ABSTRACT: This thesis presents a method for the parametric generation of a three-dimensional surface model of merchant ship hulls. First, a brief analysis of the hull shape of some existing merchant ships was carried out, focusing on containerships, bulk carries, tankers and ferry ships. Some geometric and property curves, as the well known FOS, FOB, DWL, deck contour, SAC, and others, were studied according to the type of ship, as well as the smaller set of parameters suitable for each curve characterization. This study was followed by a determination of a suitable variation range of each parameter in order to create more realistic curves. A parametric model was developed using the FRIENDSHIP-Framework system in order to evaluate the suitability of the parameters chosen and their variation ranges to correctly describe the hull form. Some hydrostatic calculations were made and the Lackenby Transformation was used in order to obtain the desired prismatic coefficient and the longitudinal position of the centre of buoyancy. Finally, the developed model was applied on some existing hull shapes, and the results were presented and discussed.

1 INTRODUCTION

Ship design is a complex activity that requires a successful coordination between different disciplines, with the objective of creating a valuable and optimum design solution. The design work is generally considered a sequential process, increasing the detail by each step, until a single design that satisfies all constraints, balancing all considerations (Evans, 1959).

This work was done focusing on shapes of merchant ships, since there is an urge to create and improve them, in order to achieve efficient and greener ships. With the increasing of fuel costs and the requirements to reduce the emissions, the ship optimization became a big part of design studies, since the hull is the most important entity in ship’s hydrodynamics and structural behaviour.

From the three hull modelling concepts presented by Harries et al. (2004), the fully-parametric, seems to be the best approach to have an improvement in the efficiency of the early stages of ship design, such as the determination of the optimal ship dimensions and configuration, CFD hull form optimization studies, and so on. In this concept the geometry is created based on relationships between parameters, and the hull is described in terms of basic curves, as the DWL and the SAC.

In ship design, the fully-parametric design was first used by Nowacki et al. (1977), who started to model hull curves by means of a cubic B-spline with seven vertices on the basis of 14 form parameters.

Since some parts of the hull are more difficult to analyse, characterize and generate, some particular studies have been made, such as the work of Krach (1978) focused on bulbous bows in which are presented a set of form coefficients to characterize the bulb. He concluded that the bulb section directly influences the hydrodynamic properties, and affects both the vertical volume distribution and the amplitude of the bulb waves. The bulb section can be classified into three main types, according to the position of its centroid. It was concluded that the volumetric parameter has the largest influence on the wave making resistance and on the phase lag of the bulb-generated waves, which is also a function of the longitudinal volume distribution of the bulb area.

Over the last few years, some research work has been carried out aiming the hull parametric modelling. Jacobsen and Kracht (1992) that presented a new model-series, called D-Series, originating from a twin screw round-bilge hull form. This model uses some parameters previously defined by Kracht and some other new parameters. They also presented a
The hull model was built considering a set of parameters that relate the main dimensions with other dimensions of hull geometry, and some dependencies between different parameters. The parameters were applied on the geometric and property distribution curves. Using this kind of approach, changes on the hull shape are easier to reach, because when the designer changes one parameter of the geometry, all the other parameters, that are dependent on the first one, are automatically actualized.

2.1 Main Dimensions

The first step of the modelling procedure was the implementation of the main dimensions. These values will influence every component of the hull model. The considered main dimensions were: the length between perpendiculars ($L_{pp}$), design beam ($B$), depth ($H$), draft ($D$) block coefficient ($C_b$), longitudinal position of the centre of buoyancy ($L_{CB}$), start longitudinal position of the parallel midbody ($x_{MainFrame}$) and the length of the parallel midbody ($L_c$). The length of the aftbody ($L_{AB}$) and the forebody ($L_{FB}$), were calculated according with $L_{pp}$, $L_c$ and $x_{MainFrame}$.

2.2 Geometric Curves

The development of the geometric curves begins with the definition of the extreme points. The $x$ position of these points is characterized with a parameter that relates the position itself and $L_{AB}$ or $L_{FB}$. The second phase is the definition of the beginning and the end points of the parallel midbody. Then, in some curves such as the FOS, some intermediate points were added, such as the intersection of the FOS and the DWL. The $x$ positions of these points are characterized with a parameter that relates the $x$ position of the point and the difference between one of the extreme points and the beginning or the ending of the linear part of the curve that includes the parallel midbody. In this way it is impossible to input values that will create a point that is not between the aft point of the FOS and the beginning of the parallel midbody, thus making the model stronger. The next step was the construction of the curve itself. For almost every curve, the construction was done using poly-curves with $F$-Spline curves that allows the user to have the control of the entrance and the run angle of each curve, and also the area and centroid of some segments of the curve. For that to be possible, some parameters were created, for the entrance and run angles, and parameters that represent a area coefficient for the segments where it is relevant to manipulate this values.

2.2.1 Main Frame

The main frame is one of the most important geometric curves on the hull form development. Its definition says that its longitudinal position is at the section with maximum beam, in particular, when the ships has cylindrical body, it was considered to be
located on the beginning of the parallel midbody, and almost every time presented the same shape type: two straight segments that coincide with the FOB and the FOS, and a curved segment commonly known as the bilge.

The bilge can have a circular or an elliptical shape. In order to cover all the possible bilge shapes, instead it was used parameters relating the bilge height ($b$), width ($b_w$) and area coefficient ($\text{coeffbillge}$).

It is important to notice that both the deadrise and the flare were considered to be angle measures, and the last was considered to be measure on the DWL. It was not considered the possibility of the existence of keel.

2.2.2 Flat of Bottom (FOB)

This curve has a direct connection with the ship’s longitudinal contour since its extreme points coincide with the beginning and the end of the keel line ($C_{\text{FOBaft}}$ and $C_{\text{FOBfwd}}$). It also has a direct connection with the Main Frame and the parallel midbody. The maximum value of $y$ is automatically defined, since it has to coincide with the lowest point of the bilge.

Defining the beginning and the $L_c$, a linear segment has to be automatically defined. Sometimes, this linear segment presents a length bigger than the $L_c$, and for that to be considered, two parameters had to be created. These parameters relate the length of each part of the linear segment that are aft and forward of the parallel midbody, and the $L_{AB}$ and the $L_{FB}$, respectively ($C_{\text{FOBstraightAft}}$ and $C_{\text{FOBstraightFwd}}$). To complete the FOB contour, two other curve segments, one on the aftbody and other on the forebody, had to be analysed, and for these two segments to be characterized, four other parameters had to be created: $\text{FOB}_{\text{run}}$, $\text{FOB}_{\text{entrance}}$, $\text{FOB}_{\text{fullnessaft}}$ and $\text{FOB}_{\text{fullnessfwd}}$.

2.2.3 Flat of Side (FOS)

This curve presents a very similar behaviour to the FOB. Its extreme points are directly related to the Deck Line and to the Transom Panel Contour. To them three parameters had to be created, two related to the $x$ position of the extreme points and another to the $z$ position of the aft point of the FOS since it is possible to have a FOS that ends on the transom panel ($C_{\text{FOSmergeAft}}$ and $C_{\text{FOSmergeFwd}}$). A linear segment appears almost every time in the contour of the FOS, and similar to the FOB, this segment can also have a length bigger than the $L_c$, and because of that, two parameters had to be analysed, relating the length of each part of the linear segment that are aft and forward of the parallel midbody, and the length of the aftbody ($C_{\text{FOSstraightAft}}$) and the forebody ($C_{\text{FOSstraightFwd}}$), respectively.

2.2.4 Design Water Line (DWL)

The DWL is one of the most important curves of the hull form, since it directly influences the ship’s hydrostatic and hydrodynamic behaviours.

This curve always presents at least 3 segments: one linear segment and two curved ones. The linear segment is directly related to the FOS definition since its extreme points coincide with the intersection between the DWL and the FOS curves ($C_{\text{FOSmergeAft}}$ and $C_{\text{FOSmergeFwd}}$). There can also be another linear segment at the aft part, in the cases where the DWL intersects the transom panel or when the aft body presents a rectangular shape ($C_{\text{DWLaftY}}$).

To define the curved segments it was necessary to have another four parameters related to the area coefficient of each segment ($\text{DWL}_{\text{fullnessaft}}$ and $\text{DWL}_{\text{fullnessfwd}}$), the entrance angle ($\text{DWL}_{\text{entrance}}$) and run angle ($\text{DWL}_{\text{run}}$).
2.2.5 Deck contour

The extreme points of this curve are directly related to the longitudinal contour, since their extreme points are the same. To define the forward point it was necessary to create the parameter that relates its x position and the length of the forebody (C\text{peak}).

Despite each deck presenting different characteristics, all of them present at least two segments: a linear and a forward curved segment. This linear segment is directly related to the definition of the FOS curve since their extremes are the same.

The aft part of the deck line can have very different behaviours. Its definition is directly influenced by the transom panel contour and, once again, by the FOS curve. If the transom panel has a beam equal to the ship design beam, the linear segment of the deck goes from the forward point of the FOS to the transom panel, if not there is another curved segment between the aft point of the linear segment and the top segment of the transom panel. To define the tow possible curved segments two parameters were created, relating the area coefficient of each segment (\text{deckfullnessAft} and \text{deckfullnessFwd}).

2.2.6 Stem

The stem is the highest forward part of the longitudinal contour. This curve does not have any influence on the ship’s hydrodynamic and hydrostatic behaviour since it’s not part of the submerge hull.

Since we wanted a full hull model, this curve was still fully studied and characterized using three parameters: the \text{C\text{StemStraight}} that relates the length of the linear segment of the stem and the depth, the \text{TgBulb} and the \text{Tgpeak} that represent the tangent angle of the stem contour at the top beginning of the bulb longitudinal contour and at the peak, respectively.

2.2.7 Bulbous Bow

One of the entities of the hull that mostly interferes with hydrodynamics, and consequently economics of ship, is the bulbous bow. Its geometry directly influences the wave resistance and the propulsive efficiency, and for that reason, it was a part of the model that was studied with special attention.

Along the years several studies have been made according to the geometry of the bulb and its influence on the ship’s behaviour, and some parameters have been presented. Some of those parameters were used in this study and some new ones were considered, in order to completely characterize the bulbous bow.

To characterize the bulbous bow, a set of three geometric curves and one property curve, were created (figure 7): the lower and upper longitudinal contour, the maximum beam elevation distribution curve and the maximum halfbeam contour.

To study the bulb longitudinal contour, the position of three points had to be analysed: the lower and the upper points of the contour on the beginning of the bulb and the tip point. To define them, the parameters related with the z-position of the lower and the upper points of the bulb longitudinal contour (\text{C_{za}} and \text{C_{zb}}), the z-position of the bulb tip (\text{C_{hb}} - Kracht parameter) and the length of the bulb (\text{C_{lp}} - Kracht parameter), had to be created. The area coefficients of the upper (\text{BulbupperFullness}) and the lower (\text{BulblowerFullness}) segments of the longitudinal contour and the tangent angle on the upper point of the longitudinal contour (\text{TgupperContour}), also had to be created.

The beam elevation distribution contour was more difficult to create. In the simpler models this contour is set as a linear horizontal curve that passes through the tip point. But, since the values of the z coordinates can be different at the maximum beam on the beginning of the bulb and at the bulb tip, the contour was considered as an inclined linear curve that passes through these two points. It is important to refer that this curve can also have a curved behaviour but since it is very difficult to analyse and to apply, a simplification was done considering the distribution as a linear curve. So, to characterize this curve only two parameters were needed, the z-coordinate of the tip of the bulb and the z-coordinate of the maximum beam on the beginning of the bulb (\text{C_{hbe}} - Kracht parameter).
Finally, with this curve, the halfbeam distribution curve was analysed intersecting a plan that passes through the beam elevation distribution and the bulb surface. To characterize it, the maximum beam on the beginning of the bulb ($C_{bb}$), its $z$ position, and the area coefficient of this curve ($B_{halfbeamFullness}$), had to be created.

Two other parameters related to the bulb transversal contour had to be created. These are the $B_{lowerTransvFullness}$ and the $B_{upperTransvFullness}$ that characterize the area of the lower transversal segment and the upper transversal segment, respectively. Finally, the $C_{moveBulb}$ that relates the longitudinal position of the beginning of the bulb and the longitudinal position of the forward perpendicular was also considered.

![Bulb Contour](image)

**Figure 7: Bulb Contour**

### 2.2.8 Stern Bulb

To completely characterize the stern bulb, two geometric curves and two property distribution curves were created. The first geometric curve (figure 8) the stern bulb longitudinal contour and to create it, it was necessary to know the $x$ and $z$ coordinates of the bulb tip ($C_{xBulbTip}$ and $C_{zBulbTip}$) and of the clearance ($C_{xClearance}$ and $C_{zClearance}$), and also to know the angle between the transom panel and the longitudinal contour at the lower point of the first one ($Tg_{Transom}$).

![Stern Bulb](image)

**Figure 8: Stern Bulb**

The second geometric curve is the boundary between the stern bulb and the bare hull, and to define it, six other coefficients were created (figure 9):

- $C_{xBilgeAft}$
- $C_{xMaxBeam}$
- $C_{yMaxBeam}$
- fullness$_{aft}$
- fullness$_{fwd}$
- and $tg_{Aft}$.

![Stern Bulb - Boundary Contour](image)

**Figure 9: Stern Bulb - Boundary Contour**

### 2.2.9 Transom Panel

The transom is directly related to the deck contour, the longitudinal contour and the flat of side curve, and usually presents a linear segment on the bottom (linearBottom), followed by a curved (transom$_{fullness}$) and another linear segments on the other side of the curve depending on the behaviour of the FOS (linearSide). Finally, it presents the top linear segment that is directly related to the deck, since it coincides with its aft linear segment (TransomTop).

![Transom Panel](image)

**Figure 10: Transom Panel**

### 2.3 Property Distribution Curves

The property curves represent the variation of some geometric properties of the hull form along one direction and therefore they are not directly obtained from the hull but result from some geometric processing.
In the following subsections, it will be presented a study of the SAC and the distribution curves of the flare at bottom, flare at design water line, flare at deck, and the property distribution curves of the stem radius and angle. In the figure 11 there is a representation of the position of each flare distribution and how they should be measured. It is important to notice that on the main frame the flare at bottom is the same as the deadrise and the flare at design water line as the flare.

2.3.1 Sectional Area Curves (SAC)
The SAC is one of the most important curves for the naval architects. With this curve, it is possible to change the distribution of the ship’s volume (by calculating and changing the LCB position) and the prismatic coefficient. To define this curve, it was necessary to measure the area of some strategically chosen sections, where the main changes on the hull form are located. In the present study the following sections were considered: aft longitudinal position of the DWL (\(C_{\text{area} \text{DWL}aft}\)), aft and fwd positions of the FOB (\(C_{\text{area} \text{FOS} \text{Base}}\) and \(C_{\text{area} \text{FOS} \text{fwd} \text{Base}}\)), and aft and fwd intersection longitudinal positions of the FOS and the DWL (\(C_{\text{area} \text{FOS} \text{merge} \text{Aft}}\) and \(C_{\text{area} \text{FOS} \text{merge} \text{Fwd}}\)).

![Figure 12: Sectional Area Curve](image)

At the beginning, one of the objectives was to develop a hull form that would follow the created SAC curve, but, with the development of the hull shape, this idea had to be abandoned because it was practically impossible to do it at the zones where the stern and bow bulbs were. An attempt was made to make a secondary SAC curve considering only the stern and the bow bulbs areas, but this showed to be completely impossible to do without having a hull already built. So, the SAC curve was applied only to the surfaces between the beginning of the parallel midbody and the end of the FOS curve.

2.3.2 Flare at Bottom (FAB)
The FAB distribution curve (figure 13) was set between the forward base longitudinal position and the bulb tip longitudinal position. To create this curve, it is necessary to specify two parameters: the \(\text{flare}_{\text{BulbTip}}\), representing the flare at the bulb tip, and the \(\text{tg}_{\text{BulbTip}}\), representing the tangent of the curve distribution.

![Figure 13: Flare at Bottom](image)

2.3.3 Flare at Design Water Line (FADWL)
This curve was developed and analysed only between the forward longitudinal position of the intersection of the FOS and the DWL, and the forward perpendicular, since it is between this two positions that there are relevant variations.

In this curve there is only one parameter that can be easily measured on existing hull shapes or in lines plan drawings, the \(\text{flare}_{\text{OnFP}}\) that represents the flare at the forward perpendicular on \(z = \text{draft}\). There are other parameters, such as \(C_{\text{max} \text{flare}}\), \(\text{max} \text{Flare}\), \(\text{tg}_{\text{AtFOSmerge} \text{fwd}}\) and \(\text{tg}_{\text{AtFP}}\), that are almost impossible to measure on existing hulls.

![Figure 14: Flare at Design Water Line](image)

2.3.4 Flare at Deck (FAD)

![Figure 15: Flare at Deck](image)
The FAD curve is developed between the forward longitudinal position of the FOS and the forward perpendicular, by using a third degree spline curve with 4 points. To buily it, it was only needed one parameter, the $\text{flare}_\text{AFP}$, that represents the flare of the hull surface at $x = L_{pp}$ and $z = \text{height}$.

2.3.5 Stem Property Distribution Curves

To characterize the stem surface is necessary to create two property distribution curves: one related with the radius of the surface and another related with the tangent angle between the radial part of the curve and the curved segment. The radius of an imaginary circle on the forward part of the intersection, and the angle that the curve makes in the point of the intersection with the imaginary circle, were analysed (figure 16).

![Figure 16: Stem Properties](image)

To analyse the radius curve distribution (figure 16) tree parameters were necessary. The first one represents the radius of the imaginary circle on $z = \text{draft}$ ($\text{radius}_{\text{DWL}}$), the second represents the radius on $z = \text{draft} + (\text{height} - \text{draft})/4$ ($\text{radius}_{25}$) and the last one the radius on $z = \text{height}$ ($\text{radius}_{\text{Deck}}$).

![Figure 17: Stem - Radius Distribution Curve](image)

To analyse the tangent angle curve distribution (figure 19) it was only necessary to have one parameter that represents the tangent of the intersection curve on $z = \text{height}$ in the point of the intersection with the imaginary circle.

![Figure 18: Stem - Angle Distribution](image)

2.3.6 Stern Bulb Property Distribution Curves

To fully characterize the stern bulb, some property parameters were needed. They are related with the characterization of the radius of the shaft and the volume distribution of the stern bulb.

To characterize the shaft radius, two parameters were created. If the values for the $\text{outer}_{\text{HorizontalAxis}}$ and the $\text{outer}_{\text{VerticalAxis}}$ are the same, the stern bulb will have a circular distribution of volume near the shaft hole, and if the values are different the stern bulb will have an elliptical distribution of volume.

2.4 Surfaces

In this procedure, most of the hull surfaces are created using Meta Surfaces, a concept available on FRIENDSHIP – Framework. The use of this concept, allows obtaining improved continuity across adjacent patches.

To use this type of surface, some Features and Curve Engines, also available on FRIENDSHIP – Framework, were needed to be used, in order to encapsulate the command construction sequence of each surface, and to set the distribution of every feature input.

The developed hull model is composed by twenty three surfaces. The aftbody has six surfaces and the forebody seventeen. The stern bulb was developed with only one surface, while the bulbous bow with three surfaces. In the foreboy the FOS and the FOB-surfaces were divided into several different surfaces, on longitudinal positions where main changes appeared (figure 19).

![Figure 19: Hull Surface Model](image)
2.5 Hydrostatic Calculations

The hydrostatic calculations were made using a feature available on FRIENDSHIP-Framework, that is based on discrete section data. The output of this feature is a set of hydrostatic characteristics: the submerge volume, longitudinal positions of the centre of buoyancy and floatation, waterplane area, and traversal and longitudinal second moment of inertia. With these results, some other hydrostatic characteristics were calculated: the block, midship, prismatic, and waterplane coefficients, and the transversal metacentric height.

2.6 Lackenby Transformation

In order to obtain the desired hull shape, with a certain hydrostatic characteristics, the “Generalized Lackenby Method” available as a Feature in FRIENDSHIP-Framework, was applied.

This transformation is based on the classical Lackenby method (Lackenby, 1950), but besides making a longitudinal shift transformation to the sections, it extends it, by means of a smooth delta curves, where the tangent angles can also be controlled. The initial offset data of the hull ship is slightly moved along the x-axis according to user-defined constraints, as the change of the prismatic coefficient or the change of the centre of buoyancy. It also allows the fixation of the parallel midbody position and length.

2.7 Control Panels

A feature was created to import the data values of each parameter, called “Control Panel”. This feature allows the user to import the data manually or importing an ASCII file. After the data import, the user can change all the input values.

Another feature was created, in order to allow the user to export the values of each parameter, after all the changes have been made.

Finally, another feature was created, in order to export all the validation parameters, the hydrostatic characteristics before and after the application of the Lackenby Transformation, and the resulting desired number of sections characterized by the desired number of points.

3 VALIDATION

After the development of the hull model, a validation was made. To analyse the result values of the validation, the error between the values of the existing hulls and the ones obtain by the application of the hull model developed, was calculated according to equation (1). With the error results, the normal distribution was calculated in order to understand if the values were acceptable or not.

\[
\text{error} \% = \frac{\text{Real} - \text{Model}}{\text{Real}} \times 100
\]

Analysing figure 20, is possible to notice that the average value of the errors are nearly zero, validating the previously presented characterization of the Main Frame curve.

Analysing figure 21 and figure 22, is possible to consider that the set of parameters used to develop the FOB and the FOS curves are suitable for the characterization of the ship types in study, since the differences between the real hulls and the hull model are considerably small. In some cases, the perimeter of the FOS presented considerable differences between the real hull form and the hull model values. This happened in the cases where the run angle of the FOS was too big or in the cases that the FOS had more than one inflection point in the aft and forward curved segments.

The DWL analysis is very important since the geometric characteristics of the waterplane have a big influence on both ship’s hydrostatic and hydrodynamic behaviour. Analysing figure 23, is possible to considered that the used parameters set is valid, since the errors are nearly zero.

The parameter set used to develop the deck contour can be considered suitable for the ship types in study, since the average value for the error were considerably small (figure 24), as well as the parameters considered for generation of the bulb longitudinal and transversal contour (figure 25).

Finally, analysing figure 26 is possible to conclude that the parameter set used to develop the transom panel are acceptable for the studied hulls, since the average error values are very small, with exception for the \(Y_{CG}\) that presented a considerable error between the real hull and the hull model. This happened in the cases where there is not a smooth transition from the linear bottom and the linear side to the curved segment. This measure parameter does not have any meaning for real hulls because every hull has the transom panel \(Y_{CG}\) always equal to zero since there is a symmetry on the hull geometry, but, in the present study, this was done using half of the transom panel in order to better understand the differences between the geometries.

3.1 Submerged hull

To measure the quality of the generated hull surfaces, some hydrostatic characteristics were analysed for the resulting hull before and after the application of the “Generalized Lackenby Method”.

"Generalized Lackenby Method"
From the analysis of figure 28, it is possible to notice that, in some cases, after the application of the Generalized Lackenby Method, the resulting hull presented fewer similarities with the existing hull, than before the application. Despite the discrepancies shown before, it could be concluded that for some cases, the method previously presented is a very good starting point to the hull modelling and reproduction.

Figure 20: Main Frame validation

Figure 21: FOB validation

Figure 22: FOS validation

Figure 23: DWL validation

Figure 24: Deck validation

Figure 25: Bulb Validation

Figure 26: Transom validation

Figure 27: Submerge hull surfaces validation - Before Lackenby

Figure 28: Submerge hull surfaces validation - After Lackenby

4 CONCLUSIONS

A parametric procedure for the generation of the hull forms of merchant ships was developed. A set of 9 geometric and 7 property distribution curves, was identified and characterized. A number of parameters representing either distances, or integral measures or angles, were defined. Some of these parameters can be difficult to define at an early stage of the hull development, especially those related with property distribution curves.

The procedure was implemented using the software tool FRIENDSHIP-Framework, starting with the definition of nearly one hundred parameters, then points, curves and finally the hull surfaces. This approach facilitates the development of a hull from scratch, allowing faster and easier changes on the
form, as well as the automation, quantification and reproduction of the exactly same hull shape with a certain set of input parameters.

In the development of the procedure, some assumptions are made that set limits to the possible shapes. For example, in the definition of the SAC curve, the values of $C_{\text{area}}$ are considered to be larger than the values of $C_{\text{area,Base}}$, and, as studied in some existing hulls, when the DWL intersects the transom panel this does not happen.

At the final stage of the hull development procedure, hydrostatic calculations are done, and the Lackenby Transformation is applied to do small adjustments to the prismatic coefficient and to the longitudinal position of the centre of buoyancy values.

The validation of the procedure was made by the attempt to reproduce existing hulls. For this, the identified parameters were measured and input into the system. The resulting hull shapes were next compared with the original ones. Due to the difficulty in comparing free forms, some metrics were established. Curves were compared based on the enclosed areas, centroids and perimeters, while the complete hulls were compared based on some hydrostatic properties. Although for some curves the discrepancies found were very small, it was possible to validate the set of parameters that were used to characterize them, as well to conclude that the developed procedure can be used to obtain the initial hull model and be applied in some other studies, such as the cargo volume estimation, CFD calculations, and so on, but does not have enough accuracy to be used for production.

4.1 Future Work

The developed hull form model presented some limitations. One of the most relevant was the inability to set the block coefficient as an input. To solve this problem, instead of using the Generalized Lackenby Transformation, that has several limitations, it is advised to apply the developed hull in an optimization procedure, allowing the modification of the SAC, and even for some other parameters chosen by the designer, especially the parameters that were set with the default values, in order to obtain the desired block coefficient.

Another important limitation of the model is the assumption of the halfbeam elevation contour of the bulbous bow as a planar curve and not a 3D curve. In future works, it would be very interesting to define new parameters to characterize this curve as a 3D curve, in order to have an increased flexibility on the bulb generation.

The developed parametric hull model was also built considering only merchant ships with bulbous bow, stern bulb and vertical transom panels, limiting the types of ships possible to reproduce. In the future, it would be very interesting to have the possibility to develop a hull form with the optional addition of bulbous bow and stern bulb, and even the possibility to have an inclined transom panel, as it happens in many merchant ships, and even to extend the study and the model to other ship types.

In order to obtain a hull form with improved fairness as required for production, is advised to introduce a set of parameters for the characterization of the surfaces itself and not only for the curves, thus having a bigger control on the hull shape and fairness, especially for the surfaces where the property distribution curves are difficult to analyse and characterize.

5 REFERENCES


