Hull Compartment Layout of Containerships

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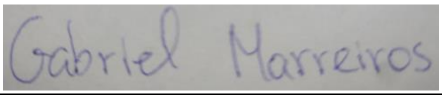
DECLARATION

I declare that this document is an original work of my own authorship and that it fulfils all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.



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Abstract

With the development of the world, the global market is rising, and the population is embracing online shopping which requires assistance from shipping industry to support global trades. Ships are the most efficient transport for trading at a lower cost. Containerships are one of the most required ship to maritime transportation resulting from the different types of goods that can carry at the same time.

As the dimensions of containership cargo holds must be multiple of the dimensions of containers, it is important to have the cargo holds appropriately fit to the hull. This dissertation aims to develop a method that given a certain hull will determine the location of compartments, the inner hull form of cargo holds and, the containers above deck, according to the requirements of the owner. This program has been applied to the four most common typical configuration of containerships. This project detects critical points in cargo holds where a minimal change would lead to an increase of cargo capacity.

To validate the method, general arrangements of existing containerships will be analysed. The method will be implemented in MATLAB® to reproduce the analysed general arrangements and to compare the results with the existing general arrangements.

Concluding, The method is suitable for application at an early stage of ship design and improves the accuracy of current estimates.

Keywords: Container, Containership, General Arrangement, Hold, Hull

Resumo:

Com o desenvolvimento do mundo, o mercado global está em constante crescimento e a população está a aderir cada vez mais a compras online, o que leva à necessidade de recorrer à indústria naval. Os navios são o meio de transporte mais eficiente para o comércio a baixo custo. Os navios porta-contentores são os navios mais utilizados no transporte marítimo uma vez que podem carregar diferentes tipos de bens numa só viagem.

Como as dimensões dos navios são racionalizadas de acordo com as dimensões dos contentores, é importante que os porões de carga se ajustem apropriadamente ao casco. O objetivo desta dissertação é desenvolver um método onde, dadas as secções do casco de um navio irá determinar a localização dos compartimentos, a forma do casco interior e as pilhas de contentores acima do convés, respeitando os requisitos do armador. Este programa funciona para as quatro configurações mais comuns de porta-contentores. Este projeto identificará ainda locais críticos nos porões de carga onde uma alteração mínima no casco poderá levar ao aumento da capacidade de carga do navio.

Para validar o método, serão analisados arranjos gerais de navios existentes. O método será implementado em MATLAB® para recriar os arranjos gerais analisados e para comparar os resultados com os arranjos gerais existentes.

Concluindo, o método é adequado para aplicação numa fase inicial da conceção do navio e melhora a precisão das estimativas atuais.

Palavras-chave: Contentor, Porta-contentores, Arranjo Geral, Casco, Porão

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Acronyms:

FEU	20-feet equivalent unit
SOLAS	Safety of Life at Sea
TEU	40-feet equivalent unit

Nomenclature:

$\boldsymbol{xStart_{ER}}$	X coordinate of the aft bulkhead of engine room
$\boldsymbol{xStart_{SS}}$	X coordinate of the aft most section of superstructure
$\boldsymbol{baysPairs_{ER \to SS}}$	Number of pairs of bays between the engine room and the superstructure
$\boldsymbol{c_b}$	Block coefficient of the ship
$\boldsymbol{D}$	Depth
$\boldsymbol{distBetweenBays}$	Distance between 2 ungrouped bays in a cargo hold
$\boldsymbol{distGuides}$	Distance between the extremity of the containers and the bulkhead in the cargo holds
$\boldsymbol{d_{MaxBlockedBiew}}$	Horizontal distance of the blocked ahead view from the foremost section of the superstructure
$\boldsymbol{h_{AccDeck}}$	Height of the accommodation decks
$\boldsymbol{h_{bridge}}$	Height of the navigation bridge
$\boldsymbol{h_{container}}$	Height of a container
$\boldsymbol{h_{db}}$	Height of the double bottom
$\boldsymbol{h_{hatch}}$	Height of the hatch coaming
$\boldsymbol{h_{LowerDeck}}$	Height of the lower deck
$\boldsymbol{h_{margin}}$	Vertical deflection of the hatch cover when loaded
$\boldsymbol{h_{max}}$	Maximum height of a container hold
$\boldsymbol{h_{maxSec}}$	Maximum height to allow cargo in a certain section on deck
$\boldsymbol{h_{Shaft}}$	Height of the shaft of the engine
$\boldsymbol{h_{SS}}$	Height of the superstructure

$l_{CargoHold}$	Length of a cargo hold
$l_{Container}$	Length of a container
l_{ER}	Length of the engine room
l_{Funnel}	Length of the funnel of the engine room
L_{pp}	Length between perpendiculars
l_{SG}	Length of steering gear system
l_{SS}	Length of the superstructure
max_{distCB}	Maximum distance from aft perpendicular to the collision bulkhead
$maxSec_{Width}$	Maximum width of a section
$maxTiers_{Deck}$	Number maximum of tiers above upper deck
min_{distCB}	Minimum distance from aft perpendicular to the collision bulkhead
$minSideDist$	Minimum distance allowed between the inner and the outer hull of a ship
nr_{Decks}	Number of superstructure decks
$nr_{HoldBays}$	Number of bays in a cargo hold
$nrMaxRow$	Maximum number of rows in a section
$nrRows_{Sec}$	Number of rows in a section of a bay
$nrTiers_{Sec}$	Number of tiers in a section
$n_{SupTiers}$	Number of supressed tiers in cargo holds aft engine room due to the shaft
T	Draught
t_{hatch}	Height of the hatch cover
$transverseGap$	Transverse distance between containers

$\boldsymbol{w_{container}}$	Width of a container
$\boldsymbol{w_{SideTanks}}$	Width of the side tanks
$\boldsymbol{xEnd_{SS}}$	Fore section of the superstructure
$\boldsymbol{xStart_{Funnel}}$	X coordinate of the aft most section of the funnel
$\boldsymbol{\Delta d}$	Difference exceeded (transverse analysis)

1 Introduction

1.1 Background and motivation

Ships have a great importance in the global trade. Sea represents about 71 percent of Earth's surface in which 96.5 percent is ocean. In the beginning ships carried people through ocean but with the development of intercontinental air travel, ships are more focused in transportation of goods, recreational cruises, and short travels as in river or sea trip. Ships can be used for a lot of different services as fishing, ocean platform installations, vacationing, and cargo transportation.

Deep sea trades started in the early 1960s. The first containerships operated in 1966, in North Atlantic. In 1970s, containerships were already operating through the major trade routes. Initially, less developed countries faced a problem because the limited infrastructure, which did not allow trading. Later in 1970s, cranes were introduced in containerships and the trades become accessible to more ports.

Global market is increasing every year due to the development of the world and as consequence, imports and exports are also growing. Global shipping industry is directly influenced by global market. Analysing the Figure 1.1, it shows a tendency to increase the volumes of international trades. Besides 2008 crisis, the volume of international trades has increased since 2009.

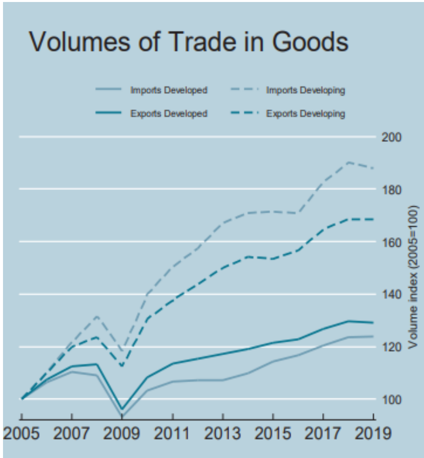

Figure 1.1 - Volumes of international trade in goods (source: *UNCTAD, 2020*)

As the volume of international trades is growing, it is important to have a reinforcement in global transports. Maritime transportation has a significant role in global transports once more than 80 percent of all goods are carried by sea. There are some advantages in maritime transportation like natural waterways, large carrying capacity and low freight. Maritime transportation is not constrained by roads and can easily have routes adjusted. Despite other modes of freight transport like trains, trucks and aircraft can handle merchandise, it is not efficient for long distance transportation. Ships can carry thousands of tonnes in each voyage. Trains and trucks are used to perform inland trades, where ships do not have access. Cargo can be dry bulk, liquid bulk, and containerized cargo. The most common type of cargo is the containerized cargo once a single containership can carry goods of different kinds from different entities, with different origins and destinations.

The Figure 1.2 shows a dominance from containerized cargo in maritime international trades, according to *UNCTAD 2020* statistics.

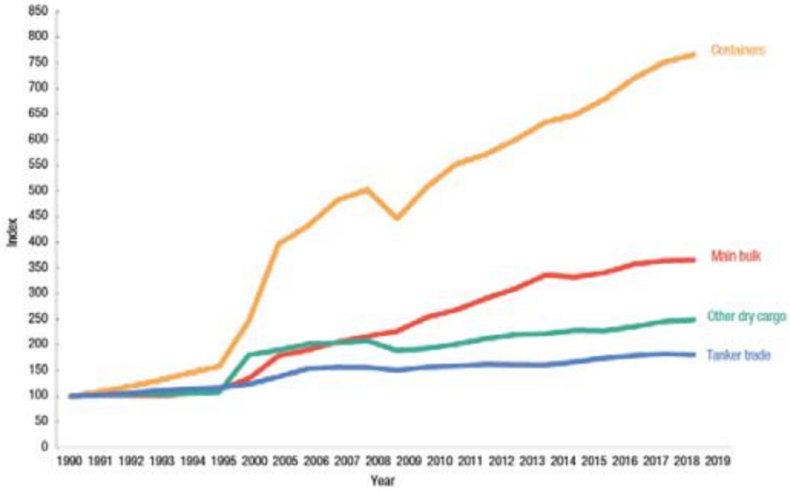

Figure 1.2 - Development of international maritime trade by cargo type (source: UNCTAD, 2020)

As global shipping keeps increasing, not only the fleet of containerships is expanding but also the total cargo capacity is rising. Through the years, containerships are upgrading, and the configuration of ships is changing in order to maximize the number of containers that a containership can carry. In the beginning the greatest part of the containers were carried in hull but nowadays, the hull form of containerships is optimized to perform faster voyages and the configuration of the containership is adapting to carry the greatest part of cargo above deck. According to *UNCTAD 2020,* "the vessel sizes have been increasing to optimize costs through economies of scale". As shown in Figure 1.3, the capacity of containerships is increasing more along the years, compared to other types of cargo ships. The average capacity of containerships is four times greater nowadays, measured with ships built 20 years ago.

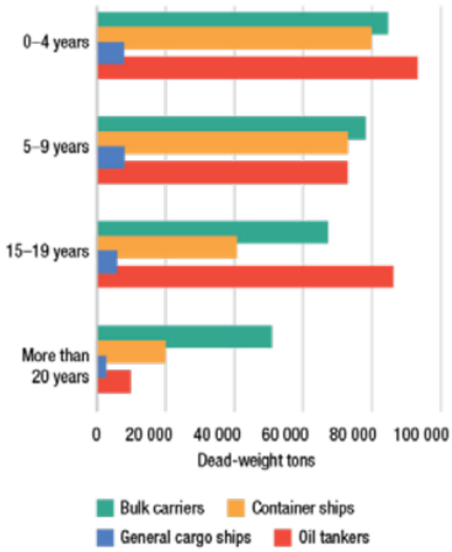

Figure 1.3 - Average vessel size and age distribution (source: UNCTAD, 2020)

With the development of industry, the trend of containerships is to increase the cargo capacity but, the length of the layout of containerships is largely kept constant. The larger containerships are round 400 meters length but the capacity carried have a range from 15,000 TEU to 24,000 TEU. In 2006, a containership named Emma Maersk was built with a length of 397.7 meters, breadth of 56.4 meters and a cargo capacity of 15,000 TEU. In 2015 a containership named MSC Oscar was built in South Korea with a length of 395.4 meters, breadth of 58.6 meters and a cargo capacity of 19,300 TEU. In 2020, a class of containerships named HMM was built in South Korea with 399.9 meters length, breadth of 61 meters and cargo capacity rounding 24,000 TEU. As it is noticeable, the hull form is very important and minimal changes in hull can result in a lot of containers added to the maximum capacity of a containerships. In 14 years, the cargo capacity of containerships increased in 9,000 TEU, without changing the length of the ships.

Containers are used to carry several types of cargo as pallets, bagged goods, and refrigerated cargo. There were several norms associated to the size of containers before the world standard creation by International Organization for Standardization in 1964. The cargo holds of containerships can carry containers with different dimensions. Since the appearance of ISO standards, the most common shipping container sizes are 20 ft container (TEU) or 40 ft container (FEU). Both these sizes are available in standard height of 8’, 8’6’’, and in high cube configuration, 9’6’’. There are less common container sizes. The extra small container size is a 10 ft container with the standard height. There are three extra-large container sizes of 45 ft, 48 ft and 53 ft length and are only available in high cube configuration. Besides general-purpose containers there are other types of containers as flat rack containers, open top containers, and reefer containers. This type of containers has the same dimensions of 20 ft and 40 ft container. Considering that requires special shipping, this project uses 20 ft high cube containers that are the most common containers used. High cube containers can carry cargo higher volumes of cargo.

The initial stages of ship design, namely the initial dimensioning of the hull and the determination of the main characteristics of the ship are the result of some holistic optimisation procedure.

Unlike other cargo ships, containerships have a particular hull geometry. The cargo hold needs to be designed according to the dimensions of cargo. Containership hulls have a low block coefficient and a high prismatic coefficient. The low block coefficient minimizes the resistance of hull but allows the ship to achieve a higher speed. The higher prismatic coefficient increases the number of containers that the containership can carry above deck.

There are several factors to analyse when designing the hull of a containership. The holds of containerships have a particular form, all the dimensions and form of holds are multiple of container measures and affects the location of bulkheads, engine room and superstructure. As the dimensions are streamlined, it can result in larger tanks than required where, if the hull was optimised, it could result in a hold with more containers and smaller bilge tanks. As the hull gets thinner near perpendiculars and the holds are adapted to the dimensions of containers, it can also result in larger bilge tanks than needed. A small change in hull form can result in a significant gain in number of containers.

With the visibility restrictions, the number of containers above deck is restricted which demonstrates the importance of the position of superstructure and consequently influences all the arrangement of the hull compartments. Another detail studied is the width of wing and bilge tanks.

1.2 Topic overview and objectives

The main objective of this work is to develop a method to be performed in the early stages of ship design, allowing to improve the calculations of the carrying capacity when the hull shape is still roughly defined.

The most common hull subdivision patterns of the main container ship types will be analysed, identifying the parameters required for design.

Subsequently, the procedure will be extended to include the load distribution above deck, allowing the total carrying capacity of the ship to be estimated.

Finally, for validation purposes, the method will be applied by comparison to existing ships.

In parallel with the generation of the compartments of inner hull, it will be performed an analysis of some locations where small changes in hull can result in the addition of more containers carried by hull.

1.3 Structure of the Thesis

This thesis is structured in five chapters. Chapter 1 is the Introduction of the topic to be discussed the background, the topic overview, and the objectives of this work. This specific subsection summarizes the structure of the dissertation and the content of the dissertation.

Chapter 2 contains the State of Art. This chapter relates previous research work, reviewing existing methods to perform parametric modelling and optimisation of cargo ships.

Chapter 3 details the methodology to model the hull compartments of a containership. First, hull compartment division is performed, and the cargo holds are identified. Next, the longitudinal sections to be transversely analysed are identified. In a third step, the transverse shape is determined and the capacity of containers in the hull is calculated. Following, the longitudinal deck configuration is performed to determine the cargo capacity on deck. For last, the total cargo capacity is determined, and the shape of the inner hull is designed. As an external procedure, a hull shape analysis is carried out to determine and record critical points on the hull that do not meet the minimum distance between the inner and outer hulls by a certain tolerance.

Chapter 4 presents the validation of the method. A replication of four containerships with different characteristics is carried out. The validation consists in a comparison of the cargo capacity in the cargo holds, on deck and, the total cargo capacity of the ship.

Chapter 5 summarizes the main conclusions of the work done and provides a set of recommendations for further work.

2 Literature review

There are several aspects of containerships that have been discussed in different studies about ship design. To gain more insights into the aspects of containership design and the hull design, the subject containership is divided into various important parts such as: containerisation, structure of containerships and the parametric CAD modelling of ships.

2.1 Containerisation

Following the advent of the container box in 1956, the movement of products was revolutionized, and the transportation sector underwent a transition. The marine sector has become more efficient and effective due to containerisation (Akbar et al., 2021). Within a short period, all major shipping lines began to accept containers, and container terminals were built in virtually every port globally, including the United States. The container idea has largely remained unaltered in the decades since its inception in the 1950s. Only the container's size and capacity have changed since 1956, but the current container retains many of the original design's attributes (Akbar et al., 2021). The container's immediate surroundings, which are rapidly changing, are driving the most significant changes. Container handling has become more efficient due to technological advancements such as the automated container terminal, robotic vehicles, multiple cranes, and liner shipping (Akbar et al., 2021).

In economic theory, the economic lifespan of a product is typically specified. When considering the exponential rise in the number of containers moved during the preceding half-century or more, containers, like any other commodity, have a shelf life. The two most significant concerns that must be answered as a consequence of this study are whether the container business follows a defined lifecycle and, more critically, what stage of the container market it is now in (Senavirathna et al., 2016). As a result, port authorities and operators are investing billions of euros in new and enhanced container capacity, making the answers to these two questions critical in their decision-making. If the container market has reached a saturation point, signalling that demand would remain steady before dropping, the additional capacity built may be redundant and hence out of date. The container, like any other product, must go through a lifespan (Buchanan et al., 2018). If the container has not been upgraded in the previous 50 years, its economic lifespan may indicate that it has reached saturation or is losing value. After a two-year slump caused by the global economic crisis from 2008 to 2010, the container market is projected to return to normalcy in 2013. Given the recent volatility in the container market, it is possible to argue that the 2008 forecasts for the next 20 years are no longer as accurate as previously thought.

Because of the rapid expansion of containerization over the last few decades, the issue of the product life cycle has not been addressed previously. To keep up with demand, the container market is expected to continue growing at its current rates (Martínez Moya et al., 2017). Because of the increase in container traffic, the question of whether the market functions in stages have emerged, all of which are tied to the economic theory of the product's life cycle, which is as follows: The creation of the first trans-Atlantic route in 1966 led in an increase in containerization. Because of the standardization of container sizes, the container market surpassed 100 million TEU in 1992, and container traffic grew to encompass more nations worldwide. The adoption period ended in 1992 when the total number of containers moved surpassed 100 million TEUs.

The container industry experienced rapid expansion between 1992 and 2000. The container market has been transformed into a single global economy due to the container industry's rapid annual growth rates in the double digits and the ongoing globalization of container traffic (Feng et al., 2020). During this decade, the global container market increased by three, with the expansion of the container market into new regions being a significant driver. The development of new container terminals with improved efficiency and automated services and the significant expansion of the container industry throughout this decade may be linked to the development of new container terminals with improved efficiency and automated services.

During this period of rapid development, containerisation experienced a golden age, widely documented. Because of the containerisation of other commodity chains, the container market has become increasingly global, and as a result, it has become a component of the global supply chain concept (Sahoo, 2022). The rapid expansion of the container industry has both positive and negative consequences, including under capacity at many ports. Many ports had insufficient demand capacity, which increased congestion and reduced port efficiency overall. Because of the rapid growth rates, many investors were looking for high rental yields, so they invested in container handling infrastructure, such as container terminals, to meet the growing demand (Luna et al., 2018). As a result of overinvestment in the market to meet market growth expectations, more capacity may be built when it is not required. The container market has reached maturity, indicating that the period of globalization and expansion has ended. Because of the inability to sustain double-digit growth rates, the only viable sources of market expansion are increases in productivity and changes in economic activity.

2.2 Structure of containerships

Container processes of loading, as well as unloading, have been prioritized throughout the design of cargo holds and associated hatches. Sheet and tarpaulin were initially used in the 1950s to keep transport containers and merchandise intact. Unlike the 40-feet and 20-feet containers that can be loaded underneath the deck, the 45-feet containers may be loaded easily on top of the stack. A precise stowage strategy ensures that shipping containers that adhere to the ISO criteria may be loaded aboard ships quickly and efficiently.

Cargo space guides, metal pegs put into the ship's hull to hold containers in place and prevent them from wobbling, are required in heavy waves. Cargo space standards are required by organizations such as the United Nations Conference on Trade and Development (UNCTAD) to distinguish these ships from conventional cargo ships (Eyres & Bruce, 2020). To ensure the stability of the container stacks, different equipment such as cables, chains, and turnbuckles are utilized and the guides. Bridges and cabins on various container ships have been relocated to the front of the ship since 2015 owing to aesthetic concerns and the need to be further away from exhaust pipes. As an extra advantage, some container ships are also equipped with an integrated cargo crane (Eyres & Bruce, 2020).

2.3 Parametric CAD modelling of ship

In 1997, the shape of the hull was not considered to estimate the number of containers carried. The number of containers carried was deducted through the analysis of existing ships. of the shape of the cargo holds was determined through (Alvariño et al.,1997) performed a work about basic project of merchant ships, where the number of containers in cargo holds is estimated through approximations, considering the breadth, the depth, the number of bays, rows and tiers and the block coefficient of the ship. The height of the navigation bridge is also estimated empirically and consequently, the number of containers above deck.

In the recent past, optimisation was done through trial and error. The method has changed by adopting different scientific and mathematical procedures like genetic algorithms, neural networks, evolutionary programming, evolution strategies, etc. The optimisation idea in ship design has its roots back in the 1980s, with a slight improvement in the 1990s (Chung et al., 2011). There has been significant improvement with the main aim of handling the ship's life cycle problems from the point of the design.

The changing world and demand for goods and services have changed the operation, production of different goods and services. In ship construction industries, there has been an increase in international competition, forcing companies to reduce the time of developing ships and the cost of production. The increasing demand does not mean the producers have to build low-quality ships; they must meet the target of their consumers by improving on their decision-making from the beginning of the construction process. The decisions to be made are on the design to settle the optimization problem. Solving optimisation problems might require different structures that had not been used initially (Bolbot, 2016).

Papanikolaou (2010) used a multi-objective approach to optimise the arrangement of Ro-Ro ships, in which the Pareto Frontier was recognised and the values of the objectives for each design were presented in two-dimensional scatter diagrams, which served as the basis for a comparison based on the designer's preferences and experiences. The aim of the work was to generate or improve significantly a vessel’s internal subdivision from scratch.

Several researchers have recently described CAD approaches for ship design and optimisation. Many previous articles and studies (Koutrokis et al., 2013; Priftis et al., 2016; Priftis et al., 2018) have focused on hydrodynamics, strength, and system approaches to ship design. For example, Priftis et al. (2016) and Priftis et al. (2018) provided an efficient holistic optimisation of a 6,500 TEU containership, using CAD/CAE/ systems, focusing on ship arrangement optimisation, and considering all the side effects on ship design, operation, and economy. These studies divided the hull into four areas: the main frame, the aft body, the fore body, and the main deck. A lot of parameters are defined here in order to accurately create the parametric model. Aside from the main dimensions of the hull, a variety of additional parameters are used to control various components. Priftis et al. (2016) and Priftis et al. (2018) showed that a decrease in ship length can lead to a much lower lightship value, thus increasing the deadweight of the ship and, consequently, its overall cost efficiency. Besides, shorter and wider designs have been proved to be more cost-efficient than longer and narrower ones.

The divisions can be shown by a binary tree used in different computer programs. The binary space partitioning (BSP) can assume a two-dimensional shaped BSP tree and several others (Lysenko et al., 2008). The method is used in modelling the internal parts of a ship. The BSP method would be considered the best method but with a challenge of representation to the client; this is because it generates several sub-spaces that may be unnecessary.

The partitioning or subdivision process can be performed using the Binary Space Partitioning (BSP) method. The BSP method is a conventional process that can handle double activities at a time. The process depends on the parameters considered by the developer as the most critical. Designers compare the space partitioning process with an intuitive process (Koningh et al., 2011). The process involves dividing space into two by a plane; the two areas are further sub-divided by another plane into four pieces, and the cycle continues. The BSP method originates from computer games, involving cell divisions until the recommended spaces are met. The technique is also used in modelling activities.

During the conceptual design of ships, the main dimensions of the hull are determined, and the main characteristics of the ship are defined. At this stage of design, there is a larger flexibility to make decisions (Gaspar & Balland, 2010). The hull form can be obtained through geometrical hull parameters which will define the curves of sections by series approaches or the hull form can be derived by a parent hull, optimising the parent hull to the pretended parameters. An alternative method to design the hull of ships was purposed (Depetro, 2013), where the arrangement of compartments would be performed before the hull.

The layout problem can be formulated using a mathematical formula depending on the issue under investigation (Chen et al., 2010). A similar procedure is formed for adjacent requirements, which generate the required outlook and size of each compartment upon analysis. The resultant layout would be each compartment with a passage to allow more effortless movement.

The interior plan of the ship's hull is determined early in the design process. The interior regions' size and position are governed by the type of ship as well as the content and purpose of the compartments. The ship's division, however, is confined by the ship's survival requirements. Furthermore, the economic competitiveness of a commercial ship is critical in its design (Koutroukis et al., 2013). It is not always possible to achieve both increased freight capacity and lower construction costs without compromising safety. To investigate vessel interior layout design, a multi-objective optimization problem with the goals of cost reduction and increased safety after damage may be applied. An optimization framework may be used to investigate numerous internal layout concepts and select the best practical one (Jafaryeganeh et al., 2019).

When the basic hull dimensions must be kept constant, the interior compartment design process is complicated by a wide range of target functions (Feng et al., 2021). Based on regulatory limitations, a good parametric model should be able to produce a number of configurations. As a result, the appropriate model must automatically analyse criteria and perform the merit function. Parametric models can be used in ship design for hull shape, hull structure, and hull compartment arrangement (Feng et al., 2021). According to (Roh & Lee, 2007), the most often used software space defining methodologies are surface-oriented and wireframe-oriented. A space may be defined in two ways: by specifying the perimeter of the planes or by utilizing a collection of lines or curves. As a result, the planes defined space in a more complicated way (Jafaryeganeh et al., 2016). (Koelman, 2012) showed some available methods to represent the internal geometry of a ship. The spaces are defined by bounding planes, wireframe model of compartment boundaries, by a non-manifold solid model, that is a complex solution of the problem based on manifold solid model. For last, the method of (Alonso et al., 2008) was excluded once the applicability cannot be evaluated. It is proposed a Binary Space Partioning method, splitting spaces in two until getting the ship's compartments. Through this method, the compartments can be composed by sub compartments. Have a hull, split planes, get compartments, subdivide compartments in sub compartments. It does not support B-spline or nurbs-based surfaces. The limitation of this program is that the compartments cannot adapt transversally to the hull, it does not show degrees in the hull.

Sections are moved forward and backward using B-Splines that are tuned for fairness (Koutroukis et al., 2013). Following that, build the aft structure and cargo arrangements. New programs or "features" were created for this aim (Priftis et al., 2018). Deck count, bay spacing, double bottom and side distances, and other criteria are utilized to construct the surfaces needed for the deckhouse and cargo arrangement below and above the main deck. When building the superstructure feature, it considers the number of layers above the main deck, the intended position along the longitudinal axis, the height of each level, and the superstructure's dimensions in both directions (Koutroukis et al., 2013).

The hull has one or more cargo holds and the numerous tanks that have been put in it, plus the engine rooms. The hull requires an optimal design to perform against the water body and increase the efficacy of the containership during sailing. Besides, the hull compartments influence the efficacy in internal operation factors and ensure that the overall optimisation is high for performance (Koutroukis et al., 2013). Hull design must be well constructed and optimised to improve its efficiency and make the containerships effective (Janić, 2018). New ships must meet minimum energy efficiency standards set by the International Maritime Organisation (IMO) based on the Energy Efficiency Design Index. As a result, the cost of gasoline will be reduced.

In Nikolopoulos et al. (2018), the cargo hold arrangement is generated with a feature of the Friendship Framework using the output surface from the Lackenby variant, and its capacity is computed. CAESES was used to create the cargo hold surfaces and their associated parametric entities. Furthermore, CAESES hydrostatic calculations were performed to calculate the cargo hold capacity, which is required for the majority of the calculations. The position of the bulkheads, the position of the Engine Room bulkhead, the frame spacing, as well as some local variables such as hopper width and angle, topside tank dimensions (width and height), lower stool height and length, and double bottom height, were the parameters/variables controlling this area. By establishing offsets for each of the tank surfaces and putting them together, the capacity of each tank can be estimated. After that, the tanks are hydrostatically calculated, and the overall capacity can be determined. In addition, a calibration factor obtained from the parent hull is incorporated to account for the volume of structural frames inside cargo holds, as well as a factor to derive with the Bale and Grain capacities.

For the automated evaluation of criteria and the merit function, a parametric model is necessary. Parametric modelling is increasingly being employed in hull design, structural organisation, and compartment layout (Roh & Lee, 2017). Ship compartment bulk density modeling in CAD software is difficult. The spaces might be characterized by their borders or by a sequence of sections, depending on how the compartments are organized (Lee et al., 2002).

A warship's layout design and the optimization to be constructed within the ship depend on generating and solving a subdivision layout problem. Subdividing a warship is essential in reducing the cost of transporting war machinery (Lee et al., 2002). The process begins with determining the best places to design the compartments and developing the best division that suits the owner's demands. The preferred shape of divisions in a warship is rectangles but must consider several factors: the space and number of portions proposed, the relation between values making up the boundaries, the size of each division, and several other factors.

3 Modelling methodology

The objective of this thesis is to determine the container cargo layout of containerships. The work is divided in two steps. In a first step, it is performed the arrangement of containers inside the hull and in the second, it is studied the arrangement of the cargo on deck.

The cargo areas of containerships are defined per bays, rows, and tiers. Bay defines each transversal section of containers, and the count starts from stern, tier is each level of containers stacked on top of each other and row is each line of containers that are longitudinally aligned. The bay-row-tier is a coordinate system for containers in ships.

The layout of the cargo containers inside the hull depends essentially on the hull form and also from a set of geometric constraints associated with different design aspects such as longitudinal strength, stability, cargo securing equipment, etc. In this work it is assumed that the outer hull form is pre-defined and constant, and it is described by a number of cross-sections, each defined by a polyline. The definition by polylines although not as accurate as free-form curves and surfaces used currently for other types of naval architecture computations, is sufficient for the intended work and is quite efficient because it allows a much faster processing, which can be quite relevant in the scope of optimization procedures.

The geometric constraints related to the inner hull form result from the requirement of different entities. The International Convention for the Safety of Life at Sea (SOLAS) is responsible for guarantee a safe navigation of a ship and its rules cannot be avoid for any ship. The constraint imposed by SOLAS in the inner hull compartment layout is the distance between the fore perpendicular and the collision bulkhead. The Classification Societies are the entities who ensure the compliance of the minimum required standards for the ships structure as the minimum height of the double bottom and the minimum width of the side tanks. Each Classification Society has different rules, and the ship designer can choose the best Classification Society for his intents. However, the ship owner has objectives that need to be respected. On the other side, the designer has the intent to help the owner and to comply with the rules, which means that even if the Classification Society determines a range for a dimension, the ship designer is the entity who defines the pretended dimensions.

In this project, the height of the double bottom is set manually as if it was defined by the ship designer and the collision bulkhead is defined to comply the range imposed by SOLAS. To perform the analysis of a ship, there are several variables to consider as the class, the length, the width, the breadth, the position and length of the engine room, the height of the double bottom, the width of the side tanks, the distance between bays, the distance between a container and the guides in cargo holds, the transverse gap between containers, the maximum number of tiers on deck, the height of the hatch, the thickness of the hatch cover and the height of the different superstructure decks.

The layout of the inner hull is divided in two phases. First, it is performed a longitudinal analysis of the hull, where it is determined the longitudinal position of the bulkheads and the existence of cargo holds, considering the position of the engine room and the superstructure. The engine room is allocated in the hull and the superstructure is above deck. However, it is not possible to carry containers in the hull below the superstructure. After identifying the cargo holds, are determined the cross-sections that will be submitted to a transverse analysis resulting in the form of the cargo holds.

To perform the layout of the deck, the alignment between the containers in the cargo holds and on deck is considered. Depending on the location of the engine room funnel and the superstructure, the existence of cargo on deck above the engine room and, in the longitudinal edges of the ship is analysed, considering the stern panel and the collision bulkhead. The distance between the fore perpendicular and the collision bulkhead and the navigation bridge visibility line are limited by the SOLAS rules. The number of rows of each bay depends on the minimum width of the bay, which is more noticeable closer to the fore perpendicular.

Depending on the cargo layout configuration of the containership analysed, there are different steps to proceed due to the different cargo areas and the different positions of the engine room and the superstructure. The typical cargo layout configurations are presented in Section 3.1.

The analysis of the ship results in the total cargo capacity of the ship by accounting the cargo capacity in the cargo holds and on deck. The results of the cargo layout analysis are stored in a 2D-matrix representing the bays of the cargo holds with the tiers and the correspondent capacity, where are observed the longitudinal steps of the cargo holds. The 2D-matrix is transformed and graphically represented as the capacity plan of the ship. The cross-sections analysed are also represented, with the form of the inner and the outer hull. Both the longitudinal and the transverse representations allow to understand if the analysis are being performed correctly.

In a further analysis, the possible improvement of the hull form is studied where the inner hull is studied to verify if, reducing the minimum distance between the inner and the outer hull, it would be possible to gain some cargo capacity without changing the outer hull form.

3.1 Typical cargo layout configurations

There are different types of configurations depending on ships' size: Feeders, Panamax, Post-Panamax, Very Large Containerships and Ultra Large Containerships.

The smallest ships, designated Feeders, are characterized by having the superstructure and the engine room located aft, with two cargo areas, one inside hull and another above deck, with cargo capacity up to 1,500 TEU. Usually, Feeders have cargo cranes for cargo handling in small ports. This may represent a disadvantage to the ship cargo capacity due to the space on deck occupied by the cranes and associated supports. In Figure 3.1 is represented a typical configuration of Feeders with correspondent cargo areas.

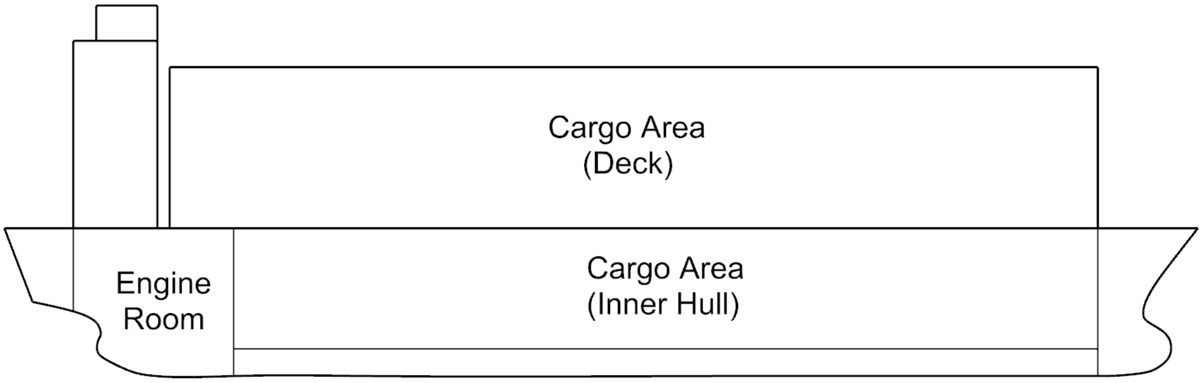

Figure 3.1 - Typical configuration of Feeders ships

The Panamax class of containerships are designed to pass through the Panama Canal. Panamax are characterized by having the superstructure and the engine room located aft, with three cargo areas, one inside hull and two above the deck, one cargo area forward superstructure and one cargo area aft superstructure. In Figure 3.2 is represented a typical configuration of Feeders with correspondent cargo areas.

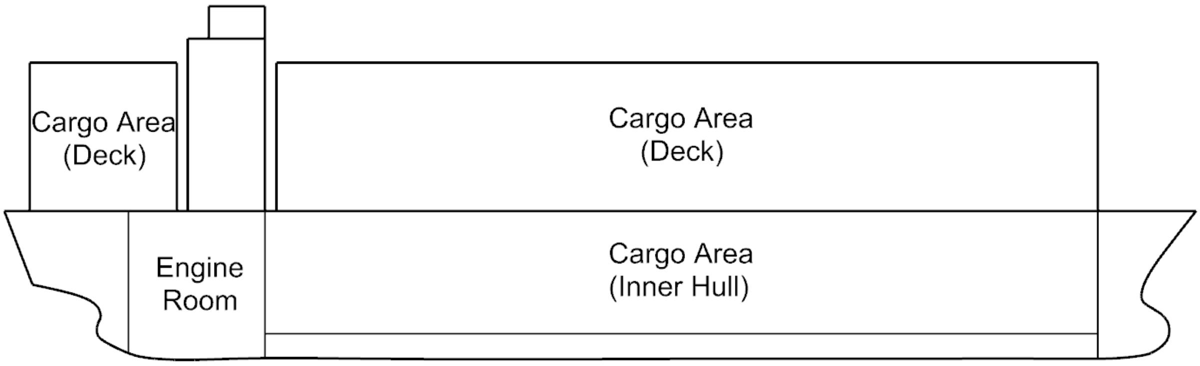

Figure 3.2 - Typical configuration of Panamax ships

Post-Panamax class consists of the containerships that are larger than the admissible in the Panama Canal. Due to the greater length, both the superstructure and the engine room are located close to midship. These ships have four cargo areas, two inside hull and two above deck. As shown in Figure 3.3, related to cargo areas above deck, one is aft superstructure, and the other is forward superstructure. The cargo areas inside hull are located aft and forward engine room. The number of tiers above deck forward superstructure is limited by visibility requirement of *SOLAS*. The cargo area aft engine room is constrained by the propeller shaft. Figure 3.3 presents a typical configuration of Post-Panamax ships with the corresponding cargo areas.

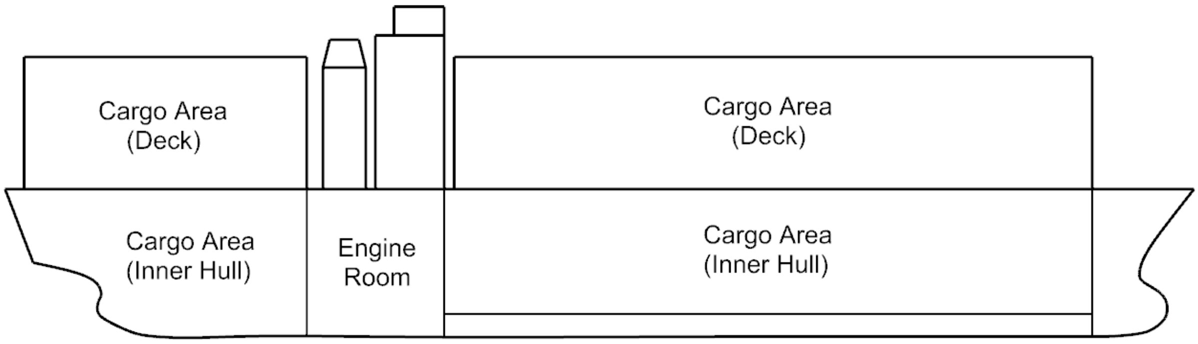

Figure 3.3 - Typical configuration of Post-Panamax ships

Very Large Containerships and Ultra Large Containerships are the most recent classes of containerships. Both classes are characterized by having six cargo areas, three inside hull and three above deck. Particularly in these containerships, the engine room is de-coupled from the superstructure. There are two cargo areas aft engine room, two cargo areas forward superstructure and two cargo areas between engine room and superstructure. The engine room is located aft, and the superstructure is located forward midships. Nowadays, there is a class of these ships called Malaccamax that can carry over 24,000 TEUs. In Figure 3.4 is represented a typical configuration of Feeders with correspondent cargo areas.

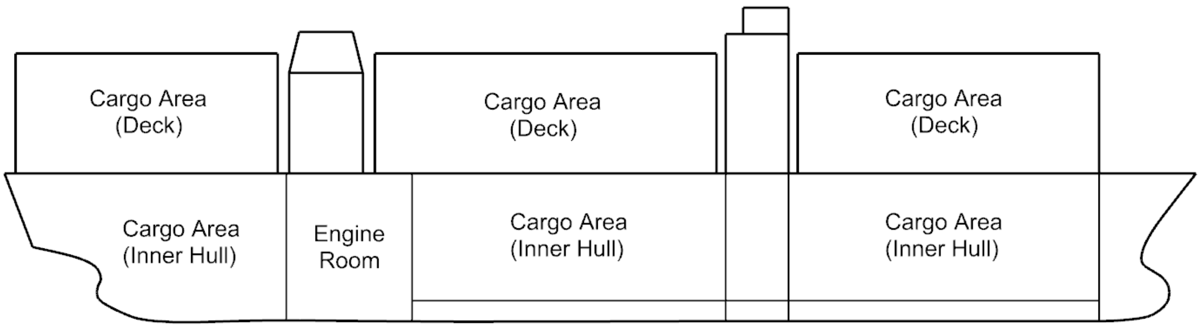

Figure 3.4 - Typical configuration of Malaccamax ships

Containerised cargo as some advantages comparing to bulk cargo. Containerised cargo requires less time in port operations, the load and unload services are faster, which means an efficient berth utilisation. Accommodation in containers add security and reduces the risk of physical damage of cargo due to operations or adverse weather conditions. Another great advantage of a containership is that the cargo can be carried above deck.

3.2 Longitudinal configuration of inner hull

Taking into consideration the designer´s intent, the longitudinal configuration of the hull consists of the analysis of the hull along the length, determining the position of the transverse bulkheads and the location and length of the cargo holds, considering the engine room, the superstructure, the stern panel and the collision bulkhead.

First, the cross-sections of the hull are imported from a file with the coordinates of the points that define the polylines and generated into an array of sections. Each section represents a transverse section of the ship in a format of cartesian coordinates.

To start the parametrization of hull compartment it is required to know the pretended configuration of the containership between the four configurations presented in Section 3.1.

After knowing the pretended configuration of the containership, it is generated a vector that represents the hull compartments configuration and the deck configuration (longitudinally). To generate the vector of inner hull configuration, the first reference point is the position of the aft bulkhead of the engine room in relation to the aft perpendicular represented in the Figure 3.5.

Depending on the containership chosen, the existence of cargo holds aft the engine room is evaluated. For Feeder and Panamax typical configuration, there are no cargo holds aft engine room. In the case of Post-Panamax and Malaccamax configuration, the number of possible holds aft engine room is determined until it reaches the maximum distance from stern where it is allowed to have cargo holds. The minimum distance between the stern panel and the beginning of the cargo areas is defined in a percentage of the length between perpendiculars once there is not any rule stipulating the value. The space between the stern panel and the first cargo hold is usually used to the steering gear system and in the most cases, it has a length greater than 2 bays of containers. Through observation of several general arrangements, it was defined that a standard cargo hold is composed by four bays aggrouped in pairs. When it is not possible to add a standard cargo hold, the excess bays are removed from the further aft cargo hold and the position of aft bulkhead of further aft cargo hold is determined. After determining the number of bays in the aft most cargo hold and the position of the aft bulkhead of the respective hold, it is started to generate the vector of the longitudinal configuration of the hull.

The Figure 3.5 represents an example of a cargo hold with four bays aggrouped in pairs allocated aft engine room attached with the location of the aft bulkhead of engine room in relation to the aft perpendicular of the ship and the identification of the collision bulkhead.

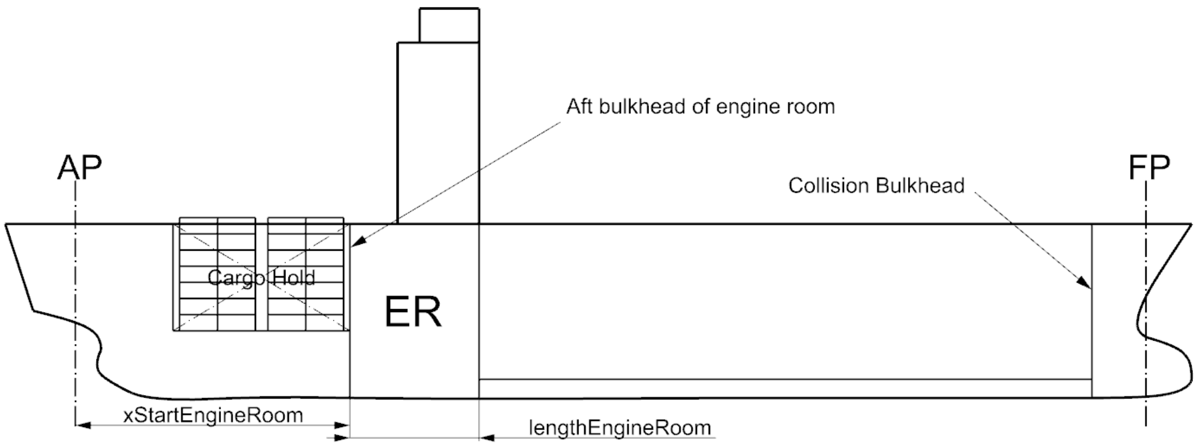

Figure 3.5 - Cargo hold allocated aft engine room

In the case of Feeders and Panamax, the aft most bulkhead of the ship, corresponds to the aft bulkhead of engine room. For post-Panamax and Malaccamax, the aft most bulkhead is the aft bulkhead of further aft cargo hold.

The vector of longitudinal configuration is an array of arrays where the compartments are described. Each array corresponds to a compartment and have two entries. The first entry represents the type of compartment. If the first entry is 0, it means that the compartment is non cargo area and the second entry of the array is the distance between the bulkheads of the compartment. If the first entry is 1, it means that the compartment is a cargo hold and the second entry will be a matrix correspondent to the hold configuration. Each entry of the matrix represents a group of bays. For a value of first entry equal to 2, it symbolizes that the present compartment is the engine room, and the second entry is the length of the engine room, stipulated by ship owner.

In Figure 3.6 is shown an example of longitudinal configuration specified by the array { {0 10} {1 [2 2]} {1 [1 2]} {0 15} }. This example represents a ship with 4 compartments. The first compartment is a non-cargo compartment with 10m length ({0 10}), followed by a cargo hold with two bays grouped in pairs ({1 [2 2]}). The third compartment is also a cargo hold with two groups of bays, one group of one bay and other group of two bays ({1 [1 2]}). The last compartment is another non-cargo area with a length of 15m ({0 15}).

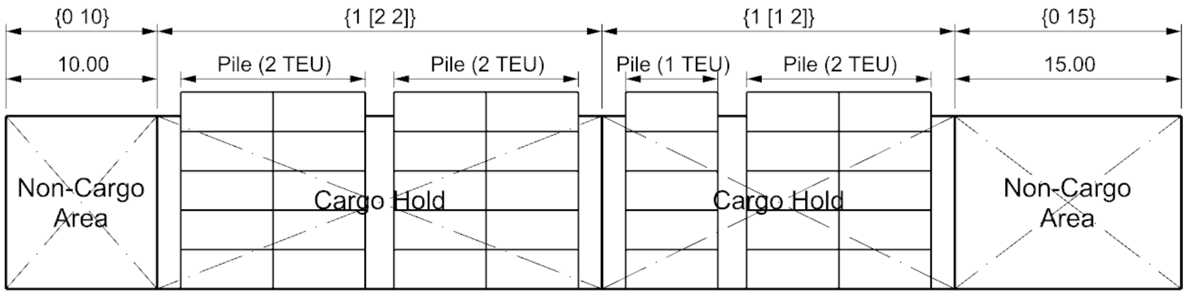

Figure 3.6 - Example of longitudinal array configuration (profile view)

The vector represents the compartments from aft to forward location of the ship. For all four configurations, the first compartment is a non-cargo area that represents the distance from stern panel to the aft bulkhead of the ship.

For Feeder and Panamax configuration, after the first compartment, the engine room is added to the vector. Otherwise, to post-Panamax and Malaccamax, the further aft cargo hold is added after first compartment and subsequently the standard cargo holds aft engine room are added. After, the engine room compartment is added.

The compartment arrangement forward engine room is similar to Feeders, Panamax and post-Panamax once the inner hull is fulfilled by cargo holds until it reaches the collision bulkhead. The process applied to determine the hull compartments fore engine room is comparable to the process for aft engine room compartments of post-Panamax and Malaccamax configuration, considering that the cargo area limit is the collision bulkhead, and the excess bays will be removed from furthest forward cargo hold, one by one until the pretended cargo hold is able to fit the hull. After determining the furthest forward cargo hold configuration, the standard cargo holds fore engine room are added to the vector and the last cargo hold is posteriorly introduced.

The Malaccamax class of ships have the superstructure separated from engine room. Therefore, for this configuration, it is required to set the number of pairs of bays between engine room and superstructure. If the number of pairs is odd, the further forward cargo hold between engine room and superstructure is composed by two bays and the remaining of cargo holds have the standard configuration. For a Malaccamax ship, the x coordinate of the aft section of the superstructure is given by the equation (3.1).

$$xStart_{SS} = xStart_{ER} + l_{ER} + baysPairs_{ER \to SS} \cdot (2 \cdot l_{container} + distBetweenBays) \quad (3.1)$$

Then, after adding the engine room to the vector of inner hull configuration, the cargo holds between engine room and superstructure are added to the vector, considering the number of bay pairs purposed by ship owner. Subsequently, the superstructure is added to the vector once that above superstructure range, it is not possible to carry containers. At last, the cargo holds forward superstructure are added applying the same process as for cargo holds forward engine room of Feeders, Panamax and post-Panamax.

The minimum and maximum distance from aft perpendicular to the collision bulkhead are restricted by regulations in *SOLAS* and determined by equations (3.2) and (3.3) respectively.

$$min_{distCB} = L_{pp} - \min(0.05 \cdot L_{pp}\ ;10) \quad (3.2)$$

$$max_{distCB} = L_{pp} - \min(0.08 \cdot L_{pp}\ ; 0.05 \cdot L_{pp} + 3) \quad (3.3)$$

Focusing on cargo holds, each grouped bay pair (two TEU length or one FEU length) need to be longitudinally spaced from each other and from bulkheads to allow crane guides to go inside cargo hold to proceed operations. In Figure 3.7 is shown an example of a cargo hold with four bays, grouped in pairs. The grouped bay pairs have a spacing between them ($distBetweenBays$) and a distance from the bulkheads ($distGuides$).

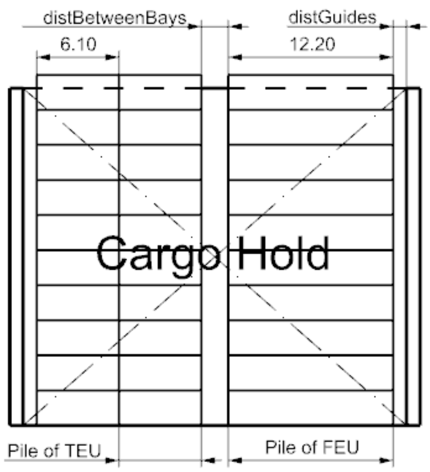

Figure 3.7 - Example of cargo hold (profile view)

The length of a cargo hold is determined by equation (3.4).

$$l_{CargoHold} = nr_{HoldBays} \cdot l_{Container} + \\ +2 \cdot distGuides + (nrPiles - 1) \cdot distBetweenBays \quad (3.4)$$

After obtaining the longitudinal array configuration, it is determined the longitudinal positions of bulkheads relatively to aft perpendicular in a form of matrix, considering all the dimensions previously mentioned and the characteristics of the ship required by owner.

To parametrize the cargo holds form, it is required to determine all longitudinal sections where the container edges are located (between each cargo hold bulkheads). Crossing the vector of longitudinal array configuration and the array of bulkheads' longitudinal position it is identified the bulkheads that limit the cargo hold. To determine the cargo hold sections that need to be shaped, it is analysed the configuration of the hold (number of group of bays and number of bays of each group) and for each hold it is created a matrix with the longitudinal position of the sections of the holds that are pretended to be studied. In addition to bulkheads limits existent, the position between containers is added to the matrix, according to the longitudinal spaces of a cargo hold shown in Figure 3.7. In Figure 3.8 is represented an example of sections where the analysis will occur in each cargo hold. Cargo hold nr 1 is transversely analysed in 5 sections, sections 1 and 5 are the bulkhead sections and sections 2, 3 and 4 are the middle sections between container bays. In sections 3 and 6 it is possible to identify a space the bays that is intended for the cell guides of containers.

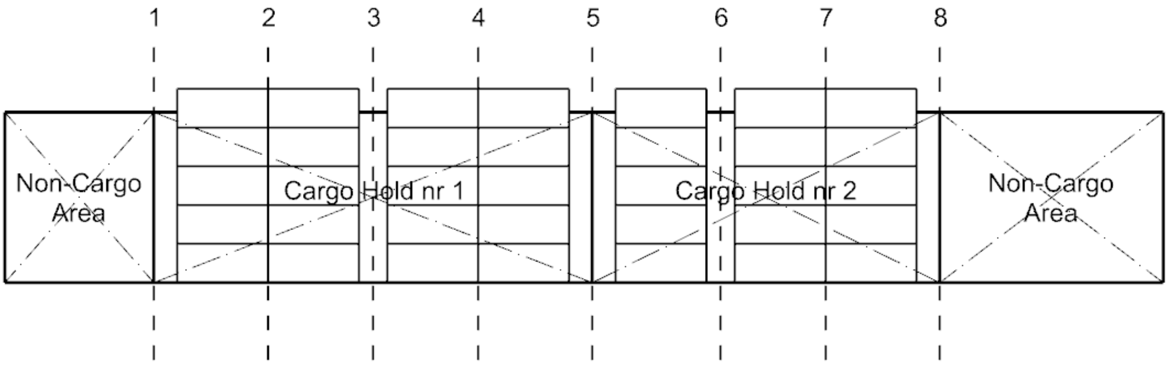

Figure 3.8 – Analysed sections of cargo hold

Considering the dimensions in Figure 3.7 and the sections in Figure 3.8 the resulting matrix of longitudinal sections for cargo hold nr 1 is:

$$xSecHoldArr\{1\} = \\ = [\ 10\ ;\ 10 + d_{1-2}\ ;\ 10 + d_{1-2} + d_{2-3}\ ;\ 10 + d_{1-2} + d_{2-3} + d_{3-4}\ ;\ 10 + d_{1-2} + d_{2-3} + d_{3-4} + d_{4-5}\ ]$$

Where, d_{a-b} is the distance between section a and section b.

3.3 Transverse analysis of inner hull

After defining the longitudinal configuration of the ship with the important positions to analyse, the transverse shape of the sections of each cargo hold is determined. As the longitudinal position of the sections imported is not equal to the longitudinal position of cargo hold sections, the transverse sections of cargo hold are interpolated. It is required to identify the hull sections between which the section to interpolate is located.

The dimensions of cargo holds are streamlined with the dimensions of containers, once that the cargo hold is only composed by containers. Streamlined means that the dimensions of cargo holds are multiple of the dimensions of containers in each axis.

To perform the transverse analysis of the section, there are some dimensions to consider: the depth, the double bottom height (h_{db}), the width of wing tanks ($minSideDist$), the distance between rows ($transverseGap$), the height of containers ($h_{container}$), the width of containers ($w_{container}$), the height of hatch cover (h_{hatch}) and the margin of deflection of hatch cover (h_{margin}). When the deck is loaded with containers, the hatch cover deflects, and this margin needs to be considered to avoid the possibility of the hatch cover pressuring the containers in cargo holds.

In Figure 3.9 is shown a transverse section of a ship with the dimensions identified.

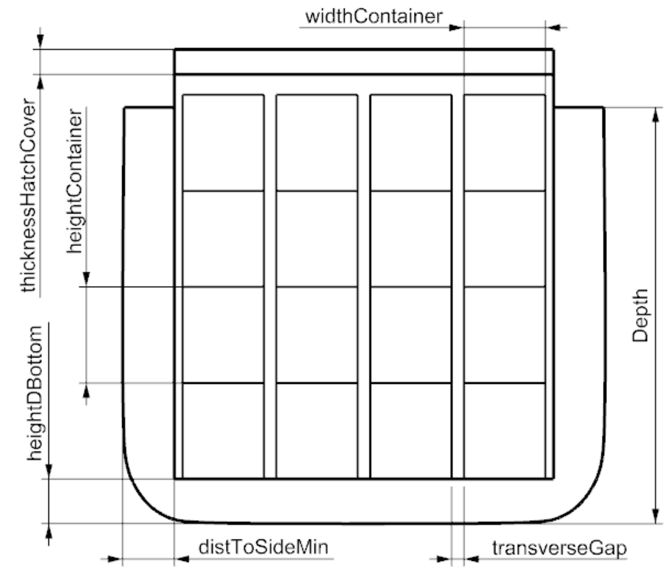

Figure 3.9 - Dimensions for transverse analysis

As the dimensions of cargo holds are multiple of the dimensions of containers, to determine the width of wing tanks, it is required to set a minimal possible width and determine the maximum number of rows that can fit the available distance between wing tanks in the largest section of the ship (cylindrical body). Considering the existence of a transversal gap between cargo hold rows (25mm or 80mm, depending on the ship), the maximum number of rows in cargo holds is given by equation (3.5).

$$nrMaxRow = RoundDown\left(\frac{B - 2 \cdot minSideDist - transverseGap}{w_{Container} + transverseGap}\right) \tag{3.5}$$

Where *RoundDown* is a function that returns the nearest down integer of a number.

Through the maximum number of rows, it is possible to determine the width of wing tanks in cylindrical body of the ship, represented by equation (3.6). The width of wing tanks is important to guarantee some structural requirements and the volume of ballast, fresh water and others that are needed to ensure the voyages of a ship.

$$w_{SideTanks} = nrMaxRow \cdot \\ \cdot (w_{Container} + transverseGap) + transverseGap \tag{3.6}$$

The inner hull analysis is made point by point where the point to be analysed is compared with the polyline of the section. Depending on the longitudinal location of the section, the analysis can start in two different coordinates. If the class of the ship is a Feeder or a Panamax, there are no containers aft the engine room and the height of the starting point is the height of the double bottom. However, if the class of the ship is a Post-Panamax or Malaccamax it is required to consider that the shaft of the engine supresses some tiers of containers in cargo holds allocated aft engine room. As the tiers of the cargo holds need to be aligned, the height of the shaft is a multiple of the height of a container (equation (3.7)).

$$h_{Shaft} = n_{SupTiers} \cdot h_{container} \tag{3.7}$$

The z coordinate of the starting point is given by equation (3.8).

$$\begin{cases} z_0 = h_{db} \ , \ if \ \ x_{Sec} < xStart_{ER} \\ z_0 = h_{shaft} \ , \ if \ \ x_{Sec} \geq xStart_{ER} \end{cases} \tag{3.8}$$

Depending on the parity of the number of tiers, if the number of tiers is even, then the starting point is at the y coordinate equal to 0. If the number of tiers is odd, then the starting point is at y coordinate of half width container plus transverse gap. The coordinate of the starting point to the transverse analysis is given by equation (3.9).

$$\begin{cases} K_0 = (x_{Sec} \ ; \ 0 \ ; \ z_0), \qquad even\ number\ of\ tiers \\ K_0 = \left(x_{Sec} \ ; \ \dfrac{w_{Container}}{2} + transverseGap \ ; \ z_0\right), \qquad odd\ number\ of\ tiers \end{cases} \tag{3.9}$$

In Figure 3.10 is represented the different starting points for each condition.

This method allows to set a minimal number of transverse containers allowed in the transverse sections. To start the transverse analysis of the section there are three dimensions to consider. The first dimension is the height of double bottom once it is set in the beginning of the project and cannot be changed. The second dimension is the minimal width of wing tanks, once the ship needs to carry fuel, ballast, fresh water, and others. The third dimension is the tolerance distance to identify points where the distance exceeded is less than this stipulated distance. This tolerance distance will be useful to identify points where the hull can be improved.

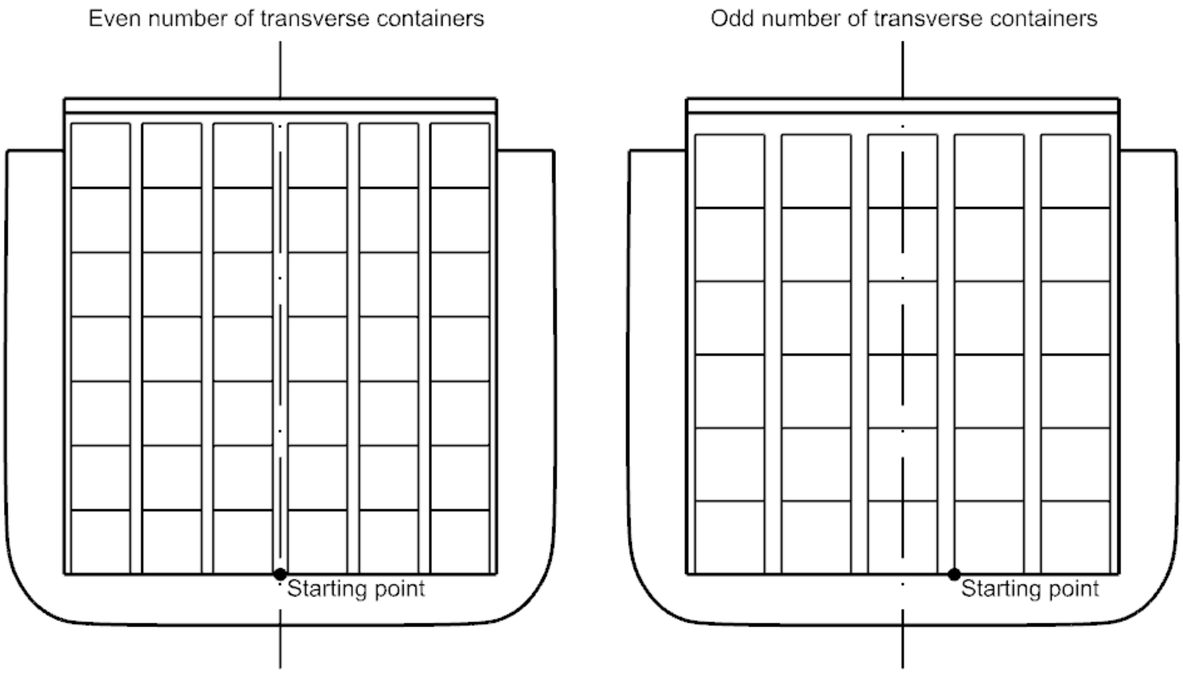

Figure 3.10 - Sketch of starting point for different number of transverse containers

Proceeding to the analysis of the selected transverse sections, if the starting point is valid, according to minimum distance stipulated (double bottom height and wing tanks minimum width, respectively), then it moves one step (equivalent to the width of a container plus the transverse gap between containers) in direction to the nearest wing tank. When a point exceeds the limit, the latest valid point is registered in a matrix of the respective section. If the analysed section is not in the cylindrical body, it can show a large bilge tank due to narrowing of hull. In the case where the minimal distance between the point analysed and the polyline of the section is exceeded but the distance exceeded is less than the tolerance distance previously set, this point is registered in a matrix in order to notify where the hull can be improved. This last process is explained in a further section.

The analysis is performed through tiers, which means that the points are analysed keeping the same height until an invalid point is reached. After, the point to be analysed jumps to the next tier, where the y coordinate of the next analysed point is set to the same of the starting point, but the z coordinate is equal to the z coordinate of the previous point analysed plus the height of a container.

The previous process is repeated through all the tiers of the section. The cycle of analysis of the transverse section ends when z coordinate of the point to be analysed exceeds the height given by equation (3.10).

$$h_{max} = D + h_{Hatch} - h_{Margin} - h_{Container} \tag{3.10}$$

Where h_{Margin} is a safety value attributed to consider the deflection of the hatch cover. When a ship is completely loaded of containers, the hatch cover is exposed to the pressure caused by the weight of the containers above deck and, despite having stiffeners, it tends to deflect some centimetres in the direction of the cargo holds. This detail is important to ensure that the hatch cover can close and to prevent damage in some containers.

Through each tier analysis, it is also calculated the number of containers that each tier can carry according to the section, creating a matrix to register the values. However, this number of containers per tier does not mean that it is the real number of containers that will be carried in that section once this number corresponds to the analysis of one container edge. An example of this situation is the analysis of two consecutive sections forward of the ship's cylindrical body are analysed, it will show a narrowing of the hull and that may provide different results between these two sections.

After getting all the shapes of inner hull to each section of correspondent hull and the capacity of each bay, the pretended the capacity plan is performed. The capacity plan is a sketch of front view of ship where the capacity of each tier is represented by the maximum number that each tier can support.

The data obtained previously is separated per hold, where each column of a matrix corresponds to one edge of a bay. To get the capacity plan, it is required to compare the neighbour columns of the matrix of each hold. With the comparison, just the smallest value will count, once the value means the maximum number of containers that the transverse section with X coordinate can support. If a section closer to the bow is narrower than the previous one, the space between both cannot handle the capacity determined of the furthest section from the bow.

3.4 Longitudinal deck configuration

The first containerships did not carry cargo above deck, but through the years, following the development of shipping industry, the cargo above deck was a big improvement in the cargo capacity of the ships. Nowadays, more than half the cargo of a containership is carried above deck, which shows how important is the layout of the deck and the distribution of the cargo areas not only in hull but also above deck.

There are several factors that influence the layout and the capacity of cargo above deck as the configuration of the containership, the length of superstructure, the location of the cargo in inner hull, the width of the hull in each section, and the height of superstructure.

Through the information presented in the Section 3.1, it can be noticed that all the typical configurations of containerships, the cargo above deck is aligned with the cargo in the holds. The only exception is when there is not a cargo hold but the deck is still filled with containers. This condition is always verified in Panamax class of ships and sometimes in Malaccamax class. In the case of Panamax class, it is verified due to the non-existence of cargo holds aft engine room. In Malaccamax class, it can be seen if the engine room has a huge length compared with the funnel. This would mean that the engine room fills up a higher space of the hull but the correspondent space above deck besides funnel's space can be available to carry more cargo.

The weight distribution of a ship influences the maximum number of tiers on deck, which outside of the scope of the work. This project is related to the layout and geometry of the ship, so the maximum number of tiers is managed as if it is a data provided from the owner of the ship. The height of the superstructure depends on the maximum number of tiers and on the number of superstructure's decks. To add height to the superstructure it is required to add an entire deck to the superstructure.

The superstructure is composed by accommodation decks and a navigation bridge. The accommodation decks are the living space of the crew and officers with cabins and hospital support and the navigation bridge is the uppermost deck. In terms of height, all the superstructure's decks need to have head space. The superstructure's deck at ship's main deck height does not have cabins, it is mostly used to be lounges and have a lower height than the other accommodation decks. The navigation bridge has a higher height than the accommodation decks once it has lot of navigation and communication equipment, and the officers need an ample space to look and control the operations and manoeuvres of the ship.

The number of superstructure's decks is given by equation (3.11).

$$nr_{Decks} = RoundUp\left(\frac{maxTiers_{Deck} \cdot h_{Container} + h_{Hatch}}{h_{StandardDeck}}\right) \tag{3.11}$$

Where $RoundUp$ is a function that returns the nearest up integer of the number. The number of decks is influenced by the number of tiers once it is required that the navigation bridge needs to at a height greater than the maximum number of tiers on deck set in the project. It is also important to notice that the cargo is placed on the hatch covers and not directly on main deck.

As shown in Section 3.1, three out of four configurations of ships have cargo located both aft and fore the superstructure on deck. According to *SOLAS 2020*, the number of tiers in each bay is restricted by the navigation bridge visibility rule. If the containership has more than 55 meters, the view of the sea surface from navigation bridge must not be blocked by two ship lengths, or 500 meters, whichever is less. In Figure 3.11 it is observed an example of the navigation bridge visibility line of a containership. The tiers of containers ahead superstructure cannot exceed the navigation bridge visibility line as shows the example, which means that closer to the forward of the ship, the number of tiers of deck cargo gets smaller.

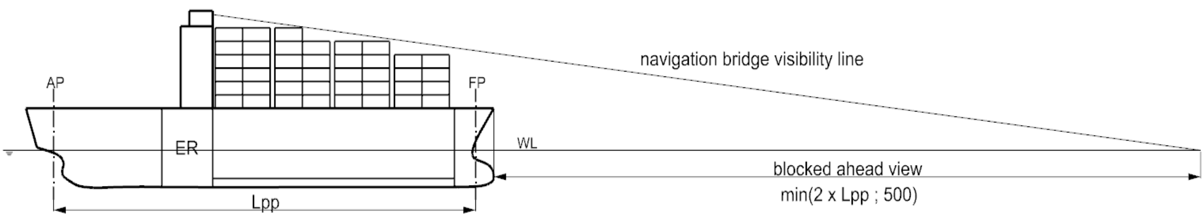

Figure 3.11 - Navigation bridge visibility

The longitudinal configuration of the deck has the same form of the longitudinal configuration of inner hull presented in Section 3.2. To determine the longitudinal configuration of the deck, it is considered the longitudinal configuration of the inner hull previously defined.

The procedure to determine the longitudinal configuration of the deck layout depends on the typical configuration of the ship in work. The main difference between the vector configuration is that the layout of deck is not directly influenced by the length of the engine room once there is the possibility of having containers over engine room. Other important factor is that for feeder, Panamax and post-Panamax class, the funnel is close to the superstructure and there is no cargo between them as opposed to the Malaccamax class of containerships.

The entries of the longitudinal configuration of deck have different meaning comparing to the previous explained in Section 3.2. When the first entry is 0, it means that the compartment is non cargo area, and the second entry of the array is the distance between the bulkheads of the compartment. If the first entry is 1, it means that the compartment is a cargo hold and the second entry will be a matrix correspondent to the hold configuration where each entry of the matrix represents a group of bays, and the number itself is associated to the number of bays in the respective group. For a value of first entry equal to 2, it symbolizes the funnel of the engine room, and the second entry is the length of the funnel that is smaller than the length of engine room. A value 3 in the first entry means that the space corresponds to the superstructure and the second entry is the length of the superstructure. Both the superstructure and funnel length are stipulated by ship owner in the project. Unless the Malaccamax class, all the other classes of containerships have the funnel and the superstructure attached together.

In the case of a feeder ship, the layout of the ship is similar both for inner hull and deck. It is determined the space between the stern panel and the beginning of the superstructure and registered as an empty space into the configuration vector and posteriorly, the length of the superstructure is added. The configuration of the ship aft superstructure on deck is the same of configuration vector on inner hull, then it is simply copied from inner hull vector.

For the Panamax class of ships, once there is cargo aft superstructure on deck, it is required to find the number of bays that the deck support between stern panel and the aftmost part of the superstructure. After allocating the cargo aft superstructure, the superstructure is added to the vector and the cargo fore superstructure are posteriorly added according to the bays of the inner hull fore engine room.

The post-Panamax class of ships has a similar configuration both in deck and inner hull once there is cargo fore and aft, superstructure on deck and engine room in inner hull. The bays of containers on deck need to be aligned with the bays of the inner hull. If there is cargo on hull, automatically, there is cargo in the same line on deck. However, it is required to examine the existence of containers in the aftmost part of the deck (aft the last aligned bay) and fore the last aligned bay aft engine room (on top of engine room before funnel).

In Malaccamax ships, due to the separation of the superstructure from the engine room, the funnel is allocated in the aftmost part of the engine room. Working on the number of bays aft funnel, it is only required to check if there are containers in the aftmost part of the deck (aft the aftmost aligned bay). After this first analysis, the funnel is allocated and posteriorly, the possibility of existing cargo between the fore section of the funnel and the fore section of the engine room. If there is any cargo in that zone, then it is added to the vector and subsequently, the vector ahead the fore section of engine room is equal in deck and inner hull, which means that the respective part of the vector is copied from inner hull vector.

Each tier above deck has the same width and transverse capacity per bay. The transverse capacity of a bay depends on the parity of the containers in the cargo holds and on the maximum width of the bay's sections. A bay is a space between two sections with the length of a container, so the maximum capacity of bay is related to the lower capacity between both sections. The transverse capacity of a section is represented by equation (3.12):

$$nrRows_{Sec} = RoundDown\left(\frac{2 \cdot maxSec_{Width}}{numMaxRow}\right) \tag{3.12}$$

If the parity of the result obtained is similar to the parity of the parity of the containers in cargo holds, then the transverse capacity is valid. Otherwise, it is subtracted one container to the previous result obtained.

After determining the number of transverse containers that can be carried in each section, the number of tiers of each section is calculated. The number of tiers of each section aft superstructure is equal to the maximum number of tiers on deck set by the ship owner and it does not require any calculations related to the navigation bridge visibility line. The number of tiers fore superstructure is determined considering the visibility line, as represented in Figure 3.11. For feeders, Panamax and post-Panamax ships, the x coordinate of the foremost section of the engine room is given by equation (3.13) and for Malaccamax class of ships is given by equation (3.14).

$$xEnd_{SS} = xStart_{ER} + l_{ER} \tag{3.13}$$

$$xEnd_{SS} = xStart_{SS} + l_{SS} \tag{3.14}$$

The horizontal distance of the blocked ahead view from the foremost section of the superstructure is given by equation (3.15).

$$d_{MaxBlockedView} = L_{pp} - xEnd_{SS} + l_{bow} + \min\,(2 \cdot L_{pp}\,; 500) \tag{3.15}$$

The height from the navigation bridge to the waterline is given by equation (3.16).

$$h_{bridge \to WL} = D + h_{SS} - T \tag{3.16}$$

For a section with x coordinate, being the section located fore superstructure, the maximum height of the cargo in a section (from the hatch cover to the top of the last container) is given by equation (3.17).

$$h_{maxSec} = \frac{h_{Bridge \to WL} \cdot (d_{MaxBlockedView} - (x_{Section} - xEnd_{SS})}{L_{pp} - d_{MaxBlockedView}} + D - T - h_{hatch} \tag{3.17}$$

The number of tiers of a section with x coordinate is given by equation (3.18).

$$nrTiers_{Sec} = Floor\left(\frac{h_{MaxSec}}{h_{Container}}\right) \tag{3.18}$$

After obtaining the matrix of each cargo area, the columns of each matrix consecutive are compared in height and transverse capacity to determine the composition of the bays. The height comparison is performed due to the visibility line requirements and the transverse capacity analysis is performed due to the narrowing of the width off the deck.

Posteriorly, the total number of containers on deck is determined.

3.5 Hull form analysis

In ship design, it is important that the compartments and the hull are fitted in order to not have some excessive volumes in tanks or a hull that have a lower efficiency, resulting in more costs to the owner of the ship. Analysing the inner hull and the outer hull of a containership, it can be noticed that sometimes, bilge tanks or wing tanks are over dimensioned.

In this chapter it is performed a study about the analysis of the inner hull where it will be detected the points where the hull is possibly over dimensioned. With this result it will be possible to adjust the hull in order to carry slightly more containers and also to determine how many containers will be added.

The assessment of the hull form occurs during the transverse analysis of the inner hull. The hull form analysis consists in determining critical points in the inner hull where they did not comply with the minimum distance between the inner and the outer hull requested but at the same time, the distance exceeded, Δd, is not more than a certain value attributed in the beginning of the method as input.

For each point that complies with the requirements are registered the coordinates of the point, the number of the cargo hold where the point is located, facilitating the identification of the critical points in order to allow the assessment of the hull. With this information it is possible to estimate the number of containers that can be gained in the cargo capacity with a few changes, both in the hull form and in the minimum distance between the inner and the outer hull.

The Figure 3.12 and the Figure 3.13 shows one example of an invalid critical point and a valid critical point respectively. In the Figure 3.12, the point is not critical once adding the stablished tolerance, the point do not comply the minimum distance required (d+dt < dmin). In the Figure 3.13, the point is a valid critical point because although the point does not meet the minimum distance requirement, when the tolerance is added the point becomes valid (d+dt > dmin).

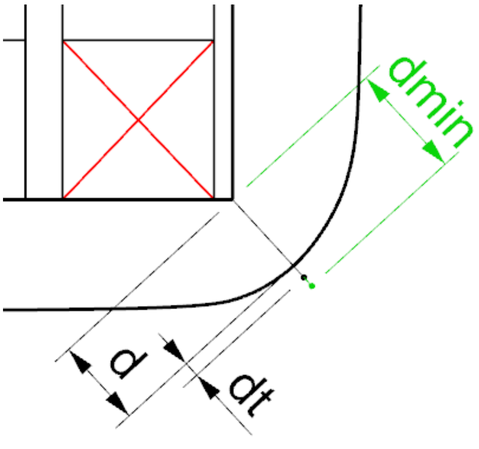

Figure 3.12 – Invalid critical point

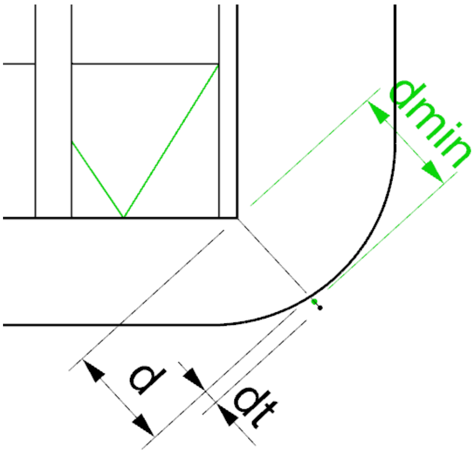

Figure 3.13 – Valid critical point

3.6 Software implementation

The software implementation was carried in MATLAB®. The code has one main script where there are several different functions. The code has seven main functions associated, detailed in Appendix A.

The seven functions in the MATLAB® implementation are composed by:

1. Main script
   - 1.1. Code for the import the hull sections
   - 1.2. Code for the generation of the longitudinal vector
   - 1.3. Code for the calculation of the longitudinal position of the transverse bulkheads
   - 1.4. Code for determining the hold sections to be analysed transversely
   - 1.5. Code for determining the transverse shape of the cargo hold sections
   - 1.6. Code for determining the cargo capacity of the ship above deck
   - 1.7. Code for plot the sketch of the capacity plan of the ship

In the Figure 3.14 is possible to observe the flow chart of the implementation in the software (MATLAB®).

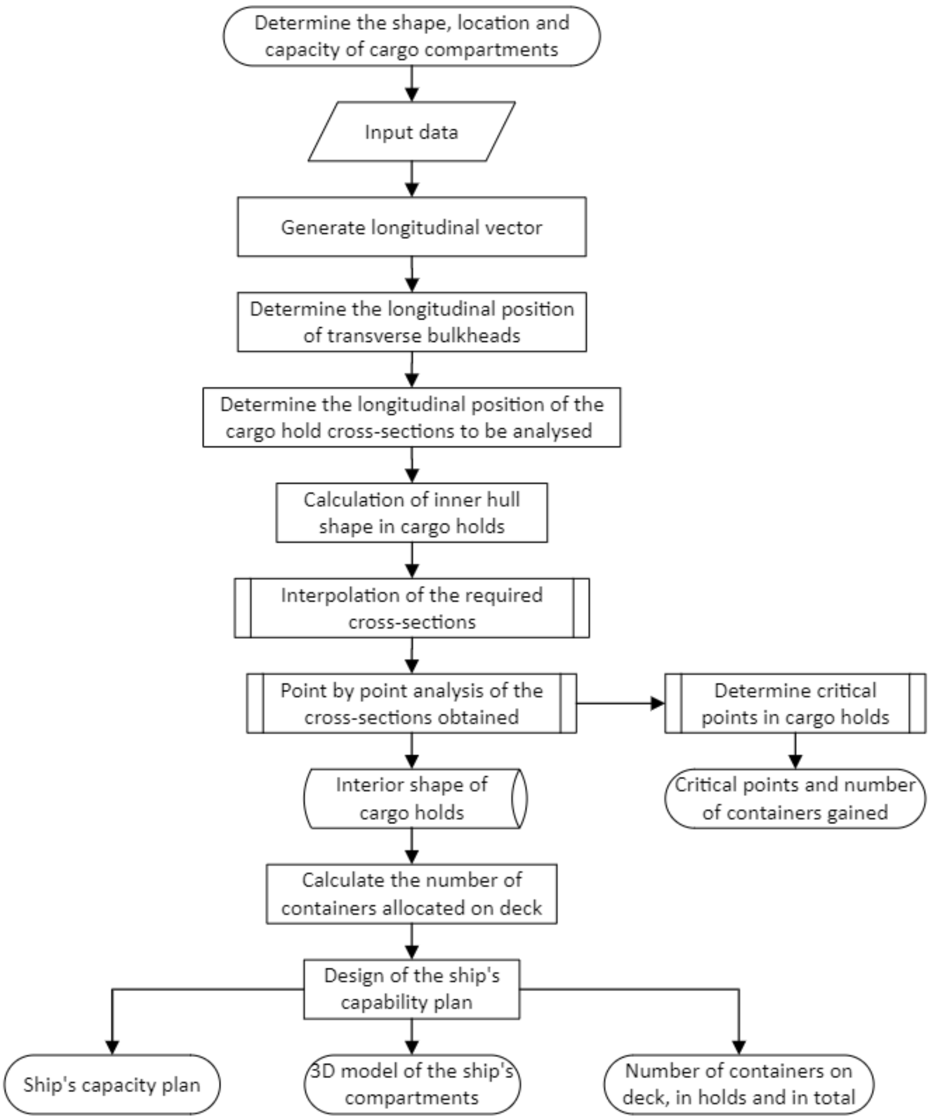

Figure 3.14 - Flowchart of the method implementation

There are several parameters required to proceed with the method. The data input is composed by:

- Class of the ship
- Length
- Breadth
- Depth
- Draught
- Height of the double bottom
- Width of the side tanks
- Longitudinal position of the aft bulkhead of the engine room
- Length of the engine room
- Longitudinal position of the aft section of the superstructure
- Length of the superstructure
- Maximum number of tiers on deck
- Transverse distance between containers
- Distance between the extremity of the containers and the bulkhead in the cargo holds
- Distance between bays
- Minimum distance between the inner and the outer hull
- Height of the hatch
- Height of the hatch cover
- Number of decks on superstructure
- Height of the lower deck on the superstructure
- Height of the accommodation decks on the superstructure
- Height of the navigation bridge

After implementing the method, are obtained several output results as:

- The cargo capacity in the cargo holds
- The cargo capacity on deck
- The total cargo capacity of the ship
- The volume of the cargo holds
- The geometric centre of the cargo holds
- A sketch of the capacity plan obtained in the comparison
- A 3D file in format .gf with the hull and the compartments determined

4 Model Validation

This section is related to the trial of replicating different containerships, showing cases for the different typical configurations presented in the Section 3.1, analysing the general arrangement of existing ships and trying to represent the same layout in a parent hull exported from Delft Ship® through a program coded in MATLAB®.

There are several obstacles during the validation process. Most of the analysed ships did not have neither the hull model nor the lines plan of the ship and the general arrangement is a pdf document with a bit map image, which means that when trying to zoom the general arrangement, the lines become thicker and the drawing imperceptible. It was used a parent hull and applied a lackenby process to reproduce the ship in study as close as possible.

Despite the main dimensions of the ships being easily reproduced, the block coefficient is one of the most important factors influencing the shape of the hull and one of the most difficult to replicate. A small variation in the block coefficient values means a great variation in the capacity cargo of a containership. Lower is the block coefficient, thinner is the shape of the hull and lower is the cargo capacity of the ship's holds. The area of the main deck also affects the cargo capacity of the ship. The term breadth of the ship is related to the maximum width of the main deck (located at midship section), but it does not describe the form of the main deck. Ideally, the aft most area of the main deck has nearly a rectangular shape and the narrowing of the bow happens closer to the fore perpendicular, comparing with other merchant ships (bulk carriers, ro-ro, etc), which results in an increased area to allocate cargo on deck and subsequently a greater cargo capacity. The shape of the main deck is another difficult to replicate in a parent hull, which can also cause inaccurate results.

In the case of having the 3D model of the hull and the general arrangement, the results can also differ from reality once MATLAB® lacks the capacity of reading a 3D model and treats the hull as 2D sections (transverse sections). The 2D sections are polylines defined by a set of points (coordinates) and these sections are not always the sections required to do the transverse analysis, which means that the 2D sections need to be interpolated in MATLAB® with a linear interpolation, risking a more inaccurate analysis.

To perform the arrangement of the spaces and cargo through the program, it is necessary to obtain a lot of details from the general arrangements of the ships as length between perpendiculars (L_{pp}), breadth (B), depth (D), draft (T), maximum number of tiers on deck, starting position of engine room (from aft perpendicular), length of the engine room (l_{ER}), length of superstructure (l_{ss}), width of the wing tanks ($w_{wing\ tank}$), height of the double bottom (h_{db}), the height of the hatch (h_{hatch}), the minimum allowed distance do the side ($minSideDist$) and the class of the ship (typical configuration). Depending on the class of the ship, the width of the deck support, the number of pair of bays between the engine room and the superstructure and the length of the funnel can also be a requirement. The space between containers (transverse and longitudinal) and the space for the guides in the holds should also be replicated but the quality of the general arrangements analysed did not allow it always.

The validation of the model is realized through the comparison of the cargo capacity in the inner hull, on deck and the total, the number of cargo holds, the number of tiers on deck in each bay aft superstructure. The relative error between the cargo results will be determined and commented posteriorly.

4.1 Feeder ship

4.1.1 Input variables

The feeder ships are used to transport containers to small ports that do not have their own cranes. The most part of the feeder ships have their own cranes, and that situation is not automatically identified by the program once the cranes are neither a cargo space nor the engine room. However, there is an option of manually inserting a vector with the dimensions of the spaces of the ship, in the format presented in Section 3.2.

In this example, it is analysed a small Portuguese ship built in 2007 with a total cargo capacity of 596 TEUs. The ship has a length between perpendiculars of 112.9 meters and the cranes located on the portside. When the cranes are not in use, they are in their resting position longitudinally to the ship. The superstructure is allocated in the aft most part of the ship, guarantying more space to the containers on deck. Some feeders with cranes can carry containers in the direction of the cranes but the program cannot recognize this situation. The spaces on deck where the cranes are located, are considered empty spaces, only containing the supports of the cranes. In this ship there are not containers in the transverse direction of the cranes, it is only used for lifting auxiliars. The transverse space in hull corresponding to the width of the cranes are fuel oil tanks.

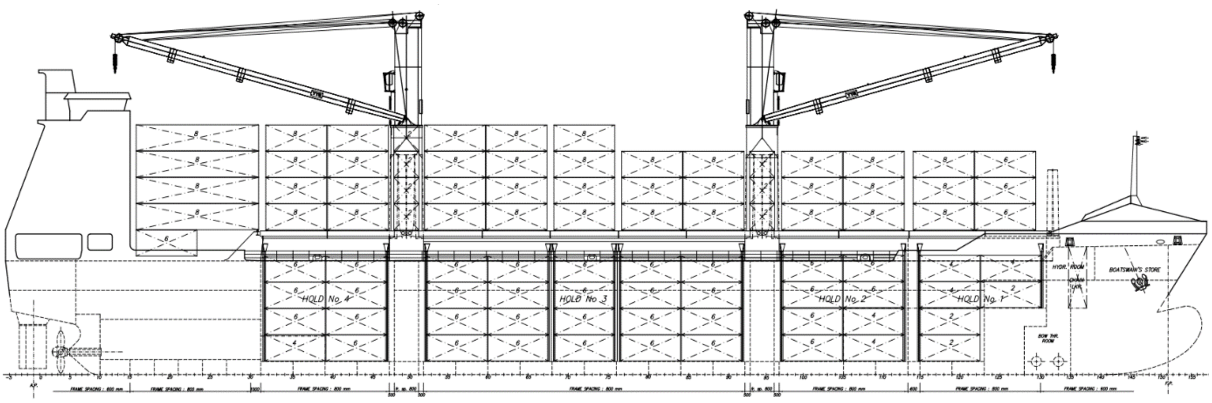

Figure 4.1 – Longitudinal cut of a feeder containership

Through the general arrangement and the capacity plan of the ship, it was approximately obtained the input values to reproduce the ship in MATLAB®. As the general arrangement of the ship in study was provided in a pdf document, it was easily analysed the document, decreasing the error margin in the lecture of the values. The ship has a breadth of 20 meters, a depth of 11.3 meters and, a double bottom with 0.8 meters height. The wing tanks have a width of 2.1 meters, which is close to the width of a container because there is a row of containers above the wing tanks on deck. The engine room starts 8 meters aft the stern panel and has a length of 21 meters. The length of the superstructure is 12 meters. The maximum number of tiers of bay on a deck is 4 containers and there are 5 superstructure decks.

The height of the hatch coaming is 1.6 meters, and the height of the hatch cover is 0.6 meters. Particularly in this ship, there is a side support with a width of 0.15 meters to support the most lateral row on deck. If the side support did not exist, it would not be possible to carry 8 rows in a single bay on deck because it would not respect the equation (4.1). Knowing that a container has a width of 2.5 meters and the breadth of the ship is 20 meters, $20/2.5 = 8$, which means that it would not be possible due to the existing transversal gap between containers.

$$B \geq 8 \cdot w_{container} + 7 \cdot transverseGap \tag{4.1}$$

Related to the minimum distance between the inner and the outer hull, it was analysed the capacity plan of the ship and through some approximated measures, it was set a value of 0.4 meters.

The superstructure decks can be distinguished by 3 different functionalities. The lower deck is usually used as a lounge, where there is a common space for the crew to stay when in voyage. The accommodation decks are the decks between the lower deck and the navigation bridge, where are the bedrooms for the crew. The highest superstructure deck is the navigation bridge, where the operations are controlled. The measured height of the lower deck is 2.6 meters, the height of the accommodation decks is 2.7 meters, and the height of the navigation bridge is 3 meters. The presented input values are shown in Table 4.1.

Table 4.1 - Input to reproduce a feeder ship

Characteristics		Units	Characteristics		Units
$Class$	feeder	-	$maxTiers_{Deck}$	4	[TEU]
L_{pp}	112.900	[m]	$transverseGap$	0.025	[m]
B	20.000	[m]	$distBetweenBays$	0.250	[m]
D	11.300	[m]	$distGuides$	0.200	[m]
T	7.900	[m]	h_{hatch}	1.600	-
h_{db}	0.800	[m]	t_{hatch}	0.600	[m]
$w_{SideTanks}$	2.100	[m]	$minSideDist$	0.400	[m]
$xStart_{ER}$	8.000	[m]	$nrDecks$	5	-
l_{ER}	21.000	[m]	$h_{LowerDdeck}$	2.600	[m]
$xStart_{SS}$	-3.000	[m]	$h_{AccDeck}$	2.700	[m]
l_{ss}	12.000	[m]	h_{bridge}	3.000	[m]
$sideSupport$	0.150	[m]			

As the program is not able to automatically represent a vector of the ship with the cranes, the vector was inserted manually. Analysing the Figure 4.1 and crossing with the values of Table 4.1, the longitudinal vector of the ship for both deck and hull are:

```
vectorDeck = {{3 12} {1 [2]} {1 [2]} {0 3.4} {1 [2 1 2]} {0 3.4} {1 [2]} {0 0.7} {1 [2]}};
```

```
vectorHull = {{0 8.6} {2 16} {1 [2]} {0 3.4} {1 [2 1 2]} {0 3.4} {1 [2]} {0 0.7} {1 [2]}};
```

For this case, there were the original sections of the hull, provided from the existing general arrangement in a CAD file. The stern overhang of the ship has 3 meters, and all the bulkheads will be located considering the stern panel has reference ($x = -3$).

4.1.2 Results and discussion

The results of the comparison between the real general arrangement of the ship and MATLAB® program are shown in Table 4.2. The results are close to the reality, and through the negative relative error, it is observed that the program supresses some containers both in cargo holds and deck.

Table 4.2 - Results of feeder ship comparison

	General Arrangement	MATLAB	Relative Error
Deck	368	356	-3.26%
Holds	228	222	-2.63%
Total	596	578	-3.02%

The difference of 12 containers in deck happens because there is a tier of 6 containers supported in the upper deck and the program only recognizes deck tiers above the height of the hatch covers. The other 6 containers are related to the width of the forward sections of the ship. The fore most tier in the general arrangement presents a width of 6 containers in each tier and the program returns a width of 4 containers per tier. Looking for the visibility line of the ship, the number of tiers on deck on each bay is the same in the general arrangement and in the program. The relative error of -3.26% is a good result given the situation observed and the capacity of the program.

One of the reasons to the difference in cargo holds is that when working around a certain section, it results from the linear interpolation of 2 sections, and it did not always return an accurate form of the section. In the general arrangement in study, there are some incomprehensible results. A closer look to the capacity plan of the ship shows that in the frame 39, the ship cannot support 6 containers in the first tier of the frame. In Figure 4.2 it is shown that the lowest tier from frame 39 to 47 can carry 6 containers transversally but in Figure 4.3 it is observed that it is not possible to carry 6 containers in the referred tier because there is no space in frame 39. The red line in Figure 4.2 identifies the frame 39 of the ship and the cargo capacity of the tier around the frame. The red area of Figure 4.3 shows the lowest tier of frame 39, carrying only 4 containers transversally.
However, even if there was space to insert a container in the section, the program would not allow it due to the minimum distance to the side, set to 0.4 meters considering the distances measured from the real capacity plan of the ship.

In the Figure 4.4 is represented a capacity plan provided by MATLAB®. The green lines represent the position of the bulkheads of the ship. The lower red line represents the height of the double bottom, and the highest red line represents the main deck of the ship. It is noticeable a space between the upper deck and the cargo on deck because the containers are resting on hatch covers. In the Appendix B is possible to observe the 3D modelling of the ship's compartment obtained when applying the method.

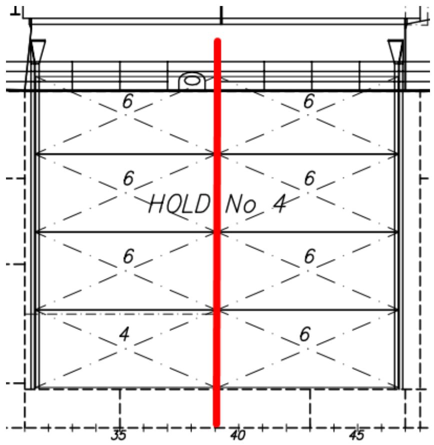

Figure 4.2 - Front view of cargo hold 4 (frame 31 to 47)

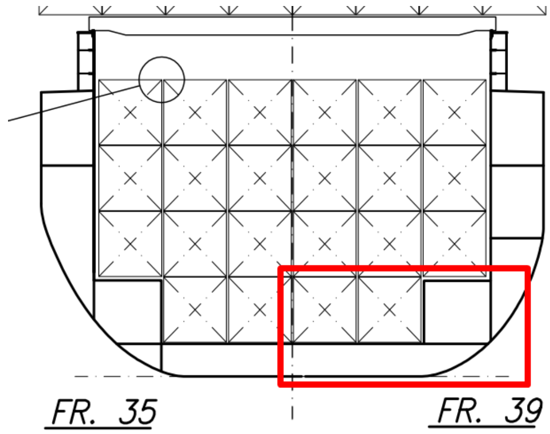

Figure 4.3 - Right view of frames 35 and 39

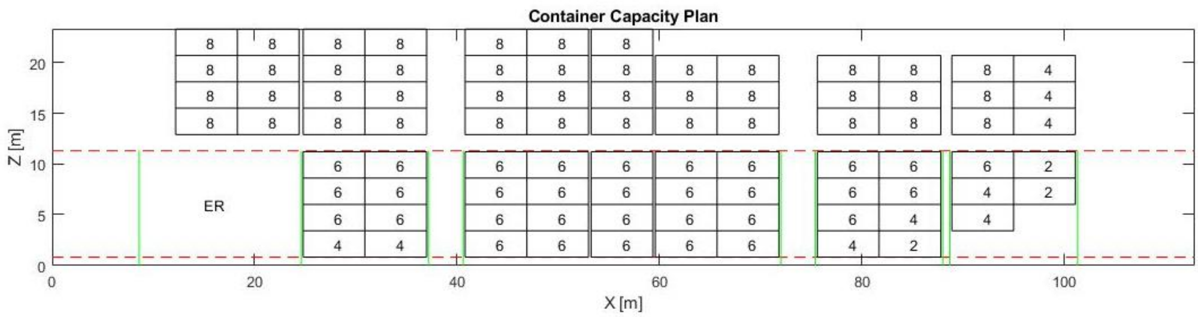

Figure 4.4 - Capacity plan provided by MATLAB®

Comparing the original capacity plan shown in Figure 4.1 and the results obtained in Figure 4.4 it is possible to see the longitudinal layout is equal and comparing the number of tiers on each bay of deck, it is observed that the bays have the same number of tiers. The space of the cranes is also represented, and the degree of the hold is also present in the MATLAB® result. However, the lowest tier of the fore most cargo hold was supressed due to the shape of the curve that cannot determined perfectly by the linear interpolation of the two sections.

In general, the results for the feeder ship are satisfactory due to the minimal error presented and the success of reproducing the longitudinal configuration of the ship. It would be possible to improve the results if the MATLAB® was allowed to read a 3D CAD and if all the dimensions were insert without any marginal error.

4.2 Panamax ship

4.2.1 Input variables

The Panamax ship analysed is KTMC Seoul, with South Korea flag and the information about it was obtained from the journal *Significant Ships 2020*. Unfortunately, the journal published the general arrangement of the ship in a bit map image, which did not allow an illegible zoom of the drawing.

The Figure 4.5 shows the longitudinal cut of a real panamax containership with a total capacity of 2540 TEUs. It is noticeable that there are 20 bays of cargo on deck (allocated 2 aft and 18 forward superstructure) and 18 bays with containers in the cargo holds, divided by 5 cargo holds. The fore most section of the superstructure is aligned with the fore most section of the engine room. Besides the superstructure and the engine room there are no tanks located longitudinally between the cargo holds. Through the Figure 4.5, it is also observed the existence of a non-cargo tank between the fore most cargo hold and the collision bulkhead. In this ship, the collision bulkhead did not match with the fore most bulkhead of the first cargo hold.

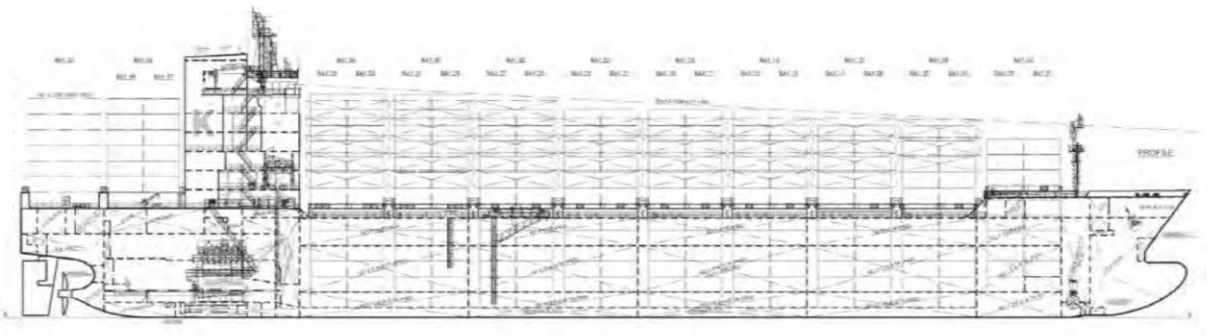

Figure 4.5 - Longitudinal cut of a panamax containership

The main characteristics of the ship were obtained by the catalogue of the ship presented in the journal, including the width of the side tanks and the height of the double bottom, but the dimensions related to the cargo holds were not possible to measure. The ship has a length of 182 meters, breadth of 32.5 meters and depth of 16.8 meters. The height of the double bottom is 1.65 meters, and the width of the wing tanks is 2.15 meters.

The values related to the position and length of both engine room and the superstructure were approximately measured supported by the number of containers aft superstructure. Through the general arrangement of the ship, it is noticeable that there are two bays grouped aft superstructure on deck and an empty space aft the cargo with an equivalent length, which means that the superstructure need to be allocated in a strategic position to allow the allocation of the aft cargo and also have the empty space to allocate other necessary material (equation(4.2)). Above the engine room are allocated the superstructure and two grouped bays, which means that the length of the engine room needs to be greater than the superstructure length plus the length of the grouped bays (equation (4.3)).

$$xStart_{SS} > (2+2) \cdot l_{container} \quad (4.2)$$

$$l_{ER} > l_{SS} + 2 \cdot l_{container} \quad (4.3)$$

The distance between bays was set to 2 meters, allowing the ship to carry containers with different sizes. The height of the hatch coaming was set to 1.5 meters and the thickness of the hatch cover is 0.6 meters approximately. The maximum number of tiers on deck is 7 and the total number of decks is 8, being 6 of them accommodation decks, 1 the navigation bridge and the other, the lower deck. The height of the lower deck is 2.8 meters, the height of each accommodation deck is 2.7 meters, and the height of the navigation bridge is 3 meters.

The Table 4.3 shows the data input used in MATLAB® to attempt to reproduce the panamax ship provided by the journal. One of the most important aspects in the Table 4.3 is the minimum distance to the side ($minSideDist$). It was set to the width of a side tank due to the lack of information about the requirement and the plan of the midship section in the journal shows a degree in the bilge tank, which means that the minimum distance between the outer and the inner hull is the width of a side tank.

Table 4.3 - Input to reproduce a Panamax ship

Characteristics		Units	Characteristics		Units
$Class$	Panamax	-	$maxTiers_{deck}$	7	[TEU]
L_{pp}	182.000	[m]	$transverseGap$	0.025	[m]
B	32.200	[m]	$distGuides$	1.000	[m]
D	16.800	[m]	h_{hatch}	1.500	[m]
T	11.700	[m]	t_{hatch}	0.600	[m]
h_{db}	1.650	[m]	$sideSupport$	0.000	[m]
$w_{SideTanks}$	2.150	[m]	$minSideDist$	2.150	[m]
$xStart_{ER}$	8.000	[m]	$nrDecks$	8	-
l_{ER}	21.000	[m]	$h_{lower\ deck}$	2.800	[m]
$xStart_{SS}$	24.500	[m]	$h_{accomodation\ decks}$	2.700	[m]
$length_{SS}$	18.000	[m]	h_{bridge}	3.000	[m]

4.2.2 Results and discussion

The results of the comparison between the real general arrangement of the panamax ship and MATLAB® program are shown in Table 4.4. The results of the deck are close to the reality, and in the cargo holds, there is a relative error of -10.32%, which is a significant error in the cargo holds capacity. However, the error between the total cargo capacity is less than -5%, with a difference of 121 TEU in a total of 2540 TEU of the original ship.

Table 4.4 – Results of Panamax ship comparison

	General Arrangement	MATLAB	Relative Error
Deck	1600	1576	-1.50%
Holds	940	843	-10.32%
Total	2540	2419	-4.76%

It is observed that the program supresses some containers both in cargo holds and deck. The error in cargo holds can be related to several factors as the hull of MATLAB® not being the same of the journal, The minimum distance between the outer and the inner hull can also affect the results obtained in MATLAB® once setting the minimum distance equal to the width of a side tank can cause over dimension of the bilge tanks. As there are no more drawings of other transverse sections besides midship section, it is not possible to obtain the real value of the minimum distance or simply estimate the value through some visual approaches.

In the case of the deck, the results are close. The MATLAB® program shows a lower capacity on deck and it can be justified due to the narrowing of the deck area and by the navigation bridge visibility line. The hull provided by DELFTship® can have a shorter cylindrical body than the original hull, which means that the number of rows per bay will reduce in an aft most bay for the DELFTship® hull. The visibility line can also influence the difference of the results because it depends specially on the location of the aft most section of the superstructure and also on the height of the decks of the superstructure, that will affect the total height of the superstructure, modifying the navigation visibility line location.

Applying the method explained in 3.5, it is determined the quantity of containers that would be gained in the cargo holds if the minimum distance between the outer and the inner hull were decreased. The Table 4.5 shows the results obtained when decreasing the minimum distance allowed between the inner and the outer hull when analysing the transverse shape of the sections of the inner hull.

Table 4.5 - Relation between the minimum distance between outer and inner hull and the relative error for Panamax ship

Distance decreased [m]	TEU gained	Hold Capacity [TEU]	Relative error (Holds)	Error Difference (Holds)	Relative error (Total)	Error Difference (Total)
0.2	20	863	-8.19%	-2.13%	-3.98%	-0.79%
0.4	42	885	-5.85%	-4.47%	-3.11%	-1.65%
0.6	62	905	-3.72%	-6.60%	-2.32%	-2.44%
0.8	**76**	**919**	**-2.23%**	**-8.09%**	**-1.77%**	**-2.99%**
1.0	78	921	-2.02%	-8.30%	-1.69%	-3.07%

Analysing the results of the Table 4.5, it is observed that decreasing the minimum distance between the outer and the inner hull in 0.8 meters is the more accurate. The difference of the results between the decreasing of 0.8 meters and 1 meter is very small, gaining only 2 containers in the hold. Decreasing the minimum distance in 0.8 meters means that it would be set to 1.35 meters, which is a very good distance to allow the side tanks to have an acceptable volume. However, the difference between the hulls can be a stronger factor to cause the differences of the results instead of the decreasing of the minimum distance.

The longitudinal vector of the deck and hull are automatically generated in the beginning of the program considering the dimensions of the Table 4.3 and the vectors obtained are:

```
vectorDeck = {{0 5.3} {1 [2]} {3 18} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2]} {0 5.65}};
```

```
vectorHull = {{0 7.5} {2 30} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2]} {0 5.65}};
```

Comparing the vectors obtained with the front view of the general arrangement of Figure 4.5, it is noticeable that the vectors obtained match the Figure 4.5. In vectorHull, there are 5 cargo holds, 4 of them with two groups of two bays and one with one pair of grouped bays and, in vectorDeck, there is a pair of grouped bays located aft the superstructure and the bays fore superstructure matched with the cargo in the holds. For more, it is possible to observe the sketch of the Panamax ship capacity plan in the Appendix C and the 3D modelling of the Panamax ship compartments in Appendix D.

The lack of information did not allow to correctly study the accuracy of the MATLAB® program for the typical configurations of Panamax ships but in general, the results are satisfactory even with the huge difference obtained in the capacity of the cargo holds.

4.3 Post-Panamax ship

4.3.1 Input variables

To analyse the MATLAB® program for a typical configuration of a post-Panamax ship, it was tested the reproduce the Savannah Express ship, an 8400 TEU capacity containership that has a liner route connecting China and Canada. The ship in study presents a large breadth (greater than the panamax canal, 36 meters) which severely influences the number of containers carried in the cargo holds. There are some problems in the general arrangement of the ship as the lack of information about the capacity on deck and in cargo holds. The general arrangement did not have any information about the quantity of containers in each cargo area. To know the number of containers in cargo holds, it was determined through the observation of the front view of the general arrangement and the upper deck top view.

The Figure 4.6 shows the front view of the ship's general arrangement with the typical configuration of the post-Panamax class of containerships. Through the analysis of the general arrangement, it is noticeable that in the case of deck, there are four pairs of grouped bays on deck, aft superstructure, which means the starting position of the engine room needs to be higher than the length of eight containers plus the longitudinal gap between bays (equation (4.4)).

$$xStart_{SS} > 8 \cdot w_{container} + 4 \cdot distBetweenBays \tag{4.4}$$

Analysing the hull, it is noticeable the existence of three pairs of grouped bays in cargo holds due to the steering gear space. Comparing the aft cargo holds with the cargo holds of the cylindrical body, it is possible to see that the number of tiers is lower. The difference happens due to the shaft of the engine that needs to connect the propeller to the engine room.

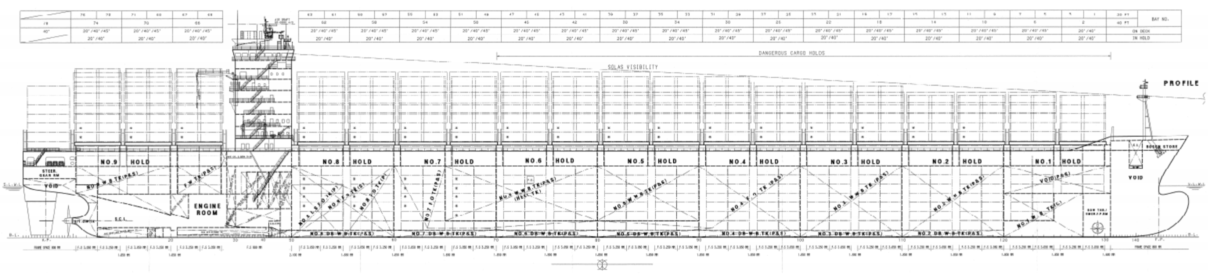

Figure 4.6 - Longitudinal cut of a post-panamax containership

For the example of the post-Panamax containership there was no catalogue to support the required information about the Savannah Express ship to insert in the MATLAB® program. The main characteristics were obtained through the general arrangement of the ship and the other necessary information were measured in the pdf file. The length of the ship is 317.2 meters, the breadth is 42.2 meters, and the depth is 24.5 meters. The width of the side tank and the height of the double bottom were approximately measured in the midship section of the general arrangement once there is no information about the dimensions in the drawings. The height of the double bottom was set to 2.1 meters, and the width of the side tanks to 2.3 meters. The height of the hatch coaming is 1.6 meters, and the thickness of the hatch cover is 0.8 meters. The distance between bays is 1.7 meters and the space for the guides is 0.7 meters.

As the hull used in MATLAB® was provided by DELFTship®, there are some measurements that need to be adjusted due to the stern overhang of the ship. The analysed ship has a stern overhang of 6.4 meters and the DELFTship® locates the stern overhang in the x coordinate equal to 0 meters, which means that to apply the value to the DELFTship® hull it is considered that all the dimensions related to the position of the engine room and the superstructure have an addition equal to the value of the stern overhang.

To implement the MATLAB® function for the typical configuration of post-Panamax ships, it was considered that the engine room area would only correspond to the x coordinates where the ship did not carry cargo holds. As the engine room and the superstructure are aligned due to the previous explanation, the x coordinate of the starting position for both is 58.3 meters and the length is 17.6 meters. The other input variable to consider the limitations of the cargo holds aft engine room was the height of the shaft. Analysing the Figure 4.6, is noticeable that the shaft supresses 5 tiers in the aft cargo holds then, through the equation (3.7) is determined that the height of the shaft is 12 meters.

Focusing on deck, the maximum number of tiers per bay is 8 and the superstructure is composed by 9 decks. The lower deck and the navigation bridge have a height of 3.2 meters and the accommodation decks have a height of 3 meters.

The Table 4.6 shows the data used in MATLAB® to attempt to reproduce the post-Panamax ship of the Figure 4.6. Through the general arrangement it was not possible to set a minimum distance between the inner and the outer hull. Consequently, it was set that the referred distance would be equal to the width of the wing tanks.

Table 4.6 - Input to reproduce a post-Panamax ship

Characteristics		Units	Characteristics		Units
$Class$	post-Panamax	-	$maxTiers_{deck}$	8	[TEU]
L_{pp}	317.200	[m]	$transverseGap$	0.025	[m]
B	42.200	[m]	$distGuides$	0.900	[m]
D	24.500	[m]	$distBetweenBays$	1.700	[m]
T	14.500	[m]	h_{hatch}	1.600	[m]
h_{db}	2.100	[m]	t_{hatch}	0.800	[m]

Characteristics		Units	Characteristics		Units
$w_{SideTanks}$	2.300	[m]	$sideSupport$	0.000	[m]
$xStart_{ER}$	58.300	[m]	$minSideDist$	2.300	[m]
l_{ER}	17.600	[m]	$nrDecks$	9	-
$xStart_{SS}$	58.300	[m]	$h_{lower\ deck}$	3.200	[m]
$length_{SS}$	17.600	[m]	$h_{accomodation\ decks}$	3.000	[m]
$heightShaft$	12.000	[m]	h_{bridge}	3.200	[m]

4.3.2 Results and discussion

The results of the comparison between the real general arrangement of the post-Panamax ship and MATLAB® program are shown in Table 4.7. The result of the total cargo is close to the reality. However, the results on deck are slightly over dimensioned, presenting a relative error of 3.89% and, the results on the cargo holds are under dimensioned in -5.93%.

Table 4.7 - Results of post-Panamax comparison

	General Arrangement	MATLAB	Relative Error
Deck	4658	4839	3.89%
Holds	3742	3520	-5.93%
Total	8400	8359	-0.49%

The error in cargo holds can be related to several factors as the hull of MATLAB® not being the same of the real ship, it is observed that the program supresses some containers in cargo holds. The minimum distance between the outer and the inner hull can also affect the results obtained in MATLAB® once setting the minimum distance equal to the width of a side tank can cause over dimension of the bilge tanks. As there are no more drawings of other transverse sections besides midship section, it is not possible to obtain the real value of the minimum distance or simply estimate the value through some visual approaches.

The error on deck can be justified due to narrowing of the deck and by the navigation bridge visibility line. The DELFTship® hull presents a larger deck area, which can influence the number of containers carried on deck. The limitation of tiers in each bay by the navigation bridge visibility line can also be a factor that over dimensions the number of containers carried on deck. The number of decks and the respective height, and the location of the superstructure are the factors that influence the number of containers carried on deck.

Applying the method explained in 3.5, it is determined the quantity of containers that would be gained in the cargo holds if the minimum distance between the outer and the inner hull were decreased. The Table 4.8 shows the results obtained when decreasing the minimum distance allowed between the inner and the outer hull when analysing the transverse shape of the sections of the inner hull.

Table 4.8 - Relation between the minimum distance between outer and inner hull and the relative error for post-Panamax ship

Distance decreased [m]	TEU gained	Hold Capacity [TEU]	Relative error (Holds)	Error Difference (Holds)	Relative error (Total)	Error Difference (Total)
0.2	40	3560	-4.86%	-1.07%	-0.01%	-0.48%
0.4	102	3622	-3.21%	-2.73%	0.73%	-1.21%
0.6	148	3668	-1.98%	-3.96%	1.27%	-1.76%
0.8	182	3702	-1.07%	-4.86%	1.68%	-2.17%
1	**212**	**3732**	**-0.27%**	**-5.67%**	**2.04%**	**-2.52%**

Analysing the results of the Table 4.8, it is observed that decreasing the minimum distance between the outer and the inner hull in 1 meter is the more accurate. The number of containers carried in cargo holds with the reduction of 1 meter is the closest to the real ship, presenting a relative error of -0.27%. Decreasing the minimum distance in 1 meter means that it would be set to 1.3 meters, which is a very good distance to allow the side tanks to have an acceptable volume. However, the difference between the hulls can be a stronger factor to cause the differences of the results instead of the decreasing of the minimum distance.

The longitudinal vector of the hull and the deck is automatically generated in the beginning of the program considering the dimensions of the Table 4.6 and the vectors obtained are:

```
vectorDeck = {{0 2.4} {1 [2]} {1 [2]} {1 [2 2]} {0 3.6} {3 15.0} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2 2]}};
```

```
vectorHull = {{0 16.4} {1 [2]} {1 [2 2]} {2 17.6} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2 2]}};
```

Comparing the vectors obtained with the front view of the general arrangement of Figure 4.6, it is noticeable that the vectors obtained match the Figure 4.6. In vectorDeck, there are four pairs of grouped bays located aft the superstructure and there are eight cargo areas with two pairs of grouped bays on deck. In vectorHull, there is an aft space to the steering gear, there are two cargo holds aft engine room and there are eight cargo holds fore engine room that are aligned with the containers above deck. For more, it is possible to observe the sketch of the Post-Panamax ship capacity plan in the Appendix E and the 3D modelling of the Post-Panamax ship compartments in Appendix F.

The lack of information did not allow to correctly study the accuracy of the MATLAB® program for the typical configurations of Panamax ships but in general, the results are satisfactory even with the differences obtained.

4.4 Malaccamax ship

4.4.1 Input variables

Nowadays, the ships with the typical configuration of Malaccamax are the largest containerships in the world. In this section, it is tried to reproduce the largest containership in the world, the HMM Algeciras, with a 24,000 TEU capacity. As the Panamax ship presented in Section 4.2, the Malaccamax ship HMM Algeciras is showcased in the journal *Significant Ships 2020* and, unfortunately presents the same problems of interpretation due to the lack of information and the illegible image of the general arrangement.

The Figure 4.7 shows the front view of the general arrangement of a Malaccamax ship. It is observed that the superstructure of the ship is not attached to the funnel. The superstructure is allocated ahead of the midship section to supress the minimum tiers possible on deck due to the navigation bridge visibility line.

Figure 4.7 – Longitudinal cut of a malaccamax containership

The main characteristics of the ship were obtained through the catalogue of the ship presented in the journal, including the width of the side tanks and the height of the double bottom, however the dimensions related to the cargo holds were not possible to measure. The length of the ship is 383.3 meters, the breadth is 61 meters, and the depth is 33.2 meters. The height of the double bottom is 2.55 meters, and the width of the wing tanks is 2.5 meters.

In the analysed Malaccamax ship, the aft section of the funnel is aligned with the aft section of the engine room and there is a minimum space higher than 8 TEU length between the referred section ($xStartEngRoom$) and the stern panel, also considering the distance between the bays of containers (equation (4.5)).

$$xStart_{ER} \geq 8 \cdot w_{container} + 4 \cdot distBetweenBays \tag{4.5}$$

Related to length of the engine room, it needs to be higher than the length of the funnel plus the length of 2 TEU to support both the funnel and the containers above the area of the engine room (equation (4.9)).

$$l_{ER} > l_{Funnel} + 2 \cdot l_{container} \tag{4.6}$$

The funnel of the engine room is allocated near to the aft section of the engine room. It is set that the x coordinate of the aft section of the funnel is allocated in the 5% of the length of the engine room (equation (4.7)).

$$xStart_{Funnel} = xStart_{ER} + 0.05 \cdot l_{ER} \tag{4.7}$$

Then, the determined x coordinate of the funnel is 58.275 meters, and the length of the funnel is approximately 9 meters.

For this typical layout it was also required a new input variable for the pairs of bays existing between the engine room and the superstructure ($baysPairs_{ER \rightarrow SS}$) due to the uncoupling of both compartments and. the x coordinate of the aft section of the superstructure, unlike in other typical configurations, is not an input variable and is determined by equation (3.1). Analysing the superstructure, it has a length of 17.6 meters and is composed by 11 decks. The height of lower deck and the accommodation decks is 3.5 meters, and the height of the navigation bridge is 3 meters.

In the Table 4.9 is represented the data inserted in MATLAB® to reproduce the Malaccamax containership of the Figure 4.7. Through the general arrangement it was not possible to set a minimum distance between the inner and the outer hull. As the ships compared in Section 4.2 and Section 4.3, there is no information about the minimum distance between the inner and the outer hull.

Table 4.9 - Input to reproduce a Malaccamax ship

Characteristics		Units	Characteristics		Units
$Class$	Malaccamax	-	$maxTiers_{deck}$	13	[TEU]
L_{pp}	383.300	[m]	$transverseGap$	0.025	[m]
B	61.000	[m]	$distGuides$	0.900	[m]
D	33.200	[m]	$distBetweenBays$	1.800	[m]
T	14.500	[m]	h_{hatch}	1.500	[m]
h_{db}	2.550	[m]	t_{hatch}	0.600	[m]
$w_{SideTanks}$	2.500	[m]	$sideSupport$	0.000	[m]
$xStart_{ER}$	57.000	[m]	$minSideDist$	2.500	[m]
l_{ER}	25.500	[m]	h_{Shaft}	12.000	[m]
$xStart_{Funnel}$	58.275	[m]	$nrDecks$	11	-
l_{Funnel}	9.000	[m]	$h_{lower\ deck}$	3.500	[m]
$baysPairs_{ER \rightarrow SS}$	12	-	$h_{accomodation\ decks}$	3.500	[m]
$length_{SS}$	17.600	[m]	h_{bridge}	3.000	[m]

4.4.2 Results and discussion

The results of the comparison between the real general arrangement of the Malaccamax ship and MATLAB® program are shown in

Table 4.10. The slight error of 3.05% on deck shows that the program oversized the cargo on deck. Looking for the results obtained, the relative error of -15.85% is clearly highlighted showing that the program supresses excessive containers (more than 1500TEU) in cargo holds, which is completely discrepant from the reality once the number of suppressed containers in cargo holds is equivalent to the total cargo on deck of the analysed Panamax ship in Section 4.2 or even almost 3 times greater than the total cargo of the feeder ship of Section 4.1.

Table 4.10 - Results of Malaccamax comparison

	General Arrangement	MATLAB	Relative Error
Deck	14032	14460	3.05%
Hold	9932	8358	-15.85%
Total	23964	22818	-4.78%

The results on deck can be oversized due to the narrowing of upper deck area because the hull of the ship HMM Algeciras can be narrower than the hull imported from DELFTship®. Another factor influencing the results on deck can be the navigation bridge visibility line only restricting the number of tiers per bay which means that the number of tiers will be the same for all the rows of a bay. The posterior factor is not completely valid once the visibility line is not straight linear, and it describes an arc from the conning position with some angle restrictions according to *SOLAS* which influences not only the tiers per bay but also the tiers per row. This restriction is more disruptive for larger ships as the Malacca class of ships.

Focusing on the relative error shown for the capacity of cargo holds, it was firstly attempted to reduce the minimum distance between the inner and the outer hull once it was set as the same value of the width of the side tanks. The Table 4.11 shows the results when reducing the minimum distance between the inner and the outer hull.

Table 4.11 - Relation between the minimum distance between outer and inner hull and the relative error for Malaccamax ship

Distance decreased [m]	TEU gained	Hold Capacity [TEU]	Relative error (Holds)	Error Difference (Holds)	Relative error (Total)	Error Difference (Total)
0.2	64	8422	-15.20%	-0.64%	-4.52%	7.57%
0.4	158	8516	-14.26%	-1.59%	-4.12%	7.17%
0.6	244	8602	-13.39%	-2.46%	-3.76%	6.81%
0.8	310	8668	-12.73%	-3.12%	-3.49%	6.54%
1	370	8728	-12.12%	-3.73%	-3.24%	6.29%
1.2	424	8782	-11.58%	-4.27%	-3.01%	6.06%
1.4	474	8832	-11.08%	-4.77%	-2.80%	5.85%

Observing the results obtained in Table 4.11 it is noticeable that even if the minimum distance between the inner and the outer hull was reduced in 1.4 meters, it would only be carried more 474 containers, decreasing the error in 4.77%. However, even with this addiction of containers, the relative error would be -11.07% and the difference between the reality and the MATLAB® program would be over 1000 TEU. Through the Table 4.11 it is concluded that the minimum distance between the inner and the outer hull is not the unique problem affecting the capacity of the cargo holds.

The significant error presented in the cargo holds can be related to several factors. Starting from the aft part of the hull, as the general arrangement of the ship is not clear, the measured height of the shaft can cause a lower number of tiers in the aft cargo holds. There are other 2 factors that can affect the cargo carried in cargo holds as the longitudinal vector generated by the MATLAB® program and the narrowing of the hull in the fore most part of the ship.

The longitudinal vectors of the deck and the hull automatically generated by the MATLAB® program when applying the input variables of Table 4.9 are:

```
vectorDeck = {{0 1.0} {1 [2]} {1 [2]} {1 [2 2]} {0 1.275} {2 9.0} {0 1.225} {1 [2]} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2 2]} {3 12.0} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2]};

vectorHull = {{0 15.0} {1 [2]} {1 [2 2]} {2. 25.5} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2 2]} {3 12.0} {1 [2 2]} {1 [2 2]} {1 [2 2]} {1 [2]};
```

Comparing the vectors generated with the front view of the general arrangement presented in Figure 4.7, the similarity between layout of both ships is noticeable. Focusing on the vector hull, the first array represents the space dedicated for the steering gear and the length of the space needs to be more than the length of two TEU (equation (4.8)). Between the steering gear and the engine room, there are three pairs of bays in vectorHull. As the general arrangement shows the existence of a funnel and a grouped bay pair above engine room, the length of engine room needs to cover both the cargo and the funnel (equation (4.9)). Between the engine room and the superstructure there are six cargo holds with two pairs of grouped bays each which also happens in the vectorHull. The superstructure has its dimensions and there is no method to verify the real value of it due to the illegibility of the drawing. Fore superstructure there are seven pairs of grouped bays each in vectorHull which also corresponds to the Figure 4.7.

$$l_{SG} \geq 2 \cdot l_{container} \tag{4.8}$$

$$l_{ER} \geq l_{funnel} + 2 \cdot l_{container} + distBetweenBays \tag{4.9}$$

Through the analysis of the longitudinal vector generated by MATLAB®, it is concluded that the problem is not the longitudinal layout of the ship once the vectorHull, represents the same layout of the containership HMM Algeciras.

For last, analysing the narrowing of the hull in the fore most cargo area, it is observed an uncommon behaviour. The Figure 4.8 shows the capacity plan obtained from MATLAB® focused on the fore most cargo area. The green lines represent the bulkheads of the ship, the lower red line represents the height of the double bottom, and the upper red line represents the upper deck height. For more, it is possible to observe the sketch of the Malaccamax ship capacity plan in the Appendix G.

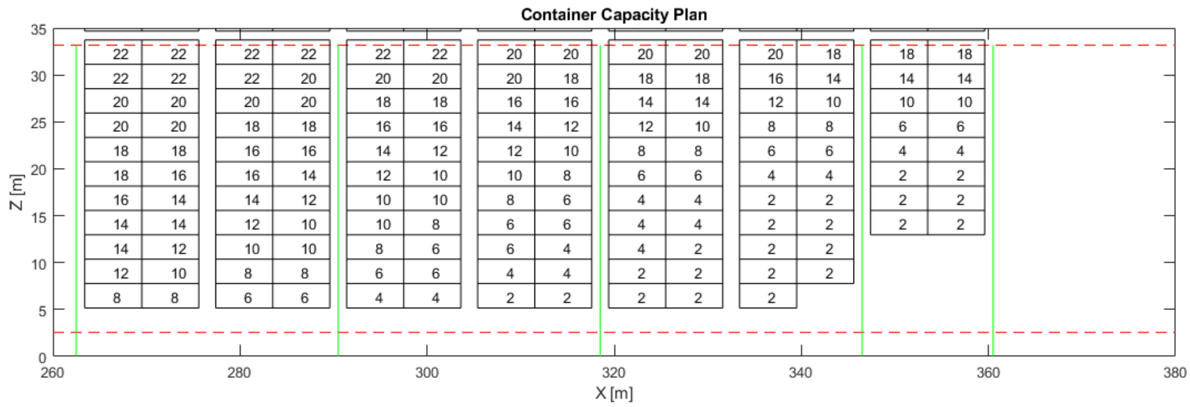

Figure 4.8 - Fore most cargo area results (capacity plan)

Firstly, the Figure 4.8 shows that all the bays of the fore most cargo area have a minimum of one tier supressed, which theoretically means that the hull is narrowing since the superstructure. A closer view to the Figure 4.8 displays that several rows are supressed in the 2 fore most cargo holds, showing many tiers with only 2 TEU capacity. Even if the hull provided from DELFTship® started narrowing closer to superstructure than HMM Algeciras, these results were not supposed to happen.

As the hulls provided from DELFTship® are saved as coordinates, it is not always possible to control if the shape of the sections is perfect or not, and as MATLAB® program requires some linear interpolations between sections it also affects the shape of the hull in the end. Consequently, as MATLAB® returns a geometric file (.gf) with the hull and the shape of the holds, it was investigated if the hull had a good shape. In Figure 4.9 is represented the hull and the shape of the cargo holds. It is seen that the shape of the fore most cargo area, ahead of superstructure is too thin and the other cargo areas present a good shape for a containership.

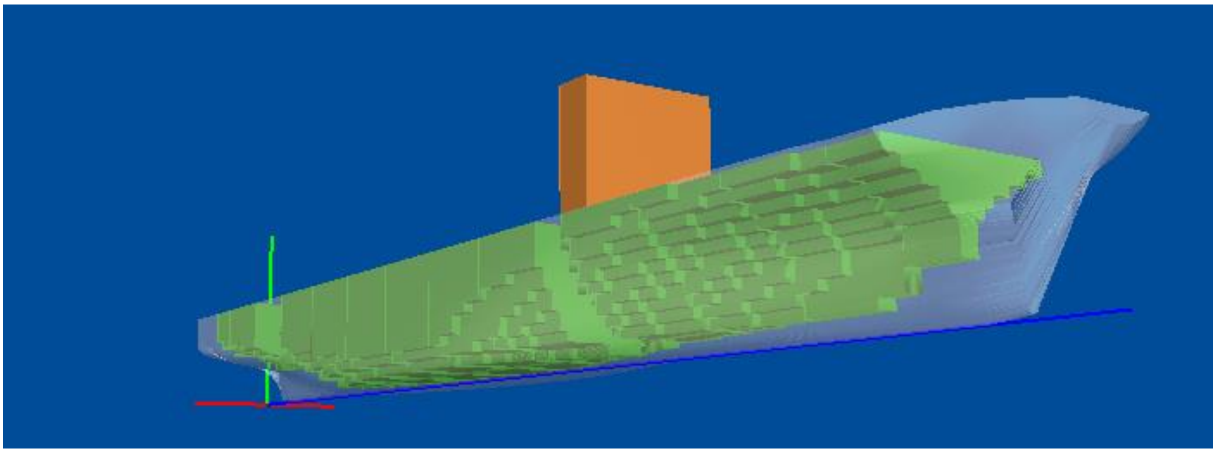

Figure 4.9 - Geometric file of the ship generated by MATLAB®

Hiding the cargo holds and the superstructure of the ship, the hull form used in MATLAB® is highlighted. The Figure 4.10 shows the hull form of the ship, obtained from DELFTship® and used in MATLAB®.

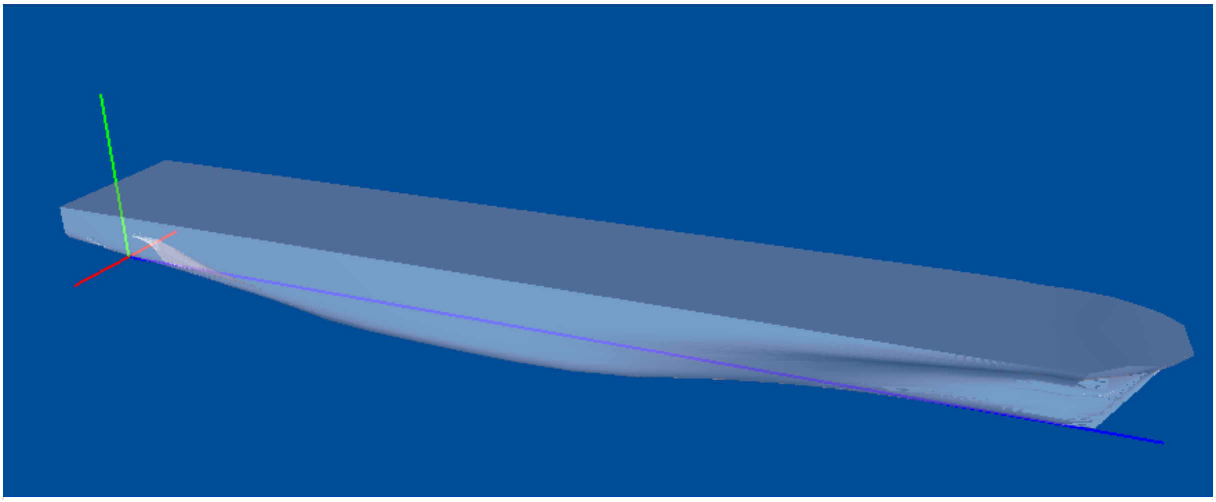

Figure 4.10 - Geometric file of the ship generated by MATLAB® (without cargo holds and superstructure)

The excessive narrowing of the ship is noticeable in the fore most part of the ship. As MATLAB® cannot work around with the bulb, it can result in a wrong read of the fore most hull sections. The problem of MATLAB® is the incapacity of reading two different segments in the same longitudinal position. Thinking on the bulb and the forecastle of a ship, those are allocated in the same x coordinates and are not connected which means that in a lines plan of a ship, they are represent by two different segments. Despite the lack of information about the block coefficient of HMM Algeciras, it is estimated that the real ship has a greater block coefficient than the hull provided from DELFTship®.

Through the previous analysis, it is concluded that the problem in the reproduce of the largest containership in the world is not the longitudinal configuration determined in MATLAB®. On the other hand, the minimum distance between the inner and the outer hull and the excessive narrowing of the bow are two factors that clearly prejudice the results presented in Section 4.4.

5 Conclusions and Recommendations Further Work

5.1 Conclusions

This thesis proposed a method capable of determining the layout of the compartments of four typical configurations of containerships in order to facilitate the early stages of the ship design process. The layout of the compartments was essentially related to the location of the cargo holds, the cargo areas on deck, the engine room, and the superstructure. Different considerations and requirements were assessed for each typical configuration due to the position of the engine room and the superstructure along the ship.

Before testing the method, several general arrangements were analysed to find the different configurations and the essential requirements related to each one. The method was divided in four phases, the longitudinal analysis of the hull, the longitudinal analysis of the cargo areas on deck, the transverse analysis of the hull, and the analysis of the number of tiers on deck. First, this method consisted in the generation of the longitudinal configuration of a containership through a selected hull, considering the class, the main dimensions, and some other characteristics, usually set by the ship owner. To generate the longitudinal configuration of a containership through a selected hull, the developed method considers the class, the main dimensions, and the additional characteristics defined by the ship owner. After obtaining the longitudinal configuration, a transverse analysis along the cargo holds was performed. The analysis consisted in designing the shape of the inner hull and determining the number of containers carried in each cargo hold.

The calculation of the minimum distance between the inner and the outer hull allowed to design the shape of the cargo holds. However, the obtained result represents some imperfections that influence the calculations along the process. The reason was the interpolation of the main sections of the hull connected by straight lines a set of points of transverse sections.

To determine the cargo areas on deck, first, the number of bays and tiers was calculated. The bays and the rows were aligned in cargo holds and above deck. In terms of the number of tiers, the height of the superstructure was considered. However, the applied navigation bridge visibility line rules did not consider the degrees from the coning position to the side that lead to greater numbers of containers on deck than supposed resulting in an overestimation of the cargo above deck.

To validate the model, four real containerships of different class were recreated using the method proposed in this thesis. As previously mentioned, several general arrangements were analysed, and numerous difficulties were found in recreation phase. Due to the lack of information, it was possible to use only one real hull that represented almost the same results as expected. In the other cases, the biggest difficulty was the lack of information regarding dimensions data, such as: the distance between the containers and the bulkheads, the space for the guides, the thickness of the hatch cover, the height of the hatch coaming, the dimensions of the engine room and superstructure.

When it was possible to use the real hull and all the required data, the achieved results represented that was expected and the relative error close to zero. In the other three studies, where it was not possible to use the real hull, there were two cases that almost matched the real data. Despite being used a hull generated in DelftShip®, the obtained cargo capacity for hulls with similar characteristics was close to the expected. In the case of the cargo holds capacity, the differences appeared due to the original hull and the hull generated having different block coefficients. The differences on cargo capacity on deck are related to the height of the superstructure and to the navigation bridge visibility line rules.

In the last case, where it was supposed to recreate one of the biggest containerships in the world, the results were not optimal. Due to a mistake in the hull file, it was generated a hull narrower than supposed, which lead to a higher error in the results. However, this mistake did not happen due to the method, and it was only associated to the read of the files with the hull sections.

In conclusion, this method can be applied in an early stage of ship designed to allocate the main compartments of any containership with one of the four main typical configurations, performing an estimation of the compartment's layout of the ship in work, including the cargo capacity.

5.2 Recommendations for Further Work

During the work with the hull compartment layout of containerships, the aim was to be as complete as possible. However, there is some space for improvements. Some of the possible corrections have been mentioned in the previous chapters, however they need to be gathered for easier accessibility.

One of the main topics that need to be improved is the interpolation of the cross-sections that need to be analysed. Due to some lack of capacity from MATLAB®, the cross-sections analysed were determined through a 2D interpolation, considering the main frames of the ship.

The assessment of the transverse section of hull combined with the minimum required distance between the inner and outer hulls are the typical input arguments to determine the shape of the inner hull. In order to guarantee the optimal design of inner hull using the most efficient method, the combined processing of input variables presents a variety of opportunities for further improvement.

As the results from the transverse analysis are associated to the edges of the bays, it would be interesting to develop a new and more efficient method to compare the results obtained from the edges of the bays.

It would be important to improve the application of the navigation bridge visibility line rules in the determination of the cargo above deck once in this method the degrees from the coning position were not considered.

For last, it would be interesting to develop empirical formulas for application in conceptual design, starting from the study of the systematic variation of the block coefficient of a hull and calculating the corresponding load capacity.

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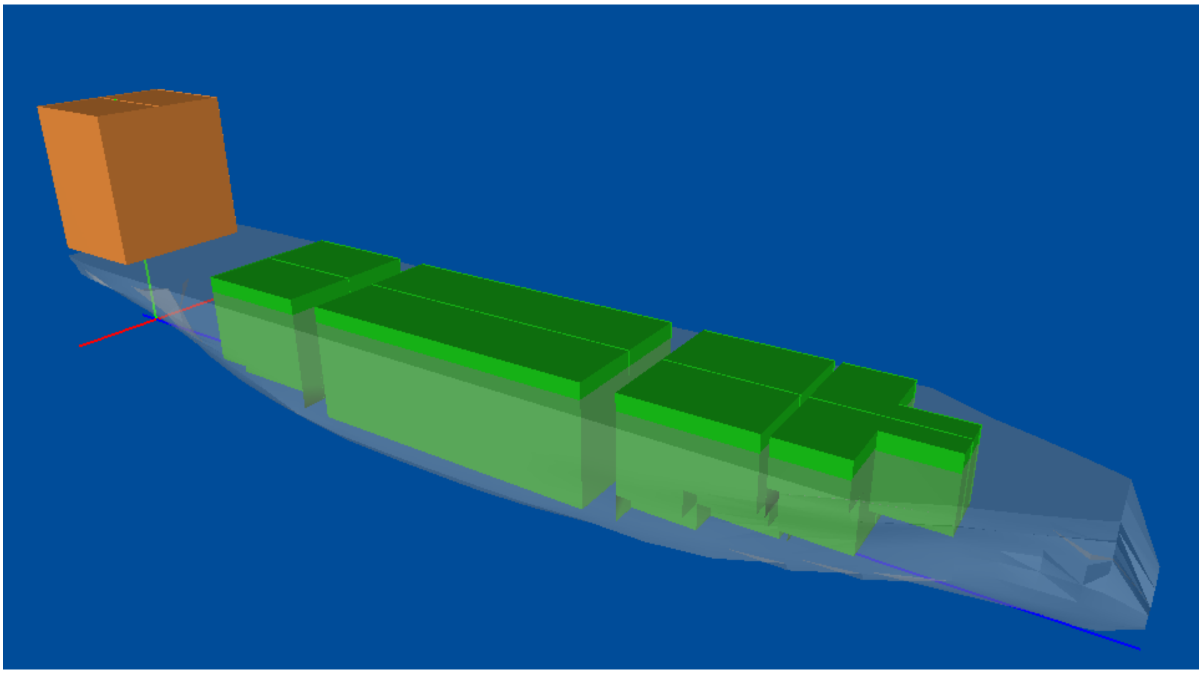
Appendixes

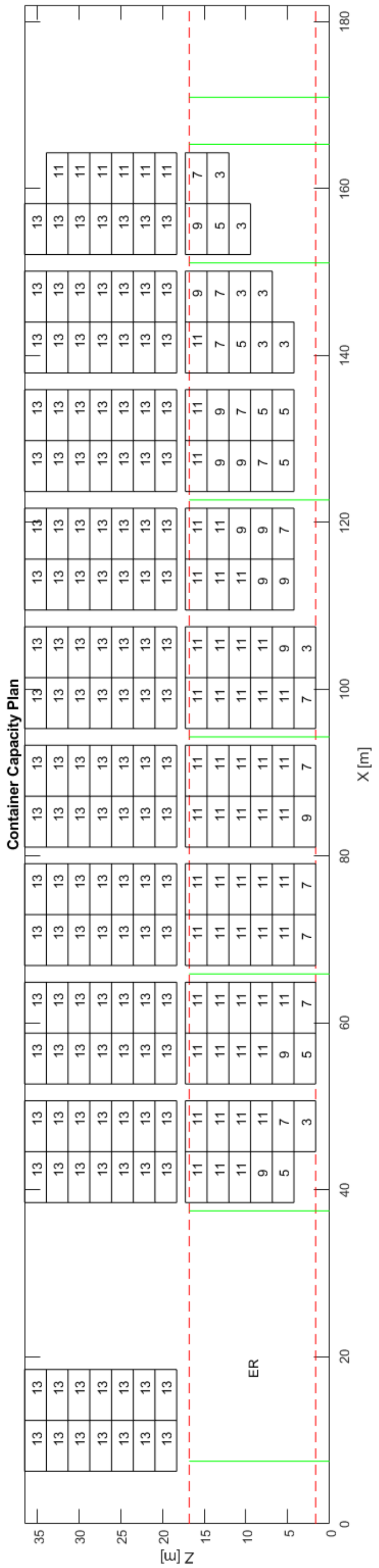
Appendix A - Software Specifications

Function	Description
GetHullSections	Read hull sections from a file
GetLongVector	Calculates the longitudinal vector of the ship
GetBulkheadsPosition	Calculates the position of bulkheads for a given vector
GetHoldConfiguration	Calculates the longitudinal position of the sections of each bay of the hold
GetTransverseShape	Get transverse shape of respective section. Get transverse capacity in each pile of hold
GetDeckCapacity	Get transverse capacity in each bay of deck
PlotCapacityPlan	Plot the sketch of the capacity plan of the ship

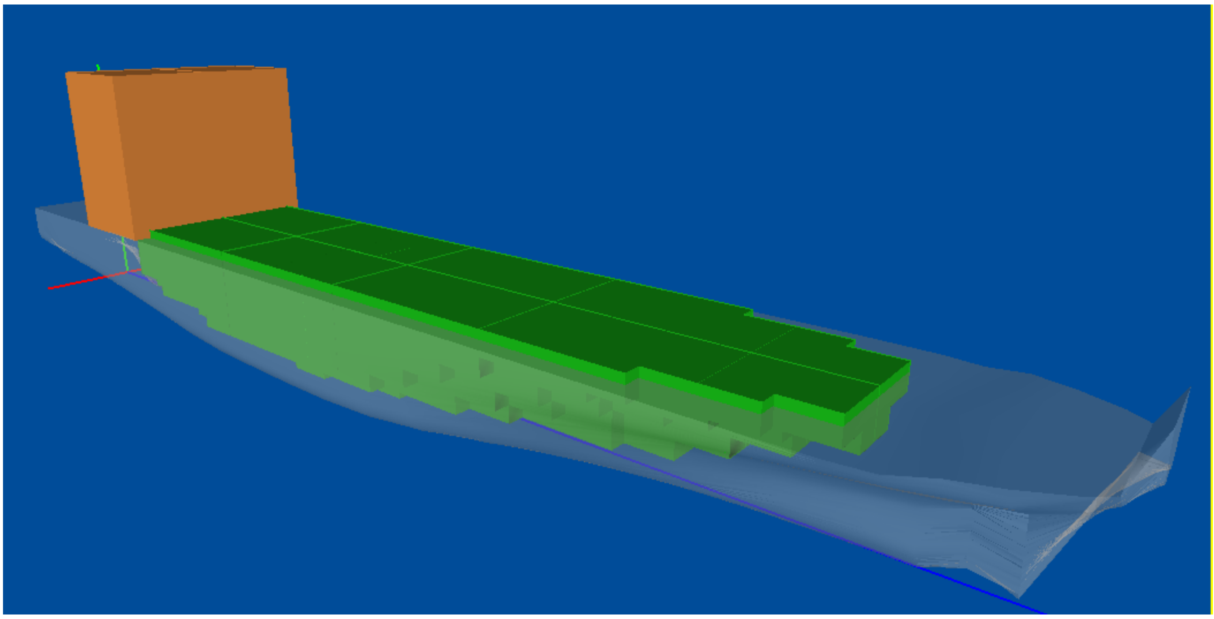
Appendix B - 3D Modelling of the Feeder ship compartments



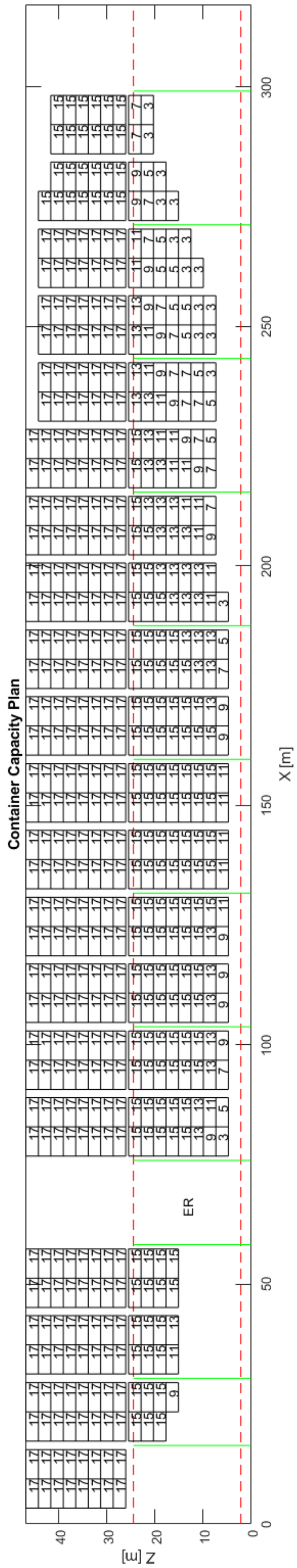
Appendix C - Sketch of the Panamax ship capacity plan



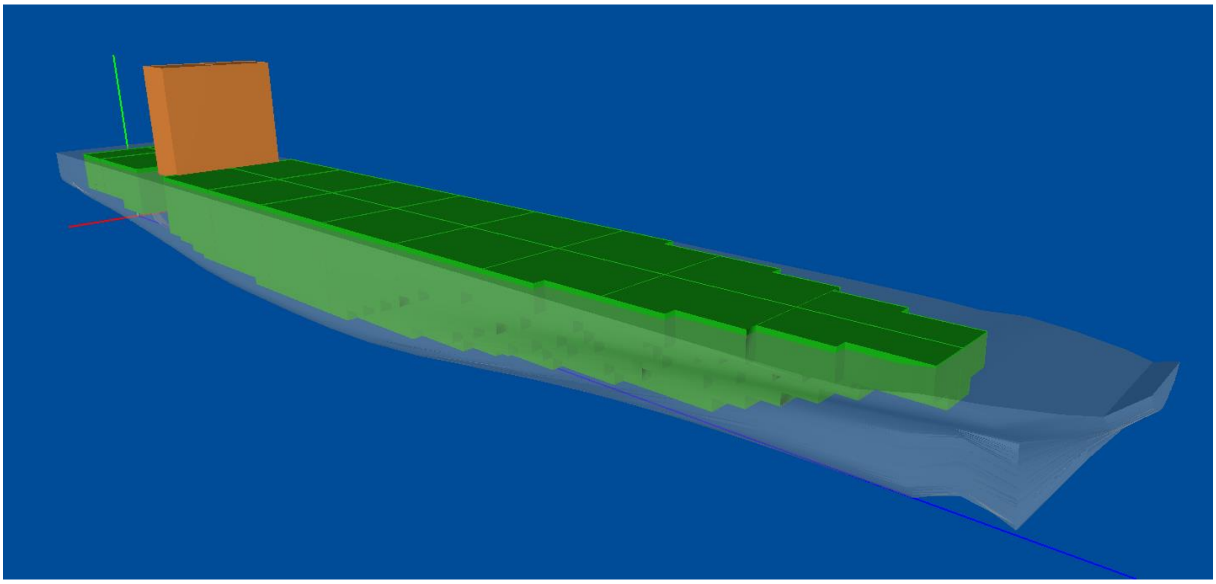
Appendix D - 3D Modelling of the Panamax ship compartments



Appendix E - Sketch of the Post-Panamax ship capacity plan



Appendix F - 3D Modelling of the Post-Panamax ship compartments



Appendix G - Sketch of the Malaccamax ship capacity plan