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Practical Design Framework for Lobster-Type Motor Yachts

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Abstract

Motor yacht design is a multidisciplinary process that includes qualitative, quantitative, and iterative analyses. There are many personalized design and engineering steps from construction material selection to interior design; therefore, a practical design guide is required. In this study, 27 active lobster-type motor yachts whose overall lengths range from 10.5 m to 22.6 m were investigated in terms of hull and superstructure design and propulsion. Hull forms are modeled with CAD and form characteristics are calculated. Moreover, the hull form, superstructure, and deckhouse design parameters are presented using CAD data, and length-based correlations are made using layouts. In addition, the Savitsky method is used for semi-planning and planning hulls to calculate resistance and power data. The existing conventional diesel-mechanical and diesel-pod drive propulsion systems onboard yachts are compared, and alternative propulsion systems are discussed. Finally, a novel and practical design framework is created for use in the preliminary design phase of lobster-type motor yachts.

Keywords: Yacht design, Motor yacht, Lobster yachts, Propulsion systems, Design framework

1. Introduction

Yacht design is a quantitative process that consists of iterations to satisfy specified requirements [1]. In general, a ship that is designed and planned to be built should include up-to-date technologies, be efficient in terms of construction and operation, and comply with applicable national and international safety and security rules [2]. Although it is a multidisciplinary study, the yacht design process is conducted under the leadership of the engineering discipline [3]. In previous studies [1,4,5], the design process of ships was illustrated with a spiral to express its iterative nature. Although the number, sequence, or name of each step in these design spirals may differ, they all consist of processes that follow sequential progress to reach the optimum solution. Therefore, a holistic approach has been used in the design of ships, and this approach aims to solve the generic design optimization problem, which is established on parametric models, and multi-objective optimization criterion under constraints [6].

Compared with sailboat forms, motor yacht forms are more open to diversity and innovation [7]. The absence of sailing and rigging equipment allows for increased freedom in the arrangement of interior spaces of motor yachts [8]. The fact that they offer more functional and larger interior volume compared with sailing yachts is among the reasons why motor yachts are preferred [9]. Although the categorization of the hull form as displacement, semi-displacement, or planning is used for motor yachts, this categorization is not sufficient to define the above-water parts of the motor yachts. At this point, the 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 [10]. Among the many motor yacht boat types used, some stand out with their historical backgrounds. One of the classical motor yacht forms, lobster-type boats, is also a prominent motor yacht type. Approximately 25% of the classical boat market in the world comprises lobster-type boats [11].

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A semi-displacement hull, a shear line rising from aft to the flared bow, and a stern form with a remarkable tumblehome are listed as the characteristics of a classic lobster boat, which has been used for fishery purposes [12]. With the effect of the depression experienced in the market in the 1930s, the companies producing luxury boats turned to the production of smaller and affordable boats, which was effective in the emergence of lobster-type yachts [11]. The lobster-type boats, which were originally a fishing boat type and manufactured from wood in the past, are now manufactured with composite materials and have become comfortable boats that can reach higher speeds thanks to their innovative forms [13]. Figure 1 illustrates a classic lobster-type boat [11].

With technological development not only in the construction material but also in the equipment used, it is possible to see an increase in variety and efficiency in lobster-type yachts. Figure 2 shows a lobster-type yacht built in Bodrum, Türkiye.

In their research, Özgel Felek and Arabacıoğlu [14] have investigated trawler-type yachts in terms of partition and layout parameters and obtained a parametric design guideline for this specific motor yacht type. In another study [11], classic lobster-type boats have been compared with other yacht types, and a lobster boat with a L_{OA} of 14,32 m has been designed. Arslan [8] has focused on the interior design process and criteria of motor yachts. Similarly, in the research of Aydın and Yılmaz Aydın [9], yacht interior design was analyzed with both qualitative and quantitative data.

This study examined 27 active lobster-type motor yachts with overall lengths ranging from 10.5 m to 22.6 m. The focus of this investigation includes the design of both the hull and superstructure, as well as the propulsion systems. Computer-aided design (CAD) is employed to model the hull forms to compute their specific characteristics. The study also presents the design parameters of the hull, superstructure, and deckhouse using CAD data. Additionally, the Savitsky method is used to calculate the resistance and power data for the modeled semi-planning and planning hulls. This study compares traditional diesel-mechanical and diesel-pod drive propulsion systems installed on these yachts and explores alternative propulsion options. Finally, a practical design framework is developed for use in the initial design stages of lobster-type motor yachts. In an area where research has traditionally focused on more common yacht types, this study delves into the features of lobster-type motor yachts that will be used in the design process, which has seen limited academic research. Moreover, by providing innovative alternative propulsion system suggestions and establishing a correlation for power estimation at the initial design stage, this research not only advances knowledge in lobster-type yacht design but also makes a valuable contribution to the yacht design and engineering sector.

2. Methodology

In this research, 27 lobster-type motor yachts were investigated to obtain hull form and superstructure design parameters. L_{OA} of the investigated yachts ranged from 10.50 to 22.58 m. The investigated yachts were built between 1996 and 2022, and all are currently in service. After the data collection phase, the 3D hull model of each0 yacht was created using Rhino3D [15] and exported to Maxsurf [16] in IGES format for hydrostatic calculations. In addition, some non-dimensional hull form and superstructure parameters are calculated manually. After obtaining the hull form characteristics and deckhouse parameters, the resistance of the hulls is estimated using the Savitsky semi-planning/planning method. Using the resistance values, power predictions were made and compared with the installed propulsion power capacities of existing yachts. Alternative propulsion systems are discussed, and a practical design framework is obtained. The workflow of the study is presented in Figure 3.

Figure 1. *A classic lobster-type boat [11]*

Figure 2. *A lobster-type yacht built in Bodrum, Türkiye*

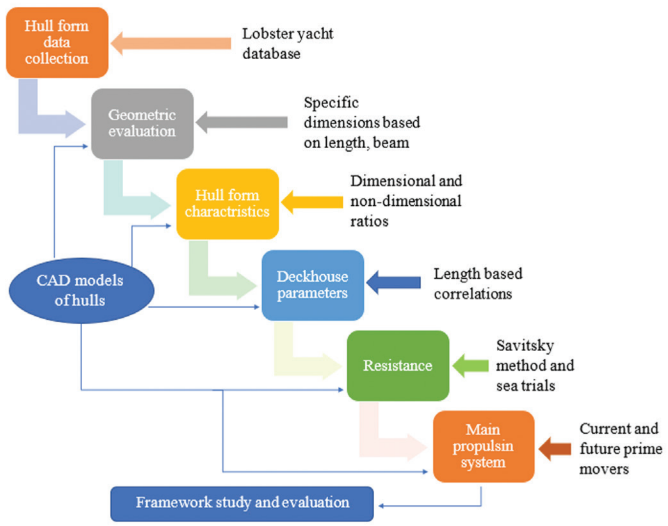

Figure 3. *Workflow of the design framework study*

3. Results

The results of the study were discussed from two main perspectives: design-based evaluation and engineering-based evaluation. Design-based evaluation includes the explanation of parameters related to the hull form and the superstructure design. In the engineering-based evaluation, the hydrostatic parameters and propulsion system selections of the investigated yachts are evaluated.

3.1. Design-Based Evaluation

In the design-based evaluation of lobster-type yachts, hull form characteristics and design parameters related to deck layout were examined. Hull form parameters are used for predicting the resistance, seakeeping, maneuvering, and hydrostatic characteristics of yachts [17,18]. Moreover, dimensionless coefficients obtained from some main dimensions are seen as distinguishing parameters in defining the hull form, as they vary depending on the type of boat. In this context, the evaluated parameters are as follows:

• Hull form design parameters;

o Hull form coefficients: C_B, C_P, C_M

o Displacement with respect to L_{OA}

o Longitudinal center of buoyancy (LCB), as a percentage of L_{WL}

o Length to beam ratios: L_{OA}/B and L_{WL}/B_{WL}

o Length ratios: L_{WL}/L_{OA} and L_{HULL}/L_{OA}

o Beam ratios: B_{WL}/B and $B_{TRANSOM}/B$

o Angle of the bow

• Superstructure and deckhouse design parameters;

o Starting and end locations of the superstructure

o $L_{SUPERSTRUCTURE}/L_{HULL}$

o B_{DECK}/B

51.9% of the motor yachts examined in the research were made of composite material and 48.1% of them were made of wood. In addition, it was observed that 78.6% of the boats made of wood were manufactured with the lamination method and the others with the traditional method.

3.1.1. Hull form design parameters

Hull form coefficients are listed among the key parameters for estimating hull form characteristics in the design process [18]. The block coefficient (C_B), prismatic coefficient (C_P), and midship coefficient (C_M) are commonly used not only for comparing different hull forms but also for making estimations by calculations. Lower values of the block coefficient (C_B) indicate low power requirements and high seakeeping characteristics [19], whereas a higher value of this coefficient is seen as an indicator of high wave resistance at some specific speeds [20]. The Prismatic coefficient (C_P) is a parameter that gives an idea about the fullness of the underwater part of the hull and the slenderness of the bow and stern [21] and is also among the factors affecting the resistance calculations of the boat [22]. Used in combination with parameters such as block coefficient (C_B) and B/T, the midship coefficient (C_M) is used to determine the wetted area of the hull and various resistance characteristics [5].

The LCB is one of the key parameters used to distribute the loads correctly and eliminate trim [23]. In addition, if the LCB is shifted too much to the bow, intense wave formation occurs around the bow shoulders, and too much shifting of this point to the aft side causes a loss in propulsion efficiency due to separation and eddy formation in the flow [5]. Table 1 represents the minimum, maximum, and mean values of LCB (% of L_{WL}), C_B, C_P, and C_M for the yachts investigated.

As the total weight of the yacht has to be equal to the displacement, determining the displacement properly is the most critical step in yacht design [23]. Figure 4 shows the distribution of displacement (ton) with respect to L_{OA} (m) for lobster-type yachts.

The ratio between L_{OA} and L_{WL} is a parameter used to estimate overhangs in the fore and aft directions of a yacht hull [18,24]. Another ratio used in the design process,

Table 1. *Minimum, mean and maximum values of LCB (% of L_{WL}), C_B, C_M and C_P*

	Minimum	Mean	Maximum
LCB (%)	43.270	46.228	49.017
C_B	0.239	0.307	0.370
C_M	0.459	0.510	0.629
C_P	0.508	0.604	0.739

LCB %: Longitudinal distance from the aft perpendicular to the center of buoyancy (as a percentage of L_{WL}), C_B: Block coefficient, C_M: Midship section coefficient, C_P: Prismatic coefficient

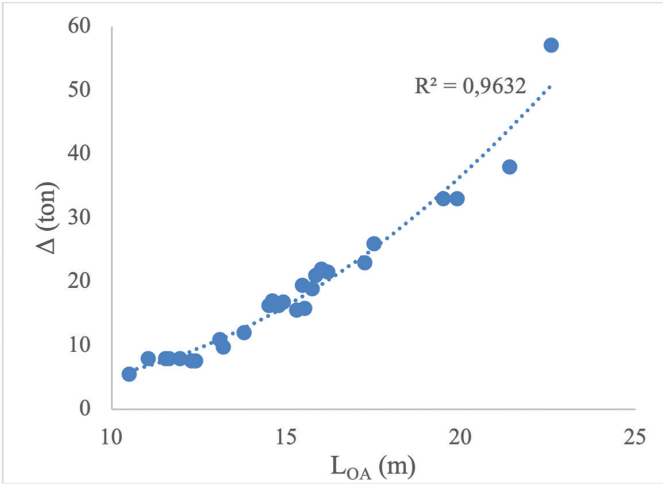

Figure 4. *LOA (m) -Displacement volume (m^3) distribution*

L_{OA}/B, provides information about the mid-section width characteristic of the boat [1] and is used in speed-resistance calculations [19]. L_{OA}/B and L_{WL}/B_{WL} are used to quantify the beaminess of a boat [25]. L_{HULL}/L_{OA} ratio is used to have an opinion about the attachments in the fore and aft direction, such as the platform or the bow spirits in the yachts. In this research, the only attachment included within the L_{OA} was the platforms. The ratio of B_{WL}/B gives an idea of the geometry of the midship section above the waterline for a hull. Because the geometry of the transom is among the distinctive characteristics of lobster-type yachts, the $B_{TRANSOM}/B$ ratio was calculated within the research. Table 2 includes the minimum, maximum, and mean values for the design parameters of the lobster yachts' hull forms.

When the type of the stern form in the transversal section was investigated for lobster-type yachts, 21 of the 27 yachts had a tumblehome form, while the others had other forms in the stern. Another design parameter related to the hull form was the angle of the bow for the lobster-type yachts, which varied between 47° to 83° and its mean value was calculated as 60.89°.

3.1.2. Deck layout parameters

The superstructures are at such a level that they can form the heart of life on the boat, as it is an area that yacht owners and guests will prefer in bad weather, but that they can always enter and exit [26]. When the design parameters related to the superstructure design were examined, it was observed that the superstructure design parameters had high variability in contrast to the hull form parameters. Figure 5 illustrates the starting point, endpoint, and partition of the superstructure + deckhouses as a portion of L_{HULL} for lobster-type yachts.

3.2. Resistance and Propulsion

The propulsion systems of lobster-type yachts are based on conventional diesel engines. The evaluated group of yachts

Table 2. *Minimum, maximum, and mean values of the hull design parameters*

	Minimum	Mean	Maximum
L_{OA}/B	3.027	3.370	4.038
L_{WL}/B_{WL}	2.801	3.291	3.750
L_{WL}/L_{OA}	0.846	0.894	0.941
L_{HULL}/L_{OA}	0.911	0.951	0.969
B_{WL}/B	0.821	0.917	0.980
$B_{TRANSOM}/B$	0.730	0.858	0.943
L_{OA}: Length overall (m), L_{WL}: Length of the waterline (m), L_{HULL}: Length of the hull (m), $B_{TRANSOM}$: Beam of waterline (m), B_{WL}: Beam of waterline (m),			

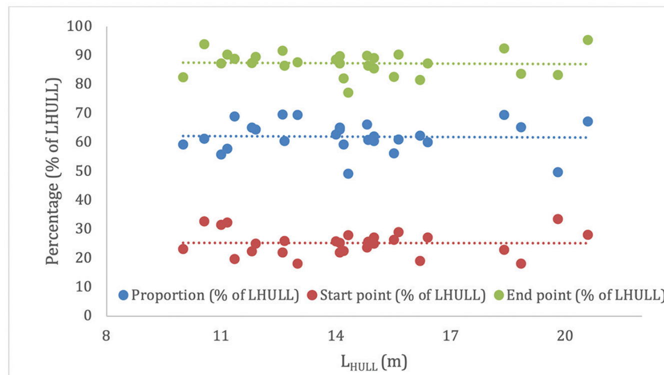

Figure 5. *Deck layout parameters*

had twin diesel engines coupled with shaft-propeller or pod drives. In this section, the resistance of the hulls is estimated for the calculation of effective and brake power. Then, the existing prime movers and available options are evaluated.

3.2.1. Resistance of hulls and power

The yacht hulls in the analyzed group are mainly planning types. The design speeds of yachts range between 13 and 35 knots. There are only two hulls designed for semi-planning in this group. Planning hulls, on the other hand, are high-speed crafts, and their design is challenging because of the complex hydrodynamic interactions that form at high speeds. These interactions can lead to problems such as porpoising, slamming, and cavitation [27]. To overcome these challenges, hull designers consider several factors, including hull geometry and configuration, hull weight and center of gravity, speed and operating conditions, and wetted surface conditions. In addition, the Savitsky method [28] is an early and effective tool based on empirical correlations developed from experiments to estimate hull resistance and performance. Empirical formulas were created after investigating the effects of length-to-beam ratio, displacement, deadrise angle, and center of gravity of hulls in regular waves or calm water [29]. Using the Savitsky method, resistance values of hulls are obtained at different speeds, as shown in Figure 6, which indicates the resistance change of a 15.5 m hull. According to the results, the calculated maximum resistances of the hulls are 10.33 kN (@35 knot), 17.82 kN (@34 knot), 28.74 kN (@30 knot), 40.25 kN (@29 knot) and 66,28 kN (@28 knot) for 10.5 m, 13.2 m, 16,20 m, 19.50 m and 22,58 m, respectively.

The effective and brake powers can be estimated using the calculated resistance, corresponding speed, and efficiencies [17,18]. The brake power of the yacht for which resistance change is presented in Figure 7 is calculated as 715 kW. The existing yacht has two pod-drive engine systems that generate 960 HP. Therefore, with an overall efficiency of 0.6, the existing brake power agrees with that of the calculated one. It is noteworthy that according to the resistance calculations based on the Savitsky planing and semi-planning models, the hull efficiency ranges between 0.50 and 0.60. Moreover, Figure 7 shows the brake power of the installed engines and the corresponding maximum speeds. According to the results, even if the overall lengths are similar, form characteristics and especially design speed determine the propulsion power.

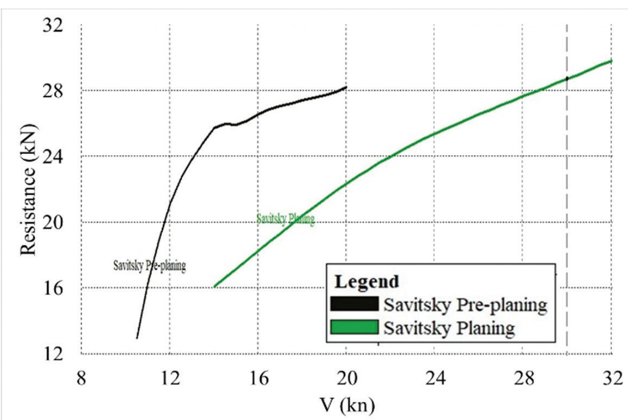

Figure 6. Resistance of a 16.2-m planning hull based on the Savitsky method

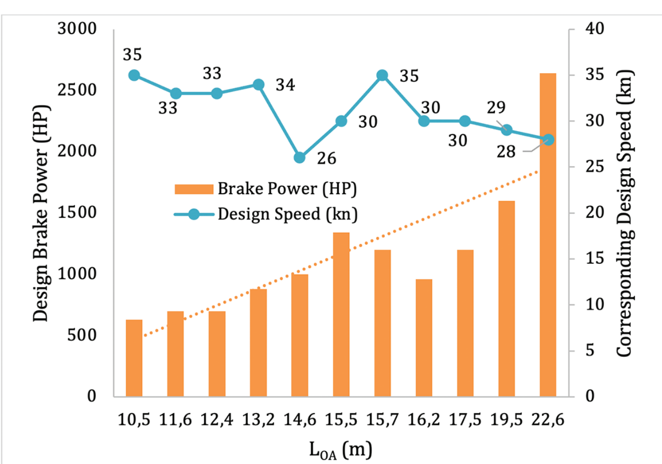

Figure 7. Brake powers of engines and corresponding design speeds of hulls

3.2.2. Main prime movers

Engine brake powers range from 450 HP to 2640 HP in accordance with the design speed and hull dimensions, as indicated in Figure 6. The propulsion system of the analyzed yachts consists of twin diesel engines coupled with shaft-propeller or twin diesel engines coupled with pod drives. Nineteen of the yachts have conventional diesel propulsion and 8 of them have an IPS (Inboard Performance System) configuration, which is claimed to be up to 30% more fuel efficient, has a lower noise level, and provides higher manoeuvrability compared to conventional diesel-shaft-propeller system [30]. The propulsion system selection for yachts is mainly based on customer choice, cost, dimensions, power requirements, and emission regulations, where marine diesel engines of above 130 kW power output have to comply with Annex VI NO_x limits [31].

Strict emission regulations have led the maritime industry to find alternative propulsion systems or fuels. Commercial ships have started to use cleaner fuels like Liquified Natural Gas (LNG) or methanol instead of Heavy Fuel Oil (HFO) or Marine Diesel Oil (MDO), which is the primary fuel for boats. Even if regulations regarding energy efficiency are not applied to yachts below 400 GT, there are many cleaner propulsion system options for small-scale boats. LNG-powered dual-fuel engines are mainly used in two-stroke divisions, and compared with methanol- and MDO-powered engines, they occupy much space onboard and are costlier [32]. On the other hand, a hybrid propulsion system that consists of diesel or gas engine-driven gensets integrated with battery units has been installed for yachts and is a viable option considering fuel saving, emission reduction, and comfort [33]. Apart from internal combustion engine-powered propulsion systems, all-electric yachts are on the agenda based on significant developments in battery technology [34]. Compared with other systems, the overall efficiency of all-electric propulsion systems is reported to be 67.8%, since the values for conventional diesel-mechanical and hybrid systems are 31.4% and 28.2%, respectively [34]. Using literature studies and engine manufacturers' reports, propulsion systems are compared in terms of basic properties, as shown in Table 3. Note that the assessments were made using the qualitative data obtained from the given references.

3.3. Design Framework

A design framework was developed based on the results obtained from design-based and resistance-propulsion analyses, as shown in Figure 8. Hull form characteristics and deck layout parameters are presented as correlations or mean values. In addition, a correlation is developed using the equation x which depends on displacement and velocity, to estimate the brake power of engines, as shown in Figure 8.

Table 3. *Comparison of Diesel-mechanical (D-M), Diesel-pod drive (D-P), Diesel-electric (D-E), and fully-electric (F-E) propulsion systems [30,33,35,36]*

Property	D-M	D-P	D-E	F-E
Engine type	Diesel	Diesel	Diesel	Electric
Drive system	Straight shaft	Pod drives	Shaft drives	Pod drives
Noise level	Louder	Quieter	Quieter	Quietest
Vibration level	Higher	Lower	Lower	Lowest
Fuel efficiency	Lower	Higher	Highest	Highest
Emissions (Hull to wake)	Higher (NOx, SOx, PM)	Lower (NOx, SOx, PM)	Lowest (NOx, SOx, PM)	Zero
Maneuverability	Less	More	Similar to D-M	Similar to D-M
Cost	Lower	Higher	Higher	Highest

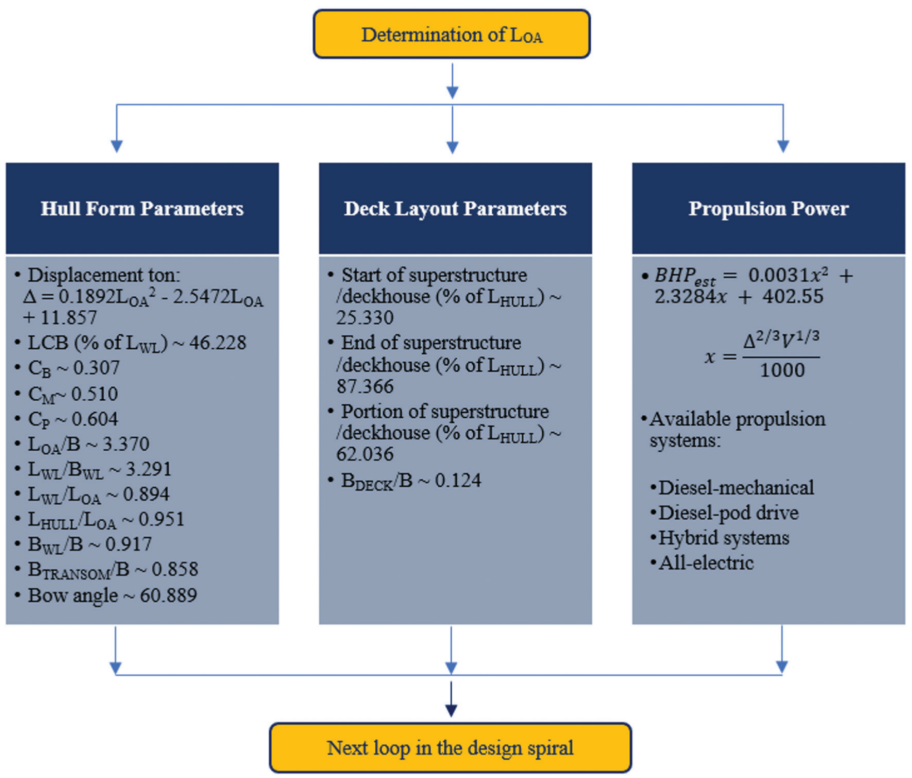

Figure 8. *Design framework for lobster-type motor yachts*

In this equation BHP_{est} shows the brake power requirement of the yacht in terms of HP. It should be noted that these correlations are practicable for lobster-type yachts whose overall lengths are between 10 and 24 m and design speeds are between 15 and 30 kt.

4. Conclusion

In this research, 27 lobster-type motor yachts are examined to collect relevant data on hull form, superstructure design parameters, and propulsion power. Collected data are used to obtain a novel design framework that enables estimating important parameters in the design phase of these motor yachts using only L_{OA} as an input. The following conclusions are drawn according to the analyzed data:

• Although the overall length range of lobster-type motor yachts varies between 10.5 and 22.6 m, it has been observed that the common usage range is between 14 and 17 m.

• When the deck layout parameters are examined, the values obtained vary in a wide range compared to the hull length of the boat. This variety is related to the design preferences and the design identity of each lobster-type yacht.

• The typical design speed of lobster-type yachts is observed at 30 kts (±2 kts). Twin diesel engines are used as prime movers coupled with shaft-propeller or pod drives.

• Lobster-type yachts are suitable for innovative solutions in areas such as propulsion systems and construction materials consistent with the general characteristics of motor yacht-type boats. Accordingly, it is possible to design and manufacture these yachts using innovative construction materials and higher energy-efficient propulsion systems.

The obtained results can be used as inputs for design optimization problems. Life-cycle assessments of alternative propulsion systems can be conducted for motor yachts in further studies.

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Authorship Contributions

Concept design: B. İ. Turan, and M. Akman, Data Collection or Processing: B. İ. Turan, and M. Akman, Analysis or Interpretation: B. İ. Turan, and M. Akman, Literature Review: B. İ. Turan, and M. Akman, Writing, Reviewing and Editing: B. İ. Turan, and M. Akman.

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