Engineering and Technology Journal e-ISSN: 2456-3358

Volume 09 Issue 05 May-2024, Page No.- 4000-4006

DOI: 10.47191/etj/v9i05.17, I.F. – 8.227

Sustainable Fishing Livelihoods: Exploring the Potential of Sail Technology Using Computational Fluid Dynamic in Traditional Fishing Boats

Richard Benny Luhulima[1], Fella Gaspersz[2], Gerald Richard Latuhihin[3]
[1,2,3] Department of Naval Architecture, Faculty of Engineering, Universitas Pattimura, Ambon 97233, Indonesia

ABSTRACT: The potential of using sails and Computational Fluid Dy namics (CFD) to improve the sustainability of traditional fishing boats in the Maluku region. This study highlights the importance of cost-effectiveness and environmental sustainability in the fishing industry. This study shows that Computational Fluid Dynamics (CFD) is effective in simulating the thrust force generated by sails. Sails were used to generate thrust forces on conventional fishing vessels by implementing CFD methodology with three different models. Various sail shapes were incorporated into the modelling process to assess their impact on the thrust force. Subsequently, a comprehensive analysis was conducted to evaluate the sail thrust force under typical operating conditions, focusing specifically on the average speed of the vessel at 15 knots in the waters surrounding the Maluku Islands. The results reveal that sail model 1 has the highest thrust force, amounting to 240.2 N. Sail models 3 and 2 generate thrust forces of 238.9 N and 227.9 N, respectively. The fluid flow conditions around sail model 1 and screen model 2 provide valuable insights into how the sail interacts with the fluid environment to produce thrust. By understanding and optimizing these fluid dynamics, designers and engineers can enhance the performance of sail models and improve their efficiency in harnessing wind power for propulsion. This study highlights the importance of ship science and technology in the design of appropriate propulsion systems for traditional fishing vessels.

KEYWORDS: CFD, sail, thrust force, traditional fishing boat

I. INTRODUCTION

The fishing profession is indeed a significant livelihood for many residents in the Maluku region, as evidenced by the socioeconomic life of the fishermen community on Maitara Island, where fishing is the primary occupation [1]. However, it is important to note that there are other livelihood strategies in place, such as agricultural work and involvement in plantations and pearl enterprises, as seen in the case of women on Seram Island [2]. Although fishing is a mainstay for many people, it is not their only livelihood option.

The livelihoods of fishermen are closely tied to the effectiveness and cost efficiency of their fishing boats. Traditional boats, which are often central to their operations, must balance their initial investment and operational costs with income generation to ensure economic viability [3]. Although these studies do not directly address the use of sails as a cost-effective solution, they offer insights into various aspects of fishing boat economics and the potential for alternative energy sources. The adoption of biodiesel as an alternative energy source for fishing boats has been explored, which suggests the willingness of the fishing community to consider changes that could enhance cost-effectiveness and environmental sustainability [4]. However, this does not directly correlate with the use of sails, but indicates a broader context of energy considerations within the fishing industry.

Figure 1. Traditional fishing boat with tarpaulin sail [5]

The successful rescue of a fishing boat stranded in the Natuna Sea for 12 days highlights the importance of resourcefulness and quick thinking in emergency situations. The utilization of tarpaulin sails in this instance potentially played a crucial role in enabling the vessel to navigate or send distress signals, although the specific circumstances leading to the boat's predicament remain unclear. It is evident that fishing boats in the area are well prepared for such emergencies, underscoring the significance of being equipped for rescue operations at all times.

The decision to resort to tarpaulin sails as a temporary measure could have been prompted by a breakdown in equipment or the exhaustion of fuel supplies, both of which are common challenges faced by Indonesian fishermen [6], [7]. Given the heavy reliance on fossil fuels in the fishing industry, it is common for vessels to encounter issues related to fuel shortages or mechanical failures. In such cases, improvisation is essential to ensure the safety and survival of those on board, as demonstrated by the rescued fishing boat crew..

The incident serves as a reminder of the risks and uncertainties that fishermen face while at sea, as well as the importance of having contingency plans in place for unforeseen emergencies [8], [9]. The swift determination of the boat's location is critical for facilitating a prompt response and successful rescue operation. Moving forward, it is imperative for fishermen to be adequately prepared and equipped to handle emergencies effectively, whether through the use of alternative sailing methods or other innovative solutions that can help ensure their safety and well-being while navigating unpredictable waters [10].

The utilization of sails on fishing boats is rooted in traditional knowledge, which often reflects a deep understanding of local environmental conditions and maritime practices. However, the effectiveness and efficiency of sail shapes have not been thoroughly investigated using modern scientific methods. These studies suggest that there is potential to improve fuel efficiency and reduce emissions by optimizing sail placement and design [11]. However, the practical application of sail technology is highly dependent on local wind conditions and cannot fully replace diesel engines [6]. Moreover, archaeological evidence from the Viking Ship indicates that historical sail proportions are not fully understood and that reconstructions rely on a combination of archaeological, iconographic, and ethnographic sources [12]. Although traditional knowledge is invaluable for resource management and cultural appreciation [13], it does not always translate into safety or efficiency in modern contexts, as in the case of traditional fishing vessel decorations that do not aid radar detection [14]. The integration of traditional sailing methods with renewable energy technologies such as hydro generators [15] and hybrid systems that combine sails, diesel engines, and solar panels [16] represents a promising avenue for enhancing the sustainability of fishing vessels.

The application of Computational Fluid Dynamics (CFD) to analyze sail thrust forces on traditional fishing boats is an emerging area of research that combines fluid mechanics with numerical analysis to predict the aerodynamic performance of sails. CFD allows the simulation of airflow around sail structures to determine the forces generated, which is crucial for optimizing sail design and improving propulsion efficiency [17]. Although CFD has been extensively used for modern yacht and ship designs, its application to traditional fishing boats is less common. Traditional fishing boats often rely on empirical knowledge and inherited design practices, which may not always consider the hydrodynamic interactions between the hull, sail, and surrounding fluids [18]. Moreover, the integration of sails as a hybrid propulsion system with fishing boat engines to enhance fuel efficiency and reduce emissions is a relatively novel concept that has not been widely studied [11].

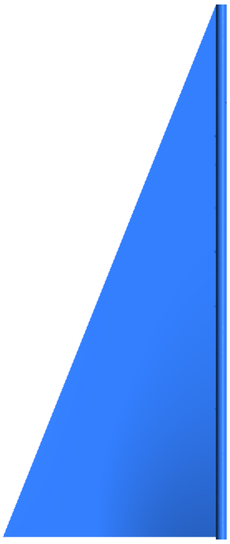
However, the literature does not directly address the specific impact of sail-shaped variations on the thrust force of traditional boats. However, several studies have provided insights into the related aspects of the performance and characteristics of traditional fishing vessels. Ridwan [19]discussed the importance of applying ship science and technology to traditional fishing vessels, including the design of appropriate propulsion systems that could influence the thrust force [19]. These approaches may affect the thrust force; however, the specific role of the sail shape has not been examined.

The primary objective of this study is to examine the effectiveness of using sails to generate thrust forces on conventional fishing vessels by implementing a CFD methodology with three different models. Various sail shapes were incorporated into the modelling process to assess their impact on the thrust force. Subsequently, a comprehensive analysis was conducted to evaluate the sail thrust force under typical operating conditions, focusing specifically on the average speed of the vessel at 15 knots in the waters surrounding the Maluku Islands. This geographical area served as the testing ground for the sail performance assessment. The research findings revealed that the optimal sail configuration was determined based on the sail shape that produced the highest thrust force. By identifying the most efficient sail design, this study provides valuable insights into enhancing the performance of traditional fishing boats through the utilization of sails.

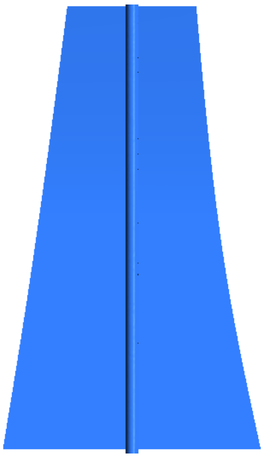
II. METHOD

2.1 Sail Modelling

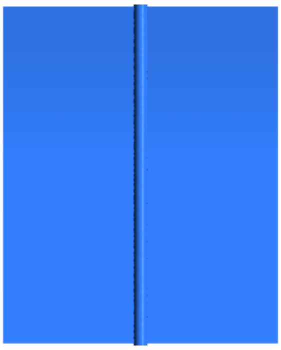
Three distinct sail shapes are employed in the modelling process: model 1, which features a triangular shape; model 2, which has a trapezoidal shape; and model 3, which has a rectangular shape. It is worth noting that all sail variations had an identical surface area of 11 m^2. For a visual representation of the sail shapes, please refer to Figure 1.



(a) Model 1



(b) Model 2



(c) Model 3

Figure 2. Sail Shapes

2.2 Governing Equation

Choosing an appropriate turbulence model is paramount when conducting wake-field modelling. In this study, the Shear Stress Transport (SST) turbulence model developed by Menter [20], [21] was considered. Numerous researchers have utilized and validated the SST model and concluded that it yields satisfactory results [22][23]. The RANS solver, which is a component of ANSYS CFX, was employed to solve the fluid flow field. Equations (1), (2), and (3) describe the continuity, RANS, and SST turbulence equations, respectively.

Continuity equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}\left(\rho U_j\right) = 0 \qquad (1)$$

In the continuity equation, ρ is the fluid density, *t* is the time, *and* U_j is the flow velocity vector field.

RANS equation:

$$\rho \bar{f}_i + \frac{\partial}{\partial x_j}\left[-\bar{p}\delta_{ij} + \mu\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right) - \overline{\rho u_i' u_j'}\right] - \rho \bar{u}_j \frac{\partial \bar{u}_i}{\partial x_j} = 0 \qquad (2)$$

The left side of the RANS equation (2) represents the change in the mean momentum of the fluid element with unsteadiness in mean flow. This change is balanced by the mean body force ($\bar{f}$), the mean pressure field ($\bar{p}$), the viscous stress, $\mu\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right)$, and apparent stress ($\rho u_i' u_j'$) to the fluctuating velocity field.

Menter's SST equation

$$\frac{\gamma}{v_t}P - \beta\rho\omega^2 + \frac{\partial}{\partial x_j}\left[\left(\mu + \sigma_\omega \mu_t\right)\frac{\partial \omega}{\partial x_j}\right] + 2\left(1 - F_1\right)2\rho_{\omega 2}\frac{1}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial \omega}{\partial x_j} - \left(\frac{\partial(\rho\omega)}{\partial t} + \frac{\partial\left(\rho u_j \omega\right)}{\partial x_j}\right) = 0 \qquad (3)$$

The SST model developed by Menter combines the advantages of the k–ω model to offer an improved formulation suitable for various applications. To achieve this objective, a blending function F1 is established, which has a value of one in the area closest to the solid surface and a value of zero in the flow domain farther away from the wall. By activating the k–ω surface area of the walls and the k–ε model for residual flow, this technique enables the use of the appealing near-wall performance of the k–ω model to determine the sensitivity of a free stream.

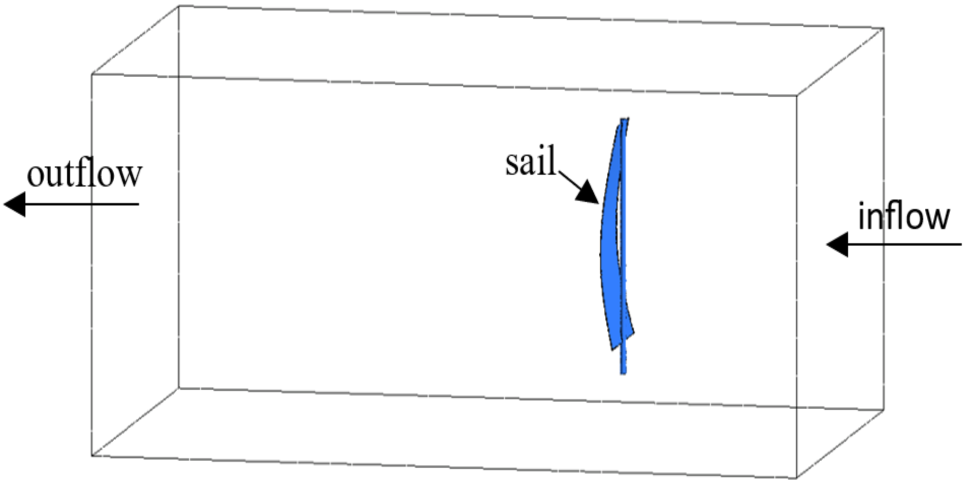


Figure 3. Sail Shapes

2.2 Numerical Domain

The preferred computational domain for simulating the intake velocity is typically positioned 2L ahead in a direction perpendicular to the front, with a pressure outlet of 5L directed towards the back and positioned perpendicularly. The transverse and vertical directions were set to counteract the effects of the transverse pressure. To prevent backflow, Ford and Winroth [24] implemented a pressure exit outflow for the downstream boundary condition, as shown in Figure 2.

2.3 Grid Independence

However, it is probable that a fine mesh will consistently yield dependable outcomes in ANSYS CFX. Nevertheless, the large number of components contained within it also results in an increase in the amount of time and resources required for computation. During the computational process, it is crucial to consider the mesh size. Mesh convergence was assessed for both subsurface models, as shown in Figure 3. For the sails, an overall mesh count of approximately 1.72 million was achieved, indicating that optimal mesh convergence was achieved. The findings of Anderson [25] support this impression, as they show that there is a difference of less than 2% in the total drag coefficient.

III. RESULT AND DISCUSSION

The impressive results obtained by simulating the thrust force on sails using Computational Fluid Dynamics (CFD) are shown in Figure 4. It is observed that sail model 1 exhibits the highest thrust force, measuring 240.2 N. Following closely, models 3 and 2 generated thrust forces of 238.9 N and 227.9 N, respectively. These findings demonstrate the effectiveness of CFD in analyzing and understanding the performance of different sail models in terms of their thrust forces.

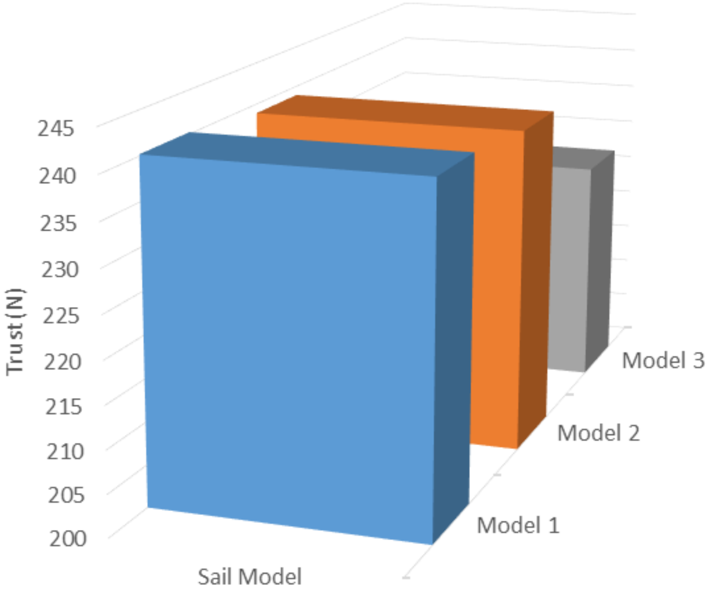


Figure 4. Trust CFD simulation of sails

Figure 5 visually represents the fluid flow conditions around sail model 1, highlighting the unidirectional nature of the flow and the lack of a discernible reverse flow. This visualization provides valuable insights into how the sail interacts with the fluid environment to generate thrust. By understanding and optimizing these fluid dynamics, designers and engineers can further enhance the performance of sail models and improve their efficiency and overall effectiveness in harnessing wind power for propulsion.

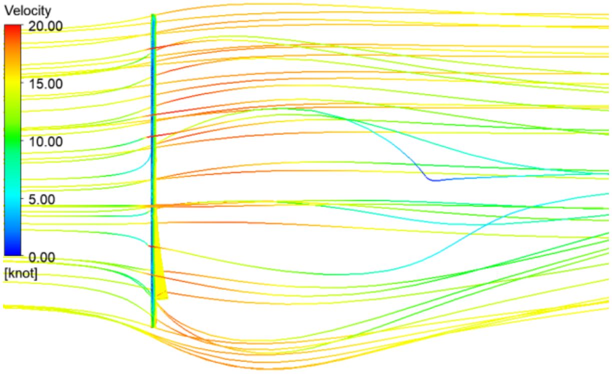


Figure 5. Fluid flow around sail model 1

The illustration presented in Figure 6 shows the fluid flow characteristics around screen model 2, highlighting the unidirectional flow pattern and notable occurrence of reverse flow. This reverse flow has a substantial impact on the thrust force, resulting in a decrease in its value. This visual representation provides vital information on how the sail interacts with a fluid medium to generate thrust.

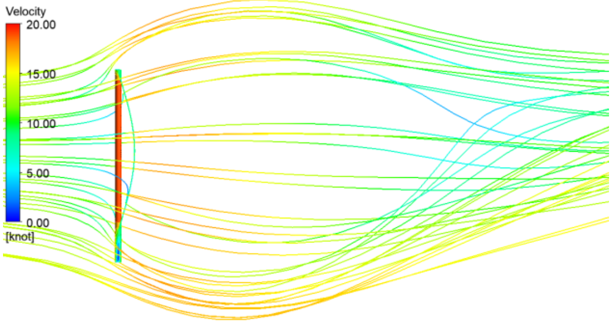


Figure 6. Fluid flow around sail model 2

Analyzing and optimizing fluid dynamics presents designers and engineers with the opportunity to improve sail models, resulting in increased effectiveness in harnessing wind power for propulsion. Enhanced efficiency can be achieved through the insights gained from Figure 7, which highlights areas in which improvements can be made. By optimizing these dynamics, sail models can be optimized, enabling increased overall efficiency and effectiveness in utilizing wind power for propulsion.

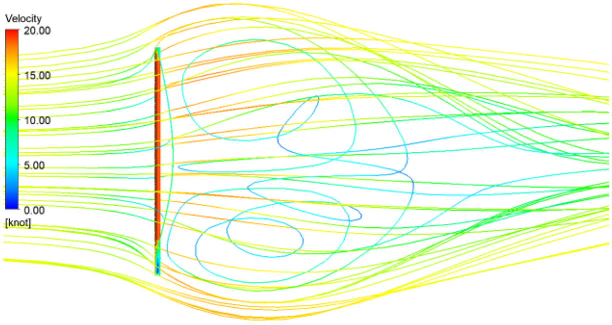
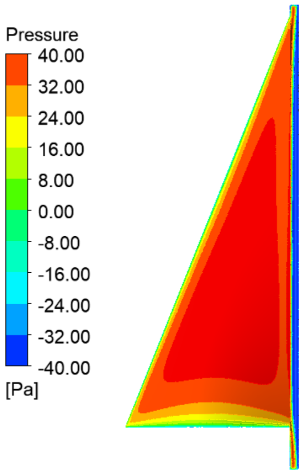
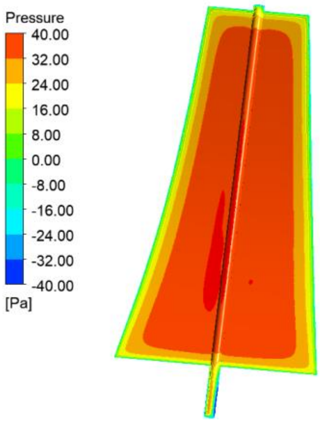


Figure 7. Fluid flow around sail model 3

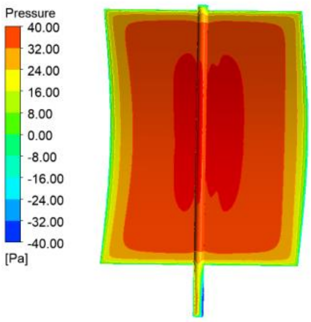
In terms of the same sail area, sail model 1 had a fairly large pressure area generated by the wind and almost the same pressure area as model 3. This large pressure area produces a high thrust force on the sail. Furthermore, model 2 has a relatively smaller pressure area when compared to the other models, as seen in figure 8. This shows that even though the screen area is the same, the pressure distribution in model 2 is more focused and efficient than in the other models.



(a) Model 1



(b) Model 2



(c) Model 3

Figure 8. Pressure distribution of sails surface

Thus, differences in the distribution of the pressure areas in each sail model can affect the sail's performance in responding to the wind and producing the required thrust. Therefore, selecting the correct sail model is very important to ensure optimal sailing efficiency and performance.

IV. CONCLUSION

This study demonstrates the effectiveness of Computational Fluid Dynamics (CFD) in simulating the thrust force on sails. The results show that sail model 1 has the highest thrust force, measuring 240.2 N. Models 3 and 2 generate thrust forces of 238.9 N and 227.9 N, respectively. The fluid flow conditions around sail model 1 and screen model 2 provide valuable insights into how the sail interacts with the fluid environment to generate thrust. By understanding and optimizing these fluid dynamics, designers and engineers can enhance the performance of sail models and improve their efficiency in harnessing wind power for propulsion.

The pressure areas generated by the wind in sail models 1 and 3 were similar, producing a high thrust force. However, model 2 has a smaller pressure area, indicating that the pressure distribution in model 2 is more focused and efficient than that in the other models. This indicates that differences in the pressure areas in each sail model can affect the sail's performance in responding to the wind and producing the required thrust. Therefore, selecting the correct sail model is crucial for ensuring optimal sailing efficiency and performance.

AKNOWLEGMENT

The researchers express their gratitude to Universitas Pattimura for all contributions to this study.

REFERENCES

1. A. O. Samili, R. Umar, and A. Malik, "Mapping of Socioeconomic Life of Fishermen Community in Maitara Island Tidore Kepulauan City in Maluku Utara Province," *UNM Geographic Journal*, vol. 1, no. 1, p. 17, Sep. 2017, doi: 10.26858/ugj.v1i1.5268.
2. J. F. Sopamena and A. E. Pattiselanno, "Women and Household Livelihood (Case Study on Villages Around Private Plantation in Seram Island, Maluku Province)," *IOP Conf Ser Earth Environ Sci*, vol. 1153, no. 1, p. 012041, May 2023, doi: 10.1088/1755-1315/1153/1/012041.
3. K. R. Ananda, M. Machmud, and H. Hasan, "Revenue and Operational Costs Impact on Net Profit: A Quantitative Analysis," *Indonesian Journal of Law and Economics Review*, vol. 18, no. 3, Nov. 2023, doi: 10.21070/ijler.v18i3.987.
4. X. XIAO and S. HUANG, "Evolutionary game analysis of emision reduction for fishing boats using biodiesel," *Journal of Fisheries of China*, vol. 37, no. 10, p. 1585, 2013, doi: 10.3724/SP.J.1231.2013.38674.
5. kompas.com, "Terkatung 12 Hari di Laut Natuna, Kapal Nelayan Selamat berkat Layar Terpal." Accessed: May 07, 2024. [Online]. Available: https://regional.kompas.com/read/2020/08/07/09150251/terkatung-12-hari-di-laut-natuna-kapal-nelayan-selamat-berkat-layar-terpal
6. N. Setiyobudi *et al.*, "Sail technology on fishing vessel for blue swimming crab catching application - A review," *IOP Conf Ser Earth Environ Sci*, vol. 1166, no. 1, p. 012026, May 2023, doi: 10.1088/1755-1315/1166/1/012026.
7. S. O'Connor, S. Kealy, L. Wattimena, A. Black, M. Husni, and Mahirta, "Sailing the deep blue sea: The rock art of Wetang Island, Maluku Barat Daya, Indonesia," *The Journal of Island and Coastal Archaeology*, pp. 1–28, Jan. 2022, doi: 10.1080/15564894.2021.1991056.
8. E. A. Dahle and D. Myrhaug, "Risk analysis applied to capsize of fishing vessels," *Marine Technology and SNAME News*, 1995.
9. T. Kuroda, A. Matsuda, H. Hashimoto, and R. Shigehiro, "Relation Between Freeboard and Capsizing Risk for Fishing Vessels," *Proceedings of the 6th International Conference on Stability of Ships and Ocean Vehicles (STAB2003)*, pp. 665–676, 2003.
10. J. O. de Kat and J. R. Paulling, "Simulation of ship motions and capsizing in severe seas," in *Transactions - Society of Naval Architects and Marine Engineers*, 1989.
11. Arif Winarno, Agung Sugeng Widodo, Gatot Ciptadi, and Atiek Iriany, "The The Effect of Sail Layout on Fishing Vessels Hydrodynamics in The North Coast of Java Using Computational Fluids Dynamic," *CFD Letters*, vol. 16, no. 1, pp. 107–120, Nov. 2023, doi: 10.37934/cfdl.16.1.107120.

12. V. Bischoff, "Viking-Age Sails: Form and Proportion," *Journal of Maritime Archaeology*, vol. 12, no. 1, pp. 1–24, Apr. 2017, doi: 10.1007/s11457-016-9167-2.
13. E. Yiu, "Traditional knowledge in the management of seascapes," in *Routledge Handbook of Seascapes*, London: Routledge, 2022, pp. 369–384. doi: 10.4324/9780429273452-29.
14. D. A. Utari, M. B. Rahmat, I. P. A. Wibawa, A. Indartono, E. Setijadi, and S. W. Mudjanarko, "Evaluation of Radar Reflector Design for Traditional Fishermen in Banyuwangi," *THE SPIRIT OF SOCIETY JOURNAL*, vol. 5, no. 1, pp. 74–79, Sep. 2021, doi: 10.29138/scj.v5i1.1557.
15. M. R. Zoolfakar, M. S. S. A. Shukur, and N. H. Suhainai, "A Portable Hydro Generator for Fishing Boats," 2022, pp. 93–105. doi: 10.1007/978-3-030-92964-0_10.
16. P. I. Santosa and I. K. A. P. Utama, "An Investigation into Hybrid Catamaran Fishing Vessel: Combination of Diesel Engine, Sails and Solar Panels," *IPTEK Journal of Proceedings Series*, vol. 0, no. 1, May 2014, doi: 10.12962/j23546026.y2014i1.383.
17. H. J. Richter, K. C. Horrigan, and J. B. Braun, "Computational Fluid Dynamics for Downwind Sails," in *Day 1 Mon, March 03, 2003*, SNAME, Mar. 2003. doi: 10.5957/CSYS-2003-002.
18. A. Windyandari, H. Dwi, and S. Suharto, "Design and performance analysis of B-series propeller for traditional purse seine boat in the north coastal region of Central Java Indonesia," *Journal of Applied Engineering Science*, vol. 16, no. 4, pp. 494–502, 2018, doi: 10.5937/jaes16-18506.
19. M. Ridwan, "PENINGKATAN KINERJA SISTEM PROPULSI KAPAL PENANGKAP IKAN TRADISIONAL TYPE PURSEINE 30 SD 90 GT MENGGUNAKAN SISTIM PROPULSI HYBRID," *Gema Teknologi*, vol. 16, no. 2, p. 106, Apr. 2011, doi: 10.14710/gt.v16i2.22136.
20. F. R. Menter, "Two-equation eddy-viscosity turbulence models for engineering applications," *AIAA Journal*, vol. 32, no. 8, pp. 1598–1605, 1994, doi: 10.2514/3.12149.
21. F. R. Menter, "Zonal two equation κ-ω turbulence models for aerodynamic flows," in *AIAA 23rd Fluid Dynamics, Plasmadynamics, and Lasers Conference, 1993*, 1993, pp. 1–21.
22. ANSYS, "ANSYS® Academic Research," *ANSYS CFX-Solver Modeling Guide*, 2013.
23. E. Bayraktar, O. Mierka, and S. Turek, "Benchmark computations of 3D laminar flow around a cylinder with CFX, OpenFOAM and FeatFlow," *International Journal of Computational Science and Engineering*, vol. 7, no. 3, pp. 253–266, 2012, doi: 10.1504/IJCSE.2012.048245.
24. C. L. Ford and P. M. Winroth, "On the scaling and topology of confined bluff-body flows," *J Fluid Mech*, no. 876, pp. 1018–1040, 2019, doi: 10.1017/jfm.2019.583.
25. J. D. Anderson, *Computational Fluid Dynamics: The Basics with Applications*. in Editions: Mechanical Engineering. New York, USA. pp. 526-532: McGraw-Hill, 1995. [Online]. Available: https://books.google.co.id/books?id=phG_QgAACAAJ