Høgskulen på Vestlandet

Master thesis

MMO5017

Predefinert informasjon

Startdato:	30-04-2020 14:39	**Termin:**	2020 VÅR
Sluttdato:	03-06-2020 14:00	**Vurderingsform:**	Norsk 6-trinns skala (A-F)
Eksamensform:	Master thesis		
SIS-kode:	203 MMO5017 1 MOPPG-1 2020 VÅR HAUGESUND		
Intern sensor:	(Anonymisert)		

Deltaker

Kandidatnr.: 308

Informasjon fra deltaker

Engelsk tittel *: Identifying Operating Limits for an Offshore Tow by Designing and Running Simulator Models

Navn på veileder *: Ove Tobias Gudmestad

Sett hake dersom besvarelsen kan brukes som eksempel i undervisning?:	Nei	**Egenerklæring *:**	Ja
		Inneholder besvarelsen konfidensielt materiale?:	Nei
Jeg bekrefter at jeg har registrert oppgavetittelen på norsk og engelsk i StudentWeb og vet at denne vil stå på vitnemålet mitt *:	Ja		

Jeg godkjenner avtalen om publisering av masteroppgaven min *

Ja

Er masteroppgaven skrevet som del av et større forskningsprosjekt ved HVL? *

Nei

Er masteroppgaven skrevet ved bedrift/virksomhet i næringsliv eller offentlig sektor? *

Nei

Identifying Operating Limits for an Offshore Tow by Designing and Running Simulator Models

Based on the Vessels EMS TUG and EMS PONTON 7

Clemens Plawenn-Salvini

Western Norway University of Applied Sciences

Master Thesis MMO5017

Supervised by Ove Tobias Gudmestad

Author note:

Clemens Plawenn-Salvini, Student ID: 581047

Faculty of Maritime Sciences, University of Applied Sciences Emden-Leer

This is the final paper for the combined master study program

Maritime Operations of Western Norway University of Applied Sciences and

University of Applied Sciences Emden-Leer

Contact: clemens.p@gmx.at

Abstract

What are the operating limits of a vessel? This is one of the most frequently raised questions raised in the maritime industry. On the one hand, if the limits are set too high it might endanger the goods, the environment, the vessel itself, and even the lives of the crew. On the other, if limits are set too conservatively, operations may be delayed or goods may not arrive on time due to stringent weather restrictions, which in turn leads to economic and reputational damage.

This thesis presents a *methodology* to develop such operating limits with the use of a full mission simulator using as an example the tow dyad of the vessel EMS TUG and the barge EMS PONTON 7.

The designing of the models, in particular their hydrodynamic behavior, is only touched upon in this thesis. To create a model which truly behaves like the actual vessels, a scaled model and runs in a test basin would be necessary.

The models, in the course of this thesis, were used to perform test runs in the full mission simulator at the maritime campus in Leer of the University of Applied Science Emden – Leer. A set of regular wave conditions were chosen in order to test the vessels' responses. The corresponding data was then extracted and examined to determine whether defined acceptance criteria, such as a maximum heeling angle due to wave induced rolling motion, were exceeded.

Maximum significant wave heights of 2.4 meters to 4 meters, depending on the wave period, have been determined to be the limit for the tow. It is however prudent for marine operations to not only define the operating limits, but also to put them into perspective with regards to the weather forecast. The further into the future a forecast predicts particular conditions the higher the uncertainty, i.e. the more safety margin has to be allowed for.

However, the results for the operating limits of the EMS TUG and the EMS PONTON 7 presented in this paper should in no way be applied to actual operations, since the *methodology* is the primary focus of this thesis.

Kurzfassung

Was sind die Leistungsgrenzen eines Schiffes? Das ist eine der häufigst gestellten Fragen in der maritimen Branche. Erlauben die Grenzen einen höheren Spielraum als angemessen, könnte dies die Ladung, die Umwelt, das Schiff selbst und sogar das Leben der Besatzungsmitglieder gefährden. Werden hingegen die Grenzen zu eng gesteckt, könnten sich der Einsatzablauf verzögern oder Güter aufgrund von schlechten Wetterbedingungen nicht zeitgerecht übergeben werden. Dies kann sowohl zu wirtschaftlichen Schäden als auch zu Reputationsverlust führen.

Diese Arbeit stellt eine *Methodik* vor, um die Leistungsgrenzen mit Hilfe eines Full-Mission-Simulators zu entwickeln. Als Beispiel dient hierzu das Schleppgespann EMS TUG und EMS PONTON 7.

Die Erstellung der Modelle, insbesondere deren hydrodynamischen Verhaltens, wird in dieser Arbeit nur oberflächlich behandelt. Um ein Modell, das sich realitätsgetreu verhält, zu entwickeln wären ein maßstabsgetreues Modell und Versuche in einem Manöverbecken nötig.

Mit den im Rahmen dieser Arbeit entwickelten Modellen wurden Versuchsreihen im Full-Mission-Simulator am Fachbereich für Seefahrt und Maritime Wissenschaften der Hochschule Emden-Leer durchgeführt. Das Verhalten der Modelle wurde im Rahmen eines Spektrums von Sinuswellen mit unterschiedlicher Wellenperiode und –höhe untersucht. Die entsprechenden Datensätze wurden verarbeitet und untersucht, um zu bestimmen ob zuvor definierte Akzeptanzkriterien, wie zum Beispiel der maximale Krängungswinkel aufgrund von Welleneinfluss, überschritten wurden.

Die maximalen signifikanten Wellenhöhen von 2.4 bis 4 Meter, abhängig von der Wellenperiode, wurden als zulässige Grenzen identifiziert. Für die gewissenhafte Planung von Tätigkeiten im maritimen Bereich ist es essentiell nicht nur die Leistungsgrenzen zu definieren, sondern Sie auch aufgrund der vorhergesagten Wetterbedingungen anzupassen. Je weiter in die Zukunft der Wetterbericht reicht, umso höher die Unsicherheit, sprich umso höher muss die Sicherheitsspanne sein.

Nichtsdestotrotz dürfen die Ergebnisse in Bezug auf die Leistungsgrenzen des EMS TUG und EMS PONTON 7, die in dieser Arbeit vorgestellt werden, keineswegs auf den tatsächlichen Betrieb angewendet werden, da hier der Fokus auf der *Methodik* liegt.

Table of Contents

Figures

Tables

Abbreviations

BSH	Bundesamt für Seeschifffahrt und Hydrographie (German Hydrographic Office)
CSV	Comma Separated Values
ECDIS	Electronic Chart Display and Information System
EOS	Ems Offshore Service
HAZID	Hazard Identification Study
HSVA	Hamburgische Schiffbau-Versuchsanstalt
IMO	International Maritime Organization
LOA	Length Over All
LPP	Length Between Perpendiculars
MSC	Maritime Safety Committee
RAO	Response Amplitude Operator
RMS	Root Mean Square
USNA	United States Naval Academy

1. Introduction and Research Question

The running of tugs has a long tradition. Nowadays there are a number of different tug types on the market, which have different handling characteristics due to the varying designs. For the purpose of towing a barge along costal waterways the conventional single or twin screw tug is still one of the best choices. This is mainly due to good steering and seakeeping abilities and the efficient bollard pull to power output. But no matter how well equipped a tug is, at certain weather conditions it is plainly not safe to conduct a towage. These conditions are the operating limits. This master thesis investigates how to identify such operating limits by creating a simulator model of a tug and barge dyad which is performing such transports on a regular basis in real life. These vessels are the EMS TUG and the EMS PONTON 7, the details and drawing of which have been provided by the operating company Ems Offshore Service (EOS).

The question this thesis seeks to answer is, how may a simulator model be created and used in order to identify dangerous situations to the tug, the barge, and the tow as a whole. Therefore, the aim is to develop a methodology of how such a model can be designed and used in a full mission simulator. Further the methodology shows how the data may be investigated to make conclusions on the basis of test runs. The results are intended to demonstrate how the vessel will react in certain conditions and identify dangerous situations to the tug, the barge, or both.

Chapter 2 will introduce the two vessels which are relevant for this thesis. In chapter three the description of how the models of the two vessels were created, visually and physically, is elaborated. The individual steps and the software involved are being described and the effort this required. Chapter four discusses the typical trading area of the vessels, the scale of the voyages and wave conditions which are likely to be encountered. The definition of the acceptance criteria, which are the limits under which the transport may be considered safe, with regards to the motion of the vessels is elaborated in chapter five. Following this, in chapter six the description of the simulator setup, the choice of environmental conditions and other settings, and the conduction of the test runs is particularized. The results of which are then investigated in detail throughout chapter seven in order to compare them to the criteria defined in chapter five. Chapter eight presents a HAZID on the basis of the acceptance criteria and the results in chapter seven. The discussion of how to categorize the results and how to improve the quality in order to apply the acquired data for the definition of the tow's operating limits is presented in chapter nine. The last chapter contains the conclusion, which sums up the findings of this thesis.

2. EMS TUG and EMS PONTON 7

The vessel EMS TUG, as depicted in Figure 1, is the newest addition to the fleet of Ems Offshore Service, a small tug company located in Leer, Germany. It's a multi-purpose tug boat of the Shoalbuster type built by Damen Shipyards, with the capacity of towing, pushing, dredging support, harbor maintenance, buoy - and anchor handling. In addition, it has some deck cargo capacity. Its flat bottom and thus shallow draught makes the tug versatile and capable of working offshore as well as in restricted waters.

Figure 1: EMS TUG at the Christening in January 2020

Table 1: Ship Particulars EMS TUG

Ship's Name	EMS TUG
Port of Registry	Madeira
Owner	EMS TUG GMBH & CO. KG
Year of Delivery	2019
Builder	Damen Shipyards
LOA (Length Over All)	27.05 m

Breadth Over All	11.63 m
Depth Molded	4.25 m
Summer Draft	2.95 m
IMO Number	989734
Goss Tonnage	321
Main Propulsion	3,500 bhp
Bow Thruster	200 bhp
Bollard Pull	45.2 t

The loadings condition in Table 2 is for full load. The simulator model adheres to this condition. The particulars in Table 1 have been taken from the official stability booklet:

Table 2: Stability Condition of EMS TUG with 98% Consumables on Board (DAMEN Shipyards, 2019)

Hydrostatics	
Volume	508.401 m3
LCF	11.023 m
Mom. change trim	4.862 ton-m/cm
Ton/cm immersion	2.523 ton/cm
Density	1.0250 ton/m3
Drafts above base:	
Draft mean (Lpp/2)	2.950 m
Draft aft (App)	2.978 m
Draft fore (Fpp)	2.922 m
Trim	-0.056 m
Transverse stability	
KM transverse	5.779 m
VCG	3.378 m
GM solid	2.401 m
GG' correction	0.104 m
VCG'	3.482 m
G'M liquid	2.297 m

The rolling period is the time the vessel requires for one full rolling motion, i.e. from one extreme to another extreme and back. For the EMS TUG is calculated as per the stability booklet: (DAMEN Shipyards, 2019)

$$T = \frac{2 * C * B}{\sqrt{GM}} [s]$$

where:

$C = 0.373 + 0.023\left(\frac{B}{d}\right) - 0.043\left(\frac{L}{100}\right)$

$L = \ waterline\ length\ of\ the\ ship\ [m]$

$B = moulded\ breadth\ of\ the\ ship\ [m]$

$d = mean\ molded\ draft\ of\ the\ ship\ [m]$

$GM = metacentric\ height\ corrected\ for\ free\ surface\ effect\ [m]$

Adopting these values to the loading condition of the tug in the presented condition gives:

$$T_{tug} = \frac{2 * \left(0.373 + 0.023\left(\frac{10.5}{2.95 - 0.15}\right) - 0.043\left(\frac{24.58}{100}\right)\right) * 10.5}{\sqrt{2.297}} = 6.2s$$

The 0.15 which are subtracted from the mean draft account for the keel plate, since the draft molded is required. When dimensions are stated as molded, they refer to the design drawings of a vessel, which are always designed without the outer hull.

Ems Offshore Service operates two barges, a smaller barge of 55 meters length, the EMS PONTON 2, and a larger barge, the EMS PONTON 7. The latter is referred to in this thesis. It’s depicted in Figure 2 and the stability condition relevant for the modelling process is stated in Table 3. The barge is in frequent use and the stability of the model is in accordance with the barge on a typical voyage within its operating area.

Figure 2: EMS PONTON 7 Carrying the Superstructure of a Yacht, Retrieved May 27, 2020, https://lh3.googleusercontent.com/proxy/VWMhiZKmfXSr_dxkBTFzGNCurvofY-ojkePHVkhtemcVCGAFa4TjB22lwOIrhRknLe42tz3bTM83pup6jAlqt95AfB4q8l-s2uxU3i8sx7C6mwc

Table 3: Stability Condition EMS PONTON 7 (Hanse Survey, 2019)

Name	Emsponton 7
LPP (Length Between Perpendiculars)	71,24 m
LOA	72.29 m
Beam	18,98 m
Side height	4,5 m
Lightship	838,7 t
Deadweight	1976,62 t
Volume	2815.317 m³
Draft mean	2,306 m
Freeboard	2,194 m
Heel angle	0,249 °
LCB	35,479 m
LCF	35,407 m
LCG	35,536 m
VCG	3,805 m
VCG'	4,167 m

VCB	1,184 m
BM	13,759 m
KM	14.943 m
GM′	10.776 m

Also, for the barge it's prudent to calculate the roll period for later use with the formula: (Gudmestad, 2010)

$$T_{barge} = Cr\frac{b}{\sqrt{GM}}$$

where:

$Cr = \frac{2\pi}{\sqrt{12g}}$

$L = \ waterline\ length\ of\ the\ ship\ [m]$

$b = \ breadth\ of\ the\ \ [m]$

$GM = metacentric\ height\ corrected\ for\ free\ surface\ effect\ [m]$

$$T_{barge} = 0.58\frac{18.98}{\sqrt{10.776}} = 3.35s$$

These two vessels are the basis for the models which have been created for the conduction and use of this thesis. The following chapter goes further into detail about how this was done.

3. Creation of the Model

The creation of a model for a ship handling simulator is a long and tedious process. Relevant data, sizes and drawings have to be acquired. Then a graphical model can be created, resembling the original vessels as closely as possible. Furthermore, physics components have to be included and maneuvering characteristics need to be adjusted. The individual steps and programs used will vary from manufacturer to manufacturer. The method described throughout the following section isn't necessarily the only existing, or even the best method. The reason for choosing specifically this approach is due to the fact that it is the method recommended by the 3D Data Base Designer from Nautitec, the company which is operating the full mission simulator in Leer, Germany. The simulator these models have been created for and in which the execution of the test runs for this thesis have been performed is from the maker Transas Marine, which is part of Wärtsilä since 2018. All software used was therefore dictated by Transas. The central tool is Transas' Virtual Shipyard (Figure 3), which embodies several applications and tools, namely:

- 3D Studio Max, which is not a Transas program, but is used in conjunction with the Virtual Shipyard and in this version contains a plug-in with additional tabs and data file formats.
- Prototype Editor, which is used to connect graphical and logical points, such as lights and bollard points.
- Motion Model Editor, which is used to tune the vessel towards the behavior it should possess.
- Scene, which allows the user to test the model within the Virtual Shipyard.

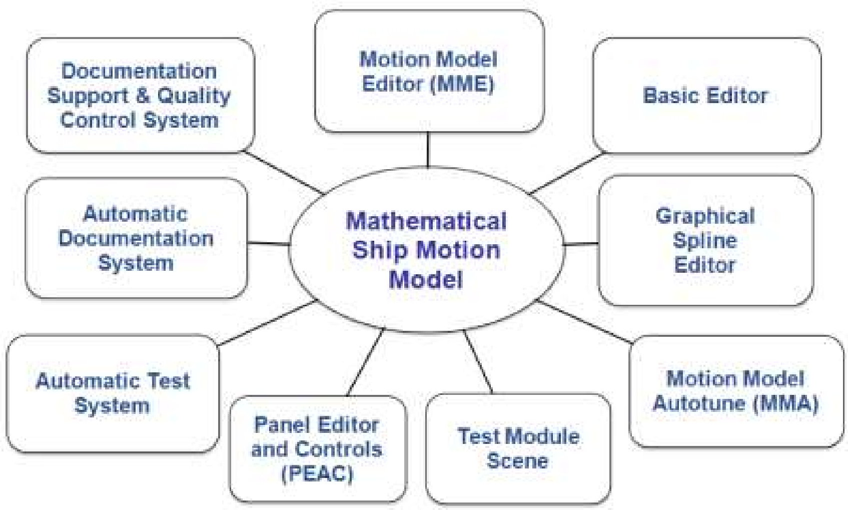


Figure 3: Virtual Ship Yard Components (Transas Marine Ltd., 2017)

These components are essential when creating a model for the Transas simulator. Basic skills in all of these have to be acquired in order to design, prepare, and tune a model. The following sub chapters will describe the development of the vessel EMS TUG in detail.

3.1. *The Visual Model*

Similar to laying the keel of a vessel when it's being built, the visual model also starts with the hull and works its way up towards the mast. For most models a simple lines plan is provided which shows the development of the hull lines at corresponding frames, an example of which is shown in Figure 4 below. The numbers on the hull lines refer to the frames. On the left-hand side, the rear section is depicted and on the right-hand side the forward section.

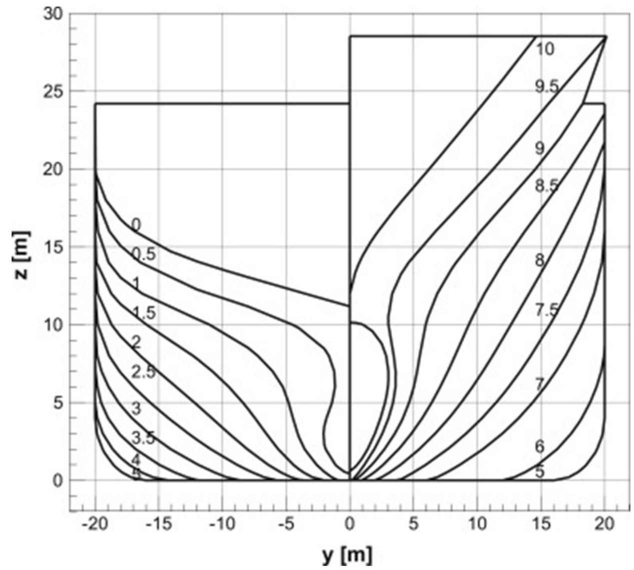


Figure 4: Lines Plan from a 6750 TEU containership, Retrieved April 15, 2020, https://www.researchgate.net/figure/Body-plan-of-the-6750-TEU-containership_fig33_302067702

Unfortunately for the EMS TUG such a drawing was not obtainable. Instead the drawings of 21 individual frames were provided in the general construction plan. In order to make use of these, each frame had to be cropped and adjusted using GIMP, which is an open source image editor. An example of a cropped and adjusted image may be seen below in Figure 5.

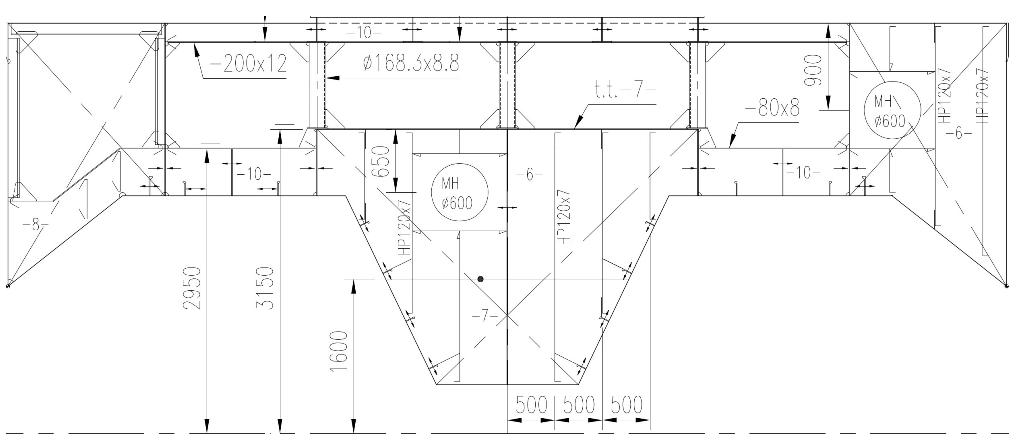


Figure 5: Frame 6, cropped and sized to be usable in 3D Studio Max

GIMP was also used to extract reference images of the side of the tug, the front and rear perspective, and the individual decks, from the general arrangement plan.

Once these preparations were completed the images could be imported in 3D Studio Max to create a blueprint. On the basis of this blueprint the 3D model was then designed. These early steps of the modeling process were not performed within the Virtual Shipyard, instead a student license for 3D Studio Max was used. This license was not used for any other purposes than this paper.

To arrange and display the above-mentioned images in 3D Studio Max correctly, minute attention has to be paid to the correct sizes, orientation and location of each individual image. Displaying the entire blueprint is not useful, as the images are stacked very closely. Instead, to illustrate this step in the creation of the model, an image showing the arrangement of the frames of the rear section may be seen in Figure 6 below.

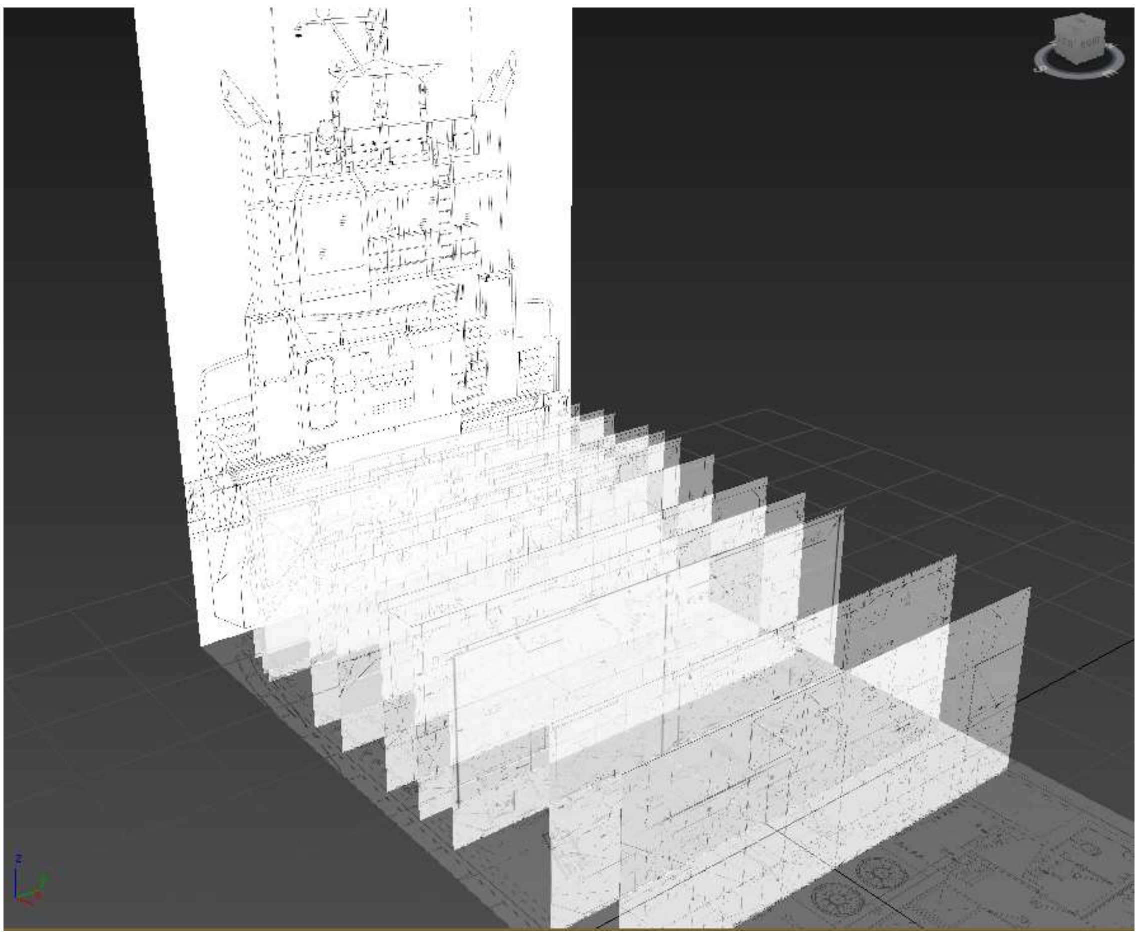


Figure 6: Rear Section Frames in 3D Studio Max

Having the frames stacked as closely as in the image above obviously is not useful for precise modeling. Instead all frames but one have to be made invisible to ensure that the shape of the hull at that particular frame is adapted according to the drawings.

There is a major difference in Virtual Shipyard to established real life ship building standards. Usually the aft perpendicular is referred to as frame 0 and the origin of the coordinate system used to draw the vessel. Everything forward from this point in the longitudinal direction (x-axis) has a positive value, whether measured in meters or inches. Varying from this, Transas refers to the middle of the ship as the origin of the coordinate systems, meaning that the forward section has positive x-values and the aft section negative x-values. For this reason, it is prudent to design the hull as a forward and an aft section and have the two sections meet along the y- and z-axis. In regards to the transverse, the international system and the Transas system coincide, as distances towards port are negative and distances towards starboard are positive values on the y-axis. In order to receive a symmetric shape of the hull on the port and starboard side, only one side was designed for the stern section and another for the forward section, which have then been mirrored and adjoined, as may be seen in the Figures 7 and 8 below.

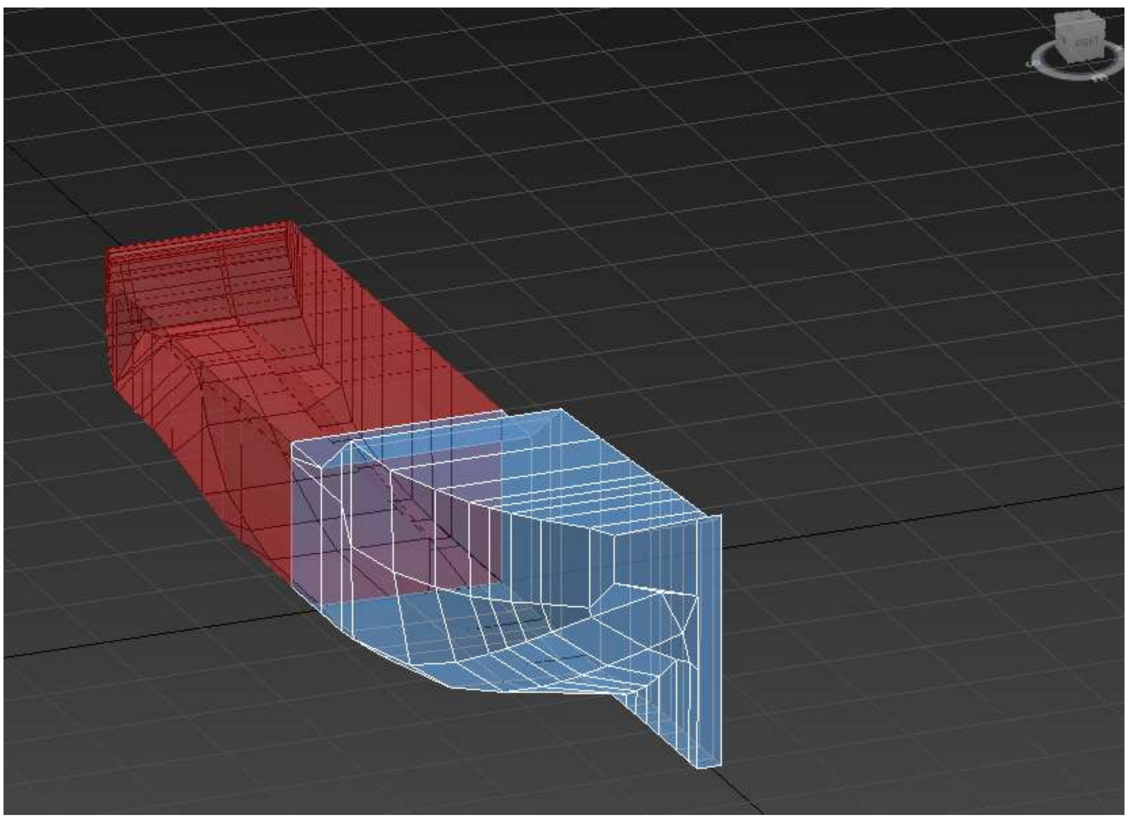


Figure 7:Starboard Stern and Forward Sections

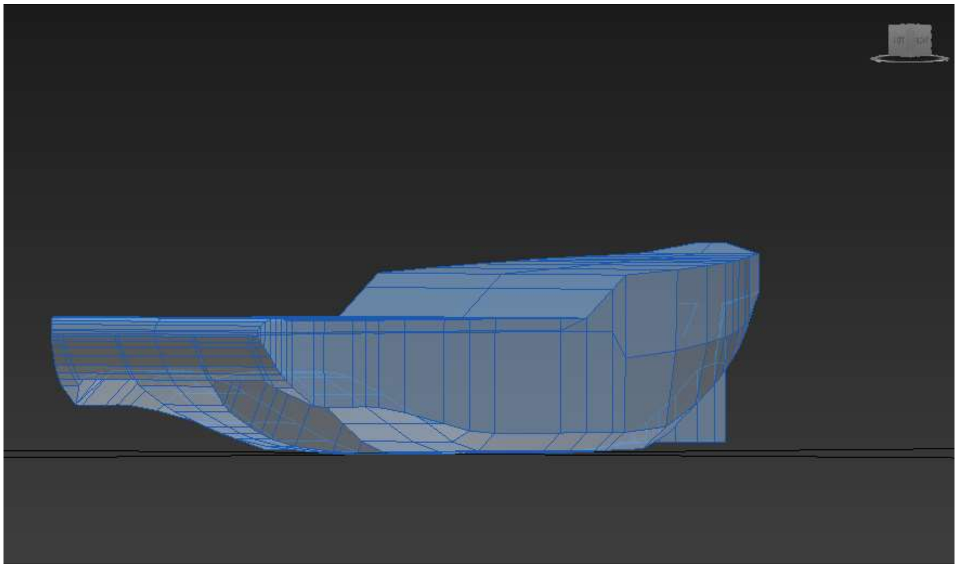


Figure 8: Mirrored and Adjoined Hull

Upon completion of the hull, next the larger deck elements and the superstructure had to be designed. From this point on the individual frames were no longer of importance, but instead images of the individual decks, the side view, the front view, and the rear view are needed to replicate the design in 3D, see Figure 9.

The objects have to be viewed from above, the side, the rear, and the front and have to be adjusted on each level in order to have some resemblance to the original EMS TUG.

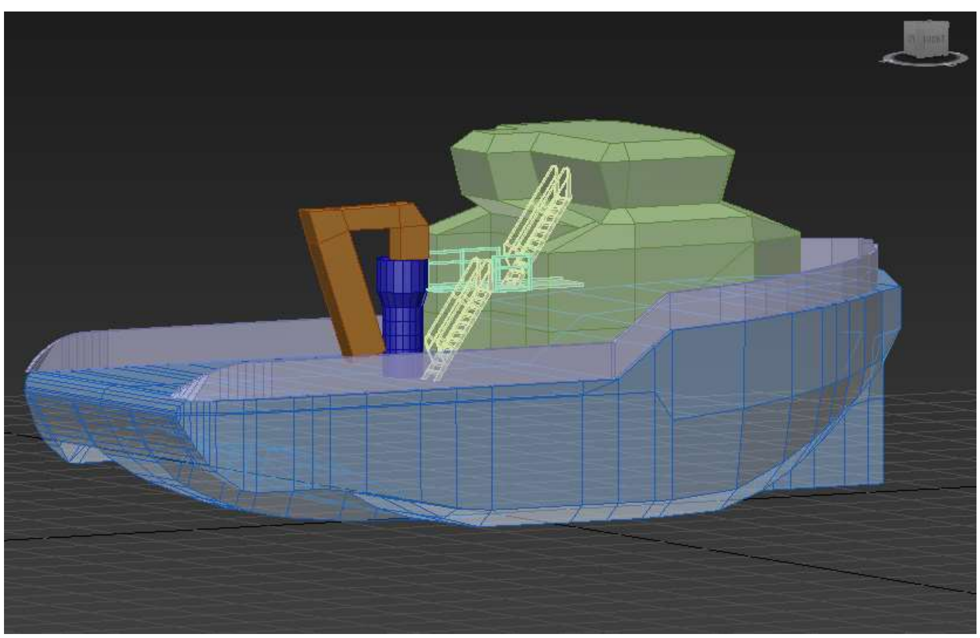


Figure 9: EMS TUG with Basic Deck Elements and Superstructure

As this thesis doesn't purely focus on the creation of the model, but also on the simulator runs and the results of the same, not every level of detail has been designed as would be standard for a simulator model being used for commercial purposes. However, some details were essential to add in order to comply with the physics that the simulator is using, such as propellers, mooring points, winch points, anchor points, navigational lights, et cetera. Thus all these and also the tire fenders around the hull were part of the final design.

As a last step in the design phase textures had to be created and applied to shapes and areas, in order to resemble not only the outline, but the actual appearance of the EMS TUG. Again, due to the limited time available the model was fitted with a mere five different textures, but these give a good enough impression of the looks of the real vessel. The textures were created in Adobe Photoshop with a private license, and fitted onto the model in 3D Studio Max using the "UVW Map" function from the available modifiers, which allows entire objects to be coated with a texture.

Below (Figures 10 to 12) are images of the completed model and in comparison, the screenshots from Damen Shipyards' animation.

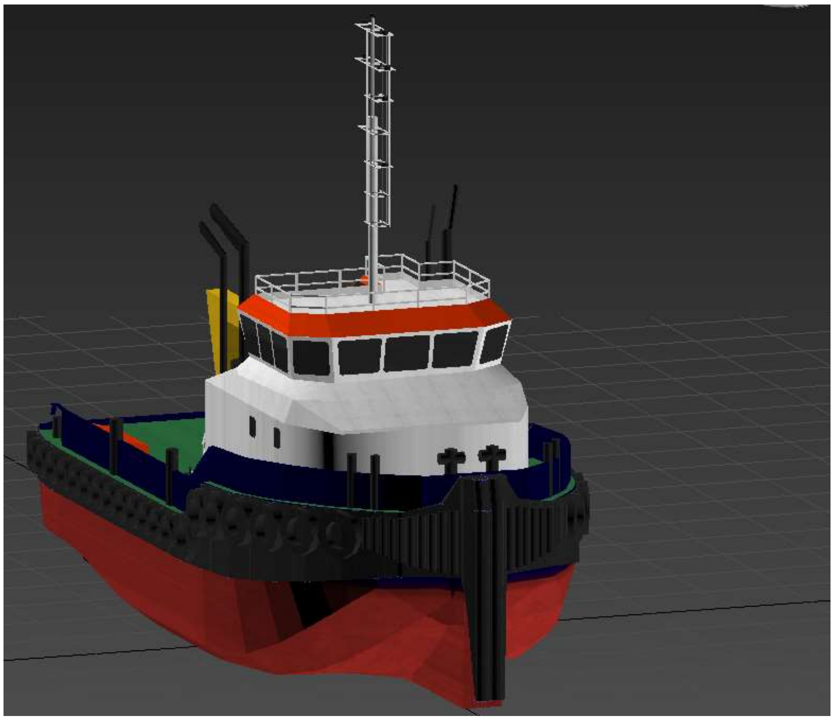


Figure 10: Starboard Forward View from the Completed Model in 3D Studio Max

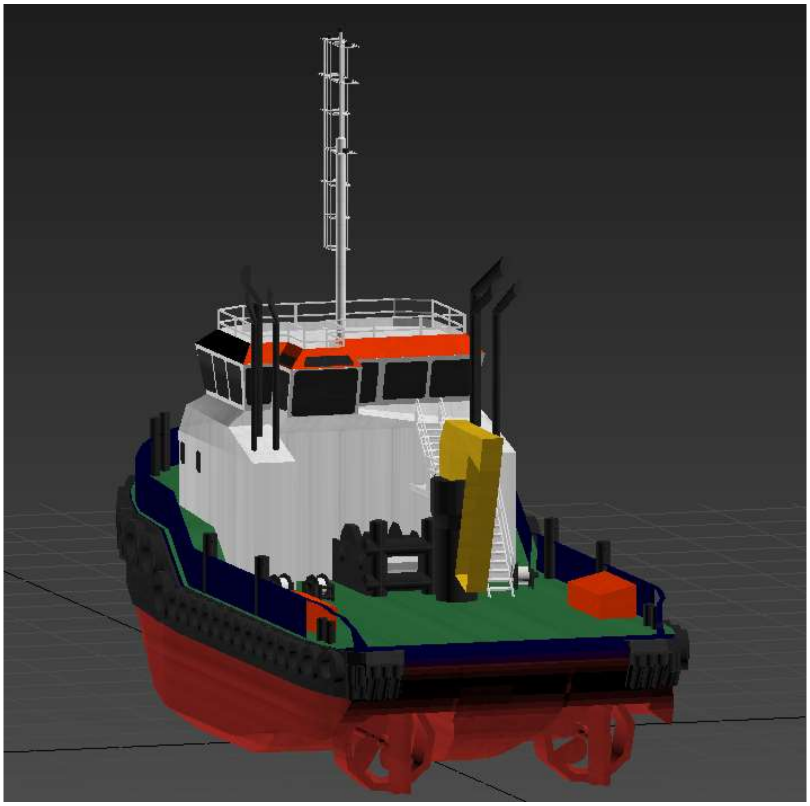


Figure 11: Port Aft View from the Completed Model in 3D Studio Max

Figure 12: Original Vessel Design from Damen Shipyards

The level of detail of the original vessel is far beyond the model created in the course of this thesis. However, additional attention to detail would not have yielded any better results on the simulator runs compared to this model.

3.2. The Reference Model

Probably the simplest way to fit a simulator model with reasonably realistic maneuvering characteristics, if the word simple can be applied to such a process, is to choose a reference model. This should be of the same type, similar size and power. The characteristics of such a reference model may then be used as a basis for the new model.

The reason being that there is a vast number of variables, curves, and hydrostatic coefficients which influence the behavior of the vessel. To make things even more complicated, changing one parameter often affects a number of others. Understanding each and every one of these factors and their possible interactions with each other is a task which would take months; therefore, the behavior of the vessel was tweaked by trial and error to come close to the actual EMS TUG. Turning circles, stopping distances, rudder delay, and acceleration are key figures to go by. The drift behavior, the motion in waves and the effect of other external factors are very difficult, if not impossible, to put into numbers without runs in a test basin. Therefore, the feel of the vessel, based on experience, has had a considerable influence on the tuning of the model. It's important to highlight one more time that this paper is about the methodology of not only creating a model, but also performing test runs in the simulator and evaluating the gathered data. This is the reason, why there was limited time available which could go into adjusting the behavior of the model.

A ship possesses six degrees of freedom: surge, sway, and heave as linear movements and roll, pitch, and yaw as rotational movements, Figure 13. For each of these a vessel has an amplitude and a phase, which differ with speed, wave height, wave period, wave direction, intact stability, and the draft. This data is referred to as RAOs (response amplitude operators) and may be obtained from analysis software or model trials in a test basin. (Orcaflex)

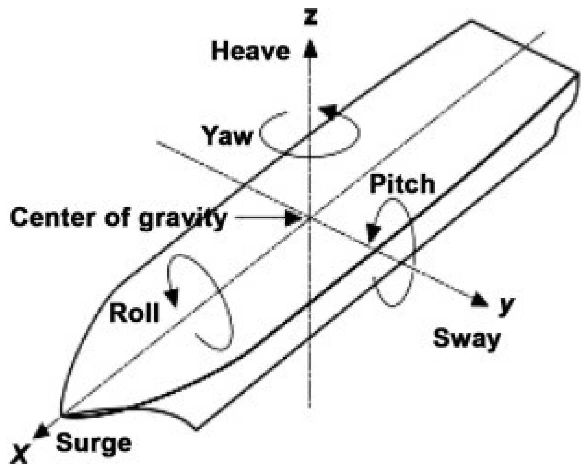


Figure 13: A Ship's Six Degrees of Freedom, Retrieved April 17, 2020, https://ars.els-cdn.com/content/image/3-s2.0-B9780081022825000041-f04-18-9780081022825.jpg

However, there are two big limiting factors to using RAOs: firstly, RAOs always refer to regular waves. This means that all waves have the same sinusoidal shape and they do not in any way differ from one another. These conditions are actually never really encountered, as the sea is always scrambled to a certain degree and sets of larger and smaller waves keep interchanging. (Ultramarine, 2011)

The other problem is the simulator. As mentioned above the model has a vast number of tweak points which may be altered to reproduce a desired effect, but there is no option to feed the data of a RAO into the model in order to make it behave in this exact manner. Instead, this again has to be done by a series of trial and error, which would take a vast amount of time.

As is customary for vessels of this size, the Damen Shipyard didn't supply RAOs.

The reference model in this case was chosen from the Transas Marine Data Base. The model name is Conventional Twin Screw Tug 7. The model has similar outer dimensions, but far less bollard pull, still it is the closest functioning model which was available.

To apply the physics of the Conventional Twin Screw Tug 7 onto the EMS TUG, the original Conventional Twin Screw Tug 7 is loaded in the Prototype Editor, whereupon the graphical model is deleted and replaced with the file created in 3D Studio Max. As a matter of fact, for a fully functioning model, not only one visual model is required, but four. Two daylight models, one with full details, and one with reduced details for further away views. Also two night models, again with full and reduced details. However, these additional layouts are for the purposes of this thesis not relevant and instead all four models have been fitted with the above described and displayed model.

Once the logic of the reference model is merged with the new design, the motion model can be accessed and changed in the Virtual Shipyard program. Here the aforementioned coefficients and curves may be accessed and altered.

One of the most useful tools of the Virtual Shipyard is the Scene function. It enables the user to perform test runs of the model throughout the design phase. Environmental conditions may be adjusted, as well as the propulsion unit of the model. Thereby, the effects of changes in the motion model may be observed in a quick and easy manner.

3.3. The Pontoon

The creation of the EMS PONTON 7 was quite easy compared with the process required for the EMS TUG. No designing in 3D Studio Max was necessary, as most pontoons used in the transportation section look roughly the same. Therefore, an existing model was adopted from the Transas library, namely the Oil Barge 255, and adapted in dimensions, displacement, and stability according to the specs and stability condition of the EMS PONTON 7, when carrying a sample section for the Meyer Shipyard as described in chapter 2. Also, for the pontoon there are no RAOs available and therefore the model has been used almost the way it was designed by the Transas engineers, only the resistance was reduced slightly to match the speed table which was delivered from the EMS TUG during towing operations.

Upon completion of the models, they have to be written as cabinet files, which may then be installed on the model server of the simulator.

4. Voyages

The company Ems Offshore Service has been running transports and tows for over 30 years. The core business has been the transportations of smaller sections for the MEYER WERFT, which is among the largest shipyards worldwide. The MEYER WERFT is building mainly passenger vessels and large luxury yachts. These are produced in three shipyards, one in Papenburg, Germany, another in Rostock, also Germany, and a third in Turku, Finland. The smaller sections which are then shipped towards one of these three shipyards by means of pontoons are being built in Klaipeda, Lithuania, Gdynia, Gdansk, and Stettin, all three located in Poland. Table 4 below gives an overview of the distances and the steaming time for four, six, and eight knots towing speed over ground.

Table 4: Sea Distances and Steaming Time for MEYER WERFT Transports

From	To	Distance	Time @ 4kts	Time @ 6kts	Time @ 8kts
Klaipeda	Papenburg	631 nm	158 hrs	105 hrs	79 hrs
Gdynia/Gdansk	Papenburg	581 nm	145 hrs	97 hrs	73 hrs
Szczecin	Papenburg	452 nm	113 hrs	75 hrs	57 hrs
Szczecin	Turku	511 nm	128 hrs	85 hrs	64 hrs
Gdynia/Gdansk	Turku	389 nm	97 hrs	65 hrs	49 hrs
Klaipeda	Turku	301 nm	75 hrs	50 hrs	38 hrs
Klaipeda	Rostock	361 nm	90 hrs	60 hrs	45 hrs
Szczecin	Rostock	183 nm	46 hrs	30 hrs	23 hrs
Gdynia/Gdansk	Rostock	311 nm	78 hrs	52 hrs	39 hrs

The steaming time varies between just under one day and over 6 days, depending on the voyage and the towing speed. These are not the only voyages that EOS is performing with its tugs and barges, but these do happen on a regular basis and are expected to be run numerous more times in the coming years. The detailed planning of the voyages is performed onboard the vessel and the distances in the table above are rough calculations performed on the website of www.searoutes.com. (Searoutes, 2020)

Before the commencement of a tow the insurer requires an insurance towing survey, or towing warranty survey of fitness to tow. These surveys have to be conducted by an approved and independent surveyor. The purpose of such a survey is to establish whether the tug, the barge, the cargo, and the equipment in use are fit for the voyage. This entails: (Shipowners' Club, 2013)

- Good condition of the entire tow, including the stowage of the cargo
- Compliance with safe manning
- Verifying that the tug’s bollard pull is adequate for the intended tow
- Good condition of the towing equipment in use, including emergency provisions
- Stability calculation of tug and barge and the thus resulting cargo securing requirements

- Full towage and passage plan

4.1. Places of Refuge

Whilst a tug is engaged in a tow its maneuverability is considerably reduced, compared to when it's not connected with a barge via the towline. During a tow the steaming speed is also lower. It may still be assumed - since the distances between the ports are quite small in the Baltic Sea and southern North Sea - that in a looming distress situation the towline could remain connected, whilst the dyad is approaching a place of refuge. This is certainly not a desirable course of action, but it highlights that in most situations the course of action required is not based on the issue of safety of life at sea. If the safety of the tug were actually threatened, the tow line would have to be released in order for the tug to perform an emergency maneuver, which would put actions under the provisions of the Search And Rescue (SAR) convention. Instead and more common, it's the vessels or - more precisely - the barge which requires shelter in order to not damage or lose the valuable sections that are being transported. For this reason, a place of refuge or save haven, as per the IMO's (International Maritime Organization) guidelines on places of refuge for ships in need of assistance should be approached. (IMO, 2003) A place of refuge is a spot where a vessel may stabilize in order to deescalate a hazardous situation. Such places, typically ports, should be mentioned in a full passage plan. In the example of the EMS TUG and the EMS PONTON 7, amongst others a hazardous situation may be unexpected heavy seas or heavy weather. In such conditions a place of refuge should be approached and used to shelter until the circumstances improve.

In the following maps (Figures 14 to 16) not only the departure and destination ports mentioned earlier are highlight, but also possible places of refuge along the routes. The voyage from Klaipeda to Rostock also covers the passages from Gdansk, Gdynia, and Szczecin to Rostock, since these ports may also serve as places of refuge. The distances and steaming times are listed in Tables 5 to 7.

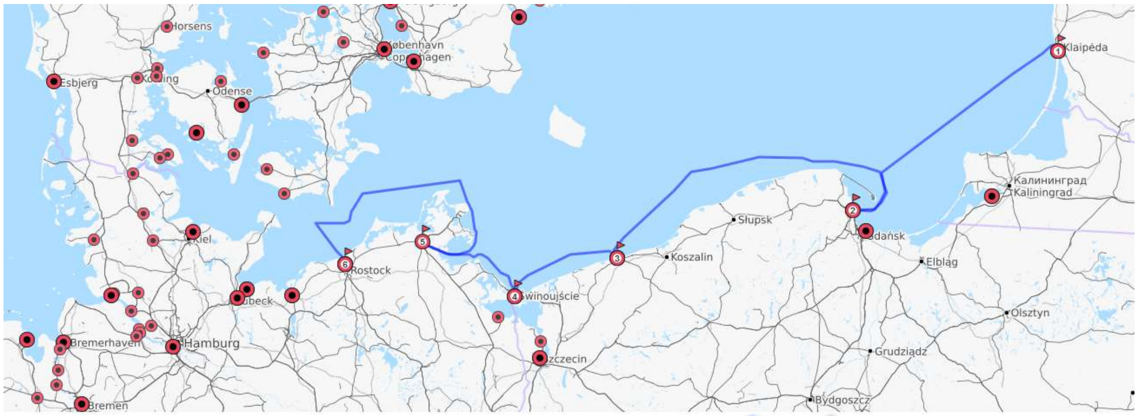


Figure 14: Places of Refuge along the Voyage Klaipeda to Rostock, Retrieved May 19, 2020, www.searoutes.com

Table 5: Distances Between Places of Refuge Along the Route Klaipeda to Rostock

Place of Refuge	Distance	Time @ 4kts	Time @ 6kts	Time @ 8kts
Klaipeda				
Gdynia/Gdansk	123 nm	31 hrs	21 hrs	15 hrs
Kolobrzeg	164 nm	41 hrs	27 hrs	21 hrs
Swinoujscie	54 nm	14 hrs	9 hrs	7 hrs
Stralsund	54 nm	14 hrs	9 hrs	7 hrs
Rostock	150 nm	38 hrs	25 hrs	19 hrs

The voyages to Papenburg may be viewed as a voyage from Rostock to Papenburg, since Rostock and all the places of refuge already mentioned are within the wake of these routes.

Figure 15: Places of Refuge along the Voyage Rostock to Papenburg, Retrieved May 19, 2020, www.searoutes.com

Table 6: Distances Between Places of Refuge along the Route Rostock to Papenburg

Place of Refuge	Distance	Time @ 4kts	Time @ 6kts	Time @ 8kts
Rostock				
Heiligenhafen	47 nm	12 hrs	8 hrs	6 hrs
Kiel	39 nm	10 hrs	7 hrs	5 hrs
Brunsbüttel	53 nm	13 hrs	9 hrs	7 hrs
Cuxhaven	17 nm	4 hrs	3 hrs	2 hrs
Wilhelmshaven	83 nm	21 hrs	14 hrs	10 hrs
Borkum	103 nm	26 hrs	17 hrs	13 hrs
Eemshaven	8 nm	2 hrs	1 hr	1 hr
Emden	15 nm	4 hrs	3 hrs	2 hrs
Papenburg	30 nm	8 hrs	5 hrs	4 hrs

In the table above the passages from Kiel to Brunsbüttel, i. e. the Kiel Canal and from Emden to Papenburg up the Ems are river passages, and therefore no heavy seas are to be expected. They have been listed here only for completeness sake.

For the passage towards Turku the voyages starting from Gdansk, Gdynia, and Klaipeda are presented as a single voyage. The passage from Szczecin to Turku follows another coastline, therefore both options are depicted below.

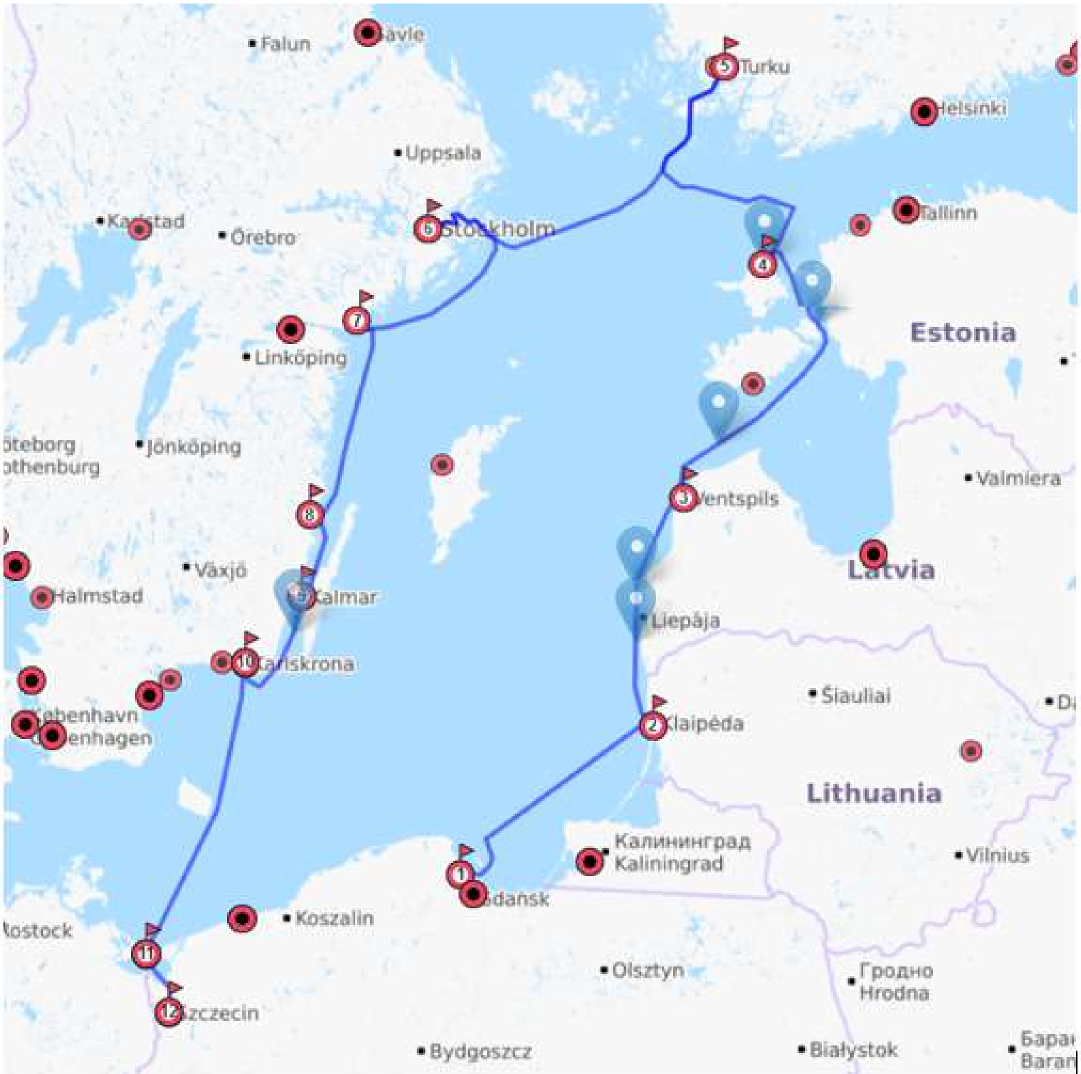


Figure 16: Places of Refuge along the Voyages towards Turku, Retrieved May 19, 2020, www.searoutes.com

Table 7: Distances Between Places of Refuge along the Routes towards Turku

Place of Refuge	Distance	Time @ 4kts	Time @ 6kts	Time @ 8kts
Rostock				
Gdynia/Gdansk	125 nm	31 hrs	21 hrs	16 hrs
Klaipeda	112 nm	28 hrs	19 hrs	14 hrs
Ventspils	149 nm	37 hrs	25 hrs	19 hrs
Lehtma	143 nm	36 hrs	24 hrs	18 hrs
Turku	125 nm	31 hrs	21 hrs	16 hrs

Szczecin				
Swinoujscie	31 nm	8 hrs	5 hrs	4 hrs
Karlskrona	145 nm	36 hrs	24 hrs	18 hrs
Oskarshamn	104 nm	26 hrs	17 hrs	13 hrs
Oxelosund	98 nm	25 hrs	16 hrs	12 hrs
Stockholm	117 nm	29 hrs	20 hrs	15 hrs
Turku	175 nm	44 hrs	29 hrs	22 hrs

4.2. Wave Conditions

Waves on oceans are a natural occurrence, however the statistical behavior of waves, the wave spectrum, is different depending on the area of trade. As mentioned earlier the main area of operations for the EMS TUG and the EMS PONTON 7 is the southern North Sea and the Baltic Sea, so the simulator runs should refer to the conditions likely to be encountered in real life. The BSH (Bundesamt für Seeschifffahrt und Hydrographie) offers environmental data from the past twelve months, recorded by various buoys and measuring stations. The wave buoy 'TW Elbe' has been used as an example to roughly determine the peak wave periods and the significant wave heights (Figures 17 and 18) for the voyages to Papenburg, where the main shipyard of the MEYER WERFT is located. The wave buoy is placed roughly half way between Helgoland and the entrance to the river Elbe, an area which tug and pontoon will cross on the voyages to Papenburg.

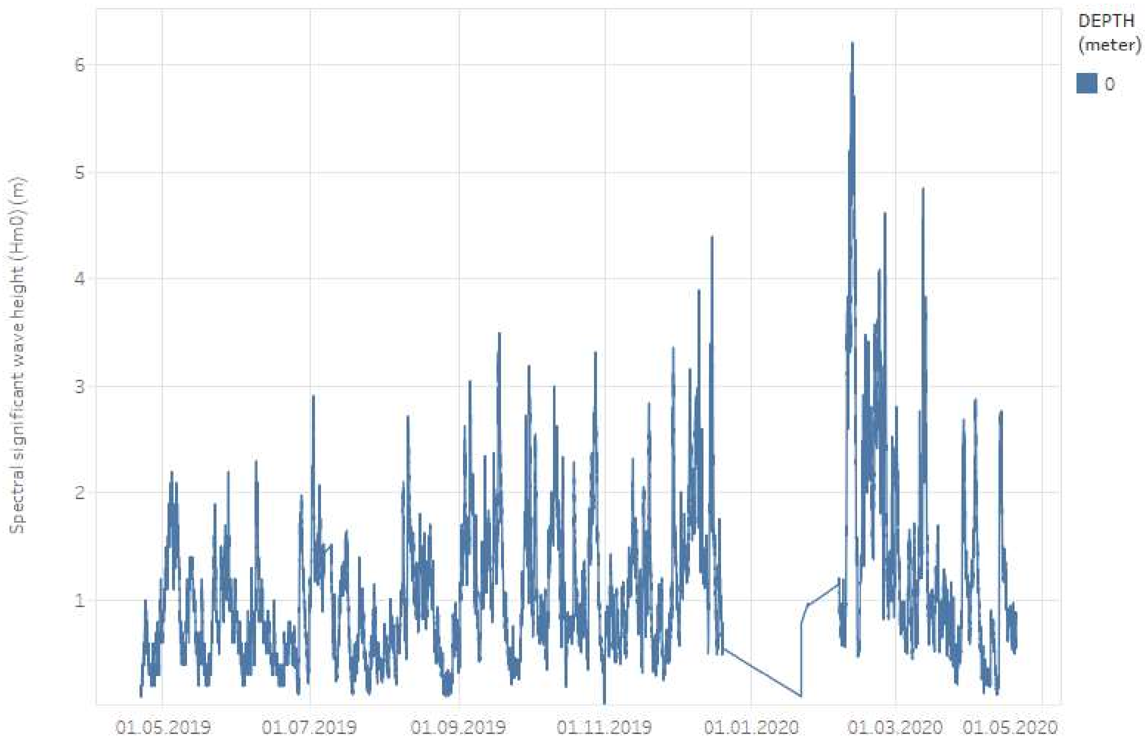


Figure 17: Significant Wave Height for the Past 12 Months, Retrieved April 20, 2020 (BSH, 2020)

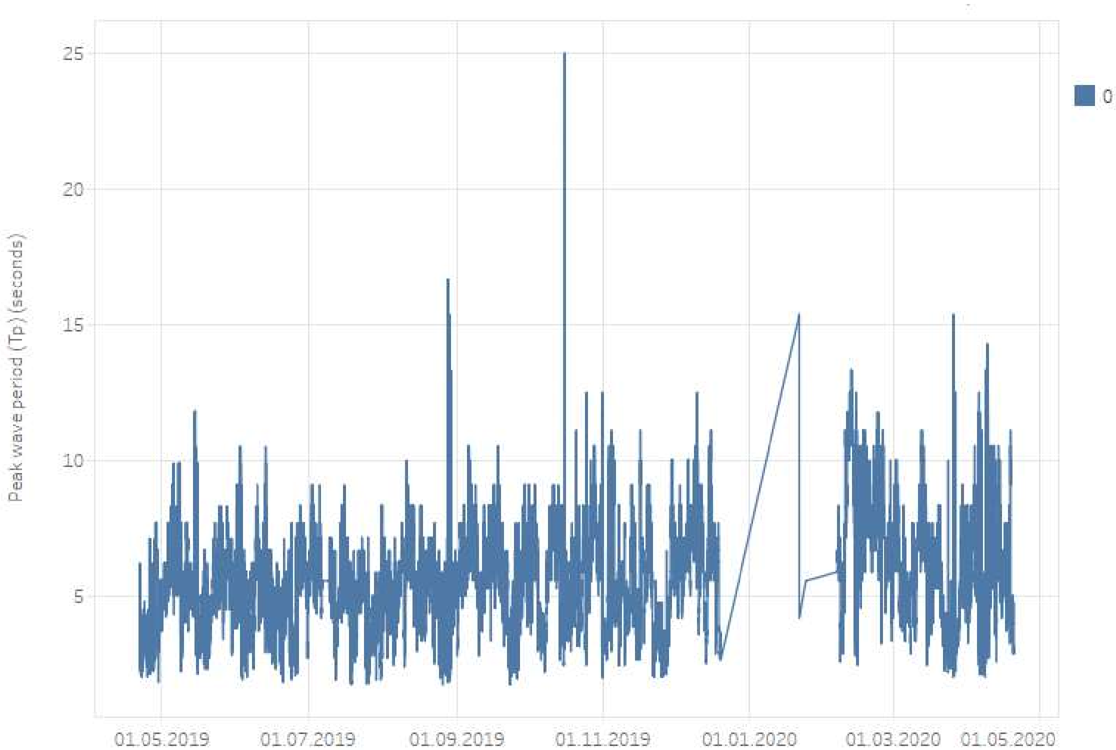


Figure 18: Peak Wave Period for the Past 12 Months, Retrieved April 20, 2020 (BSH, 2020)

Even though these graphs are densely populated it is fair to say, that on average at a significant wave height of more than one meter, the mean peak wave period ranges from six to eight seconds. A team of researchers from the Department of Civil Engineering, Ghent University have found comparable results for the island Borkum, which is also along the route of the voyages towards Papenburg, see Table 8.

Table 8: : Characteristic Sea States on the German Continental Shelf, Retrieved April 20, 2020 (Beels & al., 2007)

Location	Fino-Borkumriff			
Mean water depth [m]	27			
Distance to shore [km]	34.5			
Average annual available wave power [kW/m]	11.6			
Sea State	1	2	3	4
H[m]	0.25	0.75	1.25	1.75
T_e[s]	4.15	4.67	5.53	5.95
Wave power [kW/m]	0.13	1.35	4.50	9.57
O.F.[%]	9.14	27.31	22.62	18.55
Sea State	5	6	7	8
H[m]	2.25	2.75	3.25	3.75
T_e[s]	6.21	6.59	7.55	8.16
Wave power [kW/m]	16.77	27.73	45.39	66.54
O.F.[%]	10.25	5.08	3.35	1.63

This data supports the aforementioned observation, that at significant wave heights of more than one meter a wave period of six to eight seconds may be expected. A wave spectrum consists of many more parameters and is expressed as complex formula.

Two wave spectra are worth mentioning here:

- The JONSWAP spectrum, the name is based on a joint research project during which it has been established, the ‘JOint North Sea WAve Project’. It has been developed on the basis of wave measurements in the southern North Sea.
- The Pierson-Moskowitz spectrum, which was Pierson’s and Moskowitz’s proposal to define a fully developed sea state with waves influenced by steadily blowing winds over a longer period of time. Contrary to the JONSWAP spectrum the Pierson-Moskowitz spectrum was developed on the basis of wave measurements in the North Atlantic.

The two spectra are for the most part quite similar, but because the JONSWAP spectrum is focusing more on developing seas the peaks in the spectrum are more pronounced. (Gudmestad,

2010) The reason for mentioning these spectra is, that the simulator offers a range of wave spectra the user may choose from.

As towing is a weather restricted operation, the DNV paper on offshore standards advises to choose a maximum significant wave height and associated period by considering: (DNV, 2011)

- Feasibility and safety of the intended tow
- Historical weather averages for the voyage during the intended season
- The uncertainties that have to be accounted for in a weather forecast

The document defines the above mentioned-uncertainties in the weather forecast as the α-Factor. It's recommended to define the operational criteria for the significant wave height in the weather forecast as α times the operational limit under which the operation may be conducted in a safe manner, i.e. until which wave height the tow is considered to be safe.

$$OP_{Weather\ Forecast} = \alpha * OP_{Limit}$$

The α-Factor varies with how long the intended operation is planned to take, see Table 9. As a tow should be seen as an uninterrupted operation, the estimated time for the voyage should be used to select the α-Factor.

Table 9: Alpha Factor for Waves (DNV, 2011)

Operational Period [h]	*Design Wave Height [m]*						
	$H_s = 1$	*$1 < H_s < 2$*	*$H_s = 2 = 2$*	*$2 < H_s < 4$*	*$H_s = 4$*	*$4 < H_s < 6$*	*$H_s \geq 6$*
$T_{POP} \leq 12$	0.65	Linear Interpolation	0.76	Linear Interpolation	0.79	Linear Interpolation	0.80
$T_{POP} \leq 24$	0.63		0.73		0.76		0.78
$T_{POP} \leq 36$	0.62		0.71		0.73		0.76
$T_{POP} \leq 48$	0.60		0.68		0.71		0.74
$T_{POP} \leq 72$	0.55		0.63		0.68		0.72

Whilst the above holds for tows to Turku and Rostock where the entire passage is through more or less open waters, the situation is somewhat different for the passages to Papenburg. The Kiel Canal is being passed on these voyages, which will not experience heavy seas. Therefore, the tow may be seen as two separate operations and each should be judged independently. As an example, a tow from Klaipeda to Papenburg is assumed. The distance from Klaipeda to Kiel is estimated at 399 nautical miles. Calculating with a towing speed of six knots this results in a voyage time of 67 hours. Referring this to table above 67 hours lies between 48 hours and 72 hours, which is situated in the bottom row. To arrive at the α-Factor an operational limit for the significant wave height has to be defined. Assuming an operational limit of 3.0 meters significant wave height the value for the α-Factor has to be interpolated between 0.63 for 2.0 meters significant wave height and 0.68 for 3.0 meters significant wave height, resulting in 0.655. Using the formula from above this gives:

$$OP_{Weath\quad Forecast} = 0.655 * 3.0m \cong 2.0m$$

Meaning, that a weather forecast of more than 2.0 meters significant wave height along the route would mean, that the departure should be delayed until conditions improve. On the other hand, when looking at the second part of the voyage, the leg from Brunsbüttel to Papenburg with 171 nautical miles, the situation differs. Since the steaming time is only 29 hours the bottom third row may be used to acquire the α-Factor. Resulting in a maximum of forecasted significant wave height allowable for safe operations of 2.2 meters:

$$OP_{Weather\ Forecast} = 0.72 * 3.0m \cong 2.2m$$

This example emphasizes that the further ahead the weather forecast looks, the less precise it becomes and a larger safety margin has to be applied.

It may be argued that due to the places of refuge along the route the α-Factor can be neglected, however it is usually more beneficial to conduct the voyage as a single passage and not to hop from port to port. However, in case of a transport with high urgency this procedure may be applied. If on the other hand a transport should be performed, which does not have numerous places of refuge along the intended route the α-Factor has to be accounted for.

5. Acceptance Criteria

Despite the transport on a barge being a more or less common occurrence in the maritime sector nowadays, this method is often wrongly considered to be of lower risk when compared with transports onboard larger vessels. (Divakaran, 2020) Tug boats being much smaller than cargo vessels is a good selling point, they are cheaper to charter and it makes them more versatile and capable of maneuvering in restricted waters with shallow draft requirements. But it also means that the small vessel is exposed to the same elements a larger vessel would be, and has to handle the same weight of the cargo, which – relative to the vessel's displacement – is many times heavier than for a cargo ship. Thus, it is essential to choose limits beyond which it is no longer safe for the tug or the barge to continue the voyage. These acceptance criteria will be compared with the results from the simulator to establish the limits under which circumstances the simulated situation would still be acceptable.

5.1. *Ability to Maintain Heading*

The ability of the tug to maintain any desired heading is indispensable. Without the possibility to choose and follow a designated course the tow may run aground, or even cause a collision, both potentially resulting in major economic and environmental damage. A combination of power setting, wave height, and wave period which would leave the vessel restricted in the choice of headings is therefore plainly unacceptable.

5.2. *Angle of Roll*

Large roll angles and strong roll acceleration are an ever-present danger for floating marine operations. The higher a structure reaches above the water line the more acceleration it will experience with the same rolling motion, even though the roll angle doesn't change. Rolling motions are induced due to the vessel interacting with the waves, but also winds and changes in stability lead to rolling motions.

5.2.1. Angle of roll for EMS PONTOON 7

Extreme rolling motions may result in the side of the barge's deck being submerged which would reduce the width and as a result reduce the stability. Such situations should therefore be avoided, in particular with the barge, since it may lead to water ingress in the block being transported. This would further decrease the stability due to the upwards shift of the center of gravity and the free surface effect and thus endanger the tow. This critical heeling angle may be calculated by the following formula: (Gudmestad, 2010)

$$\tan \phi_{max} = \frac{h - T}{\frac{b}{2}}$$

where h = side height [m]

T = draft [m]

b = beam [m]

Adopting this to the measurements of the barge in the condition described earlier ϕ_{max} results as follows:

$$\phi_{max} = tan^{-1}\left(\frac{h-T}{\frac{b}{2}}\right) = tan^{-1}\left(\frac{4.5-2.306}{\frac{18.98}{2}}\right) \cong 13.02°$$

The MSC (Maritime Safety Committee), which addresses matters of maritime safety within the domain of the IMO, has established a severe weather and rolling criterion. According to this, the angle of heel should not exceed 16 degrees or 80%, whichever is less, of the angle under which the side of the deck will be submerged as a result of a steady wind pressure. (Resolution MSC.267(85), 2008) This value is a general rule and may be applied to stability calculations for all transports. Adopting the 80 % to the maximum heel angle calculated above gives:

$$\phi_{Wind\,\mathrm{max}\,general} = 80\% * 13.02° \cong 10.42°$$

This in turn leaves 20% of the maximum heeling angle for waves.

$$\phi_{Wave\,\mathrm{max}\,general} = 20\% * 13.02 \cong 2.6°$$

However, these values and limits are general criteria. Looking further into the document reveals a section which specifically addresses the stability of pontoons. In this section it's stated that a static heel due to wind should not exceed an angle which would reduce the available freeboard by half. This applies for wind speeds of up to 30 m/s. (Resolution MSC.267(85), 2008) When looking at the Beaufort scale, this wind speed is in the second highest category, named violent storm. In these conditions, waves of 11.5 meters up to 16 meters are possible, making a safe transport of goods onboard a barge unthinkable and therefore the assumption that no larger wind induced heeling angles are to be expected.

The angle at which the freeboard is reduced to zero has already been calculated it may be divided by two to result in the angle leaving half the freeboard.

$$\phi_{Windmax} = \phi_{Wavemax} = 50\% * 13.02° \cong 6.51°$$

Thus, the maximum heeling angle induced by waves must not exceed 6.51 degrees.

5.2.2. <u>Angle of roll for EMS TUG</u>

The flooding angle of the EMS TUG is much larger with 42.38 degrees. Applying the rule of the MSC's resolution the smaller angle here would be the 16 degrees, leaving a maximum angle of 26.38 degrees which should not be exceeded.

5.3. Roll Acceleration

The DNVGL has published design criteria for barges in the paper about sea transport operations. According to the document there are certain criteria for unrestricted wave heights, for significant wave heights of less than six meters, and for significant wave heights for less than four meters. Since in the southern North Sea and the Baltic Sea a significant wave height of more than four meters is very rare these criteria may be adopted, Table 10.

Table 10: Criteria for Hs ≤ 4 Meters (DNV, 2015)

Acceleration/wind force	*Roll Case*	*Quartering*	*Pitch Case*
ay at waterline	0.26 g	0.20 g	0
ay increase for each metre (z) above waterline	0.017 g/m	0.013 g/m	0
ax at waterline (wl)	0	0.08 g	0.12 g
ax incr. each metre (z) above waterline	0	0.003 g/m	0.004 g/m
az at centre (C) barge	0.15 g	0.12 g	0.08 g
az incr. each metre (y, d or x respectively) from C	0.017 g/m	0.009 g/m	0.004 g/m
Wind pressure	0.3 kN/m2	0.3 kN/m2	0.3 kN/m2

Roll case refers to a beam sea situation and pitch case to head sea conditions. The values of 0.26g and 0.20g have to be amended due to the freeboard and the height of the COG (Center of Gravity) of the block, which is assumed to be at half its height.

$$ay_{Roll\ Case\ Max} = 0.26 + 0.017 * \left(2.306 + \frac{8.6}{2}\right) = 0.37g$$

$$ay_{Quartering\ Max} = 0.20 + 0.017 * \left(2.306 + \frac{8.6}{2}\right) = 0.31g$$

The above is specific to the loading case, for a more generic acceptance criterion the acceleration at the height of the deck may be assumed, due to the fact that the barge is simulated with the correct dimensions, weights, and their distribution, but without the actual block on the deck.

$$ay_{Roll\ Case\ Deck} = 0.26 + 0.017 * 2.306 = 0.3g$$

$$ay_{Quartering\ Deck} = 0.26 + 0.017 * 2.306 = 0.24g$$

The roll acceleration should therefore not exceed 0.3g or 2.94m/s² in beam seas and also not exceed 0.24g or 2.35m/s² in quartering seas.

The EMS TUG has some deck storage capacity, which is however not relevant for this observation, therefore no maximum roll acceleration is adopted for the tug. Howevertaking the crew's comfort into consideration, the acceleration should not exceed 0.4g, as the life onboard will become very uncomfortable under such conditions.

5.4. *Pitching Motion for EMS TUG*

When a ship's hull is subjected to strong opposing trimming moments a large angular acceleration is being produced, resulting in violent motions. This may still be the case, even if the pitching angles aren't excessive. If the ship is sailing into head waves there is a possibility that slamming may be encountered. This happens when the fore part of the ship's bottom is coming clear of the water on the wave crest and then slams into the wave trough violently, much like a belly flop. (Clark, 2008) Upon impact a large force acts on the flat surface of the keel and sends a jolt though the entire vessel. Slamming can be felt from the engine room all the way to the bridge and therefore causes strain on multiple components. More than three slams per minute should therefore be avoided. (Clark, 2008)

5.5. *Tow Wire Tension*

As mentioned earlier, a vessel has 6 degrees of freedom. When a tow is viewed, it's not only the six degrees of a single vessel, but of each vessel, resulting in a total of twelve degrees of freedom which are producing, to a larger or lesser degree, an effect onto the tow line. A tow wire forms a catenary, depending on the distance between the tug and the barge, the tension, and the weight of the wire. This catenary functions as a spring, deepening and straightening as the tension in- or decreases. Considerable safety factors are in place to safeguard against failures in the tow line, but accidents are still happening occasionally. (U.S. Army, 1991) The EMS TUG is using a 44 millimeter steel wire rope as a tow line, which has a minimum breaking strength of 1,350 kilo Newton, which equals roughly to 138 tons. This is more than three times the 45 tons bollard pull of the tug. But failures still may occur due to extreme shock loads on the wire. Any tensions which go beyond 100 tons should certainly be considered as extremely dangerous to the tow as a whole.

6. Running the Simulation

To conduct useful runs in the simulator of the EMS TUG towing the EMS PONTON 7 a number of factors have to be considered. Wind, waves, swell, and current influence a vessel's movement. Accounting for all of these individually and in different combinations would have exceeded the time frame of this thesis by a long way, therefore only the influence of swell was addressed in the simulation. As mentioned earlier, a regular wave isn't a natural occurrence on our oceans, but wave spectra, such as the Pierson-Moskowitz or the JONSWAP spectrum may be expected. In such a spectrum the wave height is usually given as significant wave height, meaning the highest third of the waves being measured. The Transas simulator is capable of replicating various wave spectra. The unit used for the conduction of these test runs is equipped, amongst others, with the Pierson-Moscowitz spectrum, but not the JONSWAP spectrum. However, performing the runs on a spectrum would require extremely long test runs with every setting and every heading. This is owed to the fact that within a spectrum there are sets of waves which are smaller, others which are medium sized, again others which are large, and even some very large sets. With the result that, in order to ensure a resemblance of the worst condition has been encountered, long runs of approximately three simulated hours would be required on every heading. This limiting factor is the reason, why the test runs have been conducted with regular waves instead. The wave period has been set between six seconds and eight seconds and the wave height has initially been defined at one meter and was increased with every additional run by half a meter.

Still, real life conditions always refer to the significant wave height. Therefore, a convergence from the regular waves to a significant wave height is essential to later bring the results into context. As the operational limits are being established for wave heights and not for swell, this transformation may be achieved by applying the Rayleigh probability distribution of waves. The USNA (United States Naval Academy) applies said distribution to random wave heights. Hereby the regular waves with the corresponding wave heights, which have been used in the simulator runs may be regarded as the mean or average height. According to the Rayleigh distribution the average wave height and the RMS (root mean square) wave height have the statistical association (United States Naval Academy):

$$H_{RMS} = \frac{2}{\sqrt{\pi}} H_{mean}$$

The RMS value may then further be used to statistically define the significant wave height (United States Naval Academy):

$$H_S = \sqrt{2}\, H_{RMS}$$

This results in the conversion from regular wave heights to significant wave height as per the Table 11 below:

Table 11: Conversion of Wave Heights of Regular Waves to Significant Wave Heights

Height of Regular Wave	Root Mean Square Height	Significant Wave Height
1.0m	1.13m	1.59m
1.5m	1.69m	2.39m
2.0m	2.26m	3.19m
2.5m	2.82m	3.99m
3.0m	3.39m	4.79m
3.5m	3.95m	5.59m
4.0m	4.51m	6.38m

The runs have been conducted by way of three different power settings being investigated, 50%, 70%, and 100%. The simulations were designed, so the swell is encountering the tow ranging from dead ahead to dead astern on one side. One side is sufficient in this case, as due to the symmetric shapes. The effects are expected to be the same, whether the wave is coming from port or from starboard, as long as the relative angle is the same, e.g.: a relative swell direction of 40 degrees from starboard should create the same effect as a relative swell direction of 40 degrees from port.

The ECDIS (Electronic Chart Display and Information System) laboratory on the Maritime Campus of the University of Applied Sciences Emden Leer, is used for ECDIS generic training, which is an STCW (Standards for Training Certification and Watchkeeping) requirement for the OOW's (Officer Of the Watch) certificate of competency. Other training purposes are electronic passage planning and investigation of maneuvering characteristics of vessels. The individual bridges, which consist of two workstation PCs each, are located in a single row and right next to each other, as may be seen in Figure 19. Due to this layout the room offers the perfect environment to do multiple test runs simultaneously.

Figure 19: ECDIS Laboratory of the Maritime Campus in Leer During the Simulation Runs

There are 6 bridges available, however one bridge was temporarily fitted with the newest version of the simulation software for testing purposes, and therefore not in the same network. This still allowed for five settings to be run simultaneously in a single exercise, meaning that all five tugs are placed in the vicinity of each other in a simulated ocean environment. The simulator is still capable of increasing the scene speed to five times the normal speed whilst using these settings. This means that five minutes of simulation require only one minute of actual time. The bridges were set up, so two were run at 50% engine power, one with the swell dead ahead, the other with the swell from dead astern. A further two with the same setup but 70% engine power. For the fifth 100% engine power was used with the swell from dead ahead. Behind each tug the pontoon was connected with a tow line length of 200 meters. The autopilot was engaged and the exercise started. Starting the exercise with a power setting of 50% and more will obviously create a yoyo effect. This means, that there is a sudden increase in tension when the towline comes tight, which slows down the tug, creating slack in the line. This effect is common when the weight is not taken carefully. The simulated environment, however, allows for such maneuvers, which safe a lot of time, considering that five bridges were being handled at one time. The relevant maneuvers were only initiated after the yoyo effect had subsided and both tug and pontoon on all five bridges moved at a steady pace. The initial heading was kept, not considering the time which was required to eliminate the yoyo effect, for 20 simulated minutes, whereupon the heading was changed by five degrees. This process was repeated, until each bridge had turned by 90 degrees and the swell was coming from abeam. By this method 60 minutes of data are acquired for every 15 degrees of relative swell direction, giving a good resolution. Upon completion the same exercise is loaded again with a single bridge which is run with 100% engine power and the swell from dead astern. Using only a single bridge the simulator is capable of running at ten times the normal speed. The advantage of this method is that the speed of the simulated time can be increased considerably. In contrast, if each pair of bridges plus the fifth bridge were run at the same time in different exercises, the simulator would only be capable to increase the simulated time to twice the actual time.

All runs were simulated without wind or current and with regular waves. First the swell period was set to six seconds and the wave height determined at one meter. With each additional run the wave height was increased by half a meter, until the headings could no longer be kept by the autopilot. Thereupon the simulation speed was reduced for the attempt to hold the heading manually, but this failed in every instance. The loss of full maneuverability happened for the bridges with 50% engine power first, as was to be expected. The same process was then repeated with wave periods of seven and eight seconds.

7. Results of the Simulation

Upon completion of the test runs the data was recorded and saved on an external drive. In order to perform this, the log file of each exercise had to be loaded individually. The log file is a recording of the exercise which may be used to revisit certain situations and investigate. An additional feature of the log file is that a ship diagram may be created with numerous choices of reference data which can be exported. The data chosen to investigate the behavior of the EMS TUG and the EMS PONTON 7 and their interactions are:

- Relative swell direction
- Angle of roll of EMS TUG
- Rate of roll of EMS TUG
- Angle of pitch of EMS TUG
- Rate of pitch of EMS TUG
- Longitudinal force on the tow line, giving the tension in tons
- Speed of the tow

- Angle of roll of EMS PONTON 7
- Rate of Roll of EMS PONTON 7
- Angle of pitch of EMS PONTON 7
- Rate of pitch of EMS PONTON 7

When the datasets for the extraction had been selected, the log file needed to be started and could then be forwarded until the end. It's essential for the log file to be forwarded until the end, or until a certain required point, because only the played data is actually recorded onto the ship diagram. In order to acquire all data, this process was repeated for every exercise and in each exercise for every tug and pontoon. The resulting files are CSV (Comma Separated Values) files which is a format compatible with Microsoft Excel.

The intended graphs however could not be created using Excel tools, as the datasets were vastly too large to be handled in an Excel graph. The largest dataset consists of almost 64,000 lines. To solve this issue, the tables were loaded into MATLAB, which is better equipped to handle such large datasets. To compile a useful structure in MATLAB each CSV file first had to be converted into an Excel file, as MATLAB is not compatible with CSV files. Thereupon, each Excel table had to be imported in MATLAB where each column was then put into a separate variable for easy identification and access, see Figure 20. The files have been sorted by wave period, wave height and engine power.

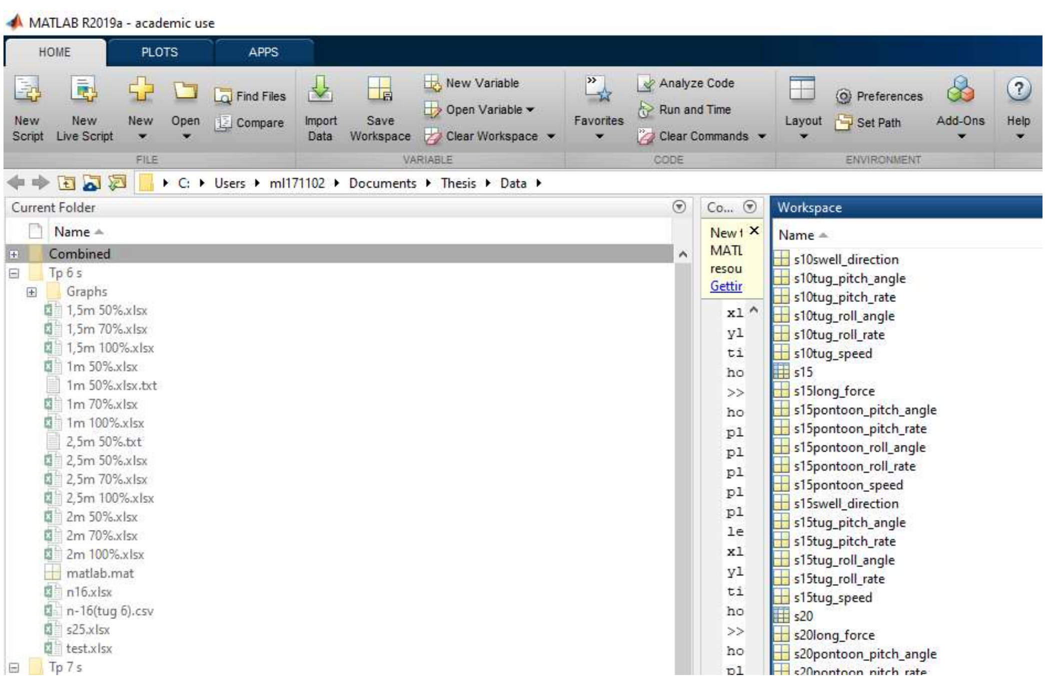


Figure 20: Example for the Structure of the Datasets within MATLAB

The command to visualize the results is a simple plot with the specification of which variable is to be the x-value and which variable is to be the y-value. By using the hold on function in addition, multiple graphs can be displayed in the same diagram. This is particularly helpful when comparing results.

In the following subchapters the results of measured values with regards to the wave height and the wave periods will be presented.

7.1. Roll Motion

The roll motion is the key criteria for tug and pontoon, as it inhibits dangers which may even lead to loss of a vessel and the crew onboard.

The MSC warns in its circular MSC.1/Circ.1228 of the reduction of the calculated intact stability whilst the vessel is on a wave crest, as the decrease in stability may be substantial. (MSC.1/Circ.1228, 2007)

The position of a vessel in a wave trough on the other hand increases the stability, due to the sections of the vessel which are submerged in the water. The effect is largest in occurrences when the length of the wave is comparable with the ship's length, but may also be observed on smaller vessels. (Vadim Belenky, 2010)

The equation for calculating the wavelength is: (MSC.1/Circ.1228, 2007)

$$\lambda = 1.56 \cdot T_W^2 \text{ [m]}$$

Adopting this to the wave periods of the simulations results in the following wavelengths:

$$\lambda_{8sec} = 1.56 \cdot 8^2 = 99.84\text{m}$$

$$\lambda_{7sec} = 1.56 \cdot 7^2 = 76.44\text{m}$$

$$\lambda_{6sec} = 1.56 \cdot 6^2 = 56.16\text{m}$$

These wavelengths do not coincide with the EMS TUG's length of 27.05m, but as will become apparent throughout the chapter the effects are still notable.

The aft and forward sections of a vessel are typically slender below the water line and become fuller when approaching the height of the main deck. On the EMS TUG mainly the forward part possesses this attribute. This means that when the vessel is in a wave trough the water plane area is increased and approaches a box shape more closely, as is depicted in Figure

21. On the other hand, if the wave crest is close to the longitudinal center of the vessel the situation switches and the water plane area is reduced, due to the bow being slimmer closer to the keel plate, see Figure 22. Therefore, according to a ship's hydrostatic properties the stability is increased in the wave trough and decreased at the wave crest. (Vadim Belenky, 2010)

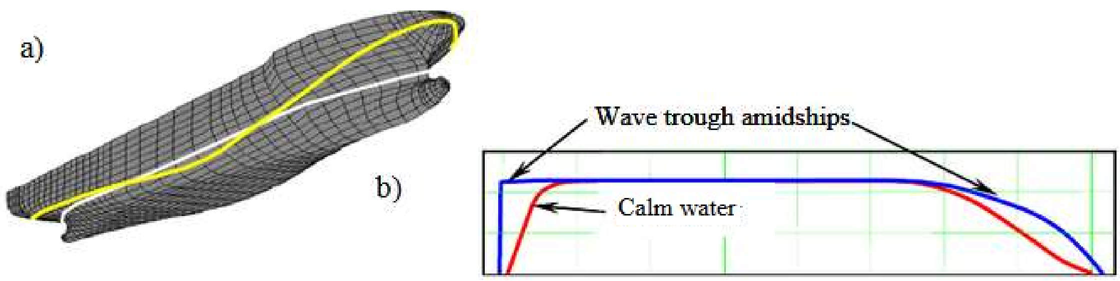


Figure 21: Change of a Container Vessel's Hull Geometry with the Wave Trough Amidships (Vadim Belenky, 2010)

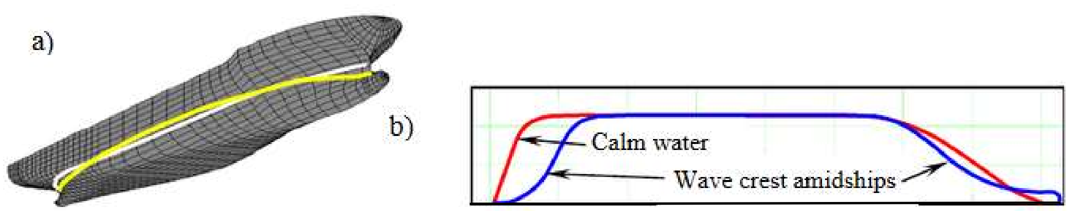


Figure 22: Change of a Container Vessel's Hull Geometry with the Wave Crest Amidships (Vadim Belenky, 2010)

The MSC's circular warns that this stability loss is expected to be severest with a wave length ranging between 0.6 and 2.3 times the ship's length. (MSC.1/Circ.1228, 2007) Adopting this to the EMS TUG the following ratios can be determined:

$$R_{8sec} = \frac{\lambda_{8sec}}{Loa_{EMS\,TUG}} = \frac{99.84}{27.05} = 3.7$$

$$R_{7sec} = \frac{\lambda_{7sec}}{Loa_{EMS\,TUG}} = \frac{76.44}{27.05} = 2.8$$

$$R_{6sec} = \frac{\lambda_{6sec}}{Loa_{EMS\,TUG}} = \frac{56.16}{27.05} = 2.1$$

Only the wave length of the six seconds wave period coincides with this ratio. However, the MSC's circular highlights, that the effect - in this case the effect of reduced stability when a vessel is on a wave crest - is most critical in the above mentioned spectrum as in this range the reduction of stability is almost proportional to the wave height, see Figure 23. This however, doesn't mean that no effects will be noticeable outside this range. There is a clear warning that effects may be larger on some vessels and smaller on others. (MSC.1/Circ.1228, 2007) On slender ships the loss of stability at the wave crest will be considerably larger than on ships with a higher block coefficient, like the EMS TUG. But the effect is still noticeable, as will become apparent later, e.g. in Figure 28: Roll Angles of EMS TUG at 8 Seconds Wave Period . The rolling angles being larger at quartering and following seas, meaning the swell is coming from abaft the beam, is a clear indication for the stability being lower. A lower stability, due to the change in water plane area, means that the distance between the center of gravity and the metacenter is smaller than in calm water conditions. Therefore, the uprighting moment, which is trying to bring the vessel back to the initial position, is smaller resulting in the vessel inclining further than it would under normal conditions. (Gudmestad, 2010)

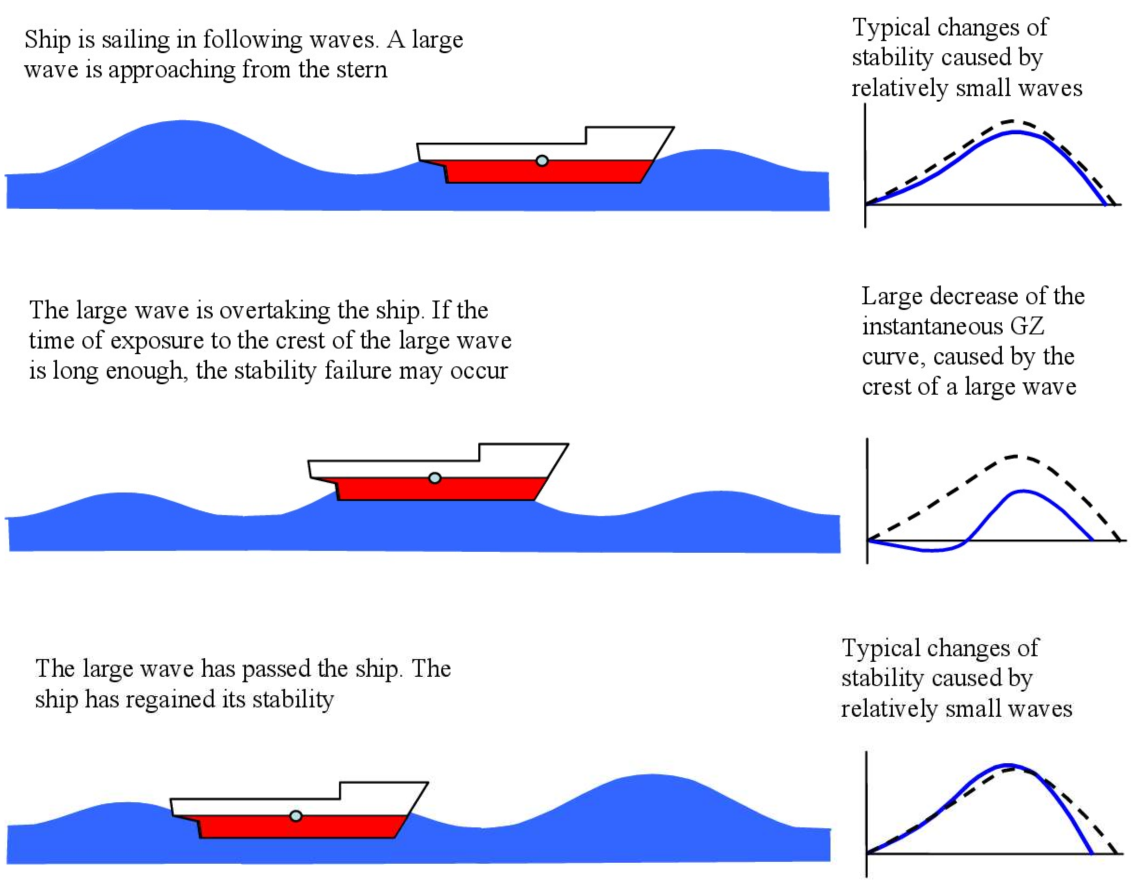


Figure 23: Development of Stability in Waves (Vadim Belenky, 2010)

The MSC's circular names conditions which may produce such effects: the parametric roll. It means that extreme roll angles and roll rates occur due to the variation of stability between wave crest and wave trough. For this effect to appear the roll period of the vessel and the encounter period of the waves have to have a certain ratio. Two types of parametric roll may be observed: (MSC.1/Circ.1228, 2007)

i) The period of encounter and the period of the vessel's roll have a ratio of approximately 1: 1. In following and quartering seas (Figure 24) the vessel sails roughly in the same direction as the waves, creating a slow relative speed and the period of encounter is increased, i.e. the encounter frequency is decreased. In this situation the wave period is therefore shorter than the encounter period. As the vessel travels from wave trough to wave trough it undergoes one complete roll motion.

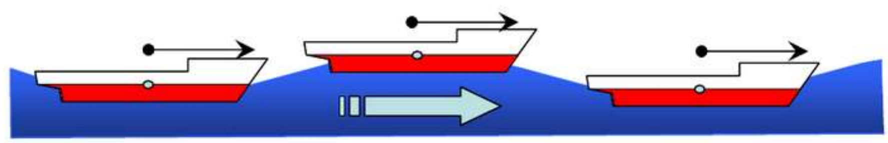


Figure 24:Ship Sailing in Following Seas (Vadim Belenky, 2010)

The vessel is heeling when at the wave trough, receiving a large uprighting moment and is travelling through the upright position while climbing the wave crest. On the wave crest the vessel then is heeling towards the other side. This heeling angle will be larger than the one in the wave trough due to the decreased stability on the wave crest. An uprighting movement is again taking place while travelling down the wave into the trough where it will be heeling again, marginally more than the first time around. If this situation keeps reoccurring the asynchronous rolling motion will increase ever more with larger rolling angles on the wave crest and smaller rolling angles in the wave trough. The reduced stability in following and quartering waves causes a tendency for vessels to have a retarded up-righting in case of large amplitudes, which in turn may shift the vessel's roll period in such a way that this type of parametric rolling motion can occur. Therefore, this effect of harmonic resonance may arise at various encounter periods. (MSC.1/Circ.1228, 2007)

ii) The period of encounter and the period of the vessel's roll have a ratio of approximately $1{:}\,0.5$. In head and bow seas vessels are heading the opposite direction of the waves (Figure 25) and therefore - as the relative speed is quite high – this leads to a small encounter period, i.e. large encounter frequency. In this situation the wave period is therefore longer than the encounter period. As the vessel undergoes one rolling motion it passes two wavelengths. This happens most frequently in head and bow seas.

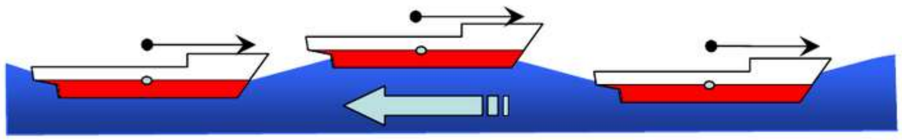


Figure 25: Ship Sailing in Head Seas (Vadim Belenky, 2010)

The vessel is heeling when at the first wave trough, due to the increased stability a large uprighting force is exerted and the vessel starts to upright whilst travelling up towards the wave crest. On the wave crest the vessel has regained its upright position, but due to the reduced stability there is little damping to slow down the rolling motion. On the way down the wave the vessel goes over to the other side until it reaches the wave trough at the maximum heeling angle, which is marginally larger than the initial heeling angle. This motion is then repeated until the original heeling side is reached again with a lightly increase heeling angle at the third wave trough, Figure 26.

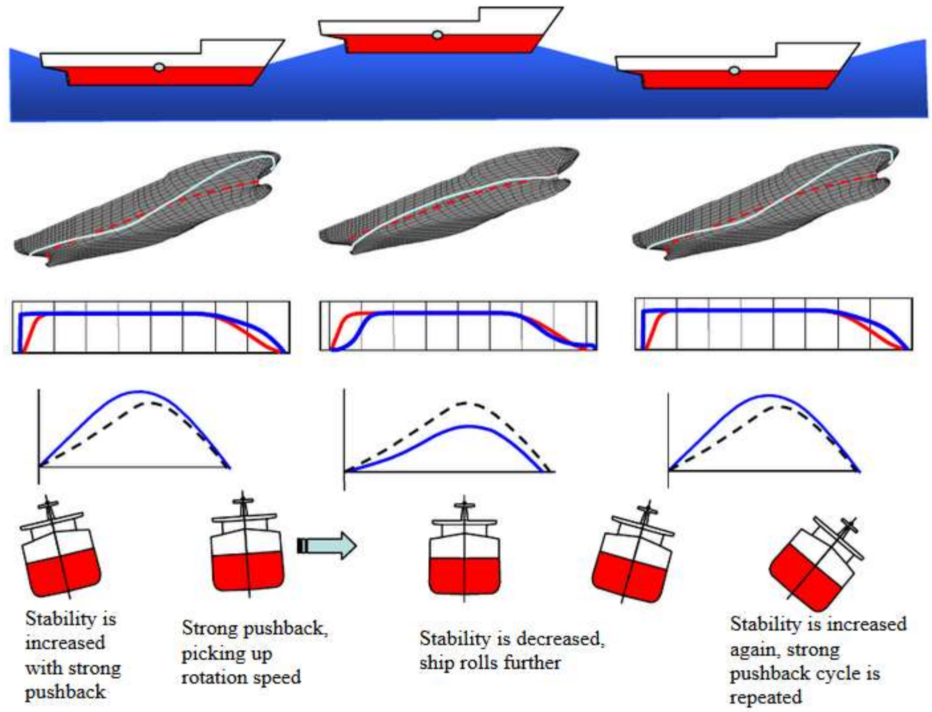


Figure 26: Parametric Rolling Motion with Encounter Ratio of 1:0.5 (Vadim Belenky, 2010)

In this situation the vessel's stability is at its lowest twice during a single roll period, creating a symmetric rolling motion with large rolling angles to each side.

However, the parametric rolling isn't the only dangerous effect the circular warns about. Another effect is the synchronous rolling motion. It may occur when the ship's period of roll is equal to the wave encounter period, causing higher roll angles, Figure 27. This poses the threat of the vessel heeling to such an extent that not only the deck, but also the lower edges of openings in the superstructure or hull, which are leading below deck and cannot be closed watertight, could be immersed.

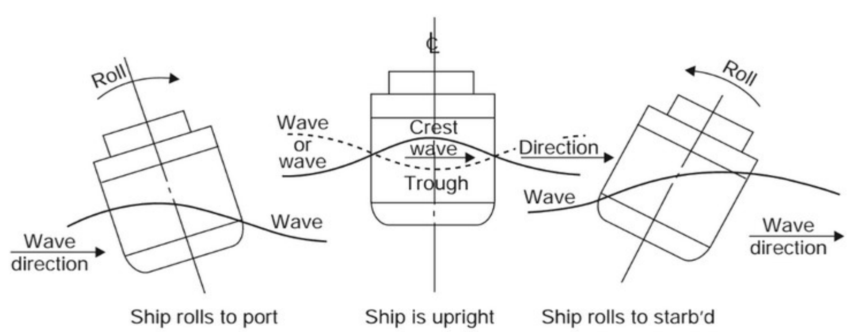


Figure 27: Synchronous Rolling Motion (B. Barrass, 2006)

7.1.1. Roll Motion of EMS TUG

In the wave period of eight seconds the tug was capable of holding it's heading the easiest, which led to test runs of a wave height of up to four meters. However, this dataset unfortunately had some gaps, therefore the recorded data for the highest wave for the purpose of this paper will be 3.5 meters. In Figure 28 the roll angles of the vessel EMS TUG at a wave period of 8 seconds and the use of 100% engine power can be seen at 1.0 meters wave height, 3.0 meters wave height and 3.5 meters wave height. As mentioned earlier, the exercises were split in two sections, one with the swell initially coming from dead ahead and the other with the swell initially coming from dead astern. In both scenarios the heading has been changed in 5 degrees steps until the swell is coming from abeam. Unfortunately, the extraction of the ship diagram data didn't always work flawlessly, which can be seen when looking at the 1.0-meter wave height dataset below. That the vessel was actually rolling was confirmed during the conduction of the exercise. All exercises were performed with daylight conditions and visual channels on, offering the view from the bridge, which would have quickly revealed a model not moving the way it should. One out of five vessels not rolling would have easily been spotted and since this isn't the only gap in the data it's safe to assume a fault in the simulator logic. Sufficient reliable data has however been gathered to observe the behavior of the vessel and the pontoon and various environmental conditions.

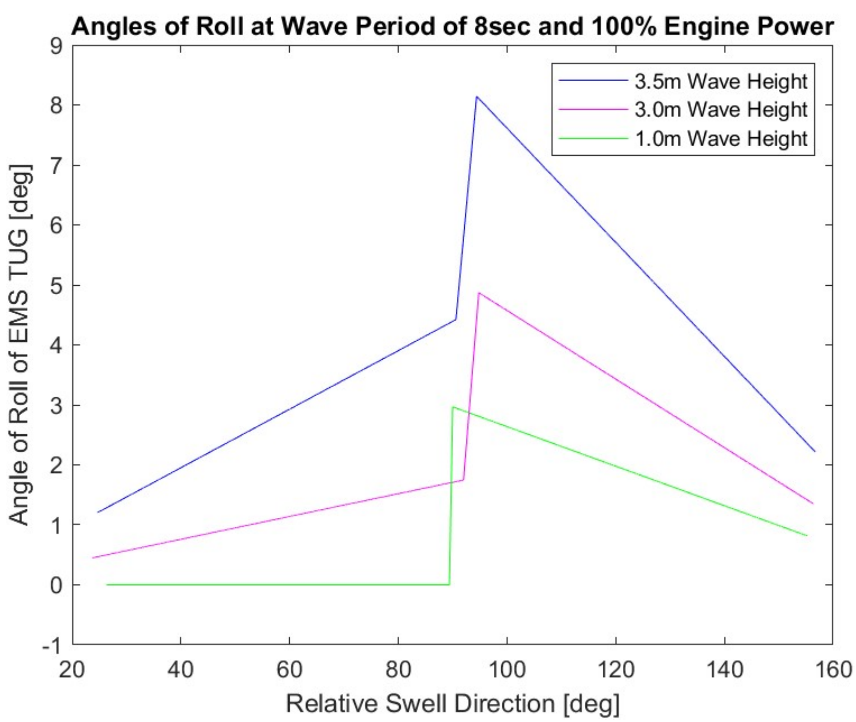


Figure 28: Roll Angles of EMS TUG at 8 Seconds Wave Period

The Figure 28 is showing the roll angles of the EMS TUG at a period of eight seconds and different wave heights. What's remarkable is, that the rolling angles in the relative swell direction of 90 degrees upwards are much larger than the rolling angles in the area below 90 degrees relative swell direction. This effect would be less significant, if the exercise had started with the swell coming from 90 degrees and changing it to ahead / astern. Nevertheless, it is fair to assume that also with such a setting a difference would be noticeable. The reason being that with the swell coming from astern and passing the tug, as the vessel travels in the same direction, it stays at or near the wave crest much longer than when the reverse situation is being observed. With the swell coming from ahead, the tug will more likely pass through the wave, or at least spend very little time at the wave crest, before diving into the next trough.

Looking at the roll rates for the same conditions in Figure 29, the effects of the change in stability become even more apparent.

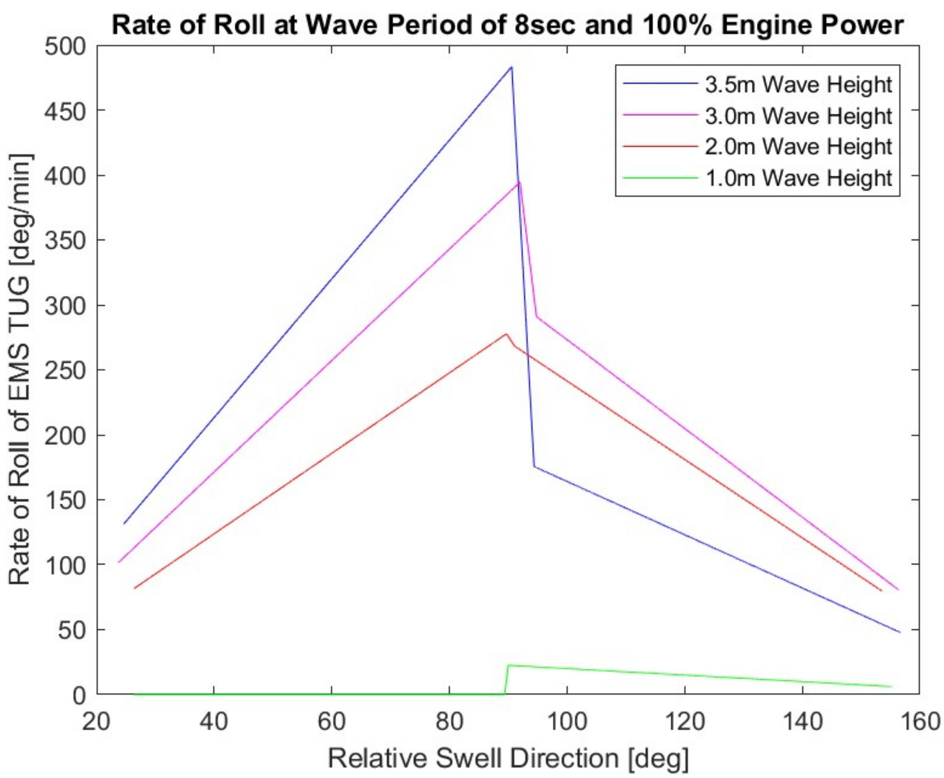


Figure 29: Rate of Roll of EMS TUG at 8 Seconds Wave Period

As mentioned earlier, the quartering and following seas cause a reduction of stability when the vessel is on the wave crest. This reduced stability causes the uprighting moment to be decreased and therefore the stability is softer, meaning that the force and therefore the acceleration to come from a heeling position back to an upright position is smaller. This results in a larger angle of roll, but a smaller rate of roll. Looking at the figure above, the rate of roll being much larger for the head sea conditions compared with the quartering and following seas is a clear indicator for the just described phenomenon. There is even an explicit warning in the stability booklet of the EMS TUG that special attention is required in case of sailing in following or quartering seas due to dangerous phenomena broaching to. Broaching to may occur in following seas, when the vessel and the wave travel at nearly the same speed. This results in the vessel surf-riding, i.e. staying a long time on the wave crest with reduced stability. Such a scenario may lead to a sudden change in heading, as the bow section is barely submersed, making the vessel extremely course instable. This sudden change in heading may be as large as 90 degrees, making the vessel roll in such a way that it can capsize. In these cases, excessive rolling may occur, which might even lead to a threat of capsizing. But also other phenomena may be encountered, like parametric resonances, or a reduction of stability. (DAMEN Shipyards, 2019)

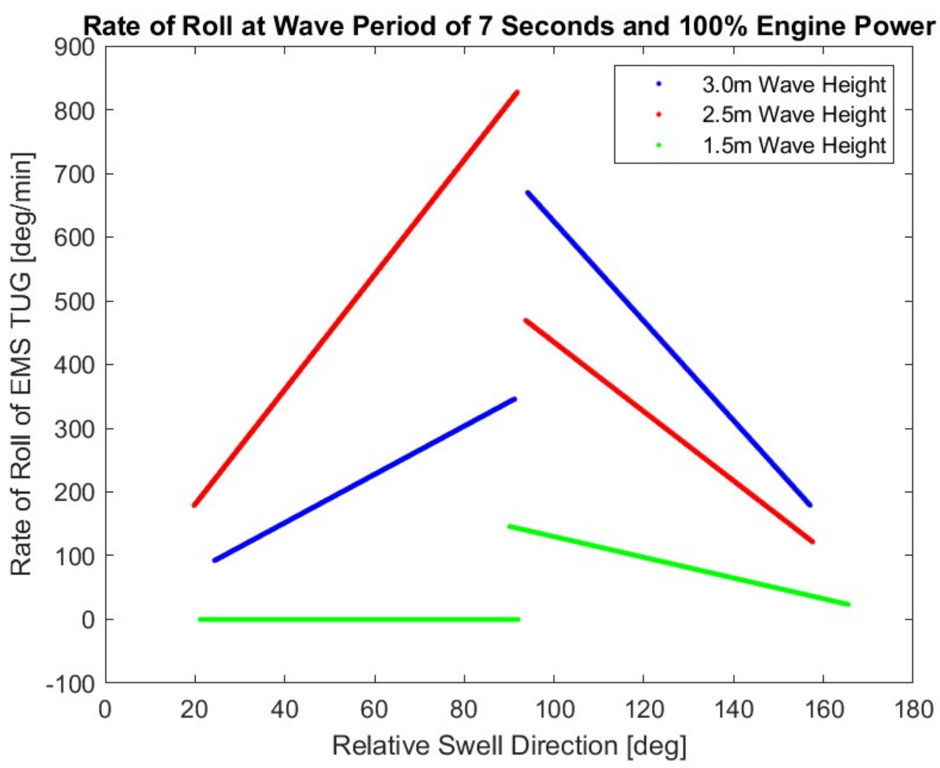


Figure 30: Rate of Roll of EMS TUG at 7 Seconds Wave Period and 100% Engine Power

When looking at Figure 30, particularly the graph for the rate of roll at a wave height of 2.5 meters, seven seconds wave period, and 100% engine power, the same effect can be seen again. However, for the 3.0-meters graph the dynamics have shifted. Here the higher rate of roll is occurring at following seas. This corresponds with the graph of the angle of roll with the same settings, see Figure 31. At 2.5 meters wave height the angle of roll is larger for following seas as is the case with the eight seconds wave period measurements. But at 3.0 meters wave height the larger roll angles occur in head sea conditions.

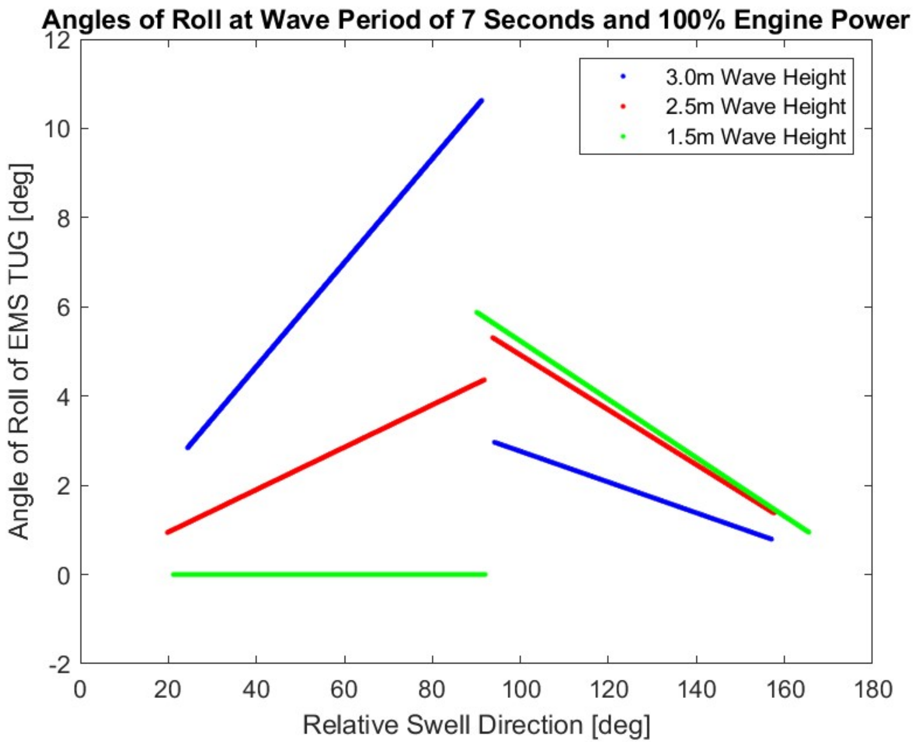


Figure 31: Angles of Roll of EMS TUG at 7 Seconds Wave Period and 100% Engine Power

In order to investigate the condition where the dynamics shifted in the 3.0-meters wave height at a wave period of seven seconds, the encounter period T_E has to be calculated. According to the MSC.1/Circ.1228 can be calculated as:

$$T_E = \frac{3T_W^2}{3T_W + v\cos(\propto)}[s]$$

Where: v=ship's speed [knots]

$\propto$=relative swell direction [°]

T_W=wave period

The period of encounter T_E is therefore depending on the wave period, the tug's speed and the relative swell direction.

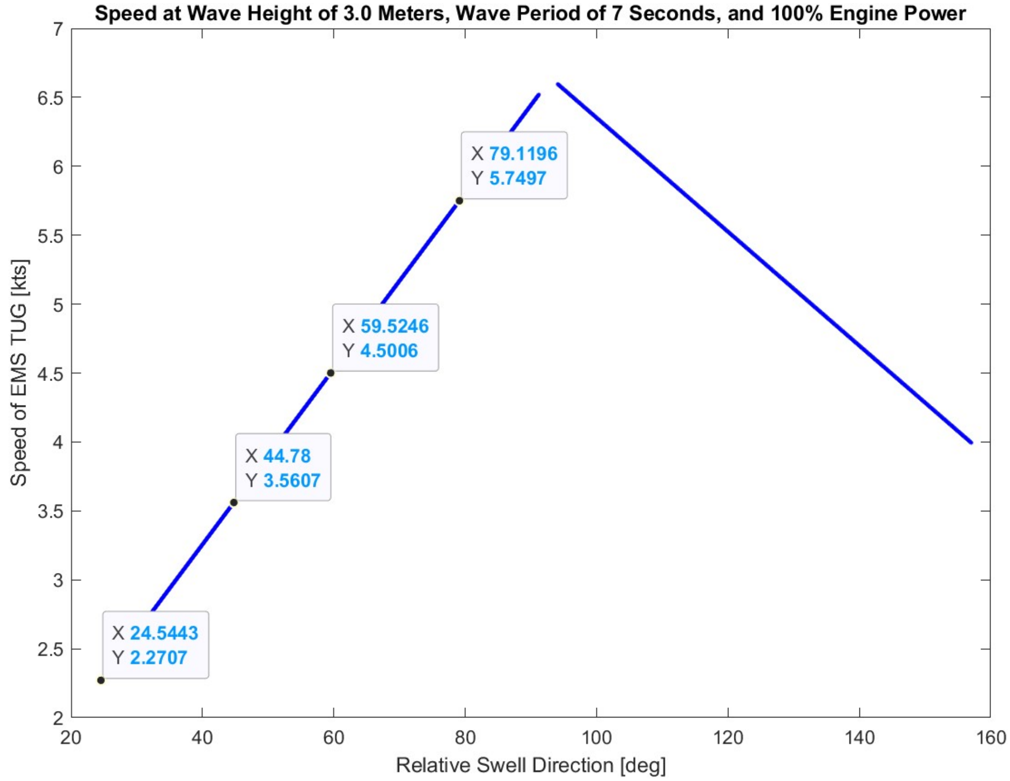


Figure 32: Speed of EMS TUG at Wave Height of 3.0 Meters Wave Height, 7 Seconds Period, and 100% Engine Power

Using the exemplary values from Figure 32, above the encounter period T_E may be calculated:

$$T_{E1} = \frac{3 * 7^2}{3 * 7 + 2.27 * \cos(24.54)} \cong 6.4s$$

$$T_{E2} = \frac{3 * 7^2}{3 * 7 + * 3.56 * \cos(44.78)} \cong 6.2s$$

$$T_{E3} = \frac{3 * 7^2}{3 * 7 + 4.5 * \cos(59.52)} \cong 6.3s$$

$$T_{E4} = \frac{3 * 7^2}{3 * 7 + 5.75 * \cos(79.12)} \cong 6.7s$$

The roll period of the vessel as discussed earlier is 6.2 second. Putting the encounter period and the vessel's roll period into context results in the following ratios:

$$R_1 = \frac{6.4s}{6.2s} = \frac{1}{0.97}$$

$$R_2 = \frac{6.2}{6.2} = \frac{1}{1}$$

$$R_3 = \frac{6.3}{6.2} = \frac{1}{0.98}$$

$$R_4 = \frac{6.7}{6.2} = \frac{1}{0.93}$$

This coincides exactly, or at least very closely with the MSC's description of the second kind of parametric roll, described with and encounter ratio of $1:1$. The circular does warn against this effect, and it may also occur in head or bow seas. Heavy heaving and pitching may contribute in such situations to the change in stability. The change in stability might be relatively small on the EMS TUG, but if this movement is periodical, as in the above shown numbers, even these small changes can produce strong parametric roll motions. (MSC.1/Circ.1228, 2007) Another cause may be the synchronous rolling effect. Unfortunately, there is no way of determining whether the vessel was heeling more to one side, than to the other. If this were possible, it would be a clear indicator, whether the rolling motion is caused by a parametric roll effect or synchronous roll effect, but the recorded data only gives absolutes in the roll angles.

Figure 30 further showed that the rate of roll for 2.5 meters wave height at a wave period of seven seconds and 100% engine power is higher in head seas, the angle higher in following seas. This is, as has already been discussed, an indicator that there is an effect of reduced stability in the following and quartering seas. However, it doesn't necessarily mean, that there is no dangerous effect such as the parametric roll in the head seas as well.

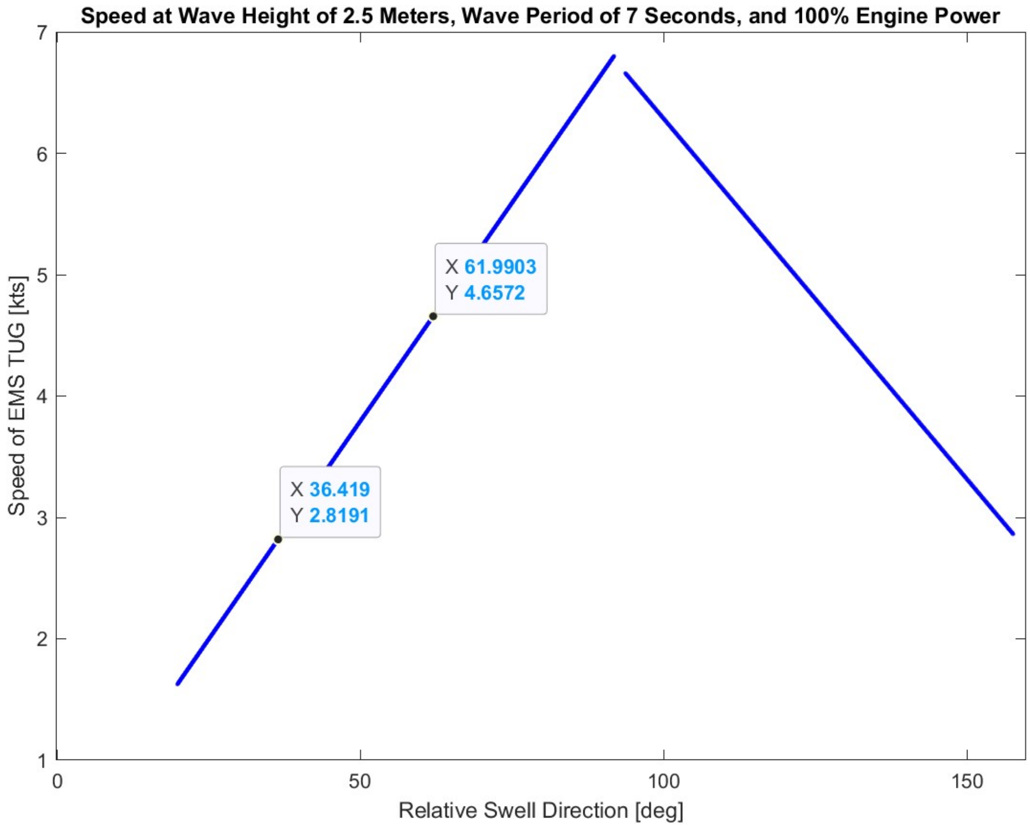


Figure 33: Speed of EMS TUG at Wave Height of 2.5 Meters Wave Height, 7 Seconds Period, and 100% Engine Power

Calculating the encounter period for the two highlighted values in Figure 33 results in:

$$T_{E1} = \frac{3 * 7^2}{3 * 7 + 2.82 * \cos(36.42)} \cong 6.3s$$

$$T_{E2} = \frac{3 * 7^2}{3 * 7 + * \, 4.66 * \cos(61.99)} \cong 6.3s$$

The resulting values $R_{1,2} = 1{:}\,0.98$ again coincide very closely with the MSC's definition of an encounter to roll ratio of $1{:}\,1$, but the angle of roll in head seas is far less compared with the 3.0-meter wave. Looking further at the seven seconds period wave conditions but reducing the power to 70% it may be seen that the rate of roll (Figure 34) is as expected higher in the head and bow seas than in the quartering and following seas. It is remarkable that the angles of roll (Figure 35) for the 3.0-meter wave are close to being mirrored abaft and ahead of the beam.

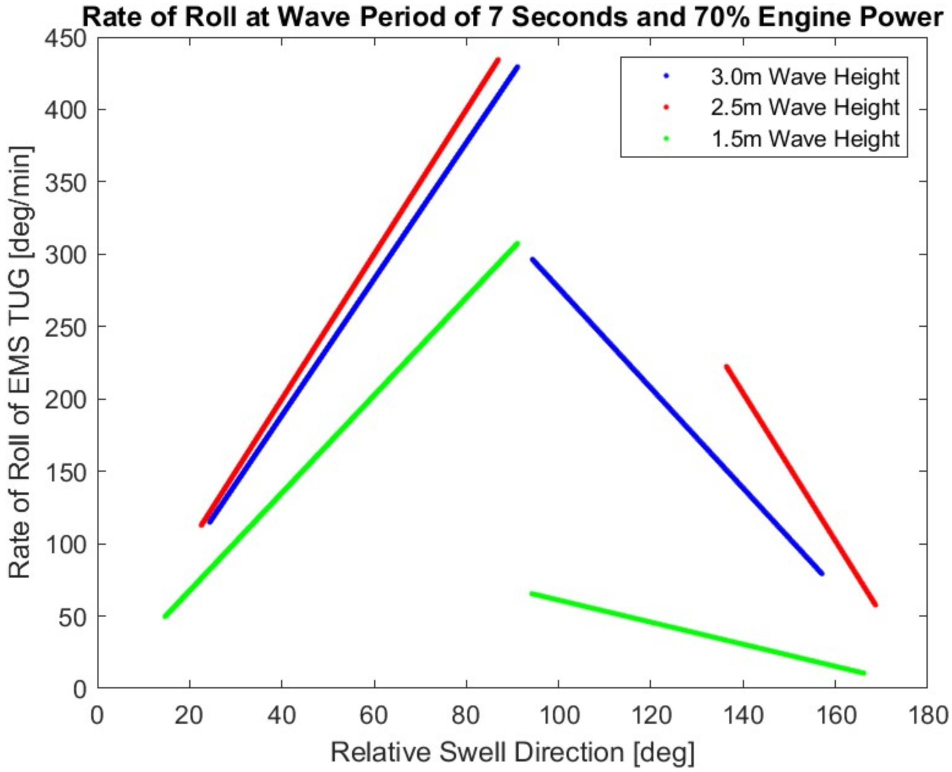


Figure 34: Rate of Roll of EMS TUG at 7 Seconds Wave Period and 70% Engine Power

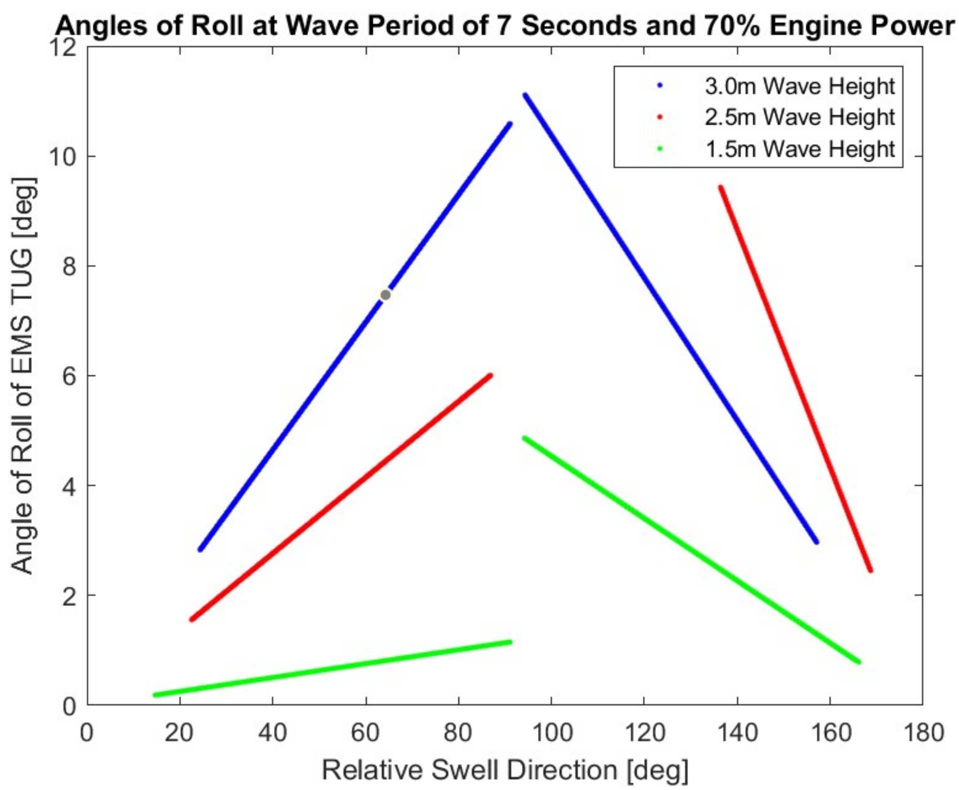


Figure 35: Angles of Roll of EMS TUG at 7 Seconds Wave Period and 70% Engine Power

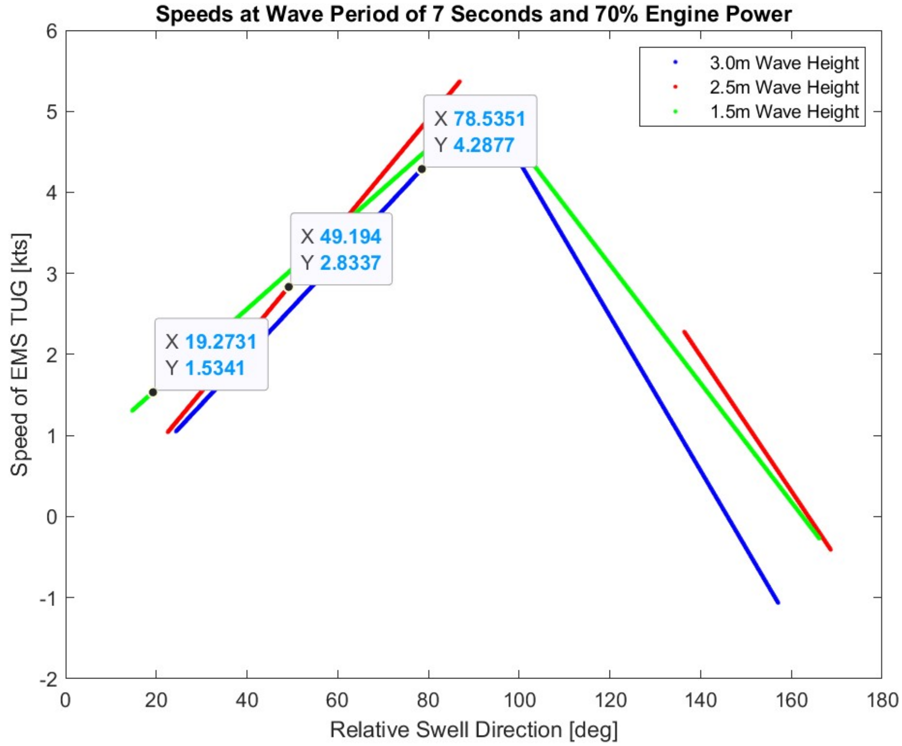


Figure 36: Speed of EMS TUG at 7 Seconds Period and 70% Engine Power

Looking once again at the encounter periods with the values from Figure 36 gives:

$$T_{1.5m\ Wave} = \frac{3 * 7^2}{3 * 7 + 1.53 * \cos(19.27)} \cong 6.5s$$

$$T_{2.5m\ Wave} = \frac{3 * 7^2}{3 * 7 + 2{,}83 * \cos(49{,}19)} \cong 6.4s$$

$$T_{3.0m\ Wave} = \frac{3 * 7^2}{3 * 7 + 4.29 * \cos(78.54)} \cong 6.7s$$

These values result in the following ratios:

$$R_{1.5m\ Wave} = \frac{6.5}{6.2} = \frac{1}{0.95}$$

$$R_{2.5m\ Wave} = \frac{6.4}{6.2} = \frac{1}{0.97}$$

$$R_{3.0m\ Wave} = \frac{6.7}{6.2} = \frac{1}{0.93}$$

These ratios are marginally lower than the previously calculated ratios but still approximate the critical level of 1: 1. Still the roll angles are not much different than at 100% engine power, but actually the rate of roll is reduced considerably.

If the engine power is reduced even further to 50% the tug is moving slower and the waves are overtaking the tug more quickly. This means that the vessel is spending less time on the wave crest. In Figure 37 here below the shift in dynamics becomes obvious, as here the higher roll rates by far appear in swell coming from abaft the beam and the roll angles in Figure 38 are much higher in head and beam seas.

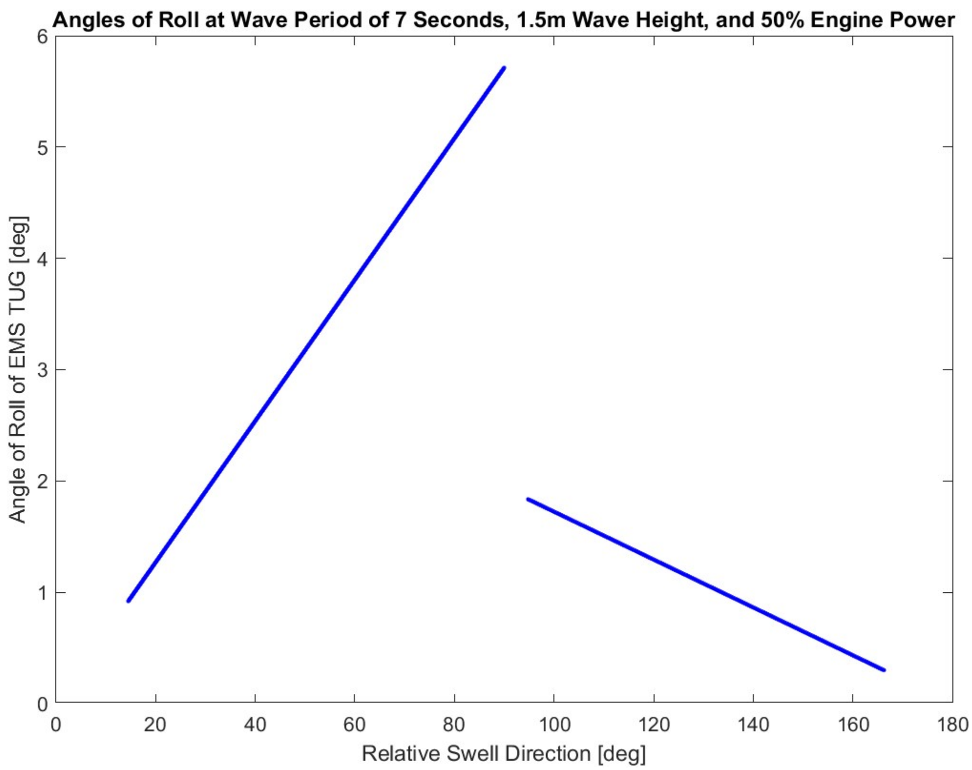


Figure 37: Angles of Roll of EMS TUG at 7 Seconds Wave Period, 1.5m Wave Height, and 50% Engine Power

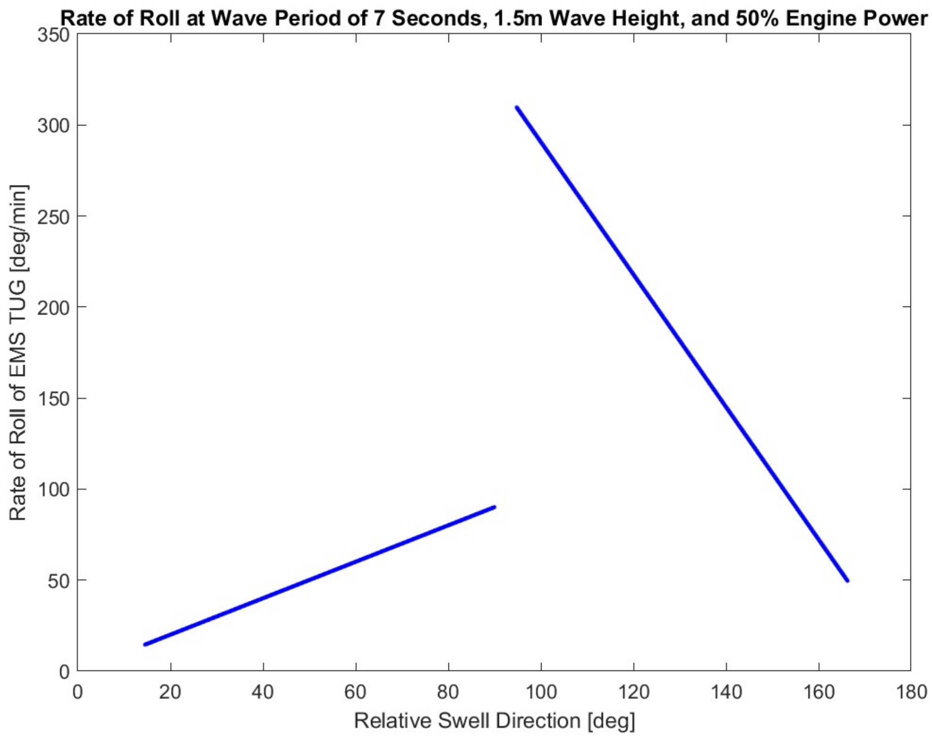


Figure 38: Rate of Roll of EMS TUG at 7 Seconds Wave Period, 1.5m Wave Height, and 50% Engine Power

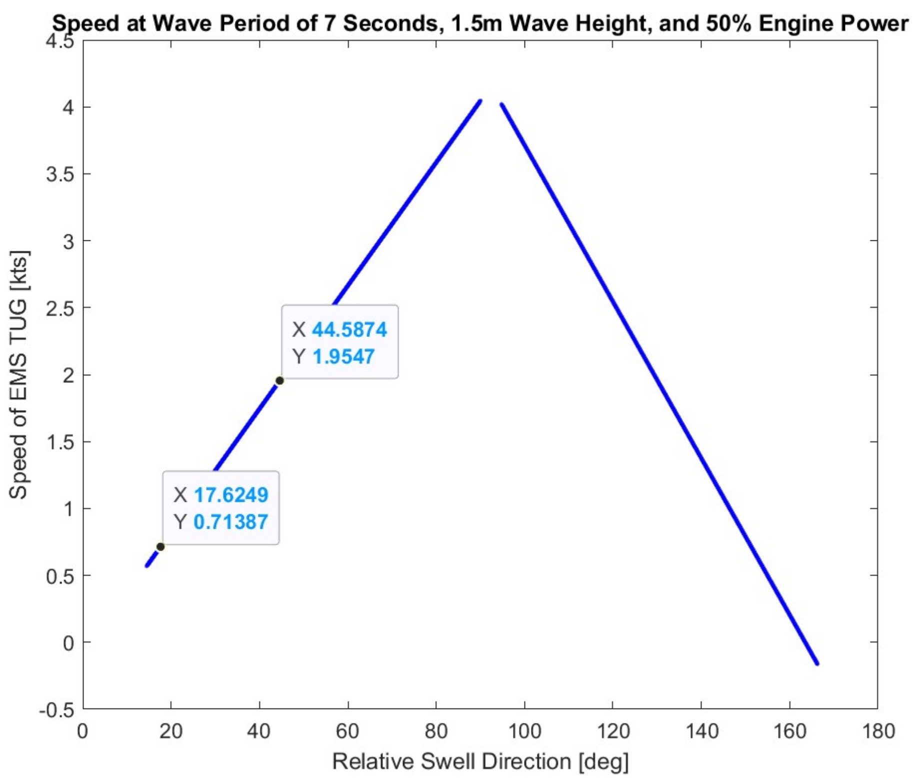


Figure 39: Speed of EMS TUG at 7 Seconds Wave Period, 1.5m Wave Height, and 50% Engine Power

When using the values for the speed and relative wave direction from Figure 39, the encounter period can again be calculated:

$$T_1 = \frac{3 * 7^2}{3 * 7 + 0.71 * \cos(17.62)} \cong 6.7s$$

$$T_2 = \frac{3 * 7^2}{3 * 7 + 1.95 * \cos(44.59)} \cong 6.6s$$

These values result in the following ratios:

$$R_1 = \frac{6.7}{6.2} = \frac{1}{0.93}$$

$$R_2 = \frac{6.6}{6.2} = \frac{1}{0.93}$$

The ratio is decreasing a bit further under these conditions from the $1{:}1$, but it is clearly evident by the data provided that there is still an effect.

The values of the six seconds wave period are unfortunately fractured, in so far, that mostly only one half of the relative range is covered. Therefore, no comparison - except for the 1.0-meter values, which are not of the utmost importance - between head and following waves can be made, see Figure 40. However, it's clearly noticeable that the rate of roll is very high when looking at the 2.5-meter wave and 100% engine power, see Figure 41.

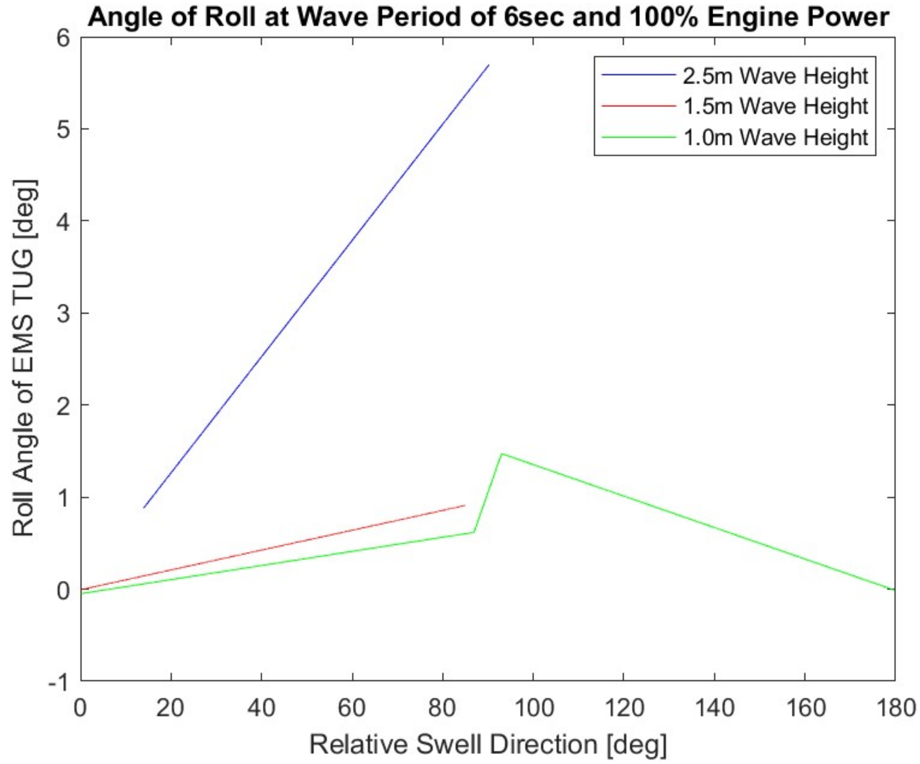


Figure 40: Angles of Roll of EMS TUG at 6 Seconds Wave Period and 100% Engine Power

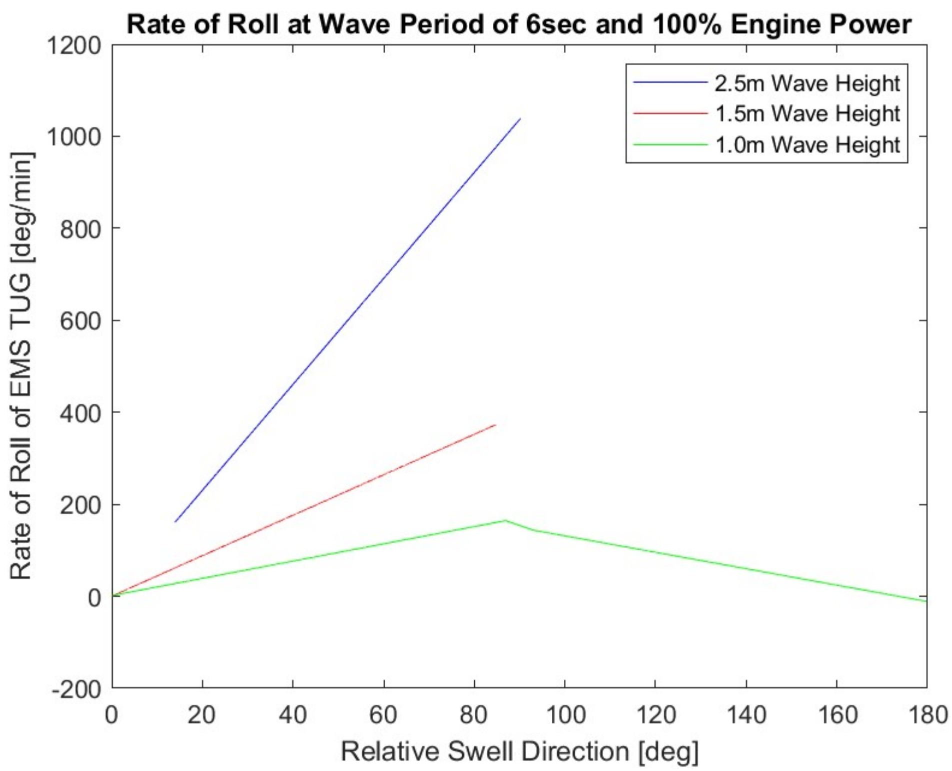


Figure 41: Rate of Roll of EMS TUG at 6 Seconds Wave Period and 100% Engine Power

Comparing the highest recorded waves of the three investigated periods at 100% engine power, it becomes evident that the six seconds period is the most unfavorable condition for the EMS TUG and 8 seconds wave period is clearly the most comfortable for the vessel, as may be seen in Figures 42 and 43.

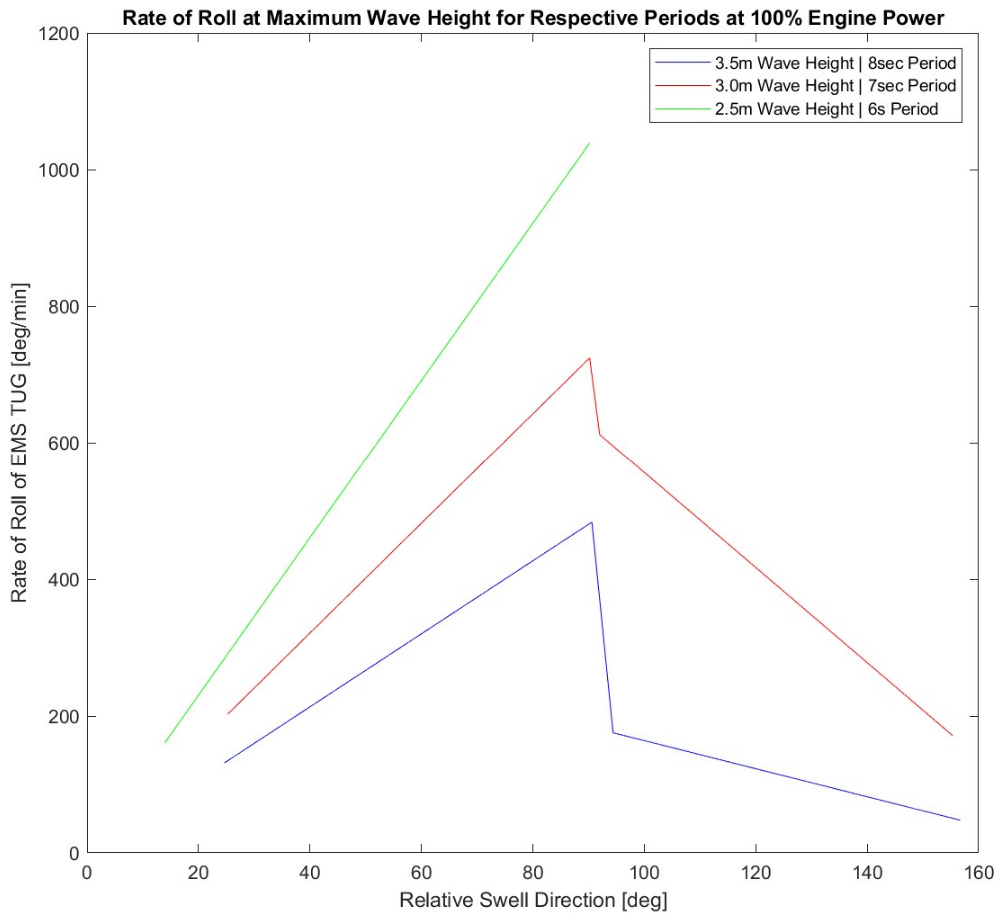


Figure 42: Rate of Roll of EMS TUG at Maximum Recorded Wave Heights, Corresponding Period and 100% Engine Power

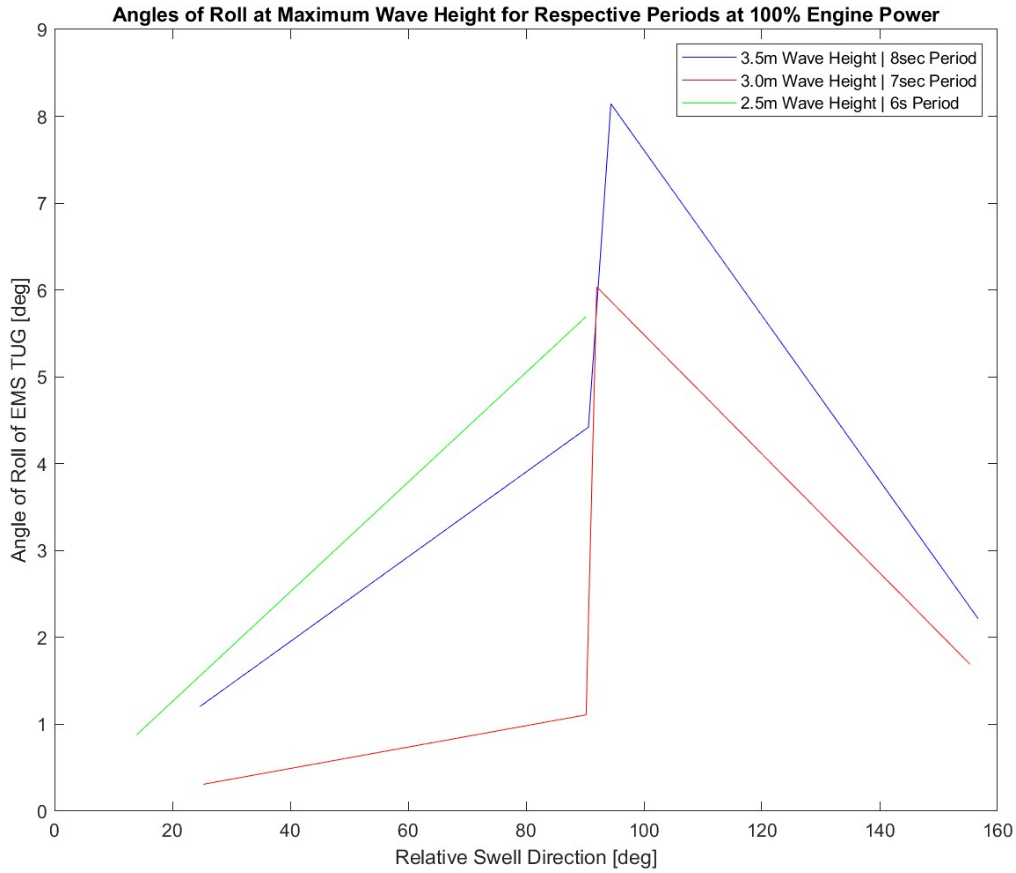


Figure 43: Angles of Roll of EMS TUG at Maximum Recorded Wave Heights, Corresponding Period and 100% Engine Power

Even though the roll angle doesn't nearly approach the flooding angle of 42.38 degrees, resonance situations should, if possible, be avoided. Since at the six seconds wave period the wave height of 2.5 meters indicates the highest roll rate and roll angle, this situation should definitely be avoided. The measurements of the 1.5-meters wave by contrast give quite low rolling motions and should therefore be the limit of operations for a six seconds wave period situation. Also, the seven seconds wave period produced unwanted resonances at wave heights above 1.5 meters, albeit less severely than compared with the six seconds wave period condition. Whereas in an eight seconds period wave a height of 3.0 meters may be viewed as the limit before the motion becomes too violent. These limits are solely covering the EMS TUG's workability.

7.1.2. Roll Motion of EMS PONTON 7

A pontoon typically has a much higher stability than a ship, due to its box-shape. This was demonstrated in chapter 2. As a result, pontoons roll less when compared to ship-shaped vessels.

$$R_{8sec} = \frac{\lambda_{8sec}}{Loa_{EMS\ PONTON\ 7}} = \frac{99.84}{72.29} = 1.4$$

$$R_{7sec} = \frac{\lambda_{7sec}}{Loa_{EMS\ PONTON\ 7}} = \frac{76.44}{72.29} = 1.1$$

$$R_{6sec} = \frac{\lambda_{6sec}}{Loa_{EMS\ PONTON\ 7}} = \frac{56.16}{72.29} = 0.8$$

The ratios of wave length to the length over all of the barge all coincide with the warning of the MSC's circular about dangerous situations in adverse conditions. However, neither the bow nor the stern of the EMS PONTON 7 is flared, hence very little change in the water plane area will occur. Due to this difference compared with the EMS TUG, a parametric roll effect is not to be expected. On the other hand, synchronous rolling and to some extent wave crest riding may still be an issue.

When examining the graphs for the roll angle of EMS PONTON 7 in a six seconds period swell the roll angle comes remarkably close at 2.5 meters wave height to the angle of roll of the EMS TUG, see Figure 44.

A second surprise is that the rate of roll is significantly higher at 1.5 meters wave height, compared with the 2.5- and 1.0-meters wave height, all at six seconds period and 100% engine power, see Figure 45. That this peak is not based on an error in the system becomes evident when looking at the data for the same wave parameters with different engine power settings in Figure 46.

This phenomenon may be caused by a combination of the wave length associated with the wave period and the speed of the tow. Unfortunately, the speed measurements are also fractured and are therefore of no support at this point. This setting in particular should be reviewed and looked into with more detail if further tests are to be conducted.

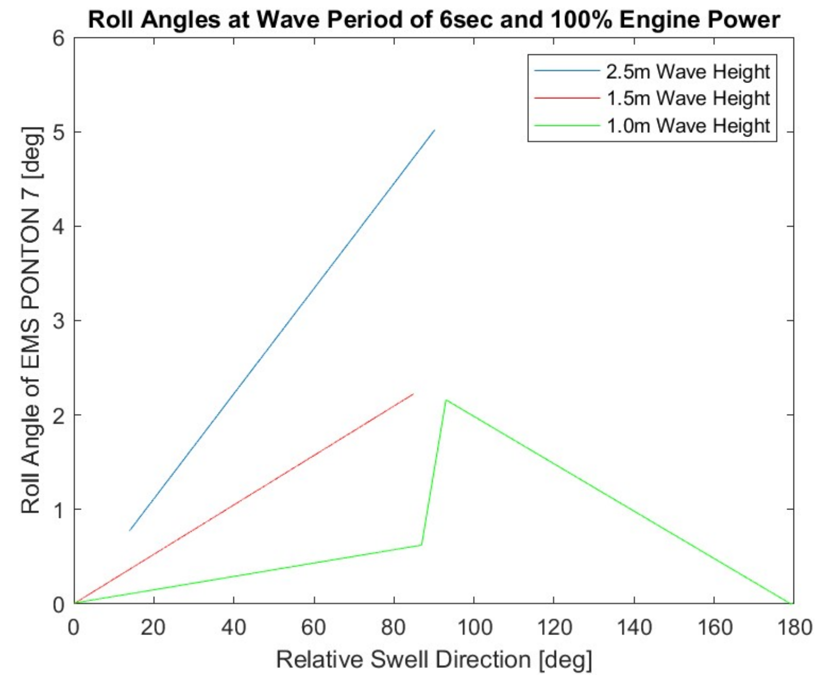


Figure 44: Angles of Roll of EMS PONTON 7 at 6 Seconds Wave Period and 100% Engine Power

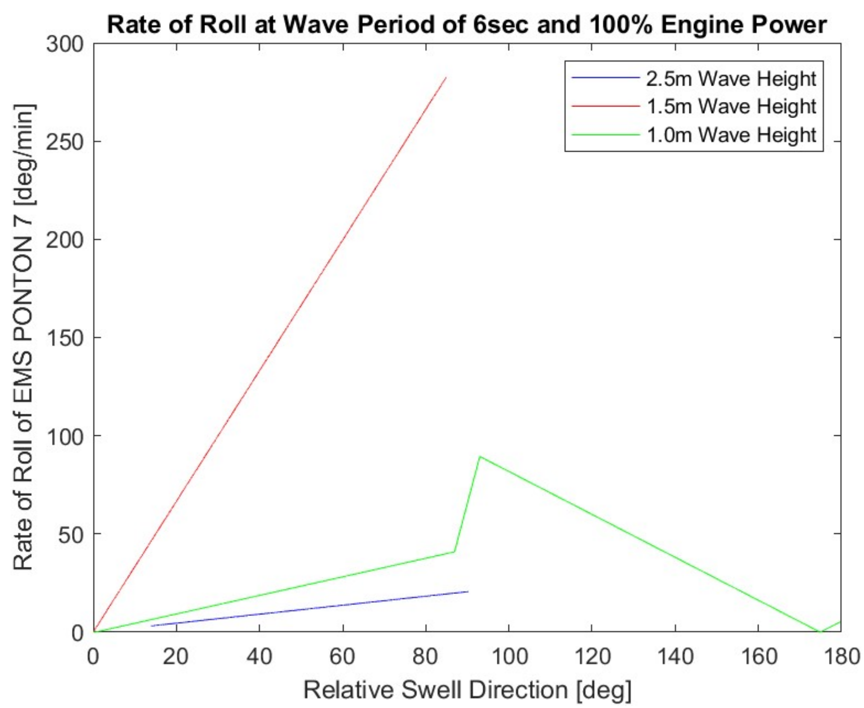


Figure 45: Rate of Roll of EMS PONTON 7 at 6 Seconds Wave Period and 100% Engine Power

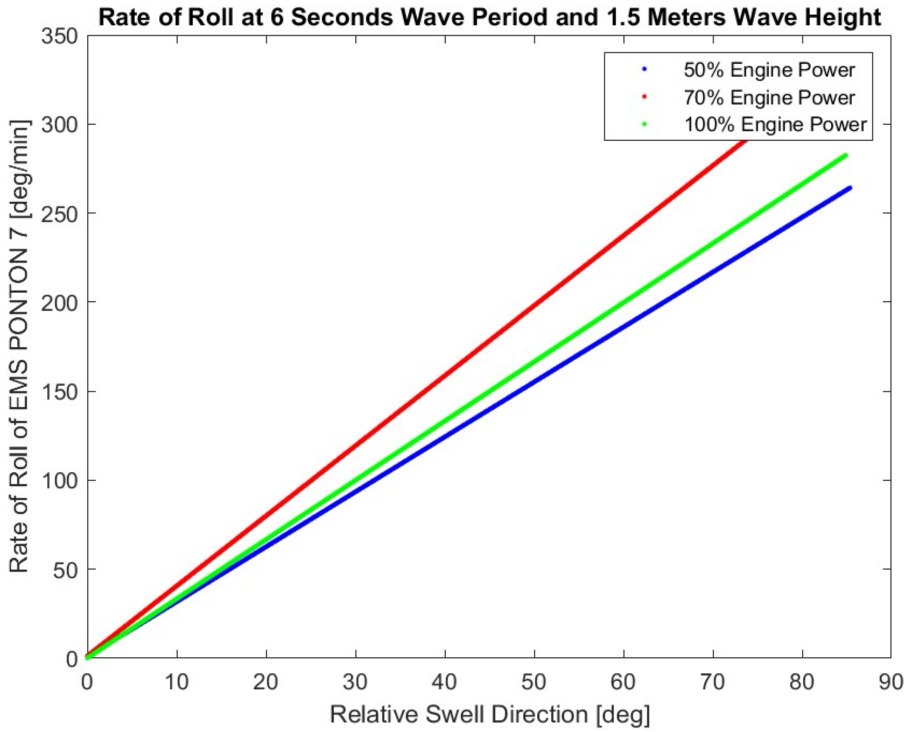


Figure 46: Rate of Roll of EMS PONTON 7 at 6 Seconds Wave Period and 1.5 Meters Wave Height

In the area of seven seconds wave period the wave height of 3.0 meters stands out. The roll rate is immensely higher in head and bow seas (Figure 48), and the roll angle is considerably larger from swell coming from abaft the beam, see Figure 47. In contrast to that the 2.5-meters wave seems to have a reverse effect judging from the angle of roll. Unfortunately, no usable roll rate data has been recorded for this wave height. At 1.5 meters wave height the rolling motion seems to be fairly evenly distributed for the head and following seas.

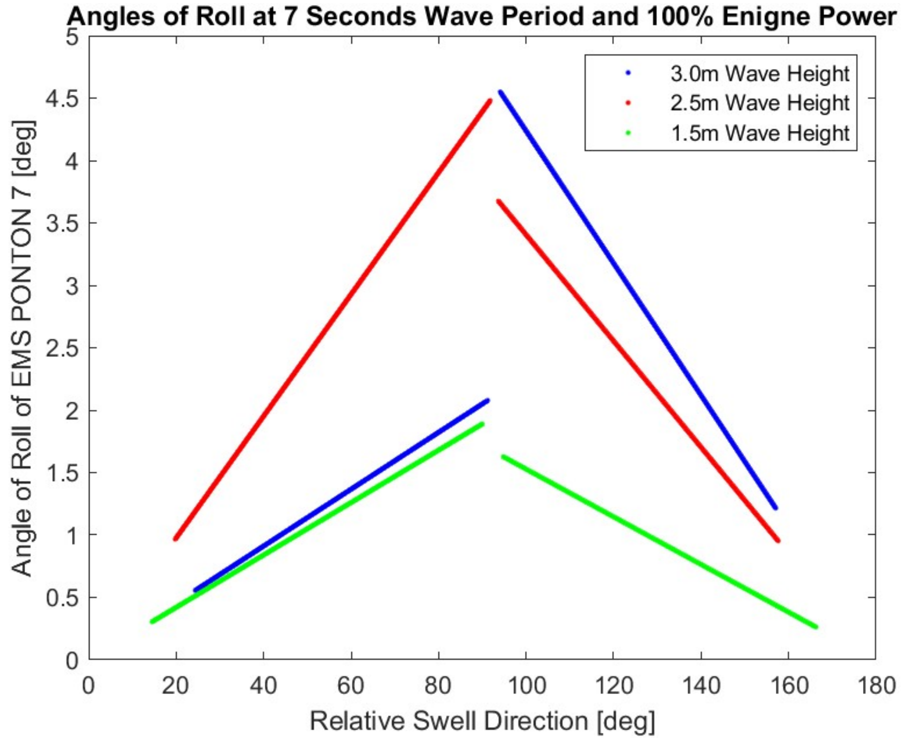


Figure 47: Angles of Roll of EMS PONTON 7 at 7 Seconds Wave Period and 100% Engine Power

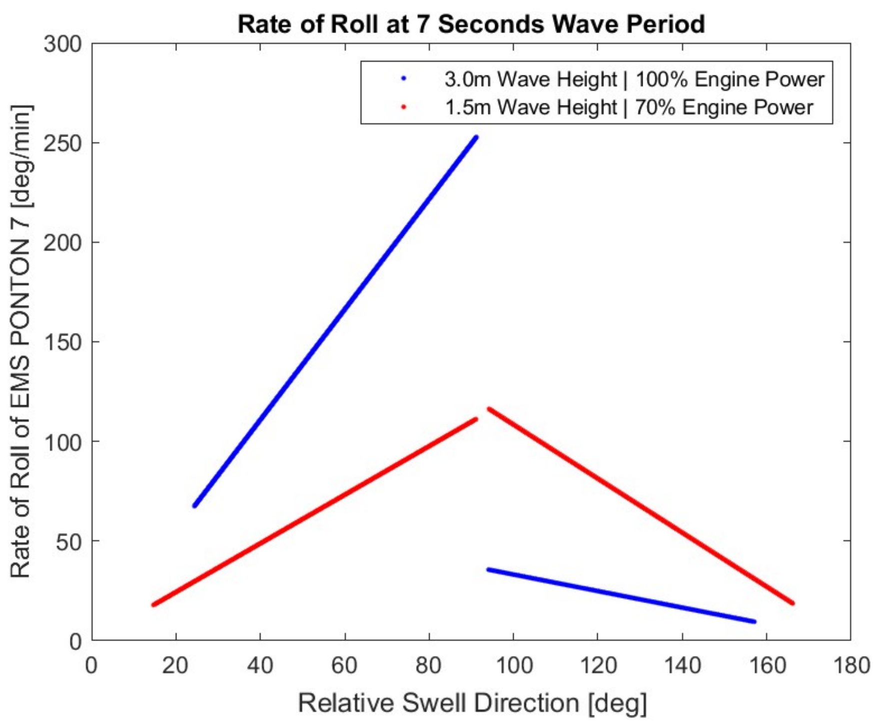


Figure 48: Rate of Roll of EMS PONTON 7 at 7 Seconds Wave Period

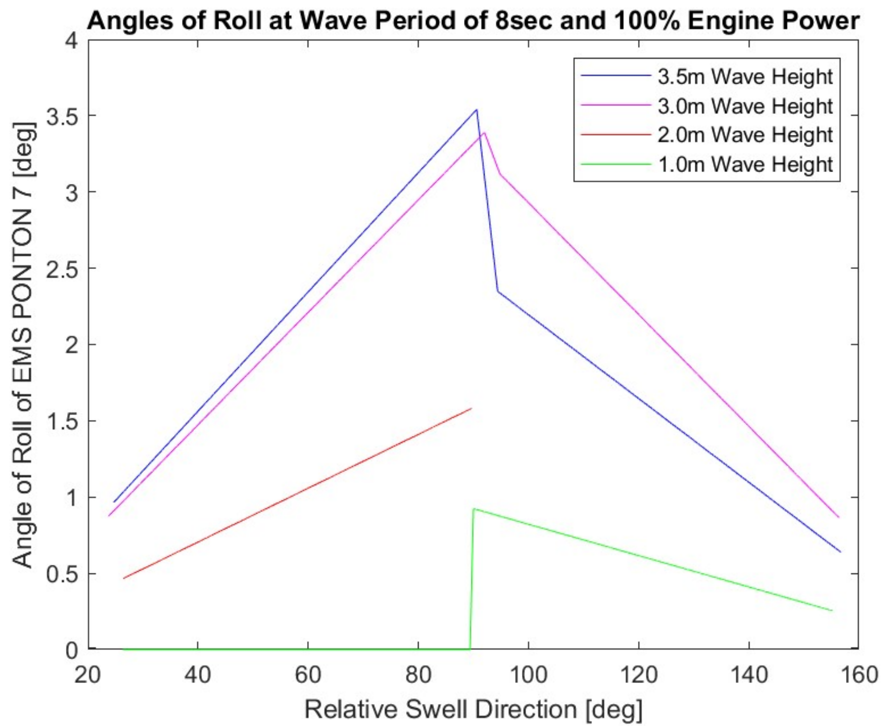


Figure 49: Angles of Roll of EMS PONTON 7 at 8 Seconds Wave Period and 100% Engine Power

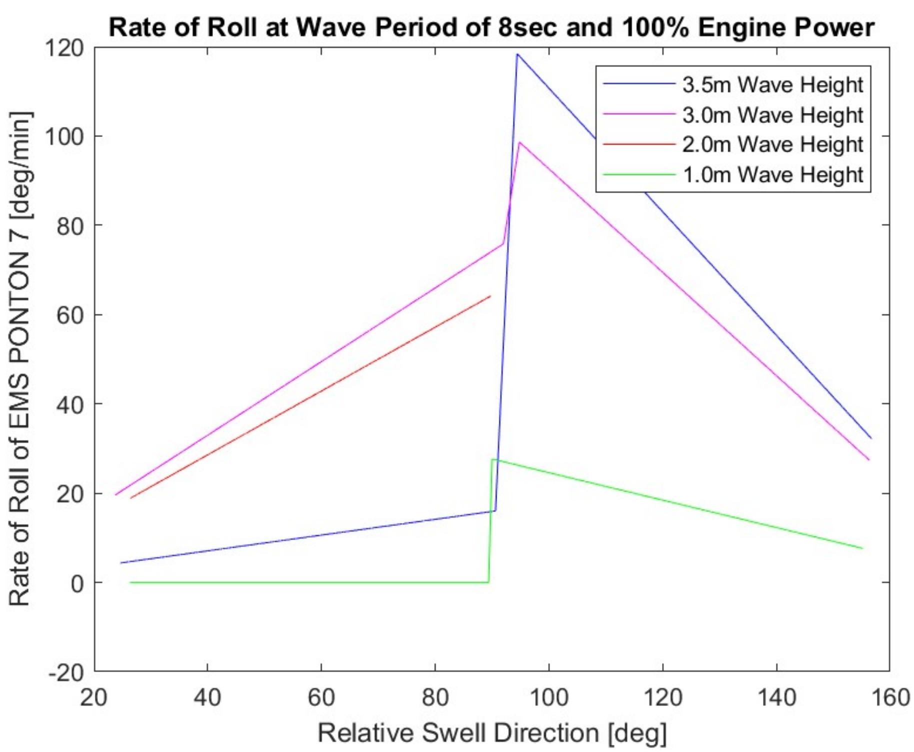


Figure 50: Rate of Roll of EMS PONTON 7 at 8 Seconds Wave Period and 100% Engine Power

In the eight seconds period waves there is a consistent difference between following and head waves. In head and bow seas the angle of roll increases (Figure 49) and the rate of roll decreases (Figure50), when compared with the following and quartering swells. This means that in swell, coming from abaft the beam, the stability is higher.

The heeling angle, as shown in chapter 5, at which the side of the barge's deck may be submerged by water, accounting for extreme winds is:

$$\phi_{Wave\ max} = 50\% * 13.02 \cong 6.51°$$

Therefore, any roll angles larger than 6.51 degrees have to be avoided. In a six seconds wave period this may already be the case at 1.5 meters wave height. Unfortunately, there is no data from abaft the beam for the values of 1.5 meters and 2.5 meters wave height. However, looking at the graph from the 1.0-meters wave it seems likely that at 2.5 meters the threshold of 6.5 degrees roll angle is already exceeded. In the condition of a seven seconds wave period the threshold isn't exceeded in the recorded data. The same applies for the eight seconds wave period, as the roll angles of the EMS PONTON 7 remain below 6.5 degrees throughout. All of this is valid assuming, that the block being transported has openings through which water may enter as soon as the side of the barge's deck is submerged. This is a likely condition, since the blocks are smaller sections of the cruise vessels which are built by the Meyer Werft. However, if the openings on the height of the deck were sealed and water may only penetrate starting from one meter above the barge's deck, this would drastically change the allowable roll angle:

$$\phi_{max} = tan^{-1}\left(\frac{h - T + 1.0}{\frac{b}{2}}\right) = tan^{-1}\left(\frac{4.5 - 2.306 + 1.0}{\frac{18.98}{2}}\right) \cong 18.6°$$

$$\phi_{Wave\ max} = 50\% * 18.6 \cong 9.3°$$

This would also remove the restrictions due to wave induced heeling angles for the six seconds wave period.

These results are all based on the 100% engine power output setting, because, this setting - as expected - produced the strongest vessel movement. It may be argued that in such situations the power could be reduced. But assuming the tow is in bad weather conditions and a further deterioration is imminent, it would be prudent for the vessel to proceed to a place of refuge at all available speed. Therefore, it is essential to choose the worst-case scenario as the basis for developing the operating limits.

7.1.3. Roll Motion of the Tow

Adjoining the results from the worst conditions concerning the roll angles and roll rates of the tug and the barge gives a quick overview of the severity of the situations. Even though some data points are missing from the six seconds wave period it becomes apparent that the roll angles of the tug and the barge are somewhat close in the head and bow seas, see Figure 51. However, the rate of roll is very low for the barge in comparison with the tug, see Figure 52. Deducing from this, the most critical situation is in a swell of six seconds wave period and the danger increases with the height of the swell.

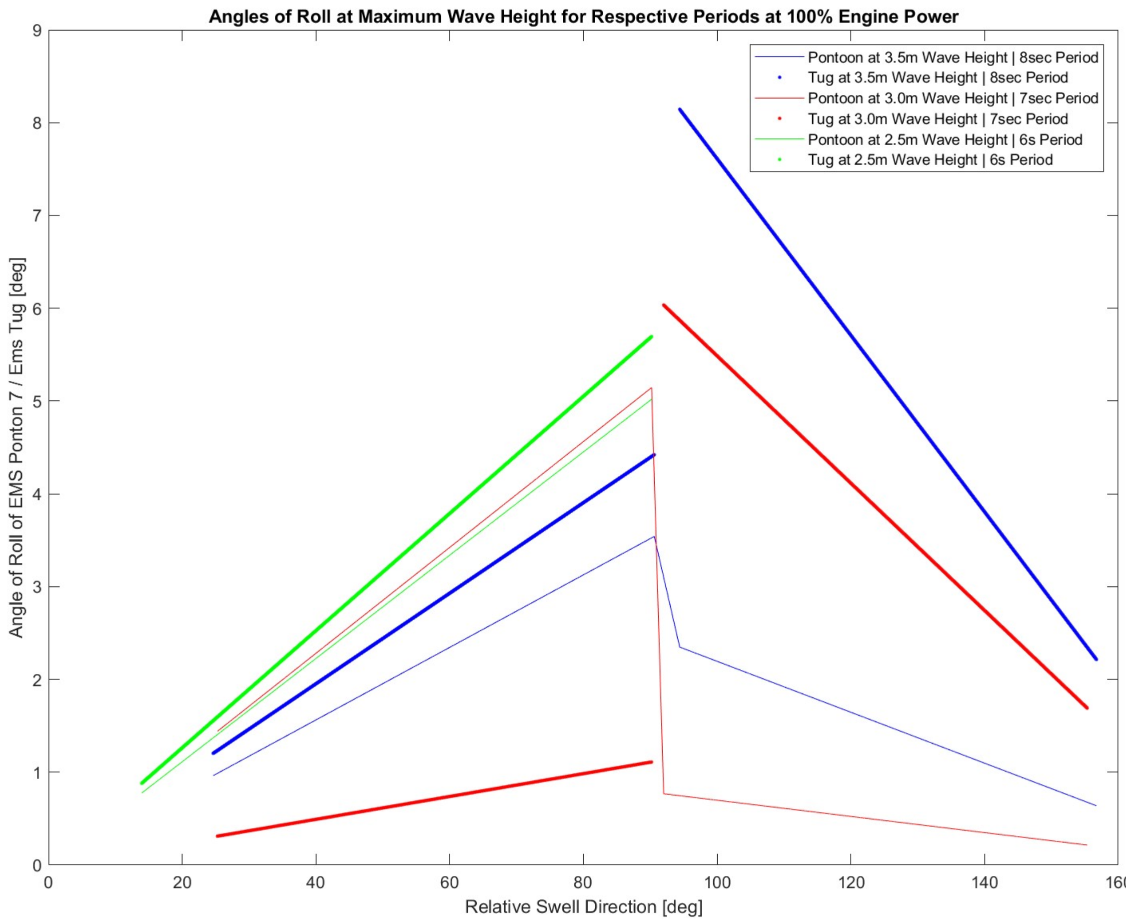


Figure 51: Angles of Roll for the Tow with Maximum Wave Height in the Respective Wave Periods

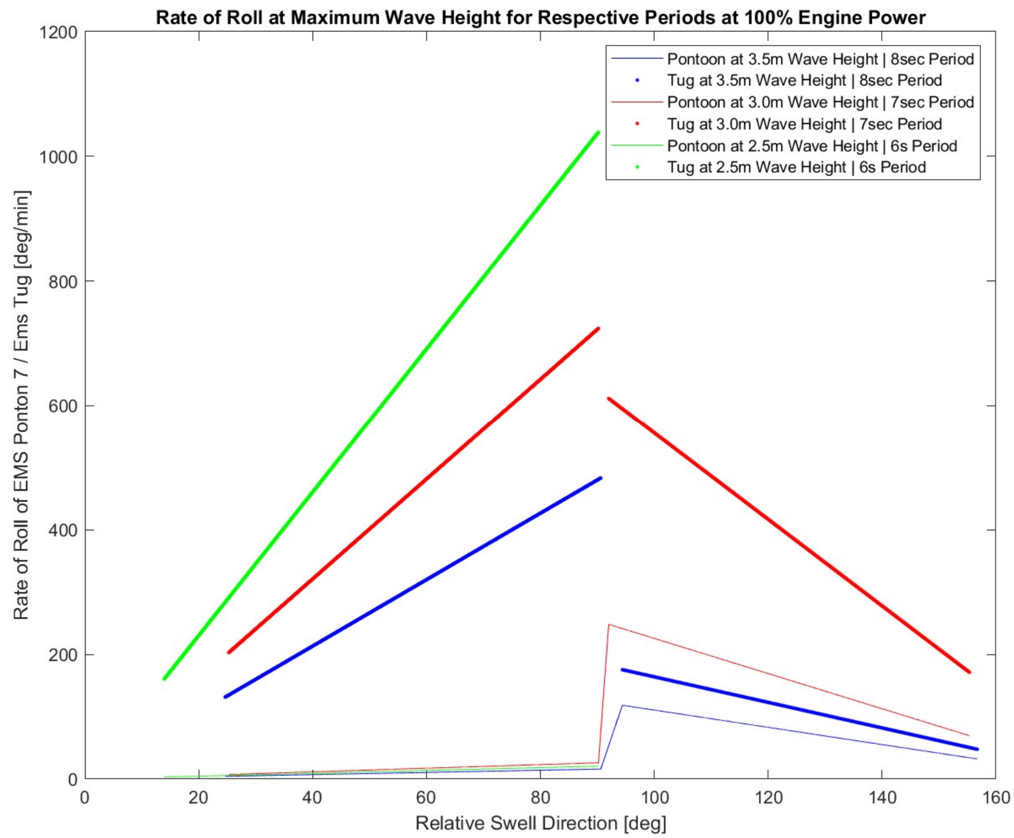


Figure 52: Rate of Roll for the Tow with Maximum Wave Height in the Respective Wave Periods

Unfortunately, the roll acceleration is not a value which was extractable form the simulator exercises. However, the rate of roll gives an indication that the movement on the barge is far less violent than on the tug, in spite of a high GM of more than ten meters. In case of accelerations still being too high the GM may be reduced by decreasing the ballast of the barge. This action would lift the center of gravity, effectively reducing the GM, which is the distance between the center of gravity and the metacenter. Thereby effectively reducing the uprighting lever and thus the acceleration. The DNVGL defines the roll acceleration as: (DNV GL, 2015)

$$a_{roll} = f_p * \theta * \frac{\pi}{180} * \left(\frac{2\pi}{T_0}\right)^2$$

In chapter 2 the roll period T has already been defined for the barge, substituting this definition in the formula above results in:

$$a_{roll} = f_p * \theta * \frac{\pi}{180} * \left(\frac{2\pi}{Cr\,\frac{b}{\sqrt{GM}}}\right)^2 = f_p * \theta * \frac{\pi}{180} * \frac{4 * \pi^2 * GM}{Cr^2 * b^2}$$

Thus, the value of roll acceleration in rad/s² is directly proportional to the value of GM. A reduction of the GM will therefore result in a reduced acceleration. However, since the barge is not equipped with a ballast system, instead pumps have to be deployed manually. Therefore, these changes in the ballast have to be done prior to departure, or when at a place of refuge. Furthermore, it is important to mention that the tanks should, if possible, be completely full or completely empty, since free water surfaces on the inside of vessel structures reduces the stability and thereby presents a potential threat.

7.2. Pitching Motion

Similar to the rolling motion a vessel's pitching response due to waves depends on the length of the encountered wave, relative to the vessel's length and on the period of encounter, as may be seen in Figure 53. The wave length being considerably longer than the vessel signifies a higher period of encounter and the vessel will follow the slope of the wave's profile easily without a noteworthy phase lag. In these cases, the vessel will easily climb and descend the wave crest in the course of which the trim angle changes. Its deck will, for the most part, remain close to parallel in regards to the waterline, producing a small pitching motion. On the other hand, if the hull is longer than the wave length the waves will exerts opposing moment on the hull of the vessel simultaneously.(Clark, 2008)

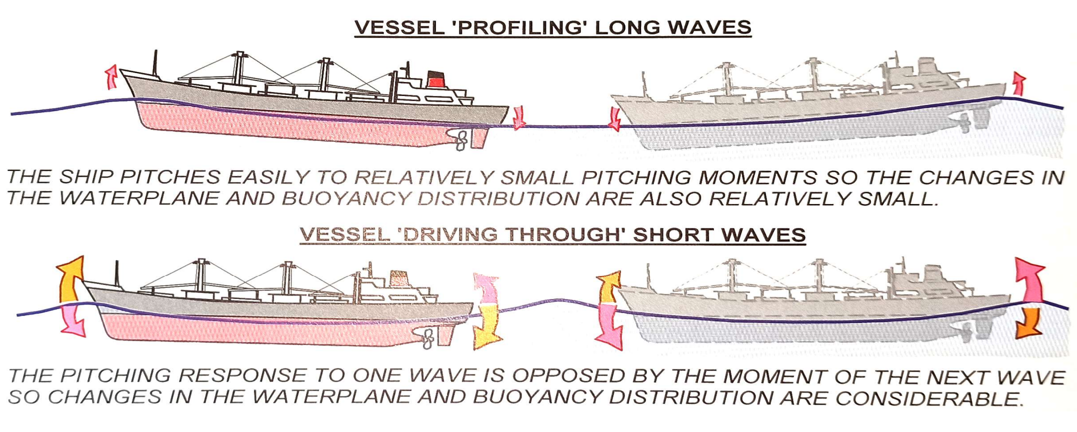


Figure 53: Pitching Motion in Different Wave Lengths (Clark, 2008)

Only EMS PONTON 7 in combination with the wavelength in a six seconds wave period condition complies with the latter described condition. The pitching motion on the EMS TUG however, due to its relative short length compared with the wavelengths in question, is not showing any unexpected effects.

Even though the wave period of eight seconds allowed for increased wave heights, the resulting pitch angle is the smallest, due to the wave steepness. The wave steepness is calculated by dividing the wave height by the wave length: (DNV, 2010)

$$S = \frac{H}{\lambda_0}$$

Applying the formula to the largest recorded wave heights for the corresponding wave period yields:

$$Steepness_{8sec} = \frac{H_{Wave}}{\lambda_{8sec}} = \frac{3.5}{99.84} = 0.035$$

$$Steepness_{7sec} = \frac{H_{Wave}}{\lambda_{7s}} = \frac{3.0}{76.44} = 0.039$$

$$Steepness_{6sec} = \frac{H_{Wave}}{\lambda_{6se}} = \frac{2.5}{56.16} = 0.044$$

Figure 54 below shows the seven seconds wave period being the highest, despite the steepness being larger for the six seconds period wave. However, this may be misleading, since the values abaft the beam for the six seconds period are missing. The ‘W-shape’ of the graph and the fact that the blue graph is not on its smallest at 90 degrees stems from the conversion of the values into absolutes. This was necessary to make the results comparable, as the data of the simulator indicated for parts of the graphs positive and for other parts negative values, making the graphs very messy.

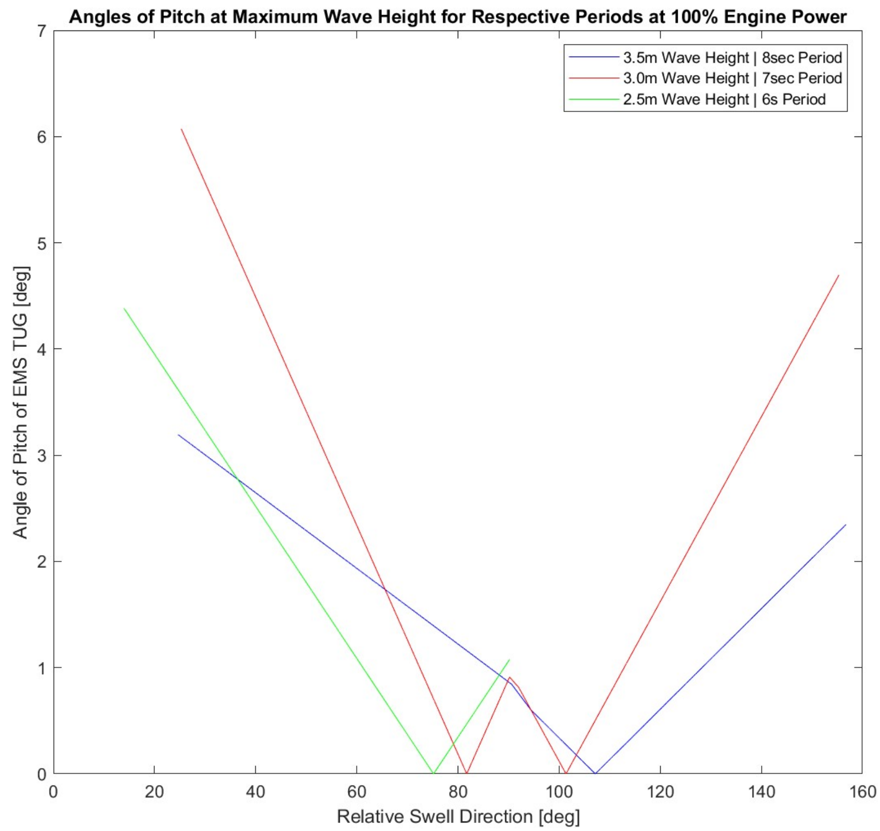


Figure 54: Angles of Pitch at Maximum Wave Height for Respective Wave Periods

The rate of pitch however, as seen in Figure 55, corresponds almost perfectly with the values of the steepness, and the graph reinforces the results from the section above: the six seconds wave period condition is the worst for the EMS TUG.

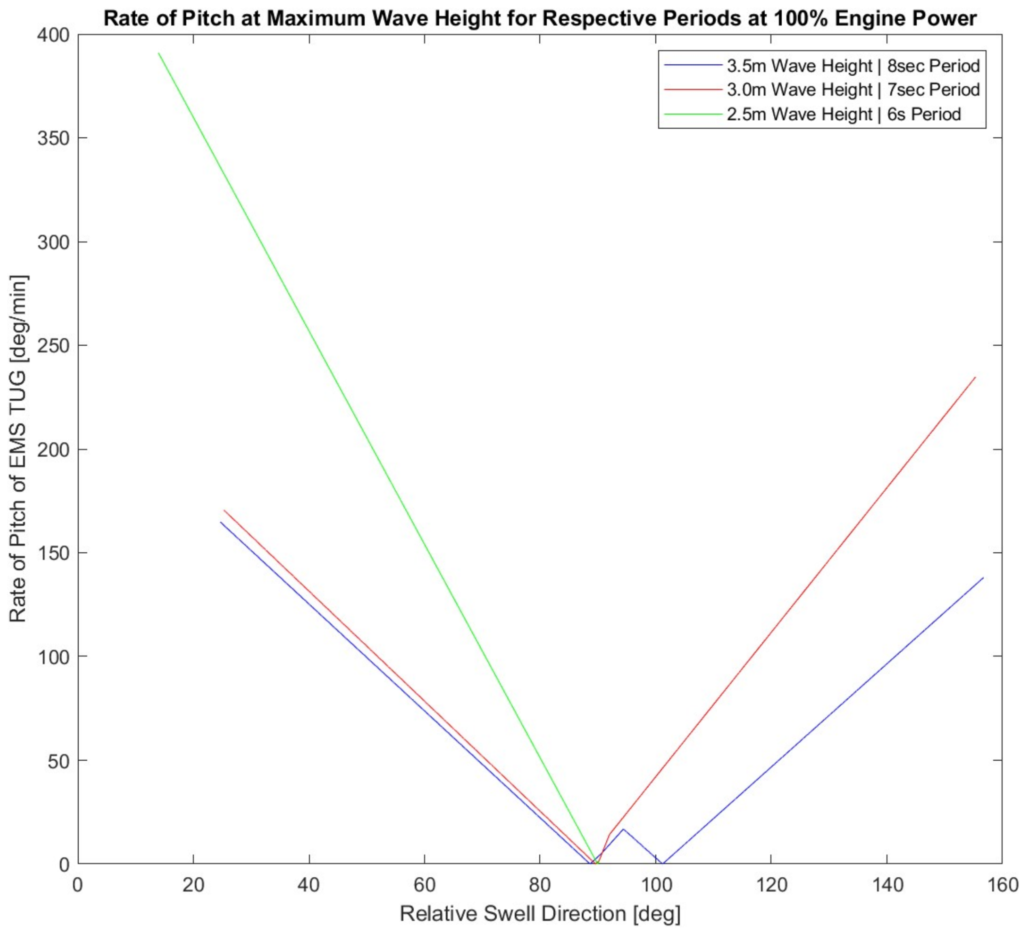


Figure 55: Rate of Pitch at Maximum Wave Height for Respective Wave Periods

The barge is experiencing comparatively little dynamic trim due to its box-shaped hull, as can be seen in Figure 56. Also, the pitch rate is lower in comparison, see Figure 57. Unfortunately, no useable data was recorded for the 2.5 meters wave height at the six seconds wave period. Judging from the steepness factor the graphs should be slightly higher than the seven seconds period graph.

However, none of the data gives an indication as to how many slams per minute there were. But, since slamming is quite unlikely on the small EMS TUG and the stable EMS PONTON 7, it may be assumed that the threshold of three slams per minute is not exceeded in these conditions.

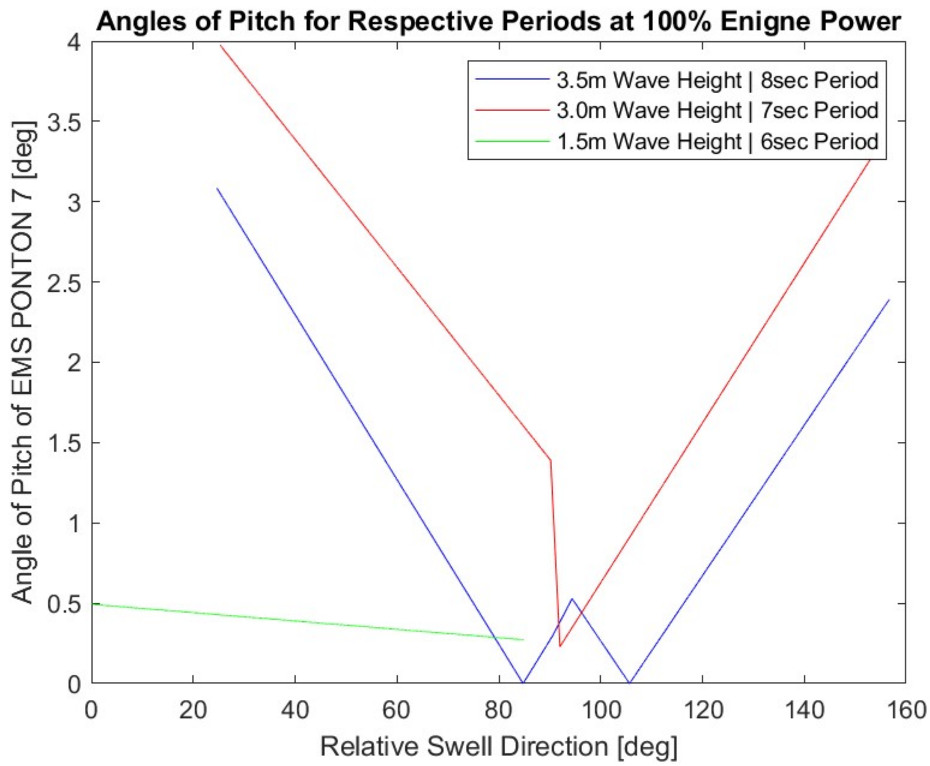


Figure 56: Angles of Pitch for EMS PONTON 7

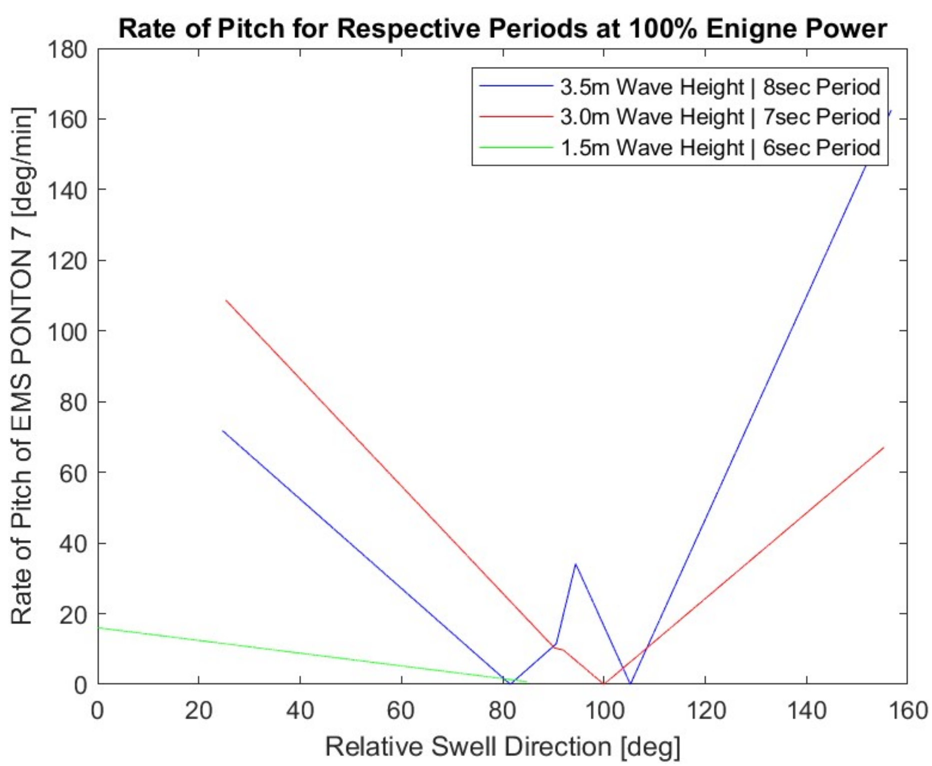


Figure 57: Rate of Pitch for EMS PONTON 7

7.3. *Tow Line Tension*

In any towing operation the tension on the tow line is of the utmost importance. It is primarily influenced by the bollard pull of the tug and its respective power setting. The lines, bridle, shackles, connection points, and all other towing equipment has to comply with the vessel's maximum bollard pull. However, Figure 58 indicates that the highest recorded tensions only range from 13 to 18 tons, far below the capability of the EMS TUG with its bollard pull of 45.2 tons.

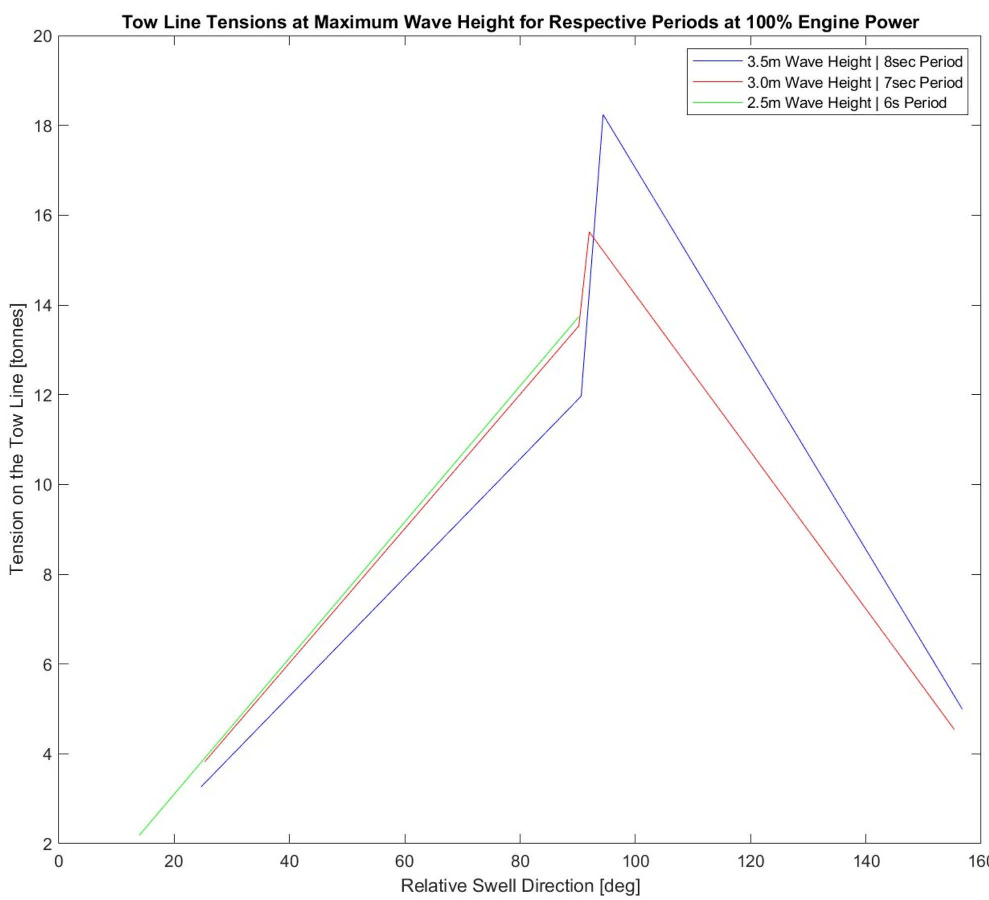


Figure 58: Tow Line Tensions at Maximum Wave Height for Respective Periods

Also looking at the data in detail no shock-loads were registered throughout the dataset, the increase or decrease in tension was in all cases gradual and more or less smooth. To clearly see any variances, the column of tension in the Excel table has been color coded, so higher tensions are displayed with an ever darker red and lower tensions with an ever darker green. Adopting such a setting makes spotting shock-loads quite easy when scrolling through the table. Table 12 depicts a small section of such a table.

Table 12: Example for Color Coding in Excel

time	Tug 5.Enviro	Tug 5.Enviro	Tug 5.Forces ParametersTowing lines.	Tug 5.Mome	Tug 5.Mome	Tug 5.Mome	Tug 5.Mome	Tug 5.Motion.Heading(degre	Tug 5.Motion.Longitudinal speed(kno	Tug 5.Motion.Pitch angle(degre	Tug 5.Motio
12:40:00	24.64429	3.5	-3.262526	-7.476585	2.144921	7.808692	-0.632742	155.538702	1.218217	3.193407	-164.85449
12:40:01	24.654563	3.5	-3.263882	-7.479637	2.145815	7.811882	-0.633005	155.528504	1.219063	3.193041	-164.82803
12:40:02	24.664837	3.5	-3.265238	-7.482688	2.146709	7.815072	-0.633269	155.518306	1.21991	3.192675	-164.80156
12:40:03	24.67511	3.5	-3.266594	-7.48574	2.147604	7.818262	-0.633533	155.508108	1.220756	3.192309	-164.77509
12:40:04	24.685383	3.5	-3.267949	-7.488791	2.148498	7.821451	-0.633796	155.49791	1.221602	3.191943	-164.74862
12:40:05	24.695657	3.5	-3.269305	-7.491842	2.149392	7.824641	-0.63406	155.487712	1.222448	3.191578	-164.72216
12:40:06	24.70593	3.5	-3.270661	-7.494894	2.150286	7.827831	-0.634324	155.477514	1.223295	3.191212	-164.69569
12:40:07	24.716204	3.5	-3.272017	-7.497945	2.15118	7.831021	-0.634588	155.467317	1.224141	3.190846	-164.66922
12:40:08	24.726477	3.5	-3.273373	-7.500997	2.152074	7.834211	-0.634851	155.457119	1.224987	3.19048	-164.64276
12:40:09	24.736751	3.5	-3.274728	-7.504048	2.152968	7.837401	-0.635115	155.446921	1.225833	3.190114	-164.61629
12:40:10	24.747024	3.5	-3.276084	-7.507099	2.153862	7.84059	-0.635379	155.436723	1.22668	3.189748	-164.58982
12:40:11	24.757298	3.5	-3.27744	-7.510151	2.154756	7.84378	-0.635643	155.426525	1.227526	3.189382	-164.56336
12:40:12	24.767571	3.5	-3.278796	-7.513202	2.15565	7.84697	-0.635906	155.416327	1.228372	3.189016	-164.53689
12:40:13	24.777845	3.5	-3.280152	-7.516253	2.156544	7.85016	-0.63617	155.406129	1.229218	3.18865	-164.51042
12:40:14	24.788118	3.5	-3.281507	-7.519305	2.157439	7.85335	-0.636434	155.395931	1.230065	3.188284	-164.48395
12:40:15	24.798392	3.5	-3.282863	-7.522356	2.158333	7.85654	-0.636698	155.385733	1.230911	3.187919	-164.45749
12:40:16	24.808665	3.5	-3.284219	-7.525408	2.159227	7.859729	-0.636961	155.375535	1.231757	3.187553	-164.43102
12:40:17	24.818939	3.5	-3.285575	-7.528459	2.160121	7.862919	-0.637225	155.365338	1.232603	3.187187	-164.40455
12:40:18	24.829212	3.5	-3.286931	-7.53151	2.161015	7.866109	-0.637489	155.35514	1.23345	3.186821	-164.37809
12:40:19	24.839486	3.5	-3.288286	-7.534562	2.161909	7.869299	-0.637752	155.344942	1.234296	3.186455	-164.35162
12:40:20	24.849759	3.5	-3.289642	-7.537613	2.162803	7.872489	-0.638016	155.334744	1.235142	3.186089	-164.32515
12:40:21	24.860033	3.5	-3.290998	-7.540664	2.163697	7.875678	-0.63828	155.324546	1.235988	3.185723	-164.29868
12:40:22	24.870306	3.5	-3.292354	-7.543716	2.164591	7.878868	-0.638544	155.314348	1.236835	3.185357	-164.27222
12:40:23	24.880579	3.5	-3.293709	-7.546767	2.165485	7.882058	-0.638807	155.30415	1.237681	3.184991	-164.24575
12:40:24	24.890853	3.5	-3.295065	-7.549819	2.166379	7.885248	-0.639071	155.293952	1.238527	3.184625	-164.21928
12:40:25	24.901126	3.5	-3.296421	-7.55287	2.167274	7.888438	-0.639335	155.283754	1.239373	3.18426	-164.19282
12:40:26	24.9114	3.5	-3.297777	-7.555921	2.168168	7.891628	-0.639599	155.273557	1.24022	3.183894	-164.16635
12:40:27	24.921673	3.5	-3.299133	-7.558973	2.169062	7.894817	-0.639862	155.263359	1.241066	3.183528	-164.13988
12:40:28	24.931947	3.5	-3.300488	-7.562024	2.169956	7.898007	-0.640126	155.253161	1.241912	3.183162	-164.11342
12:40:29	24.94222	3.5	-3.301844	-7.565075	2.17085	7.901197	-0.64039	155.242963	1.242758	3.182796	-164.08695
12:40:30	24.952494	3.5	-3.3032	-7.568127	2.171744	7.904387	-0.640654	155.232765	1.243604	3.18243	-164.06048
12:40:31	24.962767	3.5	-3.304556	-7.571178	2.172638	7.907577	-0.640917	155.222567	1.244451	3.182064	-164.03401
12:40:32	24.973041	3.5	-3.305912	-7.57423	2.173532	7.910767	-0.641181	155.212369	1.245297	3.181698	-164.00755
12:40:33	24.983314	3.5	-3.307267	-7.577281	2.174426	7.913956	-0.641445	155.202171	1.246143	3.181332	-163.98108
12:40:34	24.993588	3.5	-3.308623	-7.580332	2.17532	7.917146	-0.641708	155.191973	1.246989	3.180966	-163.95461
12:40:35	25.003861	3.5	-3.309979	-7.583384	2.176214	7.920336	-0.641972	155.181775	1.247836	3.180601	-163.92815
12:40:36	25.014135	3.5	-3.311335	-7.586435	2.177109	7.923526	-0.642236	155.171578	1.248682	3.180235	-163.90168
12:40:37	25.024408	3.5	-3.312691	-7.589487	2.178003	7.926716	-0.6425	155.16138	1.249528	3.179869	-163.87521
12:40:38	25.034682	3.5	-3.314046	-7.592538	2.178897	7.929906	-0.642763	155.151182	1.250374	3.179503	-163.84874
12:40:39	25.044955	3.5	-3.315402	-7.595589	2.179791	7.933095	-0.643027	155.140984	1.251221	3.179137	-163.82228
12:40:40	25.055229	3.5	-3.316758	-7.598641	2.180685	7.936285	-0.643291	155.130786	1.252067	3.178771	-163.79581
12:40:41	25.065502	3.5	-3.318114	-7.601692	2.181579	7.939475	-0.643555	155.120588	1.252913	3.178405	-163.76934
12:40:42	25.075776	3.5	-3.31947	-7.604743	2.182473	7.942665	-0.643818	155.11039	1.253759	3.178039	-163.74288

Since no shock loads have been recorded and the maximum tension is far below the EMS TUG's bollard pull, no restrictions due to the tow line tensions have to be taken into consideration.

7.4. *Ability to Maintain Heading*

The ability for the vessel to maintain the desired heading in adverse conditions is clearly essential for safe navigation. If more engine power is used, more thrust is created by the propellers. The thus created dynamic water pressure exerts force onto the rudder blade, which is used to alter the vessel's heading. Therefore, it is evident that the more engine power is used, the easier it is to maintain a heading, as the rudder blades' effect is magnified. An overview of the capabilities of the model EMS TUG towing the EMS PONTON 7 can be seen in Table 13 hereafter:

Table 13: Ability of the Tow to Maintain Heading

Wave Period	Wave Height	Range of Maintainable Headings at Engine Power of:		
		50%	70%	100%
6 Seconds	1.0m	0°-180°	0°-180°	0°-180°
	1.5m	0°-180°	0°-180°	0°-180°
	2.0m	0°-180°	0°-180°	0°-180°
	2.5m	90°-180°	90°-180°	0°-180°
	3.0m	-	120°-180°	0°-60°; 90°-180°
7 Seconds	1.0m	0°-180°	0°-180°	0°-180°
	1.5m	0°-180°	0°-180°	0°-180°
	2.0m	0°-180°	0°-180°	0°-180°
	2.5m	90°-180°	0°-180°	0°-180°
	3.0m	90°-180°	0°-180°	0°-180°
	3.5m	-	90°-180°	90°-180°
8 Seconds	1.0m	0°-180°	0°-180°	0°-180°
	1.5m	0°-180°	0°-180°	0°-180°
	2.0m	0°-180°	0°-180°	0°-180°
	2.5m	90°-180°	0°-180°	0°-180°
	3.0m	0°-90°	0°-180°	0°-180°
	3.5m	-	0°-90°	0°-180°
	4.0m	-	-	0°-90°

Even though the higher power settings preserve maneuverability in deteriorating weather conditions, the limit should be the values of the 50% power settings. This is owed to the fact that, as mentioned earlier, the worst-case scenario should always be the basis for developing operating limits. Often, accidents only happen when a number of factors coincide. Ergo, if as a result of violent rolling or pitching motions the propulsion unit delivers reduced power, it should still be possible for the ship's command to maintain a safe heading and steer clear of dangerous areas.

8. HAZID

Risk is generally referred to as the product of the probability of an event happening times its consequence. Towing operations inherit a number of risks, even more in heavy weather situations. A popular tool to highlight the risks in a process is the HAZID (Hazard Identification Study). Such a method is essential to determine, evaluate, control, and mitigate risks. In the course of a HAZID different aspects of the operation are reviewed and assessed, in order to identify hazards which could be the cause for injury to personnel, damage or total loss of assets, environmental damage, and liabilities. (Siddiqui, 2014)

For the conduction of the HAZID a basic risk matrix from DNV GL has been used, see Figure 59.

			Likelihood categories		
			1	2	3
			Failure not heard of in industry	Failure occurred in industry	Failure occurred several times in industry
Consequence categories	1	No or minor - injuries to personnel - damage to material/environment	L	L	M
	2	Serious - injuries to personnel - damage to material/environment	L	M	H
	3	1 or more fatalities to personnel Major damage to material/environment	M	H	H

Figure 59: Risk Matrix (Søfartsstyrelsen/ Danish Maritime Authority, 2017)

The green section defines the area of low risk, the red of high risk. The yellow area is of medium risk and is often referred to ALARP (as low as reasonably possible). This should be the limit for any operation. No operation should ever be started with a high risk which may not be decreased to ALARP by means of mitigating measures.

The HAZID below (Table 14) does not cover every aspect of towing operations, but instead focuses on hazards which may arise due to the encounter with heavy weather. Any aspects of maintenance and machinery break down is not relevant to this thesis and therefore the assumption is therefore that all equipment is in good condition and inspected regularly.

Table 14: HAZID for Towing Operations

ID	Hazard	Cause	Consequence	Existing Barriers	Probability	Consequence	Risk	Mitigating measures	New probability	New consequence	New Risk
1	High roll angles / high roll rates	Heavy seas, parametric, and synchronous rolling motion	Loss of stability, damage or loss of cargo	Adequate sea fastening, Voyage will be undertaken only with acceptable weather forecast	2	2	M	Approaching a place of refuge for the duration of heavy weather, changing course and / or speed to avoid dangerous resonances	1	2	L
2	High rolling motion acceleration	Heavy seas, parametric and synchronous rolling motion,	Sea fastening inadequate	Voyage will be undertaken only with acceptable weather forecast	2	2	M	Approaching a place of refuge for the duration of heavy weather, changing course and / or speed to avoid dangerous resonances, reducing GM to decrease roll accelerations	1	2	L

3	Inability to maintain heading	High waves, short wave periods	Inability to maneuver, potential for collision or grounding	Voyage will be undertaken only with acceptable weather forecast	2	3	H	Approaching a place of refuge for the duration of heavy weather	1	3	M
4	Strong pitching motion	Heavy seas	Discomfort and wear and tear due to slamming	Voyage will be undertaken only with acceptable weather forecast	2	1	L	Approaching a place of refuge for the duration of heavy weather	1	1	L
5	Snapping of tow line	Shock loads on tow line	Loss of control over barge	Tow line working load exceeding bollard pull, voyage will be undertaken only with acceptable weather forecast	3	2	H	Using tow line with high flexibility, carrying a spare tow line, alarm function if tension drops to zero, paying out more tow line to increase catenary	2	2	M
6	Contact with barge	Tow line too short	Damage on barge and/ or tug, inability to maneuver	Tow line only shortened for river passages	2	2	M	Including minimum tow line length throughout sea passages in the SMS (Safety Management System)	1	2	L

9. Further Steps

The model of the EMS TUG and the EMS PONTON 7 are approximations in terms of hydrostatic behavior, but certainly do not fully comply with the true maneuvering characteristics of the vessels. To come closer in reproducing the true behavior, scaled models would have to be built and tested in a ship model basin. An example of an institution which makes these kinds of tests is the HSVA (Hamburgische Schiffbau-Versuchsanstalt) in Hamburg. Other European facilities are also available. But even the faculty of Maritime Sciences of the University of Applied Sciences in Leer is currently building a new facility to conduct such studies.

The results from such an investigation would then have to be applied to the model of the EMS TUG and the EMS PONTON 7. A possibility would be to use the same conditions as in the simulation experiments that were conducted in the course of this thesis. When this process is completed, experiments with other wave conditions should be performed both on the simulator and with the model in the basin. Only if these results coincide the simulator model may be used to evaluate the behavior in further wave conditions.

Once this is achieved, another important step would be to not only run the model in regular waves, but use the Pierson-Moskowitz spectrum, or even better the JONSWAP spectrum. As discussed in chapter 4.2 these spectra are created to mirror wave spectra which are encountered in the Atlantic Ocean and the North Sea respectively. Then, it is possible to investigate the worst-case condition of very high wave groups by testing the models in situations as close to real life as possible.

Furthermore, the newest version of the Transas simulator software, which is about to be installed on the simulator in the faculty in Leer, has to be checked. The two most important issues are, whether the problem of lacking and faulty data recording is rectified, and if there is a possibility of extracting values for the barge's roll acceleration, since these are most critical for sea fastening. Also, the recording of the tow line tensions has to be double checked, as the changes are gradual throughout, which may be realistic with regular waves, but the same may not be the case for actual wave spectra.

10.Conclusion

The process of designing of even a simplified simulator model is a time-consuming task, even more with little to no experience with the software solutions beforehand.

The simulator runs indicated, that the operating limit for the EMS TUG towing the EMS PONTON 7 in a six seconds wave period condition is at a wave height of 1.5 meters in regular waves. This equals to a maximum allowable significant wave height of 2.39 meters. The limit is established due to the roll motion of the barge. Applying this restriction to the first part of the sample voyage Klaipeda to Papenburg, which was also considered in chapter 4, the maximum forecasted significant wave height can be deduced. The first leg of the voyage is to Kiel and requires 67 hours towing time at a towing speed of six knots. Taking the α-Factor into account, this leaves an allowable significant wave height in the weather forecast of:

$$OP_{Weather\ Forecast\ 6sec} = 0.640 * 2.39m \cong 1.5m$$

Taking the places of refuge along the route into account, the distance, and therefore the steaming time, reduces considerably. The longest towing time between two places of refuge is then estimated at 27 hours at a towing speed of six knots. Choosing the α-Factor on the basis of this steaming time results in an allowable significant wave height in the weather forecast of:

$$OP_{Weath\quad Forecast\ 6\,\mathrm{sec}\,Plac\quad of\ Refuge} = 0.714 * 2.39m = 1.7m$$

For the seven seconds wave period condition the allowable regular wave height is 2.5 meters, i.e. 3.19 meters significant wave height. The limiting factor is in this case is the tug's inability to maintain the heading in head sea situations. Multiplying this value with the relevant α-Factor for the voyage to Kiel leaves more than two meters significant wave height allowance for the safe planning of the voyage.

$$OP_{Weather\ Forecast\ 7se} = 0.660 * 3.19m \cong 2.1m$$

Considering only the maximum distance between the places of refuge further increases the forecast significant wave height limit to:

$$OP_{Weather\ Forecast\ 7\,\mathrm{sec}\,Place\ of\ Refuge} = 0.722 * 3.19m = 2.3m$$

With the eight seconds wave period a regular wave height of 2.5 meters was found to still be acceptable, equaling 3.99 meters significant wave height. This limit is based on the inability of the tug to maintain the heading in following seas starting at a regular wave height of 3.0 meters.

$$OP_{Weath\quad Forecast\ 8sec} = 0.680 * 3.99m \cong 2.7m$$

Taking the shorter distance and steaming time towards a place of refuge into account leaves an operational limit of forecasted significant wave heights of:

$$OP_{Weather\ Forecast\ 8\,\mathrm{sec}\ Place\ of\ Refuge} = 0.730 * 3.99m = 2.9m$$

According to Guedes Soares and Carvalho the Rayleigh distribution, which has been used for the conversion of regular wave heights to significant wave heights, has a tendency towards overprediction. (Carvalho & Soares Guedes, 2001) The figures of the operational limit due to the weather forecast and including the place of refuge could on the other side arguably be calculated with a higher α-Factor. Upon receiving a new weather forecast the tow could turn around and approach the closer place of refuge. The over prediction of the significant wave height and the conservative choice of the α-Factor should therefore approximately even out.

However, none of these results should be used to actually determine the operational limits of the tow. The focus of this thesis is the *methodology* of how a simulator model may be created, how it can be used in the simulator, and how the results may be interpreted.

I do believe that it would be very useful to create scaled models and run them in a test basin. A number of conditions could be recorded this way and the simulator models would need to be adapted. Once the simulator models reflect the actual behavior of the vessels very closely, they may be used time and time again to determine the operating limits in varying conditions in a comparatively quick and inexpensive manner. Even the loading conditions may easily be changed in the Virtual Shipyard to adapt to a specific scenario.

Yet, whether or not the gain is worth the time and cost that would be required to create such a well-functioning model, is questionable. Especially considering the difficult economic situation due to the current Corona pandemic situation due to which the production of passenger vessels has practically come to a standstill. Nevertheless, the models that were created throughout this thesis could be used to perform training and prepare the crew, which would be particularly beneficial for officers with limited ship handling experience in towing operations.

10. Schlusswort

Die Erstellung eines Simulationsmodelles ist ein langwieriger Prozess, selbst wenn das Modell vereinfacht wird. Den Umgang mit der relevanten Software zu erarbeiten, benötigt ebenfalls Zeit.

Die Versuchsreihen im Simulator legen nahe, dass das Schleppgespann EMS TUG und EMS PONTON 7 bei einer Wellenperiode von sechs Sekunden und einer Sinuswellenhöhe von 1.5 Metern an ihre Leistungsgrenzen stößt. Diese Begrenzung ergibt sich aus dem wellenbedingten Rollwinkel des Pontons und entspricht einer maximal erlaubten signifikanten Wellenhöhe von 2.39 Metern.

Um die maximale vorhergesagte signifikante Wellenhöhe zu bestimmen, bei der sich der Schleppzug auf den Weg machen darf, wird diese Beschränkung beispielhaft auf den ersten Teil der Reise von Klaipeda nach Papenburg angewendet. Diese Strecke diente bereits im Kapitel vier als Anschauungsbeispiel.

Bei einer Schleppgeschwindigkeit von sechs Knoten werden für die erste Teilstrecke nach Kiel 67 Stunden Fahrtzeit benötigt. Aufgrund dieser Zeitspanne lässt sich der α-Factor bestimmen, mit dessen Hilfe die maximale signifikante Wellenhöhe gemäß dem Wetterbericht berechnet werden kann:

$$OP_{Weather\ Forecast\ 6sec} = 0.640 * 2.39m \cong 1.5m$$

Zieht man die Zufluchtsorte entlang der Küste mit in Betracht, so verringert sich die Distanz und somit auch die Fahrtzeit erheblich. Bei einer Geschwindigkeit von sechs Knoten werden in etwa 27 Stunden benötigt, um den längsten Streckenabschnitt zwischen zwei Zufluchtsorten zurückzulegen. Passt man daraufhin den α-Factor an, so ergibt sich eine neue maximale signifikante Wellenhöhe im Wetterbericht von:

$$OP_{Weather\ Forecast\ 6\,\mathrm{sec}\ Place\ of\ Refuge} = 0.714 * 2.39m = 1.7m$$

Bei einer Wellenperiode von sieben Sekunden erhöht sich die Sinuswellenhöhe auf 2.5 Meter, was in etwa einer signifikanten Wellenhöhe von 3.19 Metern entspricht. Die Leistungsgrenze ist in diesem Fall der Schlepper. Bei größeren Wellen ist er nicht mehr in der Lage jeden gewünschten Kurs zu halten. Berechnet man diese Wellenhöhe, unter

Berücksichtigung des entsprechenden α-Factor, so erhält man einen Wert für die signifikante Wellenhöhe gemäß Wetterbericht von:

$$OP_{Weather\ Forecast\ 7sec} = 0.660 * 3.19m \cong 2.1m$$

Bezieht man sich nun wieder nur auf die größte Entfernung zwischen zwei Zufluchtsorten, so erhöht sich der Wert folgendermaßen:

$$OP_{Weather\ Forecast\ 7\sec Place\ of\ Refuge} = 0.722 * 3.19m = 2.3m$$

Wählt man eine Wellenperiode von acht Sekunden, so ist selbst eine Sinuswellenhöhe von 2.5 Metern akzeptabel. Dies entspricht einer signifikanten Wellenhöhe von 3.99 Metern. Diese Leistungsgrenze bezieht sich ebenfalls auf die Tatsache, dass der Schlepper in höheren Wellen nicht mehr zuverlässig alle Kurse steuern kann. Im Gegensatz zur sieben Sekunden Wellenperiode, in der die Wellen von voraus die Probleme bereiten, sind es in diesem Fall nachfolgende Wellen, die die Manövrierfähigkeit des Schleppers einschränken. Unter Einbezug des α-Factors ergibt sich ein maximaler signifikanter Wellenhöhenwert im Wetterbericht von:

$$OP_{Weath\quad Forecast\ 8se} = 0.680 * 3.99m \cong 2.7m$$

Angepasst auf die kürzere Distanz zwischen den Zufluchtsorten ergibt sich eine Leistungsgrenze bezogen auf den Wetterbericht von:

$$OP_{Weather\ Forecast\ 8\sec Plac\quad of\ Refuge} = 0.730 * 3.99m = 2.9m$$

Gemäß der Arbeit von Guedes Soares und Carvalho neigt die Rayleigh Streuung, welche in dieser Arbeit zur Umwandlung von Sinuswellenhöhen zu signifikanten Wellenhöhen benutzt wurde, zu einer Überschätzung der Wellenhöhe. (Carvalho & Soares Guedes, 2001) Bezogen auf die Wettervorhersage und die Distanzen zwischen den Zufluchtsorten könnten die Werte für die Leistungsgrenzen allerdings mit einem höheren α-Factor berechnet werden, da der Schlepper beim Empfang eines neuen Wetterberichtes umdrehen könnte, um den nächstgelegenen Zufluchtsort anzusteuern, wodurch sich die Fahrzeit verkürzt. Die Überschätzung der signifikanten Wellenhöhe und die niedrige Wahl des α-Factors dürften sich somit in etwa gegenseitig aufwiegen.

Nichtsdestotrotz sollte keines der hier genannten Resultate benutzt werden, um die tatsächlichen Leistungsgrenzen des Schleppgespanns einzuschätzen. Das Augenmerk dieser Arbeit liegt auf der *Methodik* Modelle für die Verwendung im Simulator zu entwickeln, diese zu benutzen und die resultierenden Daten sowohl richtig zu verarbeiten als auch korrekt zu interpretieren.

Ich bin überzeugt, dass es zweckdienlich wäre maßstabsgetreue Modelle für den Gebrauch in einem Manöverbecken zu erstellen. Das Verhalten der Modelle könnte so in einer Reihe von unterschiedlichen Umweltbedingungen beobachtet werden, um die virtuellen Modelle entsprechend abzustimmen. Wenn sich diese Modelle dann annähernd realitätsgetreu verhalten könnten sie immer wieder verwendet werden um die Leistungsgrenzen unter unterschiedlichen Einflussfaktoren zu bestimmen. Entsprechende Simulationen könnten dann vergleichsweise schnell und kostengünstig durchgeführt werden. Selbst der Beladungszustand - und somit die Stabilität - lässt sich in der Virtual Shipyard relativ einfach ändern um eine gewünschte Situation darzustellen.

Fraglich bleibt ob der tatsächliche Mehrwert im Verhältnis zu den zeitlichen und monetären Investitionen, die für entsprechend gut funktionierende Modelle nötig sind, steht. Insbesondere unter Anbetracht der derzeitigen Covid19-Pandemie-bedingten schwierigen wirtschaftlichen Situation für den wichtigsten Kunden von EOS, nämlich die Kreuzfahrtindustrie. Nichtsdestotrotz können die im Rahmen dieser Arbeit erstellten Modelle für Schulungen im Simulator genutzt werden. Mitglieder der Brückenbesatzung mit wenig Erfahrung in der Handhabung eines Schleppgepanns können so bestmöglich auf ihren Einsatz vorzubereiten werden.

11.References

B. Barrass, D. R. (2006). *Ship Stability for Masters and Mates.* Burlington: ELSEVIER.

Beels, C., & al. (2007). Proceedings of the 7th European Wave and Tidal Energy Conference, Porto, Portugal, 2007. *Wave energy resource in the North Sea.* Ghent.

BSH. (2020, 04 20). *Marine environmental monitoring network*. Retrieved from https://www.bsh.de/EN/DATA/Marine_environment_monitoring_network/marine_environment_monitoring_network_node.html

Carvalho, A. N., & Soares Guedes, C. (2001). Probabilityy Distributions Of Wave Heights And Periods In Measured Two-Peaked Spectra From The Portuguese Coast. *20th International Conference on Offshore Mechanics and Artic Engineering.* Rio de Janeiro.

Clark, I. C. (2008). *Stability, Trim and Strenght for Merchant Ships and Fishing Vessels.* London: The Nautical Institute.

DAMEN Shipyards. (2019, February). Trim and Stability Manual Shoalbuster. Hardinxveld, Netherlands.

Divakaran, S. (2020). *Tug & Barge - Understanding Pitfalls & Learn Tips to Avoid Them*. Retrieved May 23, 2020, from CHUBB: https://www.chubb.com/sg-en/articles/tug-barge-understanding-pitfalls-learn-tips-to-avoid-them.aspx

DNV. (2010, October). RECOMMENDED PRACTICE DNV-RP-C205 - ENVIRONMENTAL CONDITIONS AND ENVIRONMENTAL LOADS.

DNV. (2011). DNV-OS-H101 Marine Operations, General. Norway.

DNV. (2015, October). Sea transport operations (VMO Standard - Part 2-2) DNV-OS-H202.

DNV GL. (2015, October). RULES FOR CLASSIFICATION Ships, Part 3 Hull, Chapter 4 Loads, Edition October 2015.

Gudmestad, O. T. (2010). *MARINE TECHNOLOGY AND OPERATION.* Stavanger: University of Stavanger.

Hanse Survey. (2019, October 19). M/V “Ems Ponton 7” / “Ems Pull”, Marine Hull Block 32 Hamburg /Pella Sietas Werft – Papenburg / Meyer Werft Ballast Sequence. Emden, Germany.

Holthuijsen, L. H. (2010). *Waves in Oceanic and Coastal Waters.* Cambridge: Cambridge University Press.

IMO. (2003, December 5). Resolution A.949(23), GUIDELINES ON PLACES OF REFUGE FOR SHIPS IN NEED OF ASSISTANCE. London, United Kindom.

MSC.1/Circ.1228. (2007). *REVISED GUIDANCE TO THE MASTER FOR AVOIDING DANGEROUS SITUATIONS IN ADVERSE WEATHER AND SEA CONDITIONS* . London: IMO.

Orcaflex. (n.d.). *Vessel theory: RAOs and phases*. Retrieved 04 17, 2020, from https://www.orcina.com/webhelp/OrcaFlex/Content/html/Vesseltheory,RAOsandphases.htm

Resolution MSC.267(85). (2008). ADOPTION OF THE INTERNATIONAL CODE ON INTACT STABILITY, 2008. London.

Searoutes. (2020). *Searoutes Route Planning Service*. Retrieved from https://www.searoutes.com

Shipowners' Club. (2013). LOSS PREVENTION | Tugs and Tows - A Practical Safety and Operational Guide. London.

Siddiqui, N. A. (2014, July). Risk Management Techniques HAZOP & HAZID Study. *INTERNATIONAL JOURNAL ON OCCUPATIONAL HEALTH & SAFETY, FIRE & ENVIRONMENT - ALLIED SCIENCE*, pp. 5-8.

Søfartsstyrelsen/ Danish Maritime Authority. (2017). DMA SAFETY ANALYSIS FOR HIGH-SPEED OFFSHORE VESSELS CARRYING UP TO 60 PERSONS. *Report of HAZID and risk-reducing measures workshops.* Høvik, Norway: DNV GL AS Maritime.

Transas Marine Ltd. (2017, May). Virtual Ship Yard - User Guide.

U.S. Army. (1991, September 30). U.S. ARMY TOWING MANUAL. Washington, D.C.

Ultramarine. (2011). *Seakeeping*. Retrieved 04 18, 2020, from http://www.ultramarine.com/hdesk/runs/samples/sea_keep/doc.htm

United States Naval Academy. (n.d.). *usna.edu.* Retrieved June 07, 2020, from https://www.usna.edu/NAOE/_files/documents/Courses/EN330/Rayleigh-Probability-Distribution-Applied-to-Random-Wave-Heights.pdf

Vadim Belenky, C. C. (2010, October). Development of Second Generation Intact Stability Criteria. West Bethesda, United States.

Appendix A: Particulars and Stability of EMS TUG

Ems Offshore Service

Tug „EMS TUG“

Call sign	CQAX8
Flag	Madeira
Builders	Damen Shipyards
Classification	Bureau Veritas I + HULL * MACH Tug, unrestricted nav. * AUT UMS
Date of class	01.2025
IMO no.	9849734
Tonnage	321 GT
Length o. a.	27,05 m
Beam o. a.	11,63 m
Beam moulded	10,50 m
Depth moulded	4,25 m
Draught	3,00 m
Speed	12,0 kn
Bollard pull	45,2 t

PROPULSION SYSTEM

Main engines	2x Caterpillar 3512C B-rating
Total Power	2610 bkW (3500 bhp) at 1600 rpm
Gearboxes	2x Reintjes WAF 773L, red. 6,44:1
Propulsion	2x Promarine Fixed pitch propeller
Diameter	2x 2250 mm Optima nozzle
Bow thruster	1x Veth VT-180, 145kW (200 bhp) electrical driven

ELECTRICAL EQUIPMENT

Generator sets	2x Caterpillar C4.4
Capacity	2x 107 kVA, 86 ekW, 230/400V, 50 Hz
Generator sets	1x Caterpillar C9.3 for bowthruster and deck equipment
Capacity	1x 375 kVA, 300 ekW, 440V, 60 Hz

ACCOMMODATION

Heated and air-conditioned living spaced for 6 persons, consisting of a captain's cabin, two single officer cabins, one double and one single crew cabin. Galley, mess and sanitary facilities are facilitated as per General Arrangement Plan. According to ILO2006 regulations.

DECK LAY-OUT

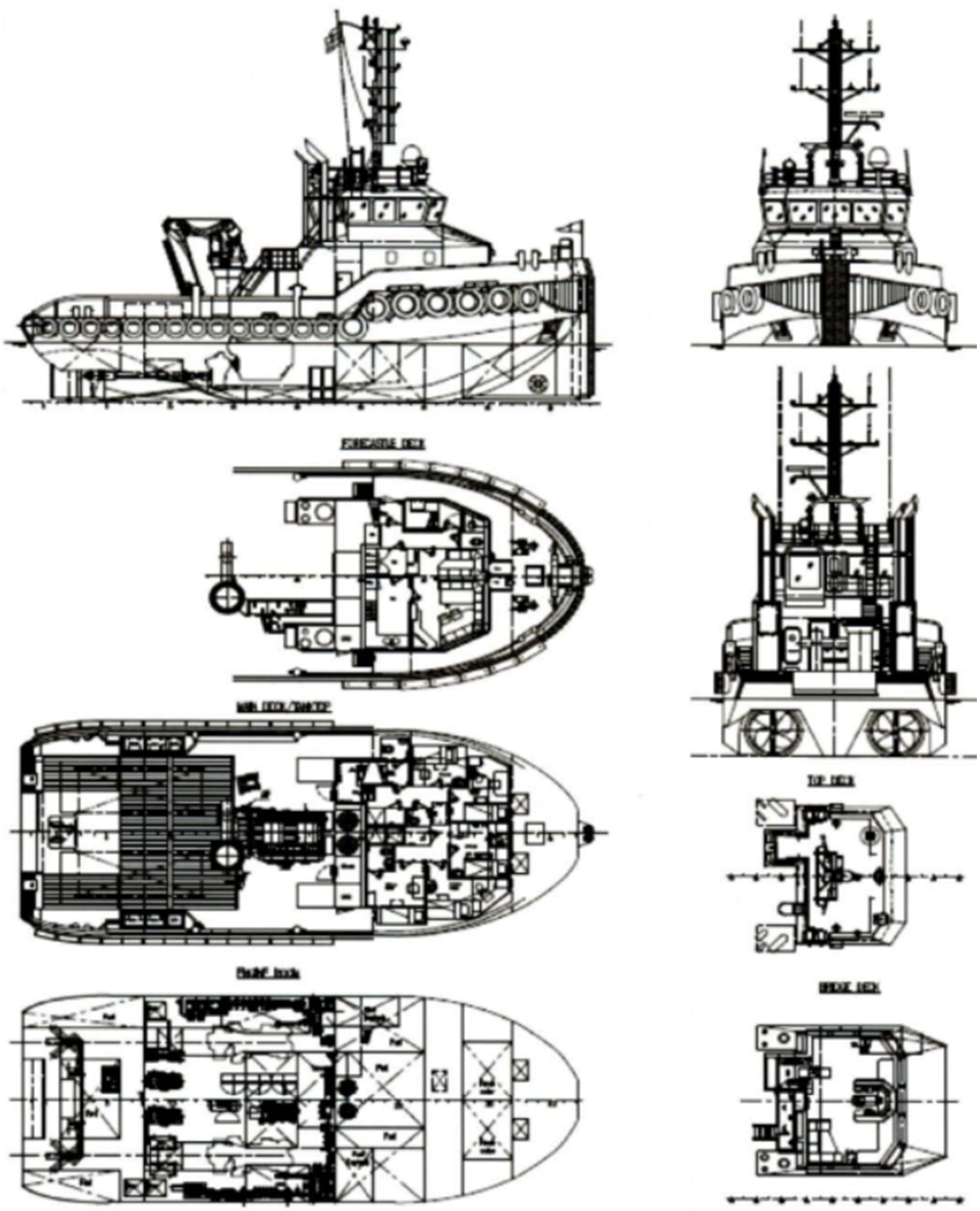
Anchor	2x 315 kg HHP pool TW anchor
Chain	2x 192,5 m, Ø19 mm
Anchor winch	2x Kraaijeveld KAB-1-H-19
Deck crane	1x HS Marine AKC185/E4, 5,5 ton at 18,5 m, 16,4 ton at 7,6 m
Anchor handling –	1x Kraaijeveld KAW-30-H-TR/TR
towing winch	Towing part: Pull 60 ton at 8,7 m/min, 12 ton at 32 m/min,
According Noble Denton	Break holding load = 135 ton, Wire capacity 800 m Ø44mm
Regulations	AH part: Pull 100 ton at 5,4 m/min, 20 ton at 19 m/min,
	Break holding load = 135 ton, Wire capacity 650 m Ø44mm
Towing pins	1x WK with integrated chain stopper
Sternroller	1x Ø1.0 m, length 4 m
Tugger winch	1x Dromec HPV-12000, 12 t at 20 m/min
Hydraulic Coupling winch (2x)	Breakholding Load 60 t, Pull 4 t, Speed 4 m/min
Moonpool	1x Integrated in pushbow
Ø A-Frame	Optional A-frame SWL 30 ton

NAUTICAL AND COMMUNICATION EQUIPMENT – GMDSS area A3

Searchlights	2x Pesch 2000W
Radar System	1x Furuno, FAR-1518BB
Magnetic compass	1x Cassens & Plath, Reflecta 1
Autopilot	1x Simrad, AP-70
Gyro compass	1x Anschutz Standard 22 Compact
EPIRB	1x Jotron, Tron-60S
SART	1x Jotron, Tron Sart-20
GPS	1x Furuno, GP-170
AIS	1x Furuno, FA-170
Echosounder	1x Furuno, FE-800
Speedlog	1x Skipper, EML-224
Intercom	1x Phontech, CIS3000
Watch alarm	1x Furuno, BR-500
VHF / DSC	2x Trane & Thrane, RT6222
Handheld VHF	2x Jotron, Tron TR-30
SSB	1x Cobham, model 6310
Inmarsat-C	2x Cobham, Sailor 6110
Navtex	1x Furuno, NX-700A
Radio – TV system	1x SEAS system, SEAS-6000

Ems Offshore Service

Tug „EMS TUG“



Hafenstraße 12 • D-26789 Leer • Tel. +49 491 4385 • info@emsoffshore.de • www.emsoffshore.de

TRIM AND STABILITY CALCULATION

Shoalbuster 2711

30 Apr 2019 12:15:45

Condition : Departure 98% consumables

Description	Filling %	Density ton/m³	Weight ton	VCG m	LCG m	TCG m	FSM tonm
Empty ship	-	-	397.803	3.904	12.027	-0.018	-
Subtotals for group : Fuel							
1) Fuel aft SB	98.0	0.8500	10.102	3.112	1.589	4.432	1.082
2) Fuel aft CL	52.0	0.8500	6.934	1.662	2.524	0.000	6.338
3) Fuel aft PS	98.0	0.8500	13.562	3.084	2.260	-4.444	1.463
4) Fuel daytank SB	90.0	0.8500	7.739	1.872	14.683	3.849	2.742
5) Fuel daytank PS	90.0	0.8500	7.015	1.877	15.253	-4.460	0.764
6) Fuel forward SB	98.0	0.8500	20.441	1.255	16.322	3.480	3.505
7) Fuel forward CL	40.0	0.8500	12.868	0.538	16.104	-0.399	14.503
8) Fuel forward PS	55.0	0.8500	7.334	0.566	15.931	-3.648	1.776
SUBTOTAL	71.5	0.8500	85.996	1.734	10.960	0.259	32.172
Subtotals for group : Freshwater							
10) Freshwater SB	98.0	1.0000	14.732	1.873	20.884	1.417	5.302
11) Freshwater PS	98.0	1.0000	14.732	1.873	20.884	-1.417	5.302
SUBTOTAL	98.0	1.0000	29.464	1.873	20.884	0.000	10.605
Subtotals for group : Miscellaneous							
12) Lub. oil PS	98.0	0.9000	4.250	0.502	10.574	-4.190	1.997
13) Hydr. oil	98.0	0.9000	3.165	0.497	11.100	4.170	1.512
14) Bilge water SB	10.0	1.0000	0.477	0.061	10.804	1.073	2.884
15) Dirty oil PS	10.0	0.9000	0.430	0.061	10.804	-1.073	2.596
16) Sewage	10.0	1.0000	0.478	0.061	13.200	-1.074	2.882
SUBTOTAL	42.8	0.9099	8.799	0.431	10.929	-0.577	11.872
Crew + stores	-	-	2.000	4.500	16.200	0.000	-
TOTAL	-	-	524.062	3.378	12.347	0.019	54.649
Deadweight	-	-	126.259	1.720	13.357	0.136	-

Hydrostatics		Drafts and trim	
Volume	508.401 m³	Drafts above base :	
LCF	11.023 m	Draft mean (Lpp/2)	2.950 m
Mom. change trim	4.862 tonm/cm	Draft aft (App)	2.978 m
Ton/cm immersion	2.523 ton/cm	Draft fore (Fpp)	2.922 m
Density	1.0250 ton/m³	Trim	-0.056 m

Transverse stability		Drafts on the draftmarks :	
KM transverse	5.779 m	T foremark	2.935 m
VCG	3.378 m	T aftmark	2.990 m
GM solid	2.401 m		
GG' correction	0.104 m		
G'M liquid	2.297 m	VCG'	3.482 m

The stability values are calculated for the actual trim.

TRIM AND STABILITY CALCULATION

Shoalbuster 2711

30 Apr 2019 12:15:45

Condition : Departure 98% consumables

Statical stability, calculated with constant LCB :

Angle(SB)	Draft mld.	Trim	KNsinφ	VCG'sinφ	TCGcosφ	G'Nsinφ	Area
degrees	m	m	m	m	m	m	mrad
0.00	2.950	-0.056	0.019	0.000	0.019	-0.001	0.000
2.00	2.950	-0.057	0.220	0.122	0.019	0.080	0.001
5.00	2.949	-0.063	0.523	0.303	0.019	0.201	0.009
10.00	2.939	-0.052	1.020	0.605	0.019	0.397	0.035
15.00	2.911	0.018	1.489	0.901	0.018	0.569	0.077
20.00	2.894	0.070	1.889	1.191	0.018	0.680	0.132
25.00	2.899	0.043	2.236	1.472	0.017	0.747	0.195
30.00	2.913	-0.066	2.539	1.741	0.017	0.782	0.262
35.00	2.939	-0.233	2.788	1.997	0.016	0.775	0.330
40.00	2.971	-0.444	2.975	2.238	0.015	0.722	0.396
50.00	3.058	-1.040	3.196	2.667	0.012	0.516	0.505
60.00	3.195	-1.967	3.261	3.016	0.010	0.236	0.572
70.00	3.470	-3.631	3.201	3.272	0.007	-0.078	0.587

Statical angle of inclination is 0.01 degrees to starboard

Contour : Windcontour

Opening	is submerged at [degrees]
ER Vent Outlet SB	42.38
ER Vent Inlet SB	65.54

Verification against the stability criteria "IMO 267(85) for vessels with a large B/H ratio & Tug criteria"

Hydrostatics			Criterion	Value	
Draft mld.			2.950	2.950	m
T foremark	2.935	m			
T aftmark	2.990	m			
Trim	-0.056	m			
Statical angle of inclination	0.01	degrees SB			
Flooding angle	42.38	degrees			

Calculated to SB	Criterion	Value	
Minimum metacentric height G'M	0.150	2.297	meter
Maximum GZ at 30 degrees or more	0.200	0.785	meter
Top of the GZ curve at least at	15.000	31.749	degrees
Area under the GZ curve up to 30 degrees	0.055	0.262	mrad
Area under the GZ curve between 30 and 40 degrees	0.030	0.134	mrad
Maximum angle of inclination acc. to IMO's A.562 weathercriterion	42.371	29.591	degrees
Maximum statical angle due to wind	16.000	1.553	degrees
Maximum statical angle 80% of angle of deck immersion	11.124	1.553	degrees
IS Code 2020 (MSC 97-22-Add.1, 2.8.4.2 (self tripping))	1.000	41.985	-
IS Code 2020 (MSC 97-22-Add.1, 2.8.4.3 (tow tripping))	42.371	3.319	degrees

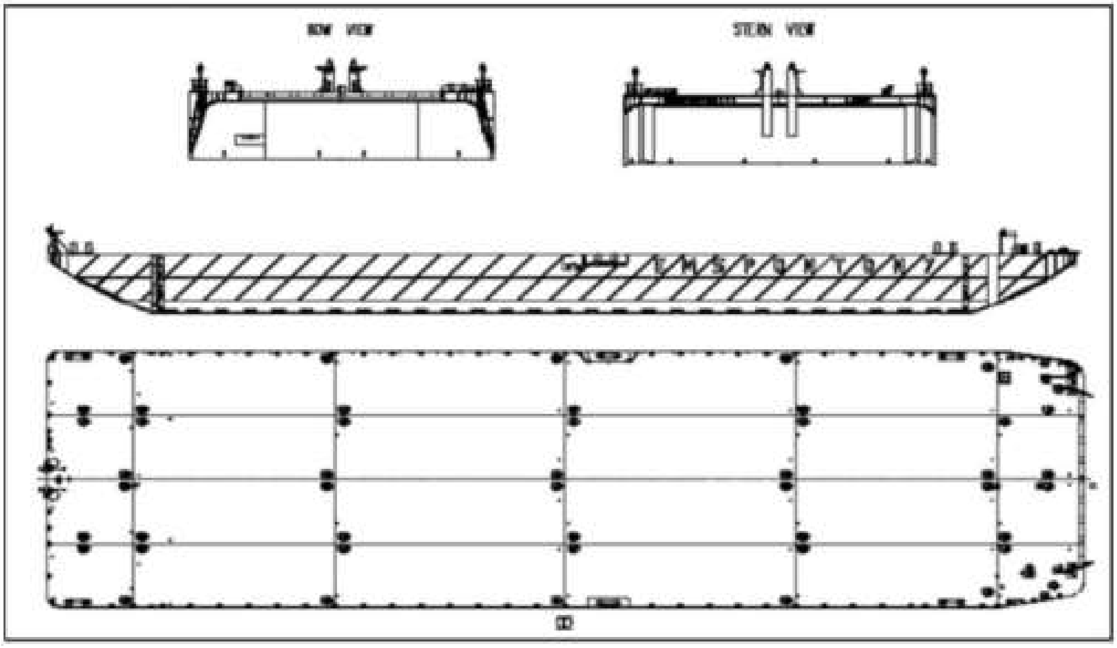
VCG'		
Maximum allowable	4.256	m
Actual	3.482	m

Loading condition complies with the stated criteria.

Appendix B: Particulars and Stability of EMS PONTON 7

EMS OFFSHORE SERVICE

Hafenstr. 12, D 26789 Leer, Germany
Tel.: +49 (0) 491 - 43 85 Fax: 43 87
e-mail: info@emsoffshore.de
homepage: www.emsoffshore.de



EMS PONTON 7

PRINCIPAL DIMENSIONS:

Length over all	: 72,295 m
Length	: 72,00 m
Beam over all	: 18,99 m
Depth moulded	: 4,50 m
Ligth draft	: 0,75 m
Loaded draft	: 3,60 m
Built	: 2004 Russia
Class	: G. L. + 100 A5 deep sea
Tonnage	: 1.546 GT / 463 NT

CAPACITIES:

Deadweight	: 3.600 to
Deckload	: 10 to/ m²
Wheel load	: 12 to at 10 bar
Point loads	: 60 to at webframes
	: 80 to at bulkheads
	200 to at bulkhead cross

4 Ro Ro ramps: L: 12,00 m, B: 4 x 1,5 m = 6 m
In total 75 lashing eyes, BL: 50,0 tons

ARRANGEMENT & FORM:

Bow	: Raked, Ro Ro conection
Stern	: Raked with 2 skegs, 2 pushpipes aft.
Bulkheads	: 3 longitudinal, 5 transverse

In total 24 compartments of which 23 can be used for ballast water.
Each compartment with 2 covers, deckplug & sounding pipe.
One compartment for chainlocker (Stb)
One compartment for storage (PS)

Deck completely flush.
Removable railing around.
Removable signal mast and anchor winch.
Position & stern lights : Gas

MOORING & TOWING:

Anchor	: SSHP pool TW, 474 kg
Anchor chain	: 165 m, ∅ 24,0 mm
Anchor winch	: Manual / with warping head
Towing arr.	: 2 smith brackets & fairleads
Bridle	: 2 x 12 m steel wire
Bollards	: Double bollards fore & aft.
	Double bollards flush at fr. 20/21