

Hull Compartment Layout of Containerships

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ABSTRACT: Containerships are the most required ship to maritime transportation resulting from the different type 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 fit to the hull. This work 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 bays of containerships above deck. This method is applicable to four different configurations of containerships. This project detects critical points in cargo holds where a minimal change would lead to the increasement of cargo capacity. To validate the method, general arrangements of existent containerships will be analysed, and the method will be implemented in MATLAB® to replicate the ship in a similar hull. The results obtained will be compared to the real results.

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

1 INTRODUCTION

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. There is a tendency to increase the volumes of international trades. As global shipping keeps increasing, not only the fleet of containerships is expanding but also the total cargo carried is rising. Through the years, containerships are upgrading, and their configuration is changing 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.

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 the container dimensions and affects the location of bulkheads, engine room and superstructure. As the dimensions are streamlined, it can result in larger bilge tanks than necessary 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 gain significant gain in number of containers.

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.

Lee et al. (2009) developed a top-down strategy based on space subdivision to be employed in an optimization procedure for compartment modelling.

During the conceptual design process, optimization approaches are becoming more and more frequent. Numerical models of ships must be utilized for this. From pure empirical approaches to the construction of genuine virtual prototypes, such models can have varying levels of intricacy and accuracy. Parametric modelling is becoming an increasingly important component in this context, and it has been used for a growing number of aspects of the design, including hull form (Papanikolaou, 2010), hull structure configuration (Roh & Lee, 2007) and hull compartment layout (Koelman, 2012).

Additionally, it will enable a better view of the interior design surfaces and solutions to complex formats in the design (Jafaryeganeh et al., 2016). The algorithm presented by Jafaryeganeh (2016) relates how to determine the number of containers carried in each hold and the respective centroids, performing two case studies of cargo hold arrangement for a single hull, one without transverse bulkheads and the other with transverse bulkheads, where the differences obtained between both is minimal.

After doing multi-objective optimisation for the problem of ship internal layout, Koutroukis et al (2014), Nikolopoulos et al (2016) and Nikolopoulos et al (2018) applied a utility function to arrive at the final preferred design. The weights assigned by evaluating sample scenarios determined the importance of each aim.

In Nikolopoulos et al (2016) and 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. CAESSES was used to create the cargo hold surfaces and their associated parametric entities. Furthermore, CAESSES 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.

The use of a multi-objective optimization process in the ship layout design results in a Pareto line and the search for the optimal solution can be done using MADM techniques. Jafaryeganeh et al. (2019) goes into greater detail on the definition of the optimisation problem, the approach used to arrive at Pareto solutions, and a review of the optimisation process's findings in the study of the internal layout design of an oil tanker.

2 MODELLING METHODOLOGY

The objective of this work is to determine the container cargo layout of container ships. 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 cargo on deck.

For this purpose, are analysed 4 different container ship classes: Feeders, Panamax, Post-Panamax and Malaccamax.

2.1 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 cargo holds, considering engine room, superstructure, stern panel and collision bulkhead.

First, the cross-sections of the hull are imported from a file with the coordinates of points that define the polylines and generated into an array of sections.

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 ($xStart_{ER}$) represented in the Figure 2.1.

Depending on the chosen containership, the existence of cargo holds aft the engine room is evaluated

considering that a standard cargo hold is composed by 4 bays with a space between each 2 bays for the guides. 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 2.1 represents an example of a standard cargo hold 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.

For the longitudinal location of compartments, it is generated a vector, attributing for each compartment a specific number and the respective length.

In Figure 2.2 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 4 bays separated in groups of 2 TEU ($\{1\ [2\ 2]\}$). The third compartment is a cargo hold with 3 bays, one bay, guides space and, other 2 bays ($\{1\ [1\ 2]\}$). The last compartment is another non-cargo area with a length of 15m ($\{0\ 15\}$). The vector represents the compartments from aft to forward location of the ship.

For Feeder and Panamax configuration, aft 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, 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

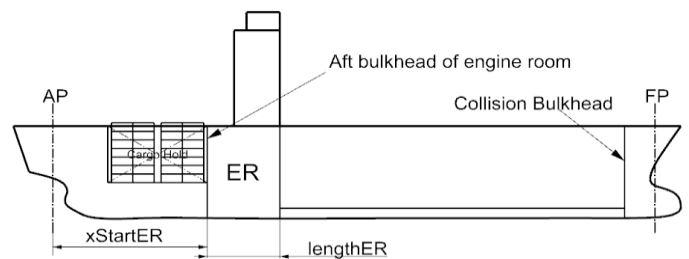


Figure 2.1 - Cargo hold allocated aft engine room

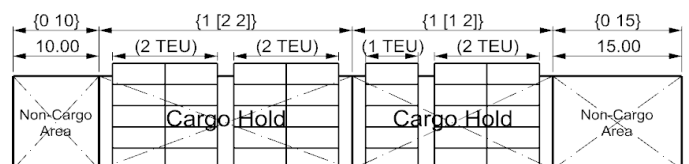


Figure 2.2 - Example of longitudinal array configuration

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 has the superstructure separated from engine room. For a Malaccamax ship, the x coordinate of the aft section of the superstructure is given by the equation (1).

$$xStart_{SS} = xStart_{ER} + l_{ER} + piles2TEU_{ER \rightarrow SS} \cdot (2 \cdot l_{Cont} + distBetweenPiles) \quad (1)$$

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 intended number of groups of 2 bays. 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 of the superstructure are added applying the same process as for cargo holds forward engine room of Feeders, Panamax and post-Panamax. The range for maximum and minimum longitudinal position of the collision bulkhead is set by SOLAS.

Focusing on cargo holds, each group of 2 bays need to be longitudinally spaced from each other (dB) and from bulkheads ($distGuides$). The length of a cargo hold is determined by equation (2).

$$l_{CargoHold} = nr_{HoldBays} \cdot l_{Cont} + 2 \cdot distGuides + (nrGroups - 1) \cdot dB \quad (2)$$

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

Crossing the vector of longitudinal array configuration and the array of bulkheads' longitudinal position, the limits of each cargo hold are identified. Posteriorly, the longitudinal position of the transverse sections required to shape analysis are determined.

2.2 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.

To perform the transverse analysis of the section,

there are some dimensions to consider: the depth, the double bottom height (h_{db}), the minimum width of the wing tanks (mSD), the distance between rows ($trGap$), 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 2.3 is shown a transverse section of a ship with the dimensions identified.

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 ($nrMaxRow$) 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).

$$nrMaxRow = RoundDown \left(\frac{B - 2 \cdot mSD - trGap}{w_{cont} + trGap} \right) \quad (3)$$

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 (4).

$$w_{ST} = nrMaxRow \cdot (w_{cont} + trGap) + trGap \quad (4)$$

The analysis of the inner hull 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 Post-Panamax or Malaccamax it is

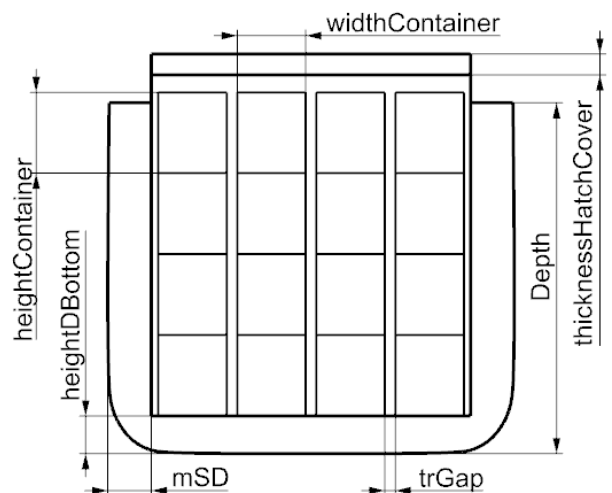


Figure 2.3 - Dimensions for transverse analysis

considered that the shaft tunnel of the engine suppresses 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 tunnel is a multiple of the height of a container (equation (5)).

$$h_{shaft} = n_{SupTiers} \cdot h_{container} \quad (5)$$

The z coordinate of the starting point is given by equation (6).

$$\begin{cases} z_0 = h_{db} , & \text{if } x_{sec} < x_{StartEngineRoom} \\ z_0 = h_{shaft} , & \text{if } x_{sec} \geq x_{StartEngineRoom} \end{cases} \quad (6)$$

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 (7).

$$\begin{cases} K_0 = (x_{sec} ; 0 ; z_0), & \text{even tiers} \\ K_0 = (x_{sec} ; \frac{w_{cont}}{2} + trGap ; z_0), & \text{odd tiers} \end{cases} \quad (7)$$

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 (8).

$$h_{max} = D + h_{Hatch} - h_{Margin} - h_{Container} \quad (8)$$

Where h_{Margin} is a safety margin value attributed to consider the deflection of the hatch cover.

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.

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 a profile view of the ship where the capacity of each tier is represented by the maximum number that each tier can support.

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.

2.3 Longitudinal deck configuration

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

The actual maximum number of tiers on deck depends on stability requirements and is outside of the scope of this work. The height of the superstructure depends on the maximum number of tiers and on the number of superstructure's decks. The superstructure is composed by accommodation decks and a navigation bridge. The number of superstructure's decks is given by equation (9).

$$nr_{Decks} = RoundUp \left(\frac{max_{TiersDeck} \cdot h_{Cont} + h_{Hatch}}{h_{StandardDeck}} \right) \quad (9)$$

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 specified 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 containers are placed on top of the hatch covers and not directly on main deck. The number of tiers in each bay is restricted by the navigation bridge visibility line regulation from SOLAS (IMO, 1974).

The longitudinal configuration of the deck has the same form of the longitudinal configuration of inner hull presented in Section 2.1. To determine the longitudinal configuration of the deck, it is considered the longitudinal configuration of the inner hull previously defined.

The entries of the longitudinal configuration of deck have different meanings comparing to the previous explained in Section 2.1. 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 bay of containers, and the number itself is associated to the number of bays in the respective bay 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. Unlike the Malaccamax class, all the other classes of containerhips have the funnel and the superstructure attached together.

In the developed procedure, first the superstructure and the funnel of the engine room are located. Next, the existence of cargo aft the funnel, between funnel and superstructure and fore superstructure is evaluated.

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. The maximum capacity of a bay is the lower capacity between the sections that delimit the bay. The transverse capacity of a section is represented by equation (10).

$$nrRows_{Sec} = RoundDown\left(\frac{2 \cdot maxSec_{width}}{numMaxRow}\right) \quad (10)$$

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 is not restricted by regulations.

The number of tiers forward of* superstructure is determined considering the visibility line. For feeders, Panamax and post-Panamax ships, the x coordinate of the foremost section of the engine room is given by equation (11) and for Malaccamax class of ships is given by equation (12).

$$xEnd_{SS} = xStart_{ER} + l_{ER} \quad (11)$$

$$xEnd_{SS} = xStart_{SS} + l_{SS} \quad (12)$$

The horizontal distance of the blocked ahead view from the foremost section of the superstructure is given by equation (13).

$$d_{MBV} = L_{pp} - xEnd_{SS} + l_{bow} + \min(2 \cdot L_{pp}; 500) \quad (13)$$

The height from the navigation bridge to the waterline is given by equation (14).

$$h_{bridge \rightarrow WL} = D + h_{SS} - T \quad (14)$$

For a section with x coordinate, being the section located fore superstructure, the maximum height of

the bay (from the hatch cover to the top of the last container) is given by equation (15).

$$h_{maxSec} = \frac{h_{bridge \rightarrow WL} \cdot (d_{MBV} - (x_{Sec} - xEnd_{SS}))}{L_{pp} - d_{MBV} + D - T - h_{hatch}} \quad (15)$$

The number of tiers of a section with x coordinate is given by equation (16).

$$nrTiers_{Sec} = Floor\left(\frac{h_{MaxSec}}{h_{Cont}}\right) \quad (16)$$

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 MODEL VALIDATION

This section is related to the trial of replicating different containerhips, showing cases for the different typical configurations, 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 replicate the ship in study as closer 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.

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 several details from the general arrangements.

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.

3.1 Feeder ship

3.1.1 Input variables

In this example, it is analysed a small Portuguese built in 2007. The ship has a length between perpendiculars of 112.9 meters and the cranes located on the portside. Through general arrangement and the capacity plan of the ship, it was approximately obtained the input values to mirror the ship in MATLAB®.

The input values are shown in Table 3.1. As the program is not able to auto represent a ship vector with the cranes, the vector was inserted manually.

```
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]}};
```

3.1.2 Results and discussion

The results of the comparison between the real general arrangement of the ship and MATLAB® program are shown in Table 3.2. 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 3.1 - Input to mirror a feeder ship

Ship Characteristics			
<i>Class</i>	Feeder	$max_{TiersDeck}$	4
L_{pp}	112.900	$nrDecks$	5
<i>B</i>	20.000	$trGap$	0.025
<i>D</i>	11.300	dBp	0.250
<i>T</i>	7.900	$distGuides$	0.200
h_{db}	0.800	h_{hatch}	1.600
$w_{SideTanks}$	2.100	t_{hatch}	0.600
$xStart_{ER}$	8.000	mSD	0.400
l_{ER}	21.000	$h_{LowerDeck}$	2.600
$xStart_{SS}$	-3.000	$h_{AccDeck}$	2.700
l_{SS}	12.000	h_{bridge}	3.000

Table 3.2 - 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%

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

3.2 Panamax Ship

3.2.1 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 Table 3.3 shows the data input used in MATLAB® to attempt to mirror the panamax ship provided by the journal.

3.2.2 Results and discussion

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

Table 3.4. The results of the deck are close to the reality, and in the cargo holds, the relative error is -10.32%, which is a significant error in 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.

It is observed that the program supresses some containers both in cargo holds and deck. As there are

Table 3.3 - Input to mirror a Panamax ship

Ship Characteristics			
<i>Class</i>	Panamax	$max_{TiersDeck}$	7
L_{pp}	182.000	$nrDecks$	8
<i>B</i>	32.500	$trGap$	0.025
<i>D</i>	16.800	dBp	1.000
<i>T</i>	11.700	$distGuides$	1.000
h_{db}	1.650	h_{hatch}	1.500
$w_{SideTanks}$	2.150	t_{hatch}	0.600
$xStart_{ER}$	8.000	mSD	2.150
l_{ER}	21.000	$h_{LowerDeck}$	2.800
$xStart_{SS}$	24.500	$h_{AccDeck}$	2.700
l_{SS}	18.000	h_{bridge}	3.000

Table 3.4 - Results of Panamax ship comparison

	General Arrangement	MATLAB	Relative Error
Deck	1600	1576	-1.50%
Holds	940	843	-10.35%
Total	2540	2419	-4.76%

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.

Decreasing the distance between the inner and the outer hull, an increase in the capacity of the cargo holds is observed.

The Table 3.5 shows the results obtained when decreasing the minimum distance allowed between the inner and the outer hull.

3.2.3 Analysing the results of the 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 3.7. The result of the total cargo is close to the reality. However,

the results on deck are slightly over dimensioned. It is observed that decreasing the minimum distance between the outer and the inner hull in 0.8 meters is the more accurate.

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.

3.3 Post-Panamax ship

3.3.1 Input variables

To analyse the MATLAB® program for a typical configuration of a Post-Panamax ship, it was tested the mirror of the Savannah Express ship, an 8400 TEU capacity containership that has a liner route connecting China and Canada.

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.

Table 3.5 - Relation between the minimum distance between the inner and the outer hull for Panamax ship

Distance decreased [m]	TEU gained	Hold Capacity [TEU]	Relative error (Holds)	Relative error (Total)
0.2	20	863	-8.19%	-3.98%
0.4	42	885	-5.85%	-3.11%
0.6	62	905	-3.72%	-2.32%
0.8	76	919	-2.23%	-1.77%
1.0	78	921	-2.02%	-1.69%

The Table 3.6 shows the data used in MATLAB® to attempt to mirror the Post-Panamax ship. 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.

3.3.2 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 3.7. The result of the total cargo is close to the reality. However, the results on deck are slightly over dimensioned.

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 suppresses some containers in cargo holds.

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 3.8 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.

Analysing the results of the Table 3.8, it is observed that decreasing the minimum distance between the outer and the inner hull in 1 meter is the more accurate.

Table 3.6 - Input to mirror a Post-Panamax ship

Ship Characteristics			
<i>Class</i>	Post-Panamax	$max_{TiersDeck}$	8
L_{pp}	317.200	$nrDecks$	9
B	42.200	$trGap$	0.025
D	24.500	dBp	1.700
T	14.500	$distGuides$	0.900
h_{db}	2.100	h_{hatch}	1.600
$w_{SideTanks}$	2.300	t_{hatch}	0.800
$xStart_{ER}$	58.300	mSD	2.300
l_{ER}	17.600	$h_{LowerDeck}$	3.200
$xStart_{SS}$	24.500	$h_{AccDeck}$	3.000
l_{SS}	17.600	h_{bridge}	3.200
h_{shaft}	12.000		

Table 3.7 - 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%

3.4 Mallacamax ship

3.4.1 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 mirror the largest containership in the world, the HMM Algeciras, with a 24000 TEU capacity.

In the Table 3.9 is represented the data inserted in MATLAB® to mirror the Malaccamax containership.

3.4.2 Results and discussion

The results of the comparison between the real general arrangement of the Malaccamax ship and MATLAB® program are shown in Table 3.10.

The results on deck can be oversized due to the narrowing of upper deck area because the hull of the

Table 3.8 - Relation between the minimum distance between outer and inner hull for post-Panamax ship

Distance decreased [m]	TEU gained	Hold Capacity [TEU]	Relative error (Holds)	Relative error (Total)
0.2	40	3560	-4.86%	-0.01%
0.4	102	3622	-3.21%	0.73%
0.6	148	3668	-1.98%	1.27%
0.8	182	3702	-1.07%	1.68%
1.0	212	3732	-0.27%	2.04%

Table 3.9 - Input do mirror a Malaccamax ship

Ship Characteristics			
<i>Class</i>	Mallacamax	<i>maxTiersDeck</i>	13
<i>L_{pp}</i>	383.300	<i>nrDecks</i>	11
<i>B</i>	61.000	<i>trGap</i>	0.025
<i>D</i>	33.200	<i>dBp</i>	1.800
<i>T</i>	14.500	<i>distGuides</i>	0.900
<i>h_{ab}</i>	2.550	<i>h_{hatch}</i>	1.500
<i>w_{sideTanks}</i>	2.500	<i>t_{hatch}</i>	0.600
<i>xStart_{ER}</i>	57.000	<i>mSD</i>	2.500
<i>l_{ER}</i>	17.600	<i>h_{LowerDeck}</i>	3.500
<i>xStart_{SS}</i>	24.500	<i>h_{AccDeck}</i>	3.500
<i>l_{SS}</i>	17.600	<i>h_{bridge}</i>	3.000
<i>h_{shaft}</i>	12.000	<i>piles2TEU_{ER→SS}</i>	12
<i>xStart_{Funnel}</i>	58.275		

Table 3.10 - Results of Malaccamax comparison

	General Arrangement	MATLAB	Relative Error
Deck	14032	14460	3.05%
Holds	9932	8358	-15.85%
Total	22818	8359	-4.78%

ship HMM Algeciras can be narrower than the hull imported from DELFTship®. Another possible factor influencing results on deck is 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.

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 3.11 shows the results when reducing the minimum distance between the inner and the outer hull.

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.

Table 3.11 - Relation between the minimum distance between outer and inner hull for Malaccamax ship

Distance decreased [m]	TEU gained	Hold Capacity [TEU]	Relative error (Holds)	Relative error (Total)
0.2	64	8422	-15.20%	-4.52%
0.4	158	8516	-14.26%	-4.12%
0.6	244	8602	-13.39%	-3.76%
0.8	310	8668	-12.73%	-3.49%
1.0	370	8728	-12.12%	-3.24%
1.2	424	8782	-11.58%	-3.01%
1.4	474	8832	-11.08%	-2.80%

4 CONCLUSIONS

A method was proposed to determine the layout of the compartments on four different typical configurations of containerships. The layout of compartments was essentially related to the location of the cargo holds, the cargo areas on deck, the engine room, and the superstructure.

First, this method consists in the generation of the longitudinal configuration of a containership, considering the class, the main dimensions, and some other characteristics, usually set by the ship owner. Posteriorly, for a given hull, a transverse analysis of the cargo hold sections was performed generating the internal shape of the cargo holds and determining the number of containers carried inside the hull. For the cargo areas on deck, the number of bays and tiers in cargo areas was calculated and allocated, and the navigation bridge visibility line was determined restricting the number of tiers located aft superstructure.

After, the number of containers carried on deck was determined.

To validate the model, four different ships were tried to mirror, representing each one a different class of containership. Besides some difficulties generating hulls for the pretended dimensions in DelftShip® and reading them in MATLAB®, the results obtained are the expected, showing small relative errors. This method can be applied in an early stage of ship designed to allocate the main compartments of a containership, performing an estimation of the compartments of the ship in work.

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