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The effect of propeller cap angle and fin size of PBCF on propeller performance

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Abstract. The propeller was one of the main propulsors in ships that consumed a lot of fuel due to the viscous force acting in the ship. Therefore many studies have been carried out to increase the performance of ship propellers. One of the ways is using Energy Saving Device (ESD) to improve propeller performance. One of the ESD is Propeller Boss Cap Fins (PBCF). PBCF was used to improve the propeller performance by reducing the hub vortex during propeller rotation. In this study, we compare the propeller performance before and after PBCF installation without changing propeller dimensions. The variations of PBCF fins were made in 0,1D, 0,2D, and 0,3D with a combination of the angle of the propeller cap were 15^0 and 20^0. The propeller performance is carried out with the computational fluid dynamics (CFD) method. It was made in the open water assumption to reduce of wall effect. B-series propeller is used in the present study. The validation of propeller performance is made using empirical results. This study aimed to determine the effect of the installation of PBCF on the performance of B-Series propellers on the Ro-Ro 1000 GT ship. The results show that variation with a fin diameter of 0,2D and a propeller cap of 20^0 can increase propeller efficiency by 0.03%. It can be concluded the addition of PBCF can improve propeller performance.

1. Introduction

The propeller was one of the main propulsor in ships that consumes a lot of fuel due to of viscous force acting in the ship. Therefore many studies have been carried out to increase the performance of propellers, such as Trimulyono and Kiryanto made a comparison of the effect of the number of the blade and rake angle [1]. Fitriadhy et al. did numerical prediction of propeller B-series in open water using CFD [2]. Moreover, there is also another way by using Energy Saving Device (ESD), which can reduce the loss of energy caused by propeller performance. ESD can minimize energy loss caused by propeller performance; thus, the ship's performance can be improved. In this study, The Propeller Boss Cap Fins (PBCF) is used to improve the propeller performance. PBCF is a small fin that is attached to the propeller hub to reduce the vortex hub. The flow generated on the propeller hub is able in line with the flow on the propeller blade. So that it can restore loss of rotational energy and reduce cavitation [3]. The advantages of PBCF are simple construction, easy installation, and maintenance, low investment, not requiring classification approval, and increasing the propeller's thrust and efficiency [4]. There are several aspects to consider in installing PBCF, i.e. the number of fins must be the same as the number of the blade on the propeller, the phase difference in the cross-section from the base of the propeller blade with fins varies from 20^0 to 30^0. The diameter fin is not more than 33% of the propeller diameter, and the leading edge of the fin is located between the two propeller blades [5]. Trimulyono et al. did a

numerical calculation of the effect of PBCF on propeller B-series, and the results showed performance of the propeller improved [6] without modification of propeller cap.
Propeller cap modification has been carried out by Abar and Utama [7], by varying the angle of inclination of the divergent and convergent hub caps by 5^0, 10^0, and 15^0. The results showed that the convergent hub increased the efficiency by 1,4% and increased by 0,8% after being converted into PBCF. Whereas the divergent type reduced the efficiency by 1,2% and further decreased about 1% after being converted to PBCF. Alfian Tri Eka Kurniawan did variations in PBCF diameter and cross-section angles, the highest efficiency was obtained at 0,2D and 49^0 however, the angle installation in the section is outside the required range [8]. Gaggero is carried out study of PBCF design using genetic algorithm [9]. The result shows efficiency increased 1%. Futhermore, Gaggero and Martinelli is used duct on PBCF design to improve the performance of PBCF [10]. Mizzi et al. conducted a study of design optimisation for PBCF using CFD [11]. Lim et al. studied a parametric study of PBCF design for the container ship to improve propeller performance [12]. It was showed that PBCF improved propeller performance.
Therefore, the aims of the present study is carried out of modification of PBCF fin diameter of 0,1D, 0,2D, and 0,3D with combination of angle of the cap hub 15^0 and 20^0. The convergent types of propeller boss cap with B-Series propeller is used in this study. The propeller has belonged to the Ro-Ro ship 1000 GT owned by PT ASDP. The results shows the PBCF installation increased the propeller performance.

2. Methods

In this study, computational fluid dynamics (CFD) was used to carry out the effect of PBCF installation in the propeller. In this study, Unsteady Navier-Stokes solver and k-ε turbulence model are used in the CFD model. Fig. 1 shows the basic of propeller B-series used by Ro-Ro ship 1000 GT owned by ASDP. The properties of the propeller are shown in Table 1. Based on the Wageningen B-Series graph, the value of the advance coefficient (J), KT, KQ, and propeller efficiency (η) were computed with the interpolation method [13]. Table 2 shows parameters of propeller performance from the Wageningen B-Series graph. It was used to validate the basic model of the propeller. Table 3 shows gearbox specifications. The propeller rotation was computed using engine revolution per minute (RPM) divided gearbox ratio (see Table 3). Equation (1) was shown as an equation of the thrust coefficient used to calculate propeller thrust. Where ϱ is density, n is the RPM of the propeller blade, and D is the diameter of the propeller, respectively. Equation (2) is the equation of torque coefficient used to calculate propeller torque, where v_a is velocity advanced. Equation (3) is the advance coefficient equation and Equation (4) is the efficiency equation for the propeller, where Q is the propeller's torque. Those equations were used to calculate propeller performance with PBCF.

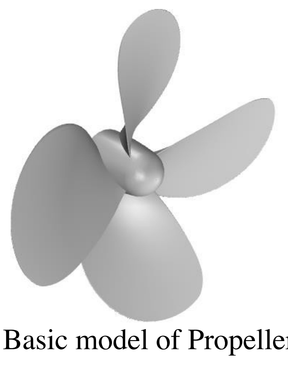

Figure 1. Basic model of Propeller B-series

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Table 1. Properties of propeller

Diameter	1750 (mm)
Pitch	1479 (mm)
No. Blades	4
A_e/A_o	0.67
Rake angle	15^0
Material	Manganese Bronze

Table 2. Parameters from Wageningen B-Series

Advance coefficient (J)	0.57
P/D	0.85
KT	0.132
KQ	0.021
η	0.588

Table 3. Properties of propeller

Model	MGN 335E
Ratio	4,72
RPM	2300
Power	1215 HP

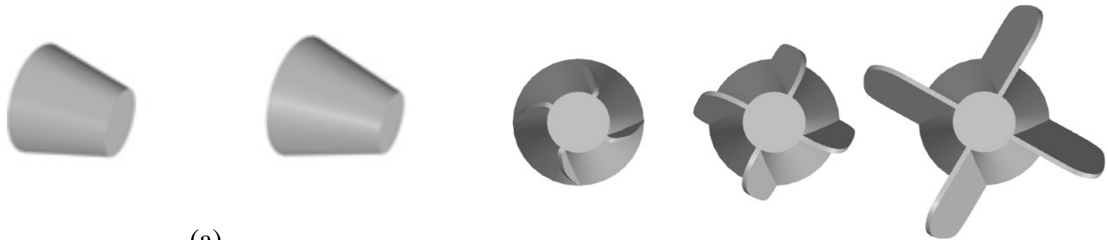
$$KT = \frac{T}{\rho \times n^2 \times D^4} \tag{1}$$

$$KQ = \frac{Q}{\rho \times n^2 \times D^5} \tag{2}$$

$$J = \frac{Va}{n \times D} \tag{3}$$

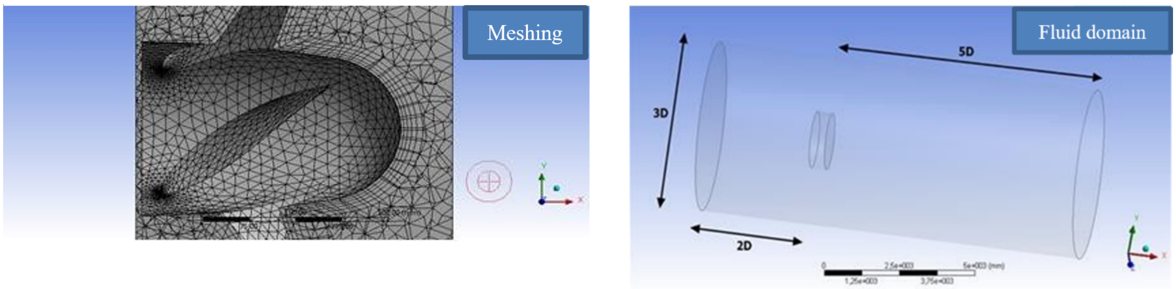
$$\eta = \frac{T \times Va}{2 \times \pi \times Q \times n} \tag{4}$$

Fig. 2 shows the model of PBCF, with Fig. 2 (a) showing the propeller cap model, and Fig. 2 (b) showing the PBCF size model used in this study. There are six models of PBCF that are used in this study. Fig. 3 (a) shows the meshing stage with the inflation model at the edge of the propeller. Fig. 3 (b) shows the setup model of the computational domain. It was showed the domain large enough to vanish the wall effect to the propeller. In this study, the computation of CFD is used the open water model.



(a) (b)

Figure 2. Propeller cap model 15^0 and 20^0 (a) and PBCF model (b)



(a) (b)

Figure 3. Meshing setup (a) and computational domain (b)

3. Results and Discussion

The validation of the CFD model shows in Table 4. Using the empirical solution from a graph of the Wageningen B-series [13]. Propeller thrust, torque, and efficiency are computed using Equation (1), (2), and (4). Table 4 shows that the CFD model has a good agreement for numerical computation of propeller performance. The next step is a modification of PBCF fin diameter and propeller angle is conducted. The results of propeller performance with PBCF installation shows in Table 5. The propeller thrust is increasing after PBCF is used in the propeller. It is because of propeller hub vortex becomes synchronized with the propeller shaft. Propeller hub vortex did not vanish indeed it only reduce from dense hub vortex becomes wider hub vortex. As a result, velocity becomes faster than before and increases propeller thrust.

It showed the angle of propeller cap 20^0 better than using propeller cap 15^0; moreover, the trend becomes better using a combination of fin $0.2D$. The highest thrust achieves using a combination of propeller cap 20^0 and $0.2D$ fin diameter. A similar result achieves for propeller efficiency where the highest efficiency is shown in the PBCF model using propeller cap 20^0 and $0.2D$ fin diameter.

Table 6 shows propeller efficiency results before and after installation of PBCF to the propeller. Similar results showed that propeller with fin diameter $0.2D$ and propeller cap 20^0 showed the highest efficiency compare to other models. Akbar and Utama [7] show that PBCF can improve efficiency by 5%. The same results are presented in this study. However, the boss cap angle is less than 20^0. This study revealed that the angle of the propeller cap has to be used in the range 15^0-20^0. It was revealed a fin diameter of $0.3D$, a poor model compared to other models.

Fig. 4 shows the trend of the PBCF model, both using propeller cap 15^0 and 20^0 increasing compare with the basic model of the propeller without PBCF. The Triangle marker depicts PBCF for 20^0; the first point shows only the propeller cap without PBCF; the next point is a combination of propeller cap 20^0 using $0.1D$, $0.2D$, and $0.3D$. The circle marker shows propeller cap 15^0, and the next point is propeller cap 15^0 using combination $0.1D$, $0.2D$, and $0.3D$. The rectangular marker represents the basic of the propeller model. Fig. 5 shows the efficiency of propeller using without and with PBCF, it showed propeller using cap 20^0 showed the highest efficiency compare without PBCF or using cap 15^0.

Table 4. Validation results using graph of Wageningen B-Series

Parameters	Empirical results	CFD results	Error (%)
Thrust	0.132	0.133	0.5
Torque	0.021	0.021	1.6
Efficiency	0.588	0.577	1.8

Table 5. Propeller thrust

Propeller model	Thrust (N)
Without PBCF	63550.7
Cap 15°	65702.2
Cap 15° + PBCF 0.1D	68560.6
Cap 15° + PBCF 0.2D	70682.7
Cap 15° + PBCF 0.3D	65498.5
Cap 20°	67916.2
Cap 20° + PBCF 0.1D	68996.0
Cap 20° + PBCF 0.2D	71371.7
Cap 20° + PBCF 0.3D	67411.9

Table 6. Propeller efficiency

Propeller model	Efficiency (%)
Without PBCF	0.577
Cap 15°	0.577
Cap 15° + PBCF 0.1D	0.578
Cap 15° + PBCF 0.2D	0.602
Cap 15° + PBCF 0.3D	0.533
Cap 20°	0.598
Cap 20° + PBCF 0.1D	0.602
Cap 20° + PBCF 0.2D	0.606
Cap 20° + PBCF 0.3D	0.548

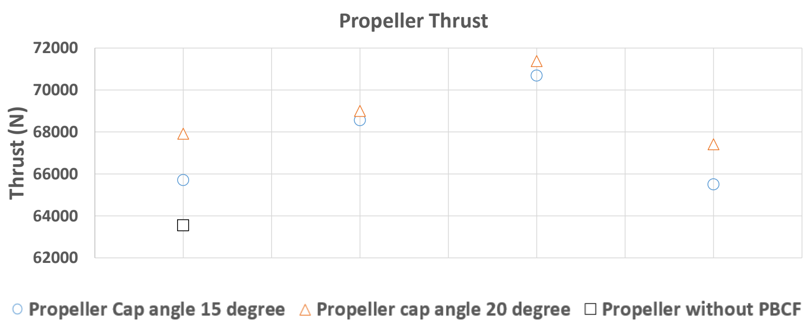


Figure 4. Comparison of propeller thrust before and after installation PBCF

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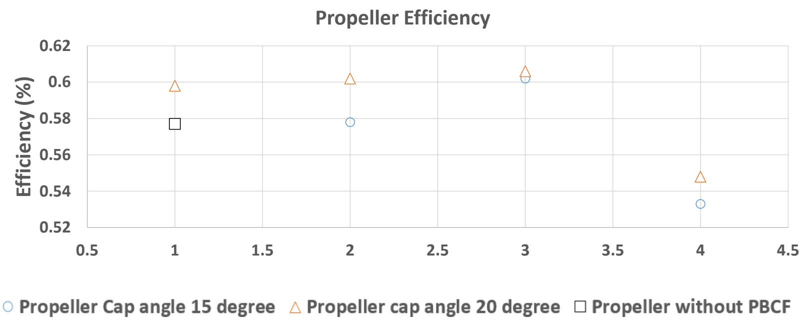
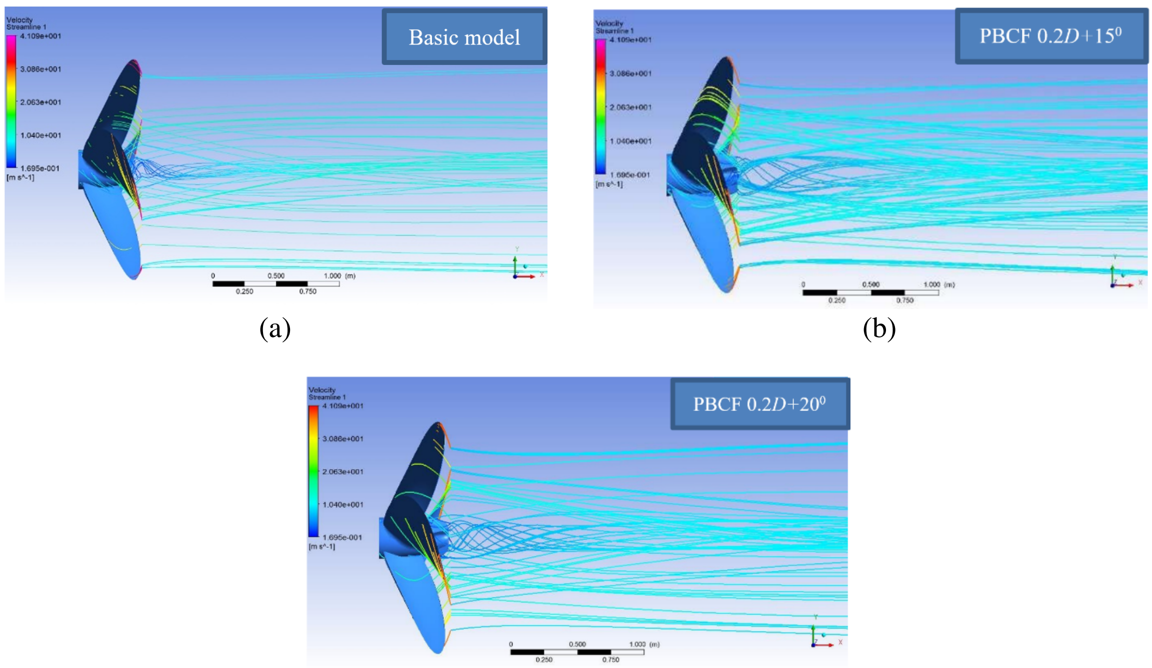


Figure 5. Comparison of propeller Efficiency before and after installation PBCF

Fig. 6 (a) shows the streamline from propeller to inlet. It was shown that the hub vortex in the propeller cap is denser in the basic model. In contrast, in the PBCF model, the hub vortex becomes wider, with the fluid flow becoming harmonious with the propeller cap (see Fig. 6 (b)). Furthermore, propeller cap angle 20^0 shows the best performances compare to other combinations; it shows in Fig. 6 (c) that the fluid is more stable and harmonious with the propeller cap.

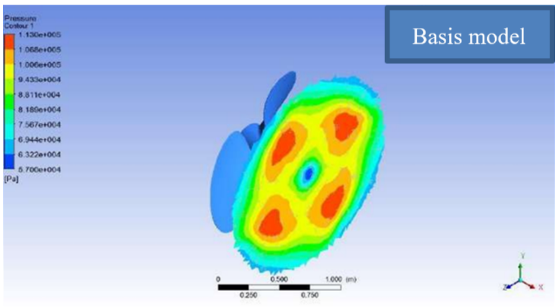
Fig. 7 (a) shows the pressure contour behind the propeller blade; it was revealed that the propeller cap's stagnation point creates pressure magnitude smaller compared to the position of in the mid and edge of the propeller. Using PBCF, the pressure magnitude becomes less than the basic model (without PBCF); moreover, with PBCF with propeller cap angle 20^0 the stagnation point disappears, and pressure magnitude increases, as shown in Fig. 6 (c). It was shown that PBCF could minimize energy loss caused by the hub vortex.



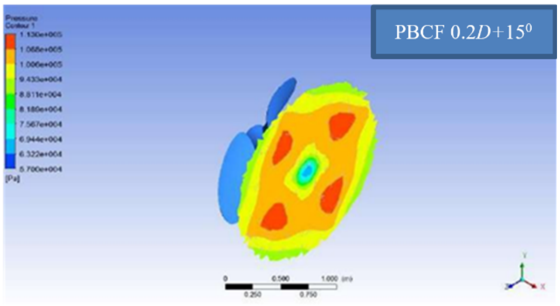
(a) (b)

(c)

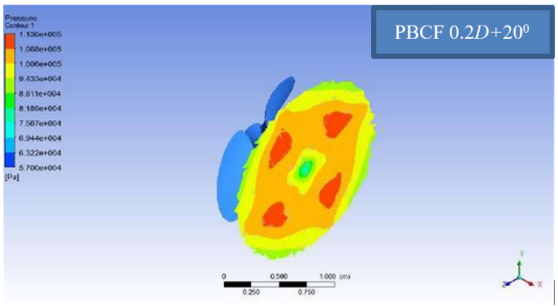
Figure 6. Streamline of propeller before and after installation of PBCF



(a)



(b)



(c)

Figure 7. Pressure contour before PBCF with and after installation PBCF located in the rear propeller

4. Conclusion

The present study shows that the Propeller Boss Cap Fins (PBCF) improved the propeller performance. By installing PBCF, it can increase propeller performance by reducing hub vortex in the propeller cap. The best combination was shown on the propeller with a PBCF of 0,2*D* fin diameter and a propeller cap angle of 20^0. It was showed the installation of PBCF can improve propeller performance compared without using PBCF. Although, the improvement is minor because the hub vortex still exists. Future work of optimization needs to carry out using a sophisticated method such as the surface response method [14].

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