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Research Article

Impact of Bulbous Bow Geometry on Ship Resistance: A Numerical Study

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Abstract – This paper presents a numerical investigation into the effects of different bulbous bow forms on a ship's total resistance using Computational Fluid Dynamics. As a preliminary optimization study, various bulbous bow designs were generated through a Genetic Algorithm to identify the geometric features of the bow form that achieves the greatest reduction in total resistance. Unlike conventional empirical and experimental methods for bulbous bow design, the ship's bow form in this study was partially parameterized using Non-Uniform Rational Basis Splines (NURBS). Based on the defined parameters, forms generated and optimized using the NSGA-II algorithm were analyzed with CFD and evaluated in terms of resistance performance. The results revealed that resistance reduction varies with the geometric characteristics of the bulb, with the bulb's length emerging as the most influential parameter within the explored design space.

Keywords – Ship Resistance, Bulbous Bow, Series 60, Partially Parametric Modelling Genetic Algorithm

I. INTRODUCTION

The optimization of ship hull forms, particularly the bulbous bow, has become a crucial aspect of naval architecture in the pursuit of energy-efficient and environmentally friendly vessels. The bulbous bow, a protrusion at the ship's bow below the waterline, plays a significant role in reducing wave-making resistance and improving overall hydrodynamic performance [1],[2]. As the maritime industry faces increasing pressure to reduce fuel consumption and emissions, the design and optimization of bulbous bows have gained renewed attention.

Research has shown that bulbous bows can effectively reduce wave-making resistance and wave breaking, with over 95% of the merchant fleet incorporating various types of bulbous bows [4]. The importance of bulbous bows is evident in their ability to significantly reduce ship resistance. In one study, a tanker model with a bulbous bow demonstrated a substantial reduction of over 8% in resistance compared to the same model without a bulbous bow in the design speed domain [3]. This reduction in resistance directly impacts fuel consumption and overall ship performance.

Geometric optimization of ship bulbous bows is a crucial aspect of naval architecture aimed at improving vessel performance and efficiency. Several papers discuss various approaches to this optimization process. One method involves parametric deformation of the bow while constraining displacement and ship length. Using the Rankine source method for wave-making resistance calculations, combined with Sobol and Nelder-Mead algorithms, researchers have successfully reduced wave-making resistance for specific ship models [1]. Another approach utilizes cubic Bezier curves and curve-plane intersection methods to generate parametric designs of bulbous bows, considering four design parameters [6]. Some studies explore unconventional designs, such as the dihedral bow, which is based on polyhedral bows used in small vessels. This design, utilizing developable surfaces, has shown significant reductions in effective power for both displacement and semi-displacement hulls [8]. Additionally, researchers have developed methods for automatic generation and modification of bulbous bows using Non-Uniform Rational B-Spline (NURBS) surfaces and Grasshopper software[9].

In conclusion, geometric optimization of ship bulbous bows involves various techniques, from parametric modeling and algorithm-based optimization to innovative designs like the dihedral bow. These methods aim to reduce wave-making resistance, improve hydrodynamic performance, and ultimately enhance vessel efficiency. The integration of computational fluid dynamics (CFD) and experimental validation plays a crucial role in refining these optimization processes [6],[7]

This paper investigates the effects of different bulbous bow shapes on the total resistance of a ship using Computational Fluid Dynamics (CFD). The bulbous bow forms were generated through a partially parametric modeling of the ship's geometry and subjected to an optimization process using a Genetic Algorithm (GA). The study aims to identify the geometric characteristics of the shape that provides the greatest reduction in resistance. Results were reported in terms of resistance components, free surface deformations and pressure field around the ship bow.

II. MATERIALS AND METHOD

The present study focuses on the integration and optimization of bulbous bow forms for a ship. The Series 60 hull model (CB=0.7) was used as the baseline in this study (see Fig. 1). The main dimensions of the ship are provided in Table 1. The flow around the hull was simulated using the commercial computational fluid dynamics (CFD) software, Simcenter StarCCM+. The solver discretized the governing equations, specifically the RANS equations, by employing the finite volume method. The computational domain was designed in accordance with ITTC recommendations [1. A uniform velocity profile corresponding to Fn = 0.25 was specified at the inflow boundary. The turbulent field was modeled using the well-known realizable k-ε turbulence model.

Fig.1 Geometry of the Series 60 hull

Table.1 Main Dimensions of the Series 60 Hull

Length (L_{BP})	7 m
Breadth (B_{MS})	0.4667 m
Draft	0.3733 m
CB	0.70
Wetted Surface Area	8.4148 m^2
Displacement	1461 kg

The solution domain is constructed using a hexahedral mesh structure. To achieve better resolution in critical flow regions, volumetric mesh refinement was applied in specific areas. The mesh density was increased around the ship, and smaller mesh sizes were used in the bow and stern regions. Additionally, a separate volumetric mesh refinement was implemented to accurately capture free-surface deformations. The surface mesh along the hull was generated to maintain y+ values between 30 and 100. The mesh structure around the ship is shown in Fig. 2.

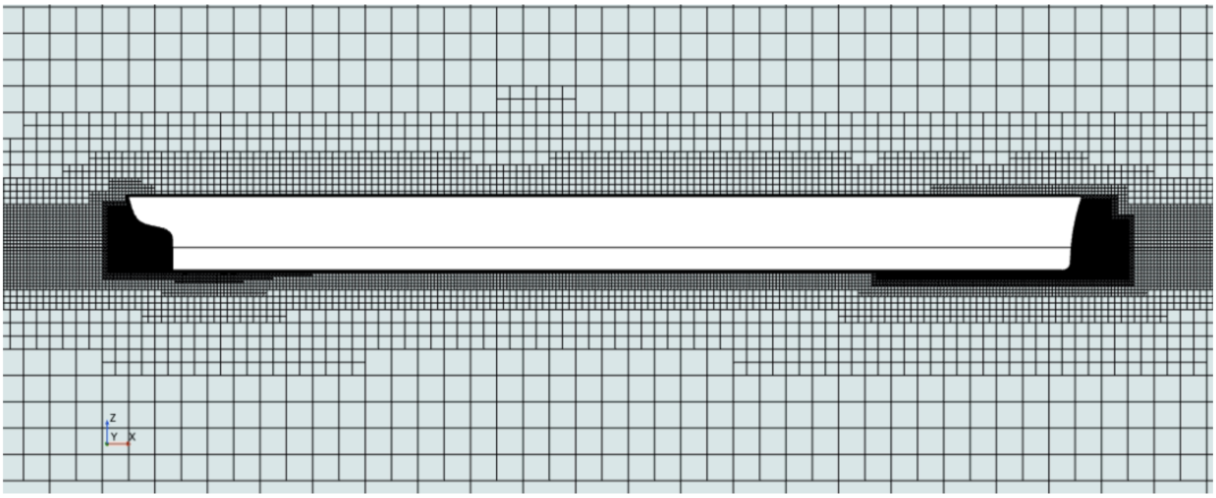

Fig.2 Mesh structure around the hull

The partially parametric modelling of the ship is performed using commercial software CAESES. The part of the original hull targeted for modification was separated using two curves taken in the frame and waterline planes. From the CPC (Center Profile Curve) of the separated surface and the surface itself, NURBS were defined (Fig. 3). The control points of the NURBS were defined as design variables. FFW (FRIENDSHIP-Framework) was employed to create a surface ensuring a smooth transition to the original hull through the curves. The ranges of the design variables were determined by considering constraints from applications such as data from the literature, existing ship designs, and empirical formulas, thus establishing an efficient design space for preliminary studies.

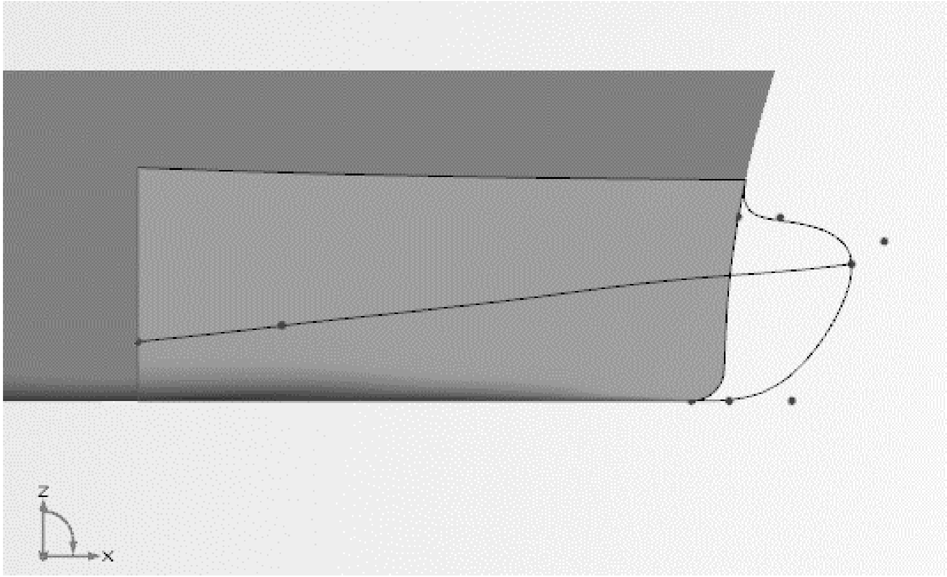

Fig.3. Sketch of the control parameters

In this study, one of the optimization algorithms, NSGA-II (Non-Dominated Sorted Genetic Algorithm), was utilized for bulbous bow shape optimization. The objective function of the study is the total ship resistance. Initially, the algorithm generates the parent population (P_0) randomly. Subsequently, individuals are ranked according to the fitness function, and those deemed insufficiently fit are eliminated. In this study, three generations with a population size of four were analyzed.

III. RESULTS

In the present study, the flow around the Series 60 hull was modeled using computational fluid dynamics. Various bulbous bow forms were integrated into the hull, and a partially parametric geometry of the ship was constructed in CAESES. The bulbous bow form of the ship was optimized using a Genetic Algorithm. The original hull form and two selected bulb forms are presented in Fig. 4. The objective of the optimization process was to achieve the maximum total drag reduction. The bulb forms shown in Fig. 4 were selected as the ones providing the best performance and an average drag reduction.

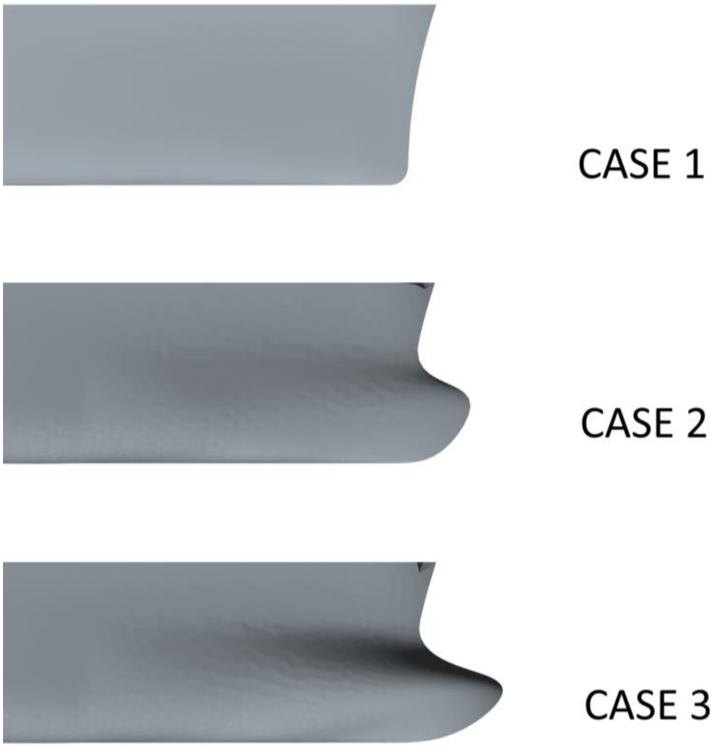

Fig.4 the geometries of original hull and selected bulb forms.

Fig. 5 shows the total resistance values of different cases, along with their resistance components. When comparing total resistance, it is observed that Case 3 achieves the greatest drag reduction compared to the original geometry. In Case 2, total resistance is also reduced, but the reduction is more limited. The total drag reduction achieved for Case 3 is 12.6% compared to the original geometry. The primary difference between Case 2 and Case 3 lies in the length of the bulb form. This suggests that performance improves as the bulb length increases. However, to draw definitive conclusions, further optimization studies with a broader design space are required.

When examining the resistance components, the frictional resistance values are found to be very similar across all three cases. The observed changes in resistance are mainly due to pressure resistance, with Case 3 producing the lowest pressure resistance value compared to the other cases.

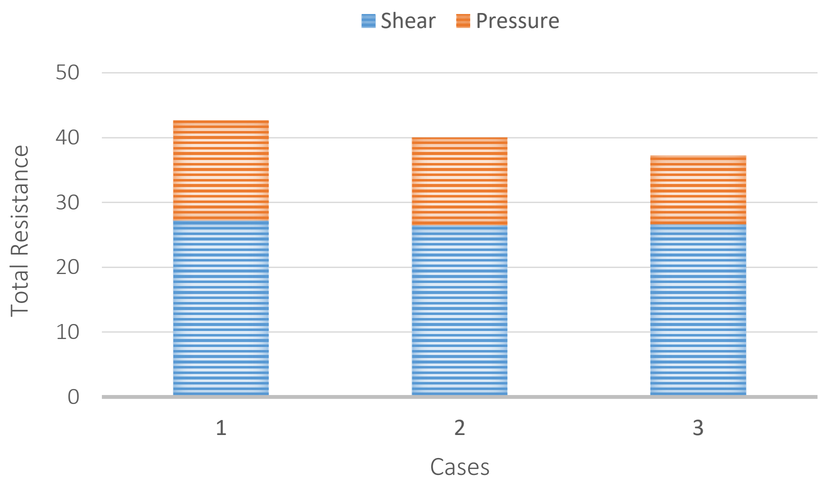

Fig.5 Total Resistance of the Different Cases

The free-surface deformations around the geometries with different bow forms are shown in Fig. 6. In all geometries, the classical Kelvin wave pattern is clearly observed. When a bulbous bow is integrated to the hull, the free-surface deformations noticeably weaken. Analyzing the results for Case 3, which generates the lowest pressure resistance, it is evident that the wave peaks and troughs in the bow region are significantly dampened compared to the original geometry.

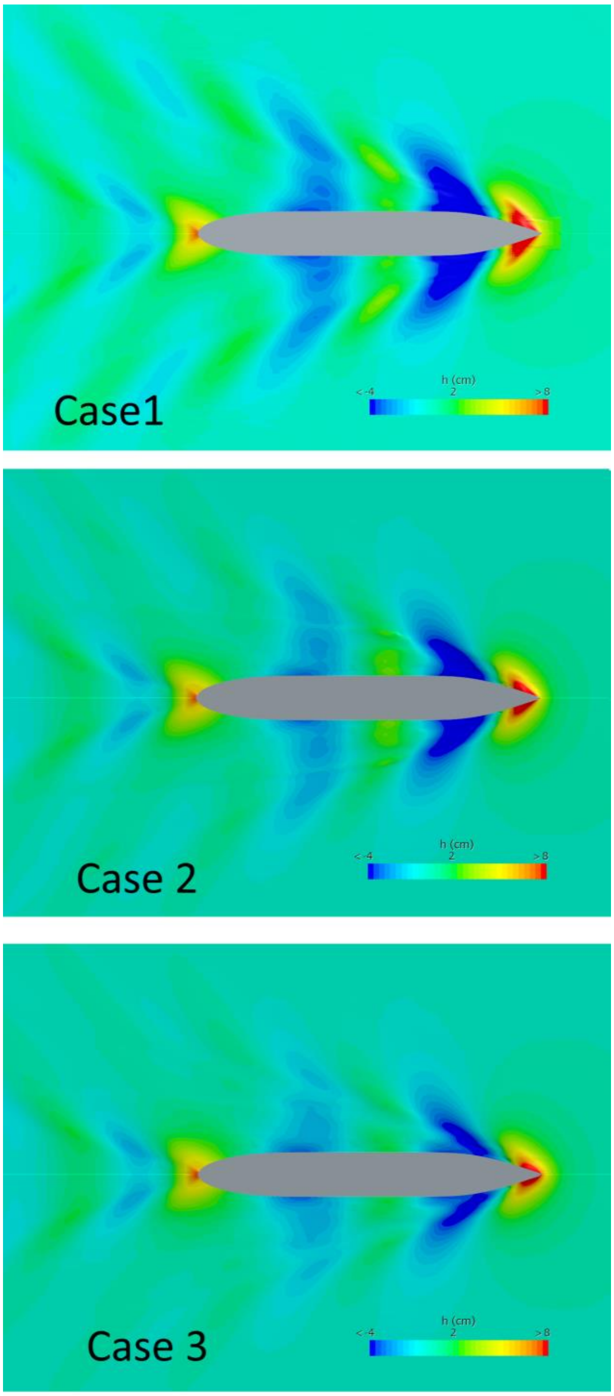

Fig.6 Free Surface Deformations of Different Cases

The pressure field around the different bow forms is presented in Fig. 7. For the original geometry, a distributed high-pressure region is observed in the bow area. This high-pressure zone acts along the bow wave and influences the hull. When a bulbous bow is integrated into the hull, the high-pressure region affecting the bow area is reduced. In Case 2, the high-pressure zone acting along the bow wave weakens considerably. This effect becomes even more pronounced in Case 3, which has a longer bulb length. In Case 3, high-pressure regions are observed only in limited areas, while pressure values in other regions are significantly diminished.

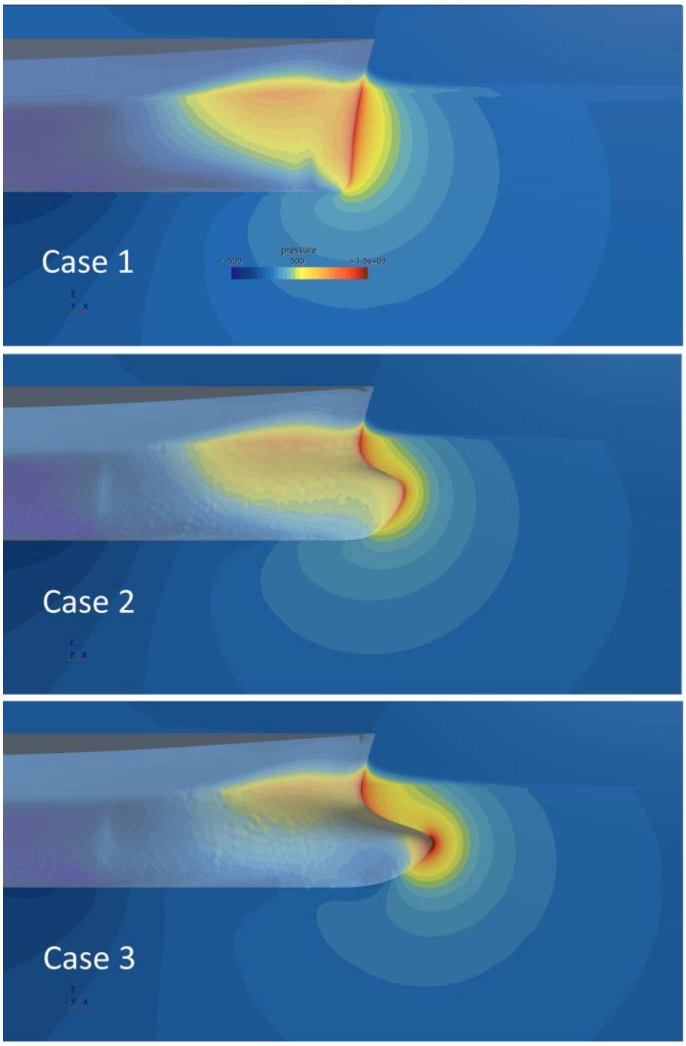

Fig.7. Pressure Field Around Different Bow Forms

IV. CONCLUSION

In this study, a bulbous bow form was integrated into the Series 60 hull form, and a preliminary optimization study was conducted to achieve the best resistance performance with the added bulbous form. The flow around the ship forms was solved using CFD. The hull form with the bulbous bow was partially parameterized using CAESES and subjected to an optimization process with the help of a genetic algorithm. The NSGA-II algorithm was utilized for the optimization.

As a result of the study, all generated forms were compared in terms of total resistance, and the flow fields around the selected cases were analyzed comparatively. It was observed that bulb length is more effective in reducing resistance compared to other design parameters. The bulbous bow with a longer length produced lower pressure resistance and demonstrated better performance in terms of free-surface deformations and pressure fields in the bow region.

However, as this was a preliminary optimization study, the design space was kept limited. To achieve the optimal resistance value and identify the most effective design parameters for the bulbous bow, further optimization studies in a broader design space are planned.

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