

A Method to Predict Full Scale Performance of the Propeller Boss Cap Fins (PBCF)

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ABSTRACT

The propeller boss cap fins (PBCF) is well known to be one of the most successful energy-saving devices for ships. More than 3,300 sets have been sold since its first introduction in 1987.

In this paper, SPIV measurements and CFD calculations were carried out in order to investigate the reasons for the difference in the energy saving effects of PBCF in model test and in full scale data. It was confirmed to be able to evaluate the full scale energy saving effect of PBCF by reversed POT with wire-mesh screen method by taking account simulated ship wake. As these results, it was suggested that the reversed POT with wire-mesh is effective prediction method to estimate the energy saving effect of PBCF in full scale. And we were carried out the experiments on the combined effect of PBCF and other energy saving devices (ESD). It was confirmed that the effectiveness of the combination of PBCF and other ESD for EEDI improvement.

Keywords

Propeller boss cap fins (PBCF), reversed POT with wire-mesh screen method, combination of PBCF and other ESD

1 INTRODUCTION

The propeller boss cap fins (PBCF) is well known to be one of the most successful energy-saving devices for ships. More than 3,300 sets have been sold since its first introduction in 1987. However, the reasons for the difference in a gain in propeller efficiency between full scale and model scale by installing PBCF have not been clarified.



Figure 1: Propeller Boss Cap Fins(PBCF)

The investigation and development of PBCF were originally performed by Ouchi et al. They confirmed that thrust increases and torque decreases, thus the efficiency increases with the introduction of PBCF. The measured increase of the efficiency in their model experiments was from 1 to 2%. Nojiri et al. reported the results of more systematic experiments regarding four, five and six-bladed propellers. The measured increase of the propeller efficiency was from 1 to 1.5%. On the other hand, Ouchi reported the results of full scale analyses for 12 different vessels, in which the average energy-saving effect of PBCF was 5.4%. Hansen et al. reported that the analysis of the sea trials showed 3.5% and 4% reduction in shaft horsepower in ballast and in full load condition. Nojiri et al. also showed the results of full scale analyses for 16 different vessels, in which the energy-saving effect ranges from 2 to 10% with the average being approximately 5%. Those results suggest that the energy saving effect of PBCF is larger in full scale than in model scale. Kawamura et al. reported results of CFD computations were carried out in order to investigate the reasons for the difference in the effects of PBCF in model test and in full scale data. They presented the computed effect in the propeller efficiency, which around 2% is still smaller than the reported value in sea trial and fleet data.

The authors have also been studying the possibility of Experimental Fluid Dynamics(EFD) and Computational Fluid Dynamics(CFD) on the performance evaluation of PBCF and propeller. In previous study, the authors discussed the various validations for the effect of PBCF, and we confirmed that the effect of PBCF in a uniform flow and an imaginary wake was qualitatively well estimated, but the difference in effect for the propeller efficiency between full scale and model scale were not sufficiently explained. So, the authors performed EFD and CFD regarding PBCF operating behind simulated full-scale ship wake, and discussed the reason of the difference in the gain between the full scale and model scale. Furthermore, we were carried out the experiments on the combined effect of PBCF and other energy saving devices (ESD). The measurement results demonstrated the effectiveness of the combination of the PBCF and

other ESD for EEDI improvement. And we described the reduction effect of underwater radiation noise by PBCF.

2 PBCF PERFORMANCE IN FULL-SCALE

2.1 REVERS PROPELLER OPEN TEST

The reverse propeller open test(rev-POT) of PBCF without/with simulated full-scale ship wake was carried out in the cavitation tunnel at Akishima Laboratory. The arrangement of reverse propeller open test was shown in Figure 2.

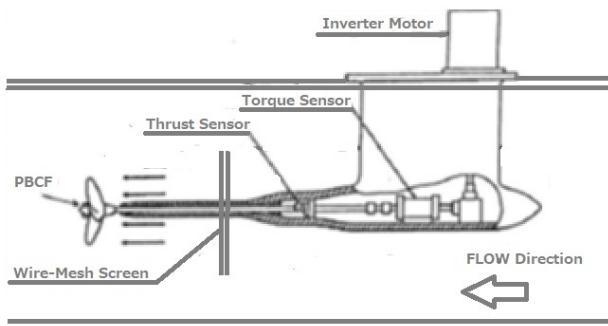


Figure 2: Reverse Propeller Open Test (rev-POT)

2.2 FLOW MEASUREMENT

The difference of flow pattern without/with the PBCF behind simulated full scale ship wake was measured by using the stereo particle image velocimetry (SPIV). And it is discussed that the influences of simulated full scale ship wake for PBCF. The SPIV set-up is shown in Figure 3 and the SPIV system configuration was shown in Table 1. The SPIV set up consisted of two CCD cameras located in both sides of the cavitation tank and the Nd-YaG laser to generate the light sheet to the measurement plane. The area of measurement was W300×H300mm.

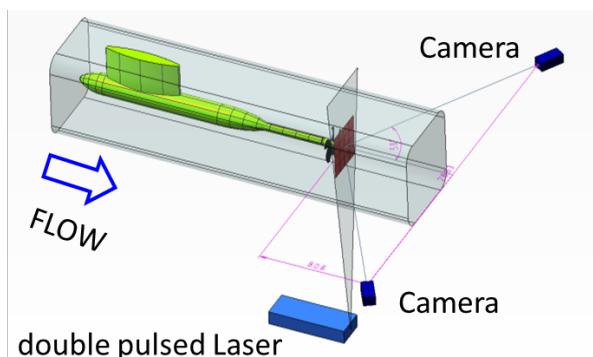


Figure 3: Arrangement of Stereo PIV System

Table 1:Stereo PIV system configuration

Cameras	ImagerProX 2M (1600×1200pixel,each being a
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	square of side 7.4μm)
Camera lens	Ai AF Zoom-Nikkor 24-85mm f/2.8-4D IF)
Measurement area	W300mm×H300mm
Laser	DPIV-L200 200mJ
Seeding Particles	Silver Coated Hollow Glass Spheres:diam 14μm
PIV analysis	Lavision FlowMaster DaVis8.1.3

2.3 MODEL PROPELLER

The practical high-skew marine propellers were applied in the several model tests. Figure 4 and 5 shows the principal particulars of the model propeller P664R and P668R. The model of PBCF was designed for the several model propellers.



Figure 4: Model Propeller P664R

MPNo.P664R		
Propeller Diameter	(M)	0.25
Number of Blades		5
Mean Pitch Ratio		0.80
Expanded Area Ratio		0.50
Boss Ratio		0.18
Turning Direction		Right



Figure 5: Model Propeller P668R

MPNo.P668R		
Propeller Diameter	(M)	0.25
Number of Blades		6
Mean Pitch Ratio		1.10
Expanded Area Ratio		0.85
Boss Ratio		0.19
Turning Direction		Right

2.4 FULL SCALE SHIP WAKE SIMULATION

In assessing the ESD performance of the full scale ship, the flow field of stern is very important. Figure 6 shows the CFD analysis results of wake distribution in model Re =107 and full scale ship Re=109. It was confirmed that very different wake between model and full scale was obtained, as full scale ship wake against model wake. Therefore, to estimate the energy saving effect of PBCF, the propeller inflow is very important and it is necessary to consider full scale ship wake. So, we estimated two type of Full scale ship wake distribution at the propeller plane in the towing condition.

The full scale ship wake flow in cavitation tunnel was simulated by a wire mesh screen method which was installed upstream the propeller. The arrangement of wire mesh screen in cavitation tunnel was shown in Figure 7.

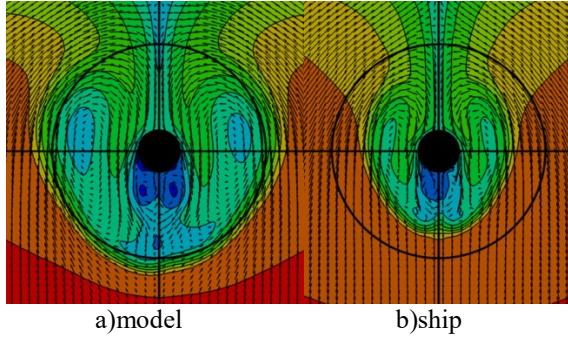


Figure 6: Comparison of wake distribution between model $Re = 10^7$ and full scale ship $Re = 10^9$.

The wire mesh screen method is usually used for the simulation of ship wake on the cavitation test. This simulation method is very effective in reproducing the designated ship wake distribution in cavitation tunnel.

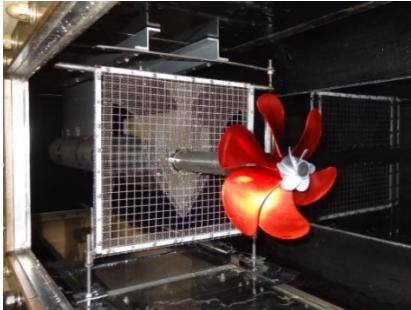


Figure 7: Arrangement of Wire mesh screen

Two type of simulated full scale ship wake in cavitation tunnel was shown in Figure 8. Ship-A wake is the full form ship and ship-B wake is the relatively slender ship.

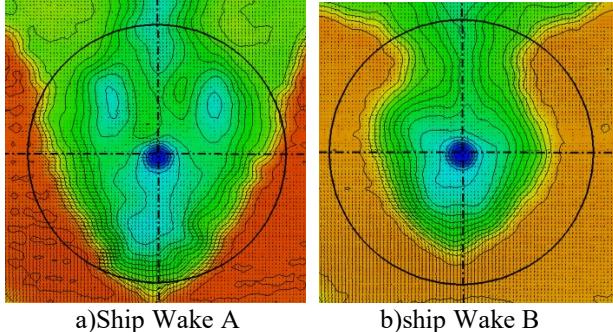


Figure 8: Simulated wake distribution in cavitation tunnel.

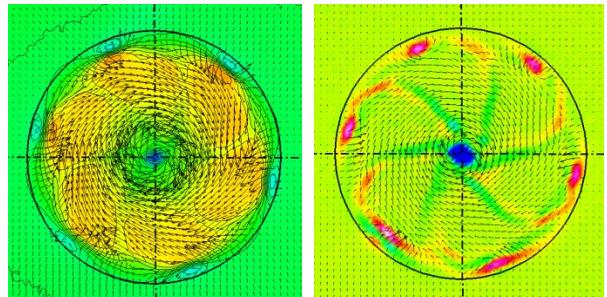
2.5 FLOW MEASUREMENT RESULTS

To confirm the effect of performance improvement of PBCF, the propeller slipstream was measured using SPIV. The test condition was shown in Table 2. The constant loading method is employed for the reversed POT.

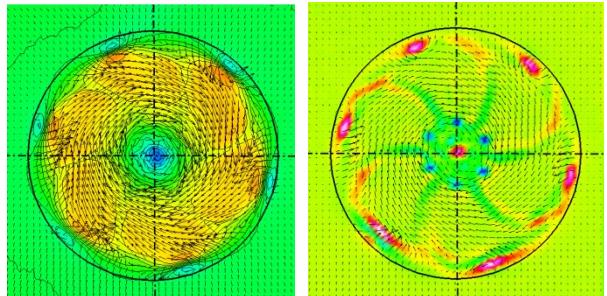
Table 2 : Test Condition

Thrust(N)	P664R	P668R
200	○	
400	○	○
600	○	○
800		○

Figure 9 shows the measurement results of the propeller slipstream of P668R without and with PBCF in uniform flow. It was confirmed that the strong hub vortex behind the propeller boss in without PBCF. On the other hand, it was confirmed that the hub vortex was disappeared with PBCF. Figure 10 shows the measurement results of the propeller slipstream of P668R without and with PBCF in full scale ship wake A. It was confirmed that the hub vortex behind the propeller boss in full scale ship wake A was stronger than uniform flow in without PBCF. And, it was confirmed that the hub vortex was disappeared with PBCF.

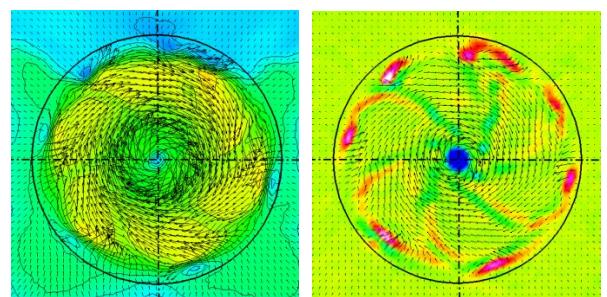


a)Thrust 600N without PBCF

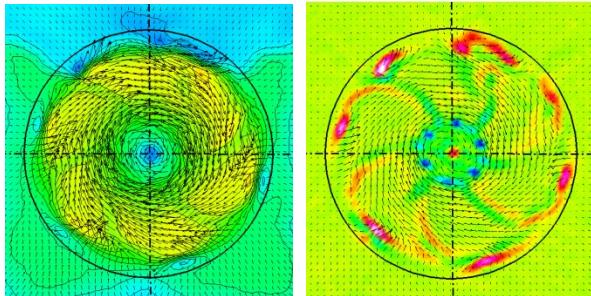


b)Thrust 600N with PBCF

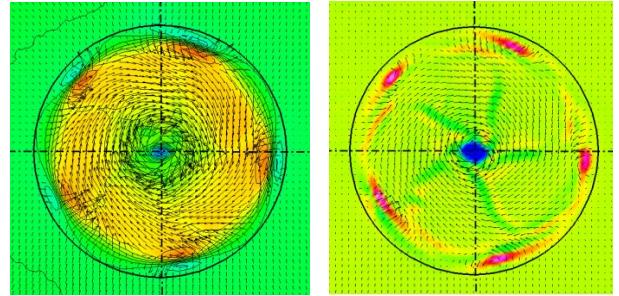
Figure 9:Comparison of Velocity(left) and Vorticity (right) distribution behind P668R in uniform flow.



a)Thrust 600N without PBCF



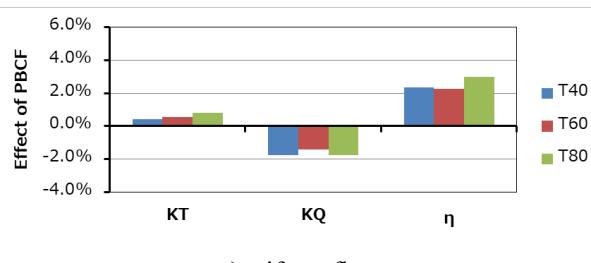
b)Thrust 600N with PBCF



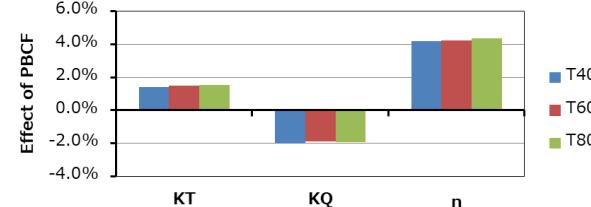
a)Thrust 600N without PBCF

Figure 10: Comparison of Velocity(left) and Vorticity (right) distribution behind P668R in Ship Wake A.

Figure 11 shows the comparison of the energy-saving effect of PBCF. The energy-savring effect of PBCF was obtained around 2 to 3% in uniform flow. The energy-saving effect of PBCF was acheived more than 4% in ship wake A, almost same magnitude of energy saving effect of PBCF in full scale.



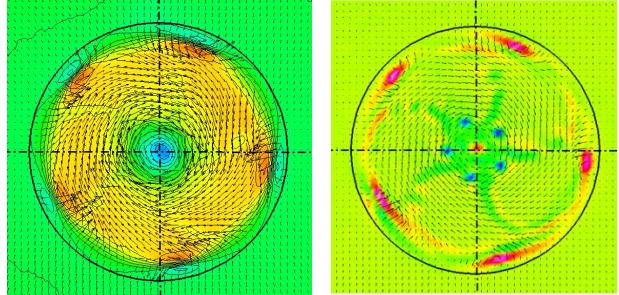
a)uniform flow



b)ship wake A

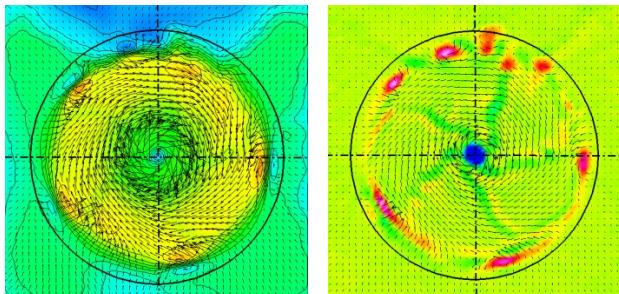
Figure 11: Comparison of the energy-saving effect of PBCF for propeller P668R.

Figure 12 shows comparison of velocity and vorticity distribution behind propeller boss cap of P644R in uniform flow. Figure 13 shows comparison of velocity and vorticity distribution behind propeller boss cap of P644R in ship wake B. As with case of propeller P668R, it was confirmed that the hub vortex was disappeared with PBCF in unifoem flow and in ship wake B.figure 14 shows the comparison of the energy saving effect of PBCF for P664R. The energy-savring effect of PBCF was obtained around 2 to 3% in uniform flow. The energy-saving effect of PBCF was acheived more than 3% in ship wake B, almost same magnitude of energy saving effect of PBCF in full scale.

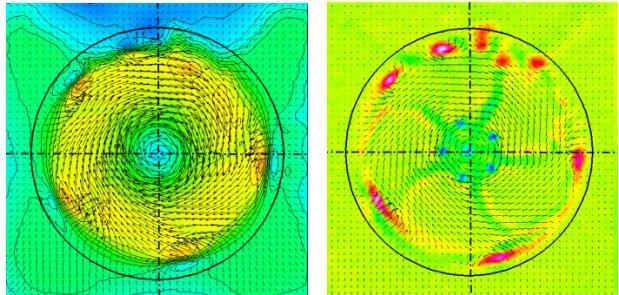


b)Thrust 600N with PBCF

Figure 12:Comparison of Velocity(left) and Vorticity (right) distribution behind P664R in uniform flow.

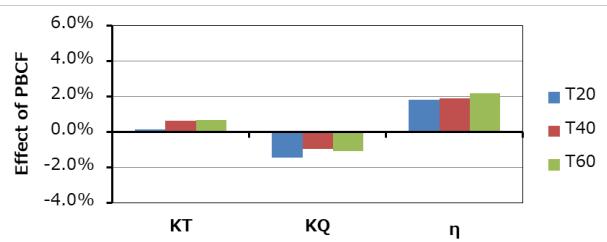


a)Thrust 600N without PBCF



b)Thrust 600N with PBCF

Figure 13: Comparison of Velocity(left) and Vorticity (right) distribution behind P664R in Ship Wake B.



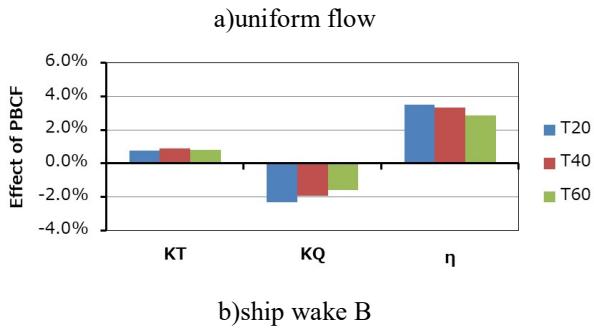


Figure 14: Comparison of the energy saving effect of PBCF for Propeller P664R.

Thus, it was confirmed that the difference in effect for the propeller efficiency between full scale and model scale was reduced by taking into account the full scale ship wake. To estimate the energy saving effect of PBCF in full scale, it is important to be close the load of the propeller to the condition in full scale. Especially, the inflow distribution of propeller is very important to estimate the energy saving effect of PBCF in full scale.

2.6 CFD Calculation

The present work uses OpenFOAM OpenSource CFD tool to compute the incompressible flow field around the propeller and PBCF in reversed POT. In this study, pimpleDyMFoam is an unsteady solver for incompressible fluids on a moving mesh using the PIMPLE (merged PISO-SIMPLE) algorithm with AMI (Arbitrary Mesh Interface) techniques. The governing equations are the Reynolds-Averaged Navier-Stokes equations and the k- ω SSTmodel was used for turbulence modelling.

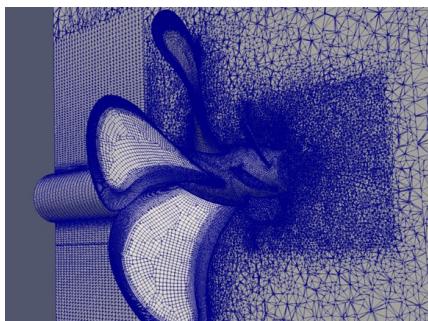


Figure 15:Calculation grid

Figure 16 and Figure 17 shows the comparison of streamline behind propeller boss cap for propeller 668R in uniform flow and in ship wake A. The hub vortex behind propeller boss cap was generated and the efficiency loss has occurred without PBCF. On the other hand, it was confirmed that the hub vortex was disappeared and the energy saving effect was achieved by PBCF. And the energy saving effect in ship wake A is increased compared with uniform flow.

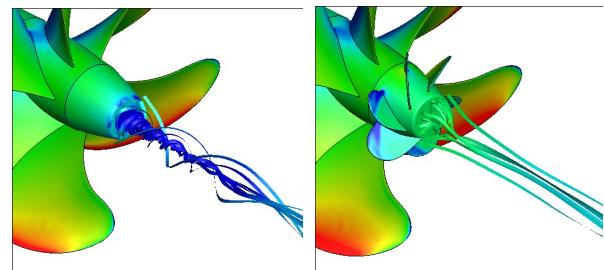


Figure 16:Comparison of streamline behind propeller P668R in uniform flow.

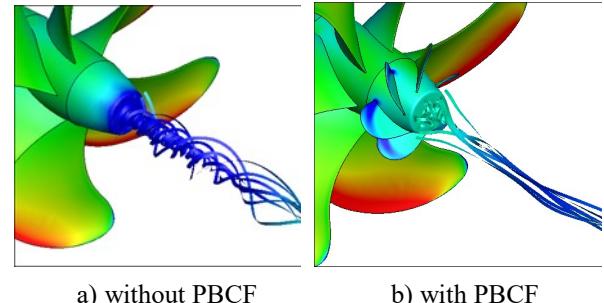


Figure 17:Comparison of streamline behind propeller P668R in Ship wake A.

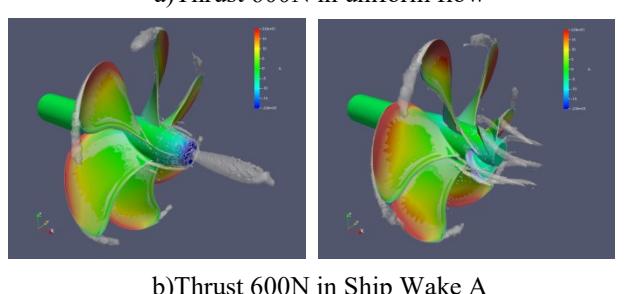
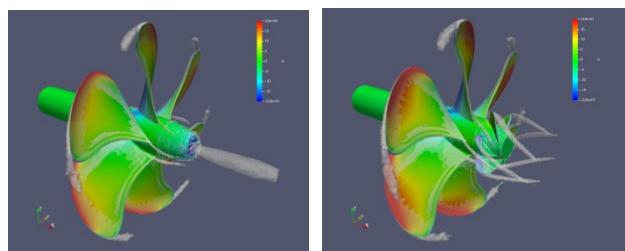


Figure 18:Comparison of Vorticity distribution around propeller P668R without(left) and with(right) PBCF.

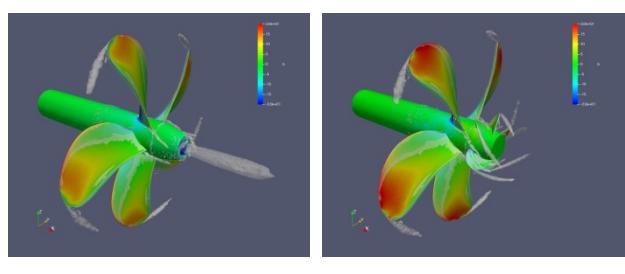


Figure 19:Comparison of Vorticity distribution around propeller P664Rwithout(left) and with(right) PBCF.

Furthermore, the comparison of isosurface of vorticity distribution around propeller was shown in Figure 18 and Figure 19. From these results, it was confirmed that the hub vortex in ship wake A was larger than in uniform flow and the hub vortex was disappeared by PBCF. Especially, it was recognized that PBCF is better ESD to decrease the efficiency loss by the hub vortex.

3 COMBINED EFFECT of PBCF AND OTHER ENERGY SAVING DEVICE.

Due to global warming and exhaustion of fossil fuels, measures in the maritime industry to reduce greenhouse gas (CO₂) and to cope with fuel consumption regulations are becoming important issues. Therefore, the development of the high-performance energy-saving device is expected. The experiments regarding the combined effect of PBCF and typical ESD were conducted in the large towing tank at Akishima Laboratory. It is confirmed about the influence of the interaction between PBCF and other ESD. Figure 20 shows the combination was used in the experiments, which PBCF, PBCF with Rudder Bulb-Fin(RBF), PBCF with Duct and PBCF with Duct and RBF.

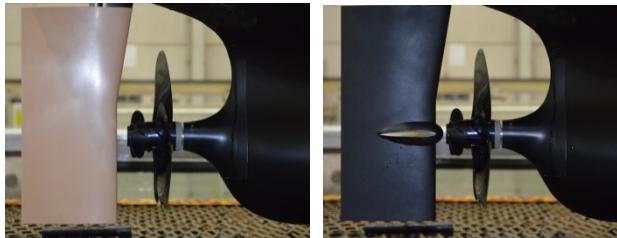
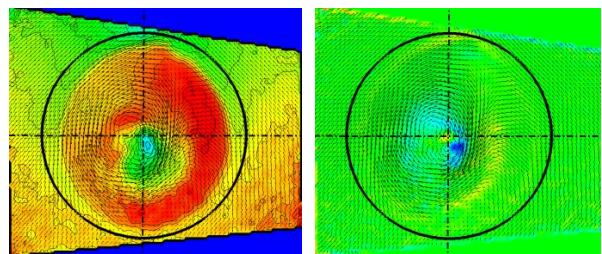
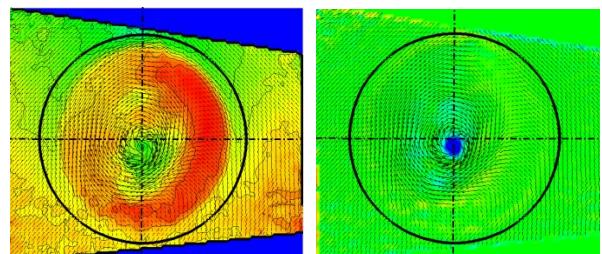


Figure 20: Combination of PBCF and typical ESD

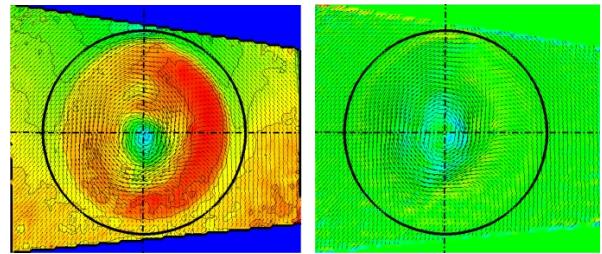


b)with PBCF

Figure 21: Velocity(left) and Vorticity(right) distribution behind propeller without Duct



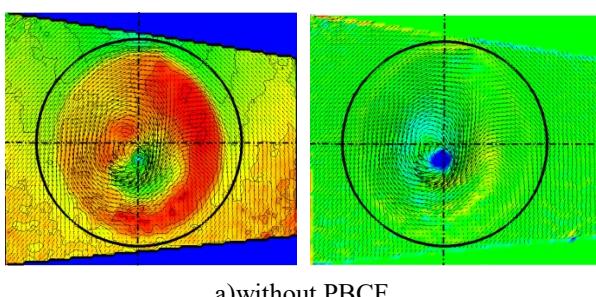
a)without PBCF



b)with PBCF

Figure 22: Velocity(left) and Vorticity(right) distribution behind propeller with Duct

Figure 21 and Figure 22 shows the comparison of velocity and vorticity distribution behind propeller was measured by SPIV. In both conditions without and with duct, the hub vortex is generated by rotating propeller. And, it was confirmed that the hub vortex was disappeared by PBCF. Since these experiments regarding the combined effect of PBCF and typical ESD were carried out in the model wake, it is expected that the energy saving effect is further improved in the full scale wake. Figure 23 shows the comparison of the energy saving effect of combination between PBCF and typical ESD by considering the energy saving effect in full scale wake. By combining PBCF and other ESD, it was predicted that more energy saving effect was achieved and more than 6% gain was obtained in case of PBCF+DUCT+RBF.



a)without PBCF

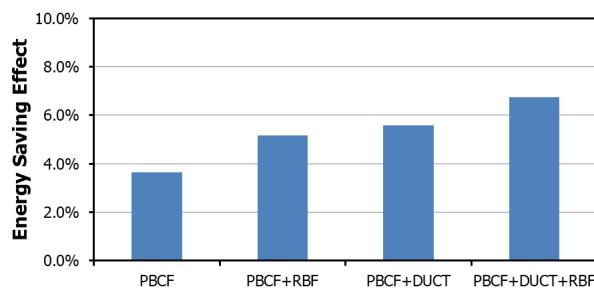


Figure 23: Comparison of the energy saving effect of combination between PBCF and typical ESD.

4 CONCLUSIONS

SPIV measurements and CFD computations were carried out in order to investigate the reasons for the difference in the energy saving effects of PBCF in model test and in full scale data. It was confirmed to evaluate the full scale energy saving effect of PBCF by taking into account the propeller inflow in the real ship. As results, it was suggested that EFD and CFD analysis using simulated full scale ship wake is effective to estimate the energy saving effect of PBCF in full scale.

And the effect of energy saving was confirmed to increase in combination with PBCF and other ESD. Also, it was confirmed that the effectiveness of the combination of PBCF and other ESD for EEDI improvement.

5 ACKNOWLEDGEMENTS

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