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The Effect of Span to Chord Ratio PBCF on C4-40 Wageningen Series Propeller with CFD Method

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***Abstract*—propeller boss cap fin is one of the efforts to increase efficiency, especially in the field of ship propulsion. boss cap fins propeller or commonly called PBCF is one of the technologies that replace the boss cap propeller technology that first exists. Increasing efficiency can certainly have an impact on fuel consumption. This study will describe changes in efficiency, thrust, torque and the phenomenon of flow in the propeller after changes in span to chord ratio of fins with a fin form in the form of NACA foil. This research begins with determining the dimensions of the propeller and its model. The next step is to design and draw the boss cap fins propeller by modifying the span to chord ratio of the fins. The final step is analyzing propeller performance with software based on fluid dynamic computation. It is believed that changes in the PBCF span to chord ratio can improve efficiency, thrust, propeller torque, and minimize the hub vortex Simulations are carried out on four variations of the span to chord ratio, namely 0.17, 0.23, 0.29 and 0.34. From this study, it can be concluded that the propeller boss cap fins can increase thrust, torque, and efficiency, but the changes of span to chord ratio PBCF have not much effect on thrust, torque, and propeller efficiency. Increasing the PBCF span to chord ratio can reduce the hub vortex on the propeller.**

Keywords—computational fluid dynamic, propeller boss cap fins, span to chord ratio.

I. INTRODUCTION

The maritime world is increasingly progressing. Many technologies were developed or discovered in this era. One of the interesting things to continue to explore is about propulsion. There are various technologies in the field of propulsion. However, the main goal of all these technologies is energy efficiency, or commonly called Energy Saving. Energy is a major concern of the developers. This is because if energy can be saved, of course, the costs incurred will decrease.

One of the energy-saving devices in the field of propulsion is Propeller Boss Cap Fins or commonly called PBCF. PBCF is one way to increase propeller performance. In several experiments that have been conducted, there is an increase in efficiency. In one study, efficiency increased by 1.3% [1]. Whereas in previous studies with propeller B-series efficiency increased by 0.60%, thrust increased by 3.21%, and torque increased by 2.64% [2]. Of course, this is a very interesting thing to apply to C-series propellers. For this reason, the author tries to analyze more deeply the effect of changes in PBCF components, namely the PBCF span to chord ratio to the performance of the C-series propeller.

The tool used to reduce the friction resistance on the stern of the ship is called the energy-saving device (ESD). The use of ESD can reduce lost energy [3]. The use of ESD greatly affects the energy in the form of fuel that must be released by the ship. The more effective energy-saving devices are used, the smaller the fuel used will be.

A propeller is an object used to move a ship. The propeller consists of several blades that convert rotational motion into thrust [4]. There are various types of propellers, some of these propellers are Wageningen B-series, C-series, and D-series. MARIN (Dutch Maritime Research Institute) is an institution that publishes B-Series, C-Series, and D-Series propellers [5]. The B-series propeller is a propeller that was published by MARIN in the sixties and seventies. Propeller B-series is designed for merchant ships [6]. Generally, B series propellers have a P / D range of 0.5 to 1.4, the number of blades 2 to 7, and Ae / Ao 0.3 to 1.05 [7]. Various types of propeller data are collected in designing C and D-series propellers. The propeller dimension is associated with its use. 4 blade CPP propeller with large blade area and high pitch ratio are used for fast ferries and cruise ships, whereas CPP 4 blade propeller with small blade area and low pitch ratio are used for port transportation. The 5 blade CPP propeller is used for navy ships [8].

PBCF is an ESD (Energy-saving device), developed by Mitsui OSK. It consists of a short propeller mounted on a propeller boss which can convert the vortex hub energy into torque and additional thrust, transmitted back to the shaft. This increase in propulsion system can reach 4% to 5%. Reduction of the vortex produced by the propeller hub can produce low aft vibration and low propeller noise. Can also reduce the problem of erosion on the steering [2]. The effectiveness of PBFC has been recognized worldwide and has been installed in more than 3000 vessels since its introduction in 1987 [9].

The effects of using PBCF include reducing the vortex hub, reducing the effect of torque to get the hydrodynamic force towards the propeller rotation,

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increasing thrust [2], and reducing fuel consumption [10].

The vortex hub behind the propeller has a strong downward pressure on the flow core. The thrust on the propeller has decreased due to the pressure down [11]. The vortex hub is produced by a flow originating from the trailing edge, where the flow produces strong downward pressure. The vortex hub results in 10% energy loss [12].

Propeller Boss Cap Fins or commonly called PBCF is used to improve the flow produced by trailing edge propellers. The PBCF will break down the flow from the trailing edge. This can produce a force that can reduce propeller shaft torque by 3% or more. Installation of PBCF will also result in an increase in driving force of more than 1% [12].

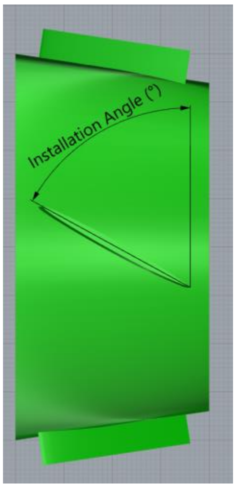

Figure. 1. Installation angle of fin PBCF

The fin installation angle is one component in addition to the span to chord ratio which has a greater effect on propeller efficiency than other design parameters [13]. Figure 1 is the position of the fin installation angle.

There are several components produced in the open water test [14]. The components are thrust coefficient (KT), torque coefficient (KQ), advance coefficient (J), and efficiency (ηo).

1) Thrust Coefficient

$$CT = \frac{T_{prop}}{\rho \times n^2 \times D^4} \quad (1)$$

2) Torque Coefficient

$$CQ = \frac{Q_{prop}}{\rho \times n^2 \times D^5} \quad (2)$$

3) Advance Propeller Coefficient

$$J = \frac{V_A}{n \times D} \quad (3)$$

4) Efficiency

$$\eta o = \frac{T \times V_a}{2 \times \pi \times n \times Q} \quad (4)$$

Where,
Va = the fluid speed that passes the propeller (m/s)
N = rotation of the propeller (rps)
D = Propeller diameter (m)
ρ = Density of the fluid (kg/m^3)

Computatio`nal fluid dynamics or commonly called CFD is a branch of fluid mechanics that are used to solve the problem of fluid flow. The methods used in CFD are numerical methods and algorithms [15]. The CFD process is divided into three, namely pre-processing, computation, and post-processing [16].

II. METHOD

This study uses computational fluid dynamics software as a tool to simulate an open water test propeller. There are several stages in this study. Some of these stages are:

A. The Propeller

Propeller used in this research is Wageningen series C4-40 propeller with propeller dimensions according to Table 1.

B. C4-40 Propeller Open Water Simulation Without PBCF

Propeller open water test simulation is used to determine thrust and torque produced by propeller C4-40 before PBCF is added (Figure 2). Table 2 and Figure 3 shows the characteristics of propeller C4-40 at open water test simulation. The data will be used as a basis for comparison of C4-40 propellers that PBCF has added.

TABLE 1.
PROPELLER DIMENSIONS

Diameter (mm)	Shaft Diameter (mm)	Blade	P/D	RPM
316.6	80	4	1.4	900

TABLE 2.
PROPELLER OPEN WATER TEST DATA

Propeller Open Water Test on C4-40				
T (N)	Q (Nm)	ηo	KT	10KQ
1082.13	74.10	0.442	0.467	1.009
866.86	62.28	0.561	0.374	0.848
644.34	50.09	0.649	0.278	0.682
411.51	36.98	0.673	0.177	0.504
166.55	22.07	0.533	0.072	0.301

Figure. 2. Propeller C4-40

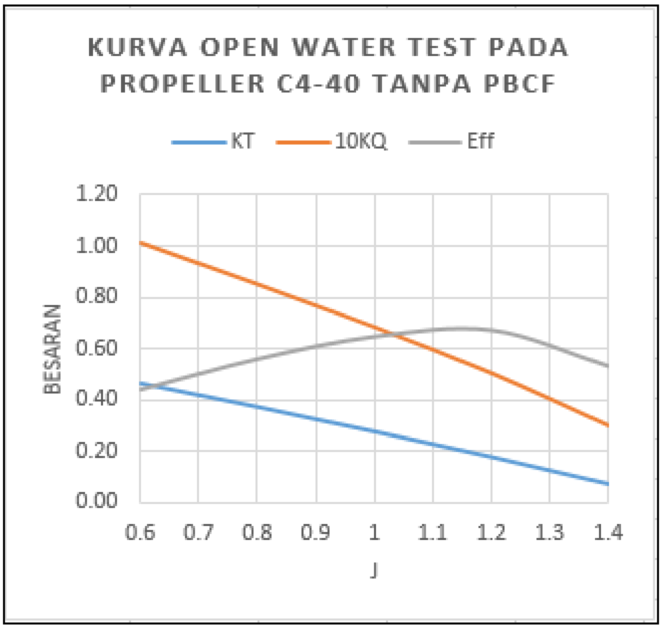

Figure. 3. Propeller open water test curve

C. Geometry Model of PBCF

One suggestion of PBCF design is that the fin diameter should not be more than 33% of the propeller diameter [2]. Based on this, the size of PBCF shown in Table 3.

Figure 4 is explains the term of some part of PBCF. The smallest PBCF diameter in this research is 91.96 mm at span to chord ratio PBCF 0.17, while the largest PBCF diameter is 103.65 mm at span to chord ratio PBCF 0.34.

In addition to the part in Figure 4, there are several things that also need to be considered in designing PBCF. They are the installation angle of fin and phase lag of fin. Figure 1 shows an explanation of the installation angle. According to Figure 1, installation angle is an angle between fin and a line which parallel with a transverse body behind of PBCF. Figure 5 shows the explanation about the phase lag of fin of PBCF. According to Figure 5, phase lag is an angle of fin position.

TABLE 3.
PBCF DIAMETER LIMITS

Span to Chord Ratio	Chord (mm)	Span (mm)	D PBCF (mm)	D Prop (mm)	% PBCF to D prop
0.17	35	6	91.96	316.6	29.05
0.23	35	8	95.85	316.6	30.27
0.29	35	10	99.75	316.6	31.51
0.34	35	12	103.65	316.6	32.74

TABLE 4.
FIN OF PBCF POSITION

Span to Chord Ratio	Fin Chord (mm)	Fin Span (mm)	Installation Angel (°)	Phase lag (°)
0.17	35	6	61.5	67.5
0.23	35	8	61.5	67.5
0.29	35	10	61.5	67.5
0.34	35	12	61.5	67.5

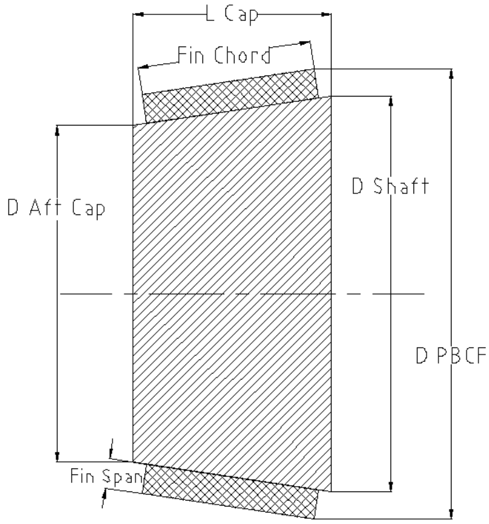

Figure. 4. Geometry of PBCF

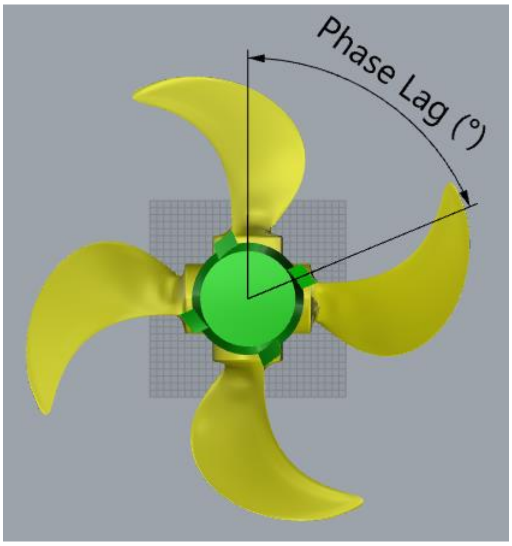

Figure. 5. Phase lag of fin PBCF

III. RESULTS AND DISCUSSION

A. Thrust, Torque, and Efficiency

To find out the thrust and torque of C4-40 propeller with the addition of PBCF, an open water test simulation was carried out with Numeca Finemarine software. The propeller open water characteristic shown in Figure 6. According to Figure 6, the efficiency of C4-40 propeller increase when the PBCF has been added to the C4-40 propeller. STC in Figure 6 stands for PBCF span to chord ratio.

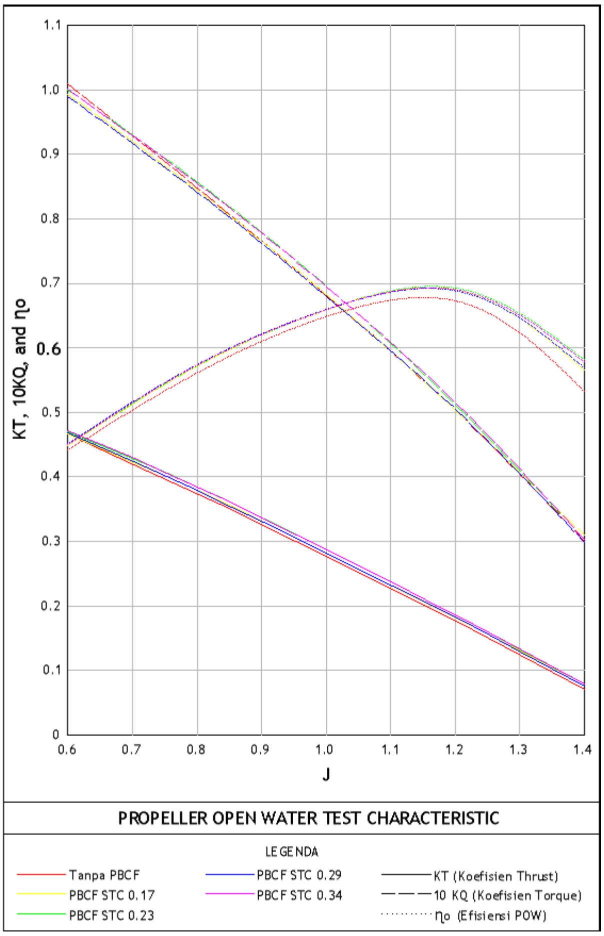

Figure. 6. The comparison of propeller open water test characteristic

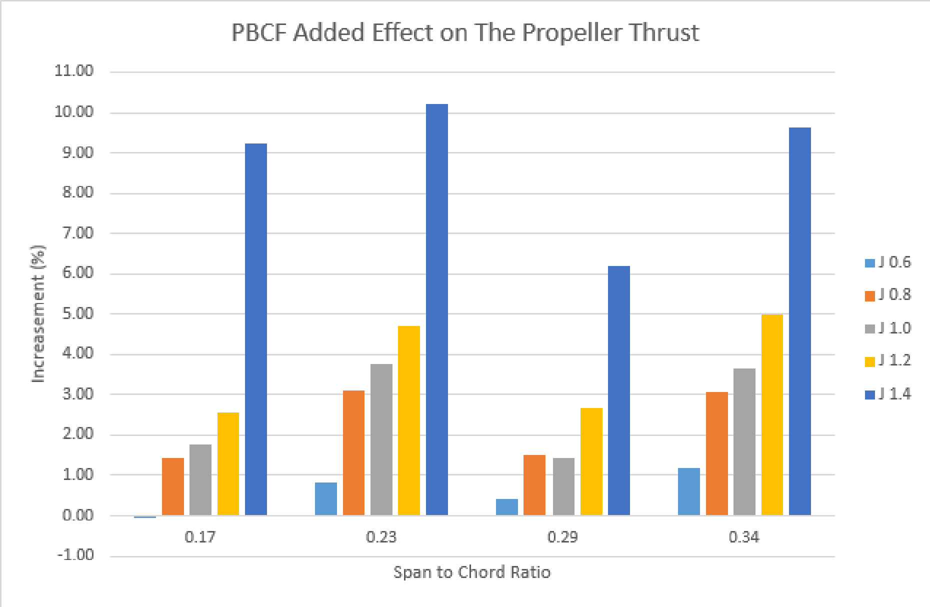

Figure. 7. PBCF added effect on the propeller thrust

Figure 7 shows that the PBCF makes the propeller thrust increase. According to this Figure, the thrust of the propeller with span to chord ratio PBCF 0.17 has a percentage increase in the thrust that is not much different to the propeller with span to chord ratio PBCF 0.29. The average thrust of the propeller with span to chord ratio PBCF 0.17 and 0.29 are 2.99 and 2.45 each. The same condition also happened to the propeller with span to chord ratio PBCF 0.23 which has a percentage increase in the thrust that is not much different to the propeller with span to chord ratio PBCF 0.34. The average thrust of the propeller with span to chord ratio PBCF 0.23 and 0.34 are 4.52 and 4.50 each. It proves that the changes of span to chord ratio have less impact on the propeller thrust.

Figure 8 shows the PBCF added effect on the propeller torque. Propeller with span to chord ratio PBCF 0.23 and 0.34 have a percentage increase in torque that is not much different. The average torque of propeller with span to chord ratio PBCF 0.23 and 0.34 are 0.99 and 1.07 each. At the propeller with span to chord ratio PBCF 0.29, the propeller torque is decreased.

The estuary of thrust and torque is efficiency. Efficiency in the propeller open water test comes from the comparison between the power produced by the propeller (THP) and the power absorbed by the propeller (DHP). Efficiency in an open water propeller test can be obtained by equation 5 and 6 [17], where:

$$THP = T \times Va \quad (5)$$

$$DHP = 2 \times \pi \times n\,Q \quad (6)$$

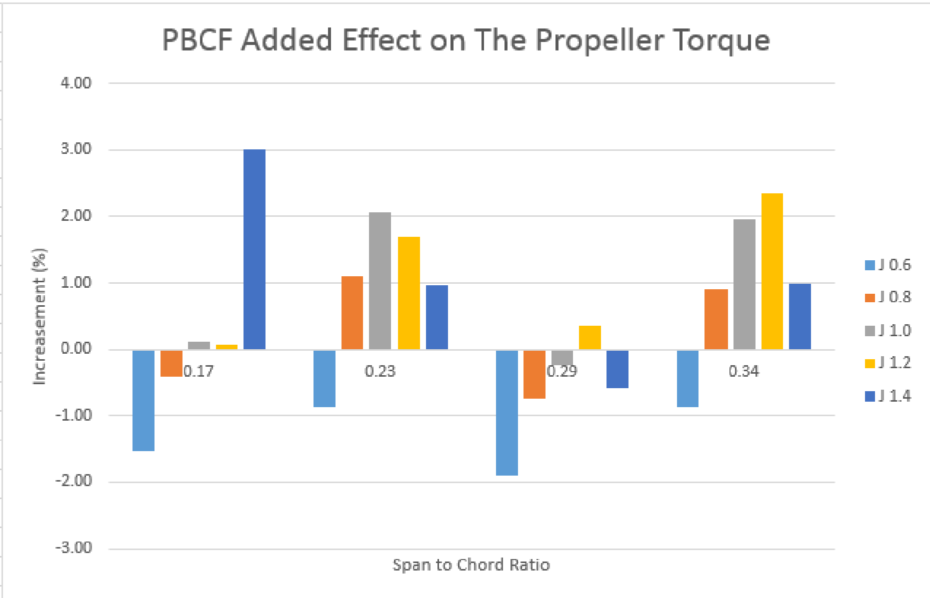

Figure. 8. PBCF added effect on the propeller torque

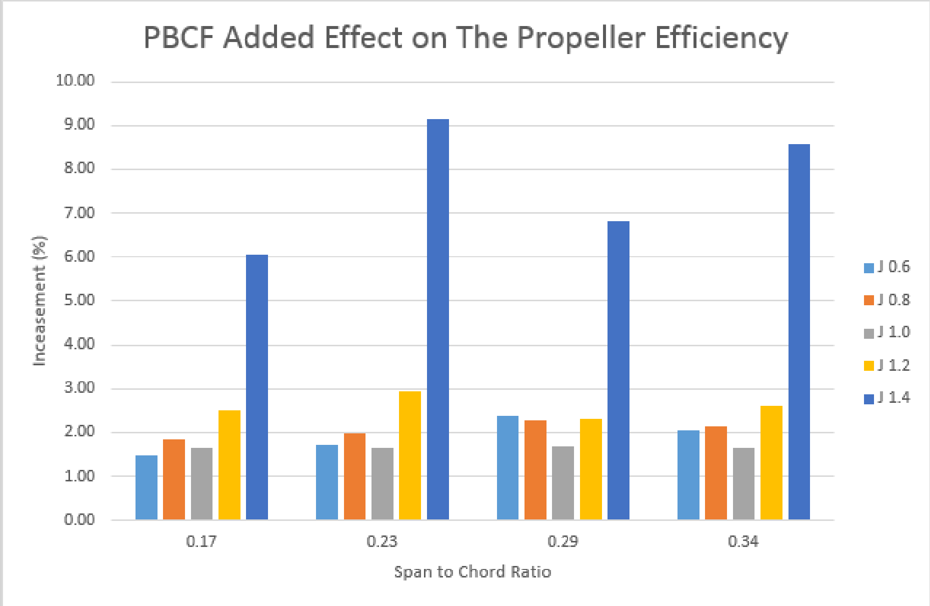

Figure. 9. PBCF added effect on the propeller efficiency

From Figure 9, it can be seen that the efficiency improvement by the propellers with span to chord ratios 0.23, 0.29 and 0.34 are not much different. A propeller with span to chord ratio PBCF 0.17, the average efficiency is 2.71. At the propeller with span to chord ratio PBCF 0.23, the average efficiency is 3.49. At the propeller with span to chord ratio PBCF 0.29, the average efficiency is 3.10. At the propeller with span to chord ratio PBCF 0.34, the average efficiency is 3.40.

B. Flow

One of the functions of using PBCF is to reduce the hub vortex. In Figure 10 can be seen that in the C4-40 propeller without PBCF the flow behind the propeller is turbulent and centered. The flow behind the propeller after adding PBCF with a span to chord ratio (STC) PBCF 0.17 looks wide. However, flow turbulence still occurs at the rear of the propeller. The effect of adding a boss cap fins propeller began to be seen clearly in propellers with span to chord ratio (STC) PBCF 0.23.

This can be seen in Figure 10. The flow at the rear of the propeller looks wider. In addition, the flow of propellers with a PBCF 0.23 span to chord ratio (STC) has begun to form laminar flow. The effect of adding propeller boss cap fins to propeller C4-40 on PBCF 0.29 and 0.34 span to chord ratios do not have a big difference. The phenomenon of reduced turbulent flow behind the propeller due to the addition of the boss cap fin propeller indicates that the addition of the propeller boss cap fins to the propeller can reduce the hub vortex.

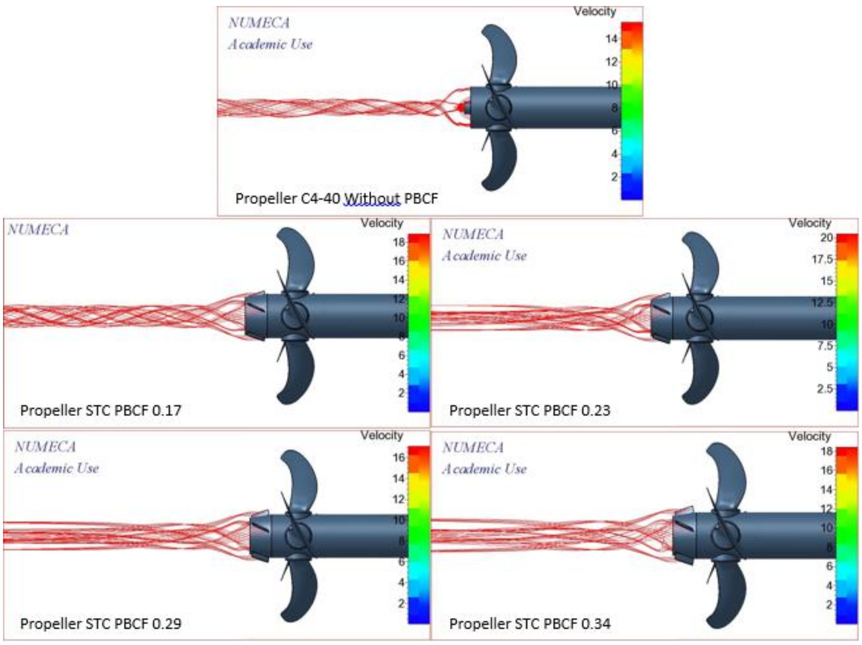

Figure. 10. The propeller flow after addition of PBC

IV. CONCLUSION

Based on the simulation, it can be taken some conclusions as follows:

1) The addition of PBCF can increase thrust, torque, and efficiency. But the PBCF span to chord ratio changes did not have a major impact on increasing thrust, torque and efficiency.
2) Increasing the span to chord ratio of PBCF can reduce the hub vortex on the propeller.

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