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Numerical Study on the Length Parameter of Nabla Type Bulbous Bow of Coastal Tanker

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Keywords: Bulbous bow, CFD, Resistance performance.

ABSTRACT

A numerical study was carried out to predict the effect of different lengths of Nabla type bulbous bow of coastal tanker scaled model. Three different speed values were chosen for this study namely 1.5 m/s, 2 m/s, and 3 m/s which are corresponding to the Froude number of 0.15, 0.2, and 0.3. The original bulbous bow length of 0.9 m corresponds to 8% of the total ship length in the first case, and four more cases of different lengths of 15%, 25%, 50%, and 75% extended bulbous bow of the original length. The results obtained show that the case of a 25% extended bulbous bow is the most effective for all speed values on drag reduction of 10.6 % at 1.5 m/s, 11.6% at 2 m/s, and 27.1% at 3 m/s. the case of 15% is most effective at 3 m/s and achieved a 28.7% on drag reduction. Meanwhile, the case of 75% works as well as the case of 25% for low speed only of 1.5 m/s. The case of 50% doesn't show promising results, the case of 25% is recommended as it works best for all different speed values.

INTRODUCTION

A bulbous bow is a bulb fixed at the front of a ship below the waterline which modified the method of the water flow around the ship hull thus reducing drag by (Szelangiewicz et al., 2021). The resistance performance of ships is one of the most important factors to be considered for ship design. Bulbous bows have been widely used in many civilians, oil tankers, and military ships.

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The use of bulbous bows is to generate a wave that omits the wave created by the ship shell and reduces the resistance of the ship thus leading to better economic benefits. Several researchers as (Huang et al., 2014) believe that a bulbous bow affects smoothing the flow which helps to reduce viscous resistance as well. The bulbous bow shape has a significant influence on the hydrodynamic performance of a ship. (Kracht, 1978) specified six parameters to be included in bulbous studies, three linear parameters: length, depth, and breath, and three nonlinear parameters: volume, lateral, and area. There are three shapes of bulbous bows namely delta type, O type, and Nabla type where this shape is the most commonly used shape in modern designs and it's the shape used for this study, the three shapes are shown in Fig 1 as discussed by (Hoyle et al., 1986; Li et al., 2016).

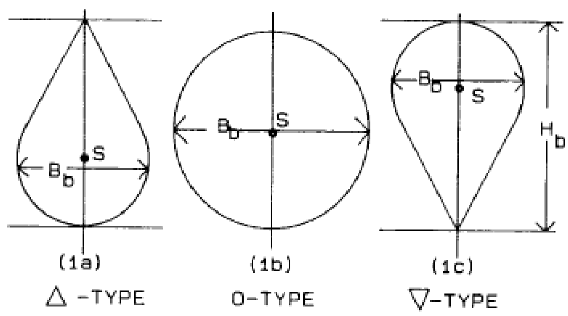

Fig. 1. Bulbous bow shapes (Hoyle et al., 1986).

To further study the influence of increasing the length of the bulbous bow on resistance reduction, three cases had been studied namely shortened 15% bulbous bow, extended 25% and 50% bulbous bows and the results obtained indicate that 5% resistance reduction for 50% extended bulbous bow where the O-type bulbous bow was used for this study as illustrated by (Li et al., 2016). (Wang et al., 2018) studied the effect of bulbous bow length increment on drag reduction for two schemes of GJ-A and GJ-B as shown in Fig 2

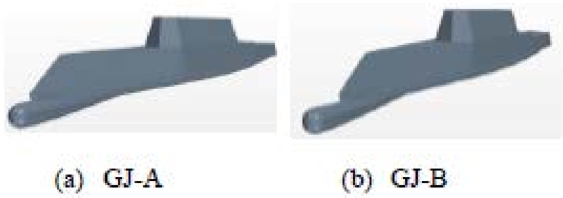

Fig. 2. Two schemes of bulbous bows (Wang et al., 2018).

The results obtained show that a drag reduction of 7.7% was achieved for GJ-A and a 6.3% drag reduction for GJ-B at higher speeds as high as 2.34 m/s. Furthermore, in a numerical study of the effect of blunt bulbous bows on drag reduction by (Le et al., 2021), the results show a 6% drag reduction in calm water and a 13% drag reduction for head wave conditions at 0.163 Froude number which indicate that the minimum resistance of a ship hull without a bulbous bow is achieved at a Froude number of about 0.16 as shown in Figure 3.

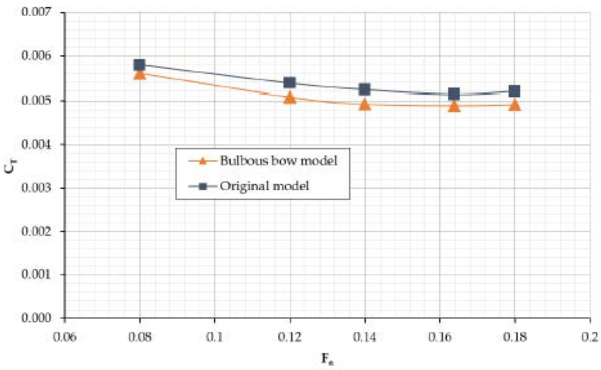

Fig. 3. Comparison of the total resistance vs Froude number (Le et al., 2021).

Correspondingly, in a study by (Kim et al., 2018) using Computational Fluid Dynamic to evaluate the effect of the three shapes of bulbous bows on resistance reduction, the results indicate that the Nabla type has the best influence on resistance reduction by 10% up to Froude number of 0.47 corresponding to 4.4 m/s however as Froude number increases to 0.65 the bulbous bow effect is insignificant. Generally, the bulbous bow is ineffective at low speed while at high speed the bulbous bow effect is significant due to the complexity of bulbous bow characteristics where different bulbous bow characteristics can be operated at certain speed conditions, the comparison of resistance reduction between the three shapes of the bulbous bow is indicated in Figure 4.

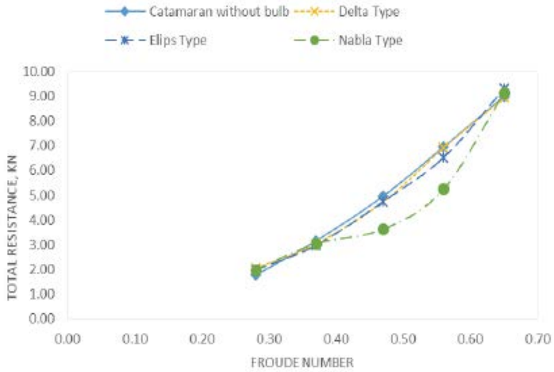

Fig. 4. Comparison of the three bulbous bow shapes (Kim et al., 2018).

The main contribution of this study is to investigate the effect of combining Nabla shape and multiple length parameter of a bulbous bow where Nabla shape is stated to be the most efficient shape and increasing the bulbous bow length reduces the resistance as illustrated by previous researchers. Correspondingly, the previous studies focused on the length effects of blunt shape bulbous bow while this paper provides results on multiple lengths Nabla shaped bulbous bows.

METHODOLOGY

Ship Design

The coastal tanker with an original length of 210 meters was selected for this study with a scale ratio of 1/20 as shown in Fig 5. Meanwhile, the main dimensions of the scaled model are shown in Table 1.

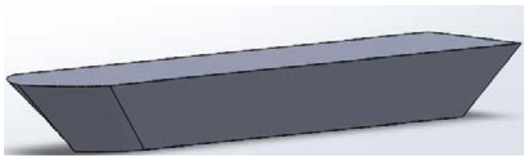

Fig. 5. Original design of the coastal tanker without a bulbous bow.

Table 1 The main dimensions of the scaled coastal tanker.

Overall length	10.78 m
Waterline length	8.58 m
Draft	0.80 m
Overall beam	1.56 m
Underwater beam	0.8 m
Blockage ratio	0.18

Bulbous Bow Design

Five cases with different lengths of Nabla-type bulbous bows have water drop shapes where most of their thickness is at the upper half. Original bulbous bow length of 0.9 m corresponded to 8% of the total ship length in the first case, four more cases of different lengths of 1.04m corresponded to 15%, 1.125m corresponded to 25%, 1.35m corresponded to 50% and 1.6m corresponding to 75% extended bulbous bows of the original length as shown in Fig 5 starting with an original bulbous bow from the left to 75% extended bulbous bow. Frontal and side views of 25% and 75% bulbs for example are shown in Fig 6.

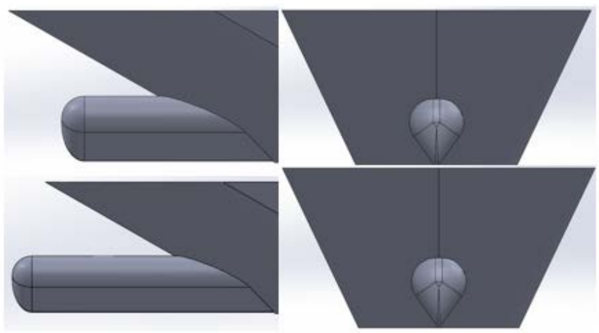

Fig. 6. Front and side views of 25% bulb (upper side) and 75% bulb (bottom side).

The theorem applied in this study is the linear wave theory which describes the waves produced by the ship where the generated waves depends on the velocity and length of the ship and this is directly related to Froude number which is the main focus in this study. Equation (1) is used to calculate the Froude number and Equation (2) is used to calculate the blockage ratio of the ship.

$$Fr = v/\sqrt{gl} \qquad (1)$$

$$\frac{Actual\ underwater\ volume\ (v)\ m\text{^}3}{Block\ Volume\ (L*B*D)\ m\text{^}3} \qquad (2)$$

Numerical Model

The dimensions of the computational domain are 1L for the inlet where L is the ship, 4L for the outlet, and 1L for the top, bottom, and two sides.

Meshing

The grid used for the resistance performance study is shown in Fig 7, the average number of elements for all cases is 10 million elements with maximum skewness quality of 0.77. Furthermore, a mesh independence study has been carried out starting with 3 million elements with increment of 1.5 times as the mesh elements reached 10 million the results are similar compared to the last case of about 7 million elements.

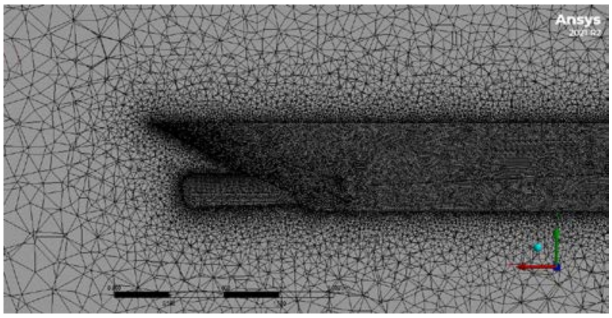

Fig. 7. Grid view of the ship with an attached bulbous bow.

Numerical Setup

The Ansys software was used to solve the flow around the ship by calculating the N-S equation for three-dimensional flow. The volumetric fluid method was selected for two phases of flow namely air and water. The K-Ɛ turbulence model was used with the first-order scheme for discretization where K is the kinetic energy of turbulence and Ɛ is the turbulence dissipation rate. Additionally, the convergence condition to ensure convergence of residual error is set to 10^{-3}.

RESULTS

This section discusses the results obtained from the simulations for five cases of Nabla-type bulbous bows with different lengths, the speed range for this study is 1.5 m/s to 3 m/s corresponding to the Froude number range of 0.15 to 0.3. Original hull test without bulbous bow has been done to validate the numerical setup by validating that the minimum resistance can be achieved at 0.16 Froud number as discussed by [9] with a speed range between 1.5 m/s and 3 m/s where the lowest resistance of 173.3 N is achieved at Froude number of 0.16 as shown in Fig 8.

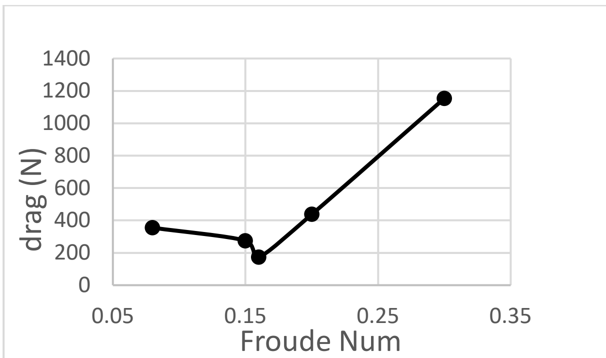

Fig. 8. comparison of the total resistance of the hull without a bulbous bow.

Original Bulbous Bow

The first case is the original length of 0.9m which is 8% of the total ship length, the results show that the total resistance recorded for this case is 254 N with resistance reduction of 7.7% at 1.5 m/s, 388 N with resistance reduction of 11.3% at 2 m/s and 850.9 N with resistance reduction of 26.2% at 3 m/s. Noticed that as the speed increases the contribution of the bulbous on total resistance reduction increases due to the change in dynamic pressure around the bow which indicates wave generation by the bow as can be seen in Fig 9. Meanwhile, the effect of the bulbous bow on total resistance is poor at low speed and significant at high speed and this is well agreed with [8].

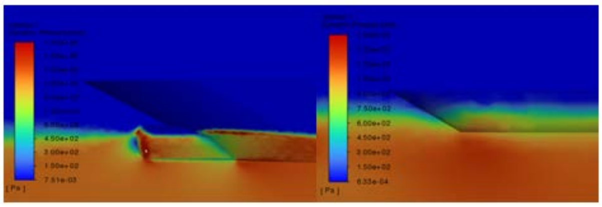

Fig. 9. Dynamic pressure comparison between an original bulbous model and the original hull model.

15% Extended Bulbous Bow

The second case is 15% extended of the original bulbous bow length which is 1.04m long, the results show that the total resistance recorded for this case is 333.7 N with slightly increased resistance at 1.5 m/s, 424 N with resistance reduction of 3% at 2 m/s and 823 N with resistance reduction of 28.68% at 3 m/s. Noticed that at 3 m/s the contribution of the bulbous on total resistance reduction increases due to the significant impact on the dynamic pressure at this speed value. Meanwhile, the effect of the bulbous bow on total resistance is insignificant at 1.5 m/s and 2 m/s due to that this bow doesn’t have an impact on the dynamic pressure which results in poor waves generation at this speed range as discussed by [8], the comparison is shown in Fig 10.

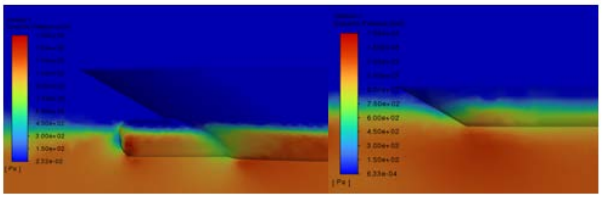

Fig. 10. Dynamic pressure comparison between a 15% extended bulbous model and original hull model.

25% Extended Bulbous Bow

The third case is 25% extended of the original bulbous bow length which is 1.125m long, the results show that the total resistance recorded for this case is 245 N with resistance reduction of 10.6% at 1.5 m/s, 386.8 N with resistance reduction of 11.6% at 2 m/s and 840.4 N with resistance reduction of 27.1% at 3 m/s. Noticed that as the speed increases the contribution of the bulbous on total resistance increases due to the impact of the bow on the dynamic pressure as the speed increases. Additionally, this bow has a significant impact on the dynamic pressure at this speed range which varies from 1.5 m/s to 3 m/s as shown in Fig 11.

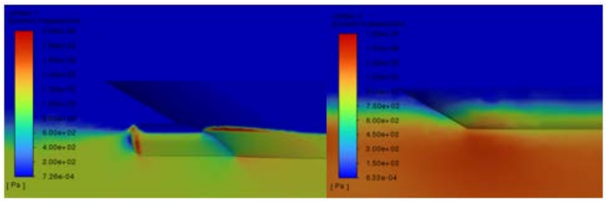

Fig. 11. Dynamic pressure comparison between 25% extended bulbous model and original hull model.

50% Extended Bulbous Bow

The fourth case is 50% extended of the original bulbous bow length which is 1.35m long, the results show that the total resistance recorded for this case is 252 N with resistance reduction of 8.4% at 1.5 m/s, 397 N with resistance reduction of 9.25% at 2 m/s and 874.6 N with resistance reduction of 24.2% at 3 m/s. Noticed that the effectiveness of this bow is slightly lower compared to the case of a 25% extended bow due to less impact on the dynamic pressure as can be observed in Fig 12 and Fig 13.

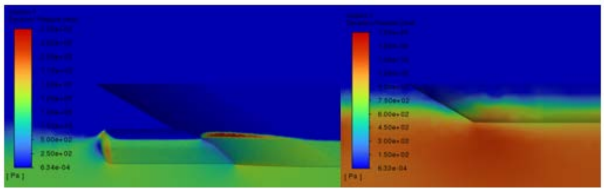

Fig. 12. Dynamic pressure comparison between 50% extended bulbous model and original hull model.

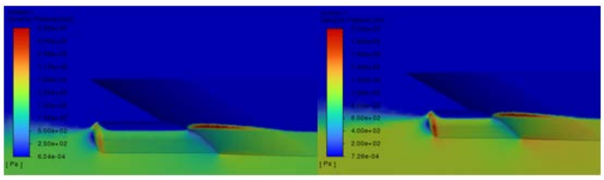

Fig. 13. Dynamic pressure comparison between 50% extended bulbous model (left) and 25% extended bulbous mode (right).

75% Extended Bulbous Bow

The last case is 75% extended of the original bulbous bow length which is 1.6m long, the results show that the total resistance recorded for this case is 246 N with resistance reduction of 10.6% at 1.5 m/s, 388 N with resistance reduction of 11.3% at 2 m/s and 849.7 N with resistance reduction of 26.4% at 3 m/s. Noticed that the effect on the dynamic pressure is similar at low and moderate speed and slightly lower at high speed compared to the case of a 25% extended bow as shown in Fig 14.

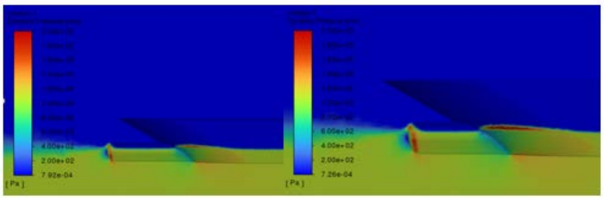

Fig. 14. Dynamic pressure comparison between 75% extended bulbous model (left) and 25% extended bulbous mode (right).

Comparison of All Cases

This section summarizes the influence of all the bulbous bow extension cases. Generally, all the cases have a significant effect on reducing the total hull resistance. However, the highest percentages of resistance reduction were achieved at high speed for all cases. The 25% extended bulbous bow and the 75% extended bulbous bow work best for all speed ranges whereas the 15% extended bulbous bow has the most significant influence on resistance reduction at high speed. The graph in Figure 15 shows the comparison between all the cases and the case of the hull without a bulbous bow.

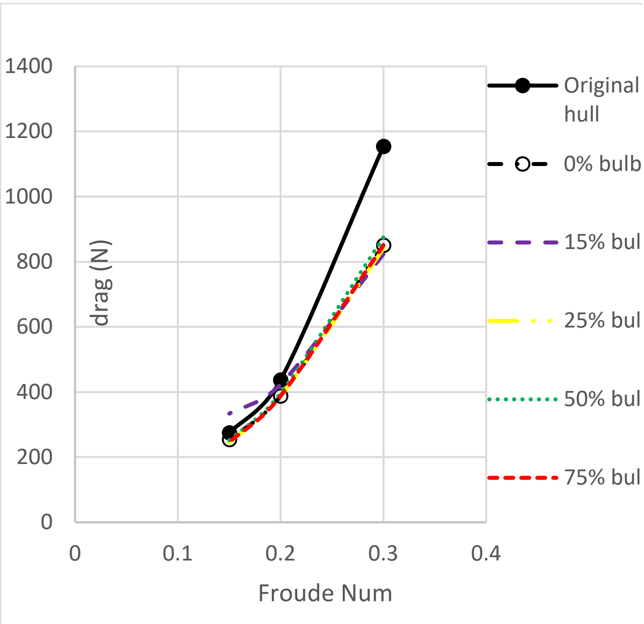

Fig. 15. Comparison of all the bulbous bow cases for the total resistance of the hull Vs. without a bulbous bow.

CONCLUSION

In this study, the resistance performance of coastal tankers with and without bulbous bows has been investigated using CFD. The used bulbous bow shape is Nabla type, five cases have been investigated in this study namely the original bow with a length of 0.9 m which is 8% of the ship's total length, 15% extended bow, 25% extended bow, 50% extended bow and 75% extended bow of the original bulbous bow length. Short bulbous bows as short as 0.9 m (original) and 1.04 m (15% extended bow) have a significant effect on resistance reduction due to the strong impact of the water on the bow which results in high dynamic pressure at high speed where the lengthy bulbous bow is not required at that speed. 25% extended bow has the best results at all speed ranges with a maximum resistance reduction of 27.1 at 3 m/s. 50% extended bow has the lowest impact on resistance reduction with a maximum resistance reduction of 24.2% at 3 m/s. Furthermore, 75% extended bow has similar results as 25% extended bow at all speeds range. Generally, bulbous bows don't work well in low-speed sailing conditions especially very short bows due to the weak water impact resulting in weak dynamic pressure thus wave generation is insignificant.

ACKNOWLEDGMENT

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