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RESEARCH ARTICLE

A Computer-Based Analysis to Study the Effect of LCB Position on Ship Resistance in the Early Design Stage: A Case Study with a Fishing Vessel Hull

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ABSTRACT

Minimising ship resistance is considered a crucial aspect of the design process, as it impacts fuel consumption during the operational phase, which in turn impacts financial and environmental aspects. Minimising the resistance is a complex issue, because different main geometrical characteristics of the hull, such as dimensional ratios, form coefficients, shape of sections and waterlines, longitudinal centre of buoyancy *LCB*, etc., may affect its value. In the early design stage, computational tools based on parametric models for the prediction of resistance can be used because they provide rapid evaluation of resistance within an acceptable accuracy level. The paper aims to present a computer-based methodology for studying the effect of *LCB* position on ship resistance at the early design stage. The tool used for the analyses is a software developed by the author based on regression models for the prediction of resistance. The methodology was illustrated with a case study analysis of a hull of the well-known Ridgely-Nevitt fishing vessel series. For the hull taken in consideration, the results of the analysis showed that the hull with the *LCB* positioned at −2% of the L_{PP} aft amidships exhibited minimal resistance characteristics.

Keywords: 3D modelling, Fishing vessels, Power, Resistance.

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1. Introduction

Nowadays, there is more and more pressure on the environmental impact of maritime transport. Minimizing the environmental impact and especially reducing ship emissions is becoming an important goal of the ship design process. This is the direct consequence not only of the efforts taken by the International Maritime Organisation (IMO) in the last decade to reduce emissions from ships but also of the growing pressure of civil society for environmentally friendly and sustainable maritime transport. In this framework, in the last decade, the IMO has taken several initiatives in order to reduce emissions from maritime transport, proposing several regulations and mechanisms to reduce pollution from ship emissions. These proposals refer to the energy efficiency design index (EEDI) [1], ship energy efficiency management plan (SEEMP) [2], energy efficiency existing ship index (EEXI) [3], and carbon intensity indicator (CII) [4]. These IMO initiatives have affected not only ship design and operations but have also contributed to the increase of the awareness of the social community towards environmentally friendly maritime transport.

Although fishing vessels are not subject to IMO regulations, minimizing their environmental impact is of high importance [5] since CO_2 emissions from global fisheries are increasing yearly [6]. This is the consequence of the fact that fishing vessels are highly dependent on fossil fuels and are a major source of greenhouse gas emissions [7], [8]. Korican *et al.* [5] reported that the fishing sector consumes about 1.2% of the global oil consumption, and emits approximately 134 million tonnes of CO_2 in the atmosphere. Emissions from fisheries represent about 4% of the overall shipping emissions [9]. Regarding the consumption of energy, it has been reported that fishing vessels are listed next to airborne transportation [5], [10], which means that fishing vessels have a significant impact on environmental pollution since they emit high values of greenhouse gases [5], [10].

Practically reducing pollution from ship emissions means reducing fuel consumption on board ships. This can be achieved by improving energy efficiency in the design and operation of ships and ports [11]. In the design stage, the energy efficiency can be improved by minimising the resistance and power, minimising the overall weight of the marine vessel, maximising propulsion and propeller efficiency, selecting the optimum engine, using alternative sources of energy, and innovative propulsion plants [11]. Vu & Nguyen [12], Papanikolaou [13], and Molland *et al.* [14] highlighted that position of *LCB*, length of the parallel middle body, shape of extremal parts of the ship such as the bow and stern, semi angle of entrance, and forms of water lines and sections are some main geometric parameters that can affect the resistance and power of ships.

Literature [12]–[14] highlights that the longitudinal centre of buoyancy, (*LCB*) is a parameter that can affect the resistance and power of the ship. Consequently, this is a parameter that can impact the fuel consumption of the ship. Finding the right *LCB* position is a crucial aspect during the ship design process to achieve optimal resistance performances, and minimize fuel consumption and environmental impact over the operational life of the ship. The paper aims to present a case study analysis of the influence of the effect of the *LCB* on the resistance of the hull of one of the models of the well-known Ridgely-Nevitt trawler methodical series. The analysis was performed using the software "Ship Power V 1.0", which is a computer program developed by the author in Visual Basic 6.0 [15]–[17] based on well-known Holtrop and Van Oortmerssen regression models for resistance predictions. Vu & Nguyen [12] have used CFD software to study the influence of LCB position on ship resistance. Although CFD software can provide accurate resistance predictions, the time needed to perform calculations is much greater. In addition, investigations performed by the author [15] have highlighted satisfactory results of resistance predictions of the software "Ship Power V 1.0" compared to the experimental data in the case of the hulls of the Ridgely-Nevitt trawlers series. The initial hull was the model W-11 of the Ridgely-Nevitt trawlers series. Geometric modelling, transformations, and calculations of the main hydrostatic characteristics needed to run the software "Ship Power V 1.0" were performed using the Maxsurf software.

2. Materials and Methods

2.1. LCB Position

The longitudinal centre of buoyancy (*LCB*) is an important parameter used in ship design practice and refers to the longitudinal position of the centre of buoyancy. This coefficient, together with the prismatic and slenderness coefficients, has a significant impact on the wave systems generated by the ship, affecting in such a way the value of resistance [13], [14]. Generally, this coefficient is expressed as a percentage of the length from a reference point, such as amidships or forward perpendicular. The suggested optimum values for the minimum resistance vary based on the speed of the vessel and the values of the coefficients of form. According to Molland *et al.* [18] for faster finer single-screw hulls forms the optimum *LCB* value for minimum resistance varies from about 2% of the L_{PP} aft of amidships to about [2–2.5%] of the L_{PP} forward for slower full-form hulls.

2.2. Hull Form Design

Designing the form of the hull is considered a crucial aspect of the entire ship design process because it affects some main characteristics of the ship in operation, such as stability, resistance, power, speed, and fuel efficiency. The main objective of hull form design is to define the shape and main characteristics of the hull (dimensions and form coefficients) to meet owner requirements and respect specific national and international requirements related to financial, environmental, and safety aspects. Designing of hull forms based on similar or methodical hull form series is a consolidated practice of the ship design process [19]. This practice enables ship designers to leverage successful features of proven hulls. Obviously, the designer based on factors related to cargo capacity or functional and operational requirements may modify and transform the initial form of the hull to meet the specific requirements and objectives for the new hull design [20]. Different methodologies for transforming or distorting existing hulls can be applied at the design stage [21], [22]. A 3D CAD modelling software can be used at this phase. Because of the transformation of the existing hull a resistance and power analysis must be performed. A CAE software for resistance and power predictions can be used at this stage. In the early stage of the design a CAE software based on regression models for resistance prediction can be used because they provide rapid predictions of resistance. A CFD tool can be used in more advanced stages.

2.3. Description of the Hull Taken in the Analysis

The hull taken into consideration in this analysis was a hull of the well-known Rigdely-Nevitt trawler series. The hull taken into consideration was the hull W-11 of the series. This hull has a length between perpendiculars L_{PP} = 30.48 m, the length-beam ratio $L/B = 3.92$, beam-draft ratio $B/T = 2.29$, prismatic coefficient $Cp = 0.65$, block coefficient $C_B = 0.494$, displacement-length ratio equal to 400, and the position of the longitudinal centre of buoyancy $LCB/L_{PP} = 0.5155$ aft of the forward perpendicular *FP*. Detailed characteristics of the hull can be found in [15], and [23]. This hull was previously studied by the author to investigate the accuracy of the resistance predictions of the software "Ship Power V.10".

2.4. Ship Power V 1.0 Software

"Ship Power V 1.0" is a software developed by the author for parametric predictions of resistance and power of ships [15]–[17]. The current version of the software is based on the Holtrop, Holtrop Mennen, and Van Oortmerssen regressions models [15], as presented in [24]–[26]. In the case of the Ridgely-Nevitt trawler series, investigations of the study presented in [15] highlighted satisfactory resistance predictions accuracy of the software "Ship Power V1.0" against experimental data and results of resistance predictions of another commercial software, such as Maxsurf resistance. In addition, for hulls of the Ridgely-Nevitt trawler series, the results of this investigation highlighted that the Holtrop computational procedure fits better than other computational procedures of "Ship Power V 1.0". Therefore, the Holtrop procedure of the software was used in this analysis.

The calculation of the total resistance in the Holtrop procedure of the software "Ship Power V 1.0", as presented in (1), is performed considering several components of resistance, such as frictional and viscous resistance [R_F and $R_F(1+k_1)$], wave resistance (R_W), additional resistance due to a bulbous bow (R_B), additional pressure resistance due to the immersed transom (R_{TR}), appendages resistance (R_{APP}), model ship correlation resistance (R_A), and additional resistance for meteorological conditions (R_{Margin}).

$$R_T = R_F(1+k_1) + R_W + R_B + R_{TR} + R_{APP} + R_A + R_{AIR} + +R_{MARGIN} \quad (1)$$

The total resistance is calculated in "Ship Power V 1.0" by taking in consideration main ship geometrical parameters such as length, beam, draft on forward perpendicular T_{FP}, draft on after perpendicular T_{AP}, block coefficient C_B, midship section coefficient C_M, water-plane area coefficient C_{WL}, prismatic coefficient C_P, and longitudinal centre of buoyancy *LCB*.

2.5. *Methodology Used for the Analysis*

The model used to analyse the effect of the LCB position on the value of the total resistance was the hull W-11 of the well-known Ridgely-Nevitt trawler series. This hull was previously studied by the author in the frame-work of the study presented in [15] and a 3D CAD model of the hull was also generated, as presented in [15].

For the purpose of the study, a procedure to analyse the effect of the *LCB* position on the value of the total resistance was initially developed, as presented in Fig. 1. The flowchart presented in Fig. 1 highlights some main steps. The first step is the variation of the *LCB* position of the initial hull. This can be done after the initial 3D hull model has been generated or imported into a 3D CAD software.

Several constraints such as constant displacement, length, and draft can be applied during the transformation and variation stage. After that new hull has been generated, it is necessary to perform the calculations of the main hydrostatic characteristics in order to identify the main characteristics needed to run the software "Ship Power V 1.0" and to obtain the results of predictions of resistance. The final stage of the procedure is the comparison of the results.

3. Results and Discussion

The methodology presented in the previous section was applied in the case of the model W-11 of the well-known Ridgely-Nevitt fishing vessels. The model has the length between perpendiculars $L_{PP} = 30.48$ m, beam $B = 7.78$ m, draft $T = 3.39$ m, displacement length ratio $\Delta/(0.01L)^3 = 400$, prismatic coefficient $C_P = 0.65$, block coefficient

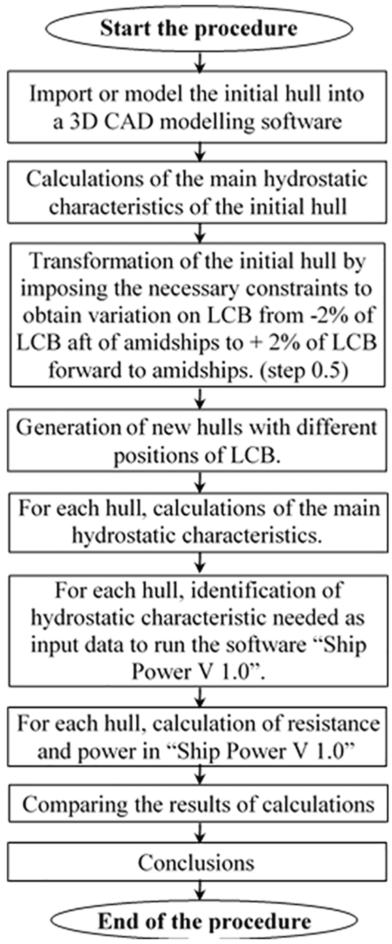

Fig. 1. Flowchart procedure for the analysis of the LCB effect on ship.

$C_B = 0.494$, and the longitudinal position of the centre of buoyancy (*LCB*) is LCB/L_{PP} of 0.5155 aft of the forward perpendicular (–1.55% of L_{PP} aft amidships). The description of the main characteristics of this hull is presented in [15], [23], [27].

As previously highlighted, the 3D CAD model of this hull was previously reconstructed and modelled by the author in the framework of the study presented in [15], based on the geometrical data presented in [23], [27]. Therefore, the 3D CAD model of the hull was directly imported into the Maxsurf Modeller software. The model was subjected to transformations and variations in order to obtain nine new hulls with LCB/L_{PP} values varying from +2% forward from amidships to –2% aft of amidships, with a step of 0.5. Fig. 2 presents the initial hull and hulls having the *LCB* position forward amidships, while Fig. 3 presents the hull with the *LCB* positioned at the mid-ship, and the hulls having the *LCB* position aft amidships.

For each of the generated hulls, the hydrostatic characteristics were calculated using the Maxsurf Stability software. The hulls were further analysed in the software "Ship Power V 1.0" based on the values of length between perpendiculars L_{PP}, length on waterline L_{WL}, bream *B*, draft on forward perpendicular T_{FP}, draft on after perpendicular T_{AP}, block coefficient C_B, midship section coefficient C_M, water-plane area coefficient C_{WL}, and prismatic coefficient C_P, longitudinal centre of buoyancy *LCB*, semi angle of entrance i_E, and hull wetted surface *S*.

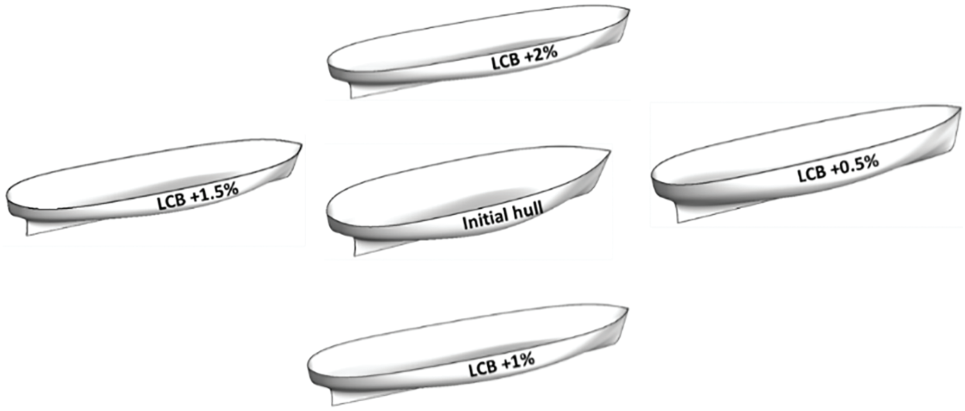

Fig. 2. The initial hull and the hulls having the *LCB* positions forward amidships.

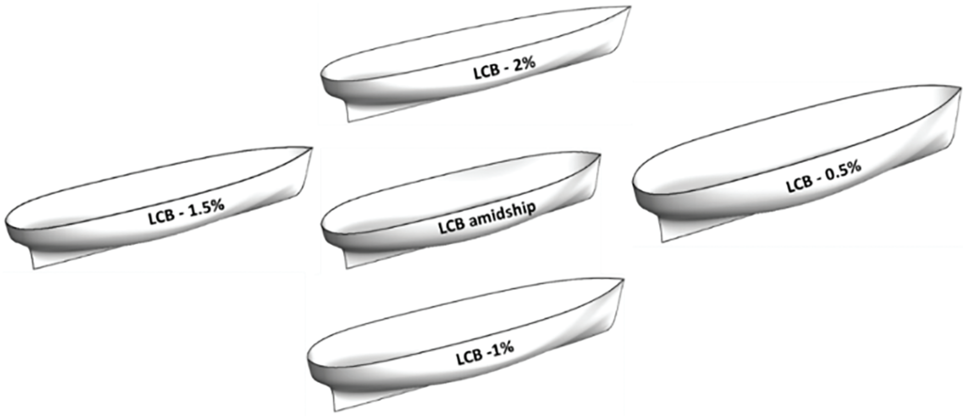

Fig. 3. Hulls with positions of LCB at amidships and after amidships.

The values of resistance were calculated within the field of speeds $V_S = 1 \div 15$ knots, step 1 knot, which corresponds to values of Froude numbers $F_N = 0.0283 \div 0.4244$. Figs. 4 and 5 present the graphical representations of resistance and power calculations for all hulls with different positions of *LCB*.

For the hulls of the fishing vessel taken into consideration, the calculated values of the components of resistance and their respective graphical representations, as shown in Figs. 4 and 5, highlight some considerations. Relating to the viscous resistance R_V it can be observed that as the longitudinal position of the *LCB* moves from +2% forward from amidships toward −2% aft from amidships, the values of viscous resistance practically remain unaffected within the entire field of speeds, showing very slight variations. Variations of *LCB* positions from +2% of L_{PP} forward to amidships to –2% of L_{PP} aft of amidships affect the values of wave resistance differently.

Results of the analyses showed that at low Froude Numbers, for which the wave resistance R_W constitutes a small percentage against the total resistance R_T, the variation of *LCB* has no relevant influence on the wave resistance. As the Froude numbers increase, and the percentage of wave resistance against the total resistance R_T increases, the values of wave resistance decrease as the *LCB* moves from +2% forwards from amidships to –2% aft of amidships, and this effect becomes more prominent.

Consequently, this effect of the influence of the *LCB* variation on components R_V and R_W influences integrally the value of the total resistance. At low Froude Numbers, for which the wave resistance R_W constitutes a small percentage against total resistance R_T, the variation of *LCB* has a small effect on the value of total resistance. For example, for Froude Number $FN = 0.17$, as the *LCB* moves from +2% of L_{PP} forwards amidships to –2% of *LCB* aft amidships the value of total resistance decreases with 1%. As the Froude numbers increase, the decrease of total resistance becomes more prominent as the *LCB* moves from 2% of L_{PP} forward amidships toward 2% aft amidships. For example, for Froude Numbers, $FN = 0.23$ (8 knots), and $FN = 0.28$ (10 knots) as the *LCB* moves from +2% of L_{PP} forwards amidships to –2% of *LCB* aft amidships the values of total resistance decrease respectively with 7% and 13%. The hull with the *LCB* positioned at –2% of L_{PP} aft the amidships exhibits the minimum values of the total resistance, within the entire interval of speeds, compared to other hulls with different positions of *LCB*.

Results of the study agree with the theoretical considerations that state that faster finer hulls can have the LCB positioned at about 2% of L_{PP} aft of amidships, contrary to slower full hulls which can have the optimum value of LCB of about 2% ÷ 2.5% of L_{PP} forward amidships [18]. Despite the results of this study, the opinion of the author is that the results of the study should not be generalised to other hulls, since the effect of *LCB* on ship resistance may vary based on the hull typology, coefficients of forms (C_B, and C_P), and the Froude number F_N.

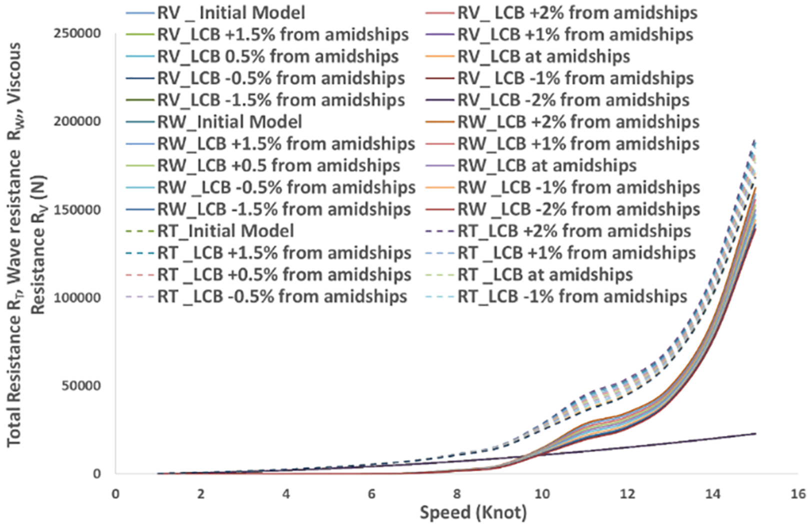

Fig. 4. Graphical representations of resistance components of hulls with different positions of *LCB*.

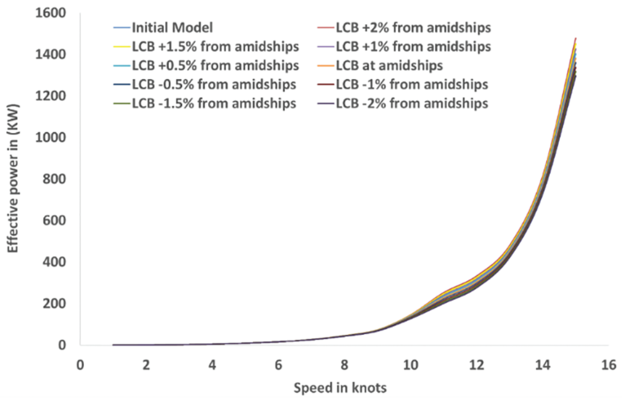

Fig. 5. Graphical representations of effective power calculations of hulls with different positions of LCB.

4. Conclusions

The paper presented a methodology for studying the effect of LCB position on resistance, in the early design stage. The methodology was illustrated with a case study analysis of the effect of LCB position variations on resistance for a fishing vessel hull. The analysis was performed using the Holtrop computational procedure of the software "Ship Power V 1.0", which is based on the Holtrol regression model for resistance predictions. At more advanced stages of the design, a more accurate analysis can be performed by using a CFD computational tool.

For the hull of the fishing vessels taken into consideration, referred to the predictions based on the Holtrop regression, the hull with LCB position –2% aft from amidships exhibited minimum values of resistance. The considerations presented in this study refers to the hull taken into consideration and should not be generalised to other type of hulls forms, since the optimum value of *LCB* for minimum resistance depends on values of Froude numbers F_N, and form coefficient (C_B, and C_P), and may vary in different typologies of hull. However, the methodology presented in this study can also be applied to other hull forms in the early design stages.

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