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A Simple Combined Method for Parametric Generation of Ship Hull Variants

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Abstract

The ship's performance at sea can be influenced by multiple parameters, especially the hull design. Its geometry affects the vessel's behavior, structural integrity, and overall efficiency while crossing the water surface. While the process of hull form generation can involve complex mathematical models, sometimes requiring considerable computational effort, this paper presents a simple method based on the combination of polynomial functions with Lewis mapping techniques. Initially, using a frigate hull as the base model, a code was developed to generate variations of its geometry according to the proposed methodology. Through this approach, it was possible to derive variations of the original hull model, each differing in only one of the considered shape parameters, providing a valuable tool for hull geometry analysis in ship design.

Keywords: Lewis mapping, Hull geometry, Parametric hull design

1. Introduction

Developing methodologies to modify hull geometry plays a key role in optimization processes. When conducting performance analyses that involve global hull shape modifications, parameterizing the geometry using specific descriptors proves to be the most effective way to evaluate such changes.

Several studies have been conducted using different parameters and performance indicators [1] aimed to optimize the geometry of destroyer-type hulls by correlating seakeeping responses with certain shape parameters through regression analysis.

The studies published by [2] were based on an analytical method for seakeeping optimization. They developed a code to generate variations of a baseline hull model, which were evaluated based on performance under certain aspects, including the response of these models to specific types of motion [3]. Assessed the influence of hull geometry and dimensional variations on vertical response motions, as well as their effects on crew comfort and the risk of propeller emergence.

Aiming to generate geometric modifications to hulls and directly obtain an optimized solution [4], proposed a methodology combining polynomial functions with Lewis transformations. Although the results demonstrated significant performance improvements under the study's assumptions, the resulting hull shape was deemed impractical for real-world applications. All of these studies employed strip theory formulations to compute ship motions.

The study presented in [5] evaluated the performance enhancement of a catamaran vessel. In this work, geometric modifications of a baseline model were generated using the Lackenby algorithm, producing variations in the block

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coefficient and the longitudinal position of the center of buoyancy within a 10% range. The results indicated that changes in specific hull parameters had a significant impact on the vessel's seakeeping performance.

Recent advancements in parametric hull modeling, optimization, and CFD-based performance evaluation have led to the development of several cutting-edge methodologies. These recent studies incorporate the latest technological innovations in the field [6]. Applied a parametric modeling approach combined with CFD simulations to optimize the hull geometry of containerships, focusing on minimizing resistance. This research is a prime example of how computational fluid dynamics can be utilized to improve vessel efficiency [7]. Introduced a novel hull modeler based on Generative Adversarial Networks, which are deep learning techniques capable of generating diverse hull forms. This approach represents a significant leap in the ability to design hulls using AI-driven methods. In [8], fully-parametric models of the hull, propeller, and rudder were used in an integrated optimization process aimed at improving overall hydrodynamic performance. The study highlights the benefits of employing a comprehensive, multi-component optimization framework for enhancing vessel performance. Finally, utilized deep neural networks to expedite the hull form optimization process for small vessels, offering an innovative solution for faster and more accurate optimization in smaller-scale applications [9].

The methodology presented in this article was originally used by [10] to analyze the effects of certain hull shape parameters on the occurrence of slamming, an event characterized by the violent impact of the vessel's structure on the sea surface. The results obtained in this study indicated the possibility of considerable performance improvements in seakeeping behavior through modifications of the analyzed geometric parameters. The detailing of the hull geometry variation process is presented in the following sections.

2. The Baseline Model and the Variation Process

This research used the hull configuration of the Dutch Friesland-class frigate as the baseline model, which has various published data, including its body plan and seakeeping performance measurements, as presented by [11] and [12]. Figure 1 represents the model through 21 bilge sections. The main characteristics are presented in Table 1.

A specific code was developed for generating new hull geometries, considering the following elements as constants relative to the original model: B, T, L_{pp} and the hull centerline profile (Figure 2 illustrates these constraints, highlighted on the baseline model).

Based on these premises, the mathematical description of the new hull geometries was obtained in two stages. Initially, the intersection curves between the flotation plane and the hull were modeled based on the variation of parameters S1, S2, and S3, using third-degree Bézier polynomial curves. For its definition, control points are established at the extremities, delimiting its beginning and end, as well as intermediate points to define the contour. The generic formulation of the

Table 1. Main characteristics

L_{pp}	112.4 m
B	11.74 m
T	4.01 m
C_B	0.562
CG	55; 0; 5 m
Displacement	3046 t

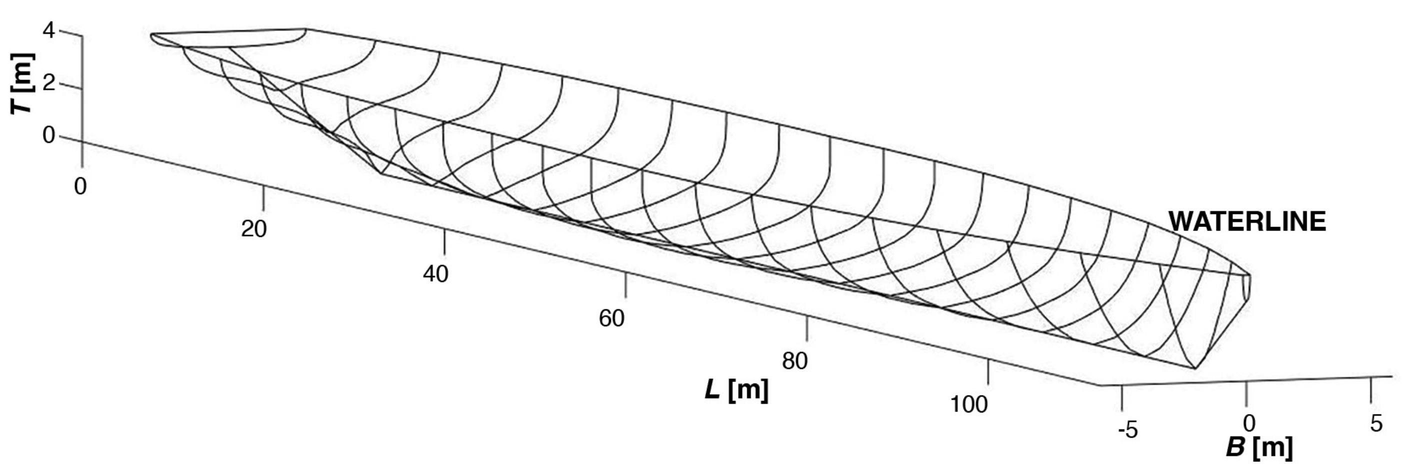

Figure 1. Hull model of the frigate "Friesland"

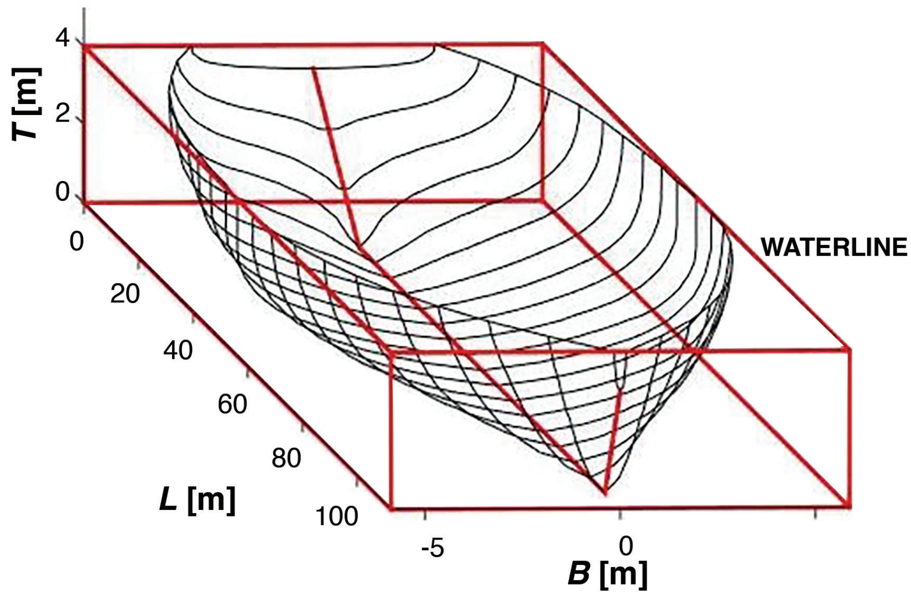

Figure 2. Variation limits on the baseline model

Bézier curve is presented in Equation 1, while its cubic form is represented in Equation 2.

$$B^n(t) = \sum_{i=0}^{n} B_i^n(t)\, b_i \quad (1)$$

$$B(t) = (1-t)^3 B_0 + 3t(1-t)^2 b_1 + 3t^2(1-t) b_2 + t^3 b_3 \quad (2)$$

Here, $B^n(t)$ are the Bernstein polynomials, b_i the control points defining the curve's shape, and t the interpolation parameter along the curve. Figure 3 illustrates a typical cubic Bézier curve and its control points.

The process of modeling the hull contour in the flotation plane is illustrated in Figure 4. The hull contour is defined by two Bézier curves connected at point B, which is fixed at the beam amidships. The first curve is governed by parameters S1 which also determines the stern width and S2, along with the fixed control points P1 and B. The second curve depends solely on parameter S3, with the other control points B, P2, and P3 held constant. Parameters S1, S2, and S3 vary only in the longitudinal direction. Figure 4 also shows five hypothetical positions for S2 and S3, highlighting the resulting variations in hull shape.

It is important to highlight that the method also constrained the Bézier curves in the transverse direction, ensuring they did not exceed the original beam (B). This restriction preserves the realistic proportions of the hull, maintaining its consistency with actual ship forms. The resulting hull contour, after applying this constraint, is shown in Figure 5.

Once the flotation contour was defined, the hull was modeled using Lewis transformations with two parameters for 21 transverse sections. This method was selected to simplify the hull generation process and reduce computational effort, while still capturing the essential geometric characteristics.

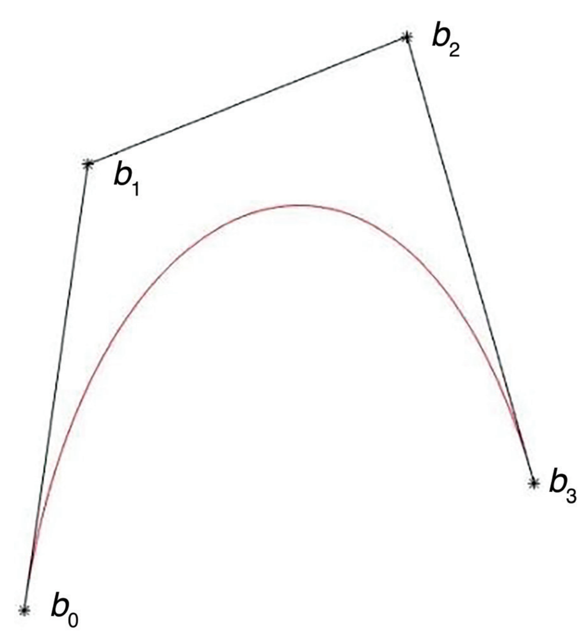

Figure 3. Cubic Bézier curve
Source: [10]

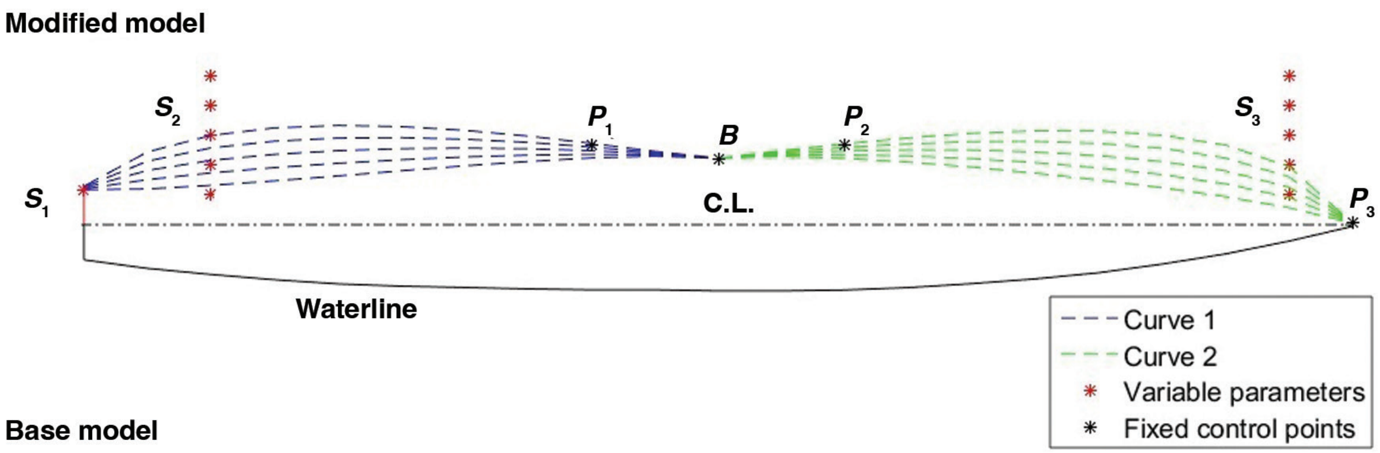

Figure 4. Variation of parameters S1, S2 and S3

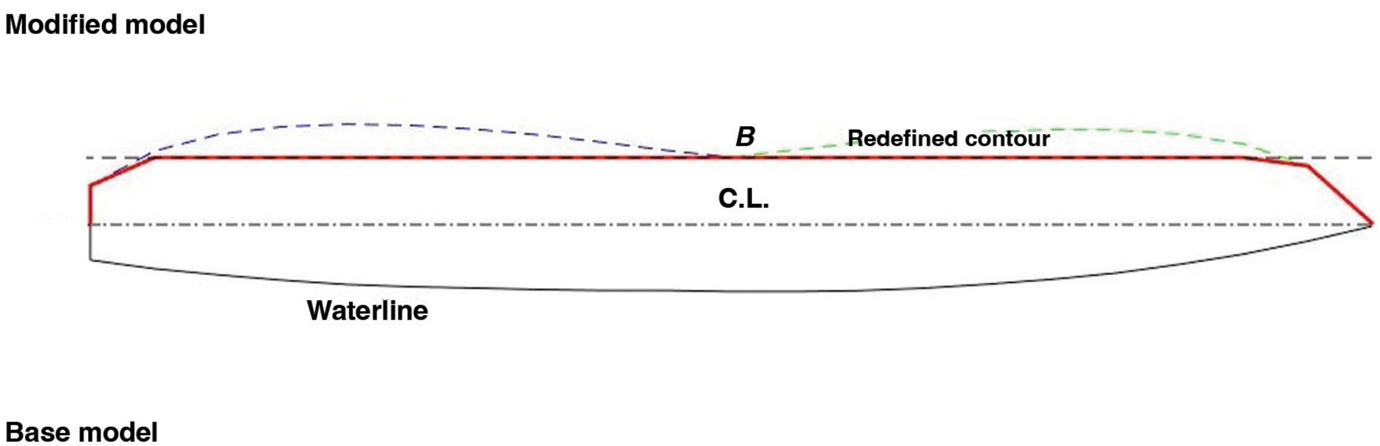

Figure 5. Limitation on the waterline contour

As discussed later in the text, a follow-up study is proposed to explore potential improvements introduced by incorporating a third parameter. The Lewis method [13] transforms a circular shape (Equation 3) into an arbitrary hull section (Equation 4):

$$\zeta = i e^{\alpha} e^{-i\theta} \tag{3}$$

$$z = x + iy \tag{4}$$

The transformation described in Equation 5 maps points from the ζ-plane to their corresponding locations in the z-plane, provided the coefficients of the mapping function are properly defined.

$$z = M_S\left(a_{-1}\zeta + a_1\zeta^{-1} + a_3\zeta^{-3} + a_5\zeta^{-5} + \dots\right) \tag{5}$$

The Lewis formulation employs only two parameters, resulting in Equation 6:

$$z = M_S\left(a_{-1}\zeta + a_1\zeta^{-1} + a_3\zeta^{-3}\right) \tag{6}$$

By substituting Equations 3 and 4 into Equation 6 and separating the real and imaginary parts, one can obtain parametric equations that map the arbitrary shapes in the z-plane, as given by Equations 7 and 8:

$$y_S = M_S((1 + a_1)\sin\theta - a_3\sin3\theta) \tag{7}$$

$$z_S = M_S((1 + a_1)\sin\theta - a_3\sin3\theta) \tag{8}$$

Where M_S is the scaling factor and a_n the mapping function coefficients. For the shape of ship sections, the section ratio between the ship's half-beam and draft can be given by Equation 9, while the section area coefficient is obtained through Equation 10.

$$H = \frac{B_S/2}{D_S} = \frac{1 + a_1 + a_3}{1 - a_1 + a_3} \tag{9}$$

$$\sigma = \frac{Area}{B_S D_S} = \frac{\pi}{4}\left(\frac{1 - a_1^{\,2} - 3a_3^{\,2}}{(1 + a_3)^2 - a_1^{\,2}}\right) \tag{10}$$

Using the described formulations, hull-like curves can be generated with only two parameters: the H ratio and the sectional area coefficient. Figure 6 shows examples of curves produced by this method, where H is the beam-to-draft ratio and σ is the sectional area coefficient.

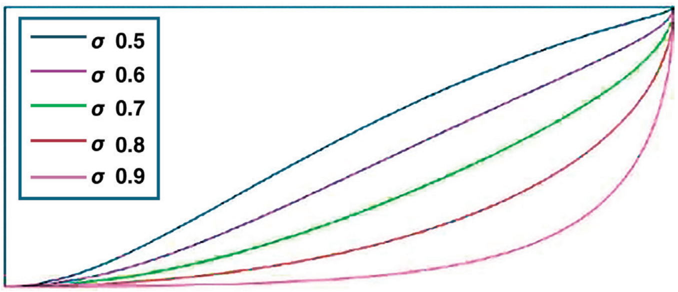

Figure 6. Typical geometries generated using Lewis' technique
Source: [10]

In each section, the H ratio is predetermined, since B_S follows the flotation contour obtained in the previous step, and the hull centerline profile remains fixed. Therefore, only the area coefficient needs to be specified. The coefficients for sections 1, 11, and 21 are directly provided (corresponding to input parameters B1, B2, and B3), while the coefficients for the remaining sections are automatically generated by the code using polynomial interpolation. This approach ensures smooth transitions between sections and prevents abrupt geometric variations. As a result, the entire process of generating hull variants requires only six input parameters.

3. Applying the Method to Obtain Specific Variations

3.1. Selection of Hull Shape Parameters

The described process combined simple formulations, enabling hull variant generation with low computational demands. This aspect is relevant when aiming to obtain a high number of variations, allowing for the filtering of characteristics in a specific manner.

In [10] work, the aim was to evaluate the effect of varying certain parameters on the slamming effect. To achieve this purpose, hull variants were used, each with only one of these parameters altered to an extreme maximum or minimum value.

For the analysis of hull geometry modification, the following shape parameters were selected:

- Dimensionless longitudinal center of buoyancy (LCB/L_{PP})
- Dimensionless longitudinal center of buoyancy (LCB/L_{PP})
- C_B
- C_{WP}

The objective of the method is to obtain variations of the original hull model in which only one of the four shape parameters differs from the baseline configuration. The resulting extreme cases, each isolating the influence of a single parameter, are designated as follows:

- *LCB*(+), with the center of buoyancy closer to the bow
- *LCB*(-), with the center of buoyancy closer to the stern
- C_B(+), with the highest block coefficient
- C_B(-), with the lowest block coefficient
- *LCF*(+), with the center of flotation closer to the bow
- *LCF*(-), with the center of flotation closer to the stern
- C_{WP}(+), with the highest waterplane area coefficient; and
- C_{WP}(-), with the lowest waterplane area coefficient

To generate these models, a large set of hull geometries was produced by systematically varying six input parameters S1, S2, S3, B1, B2, and B3 using a custom-coded routine. These parameters control the shape of the Bézier waterline curves and the Lewis section profiles. Although they do not directly correspond to high-level form coefficients, the code automatically filters the generated hulls, retaining only those in which a single coefficient C_B, C_{WP}, *LCB*, or *LCF* varies significantly, while the others remain within a narrow tolerance based on the form coefficients of the baseline hull. This indirect approach enables the construction of controlled geometry sets suitable for isolated parameter analysis, as illustrated in Figure 7.

The calculation of the four hull shape parameters is straightforward and accurate, given that the bilge and waterline contours are defined using Bézier and Lewis formulations. To compute these parameters, the generated hull is decomposed into simple geometric elements such as trapezoidal prisms whose centroids and volumes can be easily determined and integrated to obtain the desired characteristics.

3.2. Results

By varying the six parameters described earlier, approximately 10 million hull configurations were generated. Owing to the simplicity of the computational method, this process could be completed on a standard personal computer in approximately one hour. After applying the filtering criteria illustrated in Figure 7 which selected only the configurations falling within one of the four predefined ranges for each form coefficient just over 2,000 variations were retained. The remaining configurations were discarded for failing to preserve three of the dimensionless parameters at values approximately equal to those of the original model.

From the filtered dataset, eight extreme variations were selected for further analysis. Tables 2 to 5 present the highest

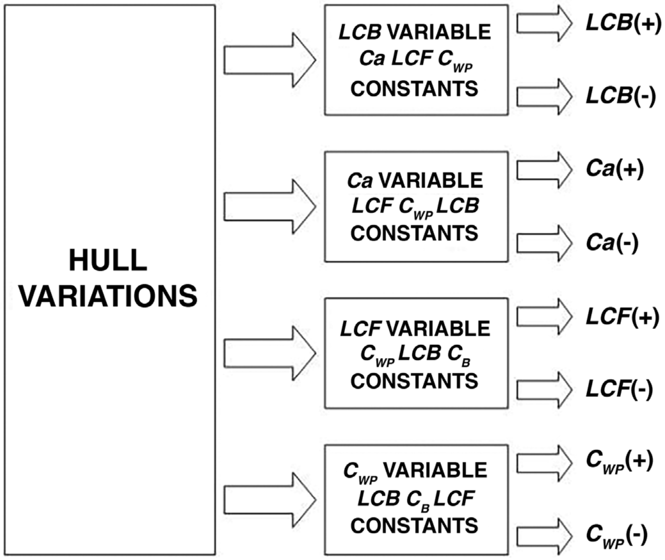

Figure 7. Variant selection process

(+) and lowest (-) non-dimensional values obtained for each form coefficient.

Figures 8-11 show the baseline plan of the 8 extreme variations obtained at the end of the process.

3.3. Stability Analysis

In order to ensure the basic feasibility of the generated hull models, the eight selected extreme configurations were subjected to initial and intact stability analyses. The initial equilibrium condition of the hull is assessed through the metacentric height (GM > 0), according to Equation 7:

$$GM = KB + BM - KG \tag{7}$$

The value of KB (Center of Buoyancy) was calculated based on the submerged geometry of the hull, while KG was previously established and fixed. The metacentric radius (BM) can be obtained from the relation in Equation 8, for small angles:

$$BM = \frac{I}{\nabla} \tag{8}$$

Where α is the heeling angle, I is the area moment of the waterplane about the ship's longitudinal axis, and ∇ is the volume displaced by the ship.

For intact stability assessment, the guidelines established by the International Maritime Organization (IMO) were adopted, according to resolution A749(18), (IMO, 1993). Basically, calculations are made based on the static stability curve for a given hull, briefly described in Table 6.

The results of the intact stability analysis for the eight hull variants are presented in Table 7, indicating compliance with the specified criteria.

Table 2. Variations *(LCB/L_{PP})*

261 variations	(%)	*LCB*(-)	Base	*LCB*(+)	(%)
LCB/L_{PP}	8.63	0.447	0.489	0.510	4.26
C_B	0.18	0.563	0.562	0.561	0.18
LCF/L_{PP}	0.24	0.462	0.461	0.461	0.14
C_{WP}	0.25	0.796	0.794	0.792	0.25

Table 3. Variations *(C_B)*

892 variations	(%)	C_B(-)	Base	C_B(+)	(%)
C_B	36.30	0.358	0.562	0.590	4.98
LCB/L_{PP}	0.21	0.490	0.489	0.489	0.06
LCF/L_{PP}	0.24	0.462	0.461	0.462	0.24
C_{WP}	0.25	0.796	0.794	0.796	0.25

Table 4. Variations *(LCF/L_{PP})*

168 variations	(%)	*LCF*(-)	Base	*LCF*(+)	(%)
LCF/L_{PP}	5.72	0.435	0.461	0.515	11.75
C_{WP}	0.13	0.793	0.794	0.793	0.13
LCB/L_{PP}	0.07	0.489	0.489	0.491	0.42
C_B	0.36	0.560	0.562	0.559	0.53

Table 5. Variations *(C_{WP})*

790 variations	(%)	C_{WL}(-)	Base	C_{WL}(+)	(%)
C_{WP}	2.14	0.777	0.794	0.867	9.19
LCF/L_{PP}	0.34	0.463	0.461	0.460	0.28
LCB/L_{PP}	0.50	0.492	0.489	0.492	0.50
C_B	0.18	0.561	0.562	0.561	0.18

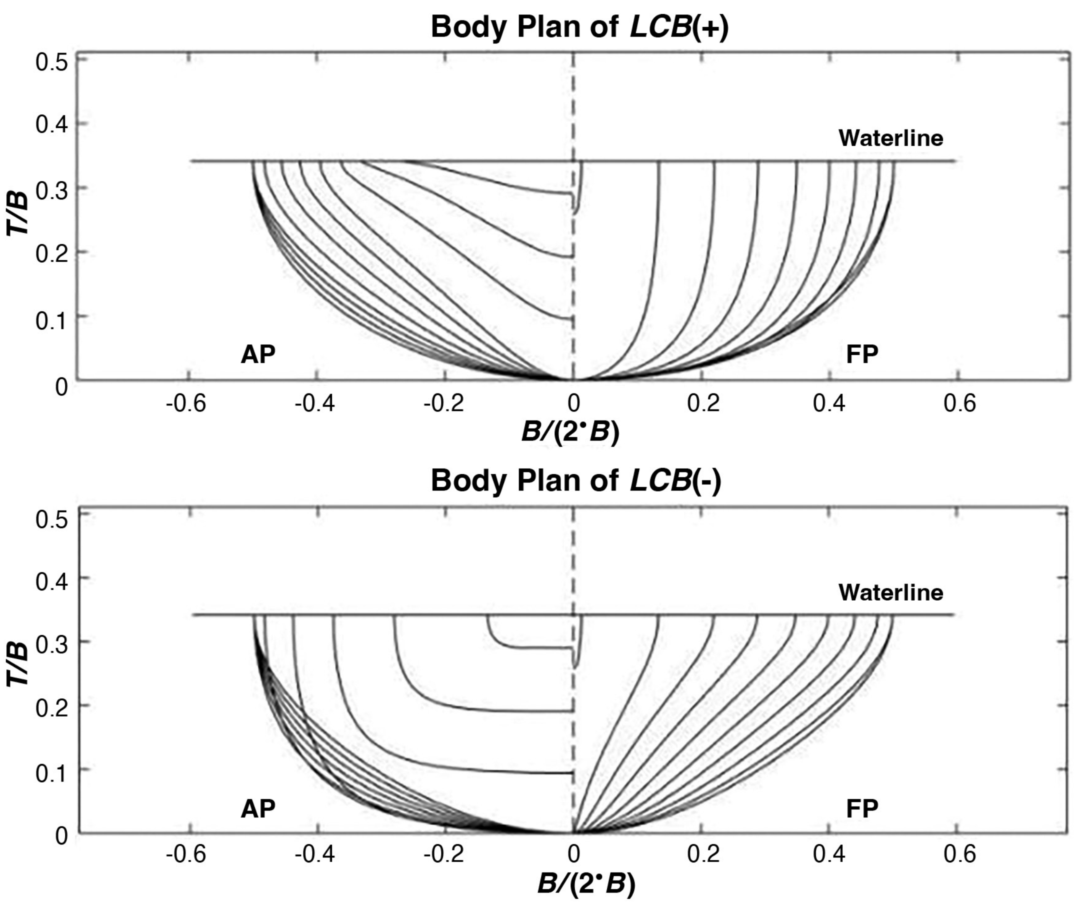

Figure 8. Extreme variations of *LCB*

3.4. Comparison with CAD-based Methods

Unlike CAD-based tools such as Rhino, Delftship, or Maxsurf, where geometric variations are usually introduced by manipulating control points or hull curves directly, the methodology presented here focuses on varying high-level form coefficients *(LCB, LCF, C_{WP},* and *C_B)*. Since most CAD tools do not allow direct manipulation of these coefficients independently, achieving isolated variations in these parameters often requires manual trial-and-error. In contrast, the approach adopted in this paper automates this process through indirect parametric control, enabling the generation of hull forms where only one parameter varies significantly while the others remain near constant.

Table 6. IMO intact stability requirements

No.	Criteria	Requirement
1	Area *GZ* < 30° (m.rad)	0.055
2	Area *GZ* < 40° (m.rad)	0.09
3	Area *GZ* 30° < < 40° (m.rad)	0.03
4	Max. angle *GZ* (°)	25
5	*GZ* at 30° (m)	0.2
6	Initial *GMt* (m)	0.15
7	Equivalent angle for crew concentration (°)	10
8	Equivalent angle for yawing (°)	10

IMO: International Maritime Organization

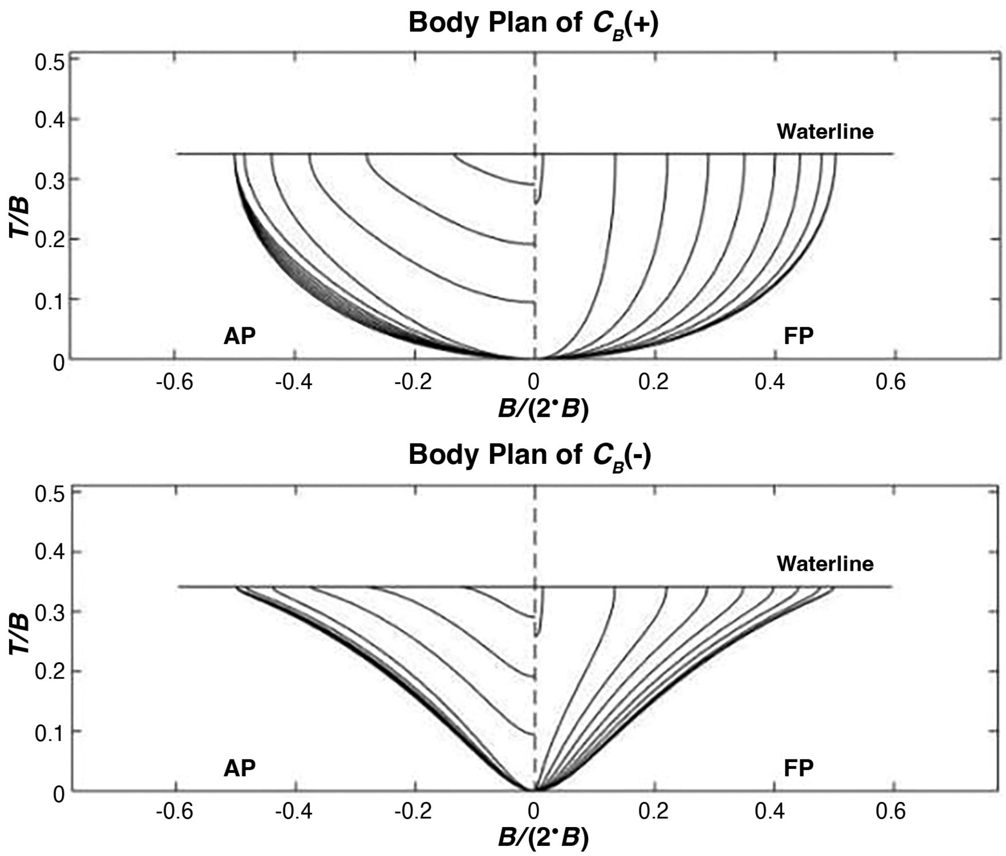

Figure 9. Extreme variations of C_B

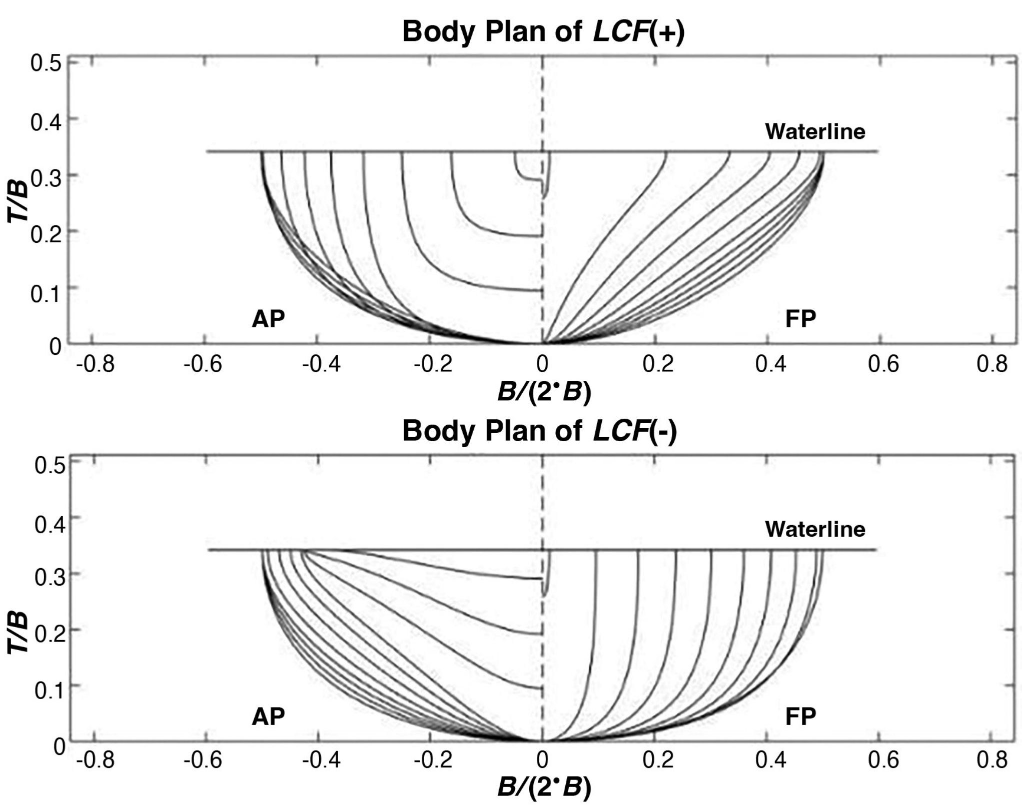

Figure 10. Extreme variations of *LCF*

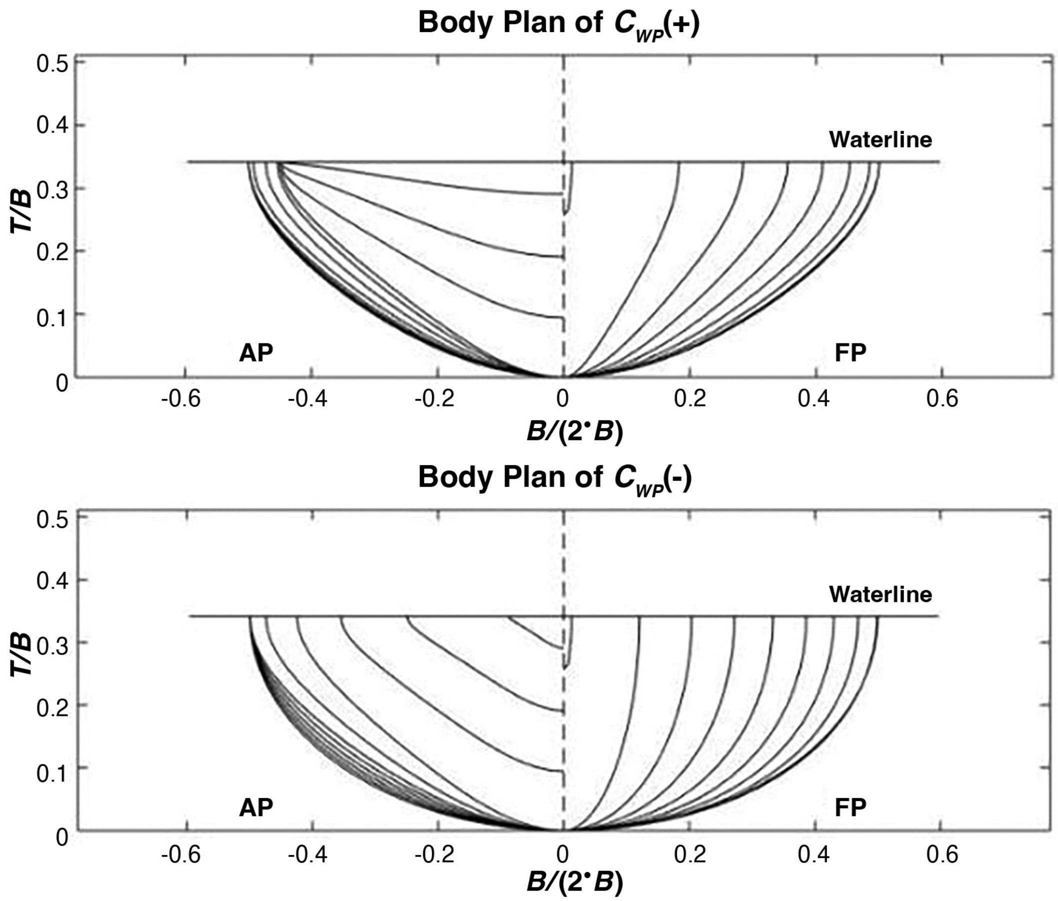

Figure 11. Extreme variations of C_{WP}

Table 7. Stability criteria results

Criteria	*LCB*(+)	*LCB*(-)	C_B(+)	C_B(-)	*LCF*(+)	*LCF*(-)	C_{WP}(+)	C_{WP}(-)
1	0.059	0.087	0.063	0.211	0.079	0.065	0.145	0.067
2	0.094	0.140	0.099	0.326	0.127	0.104	0.230	0.105
3	0.035	0.054	0.037	0.115	0.047	0.039	0.085	0.038
4	31.8	31.8	30.9	36.4	31.8	31.8	32.7	30.9
5	0.217	0.322	0.234	0.669	0.286	0.238	0.501	0.241
6	0.481	0.658	0.456	2.611	0.656	0.572	1.259	0.518
7	3.5	2.5	3.3	1.2	2.5	3.1	1.3	3.1
8	5.6	3.9	5.6	1.2	4.0	5.0	2.1	5.0

The ranges used for comparison in Table 8 are based on values typically found in naval architecture literature and CAD-based modeling tools. For instance, [14] indicate block coefficient values between 0.55 and 0.60 for fast naval vessels such as frigates, while typical waterplane coefficients range from 0.75 to 0.85. These values are consistent with those observed in parametric CAD platforms such as Maxsurf [15], reinforcing the validity of the generated hull forms.

To validate the effectiveness of the proposed methodology, a hull form was generated through automated variation of the six parametric inputs and compared against a reference model of the Friesland frigate, digitized from its original lines plan. As shown in Figure 12, the generated hull approximates the shape of the CAD-based reference model with reasonable accuracy. The original measurement points used for digitization are also shown to illustrate data fidelity. While some discrepancies are observed particularly in the aft sections where hull curvature is more complex the overall geometry is sufficiently close to support the feasibility of the approach.

Table 8. Comparison with typical design coefficient ranges

Dimensionless	Typical range (CAD/literature)	Range with proposed method	Relative variation [%]
LCB/L_{PP}	0.46-0.50	0.447-0.510	14.09
C_B	0.50-0.65 (frigates)	0.358-0.590	64.8
LCF/L_{PP}	0.45-0.49	0.435-0.515	18.39
C_{WP}	0.75-0.85	0.777-0.867	11.58

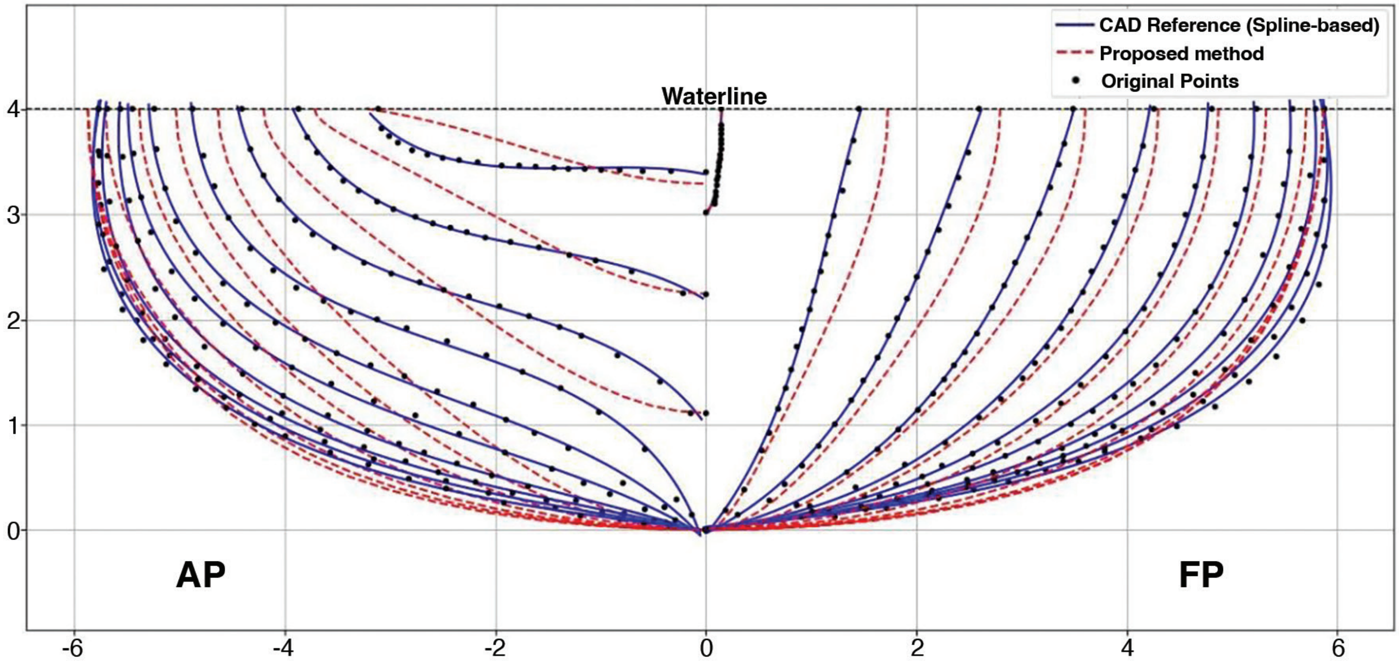

Figure 12. Body plan comparison

One noteworthy limitation observed is that Lewis sections are always tangent to the baseline and to the hull side at the waterline, which tends to produce vertical surfaces above the waterline. This behavior, visible in the comparative plots, can lead to unrealistic geometry in areas where the reference hull has more pronounced flare. It highlights the need for additional fairing if more complex hull shapes are to be accurately reproduced.

4. Practical Applications of the Proposed Method

4.1. Sensitivity Studies Using Simplified Performance Evaluation

The proposed method can support design investigations focused on understanding how individual geometric parameters affect ship behavior. A representative example is found in [4], who employed a parameterized hull model, defined through polynomial distributions and Lewis sections, to assess the influence of form modifications on seakeeping characteristics. By applying a linear strip theory solver, the study revealed that even moderate shape adjustments could lead to noticeable differences in vertical accelerations and bow motions. Such approaches demonstrate the practical value of simplified geometric tools when seeking directional insight during concept refinement or prior to detailed analysis.

A related application is presented in [5], where hull variants of a fast displacement catamaran were generated by varying form coefficients such as block coefficient and longitudinal center of buoyancy by ±10%. Seakeeping performance was assessed through strip theory codes (PDStrip, Maxsurf), and the study confirmed that relatively simple geometric changes can produce measurable improvements in motion behavior, particularly regarding vertical accelerations and seasickness index.

4.2. Parametric Hull Libraries and Design Space Exploration

The method is also well suited for generating systematic sets of hull variants to explore the influence of geometric characteristics. This is illustrated in [10], where a large number of configurations, produced using the same approach described in this article, were evaluated to estimate slamming probability for a frigate-type hull. Each variant featured the isolated modification of a single form parameter, enabling a clear assessment of its effect on wave impact behavior. Simulations based on simplified seakeeping tools showed that even these targeted changes could significantly influence slamming occurrence. Figure 13 summarizes these findings, presenting results for both extreme and intermediate cases.

A similar strategy is adopted by [16], who developed multiple hull forms by systematically modifying form coefficients of reference designs. Using basic performance estimators, they analyzed resistance and motion behavior across the generated shapes and identified favorable trends for ship types such as destroyers and reefers. This type of exploration highlights the potential of automated variant generation methods to support informed design decisions from an early stage of development.

4.3. Integration with Simplified Estimators

The proposed method can also support early design workflows by supplying structured hull variants to simplified performance prediction tools. Its low computational cost and ability to isolate specific geometric characteristics make it suitable for integration into processes where a large number of alternatives must be screened before detailed analysis.

A related example is presented by [17], who employed a multiparameter conformal mapping technique, conceptually similar to the Lewis approach, to generate arbitrary hull section shapes. The generated variants were evaluated using low-order hydrodynamic tools, highlighting their utility for trend identification and pre-selection in exploratory studies. Although the resulting geometries were not immediately suitable for advanced solvers, they enabled efficient scanning of the design space and informed the refinement of promising configurations.

5. Conclusion

In this work, a simplified methodology for hull geometry modifications was presented. To verify its effectiveness, variants of a baseline model were generated by singular alterations of the established geometric parameters.

The use of the two-parameter Lewis formulation offered a simplified and analytically efficient means of generating sectional shapes for preliminary design studies. While this method facilitates the rapid production of hull variants, it presents inherent limitations in defining complex geometries, particularly above the waterline, due to its tangency constraints at the baseline and hull side. In this study, the focus remained on submerged shapes, with the understanding that the resulting point distributions are intended for early-stage exploration and can later be faired using external CAD or hull design tools prior to CFD or FEM applications. Each transverse section was defined using Bézier curves to ensure local smoothness and geometric control, and the sectional area coefficients were polynomially interpolated along the hull to maintain gradual shape transitions. For future work,

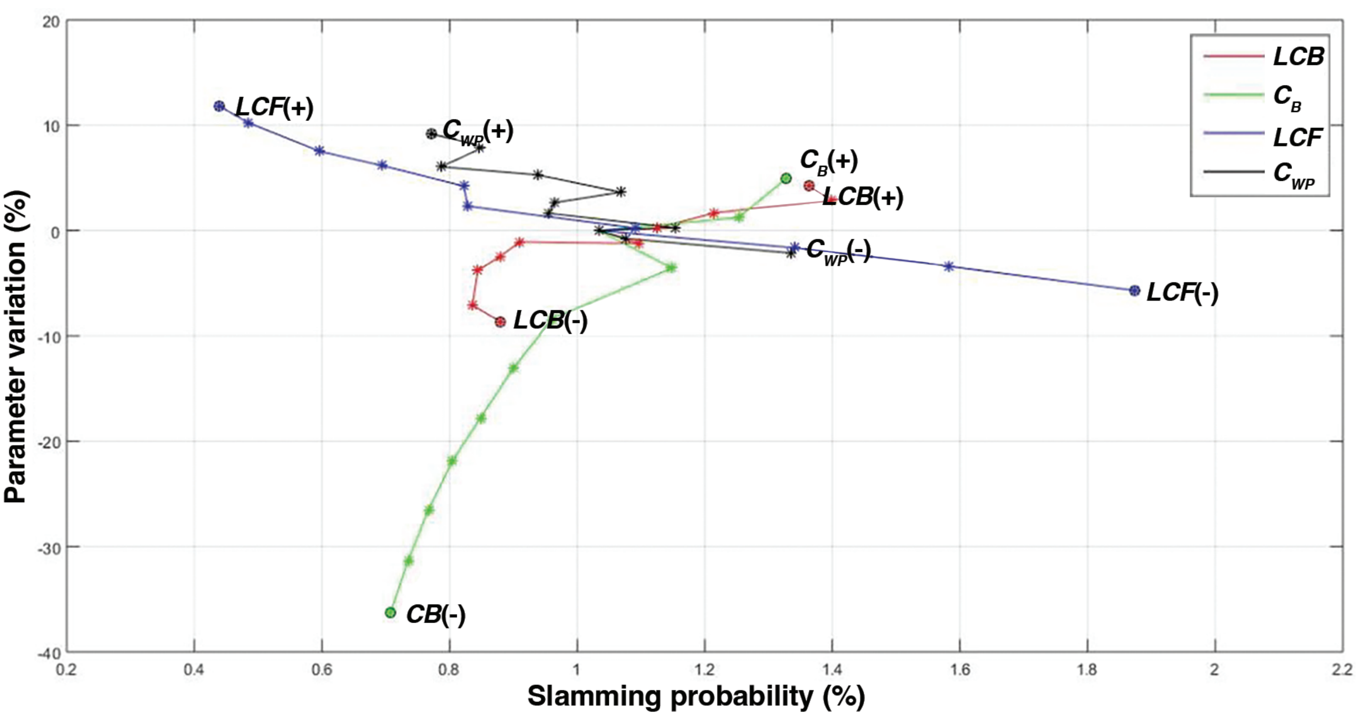

Figure 13. Slamming occurrence vs. parameter variation
Source: [10]

the adoption of the three-parameter Lewis technique may provide greater flexibility in capturing complex section profiles. Furthermore, the use of more advanced hull variation procedures such as Moor's method, in combination with a fair parent hull is recommended to enhance surface fairness and geometric realism in the generation of CFD-ready hull forms.

Footnote

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NOMENCLATURE

B	[m]	Beam at the waterline
L_{pp}	[m]	Length between perpendiculars
T	[m]	Draft
C_B	[-]	Block coefficient
C_{WP}	[-]	Waterplane area coefficient
CG	[m]	Center of gravity
LCB	[m]	Longitudinal center of buoyancy
LCF	[m]	Longitudinal center of flotation

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