INVOTEK

Jurnal Inovasi Vokasional dan Teknologi

http://invotek.ppj.unp.ac.id/index.php/invotek

Vol. 23, No. 3, Oct 2023

ISSN: 1411 – 3411 (p)
ISSN: 2549 – 9815 (e)

Fluid Dynamic Simulation of Sail Design Performance on Sail-Assisted Ship; A Preliminary Study

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Abstract

Ships are a reliable means of transportation in an archipelagic country like Indonesia. The high use of fossil fuels in sea transportation is one of the contributors to emissions that needs attention apart from their dwindling availability. Efforts to use sails as an additional propulsion force on ships are one of the green technology issues in shipping for reducing the use of fossil fuels. It is about how the design affects the thrust on the ship. Tests were carried out on models M_1, M_2, and M_3 in variations 0°, 30°, and 45° wind angles in computational fluid dynamic simulation at 12 knots constant speed. Through this article, there will be a discourse related to optimizing the design of the sail to produce energy efficiency and reduce the use of fossil fuels on ships. The shaped M_3 makes greater thrust on the ships than the other two models. The tendency of a decrease in the thrust of the sails with an increase in the wind direction angle, the distribution of force in two directions, namely as normal and parallel to the sails, is suspected as the cause.

Keywords: Fossil Fuels, Energy Efficiency, Thrust, Computational Fluid Dynamics, Sails.

1. Introduction

Based on the predictions submitted by the International Maritime Organization (IMO) in 2050, there will be an increase in global emissions from the shipping sector by 50% to 250%. It is the impetus for IMO to enforce stricter regulations and will encourage ship owners and the shipbuilding industry to carry out technological innovations related to renewable energies [1]. Moreover, there has been an increase in demand for global shipping transportation by 4% per year, while world trade by sea has reached more than 90% [2]. These facts concluded by the world regulatory body IMO that there is a need to have regulations related to energy efficiency. One effort that is a solution and efficient program to reduce carbon dioxide emissions and increase energy efficiency in shipping is using technology and renewable energy on ships. The discourse on using renewable energy on ships is an important issue. Some related research, such as biofuels [3], [4] as an alternative fuel, natural gas applications [5], [6], hydrogen application [7], [8] and dual fuel [9], [10] is proof of the seriousness of efforts to reduce the use of fossil fuels and emissions in shipping activities.

The Sail-assisted ship is one of the green technologies that utilize wind thrust. Ship propulsion is assisted by the wind, according to research conducted by [11]–[13] has the potential to reduce the level of fuel consumption and carbon emissions generated in shipping. Nyanya et al [11] said that when a ship sails at an optimal sail angle and optimal deck area, the potential for reducing CO_2 emissions is 36% compared to ships without the intervention of sailing technology innovation. Yunlong Wang et al [13], the development of wind-assisted ship propulsion (WASP) technology in various forms and types

Received date 31/07/2023, Revised date 21/09/2023, Accepted date 26/09/2023

P-ISSN: 1411-3414
E-ISSN: 2549-9815

contributes to reducing emissions, without forgetting the challenges of implementation technology won the suitability of the ship's operational needs. However, the percentage of savings and emission reductions depends on ship design, hull shape, operational speed, wind speed and direction of wind [14]. Some opinions seem to state that using sails is like doing old technology that existed before machinery in the shipping sector. But that current technological developments must also be accompanied by efforts to protect the environment. In terms of application development, sails have experienced many innovations, such as the emergence of soft and rigid types as hybrid combinations with solar panels.

Several studies on ship sails have been carried out by [15]–[18]. Cairns has conducted research on sails related to optimization related to wind speed using foil sails [15]. Lu and Ringsberg has conducted research on the performance of sails using rotors on the thrust characteristics of ships [16]. Tian has conducted research on the shape of the U screen on its thrust characteristics [17]. Meanwhile, Mboumba has conducted research on the effective sail distance on the characteristics of the prevailing wind [18]. From various existing studies, the influence of the shape of the screen is not widely discussed.

This article presents the results of a preliminary study of how sail design influences ship thrust computationally. Initial studies determining the optimal design for ship operations are the key to optimizing the energy efficiency obtained. Furthermore, the results obtained will be a reference for further development regarding the potential use of hybrid solar Sailor on energy efficient ferries with a catamaran hull shape in order to double benefits.

2. Methodology

The aim of this discussion is to reference prior research, specifically focusing on the methodology of data collection and computational fluid dynamics (CFD) simulation. The collected research data encompass various elements such as lines plan and general plan data for catamaran crossings, obstacle data, and the calculation of sail area. The sail configurations considered in the study comprise Model 1 featuring a basic square-shaped design, while Models 2 and 3 adopt a basic trapezoidal design, all having an identical area size of 130.2 m^2. Subsequently, the next phase involves modeling the sails using CFD to ascertain the respective thrust generated by each design. The analysis commences with the modeling process and inputting multiple parameters into the boundary conditions. The variable parameter under scrutiny is the variation of wind direction angle, maintaining constant ship speed and consistent wind conditions throughout the simulations. Figure 1 is a flow diagram illustrating the stages of research work as explained above.

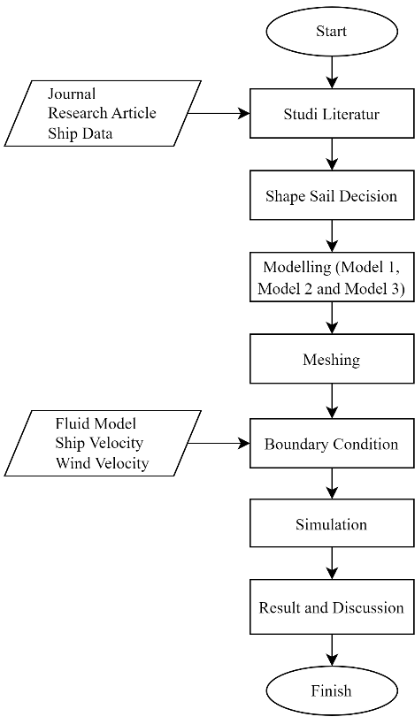

Figure 1. Flow Chart Diagram

P-ISSN: 1411-3414
E-ISSN: 2549-9815

The simulation method used in this simulation is shown in Table 1 as follows:

Table 1. Simulation Method

Model	Remarks
Condition	Steady State
Fluid	k-epsilon
Near Wall Treatment	Realizable
Initialization	Hybrid

The boundary conditions used in this simulation are shown in Table 2 as follows:

Table 2. Boundary Condition

Name Selection	Remarks	Value	Unit
Inlet	Velocity Inlet	6.173	m/s
Outlet	Pressure Outlet	Gauge = 0	Pa
Sails	Wall	-	-

An independent grid study was carried out to ensure that the model that had been simulated has been valid. Meshing is carried out in various sizes including in meters 0.55, 0.5, 0.45 and 0.35. The number of element result based on element size are 141687, 177312, 228598 and 417427 respectively. An element size of 0.35 was used for all models because the result of the force is heading to a certain point. The results of grid independence can be seen below at Figure 2.

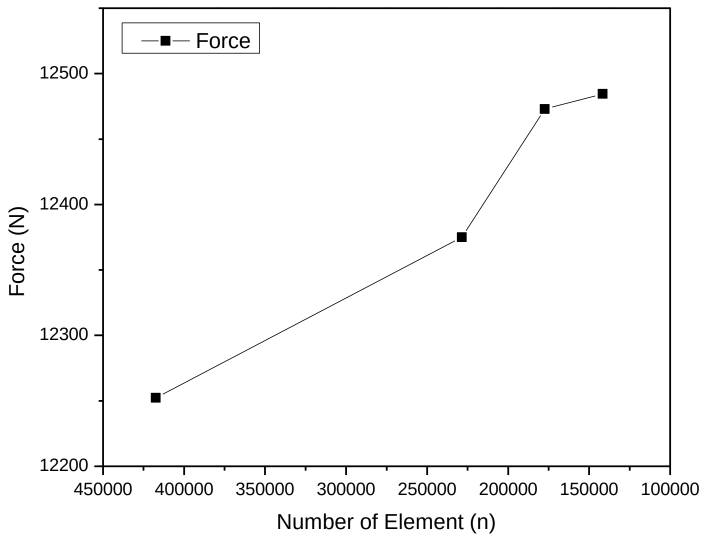

Figure 2. Grid Independence Study

3. Result and Discussion

3.1 Data of Ship

A catamaran vessel is used in this analysis. The overall length of the vessel is 106.019 and it has a width of 21.668. The vessel has a height of 6.2 meters and a draft of 2.9 meters. The vessel is designed with a speed of 12 knots and has a displacement of 1,931 tons. The following is the main data of ships that are designed based on the displacement parameters are shown in Table 3 below:

Table 3. Data of ship

Parameter	Value	Unit
Length Overall (LOA)	106.019	meter

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Length Between Perpendicular (LBP)	97.414	meter
Beam (B)	21.668	meter
Height (H)	6.2	meter
Draft (T)	2.9	meter
Speed (V_s)	12	knot
Mass Displacement (Δ)	1,931	ton

Ship data from existing, keeping displacement at a constant value. The ship was equipped with solar panel sails to generate energy for efficiency and reduce fuel consumption. The following is a ship lines plan to calculate ship resistance and seakeeping. Resistance is carried out on the existing model, and the seakeeping test for assessment performance of three models when operating at sea at various wave heights.

3.2 Lines Plan

Figure 3 shows the catamaran lines plan. Catamaran has a larger deck area, which is the reason for choosing the ship model used as the object. Having these advantages, researchers can freely modify the sail model and configuration.

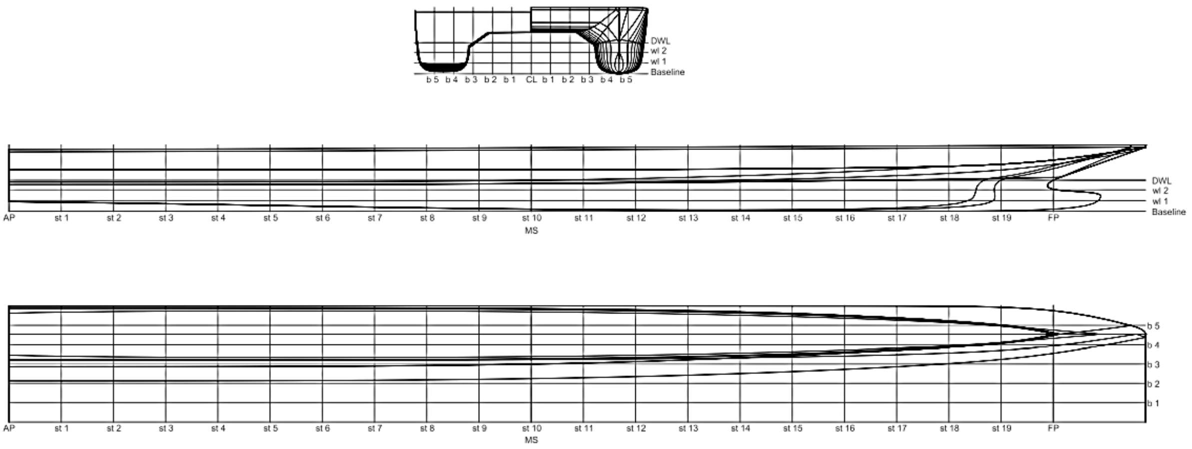

Figure 3. Lines Plan Catamaran

Catamaran are favored as sail propulsion due to their advantageous features. The dual-hulled design allows for a larger sail area compared to monohull vessels of similar width, enabling them to harness more wind energy and generate increased thrust. This design also enhances stability, mitigating the tendency to roll even under substantial wind loads, thereby optimizing sail propulsion efficiency. Additionally, the twin hulls reduce hydrodynamic resistance in the water, promoting higher speeds with less power, thus maximizing sail efficiency. The maneuverability of catamarans is superior, facilitating quick turns and direction changes without significant speed loss. Furthermore, the hydrofoil effect created by water flowing between the hulls enhances efficiency and speed by reducing water friction. Overall, these features make catamarans an excellent choice for utilizing wind power efficiently for propulsion.

3.3 Analysis of Ship Resistance and Power

Figure 4 shows a graph of the relationship between the drag and the speed of the ship. The figure shows that the relationship between the two parameters is exponential. The higher the speed, the higher the resistance generated. The ship resistance is calculated up to the maximum speed of the ship 12 knots.

In the context of the relationship between resistance (R) and power (P) with ship speed (V), it is found that the resistance on a ship (R) increases exponentially with the cube of the ship's speed (V^3). This implies that each increment in speed results in a threefold increase in the resistance faced by the ship. Simultaneously, the power required to maintain the ship's speed (P) also follows a similar law, increasing threefold with the cube of the ship's speed (V^3). Therefore, endeavors to augment the ship's speed necessitate a significant amount of power, and a careful understanding of this correlation becomes

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crucial in devising strategies for efficient power utilization on the vessel, aiming to minimize power consumption while achieving the desired speed.

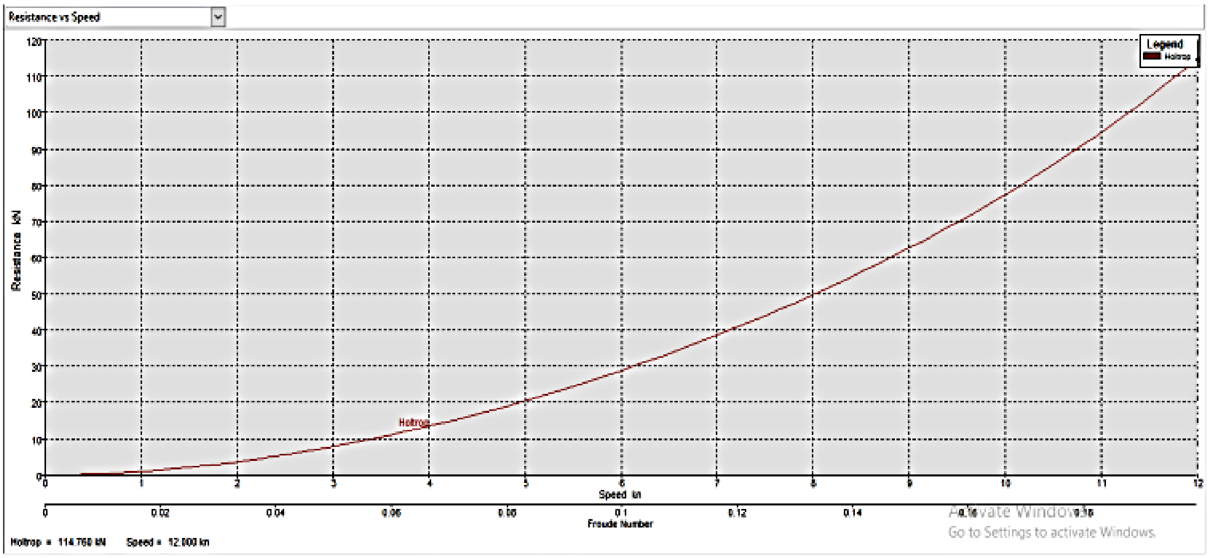

Figure 4. Graph of Resistance - Ship Speed

Figure 5 shows the relationship between the required ship power and the speed. The relationship between the two parameters is also exponential, like the graph of the ship's resistance and speed. The higher the speed, the higher the power needed. The power requirements of the ship are calculated up to the maximum speed of the ship which is equal to 12 knots.

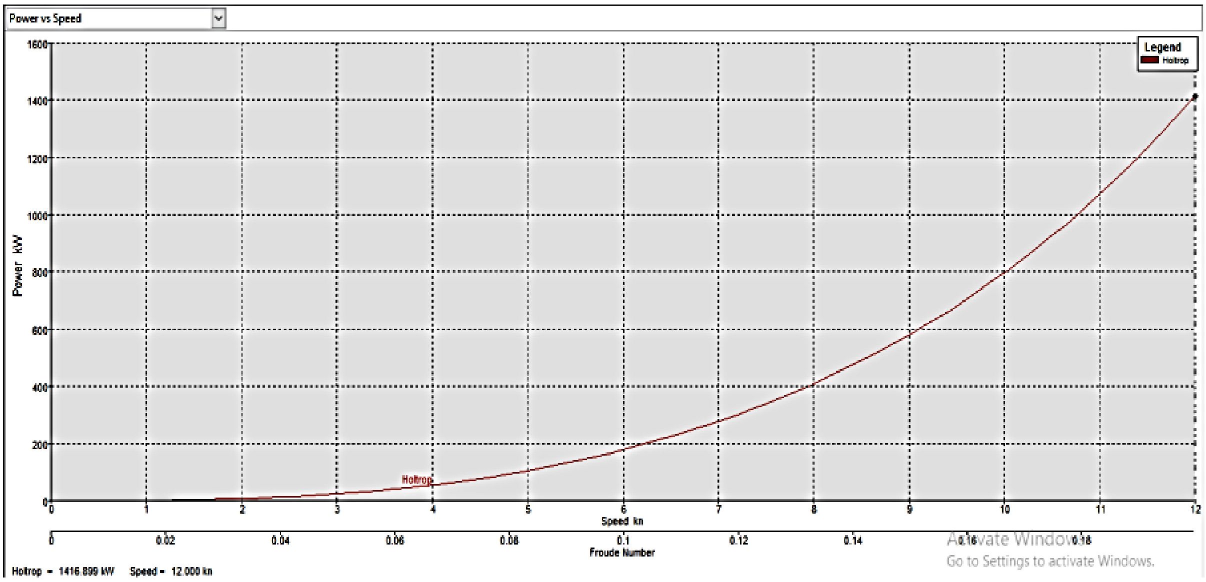

Figure 5. Graph of Ship Power - Ship Speed

Figure 6 shows result of the simulation analysis obtained from Maxsurf Resistance, the calculated resistance for the ship is determined to be 114.76 kN. This resistance represents the opposing force that the ship encounters as it moves through the water. To effectively propel the ship against this resistance, a certain amount of power is required. Considering an efficiency of 50% for the ship, which is a typical approximation accounting for various losses and inefficiencies in the propulsion system, the calculated ship power amounts to 1,416.89 kW or approximately 1,900.08 horsepower (Hp). This power output is the effective power needed to overcome the resistance and move the ship at a specified speed. The mentioned efficiency of 50% encompasses diverse losses experienced during the power transmission process from the engine to the propulsor. These losses can arise from factors such as friction in the

P-ISSN: 1411-3414
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engine, gearbox losses, mechanical losses, and hydrodynamic losses in the propulsor. Additionally, losses related to heat dissipation, electrical inefficiencies, and other mechanical components contribute to this efficiency reduction.

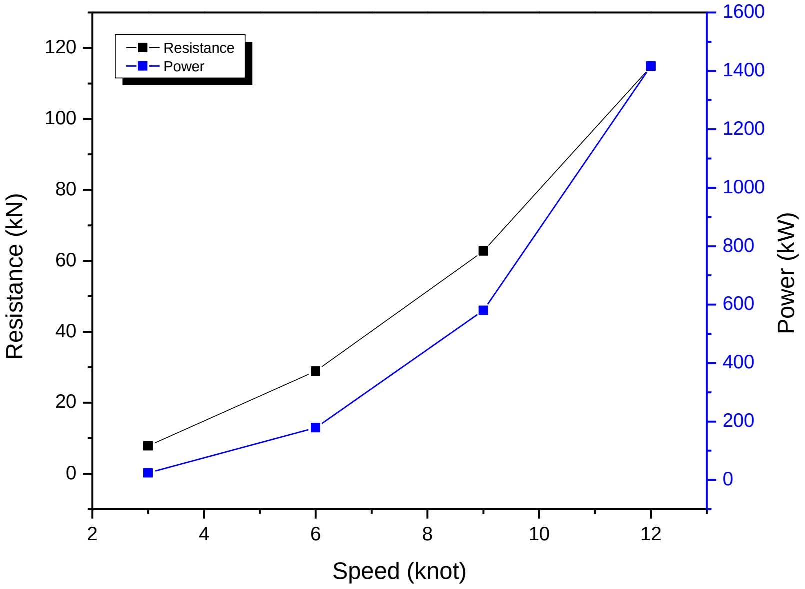

Figure 6. Ship Resistance – Ship Power Requirements

Efficiency is a critical factor to consider in ship design and operation. Engineers and designers strive to optimize the ship's components and systems to enhance efficiency, reduce losses, and ultimately improve overall performance. This might involve refining the design of the hull to minimize resistance, employing more efficient propulsion systems, or enhancing the power transmission mechanisms to decrease losses, all aimed at achieving a higher overall efficiency and reducing the power required to propel the ship effectively. The validation calculation of the results obtained on Maxsurf is carried out. Validation is done by comparing the values obtained from the software with mathematical calculations. A comparison of calculations can be seen in Table 4.

Table 4. Comparison of Mathematical and Computational Calculation Results

Speed (knot)	Mathematic (kW)	Computational (kW)	Error (%)
3	24.237	24.000	1.0099
6	178.554	178.331	1.0013
9	581.937	580.307	1.0028
12	1,419.821	1,416.899	1.0021

From the results of the comparison of the calculations performed, it was found that the error value of several ship speeds is 1%. The value obtained from a comparison of mathematical and computational calculations is quite small. So that the simulation results obtained can be used as a basis for further calculations.

3.4 Modelling of Sail

During the sail design phase, one of the key tasks involved is establishing the specifications of the sail based on constant area parameters. Adopting a constant area is deemed essential to accurately assess the impact of sail shape on the thrust generated by the ship, considering dynamic parameters such as wind direction and angle. Three planned models are as follows:

3.4.1 Model 1 (M_1)

Figure 7 shows model 1 (M_1) has a basic rectangular shape with main dimensions of 21 m wide, 6.2 m high, and 100 m thick. This model has a total area of 130.2 m^2.

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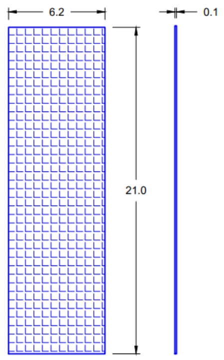

Figure 7. Model M_1

3.4.2 Model 2 (M_2)

Figure 8 shows model 2 (M_2) has a basic trapezoid shape with a total area of 130.2 m^2 with the following dimensions:

- Trapezoid 1 parallel side 6.9 and 6.3 meters, 8.0 meters high and 100 mm thick
- Trapezoid 2 parallel sides 5.6 and 5.1 meters, 8.0 meters high and 100 mm thick
- Trapezoid 3 parallel sides 4.6 and 4.1 meters, 8.0 meters high and 100 mm thick

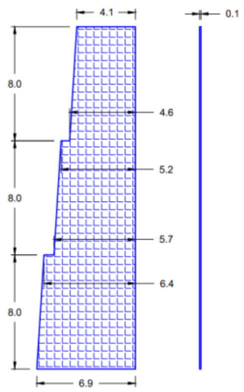

Figure 8. Model M_2

3.4.3 Model 3 (M_3)

Figure 9 shows Model 3 (M_3) has the basic shape of an isosceles trapezoid with a total area of 130.2 m^2 with the following dimensions:

- Trapezoid 1 parallel sides 5.8 and 6.4 meters with a height of 4 meters
- Trapezoid 2 parallel sides 6.4 and 7.0 meters with a height of 4 meters
- Trapezoid 3 parallel sides 7.0 and 7.0 meters with a height of 4 meters
- Trapezoid 4 parallel sides 7.0 and 7.0 meters with a height of 4 meters
- Trapezoid 5 parallel sides 6.4 and 5.8 meters with a height of 4 meters

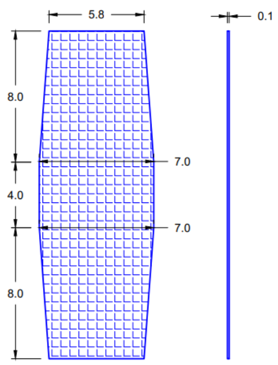

Figure 9. Model M_3

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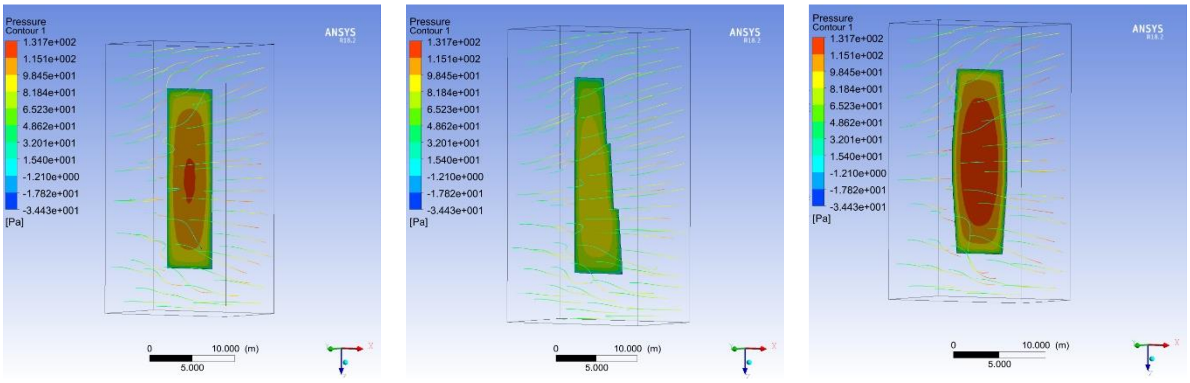
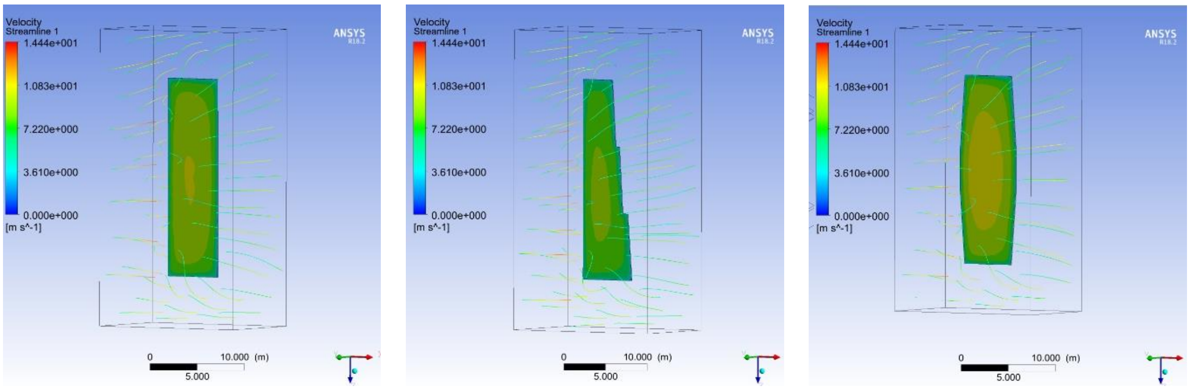
3.5 Simulation

After the sail model is designed, the fluid domain is created into ANSYS. The fluid model used is k-epsilon. The results of the simulation using ANSYS are as follows:



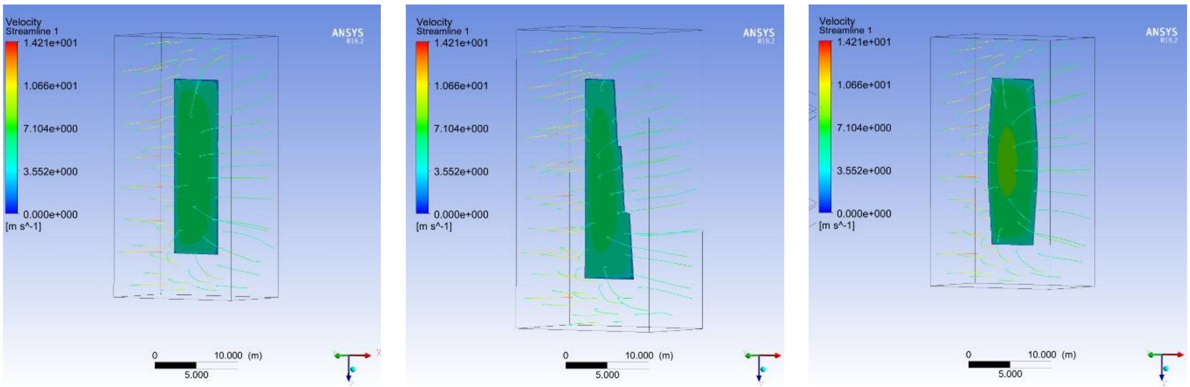
(a) (b) (c)

Figure 10. Simulation with Wind Direction Angle 0˚ (a) M_1, (b) M_2, (c) M_3



(a) (b) (c)

Figure 11. Simulation with Wind Direction Angle 30˚ (a) M_1, (b) M_2, (c) M_3



(a) (b) (c)

Figure 12. Simulation with Wind Direction Angle 45˚ (a) M_1, (b) M_2, (c) M_3

Figure 10, Figure 11, and Figure 12 shows the results of an experiment that tested three different sail models (M_1, M_2 and M_3) at several angles (0˚, 30˚ and 45˚). The values listed describe the magnitude of the thrust in Newtons. From these data, it can be concluded that Model M_3 produces the highest thrust among the three models at all angles, while Model M_2 has the lowest thrust. The Model M_1 has a higher thrust than M_2, but still lower than M_3. In addition, it can be seen that on various angle from 0˚ to 45˚, the overall thrust tends to decrease for all models.

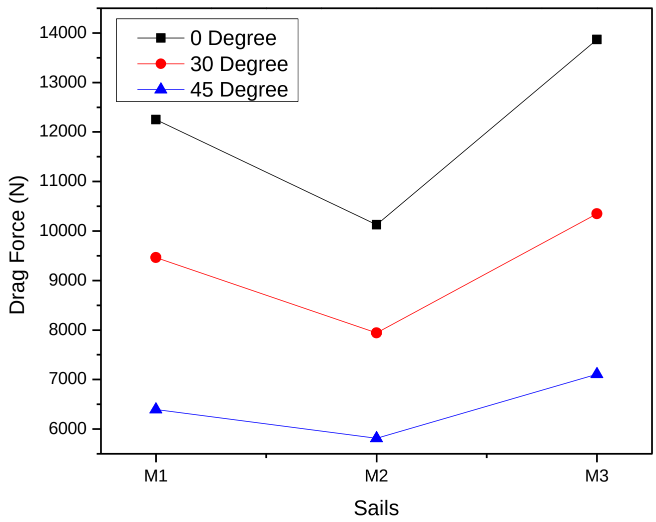


Figure 13. Simulation Result on various angle

From the simulation results Figure 13, it was found that with an enlarged wind angle variation, the value of the force obtained was getting smaller. This is because there is an angular effect that causes the force to be distributed in two directions, one of which is the normal direction and the direction parallel to the sail. The results obtained from the simulation are consistent with the findings obtained by Mboumba [18]. According to the study, the optimal angle for sail installation is 90 degrees relative to the ship's direction or 0 degrees from the wind direction.

4. Conclusion

From the simulation results, it is evident that the M_3 shape significantly contributes to the highest thrust. A larger angle formed between the sail and the wind direction leads to a reduction in the thrust value. The optimal angle to achieve the highest thrust is 0 degrees relative to the wind direction. This study recommends the application of the M_3 shape for ship sail usage. Additionally, it suggests that the wind direction with respect to the sail should ideally form angles of 90 degrees and 0 degrees relative to the ship's axis. Additionaly, this research suggests considering the sail reinforcement structure against the hull and evaluating the ship's stability due to the use of sails on the ship's deck.

5. Acknowledgement

Thank you to Diktilitbang PP Muhammadiyah for funding your research batch VI. Green Maritime Technology Research Group, University of Muhammadiyah Surabaya and team.

References

[1] P. Pan, Y. Sun, C. Yuan, X. Yan, and X. Tang, "Research progress on ship power systems integrated with new energy sources: A review," *Renew. Sustain. Energy Rev.*, vol. 144, p. 111048, 2021, doi: https://doi.org/10.1016/j.rser.2021.111048.

[2] C. E. Delft and D. S. Lee, "Update of Maritime Greenhouse Gas Emission Projections," 2019. [Online]. Available: www.cedelft.eu

[3] M. Bošnjaković and N. Sinaga, "The perspective of large-scale production of algae biodiesel," *Appl. Sci.*, vol. 10, no. 22, pp. 1–26, 2020, doi: https://doi.org/10.3390/app10228181.

[4] S. T. Keera, S. M. El Sabagh, and A. R. Taman, "Castor oil biodiesel production and optimization," *Egypt. J. Pet.*, vol. 27, no. 4, pp. 979–984, 2018, doi: https://doi.org/10.1016/j.ejpe.2018.02.007.

[5] N. S. Octaviani, Semin, M. B. Zaman, and B. Sudarmanta, "The implementation of CNG as analternative fuel for marine diesel engine," *Int. J. Mech. Eng. Technol.*, vol. 9, no. 13, pp. 25–33, 2018.

P-ISSN: 1411-3414
E-ISSN: 2549-9815

[6] J. C. Nwafor and Z. Hu, "An Experimental and Numerical Analysis of Gap Resonance Applicable for FLNG Side-by-Side Offloading," in *International Conference on Offshore Mechanics and Arctic Engineering*, 2021, vol. 85161, p. V006T06A024. doi: https://doi.org/10.1115/OMAE2021-62059.

[7] Y. Bicer and I. Dincer, "Comparative life cycle assessment of hydrogen, methanol and electric vehicles from well to wheel," *Int. J. Hydrogen Energy*, vol. 42, no. 6, pp. 3767–3777, 2017, doi: https://doi.org/10.1016/j.ijhydene.2016.07.252.

[8] F. Dawood, M. Anda, and G. M. Shafiullah, "Hydrogen production for energy: An overview," *Int. J. Hydrogen Energy*, vol. 45, no. 7, pp. 3847–3869, 2020, doi: https://doi.org/10.1016/j.ijhydene.2019.12.059.

[9] S. Stoumpos, G. Theotokatos, E. Boulougouris, D. Vassalos, I. Lazakis, and G. Livanos, "Marine dual fuel engine modelling and parametric investigation of engine settings effect on performance-emissions trade-offs," *Ocean Eng.*, vol. 157, pp. 376–386, 2018, doi: https://doi.org/10.1016/j.oceaneng.2018.03.059.

[10] S. Verma, L. M. Das, and S. C. Kaushik, "An experimental study on gas-to-liquids and biogas dual fuel operation of a diesel engine," *Int. J. Exergy*, vol. 36, no. 2–4, pp. 330–344, 2021, doi: https://doi.org/10.1504/IJEX.2021.118724.

[11] M. N. Nyanya, H. B. Vu, A. Schönborn, and A. I. Ölçer, "Wind and solar assisted ship propulsion optimisation and its application to a bulk carrier," *Sustain. Energy Technol. Assessments*, vol. 47, p. 101397, 2021, doi: https://doi.org/10.1016/j.seta.2021.101397.

[12] S. Al Mamun, Z. I. Chowdhury, M. S. Kaiser, and M. S. Islam, "Techno-financial analysis and design of on-board intelligent-assisting system for a hybrid solar–DEG-powered boat," *Int. J. Energy Environ. Eng.*, vol. 7, pp. 361–376, 2016, doi: 10.1007/s40095-016-0218-0.

[13] Y. Wang, X. Zhang, S. Lin, Z. Qiang, J. Hao, and Y. Qiu, "Analysis on the Development of Wind-assisted Ship Propulsion Technology and Contribution to Emission Reduction," in *IOP Conference Series: Earth and Environmental Science*, 2022, vol. 966, no. 1, p. 12012. doi: 10.1088/1755-1315/966/1/012012.

[14] M. Petković, M. Zubčić, M. Krčum, and I. Pavić, "Wind Assisted Ship PropulsionTechnologies–Can they Help in Emissions Reduction?," *NAŠE MORE Znan. časopis za more i Pomor.*, vol. 68, no. 2, pp. 102–109, 2021, doi: https://doi.org/10.17818/NM/2021/2.6.

[15] J. Cairns, M. Vezza, R. Green, and D. MacVicar, "Numerical optimisation of a ship wind-assisted propulsion system using blowing and suction over a range of wind conditions," *Ocean Eng.*, vol. 240, p. 109903, 2021, doi: https://doi.org/10.1016/j.oceaneng.2021.109903.

[16] R. Lu and J. W. Ringsberg, "Ship energy performance study of three wind-assisted ship propulsion technologies including a parametric study of the Flettner rotor technology," *Ships Offshore Struct.*, vol. 15, no. 3, pp. 249–258, 2020, doi: https://doi.org/10.1080/17445302.2019.1612544.

[17] F. Tian, L. Huang, Y. Wang, K. Wang, and R. Ma, "Numerical Simulation of the Aerodynamic Performance of A U-Shaped Sail," in *Journal of Physics: Conference Series*, 2023, vol. 2508, no. 1, p. 12029. doi: 10.1088/1742-6596/2508/1/012029.

[18] D. Mboumba Mboumba, "Analysis of wind assisted ship propulsion through 3D-computational fluid dynamics: application of rigid wind sails on a bulk carrier," WORLD MARITIME UNIVERSITY, 2022.