Investigation of Propeller Performance KM. Dharma Kartika After The Installation of PBCF and Pre-Swirl Stator

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Abstract. The energy-saving device has been used to decrease fuel consumption on ships by increasing the efficiency of ship propulsion systems. Pre-swirl Stator (PSS) is an ESD that changes the axial and tangential speed component of the propeller's inflow which produces an additional gain of thrust by 4.7%. By using a pre-swirl stator, there is still an indication of a hub vortex developed behind the propeller. Another type of ESD is Propeller boss-cap fins which can decrease the development of hub vortex. A combination of PSS and PBCF ESD could gain another 1-1.5% of propeller efficiency rather than only using a pre-swirl stator and decrease hub-vortex. The goal of this study is to increase KM. Dharma Kartika IX propeller's performances by using PSS and PBCF. The computational fluid dynamics method was employed with variated angles of attack are 3° and 5° for PSS fin. The numerical approach is based on the Reynolds Averaged Navier Stokes (RANS) equation with k-ε as the turbulence model. The results showed a combination of PSS and PBCF gives an additional 5-30% of thrust, 5-30% of torque, and 0.8-5% of efficiency.

1 Introduction

Many studies were carried out to reduce the emission of ships by applying solar energy, and electrical or by integrating new energy resources into ship power systems, including single solar-powered and hybrid new energy resources [1]. One of the ways to reduce the emissions of ships is by implementing energy efficiency using energy-saving devices (ESD). Studies on the development of ESD in the maritime sector are still in demand because ESD could improve the ship propellers as a result it reduces fuel consumption. There are three methods commonly used to carry out ESD performance, experimental, numerical, and empirical methods. One of the numerical methods and well-established methods is computational fluid dynamics (CFD), which is able to calculate accurately the propeller performance such as thrust, torque, and efficiency [2], [3] and ship resistance [4], [5]. Based on previous studies PBCF is one of the well-known devices to improve ship propeller by adding a fin on propeller

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cap, that PBCF could reduce propeller hub vortex and improve propeller thrust by changing the vortex hub into propeller thrust. PBCF is one of the ESD that is very simple to install and there is no additional construction to build in the ship hull.

The studies of PBCF have been performed using CFD to improve propeller thrust and efficiency by adding PBCF with variation in fin size in PBCF[6]. Later on, the implementation of PBCF was combined with the Mewis duct to improve the propeller thrust and efficiency [7]. The studies showed that PBCF improved the propeller thrust and efficiency by removing the hub vortex as mentioned in the literature. Application of PBCF was carried out using Wageningen B-series propeller by experimental and numerical method [8], later on using B-series and Kaplan propeller, they improved the propeller thrust and efficiency by CFD method [9]. The pre-swirl stator (PSS) was another ESD that could installed to improve propeller performance by adding fins, which are mounted right in front of the propeller. By modifying the inflow and swirl into the propeller, the fins of a PSS can increase the total propulsion efficiency [10]. The studies of PSS configuration on the KP505 propeller behind the KCS were performed on CFD by Nadery [11]. It indicates PSS works well in the low ship speed, and also increases efficiency with decreased delivered power. Furthermore, PSS's effect reduces the pressure fluctuation by 16.48% in the backside of the propeller blade. PSS devices improve efficiency that can be produced by pre-swirl devices ranging from 2-6%. PSS generally consists of 3-5 fins that are attached to the front of the propeller and work to change the axial and tangential velocity components of the flow that will enter the propeller. The flow before entering the propeller will form a slight rotation in the opposite direction to the propeller rotation and convergence. Even though using PSS on the propeller can increase thrust and efficiency, this is still an indication of the formation of a hub vortex in the flow produced by the propeller. Another alternative may be applied in order to use the kinetic energy of the hub vortex Therefore, there is still a possibility to improve propeller performance by adding Propeller boss-cap fins (PBCF) to propellers that have been equipped with PSS previously. This addition provides 1-1.5% additional efficiency to the propeller [10].

The aim of the present study is to improve propeller performance by using a combination of PSS and PBCF on propeller KM. Dharma Kartika IX. The propeller type is the Wageningen series B5-62, single screws propeller. The propeller performance was performed in the CFD approach and the propeller calculation assumption was in the open water schema.

2 Numerical Methods and Setup

Firstly, the hull model of KM. Dharma Kartika IX was made using a scale of 1:1, the details of the main dimensions of the KM. Dharma Kartika IX can be seen in Table 1 according to the actual linesplan, Figure 1 shows the 3D model of KM. Dharma Kartika IX. The main object used in this study is the KM. Dharma Kartika IX ship propeller, which is of the B5-62 type with B5-62 propeller specifications is listed in Table 2 based on the original propeller drawing. The B5-62 propeller model used a scale 1:1 based on actual size with a diameter of 4.5 m with and without PBCF as shown in Figure 2. The PBCF model that has been made and complies with the provisions studies [12] which is the fin same number of fins as the number of propeller blades, has a fin diameter that does not exceed 33% of the propeller diameter, and the leading-edge fins are located near the base of the propeller blades. The variations of PSS were 3° (variation 1) and 5°(variation 2). Figure 3 indicates the setup of the numerical method and meshing strategy, and Table 3. indicates the setup of the rotating propeller domain.

Table. 1 KM. Dharma Kartika IX principal dimensions

Parameter	Dimension (in m)
LPP	145.00
LWL	143.75
B	19.00
T	5.85
Cb	0.516

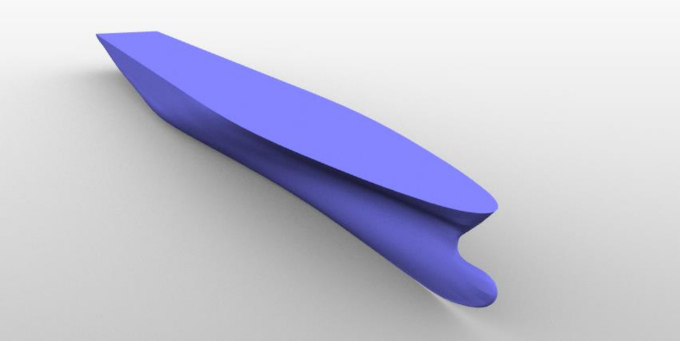
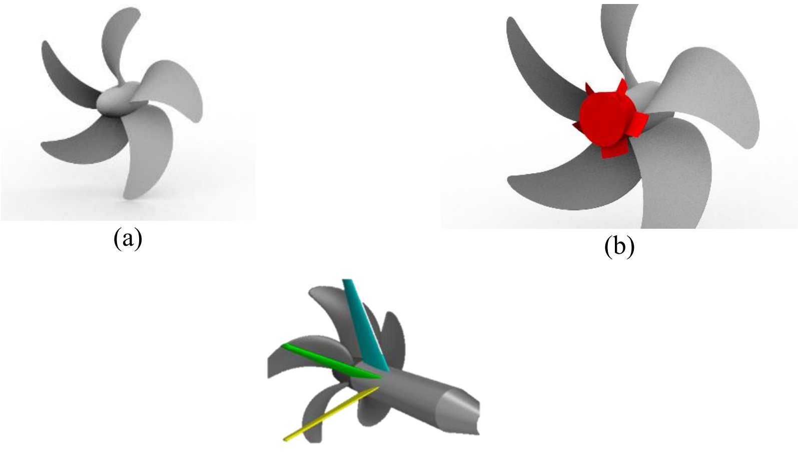


Fig. 1. 3D model hull of KM. Dharma Kartika IX

Table 2. KM. Dharma Kartika IX propeller Specification

Parameter	Value
Number of blades(n)	5
Diameter (m)	4.5
Ae/Ao ratio	0.62
Rotational Direction of the starboard propeller	Counterclockwise
Pitch (m)	6.25



(a)

(b)

(c)

Fig. 2. Propeller without PBCF (a), with PBCF (b), and PBCF with PSS (c)

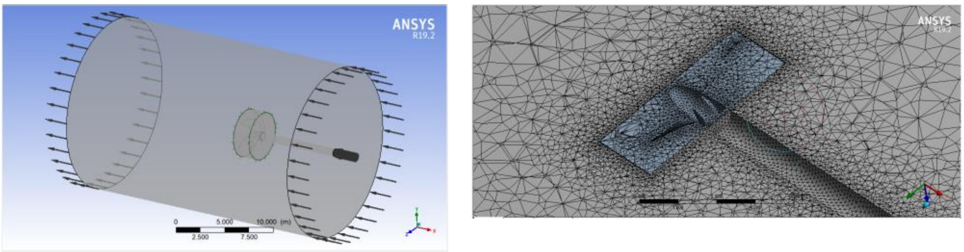


Fig. 3. Setup of boundary condition and meshing

Table 3. Setup of the rotating propeller

Domain Rotating Settings	
Type	Fluid
Location	Rotating
Materials	Water
Fluid Definition	Material Library
Fluid Morphology	Continuous Fluid
Buoyancy Model	Non-buoyant
Domain Motion	Rotating
Angular Velocity (RPS)	1.69, 2.06, 2.57
Rotation Axis	Global X
Reference Pressure	1 atm
Heat Transfer Model	None
Turbulence Model	K-epsilon
Turbulent Wall Functions	Scalable

3 Results and Discussion

The calculation of the propeller thrust and torque values in this study was validated by using the interpolation results of the thrust and torque values based on K_T-K_Q-J on the diagram Wageningen propeller B-series. Table 4 shows the results of validation for K_T and K_Q between CFD and Wageningen propeller B-series. It indicates that CFD-calculated thrust and torque have good accuracy in predicting propeller performance by indicating the difference between the calculated thrust and torque below 2%, where the K_T and K_Q were based on an empirical approach based on the thrust and torque diagram.

The next step is to calculate of thrust and propeller with PBCF and PSS. Table 5 shows the thrust, torque, and efficiency of the propeller after installing PBCF and PSS. It indicates the combination of PBCF and PSS has improved the propeller performance shown in the column difference. The results showed the thrust increased between 20 to 21%, torque below 10%, and efficiency up to 5%. The propeller efficiency before installing the PSS and PBCF is 43.50% later on it increases to 48.57% or in other words, there is a 5% improvement in efficiency.

Figure 4 shows the pressure contour before and after the propeller, it illustrates that PSS improves the flow before entering the propeller by increasing the fluid velocity as a result the pressure becomes lower compared without PSS. Opposite to PSS, PBCF improves the propeller performance by reducing the hub vortex and increasing pressure behind the propeller as shown in Figure 4, as a result combination of PBCF and PSS improved the propeller performance by increasing the thrust propeller. However as shown in Figure 4, cavitation is also increasing as a consequence of increasing pressure in the near tip of the propeller. This could be as future works that can be carried out for the next works. Figure 5 showed the streamline flow before and after installation of PBCF and PSS, it illustrated the flow affected flow before enter propeller and after pass the propeller.

Table 4. Validation of K_T-K_Q

Parameter	Wageningen B-series	CFD	Difference (%)
K_T	0.419	0.412	1.846
K_Q	0.090	0.091	0.655

Table 5. Calculation of thrust, torque, and efficiency of propeller.

Propeller	Fn	Thrust (N)	Difference (%)	Torque (N.m)	Difference (%)	Efficiency (%)
Base propeller	0.177	503.120	-	496.800	-	43.501
	0.205	747.740	-	738.010	-	43.521
	0.232	1.111.500	-	1.109.650	-	43.026
Variation 1	0.177	605.420	20.33	535.480	7.79	48.565
	0.205	900.120	20.38	795.960	7.85	48.576
	0.232	1.338.300	20.40	1.182.200	6.54	46.382
Variation 2	0.177	611.580	21.56	544.840	9.67	48.216
	0.205	909.950	21.69	810.280	9.79	48.238
	0.232	1.354.200	21.84	1.205.200	8.61	46.038

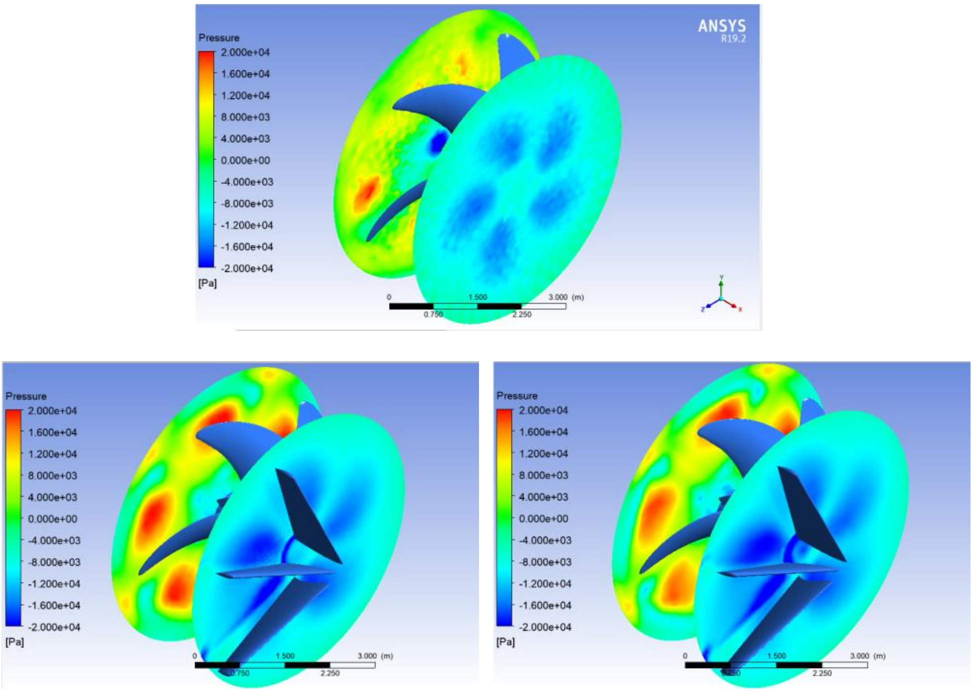


Fig. 4. Pressure contour of propeller with and without PBCF and PSS

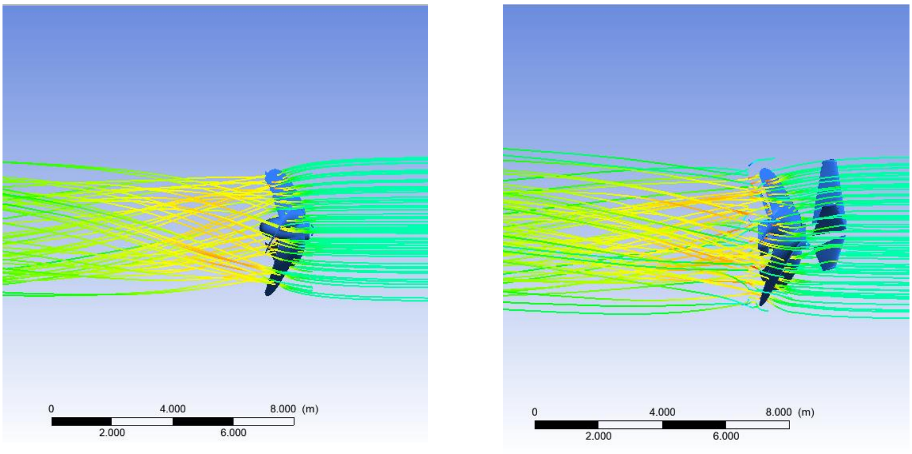


Fig. 5. Streamline of fluid before and after installation of PSS and PBCF

4 Conclusion

Based on present studies, it can be concluded that the PSS and PBCF have an impact on the improvement of the performance of propeller KM. Dharma Kartika IX. The improvements are increased thrust, torque, and efficiency. In this study, the use of the PSS and PBCF provides increases up to 20.3%, an increase in torque of 7.8%, and an increase in efficiency of 4.4% with lesser cavitation produced and the highest efficiency.

This research was financially supported by The Faculty of Engineering, Diponegoro University, Indonesia through Strategic Research Grant 2024

References

1. Tuswan, S. Misbahudin, S. Junianto, H. Yudo, A. W. B. Santosa, A. Trimulyono, O. Mursid, D. Chrismianto, Current research outlook on solar-assisted new energy ships: representative applications and fuel & GHG emission benefits. IOP Conf. Ser. Earth Environ. Sci. 1081 (2022).
2. I. E. Sandjaja, I. M. Ariana, E. Erwandi, Mahendra Indiaryanto, M. Muryadin, and B. A. Adietya, Numerical Analysis of the Effects of Propeller High Thrust Distribution on Propulsion Sytem Performance. Kapal: J. Ilmu Pengetah. dan Teknol. Kelaut. **20** (2023). https://doi.org/10.14710/kapal.v20i3.54715
3. A. Machfudin, A. A. B. Dinariyana, and D. Purnama Sari, Numerical Investigation on The Open Water Characteristics of B-Series Propeller. Kapal: J. Ilmu Pengetah. dan Teknol. Kelaut. **20** (2023). https://doi.org/10.14710/kapal.v20i2.54507
4. A. Trimulyono, M. L. Hakim, C. Ardhan, S. T. P. Ahmad, T. Tuswan, and A. W. B. Santosa, Analysis of the double steps position effect on planing hull performances. Brodogradnja. **74** (2023). http://dx.doi.org/10.21278/brod74403
5. S. Samuel, A. Wicaksono, W. A. Kurniawan, E. S. Hadi, T. Tuswan, A. Trimulyono,

M. Muryadin, Investigation of An Inverted Bow on Frigate Hull Resistance. *J. Appl. Fluid Mech*. **17** (2024).
https://doi.org/10.47176/jafm.17.1.2122

6. A. Trimulyono, A. B. Jatmiko, I. P. Mulyatno, and H. Yudo, The effect of propeller cap angle and fin size of PBCF on propeller performance. IOP Conf. Ser. Earth Environ. Sci, 972 (2022). https://doi.org/10.1088/1755-1315/1098/1/012076
7. A. Trimulyono, I. P. Mulyatno, and A. F. Rachmat, The Effect of Mewis Duct Energy Saving Device to Propeller Performance. IOP Conf. Ser. Earth Environ. Sci. 1098 (2022). https://doi.org/10.1088/1755-1315/1098/1/012076
8. B. A. Adietya, I. K. A. P. Utama, W. D. Aryawan, M. Nasir, Nurcholis, M. Indiaryanto, N. Asrowibowo, R. D. Permana, Nurhadi, Numerical and Experimental Investigations into the Characteristics of Wageningen B4-70 Series of Propeller with Boss Cap Fins. CFD Lett. **15** (2023). https://doi.org/10.37934/cfdl.15.10.152169
9. B. A. Adietya, H. Syahab, M. Indiaryanto, W. D. Aryawan, and I. K. A. P. Utama, Influence Evaluation of Open Propellers with Boss Cap Fins: Case Studies on Types B4-70 and Ka4-70. CFD Lett. **16** (2024). https://doi.org/10.37934/cfdl.16.9.143177
10. K. Koushan, V. Krasilnikov, M. Nataletti, L. Sileo, and S. Spence, Experimental and Numerical Study of Pre-Swirl Stators PSS. Journal of Marine Science and Engineering. **8** (2020). https://doi.org/10.3390/jmse8010047
11. A. Nadery, H. Ghassemi, and L. Chybowski, The effect of the PSS configuration on the hydrodynamic performance of the KP505 propeller behind the KCS,Ocean Eng. **234** (2021). https://doi.org/10.1016/j.oceaneng.2021.109310
12. A. Trimulyono, P. Manik, and N. Huda, Pengaruh Penggunaan Energy Saving Device Pada Propeller B4 55 Dengan Metode CFD. Kapal: J. Ilmu Pengetah. dan Teknol. Kelaut. **10** (2013).