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Design of a 5 GT Pilot Boat with a 700 HP Outboard Engine for Optimal Efficiency and Performance Suitable for Indonesian Waters

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***Abstract*— The development of maritime technology drives innovation in ship design, including a 5 GT pilot boat designed for high efficiency and performance in Indonesian waters. This vessel is constructed using Fiberglass-Reinforced Plastic (FRP), a material known for its strength and cost-effectiveness compared to wood. Measuring 12.4 meters in length, the boat is powered by a total of 700 HP from two Yamaha F350UCB V8 5.3L F350 outboard engines, enabling it to reach an optimal speed of approximately 25 knots. Stability and power analysis, conducted using the Maxsurf application, indicate that positioning the engines at the stern on both the right and left sides provides the best stability with an inclination angle of 73.6°. This design is expected to enhance operational efficiency and support pilotage activities in dynamic waters.**

Keywords—pilot boat, fiberglass-reinforced plastic (frp), outboard engine, ship stability, maxsurf.

I. INTRODUCTION

The advancement of time influences humans to develop fishing vessel types made from composite materials. The composite material in question is Fiberglass-Reinforced Plastic (FRP). Fiberglass is a primary material in shipbuilding, used to construct vessels like yachts and patrol boats. In Indonesia, fiberglass-based vessels are popular due to their strength, lower cost, and advantages in maintenance and depreciation compared to wooden ships. However, fiberglass can suffer from osmosis, leading to moisture ingress and potential fragility in the fibers [1]. Fiberglass, or glass fiber, is made by drawing molten glass into fine fibers (0.005–0.01 mm in diameter), which are then used in shipbuilding after being impregnated with resin.

The engine specifications and power of a ship are determined by calculating its resistance and the propulsion system. Fuel consumption is a major operational cost, so optimization is critical. Ship resistance is often calculated experimentally in towing tanks, though this method is costly. Alternatively, ship design software can be used to estimate resistance, particularly for low-speed vessels with high block coefficients [2].

Accurate ship resistance testing is essential, with experimental methods being more reliable than theoretical predictions. Full-scale towing tests provide insights into required engine power by measuring the speed and power necessary to move through water at a set velocity. For fiberglass vessels, towing tests help identify engine power requirements to match ship resistance and optimize fuel consumption [3]. Conducting feasibility tests, including resistance testing, is crucial to ensuring engine power meets the ship's operational needs [4].

One of the goals of marine engineering is to align ship design and propulsion systems effectively. However, the method used to determine required engine power is often not specified in completed vessels. This paper explores using established methods to calculate power requirements and compares the results with installed power, assessing their accuracy [5].

The efficiency of a fishing vessel, which relies on the correct engine power, directly affects the business. Propulsion power must be tailored to the vessel's size, speed, and intended use. Studies help ensure that engine power matches these factors, improving operational performance and efficiency [6].

A study on a fiberglass fishing boat with a 5 GT design showed that reducing running resistance was key to optimizing engine power. Further research is needed to refine engine selection methods for various vessel types, particularly pilot boats, and to ensure that engines meet the vessel's specific power needs [7]. Proper calculation methods, such as Holtrop and Savitsky, are essential for determining suitable engine capacities [8].

Ship resistance, influenced by the hull's shape and submerged area, impacts engine power. A study using ship design software, like Maxsurf, analyzed resistance for a 5 GT vessel operating in coastal areas, aiming to reduce energy consumption by identifying the lowest resistance values [9]. Simulation tools offer an efficient way to test various hull shapes and engine combinations, saving time and costs in the design process [10].

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The shape of the hull and the resistance it encounters in water play a crucial role in determining engine requirements. A study focused on minimizing resistance to improve fuel efficiency and performance [11]. The efficiency of a ship's propulsion system directly impacts fuel consumption, with optimized designs leading to lower costs [12].

Finally, the role of fiberglass in shipbuilding is vital due to its strength and resistance to environmental stressors, yet careful material usage is essential for maintaining performance [13]. Furthermore, exploring alternative fuels and propulsion systems in future research could reduce environmental impact and fuel costs, contributing to sustainability in shipbuilding [14].

Several studies emphasize the importance of accurate resistance calculations for optimizing propulsion system design. While experimental methods yield high accuracy, computational simulations have become more common for smaller-scale ships, offering significant cost savings and efficiency [15]. Understanding the hydrodynamic properties of different hull designs is essential for selecting the most effective engine power [16].

Further research is also required to investigate the effect of varying environmental conditions on ship resistance, including water temperature and salinity. These factors influence the ship's performance and fuel efficiency [17]. The growing use of computational fluid dynamics (CFD) in ship design allows for more accurate predictions of resistance, providing valuable data for shipbuilders [18].

As ship designs become more complex, it is necessary to develop more advanced methods for estimating engine power. Using hybrid techniques that combine experimental data and CFD simulations can provide more accurate results while minimizing costs [19]. These approaches will likely become more common as shipbuilding technology advances [20].

The interaction between ship hulls and water is complex, with variables such as wave-making resistance playing a role in overall efficiency. Minimizing these resistances is key to achieving better fuel economy and performance, especially for long-distance vessels [21]. Additionally, the shape and design of propellers can significantly influence the overall energy efficiency of the ship's propulsion system [22].

Materials like fiberglass offer distinct advantages in terms of strength, weight, and durability, which helps enhance fuel efficiency by reducing overall vessel weight. Advances in material science continue to drive innovation in shipbuilding [23]. Studies also show that incorporating sustainable materials and practices into ship design can further reduce the environmental impact of the maritime industry [24].

Shipbuilding standards and regulations are evolving, pushing for more efficient and environmentally friendly vessels. These standards are increasingly based on comprehensive data from resistance and propulsion system studies, ensuring that new vessels meet both performance and environmental benchmarks [25]. Ultimately, ongoing research into ship resistance and propulsion optimization will lead to better-designed vessels, reducing operational costs and improving environmental sustainability [26].

II. METHOD

A. Initial Data Collection and Analysis

Before conducting the analysis, initial data collection was carried out, including the design and principal dimensions of the ship. Afterward, resistance calculations were performed manually and using Maxsurf software with the Holtrop method. The results from both calculations were compared, and once the power requirements were determined, a stability simulation was conducted in Maxsurf at a maximum speed of 25 knots. The analysis results provide data on power requirements and ship stability.

B. Flowchart

To analyze the research problem, the process stages are illustrated in the research flowchart, as shown below:

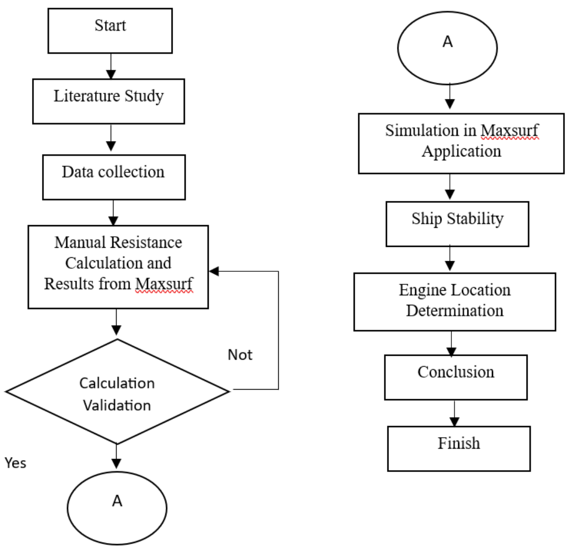

Figure. 1. Flowchart

C. Literature Review

The literature review includes gathering reference sources and ship data with similar dimensions and engines, which serve as references for calculations and simulations to complete the final project report. Before proceeding further, collecting references and data is essential to determine the appropriate power and placement of the outboard engine for the pilot boat.

D. Comparison of Outboard Engine Placement

In this stage, a comparison is made between different engine placements for the pilot boat, which are then simulated using Maxsurf software:

a. Simulation Model 1: The ship has dimensions of 12.6 meters in length and 3.6 meters in width, moving at a speed of 25 knots with the outboard engine placed in the center.

b. Simulation Model 2: The ship has dimensions of 12.6 meters in length and 3.6 meters in width, moving at a speed of 25 knots with the outboard engine placed at the stern corners, both on the right and left sides.

Before conducting the simulations, it is necessary to determine the required engine power using both the Holtrop method and manual calculations.

E. Resistance Calculation Methods

Harvald-Guldhammer Method, The Guldhammer-Harvald method is used in ship propulsion systems to determine the appropriate engine power based on the propeller. The steps in this method include calculating:

- Effective Horse Power (EHP)
- Delivered Horse Power (DHP)
- Shaft Horse Power (SHP)
- Brake Horse Power (BHP)

From these calculations, a power output of 5,820.071 HP was obtained, which matches commercially available engines such as the CAT 280-16. By determining the appropriate power requirement, the ship can achieve the desired speed.

F. Holtrop Method

The Holtrop and Mennen method is widely used to estimate the resistance and power requirements of displacement-type vessels. It is based on regression analysis from a large dataset of model tests and full-scale trials, making it broadly applicable. The Holtrop method breaks total resistance into several components:

- Frictional resistance
- Appendage resistance
- Wave resistance
- Resistance due to bulbous bows near the water surface
- Pressure resistance from the immersed transom
- Correlation model resistance
- Air resistance

Power estimation begins by calculating the thrust deduction fraction and the relative rotative efficiency.

G. Savitsky Method

The Savitsky method is used to estimate the resistance of a vessel during the planning phase before construction, known as pre-planning resistance analysis. This method is particularly useful for estimating hull resistance based on adjusted ship speeds.

H. Ship Data

This study models a pilot boat using real ship data. The principal dimensions used in this final project are presented in the table below:

TABLE 1.
PRINCIPAL DIMENSIONS

PRINCIPAL DIMENSION	VALUE
LOA (Length Overall)	12.40 m
B (Breadth)	3.60 m
H (Height)	1.60 m
D (Draft)	0.60 m
Outboard Engine	Yamaha
Power	2 x 350 HP
FOT (Fuel Oil Tank)	2000 liters
FWT (Fresh Water Tank)	250 liters
Crew	4 persons
Passenger Capacity	6 persons
Speed	25 knots

I. Pilot Boat Design

The 12.4-meter-long pilot boat is designed to support ship piloting activities. The design includes various perspectives that provide a comprehensive view of the vessel’s shape and structure, including side, top, front, and rear views.

- Side View: Displays the hull shape, superstructure, and overall proportions.
- Top View: Shows the deck layout, cabin positions, and operational spaces for the crew and navigation equipment.
- Rear View: Highlights the stern configuration, propulsion system, and deck access.
- Front View: Illustrates the bow structure, superstructure design, and weight distribution.

J. Pilot Boat Power Requirements

In this design, ship resistance analysis is conducted to determine the required engine power. The analysis is performed using Maxsurf Resistance software, which estimates the power requirement based on the vessel's speed.

K. Ship Resistance Analysis

The resistance analysis is carried out using the Holtrop method, which calculates ship resistance at various speeds.

L. Engine Power Requirements Table

The following table presents the required engine power based on the ship's speed:

TABLE 2.
ENGINE POWER REQUIREMENTS

No	Speed (knots)	Froude No. LWL	Froude No. Vol.	Holtrop Resistance (kN)	Holtrop Power (HP)
1	0.0	0.000	0.000	--	--
2	0.625	0.032	0.068	0.0	0.007
3	1.25	0.063	0.136	0.1	0.047
4	1.875	0.095	0.204	0.1	0.148
5	2.5	0.126	0.272	0.2	0.336
...	...	...	...	...	...
41	25.0	1.260	2.722	40.4	649.029

The pilot boat design incorporates various crucial aspects, ranging from structural appearance to power requirements necessary for optimal performance. By conducting resistance analysis, an estimated power requirement can be obtained to ensure efficient vessel operation under different conditions.

M. Principal Ship Dimensions

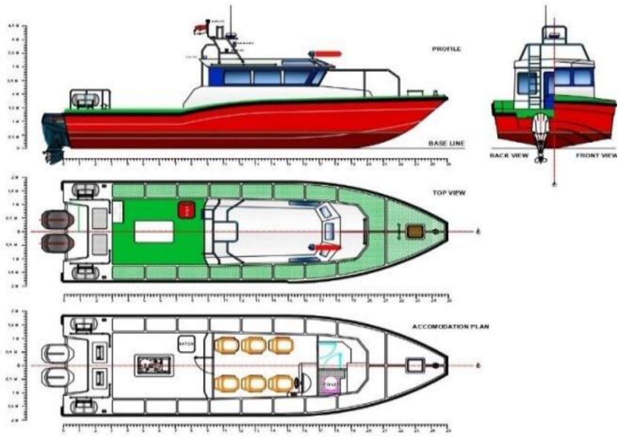

Figure. 2. Pilot Boat Design

The primary dimensions of the fiberglass pilot boat are as follows:

- Overall Length (LOA): 12.40 m
- Waterline Length (LWL): 9.40 m
- Full Load Waterline Length (LBP): 10.80 m
- Maximum Beam (B): 3.60 m
- Height (H): 1.60 m
- Draft (T): 0.60 m
- Block Coefficient (Cb): 0.81
- Displacement: 4 tons
- Speed: ± 25 knots

III. RESULTS AND DISCUSSION

A. Ship Resistance Calculation

The resistance calculation uses the Holtrop method. The purpose of the resistance calculation is to determine the power required for the ship, with the expectation that the research results will determine the optimal placement of the outboard engine and analyze the ship's stability using the Maxsurf application. The analysis is conducted with three different speed variables: 5, 15, and 25 knots, and two engine placement configurations: center placement and right-left placement at the stern of the patrol pilot boat, to determine the best stability configuration.

B. Resistance Calculation

The resistance calculation uses the Holtrop method, which simplifies the determination of the required power. Three different speed variables are used to determine the power requirement and wave contour. The speed variables in meters per second (m/s) are as follows:

1. 5 knots = 2.572 m/s
2. 15 knots = 7.716 m/s
3. 25 knots = 12.86 m/s

The following is a manual calculation of the ship resistance components:

- Speed Coefficient:

Where: Cv = speed coefficient Vs = ship speed (m/s) g = gravity Lwl = Waterline length

- Speed 5 knots = 2.572 m/s The calculated speed coefficient resistance value is 0.283 m/s.
- Speed 15 knots = 7.716 m/s The calculated speed coefficient resistance value is 0.851 m/s.
- Speed 25 knots = 12.86 m/s The calculated speed coefficient resistance value is 1.416 m/s.

- Reynolds Number:

Where: Rn = Reynolds Number Vs = ship speed (m/s) Lwl = Waterline length υ = seawater temperature

- Speed 5 knots = 2.572 m/s The calculated Reynolds number resistance value is 0.864 m/s.
- Speed 15 knots = 7.716 m/s The calculated Reynolds number resistance value is 2.872 m/s.

- Wetted Surface Area and Waterline S:

S = 1.025 x Lbp (Cb x B - 1.7.T) = 1.025 x 10.8 (0.81 x 3.6 - 1.7 x 0.6) = 8.789 m^2

S' = 1.025 x Lwl (Cb x B - 1.7.T) = 1.025 x 9.4 (0.81 x 3.6 - 1.7 x 0.6) = 6.268 m^2

- Frictional Resistance:

Rf = 1/2 x ρ x Vs^2 x S Where: Rf = Frictional Resistance ρ = Fluid density (seawater) Vs = Ship service speed (m/s) S = Wetted Surface Area

- Speed 5 knots = 2.572 m/s Rf = 22.92
- Speed 15 knots = 7.716 m/s Rf = 206.29
- Speed 25 knots = 12.86 m/s Rf = 573.12

- Air Resistance:

Rd = C x Vs^2 Where: Rd = Air Resistance Vs = Ship service speed (m/s)

- Speed 5 knots = 2.572 m/s Rd = 0.337 m/s
- Speed 15 knots = 7.716 m/s Rd = 2.972 m/s
- Speed 25 knots = 12.86 m/s Rd = 8.268 m/s

- Residual Resistance:

Rr = Lwl x B x T x Cb Where: Lwl = Waterline Length B = Ship Width T = Draft Cb = Block Coefficient

Rr = 9.4 x 3.6 x 0.6 x 0.81 = 1.469 m^3

3.3.7 Total Resistance:

Rt = Rf + Rd + Rr + S

- Speed 5 knots = 0.998 KN
- Speed 15 knots = 58.872 KN
- Speed 25 knots = 394.812 KN

- Effective Horse Power:

Ehp = Rt x Vs

- Speed 5 knots = 2.566 hp
- Speed 15 knots = 311.256 hp
- Speed 25 knots = 680.115 hp

C. Calculation Results Table (Manual and Maxsurf Application)

Since this study uses two types of calculations with the Holtrop method, the following table presents the results of manual calculations with speed variables of 5, 15, and 25 knots:

From the table above, there are three speed variables in knots. The first is a speed of 5 knots, resulting in a power requirement of 2.566 horsepower (hp). The second is a speed of 15 knots, with a power requirement of 311.266 horsepower (hp). Lastly, at a speed of 25 knots, the power requirement is 680.115 horsepower (hp).

TABLE 3.
MANUAL POWER CALCULATION

No	Speed (kn)	Horse Power (hp)
1	5	2.566
2	15	311.266
3	25	680.115

- Power from Maxsurf Application:

Below are the results of the analysis, the calculation method that will be used is the Holtrop method using the Maxsurf Resistance application as follows;

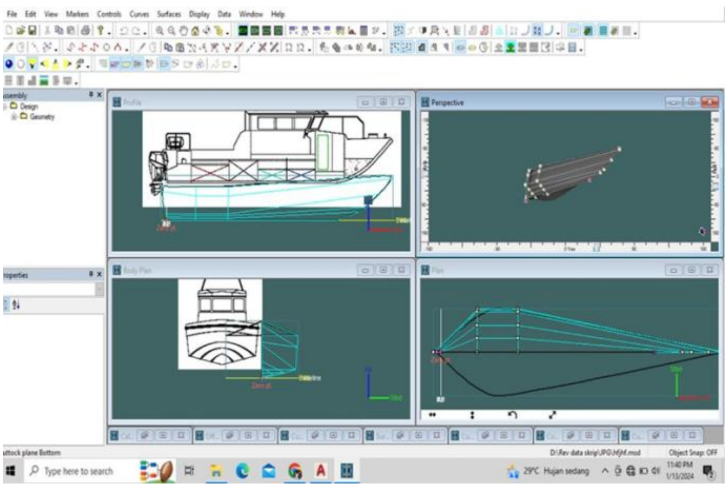

Figure. 3. Pilot Boat Design

TABLE 4.
MANUAL POWER CALCULATION

No	Speed (kn)	Froude No. LWL	Froude No. Vol.	Holtrop Resist (kN)	Horse Power (hp)
1	5	0.252	0.544	0.9	2.861
2	15	0.756	1.633	29.1	281.101
3	25	1.26	2.722	40.4	649.029

From the table above, there are three speed variables in knots. The first is a speed of 5 knots, resulting in a power requirement of 2.861 horsepower (hp). The second is a speed of 15 knots, with a power requirement of 281.101 horsepower (hp). Lastly, at a speed of 25 knots, the power requirement is 649.029 horsepower (hp).

- Wave Contours Due to Ship Speed

The following is a wave contour model resulting from the speed generated by the pilot boat. Based on the source, the vessel is designed for a maximum speed of 25 knots. Therefore, three speed variables were selected: 5, 15, and 25 knots, as shown below:

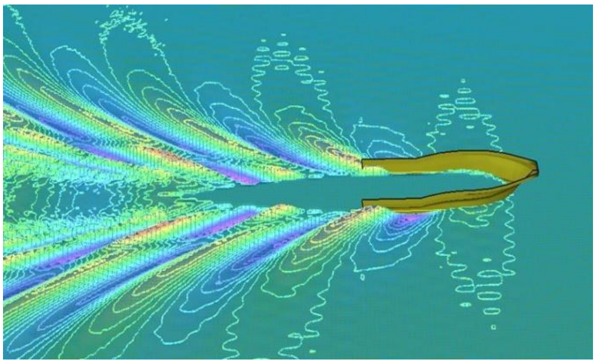

Figure. 4. Speed of 5 Knots

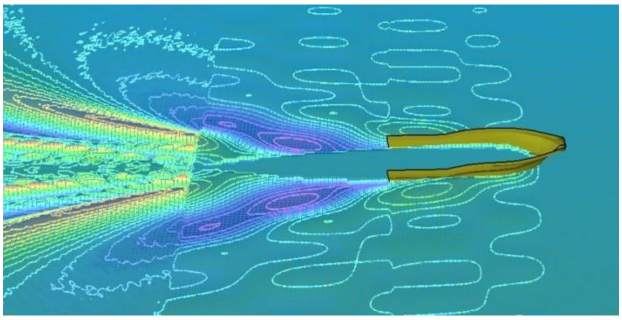

Figure. 5. Speed of 15 Knots

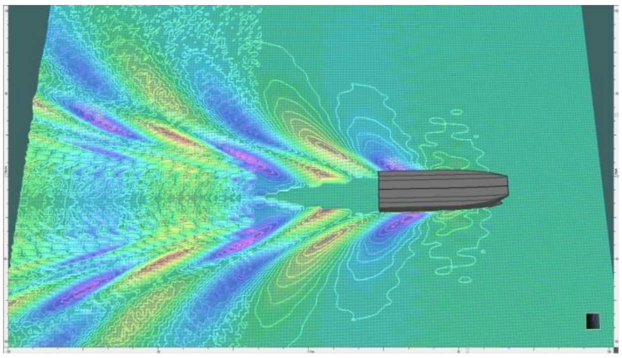

Figure. 6. Speed of 25 Knots

There is a 4-5% difference in engine power requirements between manual calculations and Maxsurf application calculations. It is concluded that the pilot boat requires 700 horsepower or two 350 hp engines to reach approximately 25 knots.

- Selection of Outboard Engine:

There are several brands that provide outboard engines with the same power, but the most familiar engine widely used in Indonesia is the Yamaha brand. Below are the specifications of the Yamaha F350BET.

Figure. 7. Yamaha outboard engine

TABLE 5.
OUTBOARD ENGINE SPECIFICATIONS

Feature	Specification
Engine Type	4-Stroke
Horsepower (HP)	350 HP
Engine Name	F350 BET
Engine Type	24 Valve DOHC
Transom Height	X = 25.3 in, U = 30.3 in
Cylinder Displacement	4169 cc
Bore x Stroke	96.0 mm x 96.0 mm
Maximum Operating Range	5000-6000 rpm
Compression Ratio	10.3
Fuel Induction System	Electronic Fuel Injection
Ignition System	TCI Micro-Computer
Fuel Consumption	96.6 l/h @ 5500 rpm
Gear Ratio	1.75 (21/12)
Lubrication System	Water Pump
Trim & Tilt Method	Power Trim Tilt
Starting System	Electric
Steering System	Remote
Weight	260-268 kg

D. Ship Stability Analysis:

Stability analysis is conducted using Maxsurf with four different stability conditions:

1. Fully loaded ship
2. Empty ship
3. Engine positioned in the center
4. Engine positioned on the right and left at the stern

Figure. 8. Right and Left Engine Position

- Full Load Ship Condition

The Load Distribution (Loadcase) table defines the weight of the ship, components, equipment, and cargo. Table 6 represents the full load condition, where the ship is loaded with all components and equipment, including six passengers, one of whom is the ship's captain.

TABLE 6.
LOAD DISTRIBUTION (LOADCASE)

Item Name	Quantity	Unit Mass	Total Mass	Unit Volume	Total Volume	Longitudinal Am	Transverse Am	Vertical Am	Tonne.m
Lightship	1	4.162	4.162			11.842	0	0	
Outboard M	2	0.25	0.5			0	0	0	User specified
Genset	1	0.155	0.155			0	0	0	User specified
Subtotal LWT			**4.817**			**10.232**	**0**	**0**	
DWT									
Ship Pilot	1	0.12	0.12			0	0	0	
Passenger	5	0.12	0.6			0	0	0	User specified
FOT 100%	1.953	1.953	2.068	2.068		2.5	0	0.436	User specified
FWT 100%	0.43	0.43	0.43	0.43		5.75	0	0.318	Actual
Sewage 10%	0.31	0.031	0.429	0.043		7.239	0	0.058	Actual
Subtotal DWT			**3.135**			**2.419**	**0**	**0.316**	Actual
Total Loadcase			7,952	2,928	2,542	7,152	0	0,125	
FS correction								0,001	
VCG fluid								0,126	

- Static Stability Results

From the graph in Figure 9, in a static state, two lines can be observed:

The green line represents the ship's inclination angle or the maximum righting moment.

- The blue line represents the GMT (Gravity Meta Center) at 0°, with a value of 2.415 meters.

IV. CONCLUSION

From the results of data analysis and simulations obtained for the pilot boat with a length of 12.4 meters, the following conclusions can be drawn:

1. The required engine power, based on manual calculations, is 680 HP (horsepower), whereas the Maxsurf Resistance application simulation results show 650 HP (horsepower). Based on both the manual calculations and the Maxsurf Resistance data, it can be concluded that the required outboard engine power is 700 horsepower, which is equivalent to two engines with 350 horsepower each. Based on this power requirement, the Yamaha F350UCB V8 5.3L F350 engine is selected to achieve a ship speed of approximately 25 knots.

2. For ship stability analysis, using Maxsurf Stability, the placement of the engines at the stern (right and left sides) results in a stability value of 1.327 meters at an inclination angle of 73.6°, whereas the stability value with the engines placed at the center of the stern is 1.324 meters at an inclination angle of 69.1°. Based on these stability values, it can be concluded that the optimal outboard engine placement for the 12.4-meter pilot boat is on the right and left sides of the stern, as it achieves an inclination angle of 73.6°, which is less than 25°. This is preferable compared to the center stern engine placement, which reaches 69.1° (exceeding 25°).

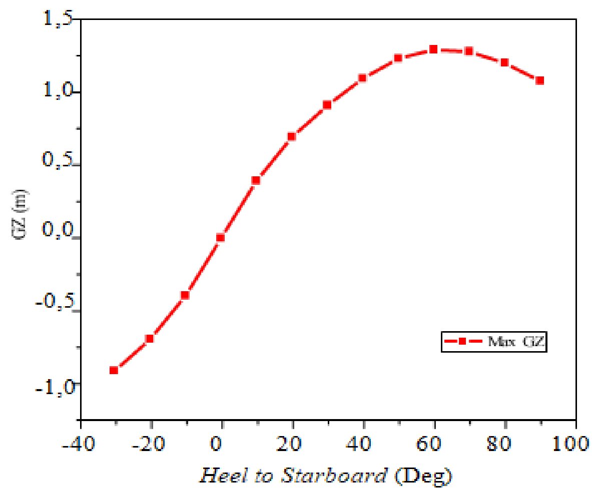

Figure. 9. Righting Lever Graph

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