				
Name / Use of Deck	m2/ person	Height [m]	Area [m2]	Volume [m3]
Galley	0,9	2,9	21,6	62,8
Galley provision store inkl. Cold and dry	1,0	2,9	25,0	72,5
Dry provision store	1,8	2,9	44,0	127,6
Total catering spaces	**3,6**		**91**	**263**

TECHNICAL SPACES IN THE ACCOMMODATION				
Name / Use of Deck	m2/ person	Height [m]	Area [m2]	Volume [m3]
AC rooms and ducting	2,0	2,9	50	145
Electric substations	0,2	2,9	5	15
Instrument room	0,3	2,9	9	25
Void spaces in deckhouse				300
Total technical spaces	**2,5**		**64**	**484**

TOTAL SERVICE FACILITIES	**14,0**		**350**	**1354**

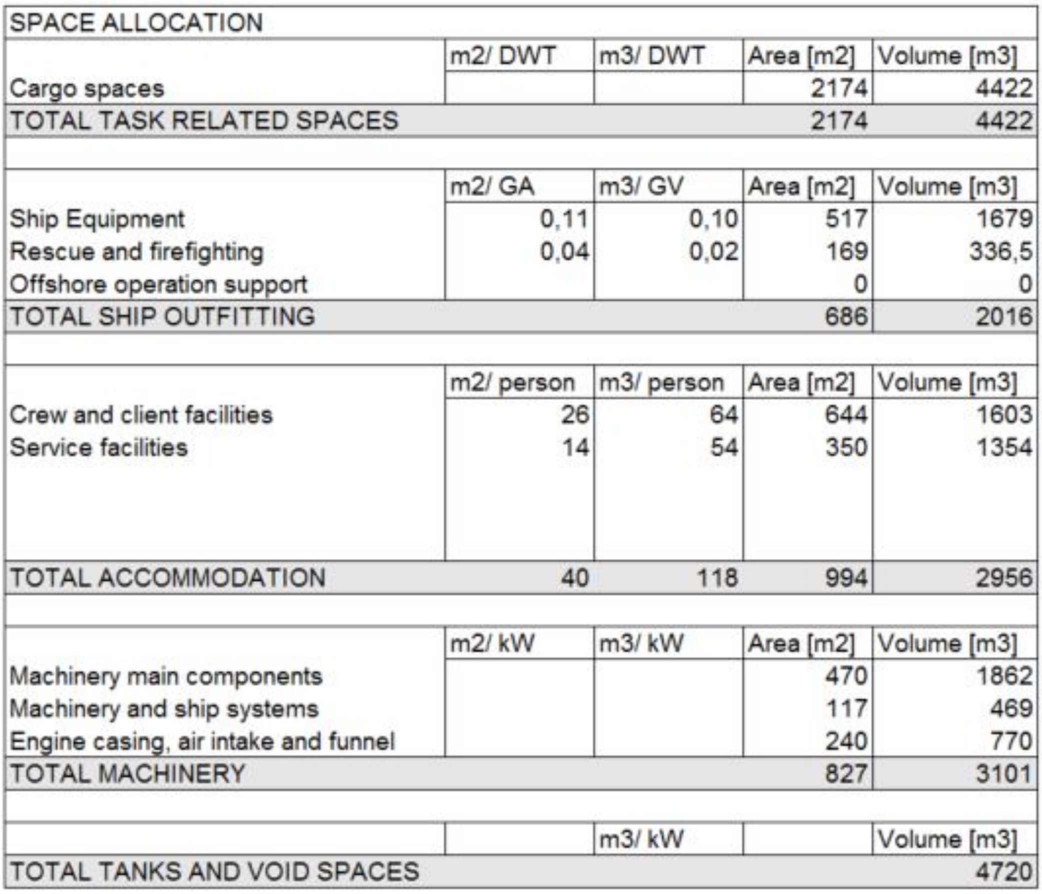
SHIP EQUIPMENT							
Name / Use of Deck	Units	Power [kW/unit]	Area [m2]/Unit	Covered %	Height [m]	Covered Area [m2]	Covered Volume [m3]
Tunnel thrusters	2	10	20	1	6	40	240
Retractable thrusters	1	895	35	1	1,5	35	52,5
Propulsion room aft	1		140	1	2,2	140	308
Hose connections station	2		20	1	6,5	40	260
Mooring deck forward	1		94	1	2,9	94	272,6
Mooring deck aft	2		10	1	2,9	20	58
Incinerator plant	1		12	1	3	12	36
Deck stores (paint + work shop)	3		14	1	3	42	126
Rope stores	1		50	1	3	50	150
Hydr. Powerpack room	1		44	1	4	44	176
Other open decks	1		150				
Total ship equipment spaces		915	589			517	1679

RESQUE AND FIREFIGHTING							
Name / Use of Deck	Number	Area [m2/unit]	Area [m2]	Covered %	Height [m]	Covered Area [m2]	Covered Volume [m3]
MOB + cradle/crane	1	40	40	1	6,0	40	240
Life saving appliances	50	0,5	25	1	2,9	25	73
FiFi equipment	24	4	96	0	3,0	0	0
Fi Eq Store	1	8	8	1	3,0	8	24
Total rescue and firefighting spaces			169			73	337

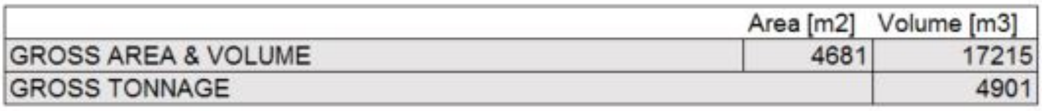
TOTAL SHIP OUTFITTING			169			590	2016

TANKS AND VOID SPACES (ship use)						
Name / Use of space	Consumption g/kWh	Consumption ton/day	Range [nm]	Endurance [days]	Margin factor	Volume [m3]
Fuel oil	200	36,48		14	2	1021
Lub oil	1	0,182		14	5	13
	l/day/person					
Fresh Water	200	5		28	1,2	168
Sewage + Gray wate	200	5		3	1,2	18
Ballast water				and drill water tanks		2000
Passive anti-roll tanks						700
Cofferdam and void						500
Other tanks						300
Tanks and void spaces						4720

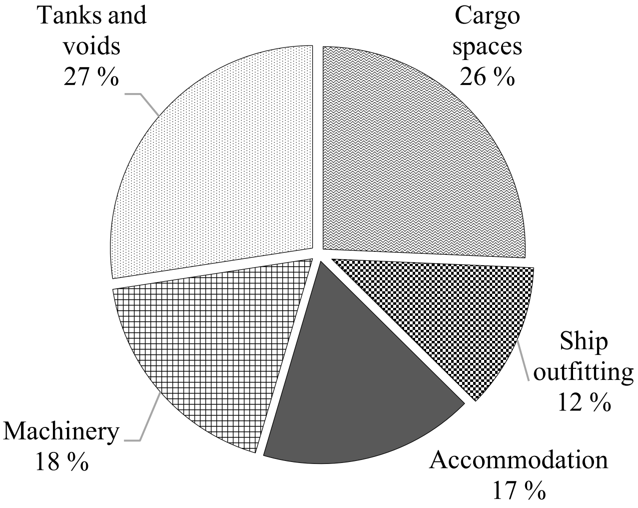
Appendix E: System summary



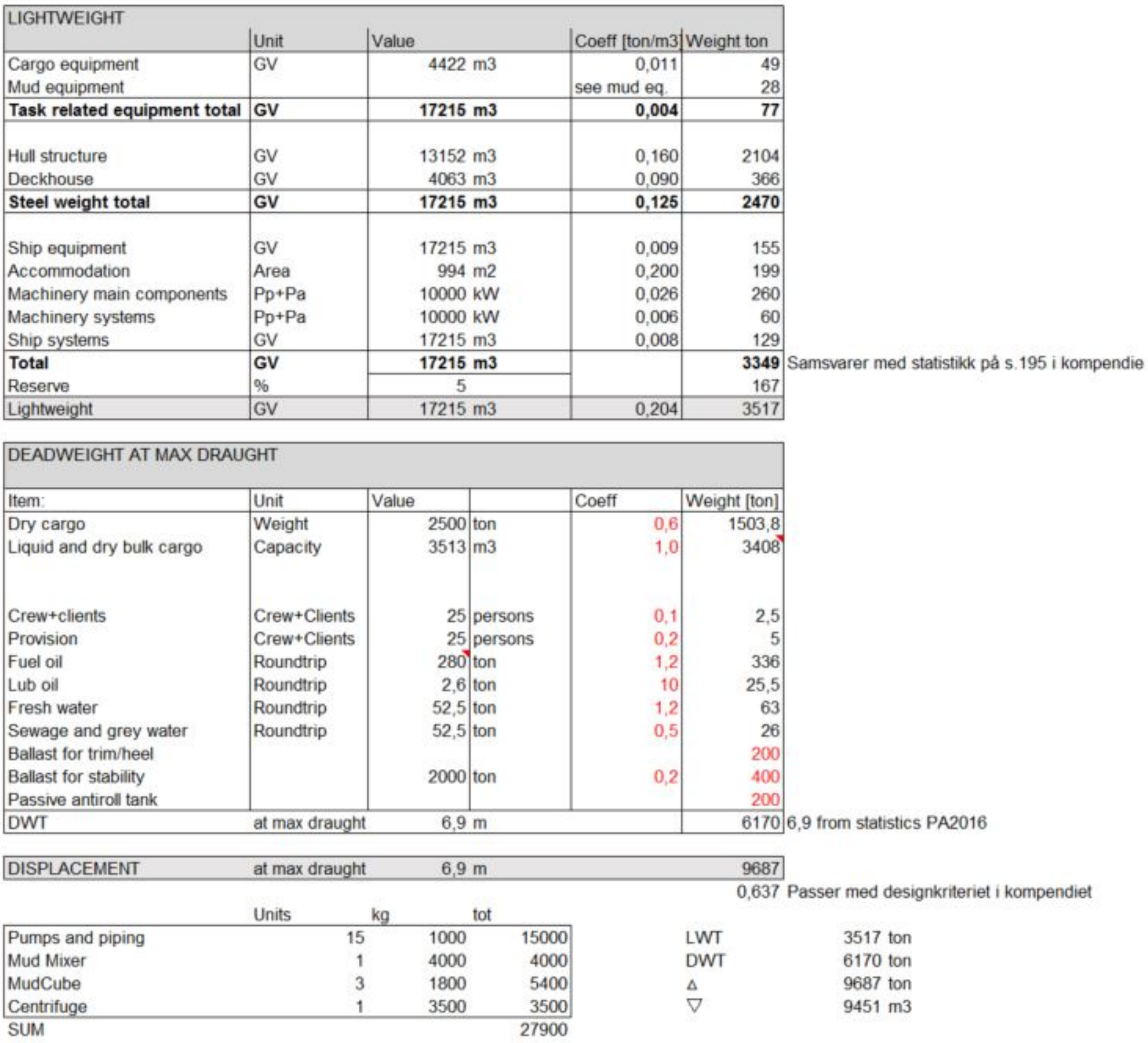
SPACE ALLOCATION				
	m2/ DWT	m3/ DWT	Area [m2]	Volume [m3]
Cargo spaces			2174	4422
TOTAL TASK RELATED SPACES			2174	4422
	m2/ GA	m3/ GV	Area [m2]	Volume [m3]
Ship Equipment	0,11	0,10	517	1679
Rescue and firefighting	0,04	0,02	169	336,5
Offshore operation support			0	0
TOTAL SHIP OUTFITTING			686	2016
	m2/ person	m3/ person	Area [m2]	Volume [m3]
Crew and client facilities	26	64	644	1603
Service facilities	14	54	350	1354
TOTAL ACCOMMODATION	40	118	994	2956
	m2/ kW	m3/ kW	Area [m2]	Volume [m3]
Machinery main components			470	1862
Machinery and ship systems			117	469
Engine casing, air intake and funnel			240	770
TOTAL MACHINERY			827	3101
		m3/ kW		Volume [m3]
TOTAL TANKS AND VOID SPACES				4720



	Area [m2]	Volume [m3]
GROSS AREA & VOLUME	4681	17215
GROSS TONNAGE		4901



Appendix F: Weight group estimations



LIGHTWEIGHT	Unit	Value	Coeff [ton/m3]	Weight ton	
Cargo equipment	GV	4422 m3	0,011	49	
Mud equipment			see mud eq.	28	
Task related equipment total	**GV**	**17215 m3**	**0,004**	**77**	
Hull structure	GV	13152 m3	0,160	2104	
Deckhouse	GV	4063 m3	0,090	366	
Steel weight total	**GV**	**17215 m3**	**0,125**	**2470**	
Ship equipment	GV	17215 m3	0,009	155	
Accommodation	Area	994 m2	0,200	199	
Machinery main components	Pp+Pa	10000 kW	0,026	260	
Machinery systems	Pp+Pa	10000 kW	0,006	60	
Ship systems	GV	17215 m3	0,008	129	
Total	**GV**	**17215 m3**		**3349**	Samsvarer med statistikk på s.195 i kompendie
Reserve	%	5		167	
Lightweight	GV	17215 m3	0,204	3517	

DEADWEIGHT AT MAX DRAUGHT

Item:	Unit	Value		Coeff	Weight [ton]	
Dry cargo	Weight	2500	ton	0,6	1503,8	
Liquid and dry bulk cargo	Capacity	3513	m3	1,0	3408	
Crew+clients	Crew+Clients	25	persons	0,1	2,5	
Provision	Crew+Clients	25	persons	0,2	5	
Fuel oil	Roundtrip	280	ton	1,2	336	
Lub oil	Roundtrip	2,6	ton	10	25,5	
Fresh water	Roundtrip	52,5	ton	1,2	63	
Sewage and grey water	Roundtrip	52,5	ton	0,5	26	
Ballast for trim/heel					200	
Ballast for stability		2000	ton	0,2	400	
Passive antiroll tank					200	
DWT	at max draught	6,9	m		6170	6,9 from statistics PA2016

DISPLACEMENT	at max draught	6,9	m	9687	
				0,637	Passer med designkriteriet i kompendiet

	Units	kg	tot
Pumps and piping	15	1000	15000
Mud Mixer	1	4000	4000
MudCube	3	1800	5400
Centrifuge	1	3500	3500
SUM			27900

LWT	3517	ton
DWT	6170	ton
Δ	9687	ton
∇	9451	m3

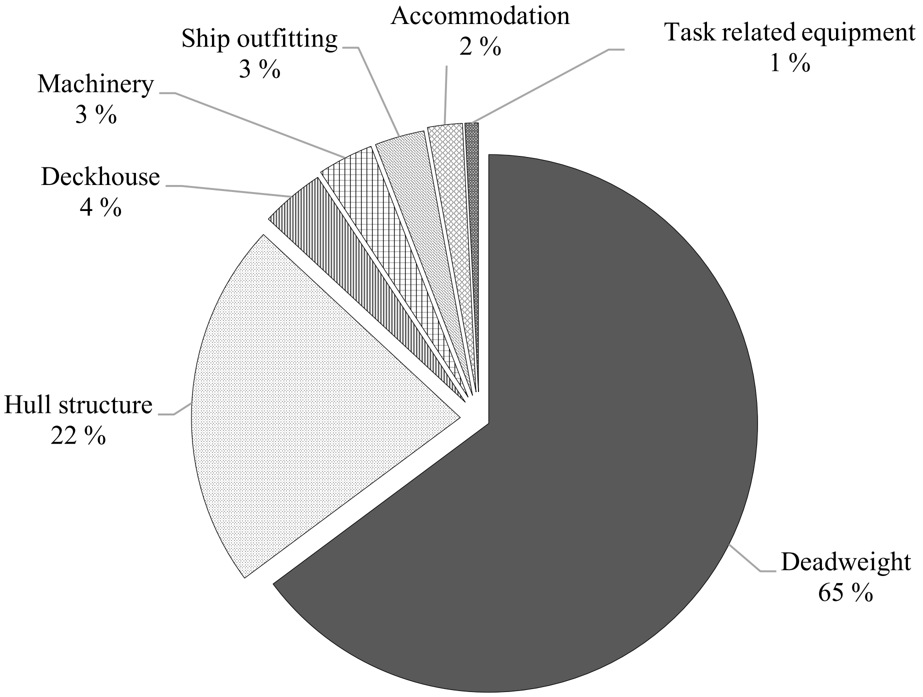
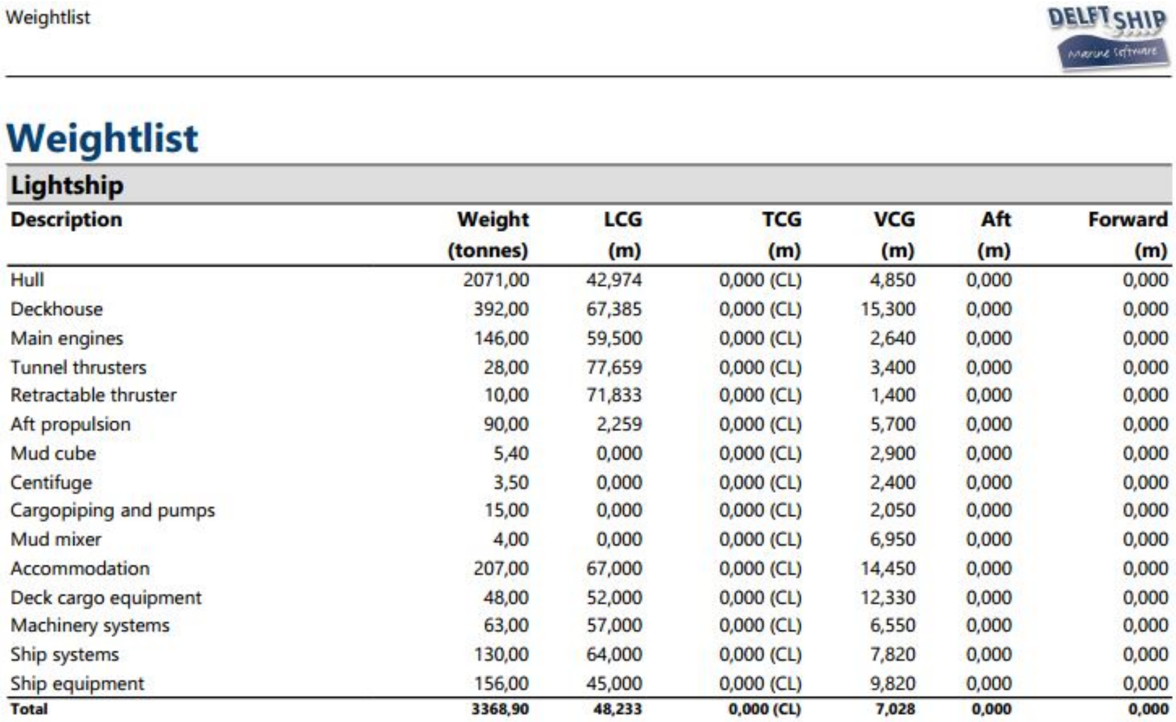


Figure 37A: Weight group estimations. Weight distribution.



Weightlist

Weightlist

Lightship

Description	Weight (tonnes)	LCG (m)	TCG (m)	VCG (m)	Aft (m)	Forward (m)
Hull	2071,00	42,974	0,000 (CL)	4,850	0,000	0,000
Deckhouse	392,00	67,385	0,000 (CL)	15,300	0,000	0,000
Main engines	146,00	59,500	0,000 (CL)	2,640	0,000	0,000
Tunnel thrusters	28,00	77,659	0,000 (CL)	3,400	0,000	0,000
Retractable thruster	10,00	71,833	0,000 (CL)	1,400	0,000	0,000
Aft propulsion	90,00	2,259	0,000 (CL)	5,700	0,000	0,000
Mud cube	5,40	0,000	0,000 (CL)	2,900	0,000	0,000
Centifuge	3,50	0,000	0,000 (CL)	2,400	0,000	0,000
Cargopiping and pumps	15,00	0,000	0,000 (CL)	2,050	0,000	0,000
Mud mixer	4,00	0,000	0,000 (CL)	6,950	0,000	0,000
Accommodation	207,00	67,000	0,000 (CL)	14,450	0,000	0,000
Deck cargo equipment	48,00	52,000	0,000 (CL)	12,330	0,000	0,000
Machinery systems	63,00	57,000	0,000 (CL)	6,550	0,000	0,000
Ship systems	130,00	64,000	0,000 (CL)	7,820	0,000	0,000
Ship equipment	156,00	45,000	0,000 (CL)	9,820	0,000	0,000
Total	**3368,90**	**48,233**	**0,000 (CL)**	**7,028**	**0,000**	**0,000**

Figure 38A: Final LWT weight list, from DELFTship.

Appendix G: General arrangement drawings

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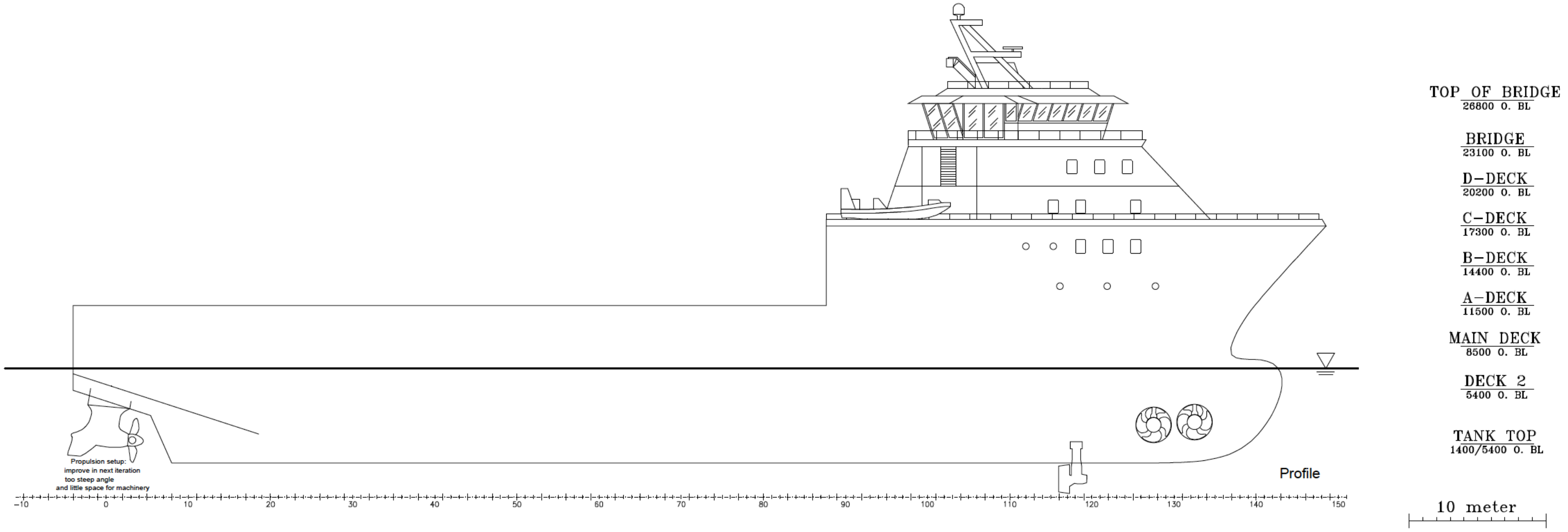
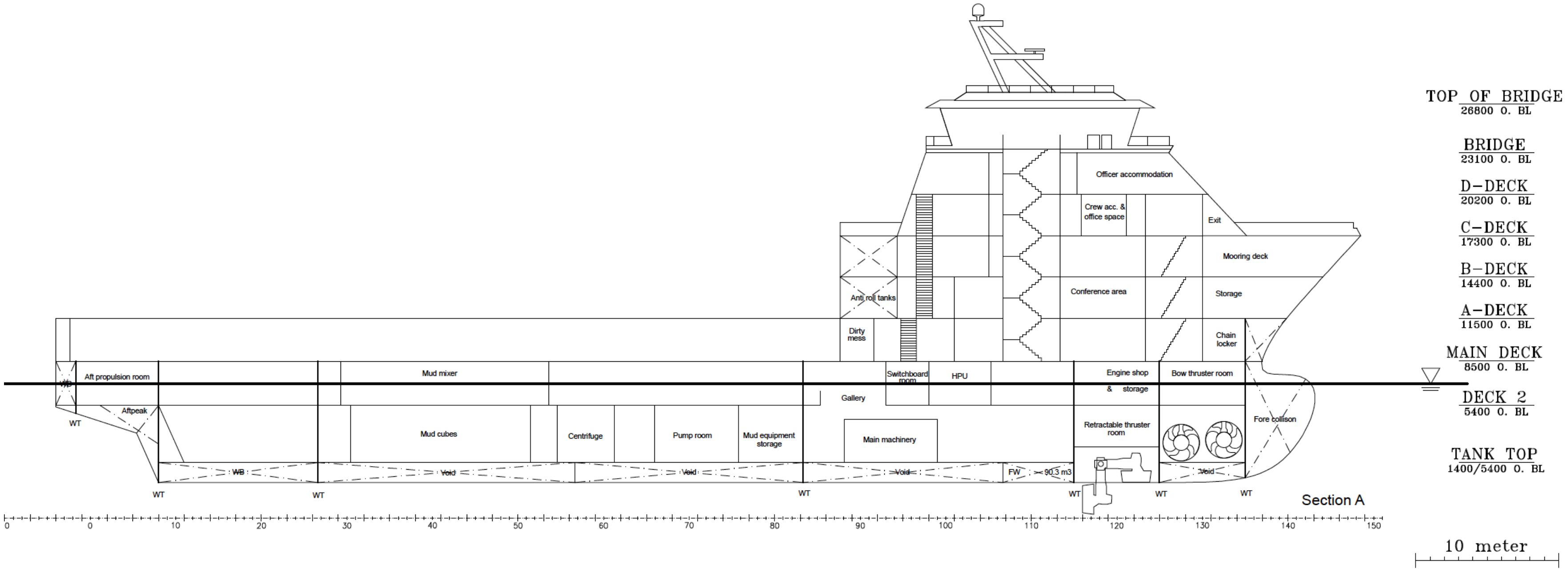
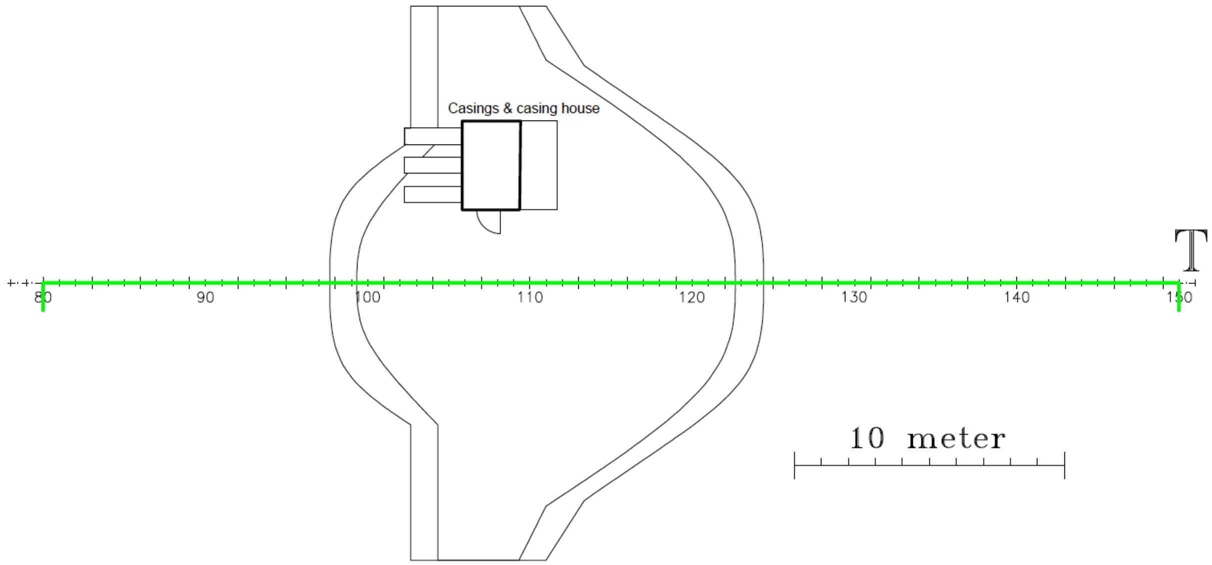
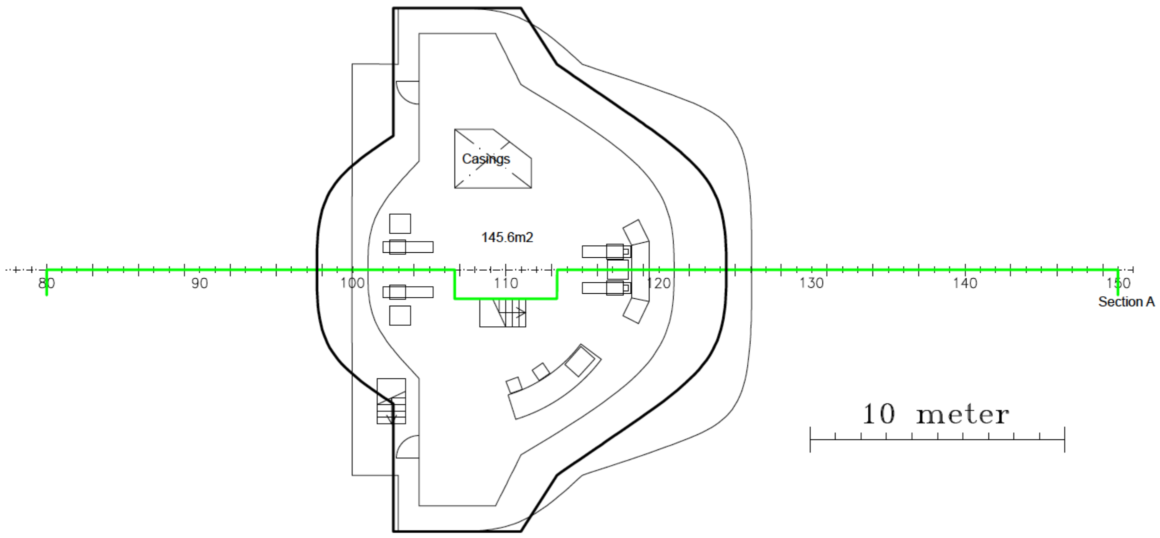

TOP OF BRIDGE
26800 O. BL
BRIDGE
23100 O. BL
D-DECK
20200 O. BL
C-DECK
17300 O. BL
B-DECK
14400 O. BL
A-DECK
11500 O. BL
MAIN DECK
8500 O. BL
DECK 2
5400 O. BL
TANK TOP
1400/5400 O. BL
10 meter
Profile
Propulsion setup:
improve in next iteration
too steep angle
and little space for machinery
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150


TOP OF BRIDGE
26800 O. BL
BRIDGE
23100 O. BL
D-DECK
20200 O. BL
C-DECK
17300 O. BL
B-DECK
14400 O. BL
A-DECK
11500 O. BL
MAIN DECK
8500 O. BL
DECK 2
5400 O. BL
TANK TOP
1400/5400 O. BL
10 meter
Officer accommodation
Crew acc. & office space
Exit
Mooring deck
Conference area
Storage
Anti roll tanks
Dirty mess
Chain locker
Aft propulsion room
Mud mixer
Switchboard room
HPU
Engine shop & storage
Bow thruster room
Aftpeak
Gallery
Mud cubes
Centrifuge
Pump room
Mud equipment storage
Main machinery
Retractable thruster room
Fore collison
WB
Void
FW
90.3 m3
WT
Section A
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150



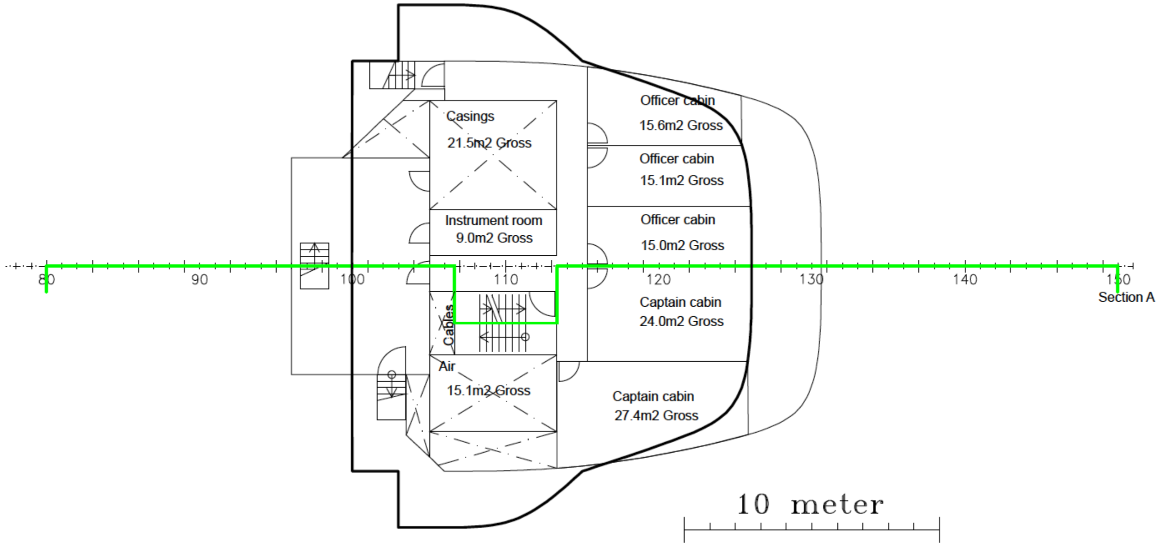
TOP OF BRIDGE

26800 O. BL



BRIDGE

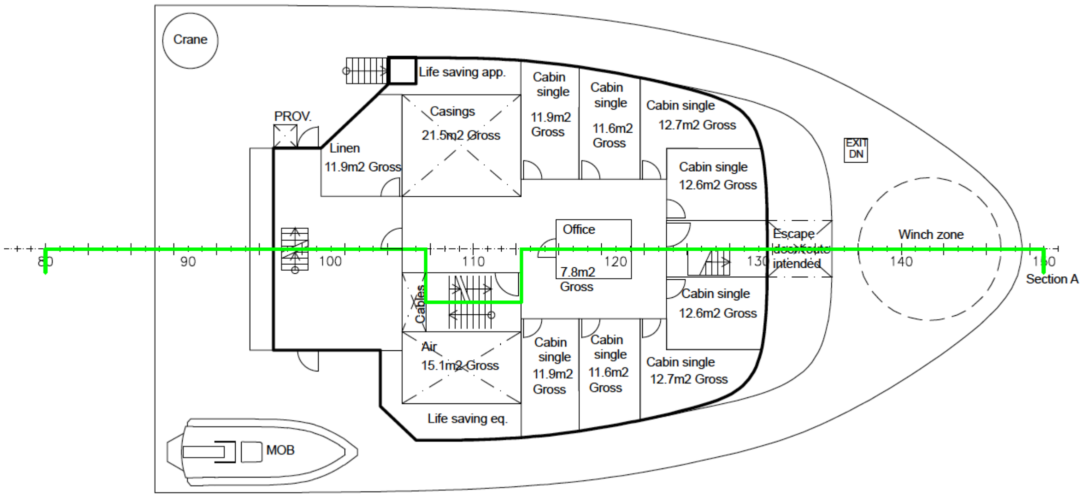
23100 O. BL

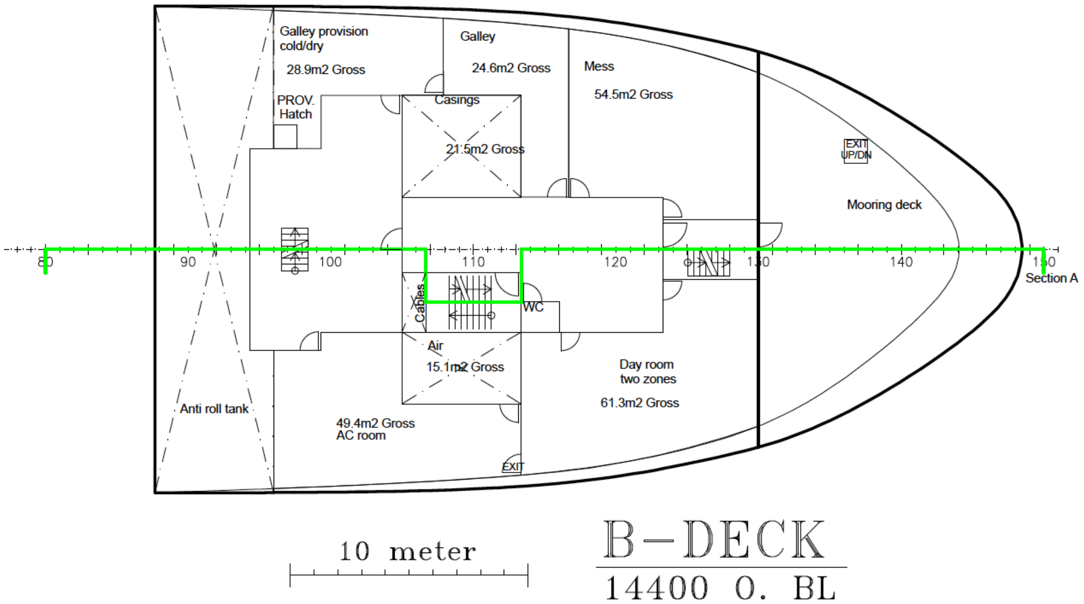


D–DECK

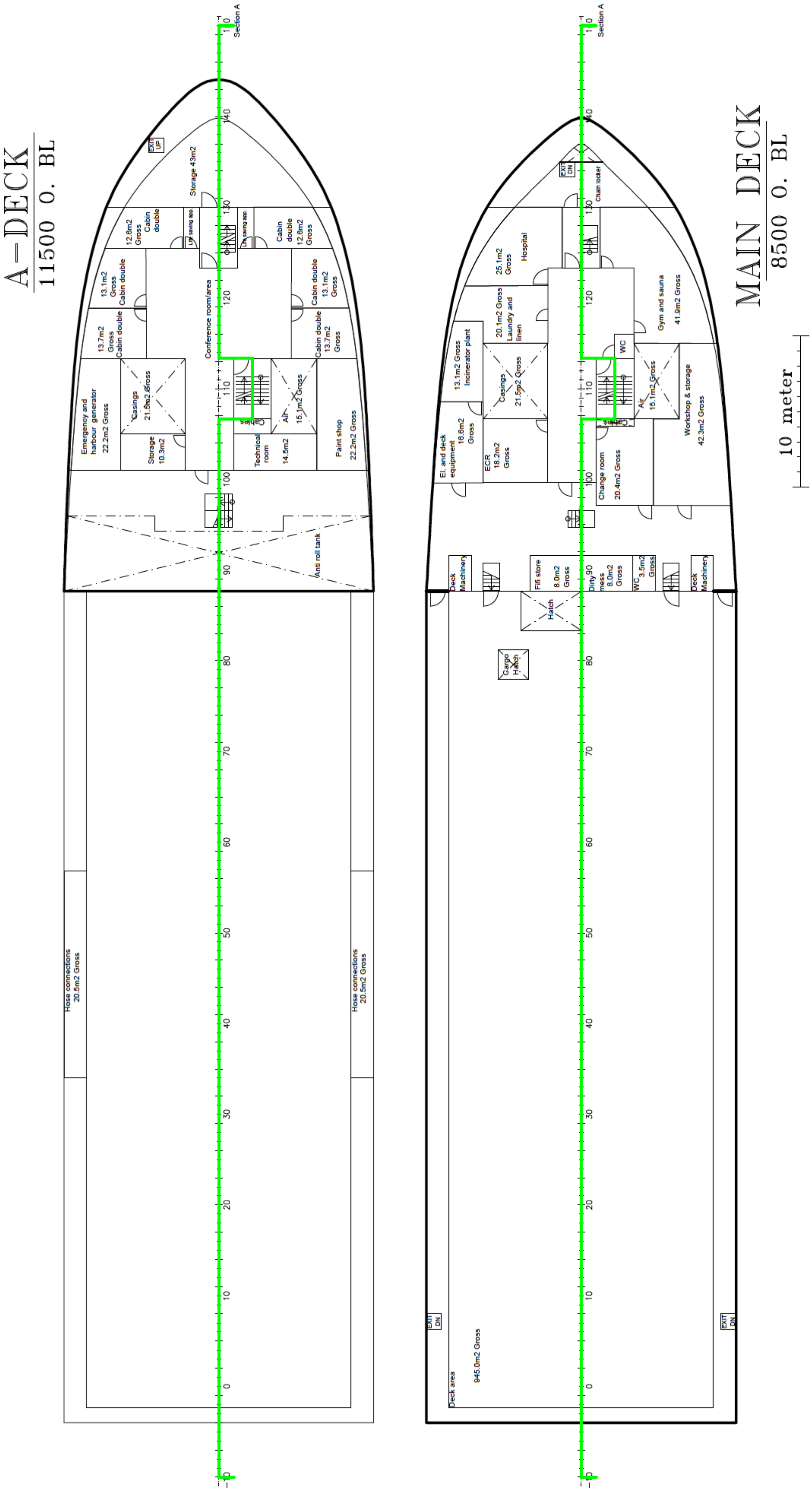
20200 O. BL

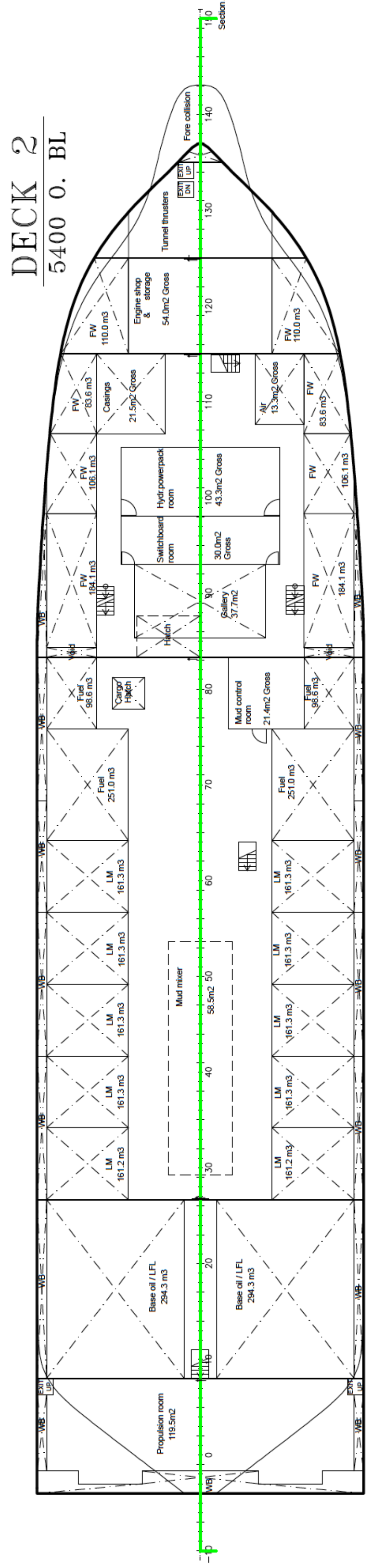
C–DECK
17300 O. BL

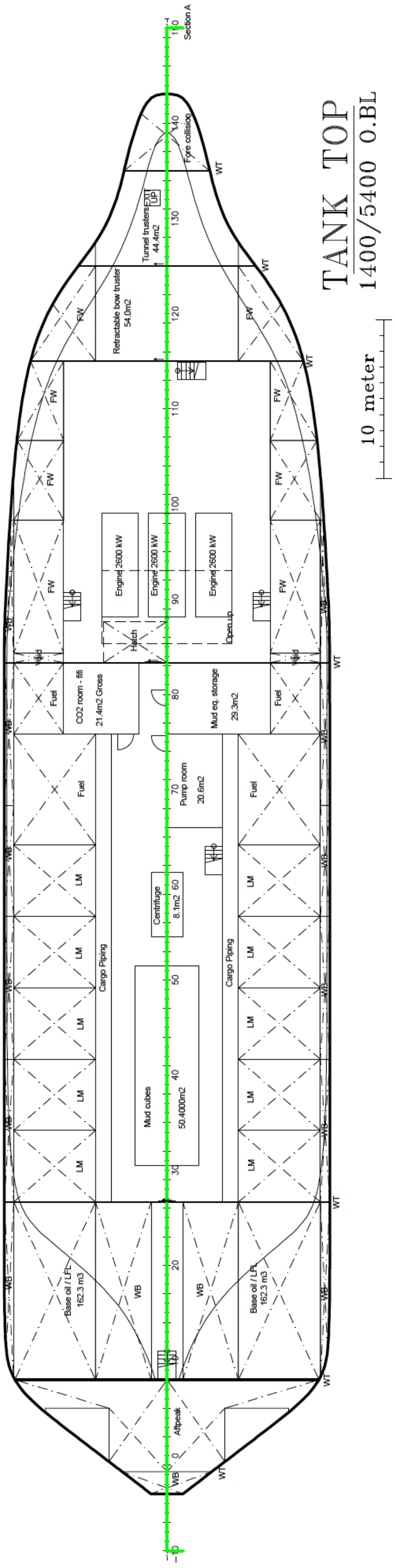




B–DECK
14400 O. BL


A–DECK
11500 O. BL
MAIN DECK
8500 O. BL
10 meter
Section A
Storage 43m2
Cabin double 12,6m2 Gross
Cabin double 13.1m2 Gross
Cabin double 13.7m2 Gross
Conference room/area
Emergency and harbour generator 22.2m2 Gross
Casings 21.5m2 Gross
Storage 10.3m2
Technical room 14.5m2
Air 15.1m2 Gross
Paint shop 22.2m2 Gross
Cables
Anti roll tank
Hose connections 20.5m2 Gross
EXIT UP
Chain locker
Hospital 25.1m2 Gross
Laundry and linen 20.1m2 Gross
Incinerator plant 13.1m2 Gross
El. and deck equipment 16.6m2 Gross
ECR 18.2m2 Gross
Gym and sauna 41.9m2 Gross
WC
Workshop & storage 42.3m2 Gross
Change room 20.4m2 Gross
Deck Machinery
Fifi store 8.0m2 Gross
Dirty mess 8.0m2 Gross
WC 3.5m2 Gross
Hatch
Cargo Hatch
Deck area 945.0m2 Gross
EXIT DN
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140


DECK 2
5400 0. BL
Section A
Fore collision
EXIT DN
EXIT UP
Tunnel thrusters
Engine shop & storage
54.0m2 Gross
FW
110.0 m3
FW
110.0 m3
FW
83.6 m3
Casings
21.5m2 Gross
Air
13.3m2 Gross
FW
83.6 m3
FW
106.1 m3
Hydr.powerpack room
43.3m2 Gross
FW
106.1 m3
Switchboard room
30.0m2 Gross
FW
184.1 m3
Gallery
37.7m2
FW
184.1 m3
Hatch
Void
Void
Fuel
98.6 m3
Cargo Hatch
Mud control room
21.4m2 Gross
Fuel
98.6 m3
Fuel
251.0 m3
Fuel
251.0 m3
LM
161.3 m3
LM
161.3 m3
LM
161.3 m3
LM
161.3 m3
LM
161.3 m3
LM
161.3 m3
LM
161.3 m3
LM
161.3 m3
LM
161.2 m3
LM
161.2 m3
Mud mixer
58.5m2
Base oil / LFL
294.3 m3
Base oil / LFL
294.3 m3
Propulsion room
119.5m2
EXIT UP
WB
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0

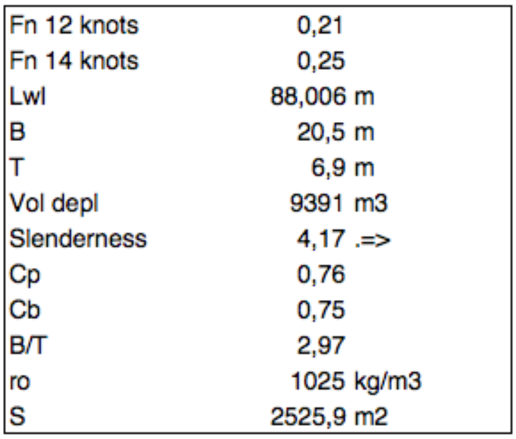

TANK TOP
1400/5400 0.BL
10 meter
Section A
Fore collision
WT
Tunnel trusters
44.4m2
EXIT UP
Retractable bow truster
54.0m2
FW
FW
FW
FW
FW
FW
Engine 2600 kW
Engine 2600 kW
Engine 2600 kW
Hatch
Open up
Void
Void
Fuel
CO2 room - fifi
21.4m2 Gross
Mud eq. storage
29.3m2
Fuel
Fuel
Pump room
20.6m2
Fuel
Centrifuge
8.1m2
LM
LM
LM
LM
LM
LM
LM
LM
LM
LM
Cargo Piping
Cargo Piping
Mud cubes
50.4000m2
Base oil / LFL
162.3 m3
WB
WB
Base oil / LFL
162.3 m3
Aftpeak
WB
WT
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0

Appendix H: Resistance and propulsion calculations

Guldhammer/Harvalds resistance calculation method

The required parameters for total vessel resistance done with Guldhammer/Harvalds method are presented in Table 16A below: The method is assumed to be well known for the reader and available in literature. The steps in the method are therefore not displayed here.

Table 16A: Vessel parameters extracted from DELFTship and empirical equations. Used in performing the GH calculations.



Fn 12 knots	0,21
Fn 14 knots	0,25
Lwl	88,006 m
B	20,5 m
T	6,9 m
Vol depl	9391 m3
Slenderness	4,17 .=>
Cp	0,76
Cb	0,75
B/T	2,97
ro	1025 kg/m3
S	2525,9 m2

The results from the GH calculation are presented in Table 17A below. Here the resistance due to the azipull bodies are also listed, these calculations are explained below. These estimations are further used in determination of propel diameter and installed engine effect in the vessel.

Table 17A: Propulsion calculations using Guldhammer/Harvalds (GH) method. Source: Marin Teknikk Grunnlag. Resistance from azipull thrusters calculated above.

V [kn]	R_N	C_F	C_R	B/T adj.	C_A	C_{Bulb}	C_T	R_T [kN]	$R_{AZIPULL}$
12	4,57E+8	1,69E-3	1,90E-3	7,54E-5	4,00E-4	0	4,07E-3	200,6	36,0 kN
14	5,33E+8	1,66E-3	3,40E-3	7,54E-5	4,00E-4	0	5,53E-3	371,5	48,9 kN

Resistance due to azipull body

These calculations are carried out in by using a similar example presented in (Steen, 2014). A requirement for successful results is to know the wake (w) around the azipull as this will affect the water flow over the azipull body and thus the drag force. In addition, the propeller jet will increase the surface-velocity over some parts of the body and strut. This jet is also unknown. To estimate a partly true resistance force due to the presence of the azipull thrusters; a constant velocity is used during the estimation and should be taken into consideration regarding the validity of the results.

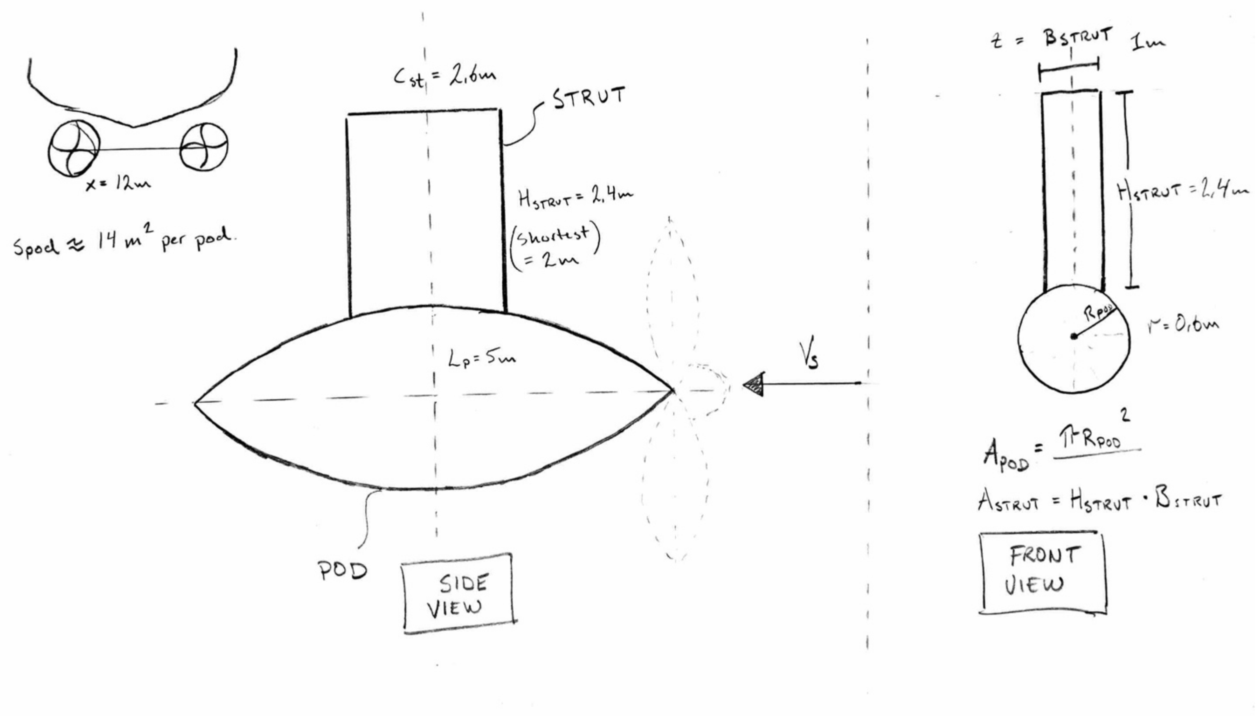


Figure 39A: Simplified drawing of the submerged azipull body.

①

$\underline{(12\,kn)}$

$$R_{NH} = \frac{V_j L_H}{\nu} = \frac{12kn \cdot 0{,}5144 \cdot 5m}{1{,}1883 \cdot 10^{-6}} = \underline{2{,}597 \cdot 10^{7}}$$

$$C_{FH} = \frac{0.075}{\left[\log(R_{NH}) - 2\right]^2} = \ldots = \underline{2{,}558 \cdot 10^{-3}}$$

$$C_{DH} = C_{FH}\left[1 + 1{,}5\left(\frac{D_H}{L_H}\right)^{1.5} + 7\left(\frac{D_H}{L_H}\right)^{3}\right]$$

$$= 2{,}558 \cdot 10^{-3}\left[1 + 1{,}5\left(\frac{1{,}2m}{5m}\right)^{1.5} + 7\left(\frac{1{,}2m}{5m}\right)^{3}\right] = \underline{3{,}257 \cdot 10^{-3}}$$

$$R_H = C_{DH}\frac{\rho_{SEA}}{2}V^2 \cdot S_H = 3{,}257 \cdot 10^{-3} \cdot \frac{1025}{2} \cdot (12 \cdot 0{,}5144)^2 \cdot 14 = \underline{890.4\ N}$$

RESISTANCE DUE TO THE POD ↑ (POD)

$$R_{Nst} = V_j \frac{C_{st}}{\nu} = \frac{12kn \cdot 0{,}5144 \cdot 2{,}6m}{1{,}1883 \cdot 10^{-6}} = \underline{1{,}351 \cdot 10^{7}}$$

$$C_{Fst} = \frac{0.075}{\left[\log(R_{Nst}) - 2\right]^2} = \ldots = \underline{2{,}849 \cdot 10^{-3}}$$

$$C_{Dst} = 2C_{F_{st}}\left[1 + 2\frac{t_{st}}{C_{st}} + 60\left(\frac{t_s}{C_{st}}\right)^4\right] = \ldots = \underline{1{,}756 \cdot 10^{-2}}$$

$$R_{st} = C_{Dst}\frac{\rho_{SEA}}{2}V^2 \cdot A_{st} = 1{,}756 \cdot 10^{-2} \cdot \frac{1025}{2} \cdot (12 \cdot 0{,}5144)^2 \cdot 1 \cdot 2{,}4$$

RESISTANCE DUE TO STRUT

$$= \underline{823{,}0\,N}$$

(STRUT) in pr. jet

②

$$C_{D_{int}} = FF\left[17\left(\frac{t_{st}}{C_{st}}\right)^2 - 0{,}05\right] = 0.2\left[17\left(\frac{1}{2{,}6}\right)^2 - 0{,}05\right]$$

$$\underline{= 0{,}493}$$

$$R_{int} = C_{D_{int}} \frac{\rho_{SEA}}{2} V_A^2 t_{st}^2 = C_{D_{int}} \frac{\rho_{SEA}}{2} \left((1-w)\cdot V_s\right)^2 t_{st}^2$$

(Assume $w = 0{,}9$ near the hull, Based on p. 299 in TMR 4220 Naval Hydrodynamics - Foil and propeller theory compendium)

$$R_{int} = 0{,}493 \cdot \frac{1025}{2} (0{,}1\cdot 12\cdot 0{,}5144)^2 \cdot 1^2 = \underline{96.3\ N}$$

interference HULL/STRUT.

$$R_{int_2} = C_{D_{int}} \frac{\rho_{sea}}{2} V_j^2 t_{st}^2 = 0{,}493 \cdot \frac{1025}{2} (12\cdot 0{,}5144)^2 \cdot 1^2$$

RESISTANCE DUE TO INTERFERENCE BETWEEN STRUT AND POD $= 9627.3\ N$ STRUT/POD (HOUSE)

$$\frac{s}{t} = \frac{x - t}{\frac{\pi}{4}\cdot D_H} = \frac{12 - 0{,}94248}{0{,}94248} = \underline{11.7324}$$

$$C_{DHH} = 0{,}155 \exp\left[\frac{-\left(s/t - 0{,}25\right)^{1.1}}{1.1}\right] = 0{,}155 \exp\left[-\frac{(11.7324 - 0{,}25)^{1{,}1}}{1.1}\right]$$

$$= 2{,}533 \cdot 10^{-7}$$

(ASSUMTION AS ABOVE)

$$R_{HH} = C_{DHH} \frac{\rho_{SEA}}{2} V_A^2 \cdot A_P \ ; \ A_P = \frac{\pi}{4} D_H^2 \ ; \ V_A \Rightarrow W = 0{,}05$$

$$= 2.533\cdot 10^{-7} \cdot \frac{1025}{2} (0{,}95\cdot 12\cdot 0{,}5144)^2 \cdot \pi/4 \cdot 1{,}2^2 = \underline{5.05\cdot 10^{-3}\ N}$$

≈ 0

RESISTANCE DUE TO INTERFERENCE BETWEEN THE TWO PODS

③ $$y/D_H = \frac{2{,}0}{1{,}2} = 1{,}67$$

← distance to hull.

$$C_{DHS} = 0.0642\left(\frac{y}{D_H}\right)^{5.7818} = 1{,}23 \Rightarrow$$

$$R_{HS} = C_{DHS}\,\frac{\rho_{SEA}}{2}\,V^2 A_{POD} = 1{,}23 \cdot \frac{1025}{2}\left(0{,}95 \cdot 12 \cdot 0{,}5144\right)^2 \cdot \pi \cdot 0{,}6^2$$

$$= \underline{24516.75\ N}$$

RESISTANCE DUE TO DRAG
FROM DISTANCE BETWEEN
HULL AND POD

$$R_{TOTAL} = R_H + R_{St} + R_{int} + R_{int_2} + R_{HM} + R_{HS}$$

$$= 890{,}4\ N + 823{,}0\ N + 96.3\ N + 9627.3\ N + 0\ N + 24516.75\ N$$

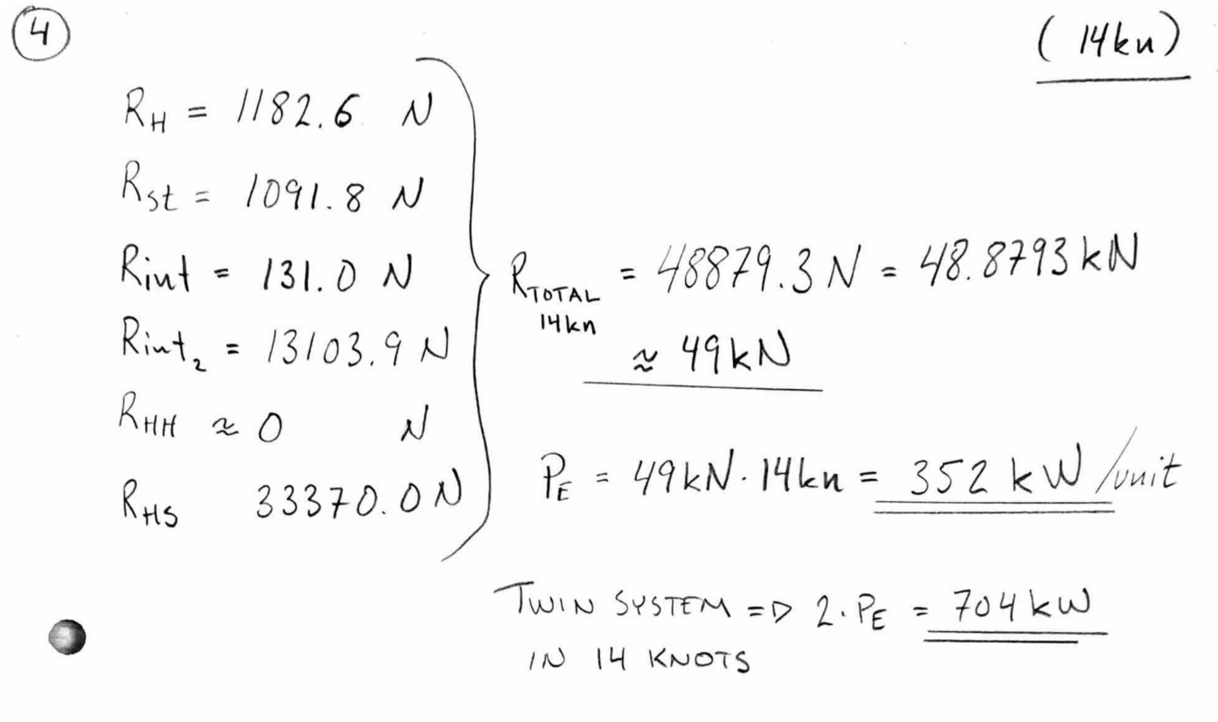
$$= 35953.75\ N = 35.954\ kN \approx 36\ kN$$

The effective power absorbed by the resistance of a pod:

$$P_E = R_{TOTAL} \cdot V_S = 36\,kN \cdot 12\,kn = 221935.308\ W$$

$$\underline{\approx 222\ kW\ /unit.}$$

TWIN SYSTEM $\Rightarrow 2 \cdot P_E = \underline{\underline{444\ kW}}$ in 12 knots



④ (14kn)

$$\left.\begin{array}{l} R_H = 1182.6\ N \\ R_{st} = 1091.8\ N \\ R_{int} = 131.0\ N \\ R_{int_2} = 13103.9\ N \\ R_{HH} \approx 0\ N \\ R_{HS}\ \ 33370.0\ N \end{array}\right\} \underset{14kn}{R_{TOTAL}} = 48879.3\ N = 48.8793\ kN \approx 49\ kN$$

$$P_E = 49\ kN \cdot 14\ kn = \underline{\underline{352\ kW}}\ /unit$$

$$\text{TWIN SYSTEM} \Rightarrow 2 \cdot P_E = \underline{\underline{704\ kW}}$$

IN 14 KNOTS

Assumptions: Constant velocity, including induced velocity over the azipull body behind the propeller. This assumption is made because we do not have enough information about the wake or propeller nor the actual form of the pod and strut. This has been done to estimate the resistance of having azipull thrusters as main propulsion. The calculations are based on theory from "TMR4220 - Naval Hydrodynamics Foil and Propeller Theory" course compendium (Steen, 2014).

Calculating required engine effect installed and propeller size

Distance from tip of propeller to the hull for twin-screw vessel (DNV GL – Rules for ships; Pt 3; Ch.3; Sec.2): Approximately 4 meters' clearance from keel to the hull where the propellers are located (checked in AutoCAD drawings and DELFTship. However, some adjustments on the aft of the vessel have to be made and therefore the required free space between propeller and hull is only an approximation in the early design stage. Clearance is estimated as follows:

$$c \geq \left(0{,}6 - 0{,}02 * Z_p\right) R$$

$$c \geq (0{,}6 - 0{,}02 * 4) * \frac{4m}{2} \approx 1m$$

Resulting in a max diameter of approximately 3m.

PROPELLER DIMENSIONS NEXT PAGE!

PE	1460 kW	Based on results from GH and vessel speed 12 knots
η_0	0,600	First assumed
η_R	0,980	Assumed based on typical values (Marin grunnkurs)
η_H	1,017	Based on w and t
η_M	0,950	Assumed based on typical values (Marin grunnkurs)
w	0,100	Assumed based on typical values for twin screw vessels. (Marin hydrodynamics compendium)
η_D	0,598	
t	0,085	Estimated from this empirical formula

For skip med 2 propeller anbefaltes:

$$\frac{t}{w} = 1.67 - 2.3\frac{C_B}{C_{WL}} + 1.5C_B$$

o/s	3	Assumed based on typical startingpoint in the iteration process. EL engine very flexible.
VA	5,6	
Pd	2442,8 kW	
Pd	**2442,8 kW**	
Pd,1/2	**1221,4 kW**	

Max propeller diameter from above ca 3 meters

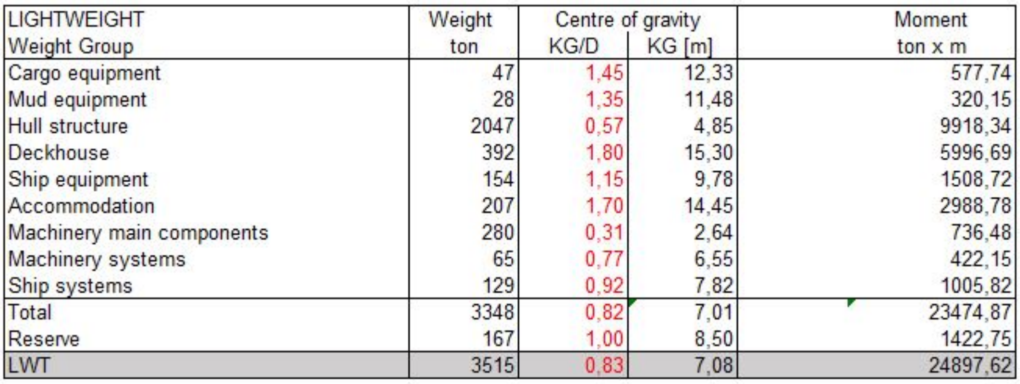
	Diagram	Ae/Ao	0,85			
Bp (pr.propeller)	0,75 .=>	Z	4	.=>	η_0	0,605 from bp diagram
					delta	1,65 from bp diagram
					P/D	0,9 from bp diagram
					D	3,06 m from delta equation
					T	130,3 kN
The assumed	$\eta_0 = 0{,}60 \approx 0{,}605$	OK!			Rt	119,3 kN
η_D	**0,603**				T x 2 propellers	260,7 kN
					Rt x 2	238,5 kN >= 236,6kN OK!
η_T	0,573					
PB	2550 kW required pr. Propeller					
PB_tot	**5100 kW installed total, + seamargin ->**				**PB =**	**6630 kW**

Burrill - diagram to measure cavitation Method explanined in TMR4247 Hydrodynamics compendium (Sverre Steen, 2011)

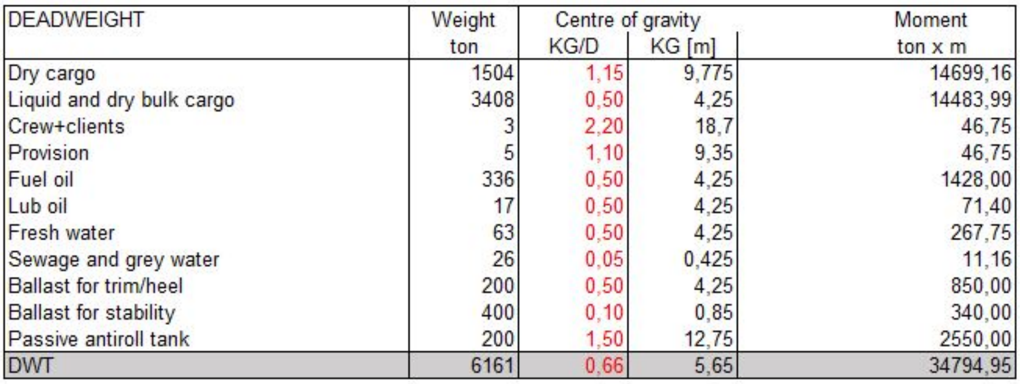
Ap	7,33
tau.c	0,079
(p0-pv)	99000
VR	20,91
VR^2	437,23
sigma(0.7R)	0,61

When checking the Burrill diagram it shows that the cavitation is way below 2,5% line and therefore the selected propeller is OK!

Appendix I: Intact stability estimations

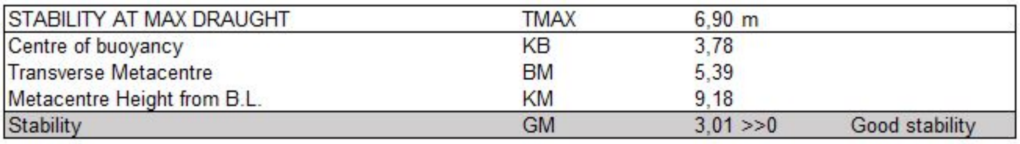


LIGHTWEIGHT Weight Group	Weight ton	Centre of gravity KG/D	 KG [m]	Moment ton x m
Cargo equipment	47	1,45	12,33	577,74
Mud equipment	28	1,35	11,48	320,15
Hull structure	2047	0,57	4,85	9918,34
Deckhouse	392	1,80	15,30	5996,69
Ship equipment	154	1,15	9,78	1508,72
Accommodation	207	1,70	14,45	2988,78
Machinery main components	280	0,31	2,64	736,48
Machinery systems	65	0,77	6,55	422,15
Ship systems	129	0,92	7,82	1005,82
Total	3348	0,82	7,01	23474,87
Reserve	167	1,00	8,50	1422,75
LWT	3515	0,83	7,08	24897,62



DEADWEIGHT	Weight ton	Centre of gravity KG/D	 KG [m]	Moment ton x m
Dry cargo	1504	1,15	9,775	14699,16
Liquid and dry bulk cargo	3408	0,50	4,25	14483,99
Crew+clients	3	2,20	18,7	46,75
Provision	5	1,10	9,35	46,75
Fuel oil	336	0,50	4,25	1428,00
Lub oil	17	0,50	4,25	71,40
Fresh water	63	0,50	4,25	267,75
Sewage and grey water	26	0,05	0,425	11,16
Ballast for trim/heel	200	0,50	4,25	850,00
Ballast for stability	400	0,10	0,85	340,00
Passive antiroll tank	200	1,50	12,75	2550,00
DWT	6161	0,66	5,65	34794,95

LWT+DWT	9676	0,73	6,17	59692,58



STABILITY AT MAX DRAUGHT	TMAX	6,90 m	
Centre of buoyancy	KB	3,78	
Transverse Metacentre	BM	5,39	
Metacentre Height from B.L.	KM	9,18	
Stability	GM	3,01 >>0	Good stability

$$KB = T\left(\frac{5}{6} - \frac{1}{3}\left(\frac{C_B}{C_W}\right)\right) \qquad [1]$$

$$BM = \frac{I_T}{\nabla} = \frac{\left[0{,}0372\,(2 \cdot C_W + 1)^3 \cdot \frac{L_{PP}B^3}{12}\right]}{\nabla} \qquad [2]$$

$$KM = KB + BM \qquad [3]$$

$$GM = KM - KG \qquad [4]$$

Values marked in red under the colon with *KG/D* is based on SBD compendium by Kai Levander and from there the KG for each weight group is found for the vessel. The stability at max draught is found to be above 3 meters, which indicated a good intact stability. Equation [1] and [2] is based on similar vessel forms form existing vessels. Equation [3] and [4] are already well-known stability measures related to vessel stability.

Appendix J: Energy consumption in service mode

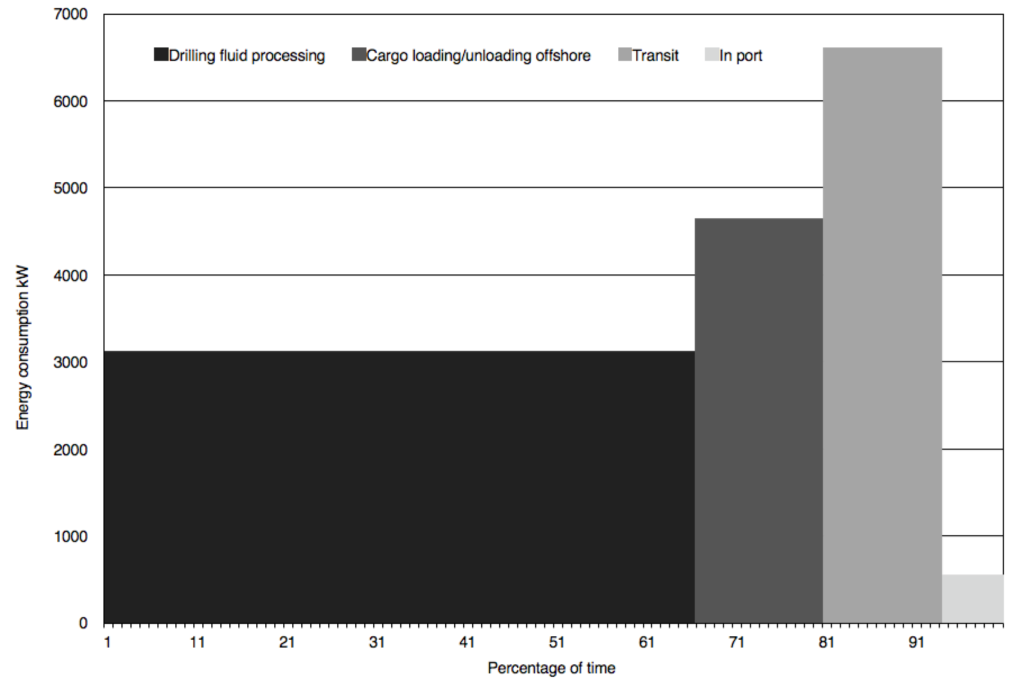
Propulsion equipment	Units	kW/unit	Total kW	
Main propellers	2	3315	6630	from propulsion estimate
Bow thrusters	2	895	1790	from parametric analysis
Azimuth thrusters bow	1	895	895	from parametric analysis
Total			9315	

Transit	Units	kW/unit	Total kW	
Main propellers	2	2550	5100	at service speed 80% MC
Hotel load	1	200	200	
Misc./hydraulics	1	50	50	
Circulating pumps	12	100	1200	
Total			**6550**	

Drilling fluid processing	Units	kW/unit	Total kW	
Solids Control Unit	3	50	150	
Centrifuge	1	200	200	
Mud Mixing eq	1	50	50	
Misc./Hydraulics	1	50	50	
Dynamic positioning	1	1397	1397	15% of total available propulsion power
Circulating pumps	12	100	1200	
Total			**3047**	

Cargo loading / unloading offshore	Units	kW/unit	Total kW	
Pumping	12	150	1800	
Dynamic positioning	1	2795	2795	30% of total available propulsion power
Hotel load	1	200	200	
Total			**4595**	

In port	Units	kW/unit	Total kW
Misc.	1	500	500
Total			**500**



Appendix K: High energy consumption

High energy consumption

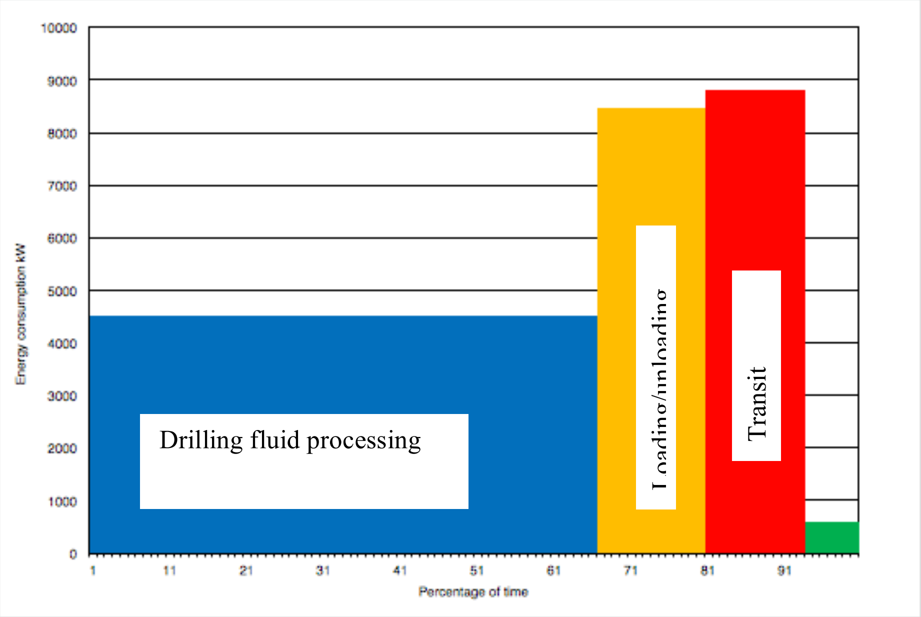
Propulsion equipment	**Units**	**kW/unit**	**Total kW**
Main propellers	2	3315	6630
Bow thrusters	2	895	1790
Azimuth thrusters bow	1	895	895
Total			9315

Transit	Units	kW/unit	Total kW	
Main propellers	2	3315	6630	at max speed 100% MCR
Hotel load	1	200	200	
Misc./hydraulics	1	50	50	
Circulating pumps	12	150	1800	
Total			**8680**	

Drilling fluid processing	Units	kW/unit	Total kW	
Solids Control Unit	3	50	150	
Centrifuge	1	200	200	
Mud Mixing eq	1	50	50	
Misc./Hydraulics	1	50	50	
Dynamic positioning	1	2795	2795	30% of total available propulsion power
Circulating pumps	12	100	1200	
Total			**4445**	

Cargo loading / unloading offshore	Units	kW/unit	Total kW	
Pumping	12	150	1800	
Thrusters	1	2685	2685	100% thrustering
Propulsion	1	3726	3726	40% of total available propulsion power
Hotel load	1	200	200	
Total			**8411**	

In port	Units	kW/unit	Total kW
Misc.	1	500	500
Total			**500**



Appendix L: Loading conditions

This page is intentionally left blanc. NB! The following loading condition reports from DELFTship will not follow the same page numbering as normal in this appendix!

Lightship

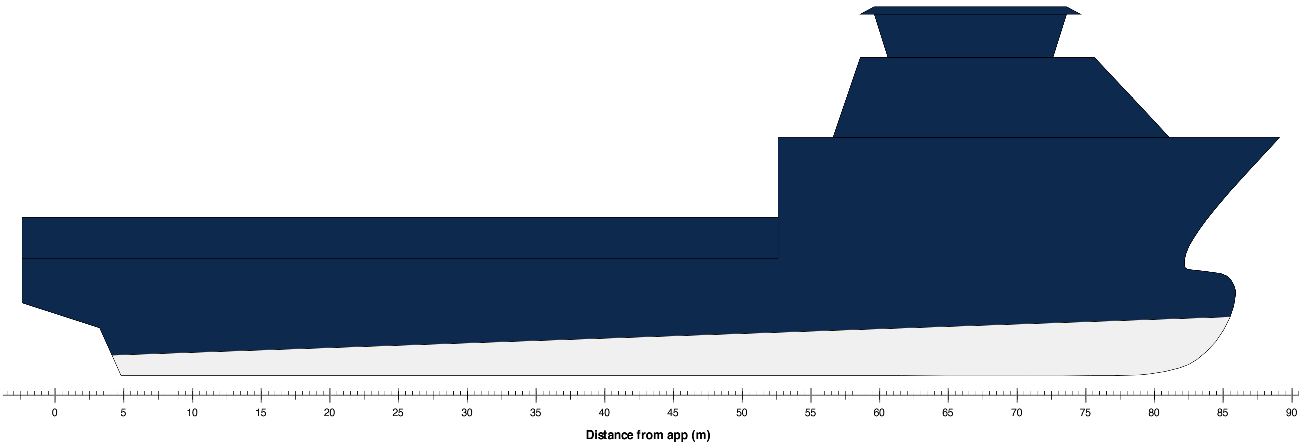
Designer	
Created by	
Comment	
Filename	TankSystems TWISTA.fbm

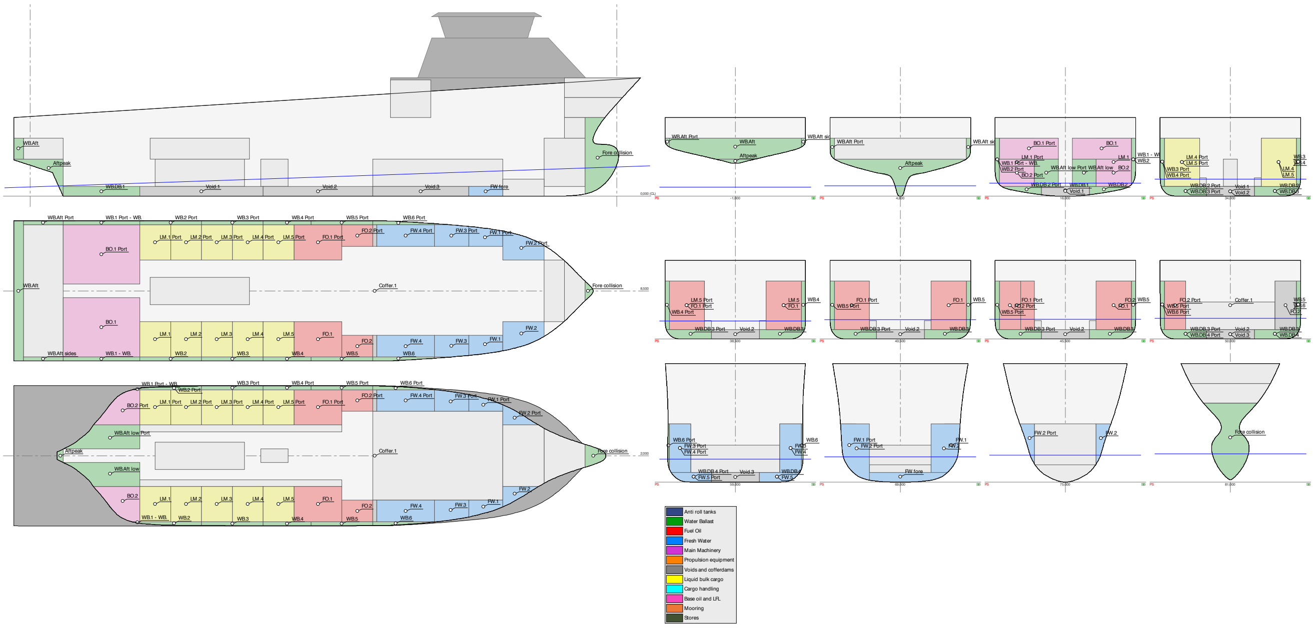
Design length	85,600 (m)	**Midship location**	42,800 (m)
Length over all	91,500 (m)	**Relative water density**	1,0250
Design beam	20,500 (m)	**Mean shell thickness**	0,0100 (m)
Maximum beam	20,500 (m)	**Appendage coefficient**	1,0000
Design draft	6,900 (m)		

Calculation settings

Center of gravity of tanks containing liquids	:	**Actual COG**

Silhouette 1





Hydrostatic particulars

List	0,0 (CL) (Degr.)	**GG'**	0,000 (m)
Draft aft pp	1,342 (m)	**VCG'**	6,927 (m)
Mean moulded draft	2,810 (m)	**Max VCG'**	9,599 (m)
Draft forward pp	4,278 (m)	**GM solid**	6,714 (m)
Trim	2,936 (m)	**G'M liquid**	6,714 (m)
KM	13,642 (m)	**Immersion rate**	13,575 (t/cm)
VCG	6,927 (m)	**MCT**	58,41 (t*m/cm)

Description	Density	Fill%	Weight	LCG	TCG	VCG	FSM
	(t/m³)		*(tonnes)*	*(m)*	*(m)*	*(m)*	*(t*m)*
Water Ballast							
Aftpeak	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
Fore collision	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.1 - WB.	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.2	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.3	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.4	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.5	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.6	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.DB.1	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.DB.2	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.DB.3	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.DB.4	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.Aft	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.Aft sides	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.1 Port - WB.	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.2 Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.3 Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.4 Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.5 Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.6 Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.DB 2 Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.DB 3 Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.DB 4 Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.Aft Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.Aft low	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.Aft low Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
Totals for Water Ballast			**0,00**	**0,000**	**0,000 (CL)**	**0,000**	**0,0**
Fuel Oil							
FO.2	0,8600	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FO.1	0,8600	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FO.1 Port	0,8600	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FO.2 Port	0,8600	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Totals for Fuel Oil			**0,00**	**0,000**	**0,000 (CL)**	**0,000**	**0,0**
Fresh Water							
FW.1	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.2	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.3	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.4	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.5	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW fore	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.1 Port	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.2 Port	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.3 Port	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.4 Port	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.5 Port	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Totals for Fresh Water			**0,00**	**0,000**	**0,000 (CL)**	**0,000**	**0,0**
Voids and cofferdams							
Void.1	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Void.2	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Void.3	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0

Description	Density	Fill%	Weight	LCG	TCG	VCG	FSM
	(t/m³)		*(tonnes)*	*(m)*	*(m)*	*(m)*	*(t*m)*
Coffer.1	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Totals for Voids and cofferdams			**0,00**	**0,000**	**0,000 (CL)**	**0,000**	**0,0**

Liquid bulk cargo

Description	Density	Fill%	Weight	LCG	TCG	VCG	FSM
LM.1	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
LM.2	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
LM.3	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
LM.4	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
LM.5	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
LM.1 Port	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
LM.2 Port	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
LM.3 Port	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
LM.4 Port	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
LM.5 Port	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Totals for Liquid bulk cargo			**0,00**	**0,000**	**0,000 (CL)**	**0,000**	**0,0**

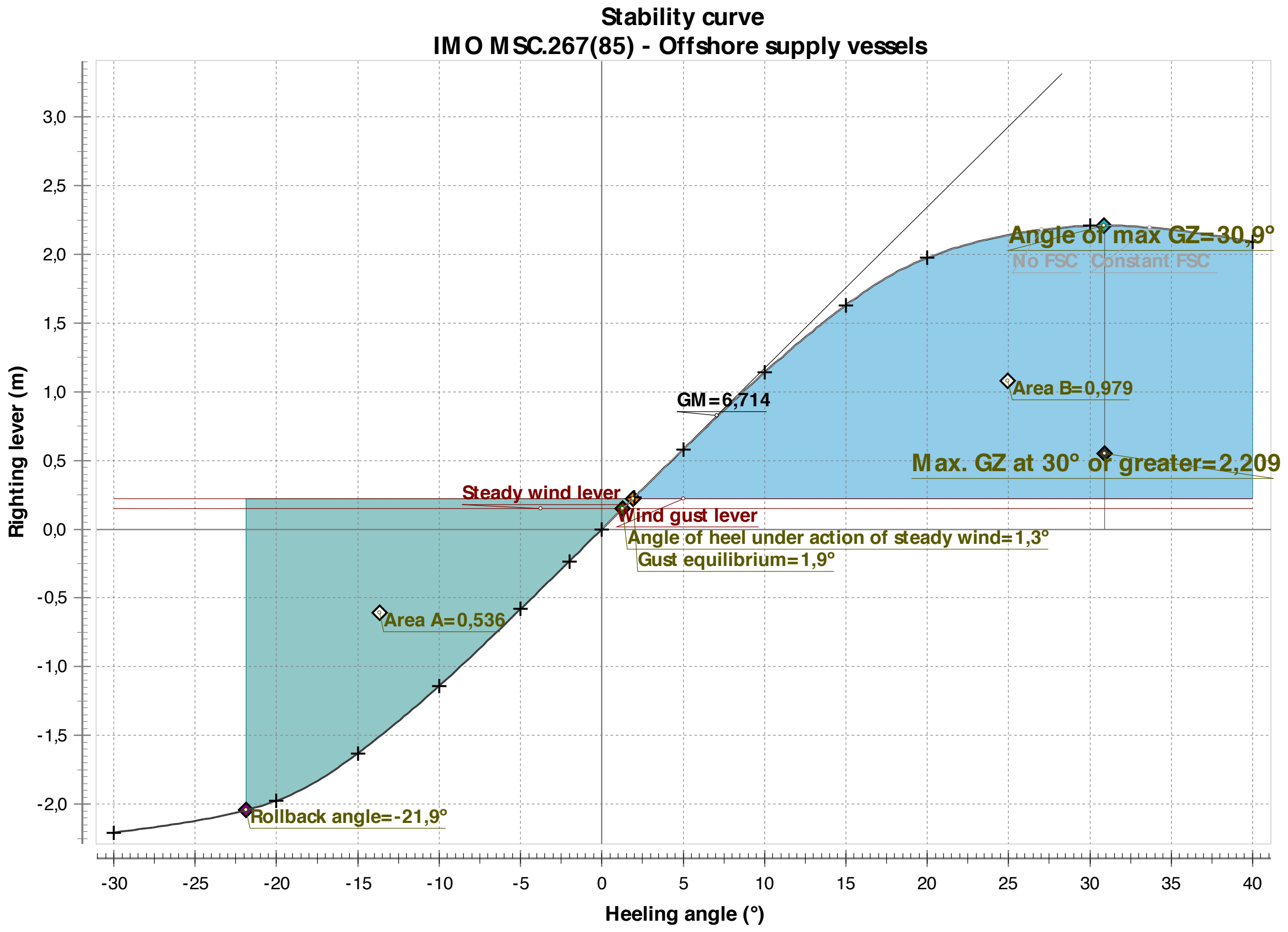
Base oil and LFL

Description	Density	Fill%	Weight	LCG	TCG	VCG	FSM
BO.1	0,9240	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
BO.2	0,9240	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
BO.1 Port	0,9240	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
BO.2 Port	0,9240	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Totals for Base oil and LFL			**0,00**	**0,000**	**0,000 (CL)**	**0,000**	**0,0**

Lightship			**3374,90**	**47,062**	**0,000 (CL)**	**6,927**	
Deadweight			**0,00**	**0,000**	**0,000 (CL)**	**0,000**	**0,0**
Displacement			**3374,90**	**47,062**	**0,000 (CL)**	**6,927**	**0,0**

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)
0,0° (CL)	2,810	2,936	3374,89	0,000	0,000	0,000	0,000	0,000	0,000
2,0° (PS)	2,808	2,943	3374,89	0,475	0,242	0,000	0,000	0,234	0,004
5,0° (PS)	2,801	2,977	3374,89	1,185	0,604	0,000	0,000	0,581	0,025
10,0° (PS)	2,768	3,106	3374,89	2,343	1,203	0,000	0,000	1,140	0,101
15,0° (PS)	2,696	3,343	3374,89	3,423	1,793	0,000	0,000	1,630	0,222
20,0° (PS)	2,556	3,719	3374,88	4,344	2,369	0,000	0,000	1,975	0,381
30,0° (PS)	1,997	4,792	3374,89	5,671	3,464	0,000	0,000	2,208	0,752
40,0° (PS)	0,975	6,334	3374,87	6,544	4,453	0,000	0,000	2,091	1,131



Evaluation of criteria

IMO MSC.267(85) - Offshore supply vessels

International Code on Intact Stability (2008), Part B, §2.4

Description	Attained value	Criterion	Required value	Complies
Area 0° - 30° / Angle of Max GZ	**0,7522 (mrad)**	**>=**	**0,0550 (mrad)**	**YES**
Angle of max GZ	30,9 (Degr.)			
Calculated angle	30,9 (Degr.)			
Area 30° - 40°	**0,3786 (mrad)**	**>=**	**0,0300 (mrad)**	**YES**
Max. GZ at 30° or greater	**2,209 (m)**	**>=**	**0,200 (m)**	**YES**
Lower angle	30,0 (Degr.)			
Upper angle	90,0 (Degr.)			
Angle of max GZ	**30,9 (Degr.)**	**>=**	**15,0 (Degr.)**	**YES**
Initial metacentric height	**6,714 (m)**	**>=**	**0,150 (m)**	**YES**

Evaluationof criteria

Severe wind and rolling criterion (weather criterion) YES

Wind silhouette:	Silhouette 1			
Wind pressure	51,4 (kg/m^2)			
Wind area	1105,40 (m^2)			
Steady wind lever	0,148 (m)			
Deck immersion angle	30,28 (Degr.)			
Wind gust lever	0,222 (m)			
Ratio of areaA/areaB	0,548	<=	1,000	YES
Maximum allowed static heeling angle	1,3 (Degr.)	<=	16,0 (Degr.)	YES
Max allowed ratio static angle/deck immersion angle	0,042	<=	0,800	YES

The condition complies with the stability criteria

Lightship with ballast

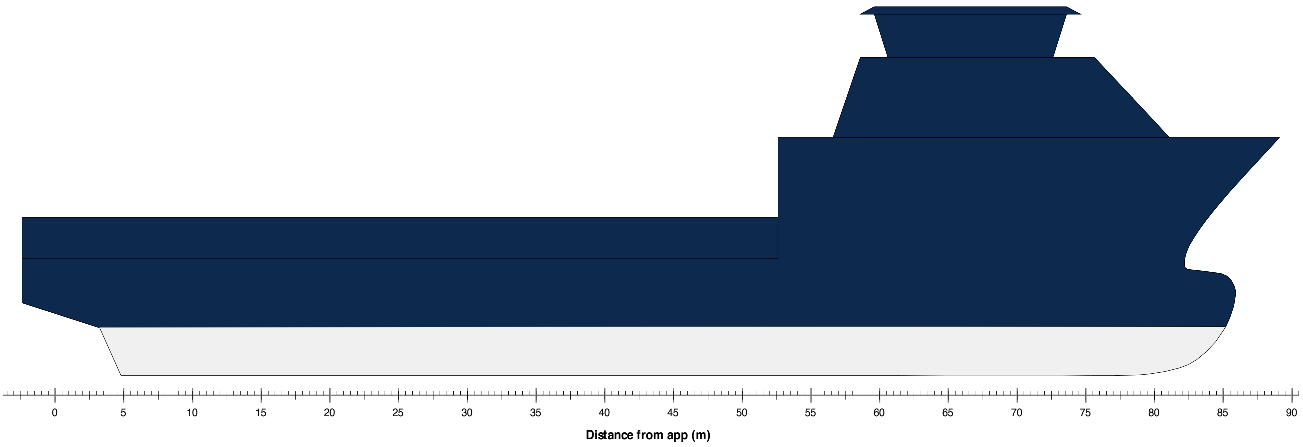
Designer	
Created by	
Comment	
Filename	TankSystems TWISTA.fbm

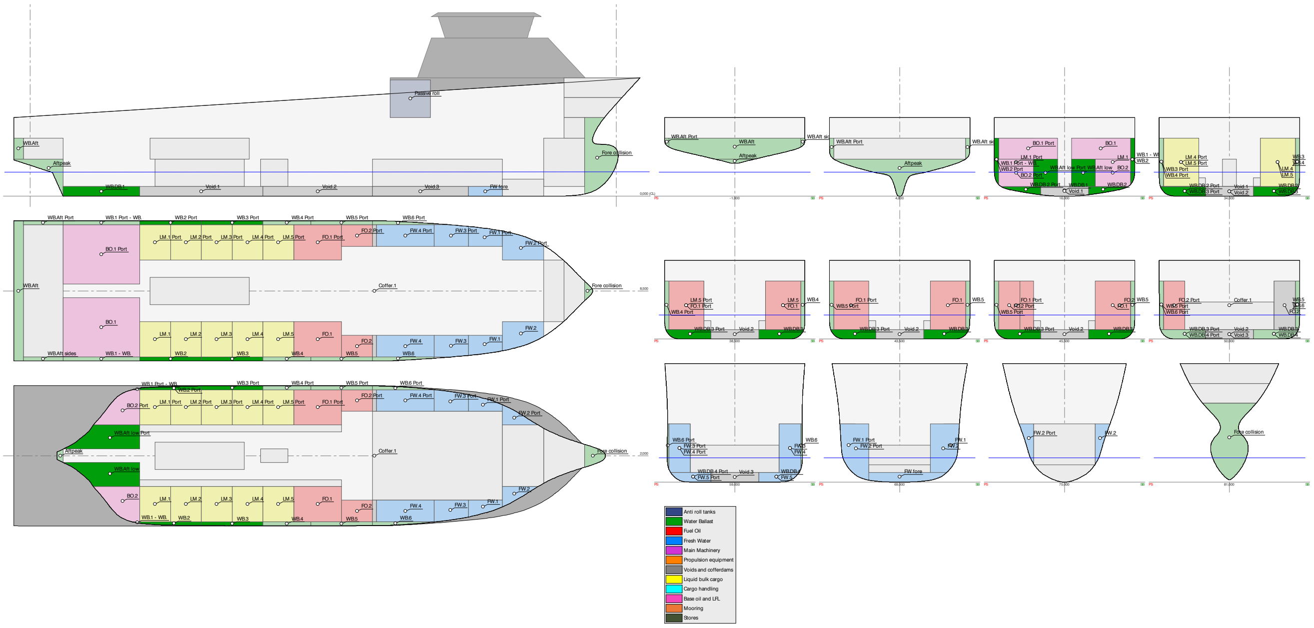
Design length	85,600 (m)	**Midship location**	42,800 (m)
Length over all	91,500 (m)	**Relative water density**	1,0250
Design beam	20,500 (m)	**Mean shell thickness**	0,0100 (m)
Maximum beam	20,500 (m)	**Appendage coefficient**	1,0000
Design draft	6,900 (m)		

Calculation settings

Center of gravity of tanks containing liquids : **Actual COG**

Silhouette 1





Hydrostatic particulars

List	0,0 (CL) (Degr.)	**GG'**	0,018 (m)
Draft aft pp	3,512 (m)	**VCG'**	5,792 (m)
Mean moulded draft	3,540 (m)	**Max VCG'**	10,459 (m)
Draft forward pp	3,567 (m)	**GM solid**	6,153 (m)
Trim	0,055 (m)	**G'M liquid**	6,135 (m)
KM	11,926 (m)	**Immersion rate**	14,450 (t/cm)
VCG	5,774 (m)	**MCT**	69,38 (t*m/cm)

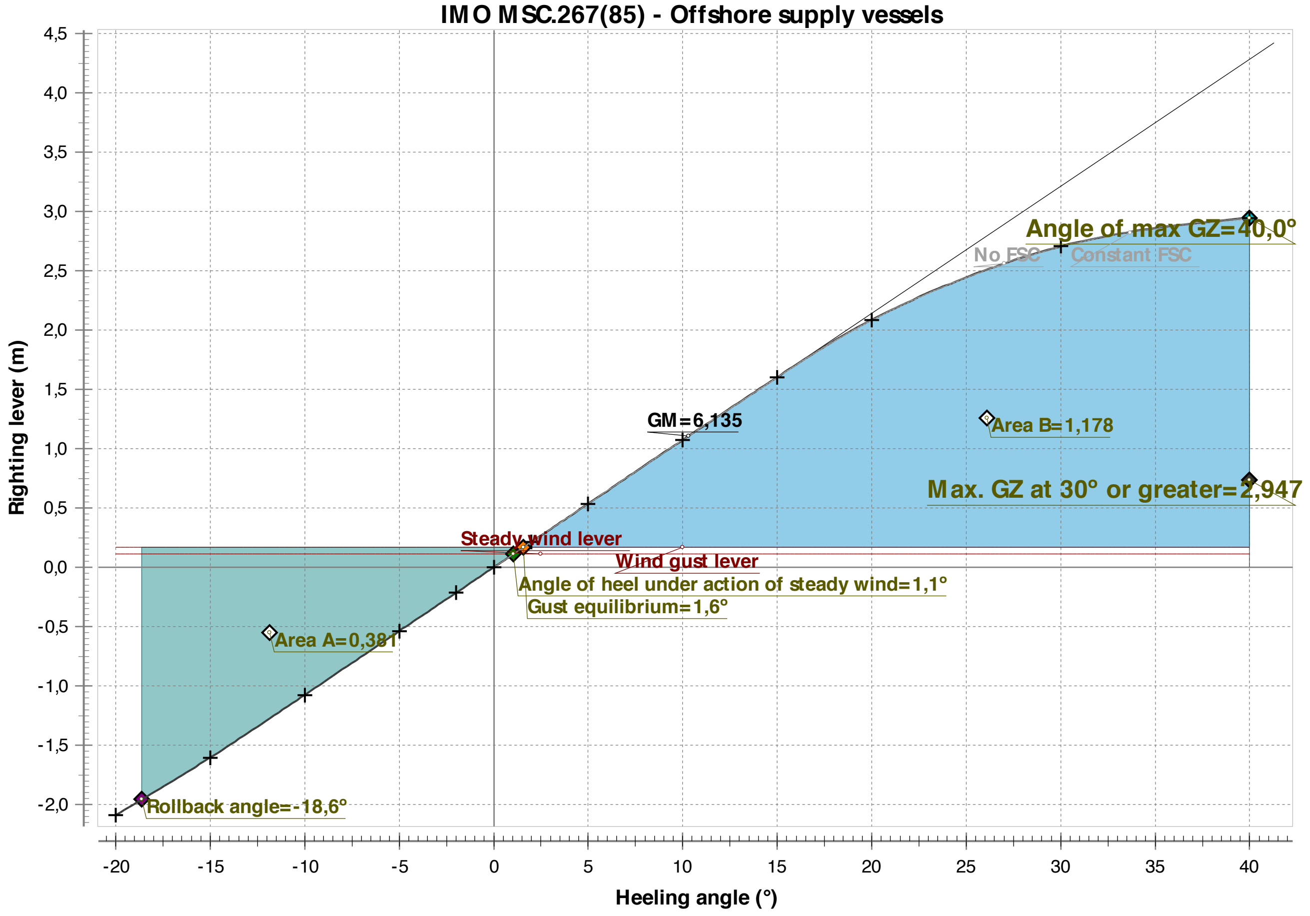
Description	Density (t/m^3)	Fill%	Weight (tonnes)	LCG (m)	TCG (m)	VCG (m)	FSM (t*m)
Anti roll tanks							
Passive roll	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Water Ballast							
Aftpeak	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
Fore collision	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.1 - WB.	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.2	1,0250	100,0	36,52	20,574	-9,941 (SB)	5,118	**0,2**
WB.3	1,0250	100,0	37,77	29,503	-9,945 (SB)	5,012	**0,2**
WB.4	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.5	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.6	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.DB.1	1,0250	100,0	82,79	12,404	0,000 (CL)	0,864	**11,9**
WB.DB.2	1,0250	100,0	136,79	25,678	-6,394 (SB)	0,769	**9,8**
WB.DB.3	1,0250	100,0	135,32	42,000	-6,528 (SB)	0,731	**10,2**
WB.DB.4	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.Aft	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.Aft sides	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.1 Port - WB.	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.2 Port	1,0250	100,0	36,52	20,574	9,941 (PS)	5,118	**0,2**
WB.3 Port	1,0250	100,0	37,77	29,503	9,945 (PS)	5,012	**0,2**
WB.4 Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.5 Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.6 Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.DB 2 Port	1,0250	100,0	136,79	25,678	6,394 (PS)	0,769	**9,8**
WB.DB 3 Port	1,0250	100,0	135,32	42,000	6,528 (PS)	0,731	**10,2**
WB.DB 4 Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.Aft Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.Aft low	1,0250	100,0	143,96	10,780	-2,703 (SB)	3,526	**13,4**
WB.Aft low Port	1,0250	100,0	143,96	10,780	2,703 (PS)	3,526	**13,4**
Totals for Water Ballast			**1063,53**	**24,686**	**0,000 (CL)**	**2,113**	**79,4**
Fuel Oil							
FO.2	0,8600	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FO.1	0,8600	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FO.1 Port	0,8600	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FO.2 Port	0,8600	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Totals for Fuel Oil			**0,00**	**0,000**	**0,000 (CL)**	**0,000**	**0,0**
Fresh Water							
FW.1	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.2	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.3	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.4	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.5	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW fore	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.1 Port	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.2 Port	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.3 Port	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.4 Port	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.5 Port	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Totals for Fresh Water			**0,00**	**0,000**	**0,000 (CL)**	**0,000**	**0,0**

Description	Density *(t/m³)*	Fill%	Weight *(tonnes)*	LCG *(m)*	TCG *(m)*	VCG *(m)*	FSM *(t*m)*
Voids and cofferdams							
Void.1	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Void.2	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Void.3	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Coffer.1	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Totals for Voids and cofferdams			**0,00**	**0,000**	**0,000 (CL)**	**0,000**	**0,0**
Liquid bulk cargo							
LM.1	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
LM.2	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
LM.3	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
LM.4	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
LM.5	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
LM.1 Port	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
LM.2 Port	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
LM.3 Port	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
LM.4 Port	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
LM.5 Port	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Totals for Liquid bulk cargo			**0,00**	**0,000**	**0,000 (CL)**	**0,000**	**0,0**
Base oil and LFL							
BO.1	0,9240	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
BO.2	0,9240	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
BO.1 Port	0,9240	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
BO.2 Port	0,9240	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Totals for Base oil and LFL			**0,00**	**0,000**	**0,000 (CL)**	**0,000**	**0,0**
Lightship			**3374,90**	**47,062**	**0,000 (CL)**	**6,927**	
Deadweight			**1063,53**	**24,686**	**0,000 (CL)**	**2,113**	**79,4**
Displacement			**4438,43**	**41,700**	**0,000 (CL)**	**5,774**	**79,4**

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)*
0,0° (CL)	3,540	0,055	4438,42	0,000	0,000	0,000	0,000	0,000	0,000
2,0° (PS)	3,539	0,059	4438,42	0,416	0,202	0,000	0,000	0,214	0,004
5,0° (PS)	3,533	0,082	4438,42	1,040	0,503	0,000	0,000	0,537	0,023
10,0° (PS)	3,513	0,168	4438,41	2,078	1,003	0,000	0,000	1,075	0,094
15,0° (PS)	3,470	0,317	4438,39	3,098	1,494	0,000	0,000	1,603	0,211
20,0° (PS)	3,389	0,544	4438,42	4,062	1,975	0,000	0,000	2,087	0,373
30,0° (PS)	2,991	1,271	4438,42	5,593	2,887	0,000	0,000	2,706	0,797
40,0° (PS)	2,162	2,256	4438,42	6,658	3,711	0,000	0,000	2,947	1,294

Stability curve
IMO MSC.267(85) - Offshore supply vessels



Evaluation of criteria

IMO MSC.267(85) - Offshore supply vessels

International Code on Intact Stability (2008), Part B, §2.4

Description	Attained value	Criterion	Required value	Complies
Area 0° - 30° / Angle of Max GZ	**0,7967 (mrad)**	**>=**	**0,0550 (mrad)**	**YES**
Angle of max GZ	40,0 (Degr.)			
Calculated angle	40,0 (Degr.)			
Area 30° - 40°	**0,4974 (mrad)**	**>=**	**0,0300 (mrad)**	**YES**
Max. GZ at 30° or greater	**2,947 (m)**	**>=**	**0,200 (m)**	**YES**
Lower angle	30,0 (Degr.)			
Upper angle	90,0 (Degr.)			
Angle of max GZ	**40,0 (Degr.)**	**>=**	**15,0 (Degr.)**	**YES**
Initial metacentric height	**6,135 (m)**	**>=**	**0,150 (m)**	**YES**

Evaluationof criteria

Severe wind and rolling criterion (weather criterion)				YES
Wind silhouette:	Silhouette 1			
Wind pressure	51,4 (kg/m^2)			
Wind area	1050,52 (m^2)			
Steady wind lever	0,113 (m)			
Deck immersion angle	21,57 (Degr.)			
Wind gust lever	0,169 (m)			
Ratio of areaA/areaB	0,323	<=	1,000	YES
Maximum allowed static heeling angle	1,1 (Degr.)	<=	16,0 (Degr.)	YES
Max allowed ratio static angle/deck immersion angle	0,049	<=	0,800	YES

The condition complies with the stability criteria

Max loading SG.1 Mud

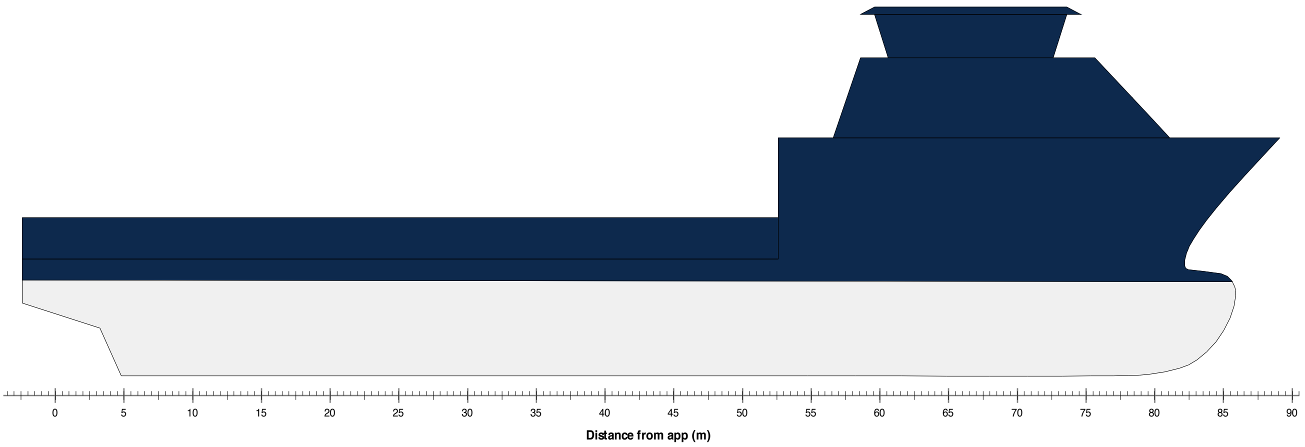
Designer	
Created by	
Comment	
Filename	TankSystems TWISTA.fbm

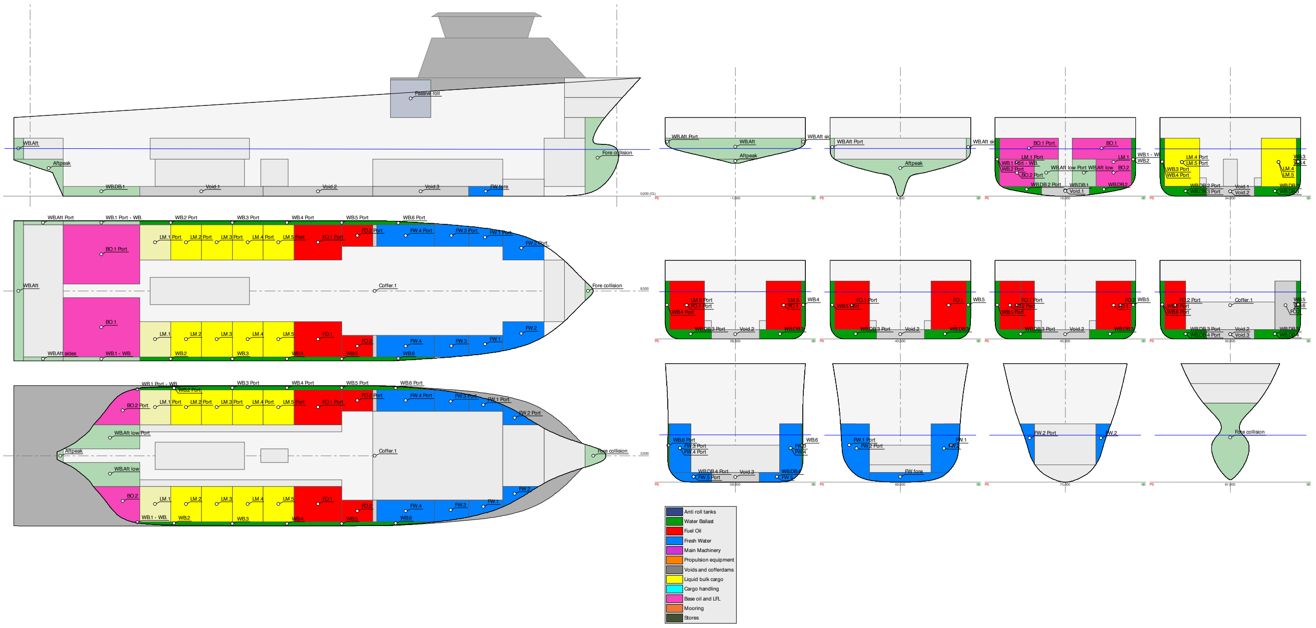
Design length	85,600 (m)	**Midship location**	42,800 (m)
Length over all	91,500 (m)	**Relative water density**	1,0250
Design beam	20,500 (m)	**Mean shell thickness**	0,0100 (m)
Maximum beam	20,500 (m)	**Appendage coefficient**	1,0000
Design draft	6,900 (m)		

Calculation settings

Center of gravity of tanks containing liquids	:	**Actual COG**

Silhouette 1





Hydrostatic particulars

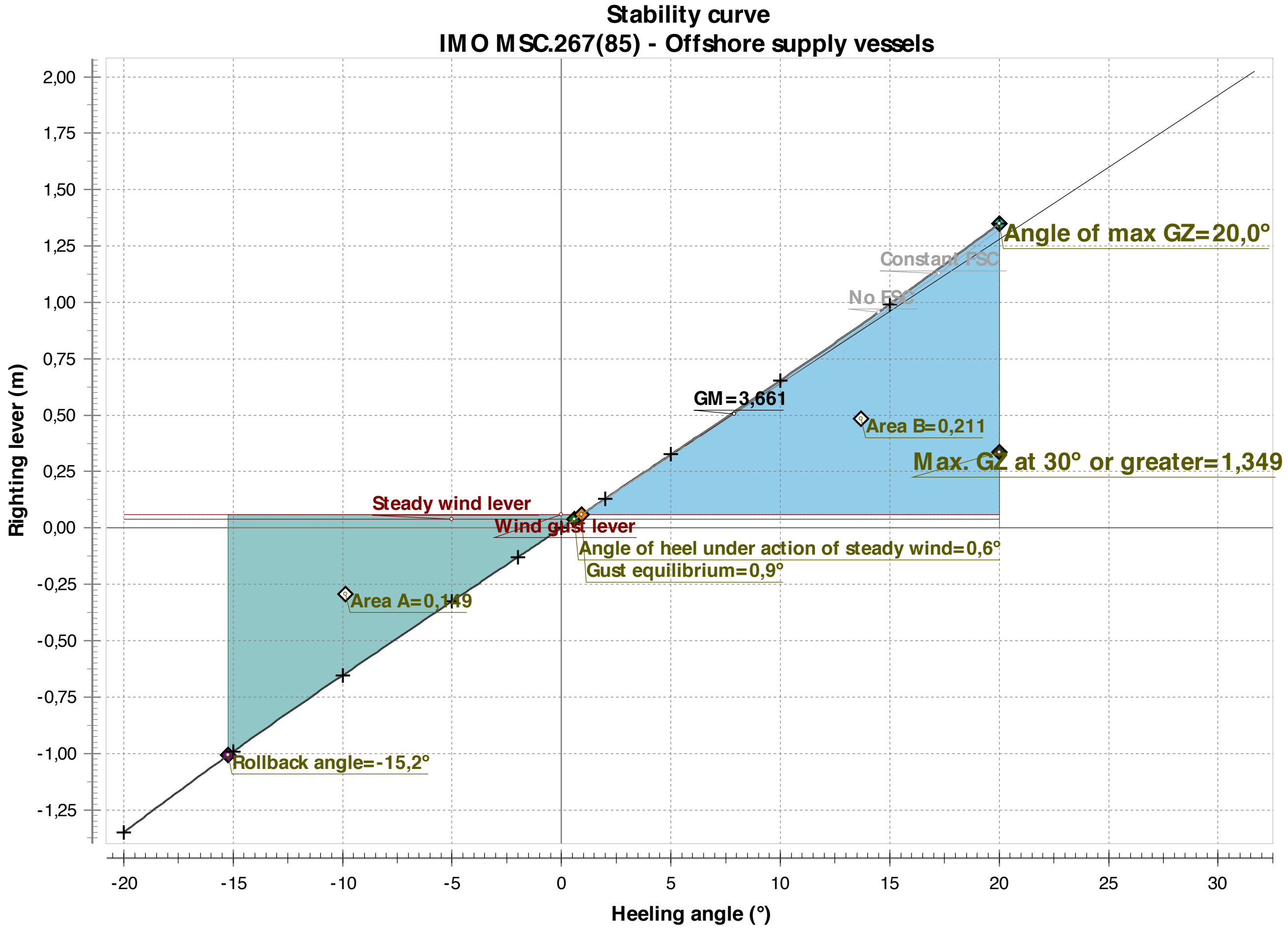
List	0,0 (CL) (Degr.)	**GG'**	0,077 (m)
Draft aft pp	6,963 (m)	**VCG'**	5,446 (m)
Mean moulded draft	6,904 (m)	**Max VCG'**	5,759 (m)
Draft forward pp	6,844 (m)	**GM solid**	3,739 (m)
Trim	-0,119 (m)	**G'M liquid**	3,661 (m)
KM	9,107 (m)	**Immersion rate**	16,281 (t/cm)
VCG	5,368 (m)	**MCT**	97,89 (t*m/cm)

Description	**Density**	**Fill%**	**Weight**	**LCG**	**TCG**	**VCG**	**FSM**
	(t/m^3)		*(tonnes)*	*(m)*	*(m)*	*(m)*	*(t*m)*
Anti roll tanks							
Passive roll	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
Water Ballast							
Aftpeak	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Fore collision	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
WB.1 - WB.	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
WB.2	1,0250	100,0	36,52	20,574	-9,941 (SB)	5,118	0,0
WB.3	1,0250	100,0	37,77	29,503	-9,945 (SB)	5,012	0,0
WB.4	1,0250	100,0	29,42	37,500	-9,945 (SB)	5,007	0,0
WB.5	1,0250	100,0	37,68	45,493	-9,944 (SB)	5,008	0,0
WB.6	1,0250	100,0	27,74	53,744	-9,888 (SB)	5,077	0,0
WB.DB.1	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
WB.DB.2	1,0250	100,0	136,79	25,678	-6,394 (SB)	0,769	0,0
WB.DB.3	1,0250	100,0	135,32	42,000	-6,528 (SB)	0,731	0,0
WB.DB.4	1,0250	100,0	71,90	54,378	-6,373 (SB)	0,736	0,0
WB.Aft	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
WB.Aft sides	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
WB.1 Port - WB.	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
WB.2 Port	1,0250	100,0	36,52	20,574	9,941 (PS)	5,118	0,0
WB.3 Port	1,0250	100,0	37,77	29,503	9,945 (PS)	5,012	0,0
WB.4 Port	1,0250	100,0	29,42	37,500	9,945 (PS)	5,007	0,0
WB.5 Port	1,0250	100,0	37,68	45,493	9,944 (PS)	5,008	0,0
WB.6 Port	1,0250	100,0	27,74	53,744	9,888 (PS)	5,077	0,0
WB.DB 2 Port	1,0250	100,0	136,79	25,678	6,394 (PS)	0,769	0,0
WB.DB 3 Port	1,0250	100,0	135,32	42,000	6,528 (PS)	0,731	0,0
WB.DB 4 Port	1,0250	100,0	71,90	54,378	6,373 (PS)	0,736	0,0
WB.Aft Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
WB.Aft low	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
WB.Aft low Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Totals for Water Ballast			**1026,28**	**37,572**	**0,000 (CL)**	**2,163**	**0,0**
Fuel Oil							
FO.2	0,8600	100,0	84,82	47,750	-8,075 (SB)	4,950	**10,0**
FO.1	0,8600	100,0	215,72	42,000	-7,075 (SB)	4,950	**34,0**
FO.1 Port	0,8600	100,0	215,72	42,000	7,075 (PS)	4,950	**34,0**
FO.2 Port	0,8600	100,0	84,82	47,750	8,075 (PS)	4,950	**10,0**
Totals for Fuel Oil			**601,08**	**43,623**	**0,000 (CL)**	**4,950**	**88,0**
Fresh Water							
FW.1	1,0000	100,0	82,70	66,328	-7,727 (SB)	5,165	**7,8**
FW.2	1,0000	100,0	108,75	71,390	-5,986 (SB)	5,360	**14,9**
FW.3	1,0000	100,0	105,77	61,456	-8,025 (SB)	5,002	**12,3**
FW.4	1,0000	100,0	184,06	54,799	-8,075 (SB)	4,951	**21,7**
FW.5	1,0000	100,0	31,62	61,400	-5,885 (SB)	0,761	**2,7**
FW fore	1,0000	100,0	90,34	66,372	0,000 (CL)	0,763	**11,1**
FW.1 Port	1,0000	100,0	82,70	66,328	7,727 (PS)	5,165	**7,8**
FW.2 Port	1,0000	100,0	108,75	71,390	5,986 (PS)	5,360	**14,9**
FW.3 Port	1,0000	100,0	105,77	61,456	8,025 (PS)	5,002	**12,3**
FW.4 Port	1,0000	100,0	184,06	54,799	8,075 (PS)	4,951	**21,7**
FW.5 Port	1,0000	100,0	31,62	61,400	5,885 (PS)	0,761	**2,7**
Totals for Fresh Water			**1116,13**	**62,313**	**0,000 (CL)**	**4,496**	**130,0**

Description	Density	Fill%	Weight	LCG	TCG	VCG	FSM
	(t/m³)		*(tonnes)*	*(m)*	*(m)*	*(m)*	*(t*m)*
Voids and cofferdams							
Void.1	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Void.2	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Void.3	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Coffer.1	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Totals for Voids and cofferdams			**0,00**	**0,000**	**0,000 (CL)**	**0,000**	**0,0**
Liquid bulk cargo							
LM.1	1,4000	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
LM.2	1,4000	100,0	225,75	22,750	-7,075 (SB)	4,950	**35,6**
LM.3	1,4000	100,0	225,75	27,250	-7,075 (SB)	4,950	**35,6**
LM.4	2,8000	100,0	451,50	31,750	-7,075 (SB)	4,950	**71,1**
LM.5	2,8000	100,0	451,50	36,250	-7,075 (SB)	4,950	**71,1**
LM.1 Port	1,4000	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
LM.2 Port	1,4000	100,0	225,75	22,750	7,075 (PS)	4,950	**35,6**
LM.3 Port	1,4000	100,0	225,75	27,250	7,075 (PS)	4,950	**35,6**
LM.4 Port	2,8000	100,0	451,50	31,750	7,075 (PS)	4,950	**71,1**
LM.5 Port	2,8000	100,0	451,50	36,250	7,075 (PS)	4,950	**71,1**
Totals for Liquid bulk cargo			**2709,03**	**31,000**	**0,000 (CL)**	**4,950**	**426,8**
Base oil and LFL							
BO.1	0,9240	100,0	271,95	10,400	-5,325 (SB)	6,950	**36,7**
BO.2	0,9240	100,0	149,32	11,457	-6,887 (SB)	3,784	**14,9**
BO.1 Port	0,9240	100,0	271,95	10,400	5,325 (PS)	6,950	**36,7**
BO.2 Port	0,9240	100,0	149,32	11,457	6,887 (PS)	3,784	**14,9**
Totals for Base oil and LFL			**842,55**	**10,775**	**0,000 (CL)**	**5,828**	**103,2**
Lightship			**3374,90**	**47,062**	**0,000 (CL)**	**6,927**	
Deadweight			**6295,08**	**36,122**	**0,000 (CL)**	**4,533**	**747,9**
Displacement			**9669,98**	**39,940**	**0,000 (CL)**	**5,368**	**747,9**

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)*
0,0° (CL)	6,904	-0,119	9669,89	0,000	0,000	0,000	0,000	0,000	0,000
2,0° (PS)	6,903	-0,115	9669,89	0,318	0,187	0,000	0,000	0,130	0,002
5,0° (PS)	6,901	-0,099	9669,98	0,794	0,468	0,000	0,000	0,326	0,014
10,0° (PS)	6,894	-0,047	9669,97	1,586	0,932	0,000	0,000	0,654	0,057
15,0° (PS)	6,882	0,036	9669,90	2,381	1,389	0,000	0,000	0,992	0,129
20,0° (PS)	6,863	0,150	9669,96	3,185	1,836	0,000	0,000	1,349	0,231



Stability curve
IMO MSC.267(85) - Offshore supply vessels

Evaluation of criteria

IMO MSC.267(85) - Offshore supply vessels

International Code on Intact Stability (2008), Part B, §2.4

Description	Attained value	Criterion	Required value	Complies
Area 0° - 30° / Angle of Max GZ	**0,2307 (mrad)**	**>=**	**0,0650 (mrad)**	**YES**
Angle of max GZ	20,0 (Degr.)			
Calculated angle	20,0 (Degr.)			
Area 30° - 40°	**0,2307 (mrad)**	**>=**	**0,0300 (mrad)**	**YES**
Max. GZ at 30° or greater	**1,349 (m)**	**>=**	**0,200 (m)**	**YES**
Lower angle	30,0 (Degr.)			
Upper angle	90,0 (Degr.)			
Angle of max GZ	**20,0 (Degr.)**	**>=**	**15,0 (Degr.)**	**YES**
Initial metacentric height	**3,661 (m)**	**>=**	**0,150 (m)**	**YES**
Severe wind and rolling criterion (weather criterion)				**YES**
Wind silhouette:	Silhouette 1			

Evaluationof criteria

Wind pressure	51,4 (kg/m^2)			
Wind area	758,93 (m^2)			
Steady wind lever	0,039 (m)			
Deck immersion angle	0,84 (Degr.)			
Wind gust lever	0,059 (m)			
Ratio of areaA/areaB	0,707	<=	1,000	YES
Maximum allowed static heeling angle	0,6 (Degr.)	<=	16,0 (Degr.)	YES
Max allowed ratio static angle/deck immersion angle	0,716	<=	0,800	YES

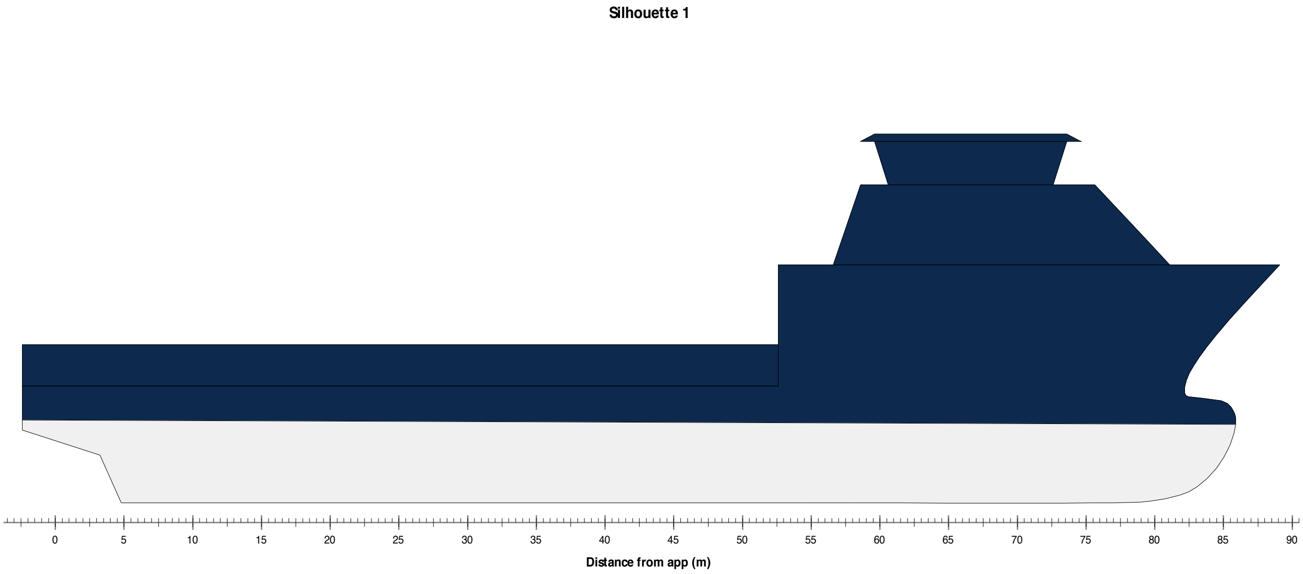
The condition complies with the stability criteria

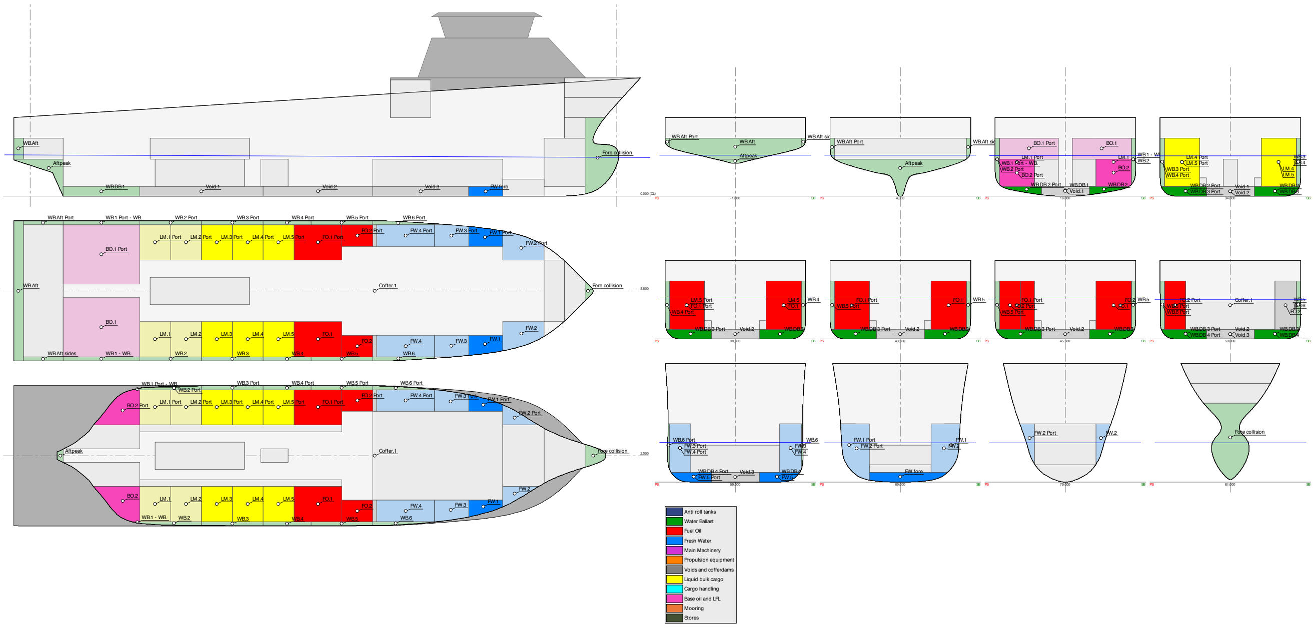
Normal operation

Designer			
Created by			
Comment			
Filename		TankSystems TWISTA.fbm	
Design length	85,600 (m)	**Midship location**	42,800 (m)
Length over all	91,500 (m)	**Relative water density**	1,0250
Design beam	20,500 (m)	**Mean shell thickness**	0,0100 (m)
Maximum beam	20,500 (m)	**Appendage coefficient**	1,0000
Design draft	6,900 (m)		

Calculation settings

Center of gravity of tanks containing liquids : **Actual COG**





Hydrostatic particulars

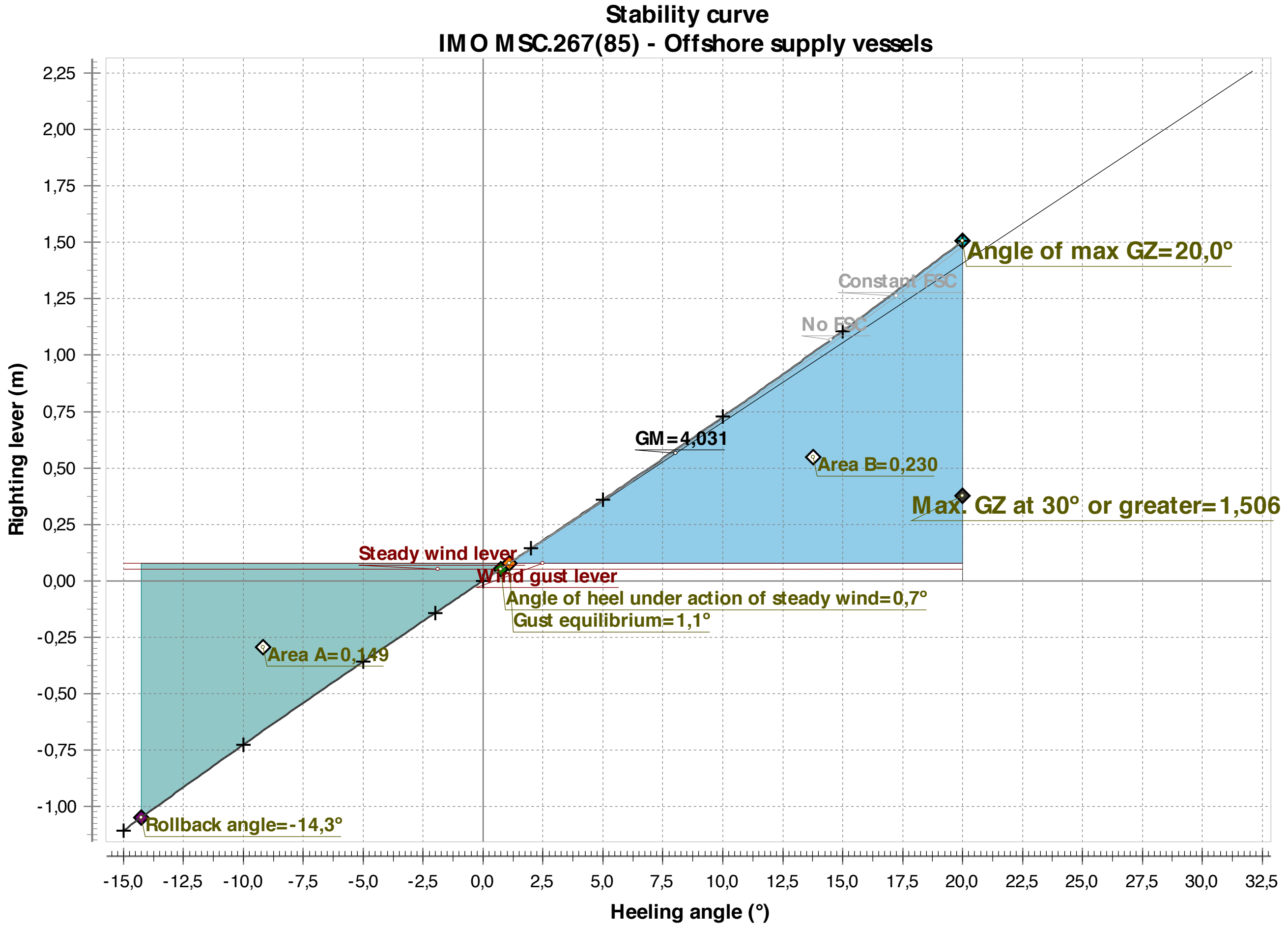
List	0,0 (CL) (Degr.)	**GG'**	0,075 (m)
Draft aft pp	6,012 (m)	**VCG'**	5,378 (m)
Mean moulded draft	5,852 (m)	**Max VCG'**	8,484 (m)
Draft forward pp	5,691 (m)	**GM solid**	4,105 (m)
Trim	-0,321 (m)	**G'M liquid**	4,031 (m)
KM	9,409 (m)	**Immersion rate**	15,998 (t/cm)
VCG	5,304 (m)	**MCT**	93,63 (t*m/cm)

Description	Density	Fill%	Weight	LCG	TCG	VCG	FSM
	(t/m^3)		*(tonnes)*	*(m)*	*(m)*	*(m)*	*(t*m)*
Water Ballast							
Aftpeak	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
Fore collision	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.1 - WB.	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.2	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.3	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.4	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.5	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.6	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.DB.1	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.DB.2	1,0250	100,0	136,79	25,678	-6,394 (SB)	0,769	**9,8**
WB.DB.3	1,0250	100,0	135,32	42,000	-6,528 (SB)	0,731	**10,2**
WB.DB.4	1,0250	100,0	71,90	54,378	-6,373 (SB)	0,736	**5,4**
WB.Aft	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.Aft sides	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.1 Port - WB.	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.2 Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.3 Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.4 Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.5 Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.6 Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
WB.DB 2 Port	1,0250	100,0	136,79	25,678	6,394 (PS)	0,769	**9,8**
WB.DB 3 Port	1,0250	100,0	135,32	42,000	6,528 (PS)	0,731	**10,2**
WB.DB 4 Port	1,0250	100,0	71,90	54,378	6,373 (PS)	0,736	**5,4**
WB.Aft Port	1,0250	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
Totals for Water Ballast			**688,02**	**38,097**	**0,000 (CL)**	**0,747**	**50,8**
Fuel Oil							
FO.2	0,8600	100,0	84,82	47,750	-8,075 (SB)	4,950	**10,0**
FO.1	0,8600	100,0	215,72	42,000	-7,075 (SB)	4,950	**34,0**
FO.1 Port	0,8600	100,0	215,72	42,000	7,075 (PS)	4,950	**34,0**
FO.2 Port	0,8600	100,0	84,82	47,750	8,075 (PS)	4,950	**10,0**
Totals for Fuel Oil			**601,08**	**43,623**	**0,000 (CL)**	**4,950**	**88,0**
Fresh Water							
FW.1	1,0000	100,0	82,70	66,328	-7,727 (SB)	5,165	0,0
FW.2	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.3	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.4	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.5	1,0000	100,0	31,62	61,400	-5,885 (SB)	0,761	0,0
FW fore	1,0000	100,0	90,34	66,372	0,000 (CL)	0,763	0,0
FW.1 Port	1,0000	100,0	82,70	66,328	7,727 (PS)	5,165	0,0
FW.2 Port	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.3 Port	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.4 Port	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
FW.5 Port	1,0000	100,0	31,62	61,400	5,885 (PS)	0,761	0,0
Totals for Fresh Water			**318,98**	**65,363**	**0,000 (CL)**	**3,045**	**0,0**
Voids and cofferdams							
Void.1	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Void.2	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Void.3	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Coffer.1	1,0000	0,0	0,00	0,000	0,000 (CL)	0,000	0,0
Totals for Voids and cofferdams			**0,00**	**0,000**	**0,000 (CL)**	**0,000**	**0,0**

Description	Density (t/m³)	Fill%	Weight (tonnes)	LCG (m)	TCG (m)	VCG (m)	FSM (t*m)
Liquid bulk cargo							
LM.1	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
LM.2	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
LM.3	2,8000	100,0	451,50	27,250	-7,075 (SB)	4,950	**71,1**
LM.4	2,8000	100,0	451,50	31,750	-7,075 (SB)	4,950	**71,1**
LM.5	2,8000	100,0	451,50	36,250	-7,075 (SB)	4,950	**71,1**
LM.1 Port	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
LM.2 Port	2,8000	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
LM.3 Port	2,8000	100,0	451,50	27,250	7,075 (PS)	4,950	**71,1**
LM.4 Port	2,8000	100,0	451,50	31,750	7,075 (PS)	4,950	**71,1**
LM.5 Port	2,8000	100,0	451,50	36,250	7,075 (PS)	4,950	**71,1**
Totals for Liquid bulk cargo			**2709,03**	**31,750**	**0,000 (CL)**	**4,950**	**426,8**
Base oil and LFL							
BO.1	0,9240	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
BO.2	0,9240	100,0	149,32	11,457	-6,887 (SB)	3,784	**14,9**
BO.1 Port	0,9240	0,0	0,00	0,000	0,000 (CL)	0,000	**0,0**
BO.2 Port	0,9240	100,0	149,32	11,457	6,887 (PS)	3,784	**14,9**
Totals for Base oil and LFL			**298,65**	**11,457**	**0,000 (CL)**	**3,784**	**29,9**
Lightship			**3374,90**	**47,062**	**0,000 (CL)**	**6,927**	
Deadweight			**4615,75**	**35,252**	**0,000 (CL)**	**4,116**	**595,4**
Displacement			**7990,65**	**40,240**	**0,000 (CL)**	**5,304**	**595,4**

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)
0,0° (CL)	5,852	-0,321	7990,63	0,000	0,000	0,000	0,000	0,000	0,000
2,0° (PS)	5,851	-0,315	7990,64	0,328	0,185	0,000	0,000	0,143	0,002
5,0° (PS)	5,848	-0,288	7990,64	0,821	0,462	0,000	0,000	0,359	0,016
10,0° (PS)	5,837	-0,195	7990,64	1,648	0,921	0,000	0,000	0,727	0,063
15,0° (PS)	5,819	-0,062	7990,64	2,480	1,373	0,000	0,000	1,107	0,143
20,0° (PS)	5,792	0,108	7990,64	3,320	1,814	0,000	0,000	1,506	0,257


Stability curve
IMO MSC.267(85) - Offshore supply vessels

Evaluation of criteria

IMO MSC.267(85) - Offshore supply vessels

International Code on Intact Stability (2008), Part B, §2.4

Description	Attained value	Criterion	Required value	Complies
Area 0° - 30° / Angle of Max GZ	**0,2568 (mrad)**	**>=**	**0,0650 (mrad)**	**YES**
Angle of max GZ	20,0 (Degr.)			
Calculated angle	20,0 (Degr.)			
Area 30° - 40°	**0,2568 (mrad)**	**>=**	**0,0300 (mrad)**	**YES**
Max. GZ at 30° or greater	**1,506 (m)**	**>=**	**0,200 (m)**	**YES**
Lower angle	30,0 (Degr.)			
Upper angle	90,0 (Degr.)			
Angle of max GZ	**20,0 (Degr.)**	**>=**	**15,0 (Degr.)**	**YES**
Initial metacentric height	**4,031 (m)**	**>=**	**0,150 (m)**	**YES**
Severe wind and rolling criterion (weather criterion)				**YES**
Wind silhouette:	Silhouette 1			

Evaluationof criteria

Wind pressure	51,4 (kg/m²)			
Wind area	851,52 (m²)			
Steady wind lever	0,052 (m)			
Deck immersion angle	6,39 (Degr.)			
Wind gust lever	0,079 (m)			
Ratio of areaA/areaB	0,649	<=	1,000	YES
Maximum allowed static heeling angle	0,7 (Degr.)	<=	16,0 (Degr.)	YES
Max allowed ratio static angle/deck immersion angle	0,114	<=	0,800	YES

The condition complies with the stability criteria

Appendix M: Tank arrangement

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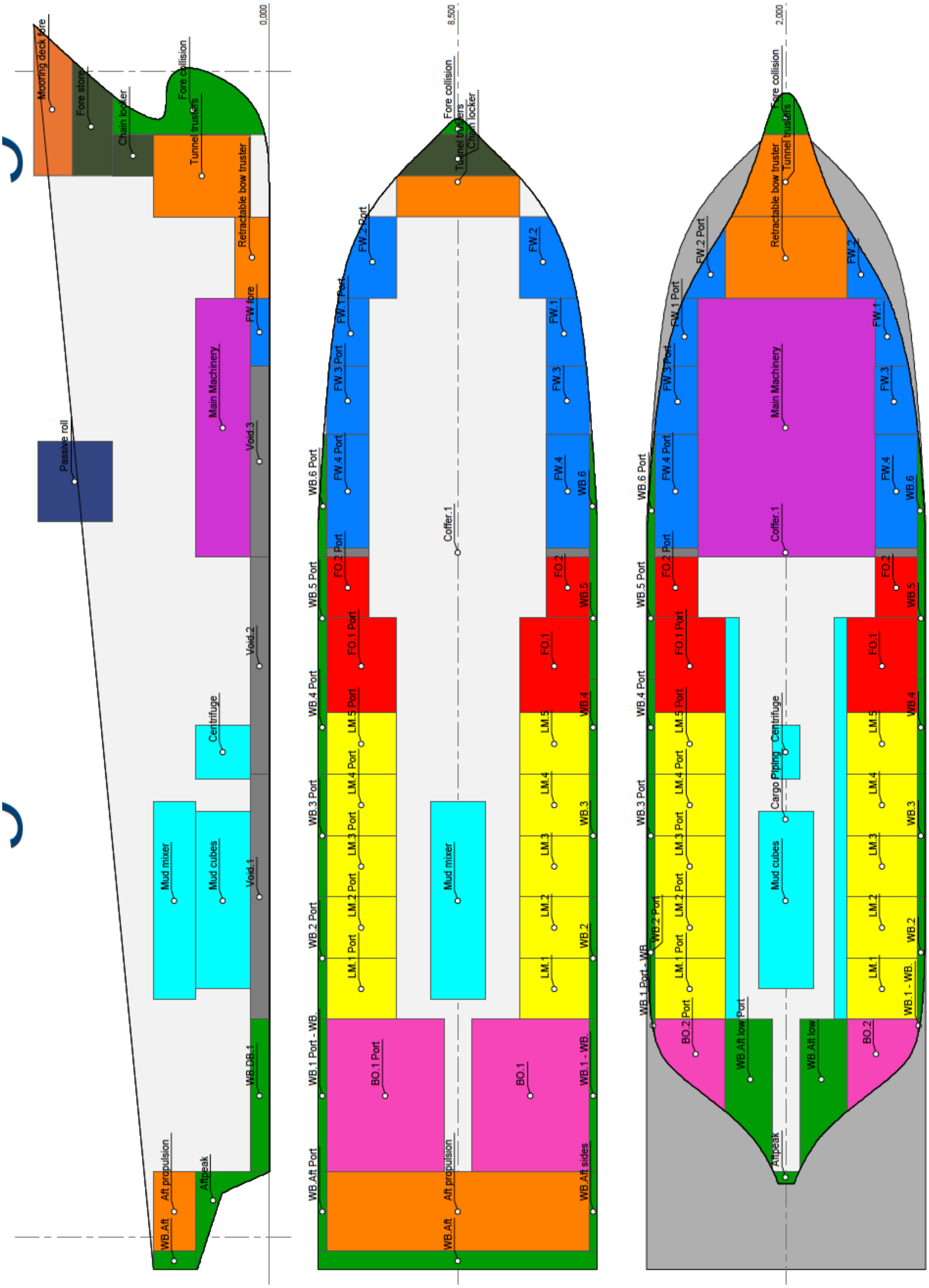
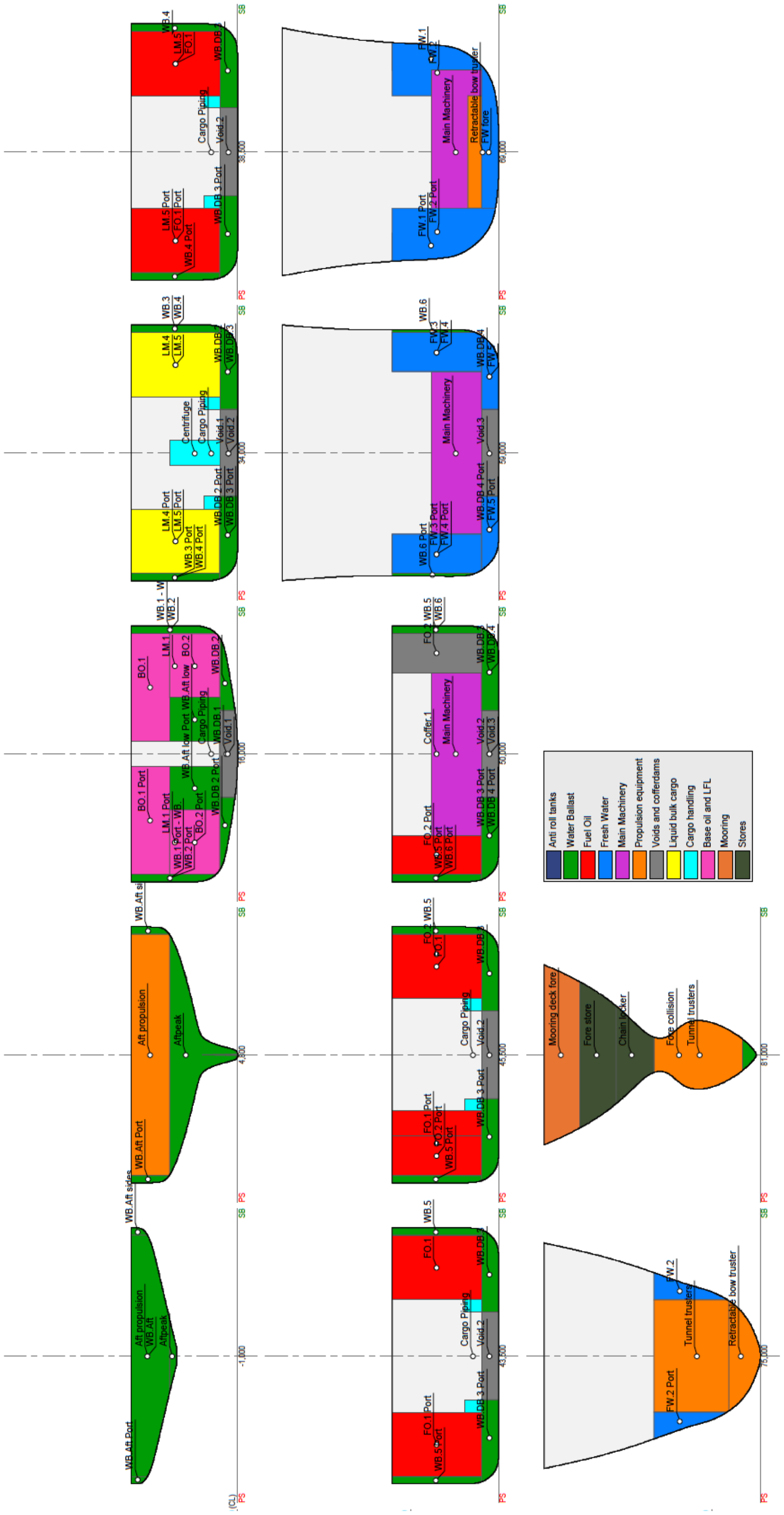

0,000
Mooring deck fore
Fore store
Chain locker
Fore collision
Tunnel trusters
Retractable bow truster
FW fore
Main Machinery
Void.3
Passive roll
Void.2
Centrifuge
Mud mixer
Mud cubes
Void.1
WB.DB.1
Aft propulsion
Aftpeak
WB.Aft
8,500
Fore collision
Tunnel trusters
Chain locker
FW.2 Port
FW.2
FW.1 Port
FW.1
FW.3 Port
FW.3
WB.6 Port
FW.4 Port
FW.4
WB.6
Coffer.1
FO.2 Port
FO.2
WB.5 Port
WB.5
FO.1 Port
FO.1
WB.4 Port
LM.5 Port
LM.5
WB.4
LM.4 Port
LM.4
WB.3 Port
LM.3 Port
LM.3
WB.3
Mud mixer
WB.2 Port
LM.2 Port
LM.2
WB.2
LM.1 Port
LM.1
WB.1 Port - WB.
WB.1 - WB.
BO.1 Port
BO.1
WB.Aft Port
Aft propulsion
WB.Aft sides
WB.Aft
2,000
Fore collision
Tunnel trusters
Retractable bow truster
FW.2 Port
FW.2
FW.1 Port
FW.1
Main Machinery
FW.3 Port
FW.3
WB.6 Port
FW.4 Port
FW.4
WB.6
Coffer.1
FO.2 Port
FO.2
WB.5 Port
WB.5
FO.1 Port
FO.1
WB.4 Port
LM.5 Port
LM.5
WB.4
Centrifuge
Cargo Piping
LM.4 Port
LM.4
WB.3 Port
LM.3 Port
LM.3
WB.3
Mud cubes
WB.2 Port
LM.2 Port
LM.2
WB.2
WB.1 Port - WB.
LM.1 Port
LM.1
WB.1 - WB.
BO.2 Port
BO.2
WB.Aft low Port
WB.Aft low
Aftpeak



Anti roll tanks
Water Ballast
Fuel Oil
Fresh Water
Main Machinery
Propulsion equipment
Voids and cofferdams
Liquid bulk cargo
Cargo handling
Base oil and LFL
Mooring
Stores
SB
PS
(CL)
-1.000
4.800
16.000
34.000
38.000
43.500
45.500
50.000
59.000
69.000
75.000
81.000
WB.Aft Port
WB.Aft sides
Aft propulsion
WB.Aft
Afterpeak
BO.1
BO.1 Port
BO.2
BO.2 Port
LM.1
LM.1 Port
LM.4
LM.4 Port
LM.5
LM.5 Port
WB.1 - WB.2
WB.Aft low
WB.Aft low Port
WB.DB.1
WB.DB.2
WB.DB.2 Port
WB.DB.3
WB.DB.3 Port
WB.DB.4
WB.DB.4 Port
WB.2
WB.3
WB.3 Port
WB.4
WB.4 Port
WB.5
WB.5 Port
WB.6
WB.6 Port
FO.1
FO.1 Port
FO.2
FO.2 Port
FW.1
FW.1 Port
FW.2
FW.2 Port
FW.3
FW.3 Port
FW.4
FW.4 Port
FW.5
FW.5 Port
FW fore
Void.1
Void.2
Void.3
Coffer.1
Centrifuge
Cargo Piping
Main Machinery
Retractable bow truster
Tunnel trusters
Mooring deck fore
Fore store
Chain locker
Fore collision

Appendix N: Tank capacities

Tank and compartments

Anti roll tanks

Tank description	Abbreviation	Relative density	Moulded volume (m^3)	Volume (m^3)	Weight (tonnes)	LCG (m)	TCG (m)	VCG (m)	Max FSM (t*m)
Passiveroll		1,000	656,66	643,53	643,53	55,528	0,000 (CL)	14,257	4122,55
Total				643,53	643,53	55,528	0,000 (CL)	14,257	4122,55

Water Ballast

Tank description	Abbreviation	Relative density	Moulded volume (m^3)	Volume (m^3)	Weight (tonnes)	LCG (m)	TCG (m)	VCG (m)	Max FSM (t*m)
Aftpeak		1,025	79,06	77,48	79,41	2,940	0,000 (CL)	4,609	1362,23
Fore collision		1,025	106,16	104,04	106,64	82,645	0,000 (CL)	5,761	36,18
WB.1	WB.	1,025	30,99	30,37	31,13	11,136	-9,936 (SB)	6,056	0,20
WB.2		1,025	36,51	35,78	36,67	20,570	-9,942 (SB)	5,106	0,16
WB.3		1,025	37,67	36,92	37,84	29,503	-9,946 (SB)	5,007	0,16
WB.4		1,025	29,33	28,75	29,46	37,500	-9,946 (SB)	5,002	0,13
WB.5		1,025	37,58	36,83	37,75	45,494	-9,945 (SB)	5,003	0,16
WB.6		1,025	27,88	27,32	28,00	53,757	-9,890 (SB)	5,071	0,12
WB.DB.1		1,025	83,90	82,22	84,28	12,404	0,000 (CL)	0,861	1445,80
WB.DB.2		1,025	137,44	134,69	138,06	25,642	-6,407 (SB)	0,766	406,12
WB.DB.3		1,025	134,99	132,29	135,60	42,000	-6,534 (SB)	0,731	381,07
WB.DB.4		1,025	71,79	70,36	72,11	54,379	-6,381 (SB)	0,735	191,71
WB.Aft		1,025	66,30	64,98	66,60	-1,688	0,000 (CL)	7,252	1012,51
WB.Aft sides		1,025	6,24	6,12	6,27	2,341	-9,928 (SB)	7,523	0,10
WB.1 Port	WB.	1,025	30,99	30,37	31,13	11,136	9,936 (PS)	6,056	0,20
WB.2 Port		1,025	36,51	35,78	36,67	20,570	9,942 (PS)	5,106	0,16
WB.3 Port		1,025	37,67	36,92	37,84	29,503	9,946 (PS)	5,007	0,16
WB.4 Port		1,025	29,33	28,75	29,46	37,500	9,946 (PS)	5,002	0,13
WB.5 Port		1,025	37,58	36,83	37,75	45,494	9,945 (PS)	5,003	0,16
WB.6 Port		1,025	27,88	27,32	28,00	53,757	9,890 (PS)	5,071	0,12
WB.DB2 Port		1,025	137,44	134,69	138,06	25,642	6,407 (PS)	0,766	406,12
WB.DB3 Port		1,025	134,99	132,29	135,60	42,000	6,534 (PS)	0,731	381,07
WB.DB4 Port		1,025	71,79	70,36	72,11	54,379	6,381 (PS)	0,735	191,71
WB.Aft Port		1,025	6,24	6,12	6,27	2,341	9,928 (PS)	7,523	0,10
WB.Aft low		1,025	143,43	140,56	144,07	10,777	-2,703 (SB)	3,525	40,20
WB.Aft low Port		1,025	143,43	140,56	144,07	10,777	2,703 (PS)	3,525	40,20
Total				1688,67	1730,88	30,342	0,000 (CL)	3,032	5897,01

Fuel Oil

Tank description	Abbreviation	Relative density	Moulded volume (m^3)	Volume (m^3)	Weight (tonnes)	LCG (m)	TCG (m)	VCG (m)	Max FSM (t*m)
FO.2		0,860	100,64	98,63	84,82	47,750	-8,075 (SB)	4,950	9,88
FO.1		0,860	255,95	250,84	215,72	42,000	-7,075 (SB)	4,950	67,15
FO.1Port		0,860	255,95	250,84	215,72	42,000	7,075 (PS)	4,950	67,15
FO.2Port		0,860	100,64	98,63	84,82	47,750	8,075 (PS)	4,950	9,88
Total				698,93	601,08	43,623	0,000 (CL)	4,950	154,06

Fresh Water

Tank description	Abbreviation	Relative density	Moulded volume (m^3)	Volume (m^3)	Weight (tonnes)	LCG (m)	TCG (m)	VCG (m)	Max FSM (t*m)
FW.1		1,000	85,32	83,61	83,61	66,333	-7,739 (SB)	5,157	7,62
FW.2		1,000	111,96	109,72	109,72	71,391	-5,996 (SB)	5,353	22,77
FW.3		1,000	108,21	106,05	106,05	61,458	-8,028 (SB)	4,999	12,27
FW.4		1,000	187,82	184,07	184,07	54,799	-8,075 (SB)	4,951	21,44
FW.5		1,000	32,50	31,85	31,85	61,402	-5,898 (SB)	0,759	68,46
FWfore		1,000	92,82	90,96	90,96	66,374	0,000 (CL)	0,763	1580,27
FW.1Port		1,000	85,32	83,61	83,61	66,333	7,739 (PS)	5,157	7,62
FW.2Port		1,000	111,96	109,72	109,72	71,391	5,996 (PS)	5,353	22,77
FW.3Port		1,000	108,21	106,05	106,05	61,458	8,028 (PS)	4,999	12,27
FW.4Port		1,000	187,82	184,07	184,07	54,799	8,075 (PS)	4,951	21,44
FW.5Port		1,000	32,50	31,85	31,85	61,402	5,898 (PS)	0,759	68,46
Total				1121,55	1121,55	62,338	0,000 (CL)	4,492	1845,41

Voids and cofferdams

Tank description	Abbreviation	Relative density	Moulded volume (m^3)	Volume (m^3)	Weight (tonnes)	LCG (m)	TCG (m)	VCG (m)	Max FSM (t*m)
Void.1		1,000	175,58	172,07	172,07	25,034	0,000 (CL)	0,703	504,21
Void.2		1,000	156,80	153,66	153,66	42,000	0,000 (CL)	0,700	448,19
Void.3		1,000	137,14	134,39	134,39	56,998	0,000 (CL)	0,700	392,16
Coffer.1		1,000	26,84	26,30	26,30	50,300	0,000 (CL)	4,950	244,61
Total				486,43	486,43	40,591	0,000 (CL)	0,931	1589,17

Liquid bulk cargo

Tank description	Abbreviation	Relative density	Moulded volume (m^3)	Volume (m^3)	Weight (tonnes)	LCG (m)	TCG (m)	VCG (m)	Max FSM (t*m)
LM.1		2,800	164,51	161,22	451,43	18,250	-7,075 (SB)	4,951	140,55
LM.2		2,800	164,54	161,25	451,50	22,750	-7,075 (SB)	4,950	140,55
LM.3		2,800	164,54	161,25	451,50	27,250	-7,075 (SB)	4,950	140,55
LM.4		2,800	164,54	161,25	451,50	31,750	-7,075 (SB)	4,950	140,55
LM.5		2,800	164,54	161,25	451,50	36,250	-7,075 (SB)	4,950	140,55
LM.1 Port		2,800	164,51	161,22	451,43	18,250	7,075 (PS)	4,951	140,55
LM.2 Port		2,800	164,54	161,25	451,50	22,750	7,075 (PS)	4,950	140,55
LM.3 Port		2,800	164,54	161,25	451,50	27,250	7,075 (PS)	4,950	140,55
LM.4 Port		2,800	164,54	161,25	451,50	31,750	7,075 (PS)	4,950	140,55
LM.5 Port		2,800	164,54	161,25	451,50	36,250	7,075 (PS)	4,950	140,55
Total				1612,46	4514,89	27,250	0,000 (CL)	4,950	1405,52

Base oil and LFL

Tank description	Abbreviation	Relative density	Moulded volume (m^3)	Volume (m^3)	Weight (tonnes)	LCG (m)	TCG (m)	VCG (m)	Max FSM (t*m)
BO.1		0,924	300,33	294,32	271,95	10,400	-5,325 (SB)	6,950	546,99
BO.2		0,924	165,65	162,34	150,00	11,453	-6,891 (SB)	3,778	115,40
BO.1Port		0,924	300,33	294,32	271,95	10,400	5,325 (PS)	6,950	546,99
BO.2Port		0,924	165,65	162,34	150,00	11,453	6,891 (PS)	3,778	115,40
Total				913,32	843,91	10,774	0,000 (CL)	5,822	1324,78

Appendix O: Task Description

Master Thesis in Marine Systems Design
for
Stud. techn. Yngve Windsland
Design of an Offshore Drilling Fluid Maintenance Vessel
Spring 2017

Background

Offshore drilling operations on the Norwegian Continental Shelf are performed to locate, identify, and extract petrochemical resources. This type of operation requires large amounts of supplies throughout the operation period, especially drilling fluids as several thousand barrels are in use when drilling a single well. Drilling fluids are used in a circulation system where the fluids are used to ensure a safe and efficient operation. In the upper part of a well, relative cheap water-based drilling fluids are used. Due to increasing technical difficulties down-hole, the need for expensive oil-based drilling fluids arises when the well depth increases. The water-based drilling fluid has to be replaced with oil-based and thus large quantities of drilling fluids have to be reallocated. Oil-based drilling fluids may also be replaced several times. Oil-based drilling fluids and the wastes accumulated during operations are not permitted to discharge to sea due to environmental impacts. It is common to transport oil-based drilling fluids and wastes to shore for treatment and storage after use. In return, new or recycled drilling fluids are transported from the storages onshore to the offshore drilling unit. There is always a loss of drilling fluids during drilling operations and since the well volume constantly increases, refilling of drilling fluids are constantly required.

Today platform supply vessels are used to transport drilling fluids in liquid bulk tanks from onshore storages to offshore installations. On the return trip wastes and used drilling fluids are transported to shore for disposal and storage, respectively. Used drilling fluids are either; treated onshore and stored to be used in a new drilling operation, or sent to a recycling facility for disposal. The cost of oil-based drilling fluids is substantial and reusing the drilling fluid increase profits. Although carefully planned, drilling operations never progress according to the drilling plan. Therefore, planning the logistics are difficult for the operators. Due to high uncertainty in drilling fluid demand during drilling operations, additional vessels are often needed in addition to the original routed vessels and dedicated storage vessels are present next to the platform during drilling operations to assist the operation.

Objective

The overall objective of this thesis is to design an offshore drilling fluid maintenance vessel to increase reuse and recycling of drilling fluids. Dedicated storage vessels present on the field today have the potential to not only store drilling fluids but also perform maintenance of the drilling fluid while operating on standby. The drilling fluid can then be used in a new drilling operation without the need for maintenance onshore.

Scope of work

The following main points should presumably be covered in the project thesis:

a) Describe offshore oil and gas drilling operations. The focus will be on oil-based drilling fluids.
b) Describe the storing, handling, and treatment process of drilling fluids during drilling operations and review functions required to improve these operations.
c) Review and describe ship design methodologies suitable for the operations, functions, and drilling fluid treatment process described in a) and b).
d) Present a vessel concept derived from main functions and discoveries from task a) – c). A typical operating context of this vessel shall be described and presented.
e) A functional breakdown for the vessel concept is to be derived from the operation context and sets the basis for the design.
f) Functional requirements, estimation of required areas, volumes and mass properties of different functions of the vessel design shall be defined.
g) A 3D-model and general arrangement drawings of the vessel shall be developed based on the required functions for the vessel.
h) The vessel stability shall be analyzed and vessel performance is to be estimated.
i) State a set of work that can further derive from the work done in this thesis.

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

Assistant Professor Svein Aanond Aanondsen will be the main supervisor from the Department of Marine Technology at NTNU. The research question where presented by and is of interest to Statoil Marine and they will contribute with some information during the project thesis work. The main contact persons at Statoil Marine will be Principal Consultant Supply Chain Management Bjørn Olav Gullberg. The work shall follow the guidelines made by NTNU for thesis work. The workload shall correspond to 30 credits, which is 100% of one school semester at NTNU.

Svein Aanond Aanondsen
Assistant Professor / Supervisor