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Investigation on the effects of the number of main engines in sailing yachts in design and engineering perspectives: A case of Bodrum Gulets

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A B S T R A C T

Yacht design consists of multidisciplinary processes to obtain optimum solution that satisfies the requirements of the users as well as regulations to assure the safety at sea. Following the determination of the yacht type, processes such as preparing the general layout plan in line with the demands and expectations of the user, making hydrostatic calculations and speed-power calculations, determining the hull and superstructure design are followed. In these processes, the main engine selection, which is made depending on the speed and performance expectations, affects not only the engine room, but also many details such as the shaft angle of the boat, the propeller-hull clearance, the placement of the areas adjacent to the engine room. In this research, Bodrum Gulets, which are among the boats unique to Türkiye and produced with custom design and manufacturing processes, are discussed and it is aimed to examine the effects of the number of engines from the design and engineering perspectives. In this context, a total of 46 Bodrum Gulets were examined, and in line with the values obtained, selected parameters have been compared from the design and the engineering perspectives. While the engine room layout plans of the investigated yachts were used for comparison in terms of design, shaft angle was used in comparison in engineering-based evaluation. Moreover, investigated models' resistance and consequently the power requirements have been compared with the installed engine powers. The results show that models with single main engine are advantageous in terms of requiring less height and consequently less space for the engine room and propulsion efficiency perspectives. The mean value for the ratio between the required height to the height of the engine is calculated as 1.428 for the single engine and 1.982 for the twin engine configuration. Moreover, the results show that the mean value of the shaft angle is 5.29 for single engine and 8.16 degrees for the twin engine configuration. Additionally, the study shows that there is a gap between the calculated power and the installed power, which causes over consumption especially for the twin-engine configuration for the Bodrum Gulets.

INTRODUCTION

Ship design, which has a multidisciplinary structure, is a process in which it is aimed to meet as the factors required in terms of engineering as well as the user expectations and limitations. Hamlin (1996), Larsson and Eliasson (2007), and Papanikolaou (2014) describe the ship design process as a spiral which constitutes of iterative sub-processes. Analyzing the requirements, generally through the utilization of either empirical formulas or by using scaled versions of a proven design establish the initial parameters of a new ship design (Moody, 1996). Unlike many other ship types, in the design process of yachts, beside concern related to functional use, operability, cost and manufacturing; aesthetic and design-related expectations are at the forefront. It is the designer's task to develop a proper layout, efficient hull form, attractive and well-balanced sheerline and superstructure (Dubois, 1998). Determining power requirements and the performance of the ship is among the fundamental keystone in ship design process (Akman and Turan, 2023). Beside the concerns about functionality and aesthetics, finding the

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optimum solution to provide the most efficient propulsion system in terms of the number and the power of the engine(s) affects not only the yachts' characteristics, but also the environmental impact of the yacht to be produced. The study of Akman and Turan (2023) shows how engine selection affects the amount of consumption and released emissions of Bodrum Gulets.

Bodrum Gulets are listed among yacht types specific to Türkiye (Kükner, 2009; Turan et al., 2021; Turan and Akman, 2021). Even the word gulet is defined as the equivalent of schooner type sailing boats (Fossati and Diana, 2004; Köyağasıoğlu, 2014; Turan and Özcan, 2023), this word has started to be used to identify a hull type with distinctive characteristic lines in Türkiye (Gür, 2020; Turan et al., 2021; Turan and Akman, 2021). Elliptical shaped stern form and a concave stem form are among the distinctive geometric features of Bodrum Gulets (Kükner, 2009; Köyağasıoğlu, 2014; Gür, 2020; Turan and Akman, 2021). Satisfactory sailing performance, comfortable interior areas and proven seaworthiness are some of the characteristics of these yachts (Gammon et al., 2005). Figure 1 shows a profile drawing and a general arrangement plan drawing of a Bodrum Gulet.

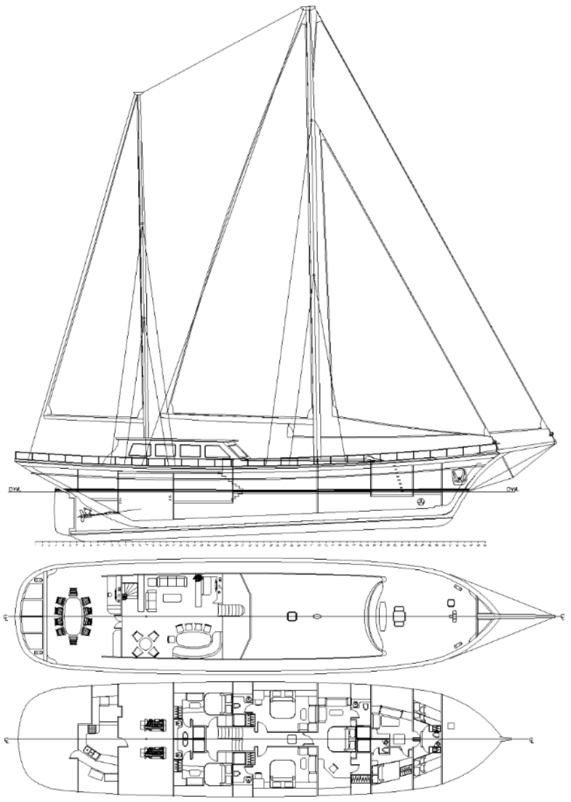

Figure 1. Profile and general arrangement drawings of a Bodrum Gulet

According to the results of the study conducted by Turan (2021b), for Bodrum Gulets, the mean value of the engine room length to the L_{OA} ratio was calculated as approximately 15%. Both single and double engine configurations are found in the Bodrum Gulets used. Ships with twin shaft and engine configuration are known to have a high maneuverability characteristic. By commanding one shaft to move the ship forward and the other to move the ship backward, a turning moment can be created, in the twin shaft configuration (Tupper, 2004). Single engine configuration, on the other hand, is advantageous in that it requires less space in the engine room, leaving more space for other equipment such as tanks, generators etc. Figure 2 illustrates layouts and sections of a yacht with a single-engine (top) and with a twin-engine (bottom) configuration.

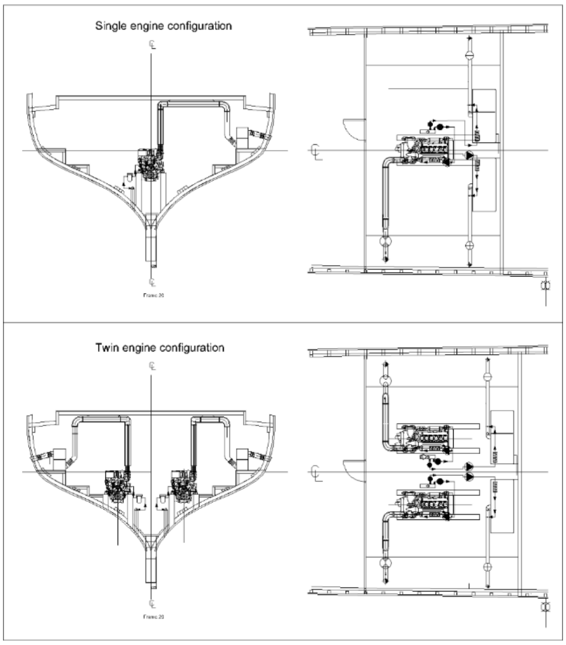

Figure 2. Section and layout of a yacht with a single-engine and with twin-engines

Previous studies address various engineering-based and design-based characteristics of Bodrum Gulets. Turan and Akman (2021) investigated hull form parameters and analyzed resistance characteristics of Bodrum Gulets. In the research of Sarıoğlu and Kükner (2018), a model was developed for form factor estimation of Bodrum Gulets by using the numerical tools. In the project conducted by Kükner et al. (2009), hull forms of Turkish type gulets are analyzed and optimized. In the research of Gammon et al. (2005), resistance, seakeeping and stability characteristics of Turkish gulets were investigated and a genetic algorithm was used for hull form optimization. Kınacı (2009) used 1-prismatic coefficient (C_P) method to model the gulet type yacht series and developed a computer program for the pre-design phase. Akman and Turan (2023) studied the Bodrum Gulets in terms of the required engine power and compered the required engine power with the installed engines to make energy efficiency-based evaluation.

All of the research conducted on Bodrum Gulets makes great contributions to both the literature and the sector by providing design parameters or improving various methods

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to be used in the preliminary design process. On the other hand, evaluating the effects of choices based on the number of machines on a sailing yacht in terms of engineering and design parameters will make a great contribution to the design process of these special yacht types. In this research, Bodrum Gulets, a sailing yacht type, were discussed and it was aimed to evaluate the single and double engine configurations for these yacht types in terms of propulsion efficiency, closed volume and parameters affecting the general layout. Moreover, the research also aimed to suggest the optimum solution by comparing the results of two different configurations depending on the number of machines in terms of energy efficiency, design solutions and dispatch efficiency. The results obtained reveal how a single decision made at the design stage has a huge impact on the production and use of a yacht.

MATERIALS AND METHODS

For the analyses, 46 Bodrum Gulets; which are still in the service are selected. LOA of the investigated yachts varies between 18.00 m to 39.00 m. Study conducted by Turan (2021a) underlines the effects of the purpose of usage in Bodrum Gulets' hull forms. Moreover, various purposes require diversity in power and speed expectations in these vessel types. To increase the accuracy and reliability of the results obtained within the scope of the research, only the Bodrum Gulets that provide charter services have been selected, and the gulets which are being used for daily cruising or fishing with different power requirements have not been included in the research. Consequently, all of the investigated yachts are equipped with sail & rigging equipment. Figure 3 represents the process flow of the research. In the research, actual measurements on the yachts regarding shaft angles and engine placements have been taken. Rhino3D, Version 7 (2020) is used for modeling the hull of the investigated Bodrum Gulets. Modeler and Resistance modules of Maxsurf (2022) are used for hydrostatic and resistance calculations. Rhino3D program is utilized by yacht designers worldwide as one of the three-dimensional modeling programs (Özgel Felek and Arabacıoğlu, 2019). Moreover, this software has been used in modeling process of the previous studies (Turan et al., 2021; Turan and Akman, 2021; Turan, 2023).

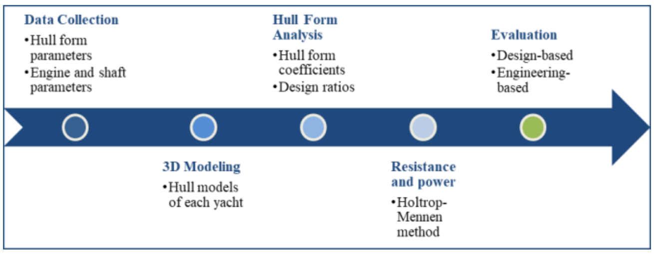

Figure 3. Process flow of the research

In the resistance calculation process of the research, Holtrop-Mennen method has been used. Holtrop-Mennen method, which bases on the regression analysis of trial data and model tests with different scales, is a useful resistance prediction method for displacement type hulls (Birk, 2019; Turan, 2009). In the study conducted by Turan (2009), the method that gave the closest results to the model test results for the gulet hull form was stated as the Holtrop-Mennen method. Moreover, this method has been used for predicting resistance and power values of Bodrum Gulets in the previous studies (Turan et al., 2021; Turan and Akman, 2021; Akman and Turan, 2023). Accordingly, the Holtrop-Mennen method has been used in resistance calculations in this research.

In the research, this method has been used for estimating the resistance of the Bodrum Gulets at 8, 10 and 12 knots. According to the mathematical model (Holtrop and Mennen, 1982; Elkafas et al., 2019), the total resistance; R_T of the ship can be calculated as summing the viscous resistance; R_V and the wave-making resistance; R_W.

The viscous resistance is calculated as;

$$R_V = (1 + k)R_F \quad (1)$$

where R_F is the frictional resistance. The form factor k is a function of the some main parameters as follows (Elkafas et al., 2019);

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

where L_R is the length of after body and c is the coefficient after body shape. The second component of the total resistance, R_W is calculated as:

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

where c_1, c_2, c_3, m_1, m_2 and λ are the coefficients which are related with the hull form (Holtrop and Mennen, 1982). Froude number F_n depends on the velocity of the vessel. It is possible to calculate effective power, P_e with the following formula:

$$P_e = R_T V \quad (4)$$

The brake power can be obtained approximately by multiplying effective power by 2 (Blount and Fox, 1976).

RESULTS AND DISCUSSION

The results are discussed in different perspectives. In the hull form parameters section, some critical parameters to be used in the preliminary design phase of Bodrum Gulets are

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given. In the design-based evaluation, effects of the engine number selection from the design choices are discussed. In the efficiency-based evaluation, effects of the engine number selection are discussed from the engineering perspective.

Hull Form Parameters

Hull form parameters are useful determinants for predicting hydrostatic and hydrodynamic characteristics of a yacht (Turan and Akman, 2021). In this research, dimensionless ratios and coefficients of the investigated Bodrum Gulets were calculated not only to determine the specific characteristics of the hull forms, but also to obtain input parameters for the parametric model. The data collected within the scope of hull form parameters were converted into dimensionless ratios and minimum, maximum, and mean values were calculated for the examined boats. This method is a common method applied in previous research (Gammon et al., 2005; Kükner et al., 2009; Turan, 2022; 2023) examining the hull form characteristics of various boat types.

The results show that L_{OA}/L_{WL} ratio for Bodrum Gulets varies from 1.192 to 1.321 and its mean value is calculated as 1.252. B/L_{OA} ratio has a mean value of 0.254 and it has a range between 0.224 and 0.300. Position of the LCB as a percentage of the L_{WL} ranges from 44.359% to 49.821% with mean value of 46,624%. Mean value of the C_B is calculated as 0.216 and the range varies between 0.196 and 0.243. C_P has a mean value of 0.622 and is varies from 0.605 to 0.697. C_M value varies from 0.318 to 0.401 and the mean value is calculated as 0.347.

Design-based Evaluation

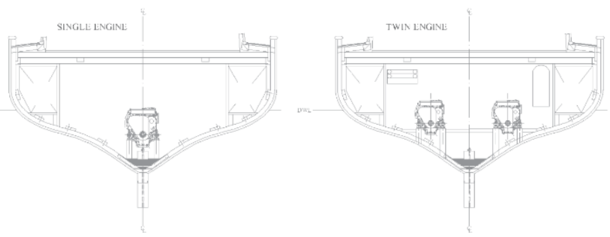

Figure 4. Transversal sections of Bodrum Gulets with a single and twin engines

Figure 4 shows the difference in engine room section for twin engines and a single engine configuration of a Bodrum Gulet with a L_{OA} of 23.90 m. As can be seen in the figure, the single engine configuration allows the engine to be positioned in lower area than the double machine configuration. This difference has a positive effect on the engine room height of the boat and the circulation areas in the engine room. Also, positioning the engine as low as possible has a contribution on the yacht's stability by decreasing the KG value. Moreover, selecting single or twin-engine configuration has a significant effect on the overall propulsion efficiency by causing the shaft angle to change. To evaluate consequences of selecting single or twin-engine configurations, length and height of the installed engines as well as the shaft angles have been used. Table 1 represents the minimum, the maximum and the mean values for the ratio of required height (from the inner keel to the top of the installed engine), to engine height for Bodrum Gulets in two different engine configurations. The difference between the minimum and maximum ratio values may increase depending on many variables such as the dimensions of the engines used and the cross-section geometry where the engines are located. Depending on the number of engines in the engine room layout, the placement of engine-related elements such as shafts, machine ventilation layouts, exhaust pipes and bearings also changes. Since these elements will require less space in a single engine configuration, there will be much more space for many auxiliary elements such as the generator, fuel tanks, battery group, boiler.

Table 1. Required height to engine height ratio for Bodrum Gulets

Required height/Engine height ratio		
	Single Engine	Twin Engine
Minimum	1.0204	1.7217
Maximum	1.5417	2.2081
Mean	1.4279	1.9817

The results show that single-engine requires less height in engine room when compared to twin-engines. Required height effects not only the available space for the other systems and equipment, but also the saloon floor level in Bodrum Gulets. engine number selection influences the closed volume and Gross Tonnage of the Bodrum Gulets.

Efficiency-based Evaluation

According to the results, the total angle obtained from the sum of the gearbox output angle and the engine angle varies between 4-6 degrees for Bodrum Gulets with single engine; 6-11 degrees for Bodrum Gulets with twin engines. The mean value of the total angle is calculated as 5.29 degree for single engine configuration and 8.16 degree for the twin engine configuration. Increase in the total shaft angle is seen as a factor that decreases the overall efficiency. As the propeller shaft angle increases, due to difference in the water flow in the top and the bottom of the propeller disk, uneven loading in propeller blades; which can cause vibration, occurs (Gerr, 2013). Due to high shaft angles, changes in the tangential component of the velocity field can cause root and butt cavitation in the propellers (Molland, 2008). Figure 5 illustrates the difference in shaft angle for according to the number of main engines in two different Bodrum Gulets. As

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shown in the Figure 5, there is no significant difference in the length of the shafts for two different configurations.

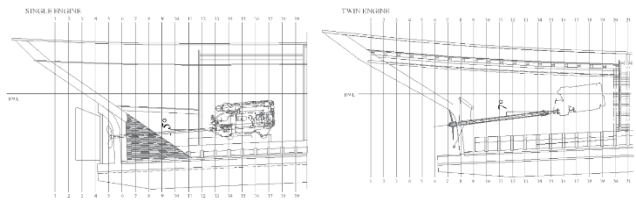

Figure 1. Bodrum Gulet with a single engine (on left) and with twin engines (on right)

Based on the modelled hulls, resistance values for 8, 10 and 12 knots speeds have been calculated with Holtrop-Mennen Method. Figure 6 illustrates the resistance values with respect to LOA of the investigated 46 Bodrum Gulets.

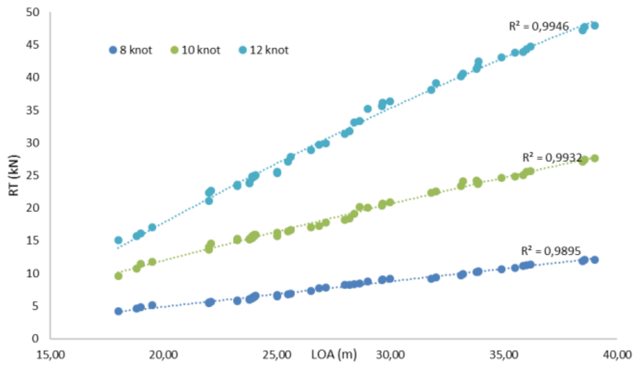

Figure 2. Resistance values with respect to LOA of the investigated Bodrum Gulets

The results show that the difference between the calculated break power in kW and the installed power in kW is greater in twin engine configuration than that of the single engine configuration in Bodrum Gulets. Figure 7 represents the distribution of the calculated and the installed power with respect to LOA of the investigated yachts. Moreover, the gap between the calculated and the installed power increase as the LOA increases for Bodrum Gulets with twin engines. It is seen that the single machine configuration is not used in Bodrum Gulets with a LOA over 30 meters.

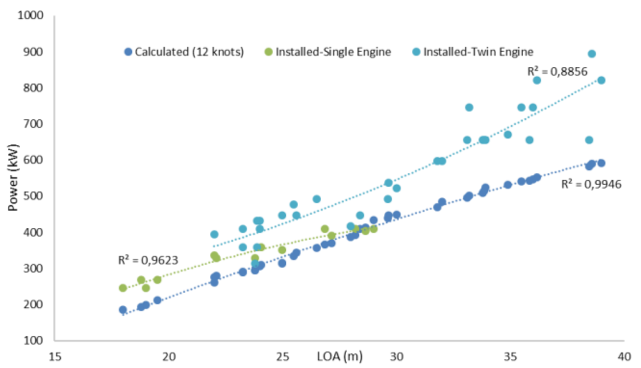

Figure 3. Calculated power-installed power comparison for Bodrum Gulets

Bodrum Gulets with single and twin-engine configurations have been analyzed to evaluate the effects in design and engineering perspectives. Moreover, hull form parameters, which can be used in pre-design stage have been obtained from the investigated yachts. According to the results obtained, following conclusions are drawn for Bodrum Gulets:

- Single engine selection provides advantage in the layout and reduced required space for Bodrum Gulets. Related with the less required height for the engines in single-engine configuration, it is possible to reduce the gross tonnage of the yacht by moving the saloon floor to the lower level.
- To provide the clearance between the propeller and the hull of Bodrum Gulets, the shaft angle in twin engine configuration is greater than that of the single engine configuration. Due to increased shaft angle, it is possible to state that twin engine configuration has a negative effect in terms of overall propulsion efficiency.
- The results of the study show that in the engine power selection of Bodrum Gulets, engine power of the installed engines is much higher than the calculated engine power. This finding is consistent with the results of the previous study conducted by Akman and Turan (2023) . The gap between the installed power and the calculated required power is greater for the Bodrum Gulets with twin-engine configuration when compared to the ones with single-engine configuration. Moreover, it is seen that the gap increases as the LOA is greater than 30 m. It is thought that the engine options available on the market or the user's preferences have an impact on this result determined in the research. In instances where a machine with half the computed power is unavailable and two machines with higher power are chosen, the disparity per engine is amplified, effectively doubling the observed difference. In this content, single engine is seen as the favorable selection especially for the Bodrum Gulets with LOA greater than 30 m. Calculated power requirement data can be used for choosing the proper engine in these yachts.

This research contributes the design process for an energy-efficient yacht design by focusing on a specific sailing yacht type, Bodrum Gulets. The results obtained reveal the effects of the decision made on the number of machines, not only for Bodrum Gulets but for all yacht types, in terms of both design and engineering.

The results of the study generally show that single engine selection has positive effects on overall propulsion efficiency and general layout-oriented design choices in Bodrum Gulets. In the examined Bodrum Gulets, the maneuvering advantage provided by the twin-engine configuration can be balanced with bow-thruster, stern-thruster or water jet systems used for maneuvering. It is possible to apply innovative system solutions such as hybrid propulsion

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system for backup power that can be used in case of emergency, which is another advantage provided by choosing a double engine configuration, on Bodrum Gulets.

CONCLUSION

In the study, it was observed that the steering system with a single rudder was used in both single and double engine configurations. Investigating the effects of the double rudder usage in Bodrum Gulets on the resistance and maneuverability characteristics of these yachts, and determining the effects of the appendages as well as the changing parameters such as the propeller dimension, number of bearings, geometry of the brackets, depending on the number of engines on the flow distribution at the cruising speed of the boat using CFD analysis are considered among the possible research topics in the future.

COMPLIANCE WITH ETHICAL STANDARDS

Authors' Contributions

Author BIT is responsible for the whole research and writing process of the article.

Conflict of Interest

The author declares that there is no conflict of interest.

Ethical Approval

The author declares that formal consent is not required for this type of study.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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