Investigation on Full Scale Performance of the Propeller Boss Cap Fins (PBCF)

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SUMMARY

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 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 these 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. Furthermore, it was confirmed that PBCF is an effective device to reduce the underwater radiation noise from the cavitation test.

NOMENCLATURE

D	Propeller diameter (m)
J	Advance coefficient
n	Rotation speed (rps)
K_T	Thrust coefficient $K_T = \frac{Thrust}{\rho n^2 D^4}$
K_Q	Torque coefficient $K_Q = \frac{Torque}{\rho n^2 D^5}$
η	Propeller efficiency $\eta = \frac{J \cdot K_T}{2\pi K_Q}$
R_{nD}	Propeller Reynolds number $R_{nD} = \frac{nD^2}{\nu}$
R_n	Ship Reynolds number $R_n = \frac{LV_S}{\nu}$
V_S	Ship Speed (m s^{-1})
υ	Kinematic viscosity (N s m^{-2})
ρ	Density of water (kg m^{-3})
P	Pressure (N m^{-2})

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 [1,2,3]. 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% [4]. 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% [3]. 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 [5]. 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% [4]. 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 [6,7]. 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 [8,9]. In precious 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 estimate, 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 PERFOMANCE 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.
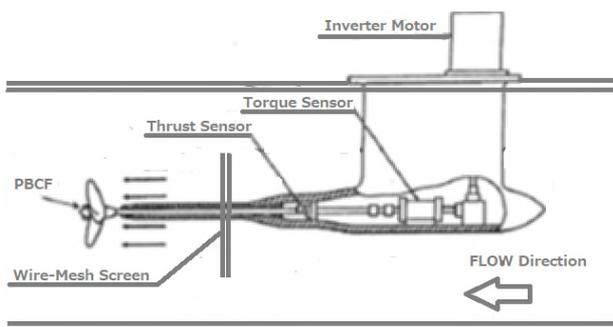
Figure 2: Reverse Propeller Open Test (rev-POT)

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 [10].
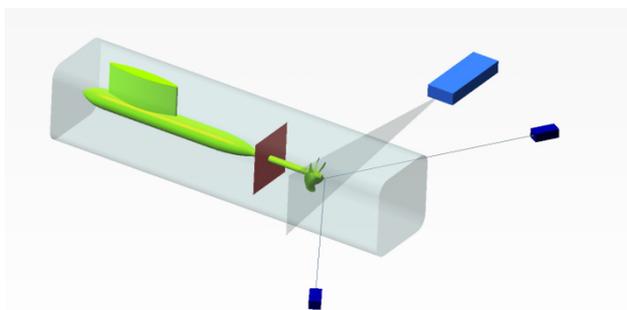

Figure 3:Arrangement of Stereo PIV System

Table 1:Stereo PIV system configuration

Cameras	ImagerProX 2M (1600×1200pixel,each being a 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.

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 4: Model Propeller P664R

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

Figure 5: Model Propeller P668R

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 $Re = 10^7$ and full scale ship $Re=10^9$. It was confirmed that very different wake between model and full scale was obtained, as full scale ship wake against model wake [11]. 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.
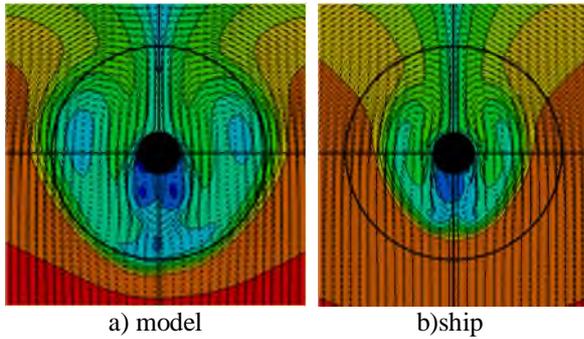
a) model   b)ship

Figure 6: Comparison of wake distribution between model Re $=10^7$ and s 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.
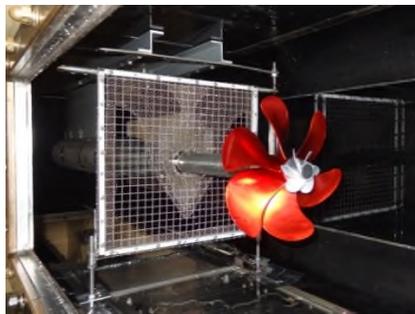

Figure 7: Arrangement of Wire mesh screen

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.

a) Ship Wake A   b) ship Wake B
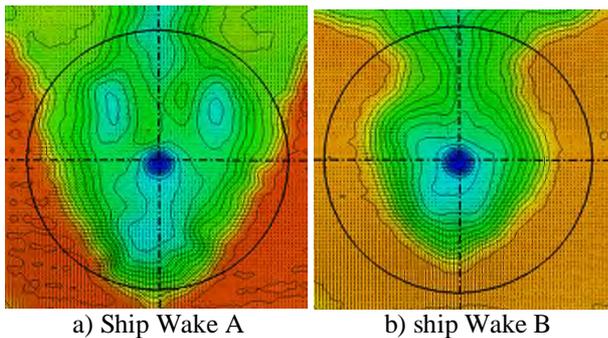
Figure 8: Simulated wake distribution in cavitation tunnel.

2.5   FLOW MEASUREMENT RESULTS

To confirm the effect of performance improvement of PBCF, the propeller slipsteam 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 wase 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 wase 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.
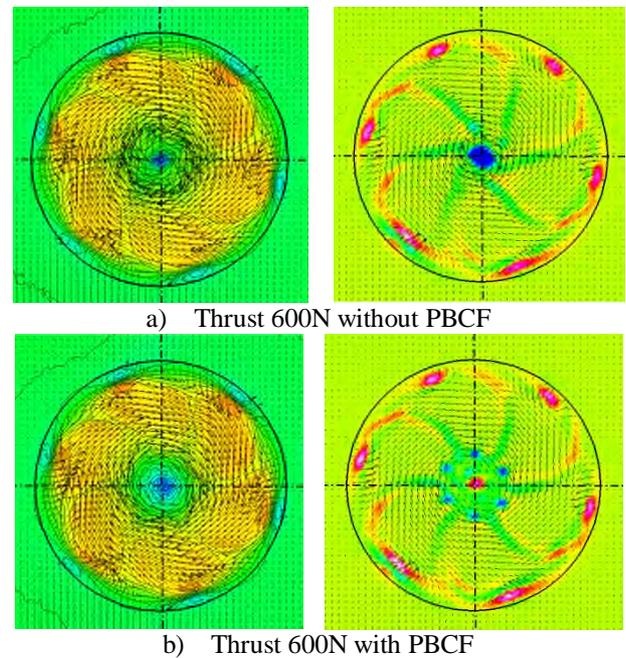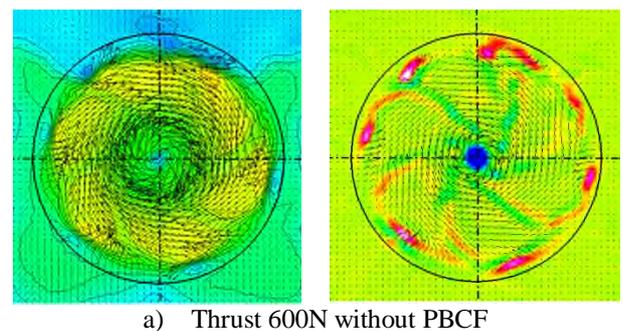

a)   Thrust 600N without PBCF

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
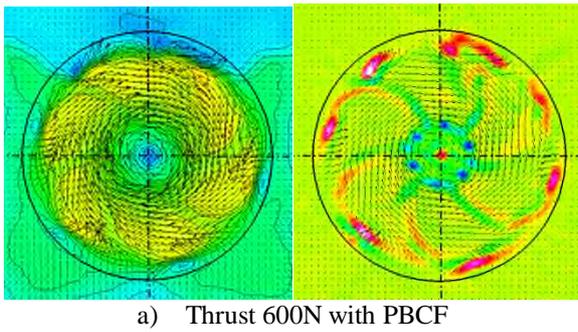
a)   Thrust 600N with PBCF

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-saving effect of PBCF was obtained around 2 to 3% in uniform flow. The energy-saving effect of PBCF was achieved more than 4% in ship wake A, almost same magnitude of energy saving effect of PBCF in full scale.
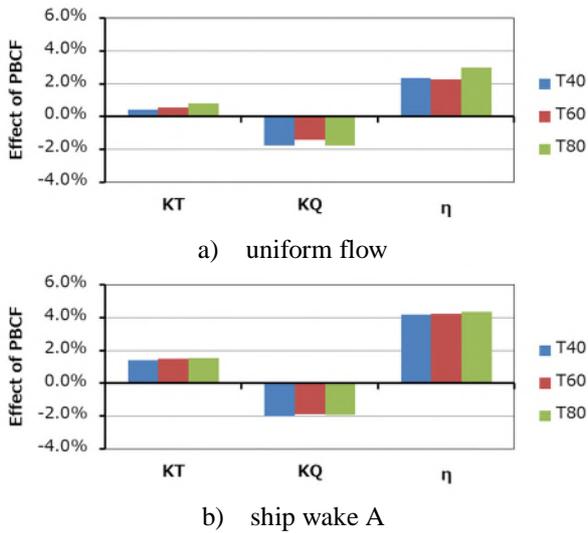

a)   uniform flow

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-saving effect of PBCF was obtained around 2 to 3% in uniform flow. The energy-saving effect of PBCF was achieved more than 3% in ship wake B, almost same magnitude of energy saving effect of PBCF in full scale.
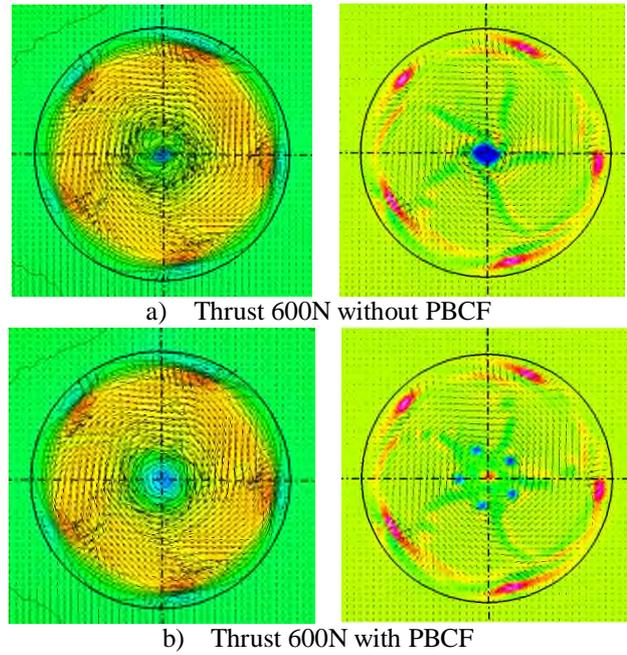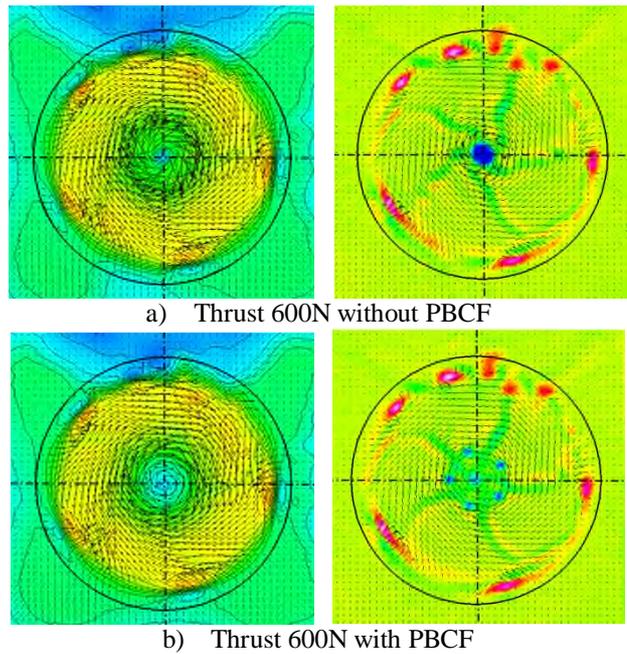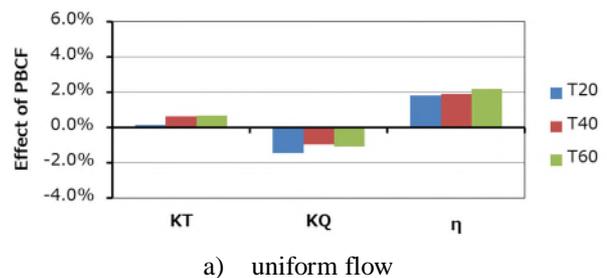

a)   Thrust 600N without PBCF

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.
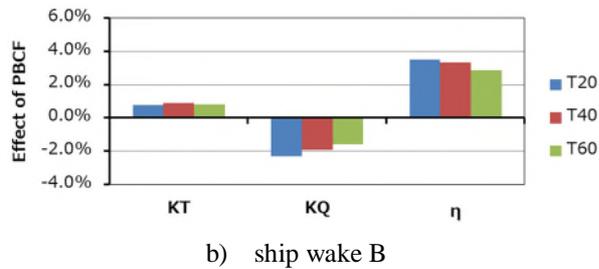

a)   uniform flow

b) 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. Especialy, the in-flow distribution of propeller is very important to esti-mate 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 incomepres-sible 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 $k\omega - SST$ model was used for turbulence modelling.

Figure 15 and Figure 16 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 efficien-cy 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.
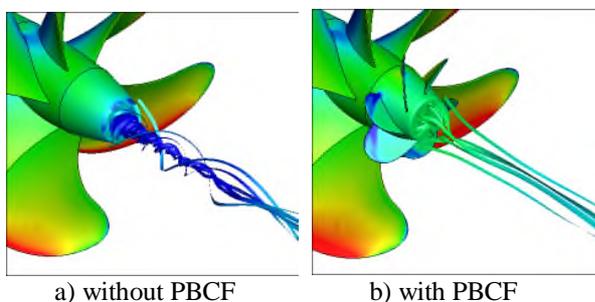

a) without PBCF   b) with PBCF

Figure 15:Comparison of streamline behind propeller P668R in uniform flow.

a) without PBCF   b) with PBCF
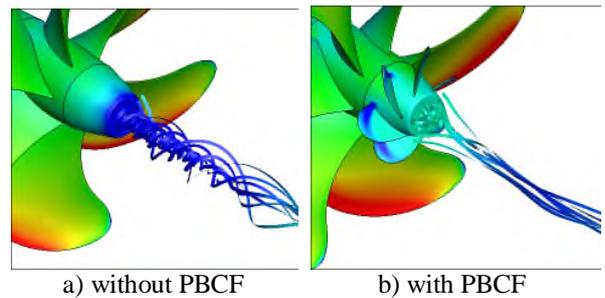
Figure 16: Comparison of streamline behind propeller P668R in Ship wake A.

a)   Thrust 600N in uniform flow

b)   Thrust 600N in Ship Wake A

Figure 17: Comparison of Vorticity distribution around propeller P668R without(left) and with(right) PBCF.
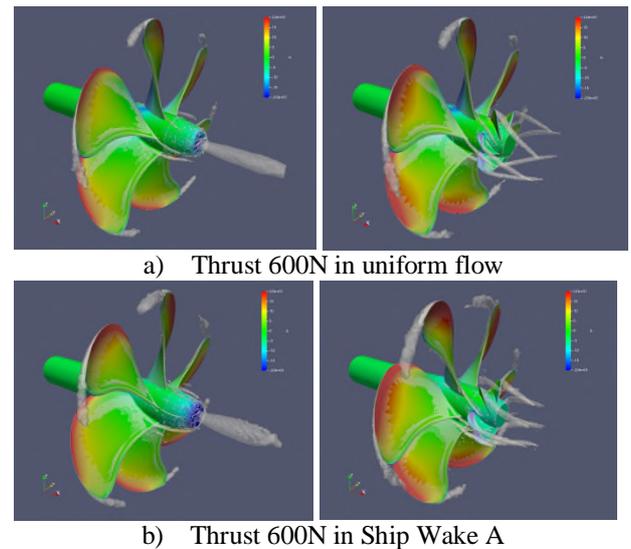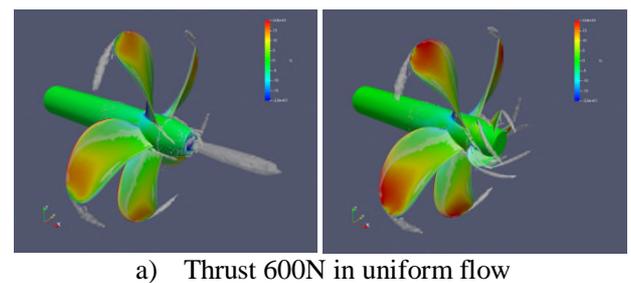

a)   Thrust 600N in uniform flow

Figure 18: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 17 and Figure 18. 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 19 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.
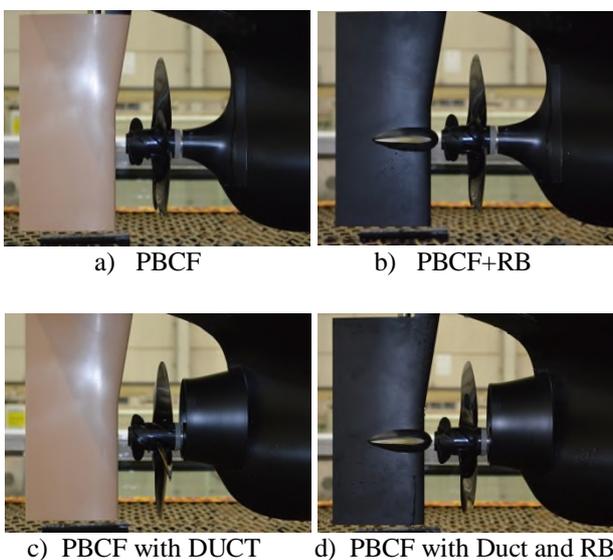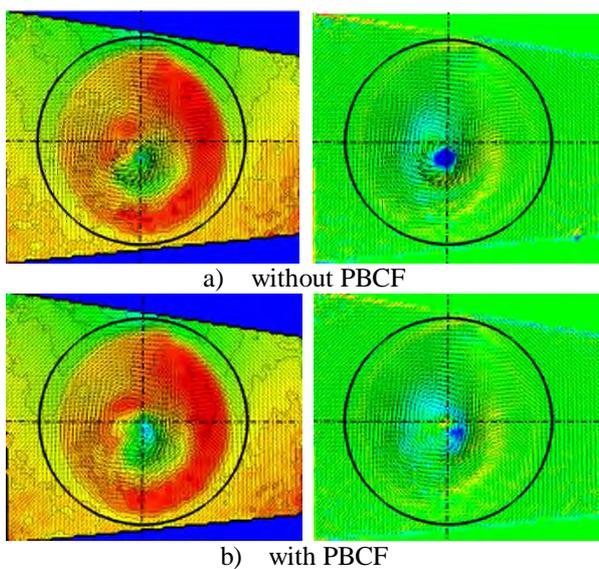

a)   PBCF   b)   PBCF+RB

c)   PBCF with DUCT   d)   PBCF with Duct and RB

Figure 19: Combination of PBCF and typical ESD

a)   without PBCF

b)   with PBCF

Figure 20: Velocity(left) and Vorticity(right) distribution behind propeller without Duct

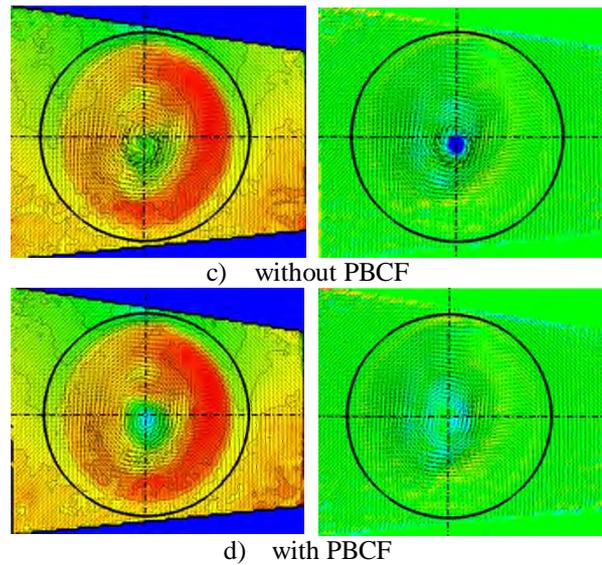
c)   without PBCF

d)   with PBCF

Figure 21: Velocity(left) and Vorticity(right) distribution behind propeller with Duct

Figure 20 and Figure 21 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 22 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.
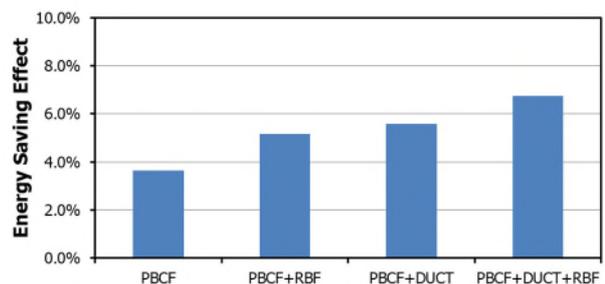

Figure 22: Comparison of the energy saving effect of combination between PBCF and typical ESD.

4.   UNDERWATER RADIATION NOISE

From the influence of radiation noise from the merchant ships to marine life attracted global attention, the development of underwater radiation noise reduction techniques have been important. Especially, the various

cavitation generated from propeller is main noise source from the ship, the reduction of these cavitation is important. The experiment regarding the underwater radiation noise was conducted in cavitation tunnel at Akihima Laboratory. Figure 23 shows the results of cavitation observation without and with PBCF. It was confirmed that the hub vortex cavitation was disappeared by PBCF. Figure 24 shows the comparison of the sound pressure level (SPL) between condition without and with PBCF. In PBCF equipped condition, the underwater radiation noise was confirmed to be reduced by around 5db in range from 100 to 1kHz. As a result, it was confirmed that PBCF is an effective device to reduce the underwater radiation noise.
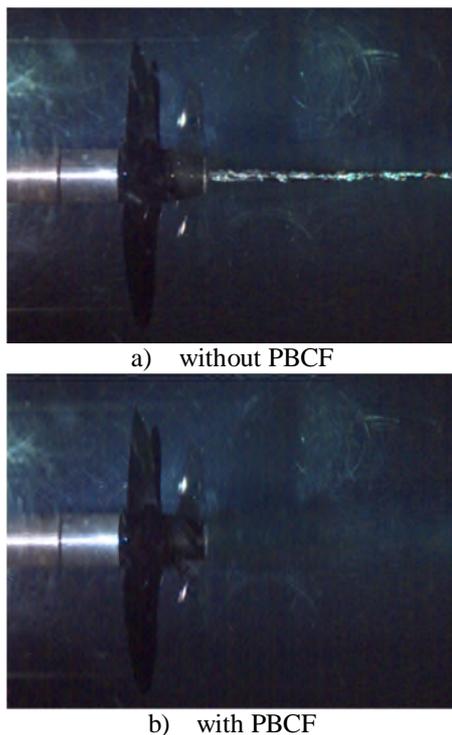

a)   without PBCF

b)   with PBCF

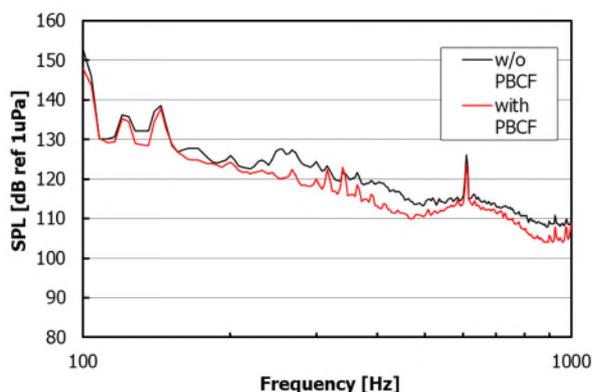Figure 23: Comparison of cavitation observation without and with PBCF for propeller..

Figure 24: Comparison of the reduction effect of PBCF for the underwater radiation noise.

5.   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. Furthermore, it was confirmed that PBCF is an effective device to reduce the underwater radiation noise from the cavitation test.

6.   ACKNOWLEDGEMENTS

7.   REFERENCES

1.   K Ouchi, Ogura M, Kono Y, Orito H, Shiotsu T, Tamashima M, Koizuka H,'A research and Development of PBCF (Propeller Boss Cap Fins) –Improvement of Flow from Propeller Boss –', Journal of Society of Naval Architects of Japan 163:66-78, 1988.

2.   K Ouchi, Tamashima M, Kawasaki T, Koizuka H,'A Research and Development of PBCF (Propeller Boss Cap Fins) : 2nd Report:Study on Propeller Slipstream and Actual Ship Performance'. Journal of Society of Naval Architects of Japan 165:43-53, 1989.

3.   K Ouchi,'Effect and Application of PBCF (Propeller Boss Cap Fins)'. Journal of MESJ 27(9):768-778, 1992.

4.   T Nojiri, N Ishii, H Kai,'Energy Saving Technology of PBCF (Propeller Boss Cap Fins) and its Evolution'. Journal of JIME 46(3): 350-358, 2011.

5.   Hansen H R, Dinham-Peren T, Nojiri T,'Model and Full Scale Evaluation of a 'Propeller Boss Cap Fins' Device Fitted to an Aframax Tanker'. Second International Symposium on Marine Propulsors smp'11, Hamburg, Germany, 2011.

6. T.Kawamura, K. Ouchi2, S. Takeuchi,' Model and full scale CFD analysis of propeller boss cap fins (PBCF)',Third International Symposium on Marine Propulsors, smp'13, Launceston, Tasmania, Australia, May 2013

7. T.Kawamura, K. Ouchi, T Nojiri, 'Model and full scale CFD analysis of propeller boss cap fins (PBCF)',Journal of marine science and technology 17(4), 469-480, 2012-12-01

8. K Kimura. et al.，'Study on Unsteady Cavitating Flow Simulation around Marine Propeller using a RANS CFD code', CAV2009 , Michigan, USA, 2009.

9. S Ando, et al., 'Study on the Hybrid Method of CFD and Bubble Dynamics for Marine Propeller Cavitation Noise Prediction', CAV2108, Baltimore, USA, 2018.

10. K Kimura, S Ando, S Matsuda, 'Development of Advanced Flow Visualization Technology using PIV and CFD', Mitsui Engineering & Shipbuilding Co Technical Review No.212, 2014.

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