ABSTRACT: The efficiency of the transport is a major aim in conceptual design of ships. The ship synthesis models used in this design stage can be quite enhanced by the inclusion of tools to obtain a more accurate estimate of the cargo and ballast capacities. Parametric geometric modelling is an efficient tool for the generation of alternatives of internal layouts of the cargo holds and their assessment during the early design stage. This work presents a contribution for the parametric modeling of the cargo holds in container ships to be used in the conceptual design stage. First the specific aspects of the container holds are analyzed. Then the parameters that must be considered to locate and restrict the container piles are identified. An algorithm is presented to determine the feasible number of containers carried in each hold and the corresponding centroids. Finally, some results are presented by considering the effect of location of the intermediate bulkheads on the container arrangements.

1 INTRODUCTION

Conceptual design is a very important stage of the ship design process, when the more relevant decisions are made about the ship hull dimensions, configuration, capacities, speed and propulsion. These decisions on a quite reduced number of aspects set the main parameters not only to the initial ship cost but also to the operational performance and costs during its entire life cycle. The definition of the internal layout of the hull compartments is an important task in the ship basic design process. The design of cargo hold space depends from the ship and cargo types. Special consideration has to be applied to the container ships internal layout design because of carrying the cargo with cubic geometry, which is the subject of current study.

Recent researches emphasis on the increment of ULCS (ultra-large container ships) capacity and building orders. Such container ships allow the reduction of slot costs due to the “economy of scale” factor. However, some analysis concerns with the barrier against the size increasing of the container ships, like, stability issues, ship strength, building cost and so on. These contradicting objective needs to be assessed in an optimization procedure.

Generally, optimization procedures are becoming more and more common during the conceptual design. For this purpose, ship numerical models must be used. Such models may have different levels of detail and accuracy, from the pure empirical approaches to the development of actual virtual prototypes. In this context, parametric modelling is becoming a very important component and it has been used for an increasing number of aspects of the design such as the hull form (Papanikolaou, 2010), the hull structures configuration (Roh & Lee, 2007), the hull compartment layout (Koelman, 2012) and fully integrated procedures of the complete hull (Lee et al. 2004; Harries et al. 2011).

Regarding the compartment modelling, Lee et al. (2009) proposed a top-down approach based on space subdivision to be used in an optimization procedure.

In some research work, the objective functions were the safety assessment and the ontology of defined function of areas of the vessel. Chen et al. (2010) studied the subdivision arrangement by optimizing the size of the ballast tanks to maximize the structural strength. Chung et al. (2011) have studied the compartment arrangement of a submarine pressure hull using a knowledge based system. Suitable knowledge representation schemes were selected to describe ship compartments and their interrelations.

Modeling the internal layout of ships introduce a challenge for defining the spaces as volumetric entities in the CAD software. Koningh et al. (2011) introduced a constraint management tool able to use a combination of volumes and planes in any fashion to determine the internal layout design during the design process and applied the concept to the cargo hold of Ro-Ro ships.

In regard to container ship design, Koutroukis et al. (2013) presented a holistic model, multi-objective optimization. A parametric model was applied to assessment of the cargo hold capacity in medium size container ships, which computes the number of containers per bay and several other characteristics of the
arrangement. They considered a number of the bays relative to the ship length to provide the boundary of internal cargo space from ship hull.

This work is a contribution to the parametric modelling modeling of the cargo area, with a special focus on the cargo holds of container ships. In the conceptual design, the estimate of the cargo and ballast capacities and the corresponding centers of volume are very important to determine the load condition and the stability of the ship, and typically have been done mainly based in empirical formulas. These formulas are usually functions of the main hull dimensions and form coefficients, as expected in the very beginning of the design process, where the hull form is still undefined. However, the availability of 3D models of the hull form creates conditions for a more accurate evaluation of the cargo areas, if they can also be modeled in some kind of automated procedure. In addition, such procedure can be combined with the parametric generation of the hull form and used in surrogate modeling techniques to develop more precise empirical formulations for the conceptual design, when no hull form is available yet.

Although the container ships carry cargo on deck, the inexistence of actual physical boundaries does not raise a problem. The specific aspect of these ships results from the modular nature of the cargo which leads to cargo holds with dimensions that are multiple of the TEU dimensions. So, to combine the maximum hold capacity with the avoidance of non-modular useless space, the geometry of the cargo hold is adapted to the actual container pile and the local hull shape.

The present work is focused on the role of container arrangement in the initial assessment of internal cargo hold design without changing the main properties of ship hull, because of the importance of consequences. The number and position of containers are evaluated as main result of container arrangements inside cargo hold, which affects to the centre of gravity of cargo and even safety issues as latter consequence. Also, the effect of transversal bulkheads is studied in provided adaptive model of cargo holds by considering different position and number for bulkheads. Possible variations in the mentioned parameters are discussed by presenting some examples.

2 METHOD OF ARRANGEMENT OF CONTAINERS INSIDE CARGO HOLDS

The arrangement of containers inside the cargo hold is performed in three steps. First, the maximum allowable containers are evaluated in a determined level of every section, which is called tier arrangement. Next, an efficient method is applied for evaluation the maximum number of containers in the allowable height of the same section. Thus, the row arrangement of containers is completed in this stage. Finally, the sectional arrangement is continued along the ship to fill the available cargo space with containers, to evaluate the maximum available bays.

A simplification is considered for arrangement of containers with standard sizes, indeed, the container's heights, widths and lengths are assumed to be the same for arranging them inside the ship hull. Though, the used methodology is able to consider containers with different sizes for other applications. Also, the containers are considered to be arranged transversally symmetric inside the cargo space of ship, it means, there is not any container on the center line of ship, unless the centerline of container is passed through the ship centerline.

2.1 Adaptive sectional arrangement

The container arrangement is a three-dimensional process inside the ship cargo space. In a simplification of the process, the evaluation of the maximum available space is studied in two main phases. First, the adaptive sectional arrangement determines the available space for arrangement of the containers in a transverse section. Then, the method utilizes for evaluation of sections along the ship hull.

2.1.1 Transversal arrangement of container in the tiers of ship hull sections

The arrangement problem is simplified by considering a determined height in a transverse section of cargo hold space. As shown in Figure 1, one last container in a tier should have a marginal distance \(T_{mar}\) from outer corner of container to the interior shell of the ship hull, this marginal distance includes the transversal distance of side tank to the ship hull \(D_{1}\). Also, a gap \(T_{gap}\) is considered between the containers in the transversal direction. Thus, the following formula can estimate the allowable number of containers \((NoC_{ij})\) in the height of \(h_i\) in the section of \(j\).

\[
NoC = \left[ \frac{B_{ij} - T_{mar}}{W_{TEU} + T_{gap}} \right] \quad (1)
\]

\[
RD = NoC \times W_{TEU} - B_{ij} \quad (2)
\]

\[
NoC_{ij} = \begin{cases} 
NoC, & RD < W_{TEU} \\
NoC + 1, & RD \geq W_{TEU}
\end{cases} \quad (3)
\]

where, \(W_{TEU}\) is the width of the containers, which is assumed to be same for all of them, and \(B_{ij}\) represents length of the adaptive line of cargo hold at height of \(h_i\) in the \(j^{th}\) section. The sectional adaptive line is defined from a point on ship center line at height of \(h_i\) to the ship hull in the mentioned section with the same height. As shown in Figure 1, this line is the base of the adaptive tier arrangement to stow the maximum allowable containers in the limited distance of centerline to the ship hull.

In the \(j^{th}\) section, the tier arrangement of containers starts from the double bottom height and continues...
to the marginal height to the hatch covers. The tier arrangement loop adds the containers one by one in each step and will be continued, unless the exterior corners of the last added container does not pass the marginal condition. In fact, the transversal coordinate of the exterior corner of each container shouldn’t cross the marginal distance to the ship hull in each tier.

Checking the marginal condition should not be limited to the one side of containers. In fact, all the exterior corners of each container should be checked for the marginal condition. Figure 2 and Figure 3 show two cases of mentioned incorrect arrangements.

As shown in Figure 2 in a container arrangement transversal section, some exterior corners of the containers does not cross the marginal distance. These corners are specified with P points for the hatched containers. While, the other exterior corners cross the marginal distance, these corners are specified with E points for the same containers.

Also, Figure 3 shows the problem of crossing the marginal distance for some containers in top view, these cases happen, when the curvature of ship hull surface increases sharply.

Therefore, it is necessary to check the marginal condition for all of the exterior corners of the last added container in the tier arrangement loop.

2.1.2 Vertical arrangement of container in the rows of ship hull sections

The transverse tier arrangement loop has to be repeated for arrangement of containers in each tier of each ship section, i.e. the tier arrangement continues in a section, unless the tier height doesn’t pass the vertical marginal condition for container rows. In fact, the vertical coordinate of the upper corner of each container shouldn’t pass the marginal distance to the hatch coaming of the main decks.

The adaptive tier arrangement of containers starts at the double bottom height and ends to the marginal distance of main deck height. Thus, the row arrangement is completed inside the cargo hold.

Figure 4 shows the main parameter of the sectional arrangement in the vertical direction, where $V_{mar}$ represents the vertical marginal distance to the deck, it includes the required space for hatch cover operation, and $V_{gap}$ represents the vertical distance between containers, although it is a small value.
2.2 Adaptive longitudinal arrangement of container along the ship hull

Figure 5 shows a schematic view of longitudinal arrangement of containers inside the cargo hold space. The adaptive sectional arrangement is performed for each section along the ship. Though, the location of sections starts from the first bulkhead of the cargo space and can be related to the container length. It means, the adaptive sectional algorithm evaluates the section in step distances, which is the sum of container length and longitudinal gap between them.

The total length of cargo holds can be the base of estimation of the available cargo space inside the ship hull. First, a simplification considers for cargo hold length, the length is measured from the first to the last transverse bulkhead. This simplification gives a rough estimation for adaptive cargo hold space inside the ship hull. Then, a more accurate approach must consider the number and location of transverse bulkheads. Thus, a distance \( L_{mar} \) should be considered as longitudinal margin from the bulkhead to the first bay of containers inside of each cargo hold. The container bays inside the cargo hold are generally fit into the cell-guides which extend up to the hatch coaming, therefore, the longitudinal marginal distance inside the cargo hold must consider the distance between the hatch coaming on the main deck and nearest bulkhead \((HC)\).

The flowchart of the method is shown in the Figure 6. The origin point of the arrangement is specified along the ship center line on the first bulkhead then adaptive line \((B_{ij})\) is evaluated by measuring the length of line from origin point to the projected point to hull in transversal direction. Afterwards, as described in previous sections, the tier and sectional arrangement is continued to satisfy the marginal condition, and finally the quantity and center of gravity of arranged containers is calculated.

3 BULKHEAD ARRANGEMENT

A series of plans are defined in the position of transverse bulkheads for generating the bulkhead model, then, they are fitted to the ship hull to reach the actual model of transversal bulkheads, as shown in Figure 7.

The algorithm of adaptive arrangement of containers is applied between two consecutive bulkheads. Therefore, the bulkheads number and positions affect the total number of containers as well as their arrangement inside the ship hull.
In fact, the bulkhead numbers and positions are in close relationship with safety assessment of the ship, due to improvement of ship survivability. However, quantifying those values are out of subject of present study. Thus, the studies are limited to evaluation the container arrangement change due to different bulkhead position.

4 CASE STUDIES

A container ship is used for the present study. Table 1 presents the particulars of the container ship.

Figure 8 shows the three-dimensional model of container ship hull, which is used for generating the adaptive arrangement.

On the other hand, container size is a significant property in the applied algorithm for the adaptive model of internal storage spaces, because the forward step of sectional arrangement is an integer multiple of container length. Although, all standard sizes can be used for the initial container arrangement. However, different standard sizes of containers, as definition of forward step for algorithm, result in different internal adaptive model. Thus, the FEU (forty-feet equivalent unit) can ensure the safe side of design. In fact, the defined longitudinal gap between the containers allows replacing the other standard size, like, TEU (twenty-feet equivalent unit), using the combination size of the standard containers in the internal arrangement is another possible initial evaluation for the layout design.

The center of gravity is considered in an arbitrary point inside the container, which is not the container center of volume necessarily. Three coefficients are defined for evaluation the container center of gravity, relative to the length, breadth and height of container.

Table 2 presents the used coefficients for evaluation of container center of gravity.

Table 1. Main particulars of the container ship.

<table>
<thead>
<tr>
<th>Particular</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{overall}$</td>
<td>198.25</td>
<td>m</td>
</tr>
<tr>
<td>$L_{PP}$</td>
<td>180</td>
<td>m</td>
</tr>
<tr>
<td>$B_{GM}$</td>
<td>32.2</td>
<td>m</td>
</tr>
<tr>
<td>$D$</td>
<td>23</td>
<td>m</td>
</tr>
<tr>
<td>$T$</td>
<td>10.5</td>
<td>m</td>
</tr>
</tbody>
</table>

Table 2. Sample of defined coefficient for CoG of containers.

<table>
<thead>
<tr>
<th>Particular</th>
<th>Value</th>
<th>CoG position relative to the container base corner</th>
</tr>
</thead>
<tbody>
<tr>
<td>$l$</td>
<td>0.5</td>
<td>3.048 m</td>
</tr>
<tr>
<td>$b$</td>
<td>0.5</td>
<td>1.174 m</td>
</tr>
<tr>
<td>$t$</td>
<td>0.4</td>
<td>1.036 m</td>
</tr>
</tbody>
</table>

4.1 Arrangement without intermediate transverse bulkheads

The containers are arranged between two points of first and last bulkhead in the cargo hold area. Although, the bulkheads should be considered in the realistic design, this kind of arrangement can help to have view before considering the bulkhead effects.

Two views from the top and sides of arranged containers are presented in the Figure 9 and Figure 10. Figure 11 presents the three dimensional view of arranged containers inside the cargo hold.

In the wall sided part of ship hull, the arrangements are parallel to the wall, and consequently the adaptive model can follow this trend.

The change of sectional arrangement of containers inside the cargo holds is noticeable near the fore ship. In fact, stepwise modification can be seen in every sectional arrangement. However, such sectional modifications are not applicable to the internal layout of the cargo hold space, due to construction limits.

As a consequence, increasing the distance of bulkheads in the wall sided part of the hull results in efficient arrangements in that part. Also, if there would be a possibility to shift the required position of bulkhead to an area of more stepwise modification, the provided adaptive model can be implemented more.
efficiently. Of course, the side effect of such internal design includes an increment of construction cost, lower volume of encapsulated area by two consecutive bulkheads, where, those effects can be studied in a Pareto design problem in optimization of internal layout beside of cargo capacity increment.

4.2 Arrangement with intermediate bulkheads

The implemented method for container arrangement is applied between consecutive bulkheads, thus, different container arrangement is a consequence of the possible bulkhead arrangement, i.e. the adaptive model of inside cargo tanks depend of the bulkhead layout.

By including the bulkheads, the number of containers is affected by the bulkhead location as well as by their arrangements. Comparison between Figure 11 and Figure 12 depicts the difference due to including the bulkhead in the modeling.

Figure 13 shows the side view of the same arrangement, which is depicted in the Figure 12 by three-dimensional view. In this sample, some part of cargo space is wasted from the point of view of container arrangement in this bulkhead layout definition. Actually, the distances between the bulkheads are chosen without considering its relation with the containers length.

Number and location of bulkheads are two main parameters of bulkhead arrangements. However, some rules have guidelines for quantifying these parameters and they are related to the ship safety directly. On the other hand, these parameters influence the internal layout design of container ships. Comparison of

<table>
<thead>
<tr>
<th>Case studies</th>
<th>Number of containers</th>
<th>CoG position (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
<td>396</td>
<td>101.88 10.08</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>394</td>
<td>101.77 10.21</td>
</tr>
</tbody>
</table>

Figure 13 and Figure 14 show the different arrangement due to considering different number of bulkheads and location for the internal layout.

The bulkhead positions are arranged with distance of multiple integer of container length for the presented sample of alternative 1 in the Figure 14, thus, in this case, all the space of cargo hold is used for arranging the containers, and the waste spaces are avoided.

Similarly, the present sample of alternative 2 in Figure 15 follows the same rule for arranging the bulkheads with different distances. This kind of arrangement results in equivalent provided adaptive models of internal layout. Table 3 presents the quantity and total center of gravity of containers in order to each arrangement. However, only small differences result from considering the marginal distance to the bulkhead.
All in all, if different adaptive internal layout is required to evaluate the arrangement design, it should be with the different distances and starting points of bulkheads layout in the cargo hold area. However, the container length should be considered in the bulkhead layout definition, but different multiple integer distances of bulkhead result in similar consequence of internal adaptive layout.

5 CONCLUSIONS

A method was developed to determine the feasible layout of container stacks inside of cargo hold, accounting for their number and center of gravity. This method can be applied for the design of the internal cargo compartments layout during the conceptual design stage. The method consists of three verification loops where four corners of each container are checked against transverse, vertical and longitudinal limit lines. These lines are determined as a function of the cargo hold dimensions amidships (height of double bottom, width of side tanks, height of hatch coaming), the local outer hull shape and some assumed minimum distance admissible between the hold space and the outer hull.

The method presented is intended to be a component of a ship synthesis model to be used in optimization studies, where the hull dimensions, the configuration of the cargo holds and the hull shape are being decided.

The number and location of the transverse bulkheads, although strongly limited by the need to be compatible with dimensions multiple of the container size, modify the internal arrangement of the containers and has an influence in the total number of TEUs carried. On the other side, the arrangements of containers are similar for different bulkhead layouts that have same position for first and final bulkhead of the cargo hold and bulkhead distances are integer multiple of container length. Thus, if a designer intends to have different adaptive layout with significant changes, a modification is required for the position of starting point of cargo hold area along the ship. Consequently, this modification influences the other main properties of the ship like, size, power, and safety and so on. Thus, evaluation of container ship internal layout can be studied in the holistic optimization approach.

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