2301-9069 (e)
1829-8370 (p)

Kapal: Jurnal Ilmu Pengetahuan dan Teknologi Kelautan
(Kapal: Journal of Marine Science and Technology)

journal homepage : http://ejournal.undip.ac.id/index.php/kapal

Ship Propeller Design using Open-Source Codes based on Lifting Line Theory

Erik Sugianto[1)*)], Niki Veranda Agil Permadi[2)], Ahmad Darori Hasan[3)]

[1)] Department of Marine Engineering, Universitas Hang Tuah Surabaya, Indonesia
[2)] Department of Marine Engineering, Shipbuilding Institute of Polytechnic Surabaya, Indonesia
[3)] Department of System and Naval Mechatronic Engineering, National Cheng Kung University, Taiwan
[*)] Corresponding Author: erik.sugianto@hangtuah.ac.id

Article Info

Keywords:
Lifting line theory;
Propeller;
Open-source code;
Propeller performance;

Article history:
Received: 04/05/2025
Last revised: 25/06/2025
Accepted: 25/06/2025
Available online: 25/06/2025
Published: 30/06/2025

DOI:
https://doi.org/10.14710/kapal.v22i2.72927

Abstract

The design of a ship's propeller is very important as it directly affects the fuel efficiency, speed, and stability of the ship. Commonly, propellers are designed using expensive commercial software. This research aims to design a ship propeller using open-source code based on lifting line theory and using MATLAB application. The ship data used is a container ship with a length of 397 meters and a width of 56 meters. The propeller design results were propeller performance such as design performance, induced velocity, inflow angle, expanded blade, blade thickness, lift coefficient, performance curve, 2-D and 3-D outlines. A qualitative and quantitative comparison was conducted between a real-world manufactured propeller, a redesigned propeller developed using open-source software (OpenProp), and a commercial design tool (PropCAD). The comparison reveals that while the overall geometry and blade shape of all three propellers are similar, consisting of 6 blades with comparable radial profiles, key differences emerge in the expanded area ratio (EAR), skew angle, and surface modeling quality. The OpenProp design features an EAR of 1.0876 and a high skew angle of 39.9°, indicating an emphasis on hydrodynamic efficiency and cavitation mitigation. In contrast, the PropCAD model presents a slightly lower EAR of 1.077 with a more moderate skew angle of 20.5°, offering a balanced compromise between performance and manufacturability. This distinction highlights a potential optimization opportunity and demonstrates the capability of the open-source design approach to approximate real-world propeller characteristics with high fidelity, while also offering flexibility for further refinement. In summary, the findings suggest that the open-source design approach can approximate real-world propeller characteristics with high fidelity and provide flexibility for iterative optimization.

1. Introduction

Proper propeller design and selection is critical as it directly affects the fuel efficiency, speed, and manoeuvring performance of the vessel. A suitable propeller can also reduce engine workload, extend operational life, and lower maintenance costs [1-2]. Ship propeller design plays an important role in determining ship performance. Propellers have an effect on reducing vibration and noise, and increasing ship speed and manoeuvrability [3-4]. The propeller design process requires high precision and in-depth technical analysis. Small errors in design can have a major impact on ship operations, both in terms of economy and safety [5-6].

Current ship design research increasingly focuses on the integration of green and digital technologies to improve energy efficiency and reduce environmental impact [7]. One major trend is the development of eco-friendly propulsion, such as biomimicry-based propellers inspired by whale fins to reduce turbulence and underwater noise [8]. In addition, the use of lightweight and corrosion-resistant composite materials is gaining popularity in propeller design as they reduce vessel weight while increasing durability. Recent research has also utilised artificial intelligence (AI) and Computational Fluid Dynamics (CFD) to optimise blade shape, pressure distribution and hydrodynamic efficiency, such as the study about machine learning to speed up design iterations with high accuracy [9].

On the other hand, modern ship design also adopts the concept of autonomous and hybridised propulsion systems. Research for autonomous surface vehicles (ASVs) explores propellers with fast response characteristics and efficiency at variable speeds [10]. Meanwhile, innovations such as ducted propellers and hybrid-electric propulsion systems are being tested for commercial vessels to minimise carbon emissions. Multidisciplinary approaches - combining cavitation analysis, vibration reduction and simulation of real sea conditions - have been key in recent research, for example in the work about combined blade geometry modification with acoustic analysis to reduce underwater noise pollution. Thus, current research pursues not only technical performance, but also sustainability and adaptation to global environmental regulations [11].

Recent ship design research is increasingly utilising open-source tools such as OpenFOAM, SU2, and QBlade to perform low-cost but high-accuracy simulations and optimisations . Researchers are using these community-based platforms to analyse hydrodynamic characteristics, cavitation and propeller efficiency in a more transparent and collaborative manner [12]. This approach not only reduces dependence on commercial software, but also enables replication and further development by other researchers.

The use of open source code and software in designing ship propellers provides various advantages. In addition to lower costs because there is no need to pay for expensive licences, open source software also provides high flexibility in development and modification according to specific user needs [13-14]. The active user community also enables collaboration and solution sharing, which is very helpful in solving complex design challenges [15]. Thus, the utilization of open-source codes and software represents an efficient, cost-effective, and forward-looking alternative to conventional approaches in supporting the development of optimized ship propeller designs. Despite its potential, the application of open-source tools in propeller design remains relatively limited within the maritime engineering community. This research contributes a novel perspective by demonstrating how open-source platforms, specifically OpenProp, can be effectively leveraged to replicate, analyze, and even enhance real-world propeller performance. As computer technology continues to advance rapidly, it paves the way for a paradigm shift from traditional empirical design methods to more accessible, analytical, and numerical approaches. This study not only bridges that gap but also validates the practicality of open-source solutions as viable tools for modern, iterative propeller design processes.

In this study, the ship data used is a container ship with a length of 397 metres and a width of 56 metres. Open code is obtained from Dartmouth University and the open software used is Matlab academic free licence. Propeller data used for input are number of blades, rotation speed, rotor diameter, thrust, ship speed, hub diameter, fluid density, radial panels, and chordwise. The results obtained are design performance, induced velocity, inflow angle, expanded blade, blade thickness, lift coefficient, performance curve, 2-D and 3-D outlines. Then validation is done by comparing the results obtained from running open code and software with a real propeller from a container ship.

2. Method

2.1. Lifting Line Theory in OpenProp Codes

Developed in MATLAB, OpenProp is an open-source toolkit intended for the design of propeller and turbine [16]. In OpenProp, the numerical model is derived from moderately-loaded lifting line theory, wherein a propeller blade is modeled as a lifting line with its trailing vorticity aligned with the local velocity field, composed of both free-stream and induced component [17].

A vortex lattice method is used to evaluate induced velocities, where helical vortex filaments are emitted from specific blade sections. The blade is modeled as a set of individual radial segments, each with its own 2D profile. The total aerodynamic loading is calculated by summing the contributions from each section along the span of the blade [18].

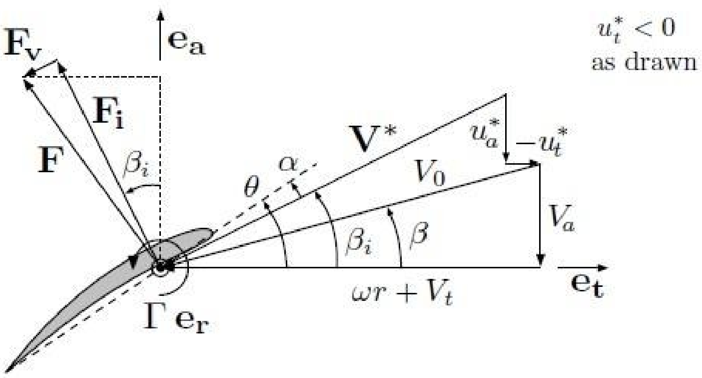


Figure 1. Propeller Velocity-Force diagram [18]

Figure 1 presents a velocity-force diagram illustrating the flow velocities and corresponding force components (per unit span) acting on a two-dimensional blade section in both axial e_a and tangential e_t directions. With the propeller shaft rotating at angular velocity ωe_a , the perceived tangential inflow at radius r becomes $-\omega\, e_t$. The figure further shows inflow velocities, $V_a = -V_a\, e_a$ and $V_t = -V_t e_t$, induced axial and tangential velocities, $u_a^* = -u_a^* e_a$ and $u_t^* = -u_t^* e_t$. Notably, $u_t^* < 0$ during normal propeller operation, hence it effectively aligned with the u_t^* direction. The resultant inflow velocity V^* is also represented, along with its magnitude and pitch angle as written in Eq. 1 adn Eq. 2.

$$V^* = \sqrt{(V_a + u_a^*)^2 + (\omega r + V_t + u_t^*)^2} \tag{1}$$

$$\beta_i = arctan\left(\frac{V_a + u_a^*}{\omega r + V_t + u_t^*}\right) \tag{2}$$

Additional elements shown in Figure 1 include the angle of attack (α), the pitch angle of the blade ($\theta = \alpha + \beta_i$), the circulation in the tangential direction (Γe_t), the inviscid lift force ($F_i = \rho V^* \times (\Gamma e_t)$) from Kutta-Joukowski theory, and viscous drag force (F_v) acting in the direction of V^*. Assuming all Z blades are geometrically identical, the total thrust and torque generated by the propeller are calculated using Eq. 3 and Eq. 4, respectively.

$$T = Z \int_{r_h}^{R} [F_i \cos \beta_i - F_v \sin \beta_i] dr (\hat{e}_a) \tag{3}$$

$$Q = Z \int_{r_h}^{R} [F_i \sin \beta_i - F_v \cos \beta_i] r dr (-\hat{e}_a) \tag{4}$$

where $F_i = \rho V^* \Gamma$ and $F_v = 1/2 \rho (V^*)^2 C_D c$ define magnitudes of the inviscid and viscous force per unit radius,. The fluid density is denoted by ρ , C_D represents the drag coefficient for the section, c is the chord length, and r_h and R correspond to the hub and blade tip radius, respectively. The power consumed by the propeller is determined as the product of torque and rotational speed as written in Eq. 5.

$$P = Q\omega \tag{5}$$

A condition where $P > 0$ indicates that power is being delivered to the fluid by the propeller, with torque acting against the motion. The useful output power is defined as the product of thrust T and ship speed V_s (i.e. free-stream speed). The efficiency of the propeller is then given by Eq. 6.

$$\eta = T V_s / Q\omega \tag{6}$$

2.2. OpenProp Features

OpenProp is designed as a GUI-based tool to support the design of propellers, with its underlying codebase developed at Dartmouth University [19]. In the main interface, presented in Figure 2, essential input parameters including diameter and rotation speed ranges are specified by the user. Default values for blade design variables, such as chord length, thickness, and skew, are provided, although modifications can be made to meet individual design goals. Once all inputs have been defined, the software is executed using the "Run" button, resulting in the generation of propeller geometry and the analysis of its performance.

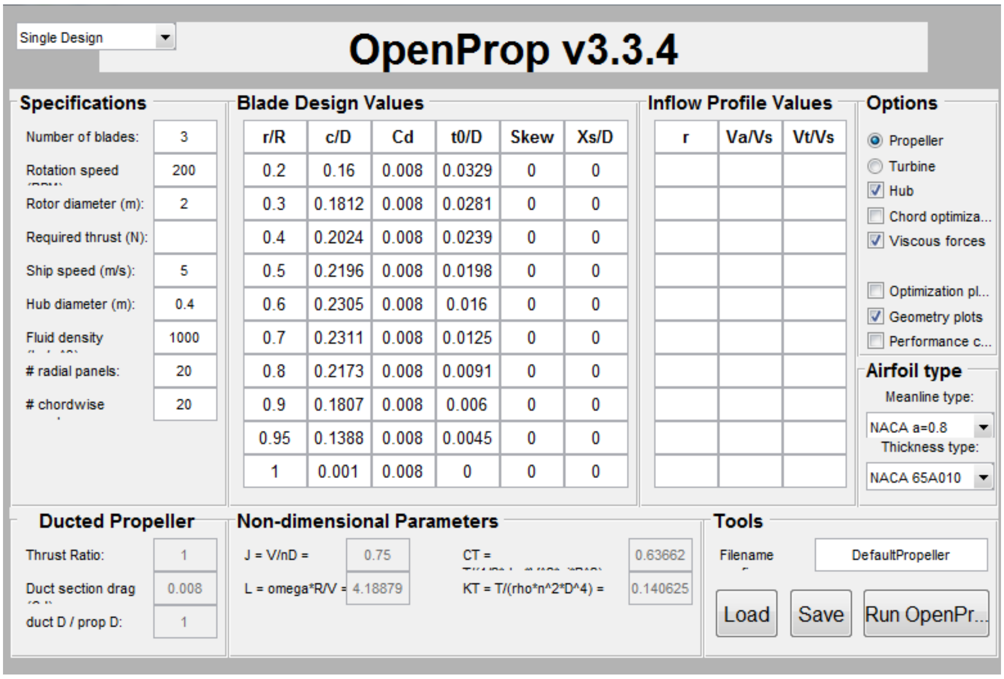


Figure 2. Main User Interface of OpenProp (Single Design Mode)

In OpenProp, input parameters, propeller design configurations, geometric data, and operating conditions are managed through structured data objects. The data flow of the OpenProp algorithm is illustrated in Figure 3. For an individual propeller, specifications such as diameter, rotational velocity, and blade number can be set, as demonstrated in Figure 2. The optimizer module is used to identify the most efficient design based on the provided inputs. This optimized design can then be subjected to off-design performance evaluation via the analyser module. Additionally, the crafter module is responsible for generating the three-dimensional geometry and preparing the necessary files for rapid prototyping.

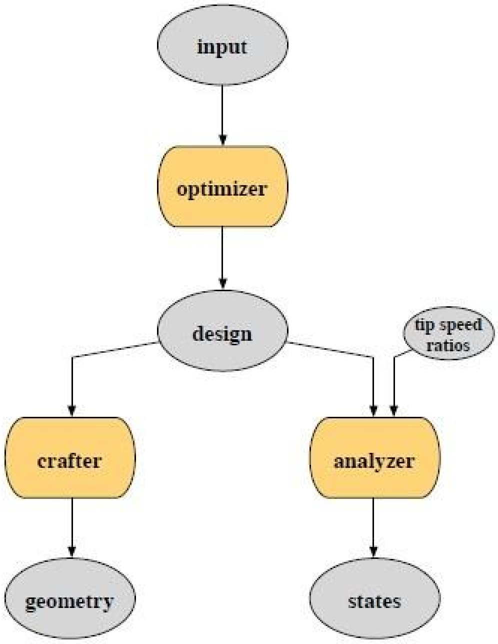


Figure 3. OpenProp Data Flow [18]

In addition to supporting single-design configurations, OpenProp offers functionality for conducting parametric studies. Such studies are generally employed to identify the most efficient propeller for a given set of operational conditions. While the single-design mode focuses on generating 2D and 3D geometries and detailed performance calculations, the parametric study uses required thrust and vessel speed as primary inputs. The output from the parametric study, namely the optimal propeller type, serves as the initial input for further refinement in the single-design module. The input interface for the parametric study is illustrated in Figure 4.

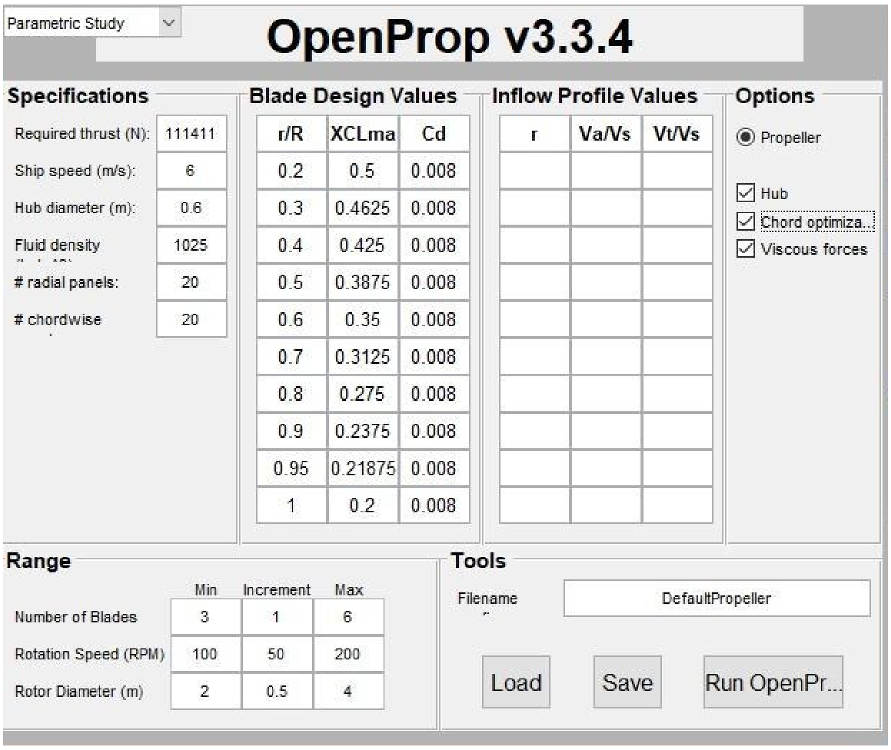


Figure 4. Parametric Study of OpenProp

2.3. Ship and Propeller Data

The Emma Maersk, a post-Panamax class container vessel, is selected as the case study for this propeller design analysis. Propellers are used on various sizes of small vessels, such as garbage collection vessels and speedboats, as well as large vessels, such as the container ship Emma Marsk [20-21]. Relevant ship and propeller specifications are summarized in Table 1 [22]. Although detailed technical data regarding the propeller are limited, several sources provide visual references and partial information. According to these sources, the vessel is equipped with a six-bladed propeller, featuring an overall diameter of 9.6 meters and operating at a rotational speed of 102 revolutions per minute (rpm).

Table 1. Ship and propeller data [22]

Variable	Value
Type	Container Ship
LOA	397.70 m
LWL	382.40 m
B	56.40 m
Max Draught (T)	15.5 m
Block Coefficient (C_B)	0.7338
Max Speed	24.5 knots
Max TEU Capacity	15,500 TEUs
Deadweight	152.800 ton
Power Output	80.080 kW
Gross Tonnage	170.794 ton
Number of Propellers Blade	6
Propeller Diameter	9.6 m
Propeller Rotation	102 rpm

In this study, the principal specifications listed in Table 1 are utilized as input parameters for the OpenProp software. When operating in single-design mode, the following data are required: the number of propeller blades, propeller diameter, rotational speed (rpm), hub diameter, thrust, ship speed, and water density. To determine the thrust input, the following Taylor wake fraction and efficiency assumptions are applied:

1) Total propulsive efficiency (η_p) = 0.58
2) Hull efficiency (η_h) = 1.01
3) $w_T = 0.50C_B - 0.05 \; = 0.3169$

Using the total brake power (BHP) of 80,080 kW and the ship speed of 12.6 m/s (equivalent to 24.5 knots), the thrust (T) is calculated using Eq. 7. The final input values are summarized in Table 2. These values are then used for a single design process in OpenProp GUI as shown in Figure 5.

$$T = \frac{THP}{V_A} = \frac{THP}{(V_S - \; w_T \, V_S)} = \frac{EHP/\eta_h}{(V_S - \; w_T \, V_S)} = \frac{(BHP \; \times \; \eta_p \,)/\eta_h}{(V_S - \; w_T \, V_S)} \tag{7}$$

Table 2. Input Data for OpenProp Codes

Input	Value
T	5,341,791.96 N
Dprop	9.6 m
Dhub (18% Dprop)	1.728 m

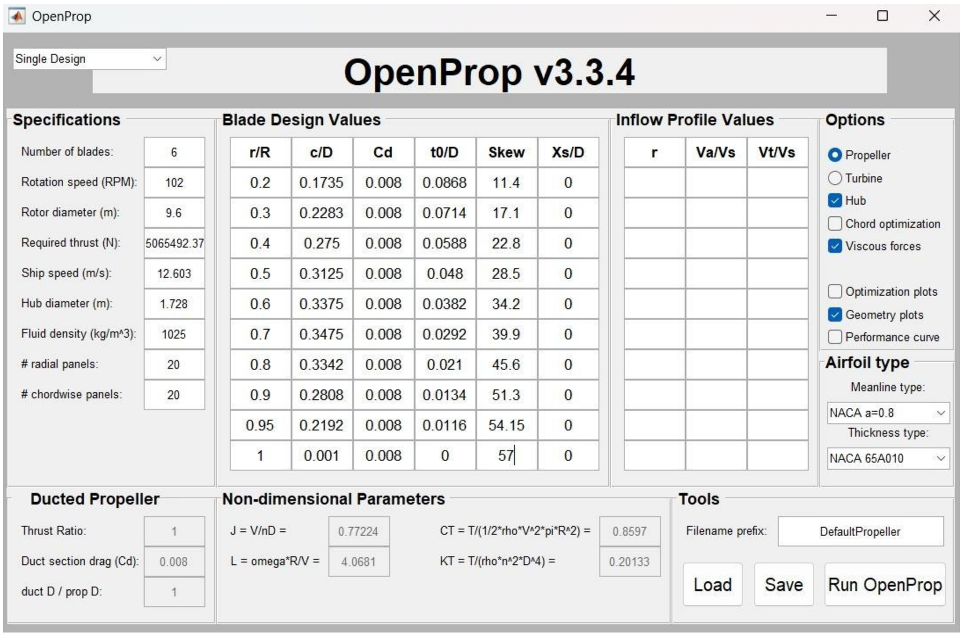


Figure 5. Input Single Design in OpenProp

3. Results and Discussion

3.1. Propeller Performance

This research focuses on designing ship propellers using open-source codes that implement lifting line theory [16-18]. The results show that this method is able to produce propeller designs with detailed performance characteristics, including induced velocity distribution, inflow angle, and expanded blade shape. In addition, the blade thickness and lift coefficient are also accurately calculated, enabling a comprehensive evaluation of the propeller's performance before production. The principal data to OpenProp software with single design mode. The global results are shown in Figure 6.

One of the key limitations of OpenProp lies in its input parameter structure, which differs significantly from commercial propeller design software. Unlike tools such as PropCAD that allow direct input of critical design parameters like Expanded Area Ratio (EAR) and Pitch Ratio (P/D), OpenProp does not provide straightforward control over these values. Instead, EAR and pitch emerge as indirect outputs that are shaped by other inputs such as blade loading coefficients, advance ratio, and thrust requirements. As a result, achieving a specific target EAR or P/D ratio often requires trial-and-error adjustments and iterative tuning of secondary parameters.This indirect approach can limit design precision and make it more difficult to replicate or modify existing propeller geometries, particularly when the designer is working from known specifications. While OpenProp is powerful for exploring performance trends and generating baseline designs, it lacks the parametric flexibility and direct control typically expected in production-oriented design environments.

The resulting propeller design also includes a performance curve that illustrates propulsion efficiency over a range of operating conditions. This research not only provides numerical analysis but also visual representation through 2-D and 3-D outlines, facilitating interpretation of the propeller blade geometry. Thus, the Lifting Line Theory-based approach and open-source code could be effective in producing an optimised propeller design, while providing an accessible tool for the development of more efficient ship propulsion [16-18].

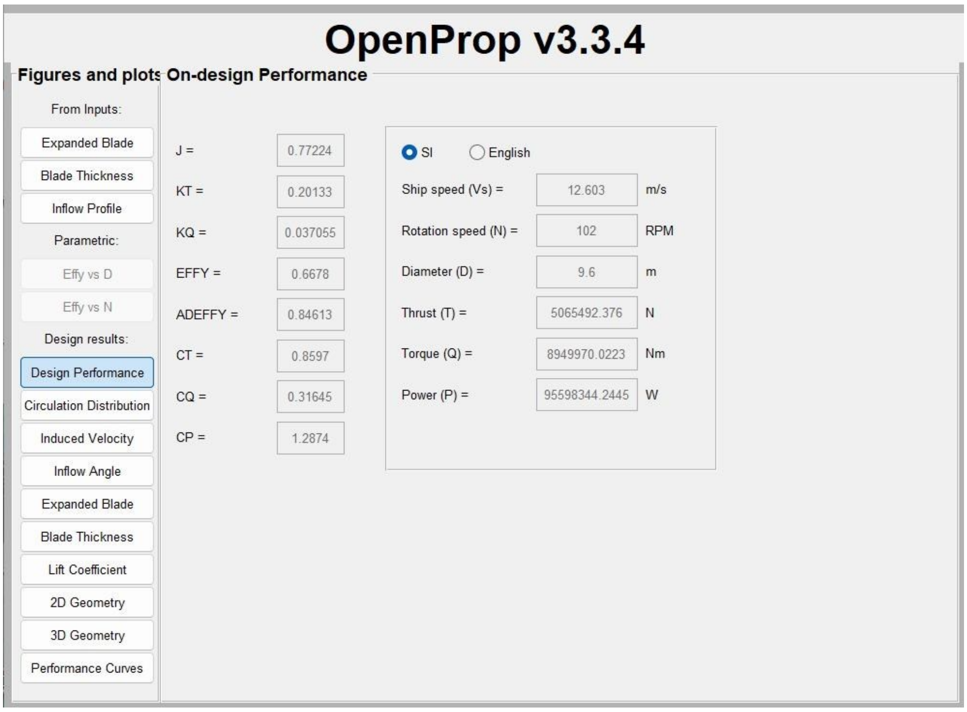


Figure 6. Result of Design Parameter from OpenProp

The results show that the induced velocity distribution of the designed propeller varies significantly along the blade (Figure 7), with the highest velocity occurring at the blade tip region due to the blade tip vortex effect. A symmetrical and controllable induced velocity distribution is proven to reduce cavitation and improve overall propeller performance, making it a critical consideration in the design optimization process [1,3]. This study reveals that uneven induced velocity can affect propulsion efficiency, which needs to be optimized through adjusting the inflow angle distribution (Figure 8) and blade shape to reduce energy loss.

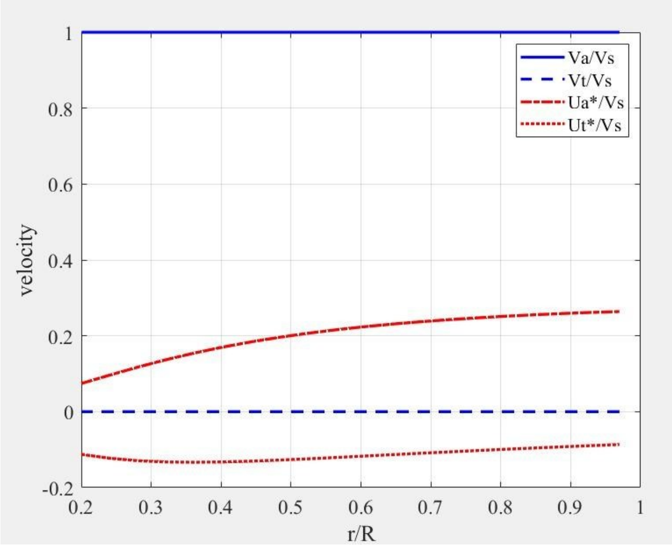


Figure 7. Result of Induced Velocity

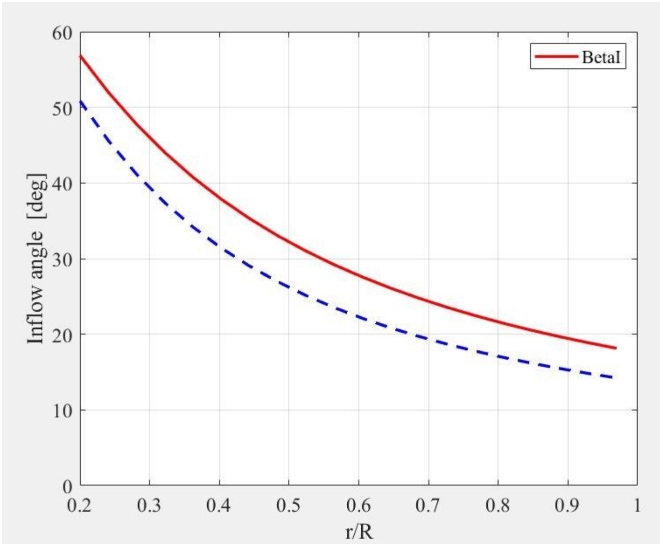


Figure 8. Inflow Angle

Furthermore, the resulting expanded blade shape has non-uniform variations in chord length and pitch along the blade, with the widest area being around 70% of the blade length from the hub centre to optimize lift distribution (Figure 9) [5]. Besides that, the blade thickness varies strategically along the blade, with the maximum thickness being near the hub (10-20% of the radius) which then thins progressively to 40-50% of the initial thickness at the tip to balance structural strength and hydrodynamic efficiency (Figure 9). Thicker blade thickness profile at the base (root) region plays an important role in resisting structural loads, while the gradual thinning towards the blade tip reduces drag and cavitation risk, thereby improving propulsion efficiency [8].

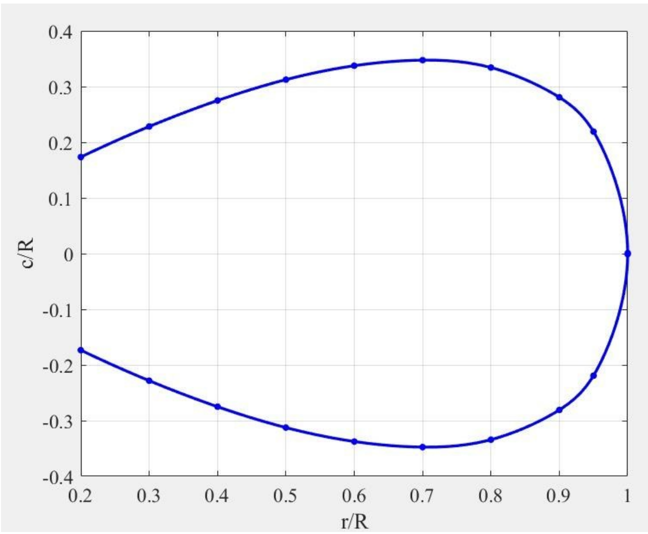


Figure 9. Expanded Blade

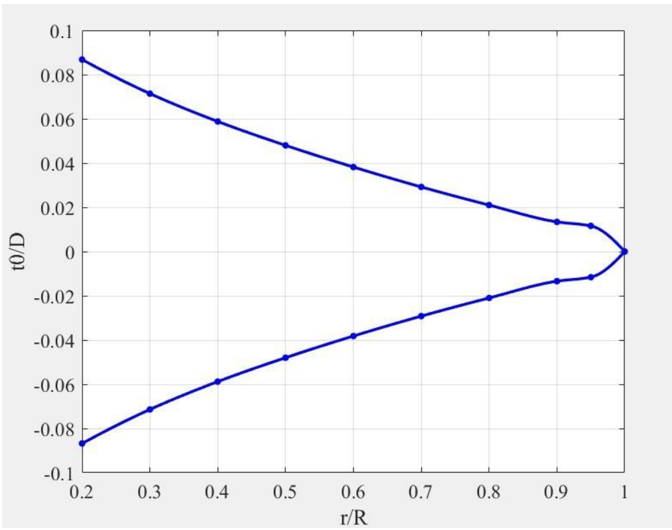


Figure 10. Result of Blade Thickness

The increase in induced velocity is also directly proportional to the increase in lift coefficient along the blade. However it needs to be controlled to avoid the flow separation causing the decrease in efficiency. The results show that the lift coefficient varies significantly along the propeller blade, with the highest value located at the mid-span region due to the optimal combination of angle of attack and flow velocity. Additionally, the progressive changes in blade thickness and chord length from the base to the tip of the blade have a direct impact on the lift coefficient distribution, where areas of thinner thickness tend to produce higher lift coefficients (Figure 11). The research found that while an increase in lift coefficient can boost propulsion efficiency, excessively high values near the blade tip can potentially trigger cavitation, requiring optimisation of the blade shape to achieve the ideal balance of performance [9].

Figure 12 represents the resulting 2D blade profiles. The result shows that the camber and thickness-to-chord ratio distributions vary along the blade radius, with aerofoil shapes which are more curved (higher camber) in the mid-span region to increase lift coefficient, and flatter near the blade tip to reduce tip vortex losses. The 2D blade design with a combination of modified NACA series at various section radii is able to generate hydrodynamic efficiency due to optimization of pressure distribution and reduction of flow separation along the blade [16-18]. Figure 13 shows the resulting 3D blade shape. It has twist angle and blade sweep distributions that vary dynamically along the blade, with pitch angles that are steeper near the hub and flatter near the blade tip. The performance of the resulting propeller design is presented in Figure 14. The optimal efficiency of the generated propeller is 75% at an advance ratio of 0.8-0.9.

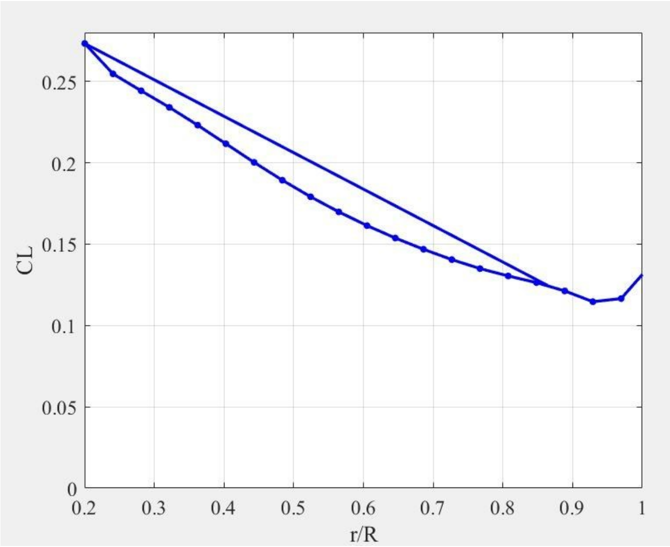


Figure 11. Lift Coefficient

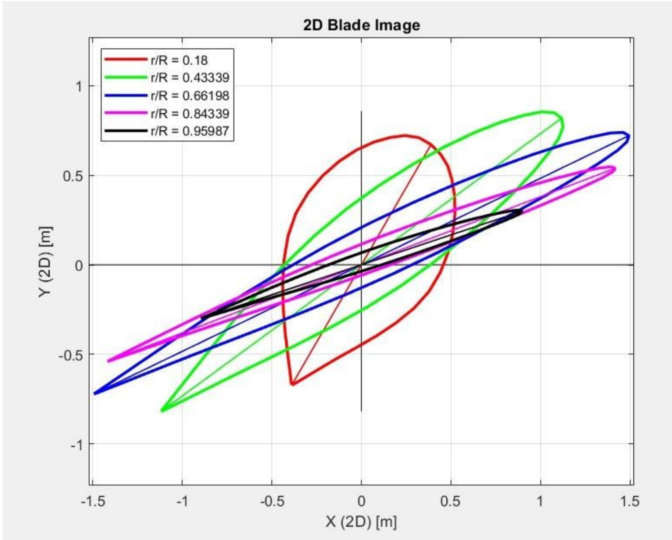
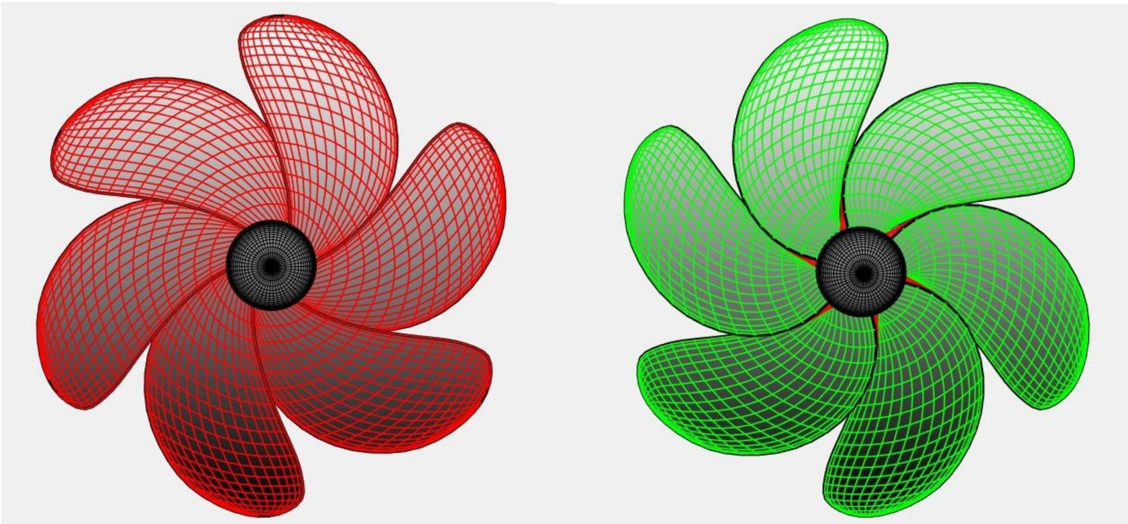


Figure 12. 2D Blade Geometry



(a) (b)

Figure 13. 3D Geometry of OpenProp-Generated Model; (a) Face, (b) Back

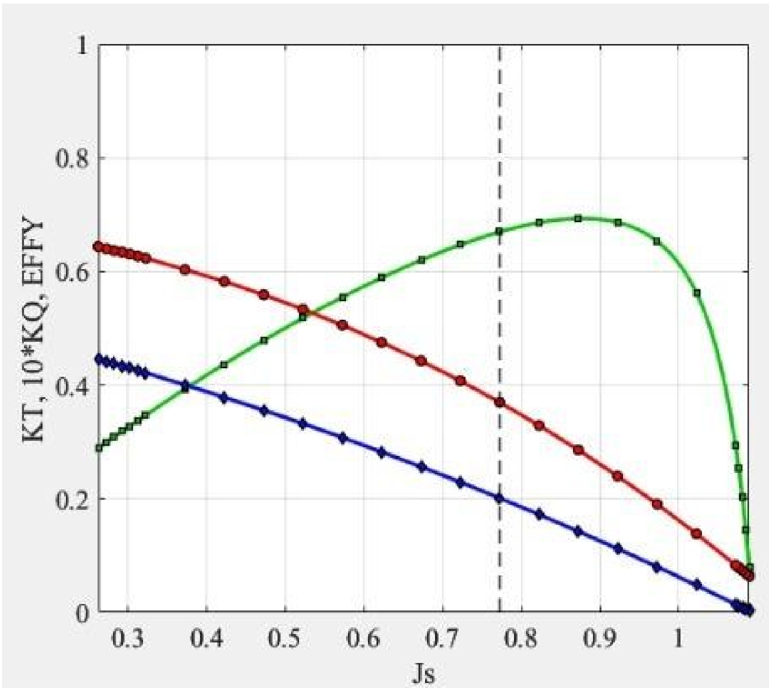
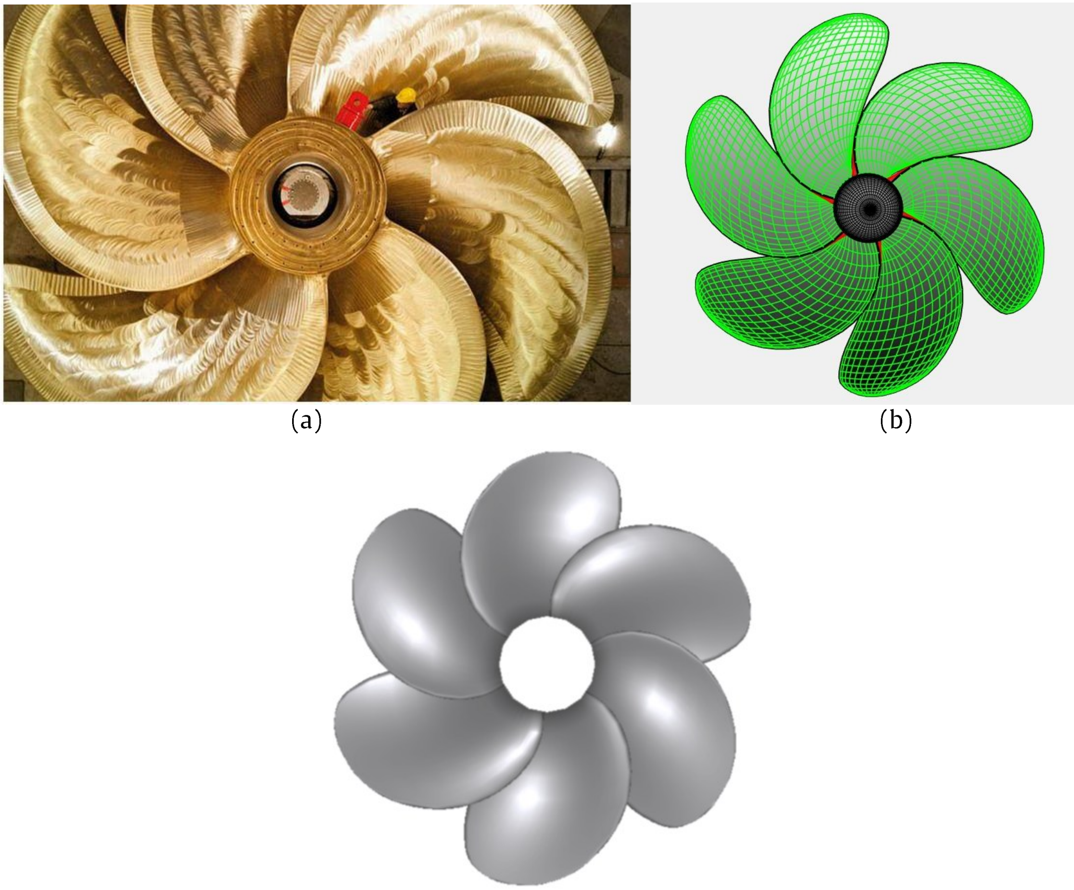


Figure 14. Performance Curve of OpenProp-Generated Model

3.2. Qualitative Comparison between Real Propeller, Redesign Propeller (OpenProp), and Commercial Software (PropCad)

Figure 15 represents the qualitative comparison of the real propeller, redesigned propeller using OpenProp codes, and commercial software using PropCAD. It can be seen that the real and redesigned propellers are geometrically identical (the left figure is a real propeller and the right figure is a redesign propeller). However, there are some differences between the real and redesign propeller. The expanded area ratio (EAR) value of a real propeller ship is higher than the value generated by OpenProp. The redesigned propeller provides an efficiency of 0.6678, thrust coefficient (KT) of 0.20133, and torque coefficient (KQ) of 0.037055 at advance coefficient J = 0.77224. In summary, the lifting line codes in OpenProp can help us to find the optimum propeller geometry from a given design target. For this case unknown data of a propeller, such as EAR, can be solved by optimization in OpenProp. Hence, it provides optimal EAR at a given design target.



(a) (b) (c)

Figure 15. The Comparison of Original Propeller (a), Redesigned Propeller – OpenProp (b), and Commercial Software – PropCAD (c)

In addition, the comparison between three marine propeller designs, manufactured (real-world), OpenProp-generated, and PropCAD-generated model highlights distinct differences in detail, fidelity, and intended use. Figure 15 (a) represents an actual 6-bladed marine propeller, exhibiting highly contoured geometry with smooth curvature, skew, and camber optimized for hydrodynamic efficiency. The surface shows real-world manufacturing characteristics such as milling textures and polished finishes, suggesting precise control of blade thickness and trailing edge geometry. This propeller reflects a fully engineered product designed through iterative analysis, testing, and physical validation, likely used in commercial or naval applications.

In contrast, Figure 15 (b) shows a propeller designed using OpenProp, an open-source software developed for preliminary hydrodynamic analysis. While it captures basic parameters such as pitch distribution, blade area ratio, and camber variation, the geometry appears mesh-based and lacks the fine surface continuity seen in manufacturable designs. OpenProp is ideal for academic studies or initial performance estimations but requires further CAD processing for physical production. Figure 15 (c) illustrates a propeller modeled using PropCAD, a commercial software tool used in industrial applications. The surface appears smooth and CAD-accurate, with well-defined hub transitions and thickness profiles, indicating readiness for manufacturing and integration into CFD or CAM workflows. PropCAD supports detailed input of blade parameters following ISO standards, allowing designers to produce production-level propeller geometries with high accuracy and repeatability. Some quantitative design properties between open-soruce codes (OpenProp) and commercial software (PropCAD) are summarized in Table 3.

Table 3. Comparison of Propeller Design: Manufactured, OpenProp, and PropCAD

Parameter	Manufactured Propeller	OpenProp Design	PropCAD Model
Number of Blades	6	6	6
Expanded Area Ratio (EAR)	Not specified (real-world reference)	1.0876	1.077
Skew Angle	Estimated high (≥30°)	39.9°	20.5°
Surface Geometry	Real, complex contours with machining marks	Mesh-based, parametric contours	Smooth solid surface, CAD-accurate
Hub–Blade Transition	Very refined and realistic	Limited, less refined	Smooth and manufacturable
Manufacturing Readiness	Fully built and tested	Not manufacturing-ready	Ready for manufacturing and CAM export
Intended Use	Real-world commercial or naval usage	Academic or early-stage hydrodynamic design	Industrial or production-grade design
Software	–	OpenProp (open-source)	PropCAD (commercial)
CFD/CAM Compatibility	–	Requires additional CAD processing	Fully compatible with CFD/CAM workflows
Key Strength	Real-world validation and optimization	Flexible and quick conceptual design	High-accuracy design with ISO compliance

4. Conclusion

This research successfully designed a container ship propeller using open-source OpenProp codes based on lifting line theory in Matlab. The propeller design must meet thrust requirement and rotation speed. The design results from OpenProp codes include performance parameters such as induced velocity, flow angle, blade thickness distribution, lift coefficient, and propeller geometry visualised in 2D and 3D. The qualitative comparison shows the existing propeller and the resulting propeller from OpenProp are geometrically identical, although the expanded area ratio (EAR) of the original propeller is larger than the redesigned one. The findings indicate that open-source lifting line codes can serve as a cost-efficient alternative in the propeller design process. It was demonstrated that a propeller design generated through an open-source approach is functionally comparable to those produced using commercial tools. However, further improvements, particularly in optimizing the expanded area ratio, is still required to achieve design performance equivalent to that of commercial software solutions.

References

[1] G. Dubbioso, R. Muscari, F. Ortolani, and A. Di Mascio, "Numerical analysis of marine propellers low frequency noise during maneuvering. Part II: Passive and active noise control strategies," *Applied Ocean Research*, vol. 125, 103201, 2022, doi: https://doi.org/10.1016/j.apor.2022.103201

[2] A. Iswantoro, J. Raharjo, and Y. Iwangsa Sima, "Performance and Vibration Analysis of Electric Outboard Propulsion using Propeller Variations Based on Experiment," *Kapal: Jurnal Ilmu Pengetahuan dan Teknologi Kelautan*, vol. 21, no. 3, pp. 145-155, Oct. 2024, doi: https://doi.org/10.14710/kapal.v21i3.66599

[3] A. Winarno, G. A. N. S. Sakti, and E. Sugianto, "The Effect of Tip Clearance Kaplan Ducted Propeller in Offshore Supply Vessel (OSV) on Hydrodynamics," *Kapal: Jurnal Ilmu Pengetahuan dan Teknologi Kelautan*, vol. 21, no. 3, pp. 156-170, Oct. 2024, doi: https://doi.org/10.14710/kapal.v21i3.64772

[4] D. Wahyudi, A. N. Coutsar, and P. A. Nugroho, "The Effect of Speed On Bow Thruster Tunnel Acoustics Using Computational Fluid Dynamics Methods," *Kapal: Jurnal Ilmu Pengetahuan dan Teknologi Kelautan*, vol. 22, no. 1, pp. 45-51, Apr. 2025, doi: https://doi.org/10.14710/kapal.v22i1.69453

[5] P. Majumder, & S. Maity, "A critical review of different works on marine propellers over the last three decades," *Ships and Offshore Structures*, vol. 18, no.3, pp. 391-413, 2023, doi: https://doi.org/10.1080/17445302.2022.2058767

[6] N. V. A Permadi, E. Sugianto, "CFD Simulation Model for Optimum Design of B-Series Propeller Using Multiple Reference Frame (MRF)." *CFD Letters*, vol. 14, no. 11, pp. 22-39, 2022, doi: https://doi.org/10.37934/cfdl.14.11.2239

[7] J. U. Mba, "Advancing sustainability and efficiency in maritime operations: Integrating green technologies and autonomous systems in global shipping." International Journal of Science and Research Archive, vol. 13, no. 2, pp. 2059-2079, 2024, doi: https://doi.org/10.30574/ijsra.2024.13.2.2419

[8] H. Singh, "Survey of new energetic and eco-friendly materials for propulsion of space vehicles." *Chemical rocket propulsion: A comprehensive survey of energetic materials*, pp. 127-138, 2017, doi: https://doi.org/10.1007/978-3-319-27748-6_4

[9] M. M. Shora, H. Ghassemi, & H. Nowruzi, "Using computational fluid dynamic and artificial neural networks to predict the performance and cavitation volume of a propeller under different geometrical and physical characteristics." *Journal of Marine Engineering and Technology*, vol. 17, no. 2, pp. 59-84, 2018, doi: https://doi.org/10.1080/20464177.2017.1300983

[10] N. P Purba, I. Faizal, D.A. Valino, H.S. Kang, E. Sugianto, M.K. Martasuganda, ... & A. M. A. Khan, "Development of autonomous multi-sensor ocean monitoring instrument designed for complex archipelagic waters," *International Journal of Environmental Science and Technology*, vol. 20, no. 10, pp. 11451-11460, 2023, doi: https://doi.org/10.1007/s13762-023-04772-5

[11] D. Weintraub, J. Koppelberg, J. Köhler, and P. Jeschke, "Ducted fans for hybrid electric propulsion of small aircraft," *CEAS Aeronautical Journal*, vol.13, no.2, 471-485, 2022, doi: https://doi.org/10.1007/s13272-022-00573-7

[12] J. B. Kodman, B. Singh, and M. Murugaiah, "A Comprehensive Survey of Open-Source Tools for Computational Fluid Dynamics Analysis," *Jounal of Advanced Research in Fluid Mechanics and Thermal Sciences*, vol. 119, no. 2, pp. 123-148, 2024, doi: https://doi.org/10.37934/arfmts.119.2.123148

[13] K. Αναστασίου, Hydrodynamic analysis of a marine propeller in open water conditions using the computational code OpenFoam. University of West Attica, 2024, doi: http://dx.doi.org/10.26265/polynoe-7835

[14] M. Liu, H. J. Wang, and J. L. Zhao, "Technology flexibility as enabler of robust application development in community source: The case of Kuali and Sakai," *Journal of Systems and Software*, vol. 85, no. 12, pp. 2921-2928, 2012, doi: https://doi.org/10.1016/j.jss.2012.06.026

[15] S. Buckingham Shum, K. Aberer, A. Schmidt, S. Bishop, P. Lukowicz, S.Anderson, Y. Charalabidis, J. Domingue, S. de Freitas, I. Dunwell, B. Edmonds, F. Grey, M. Haklay, M. Jelasity, A. Karpištšenko, J. Kohlhammer, J. Lewis, J. Pitt, R. Sumner & D. Helbing, "Towards a global participatory platform: democratising open data, complexity science and collective intelligence," *The European Physical Journal Special Topics*, vol. 214, pp. 109-152, 2012, doi: https://doi.org/10.1140/epjst/e2012-01690-3

[16] B. Epps, J. Chalfant, R. imball, A. Techet, K. Flood, & C. Chryssostomidis, "OpenProp: An open-source parametric design and analysis tool for propellers, In Proceedings of the 2009 grand challenges in modeling & simulation conference, pp. 104-111, July, 2009

[17] W. Zhang, L. Wu, X. Jiang, X. Feng, , Y. Li, J. Zeng, & C. Liu, "Propeller design for an autonomous underwater vehicle by the lifting-line method based on OpenProp and CFD," *Journal of Marine Science and Application*, vol. 21, no. 2, pp. 106-114, 2022, doi: https://doi.org/10.1007/s11804-022-00275-w

[18] B. Epps, 2010. "OpenProp v2.4 Theory Document", Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=a50d4c0fd133226578b6e9d9977ec8bb19c221ef

[19] Dartmouth University. (2024). OpenProp 3.3.4 source code and documentation. http://engineering.dartmouth.edu/openprop/openprop1a2s3f976265E526hhl234l6tv487nyy4vy336v.htmlhttp://www.containership-info.com/vessel_9260421.html

[20] E. Sugianto, J-H. Chen, and N. V. A. Permadi, "Effect of Monohull Type and Catamaran Hull Type on Ocean Waste Collection Behavior Using OpenFOAM," *Water*, vol. 14, no. 17, 2022, doi: https://doi.org/10.3390/w14172623

[21] E. Sugianto, J-H. Chen, and N. P. Purba, "Cleaning technology for marine debris: A review of current status and evaluation," *International Journal of Environmental Science and Technology*, vol. 20, no. 4, pp. 4549-4568, 2023, https://doi.org/10.1007/s13762-022-04373-8

[22] O. K. Kinaci, A. Kukner, and S. Bal, "On Propeller Performance of DTC Post-Panamax Container Ship", *International Journal of Ocean System Engineering*, vol. 3, no.2, pp. 77-89, 2013, doi: http://dx.doi.org/10.5574/IJOSE.2012.3.2.077