Development of a hull generation method based on FORMDATA systematic series

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Abstract

Hull design is an important, demanding and time-consuming component of ship design. Therefore, hull design tools to be used in the preliminary steps to quickly generate one or several hulls could have a significant impact on the ship design process. Developing a method to generate such a tool was the primary objective of this project based on a systematic series existing in the public domain, the FORMDATA series. A FORMDATA hull was created and tested using MATLAB software, by modelling based on parameters (e.g. slopes, number of sections and hull type). Further development of the generated FORMDATA hull was made by adding parameters and constraints allowing for a more detailed hull form. This detailed hull provides the designer with more information, e.g. flat of bottom, deck at edge curve, waterlines, giving a better understanding of its shape, constraints and determinants. Several solutions for different hull forms and initial parameters were tested. The results showed a positive performance of the method, thus opening new perspectives on the use of these methods in hull design. A relevant initial result was the digitalisation of the FORMDATA series sections, previously only available in raster graphics format, thus making it available for future use by hull designers or researchers.

Keywords: Hull shape generation, FORMDATA, systematic series, hull design, ship design.

1. Introduction

Ship design is a long process involving several steps that are repeated in a series of optimization iterations. Hull design is, therefore, the first and probably the most time-consuming step and with the greater impact on the ship's performance, since it is the core of the ship, determining cargo layout, ship's systems and its hydrodynamic behaviour (Maisonneuve et al. 2003). Several research and development studies have addressed the complexity of the hull shape due to the complicated surfaces which are very difficult to represent mathematically and, therefore, to define the form in a manner suitable for construction purposes.

A fully parametric design method where the hull shape is directly connected to parameters that the designer can easily change to quickly modify the hull shape would be the best goal. The increasing computing power available to designers and the advances o CAD software made possible the development of the hull shape as a whole, translating into a faster and more detailed design. Unfortunately, most known CAD programs do not support parametric design and the steps taken to bring parametric methods into these programs, mostly by way of plugins, still have a long way to go, especially when dealing with complex surfaces, like the ones found in bows and sterns of ships.

The main objective of hull form definition is to develop a geometric description, where all the relevant physical and geometrical characteristics, such as displacement or waterplane area, are met with an acceptable fair shape. Adapting an existing hull shape is a common practice for the shipyards, which use data from previous projects to set up an initial hull which serves as a starting point for the new vessel. An advancement in the modelling approach will improve significantly both the design process and the results achieved. Wilson et al. (2010) created a computational tool for early stages ship design optimization which saves developing time and allows for better decisions that will reduce costs along the process.

As a fully parametric design is not a feasible option for now, most hull shapes are still designed based on a parent hull. This initial hull shape needs to comply with the targeted parameters and have an adequate general form. Ship hull design and its representation through mathematical descriptions has a long tradition (Nowacki et al. 1995, Walker 2010). Systematic hull forms using mathematical functions have been presented since 1915 (Taylor 1915) and subsequently developed, often for specific ships types. The FORMDATA series developed by the Technical University of Denmark (Guldhammer, 1963) is the most complete and modern of all the series available in the public domain and responds well to the hull form requirements of modern merchant ships. This series has been developed based on the analysis of the geometric data of a high number of existing ships in the 1960’s and of earlier systematic series, also considering their hydrodynamics. Other series exist resulting from hull form optimization with CFD tools and accumulated experience of ship model experiments, although not in the public domain.

The FORMDATA series provides data both for the determination of the hydrostatic/stability characteristics of the ship during the preliminary design stage and for the required propulsive power (Guldhammer and Harvald 1974). It provides, in a systematic way, “*the ordinates of sections (offsets) in dimensionless percentages of the beam and of the reference draft*” (Papanikolaou, 2014). The ship sections forms are given in proper scale instead of needing to be developed based on determined sectional areas, thereby greatly reducing the effort for the drafting of the ship lines.

The objective of this study is to develop a hull shape generator method based on FORMDATA systematic series. By transforming the FORMDATA series and using the initial parameters, a hull shape can be generated through a series of interpolations. This is meant to be a fast process, allowing the designer to test several ideas and designs in a short period of time. The solutions obtained for the ship are not optimal, but they are possible solutions that can further be refined along the optimization design process.

2. Method

The developing process is divided into three parts: definition of the initial parameters, FORMDATA series hull form and new hull shape, with each part having its own purpose. The tool used to support and test the creation of the hull shapes was MATLAB, a mathematical programming tool.

Base data on hull shapes for different types of hulls was obtained from FORMDATA, by determining the coordinates of points directly on the figures containing the hull sections. Since FORMDATA is only available on paper or raster format, the coordinates from all sections available in FORMDATA series (DocNet 2019) were measured and compiled into one digital file. These coordinates are grouped by section. Each section has a longitudinal coordinate on the hull. The hull is defined length wise with the origin of the coordinate system at the intersection of the aft perpendicular with the base line. The division between stern and bow is made at half the length.

The initial parameters of the hull shape design are the first thing to define and specify. The basic properties defined are length between perpendiculars (L_{pp}), breadth (B), draught (T), depth (D), block coefficient (C_b) and longitudinal centre of buoyancy (L_{cb}). It is important to note that the L_{cb} has its zero at half the L_{pp}, being positive if it is forward or negative if behind.

To develop a FORMDATA hull shape using the initial parameters given, two additional coefficients are needed: the aft block and the fore block coefficients, or C_{ba} and C_{bf} respectively.

Once both these coefficients are defined it is necessary to convert the FORMDATA section figures into points. The points chosen were spaced vertically along the section lines with an even spacing of 0.1 in the y-axis in order to keep a constant variation.

This method was applied to all sections, for all types of sterns and bows resulting in a large list of points. All these points were gathered in a matrix for each section and each type of hull. The bulb sections were divided into two segments: Section 10A and Section 10B. Section B is the bulbous part and section A is the rest of the section.

These sets of points were arranged by type of hull. First was by stern (T type, U type, V type or C type) for the sections between the stern and midship then by types of bow (U type, N type, V type, Bulb 4% of A_M, Bulb 5% of A_M, Bulb 8% of A_M and Bulb 10% of A_M).

Once the pretended type of stern or bow is identified, another condition is necessary to align the correct set of points to its corresponding section, which is the C_b. Only the U type stern for non-tanker ships has two C_b possibilities: 0,98 or 0,995. Once the corrected C_b is identified it is possible to proceed to assemble the sets of points depending on the C_{ba}, for sterns, or the C_{bf}, for bows. Multiple values for $C_{ba/}$ C_{bf} exist for each C_b.

To account for the possibility of the pretended $C_{ba/}$ C_{bf} not matching exactly an existing value, the program will do a linear interpolation between both sets of points from the adjacent $C_{ba/}$ C_{bf}. All sections are calculated using this method. However, depending on the type of stern or bow, the number of sections differs.

Once every section is defined by its set of points, a smoothing spline is fitted to the set. This allows to maintain the slope at each point, but the line shape will be smoother between each point despite missing, by a very small margin, the intended point.

In order to obtain more information and thus improving the method, a complete set of waterlines is obtained from the sections. By crossing each section at several heights, in this case evenly spaced by 0.1, the waterlines points are obtained. Filtering these points by height, a set of lines, the waterlines, can be obtained. The top waterline, at deck height, is the deck edge curve, while the bottom waterline represents the flat of bottom. Using these waterlines, any number of sections can be extracted. In this project, 21 equally spaced sections were developed, and a shape preserving spline was fitted to the extracted points.

This new set of sections was further developed by splitting the curves in two: above waterline and below waterline. To the sections below the water line a condition was used to define the bottom slope and the waterline slope. To the sections above the waterline, the same waterline slope was used, and the deck slope was added.

All possible adjustments are implemented, and a final representation of the designer's intention can be developed. Of course, this does not mean that it will only take one attempt to get the hull shape. However, this fast method will not only aid the designer in the hull shape definition but also provide visual aid to continue the design process or repeat this first part with new or improved information.

Four cases of different hull forms were tested to prove the performance of the developed method: 1) U shape hull – Tanker ship; 2) T-transom hull – Container ship;3) V shape hull – Ro-Ro ship; 4) N shape hull – Bulk carrier ship. The initial parameters set for the different ships are compiled in Table 1.

Table 1 - Initial parameters set for the four tested cases: Case 1: Tanker ship; Case 2: Container ship; Case 3: Ro-Ro ship; Case 4: Bulk carrier ship

Parameter	Case 1	Case 2	Case 3	Case 4
Lpp (m)	320.00	286.00	43.50	173.00
B (m)	44.00	40.00	9.00	29.80
D (m)	21.00	24.20	2.70	16.10
T (m)	14.60	13.75	1.80	10.60
CB (-)	0.7	0.63	0.7	0.68
CM (-)	0.98	0.98	0.98	0.98
LCB (m)	-5.0	-10.0	-5.0	0.8
BowTypeU (-)	1	1	1	1
SternU (-)	1	1	1	1

3. Results and discussion

The first result was the digitalization of the FORMDATA series sections. This involved the measurement of a large number of points in a very laborious and time-consuming process. The MATLAB program, which was developed, incorporates the whole point cloud from the FORMDATA series and was built to test the method without producing errors. The program is light and fast and was designed with an easy to use approach.

All the four cases with different hulls that were tested, using the developed program, produced good results. Here only the first case regarding a tanker ship will be thoroughly analysed and graphically represented.

The parameters selected for the tanker ship produced the FORMDATA hull represented in Figure 1, demonstrating a good shape that can be used to begin the hull development. This shape is adequate but also demonstrates a possibility for improvement, especially around the turn of bilge since this area should show a more rounded contour. The waterlines, deck at edge and flat of bottom curves obtained with the method proved to be fitting for the hull type chosen, as shown in Figure 2.

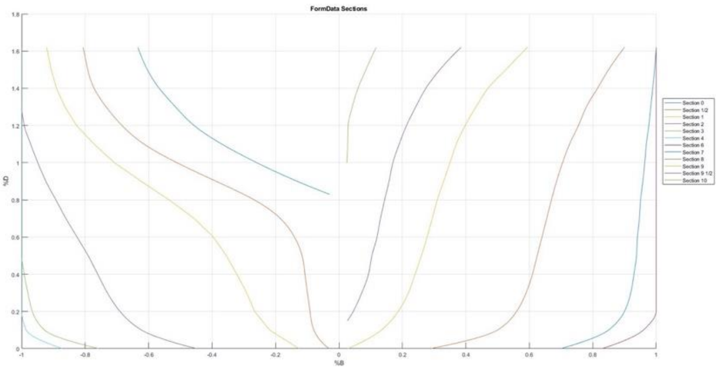

Figure 1 - Case 1: FORMDATA hull sections

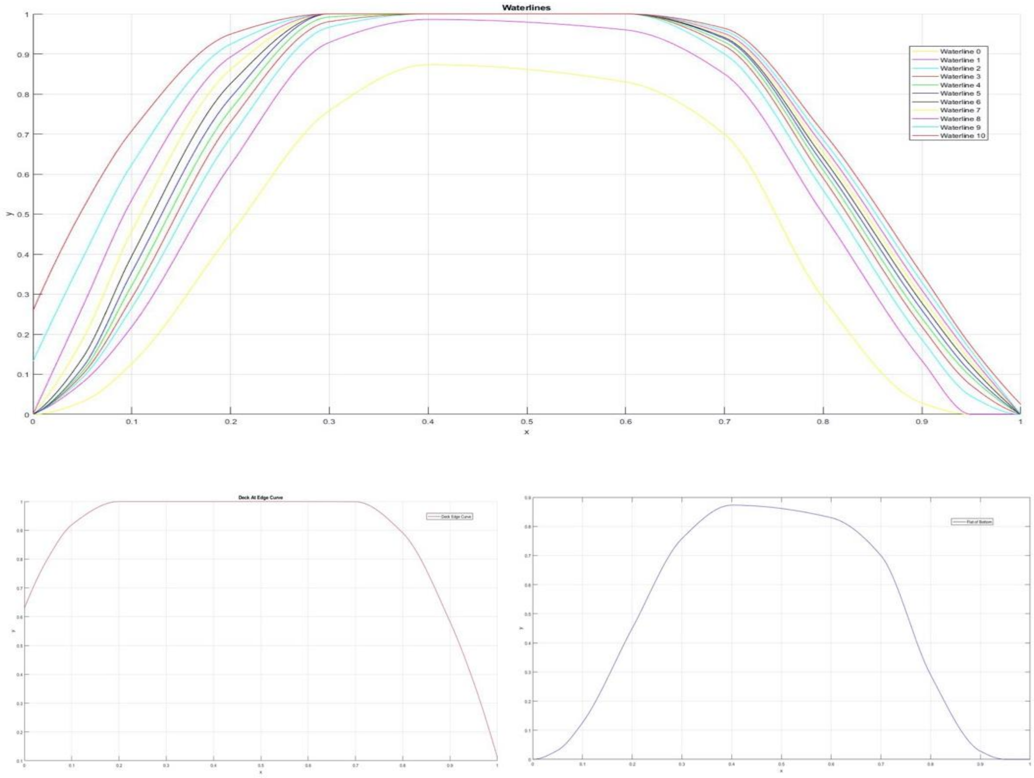

Figure 2 - Case 1: Waterlines (upper figure), Deck Edge Curve (bottom left) and Flat of Bottom curves (bottom right)

By combining the curves obtained and the slope curves, the final sections can be defined. Figure 3 represents the section lines above and below waterline where it is possible to see that good results were obtained for the hull sections of this tanker. In fact, the generated section lines have a better shape when comparing them to those from the previously generated FORMDATA hull.

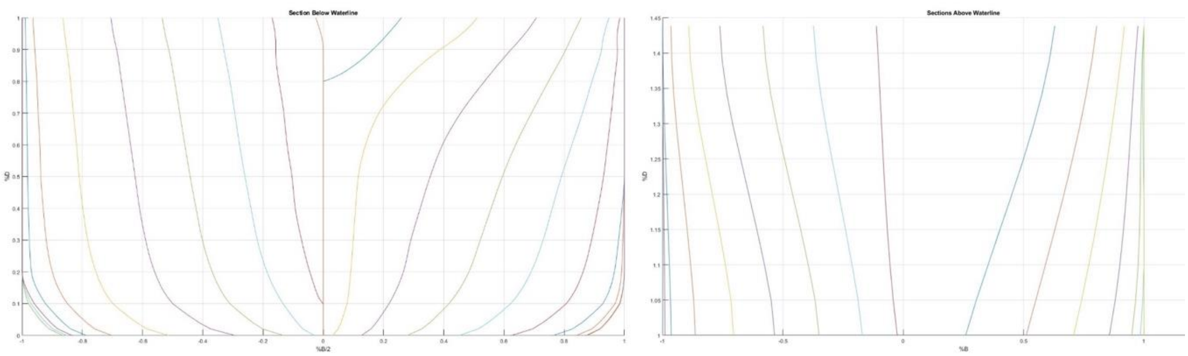

Figure 3 - Case 1: Sections below (left) and above (right) the waterline

The section area curve can be defined from the previous results as represented in Figure 4. The final results can be developed and their representation in Figure 5 proves that the method not only works but also that it produces good results. The final sections look very satisfactory and make a good base to start developing a hull based on them. The turn of bilge still needs some improvement, but the general shape is very adequate. The connection between the two parts below and above waterline also needs some refinement, which will improve the development of the section from the waterline up.

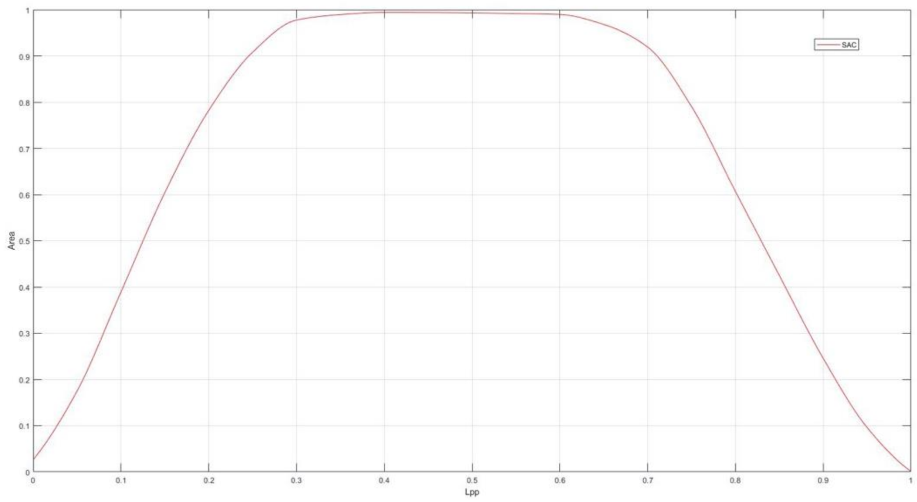

Figure 4 - Case 1: Sectional Area Curve

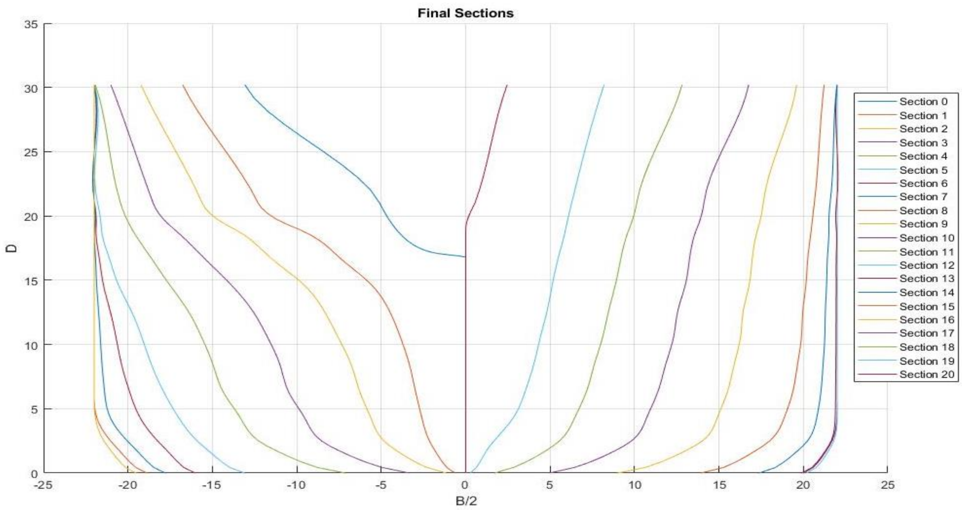

Figure 5 - Case 1: Final Sections

All the other cases were tested in the same conditions and produced similar good results. The hull shapes that represent the bulbous part will require further development at a later stage in the design spiral of ship design, since it is a difficult shape to represent. However, the bulbous part is an area that has its own development stage due to the huge impact it has on the hull performance.

4. Conclusion

Hull form design is a laborious and time-consuming task which keeps evolving as new designs and new optimization methods are developed. In this context, the goal of this project was to facilitate this process by speeding up the first step of producing a numeric description of a hull shape on which further work can start. This initial hull form is not optimized, but rather a possible hull that meets the initial dimensions and form parameters of the designer. The possibility to quickly change the parameters or hull type allows the designer to quickly and efficiently produce, test or study new hulls.

The results obtained were good and showed that the initial goals were met. This method can be useful to create several different hulls and can be further developed to improve its outputs and range. The process was rather difficult and required an in-depth study of the hull development and its requisites. The program, however, has limitations, some derived from the FORMDATA series it incorporated and others from the written code itself.

Some improvements are possible, starting by expanding the point cloud obtained from FORMDATA and combine it with newer data obtained from recently build ships, and also by incorporating the data points from the fully developed and optimized hulls that derive from this method. In this way an expandable database of hull forms could be developed, producing better results every time.

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