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INVESTIGATION OF HULL DESIGN TO QUANTIFY RESISTANCE CRITERIA USING HOLTROP'S REGRESSION-BASED METHOD AND SAVITSKY'S MATHEMATICAL MODEL: A STUDY CASE OF FISHING VESSELS

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Abstract

Fishing vessels are generally used for finding, fishing, and containing fish during their operations. To meet the industrial demands in fishing, one of the potential research is performance analysis for a variety of hull types of fishing vessels. The conventional design. This research is conducted considering the monohull type as the main subject. Hull analysis on the fishing vessel is focused on the resistance criteria with expectation the results can be used as a reliable reference for the fishing vessel industry to increase the effectiveness of the hull design, which furthermore gives positive benefit for the fishermen and the industries. The resistance criteria are estimated using two well-known approaches, i.e., Savitsky's mathematical model and Holtrop's regression-based method. Comparative study of the hull design is extended to discussion of methodology effectiveness in resistance analysis. Research results concluded that in the comparison of three variations of the hull, the type of monohull with dagger board fin has the smallest total resistance value compared to other introduced hull models. The total resistance value of the monohull with a dagger board fin of 30^{o} using the Savitsky model is 34 kN while the Holtrop method provides 35 kN. Compared to the numerical calculation, both methods show gaps below 15% which makes the methods well enough to be used for resistance estimation, especially for the fishing vessel.

Keywords: Fishing vessel, Holtrop regression-based method, Hull characteristics, Resistance criteria, Savitsky's mathematical model.

1. Introduction

Fishing vessels are a ship, a boat, or a buoyant serve as fishing, pisciculture, and research or exploration activities fish. In addition, the use of fishing vessels is needed in the world economy in the area of maritime. The loading process of fishing vessels unlike general ship, which is largely loaded in port, but it can be loaded off at the coast and usually in severe weather condition. On the fishing vessel, it is required the hull type that can perform well on the state of the sea tidal. These days, in general, fishing vessels are still using monohull because this hull type has a slim characteristic and easy to use which can make the ship easy to catch marine species. In addition, the monohull is usually attached by a bulbous bow or fin which makes the ship is more stable [1]. Therefore, in this case, it is necessary to analyse the hull of fishing vessel model that fits with coastal criteria.

Afterward, the problems that existed were still identified. When it comes to increasing ship's efficiency, improving the hull efficiency is one of the most debated topics. Lately, numbers of research have been dedicated to developing ways in reducing the effects of friction on the ship's hull and resistance tendency during operation, i.e., [2-10]. Ships use large quantities of fuel to provide the necessary propulsive power to overcome resistance in their motion across ocean surfaces. There is always a demand to improve hull characteristics to reduce resistance in ship operation. The fishing vessel is one of them since it operates to follow the fishing target, which reduced resistance on hull will be good for fuel consumption efficiency and finally increase the profit.

One of viable methods to improve hull characteristic and reduce fuel consumption is through the optimization. Introduced by Legović and Dejhalla [11], depending on the capital costs and expected gains in vessel fuel efficiency, two approaches are possible in terms of hull optimization, i.e., to modify the existing and partially optimized hull form, and the development of a new design (see Tables 1 and 2). The first approach involves alteration and modification to the fore-body design and stern shape.

The second approach is conducted by developing new hull particulars, propulsion system, and power plant will be adjusted to reach the maximum efficiency. Based on these approaches, the improved hull characteristic, e.g., drag/resistance criteria can be achieved. With the development of calculation method, the improved performance of vessel hull can be investigated in detailed and accurate using various methods, i.e., regression-based method and empirical method as proposed by Holtrop and Savitsky, consecutively [12-15]. Hull details and appendages are possibly assessed repeatedly which only cost the calculation time and less experimental expenses.

Considering the discussed case and research opportunity, the purpose of this study was addressed to compare several designs to investigate the resistance criteria of fishing vessels. The research in this study used two methodologies, namely Holtrop method and Savitsky formula to calculate hull resistance based on several proposed designs. A simple monohull is designed based on existing ship data as comparison. Other designs are introduced by modify the simple monohull to observe resistance criteria of each hull and select hull with the best performance. Discussion to compare methodologies of Holtrop and Savitsky is presented to complete the technical investigation of the fishing vessel.

Table 1. Optimization effect of ship criteria to fuel consumption.

Criteria	Savings	Applicability	Ship type
Ship-size capacity	10-25% of fuel consumption per ton-mile by increasing ship's capacity by 50-75%	Largest savings for higher speed ships and smaller sized vessels	All New and existing
Service speed	12-22% in PFC* by reducing the speed by 1 knot	Depending on the ship type and design speed	All New and existing
Principal dimension	3-5% in PFC by increasing the *L*/*B* ratio or by reducing the C_B	Depending on the ship type and construction costs	All New

*PCF: propulsion fuel consumption

Table 2. Effect of hull form optimization on fuel consumption.

Hull form	Savings	Applicability	Ship type
Optimizing the hull form	12-16% in resistance by optimizing the ballast waterline together with the full load waterline	Different drafts, trims, and speed ranges optimization. Due to high costs, it is justified for multiple ship programs	All New
Fore-body optimization	1-5% in PFC by modifying the bulbous bow	Bulb design, waterline entrance, forward shoulder, and transition to the turn of the bilge	All New and existing
Aft-body optimization	No relevant data	Improvement of flow into the propeller and minimization eddy effects	All New
Appendage resistance	Compared to the bare hull, no savings are possible, but the increase of appendage resistance can be minimized	Optimization of bilge keels, rudders and bow thruster tunnels	All New and existing

2. Theoretical Basis

2.1. A general definition of a fishing vessel

Fishing vessels in the operational function of the ship required some special requirements owned by fishing vessels, namely (1) stability, (2) endurance, (3) speed, and (4) ability to move the ship. According to a statement from Nomura and Yamazaki [16], fishing vessels have the characteristics and features of other types of ships, including the following:

- Speed ship

  In general, fishing vessels require high speeds that are adjusted to the needs for fishing activities.

- Ship movement

  Fishing vessels require particular good movement when operating, such as functional steer abilities, small turning radius, and propulsive engine that can quickly move forward and backward.

- Strong ship construction

  Strong ship construction in fishing operations will face changing natural conditions, and ship construction must be able to withstand the vibration generated by ship engines.

- Propulsion engines

  Fishing vessels need a pretty large engine, while as much as possible, the engine volume and vibration caused must be small because it can affect the presence of fish in the water. Fishing vessels commonly used for fishing operations are not only ships with one hull, but there are two hulled vessels or so-called catamarans and trimarans that have been developing rapidly for more than 20 years.

2.2. The resistance of the fishing vessel

Vessel resistance is one important factor that must be taken into account when wanting to build a hull. When the hull operates in the water, there will be resistance (resistance) from the fluid that passes through. These obstacles will be the primary influence on the performance of the ship.

2.2.1. Savitsky's mathematical model

In the discussion of ship hull with the hydrodynamic characteristics in numerical planning and calculation to find wet areas, drag, pressure centres, stability, and resistance that can function at speed, deadrise angle, and trim [17]. In the ship's speed coefficient, a ship can perform good procedure levels in the center of gravity, trim, and bow height by having a dynamic lift on the ship [18]. The speed coefficient by Savitsky is stated in Eq. (1) [17]

$$C_v = \frac{v}{\sqrt{g.b}} \tag{1}$$

where, C_v is the coefficient of speed; v is the speed of ship (m/s); g is the center of gravity $\left(9.81\ m/s^2\right)$; b is the maximum beam over chine (m).

As for displacement of the designed hull in volume, it can be calculated using expression in Eq. (2)

$$\nabla = L\,.\,B\,.\,T\,.\,C_b \tag{2}$$

where, L is the length of waterline (lwl, m); B is the breadth (m); T is the draught (m); C_b is the coefficient of block; ∇ is the displacement volume (m^3).

Savitsky approaches to find out the value of Reynolds with formulas in Eq. (3)

$$R_n = \frac{V_s\,.Lwl}{\upsilon} \tag{3}$$

where, V_s is the service speed (m/s); Lwl is the length of waterline (m); υ is the viscosity of seawater (m^2/s).

The friction component D_f is shown in to be calculated by Eq. (4),

$$D_f = \frac{C_f \rho V_1{}^2 (\lambda b^2)}{2\cos\beta} \quad (4)$$

where, C_f is the coefficient of friction resistance; ρ is the water density (m^3); V_1 is the average bottom velocity; b is the maximum beam over chine (m); β is the deadrise angle (deg); λ is the wetted length-beam ratio.

When the friction component D_f occurs, the tangential is added to the bottom, the total drag (*D*) is shown in the total drag, *D*, is shown in Eq. (5)

$$D = \Delta \tan\tau + \frac{D_f}{\cos\tau} \quad (5)$$

where, *D* is the total drag (kN); τ is the trim angle (deg); D_f is the friction component.

2.2.2. Holtrop's regression-based method

In the latest publication, numerical methods are used to find the initial stages of design. This method is then developed by experimental regression. The method can be inappropriate if the parameters used are not in accordance with the modeling. Therefore, expansion was carried out using a low *L*/*B* ratio and adjusting the submerged transom stem. For the hull form factor, the prediction formula as presented in Eq. (6) [19].

$$1 + k_1 = c_{13}\left\{0.93 + c_{12}\left({}^{B}/_{L_R}\right)^{0.92497}\left(0.95 - C_p\right)^{-0.521448}\left(1 - C_p + 0.0255\, lcb\right)^{0.6906}\right\} \quad (6)$$

and determination of the addition of resistance id shown in Eq. (7),

$$R_{APP} = 0.5\, \rho\, V^2\ S_{APP}\ (1 + K_2)_{eq}\ C_f \quad (7)$$

where, ρ is the water density; V is the ship speed; S_{APP} is the wetted area of appendage; $1{+}K_2$ is the resistance factor of appendage (see Table 3); C_f is the frictional resistance coefficient of the ship according to the ITTC-1957 formula.

Table 3. Streamlined flow-oriented appendage $1 + K_2$ value [19].

Approximate $1 + K_2$	**Value**
Rudder behind skeg	1.5 – 2.0
Rudder behind stern	1.3 – 1.5
Twin-screw balance rudders	2.8
Shaft brackets	3.0
Skeg	1.5 – 2.0
Strut bossings	3.0
Hull bossings	2.0
Shafts	2.0 – 4.0
Stabilizer fins	2.8
Dome	2.7
Bilge keels	1.4

The equivalent $1 + K_2$ value for a combination of appendages is determined and presented in Eq. (8) and the wave resistance is determined and presented in Eq. (9)

$$(1+K_2)_{eq} = \frac{\sum(1+K_2)\,S_{APP}}{\sum S_{APP}} \quad (8)$$

$$R_w = c_1\, c_2\, c_5\, \nabla\, \rho\, g\, exp\left\{m_1\, F_n{}^d + m_2 \cos\left(\lambda F_n{}^{-2}\right)\right\} \quad (9)$$

The additional resistance due to the presence of a bulbous bow near the surface is determined in Eq. (10),

$$R_B = 0.11 \exp\left(-3\, P_B{}^{-2}\right) F_n{}^3 A_{BT}{}^{1.5}\, \rho\, g / \left(1 + F_n{}^2\right) \quad (10)$$

where, P_B is the measure for the emergence of the bow; F_n is the Froude number.

Similarly, the additional pressure resistance due to the immersed transom can be determined as presented in Eq. (11),

$$R_{TR} = 0.5\, \rho\, V^2\, A_T\, c_6 \quad (11)$$

The model-ship correlation resistance R_A is presented in Eq. (12),

$$R_A = 0.5\, \rho\, V^2\, S\, C_A \quad (12)$$

The total resistance of a ship has been subdivided as summarized in Eq. (13),

$$R_{Total} = R_F(1+K_1) + R_{APP} + R_W + R_B + R_{TR} + R_A \quad (13)$$

where, R_F is the frictional resistance according to the ITTC-1957 friction formula; $1+K_1$ is the form factor describing the viscous resistance of the hull form in relation to R_F; R_{APP} is the resistance of appendages; R_W is the wave-making and wave-breaking resistance; R_B is the additional pressure resistance of bulbous bow near the water surface; R_{TR} is the additional pressure resistance of immersed transom stern; R_A is the model-ship correlation resistance.

3. Research Methodology

In this research, the aim is addressed to develop the shape of the monohull, then conduct a comparative analysis of the hull to conclude which hull is more effective in terms of resistance criteria. The initial stage is started by determining the initial dimensions by the ship comparison method. In the next stage, the research proceeds with monohull variation by adding bilge keel. After that, hull shape is adjusted in the lines plan as a modification of the curved shape. Then, the hull form performance is investigated by using Savitsky's mathematical model and Holtrop's regression-based method to quantify resistance characteristic. A comparative study is extended to discuss calculation process and result of each method.

3.1. Main dimension of the fishing vessel

The main dimension selection of the ship is performed by the comparative ship method to determine the main dimensions of the current fishing vessel design. The selected reference ships and their main dimensions is presented in Table 4. Then there are steps to determine the main dimensions, i.e.:

- Determining the main dimension of the new design as a reference. In this work, it is the overall length of the ship (LOA) with value 1 m. This length is scaled down to simplify the calculation.
- Finding the ratio of ships from *L*/*B*, *L/H*, and *B/T*, where *L*/*B* is the Length/Beam ratio; *L*/*H* is the Length/Depth ratio; *B*/*T* is the Beam/Draught

ratio. The ratio is, then, used as reference data to conduct regression analysis to determine the ship dimension at the preliminary design stage.

- The obtained dimensions for new vessel design are presented in Table 5 with lines plan designs are presented in Figs. 1-3.

Table 4. Ship comparison data to determine main dimension.

No.	Type of Hull (Monohull)	Dimension of hull					
		LOA (m)	B (m)	D (m)	T (m)	GT (ton)	Speed (knot)
1	Almirante 1	76.75	13.5	8.7	5.9	1967	15.8
2	Madidihang -03	50	9.8	6.65	3.85	693	13.5
3	Armaven Uno	31.65	7.7	5.7	3.99	270	10.6
4	Sea Fisher 3208 (Purse Seiner)	32	8.21	4.25	3.30	200	12.5
5	Sea Fisher 2608 (Stern Trawler)	25.7	7.5	3.75	2.85	163	8.9

Table 5. Main dimensions of the new vessel design.

No.	Parameter	Main dimension	Unit
1	LOA	1	m
2	LWL	0.960	m
3	LPP	0.860	m
4	B	0.196	m
5	D	0.133	m
6	T	0.077	m

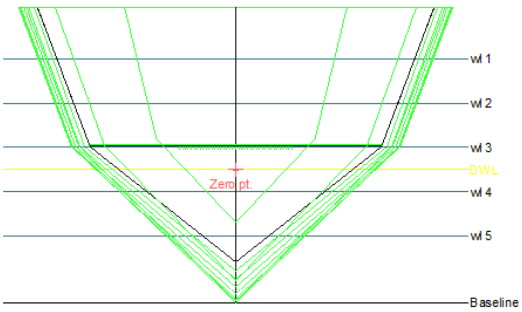


Fig. 1. Body plan of the new vessel design.

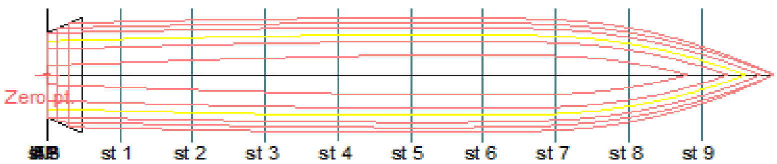


Fig. 2. Breadth plan of the new vessel design.

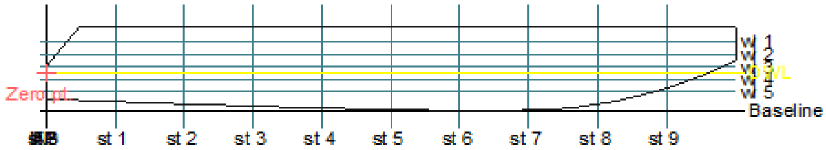


Fig. 3. Sheer plan of the new vessel design.

3.2. Three-dimensional modeling

The 3D model was made using the process of reverse engineering. The physically measured point coordinates were used in this stage so that the hull lines and surfaces could be idealized. Then, the optimized model of the fishing vessel hull was achieved using the interpolation and optimization processes. Characteristics of the new design are presented in Tables 6 and 7. The design in Fig. 4 depicts several variations on the hull of the ship, which including by adding fins to the new hull design so that it can provide an effect to the resistance. In the hull design, there are three sequences in the following design:

- Curve design of the hull
- The building of the hull surface
- Smoothing of the hull surface

Table 6. Data design of the new design for resistance calculation.

No.	Item	Value	Units	Savitsky	Holtrop
1	LWL	0.96	m	0.96	0.96
2	Beam	0.196	m	0.196	0.196
3	Draft	0.06	m	-	0.06
4	Displaced volume	0.003	m^3	0.003	0.003
5	Wetted area	0.143	m^2	-	0.143
6	½ angle of entrance	17.8	deg.	-	17.8
7	Deadrise at 50% LWL	42.6	deg.	42.6	-
8	Hard Chine or Round bilge	Hard chine		-	-
9	Kinematic Viscosity	0.0000011	m^2/s	0.0000011	0.0000011
10	Water density	1.026	tonne/m^3	1.026	1.026

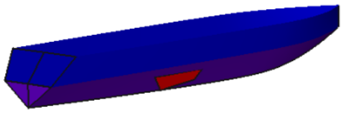
Table 7. Hull form data of the new design.

No.	Parametric Hydrodynamics	Variations in ship hull*		
		Model 1	Model 2	Model 3
1	Prismatic coefficient	0.752	0.647	0.397
2	Block coefficient	0.241	0.249	0.221
3	Midship coefficient	0.500	0.687	0.864
4	Water-plane Area coefficient	0.552	0.552	0.552

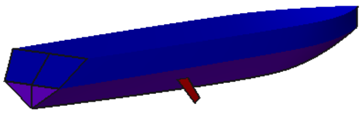
* see the introduced models in Fig. 4.

After the design stage, identification step is conducted to observe the occurrence of errors which usually takes place during the insertion of coordinates. This step is necessary after the design in order to get the appropriate hull form [20, 21].

(a) Monohull without fin.



(b) Monohull with low fin the ratio of 30º.



(c) Monohull with dagger board fin of 30º.

Fig. 4. Hull variation of the new fishing vessel design.

4. Results and Discussion

4.1. Resistance calculation

Analysis of ship resistance aims to find the resistance on the submerged hull (below the waterline). Large resistance can be technical references for estimation of the power needed by the ship. In the analysis of ship resistance, a series of scenario is tested using a variety of Froude number, Reynold number, and ship speed. As a comparison data of Savitsky and Holtrop, analysis result using Maxsurf's numerical calculation is presented.

4.1.1. Calculation using Savitsky's mathematical model

The analysis results of the monohull are summarized in Table 8 and Fig. 5 which the hull without fins has a variation of the speed taken from 4 to 20 knots. Based on the obtained data, monohull with no fin has a total value of the minimum resistance 1.63 kN and the maximum 34.01 kN for the Savitsky mathematical model. In comparison, the numerical calculation provided the minimum resistance 2.38 kN and the maximum value of 35.12 kN.

Table 8. Data of the total resistance using the Savitsky model: The monohull without fin (Model 1).

Monohull Without Fin				
F_n (-)	R_e (-)	V (knot)	Savitsky Model (kN)	Numerical Calculation (kN)
0	0	0	0	0
0.688	1575322.635	4	1.63	2.38
1.377	3150645.271	8	6.44	8.26
2.066	4725967.906	12	13.43	16.15
2.754	6301290.541	16	22.66	26.20
3.443	7875513.176	20	34.01	35.12

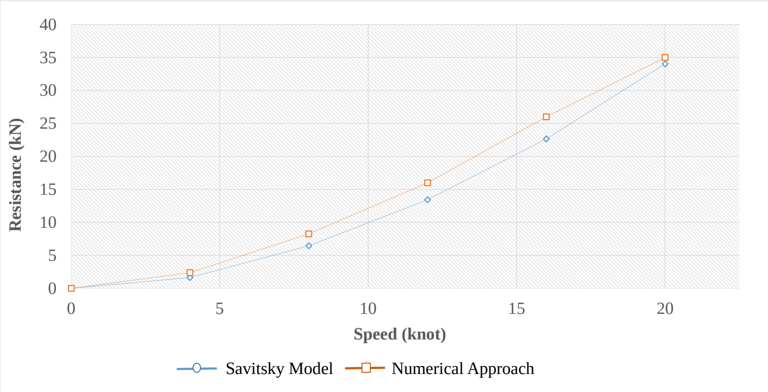


Fig. 5. Savitsky's mathematical model for the monohull without fin (Model 1).

In the results of the monohull model 2 in Table 9 and Fig. 6, the hull with a low aspect ratio keel of 30° has a variation of speed taken from 4 knots to a maximum limit of 20 knots. From the obtained analysis data on the monohull with the addition of fin, the total resistance value of the Savitsky approach is 1.29 kN for minimum value and 23.7 kN for the maximum value. The numerical method presented minimum total resistance 1.73 kN and maximum of 25.8 kN.

Table 9. Data of the total resistance using the Savitsky model: The monohull with low fin the ratio of 30° (Model 2).

Monohull with low fin the ratio of 30°				
F_n (-)	R_e (-)	V (knot)	Savitsky Model (kN)	Numerical Calculation (kN)
0	0	0	0	0
0.688	1575322.635	4	1.29	1.73
1.377	3150645.271	8	4.50	6
2.066	4725967.906	12	9.38	12
2.754	6301290.541	16	15.8	18.9
3.443	7875513.176	20	23.7	25.8

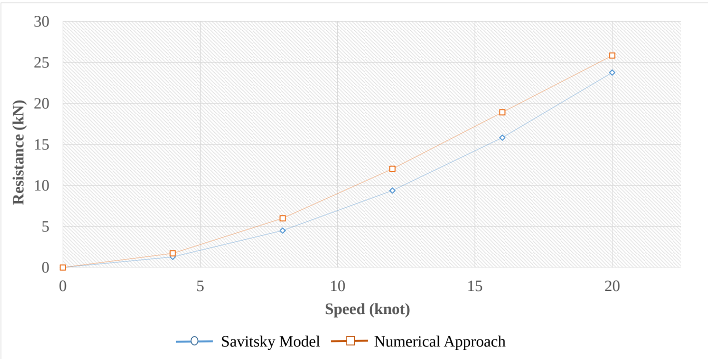


Fig. 6. Savitsky's mathematical model for the monohull with low fin the ratio of 30° (Model 2).

Results of the monohull model 3 as summarized in Table 10 and Fig. 7 depicts the hull with a daggerboard 30º has a variation of speed taken from 4 knots to a maximum limit of 20 knots. Based on the obtained calculation results using the Savitsky model, the monohull with the addition of fin has total resistance value with the minimum value 1.63 kN and the maximum value 30.01 kN. The numerical calculation presented the minimum total resistance 2.37 kN and the maximum of 35 kN.

Table 10. Data of the total resistance using the Savitsky model: The monohull with daggerboard fin of 30º (Model 3).

Monohull with Daggerboard fin of 30º				
F_n (-)	R_e (-)	V (knot)	Savitsky Model (kN)	Numerical Calculation (kN)
0	0	0	0	0
0.688	1575322.635	4	1.63	2.37
1.377	3150645.271	8	5.68	8.24
2.066	4725967.906	12	11.8	16.5
2.754	6301290.541	16	19.9	26.02
3.443	7875513.176	20	30.01	35

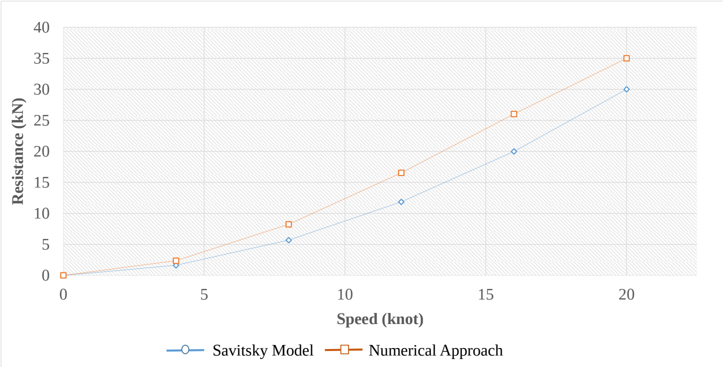


Fig. 7. Savitsky's mathematical model for the monohull with daggerboard fin of 30º (Model 3).

Result comparison of the three hull variations, the minimum total resistance is achieved by the monohull with a low aspect ratio of 30º (Model 2) with a value 1.29 kN while the maximum value occurred on the monohull without fins (Model 1) with value 35.12 kN. Therefore, based on the results of three hull variations, it can be concluded that in terms of the average value of the total resistance, hulls with a low aspect ratio variation keel have the least resistance at the maximum speed 20 knots, i.e., occurred resistance value 23.7 kN.

4.1.2. Numerical calculation using Holtrop method

Based on the results in Table 11 and Fig. 8, it is obtained that the value of the total resistance on the hull without fin using the Holtrop method is 3.09 kN for the minimum value of while the maximum value is 32.5 kN. As a comparison, the numerical calculation provides minimum resistance value 2.47 kN, and the maximum value is 38 kN.

Table 11. Data of total resistance using Holtrop method: The monohull without fin (Model 1).

Monohull Without Fin				
F_n (-)	R_e (-)	V (knot)	Holtrop Method (kN)	Numerical Calculation (kN)
0	0	0	0	0
0.688	1575322.635	4	3.09	2.47
1.377	3150645.271	8	6.04	7.84
2.066	4725967.906	12	12.5	15.9
2.754	6301290.541	16	21.3	26.3
3.443	7875513.176	20	32.5	38

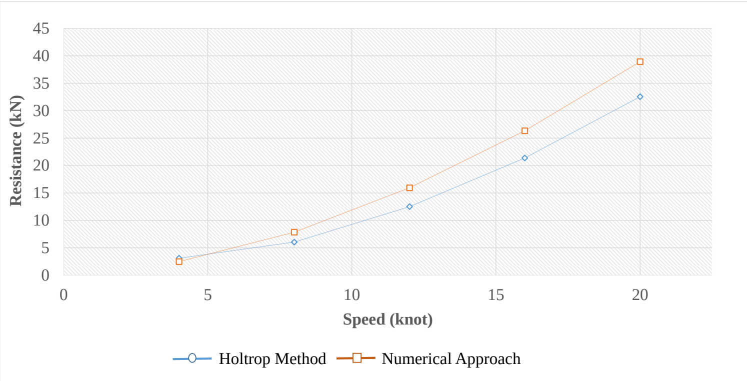


Fig. 8. Results of the Holtrop method for the Monohull without fin (Model 1).

Analysis results in Table 12 and Fig. 9 indicated that total resistance value on the hull with the addition of fin (Model 2) using the Holtrop's regression-based method is 2 kN for the minimum value while the maximum is 31 for the numerical method. On the other hand, the numerical shows 2.44 kN as the minimum value, and 40.5 kN as the maximum value.

Table 12. Data of total resistance using Holtrop method: The monohull with low fin the ratio of 30º (Model 2).

Monohull with low Fin the ratio of 30º				
F_n (-)	R_e (-)	V (knot)	Holtrop Method (kN)	Numerical Calculation (kN)
0	0	0	0	0
0.688	1575322.635	4	2	2.44
1.377	3150645.271	8	5.5	7.6
2.066	4725967.906	12	11.8	16.5
2.754	6301290.541	16	20.3	27.3
3.443	7875513.176	20	31	40.5

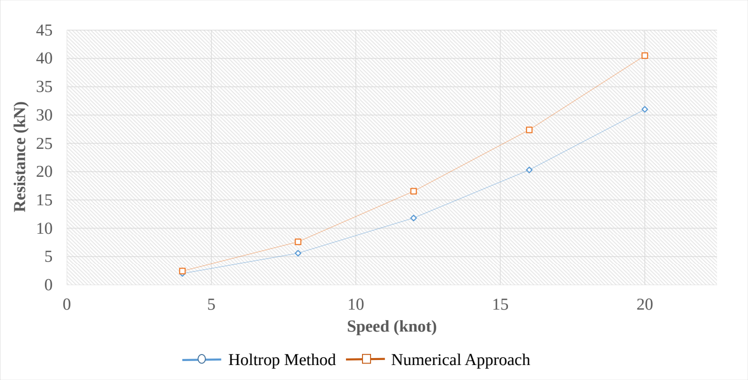


Fig. 9. Results of the Holtrop method the monohull with low fin the ratio of 30º (Model 2).

From the analysis results in Table 13 and Fig. 10, it is obtained that total resistance value on the hull with the addition of daggerboard fin by Holtrop method has the minimum value 1.63 kN while the maximum value is 34 kN. The numerical calculation, on the other hand, shows 2.38 kN as the minimum value and 35 kN as the maximum value.

Table 13. Data of total resistance using Holtrop method: The monohull with daggerboard fin of 30º (Model 3).

Monohull with daggerboard Fin of 30º				
F_n (-)	R_e (-)	V (knot)	Holtrop Method (kN)	Numerical Calculation (kN)
0	0	0	0	0
0.688	1575322.635	4	1.63	2.38
1.377	3150645.271	8	6.44	8.26
2.066	4725967.906	12	13.4	16
2.754	6301290.541	16	22.6	26
3.443	7875513.176	20	34	35

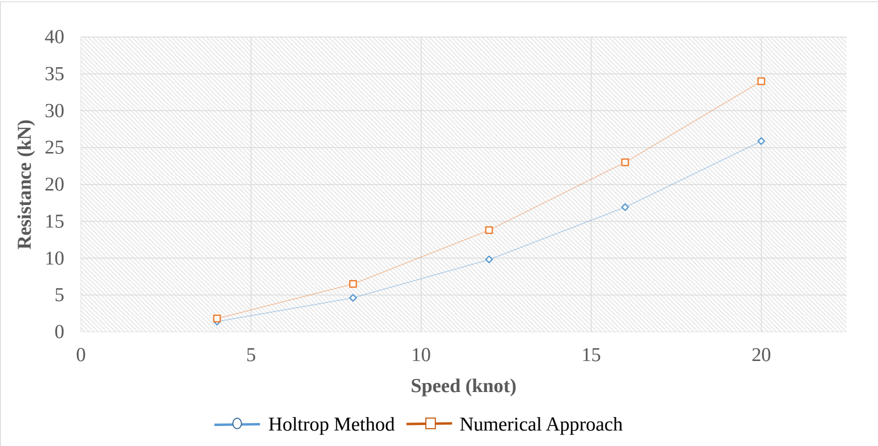


Fig. 10. Results of the Holtrop method for the monohull with daggerboard fin of 30º (Model 3).

Result comparison of three hull variations using the Holtrop method indicated that the average results in terms of total resistance at the speed 4 to 12 knots is a reasonably similar for the regression-based and numerical calculations. It increases in value, but not in significant level at the speeds of 16 to 20 knots.

4.2. Comparison between Savitsky's mathematical model and Holtrop's regression-based method

Results of the comparative study in terms of calculation methods involving three hull variations are summarized in Figs. 11-13. The Savitsky model and the Holtrop method obtained the smallest total resistance at the maximum speed 20 knots on the monohull with fin daggerboard (Model 3) with the value for the Savitsky is 30 kN and the Holtrop is 34 kN. Then, in terms of the comparison data between the deployed methods and numerical calculation, the difference is 14% for the Savitsky's mathematical model and 2% for the Holtrop's regression-based method. In this case, it can be concluded that the calculation using the proposed methods is acceptable, and presents similar results compared to the numerical approach with error less than 15%. This finding may be extended into future study to observe and quantify link-and-match relationship between calculation method and hull type. Therefore, specific calculation method can be introduced for certain hull type to achieve better accuracy.

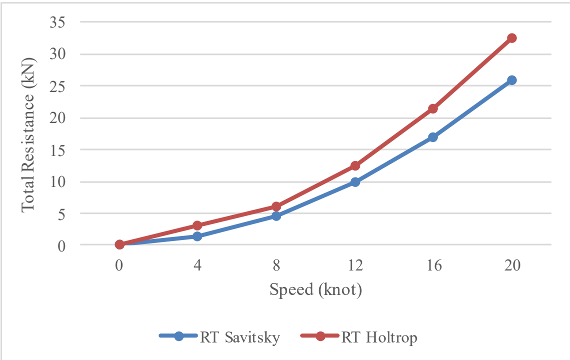


Fig. 11. Savitsky model vs. Holtrop method: The monohull without fin (Model 1).

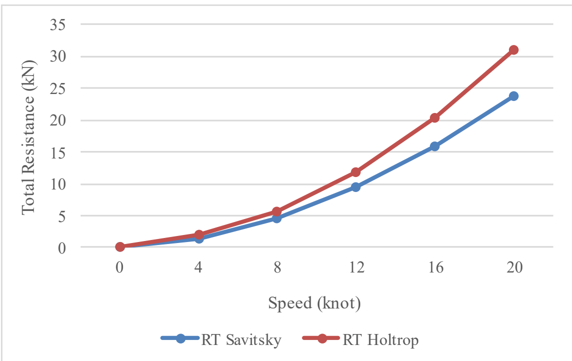


Fig. 12. Savitsky model vs. Holtrop method: The monohull with low fin the ratio of 30° (Model 2).

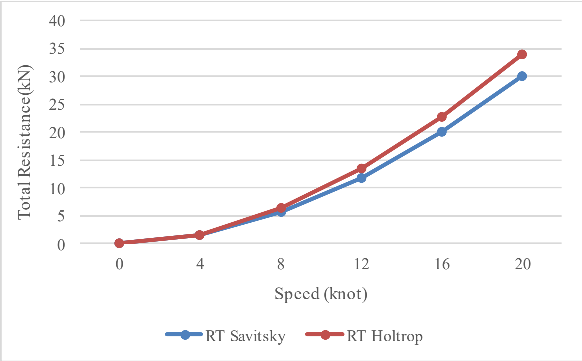


Fig. 13. Savitsky model vs. Holtrop method: The monohull with daggerboard fin of 30º (Model 3).

5. Conclusions

Based on the results of calculation, the investigation of the design of the introduced fishing vessel hull design in terms of resistance criteria, several information can be concluded as follows:

i. Results of the calculation of three hull variations using the Savitsky model are summarized as the following list.
   a. Monohull without fin
      - At the speed of 4 knots (minimum) = 1.63 kN
      - At the speed of 20 knots (maximum) = 34 kN
   b. Monohull with low fin the ratio of 30º
      - At the speed of 4 knots (minimum) = 1.29 kN
      - At the speed of 20 knots (maximum) = 23.7 kN
   c. Monohull with daggerboard fin of 30º
      - At the speed of 4 knots (minimum) = 1.63 kN
      - At the speed of 20 knots (maximum) = 30 kN

ii. The calculation results of three hull variations using the Holtrop method are given in the following list.
   a. Monohull without fin
      - At a speed of 4 knots (minimum) = 3.09 kN
      - At a speed of 20 knots (maximum) = 32.5 kN
   b. Monohull with low fin the ratio of 30º
      - At a speed of 4 knots (minimum) = 2 kN
      - At a speed of 20 knots (maximum) = 31 kN
   c. Monohull with daggerboard fin of 30º
      - At a speed of 4 knots (minimum) = 1.63 kN
      - At a speed of 20 knots (maximum) = 34 kN

iii. Data results of the three hull variations indicate that the smallest total resistance value is the monohull with a daggerboard fin of 30º (Model 3) with value in the Savitsky model is 34 kN and Holtrop method is 35 kN. The gaps of these approaches with the numerical calculation are 14% and 2% for Savitsky and Holtrop, consecutively.

iv. The addition of fins on the introduced hull model provides a statement that the occurred total resistance becomes smaller when the model is calculated in high-speed states, which is followed by smaller error compared to the resistance in lower speeds. The deployed method in this work is concluded reliable enough to estimate resistance criteria of the fishing vessel.

v. Future works are recommended to investigate effect of propulsion geometry to the hydrodynamic performances. Optimization of the hull design can be collaborated with development of the propeller. Pioneer works by Bahatmaka [22, 23] may be reliable references for preliminary study.

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Nomenclatures

τ	Trim angle of keel, deg.
C_v	Speed coefficient
D_f	Viscous component of drag, lb
R_A	Model-ship correlation resistance
R_B	Additional pressure resistance of bulbous bow near the water surface
R_e	Reynolds number
R_F	Frictional resistance according to the ITTC-1957 friction formula
R_W	Wave-making and wave breaking resistance
R_{TR}	Additional pressure resistance of immersed transom stern
R_{APP}	Resistance of appendages
$1+k1$	Form factor describing the viscous resistance of the hull form concerning R_F

References

1. Bahatmaka, A.; Kim, D.J.; Samuel; Prabowo A.R.; and Zaw, M.T. (2018). Investigation on the performance of the traditional Indonesian fishing vessel. *MATEC Web of Conferences*, 159, 02056.
2. Samuel; Kim, D.J.; Iqbal, M.; Bahatmaka, A.; and Prabowo, A.R. (2019). Bulbous bow applications on a catamaran fishing vessel for improving performance. *MATEC Web of Conferences*, 159, 02057.
3. Bahatmaka, A.; and Kim, D.J. (2019). Numerical approach for the traditional fishing vessel analysis of resistance by CFD. *Journal of Engineering Science and Technology*, 14(1), 207-217.

4. He, N.V.; Mizutani, K.; and Ikeda, Y. (2016). Reducing air resistance acting on a ship by using interaction effects between the hull and accommodation. *Ocean Engineering*, 111, 414-423.
5. Zhao, Y.; Zong, Z.; and Zou, L. (2015). Ship hull optimization based on wave resistance using wavelet method. *Journal of Hydrodynamics, Ser. B*, 27(2), 216-222.
6. Andersson, J.; Oliveira, D.R.; Yeginbayeva, I.; Andersen, M.L.; and Bensow, R.E. (2020). Review and comparison of methods to model ship hull roughness. *Applied Ocean Research*, 99, 102119.
7. Esmailian, E.; Gholami, H.; Røstvik, H.N.; and Menhaj, M.B. (2019). A novel method for optimal performance of ships by simultaneous optimisation of hull-propulsion-BIPV systems. *Energy Conversion and Management*, 197, 111879.
8. Xu, L.; and Wang, Y.Y. (2001). The fine optimization of ship hull lines in resistance performance by using CFD approach. *Practical Design of Ships and Other Floating Structures*, 1, 59-65.
9. Yanuar; Ibadurrahman, I.; Gunawan, A.; Wibowo, R.A.; and Gunawan. (2020). Drag reduction of X-pentamaran ship model with asymmetric-hull outrigger configurations and hull separation. *Energy Report*, 6(supplement 2), 784-789.
10. Jang, J.; Choi, S.H.; Ahn, S.M.; Kim, B.; ad Seo, J.S. (2014). Experimental investigation of frictional resistance reduction with air layer on the hull bottom of a ship. *International Journal of Naval Architecture and Ocean Engineering*, 6(2), 363-379.
11. Legović, D.; and Dejhalla, R. (2016). An overview of measures for ship's energy efficiency improvement. *22nd Symposium Sorta 2016*. Trogir, Croatia, 1-12.
12. Birk, L. (2019). Holtrop and Mennen's method. *Fundamentals of Ship Hydrodynamics: Fluid Mechanics, Ship Resistance and Propulsion*, Chapter 50, John Wiley and Sons Ltd.
13. Lützen, M.; and Kristensen, H.O. (2013). *Prediction of resistance and propulsion power of ships*. Project no. 2010-56, Emissionsbeslut ningsstøttesystem, Work Package 2, Report No. 04.
14. Roh, M.I.; and Lee, K.Y. (2017). Prediction of resistance and power. *Computational Ship Design*. Springer, Singapore, 37-57.
15. Khazaee, R.; Rahmansetayesh, M.A.; and Hajizadeh, S. (2019). Hydrodynamic evaluation of a planning hull in calm water using RANS and Savitsky's method. *Ocean Engineering*, 187, 106221.
16. Nomura, M.; and Yamazaki, T. (1977). *Fishing Techniques* (1). Japan International Cooperation Agency-Tokyo, 206.
17. Savitsky, D.; and Ward, B.P. (1964). Procedures for hydrodynamic evaluation of planning hulls in smooth and rough water. *Journal Marine Technology*, 13(4), SNAME-MTSN-1976-13-4-381.
18. Faltisen, O.M. (2005). *Hydrodynamic of a high-speed marine vessel*. Cambridge: Cambridge University Press.
19. Holtrop, J.; and Mennen G.G.J. (1982). An approximate power prediction method. *International Shipbuilding Progress*, 29(335), 166-170.

20. Francescutto, A. (2007). The intact ship stability code: present status and future developments. *Proceeding of the 2nd International Conference on Marine Research and Transportation*. Napels, Italy, 199-208.
21. Lapa, K.N. (2018). Estimation of stability for a fishing vessel and some considerations. *IOP Conference Series: Materials Science and Engineering*, 400(8), 082014.
22. Bahatmaka, A.; Kim, D.J.; Chrismianto, D.; Setiawan, J.D.; and Prabowo, A.R. (2017). Numerical investigation on the performance of ducted propeller. *MATEC Web of Conferences*, 138, 07002.
23. Bahatmaka, A.; Kim, D.J.; Chrismianto, D.; Hai, N.; and Prabowo, A.R. (2017). Optimization of thrust propeller design for an ROV (Remotely Operated Vehicle) consideration by Genetic Algorithms. *MATEC Web of Conferences*, 138, 07003.