A comparison between the 'Smart-Stabiliser' and a wider ship

The case of Jumbo Maritime

K.E.B. Span

Report Number: SDPO.19.017.m

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by

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to obtain the degree of Master of Science
at the Delft University of Technology,
to be defended publicly on Wednesday 21 August 2019 at 10:00.

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Project duration:	06/2018 – 07/2019	
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This thesis is confidential and cannot be made public until June 30, 2024.

Preface

This report represents the final thesis to complete my Masters of Science of Shipping Management at the Delft University of Technology. Carried out at Jumbo Maritime

I would like to thank Jumbo Maritime to giving me the opportunity to executing this thesis, for the nice atmosphere and helpfully colleagues who helped answering questions and providing advice. I want to specially thank the following persons, Kasper van der Heiden, supervisor from Jumbo Maritime. He helped and provided me guidelines to go in the right direction with my thesis, and gave a lot of input and advice. Furthermore thanks to the daily supervisors Koos Frouws and Edwin van Hasselt from TU Delft. They also helped helped me during the process to send me in the right direction and discuss my work during the project. Beside my daily supervisors, I would like to thank Robert Hekkenberg to preside my exam committee and in addition Sebastian Schreier to complete my exam committee. Also thanks to the other thesis students at Jumbo for providing tips and support while writing this report, for the useful brainstorm sessions and coffee breaks. Finally, I would like to thank my parents and girlfriend who supported me during my studies.

K.E.B. Span
Delft, January 2019

Abstract

Jumbo Maritime is a shipping company active in the heavy lifting market. Jumbo uses stabilisers to enlarge the stability of the ship during lifting. By using stabilisers Jumbo can perform heavy lifts with a relative small ship, this is one of the major advantages. Downside of using stabilisers is that the installation and de-installation is a time-consuming process. Besides that the usage also causes safety issues, more and more port authorities no longer approve the usage of stabilisers. Research is done in finding alternatives for the use of stabilisers, focusing on alternatives for new ships that need to be build.

Looking at Jumbo's position in the market shows the following unique selling points, for the J-type:

- Limited draft compared to its competitors
- Length < 150 meters

On the one hand the usage of smart stabiliser to speed up the installation and de-installation of stabilisers is looked at. Because smart stabilisers are still stabilisers, also alternatives are analysed that do not require a stabiliser at all. By widening the ship, the ship can be stable enough to perform lifts without extra support from stabilisers.

A model is created to be able to determine the required width for each concept. This model is generated based on the input and requirements set by literature, market analysis and Jumbo's specifications. Some of these requirements are: limited dimensions, minimum required stability, anti heeling and deadweight. The four concepts that are created as input for the model are:

- Base concept, concept 1: Current situation with the usage of stabilisers
- Concept 2: Usages of **smart stabilisers** instead of the current stabilisers, this is the only thing that varies, the rest is equal to concept 1
- Concept 3: Wider ship with **U-shaped hull** that does not require use of stabilisers during lifting
- Concept 4: Wider ship with **V-shaped hull** that does not require use of stabilisers during lifting

A case study is performed to be able to compare the concepts. Three cases are created, which are actual relevant cases for Jumbo Maritime:

- Case 1: Stabiliser is used in 30% of the jobs
- Case 2: Stabiliser is used in 70% of the jobs
- Case 3: Stabiliser is used 50% of the jobs, with less jobs than in case 1 and 2 because the distance between the jobs is bigger.

For each concept the costs are determined to sail the certain case. Because the heavy lift market consists of so many single jobs that differ a lot on weight, complexity and distance it is difficult to map the revenues. The costs are determined per job, to be able to compare the different concepts. Costs consists of the capital costs, fuel costs and operational related costs. Besides cost per job, also cost per ton/mile is calculated to determine the economical speed. For case 1 the economical speed is 14 knots, which is similar to the required design speed. This means that the ships sails most cost efficient at this speed.

The time that is saved by eliminating the stabiliser is used to reduce the sailing speed. In this way the same amount of jobs can done in the same time. This research shows that the saved fuel consumption as a result of slower sailing can compensate the longer sailing time and increased resistance for a wider hull concept.

Comparing the concepts in the different cases shows that concepts 3 and 4 are more beneficial in case the stabiliser usages goes up. It can be concluded that a wider hull shape can operate at 2-5 % lower costs. The fuel consumption of the V-shape decreases more significantly at lower drafts. It is an advantage at ballast sailing or during sailing light cargoes. Besides the lower costs, the increase of deck space for the wider concepts is added value in the heavy lift market. An other important advantage of the wider ship concepts is the elimination of safety issues because the usage of stabilisers is not needed any more to lift heavy cargoes safely.

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Nomenclature

Abbreviations

$CAPEX$	Capital Expenditures
CPP	Controllable Pitch Propeller
FPP	Fixed Pitch Propeller
HFO	Heavy Fuel Oil
kWh	kilo Watt hour
LCG	Longitudinal Centre of Gravity
MCR	Maximum Continuous Rating
MGO	Marine Gas Oil
MPP	Multi Purpose Vessel
$OPEX$	Operational Expenditures
RPM	Revolutions per Minute
sfc	specific fuel consumption
SWL	Save Working Load
TCG	Transverse Centre of Gravity
VCG	Vertical Centre of Gravity

Symbols

$\triangle$	Displacement mass	$tons$
η_D	Propulsive efficiency	
η_{pi}	Ideal propeller efficiency	
η_p	Propeller efficiency	
η_S	Shaft efficiency	
∇	Displacement volume	m^3
A_p	Propeller area	m^2
B	Beam	m
BM	Height of transverse metacentre(M) above centre of buoyancy(B)	m
C_b	Block Coefficient	
C_{crane}	Costs of crane	£
C_m	Midship area coefficient	
C_p	Prismatic coefficient	

C_t	Thrust loading coefficient	
C_{wp}	Waterplane area coefficient	
D	Depth	m
D_p	Propeller Diameter	m
D_p	Propeller diameter	m
F_n	Froude number	
GM	Height of metacentre(M) above centre of gravity(G)	m
KB	Height of centre of buoyancy(B) above keel(K)	m
KM	Height transverse metacentre(M) above keel(K)	m
L_{oa}	Length over all	m
L_{pp}	Length between perpendiculars	m
P_B	Brake Power	kW
R_F	Frictional Resistance	kN
R_n	Reynolds number	
R_r	Residual Resistance	kN
R_T	Total Resistance	kN
T	Draft	m
T	Thrust	kN
t	Thrust deduction fraction	
V	Velocity	$knots$
V	Velocity	m/s
V_a	Speed of advance	kn
V_s	Speed of ship	kn
w	Wake fraction	
W_2	Maximum outreach	m
W_{crane}	Weight of crane	ton
W_d	Weight Machinery	ton
W_{ls}	Weight Lightship	ton
W_o	Weight Outfitting	ton
W_r	Weight Remainder	ton
W_{st}	Steel Weight	ton

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Introduction

The introduction will describe the background of the research and the company where the research is being conducted, Jumbo Maritime. After the background the scope will be described and an outline will be shown.

1.1. Company

Jumbo Maritime is a shipping company specialised in heavy transport and lifting. Jumbo has ten heavy lift vessels, which are all equipped with two cranes on deck.

Figure 1.1: Jumbo Javelin

Jumbo was founded in 1968 and the first ship was called the Stellaprima, an A-type, provided with four 12-tonnes derrick cranes. The ship was an innovative and progressive ship for the time. At that time the rise of the container was started. Jumbo's founder had a vision that definitely not all cargo would fit into a container, therefore Jumbo specialised in that cargo which not fits a container.
In the past 50 years Jumbo Maritime was a pioneer in the heavy lift and shipping industry. Every few years a new ship type was developed which was bigger and had more lifting capacity than competitors. One of the innovations was the stabiliser. The stabiliser is a pontoon which is added on the hull and improves the stability. A stabiliser is only in use during lift operations and has no influence on the ship performance. Nowadays the K-type has two 1500 tonnes cranes. Table 1.1 shows the current fleet and their lifting capacity of Jumbo Maritime.

Type	Lift Capacity [T]	Quantity
E650	650	2
H800	800	2
J1800	1800	4
K3000	3000	2

Table 1.1: Fleet of Jumbo Maritime

Two of the J-type vessels are equipped with DP2 to be able to perform offshore operations. Jumbo Maritime consists two departments, Jumbo Shipping and Jumbo Offshore. This research is performed for Jumbo Shipping and specific on the J-type.

1.2. Background

The stability of the ship is a decisive characteristic. Especially during heavy lifting operations it is really important that a ship is stable. The width of a ship has a big influence on stability. A wider ship is more stable. However, there are disadvantages and restrictions for having really wide ships. The resistance and fuel consumption are dependent on the size and shape of the hull. The dimensions of a ship and certainly the width of a ship directly affect the resistance of the vessel. A method to increase stability without increasing the width of the ship, can be done by adding stabilisers at the side of the ship during heavy lift operations. At Jumbo Maritime, these stabilisers are called flippers. These stabilisers are partly above and under water. In current situations the stabilisers are stored on deck during sailing. When it is needed to improve stability, the stabiliser is hoisted overboard and installed at the hull. Figure 1.2 shows the stabiliser installed and when it is stored on deck.


(a) Installed stabiliser

(b) Slots to install stabiliser

(c) Stored stabiliser

Figure 1.2: Stabiliser

Benefits from using a stabiliser to stabilise a ship is that it is a cheap, flexible and really workable solution. With small means a smaller ship can have the same performance on stability during lifting as a much wider ship.

Installing a stabiliser is a time-consuming operation that takes at least 8 hours (4 hours to install and 4 hours to un-install). During this procedure the cranes cannot be prepared for the actual lifting operation, because the cranes (and employees) are required to install the stabiliser. Preparing cranes for lifting the cargo should be done after installing the stabilisers.

In the past, studies have been done on other concepts that can be used to stabilise a ship during lifting operations. One of them is called the 'smart flippers'. Main difference between current stabilisers and the smart stabiliser is a smart stabiliser can be installed without cranes.

Another risk of stabiliser use is the limited height of a stabiliser. This height determines the range of inclination angles whereat the stabiliser contributes to stability. When the inclination angle is too big, the whole stabiliser comes out of the water or disappears under water. If this happens the stabiliser does not contribute to the stability of the system and the whole ship can capsize. This is a very undesirable situation, especially during lifting operations. This is one of the disadvantages of using a stabiliser to increase stability of a ship.

Therefore some parties do not want to insure the cargo for using a stabiliser. Some port authorities do not give permission for using stabilisers because the port must be closed to ensure safety. So if Jumbo will continue with using stabilisers to stabilise their ships during heavy lifting operations it could be that it looses projects

to competitors because clients choose other options to transport their equipment. At Jumbo the opinions are divided about the use of stabilisers. On the one hand, it is cheap, flexible, workable and it is possible to sail with a small ship. On the other hand, it is time consuming, can lose potential clients and has limitations.
For a new ship to be built Jumbo Maritime is really interested to see what alternatives there are for ensuring stability of a ship and what the effect of these alternatives have on the desired operational profile of a ship. The new ship is called the J-Light, because it is based on the current Jumbo J-Type. The J-Light should be a 'cheaper' and more simple version of the J-Type.

1.3. Objective

Comparing different J-light ship concepts which are able to perform heavy lifting operations without using the current stabiliser.

1.4. Scope

This research starts with Jumbo Maritime having the desire to compare the use of a smart flipper with widening a ship so that a stabiliser is not required any more. The base ship for this research is the J-type, other ship types are not taken in consideration. As described in one of the previous sections, heavy lifting operations can be divided into two fields of operation: shipping and offshore. This research will mainly focus on the shipping department.

A market analysis is conducted to determine Jumbo's position compared to their competitors in the heavy lift market. Besides Jumbo's position in the market, also the position of the J-type ship compared to other types will be looked at. Main focus on who are the other competitors and what are the properties of the ships they use. After this analysis unique selling point can be indicated. These unique selling points will be taken into account during set up the requirements for the J-light.

To be able to insure the stability of a ship during lifting operation this research will describe the concepts of ship stability. Focus will be on transverse stability of the ship. Literature study only provides information on static stability, because lifting operations are only carried out in still and calm water. It is necessary to perform a literature study on the transverse stability to be able to understand the effect of the stabiliser and the wider ship for modifications and different sizes.
The current procedures and materials are used as a starting point for this analysis. Analysing the conditions and restrictions of the current system and describe the install and un-install procedure of the stabiliser, focused on time, equipment use and safety. So taking into account the current dimensions of the ship and the stabiliser and the effect on the actual stability of a ship when using a stabiliser.
Two alternatives for the stabiliser will be taken into account, widening the ship to ensure stability and changing from a standard stabiliser to a smart one. Necessary changes to procedures to be able to use the smart stabiliser will be presented.
Regarding the alternative of widening the ship, this ship still needs to be build, it has to be based on the current J-type and has to take into account all supplied demands set by Jumbo. Jumbo has set up specific demands regarding the desired length, lifting capacity and of the new to build ship. To be able to provide the required width a simplified model of the J-type is used to determine the desired width at certain heavy lift operations. Focus will be on using the ballast tanks and crane specifications to determine maximal load and outreach. The model will calculate the transverse stability, not taking trim into consideration because during lifting operations the transverse stability is the most important factor which has the most impact. Once the required widths at certain lifting weights are determined, different resistances at different speeds can be determined.
When comparing the base case with the alternatives the focus will be on comparing the minimal required day rate. The heavy lift market consists of really unique transports. The transports differentiating on complexity, weight and required travel distance, this makes it difficult to determine a typical cost-benefit analysis. The benefits can not be determined, for that reason a minimum required day rate is determined. There are preset load cases created, which will differentiate in number of jobs/year, loaded and unloaded sailing days, to be able to provide a comparable indication. Other parameters that are taken into account are stabiliser use, capital costs of the ship and fuel prices.

1.5. Outline

Chapter 2 provides an overview of the present heavy lifting market in which Jumbo Martime is active. It will also go in depth on what Jumbo's position is on that specific market and what Jumbo's unique selling points are compared to its competitors. To be able to determine what can be improved, the current situation is analysed in Chapter 3. The current situation is used as a starting point for the further analysis and comparison of the different alternatives: widening the ship to eliminate the use of a stabiliser or changing from a standard stabiliser to a smart stabiliser. These alternatives will be presented in Chapter 4, first the concept of a smart stabiliser is defined and its advantages compared to the standard stabiliser. After that a concept for a ship without stabiliser is described. Chapter 5 will provide an overview of the model which is created to determine the minimal required width of a ship to eliminate the use of a stabiliser. Comparison of all alternatives and how they relate to the current situation is presented in Chapter 6. This will done on the basis of certain sailing cases. Finally in chapter 7 the conclusions and recommendations are presented.

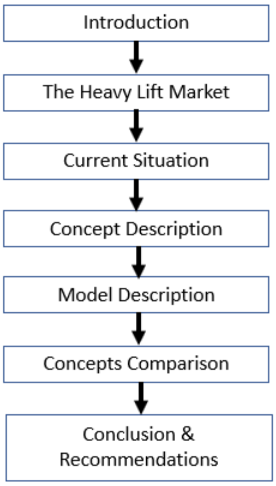


Figure 1.3: Outline

2

The Heavy LiftMarket

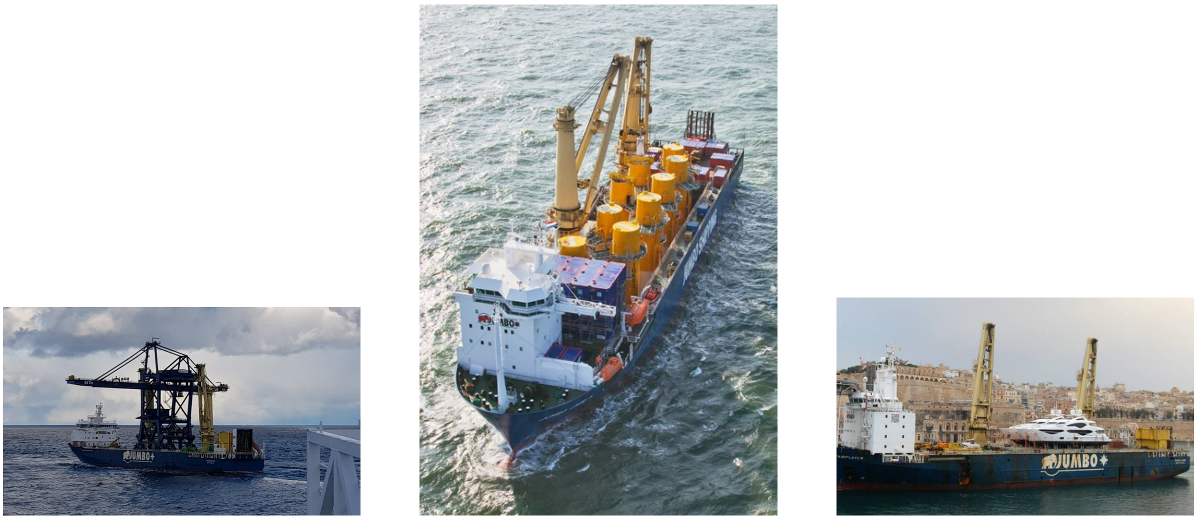
In this chapter the market for heavy lift will be described. Jumbo's competitors in the heavy lift market will be researched and the position of Jumbo Maritime in this market is considered. Based on the market analysis, valuable advantages of a Jumbo J-Type can be pointed out, so called unique selling points. More efficient ways to use the stabiliser will also be described in this chapter. The unique selling points set the basis for the requirements and boundaries for a wider ship.

2.1. Heavy lift market

In the maritime industry cargo ships can be loaded with different types of cargo: dry bulk, oil and chemicals, liquid gas and general cargo. Examples of general cargo are containers and cars. For all these types of cargo are specialised vessels. There are also products that can not classified as one of these types of cargo easily. Multi purpose vessels (MPP) can transport different types of cargo (break bulk). A special type in the multi purpose vessels are the heavy lift vessels. In shipping industry is talked about heavy lift when a cargo does not fit a container[Stopford, 2009], examples of heavy lift operations are project cargo, ship sections, locomotives, modular industrial plants and yachts. The heavy lift vessels are build to transport this cargo across sea and equipped to handle the cargo. Subsection 2.1.2 describes the different types of ships in the heavy lift industry. A feature of the heavy lift market is that the cargo is not build on the location where it is needed. For example, factories or oil fields can be located in remote placed. It can be the knowledge to build a piece of cargo is not present on a location or labour costs are to high to build it on location. Therefore a lot of heavy cargo has to be transported by ships all over the world.

2.1.1. Types of heavy cargo

According to Stopford heavy lift cargo can divided in three groups. The first group is cargo for the industry, like reactors, ship loaders, engines, factory modules and trains. The second group is off shore cargo such as monopiles, parts of oil platforms, jack ups and mooring systems. And the third group is floating cargo like yachts or tugs small ferries and barges [Stopford, 2009]. Jumbo Maritime transported all these types of cargo. Figure 2.1 provides examples of the different types of cargo.



(a) Container crane (b) Transition pieces (c) Yacht

Figure 2.1: Examples of heavy cargo loading

2.1.2. Types of heavy cargo ships

Stopford also classified heavy cargo ships in three types [Stopford, 2009]. First one is a tug barge systems, the heavy load is placed on a pontoon and the pontoon is being pulled by a tug. These tugs are used are different from the tugs used in ports to accompany ships. The second ship type is the semi-submersible. This type is shown in figure 2.2b. This ship type can take ballast to bring down the deck till under the water surface as shown in figure 2.2b. The cargo can float on and off board. This ship type is often used for transport of other ships and floating offshore structures. The third ship type Stopford describes is the heavy lift ship, often equipped with two heavy lift cranes and they can lift in tandem. The ships operated by Jumbo Maritime belongs to the third group.

(a) Tug Barge system (b) Float on Float off (c) Heavy lift cranes

Figure 2.2: Examples of heavy cargo ships

2.1.3. Features of heavy lift transport

The heavy lift market where Jumbo Maritime is operating in, is different from the container or tramp market. In the container market the shipping companies operate liners. These companies sail in fixed schedules around the world. The tramp market consist of oil and bulk vessels and the cargo's of these ships can be traded during sailing times so that destinations can change. In the heavy lift market the transport of cargo is more specific and project based. The cargo consist of smaller number of quantities with large dimensions and large weights. The cargo is not certainly standardised, like with containers. The result is that heavy lift vessels sail large distances without cargo because supply for transport is often not at the destination location of another transport. Another characteristic is that the cargo is transported from or to ports without special facilities. The projects are unique and it could be a location does not have cranes or facilities to handle these unique and uncommon transports. It could be that the departure or destination location is not a port. The Jumbo ships are equipped with heavy cranes to overcome this problem.

Valuable parameters for heavy lift ships

Except the specific properties each ship has, like dimensions of a ship, velocity and resistance, there are other properties which are really important for heavy lift vessels. At first the crane parameters are important. Crane specifications are expressed in outreach and maximum lift capacity. At a certain outreach in meters the ship can lift a specific load in tonnes. Figure 2.5 shows the outreach vs. the safe working load (SWL) for different ships in the heavy lift market. The safe working load (SWL) is the lifting capacity without gear and accessories [DNV GL, 2016]. Cargo that needs to be transported can be really large, so it is important to see what the maximum lift height is of a crane. The lift height and the outreach of the crane are correlated. The maximum lift capacity can not lift at maximum outreach. This is a result of the moment that is caused by the load and the outreach (arm). The maximum load by an specific outreach is dependent on crane dimensions, crane strength and the stability of the ship. Some cargo must be transported in the hold of the ship so that the cargo is protected, herefore dimensions of the hold are really important. Especially the width of the ship is a significant property of the vessel. As well deck strength is a valuable quality of heavy lift ships. One of the properties of the heavy lift market is the cargo have a high weight. For this reason strength of tanktop, tweendecks and hatchcovers are valuable properties. The hold is one open space to not be limited to transport large pieces of cargo. This results in hatchcovers which must span the width of the hold in one time. When the hold has more width, the hatchcovers must have more strength. The stronger the hatch covers are, the heavier the construction becomes. In this way, the width of the hold influences the stability of ship. In most cases deadweight is not a limiting factor. Lift and transport operations will be limited by crane capability and ship stability. In heavy transport it occurs the ship need extra ballast to meet stability. The cargo can have relative low weight, but is placed on deck and has a high centre of gravity.

2.2. Position Jumbo Shipping in heavy lift market

To find out what is the position of Jumbo in the heavy lift market, the heavy lift market itself has to be analysed. In 2018 research is done about the heavy lift market by Hagenbeek [Hagenbeek, 2018]. The reasearch is focused on the market for heavy lift vessels with a combined crane capability of above 250 tons. Figure 2.3 shows the number of vessels in the market which have a maximum crane capability above a certain value. A separation can be roughly made at 1000 tons of crane capability. The figure makes clear that above 1000 tons crane capability the supply of vessels is much smaller than between 250 and 1000 tons. In case of Jumbo Maritime they have four ships in the category between 250 and 1000 tons, two E-types (650 tons) and two H-types (800 tons). In the category above 1000 tons crane capability Jumbo Maritime has six vessels. Four J-types (1800 tons) and two K-types (1500 tons). In the heavy lift market there are also vessels that can lift heavier loads than 3000 tonnes. The ships which are presented in figures 2.3 and 2.4 are multi purpose ships. The ships are designed to transport cargo and are equipped with cranes and. Ships which can lift more than 3000 tons are focused on offshore operations. Ships like the Aegir or Thialf have not a typical hull form and are not optimised to transport equipment.

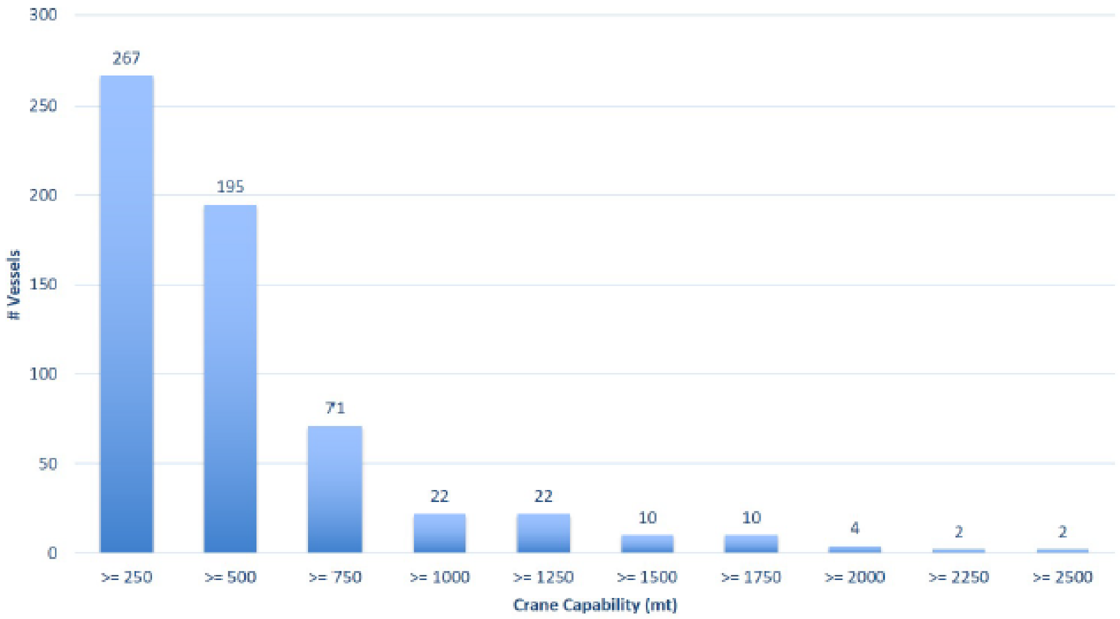


Figure 2.3: Number of vessels for different levels of required crane Capacity (2017) [Hagenbeek, 2018]

There are a lot of providers active in the range between 250 tons and 1000 tons lift capability. For lift capability above 1000 tons there are only 5* operators in the market. Figure 2.4 shows what the market shares are for lift capability for each provider [1]. The figure makes clear Jumbo is market leader in the heaviest segment. For lift capability above 2250 tonnes (till 3000 tonnes)[2], Jumbo Maritime is the only provider that can lift and transport cargo with one vessel.

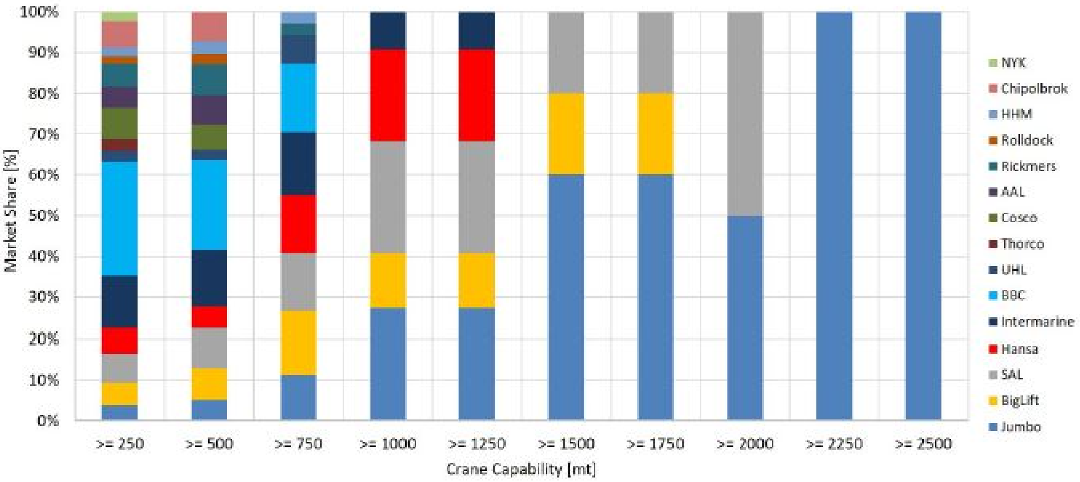


Figure 2.4: Market Share vs. Crane Capability [Hagenbeek, 2018]

2.2.1. Competitors for Jumbo's J-type vessels

This research is focused on the J-type vessels. It is useful to find out what type of ships the competitors have and thereby get to know the specifications of these vessels. Vessels owned by competitors which have crane capability in the same range as the Jumbo J-type vessels are taken in considering. These vessels have maximum capabilities between 1400 and 2200 tons. Table 2.1 gives an overview of the competitive vessels.

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[1] January 2019, Hansa went bankrupt.The ships owned by Hansa will remain in the market and operated by BigLift (part of Spliethoff Group).

[2] Biglift has upgraded one of their ships from 2 times 900 to 2 times 1100 ton crane capacity (February 2019).

In the market between 1400 and 2200 tonnes Jumbo Shipping is one of the five companies who operate in the market. The competitors are BigLift, SAL, (Hansa) and Intermarine [3]. Some companies also have more than 1 ship per ship type, like Jumbo has 4 J-type vessels. Table 2.1 presented the main particulars of the competitive ships. The ships differ in all their dimensions. It is clear Jumbo's J-type is the shortest ship and has the smallest draft. In terms of deadweight the Jumbo J-type has one of the lowest deadweights. Beside these main particulars there are differences in deck strengths, engine power and maximum speed.

		Ship Dimensions [m]					Hold Dimensions [m]		
Ship(type)	**Company**	**LOA**	**Beam**	**Draft**	**Deadweight (tonnes)**	**LiftCapacity (tonnes)**	**L**	**B**	**H**
J-Type	Jumbo	144,80	26,84	7.5	11036	2 x 900	82,0	17,00	12,50
Bucaneer	Biglift	145,89	28,43	8,24	13740	2 x 700	67,0	20,00	12,25
Happy Sky	Biglift	154,80	26,64	9,50	17775	2 x 900	92,0	17,70	12,50
Happy Star	Biglift	156	29,00	9,50	19000	2 x 1100	89,6	17,87	12,50
183	SAL	160,50	27,50	9,01	12501	2 x 1000	107,0	17,00	13,50
176	SAL	159,80	24,00	9,00	12007	2 x 700	107,0	17,00	13,10
P2-1400	Hansa	168,68	25,20	9,50	19450	2 x 700	82,4	18,66	14,84
G-Class 1400	InterMarine	168,68	25,20	9,50	19347	2 x 700	82,4	18,66	14,84

Table 2.1: Main particulars of vessels used by competitors

The lifting capability at a certain outreach is even more important than the maximum lifting capability of the cranes In figure 2.5 all capacities for a single crane in tonnes are plotted against the outreach. The outreach is the horizontal distance between the side of the ship and the crane tip in meters. By using both cranes, a dual lift, the lifting capacities can be doubled at the same outreach. The lifting capability by a specific outreach is depending on ship stability and crane length and crane strength.

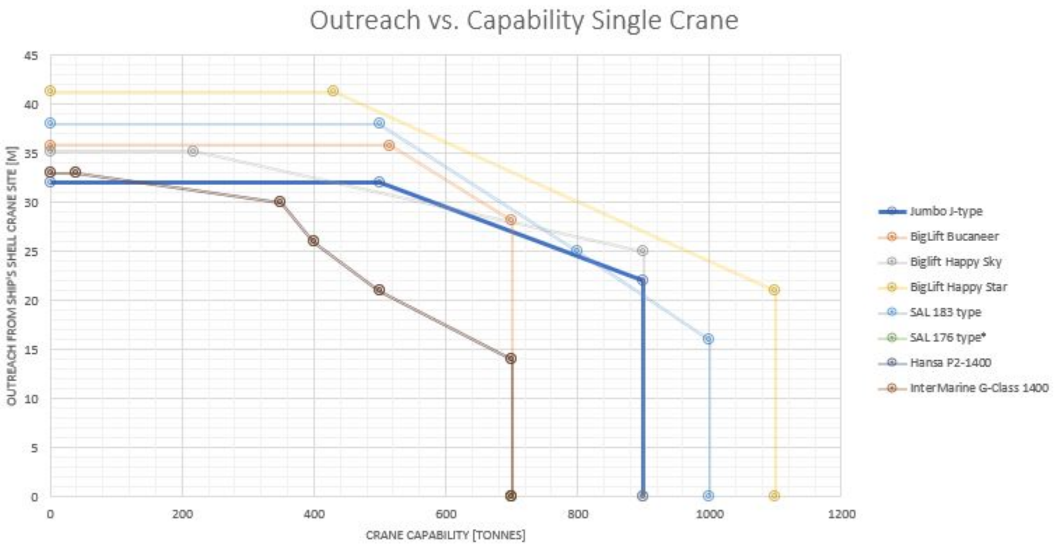

Figure 2.5: Outreach vs. Single Crane Capability

Figure 2.5 shows that the Jumbo J-type has a lower outreach than most competing vessels. However, Jumbo has two K-type ships with a capability of 2 times 1500 ton and therefore Jumbo has the largest capability in the market. For Jumbo it is not necessary expanding crane capability, Jumbo has the highest crane capability in this market segment. Ships equipped with cranes which can lift heavier loads can not transport cargo like the Jumbo vessels. Examples of these ships are the Thialf operated by Heerema or the Seaway Strashnov.

The BigLift Happy Star can lift the most weight at the highest outreach. The Happy Star is the widest vessel in this range and it is also one of the deepest ships. The width and draft will affect the resistance of the

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[3] 2018, Intermarine has entered into an alliance with ZeaBorn under the name ZeaMarine.

vessel. The vessels owned by Intermarine and before by Hansa are exactly the same. These vessels have less crane capability, but the width of the vessels is the smallest of all the considered vessels. All parameters affect stability, resistance and crane capabilities and is the result of choices made during the design of the ships.

2.3. Unique selling points

By considering the vessels in figure 2.5 and table 2.1 it is possible to find advantages for the J-type vessels compared to competing vessels. Also through discussions with employees inside Jumbo Maritime it became clear what the unique selling points of the Jumbo Maritime fleet are. The two biggest advantages that emerged are limited draft and the length of the J-type vessels. In figure 2.6 the draft against the deadweight is shown. The vessels can be split up in two groups, one group with a deadweight around 13000 tons and the other with a draft of 9.5 meters. The Jumbo J-type has the lowest draft of all competitive vessels, but with a deadweight approximately the same value as the three other vessels.
The design draft of the Jumbo J-type vessels is 7.5 m. The ships of competitors have more draft but also more deadweight. In heavy lift transport mostly lift capability, stability and cargo hold volume are limiting factors, not the deadweight of a ship. Figure 2.6 shows the draft versus deadweight for the ships in de market.
The Jumbo J-type is also the shortest vessel in comparison with the competing vessels. An advantage here is the vessel is more easy to manoeuvre in smaller ports. The quay length can also be a limiting factor, a departure or destination port can have limiting quay length. Ports have their own regulations about tug assistance, based on length, installed propellers and ruder configurations. The required tug assistance depends on weather conditions and specific location in the port. In general a ship length of 150 is the maximum length where a ship can enter and leave the port with minimal tug assistance. Port authorities require more assistance by ships above 150 meter length.
For Jumbo Maritime, the length of 150 meter is unique selling point to save costs in ports and from experience has shown the draft of 7.5 meter deliver orders in a niche market. The design draft is 7.5. meter, but the jumbo J-type can also operate at a draft of 6.5 meter and the ballast draft is 5.8 meter.
The draft of a ship results in a maximum propeller diameter. For a propeller applies, the bigger the more efficient the propeller is.

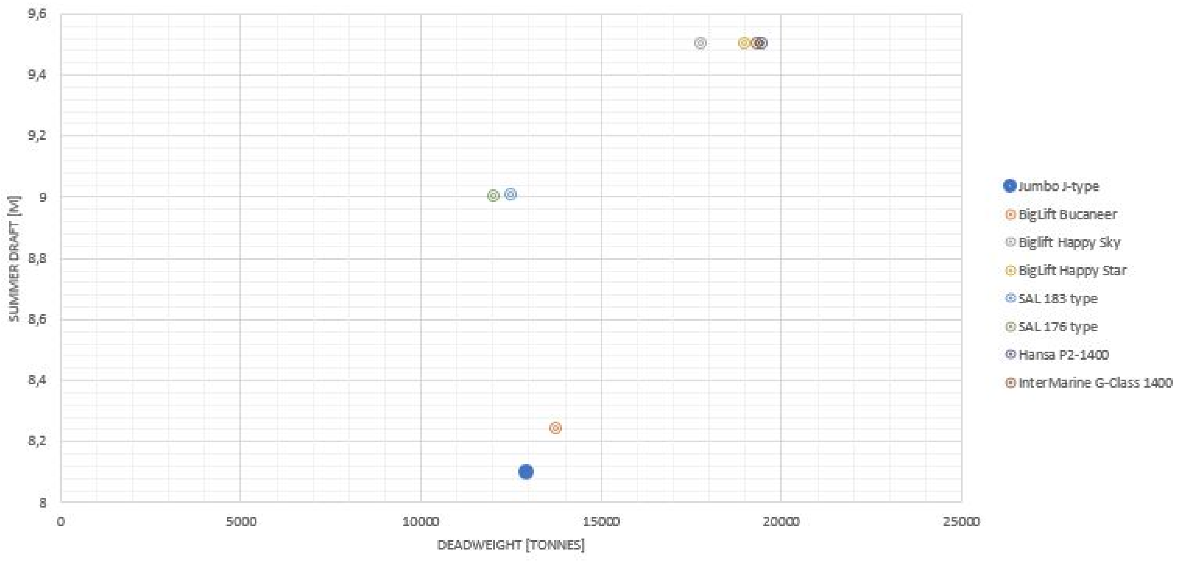


Figure 2.6: Summer Draft vs. Deadweight

2.4. Conclusion

Jumbo Maritime is a supplier in the shipping market where general cargo ships have their own heavy lift equipment. No additional equipment is required in ports to load or unload the ships.
Jumbo Maritime has a large market position for lifting operations above 1000 tons. With the K-type, Jumbo is the only one of its kind that can lift such a heavy load with a general cargo ship. The J-type has her length and draft as major advantages over competitor ships. Both characteristics are advantages to operate in a niche market. These characteristics are requirements that the concepts must meet.

3

Current situation

In this chapter the current situation will be described. Because the J-type is the starting point, the main characteristics are shown. Also the situations in case stabilisers are used will be explained and the procedures how to use a stabiliser will be described in this chapter. The current situation is considered to find out what the starting point for the J-Light concept is and where improvements can be find in the stabiliser installation and the installation process. The described current situation is used in chapter 6 as the benchmark case.

3.1. Characteristics J-type and stabiliser

Ship

The main dimensions of the J-type are shown in table 3.1

	Weight [ton]	**Unit**
L_{pp}	133.8	m
L_{oa}	144.8	m
Beam oa	26.84	m
Depth	14.5	m
Draft	7.5	m
Main Engine	2 x 4500	kW
Propellor	2 x 4.1	m
Velocity	17	knots
Hold	102 x 17 x 12.5	m
Cranes	2 x 900	ton
Deadweight	11,036	ton

Table 3.1: Main characteristics J-type

Figure 3.1 shows the layout of the J-type. The ship is divided into different compartments. The left side is a cross section, top right is a top view and bottom right is a side view. The large grey block in the middle is the hold. The ballast tanks are placed along the cargo hold, between the hull and the hold. In the fore and aft ship the fuel tanks, engine room ect. are shown. The side view of the J-Type, the bottom down picture, shows the two spaces for crane installations and a corridor which connect the crane installations and the accommodation.

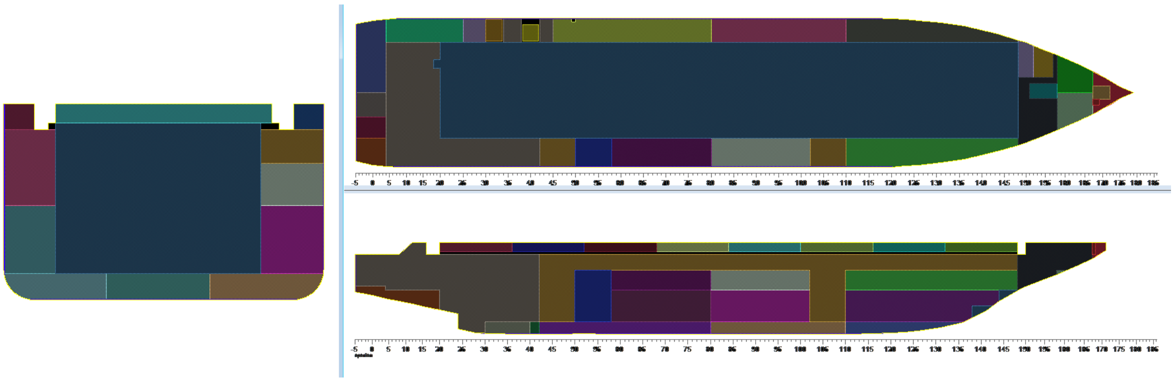


Figure 3.1: Layout J-type compartments

An important characteristic is the box shape of the cargo hold. First, it is more practical to store cargo. On the other hand a box shaped hold without sloping sides is more safe. Accidents in the past have led to the elimination of sloping sides in the cargo holds in design for new building ships.

Draft

The design draft of the J-type is 7.5 meter. In the heavy lift market it is part of operation to have empty trips. The ballast draft is 5.8 meter. By sailing with deckload, it can be required to improve stability. The draft can maximized up to 8.1 meter (scantling draft).

Stabiliser

The current stabiliser consists of 2 parts. The parts are stored on deck during sailing. On the aft deck there is a place equipped with lashings to store the stabilisers. When a cargo is too large to store the stabiliser on the aft deck, the stabilisers can be stored on an other place on deck or in the hold. When the stabilisers are stored in the hold because there is a large piece of cargo on deck, it can be impossible to use the stabilisers. Figure 3.2 shows an installed stabiliser which consists of two parts. Table 5.2 shows the dimensions and weights of both parts. It is possible to use only one stabiliser, if it meets the stability requirements.

Figure 3.2: Stabiliser installed

	Stabiliser 1	**Stabiliser 2**	**Connected**
Lenght [m]	11	10.5	11
Width [m]	8	5	13
Depth [m]	3.7	3.7	3.7
Weight [ton]	69.4	30.4	99.8

Table 3.2: Dimensions Stabiliser

3.2. Kahn Rule

At Jumbo Maritime there is a rule of thumb developed to determine the GM that is sufficient to be able to work safe. The rule is named after the founder, the Kahn rule. The Kahn rule determines the minimum GM at the start of an lifting operation. The Kahn rule is used in operations and the value which is determined by the rule is the minimal GM by starting a lifting operation. The Kahn rule is based on calculations, experiences and performance by Jumbo Maritime employees. If a new ship type is build, a new Kahn Rule specificity for that ship type will be created. The Kahn Rule is based on two criteria is as follows:

- 1. When moving the crane tip 0.5 meter in transverse direction the heel of the vessel may not exceed 1 degree.

- 2. With ballast pumps running at full capacity for 30 seconds the heel of the vessel may not exceed 1 degree.

For the Jumbo J-type the Kahn rule is:

$$MG'_{req} = 1 + (1.5 \times \frac{Load}{1800}) \tag{3.1}$$

In this formula 'Load' is the load in the cranes in tonnes. MG is the required GM in metres for the J-Type. In Appendix B the origin of the Kahn rule for the K-Type is explained. Figure 3.3 shows the range for the minimal required GM.

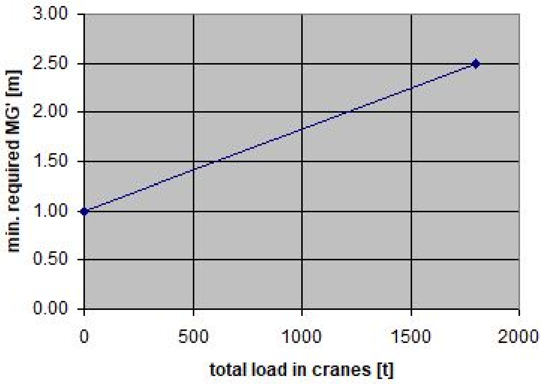


Figure 3.3: Kahn rule for J-type

3.3. Increased Stability by stabiliser use

A stabiliser is used to improve the stability during lifting operations. A stabiliser is not used as a contra weight to compensate the load in the cranes, but it is used to improve the breadth of the ship. The stability is expressed as GM, formula 3.2. This formula is explained in C.

$$GM = KM - KG = KB + BM - KG \tag{3.2}$$

$$BM = \frac{I_t}{\nabla} \tag{3.3}$$

$$I_t = \frac{LB^3}{12} \tag{3.4}$$

As described in formula 3.4 the breadth of a floating structure has great influence on stability, because the breadth is to the third power to calculate the moment of inertia. Figure 3.4 shows a cross section of a Jumbo ship equipped with a stabiliser.

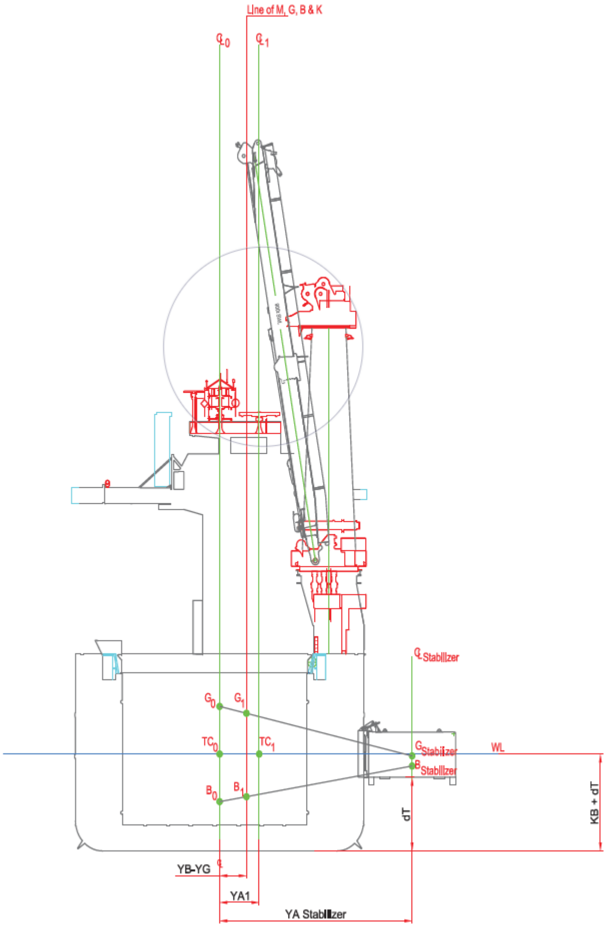


Figure 3.4: Stabiliser installed [Jumbo Maritime]

As described the GM value is determining the stability of a ship. Thereby the Kahn Rule requires a minimal GM. Formula 3.4 shows the breadth of the ship is used to the third power and that is exactly why a stabiliser adds stability. The stabiliser improves the moment of inertia which results in a higher BM value. Figure 3.5 shows an example of the cross section of a pontoon where a stabiliser is attached to the pontoon. In this example the length of the pontoon is 50 meters and the length of the stabiliser is 10 meters.

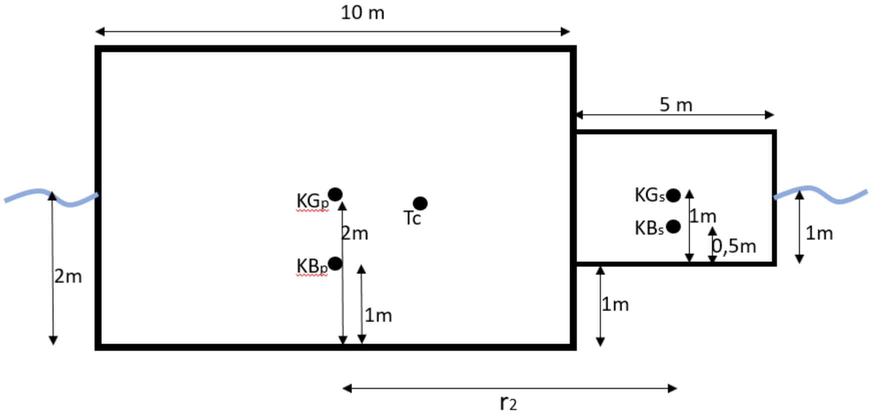


Figure 3.5: Example pontoon with stabiliser

This example shows how the use of a stabiliser influences the ship's stability. Table 3.3 provides values of the pontoon, stabiliser and combined situation. This example is a simplified view of a pontoon and a stabiliser. For this situation it is easy to calculate values for KB, KG and BM. In appendix C is described how to calculate these values for more complex vessel shapes. This example is only to illustrate how the stabiliser works.

	Pontoon	Stabiliser	Combined
KB [m]	1	1.5	1.023
KG [m]	2	2	2
Vol [m^3]	1000	50	1050
I [m^4]	4167	104.16	6827
BM [m]	4.16		6.5
GM [m]	3.16		5.52

Table 3.3: Values for pontoon with stabiliser

To calculate the combined moment of inertia the Parallel Axis Theorem (appendix C.2) is applied. First the location of combined tipping centre T_c is determined by formula 3.5

$$T_c = \frac{A_{bot,p} * r_1 + A_{bot,p} * r_2}{A_{total}} = \frac{500 * 0 + 50 * 7.5}{550} = 0.68m \tag{3.5}$$

- $A_{bot,p}$ = Bottom area pontoon
- $A_{bot,s}$ = Bottom area stabiliser
- A_{total} = Total bottom area
- r_1 = Arm $KG_{stabiliser}$ to $KG_{stabiliser}$
- r_2 = Arm $KG_{stabiliser}$ to $KG_{pontoon}$

For both pontoon and stabiliser the moment of inertia can be calculated and used to determine the BM.

$$I_{t,p} + I_{t,s} = 4167 + (500 * 0.68^2) + 104 + (50 * 6.82^2) = 6827m^4 \tag{3.6}$$

- $I_{t,p}$ = Moment of Intertia of pontoon
- $I_{t,s}$ = Moment of Intertia of stabiliser

The value of the moment of inertia results in a BM of 6.5 m and a GM value of 5.52 m. The GM value increased more than 2 meters by only adding a relative small stabiliser.

3.4. Procedure Stabilizer use

When stabilisers are used during lifting operations, several tasks to be executed. To be able to determine the total time that is needed for using a stabiliser is shown in the flowchart (figure 3.6). This flowchart clarifies a lifting operation step by step. To lift the stabilisers in or out the water the aft crane satisfies. Before each lifting operation the cranes have to be tested. Technically it is possible to test both cranes at the same time, however the staffing can not handle this, so each crane test step is put down after each other. During crane testing the stabilisers can be unlashed, to save time and to do the process more efficient. There is not much staff to do these tasks at the same time. The fore crane can be prepared simultaneously, however this crane is inessential to install the stabilizers the fore crane is not taken in the process.

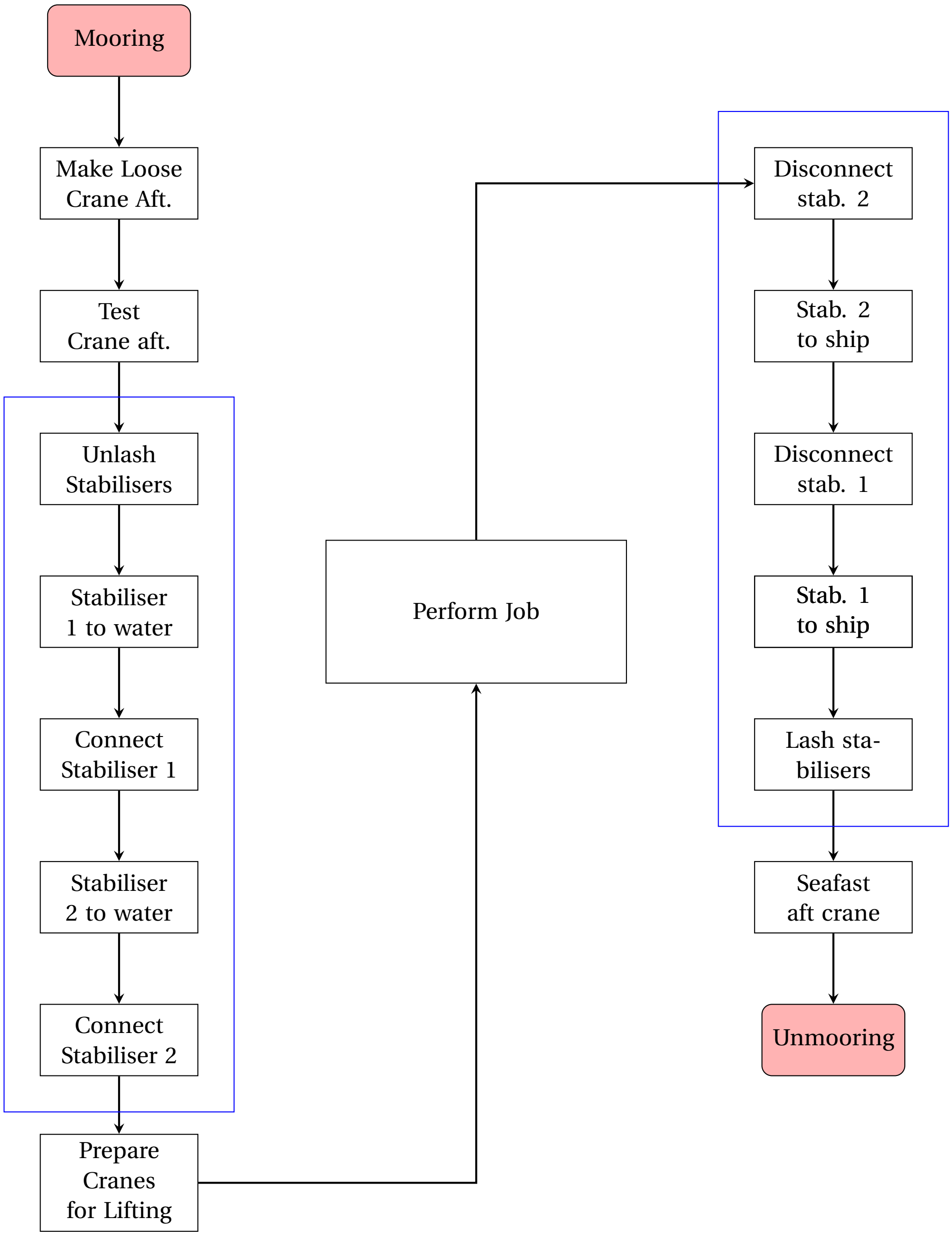


Figure 3.6: Process stabilizer use

The stabiliser installation procedure is divided in a number of steps. The blue boxes in the flowchart represent the steps that need to be taken to install the stabiliser. Through experience from performed operations the duration of each step is determined. For the J-type these durations are shown in tables 3.4 and 3.5. The tasks are split into crane tasks and stabiliser tasks. The crane tasks must always be executed when a lifting operation will be done. Off course the stabiliser tasks are only performed if the stabilisers are necessary. The process to prepare the fore crane can be performed parallel to the aft crane process. The fore crane can be released on the cargo during installation the stabilisers. It can be the cranes prepared after each other and not parallel, because it has no influence on the time required to install of stabilisers, the fore crane is not part of the critical path.

Operation task	Time[m]
Make loose FWD crane	30
Make loose AFT Crane	30
Test FWD crane	15
Test AFT crane	15
Seafast FWD crane	90
Seafast AFT crane	90

Table 3.4: Crane tasks

Operation task	Time [m]
Stabilizer unlash	80
Stabilizer 1 to water	40
Stabilizer 2 to water	40
Stabilizer 1 connect	60
Stabilizer 2 connect	60
Stabilizer lash	80

Table 3.5: Stabilizer tasks

The total time it takes to install the stabiliser is 4.5 hours. To de-install the stabilisers the process has to be reserved and it takes approximately the same time. During lifting operations in ports, the working days are from 7:00 to 19:00. Installing and de-installing a stabiliser costs 0.75 working day, if this is done in a port it means that it results in high costs because, so called port days, can be really expensive. When lifting a load over 800 tonnes it is required to add a stabiliser in the plan of approach. If the load is less than 800 tonnes the ballast tanks in a ship are sufficient to guarantee stability. Lifting operations can consist of multiple lifts, even if the loads for these lifts are less than 800 tonnes it can be faster to use stabilisers instead of depending on the ballast tanks. During every lift of a piece of cargo the water in the ballast tanks needs to be continuously pumped back and forth between the starboard and port side ballast tanks. When using a stabiliser less adjustments have to be made on dividing the ballast over the ship, so in the end it will save time. Therefore a stabiliser is also used for lifting operations under 800 tonnes. The decision for using a stabiliser is an executive decision made by the captain of the ship. It is not noted when captains use stabilisers, they do not have to report this, therefore it is difficult to define in how many cases a stabilisers is used. Besides that every heavy lifting operation is unique, which makes it even more difficult to determine the exact number of times a stabiliser is used to support the stability in lifting operations.

3.5. Crane Characteristics

The cranes on a heavy lift ship cannot lift the maximum weight at each distance from the crane. Figure 3.7 shows the crane curves for the J-type. The crane curves show the loads that can be lifted by the cranes, the ship-crane combination can be different. In case of the Jumbo J-Type, for maximum crane capacity use the ship requires more ballast than the ballast tanks volume can provide. For these situations additional weights have to be added. The figure shows also the situation where the crane is extended with a flyjib. This piece equipment increases the outreach and the lift height of the crane.

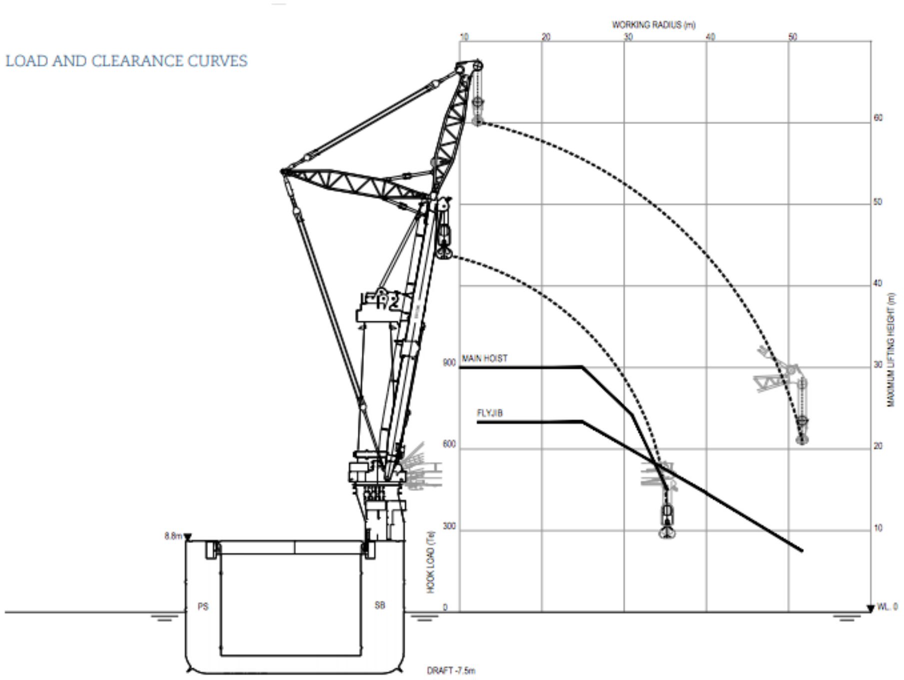


Figure 3.7: Crane curve of the J-Type (inclusive fly-jib) [Jumbo]

3.6. Fuel Consumption

The current fuel consumption for the J-Type in tons per 24 hours is shown in figure 3.8. The average fuel consumption is determined from measured data from the current four J-Type ships. The J-type is equipped with two engines, during sailing at lower speeds, one of the engines is turned off. The measuring points on the left side of the graph, from 9 knots to 11 knots, are measurements when a ship sails with one engine. On the right side of the graph are the measurements for a ship which is sailing with two engines.

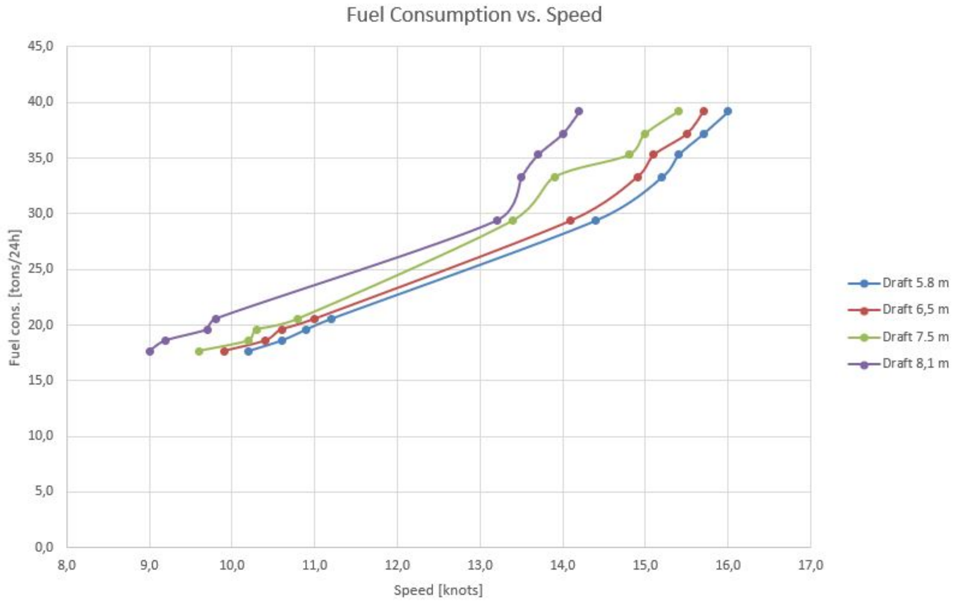


Figure 3.8: Average Fuel Consumption J-type (tons per hour)

The current fuel consumption in kilograms per nautical mile is shown in figure 3.9.

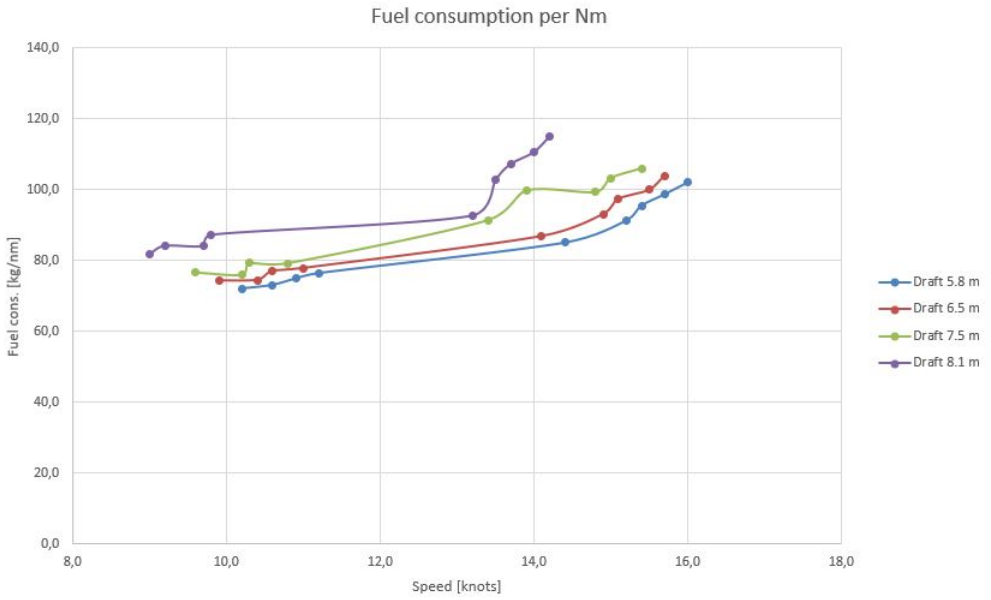


Figure 3.9: Average Fuel Consumption J-type (kilograms per mile)

Figure 3.8 shows the typical fuel consumption expected at certain speeds. For higher speeds at draft 8.1 meters the fuel consumption raises faster than the lower drafts. The J-type is designed for a draft of 7.5 meters, when the draft increases, the block coefficient increases too. The stern of the ship is at a draft of 8.1 meters under water and induce more resistance. This results in relatively more increase in fuel consumption.
Figure 3.9 shows that the fuel consumption per nautical mile at 10 knots is almost as much as sailing at 14 knots. An explanation is that the J-type is designed for 14 knots or faster. The engines and fixed pitch propellers (FPP) are most efficient at this speeds. Beside that the vessel is equipped with two engines. To sail a lower speed, one engine is turned off. To prevent the oil film around the propeller shaft from disappearing, the propeller that is not driven by an engine must continue to rotate. To rotate this propeller, the propeller is like a wind mile and is driven by the flow around the ship. The rotation of this propeller results is resistance.

3.7. Anti heeling ballast

To keep the ship stable and straight during lifting operations, ballast water is pumped to the opposite side from where the load is in the crane. The ballast tanks are not large enough to fully compensate the load in the crane when the maximum load is lifted at the maximum outreach. In the case that the maximum load is lifted at maximum outreach, extra 'tricks' are used to ensure that the ship has no inclination. This can be done by using equipment as a counter ballast or by moving the hatch cover so that they act as counter ballast. There are also cases that there is more than one piece of cargo on board. In that case, the lifting plan can be designed in such a way that the other cargo compensates for anti-heeling.

4

Concept Description

In this chapter a concept description is made. To improve the current situation there are two options, a smart stabiliser or a wider ship. This chapter describes first the advantage and disadvantage of the stabiliser use. There after the concept of a smart stabiliser will be described. Next the options for a wider ship are described.

Heavy lift ships have as main tasks lifting and transport of heavy cargoes. For lifting heavy loads the crane properties and the stability of the ship are the most important requirements. For transport the sailing characteristics and cargo capacity are important requirements. The stabiliser increase stability of the ship so that a heavy load can be lifted. In the current situation there are advantages and disadvantages to sail and lift with a stabiliser. In table 4.1 the advantages and disadvantages are shown.

Advantage	**Disadvantage**
• Fuel consumption	• Time consuming
• Great influence on stability	• Safety
• Only used when necessary	• No permission by authorities

Table 4.1: Advantages and disadvantages of current stabiliser

The main advantage is that the ship has a relative small width and is beneficial for the resistance of the ship during sailing. The width of the ship will affect the resistance and therefore fuel consumption for the whole life-cycle of the ship. A second advantage is that the current stabiliser has a large impact on the stability, the GM becomes much larger by using the stabiliser. The current stabiliser is a simple box without complex technical parts or intensive maintenance requirements, but it is not an inexpensive box. The stabiliser is made of high tensile steel and in the hull of the ship connection construction are required. The price of a stabiliser is about €2.5 million. These costs are for both the stabiliser and the ship adjustments to install and store the stabiliser.

Main disadvantage is that the procedure to install and de-install the stabiliser is time consuming. Section 3.4 describes the required time to install and de-install the stabiliser. The need to use the cranes is not only time-consuming but also a safety point. Lifting a piece of equipment involves more risks than moving equipment without a crane. A limitation of the stabiliser is that it no longer works when it comes above or under water. This can be done by inclining the ship, but also by a wave passing over the stabiliser. For this reason some port authorities do not accept stabiliser use. Passing ships can cause waves that eliminate the effect of the stabiliser and prevent that, they have to close the port or part of the port. After considering the current situation and the advantages and disadvantages, two opportunities will be researched.

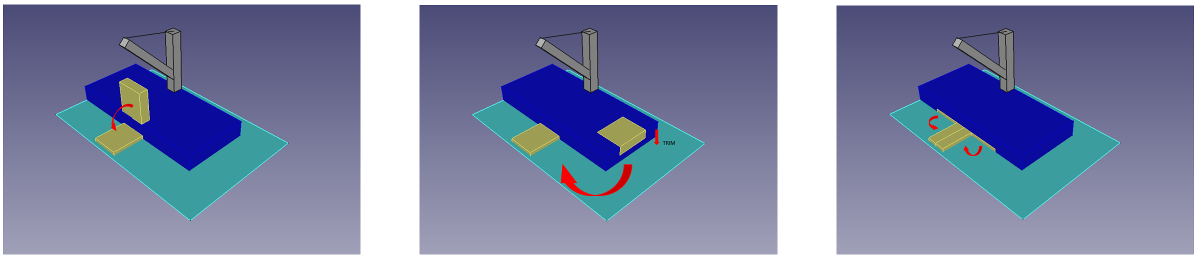
- Smart Stabiliser
- Wider ship

A smart stabiliser is a stabiliser which can be installed without cranes and is a change in operation and the procedure of the current stabiliser. The goal is save time and remove crane use in the procedure. A wider ship is a much larger change. The stabiliser concept will be removed and the wider vessel must satisfy the stability requirements to compensate the stabiliser. Changes in hull form will have many more consequences for the operational performance. An advantage of a wider ship is the increase of deckspace. Deckspace is an important characteristic for heavy lift ships. During sailing a wider ship requires more sea fastening on the cargo. The wider ship results in higher accelerations which are caused by ship motions.

4.1. Concept for a smart stabiliser

In case of a smart stabiliser, nothing changes in the ship dimensions and properties. A smart stabiliser is called smart because the installation does not require cranes. Eliminate the crane use should result in time savings and more safe operations. In section 3.4 the procedure to install a stabiliser is described . The requirements for a smart stabiliser are that it consist of one part and can be installed without cranes. The smart stabiliser can be installed parallel in time with testing the cranes.
For a smart stabiliser three concepts are conceived and analysed. For each concept advantages and disadvantages are summed up.

- 1: Ramp: The stabiliser stands up on deck along the ship side. It can be rotated around the edge of the ship by hydraulic arms.
- 2: Float-on Float-off; a stabiliser is integrated in the deck at the aft of the ship. When the ship is trimmed afterwards or has enough draft, the stabiliser can float out and can be attached to the hull. (Possibly self-propelled)
- 3: Turn-in Turn-out. The stabiliser is integrated in de side of the hull and can turn out.



(a) A stabiliser as a ramp (b) Float on Float off Stabiliser (c) Stabiliser turn in and out the hull

Figure 4.1: Smart Stabiliser Concepts

Table 4.2 gives advantages en disadvantages for all three concepts.

	1.Ramp	2.Float	3.Turn
Advantage	• Direct on location • Fast • Possibility to act as ro-ro	• Maintenance • Cheap • No hydraulic parts	• Location • No deck space
Disadvantage	• Maintenance • Deck space • Only SB or PS	• Part of deck space • Time to float • Trim needed	• Construction • Maintenance • Size limitation • Loss of ballast tanks

Table 4.2: Pros and cons per concept

Chosen Smart Stabiliser

Storing the stabiliser in the side of the ship is most practical concept for storage and usage of the stabiliser, the turn-in Turn-out concept. The stabiliser is immediately on the right place and no space is required to store the stabiliser on deck. Downside of this concept is the loss of ballast tanks, which are needed to make sure no inclination angle occurs during lifting operations. Besides that the construction of the side tanks around the stabiliser is more complex and expensive than ballast tanks without slide-constructions.
Another option is to have the floating stabiliser, downside of this option is that the ship needs to be sunk or

trimmed to float the stabiliser to his right location. This floating operation takes time and if a port is shallow it will cause problems. Besides that the stabiliser is unusable if there is cargo placed on it. Beneficial of the floating concept is that the concept does not require much maintenance. The floating stabiliser can be made self-propelled to make it more easy to install. The complexity, costs and maintenance will increase in that case.

The ramp concept requires deck space, but it can easily and quickly be installed. This concept only requires to be turned overboard and set to the hull. It has a fixed location on the deck and it cannot be moved if large cargo needs to be stored on deck. So it limits the maximum cargo that can be transported with the ship. Because of the ease of installing it, the ramp concept is preferred over the other concepts. This concept can maybe used as a ramp to ride cargo on or off the ship. Another possibility is to make the stabiliser extendible in height, causing it to take less space on the deck and it can still meet the required height which the stabiliser needs.

By using a smart stabiliser there is still stabiliser use. It is time saving but it does not tackle problems such as no permission from port authorities and safety issues during lift operations. As by waves or too much heeling angle the stabiliser is not on the waterline, the stabiliser adds no stability and the ship can capsize. For safety reasons it desirable to eliminate the stabiliser use as described above.

4.2. Wider ship, the J-light

The other option is to remove the stabiliser usage and make a wider ship. A wider ship has much more consequences than the change of a stabiliser. The case for a wider ship will be a new build ship, the J-Light. The concept for a new ship is named J-light because the starting point is the current J-Type and 'light' is from the idea that lighter cranes can be installed on a new ship. The reason for Jumbo to choose lighter cranes than the J-type is that Jumbo already has four J-type and two K-type (2*1500 ton cranes) and can use these ships for more heavy cargo loads. The J-Light concept is focused on fast port operations and a low fuel consumption.

4.2.1. Requirements wider ship

Main idea behind the J-Light concept is that the ship has to be 'cheap and simple'. It should be cheap in two ways, manufacturing cost should stay low as well as the operational costs. The J-Light concept has to be available on the market under the price of the J-type, but with a comparable operational profile. More advanced assignments can be handled by the J-type and K-type ships. The starting point of the J-Light is the current J-type. The market research identified the two unique selling points, these are boundaries for J-light concept. The company makes choices in which market segment the J-light will operate and has set requirements concerning the cranes. This results in the following requirements for a J-Light concept:
Requirements for a J-Light concept :

- Max length (L_{oa}) is 150 m
- Design draft is 7.5m
- Hold dimensions at least equal to J-type in size and box shaped
- 2 * 800 crane capability (Pedestal cranes)
- Cranes operate only over side where cranes are installed (Starboard)
- Lifting height >45 meter above deck
- 1 engine and propeller
- Design speed is 14 knots
- Deadweight >11000 ton
- Meet stability requirements (anti heeling and GM)

Length of the ship influences how many tugs that are required to assist a ship in the ports, therefore the length is a limiting factor. These requirements differ per port and under different weather conditions. Based on Jumbo's experience ships under 150 meter require less assistance and therefore have lower operational costs than ships longer than 150 meter. Besides length also the **draft** of the ship is limited, this provides an advantage over others competitor, due to the different drafts of ports, this is already indicate in chapter 2. With regard to the **cranes**, the choice is made to install pedestal cranes. These cranes are less expensive than mast cranes. Downside is that the construction of a pedestal crane is heavier than a mast crane and the centre of gravity is higher. The cranes at the J-light only have to lift over the starboard side of the ship, this means the cranes will not lift over the ship anymore. The cranes do have to keep a certain outreach because they have to be able to operate over the entire hold. Also the length of the boom of a crane determines how the height a crane can lift.

The design speed is set at 14 knots, to obtain this speed **one propulsion line and one propeller** are installed. The choice for one engine and propeller corresponding with the fact that the concept must be cheap and simple. Installing twin propulsion will lead to more efficient use of the propellers, but it will also lead to a more complex and expensive construction of the aft ship. Besides that installing twin propulsion and double propulsion line will also lead to higher maintenance costs. The higher building costs for a more complex aft ship and two propulsion lines it is not in line with the goal for the J-light concept, keeping the building costs low. It is a choice to build cheap and accept the corresponding fuel costs during his life time. Disadvantage of one propulsion line there is no back up when the line or propeller broke. To operate in harbours and the use of cranes generators are installed. These generators can be used as a PTI/PTO system. Power take in(PTI) to give more power to the propellers during sailing and power take off (PTO) for electricity in accommodations. The stability requirements are not based on the maximum cargo weight at a maximum outreach. The J-light must meet the stability requirement for a cargo of 1200 tons at an outreach of 15 meters. No other cargo or special ballast is on the ship in this case. To lift heavier cargo or lifting cargo at more outreach, the ship can be extra ballasted. If the ship will be designed to lift the maximum weight at a maximum outreach the ship becomes too wide to operate economical.

Blockcoefficient A typical block coefficient for a ship based on the requirements is determined with the Ayre formula 4.1.

$$C_B = 1.08 - 1.68 F_N = 1.08 - 1.68 \cdot 0.1929 = 0.75 \tag{4.1}$$

$$F_N = \frac{v}{\sqrt{gL}} = \frac{7.2}{\sqrt{9.81 \cdot 142}} = 0.1929 \tag{4.2}$$

The Froude number for a ship with a $L_{pp} = 142$ m and a design speed of 14 knots (7.20 m/s) is 0.1967. This Froude number gives a C_B of 0.75.

The block coefficient depends on deadweight and the dimensions of the ship. The deadweight, draft and length of the ship are requirements for a J-Light. The width of the J-Light will influence the block coefficient. In the case of fixed values for deadweight, draft and length, a wider ship results in a lower block coefficient. Because the width of the J-light is required to guarantee stability during lift operations, the block coefficient will be lower than the typical value of 0.75.

4.2.2. U and V shape hull

The width of the ship must be stretched up to guarantee the stability and anti heeling during lifting operations. To lift heavy loads there is ballast weight required to compensate the moment which is caused by the weight in the cranes. A wider hull shape will have an impact on the resistance of the ship. The hull is getting bigger, but the hold remains the same. A wider hull is required to have room for the ballast during lifting, otherwise to guarantee stability. For this reason 2 hull shapes are considered. The hull shape of the J-type is a U-shape. It is a possibility to change the hull form to a V-shape. Figure 4.4 shows a cross section of both shapes.

Figure 4.2: Cross section U and V shape

An advantage for the V-shaped hull compared to the U-shaped hull is that it can have less displacement during sailing. The block coefficient decreases as well. The decrease in volume and block coefficient are beneficial for lowering the resistance. Beside a lower volume the V-shape has a lower wetted surface, which is also advantageous for the resistance.

The option to make a dual draft hull by using fly deck (figure 4.3 is unsuitable to increase stability during lifting operations. In the past Jumbo has done research into fly decks. Disadvantage is that when the fly deck is too low at the side of the hull, the waves during sailing have too much influence on the ship motions. A solution for this problem is to design the fly decks higher on the side of hull.

Figure 4.3: Cross section incl. fly decks

Higher fly decks results in a higher centre of gravity. Especially by heavy lift ships it is undesirable. Beside that, one of the unique selling points is the draft of the J-type, when a the vessel must sink so that the fly decks add stability, the draft becomes too large. From an operational point of view, fly decks are undesirable. Mooring in ports and on- and off boarding of pilots is more complex or impossible. Also bunkering gives difficulties when a fly deck is used. Therefore a V-hull has been chosen.

According to Schneekluth & Bertram a midship section for a hull shape with flared side walls is determined. In this method the prismatic coefficient of the V-hull is equal to the prismatic coefficient of the U-hull. Figure 4.4 shows this method.

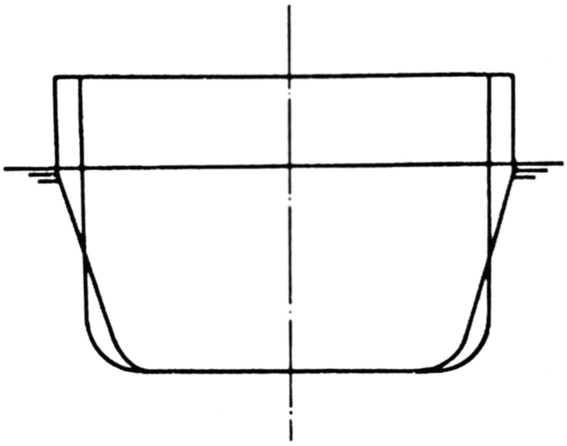


Figure 4.4: Trapezoidal Midship [Schneekluth und Bertram, 1998]

Because Jumbo has an advantage by a low draft, the knuckle in the side of the hull will be set on the design draft. This is done to ensure a maximum width at a draft of 7.5 meters, which is beneficial for the stability of the ship. If the knuckle is placed higher the ship has to increase draft during lifting operations to enhance its stability. Lowering the draft is then not applicable anymore. Biggest advantage is when a ship can sail at a smaller draft. The total displacement and wet surface will decrease, so will the resistance. Figure 4.5 shows the two concepts for a wider ship. The layout of the ballast tanks is based on the J-type.

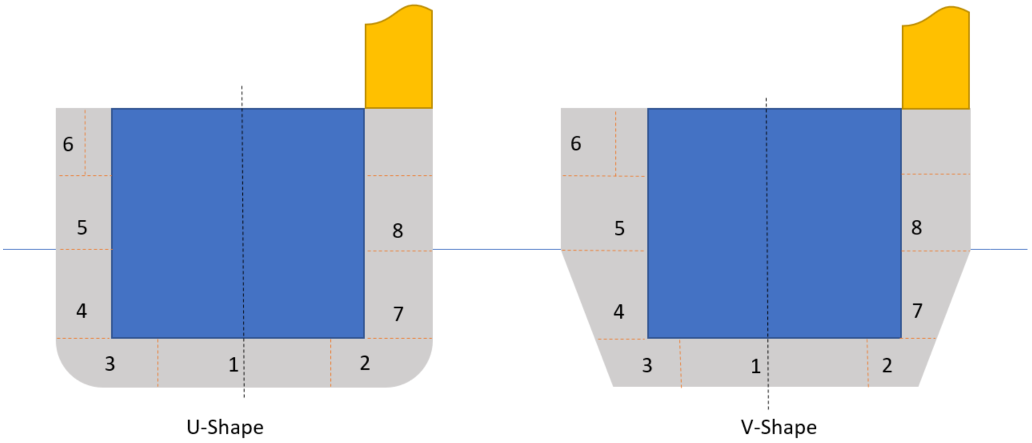


Figure 4.5: U and V midship section

4.2.3. V-shape determination

Table 4.3 gives an how the V-shaped hull can be determined based on the basis of a certain U-shaped hull. The V-shape determination is done by the method described in 4.2.2. Within the V-shape the knuckle is set on 7.5 meters above the bottom. The reason for doing this is to maximise the ship's width on the water surface on the design draft. This maximum width ensures the stability of a ship.

	U-Shape	**V-Shape**
Length[m]	142	142
Width[m]	25.98	28.57
Depth[m]	14.1	14.1
Draft[m]	7.5	7.5
Deadweight [tons]	11000	11000
Displacement [tons]	20953	20776
Cb	0.739	0.666
Cm	0.98	0.88
Cwp	0.82	0.82
Cp	**0.75**	**0.75**
Area midschip[m^2]	**385**	**385**
Height knuckle[m]		7.5
Angle flared side[°]		30
Width bottom[m]		21.00
Width T=5.8m		27.70

Table 4.3: Main characteristics for U-shape and corresponding V-shape

4.2.4. Underdeck volume

To check if the V-shape hull can correspond with the U-shape, for both hulls underdeck volumes are analysed. Used is a empirical equation from Schneekluth.

$$\nabla_D = L \cdot B \cdot D \cdot C_{BD} \tag{4.3}$$

$$C_{BD} = C_B + c \cdot (\frac{D}{T} - 1 \cdot (1 - C_B)) \tag{4.4}$$

- c = 0.3 for U-shape
- c = 0.4 for V-shape

4.3. Concepts to be compared

To determine the right width for the J-light concept a model is made, this model is explained in chapter 5. This model will determine the required width for a U-shaped J-light to lift a certain weight at a certain outreach without a heeling angle and a minimal GM. Besides that the model will provide information on the V-shape with the corresponding characteristics.

The four different concepts that will be calculated and compared on costs are:

- Ship with current stabiliser (basic case)
- Ship with smart stabiliser
- Wider ship U-shape, without stabiliser
- Wider ship V-shape, without stabiliser

4.4. Criteria

Most important criteria on which the different concepts are compared are the costs. All concepts must meet the requirements. Ships need to have a certain width to prevent it from having an inclination angle during lifting. Beside the opportunity to lift without inclination, the GM is an important value for stability (1200 tons at 15 meters outreach). The higher the GM, the higher the stability during lifting operations, but a high GM as possible is undesirable for ship motions. The resistance influences fuel consumption and so a considerably part of the sailing costs. The combination between time consuming stabiliser use and a smaller ship, or a 'fast operate in port' and wider ship determined the best concept for a certain operational profile. All these values result in a minimal required day rate and give the opportunity to compare the concepts.

5

Model Description

The model that is build to obtain the properties of the concepts is described in this chapter. Chapter five describes the structure of the model, which assumptions have been made and which methods and formulas are used.
The model consists of two parts. A parametric model to determine the hull shape and the resistance of the hull and a model to determine the stability at which the ship meets the requirements to be able to lift a certain weight at a certain outreach. Figure 5.1 shows the schematic overview of the model.

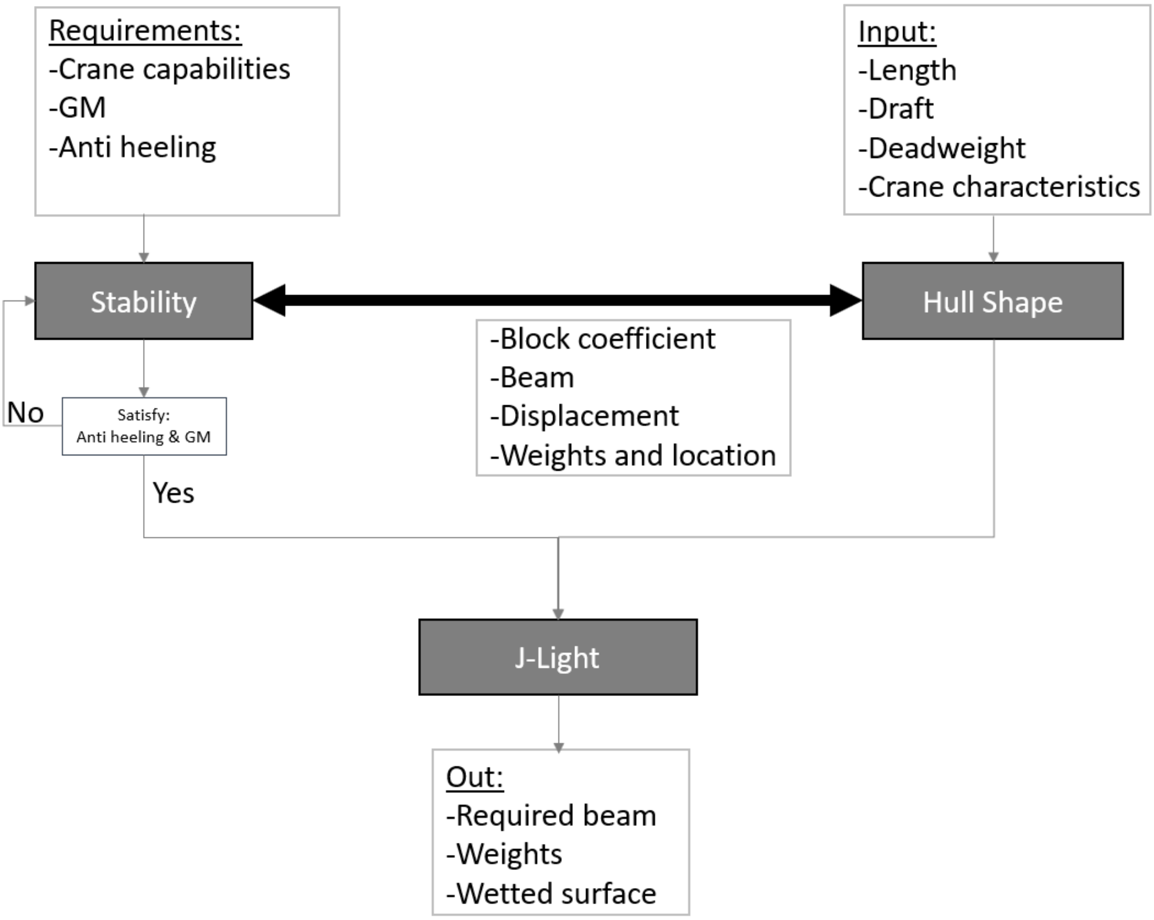


Figure 5.1: Overview of the model

The two model parts, a hull shape determination model and a stability calculations part, are linked with each other. A wider ship results in changes in weight, dimensions, tank volumes, center of gravities etc., these changes then influence the stability. This is an on going process until the model reached a certain width at which the ship is straight during a lifting operation and match the required minimal GM. This width is then used as input to calculate hull shape part of the model. Chapter 4 already discussed the several requirements for this model. So the stability part of the model determines the required width and the hull shape model the ship characteristics. The two parts, stability and hull shape, results in a J-Light concept. Now, the J-Light characteristics are known, the costs can be calculated by using the weight and resistance. This results in a minimum required day rate for a certain concept which meets the requirements.

5.1. Non-lineair Programming

The two parts of the model do influence each other. Because of this ongoing process a non-linear solver is used to find the optimum, the minimal required width. To be able to solve such a mathematical problem, several factors have to be defined, these are [Birk und Harries, 2003]:

- Objective function
- Free variables
- Constraints

The objective function consists of the sum of the widths of the ballast tanks and hold. Free variables are the width of the left tank and the filling rate of all the ballast tanks. There are several constraints, ship floats without inclination, tanks cannot be filled more than 95% and the total ballast cannot exceed the weight which is necessary to reach the required draft. The draft is 7.5 meters, arises from the requirements. It is possible to lift at other drafts, but this draft is used because it is the maximum draft as a unique selling point. Output is the width that is used to define the performance of the ship. Figure 5.2 shows the stability part of the model and a graphic representation of the midship section. Below the objective function, free variables and constraints are summed up.

5.1.1. Objective function

- Width of the ship, small as possible
- Consists of SB tank, hold and PS tank

5.1.2. Free variables

- Width of PS tanks
- Volume of ballast water in tanks
- Block coefficient is variable to match the deadweight

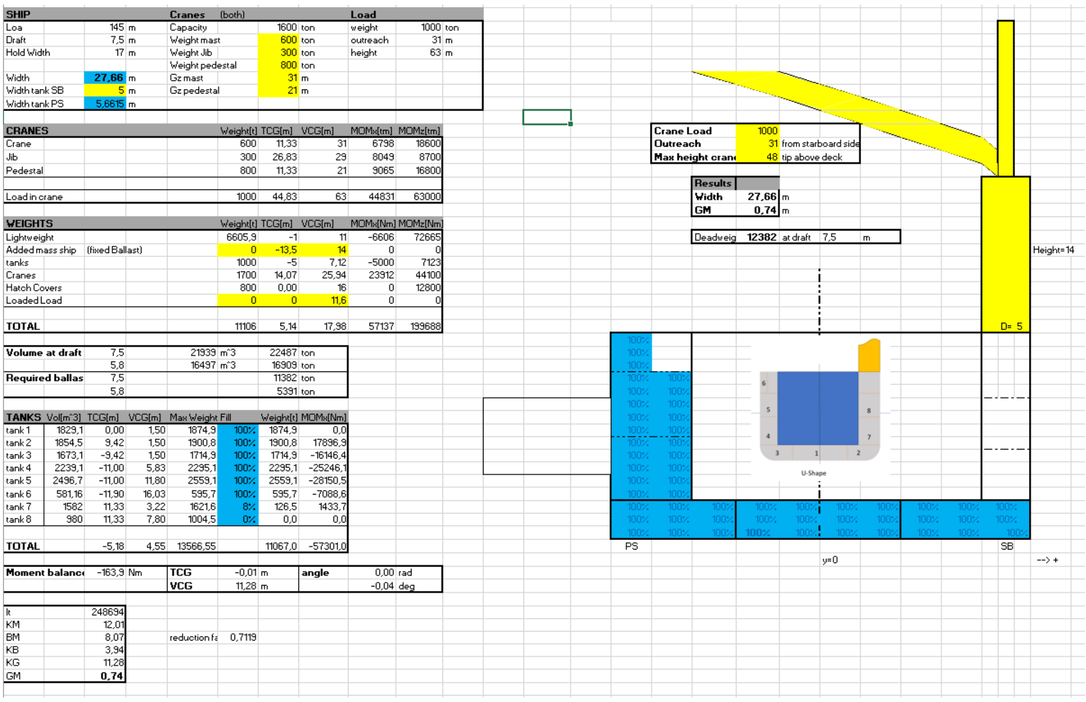
5.1.3. Constraints

- Water volume in ballast tanks lower than 95 percent
- GM > requirement
- No heeling, moment is 0
- Weight of lightship, ballast, cargo is equal to displacement
- Deadweight = Requirement

5.1.4. Fixed input values

- Length
- Draft
- Deadweight
- Weights of cranes and tanks

- Crane outreach and height
- Cargo load in crane
- Possibly other cargo’s or fixed ballast



SHIP			**Cranes** (both)			**Load**		
Loa	145	m	Capacity	1600	ton	weight	1000	ton
Draft	7,5	m	Weight mast	600	ton	outreach	31	m
Hold Width	17	m	Weight Jib	300	ton	height	63	m
			Weight pedestal	800	ton			
Width	**27,66**	m	Gz mast	31	m			
Width tank SB	5	m	Gz pedestal	21	m			
Width tank PS	5,6615	m						

CRANES	Weight[t]	TCG[m]	VCG[m]	MOMx[tm]	MOMz[tm]
Crane	600	11,33	31	6798	18600
Jib	300	26,83	29	8049	8700
Pedestal	800	11,33	21	9065	16800
Load in crane	1000	44,83	63	44831	63000

WEIGHTS		Weight[t]	TCG[m]	VCG[m]	MOMx[Nm]	MOMz[Nm]
Lightweight		6605,9	-1	11	-6606	72665
Added mass ship	(fixed Ballast)	0	-13,5	14	0	0
tanks		1000	-5	7,12	-5000	7123
Cranes		1700	14,07	25,94	23912	44100
Hatch Covers		800	0,00	16	0	12800
Loaded Load		0	0	11,6	0	0
TOTAL		11106	5,14	17,98	57137	199688

Volume at draft	7,5	21939	m^3	22487	ton
	5,8	16497	m^3	16909	ton
Required ballas	7,5			11382	ton
	5,8			5391	ton

TANKS	Vol[m^3]	TCG[m]	VCG[m]	Max Weight	Fill	Weight[t]	MOMx[Nm]
tank 1	1829,1	0,00	1,50	1874,9	100%	1874,9	0,0
tank 2	1854,5	9,42	1,50	1900,8	100%	1900,8	17896,9
tank 3	1673,1	-9,42	1,50	1714,9	100%	1714,9	-16146,4
tank 4	2239,1	-11,00	5,83	2295,1	100%	2295,1	-25246,1
tank 5	2496,7	-11,00	11,80	2559,1	100%	2559,1	-28150,5
tank 6	581,16	-11,90	16,03	595,7	100%	595,7	-7088,6
tank 7	1582	11,33	3,22	1621,6	8%	126,5	1433,7
tank 8	980	11,33	7,80	1004,5	0%	0,0	0,0
TOTAL		-5,18	4,55	13566,55		11067,0	-57301,0

Moment balance	-163,9	Nm	**TCG**	-0,01	m	**angle**	0,00	rad
			VCG	11,28	m		-0,04	deg

It	248694		
KM	12,01		
BM	8,07	reduction fa	0,7119
KB	3,94		
KG	11,28		
GM	**0,74**		

Crane Load	1000	
Outreach	31	from starboard side
Max height crane	48	tip above deck

Results		
Width	**27,66**	m
GM	**0,74**	m

Deadweig	**12382**	at draft	7,5	m

Figure 5.2: Graphical overview of the stability calculation

5.2. Stability calculation

Ballast is used in ships to ensure a ship can lift cargo without inclination. For every weight, tank and ballast centres of gravity can be calculated. The position of these centres of gravity relative to the y-axis and the weights they create a momentum on the total construction around the x-axis. Setting up a moment balance it can be determined whether the ship is in balance or not. If the sum of moments around the x-axis is zero the ship has no inclination.

$$\Sigma M_x = 0 = \Sigma(m \cdot r_y) \tag{5.1}$$

In formula 5.1 m is the mass and r_y the distance between the centre line of the ship and the centre of gravity of the mass in y-direction. Aim is to find the minimum ship width for which the use a stabiliser is not required to ensure the stability of a ship during lifting. In the model only the width of the ship and the distribution of the ballast water inside the ballast tanks are variable.

A displacement can be defined with certain ship dimensions and characteristics. Knowing the displacement and the weights makes it possible to determine the amount of ballast that is required to meet the design draft. This ballast is divided over the ship in such a way that the sum of moments is zero. If it is not possible to reach zero, the ballast need to be enlarged resulting in a wider ship. Figure 5.3 will provide a schematic overview of how the width is determined.

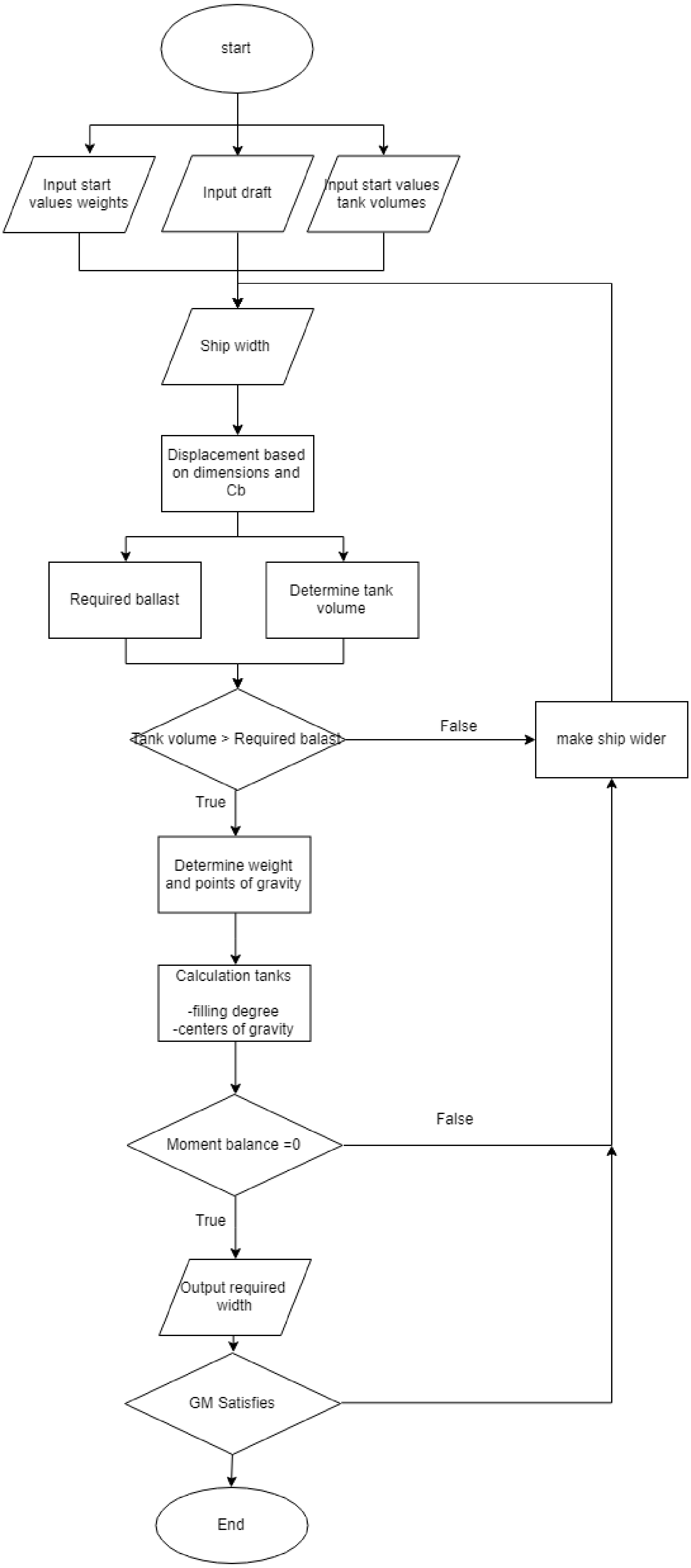


Figure 5.3: Process to determine required width

5.2.1. Tankvolumes

Ballast tanks are modelled based on the J-type. Figure 5.4 provides a cross section of the J-type. All the ballast tanks are numbered. In the J-type the tanks consist of three parts in the length of the ship. In the model these three tanks are merged resulting in eight long tanks. For every tank the center of gravity and volume are defined.

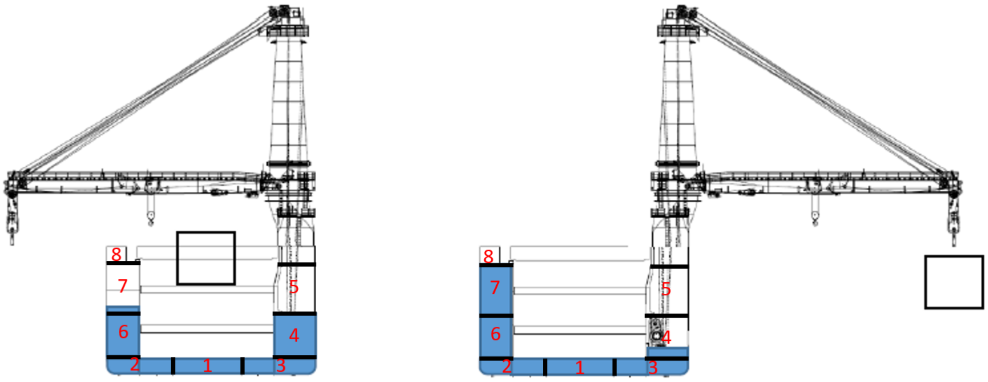


Figure 5.4: Process to determine required width

Simplifications are made to determine the ballast tanks on the ship. In the fore and aft of the ship the ballast tanks are reduced. To be able to determine the volume of the tanks for different widths, the length of the tanks is based on the PIAS model for the J-type. Exact volumes are defined for the ballast tanks. By dividing the tank volumes with the total surface of the midship section an approximate length is defined. This length is used to determine the volume of the ballast tanks in the model. The portside and bottom has the same length. Starboard, the crane side, is shorter because the cranes need space underdeck to store cables and required equipment. Table 5.1 provides an overview of all defined ballast tank lengths. The tank on the crane side is 14 meters shorter than the tanks in the bottom and portside of the ship. These 14 meters correspond with the 2 $*$ 7 meters that are required for the crane installations on the double side of the hull. Table 5.1 shows all the dimensions of the ballast tanks. These dimensions are based on the assumption that the length of the ship is the limiting factor. If the length changes the dimensions of the tanks have to be recalculated.

	Length [m]	**Width** [m]	**Height** [m]	**Volume model**[m^3]	**Volume PIAS** [m^3]	**Difference** [%]
Bottom	70	26.5	2.15	3859	3937	-2.23
Left side	70	4.3	11.95	3973	3943	0.77
Right side	56	5.2	9.5	2665	2584	3.11
Total				10487	10646	0.22

Table 5.1: Tank Volumes Model vs. PIAS

In the model the width of the hull varies to find a hull which matches all requirements. That results in varying of the volume of the ballast tanks. The ballast tanks in de port side of the ship are most important for anti heeling. For that reason the only the ballast tanks at port side increase. The ballast tanks at star board (crane side) are fixed.

5.2.2. GM

As soon as the model determined a width the stability of the ship can be defined based on the GM. Appendix C provides the basic rules for ship stability.

$$GM = KM - KG = KB + BM - KG \tag{5.2}$$

An approach to determine the KB value formula 5.3 can be used [Munro-Smith, 1957]. This method takes into account the hull form by using C_w and C_b.

$$KB = \frac{C_{w,0}}{C_{w,0} + C_{b,0}} \cdot T \tag{5.3}$$

- $C_{w,0}$ = Waterline area coefficient at design draft
- $C_{b,0}$ = Block coefficient at design draft
- T = Draft

KG is determined based on all the centre of gravities and weights. BM is determined based on the width, draft and block coefficient of the ship.

$$BM = \frac{I_t}{\nabla} \tag{5.4}$$

$$I_t = \frac{LB^3}{12} \cdot f(C_{wp}) \tag{5.5}$$

$$C_{wp} = 0.95 \cdot C_p = 0.17(1 - C - p^{1/3} \tag{5.6}$$

Formula 5.6 is from table 5.5 and calculate the waterplane coefficient. The prismatic coefficient is C_p is determined by dividing the block coefficient by the prismatic coefficient, where the prismatic coeffcient is a typical value from table 5.5, 0.98.

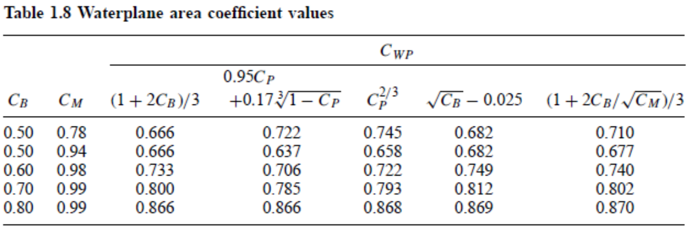


Table 1.8 Waterplane area coefficient values

		C_{WP}				
C_B	C_M	$(1+2C_B)/3$	$0.95C_P$ $+0.17\sqrt[3]{1-C_P}$	$C_P^{2/3}$	$\sqrt{C_B} - 0.025$	$(1+2C_B/\sqrt{C_M})/3$
0.50	0.78	0.666	0.722	0.745	0.682	0.710
0.50	0.94	0.666	0.637	0.658	0.682	0.677
0.60	0.98	0.733	0.706	0.722	0.749	0.740
0.70	0.99	0.800	0.785	0.793	0.812	0.802
0.80	0.99	0.866	0.866	0.868	0.869	0.870

Figure 5.5: Waterplane Coefficient determination [Schneekluth und Bertram, 1998]

Moment of Inertia is determined by the length of the ship. The ship does not have the same width over the entire length of the ship, therefore the BM is multiplied with a reduction factor f(Cwp) [Schneekluth und Bertram, 1998], the method of Normand is used. The reduction factor is a formula of the waterplane area.

$$f(C_{wp}) = 0.096 + 0.89 \cdot C_{wp}^2 \tag{5.7}$$

5.2.3. GM with Stabiliser

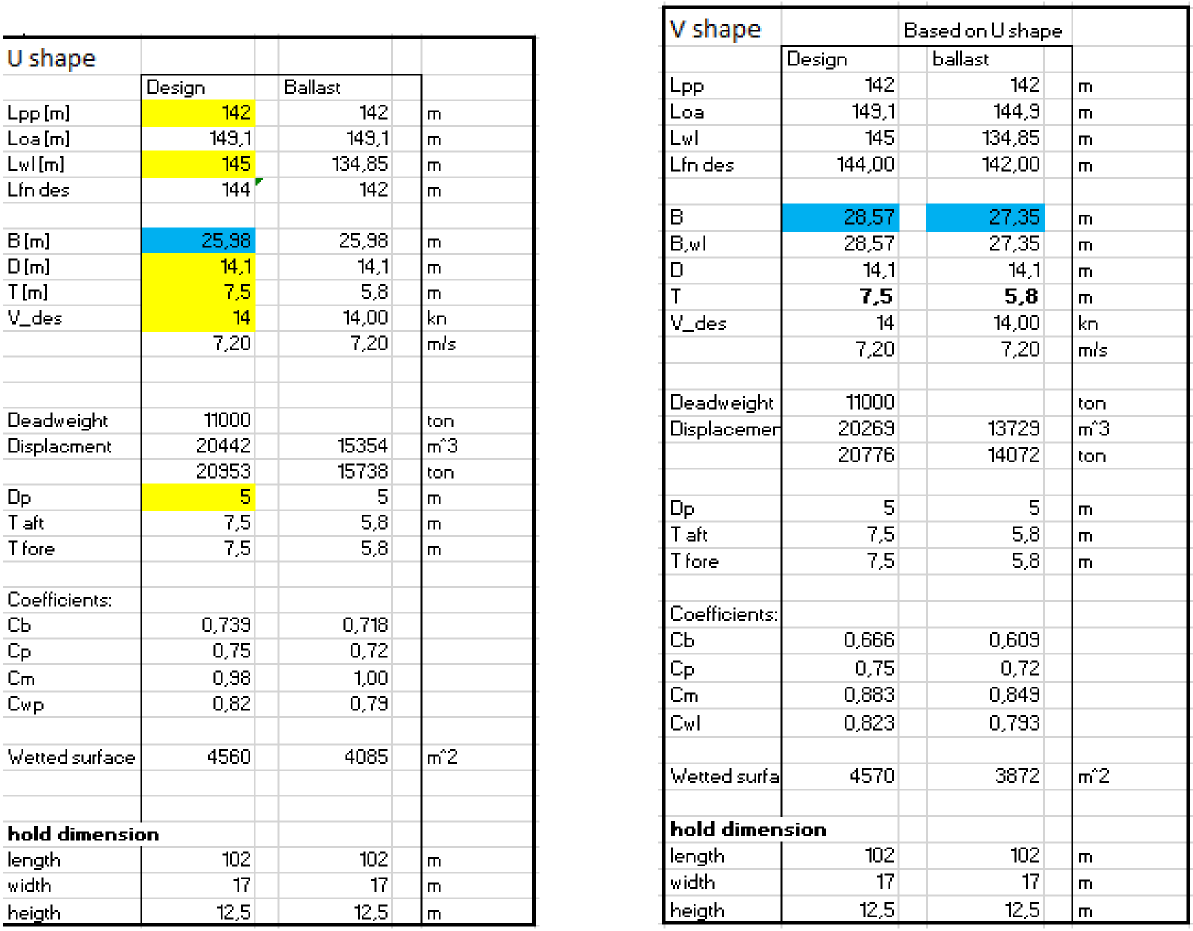
To be able to determine the effect of the stabiliser it is added to the stability, as described in section 3.3. Determining the new locations of the KB, BM and KG depends of combined construction, ship and stabiliser. The dimensions of the stabiliser that is already used on the current J-type will be used in the calculations. The stabiliser is added on the side of the ship and has a width of 13 meters from hull. The length is 11 meters and the depth is 3.7 meters, half under waterline, half above waterline.

	Stabiliser
Lenght [m]	11
Width [m]	13
Depth [m]	3.7
Weight [ton]	100

Table 5.2: Dimensions Stabiliser

5.3. Hull Shape

The hull shape part of the model is created to determine the characteristics of the ship, like its weight and resistance. Inputs of the parametric model are the main dimensions of the ship. Some of the dimensions, like described in 4, have preconditions they have to meet. The other values and coefficients are defined based on the parametric methods described in [Lamb, 2004] and [Schneekluth und Bertram, 1998]. Formulas to determine these values are presented in Appendix E. Figure 5.6 provides an overview of the parametric part of the model. The figures highlighted in yellow are values have to be filled in before being able to run the model. Only the figure presented in blue can variate, this is the width of the ship. This blue value is the output from the stability part of the model. This model also defines the characteristics of the corresponding V-hull. This V-hull is based on the U-shape by keeping the prismatic coefficient equal, like described in 4. In combination with the location of the knuckle and the angle of the flared side of the hull, a width can be determined. Once this is achieved, the ship characteristics can be defined.



U shape			
	Design	Ballast	
Lpp [m]	142	142	m
Loa [m]	149,1	149,1	m
Lwl [m]	145	134,85	m
Lfn des	144	142	m
B [m]	25,98	25,98	m
D [m]	14,1	14,1	m
T [m]	7,5	5,8	m
V_des	14	14,00	kn
	7,20	7,20	m/s
Deadweight	11000		ton
Displacment	20442	15354	m^3
	20953	15738	ton
Dp	5	5	m
T aft	7,5	5,8	m
T fore	7,5	5,8	m
Coefficients:			
Cb	0,739	0,718	
Cp	0,75	0,72	
Cm	0,98	1,00	
Cwp	0,82	0,79	
Wetted surface	4560	4085	m^2
hold dimension			
length	102	102	m
width	17	17	m
heigth	12,5	12,5	m

(a) U-shape

V shape		Based on U shape	
	Design	ballast	
Lpp	142	142	m
Loa	149,1	144,9	m
Lwl	145	134,85	m
Lfn des	144,00	142,00	m
B	28,57	27,35	m
B,wl	28,57	27,35	m
D	14,1	14,1	m
T	**7,5**	**5,8**	m
V_des	14	14,00	kn
	7,20	7,20	m/s
Deadweight	11000		ton
Displacemer	20269	13729	m^3
	20776	14072	ton
Dp	5	5	m
T aft	7,5	5,8	m
T fore	7,5	5,8	m
Coefficients:			
Cb	0,666	0,609	
Cp	0,75	0,72	
Cm	0,883	0,849	
Cwl	0,823	0,793	
Wetted surfa	4570	3872	m^2
hold dimension			
length	102	102	m
width	17	17	m
heigth	12,5	12,5	m

(b) V-shape

Figure 5.6: Parametric part of model and corresponding parametric V-hull

5.3.1. Resistance

Hollenbach's method is used to determine the resistance. The method is usable to forecast the performance of cargo ships in an early design stage and helps to compare the concepts. This method is based on empirical formulas and consists of ship dimensions, -coefficients and constant values. It makes a distinction between the design draft and the ballast draft. Resistance of a ship is based on the frictional resistance and the residual resistance. The frictional resistance is multiplied with the form factor k.

$$R_T = R_F + R_R \tag{5.8}$$

$$R_F = C_F \cdot \frac{\rho}{2} \cdot \cdot S \cdot (1 + k) \tag{5.9}$$

The term C_F is a function of the Reynold number R_n and V is the speed in $\frac{m}{s}$. The wetted surface, S, is determined based on HoltropMennen's method, which is described in Appendix E. Form factor k is based on van Watanabe's method, this formula is shown in equation 5.10

$$k = -0.095 + 25.6 \cdot C_b / [(L/B)^2 \cdot \sqrt{B/T}] \tag{5.10}$$

The residual resistance is based on the method from van Hollenbach, which is also described more in detail in Appendix E.

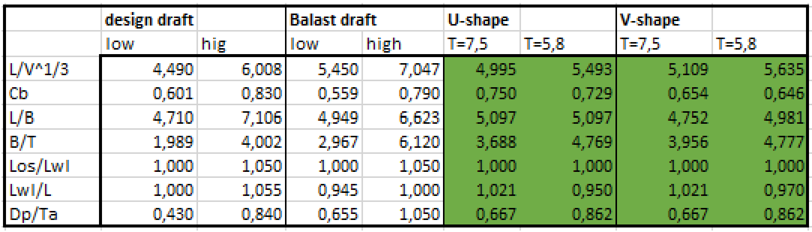
$$R_R = C_R \cdot \frac{\rho}{2} \cdot V^2 \cdot (\frac{B \cdot T}{10}) \tag{5.11}$$

Formula 5.12 is a formula determined by Hollenbach. The coefficients b1..b6 are described in Appendix E, just like the other values used in this formula.

$$C_R = C_{R,Standard} \cdot C_{R,Fnkrit} \cdot k_L \cdot (T/B)^{b1} \cdot (B/L)^{b2} \cdot (L_{os}/L_{wl})^{b3} \cdot (L_{wl}/L)^{b4} \cdot (1 + (T_A - T_F)/L)^{b5} \cdot (D_p/T_A)^{b6} \tag{5.12}$$

Resistance control method

Hollenbach created a table with values to control the resistance estimation can be used. This method is based on ship dimensions they gave certain ratios. If these ratios fall within a certain range the method of Hollenbach can be used to determine the resistance of a ship. Figure 5.7 shows an example of this validation taking the parametric model from figure 5.6 into account.
The table shows ranges which the ratios must comply. There is a difference between the design draft and the ballast draft. In this example the ratios for the U-shape and the corresponding V-shape are determined for the design draft as well as for the ballast draft. All these ratios fall within the range set by Hollenbach.



	design draft		Balast draft		U-shape		V-shape	
	low	hig	low	high	T=7,5	T=5,8	T=7,5	T=5,8
L/V^1/3	4,490	6,008	5,450	7,047	4,995	5,493	5,109	5,635
Cb	0,601	0,830	0,559	0,790	0,750	0,729	0,654	0,646
L/B	4,710	7,106	4,949	6,623	5,097	5,097	4,752	4,981
B/T	1,989	4,002	2,967	6,120	3,688	4,769	3,956	4,777
Los/Lwl	1,000	1,050	1,000	1,050	1,000	1,000	1,000	1,000
Lwl/L	1,000	1,055	0,945	1,000	1,021	0,950	1,021	0,970
Dp/Ta	0,430	0,840	0,655	1,050	0,667	0,862	0,667	0,862

Figure 5.7: Validation values Hollenbach

5.3.2. Installed power

To be able to sail the propulsion has to overcome the ship resistance, the required power to do so can be determined with formula 5.16. The efficiency of the propulsion, hull and propeller determine how much power the engines have to provide to overcome the resistance.

$$P_B = \frac{R_T * V}{\eta_D * \eta_S} \tag{5.13}$$

- P_B = Brake Power in kW
- R_T = Total resistance in kN
- V = Velocity in m/s
- η_D = Propulsive efficiency
- η_s = Shaft efficiency with typical value 0.98

De propulsive efficiency, η_D, consists of the open-water propeller efficiency η_o, the hull efficiency η_H and the relative rotative efficiency η_R.

$$\eta_D = \eta_o \cdot \eta_H \cdot \eta_R \tag{5.14}$$

The propeller efficiency η_{pi} changes if the resistance it has to overcome varies, if the propeller has the same diameter. The concepts have a similar propeller diameter, because the draft are equal. The hull shapes do differ and therefore the propeller efficiency will change. Also the velocity of the ship has an impact on the resistance and thereby also on the propeller efficiency. The method of Aalbers is used to determine the different propeller efficiencies of the different concepts and hull shapes [Aalbers]. This method determines the ideal propeller efficiency based on the resistance, speed and propeller diameter, the formula is described in 5.15. Furthermore the formulas to determine the thrust and the speed of advance are presented in 5.19. The ideal efficiency is lowered with 0.175 to determine the actual propeller effiency, see formula 5.21.

$$= \frac{2}{1+\sqrt{1+C_t}} \tag{5.15}$$

$$C_t = \frac{T}{0.5 \cdot \rho \cdot V_a^2 \cdot A_p} \tag{5.16}$$

- η_{pi} = Ideal propeller efficiency
- T = Thrust propeller
- V_A = Speed of advance of propeller
- A_p = Area of propeller

Thrust:

$$T = \frac{R}{1-t} \tag{5.17}$$

Thrust deduction factor, (Heckscher)

$$t = 0.5 \cdot C_p - 0.12 \tag{5.18}$$

Speed of advance

$$V_a = (1-w) \cdot V_s \tag{5.19}$$

Wake fraction, (Heckscher)

$$w = 0.7 \cdot C_p - 0.18 \tag{5.20}$$

Formula 5.21 is used to determine the real propeller efficiency based on the ideal efficiency.

$$\eta_p = \eta_{pi} - 0.175 \tag{5.21}$$

The hull efficiency η_H is determined with formula 5.22. The relative rotative efficiency η_R has a typical value of 1.02 [Schneekluth und Bertram, 1998].

$$\eta_H = \frac{1-t}{1-w} \tag{5.22}$$

Auxiliary Power

Next to the main engine a heavy lift ship also has auxiliary engines making it possible to perform heavy lifting operations. The cranes consume power to lift and turn and the pumps also consume power to move around the ballast in the tanks. Besides that also the ship accommodations require power. Current J-type has several auxiliary engines to meet the different amount of required electricity. In the J-type a 2000kW auxiliary engine will be installed, this engine can be used to provide extra power to the propulsion to sail faster. In the calculations is it assumed that the auxiliary engines provide 1500kW in ports and run on MGO.

5.3.3. Fuel Consumption

Required fuel per time unit is based on the specific fuel consumption. Table 5.3 provides the typical values for specific fuel consumptions for HFO and MGO [Klein Woud und Stapersma, 2002].

	SFC [g/kWh]	Price [$/ton]	Price [€/ton]
HFO	180	450	400
MGO	220	700	630

Table 5.3: Specific fuel consumption and price

Taking these figures into account will lead to the required fuel for 24 hours. Costs for this are determined by multiplying the bunker price per tonne fuel with the total amount of required fuel. Bunker prices differ all around the world and depend on the exchange rates. Prices taking into account are from April 2019 [Shipandbunker, 2019] [Bloomberg.com, 2019].

5.3.4. Weights

Weight of the ship is divided into several groups:

- Lightship
- Filled tanks (Fuel/oil/fresh water)
- Hatchcovers
- Water in ballast tanks
- Cargo

Weight of the hatchcovers and the filled tanks are based on the current J-type and are fixed for each concept, table 5.4. The weight of the cranes is an assumption and described in subsection 5.3.5. The weight of the lightship is determined by using the model and is dependent on the dimensions of the ship. The method used to make an estimation of this weight is described below in detail. The cargo weight and location is input for the model. The weight and centre of gravities will be determined by the model and are used for calculations to induce anti heeling and the minimal required GM. All the weights are in ton and locations of centres of gravity in meter.

Lightship Total weight of the ship. W_{ls} is build up according to the method of van Watson [Watson, 1998] and is based on the dimensions of the ship.

$$W_{ls} = W_{st} + W_o + W_d + W_r \tag{5.23}$$

- W_{St} = Steel weight
- W_o = Outfitting weight
- W_d = Propulsion machinery weight
- W_r = Remainder weight

$$W_{St} = C_B^{2/3} * \frac{1}{6} L * B * D^{0.72} * [0.002(\frac{L}{D})^2 + 1] \tag{5.24}$$

- W_{St} = Steel Weight
- C_B = Block Coefficient
- L_{oa} = Length over all
- B = Beam
- D = Draft

$$W_o = K \cdot L_{pp} \cdot B \tag{5.25}$$

The constant K has a value in the range 0.40-0.45 t/m^2. In this model the value is set on 0.45 t/m^2. The ship can be categorized as a general cargo ship, but the heavy lift cranes with their associated control and safety systems are complex pieces of equipment. For that reason, the outfitting weight is set as the heaviest constant according Watson.

$$W_d = 12(\frac{MCR}{RPM})^{0.84} \tag{5.26}$$

- MRC = Maximum Continuous Rating

- RPM = Revolutions per Minute of Engine, set on 700

$$W_r = K \cdot MCR^{0.70} \tag{5.27}$$

The constant K has a value of 0.69 for cargo ships [Watson, 1998]

An overview of the weights and the corresponding centre of gravities can be found in table 5.4. Weight of the lightship is calculated as described above. Centre of gravity in the y-direction of the light ship is not on the centreline. This centre of gravity is changed to the portside of the ship to compensate a part of the crane weights. In the detail design of the ship the layout can be made so that the centre of gravity is on the port side of the hull. The KG value is based on the J-type and the percentage height of top-side deck above keel. Typical value is between 0.7 and 0.8 [Schneekluth und Bertram, 1998] and is set on 11m.

	Weight [ton]	**TCG [m]**	**VCG [m]**
Lightship	W_{ls}	-1.5	10.0
Tanks	1000	-5	7
Hatchcovers	800	-0.5	16

Table 5.4: Fixed input ship weights

The weight and points of gravity of the filled tanks and hatchcovers are assumptions based on the J-type ship. The filled tanks consist of fuel, oil and frsh water tanks and is based on the current J-type and set at 1000 tons.

5.3.5. Crane Characteristics

The cranes have to meet Jumbo's requirements, they have to have an outreach of 31 meters from the hull, at that outreach they should be able to lift 2*500 ton. These cranes are split into 3 parts, mast, jib and the pedestal. The mast and the pedestal have fixed centres of gravities. The centre of gravity of the jib is in the middle of the jib, relative to the ship its centre of gravity depends on the position of the jib. Weights and centre of gravities of the cranes are defined based on the known information on the Huisman cranes, in Appendix F a general arrangement of the Huisman crane is added. Besides that Frouws's method is used to determine the weights. Table 5.5 shows the calculated crane weights in case of the J-light, lifting 2*800 ton with a maximum outreach of 31 meters. The centre of gravities are for a specific situation and will be hull dependent in the model. Figure 5.8 shows the layout of a pedestal crane.

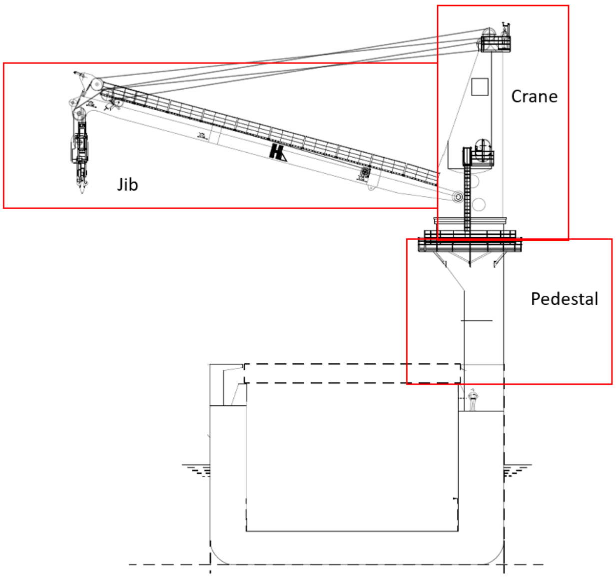


Figure 5.8: Layout pedestal crane

The jib (boom) has a length of 33 meters and cannot be fully turn in the vertical direction, like shown in the general arrangement (Appendix F). The minimal angle of the jib relative to the crane is 7 degrees. The pivot point of the jib is 2.3 meters above the lowest part of the crane. Therefore maximum height of the point of the jib is 35 meters above the bottom of the crane. The minimum required height above deck is 45 meters. To be able to reach this height the pedestal crane has to be 10 + 2 meters. These 2 meters are the distance from the top part of the hull up to topside of the hatch covers, the deck.

Method developed by Frouws provides an algorithm for different types of cranes. Formula 5.28 provides the formula for the pedestal wire luffing cranes, 150 till 1000 tonnes. This is the weight of the crane without pedestal, the weight of pedestals is estimated based on the figure 5.7. The safe working load (SWL) is 800 tons and a maximum outreach of 33 meters. This gives approximately 32 tonne per meter pedestal. The pedestal is 12 meters long, so it weighs 384 tonne. Weight for both pedestals is set to 800 tonne.

$$W_{crane} = 138.63 + 0.000013 \cdot SWL^{1.993} \cdot W_2^{1.054} \tag{5.28}$$

- W_{crane} = Weight Crane
- SWL = Safe Working Load
- W_2 = Maximum Outreach

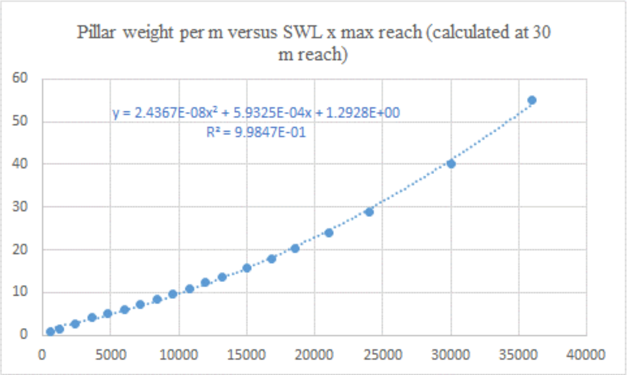


Figure 5.9: Weight of pedestal per meter (Frouws, 2019)

Table 5.5 gives an overview of the used crane weights per crane part.

	Weight [ton]	**TCG [m]**	**VCG [m]**
Crane	600	Dependent on width	29
Jib	300	0.5*outreach	Dependent on outreach
Pedestal	800	Dependent on width	18

Table 5.5: Crane characteristics for two 800tons crane

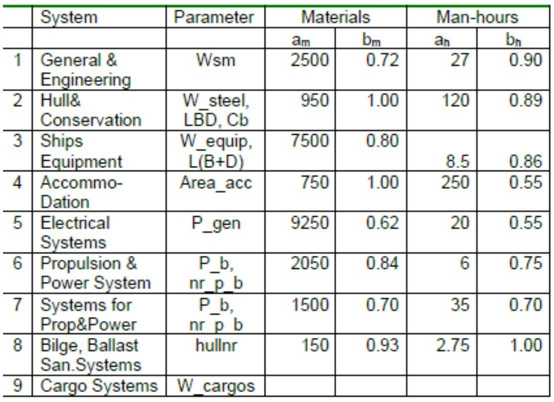
As shown in figure 5.8 the footprint of the crane is wider than the side tanks on starboard. The space in the double hull on the starboard side is not necessary for anti heeling ballast. Meaning that the double hull can be small as possible. However the construction of the double hull is required for the strength of the ship and the double hull on starboard has to be strong enough to support the pedestal and the crane. Figure 5.8 makes clear the side of the ship can be constructed narrower than the diameter of the pedestal of the crane.

5.4. Building costs

To make an estimation of the building costs of the concepts the method of Aalbers [Aalbers] is used. This method is based on main parameters of the ship and coefficients determined by Aalbers. The costs are split up in material and labour costs. Formula 5.29 gives the formule to estimate the cost per category and figure 5.10 shows the coefficients per category. The sum of all these costs is the estimation of the building costs of the hull of the J-light.

$$K = c \cdot a \cdot W^b \tag{5.29}$$

- K = Costs/man hours
- a = Factor for local conditions
- b = Factor in the range 0.5-1.0
- c = Factor of complexity of specific equipment
- W = Weight/size



	System	Parameter	Materials		Man-hours	
			a_m	b_m	a_h	b_h
1	General & Engineering	Wsm	2500	0.72	27	0.90
2	Hull& Conservation	W_steel, LBD, Cb	950	1.00	120	0.89
3	Ships Equipment	W_equip, L(B+D)	7500	0.80	8.5	0.86
4	Accommo-Dation	Area_acc	750	1.00	250	0.55
5	Electrical Systems	P_gen	9250	0.62	20	0.55
6	Propulsion & Power System	P_b, nr_p_b	2050	0.84	6	0.75
7	Systems for Prop&Power	P_b, nr_p_b	1500	0.70	35	0.70
8	Bilge, Ballast San.Systems	hullnr	150	0.93	2.75	1.00
9	Cargo Systems	W_cargos				

Figure 5.10: Coefficients used by Aalbers method

Values a and b originate from the table. The ship is a standard general cargo ship, therefore value c is set at 1. Value W is determined by the model and differs per concept. The man hours have to be multiplied by a hourly wage. This wage varies per category. Engineering hours are in general more expensive than welding hours. Besides that, height of the wages also depends on the location where the ship is built. In this research the wage is set at €40,-. The cost of the cranes and stabiliser are not taken into account in this method. Therefore table 5.6 shows the costs for the cranes and stabiliser. The costs of the cranes is for both cranes and the pedestal inclusive. The smart stabiliser is 20% more expensive than the current stabiliser.

	Costs [€]
Cranes 800 ton	12,000,000
Stabiliser	2,500,000
Smart stabiliser	3,000,000

Table 5.6: Costs Cranes and Stabiliser

Total costs of the cranes are determined based on the information provided by Jumbo Maritime and the method developed by Frouws, formula 5.30.

$$C_{crane} = 36346.78 - 3431.32 ln(0.1x) \tag{5.30}$$

C_{crane} are the costs per tonne crane and x is SWL times maximum outreach.

For this case, a SWL of 800 ton and a max. outrach of 33meter, the cost is €9313,- per ton. The weight of both the cranes (jib and crane parts) is 900 ton and costs are €8.4 million for both cranes. Beside the crane the pedestal costs €4000,- per ton. The weight of both pedestals is 800 ton, so the costs are €3.2,- million. The costs for the cranes and pedestals together is set on €12,- million.

- K = Costs/manhours
- a = Factor for local conditions
- b = Factor in the range 0.5-1.0
- c = Factor of complexity of specific equipment
- W = Weight/size

A risk margin of 5% is added to the total sum of construction costs.

6

Comparison Concepts

The different concepts originating from the model are compared in this chapter. Besides a comparison between the concepts also the minimum required day rate of every concept is determined. In Appendix G all detailed model calculations are shown.

6.1. Sailing profiles

It is difficult to determine the exact sailing profile in the heavy lifting market, because the market consists of several jobs all over the world. These jobs vary in complexity, weight, dimensions and distance to transfer. To be able to compare the different concepts, 3 cases are created which are all relevant for a Jumbo Maritime ship. These cases are based on 1 year. Several assumptions had to made, one of them is that a ship is operational 350 days per year. The ship will perform 15 to maximum of 25 jobs per year. Every job has an average of required port days. 30% to 70% of all those jobs require the usage of a stabiliser. The number of nautical miles that are sailed in one year is based on the speed of 14 knots.
Goal is to use the J-light for the less complex jobs, because there are already ships that can carry out the more complex jobs, namely the J-type and the K-type. Case 1 and 2 are equal except for the usage of a stabiliser. Therefore the impact of the smart stabiliser and the wider ship can be determined. Case 3 shows the situation in which less in number but more time consuming jobs are being performed in 1 year. The time spent in the harbour per job is longer and the stabiliser usage is average. The three cases for which the concepts are compared:

- Case 1; 30 % stabiliser use
- Case 2; 70 % stabiliser use
- Case 3; 50 % stabiliser use and more time consuming projects

The ballast sail is set on 15 %, based on historical data from Jumbo. Experiences and measurements from the past show that how more ships of one ship type are part of the fleet, how low the percentage of sail in ballast. The ships can be strategically distributed around the world in order to keep the percentage of ballast sailing low. The cases are shown in table 6.1.

Cases	**1**	**2**	**3**	
Operational days /year	350	350	350	days
Sail loaded	85	85	85	%
Sail ballast	15	15	15	%
Jobs/year	25	25	15	
Port days/job	4	4	5	day
Stabiliser use	30	70	60	%
Average speed	14	14	14	knots

Table 6.1: Cases

6.2. Concepts to compare

Four concepts are compared. The base case is the current ship, J-type, with the old stabiliser. Second concept is the J-Light with a smart flipper. The characteristics of the J-light ship are the same as the J-type from the base case, so only the process of the stabiliser changes. Furthermore there are two concepts for a wider ship, the U- shaped hull and the V-shaped hull. These two ships will work without a stabiliser and have different hull characteristics.

The four different concepts that will be calculated and compared are:

- 1) Ship with current stabiliser (basic case)
- 2) Ship with smart stabiliser
- 3) Wider ship U-shape, without stabiliser
- 4) Wider ship V-shape, without stabiliser

Besides the given requirements the concepts have to meet as described in chapter 4, there are also other criteria, which must be met during lifting operations. All concepts have a minimum requirement of 1200 tons lifting capacity at an outreach of 15 meters. The designed lift capacity of these cranes is higher than the aforementioned requirement. There are different reasons to do equip the ships with these type of cranes. The model assumes that there is no other cargo on board on the ship. If the ship is required to perform jobs in critical situations, extra weight can be added which can either be fixed ballast or other cargo. These weights then ensure enough stability and anti-heeling. Besides that the ship is designed to perform easily average cargoes. For the critical situations it is allowed to add weights. If the ship is built to be able to lift maximum crane capacities while being empty, the hull will be much wider. This results in higher building costs and an increase in resistance. In addition, the cranes of 800 tons give flexibility to lift cargo (max 800 tons) by using one crane. It is faster and less complex to lift these cargo's with use of one crane instead of two cranes.

- 1) Ballast prevents the ship from heeling
- 2) If the cranes are at their highest point the GM must be at least 2.15 meters

This minimum is based on the Kahn Rule from the J-type. For every ship type the rule has to be adjusted, but the J-type rule provides a good starting point. Table 6.2 provides an overview of all the different characteristics of the different concepts.

Concepts	**1**	**2**	**3**	**4**	
L_{pp}	142	142	142	142	[m]
B	25.98	25.98	28.97	30.98	[m]
D	14.1	14.1	14.1	14.1	[m]
T	7.5	7.5	7.5	7.5	[m]
$T_{ballast}$[m]	5.8	5.8	5.8	5.8	[m]
V_{design}	14	14	14	14	[knots]
C_b	0.74	0.72	0.68	0.63	
Resistance					
R_{load}	396	396	402	409	[kN]
$R_{ballast}$	355	355	370	333	[kN]
Installed power					
Main Engine	7029	7029	6923	7101	[kW]
Auxiliary	2000	2000	2000	2000	[kW]
Consumption/24h					
Sail loaded 14 knots	21.94	21.94	21.61	22.16	[ton 24h]
Sail ballast 14 knots	19.18	19.18	19.44	16.92	[ton 24h]
Fuel during port	7.92	7.92	7.92	7.92	[ton 24h]
Deadweight	11000	11000	11000	11000	[ton]
Building cost	41,940,873	41,94,0873	43,188,485	43,387,622	[€]
GM	-0.47	-0.47	2.15	2.37	[m]
GM by stab. use	4.8	4.8	x	x	[m]

Table 6.2: Main characteristics of the concepts

The GM values in table 6.2 are calculated for a cargo of 1200 tons in the crane at its highest position. The negative values for concept 1 and 2 are for a situation without stabiliser.

Concept 1 forms the base case. This concept corresponds with the current situation. The base case is also calculated with the model, because the cranes of the J-light differ from the J-type. In the model assumptions are made, to be able to perform a fair comparison. The assumptions must be the same for each concept. For that reason the J-Type is recalculated. The J-type which comes from the model is narrower than the current J-Type. The cranes and the lift requirements are the reason for the dimensions in the model.
Concept 2 uses the ‘smart stabiliser’. Differences between concept 1 and 2 are only operational. The ship has the same dimensions, only the procedure how to use the stabiliser is different. This smart stabiliser is more expensive than the ones that are currently used.
Concept 3, the U-shape hull without using a stabiliser, is optimised so it meets the anti-heeling and the minimal required GM. This minimum GM is crucial in determining the width. Because the deadweight is set on 11000 tons, the block coefficient decreases. This results in almost equal fuel consumption at design draft. The larger width results in more deck area. Concept 4, the V-shape hull, is determined as described in section 4.2.3. This concept is not optimised for anti-heeling or minimal required GM, but this concept satisfies both criteria. For this concept, also with a deadweight of 11000 tons the fuel consumption is almost equal to the other concept at 14 knots. However, the deck area increases more than concept 3.
The building costs for each concept are comparable to each other. Concept 3 and 4 has around 1 million more cost to build.

6.3. Fuel Consumption

Graph 6.3 provides information on the fuel consumption at different speeds per concept. Concepts 1 and 2 have a similar hull shape and therefore their fuel consumption is similar. These concepts are visualised in one line. The V-shape (concept 4) has a higher resistance at lower speeds relative to concepts 1 and 2. From 14.5 knots onwards the fuel consumption of the V-shape hull is lower than all other concepts. This is due to the fact that the residual resistance increases exponentially at higher speeds.

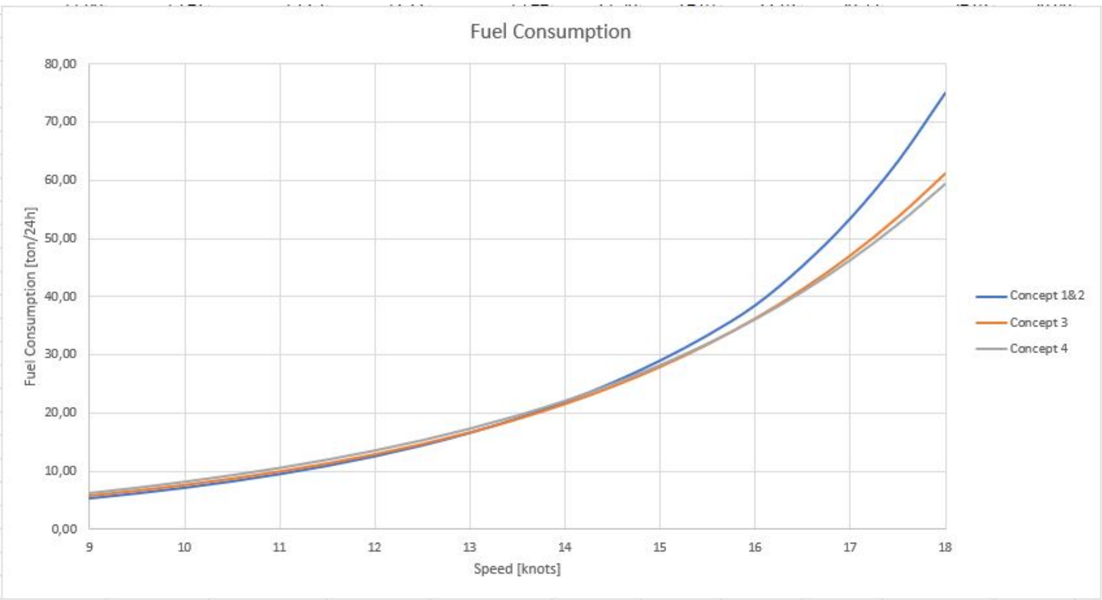


Figure 6.1: Fuel Consumption per concept in ton/24hour

In figure 6.2 the measured fuel consumption from the J-type is added. The determined fuel consumption for the concepts is lower than the measured fuel consumption. This is caused by several things, namely the base case is smaller than the J-type, the block coefficient is a bit lower, the propeller is a bit larger and the propulsion line is determined in the most efficient way.

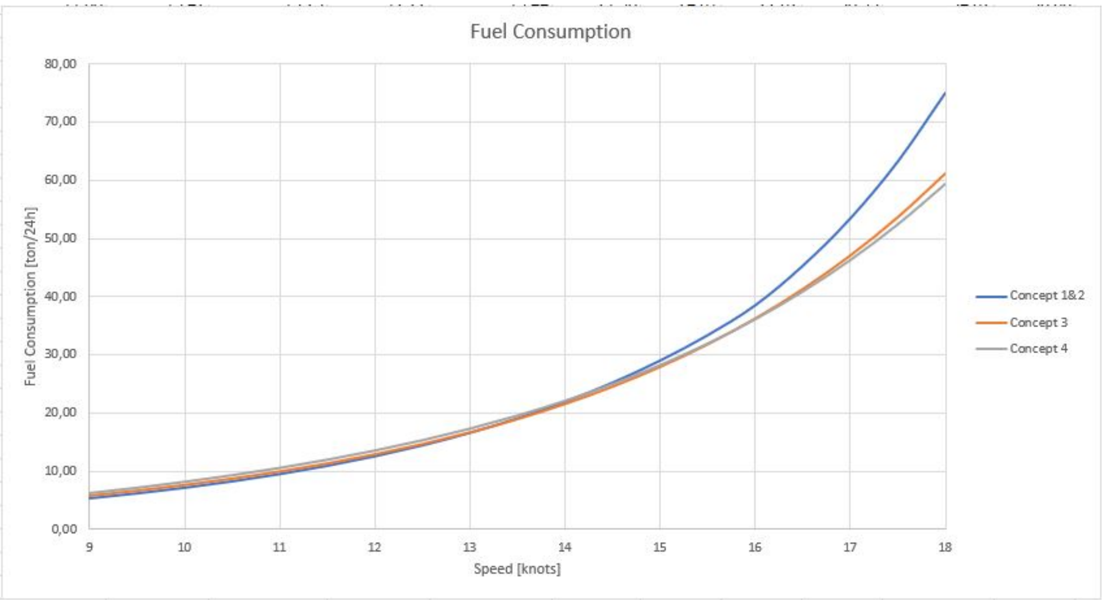


Figure 6.2: Fuel Consumption per concept versus J-Type in ton/24hour

6.4. Costs

The costs per year are determined to be able to compare the concepts based on the minimum required dayrate. Costs consist of three categories: operational costs, voyage costs and capital costs [Watson, 1998]. Capital cost relate to the financing of the ship, including interests and return on equity. The operational costs are fixed cost to keep the ship operational. These costs will not disappear if the ship is not sailing or does not have a job. Among these operational costs are: crew costs, insurances and maintenance. Final category is the voyage costs. These are the costs that be made to be able to execute a job, like costs for port services and fuel. Concepts 3 and 4, the concepts that do not use a stabiliser, require less days in a port to execute the job.

Limiting the port days leaves more time to sail to the next destination. Therefore the ship can sail at a lower speed, resulting in lower fuel consumption per 24 hours.
The model determined the fuel consumption and construction costs for all the concepts. Based on the parameters and the assumptions that are made the required dayrate can be determined and compared for every concept. Because the heavy lifting market consists of single jobs and contracts, it is really difficult to make assumptions on the income. All jobs are completely different in terms of weight, complexity, distance and duration.
Table 6.3 provides an overview of the costs and which assumptions are used to calculate the costs. Port costs are different for each port. Assumptions are made that it will cost €10000,- to enter and exit the port on the same day. Every extra day in a port will cost €3000,-. These extra costs per day are important because they determine the savings that can be made by reducing the time in the port by using the smart stabiliser, or not even using a stabiliser anymore like concepts 3 and 4.

Cost Item	Unit	Assumptions
Capital Cost:		
Loan Interest	€	Ratio loan/equity is 0.6/0.4, interest is 5%
Equity Interest	€	Ratio loan/equity is 0.6/0.4, interest is 10%
Operational Cost:		
Crew	€	€750,000 per year
Maintenance	€	0.5% of new building costs per year
Insurance	€	1% of new building costs per year
Administration	€	0.5% of new building costs per year
Voyage Cost:		
Fuel Sail Loaded	€	Consumption * loaded sailing days * fuel price HFO
Fuel Sail Ballast	€	Consumption * ballast sailing days * fuel price HFO
Fuel Port (MGO)	€	Consumption * port days * fuel price MGO
Port Costs	€	€10000,- for port facilities, €3000,- per extra day

Table 6.3: Cost items per category and assumptions

6.5. Dayrates per concept

Now the sailing cases and the concepts are described the day rates can be determined. For every sailing case the minimum required day rate is determined per concept. Assumptions are made that concepts 2, 3 and 4 will sail at a lower speed because these concepts save time during their operation in ports. If the demand is high on the market, the saved time could also be used to perform more jobs, instead of sailing slower. Table 6.5 provides an overview of the costs per concept for sailing case 1. The fuel costs are based on the sailing-/port days as discussed in section 6.1.

6.6. Case 1

Case 1 perform 25 jobs per year and use the stabiliser for 30% of the jobs. The average time in port per job is 4 days and 15 % of the sailing distance will be sailed in ballast draft. Table 6.4 shows the new required speed to perform all jobs in one year.

Table 6.5 shows all costs for each concept for case 1.

Slower sail situation Case 1		
Saved harbour days	5.625	days
Load sail	217.28	days
Ballast sail	38.34	days
New speed	13.69	knots
New fuel cons. 'smart' load	20.13	ton/24h
New fuel cons. 'smart' ballast	17.77	ton/24h
New fuel cons. 'U' load	19.95	ton/24h
New fuel cons. 'U' ballast	18.04	ton/24h
New fuel cons. 'V' load	20.55	ton/24h
New fuel cons. 'V' ballast	15.76	ton/24h

Table 6.4: Speed and fuel consumption for slower sailing for Case 1

Cost Item	Concept 1	Concept 2	Concept 3	Concept 4
Capital Cost:				
Loan Interest	€1,303,226	€1,312,226	€1,295,655	€1,301,629
Equity Interest	€1,737,635	€1,749,635	€1,727,539	€1,735,505
Operational Cost:				
Crew	€750,000	€750,000	€750,000	€750,000
Maintenance	€217,204	€218,704	€215,942	€216,938
Insurance	€434,409	€437,409	€431,885	€433,876
Administration	€217,204	€218,704	€215,942	€216,938
Voyage Cost:				
Fuel Sail Loaded	€2,097,925	€1,968.712	€1,950,642	€2,009,308
Fuel Sail Ballast	€323,640	€306,533	€311,275	€271,934
Fuel Port (MGO)	€498.960	€470.894	€470.894	€470,894
Port Costs	€475,000	€475,000	€475,000	€475,000
Saved port costs		€-16,875	€-16,875	€-16,875
Required Day Rate	**€37,907**	**€36,317**	**€36,027**	**€36,198**
Fuel cons. kg per nautical mile	**64.06**	**60.19**	**59.84**	**60.35**

Table 6.5: Dayrates per concept for sailing case 1

In the end the dayrates for each concept are almost equal. Looking more close how the dayrates are built up, differences are made by the fuel related costs. Due reducing sailing speed, the fuel costs are lower than the base case. The saved port days deliver enough time to sail slower and use less fuel per year to sail the same distance. For concept 4, the V-shape, the fuel costs for sailing in ballast condition are much lower than the other concepts.
This case makes clear that it is possible to sail with a wider ship for lower costs than a ship with stabiliser. The saved port days must be used to reduce the sailing speed and save fuel.

6.7. Case 2

Case 2 is equal to case 1, but the stabiliser is used in 70% of the jobs instead of 30% of the jobs. The saved port days results in a possible speed reduction of 0.7 knots and his related fuel savings. When sailing at 13.3 knots it is possible to do same amount of jobs. Table 6.6 shows the new fuel consumptions for each concept.

The cost comparison of case 2 is shown in table 6.7.

Slower sail situation		
Saved harbour days	13.125	days
Load sail	223.66	days
Ballast sail	39.47	days
New speed	13.3	knots
New fuel cons. 'smart' load	18.26	ton/24h
New fuel cons. 'smart' ballast	16.10	ton/24h
New fuel cons. 'U' load	18.04	ton/24h
New fuel cons. 'U' ballast	16.40	ton/24h
New fuel cons. 'V' load	18.69	ton/24h
New fuel cons. 'V' ballast	14.39	ton/24h

Table 6.6: Speed and fuel consumption for slower sailing for Case 2

Cost Item	1	2	3	4
Capital Cost:				
Loan Interest	€1,303,226	€1,312,226	€1,295,655	€1,301,629
Equity Interest	€1,737,635	€1,749,635	€1,727,539	€1,735,505
Operational Cost:				
Crew	€750,000	€750,000	€750,000	€750,000
Maintenance	€217,204	€218,704	€215,942	€216,938
Insurance	€434,409	€437,409	€431,885	€433,876
Administration	€217,204	€218,704	€215,942	€216,938
Voyage Cost:				
Fuel Sail Loaded	€1,097,925	€1,817,996	€1,815,641	€1,881,061
Fuel Sail Ballast	€232,640	€285,976	€291,279	€255,580
Fuel Port (MGO)	€498,960	€433,472	€433,472	€433,472
Port Costs	€475,000	€475,000	€475,000	€330,000
Saved port costs		€-39,375	€-39,375	€-39,375
Required Day Rate	**€37.907**	**€34.248**	**€34,139**	**€34,352**

Table 6.7: Dayrates per concept for sailing case 2

For case 2 the conclusion is more or less the same as for case 1. Concept 2,3 and 4 have a lower dayrate than the base case. The stabiliser use in 70% of the jobs saves more port days and the sailing speed can be more reduced. The difference between concept 1 and the other concept are bigger.

6.8. Case 3

Case 3 shows a situation where the ship sails larger distances and has less port days per year. Table 6.8 gives the new speed and fuel consumptions for case 3. Because there are less jobs, the saved port days are limited.

Slower sail situation		
Saved harbour days	5.625	days
Load sail	238.53	days
Ballast sail	42.09	days
New speed	13.72	knots
New fuel cons. 'smart' load	20.29	ton/24h
New fuel cons. 'smart' ballast	17.89	ton/24h
New fuel cons. 'U' load	19.95	ton/24h
New fuel cons. 'U' ballast	18.04	ton/24h
New fuel cons. 'V' load	20.55	ton/24h
New fuel cons. 'V' ballast	15.76	ton/24h

Table 6.8: Speed and fuel consumption for slower sailing for Case 1

Cost Item	1	2	3	4
Capital Cost:				
Loan Interest	€1,303,226	€1,312,226	€1,311,452	€1,296,535
Equity Interest	€1,737,635	€1,749,635	€1,748,602	€1,728,714
Operational Cost:				
Crew	€750,000	€750,000	€750,000	€750,000
Maintenance	€217,204	€218,704	€215,942	€216,938
Insurance	€434,409	€437,409	€431,885	€433,876
Administration	217,204	€218,704	€215,942	€216,938
Voyage Cost:				
Fuel Sail Loaded	€2,307,718	€2,177,828	€2,141,414	€2,205,818
Fuel Sail Ballast	€356,004	€338,828	€341/,717	€298,529
Fuel Port (MGO)	€374,220	€346,154	€346.154	€346.154
Port Costs	€330,000	€330,000	€330,000	€330,000
Saved port costs		€-16,875	€-16,875	€-16,875
Required Day Rate	**€34,343**	**€32,963**	**€32,614**	**€32,778**

Table 6.9: Dayrates per concept for sailing case 3

Case 3 looks like case 1. Concep 2,3 and 4 can perform the same amount of jobs at a lower dayrate.

6.9. Overview cases

To analyse the differences per concept per case, an overview of the day rates is shown in table 6.10. The table shows how more the current stabiliser is used how more the cost can be reduced when concept 2,3 or 4 is chosen.

	Concept 1	**Concept 2**	△ Concept 1	**Concept 3**	△ Concept 1	**Concept 4**	△ Concept 1
Case 1	€37,907	€36,317	-4.19%	€36,027	-4.96%	€36,198	-4.51%
Case 2	€37,907	€34,486	-9.65%	€34,139	-9.94%	€33,906	-9.38%
Case 3	€34,343	€32,963	-4.02%	€32,691	-4.81%	€32,854	-4.34%

Table 6.10: Overview day rates per concept for each case and difference in % to the base case

A result of slower sailing is a certain distance costs more time to sail. For that reason it is interesting what the are the differences in costs between the concepts to perform a job. Table 6.11 shows the job rate for each case per concept. The job rate differences are smaller than the day rate differences and is a consequence of the longer sailing time per job. Overall the conclusion is the same. It is possible to sail with a smart stabiliser or a wider ship with lower costs.

	Concept 1	**Concept 2**	△ Concept 1	**Concept 3**	△ Concept 1	**Concept 4**	△ Concept 1
Case 1	€322,208	€315,638	-2.04%	€313,116	2.82%	€314,606	-2.36%
Case 2	€322,208	€306,390	-4.91%	€305,419	-5.21%	€307,325	-4.62%
Case 3	€535,175	€524,174	-2.06%	€519,862	-2.86%	€522,446	-2.38%

Table 6.11: Overview job rates per concept for each case and difference in % to the base case

6.10. Cost per ton/mile

In the heavy lift market the deadweight of a ship is most of time not the limiting factor. Each cargo has other dimensions and weights. To choose for each concept the economical speed, the cost per ton/mile is calculated. The economical speed per concept is determined for Case 1.

- 125000 tons per year (5000 tons per voyage)
- 202 loaded sailing days per year
- 100 port day per year

- 67.5 ballast sailing days per year

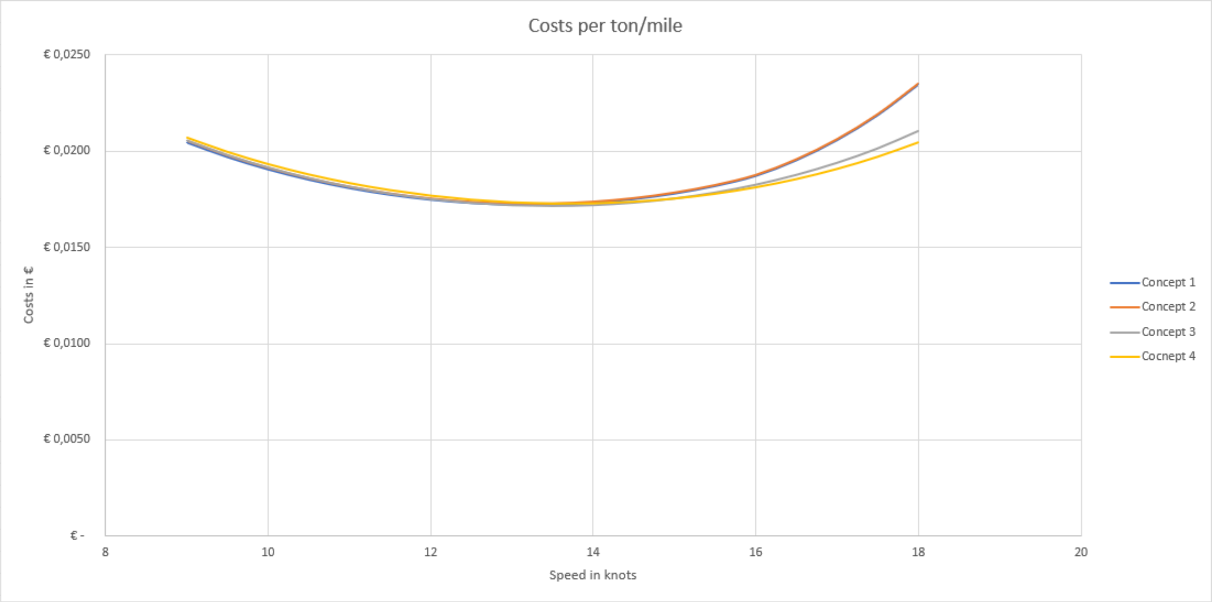


Figure 6.3: Cost per ton/mile for each concept

The economical speed is around 13.5 knots. This is comparable to the design speed for of 14 knots. At higher speeds, concept 3 and 4 have lower costs. In appendix G the table is shown with costs per ton/nautical mile for each speed per concept.

6.11. Sensitivity analysis

Fuel prices are fluctuating. It is a real scenario that fuel prices can rise in the future. Beside that, the authorities are setting even stricter emission requirements for ships. In general, 'cleaner fuels' are more expensive than HFO. MGO, the fuel which is required in ports, has lower emissions than HFO. To analyse consequences of this two scenarios, the cases are recalculated. Scenario 1 is a fuel price increase of 20%, for both HFO and MGO. Scenario 2 is a situation where HFO is changed for MGO. For both situations the job rate per concept is determined.

6.11.1. Scenario 1, fuel price increases 20 %

Fuel price increase of 20%, for both HFO and MGO. The cost if HFO is €480,- per ton and the price of MGO is €756,- per ton.

	Concept 1	**Concept 2**	△ Concept 1	**Concept 3**	△ Concept 1	**Concept 4**	△ Concept 1
Case 1	€332,657	€325,472	-2.16%	€322,915	-2.93%	€324,456	-2.47%
Case 2	€332,657	€315,468	-5.17%	€323,950	-2.62%	€325,516	-2.15%
Case 3	€552,003	€539.975,828	-2.18%	€534,276	-3.21%	€536,960	-2.72%

Table 6.12: Overview job rates per concept for fuel price increase of 20%

When fuel prices increase 20 %, concept 2 has even lower costs than the base case.

6.11.2. Scenario 2, HFO replaced by MGO

The fuel price is increased to €630,- per ton, the current price of MGO.

	Concept 1	**Concept 2**	V(con2-con1)	**Concept 3**	V(con2-con1)	**Concept 4**	V(con2-con1)
Case 1	€363,173	€354,674	-2.34%	€385,153	6.05%	€362,814	-0.10%
Case 2	€363,173	€342,356	-5.73%	€370,110	1.91%	€351.049	-3.34%
Case 3	€610,317	€596,093	-2.33%	€652,422	6.90%	€611,314	0.16%

Table 6.13: Overview job rates per concept for fuel is MGO

6.12. Conslusion

Fuel costs are the biggest costs and also cause big differences between the concepts. The building costs and the other costs linked to this do not differ that much. In the cases, where saving port time is used to sail slower, the use of a smart stabiliser has the lowest costs. The wider U-shape uses way more fuel, for this concept the time saved in ports does not compensate the increase in fuel costs. The V-shaped hull has almost equal costs and fuel consumption compared to concept 2. The V-hull can lift similar weights as al concepts without using a stabiliser. Concept 4 has an increase of deck space, which is a valuable property of a heavy lift ship.

The sensitivity analysis shows the increase of fuel prices has an impact on the cost differences between the concepts. The opportunity to sail slower, because they have more time to sail from A to B due to saved port days. Making these concepts ever more preferable with a increasing fuel price.

7

Conclusions and Recommendations

7.1. Conclusions

Jumbo is market leader in heavy lifts above the 1000 tonnes. Unique selling points for Jumbo's ships are that they are relative short compared to competitors, maximum of 150 meters, and the draft of the ship is small, making it possible to reach more areas than ships with a higher draft. It is not known in how many lifting operations Jumbo uses stabilisers. By using a stabiliser the ship's stability increases, good stability is required during lifting. Using a stabiliser also has some downsides, operationally and safety wise. Regarding operations it takes some time to install the stabiliser in which the cranes cannot perform any other tasks because they are busy with installing the stabiliser. Regarding safety, if a stabiliser rises above the water or is fully under water it looses its function. This can be caused by waves, which are created by other ships passing by. So by insuring a safe use of the stabiliser, ports or parts of a port need to be closed during installation. Which is not preferred, due to high costs and impact.

Other options to enable a stable ship are the usage of smart stabiliser, these stabiliser do not require any cranes while installing, so called: ramp, float-on float-off and turn-in turn- out stabilisers. Because they do not require to be installed by cranes using smart stabilisers saves a lot of time. However a downside is that these stabilisers are less flexible in storing. For port authorities smart stabilisers are still stabilisers, which are banned in some ports due to the safety issues. So other options to enable stability need to be looked at. In this case: widening the ship.

A model is created to be able to determine the required width for each concept. This model is generated based on the input and requirements set by literature, market analysis and Jumbo's specifications. Some of these requirements are: limited dimensions, minimum required stability, anti heeling and deadweight. The four concepts that are created as input for the model are:

- Base concept, concept 1: Current situation with the usage of stabilisers.
- Concept 2: Usages of **smart stabilisers** instead of the current stabilisers, this is the only thing that varies, the rest is equal to concept 1
- Concept 3: Wider ship with **U-shaped hull** that does not require use of stabilisers during lifting
- Concept 4: Wider ship with **V-shaped hull** that does not require use of stabilisers during lifting

The base case is the current J-type en recalculated to verify the model. Beside that the concept has all the assumptions and calculations methods equal to get a fair comparison. The required width for each concept is summed up:

- Concept 1: 25.98 meter
- Concept 2: 25.98 meter
- Concept 3: 28.97 meter

- Concept 4: 30.98 meter

Looking at the minimum day rate provides similar results for all concepts. There is not one concept that is outstanding cheap compared to the others. Looking more closely the fuel costs do differ per concept. Fuel costs is a big chunk of the total costs. Where as the building costs are more or less equal for each concept ,the fuel cost are really variable. Because concept 3 and 4 save time during lifting operations because they don't have to install a stabiliser to be able to lift they have more time to go from one job to the next. Therefore they can either sail at a lower speed and consume less fuel or take on more jobs and make time the ship is operational higher.
It can be concluded that the fuel savings as a result of slower sailing compensate the small increase of capital costs and the increase of fuel consumption cause by widening the hull.
If fuel prices rise concept 3 and 4 are more preferred because by adjusting the sailing speed the total operational costs can be influenced more than with the use of stabilisers like in concept 2.

To conclude, it is possible to operate without the usages of (smart) stabilisers without an increase of costs. It is even really likely that more jobs can be taken, due to safety related issues that are connected to the usage of smart stabilisers. Clients do seem to dislike stabilisers, because port authorities refuse the usages in their ports. The increase of deck space is a valuable characteristic in heavy lift industry.

If higher speeds are required, the V-shape will be more and more beneficial to the other concepts. Also for sailing at lower drafts, the V-shape is preferred.

7.2. Recommendations

Optimisation V-hull The V-hull is based on a U-shape and determined by parameters. It is useful to do more research to optimize the hull form. Also an analysis of ship motions for this concept is recommended. The width of the ship will result in higher accelerations on the ship. This has consequences for the lashing of cargo on board.

Fixed ballast can decrease width The width of the hull concepts is determined by the GM requirements. When fixed ballast is added in tank 3, like iron ore, the GM is going down and the weight of the cranes can me compensated. Iron ore has a weight per cubic meter which is 8 times the weight of water. The volume of required ballast decreases and the hull can be smaller. Disadvantage of fixed ballast is that it is difficult to remove and is always in the ship. The fixed ballast decreases the width but also the deadweight of the ship.

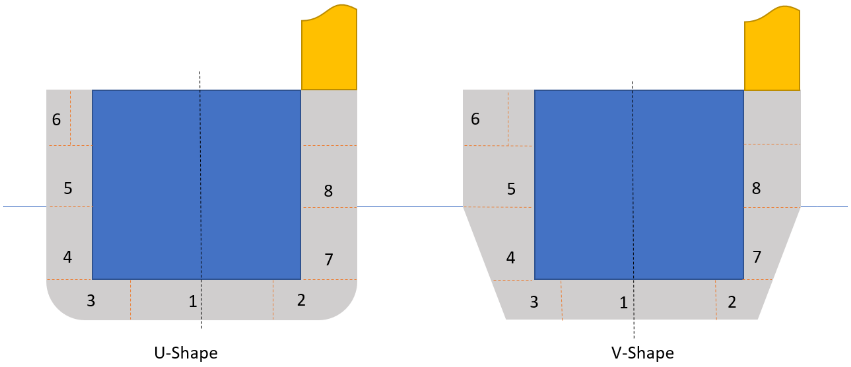


Figure 7.1: Layout ballast tanks

Analyse the inquiries to estimate the value of increased deck space The wider hull shapes can operate at lower costs, additional advantage is the large deck area, because the stabiliser does not have to be stored on deck and the ship is itself is wider. It is recommended to research what the actual added value is for this increased deck space, how many and what type of cargo can be executed with this type of ship. The total fleet of Jumbo becomes more versatile. Jobs that are now turned down because the deck space is too small can be picked up with the newly designed ships.

Think about fuel choice and propulsion systems Regulations for emissions are constantly being tightened. The life cycle of a ship is at least 20 years, so when designing ships it is important to look how the future evolves regarding the different regulations.

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A

Appendix A

J1800 Class

HLV Jumbo Jubilee

Call sign:	PBSA
IMO no.:	9371581
Port of registry:	Rotterdam
Flag:	Netherlands
Classification:	Lloyd's Register +100 A1 strengthened for heavy cargoes +LMC, UMS, CG, LI, IWS, with the descriptive note SCM and loading & unloading aground during crane operations, with hatchcovers omitted draught restricted to 7.5 m
Built:	2009
Owner:	Jumbo Jubilee N.V.
Charterers:	Kahn Special Transport B.V. Rotterdam
General agent:	Kahn Scheepvaart B.V. Rotterdam
Owners p.i. club:	Gard A.S. Arendal, Norway
Deadweight (summer) abt:	11,036 T (7.5 m) / 13,017 T (8.1 m) all told
Draft (above bottom of keel):	7.5 m (open condition) / 8.1 m
Length o.a.:	144.80 m
Beam o.a. (hull):	26.84 m
Air draft (above keel, jibs & derricks down):	47.32 m
G.T.:	15,012 T
N.T:	4,503 T
G.T. Suez Canal:	15,229.22 T
N.T. Suez Canal:	12,581.29 T
G.T. Panama:	
N.Y. Panama:	12,584 T
Number of holds:	1
Number of hatches:	1
Bale capacity (with tweendecks in holds) abt.:	18,130 m^3
Free deckspace abt.:	3,100 m^2
Hold: dimensions lowerhold:	82.70 x 17.00 x 5.65 m
Hold: dimensions tweendeck:	102.00 x 17.00 x 6.85 m
Hold: total height:	12.50 m
Strength of tanktop:	12.00 T/m^2
Strength of tweendecks:	7.00 T/m^2
Strength of hatchcovers:	5 x 8.7 T/m^2 + 3 x 12 T/m^2
Number of tweendecks:	1 (flush) adjustable in height
Cargo gear:	2 cranes each 900 T / combined 1,800 T Auxiliary hoist 2 x 37.5 T (traveling trolley) Manriding approved 2 x 10 T slinghandling hoist
Main engine(s):	2 x CPP/ME with MAK 9M32C engines (9,000 kW total)
Thrusters:	Bowthruster: Wartsila 1,500 kW
Speed about:	17.00 knots
Bunker capacity:	1,340 T HFO / 290 T MGO
Fresh water capacity:	140.00 T
No. insulated cargo spaces:	
No. cargo tanks:	
Container intake (sub weight):	192 FEU in hold w/o tweendeck hatchovers / 426 TEU

B

Appendix B

BACKGROUND KAHN-RULE 3
Minimum lifting stability of the K-type

MEMO no. : -
Revision : 0
Page : 1 of 2
Date : 05 Jun 2015

1. INTRODUCTION

This MEMO gives the background information how the minimum lifting stability for the K-type is obtained, as presented in memo: E-2014-003 “Minimum lifting stability K-Type “Kahn-Rule-3”.

2. METHOD

This chapter describes the method used to obtain the Kahn-rule 3 step by step.

2.1 Initial proposal

The initial Kahn-rule 3 proposal was based on two criteria:

1. When moving the crane tip (s) 0.5 meter in transverse direction the heel of the vessel may not exceed 1 degree.
2. With the pumps running at full capacity for 30 seconds the heel of the vessel may not exceed 1 degree

The minimum G’M value following from these criteria is obtained with:

$$G'M = \frac{\left(\frac{M_x}{\Delta}\right)}{\sin(\alpha)}$$

In which:

G’M = Transverse metacentric height (GM) corrected for free surface effects [m]
M_x = Moment around the x-axis [t*m]
Δ = Displacement [t]
α = Heel of the vessel [degree]

For the criteria, M_x can be calculated with:

1. Moving the load in the cranes 0.5m in transverse direction: $M_x = 0.5 * L$ (L = Load in both cranes together)
2. Pumps running at full capacity for 30 seconds:
   a. Pump capacity = 2900 t/hr
   b. Distance from PS to SB tanks = 22.3 m
   c. $M_x = \left(\frac{2900}{120}\right) 22.3 \approx 540tm$

This resulted in two formula for the minimum lifting stability:

1. $G'M = \frac{L \times A}{\Delta}$
   a. The factor A is calculated with:

   $$A = \frac{1}{\sin(1)} \cdot 0.5 \approx 28.65$$

   b. So the formula becomes:

   $$G'M = \frac{L \times 28.65}{\Delta}$$

2. $G'M = \frac{B}{\Delta}$
   a. The factor B is calculated with:

   $$B = \frac{540}{\sin(1)} \approx 30941$$

   b. So the formula becomes:

   $$G'M = \frac{30941}{\Delta}$$

2.2 Test-lift

In order to check if the proposed criteria which resulted in the initial kahn-rule gives sufficient stability during lifting, a test-lift of 3002t is performed.

The test-lift was started with a G'M according to the initial Kahn-rule and during the test-lift the G'M was reduced. With a G'M of 2.95m and a displacement of 23723 ton the crew had still sufficient trust and confident in the stability of the vessel.

By using these values in formula 1 of the initial Kahn-rule the new factor (A) of formula 1 can be found:

$$G'M = \frac{L \times A}{\Delta}$$

$$A = \frac{G'M \cdot \Delta}{L} = \frac{2.95 \cdot 23723}{3002}$$

$$A \approx 23.31$$

This factor (A) is rounded up to 23.5.

This factor is equal to an allowable heeling angle of 1.22 degrees for criteria 1 and 2:

$$\alpha = \operatorname{asin}\left(\frac{1}{\left(\frac{A}{0.5}\right)}\right) \approx 1.22$$

So the factor (B) for the second formula which represent the 30min pumping at full capacity becomes:

$$B = \frac{540}{\sin(1.22)} \approx 25362$$

This factor (B) is rounded up to 25500.

3. KAHN-RULE 3

By adjusting the initial Kahn-rule with the results of the test-lifts the Kahn-rule 3 becomes:

$G'M_{min} = \frac{L \times 23.5}{\Delta}$, or $G'M_{min} = \frac{25500}{\Delta}$ whichever is more.

C

Appendix C

C.1. Stability

Stability is important for ships, when stability is incorrect, the ship is un-usable as a ship. For heavy lifting operations on ships, stability is more important, because the heavy loads in the ships or hoisting by cranes changes stability parameters. From now the characteristics of ship stability will be described and explained according to[Stokoe, 1991]

In figure C.1 the general axes convention for ships is showed. A ship has 6 degrees of freedom. Three translational motions in X, Y and Z direction and three rotational motions around the three axes. In table C.1 the names of the six different motions are presented.

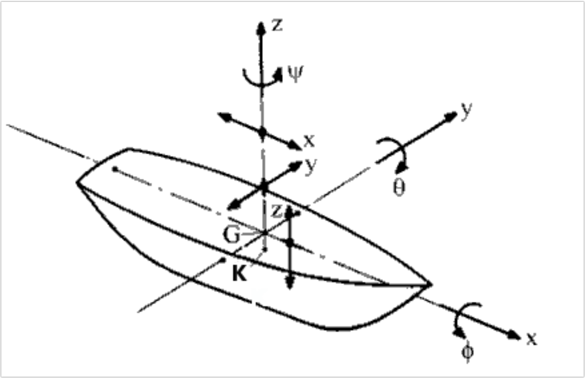


Figure C.1: Reference axes ship

Direction	**Motion**
X	Sway
Y	Surge
Z	Heave
Φ	Roll
Θ	Pitch
Ψ	Yaw

Table C.1: Degrees of Freedom

C.1.1. Centre of Buoyancy and Centre of Gravity

A ship is a floating object. An object floats because there is an equilibrium between the forces downwards and upwards. The forces downwards are caused by the weight of the ship, the forces upwards are caused by the water against the surface of the ship under the waterline.

The centre of buoyancy (COB) is an imaginary point in the under water part of the hull of the ship. This point is the centre of gravity of the part of the ship below the waterline. In the same way as described the centre of buoyancy , there can also described an imaginary point for the resulting downward forces. This point is called centre of gravity (COG). This point is the centre of gravity of the whole system. In figure C.2 a midship section is shown. The B gives the centre of buoyancy and the G gives the centre of gravity.

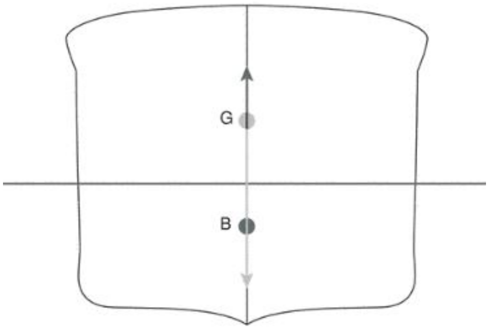


Figure C.2: Centre of buoyancy and centre of gravity

The centre of buoyancy and the centre of gravity are described by using a 3-dimensional coordinate system. The lowest part of the ship is the keel, indicated with the letter K. In this way there are two vertically distances for centre of buoyancy KB and centre of gravity KG. The two centres will be also described in longitudinally and transversely direction. In figure C.3 the centre of buoyancy is described by means of KB, LCB and TCB.

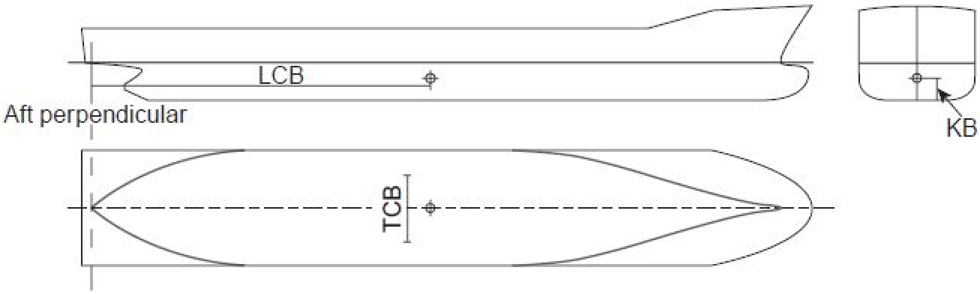


Figure C.3: Centre of buoyancy

C.1.2. KG value and loadings

The KG value is the distance between the keel (K) en the centre of gravity (G). Assumed is the place of K and G is on midship. When the place of G deviates from the midship-axis, the ship will be incline. To prevent a ship inclining by a weight it can be compensated with ballast loads. The KG value is determined for a lightship situation. The lightship situation is determined by the weight of the ship itself including engines and needed equipment. When there are loadings on a ship the centre of gravity will be changed. Loadings can be proposed for example as fuel mass, crew and cargo mass. The new KG value can be found by determining all vertical moments for every individual mass. The vertical moment is multiply the individually mass and the individually KG. The sum of al vertical moments divided by the total mass gives the KG for a loaded situation.

$$\text{Overall KG after loading} = \frac{\text{Total vertical moment}}{\text{Total mass}} \tag{C.1}$$

When a mass is suspended by a crane the centre of gravity of the suspended mass do not act on the actual point of the mass. The centre of gravity is where the mass is suspended by the crane. The crane tip is the centre of gravity when the mass is free in the air and only connected by a hoisting cable.
The KG value is measured in vertical direction. The centre of gravity can be also changed in longitudinal and transverse direction. When a mass is moved in the ship, formula C.2 shows a general formula for change in centre of gravity in a certain direction.

$$\text{Change in G} = \frac{w * \text{Distance moved}}{\triangle} \tag{C.2}$$

Where w is the weight of the load in tonnes which is moved over a certain distance in metres. △ is the displacement of the ship in tonnes, including the moved mass.

C.1.3. Metacentre

When a ship is exactly upright, G and B are on the centreline, see figure C.2. The force in G downwards is equal to the force in B upwards. That is the reason the vessel floats. If the ship rolls, the location of the centre of buoyancy will be changed. In that case the mass of the ship and the mass of loads do not change. So, the coordination of the centre of gravity stays the same. The underwater volume of the vessel do not changes too, because there is no change in weight. In figure C.4 the situation by roll is shown. In the roll situation there can designated a new point. From point B vertical upwards is an intersection with the centreline. This point is called the metacentre (M). The position is dependent on the width of the ship and the position of B [Jumbo Maritime].

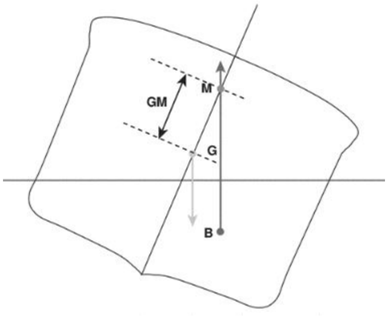


Figure C.4: Location of metacentre

The **initial stability** of a ship is measured by the distance between centre of gravity and metacentre along the ships centreline.
A ship is stable when M is above G. When G is above M the ship is unstable and if G and M are on the same location the ship is neutral. In figure C.5 the three situations are illustrated. When the GM is positive and the ship is stable, the ship will roll back in upright position when she is inclined.

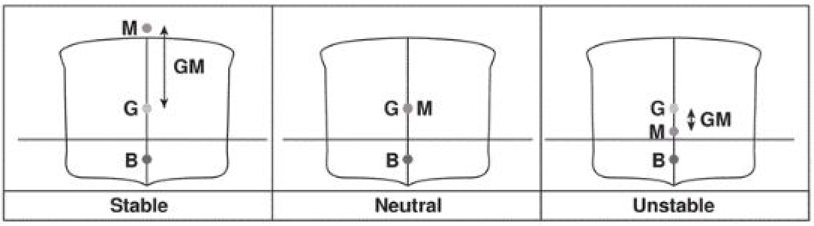


Figure C.5: Three different GM situations

C.1.4. Initial stability

To determine the stability of the ship, the locations of the variables must be determined. On the basis of the pictures above it is possible to find formulas to determine the distance from G to M. For a box shaped vessel, it is possible to make an easy calculation. Most ships has more complex hull shapes. The values can be determined by doing more extensive calculations or by using specialised software. The general formula to find GM is formula C.3

$$GM = KM - KG = KB + BM - KG \tag{C.3}$$

Every term can be calculated by characteristics of the ship. The KB is simplified for a box shaped vessel. For a more complex hull, the B can be determined once for different drafts and used as long as the the ship itself is not adjusted. In formula C.4 D is draft of a box shaped vessel.

$$KB = \frac{D}{2} \tag{C.4}$$

A ship has a more complex hull form than a simple box. To more accurately approach the KB value formula C.5 can be used [Munro-Smith, 1957].

$$KB = \frac{C_{w,0}}{C_{w,0} + C_{b,0}} \cdot D \tag{C.5}$$

- $C_{w,0}$ = Waterline area coefficient at design draft
- $C_{b,0}$ = Block coefficient at design draft
- D = Draft

This formula is based on the assumption the ratio between waterline area coefficient and block coefficient is constant for each depth. By means of this method the KB can be determined for each depth when the waterline area coefficient and block coefficient are known for one specific depth.

For BM the moment of inertia (transverse) is needed. Formula C.7 gives the equation. L_{pp} is the ship length and B is beam. In formula C.6 ∇ is under water volume of the hull. This value is changed by changing the depth of trim of the ship.

$$BM = \frac{I_t}{\nabla} \tag{C.6}$$

$$I_t = \frac{LB^3}{12} \tag{C.7}$$

As shown in this paragraph each change in a design affects the stability. Variations in dimensions, weights and locations of ship components, tanks and equipment affect stability immediately.

C.2. Parallel-Axis Theorem

To increase stability the GM must be increased. Because the width in formula C.7 is cubed it has the most influence in the formula. By using a stabiliser, the beam of the ship will be expanded. To involve the moment of inertia of the stabiliser, the Parallel Axis Theorem can be used [Hibbeler, 2007]. Also known as the Steiner Theorem. The formula determines the added moment of inertia corrected for the distance that is deviated from the symmetry axis of the ship.

$$I_x = \bar{I}_{x'} + Ad_y^2 \tag{C.8}$$

- d_y = Distance to combined tipping centre
- A = Surface of added stabiliser
- $\bar{I}_x$ = Moment of inertia of stabiliser

C.3. Rolling period

When a ship is set in motion by a external force the ship can get in motion around the x-axis, roll-motion. The rolling period is affected by GM and B. According to J. Pinkster [Pinkster, 2006] the rolling period can be approximated for small rolling angles and bigger rolling angles separate. For small rolling angles formula C.9 is given. To analyse the rolling motion is not necessary for operations in still water. It is useful to consider what the consequences are for rolling periods and accelerations during sailing on sea when the hull shape changes.

$$T_\varphi = \frac{2\pi k_\varphi}{\sqrt{g * GM}} \tag{C.9}$$

In this formula is k_φ is for each ship specifically and can be determined by formula C.10. A typical value for cargo ships is $k_\varphi = 0.38$ B. Where B is ship beam. In table C.2 typical k_φ values are given per ship type. The ’g’ is the gravitational acceleration and GM is ship specific and changed by different loadings and ballast. GM must be positive to have a stable ship as described in section C.1.3. Formula C.9 shows the GM value can influence the rolling period and a higher GM induces a shorter rolling period.

$$k_\varphi^2 = \frac{I_\varphi}{\rho * \nabla} \tag{C.10}$$

Ship type	k_φ
Cargo- & Passenger vessels	0.35 - 0.45 B
Sailing yacht	0.55 - 0.65 B
Pontoons	0.45 - 0.55 B

Table C.2: Typical k_φ values

An approximation for larger rolling angles is given by formula C.11. This approximation is suitable in waves. In this formula an angle is added, φ_a. φ_a gives the angle how much the ship is rotated around the x-axis.

$$\frac{T}{T_\varphi} = \frac{1}{\sqrt{1 + \frac{3*BM}{8*GM}\varphi_a^2}} \tag{C.11}$$

In this formula T_φ is the rolling period for small angles. GM and BM are ship and situation dependent. Figure **??** shows the change in rolling period for various GM and different ship beam. A wider ship leads to a longer rolling period for the same GM. If a hull shape is making wider, the GM is going up and results in shorter rolling periods.

To determine accelerations for a point on a certain place on board, for example a crane tip or the bridge, the rolling period is converted to angular velocity, ω by formula C.12 in rad/s.

$$\omega = \frac{2 * \pi}{T_\varphi} \tag{C.12}$$

To say more about accelerations a simple harmonic motion is used and described in formula C.13.

$$\varphi = \varphi_a * cos(\omega * t) \tag{C.13}$$

To determine the accelerations at a specific point above G, the distance in height between G and the specific point must be multiplied by the rotational acceleration of point G. Formula C.14 shows the acceleration

$$a_p = \ddot{\varphi} * h = -h * \varphi_a * \omega^2 * cos(\omega t) \tag{C.14}$$

The formula shows the smaller the period, the greater the accelerations and large accelerations induce great forces on deck structures and lashings by Newton Second Law.

C.4. Resistance

Resistance consists of different components of resistance. Figure C.6 shows the resistance is divided.

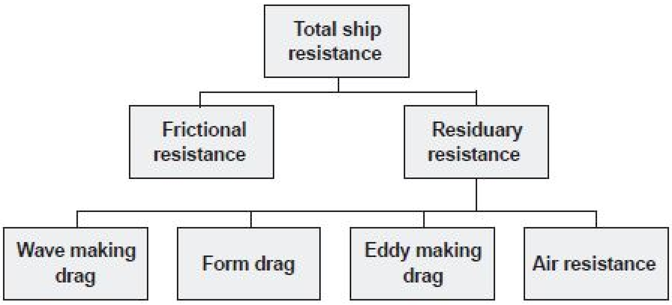


Figure C.6: Resistance components [Patterson und Ridley, 2014]

Figure C.7 shows how frictional resistance and residual resistance are divided. Wave making drag is the biggest part of residual resistance. By higher velocities the wave making drag induces most resistance.

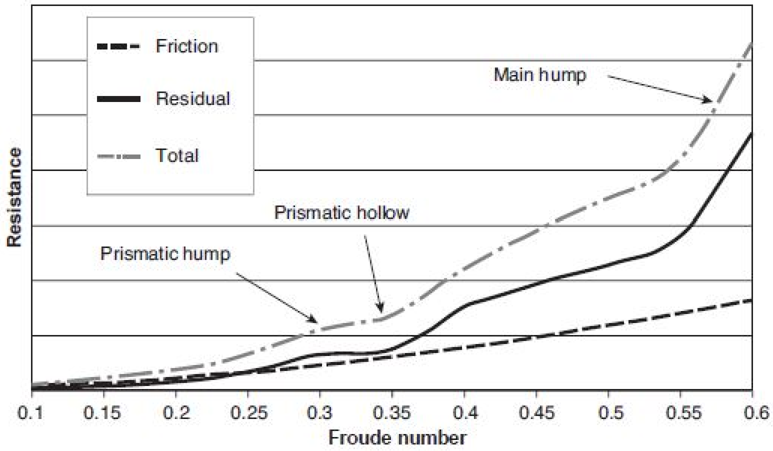


Figure C.7: Resistance Components

C.5. Froude number and Economical speed

The Froude number is a non-dimensional number and gives a relation between velocity and length of the ship. Equation C.15 shows the formula.

$$F_n = \frac{V}{\sqrt{gL}} \tag{C.15}$$

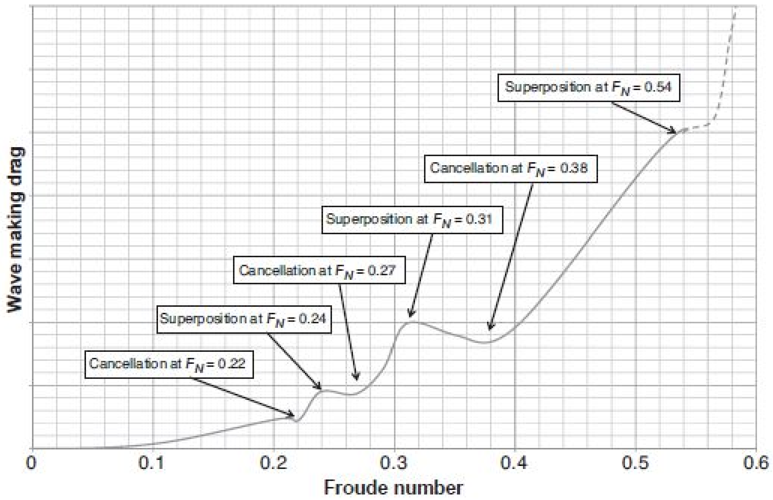


Figure C.8: Froudenumber vs. wave making drag (exaggerated)

Figure C.8 shows the relation between the Froude number and the resistance. The figure is exaggerated, so that humps and hollows are more visible. For example, the Froude number is 0.24, it is more economical to increase the Froude number to 0.27. Assuming the length of the vessel stays equal, the velocity increases. The resistance decreases and the fuel consumption is lower.

C.6. Resistance prediction methods

To predict the resistance of a ship, there are various methods to determine the expected resistance for several velocities or drafts. The methods can be divided into three types [Patterson und Ridley, 2014];

- Model tests
- Numerical estimation
- Empirical method

For this research model tests and numerical estimation are not suitable. In the early design stage of a ship, an empirical method gives a good indication of the resistance.

C.6.1. Empirical Methods

Empirical methods are based on data. Data from standard series or data of existing ships have been used for regression[Patterson und Ridley, 2014]. Holtrop & Mennen is a method based on regression analysis and published in 1982 [Holtrop und Mennen, 1982]. The resistance is built up from different types of resistance. The method is based on data series and test results collect of other ships. This method is useful in a early design stage for a ship.

$$R_{total} = (1+k)R_f + R_w + R_{app} + R_b + R_{TR} + R_a \tag{C.16}$$

- R_f = Frictional Resistance
- $(1+k)$ = Form Factor
- R_w = Wave-making and wave-breaking resistance
- R_{app} = Resistance of appendages
- R_b = Additional pressure resistance of bulbous bow near the water surface
- R_{TR} = Additional pressure resistance of immersed transom stern
- R_a = Model-ship correlation resistance

For all these parameters formulas are described by Holtrop & Mennen. Design programs like PIAS makes an estimation for resistance by using this method.

C.7. Specific fuel consumption

After determining the resistance of a ship, it is useful to know how much fuel is required to overcome the resistance. It is important to calculate operational costs and corresponding emissions. To calculate the fuel consumption for a known resistance, it is important to know the losses in the drive system. The fuel in the engine is not fully converted into mechanical energy. In the gearbox after the engine and the shaft to the propeller are also losses. The energy that reaches the propeller is not completely transformed into propulsive forces, here too a part of the energy is lost. A relevant measure to describe fuel consumption is the 'specific fuel consumption' (sfc) [Klein Woud und Stapersma, 2002]. The sfc expresses how many grams of fuel is needed to get 1 kWh from the engine. Equation C.17 shows the sfc in grams per kilo Watt hour.

$$sfc = \frac{3600000 * \dot{m}_f}{P_B} = \frac{3600000}{\eta_e * h^L} [g/kWh] \tag{C.17}$$

- P_B = Brake power in kW
- $\dot{m}_f$ = mass flow fuel in kg/s
- η_e = Engine efficiency
- h^L = Nominal lower heating value in kJ/kg

To calculate the fuel consumption for a known resistance, it is important to know the losses in the drive system. The fuel in the engine is not fully converted into mechanical energy. In the gearbox after the engine and the shaft to the propeller are also losses. The energy that reaches the propeller is not completely transformed into propulsive forces, here too a part of the energy is lost.

Typical efficiency range for a diesel engine η_e = 0.38-0.52 and the value for nominal lower heating value for HFO is 42.500 kJ/kg [Klein Woud und Stapersma, 2002]. By this values the sfc is 160-220 g/kWh.

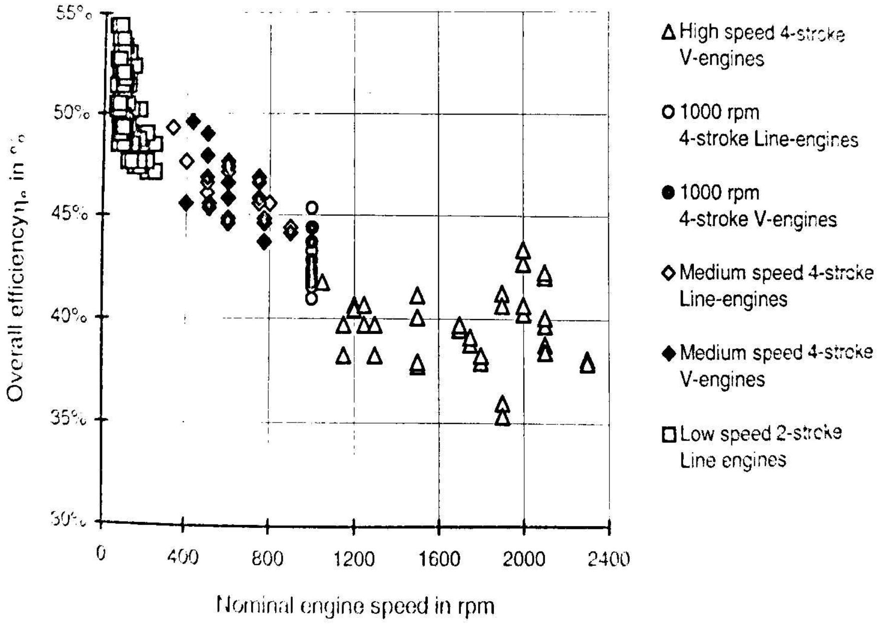


Figure C.9: Engine efficiencies [Klein Woud und Stapersma, 2002]

Parameter η_d is the propulsive efficiency and is a combination of hull efficiency η_H, propeller efficiency η_O and relative rotative efficiency η_R. To transport power from engine to propeller a shaft and gearbox are used and this equipment also have losses. Table C.3 shows typical values to determine fuel consumption when ship resistance is known.

	value	unit
Engine efficiency	0.38-0.52	
Nominal lower heating value	42.500	kJ/kg
Propulsive efficiency	0.65	
Gearbox efficiency	0.98	
Shaft efficiency	0.99	

Table C.3: Typical values used by calculating fuel consumption [Klein Woud und Stapersma, 2002]

C.8. Regulations: Loss of Hook Load

The IMO (International Maritime Organisation) introduce amendments to the code on intact stability 2008 [IMO, 2016]. The rules must apply to new-build vessels whose keel laying is after 1-1-2020. The most important amendment for heavy lifting is the 'sudden loss of hook load rule'. The rule is intended for lift operations where ballast water is pumped into ballast tanks during the operation to maintain stability. Figure C.10 in combination with table C.4 shows the rule.

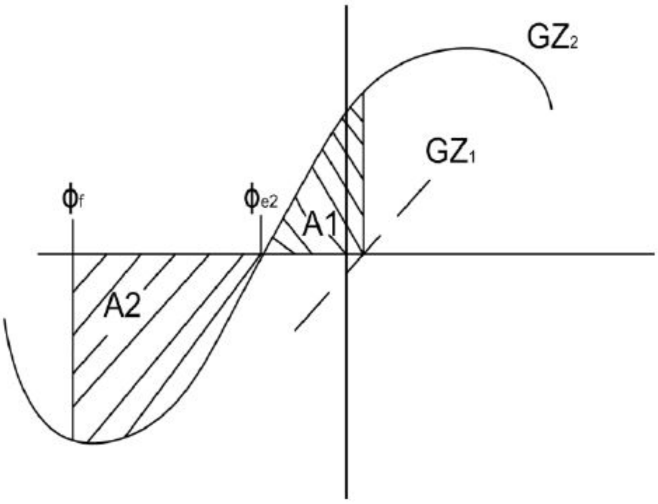


Figure C.10: Sudden loss of hook load rule

- GZ_1 = Net righting lever curve before loss of load
- GZ_2 = Net righting lever curve after loss of load
- ϕ_{e2} = Angle of static equilibrium after loss of load
- ϕ_f = Angle of down flooding

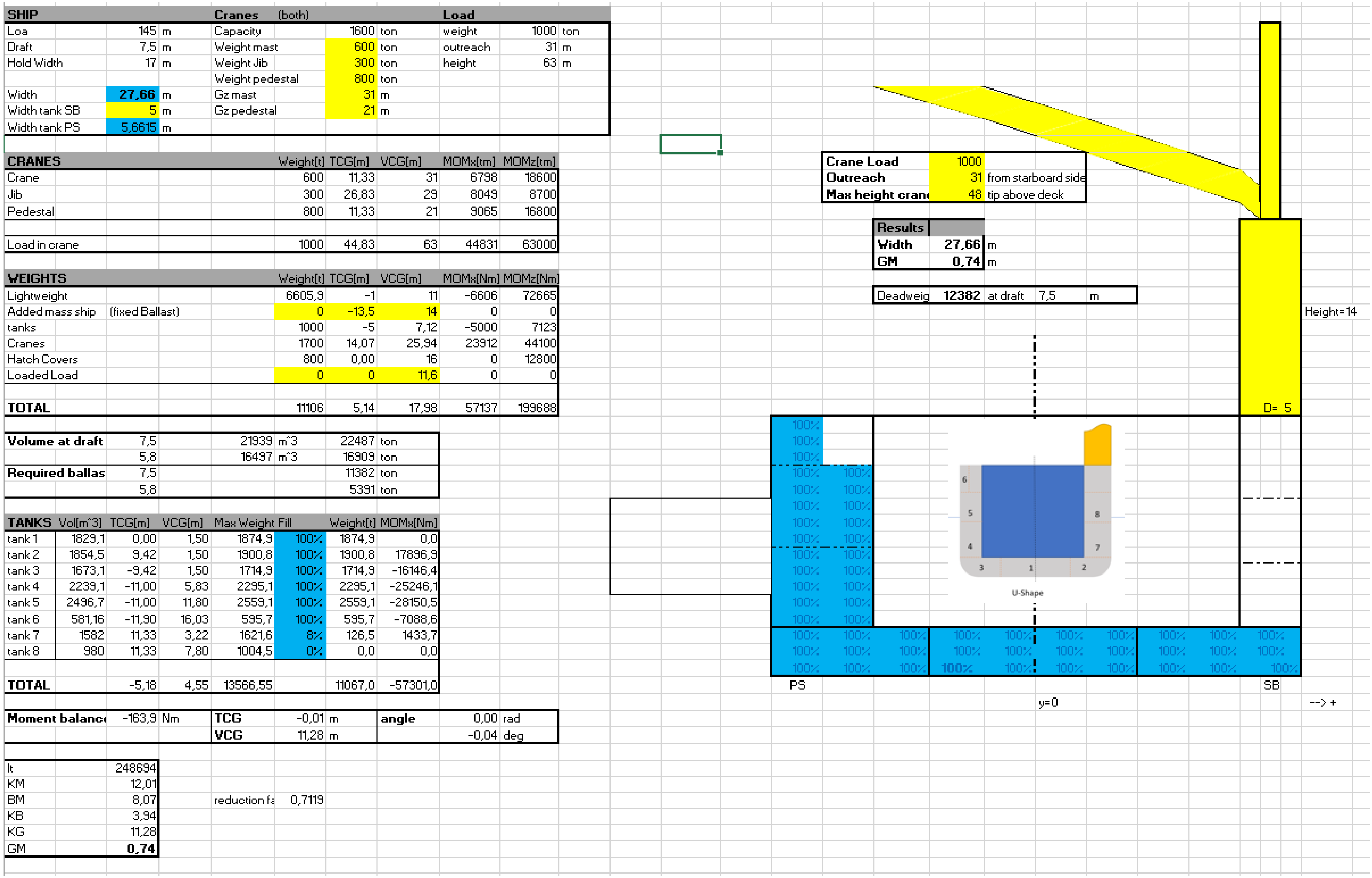
During a lifting operation ballast water being pumped in ballast tanks to keep ship in balance. By a sudden loss of hook load the ship will turning to the ballast side and shoot through the balance point of the ship. This is caused by the restoring energy, showed by area A1. In order to prevent the ship capsizing the potential energy, area A2, should be sufficient to compensate the restoring energy. A ratio is decided between the areas A1 and A2. Table C.4 gives these ratios for exposed and not exposed water.

	A2/A1
Exposed waters	1.4
Not exposed waters	1

Table C.4: Requirements

D

Appendix D



SHIP			Cranes	(both)		Load		
Loa	145	m	Capacity	1600	ton	weight	1000	ton
Draft	7,5	m	Weight mast	600	ton	outreach	31	m
Hold Width	17	m	Weight Jib	300	ton	height	63	m
			Weight pedestal	800	ton			
Width	27,66	m	Gz mast	31	m			
Width tank SB	5	m	Gz pedestal	21	m			
Width tank PS	5,6615	m						

CRANES	Weight[t]	TCG[m]	VCG[m]	MOMx[tm]	MOMz[tm]
Crane	600	11,33	31	6798	18600
Jib	300	26,83	29	8049	8700
Pedestal	800	11,33	21	9065	16800
Load in crane	1000	44,83	63	44831	63000

WEIGHTS		Weight[t]	TCG[m]	VCG[m]	MOMx[Nm]	MOMz[Nm]
Lightweight		6605,9	-1	11	-6606	72665
Added mass ship	(fixed Ballast)	0	-13,5	14	0	0
tanks		1000	-5	7,12	-5000	7123
Cranes		1700	14,07	25,94	23912	44100
Hatch Covers		800	0,00	16	0	12800
Loaded Load		0	0	11,6	0	0
TOTAL		11106	5,14	17,98	57137	199688

Volume at draft	7,5	21939	m^3	22487	ton
	5,8	16497	m^3	16909	ton
Required ballas	7,5			11382	ton
	5,8			5391	ton

TANKS	Vol[m^3]	TCG[m]	VCG[m]	Max Weight	Fill	Weight[t]	MOMx[Nm]
tank 1	1829,1	0,00	1,50	1874,9	100%	1874,9	0,0
tank 2	1854,5	9,42	1,50	1900,8	100%	1900,8	17896,9
tank 3	1673,1	-9,42	1,50	1714,9	100%	1714,9	-16146,4
tank 4	2239,1	-11,00	5,83	2295,1	100%	2295,1	-25246,1
tank 5	2496,7	-11,00	11,80	2559,1	100%	2559,1	-28150,5
tank 6	581,16	-11,90	16,03	595,7	100%	595,7	-7088,6
tank 7	1582	11,33	3,22	1621,6	8%	126,5	1433,7
tank 8	980	11,33	7,80	1004,5	0%	0,0	0,0
TOTAL		-5,18	4,55	13566,55		11067,0	-57301,0

Moment balanc	-163,9	Nm	**TCG**	-0,01	m	**angle**	0,00 rad
			VCG	11,28	m		-0,04 deg

It	248694
KM	12,01
BM	8,07
KB	3,94
KG	11,28
GM	**0,74**

reduction fa 0,7119

Crane Load	1000	
Outreach	31	from starboard side
Max height crane	48	tip above deck

Results		
Width	27,66	m
GM	0,74	m

Deadweig 12382 at draft 7,5 m

Figure D.1: Graphical overview of model to determine width

E

Appendix E

Viscous resistance

$$R_F = C_F \cdot \frac{\rho}{2} \cdot V^2 \cdot S \cdot (1+k) \tag{E.1}$$

Friction coefficient; According to ITTC 1957

$$C_F = 0.075/(logR_n - 2)^2 \tag{E.2}$$

Determination wetted surface

$$S_{total} = L(2T+B) \cdot \sqrt{C_M} \cdot (0.453 + 0.4425 \cdot C_B - 0.2862 \cdot C_M - 0.003467\frac{B}{T} + 0.3969 \cdot C_{WP}) \tag{E.3}$$

Residual resistance

$$R_R = C_R \cdot \frac{\rho}{2} \cdot V^2 \cdot \frac{B \cdot T}{10} \tag{E.4}$$

Coefficients for residual resistance for Hollenbach method. Figure E.1 gives coefficients they are required in the next formula's.

$$C_R = C_{R,Standard} \cdot C_{R,Fnkrit} \cdot k_L \cdot (T/B)^{b1} \cdot (B/L)^{b2} \cdot (L_{os}/L_{wl})^{b3} \cdot (L_{wl}/L)^{b4} \cdot (1+(T_A - T_F)/L)^{b5} \cdot (D_p/T_A)^{b6} \tag{E.5}$$

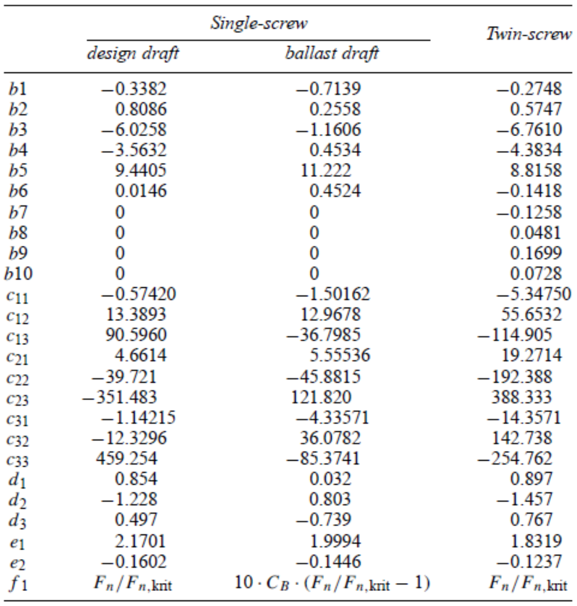
$$C_{R,Standard} = c_{11} + c_{12}F_n + c_{13}F_n^2 + C_B \cdot (c_{21} + c_{22}F_n + c_{23}F_n^2) + C_B^2 \cdot (c_{31} + c_{32}F_n + c_{33}F_n^2) \tag{E.6}$$

$$C_{R,Fnkrit} = max(1.0, (F_n/F_{n,krit})^{F_1}) \tag{E.7}$$

$$F_{n,krit} = d_1 + d_2 \cdot C_B + d_3 \cdot C_B^2 \tag{E.8}$$

$$k_L = e_1 \cdot L^{e_2} \tag{E.9}$$

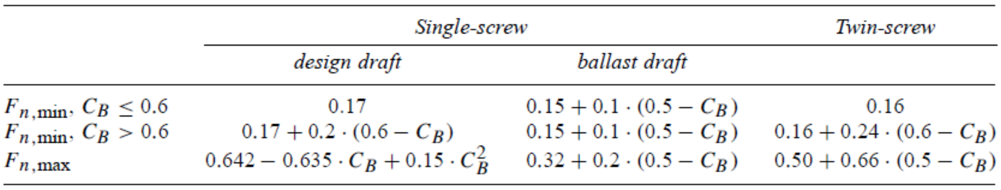
Coefficients to use in formula's to calculate residual resistance.



	Single-screw		Twin-screw
	design draft	ballast draft	
$b1$	−0.3382	−0.7139	−0.2748
$b2$	0.8086	0.2558	0.5747
$b3$	−6.0258	−1.1606	−6.7610
$b4$	−3.5632	0.4534	−4.3834
$b5$	9.4405	11.222	8.8158
$b6$	0.0146	0.4524	−0.1418
$b7$	0	0	−0.1258
$b8$	0	0	0.0481
$b9$	0	0	0.1699
$b10$	0	0	0.0728
c_{11}	−0.57420	−1.50162	−5.34750
c_{12}	13.3893	12.9678	55.6532
c_{13}	90.5960	−36.7985	−114.905
c_{21}	4.6614	5.55536	19.2714
c_{22}	−39.721	−45.8815	−192.388
c_{23}	−351.483	121.820	388.333
c_{31}	−1.14215	−4.33571	−14.3571
c_{32}	−12.3296	36.0782	142.738
c_{33}	459.254	−85.3741	−254.762
d_1	0.854	0.032	0.897
d_2	−1.228	0.803	−1.457
d_3	0.497	−0.739	0.767
e_1	2.1701	1.9994	1.8319
e_2	−0.1602	−0.1446	−0.1237
f_1	$F_n/F_{n,\text{krit}}$	$10 \cdot C_B \cdot (F_n/F_{n,\text{krit}} - 1)$	$F_n/F_{n,\text{krit}}$

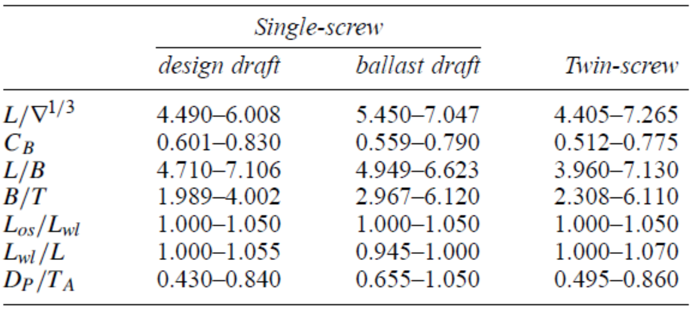
Figure E.1: Coefficients for Hollenbach method

Validation method of Hollenbach



	Single-screw		Twin-screw
	design draft	ballast draft	
$F_{n,\text{min}}$, $C_B \leq 0.6$	0.17	$0.15 + 0.1 \cdot (0.5 - C_B)$	0.16
$F_{n,\text{min}}$, $C_B > 0.6$	$0.17 + 0.2 \cdot (0.6 - C_B)$	$0.15 + 0.1 \cdot (0.5 - C_B)$	$0.16 + 0.24 \cdot (0.6 - C_B)$
$F_{n,\text{max}}$	$0.642 - 0.635 \cdot C_B + 0.15 \cdot C_B^2$	$0.32 + 0.2 \cdot (0.5 - C_B)$	$0.50 + 0.66 \cdot (0.5 - C_B)$

Figure E.2: Validity ranges for resistance, Hollenbach's method



	Single-screw		Twin-screw
	design draft	ballast draft	
$L/\nabla^{1/3}$	4.490–6.008	5.450–7.047	4.405–7.265
C_B	0.601–0.830	0.559–0.790	0.512–0.775
L/B	4.710–7.106	4.949–6.623	3.960–7.130
B/T	1.989–4.002	2.967–6.120	2.308–6.110
L_{os}/L_{wl}	1.000–1.050	1.000–1.050	1.000–1.050
L_{wl}/L	1.000–1.055	0.945–1.000	1.000–1.070
D_P/T_A	0.430–0.840	0.655–1.050	0.495–0.860

Figure E.3: Standard deviation for resistance, Hollenbach's method

Cb voor ballast draft [Munro-Smith, 1957]

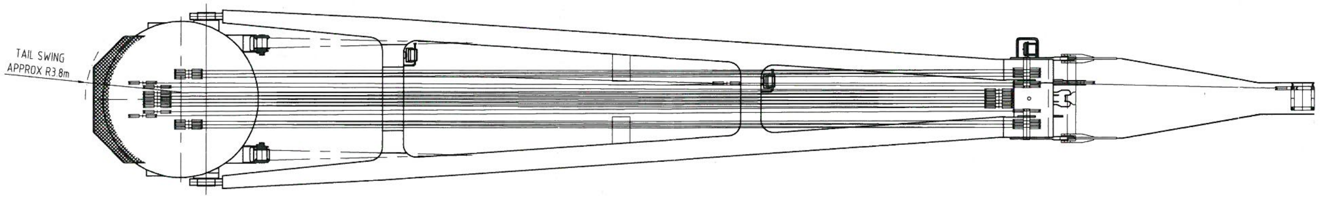
$$C_B = C_{B_0} \cdot (\frac{T}{T_0})^{(}(C_{wl_0}/C_{B_0}) - 1) \tag{E.10}$$

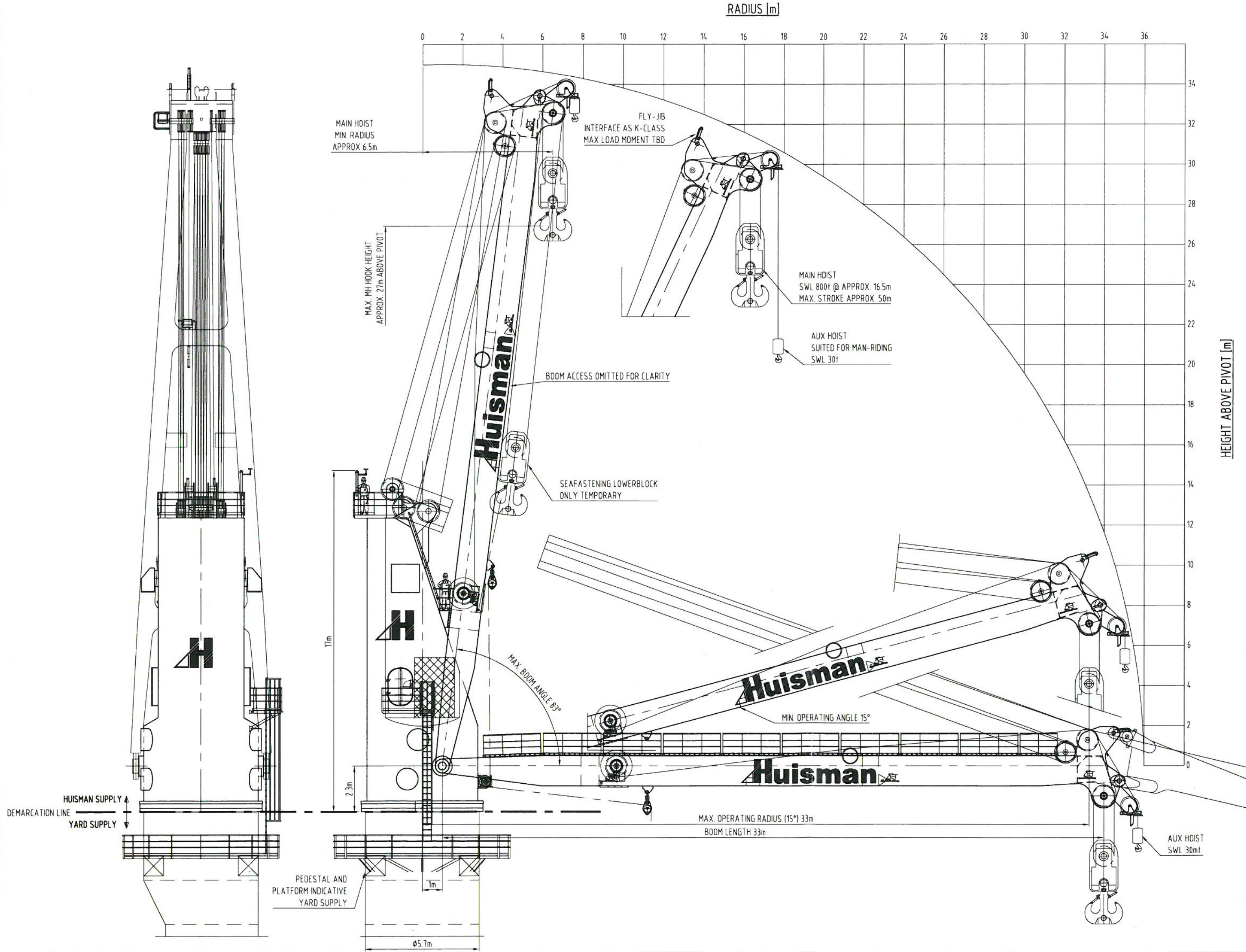
Form Factor

$$k = -0.095 + 25.6 \cdot \frac{C_B}{(\frac{L_{pp}}{B})^2 \cdot \sqrt{\frac{B}{T}}} \tag{E.11}$$

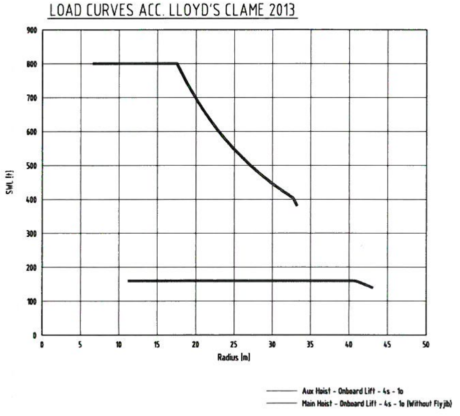
F

Appendix F





LOAD CURVES ACC. LLOYD'S CLAME 2013



D	T N I 28-10-'13	FOR INFO				
Rev.	Drawn Date	Description,	Proj. Hydr.	Bas.	Stru. Elect.	Det.

Issued for :
FOR INFORMATION ONLY

Proj. method	Scale :	Copy Date :
	1:100	08-11-2013

Notation	According	Tolerances	According
Dimensions Geometrics Roughness	ISO 406 ISO 1101 ISO 1302	Welding Cutting Machining Plate Thickness Castings	ISO 13920-AE DIN 2310-IA,IC,IG,IK ISO 2768-mK EN 10029 ISO 8062-CT11

Client :
JUMBO

Project :
800t HEAVY LIFT PEDESTAL CRANE

Title :
GENERAL ARRANGEMENT

Huisman
Huisman Equipment b.v.
Admiraal Trompstraat 2
3115 HH Schiedam, The Netherlands
Telephone : +31(0)10 245 22 22
Telefax : +31(0)10 245 22 20

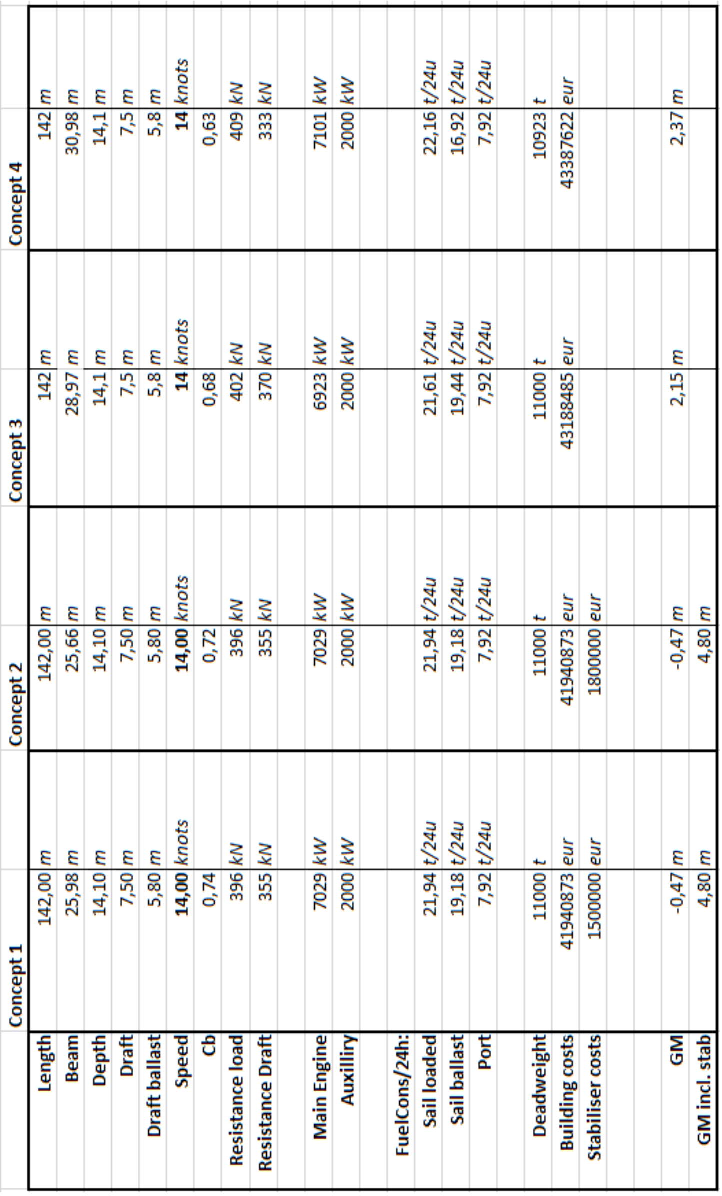
Format	Order No.	Drawingno.	Rev.
A1	A13-10370	A13-10370-30-01	D

Plotted: Friday 08-11-2013, 14:27 by: GRoks from system: SCH01-11-251M in city: Filename: J:\Quotations 13\A13-10370 JUMBO - 800mt HLPMC (4x)\Rev D - November 2013\A13-10370-30-01D GENERAL ARRANGEMENT.dwg

G

Appendix G

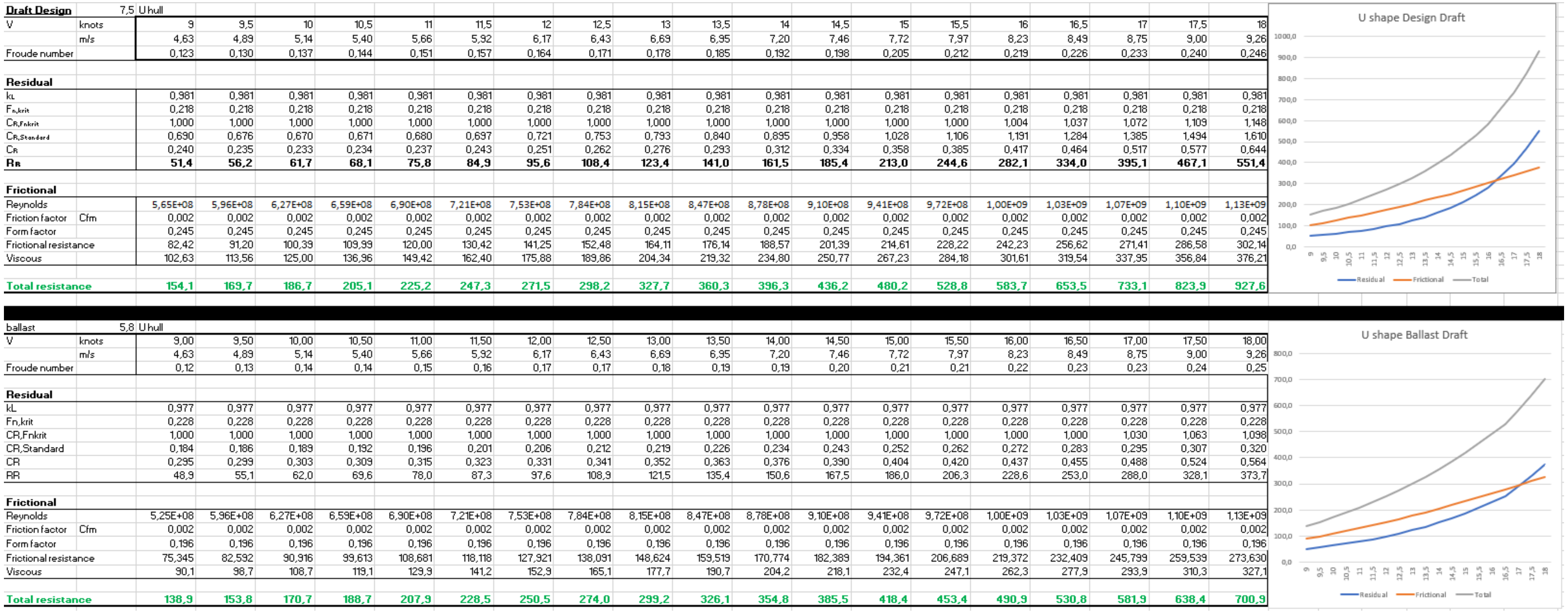
G.1. Overview concept characteristics



	Concept 1		Concept 2		Concept 3		Concept 4	
Length	142,00	*m*	142,00	*m*	142	*m*	142	*m*
Beam	25,98	*m*	25,66	*m*	28,97	*m*	30,98	*m*
Depth	14,10	*m*	14,10	*m*	14,1	*m*	14,1	*m*
Draft	7,50	*m*	7,50	*m*	7,5	*m*	7,5	*m*
Draft ballast	5,80	*m*	5,80	*m*	5,8	*m*	5,8	*m*
Speed	**14,00**	*knots*	**14,00**	*knots*	**14**	*knots*	**14**	*knots*
Cb	0,74		0,72		0,68		0,63	
Resistance load	396	*kN*	396	*kN*	402	*kN*	409	*kN*
Resistance Draft	355	*kN*	355	*kN*	370	*kN*	333	*kN*
Main Engine	7029	*kW*	7029	*kW*	6923	*kW*	7101	*kW*
Auxilliry	2000	*kW*	2000	*kW*	2000	*kW*	2000	*kW*
FuelCons/24h:								
Sail loaded	21,94	*t/24u*	21,94	*t/24u*	21,61	*t/24u*	22,16	*t/24u*
Sail ballast	19,18	*t/24u*	19,18	*t/24u*	19,44	*t/24u*	16,92	*t/24u*
Port	7,92	*t/24u*	7,92	*t/24u*	7,92	*t/24u*	7,92	*t/24u*
Deadweight	11000	*t*	11000	*t*	11000	*t*	10923	*t*
Building costs	41940873	*eur*	41940873	*eur*	43188485	*eur*	43387622	*eur*
Stabiliser costs	1500000	*eur*	1800000	*eur*				
GM	-0,47	*m*	-0,47	*m*	2,15	*m*	2,37	*m*
GM incl. stab	4,80	*m*	4,80	*m*				

Figure G.1: Overview concept characteristics

G.2. Resistance details

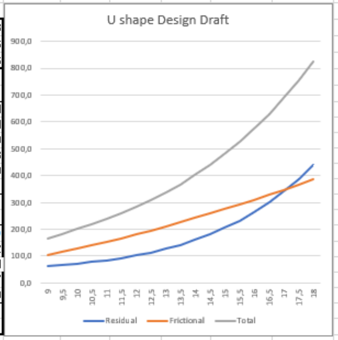


Draft Design	7,5	U hull																		
V	knots	9	9,5	10	10,5	11	11,5	12	12,5	13	13,5	14	14,5	15	15,5	16	16,5	17	17,5	18
	m/s	4,63	4,89	5,14	5,40	5,66	5,92	6,17	6,43	6,69	6,95	7,20	7,46	7,72	7,97	8,23	8,49	8,75	9,00	9,26
Froude number		0,123	0,130	0,137	0,144	0,151	0,157	0,164	0,171	0,178	0,185	0,192	0,198	0,205	0,212	0,219	0,226	0,233	0,240	0,246
Residual																				
k_L		0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981
$F_{n,krit}$		0,218	0,218	0,218	0,218	0,218	0,218	0,218	0,218	0,218	0,218	0,218	0,218	0,218	0,218	0,218	0,218	0,218	0,218	0,218
$C_{R,Fnkrit}$		1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,004	1,037	1,072	1,109	1,148
$C_{R,Standard}$		0,690	0,676	0,670	0,671	0,680	0,697	0,721	0,753	0,793	0,840	0,895	0,958	1,028	1,106	1,191	1,284	1,385	1,494	1,610
C_R		0,240	0,235	0,233	0,234	0,237	0,243	0,251	0,262	0,276	0,293	0,312	0,334	0,358	0,385	0,417	0,464	0,517	0,577	0,644
R_R		**51,4**	**56,2**	**61,7**	**68,1**	**75,8**	**84,9**	**95,6**	**108,4**	**123,4**	**141,0**	**161,5**	**185,4**	**213,0**	**244,6**	**282,1**	**334,0**	**395,1**	**467,1**	**551,4**
Frictional																				
Reynolds		5,65E+08	5,96E+08	6,27E+08	6,59E+08	6,90E+08	7,21E+08	7,53E+08	7,84E+08	8,15E+08	8,47E+08	8,78E+08	9,10E+08	9,41E+08	9,72E+08	1,00E+09	1,03E+09	1,07E+09	1,10E+09	1,13E+09
Friction factor	Cfm	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002
Form factor		0,245	0,245	0,245	0,245	0,245	0,245	0,245	0,245	0,245	0,245	0,245	0,245	0,245	0,245	0,245	0,245	0,245	0,245	0,245
Frictional resistance		82,42	91,20	100,39	109,99	120,00	130,42	141,25	152,48	164,11	176,14	188,57	201,39	214,61	228,22	242,23	256,62	271,41	286,58	302,14
Viscous		102,63	113,56	125,00	136,96	149,42	162,40	175,88	189,86	204,34	219,32	234,80	250,77	267,23	284,18	301,61	319,54	337,95	356,84	376,21
Total resistance		**154,1**	**169,7**	**186,7**	**205,1**	**225,2**	**247,3**	**271,5**	**298,2**	**327,7**	**360,3**	**396,3**	**436,2**	**480,2**	**528,8**	**583,7**	**653,5**	**733,1**	**823,9**	**927,6**

ballast	5,8	U hull																		
V	knots	9,00	9,50	10,00	10,50	11,00	11,50	12,00	12,50	13,00	13,50	14,00	14,50	15,00	15,50	16,00	16,50	17,00	17,50	18,00
	m/s	4,63	4,89	5,14	5,40	5,66	5,92	6,17	6,43	6,69	6,95	7,20	7,46	7,72	7,97	8,23	8,49	8,75	9,00	9,26
Froude number		0,12	0,13	0,14	0,14	0,15	0,16	0,17	0,17	0,18	0,19	0,19	0,20	0,21	0,21	0,22	0,23	0,23	0,24	0,25
Residual																				
kL		0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977
Fn,krit		0,228	0,228	0,228	0,228	0,228	0,228	0,228	0,228	0,228	0,228	0,228	0,228	0,228	0,228	0,228	0,228	0,228	0,228	0,228
CR,Fnkrit		1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,030	1,063	1,098
CR,Standard		0,184	0,186	0,189	0,192	0,196	0,201	0,206	0,212	0,219	0,226	0,234	0,243	0,252	0,262	0,272	0,283	0,295	0,307	0,320
CR		0,295	0,299	0,303	0,309	0,315	0,323	0,331	0,341	0,352	0,363	0,376	0,390	0,404	0,420	0,437	0,455	0,488	0,524	0,564
RR		48,9	55,1	62,0	69,6	78,0	87,3	97,6	108,9	121,5	135,4	150,6	167,5	186,0	206,3	228,6	253,0	288,0	328,1	373,7
Frictional																				
Reynolds		5,25E+08	5,96E+08	6,27E+08	6,59E+08	6,90E+08	7,21E+08	7,53E+08	7,84E+08	8,15E+08	8,47E+08	8,78E+08	9,10E+08	9,41E+08	9,72E+08	1,00E+09	1,03E+09	1,07E+09	1,10E+09	1,13E+09
Friction factor	Cfm	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002
Form factor		0,196	0,196	0,196	0,196	0,196	0,196	0,196	0,196	0,196	0,196	0,196	0,196	0,196	0,196	0,196	0,196	0,196	0,196	0,196
Frictional resistance		75,345	82,592	90,916	99,613	108,681	118,118	127,921	138,091	148,624	159,519	170,774	182,389	194,361	206,689	219,372	232,409	245,799	259,539	273,630
Viscous		90,1	98,7	108,7	119,1	129,9	141,2	152,9	165,1	177,7	190,7	204,2	218,1	232,4	247,1	262,3	277,9	293,9	310,3	327,1
Total resistance		**138,9**	**153,8**	**170,7**	**188,7**	**207,9**	**228,5**	**250,5**	**274,0**	**299,2**	**326,1**	**354,8**	**385,5**	**418,4**	**453,4**	**490,9**	**530,8**	**581,9**	**638,4**	**700,9**

Figure G.2: Detailed resistance determination for concept 1 and 2

Draft Design	7,5	U hull																		
Velocity	knots	9	9,5	10	10,5	11	11,5	12	12,5	13	13,5	14	14,5	15	15,5	16	16,5	17	17,5	18
	m/s	4,63	4,89	5,14	5,40	5,66	5,92	6,17	6,43	6,69	6,95	7,20	7,46	7,72	7,97	8,23	8,49	8,75	9,00	9,26
Froude number		0,123	0,130	0,137	0,144	0,151	0,157	0,164	0,171	0,178	0,185	0,192	0,198	0,205	0,212	0,219	0,226	0,233	0,240	0,246
Residual																				
k_L		0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981
$F_{n,krit}$		0,251	0,251	0,251	0,251	0,251	0,251	0,251	0,251	0,251	0,251	0,251	0,251	0,251	0,251	0,251	0,251	0,251	0,251	0,251
$C_{R,Fnkrit}$		1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
$C_{R,Standard}$		0,656	0,635	0,619	0,609	0,604	0,606	0,614	0,627	0,647	0,672	0,703	0,740	0,783	0,831	0,886	0,946	1,013	1,085	1,163
C_R		0,259	0,251	0,244	0,240	0,239	0,239	0,242	0,248	0,255	0,265	0,277	0,292	0,309	0,328	0,350	0,374	0,400	0,428	0,459
R_R		**61,9**	**66,6**	**72,0**	**78,1**	**85,1**	**93,3**	**102,8**	**114,0**	**127,1**	**142,5**	**160,3**	**181,0**	**204,9**	**232,4**	**263,9**	**299,8**	**340,6**	**386,7**	**438,5**
Frictional																				
Reynolds		5,65E+08	5,96E+08	6,27E+08	6,59E+08	6,90E+08	7,21E+08	7,53E+08	7,84E+08	8,15E+08	8,47E+08	8,78E+08	9,10E+08	9,41E+08	9,72E+08	1,00E+09	1,03E+09	1,07E+09	1,10E+09	1,13E+09
Friction factor	Cfm	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002
Form factor		0,271	0,271	0,271	0,271	0,271	0,271	0,271	0,271	0,271	0,271	0,271	0,271	0,271	0,271	0,271	0,271	0,271	0,271	0,271
Frictional resistance		82,98	91,81	101,06	110,73	120,81	131,30	142,20	153,50	165,21	177,32	189,84	202,75	216,05	229,76	243,86	258,35	273,23	288,51	304,17
Viscous		105,48	116,72	128,48	140,77	153,58	166,92	180,77	195,15	210,03	225,43	241,33	257,75	274,66	292,09	310,01	328,43	347,36	366,77	386,69
Total resistance		**167,3**	**183,4**	**200,5**	**218,8**	**238,7**	**260,2**	**283,6**	**309,2**	**337,2**	**367,9**	**401,6**	**438,7**	**479,6**	**524,5**	**573,9**	**628,3**	**688,0**	**753,4**	**825,2**



ballast	5,8	U hull																		
Velocity	knots	9,00	9,50	10,00	10,50	11,00	11,50	12,00	12,50	13,00	13,50	14,00	14,50	15,00	15,50	16,00	16,50	17,00	17,50	18,00
	m/s	4,63	4,89	5,14	5,40	5,66	5,92	6,17	6,43	6,69	6,95	7,20	7,46	7,72	7,97	8,23	8,49	8,75	9,00	9,26
Froude number		0,12	0,13	0,14	0,14	0,15	0,16	0,17	0,17	0,18	0,19	0,19	0,20	0,21	0,21	0,22	0,23	0,23	0,24	0,25
Residual																				
kL		0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977
Fn,krit		0,241	0,241	0,241	0,241	0,241	0,241	0,241	0,241	0,241	0,241	0,241	0,241	0,241	0,241	0,241	0,241	0,241	0,241	0,241
CR,Fnkrit		1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,028
CR,Standard		0,175	0,175	0,176	0,177	0,179	0,181	0,184	0,188	0,192	0,197	0,202	0,208	0,215	0,222	0,230	0,239	0,248	0,257	0,268
CR		0,313	0,313	0,314	0,316	0,319	0,324	0,329	0,335	0,343	0,352	0,361	0,372	0,384	0,397	0,411	0,426	0,442	0,460	0,491
RR		57,7	64,3	71,5	79,4	88,0	97,5	108,0	119,5	132,1	146,1	161,5	178,4	197,0	217,4	239,8	264,4	291,3	320,7	362,8
Frictional																				
Reynolds		5,25E+08	5,96E+08	6,27E+08	6,59E+08	6,90E+08	7,21E+08	7,53E+08	7,84E+08	8,15E+08	8,47E+08	8,78E+08	9,10E+08	9,41E+08	9,72E+08	1,00E+09	1,03E+09	1,07E+09	1,10E+09	1,13E+09
Friction factor	Cfm	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002
Form factor		0,216	0,216	0,216	0,216	0,216	0,216	0,216	0,216	0,216	0,216	0,216	0,216	0,216	0,216	0,216	0,216	0,216	0,216	0,216
Frictional resistance		75,836	83,130	91,508	100,262	109,389	118,887	128,755	138,991	149,592	160,558	171,887	183,577	195,627	208,036	220,802	233,924	247,400	261,231	275,413
Viscous		92,2	101,1	111,2	121,9	133,0	144,5	156,5	169,0	181,9	195,2	209,0	223,2	237,8	252,9	268,4	284,4	300,8	317,6	334,8
Total resistance		**149,9**	**165,4**	**182,8**	**201,3**	**221,0**	**242,1**	**264,5**	**288,4**	**314,0**	**341,3**	**370,4**	**401,5**	**434,8**	**470,3**	**508,3**	**548,8**	**592,1**	**638,3**	**697,7**

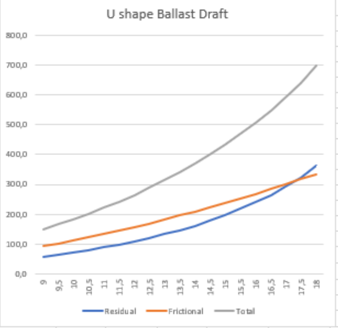
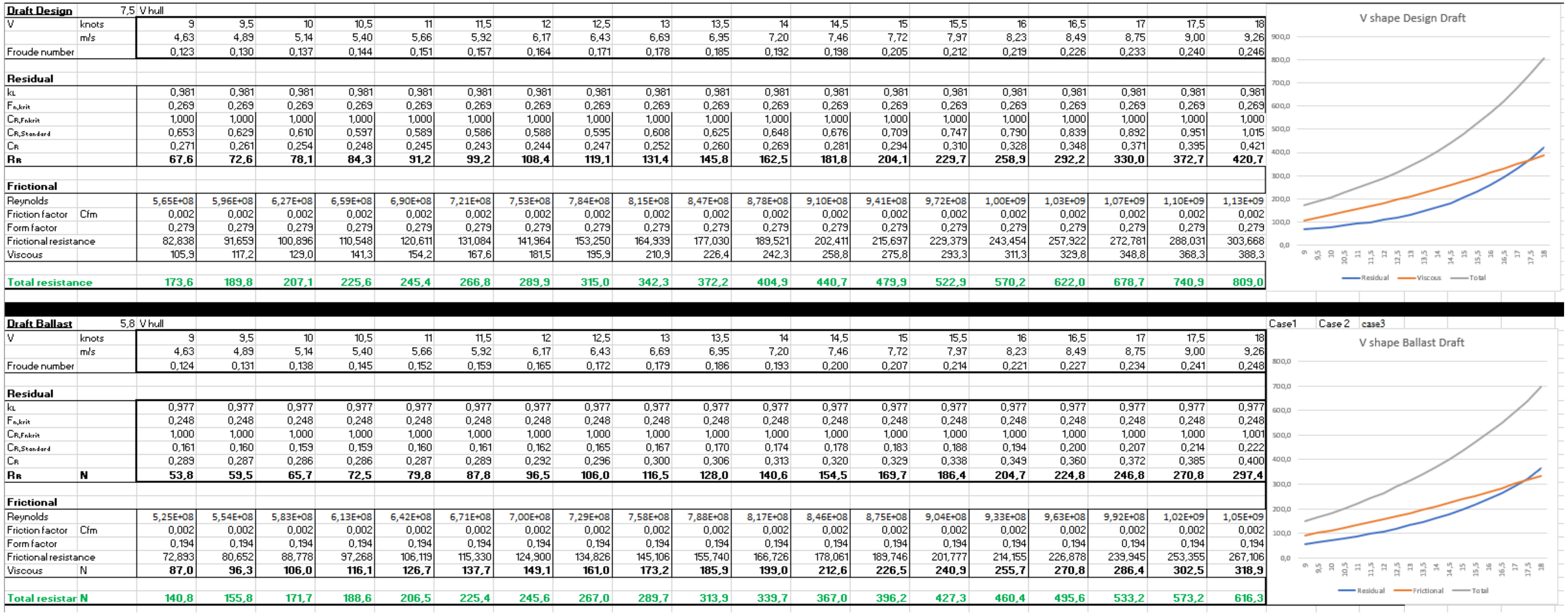


Figure G.3: Detailed resistance determination for concept 3

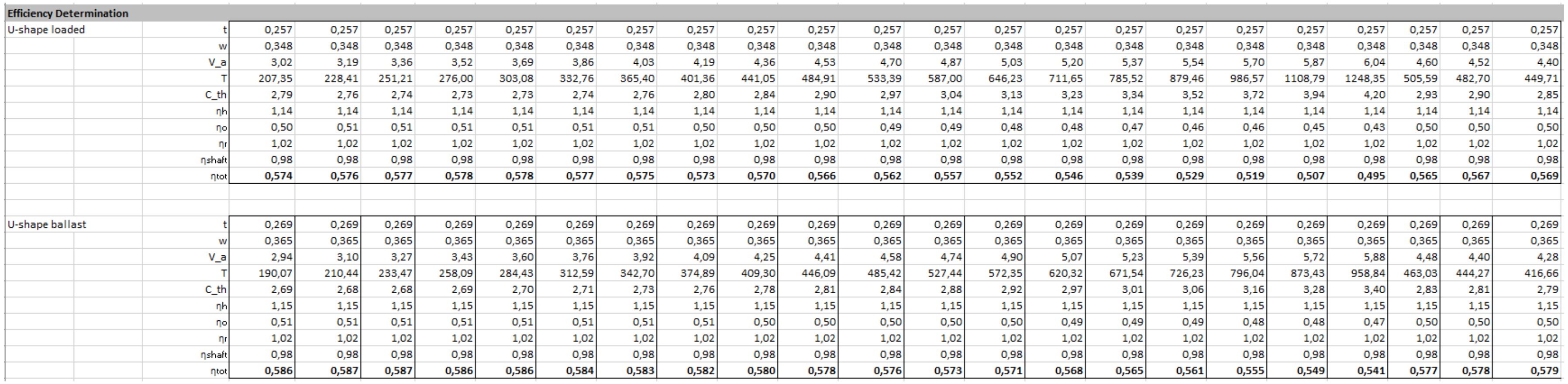


Draft Design	7,5	V hull																		
V	knots	9	9,5	10	10,5	11	11,5	12	12,5	13	13,5	14	14,5	15	15,5	16	16,5	17	17,5	18
	m/s	4,63	4,89	5,14	5,40	5,66	5,92	6,17	6,43	6,69	6,95	7,20	7,46	7,72	7,97	8,23	8,49	8,75	9,00	9,26
Froude number		0,123	0,130	0,137	0,144	0,151	0,157	0,164	0,171	0,178	0,185	0,192	0,198	0,205	0,212	0,219	0,226	0,233	0,240	0,246
Residual																				
k_L		0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981	0,981
$F_{n,krit}$		0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269
$C_{R,Fnkrit}$		1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
$C_{R,Standard}$		0,653	0,629	0,610	0,597	0,589	0,586	0,588	0,595	0,608	0,625	0,648	0,676	0,709	0,747	0,790	0,839	0,892	0,951	1,015
C_R		0,271	0,261	0,254	0,248	0,245	0,243	0,244	0,247	0,252	0,260	0,269	0,281	0,294	0,310	0,328	0,348	0,371	0,395	0,421
R_R		**67,6**	**72,6**	**78,1**	**84,3**	**91,2**	**99,2**	**108,4**	**119,1**	**131,4**	**145,8**	**162,5**	**181,8**	**204,1**	**229,7**	**258,9**	**292,2**	**330,0**	**372,7**	**420,7**
Frictional																				
Reynolds		5,65E+08	5,96E+08	6,27E+08	6,59E+08	6,90E+08	7,21E+08	7,53E+08	7,84E+08	8,15E+08	8,47E+08	8,78E+08	9,10E+08	9,41E+08	9,72E+08	1,00E+09	1,03E+09	1,07E+09	1,10E+09	1,13E+09
Friction factor	Cfm	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002
Form factor		0,279	0,279	0,279	0,279	0,279	0,279	0,279	0,279	0,279	0,279	0,279	0,279	0,279	0,279	0,279	0,279	0,279	0,279	0,279
Frictional resistance		82,838	91,659	100,896	110,548	120,611	131,084	141,964	153,250	164,939	177,030	189,521	202,411	215,697	229,379	243,454	257,922	272,781	288,031	303,668
Viscous		105,9	117,2	129,0	141,3	154,2	167,6	181,5	195,9	210,9	226,4	242,3	258,8	275,8	293,3	311,3	329,8	348,8	368,3	388,3
Total resistance		**173,6**	**189,8**	**207,1**	**225,6**	**245,4**	**266,8**	**289,9**	**315,0**	**342,3**	**372,2**	**404,9**	**440,7**	**479,9**	**522,9**	**570,2**	**622,0**	**678,7**	**740,9**	**809,0**

Draft Ballast	5,8	V hull																		
V	knots	9	9,5	10	10,5	11	11,5	12	12,5	13	13,5	14	14,5	15	15,5	16	16,5	17	17,5	18
	m/s	4,63	4,89	5,14	5,40	5,66	5,92	6,17	6,43	6,69	6,95	7,20	7,46	7,72	7,97	8,23	8,49	8,75	9,00	9,26
Froude number		0,124	0,131	0,138	0,145	0,152	0,159	0,165	0,172	0,179	0,186	0,193	0,200	0,207	0,214	0,221	0,227	0,234	0,241	0,248
Residual																				
k_L		0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977	0,977
$F_{n,krit}$		0,248	0,248	0,248	0,248	0,248	0,248	0,248	0,248	0,248	0,248	0,248	0,248	0,248	0,248	0,248	0,248	0,248	0,248	0,248
$C_{R,Fnkrit}$		1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,001
$C_{R,Standard}$		0,161	0,160	0,159	0,159	0,160	0,161	0,162	0,165	0,167	0,170	0,174	0,178	0,183	0,188	0,194	0,200	0,207	0,214	0,222
C_R		0,289	0,287	0,286	0,286	0,287	0,289	0,292	0,296	0,300	0,306	0,313	0,320	0,329	0,338	0,349	0,360	0,372	0,385	0,400
R_R	**N**	**53,8**	**59,5**	**65,7**	**72,5**	**79,8**	**87,8**	**96,5**	**106,0**	**116,5**	**128,0**	**140,6**	**154,5**	**169,7**	**186,4**	**204,7**	**224,8**	**246,8**	**270,8**	**297,4**
Frictional																				
Reynolds		5,25E+08	5,54E+08	5,83E+08	6,13E+08	6,42E+08	6,71E+08	7,00E+08	7,29E+08	7,58E+08	7,88E+08	8,17E+08	8,46E+08	8,75E+08	9,04E+08	9,33E+08	9,63E+08	9,92E+08	1,02E+09	1,05E+09
Friction factor	Cfm	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002
Form factor		0,194	0,194	0,194	0,194	0,194	0,194	0,194	0,194	0,194	0,194	0,194	0,194	0,194	0,194	0,194	0,194	0,194	0,194	0,194
Frictional resistance		72,893	80,652	88,778	97,268	106,119	115,330	124,900	134,826	145,106	155,740	166,726	178,061	189,746	201,777	214,155	226,878	239,945	253,355	267,106
Viscous	N	**87,0**	**96,3**	**106,0**	**116,1**	**126,7**	**137,7**	**149,1**	**161,0**	**173,2**	**185,9**	**199,0**	**212,6**	**226,5**	**240,9**	**255,7**	**270,8**	**286,4**	**302,5**	**318,9**
Total resistar	**N**	**140,8**	**155,8**	**171,7**	**188,6**	**206,5**	**225,4**	**245,6**	**267,0**	**289,7**	**313,9**	**339,7**	**367,0**	**396,2**	**427,3**	**460,4**	**495,6**	**533,2**	**573,2**	**616,3**

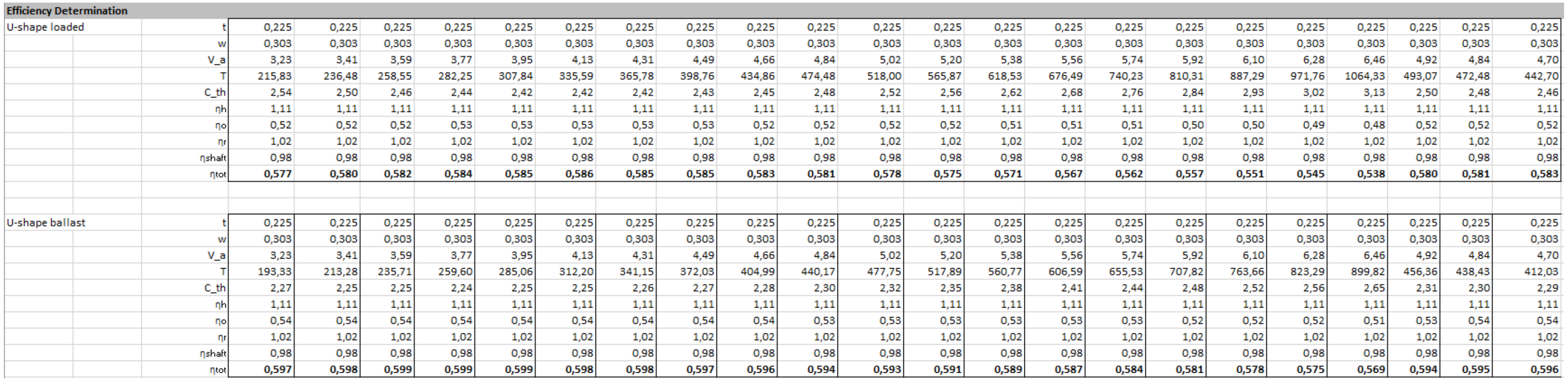
Figure G.4: Detailed resistance determination for concept 4

G.3. Efficiency details



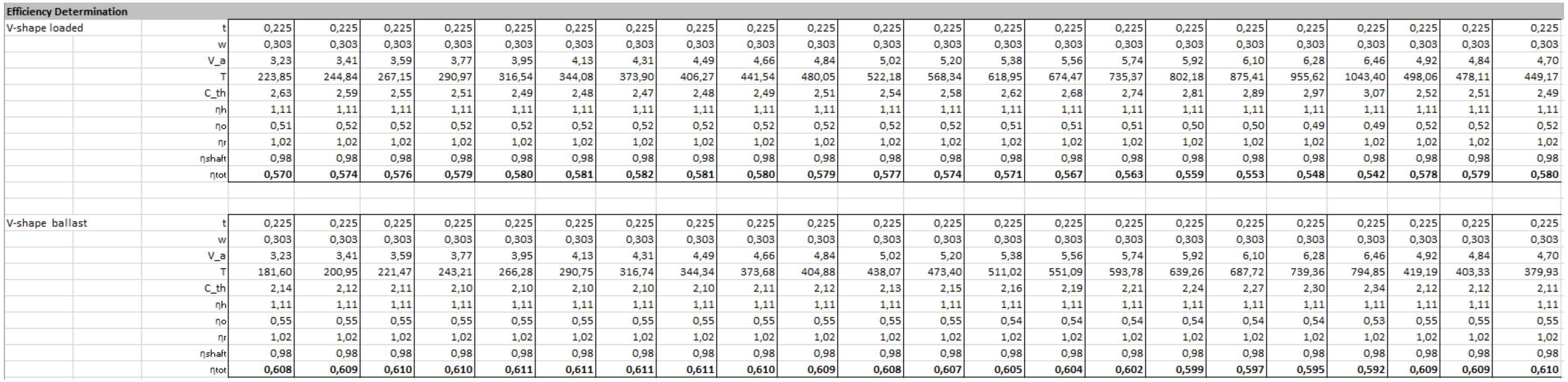
Efficiency Determination																							
U-shape loaded	t	0,257	0,257	0,257	0,257	0,257	0,257	0,257	0,257	0,257	0,257	0,257	0,257	0,257	0,257	0,257	0,257	0,257	0,257	0,257	0,257	0,257	0,257
	w	0,348	0,348	0,348	0,348	0,348	0,348	0,348	0,348	0,348	0,348	0,348	0,348	0,348	0,348	0,348	0,348	0,348	0,348	0,348	0,348	0,348	0,348
	V_a	3,02	3,19	3,36	3,52	3,69	3,86	4,03	4,19	4,36	4,53	4,70	4,87	5,03	5,20	5,37	5,54	5,70	5,87	6,04	4,60	4,52	4,40
	T	207,35	228,41	251,21	276,00	303,08	332,76	365,40	401,36	441,05	484,91	533,39	587,00	646,23	711,65	785,52	879,46	986,57	1108,79	1248,35	505,59	482,70	449,71
	C_th	2,79	2,76	2,74	2,73	2,73	2,74	2,76	2,80	2,84	2,90	2,97	3,04	3,13	3,23	3,34	3,52	3,72	3,94	4,20	2,93	2,90	2,85
	ηh	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14
	ηo	0,50	0,51	0,51	0,51	0,51	0,51	0,51	0,50	0,50	0,50	0,49	0,49	0,48	0,48	0,47	0,46	0,46	0,45	0,43	0,50	0,50	0,50
	ηr	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02
	ηshaft	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98
	ηtot	**0,574**	**0,576**	**0,577**	**0,578**	**0,578**	**0,577**	**0,575**	**0,573**	**0,570**	**0,566**	**0,562**	**0,557**	**0,552**	**0,546**	**0,539**	**0,529**	**0,519**	**0,507**	**0,495**	**0,565**	**0,567**	**0,569**
U-shape ballast	t	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269	0,269
	w	0,365	0,365	0,365	0,365	0,365	0,365	0,365	0,365	0,365	0,365	0,365	0,365	0,365	0,365	0,365	0,365	0,365	0,365	0,365	0,365	0,365	0,365
	V_a	2,94	3,10	3,27	3,43	3,60	3,76	3,92	4,09	4,25	4,41	4,58	4,74	4,90	5,07	5,23	5,39	5,56	5,72	5,88	4,48	4,40	4,28
	T	190,07	210,44	233,47	258,09	284,43	312,59	342,70	374,89	409,30	446,09	485,42	527,44	572,35	620,32	671,54	726,23	796,04	873,43	958,84	463,03	444,27	416,66
	C_th	2,69	2,68	2,68	2,69	2,70	2,71	2,73	2,76	2,78	2,81	2,84	2,88	2,92	2,97	3,01	3,06	3,16	3,28	3,40	2,83	2,81	2,79
	ηh	1,15	1,15	1,15	1,15	1,15	1,15	1,15	1,15	1,15	1,15	1,15	1,15	1,15	1,15	1,15	1,15	1,15	1,15	1,15	1,15	1,15	1,15
	ηo	0,51	0,51	0,51	0,51	0,51	0,51	0,51	0,51	0,50	0,50	0,50	0,50	0,50	0,49	0,49	0,49	0,48	0,48	0,47	0,50	0,50	0,50
	ηr	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02
	ηshaft	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98
	ηtot	**0,586**	**0,587**	**0,587**	**0,586**	**0,586**	**0,584**	**0,583**	**0,582**	**0,580**	**0,578**	**0,576**	**0,573**	**0,571**	**0,568**	**0,565**	**0,561**	**0,555**	**0,549**	**0,541**	**0,577**	**0,578**	**0,579**

Figure G.5: Detailed efficiency determination for concept 1 and 2



Efficiency Determination																							
U-shape loaded	t	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225
	w	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303
	V_a	3,23	3,41	3,59	3,77	3,95	4,13	4,31	4,49	4,66	4,84	5,02	5,20	5,38	5,56	5,74	5,92	6,10	6,28	6,46	4,92	4,84	4,70
	T	215,83	236,48	258,55	282,25	307,84	335,59	365,78	398,76	434,86	474,48	518,00	565,87	618,53	676,49	740,23	810,31	887,29	971,76	1064,33	493,07	472,48	442,70
	C_th	2,54	2,50	2,46	2,44	2,42	2,42	2,42	2,43	2,45	2,48	2,52	2,56	2,62	2,68	2,76	2,84	2,93	3,02	3,13	2,50	2,48	2,46
	ηh	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11
	ηo	0,52	0,52	0,52	0,53	0,53	0,53	0,53	0,53	0,52	0,52	0,52	0,52	0,51	0,51	0,51	0,50	0,50	0,49	0,48	0,52	0,52	0,52
	ηr	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02
	ηshaft	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98
	ηtot	**0,577**	**0,580**	**0,582**	**0,584**	**0,585**	**0,586**	**0,585**	**0,585**	**0,583**	**0,581**	**0,578**	**0,575**	**0,571**	**0,567**	**0,562**	**0,557**	**0,551**	**0,545**	**0,538**	**0,580**	**0,581**	**0,583**
U-shape ballast	t	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225
	w	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303
	V_a	3,23	3,41	3,59	3,77	3,95	4,13	4,31	4,49	4,66	4,84	5,02	5,20	5,38	5,56	5,74	5,92	6,10	6,28	6,46	4,92	4,84	4,70
	T	193,33	213,28	235,71	259,60	285,06	312,20	341,15	372,03	404,99	440,17	477,75	517,89	560,77	606,59	655,53	707,82	763,66	823,29	899,82	456,36	438,43	412,03
	C_th	2,27	2,25	2,25	2,24	2,25	2,25	2,26	2,27	2,28	2,30	2,32	2,35	2,38	2,41	2,44	2,48	2,52	2,56	2,65	2,31	2,30	2,29
	ηh	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11
	ηo	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,53	0,53	0,53	0,53	0,53	0,53	0,52	0,52	0,52	0,51	0,53	0,54	0,54
	ηr	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02
	ηshaft	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98
	ηtot	**0,597**	**0,598**	**0,599**	**0,599**	**0,599**	**0,598**	**0,598**	**0,597**	**0,596**	**0,594**	**0,593**	**0,591**	**0,589**	**0,587**	**0,584**	**0,581**	**0,578**	**0,575**	**0,569**	**0,594**	**0,595**	**0,596**

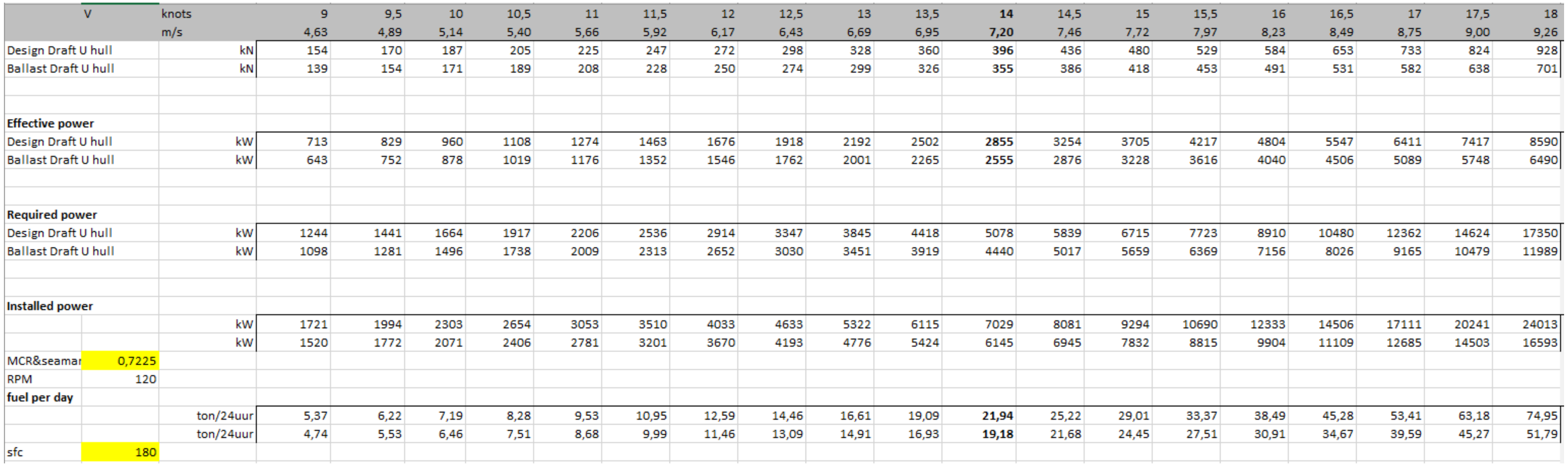
Figure G.6: Detailed efficiency determination for concept 3



Efficiency Determination																							
V-shape loaded		t	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225
		w	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303
		V_a	3,23	3,41	3,59	3,77	3,95	4,13	4,31	4,49	4,66	4,84	5,02	5,20	5,38	5,56	5,74	5,92	6,10	6,28	6,46	4,92	4,84	4,70
		T	223,85	244,84	267,15	290,97	316,54	344,08	373,90	406,27	441,54	480,05	522,18	568,34	618,95	674,47	735,37	802,18	875,41	955,62	1043,40	498,06	478,11	449,17
		C_th	2,63	2,59	2,55	2,51	2,49	2,48	2,47	2,48	2,49	2,51	2,54	2,58	2,62	2,68	2,74	2,81	2,89	2,97	3,07	2,52	2,51	2,49
		ηh	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11
		ηo	0,51	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,51	0,51	0,51	0,50	0,50	0,49	0,49	0,52	0,52	0,52
		ηr	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02
		ηshaft	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98
		ηtot	**0,570**	**0,574**	**0,576**	**0,579**	**0,580**	**0,581**	**0,582**	**0,581**	**0,580**	**0,579**	**0,577**	**0,574**	**0,571**	**0,567**	**0,563**	**0,559**	**0,553**	**0,548**	**0,542**	**0,578**	**0,579**	**0,580**
V-shape ballast		t	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225	0,225
		w	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303	0,303
		V_a	3,23	3,41	3,59	3,77	3,95	4,13	4,31	4,49	4,66	4,84	5,02	5,20	5,38	5,56	5,74	5,92	6,10	6,28	6,46	4,92	4,84	4,70
		T	181,60	200,95	221,47	243,21	266,28	290,75	316,74	344,34	373,68	404,88	438,07	473,40	511,02	551,09	593,78	639,26	687,72	739,36	794,85	419,19	403,33	379,93
		C_th	2,14	2,12	2,11	2,10	2,10	2,10	2,10	2,10	2,11	2,12	2,13	2,15	2,16	2,19	2,21	2,24	2,27	2,30	2,34	2,12	2,12	2,11
		ηh	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11	1,11
		ηo	0,55	0,55	0,55	0,55	0,55	0,55	0,55	0,55	0,55	0,55	0,55	0,55	0,54	0,54	0,54	0,54	0,54	0,54	0,53	0,55	0,55	0,55
		ηr	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02
		ηshaft	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98
		ηtot	**0,608**	**0,609**	**0,610**	**0,610**	**0,611**	**0,611**	**0,611**	**0,611**	**0,610**	**0,609**	**0,608**	**0,607**	**0,605**	**0,604**	**0,602**	**0,599**	**0,597**	**0,595**	**0,592**	**0,609**	**0,609**	**0,610**

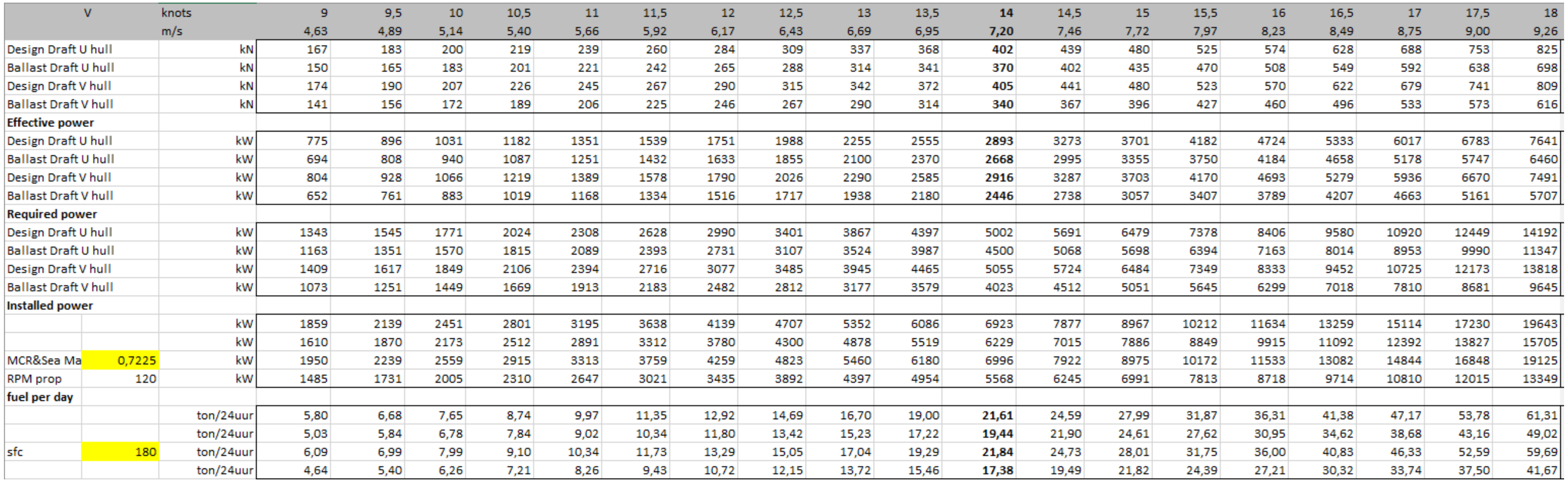
Figure G.7: Detailed efficiency determination for concept 4

G.4. Required power and fuel consumption



V		knots	9	9,5	10	10,5	11	11,5	12	12,5	13	13,5	**14**	14,5	15	15,5	16	16,5	17	17,5	18
		m/s	4,63	4,89	5,14	5,40	5,66	5,92	6,17	6,43	6,69	6,95	**7,20**	7,46	7,72	7,97	8,23	8,49	8,75	9,00	9,26
Design Draft U hull		kN	154	170	187	205	225	247	272	298	328	360	**396**	436	480	529	584	653	733	824	928
Ballast Draft U hull		kN	139	154	171	189	208	228	250	274	299	326	**355**	386	418	453	491	531	582	638	701
Effective power																					
Design Draft U hull		kW	713	829	960	1108	1274	1463	1676	1918	2192	2502	**2855**	3254	3705	4217	4804	5547	6411	7417	8590
Ballast Draft U hull		kW	643	752	878	1019	1176	1352	1546	1762	2001	2265	**2555**	2876	3228	3616	4040	4506	5089	5748	6490
Required power																					
Design Draft U hull		kW	1244	1441	1664	1917	2206	2536	2914	3347	3845	4418	5078	5839	6715	7723	8910	10480	12362	14624	17350
Ballast Draft U hull		kW	1098	1281	1496	1738	2009	2313	2652	3030	3451	3919	4440	5017	5659	6369	7156	8026	9165	10479	11989
Installed power																					
		kW	1721	1994	2303	2654	3053	3510	4033	4633	5322	6115	7029	8081	9294	10690	12333	14506	17111	20241	24013
		kW	1520	1772	2071	2406	2781	3201	3670	4193	4776	5424	6145	6945	7832	8815	9904	11109	12685	14503	16593
MCR&seamar	0,7225																				
RPM	120																				
fuel per day																					
		ton/24uur	5,37	6,22	7,19	8,28	9,53	10,95	12,59	14,46	16,61	19,09	**21,94**	25,22	29,01	33,37	38,49	45,28	53,41	63,18	74,95
		ton/24uur	4,74	5,53	6,46	7,51	8,68	9,99	11,46	13,09	14,91	16,93	**19,18**	21,68	24,45	27,51	30,91	34,67	39,59	45,27	51,79
sfc	180																				

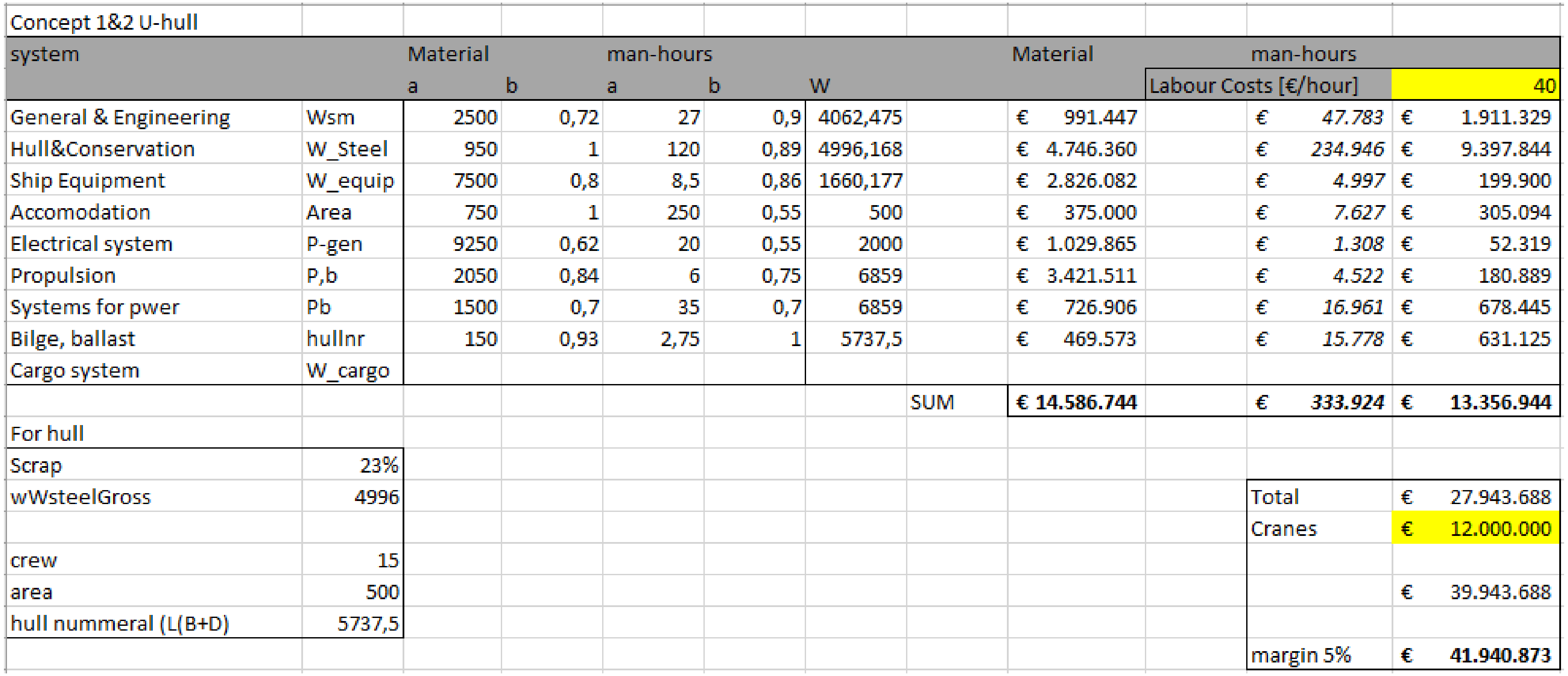
Figure G.8: Required power and fuel consumption for concept 1 and 2



V		knots	9	9,5	10	10,5	11	11,5	12	12,5	13	13,5	**14**	14,5	15	15,5	16	16,5	17	17,5	18
		m/s	4,63	4,89	5,14	5,40	5,66	5,92	6,17	6,43	6,69	6,95	**7,20**	7,46	7,72	7,97	8,23	8,49	8,75	9,00	9,26
Design Draft U hull		kN	167	183	200	219	239	260	284	309	337	368	**402**	439	480	525	574	628	688	753	825
Ballast Draft U hull		kN	150	165	183	201	221	242	265	288	314	341	**370**	402	435	470	508	549	592	638	698
Design Draft V hull		kN	174	190	207	226	245	267	290	315	342	372	**405**	441	480	523	570	622	679	741	809
Ballast Draft V hull		kN	141	156	172	189	206	225	246	267	290	314	**340**	367	396	427	460	496	533	573	616
Effective power																					
Design Draft U hull		kW	775	896	1031	1182	1351	1539	1751	1988	2255	2555	**2893**	3273	3701	4182	4724	5333	6017	6783	7641
Ballast Draft U hull		kW	694	808	940	1087	1251	1432	1633	1855	2100	2370	**2668**	2995	3355	3750	4184	4658	5178	5747	6460
Design Draft V hull		kW	804	928	1066	1219	1389	1578	1790	2026	2290	2585	**2916**	3287	3703	4170	4693	5279	5936	6670	7491
Ballast Draft V hull		kW	652	761	883	1019	1168	1334	1516	1717	1938	2180	**2446**	2738	3057	3407	3789	4207	4663	5161	5707
Required power																					
Design Draft U hull		kW	1343	1545	1771	2024	2308	2628	2990	3401	3867	4397	5002	5691	6479	7378	8406	9580	10920	12449	14192
Ballast Draft U hull		kW	1163	1351	1570	1815	2089	2393	2731	3107	3524	3987	4500	5068	5698	6394	7163	8014	8953	9990	11347
Design Draft V hull		kW	1409	1617	1849	2106	2394	2716	3077	3485	3945	4465	5055	5724	6484	7349	8333	9452	10725	12173	13818
Ballast Draft V hull		kW	1073	1251	1449	1669	1913	2183	2482	2812	3177	3579	4023	4512	5051	5645	6299	7018	7810	8681	9645
Installed power																					
		kW	1859	2139	2451	2801	3195	3638	4139	4707	5352	6086	6923	7877	8967	10212	11634	13259	15114	17230	19643
		kW	1610	1870	2173	2512	2891	3312	3780	4300	4878	5519	6229	7015	7886	8849	9915	11092	12392	13827	15705
MCR&Sea Ma	0,7225	kW	1950	2239	2559	2915	3313	3759	4259	4823	5460	6180	6996	7922	8975	10172	11533	13082	14844	16848	19125
RPM prop	120	kW	1485	1731	2005	2310	2647	3021	3435	3892	4397	4954	5568	6245	6991	7813	8718	9714	10810	12015	13349
fuel per day																					
		ton/24uur	5,80	6,68	7,65	8,74	9,97	11,35	12,92	14,69	16,70	19,00	**21,61**	24,59	27,99	31,87	36,31	41,38	47,17	53,78	61,31
		ton/24uur	5,03	5,84	6,78	7,84	9,02	10,34	11,80	13,42	15,23	17,22	**19,44**	21,90	24,61	27,62	30,95	34,62	38,68	43,16	49,02
sfc	180	ton/24uur	6,09	6,99	7,99	9,10	10,34	11,73	13,29	15,05	17,04	19,29	**21,84**	24,73	28,01	31,75	36,00	40,83	46,33	52,59	59,69
		ton/24uur	4,64	5,40	6,26	7,21	8,26	9,43	10,72	12,15	13,72	15,46	**17,38**	19,49	21,82	24,39	27,21	30,32	33,74	37,50	41,67

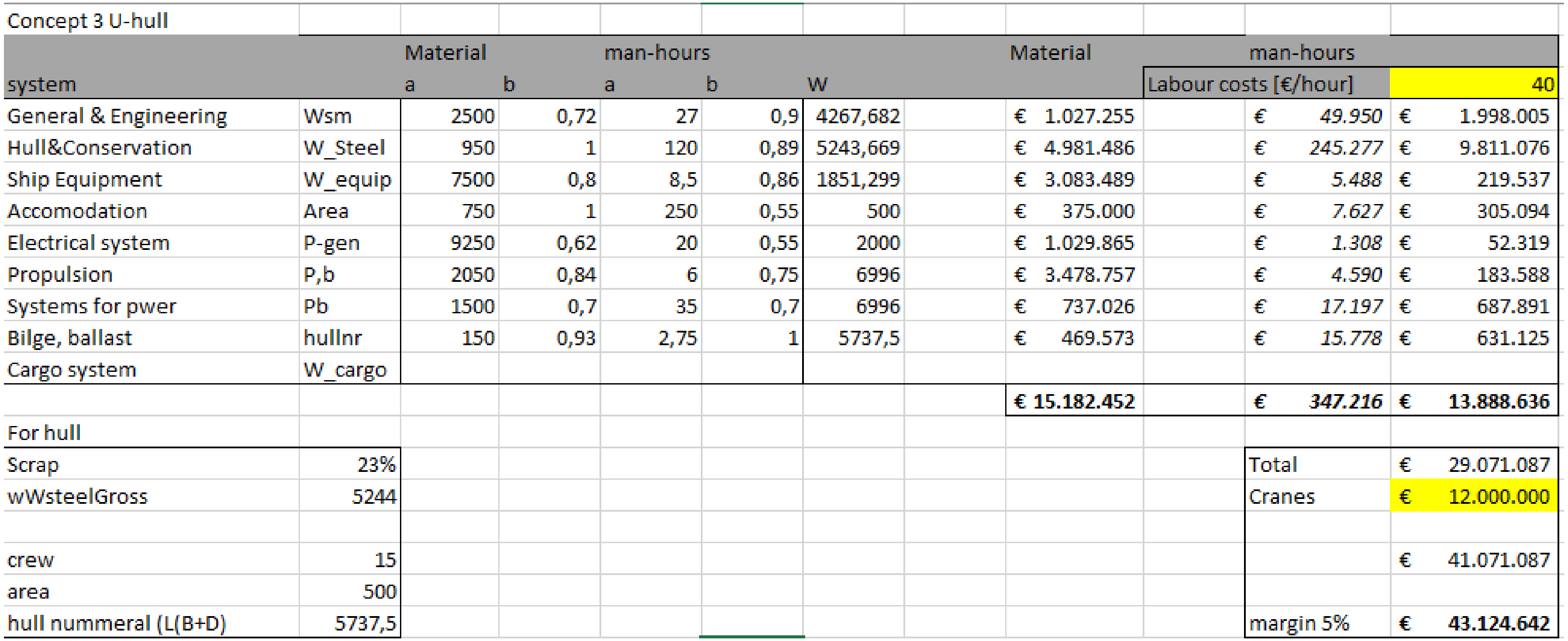
Figure G.9: Required power and fuel consumption for concept 3 and 4

G.5. Building costs



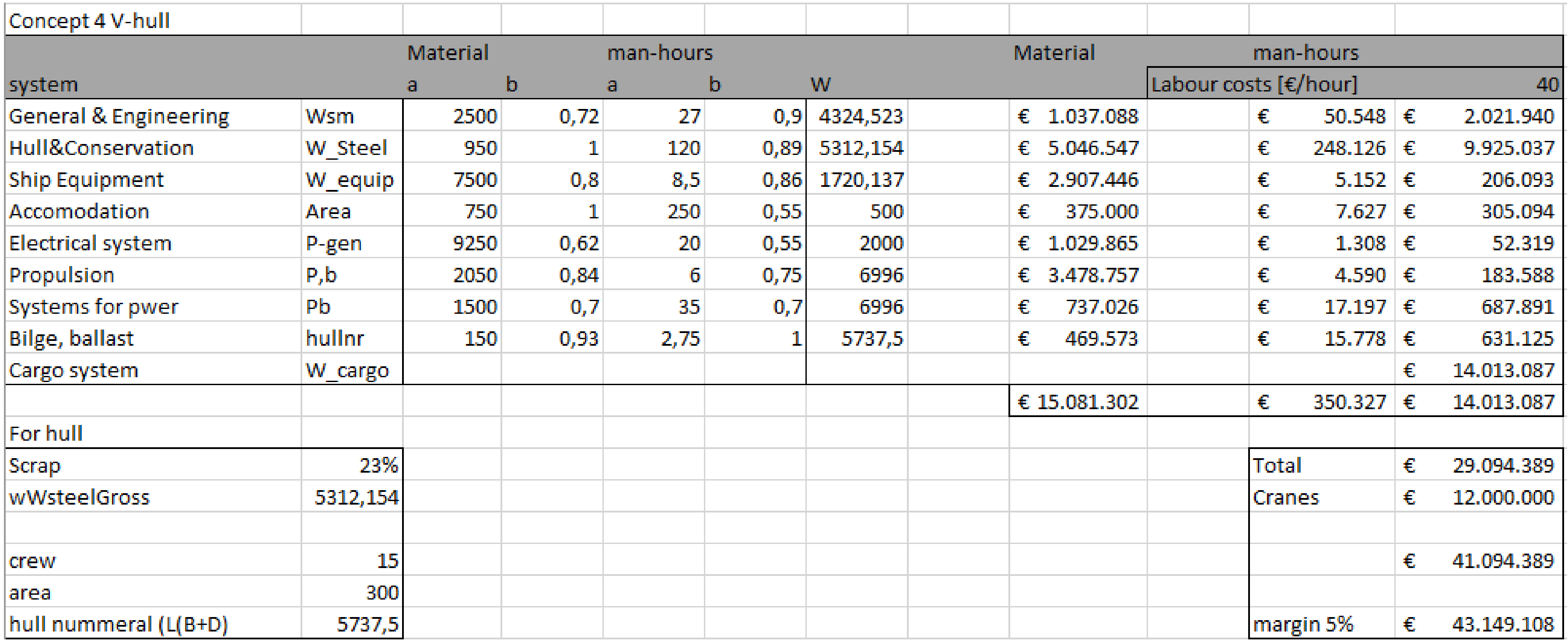
Concept 1&2 U-hull											
system		Material		man-hours				Material		man-hours	
		a	b	a	b	W			Labour Costs [€/hour]		40
General & Engineering	Wsm	2500	0,72	27	0,9	4062,475		€ 991.447		€ *47.783*	€ 1.911.329
Hull&Conservation	W_Steel	950	1	120	0,89	4996,168		€ 4.746.360		€ *234.946*	€ 9.397.844
Ship Equipment	W_equip	7500	0,8	8,5	0,86	1660,177		€ 2.826.082		€ *4.997*	€ 199.900
Accomodation	Area	750	1	250	0,55	500		€ 375.000		€ *7.627*	€ 305.094
Electrical system	P-gen	9250	0,62	20	0,55	2000		€ 1.029.865		€ *1.308*	€ 52.319
Propulsion	P,b	2050	0,84	6	0,75	6859		€ 3.421.511		€ *4.522*	€ 180.889
Systems for pwer	Pb	1500	0,7	35	0,7	6859		€ 726.906		€ *16.961*	€ 678.445
Bilge, ballast	hullnr	150	0,93	2,75	1	5737,5		€ 469.573		€ *15.778*	€ 631.125
Cargo system	W_cargo										
							SUM	**€ 14.586.744**		**€ *333.924***	**€ 13.356.944**
For hull											
Scrap	23%										
wWsteelGross	4996									Total	€ 27.943.688
										Cranes	€ 12.000.000
crew	15										
area	500										€ 39.943.688
hull nummeral (L(B+D)	5737,5										
										margin 5%	**€ 41.940.873**

Figure G.10: Buildingcost calculation for concept 1 and 2 (ex. stabiliser)



Concept 3 U-hull											
		Material		man-hours				Material		man-hours	
system		a	b	a	b	W			Labour costs [€/hour]		40
General & Engineering	Wsm	2500	0,72	27	0,9	4267,682		€ 1.027.255		€ *49.950*	€ 1.998.005
Hull&Conservation	W_Steel	950	1	120	0,89	5243,669		€ 4.981.486		€ *245.277*	€ 9.811.076
Ship Equipment	W_equip	7500	0,8	8,5	0,86	1851,299		€ 3.083.489		€ *5.488*	€ 219.537
Accomodation	Area	750	1	250	0,55	500		€ 375.000		€ *7.627*	€ 305.094
Electrical system	P-gen	9250	0,62	20	0,55	2000		€ 1.029.865		€ *1.308*	€ 52.319
Propulsion	P,b	2050	0,84	6	0,75	6996		€ 3.478.757		€ *4.590*	€ 183.588
Systems for pwer	Pb	1500	0,7	35	0,7	6996		€ 737.026		€ *17.197*	€ 687.891
Bilge, ballast	hullnr	150	0,93	2,75	1	5737,5		€ 469.573		€ *15.778*	€ 631.125
Cargo system	W_cargo										
								€ 15.182.452		€ ***347.216***	€ **13.888.636**
For hull											
Scrap	23%									Total	€ 29.071.087
wWsteelGross	5244									Cranes	€ 12.000.000
crew	15										€ 41.071.087
area	500										
hull nummeral (L(B+D)	5737,5									margin 5%	€ **43.124.642**

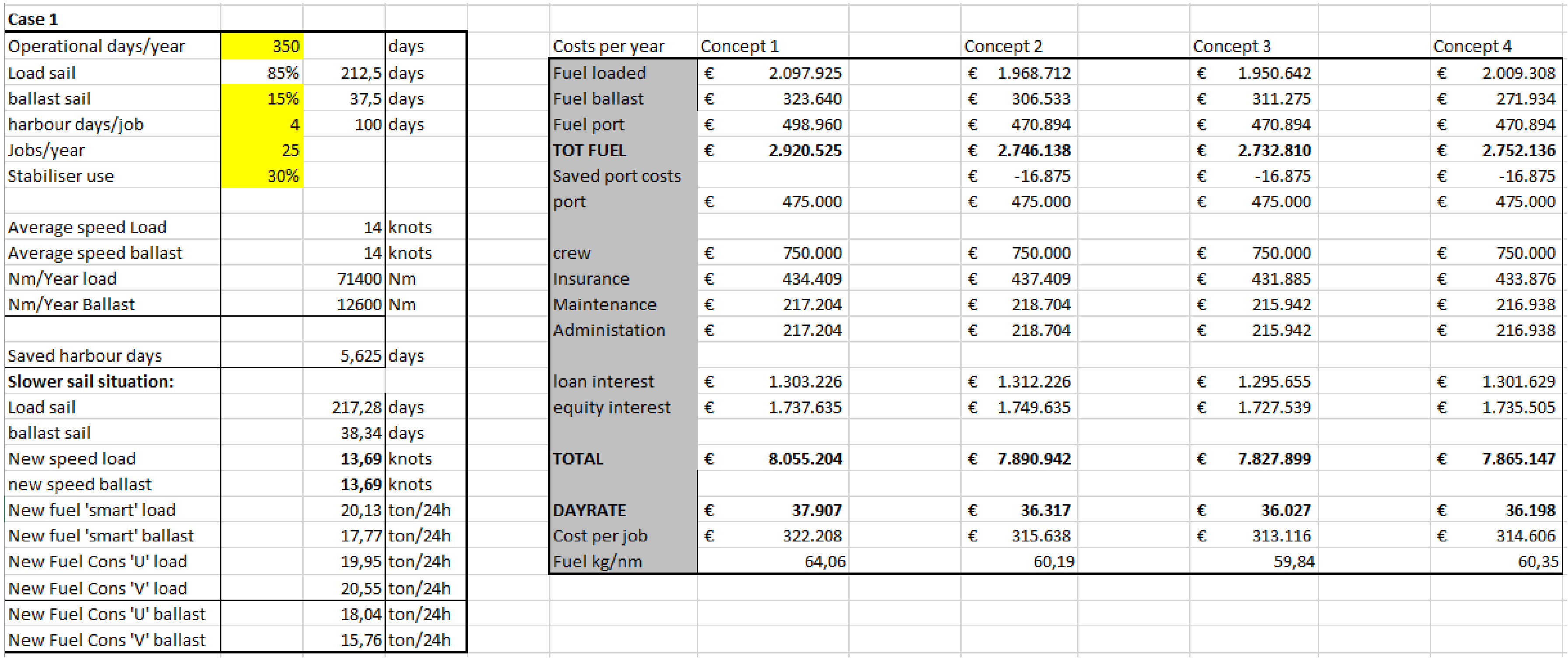
Figure G.11: Buildingcost calculation for concept 3



Concept 4 V-hull									
		Material		man-hours			Material	man-hours	
system		a	b	a	b	W		Labour costs [€/hour]	40
General & Engineering	Wsm	2500	0,72	27	0,9	4324,523	€ 1.037.088	€ 50.548	€ 2.021.940
Hull&Conservation	W_Steel	950	1	120	0,89	5312,154	€ 5.046.547	€ 248.126	€ 9.925.037
Ship Equipment	W_equip	7500	0,8	8,5	0,86	1720,137	€ 2.907.446	€ 5.152	€ 206.093
Accomodation	Area	750	1	250	0,55	500	€ 375.000	€ 7.627	€ 305.094
Electrical system	P-gen	9250	0,62	20	0,55	2000	€ 1.029.865	€ 1.308	€ 52.319
Propulsion	P,b	2050	0,84	6	0,75	6996	€ 3.478.757	€ 4.590	€ 183.588
Systems for pwer	Pb	1500	0,7	35	0,7	6996	€ 737.026	€ 17.197	€ 687.891
Bilge, ballast	hullnr	150	0,93	2,75	1	5737,5	€ 469.573	€ 15.778	€ 631.125
Cargo system	W_cargo								€ 14.013.087
							€ 15.081.302	€ 350.327	€ 14.013.087
For hull									
Scrap	23%							Total	€ 29.094.389
wWsteelGross	5312,154							Cranes	€ 12.000.000
crew	15								€ 41.094.389
area	300								
hull nummeral (L(B+D)	5737,5							margin 5%	€ 43.149.108

Figure G.12: Buildingcost calculation for concept 4

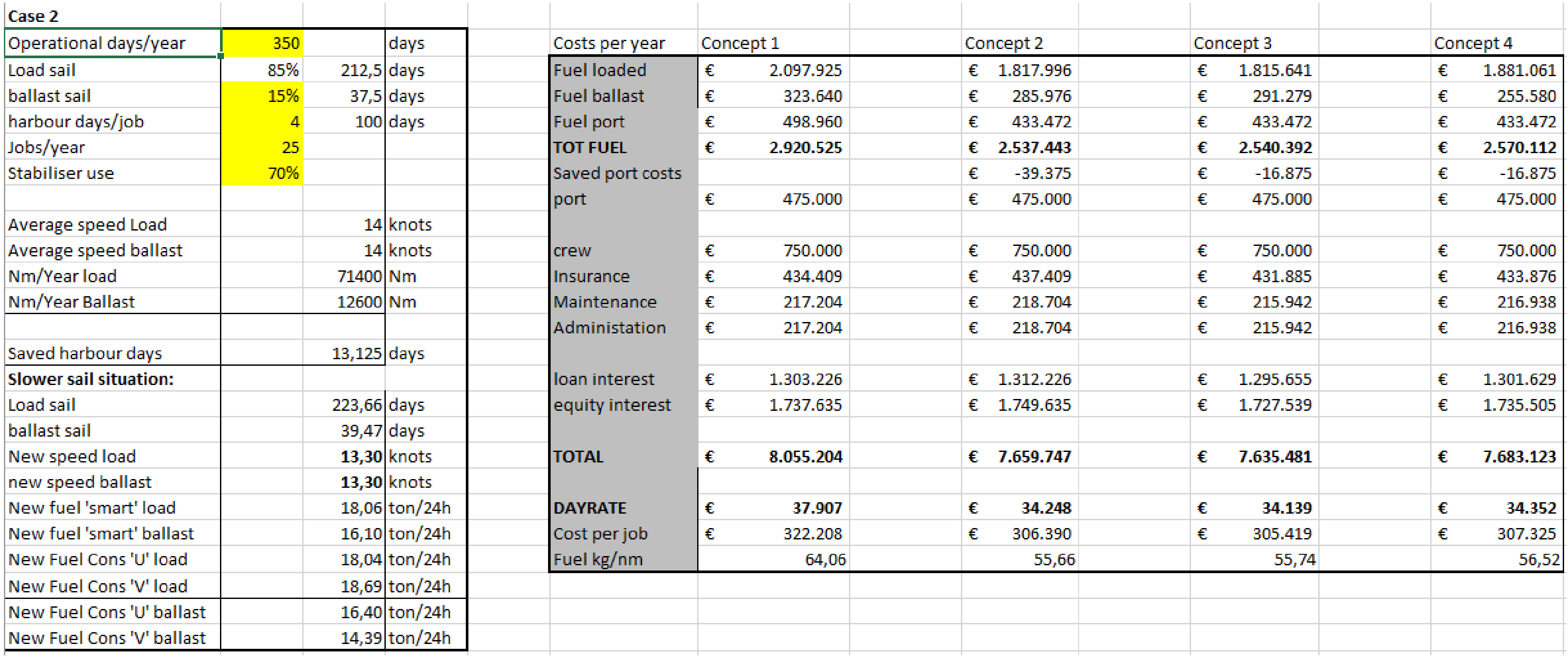
G.6. Day rate determination



Case 1			
Operational days/year	350		days
Load sail	85%	212,5	days
ballast sail	15%	37,5	days
harbour days/job	4	100	days
Jobs/year	25		
Stabiliser use	30%		
Average speed Load		14	knots
Average speed ballast		14	knots
Nm/Year load		71400	Nm
Nm/Year Ballast		12600	Nm
Saved harbour days		5,625	days
Slower sail situation:			
Load sail		217,28	days
ballast sail		38,34	days
New speed load		**13,69**	knots
new speed ballast		**13,69**	knots
New fuel 'smart' load		20,13	ton/24h
New fuel 'smart' ballast		17,77	ton/24h
New Fuel Cons 'U' load		19,95	ton/24h
New Fuel Cons 'V' load		20,55	ton/24h
New Fuel Cons 'U' ballast		18,04	ton/24h
New Fuel Cons 'V' ballast		15,76	ton/24h

Costs per year	Concept 1	Concept 2	Concept 3	Concept 4
Fuel loaded	€ 2.097.925	€ 1.968.712	€ 1.950.642	€ 2.009.308
Fuel ballast	€ 323.640	€ 306.533	€ 311.275	€ 271.934
Fuel port	€ 498.960	€ 470.894	€ 470.894	€ 470.894
TOT FUEL	**€ 2.920.525**	**€ 2.746.138**	**€ 2.732.810**	**€ 2.752.136**
Saved port costs		€ -16.875	€ -16.875	€ -16.875
port	€ 475.000	€ 475.000	€ 475.000	€ 475.000
crew	€ 750.000	€ 750.000	€ 750.000	€ 750.000
Insurance	€ 434.409	€ 437.409	€ 431.885	€ 433.876
Maintenance	€ 217.204	€ 218.704	€ 215.942	€ 216.938
Administation	€ 217.204	€ 218.704	€ 215.942	€ 216.938
loan interest	€ 1.303.226	€ 1.312.226	€ 1.295.655	€ 1.301.629
equity interest	€ 1.737.635	€ 1.749.635	€ 1.727.539	€ 1.735.505
TOTAL	**€ 8.055.204**	**€ 7.890.942**	**€ 7.827.899**	**€ 7.865.147**
DAYRATE	**€ 37.907**	**€ 36.317**	**€ 36.027**	**€ 36.198**
Cost per job	€ 322.208	€ 315.638	€ 313.116	€ 314.606
Fuel kg/nm	64,06	60,19	59,84	60,35

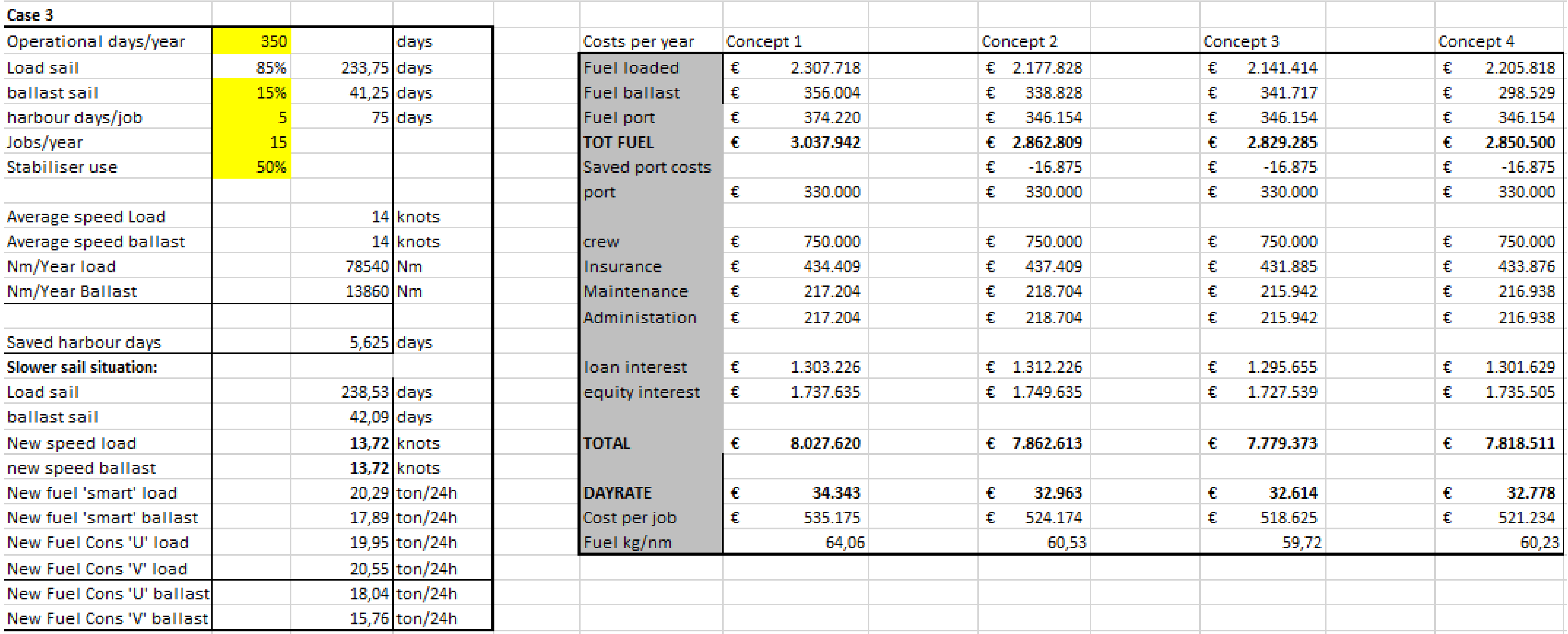
Figure G.13: Cost calculation per concept for case 1



Case 2			
Operational days/year	350		days
Load sail	85%	212,5	days
ballast sail	15%	37,5	days
harbour days/job	4	100	days
Jobs/year	25		
Stabiliser use	70%		
Average speed Load		14	knots
Average speed ballast		14	knots
Nm/Year load		71400	Nm
Nm/Year Ballast		12600	Nm
Saved harbour days		13,125	days
Slower sail situation:			
Load sail		223,66	days
ballast sail		39,47	days
New speed load		**13,30**	knots
new speed ballast		**13,30**	knots
New fuel 'smart' load		18,06	ton/24h
New fuel 'smart' ballast		16,10	ton/24h
New Fuel Cons 'U' load		18,04	ton/24h
New Fuel Cons 'V' load		18,69	ton/24h
New Fuel Cons 'U' ballast		16,40	ton/24h
New Fuel Cons 'V' ballast		14,39	ton/24h

Costs per year	Concept 1	Concept 2	Concept 3	Concept 4
Fuel loaded	€ 2.097.925	€ 1.817.996	€ 1.815.641	€ 1.881.061
Fuel ballast	€ 323.640	€ 285.976	€ 291.279	€ 255.580
Fuel port	€ 498.960	€ 433.472	€ 433.472	€ 433.472
TOT FUEL	**€ 2.920.525**	**€ 2.537.443**	**€ 2.540.392**	**€ 2.570.112**
Saved port costs		€ -39.375	€ -16.875	€ -16.875
port	€ 475.000	€ 475.000	€ 475.000	€ 475.000
crew	€ 750.000	€ 750.000	€ 750.000	€ 750.000
Insurance	€ 434.409	€ 437.409	€ 431.885	€ 433.876
Maintenance	€ 217.204	€ 218.704	€ 215.942	€ 216.938
Administation	€ 217.204	€ 218.704	€ 215.942	€ 216.938
loan interest	€ 1.303.226	€ 1.312.226	€ 1.295.655	€ 1.301.629
equity interest	€ 1.737.635	€ 1.749.635	€ 1.727.539	€ 1.735.505
TOTAL	**€ 8.055.204**	**€ 7.659.747**	**€ 7.635.481**	**€ 7.683.123**
DAYRATE	**€ 37.907**	**€ 34.248**	**€ 34.139**	**€ 34.352**
Cost per job	€ 322.208	€ 306.390	€ 305.419	€ 307.325
Fuel kg/nm	64,06	55,66	55,74	56,52

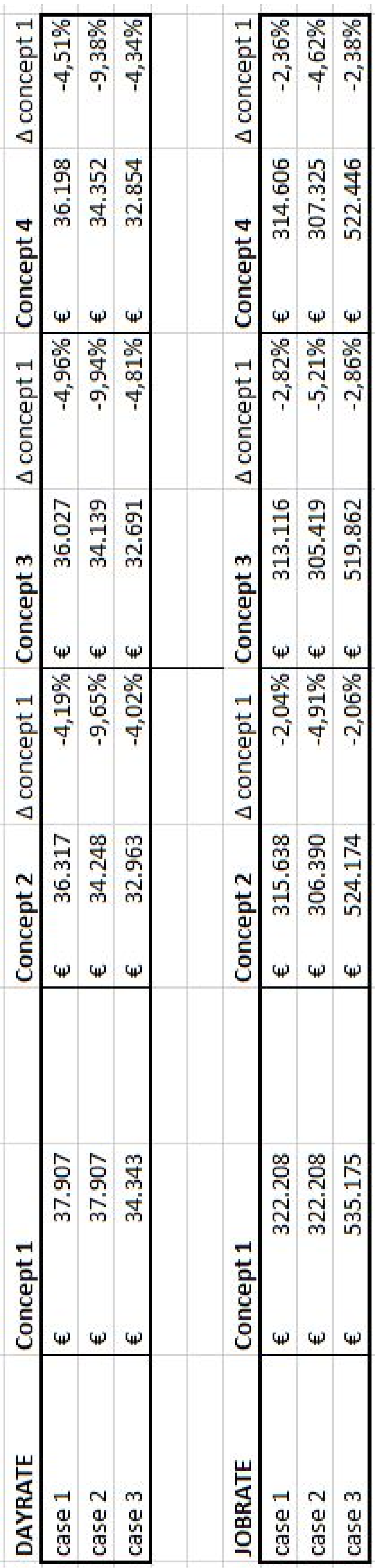
Figure G.14: Cost calculation per concept for case 2



Case 3			
Operational days/year	350		days
Load sail	85%	233,75	days
ballast sail	15%	41,25	days
harbour days/job	5	75	days
Jobs/year	15		
Stabiliser use	50%		
Average speed Load		14	knots
Average speed ballast		14	knots
Nm/Year load		78540	Nm
Nm/Year Ballast		13860	Nm
Saved harbour days		5,625	days
Slower sail situation:			
Load sail		238,53	days
ballast sail		42,09	days
New speed load		**13,72**	knots
new speed ballast		**13,72**	knots
New fuel 'smart' load		20,29	ton/24h
New fuel 'smart' ballast		17,89	ton/24h
New Fuel Cons 'U' load		19,95	ton/24h
New Fuel Cons 'V' load		20,55	ton/24h
New Fuel Cons 'U' ballast		18,04	ton/24h
New Fuel Cons 'V' ballast		15,76	ton/24h

Costs per year	Concept 1	Concept 2	Concept 3	Concept 4
Fuel loaded	€ 2.307.718	€ 2.177.828	€ 2.141.414	€ 2.205.818
Fuel ballast	€ 356.004	€ 338.828	€ 341.717	€ 298.529
Fuel port	€ 374.220	€ 346.154	€ 346.154	€ 346.154
TOT FUEL	**€ 3.037.942**	**€ 2.862.809**	**€ 2.829.285**	**€ 2.850.500**
Saved port costs		€ -16.875	€ -16.875	€ -16.875
port	€ 330.000	€ 330.000	€ 330.000	€ 330.000
crew	€ 750.000	€ 750.000	€ 750.000	€ 750.000
Insurance	€ 434.409	€ 437.409	€ 431.885	€ 433.876
Maintenance	€ 217.204	€ 218.704	€ 215.942	€ 216.938
Administation	€ 217.204	€ 218.704	€ 215.942	€ 216.938
loan interest	€ 1.303.226	€ 1.312.226	€ 1.295.655	€ 1.301.629
equity interest	€ 1.737.635	€ 1.749.635	€ 1.727.539	€ 1.735.505
TOTAL	**€ 8.027.620**	**€ 7.862.613**	**€ 7.779.373**	**€ 7.818.511**
DAYRATE	**€ 34.343**	**€ 32.963**	**€ 32.614**	**€ 32.778**
Cost per job	€ 535.175	€ 524.174	€ 518.625	€ 521.234
Fuel kg/nm	64,06	60,53	59,72	60,23

Figure G.15: Cost calculation per concept for case 3

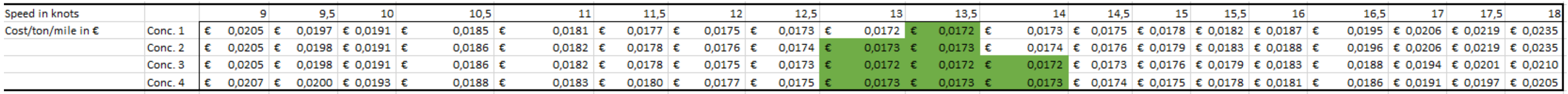


DAYRATE	Concept 1	Concept 2	Δ concept 1	Concept 3	Δ concept 1	Concept 4	Δ concept 1
case 1	€ 37.907	€ 36.317	-4,19%	€ 36.027	-4,96%	€ 36.198	-4,51%
case 2	€ 37.907	€ 34.248	-9,65%	€ 34.139	-9,94%	€ 34.352	-9,38%
case 3	€ 34.343	€ 32.963	-4,02%	€ 32.691	-4,81%	€ 32.854	-4,34%

JOBRATE	Concept 1	Concept 2	Δ concept 1	Concept 3	Δ concept 1	Concept 4	Δ concept 1
case 1	€ 322.208	€ 315.638	-2,04%	€ 313.116	-2,82%	€ 314.606	-2,36%
case 2	€ 322.208	€ 306.390	-4,91%	€ 305.419	-5,21%	€ 307.325	-4,62%
case 3	€ 535.175	€ 524.174	-2,06%	€ 519.862	-2,86%	€ 522.446	-2,38%

Figure G.16: Dayrates and job rates overview

G.7. Cost ton/mile



Speed in knots		9	9,5	10	10,5	11	11,5	12	12,5	13	13,5	14	14,5	15	15,5	16	16,5	17	17,5	18
Cost/ton/mile in €	Conc. 1	€ 0,0205	€ 0,0197	€ 0,0191	€ 0,0185	€ 0,0181	€ 0,0177	€ 0,0175	€ 0,0173	€ 0,0172	€ 0,0172	€ 0,0173	€ 0,0175	€ 0,0178	€ 0,0182	€ 0,0187	€ 0,0195	€ 0,0206	€ 0,0219	€ 0,0235
	Conc. 2	€ 0,0205	€ 0,0198	€ 0,0191	€ 0,0186	€ 0,0182	€ 0,0178	€ 0,0176	€ 0,0174	€ 0,0173	€ 0,0173	€ 0,0174	€ 0,0176	€ 0,0179	€ 0,0183	€ 0,0188	€ 0,0196	€ 0,0206	€ 0,0219	€ 0,0235
	Conc. 3	€ 0,0205	€ 0,0198	€ 0,0191	€ 0,0186	€ 0,0182	€ 0,0178	€ 0,0175	€ 0,0173	€ 0,0172	€ 0,0172	€ 0,0172	€ 0,0173	€ 0,0176	€ 0,0179	€ 0,0183	€ 0,0188	€ 0,0194	€ 0,0201	€ 0,0210
	Conc. 4	€ 0,0207	€ 0,0200	€ 0,0193	€ 0,0188	€ 0,0183	€ 0,0180	€ 0,0177	€ 0,0175	€ 0,0173	€ 0,0173	€ 0,0173	€ 0,0174	€ 0,0175	€ 0,0178	€ 0,0181	€ 0,0186	€ 0,0191	€ 0,0197	€ 0,0205

Figure G.17: Cost per ton/mile per concept