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RESEARCH ARTICLE

Guideline for preliminary design phase of trawler type yachts

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ABSTRACT

Yacht design is a multidisciplinary process that consists of set of iterative sub-processes. The main aim of the whole process is to reach the optimum design that satisfies not only the engineering-related requirements, but also the user's expectations. In the preliminary design process, determination of the type and the main dimensions of the yacht according to the user's preferences is followed by the processes such as the general arrangement plan, determination of the hull form and superstructure design, estimation of hydrostatic and hydrodynamic characteristics, etc. In this research, it is aimed to obtain a parametric design framework which enables to reach hull form characteristics, layout parameters and resistance estimation values with respect to various speeds, only by using only L_{OA} of trawler type motor yachts. In this content, 26 trawler type motor yachts were investigated and their hull were modeled for speed-resistance calculations. As a result of the research, graphics and tables were presented that allow to reach the characteristic parameters, which are important in terms of design and engineering, by using only the L_{OA} value in the preliminary design phase of the trawler type motor yachts.

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Nomenclature

B : Beam of the hull (m)
$B_{TRANSOM}$: Beam of the transom on top (m)
B_{WL} : Beam of waterline (m)
C_B : Block coefficient
C_M : Midship section coefficient
C_P : Prismatic coefficient
LCB : Longitudinal center of buoyancy
L_{HULL} : Hull length (m)
L_{OA} : Length overall (m)
$L_{PLATFORM}$: Length of the platform (m)
L_{WL} : Length of waterline (m)
T : Draft (m),
Δ : Displacement tonnage (tonnes)

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Introduction

Yacht design is a process involving iterative procedures until a result is achieved that satisfies various predetermined requirements (Larsson & Eliasson, 2007). The number, sequence and the contents of these procedures may differentiate according to the type of the yacht. For instance, design spiral which is presented by Hamlin (1996) includes a procedure related with sail & rigging design (see Figure 1). If a satisfactory result is achieved at each procedure of the design spiral, the next stage is passed, otherwise the process is renewed (Arslan, 2010). To start this iterative process, the designer uses a set of assumptions (Larsson & Eliasson, 2007). Formulas and frameworks developed by utilizing previous projects in yacht design play a major role in establishing the assumptions for the desired yacht.

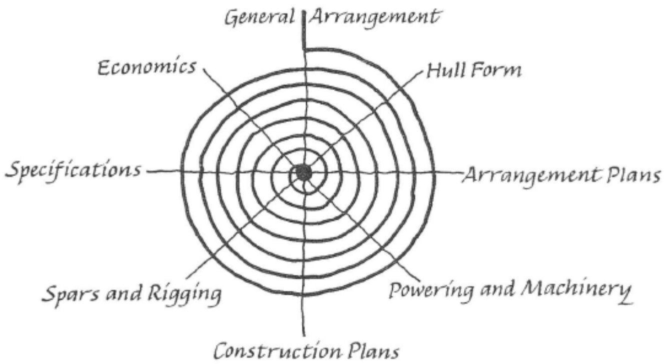

Figure 1. Design spiral presented by Hamlin (1996)

Clarifying the type of the yacht is among the initial steps in the early stage of the yacht design process. Yachts can be categorized as motoryachts and sailing yachts according to the propulsion type (Tokol, 2020). The form and variety of motor yachts differ from sailing yachts (Turan, 2021). It is very difficult to generalize the form in motor yachts that do not have a traditional form and therefore are open to diversity (Büyükkeçeci & Turan, 2018). Although it is possible to distinguish the displacement, semi-displacement or planning form for the underwater form of the hull, this distinction is not sufficient to define the above-water parts of the boats and at this point type names of lobster, trawler, open, sport, weekend, flybridge or hard-top etc. are used based on all or some of the parts of these yachts above the water (Turan, 2021). Trawler type yachts, which have been used for fishing purposes are re-designed to be used for pleasure purposes (Özgel Felek & Arabacıoğlu, 2019). These yachts are defined as motoryachts that offer spacious interior space thanks to the difference in grades on their main decks (Turan, 2021). Figure 2 shows the profile drawing and the general arrangement plan of a trawler type yacht. In these yachts, sunbathing area is located in the flybridge area.

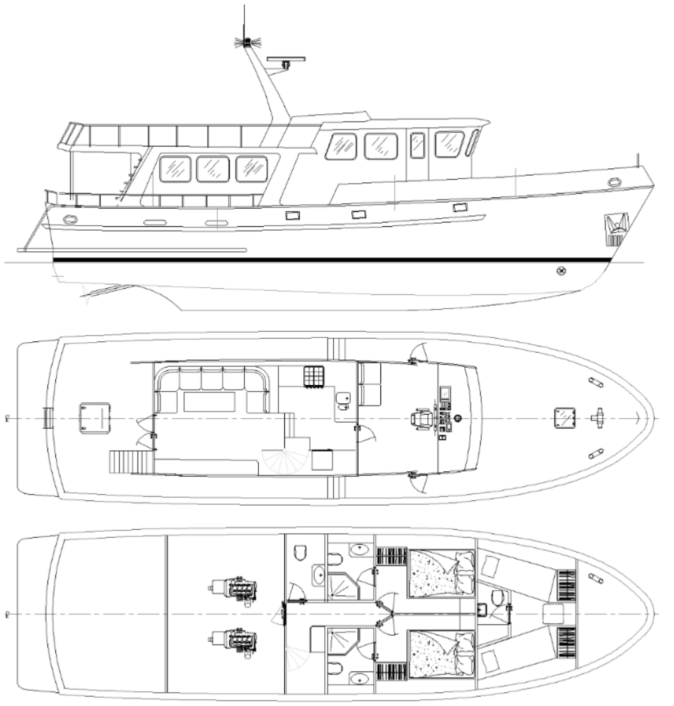

Figure 2. Profile drawing and general arrangement plan of a trawler yacht

As shown in Figure 2, trawler yachts have a stern with a transom and a platform, large closed area in the main deck and a flybridge that is located in the aft part of the yacht. Various studies address design process of different yacht types and contribute this iterative process by providing methods or guidelines. Turan (2021) presents non-dimensional parameters that indicate the location of the engine room for preliminary design stage of different yacht types. In their research, Turan & Akman (2021) investigated Bodrum Gulets with different stern forms and they developed a design framework for that specific sailing yacht type. In the research of Sarıoğlu & Kükner (2018) a numerical method to calculate the form factor of Bodrum gulets has been developed and an artificial neural network (ANN) has been used to estimate the form factor of hull forms in the design process of these yachts. The number of the studies conducted on the trawler type yachts are limited. In the research of Özgel Felek & Arabacıoğlu (2019), trawler type yachts have been investigated to obtain design parameters for general layout and superstructure design of these yachts. In another research (Lane, 2010) the effect of various bulb types on the resistance and performance characteristics of the selected trawler yacht hull have been studied. In the previous studies on trawler type yachts, these motor yacht types were handled from different disciplines and made important contributions in the design process. On the other hand, there is no design guide regarding hull form characteristics of these boat types. This study aims to fulfil this gap by providing a framework that enables the designer to obtain hull and superstructure parameters by using only L_{OA} of trawler type yachts.

Material and Method

In the research, 26 trawler type motor yachts' hulls and superstructures were investigated. L_{OA} of the investigated trawler yachts varies from 14,20 m to 36,80 m. 19 of the investigated yachts have been built between the years 1998 to 2023 while 7 of them are in the project or production phase. Table 1 includes main dimensions of the investigated trawler yachts. Figure 3 and Figure 4 illustrates render images of two different trawler yachts, which have been involved in the research.

After collecting data, investigated yachts' hulls were modelled in Rhino3D Version 7 (2020) and exported as IGES file to Maxsurf (2022) software program for hydrostatic and resistance calculations. Figure 5 represents the work flow of the research.

Figure 3. A render image of one of the investigated trawler yachts

Figure 4. A render image of one of the investigated trawler yachts

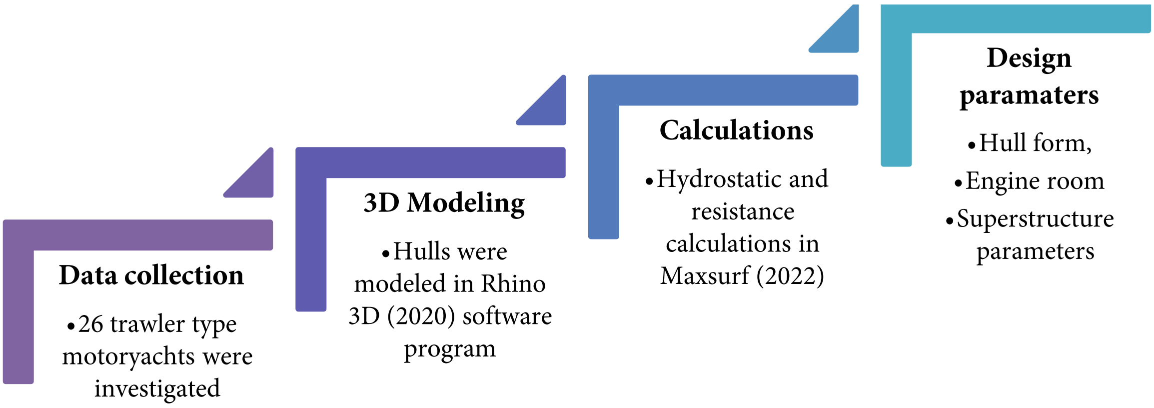

Figure 5. Workflow of the research

Table 1. Main dimensions of the investigated yachts

Yacht Code	L_{OA} (m)	L_{WL} (m)	L_{HULL} (m)	B (m)	B_{WL} (m)	$B_{TRANSOM}$ (m)	T (m)	Δ (ton)
Trawler_1	14.20	12.63	13.60	4.12	3.84	3.76	1.10	22.00
Trawler_2	15.00	13.60	14.35	4.26	4.00	3.96	1.16	24.00
Trawler_3	15.80	14.27	15.10	4.78	4.41	4.28	1.55	30.20
Trawler_4	16.50	14.45	15.80	4.68	4.33	4.31	1.28	29.00
Trawler_5	16.55	14.10	15.75	4.71	4.44	4.32	1.23	32.44
Trawler_6	18.80	16.45	18.00	5.26	4.88	4.78	1.41	40.00
Trawler_7	19.10	16.82	18.25	5.34	4.92	4.82	1.42	42.00
Trawler_8	19.38	17.56	18.48	5.23	5.07	4.92	1.58	48.51
Trawler_9	20.00	17.44	19.10	5.70	5.00	5.21	1.44	46.00
Trawler_10	20.50	18.20	19.60	5.62	5.22	5.10	1.61	57.00
Trawler_11	20.73	18.10	19.73	5.65	5.21	5.16	1.75	59.00
Trawler_12	20.80	18.92	19.70	5.82	5.51	5.24	1.68	62.00
Trawler_13	21.33	18.60	20.23	5.90	5.48	5.32	1.49	66.00
Trawler_14	21.77	19.68	20.77	5.69	5.42	5.30	1.70	68.60
Trawler_15	22.10	20.50	20.90	6.05	5.47	5.41	1.71	72.00
Trawler_16	23.60	20.91	22.35	6.46	5.83	5.76	1.68	75.00
Trawler_17	24.50	22.66	23.30	6.50	5.92	5.92	1.71	78.00
Trawler_18	24.90	22.80	23.60	6.55	6.18	5.81	1.70	76.00
Trawler_19	24.95	22.86	23.55	6.51	6.24	5.71	1.68	81.00
Trawler_20	25.00	21.50	23.50	6.62	6.32	5.84	1.71	84.00
Trawler_21	25.00	22.06	23.60	6.58	6.24	5.82	1.62	86.00
Trawler_22	25.20	23.60	23.70	6.60	6.18	5.92	1.80	92.00
Trawler_23	25.90	23.72	24.40	6.80	6.22	6.06	1.81	96.00
Trawler_24	27.00	25.70	25.40	6.88	6.61	6.11	1.81	112.00
Trawler_25	29.50	25.82	27.75	7.18	6.92	6.52	1.86	141.00
Trawler_26	36.80	34.50	34.40	7.96	7.56	7.16	2.30	248.00

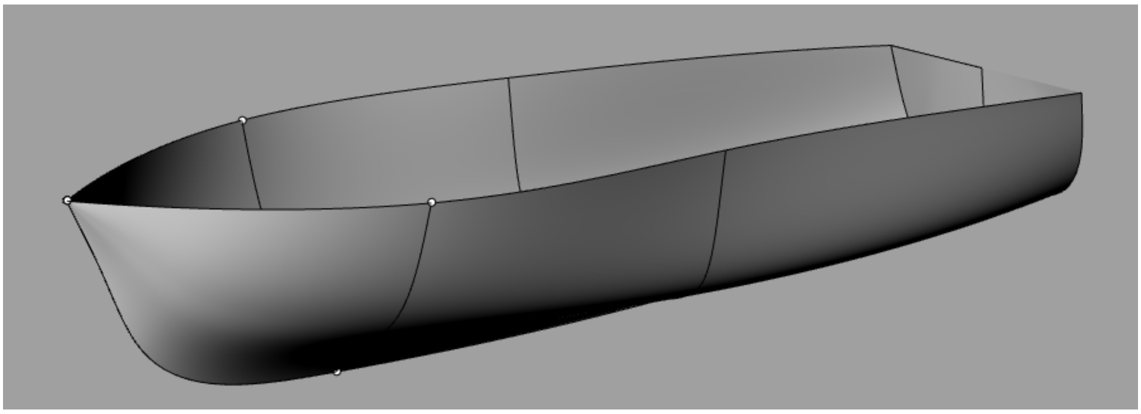

Figure 6. Modeled hull in Rhino3D

For the hydrostatic calculations, the reference point is taken as the intersection of the sternpost with the loaded waterline in the longitudinal direction; centerline for the transversal direction and baseline for the vertical direction. Figure 6 shows one of the modeled hulls for the analyses.

In the resistance calculations, Holtrop-Mennen method was used. The method is seen as a useful tool for displacement type hulls' resistance prediction calculation and it bases on the regression analysis of different scale model tests and trial data (Holtrop & Mennen, 1982; Turan, 2009). According to mathematical model of Holtrop-Mennen, viscous resistance R_V and the wave-making resistance R_W are two components of the total resistance R_T (Holtrop & Mennen, 1982; Elkafas et al., 2019). R_V is formulated as Eq (1):

$$R_V = (1 + k)R_F \tag{1}$$

R_F is frictional resistance according to the ITTC-1957 formula. The form factor k is a function of following hull form parameters (Elkafas et al., 2019) and formulated as in Eq (2):

$$k = f\left(\frac{B}{L}, \frac{T}{L}, \frac{L}{L_R}, \frac{L^3}{\nabla}, C_P, c\right) \tag{2}$$

where L_R is the length of after body and c is the coefficient based on the shape after body. The second main component, R_W is estimated by the Eq (3):

$$R_W = c_1 c_2 c_3 \nabla \rho g e^{(m_1 F_n^d + m_2 \cos(\lambda F_n^{-2}))} \tag{3}$$

where c_1, c_2, c_3, m_1, m_2 and λ are the coefficients (Holtrop & Mennen, 1982) which are the functions of the hull form. *Fn* is the Froude Number which depends on the speed of the vessel.

Results and Discussion

Results of the research are discussed in tree main perspectives as; hull form parameters, layout parameters and resistance characteristics. The hull form parameters perspective includes evaluation of the hydrostatic values of the investigated vessels as well as some design ratios of the hull. In the layout parameters perspective, location and proportion of the engine room and superstructure are presented. In the resistance characteristics, resistance values of the investigated yachts' hulls for different speed values are presented.

Hull Form Parameters

Hull form coefficients as well as the design ratios are among the key parameters to predict hull form characteristics in the design process of yachts. Block coefficient, C_B determines the fullness of a hull and it is one of the major factors on weight and resistance (Turan & Akman, 2021). Prismatic coefficient, C_P describes the fullness or fineness of the hull's ends by considering the immersed volume and midship section area (Killing & Hunter, 1998). Midship area coefficient, C_M is among important determinants for predicting wetted surface area, frictional resistance and pressure-viscous resistance characteristics when used with other parameters such as C_B, bilge radius and B/T ratio (Papanikolaou, 2014). Longitudinal center of buoyancy, *LCB* is an important determinant of the volume distribution of the hull when it is used with C_P (Killing & Hunter, 1998).

Beside hull form coefficients and LCB, ratios of L_{OA}/L_{WL}, L_{OA}/B, B_{WL}/T are calculated for the investigated trawler yachts. Determining L_{WL}, B, B_{WL} and T in the initial design process provides insight into not only the aesthetic aspects of the hull design, but also the hydrostatics and hydrodynamics characteristics. L_{OA}/L_{WL} ratio is used to determine overhangs of a yacht in longitudinal direction (Turan & Akman, 2021). Length-to-beam ratio has a direct effect on the resistance and consequently the power requirement of a ship (Molland, 2008). Moreover, L_{OA}/B ratio helps to understand how beamy the yacht is (Larsson & Eliasson, 2007). B_{WL}/T ratio is used to predict the resistance characteristics. The experiments show that the desired values for the frictional and the wave resistance aspects are around 2.500 for the beam to draft ratio (Papanikolaou, 2014). Table 2 represents the minimum, the maximum and the mean values of hull form parameters for the investigated trawler yachts' hulls.

Table 2. The minimum, the maximum and the mean values of hull form parameters of the investigated yachts

	Min	Mean	Max
C_B	0.302	0.360	0.424
C_M	0.562	0.599	0.656
C_P	0.511	0.603	0.702
LCB (% of L_{WL})	41.891	43.309	45.010
L_{OA}/L_{WL}	1.051	1.115	1.174
L_{OA}/B	3.305	3.715	4.623
L_{WL}/B_{WL}	3.176	3.572	4.563
B_{WL}/T	2.845	3.435	3.852

Estimation of the displacement weight of a ship depending on the sufficient comparative data from similar ships constitutes the starting point of the preliminary design (Papanikolaou, 2014). Figure 7 represents the distribution of the displacement weight in tones with respect to L_{OA} (m) for the investigated trawler type yachts.

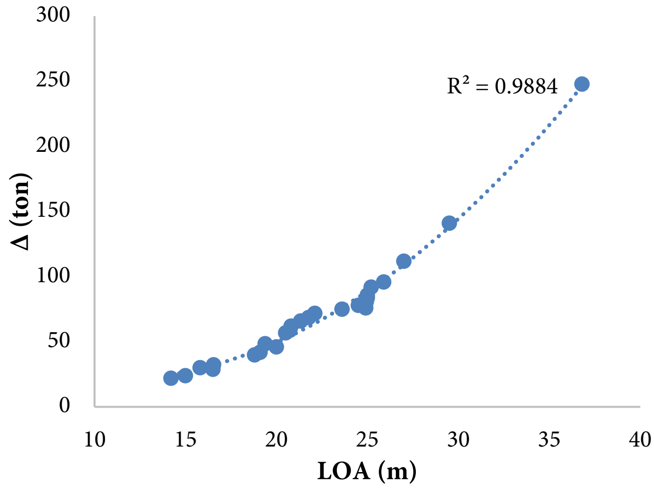

Figure 7. Distribution of displacement weight (Δ) with respect to L_{OA}

The ratios of B/B_{WL} and $B/B_{TRANSOM}$ have been calculated for the investigated trawler type yachts in order to give an idea about the hull form. The ratio of B/B_{WL} varies between 1.032 and 1.140 and the mean value of the ratio is calculated as 1.071. $B/B_{TRANSOM}$ ratio has a mean value of 1.106 and the ratio varies from 1.063 to 1.140. Moreover, Figure 8 shows the B, B_{WL} and $B_{TRANSOM}$ with respect to L_{OA} for the investigated yachts.

Angle of the stempost with the loaded waterline varies between 58° and 79° and the mean value of this parameter was calculated as 66.58° for the investigated trawlers.

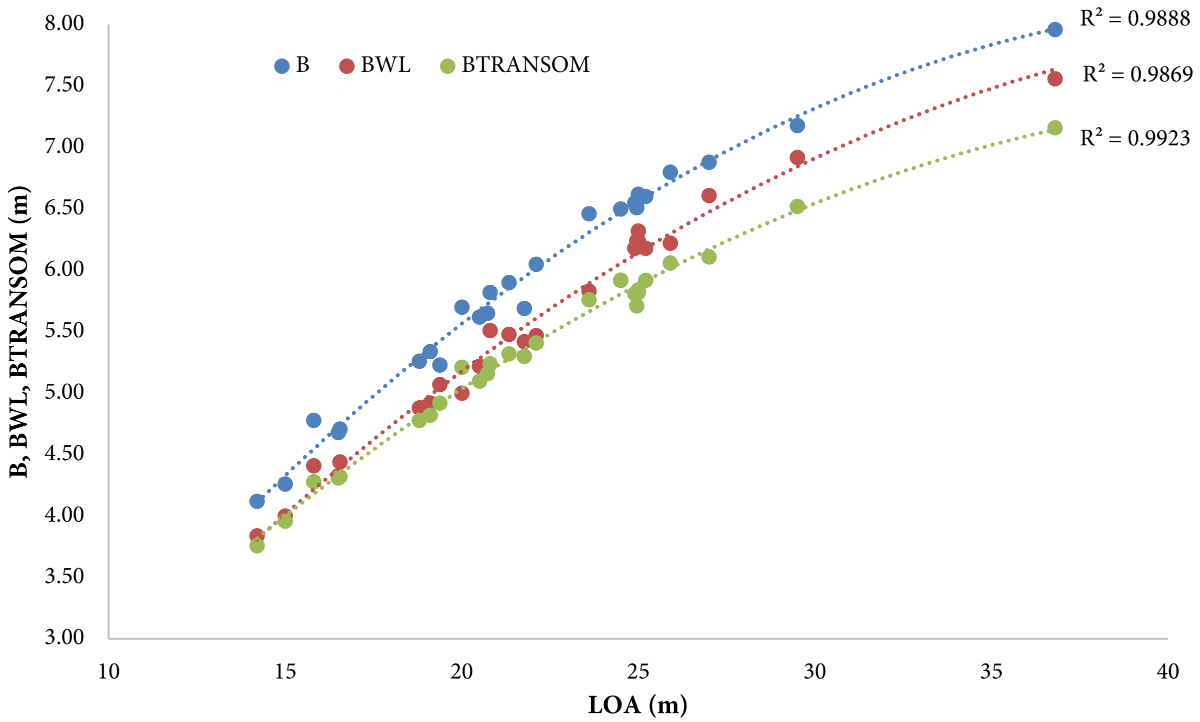

Figure 8. B, B_{WL} and $B_{TRANSOM}$ with respect to L_{OA}

Layout Parameters

The length of the platform located in the stern part of the trawler yachts varies from 0.60 m to 1.80 m. The dimension of this part is in correlation with the main dimensions of the yachts. Figure 9 shows the distribution of the length of the platform to L_{OA}. The deck clearance varies from 0.55 m to 1.00 m for the investigated yachts.

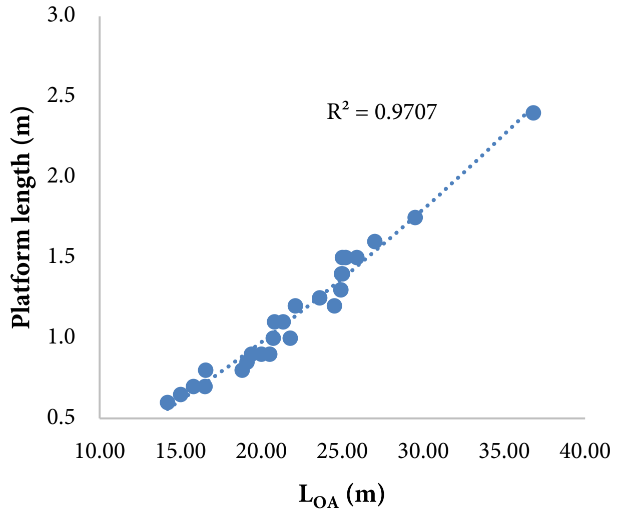

Figure 9. Platform length to L_{OA}

Voluminous closed space in the main deck that includes a saloon, galley, dining areas and the bridge space is among the characteristics of a trawler type yacht. To provide a design guideline for these closed areas, the starting point, the ending point and the part it occupies on the main deck are presented by calculating in terms of percentage of L_{OA} in Figure 10. The results show that closed areas occupy the major part of the main deck; approximately 65% of the L_{OA} and they end at approximately 85 % of the L_{OA}. Moreover, the results show that percentages that indicate the location of these closed areas do not change significantly due to change in L_{OA}.

At the beginning of the design process of marine vessels, determining technical information such as the space needed for technical equipment such as engines, installations and tanks plays an important and critical role (Özer & Tokol, 2021). In the interior design of a boat, it is of great importance to determine the location of the engine room for designing the remaining empty spaces (Arslan, 2010). To provide such data for the preliminary design, starting and end locations as well as the length of the engine room is presented as the percentage of L_{OA} in Figure 11. The results show that percentage of the length of the engine room decreases down to 15% as the L_{OA} increase for the investigated trawler type yachts.

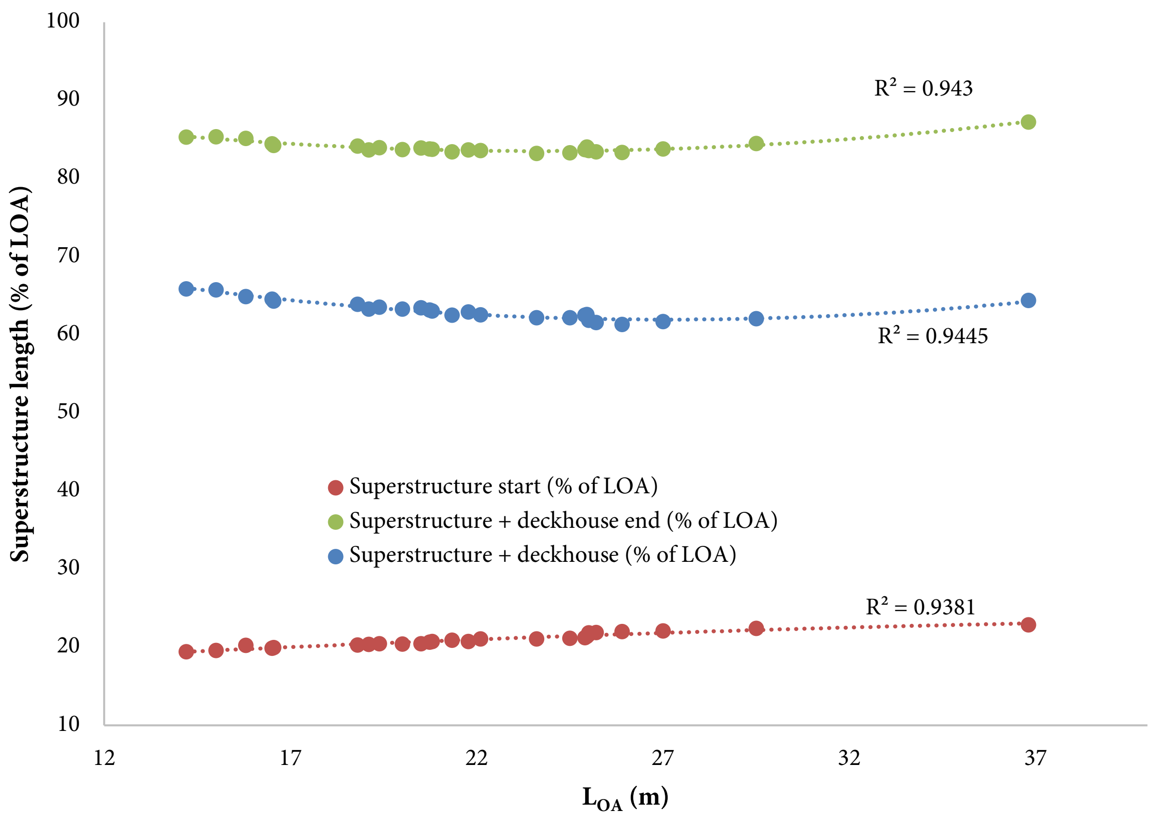

Figure 10. Percentage of the closed spaces in the main deck

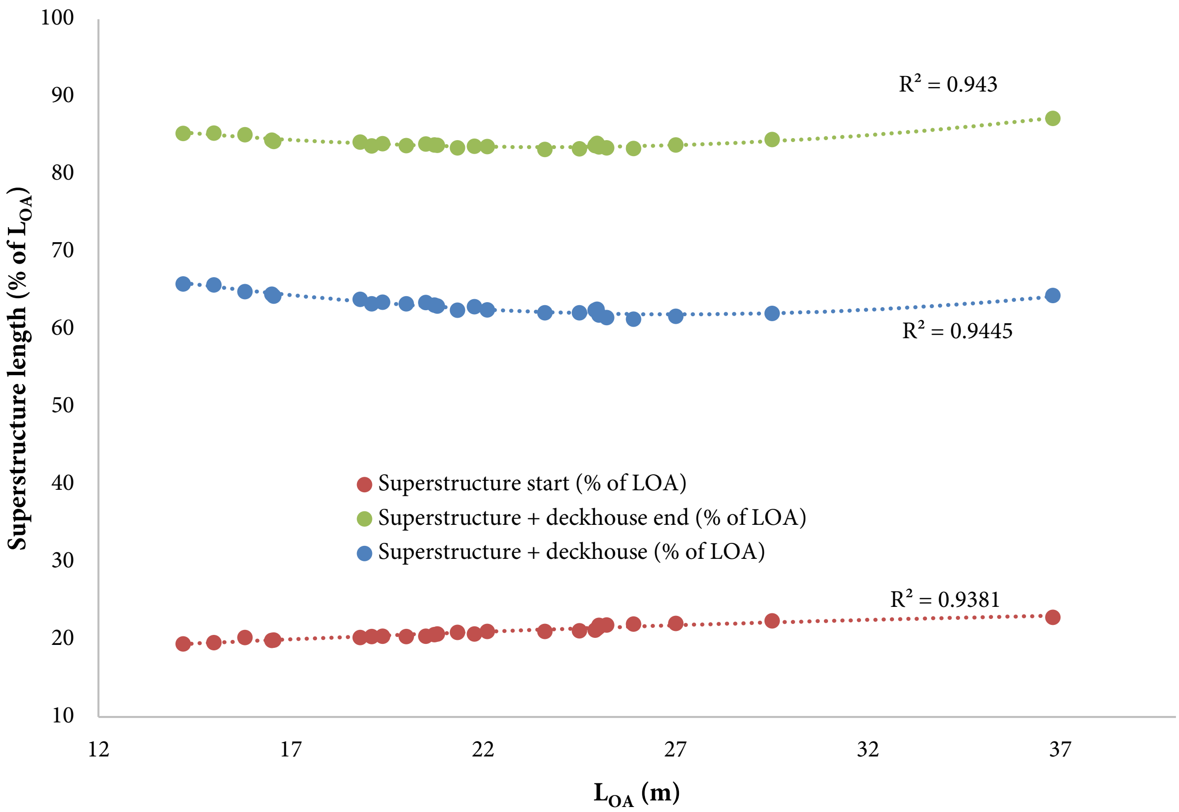

Figure 11. Engine room parameters for the trawler type yachts

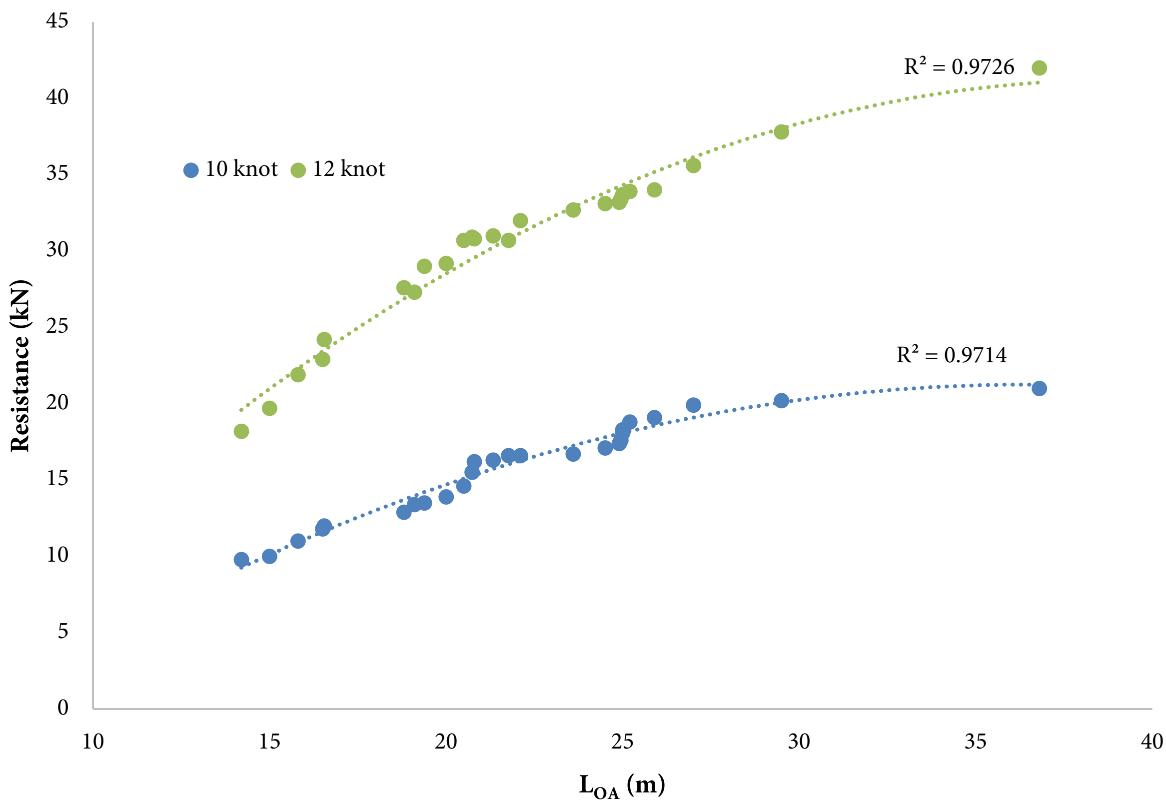

Figure 12. Resistance values with respect to LOA

Resistance Characteristics

It is seen that the maximum speed of the investigated trawler yachts range between 10 and 12.8 knots. To compare the calculated resistance values with the actual given performance values of the produced trawlers, two different speed values: 10 and 12 knots are selected for the resistance prediction calculations. Figure 12 represents the resistance values in kN of the investigated trawler hull models with respect to L_{OA}.

It is seen that investigated some of the investigated trawler yachts are equipped with a single engine while the major parts (18 of 26 trawlers) are equipped with twin-engines.

Conclusion

The study provides a design guideline that enable the designer to estimate not only layout parameters, but also some hydrostatic and hydrodynamic characteristics of the existing trawler type yachts. The following conclusions are obtained based on the results of the study:

- Even the L_{OA} of the trawler type yachts starts from 14.20 m and reaches up to 36.80 m, the common L_{OA} range was found to be 18-25 meters.
- Even the superstructure design can vary due to design characteristics and the design identity of the yacht, the results show that the location of the superstructure of trawler type yachts do not change due to change in L_{OA}. As a result, parameters related with the location of the closed spaces can be listed among distinctive characteristics of the trawler type yachts.
- It has been observed that B_{WL} and $B_{TRANSOM}$ values for the commonly used L_{OA} range are quite close to each other.
- B_{WL}/T ratio has greater values than the ratio desired ratio of 2.500 for the resistance aspects. Even the Holtrop-Mennen method is an efficient resistance prediction method and is used widely for the displacement type hull forms, there is a need for CFD analysis for further investigation of the trawler type yachts' resistance and hydrodynamic analysis.
- It is observed that hull forms of trawler yachts with a single engine do not have significant differences with the ones of the trawler yachts with twin engines. A CFD analysis, in which the appendages such as rudder and shafts are added to the model, will be of great importance in determining the total efficiency of trawler type yachts with single-engine and double-engine configurations.
- As a growing trend in marine industry, research that focuses on energy efficient trawler design with hybrid propulsion systems can be conducted as a further study. Considerably low maximum speed values and generous closed spaces that provide large areas on top that can be equipped with solar panels make trawler yachts appropriate for this purpose.

Compliance With Ethical Standards

Conflict of Interest

The author declares that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Data Availability Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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