IMPROVED PROPELLER EFFICIENCY OF A FERRY SHIP WITH ASYMMETRIC PRE-SWIRL STATOR

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ABSTRACT

The International Maritime Organization (IMO) has introduced the importance of the Energy Efficiency Design Index (EEDI) to anticipate global warming and depletion of fuel oil through the development of an Energy Saving Device (ESD) in ship propulsion systems. Pre-swirl stator is a type of ESD installed in front of the propeller which aims to increase propulsion efficiency by reducing the loss of rotational energy in the propeller flow. This study was conducted to determine the effect of 4 blades pre-swirl asymmetric stator diameter on the improved propeller efficiency of KMP Bontoharu using Computational Fluid Dynamics (CFD) software (Ansys-CFX 18.1). The results showed that the use of a pre-swirl stator on the propeller of KMP Bontoharu could increase the propeller efficiency by 6.64% at a stator diameter of 1.1 D_P.

Keywords: Pre-swirl stator; Computational Fluid Dynamic; Propeller efficiency.

1. INTRODUCTION

More than 80% of passenger and cargo transportation is carried out by sea. This marine transportation sector is responsible for more than 30% of CO_2 emissions and around 3 - 4% of CO_2 emissions that have impacted humans (Bennabi et al., 2017). Efforts to reduce the use of fuel oil and exhaust gas emissions (NOx, SOx, and CO_2) in the marine transportation sector as regulated by the International Maritime Organization (IMO) continue to be improved through the development of an Energy Saving Device (ESD) in ship propulsion systems according to the Energy Efficiency Design Index (EEDI) required. The pre-swirl stator is a type of ESD that is installed in front of the propeller. The use of pre-swirl stator has been shown to increase propulsion efficiency by reducing the loss of rotational energy in the flow of the propeller (Takekuma et al., 1981). Some of the advantages of the pre-swirl stator compared to other types of ESD (such as contra-rotating propellers and ducted propellers) are simple shaft system, relatively low cost, high efficiency gains, and high reliability (Kim et al., 2004).

At the beginning, the pre-swirl stator (PSS) design consisted of 6-blades. This type is known as the symmetric axis pre-swirl stator design placed in front of the propeller and has been used on a number of commercial vessels to improve propulsion efficiency of ships. However, the stator design information is not widely found in a number of publications. Takekuma et al. (1981) have conducted some basic research with respect to the pre-swirl stator. They developed the calculation of the Stokes Theorem and simple experiment in designing the pre-swirl stator. The design has been applied to full-scale vessels with an efficiency increase of 7 - 8%. The KRISO Team has developed several fundamental studies about the pre-swirl stator design (Kim et al., 1993 and Lee et al., 1994), particularly related to procedures and analysis of the use of pre-swirl stator (symmetric and asymmetric) in increasing propulsion efficiency through numerical methods and model testing. Kim et al. (2004) have developed a 4-blade asymmetric pre-swirl stator from the previous 6-blade symmetric pre-swirl stator. The pre-swirl stator design configuration with 4-blades which includes 3 stator blades on the starboard and 1 other blade on the port side which called as the starboard stator or vice versa (see Figure 1). They concluded that using a pre-swirl stator with 4-blades on a single propeller increased propulsion efficiency by 5.6% compared to without

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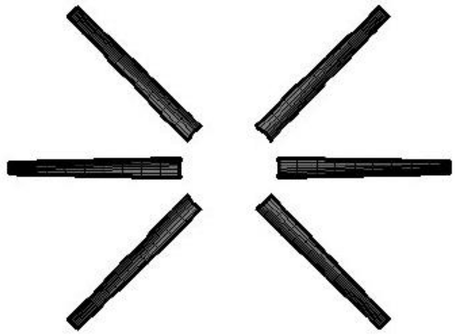
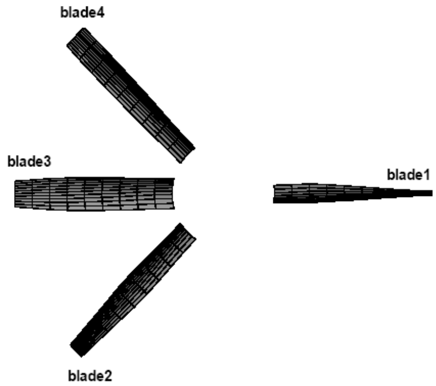
PSS. Although this result does not increase significantly compared to the use of 6 or 5 blades in previous studies, this reduction of blades can reduce the weight, volume and cost of making the stator by around 30%.



a) 6-blades stator (Takekuma et al., 1981)



b) 4-blades stator (Kim et al.,2004)

Figure 1. Blades design of pre-swil stator

Research on the 4-blade asymmetric pre-swirl stator that has been developed by Kim et al. (2004) continued to be improved by a number of researchers through optimization of a number of parameters either through numerical simulations or model testing. Zondervan et al. (2011) and Hassellar and Xing-kaeding et al. (2017) concluded that the usage of pre-swirl stator with a stator diameter greater than the propeller diameter (1.1 D_P) is able to improve propeller efficiency and prevent vortex tip cavitation. While Kim et al. (2013) in their research stated that the effect of this stator diameter has an effect on the amount of torque (Q) on the stator diameter of 1.0 D_P. They also mentioned that the optimum torque is very much influenced by the direction of rotation and the tilt of the stator blades.

Based on the above study, the 4-blades asymmetric pre-swirl stator design has a number of advantages to improve propulsion efficiency and is able to directly reduce fuel consumption and the emission of exhaust gas (NOx, SOx, and CO_2). This paper focuses towards the usage of asymmetric 4-blades pre-swirl stator of improved propeller efficiency of *KMP Bontoharu* ferry ship through CFD Sotware (Ansys CFX 18.1).

2. METHODOLOGY

2.1 Ship Data

KMP Bontoharu has been used as the object of this research. The ship has a capacity of 1050 GT, power propulsion (PB) 2x1000 HP with service speed (V_S) 6,618 m/s is owned by PT (Persero) ASDP Indonesia Ferry and operated on South Sulawesi in Bira-Pamatata crossing route. The lines plan, main dimension and propeller parameters of the ship are shown in Figure 2, Tables 1 and 2, respectively.

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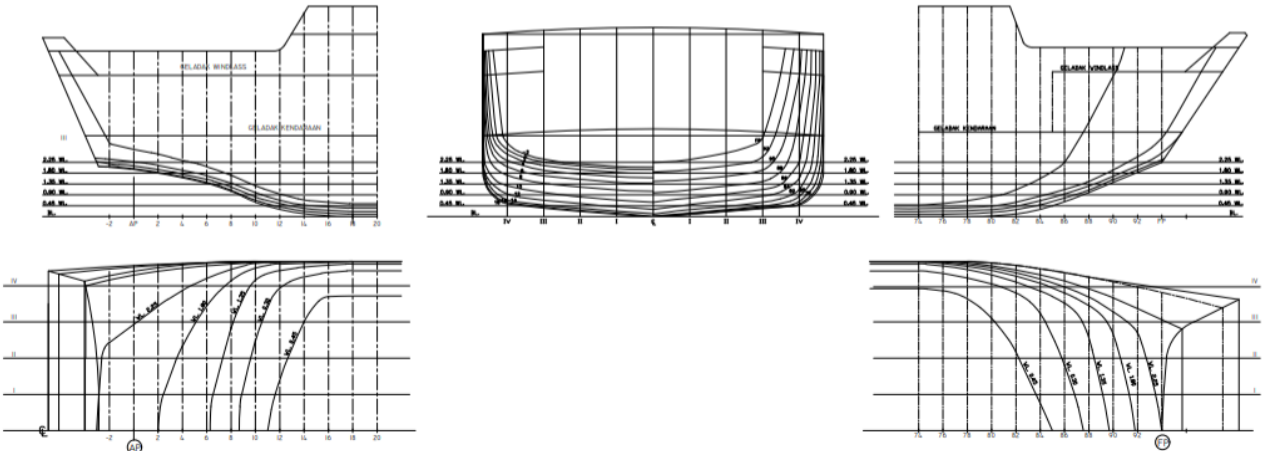

Figure 2. Lines plan of *KMP Bontoharu*

Table 1. Main dimension of ship

Parameters	Dim.
Length between perpendiculars, LBP (m)	47.45
Breadth, B (m)	14.00
Draft, H (m)	2.45
Speed, V_S (m/s)	6.618
Displacement, Δ (ton)	1148

Table 2. Parameters of propeller

Parameters	Dim.
Blade propeller number, Z	2 x 4
Propeller diameter, D (m)	1.422
Blade area ratio, Ae/Ao	0.550
Pitch diameter ratio, P/D	0.928
Propeller revolution, n (rot/s)	8.764

2.2 Design of Pre-Swirl Stator

The design and parameters of the pre-swirl stator (PSS) used in this study are the 4 blades type (Park et al., 2015). The pre-swirl stator is installed 0.5R or 0.335 m in front of the propeller with a distance of 2.3 m between the propellers. The stator blade design and parameters are shown as in Figure 3 and Table 3.

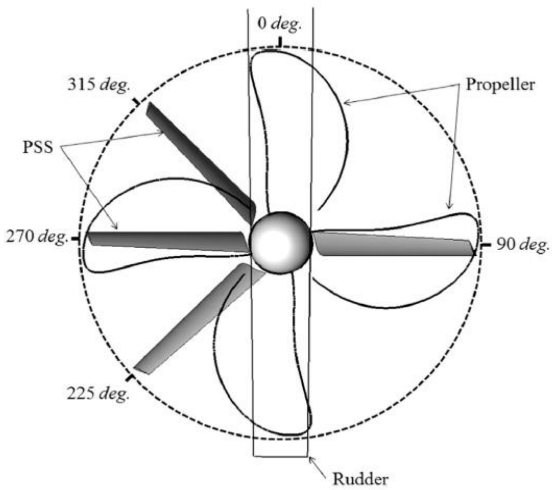

Figure 3. Design of pre-swirl stator blade

Table 3. Parameters of pre-swirl stator blade

Stator	Port side (deg.)	Starboard (deg.)	Angle (deg.)
Blade 1	270	90	7
Blade 2	145	225	10
Blade 3	90	270	8
Blade 4	45	315	4

2.3 CFD Setup

The prediction of thrust force and torque moment affecting the pre-swirl stator in this study uses a commercial CFD software (Ansys-CFX 18.1). The analyzed geometry models including the hull, propeller and pre-swirl stator have been modeled previously with the Rhinoceros 5.0 software as shown in Figure 4. The model of motion fluid flow around the object has been imitated using the incompressible, isothermal Reynolds-Averaged-

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Navier-Stokes (RANS) equation. This equation was used to determine cartesian flow field and water pressure around the ship model. This equation consists of a general solution of the three-dimensional Navier-Stokes equation, and the Shear Stress Transport (SST) turbulence model has been used in simulation. The SST turbulence model is the best combination model of the two model equations (k-ε and k-ω) (Menter, 2013). The k-ε model is excellent for predicting flows far from the boundary (wall), while the k-ω model is good for flows near walls. Bardina et al. (1997) stated that the SST model is the most accurate turbulent model used for flow modeling in the NASA Technical Memorandum. The turbulent models used by Purnamasari et al. (2017) in CFD simulation to resistance prediction of 17.500 DWT Tanker and compared by experiment. The boundary conditions are formed with a rectangle domain shape as shown in Figure 5. The length, width and height of the domain are 4.5, 3.0 and 3.0 times longer than the ship model (L), as shown by Kim et al. (2017). The dimensions of the domain was made quite long so that the wake shape of the object can be observed and also reducing the wall effect. ANSYS Workbench-CFX-Mesh was used in the meshing process as shown in Figure 6. Then, the element of boundary layer was formed around the object (20 layers) using this mesh. Meanwhile, the tetrahedral (unstructured) mesh is used in the areas that is far from the object.

A grid independence is the number of element to obtain a constant value of propeller thrust. The propeller thrust was compared by the Holtrop method (Holtrop and Mennen, 1982; Holtrop, 1984). Table 4 shows a summary of the propeller thrust from different numbers of elements. It was discovered that by using 3,155,002 elements the error was around -0.01 % and the simulation time 4 hours 20 minutes.

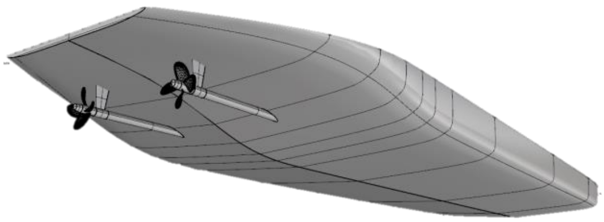

Figure 4. Geometry ship model (hull – propeller - PPS)

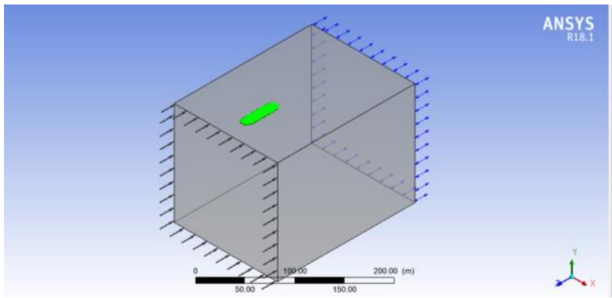

Figure 5. Domain setup

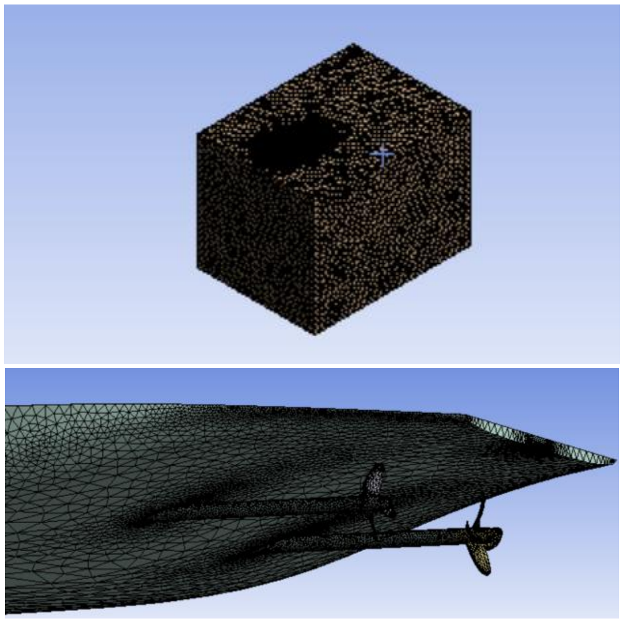

Figure 6. Meshing process

Table 4. Grid independence

Number of Element	867811	1870081	3155002
T	153.736	148.721	143.669
T (prediction)	144.422	144.422	144.422
Percentage (%)	0.06	0.03	-0.01
Time of Simulation	45m	2h 15m	4h 20m

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2.4 Data Analysis

The analysis of propeller efficiency (η_P) and propulsive efficiency (η_D) can be predicted by Xing-kaeding et al. (2017) in Equation 1 and 2:

$$\eta_P = \frac{TV_S}{2\pi\ nQ} = \frac{K_T}{K_Q}\frac{J_S}{2\pi} \qquad (1)$$

$$\eta_D = \frac{P_E}{P_D} = \frac{R_V V_S}{2\pi\ nQ} = \frac{TV_S}{2\pi\ nQ}\frac{R_T}{T} = \eta_P(1-t) \qquad (2)$$

where: T shows the thrust of propeller; Q is the torque of propeller; Vs is the ship speed; n is the propeller rotation; K_T is the thrust coefficient of propeller; K_Q is the torque coefficient of propeller; J_S is the speed advaced coeficient.

3. RESULT AND DISCUSSION

Figure 7 shows the relationship graph between the thrust (kN) and the ship speed (V_S) as a result of the combined hull-propeller model (self-propulsion) simulation with CFD Software (Ansys CFX 18.1). At the ship speed of 6.618 m/s, the thrust is 143.669 kN. This thrust value is 0.42% smaller than the simulation results through the open propeller. However, at a ship speed of 7.618 m/s the value of the thrust is greater than 0.34%. Furthermore, Figure 8 shows the relationship between torque (kN.m) and ship speed (V_S), at speeds of 6.618 and 7.618 m/s, respectively, the torque moment are 21.842 and 22.730 kN.m. The torque value are 9.43 and 9.15% smaller than the simulation results through the open water test. The complete results of the prediction of thrust and torque can be seen in Table 5.

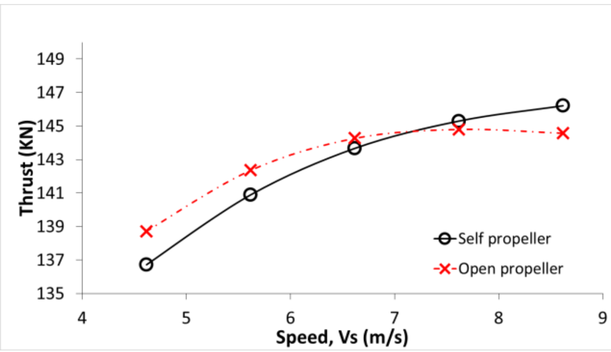

Figure 7. The relationship between thrust (kN) and ship speed (VS).

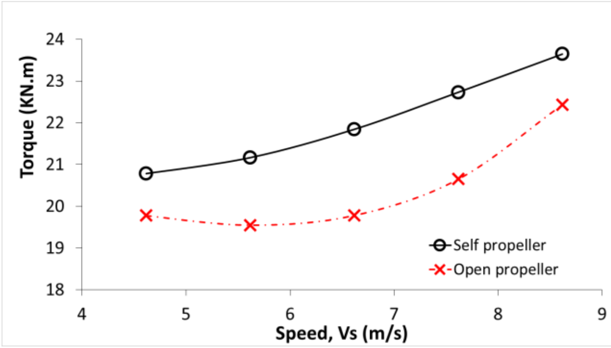

Figure 8. The relationship between torque (kN) and ship speed (V_S).

Figure 9 shows the simulation results of the relationship between thrust (kN) and pre-swirl stator (PSS) diameter (m) at ship speed and propeller rotation constant (Vs = 6,618 m/s and n = 8,764 rot/s) by software CFD software (Ansys CFX 18.1). At the PSS diameter equal to the propeller diameter (D_S = D_P), the thrust propeller is 149,676 kN or 4.18% larger than without the stator. At the same condition, a torque value of 21.96 kN.m is obtained or 0.50% greater than without the stator as shown in Figure 10. Furthermore, Figures 9 and 10 also shows the increasing trend of thrust and torque at D_S = 1.1 and 1.2 D_P.

Figure 11 shows the simulation results of the relationship between propeller efficiency (η_P) and propulsive efficiency (η_D) to changes in the pre-swirl stator diameter (D_S). At the PSS diameter equal to the propelle diameter (D_S = D_P), the propeller efficiency (η_P) and the propulsive efficiency (η_D) were obtained 0.82 and 0.74, respectively. This efficiency value was greater 4.91 and 0.70% than without using stator, respectively. Furthermore, the PSS diameter was greater than the propeller diameter (D_S = 1.1 D_P), the propeller efficiency (η_P) and the propulsive efficiency (η_D) increased by 6.64 and 1.37 respectively compared to without using a stator, while the PSS diameter was greater than the diameter. propeller (D_S = 1.2 D_P) propeller efficiency (η_P) and propulsive efficiency (η_D) were reduced by 5.18 and 0.58%, respectively. The complete results of the propeller performanec prediction are as

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shown in Table 6. Genaraly, the flow visualisation of the effect of pre-swirl stator's configuration are show in Figure 12 to 17.

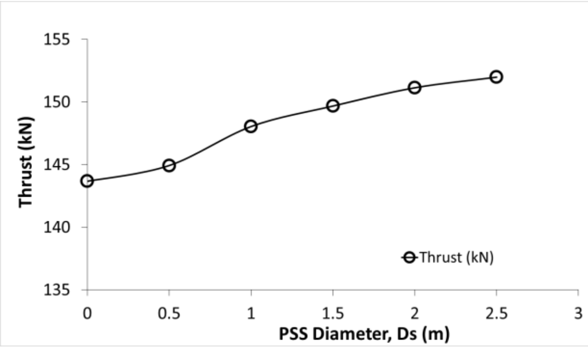

Figure 9. The relationship between thrust (kN) and PSS diameter (m).

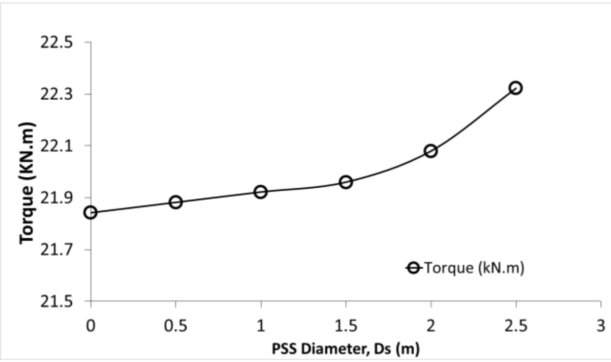

Figure 10. The relationship between torque (kN.m) and PSS diameter (m)

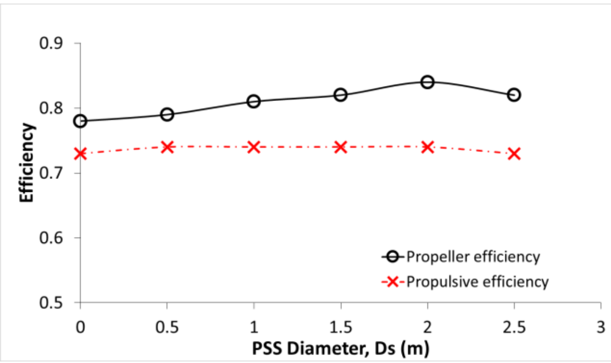

Figure 11. The relationship between propeller efficiency (ηP), propulsive efficiency (ηD) and PSS diameter (DS).

Table 5. Thrust and torque parameter

Speed (m/s)	Thrust (kN)		Torque (kN.m)	
	Self-prop	Open-prop	Self-prop	Open-prop
4.618	136.725	138.718	20.782	19.778
5.618	140.896	142.362	21.164	19.550
6.618	143.669	144.276	21.842	19.782
7.618	145.301	144.810	22.730	20.650
8.618	146.218	144.586	23.644	22.432

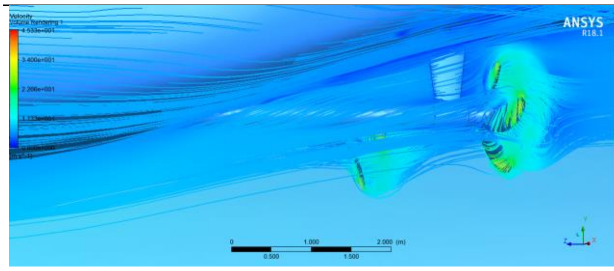

Figure 12. Simulation result without PSS

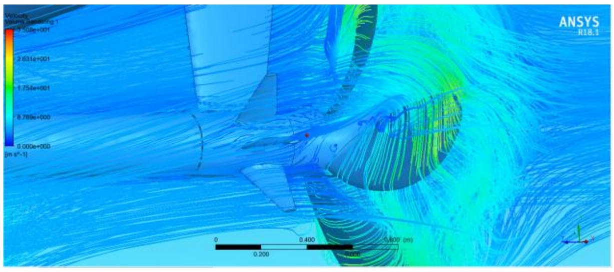

Figure 13. Simulation result with PSS (D_S=0.5 D_P)

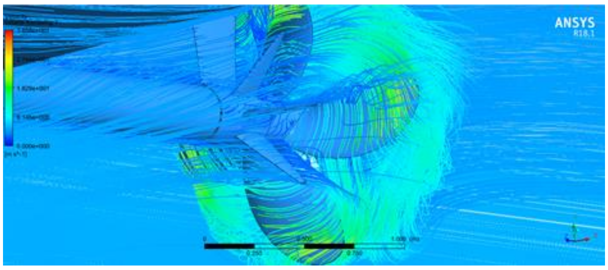

Figure 14. Simulation result with PSS (D_S=0.75 D_P).

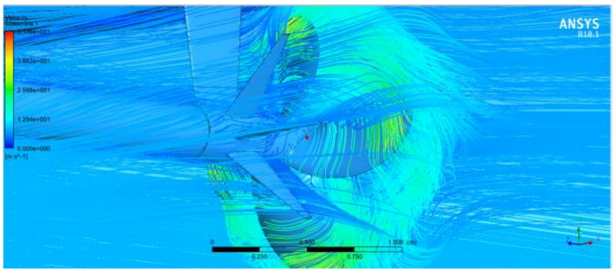

Figure 15. Simulation result with PSS (D_S=D_P).

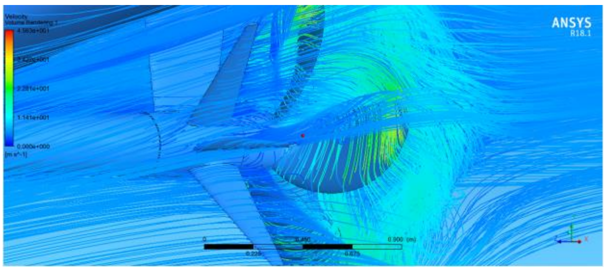

Figure 16. Simulation result with PSS (D_S=1.1 D_P).

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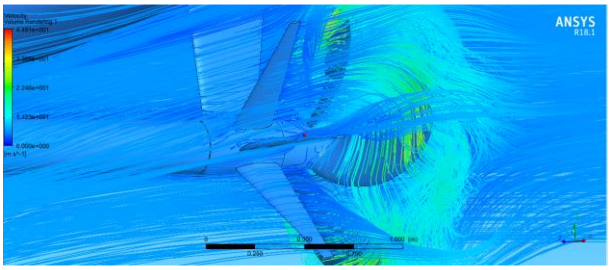

Figure 17. Simulation result with PSS (D_S=1.2 D_P).

Table 6. Propeller performance

Parameters	Stator's Diameter (D_S)					
	wo stator	0.5 D_P	0.75 D_P	1.0 D_P	1.1 D_P	1.2 D_P
n (rot/s)	8.843	8.790	8.773	8.734	8.630	8.703
Vs (m/s)	6.618	6.618	6.618	6.618	6.618	6.618
Thrust (kN)	143.669	144.927	148.038	149.676	151.133	151.982
Torque (kNm)	21.842	21.882	21.922	21.960	22.080	22.322
η_P	0.78	0.79	0.81	0.82	0.84	0.82
ηD	0.73	0.74	0.74	0.74	0.74	0.73
%Gain (ηP)	0.00	1.30	3.49	4.91	6.64	5.18
%Gain (ηD)	0.00	0.42	0.44	0.70	1.37	-0.58

4. CONCLUSION

The pre-swirl stator effect on propulsion system of *KMP Bontaharu* has been analyzed by using CFD software (Ansys CFX 18.1). It was concluded that the use of pre-swirl stator had significantly increased the thrust and torque on the propeller, the increasing thrust and torque is significant with the increase of the pre-swirl stator diameter, while the optimum propeller efficiency is obtained at the pre-swirl stator diameter (D_S = 1.1 D_P) which is equal to 0.84.

REFERENCES

Bardina, J.E., Huang, P.G., and Coakley, T.J. (1997). Turbulence Modelling, Validation, Testing and Development". NASA Technical Memorandum 110446.

Bennabi N, Menana H, Charpentier J.F,, Billard J.Y., Nottelet B. (2017), "Improving Efficiency and Emissions of Small Ships by the Use of Hybrid Electrical Propulsion", *Journal of Power Supply*, Vol. 15, No.2, pp 12-23. DOI:10.13234/j.issn.2095-2805.2017.2.001

Hasselaar, T. W. F. and Xing-kaeding, Y. (2017)," Evaluation of an energy saving device via validation speed /power trials and full scale CFD investigation", *International Shipbuilding Progress*, Vol. 63. No 3-4. pp169–195. doi:10.3233/isp-170127

Holtrop, J. (1984). "A Statistical Re-Analysis of Resistance and Propulsion Data", *International Shipbuilding Progress*, Vol. 31, pp. 272–276

Kim, M.C., Lee, J.T., Suh, J.C. and Kim, H.C. (1993), "A Study on the Asymmetric Preswirl Stator System," *Journal of Society of Naval Architect of Korea*, Vol. 30, No. 1, pp. 30-44.

Kim, M.C. V, Chun, H. H. M. and Kang, Y. D. V. (2004), "Design and Experimental Study on a New Concept of Preswirl Stator as an Efficient Energy-Saving Device for Slow Speed Full Body Ship", *SNAME Annual Meeting* pp. 1–11.

Kim, K., Andersen, M.L., Werner, S. Orych, M., and Choi, Y. (2013), "Hydrodynamic optimization of pre-swirl stator by CFD", *International Shipbuilding Progress*, Vol. 60,No. 1, pp. 233–276. DOI:10.3233/ISP-130092

Kim, M.C., Shin, Y.J., Lee, W.J., Lee, J.H. (2017), "Study on Extrapolation Method for Self-Propulsion Test with Pre-Swirl Device", *Fifth International Symposium on Marine Propulsion smp'17*, Espo, Finland.

corresponding author: andi_haris@ft.unhas.ac.id
DOI: 10.12962/j27745449.v2i1.73

Lee, J.T., Kim, M.C., Van, S.H., Kim, K.S. and Kim, H.C. (1994), "Development of a Preswirl Stator System for 300K VLCC", *Journal of Society of Naval Architect of Korea*, Vol. 31, No. 1, pp. 1-13.

Menter, F. R. (2009), "Review of the shear-stress transport turbulence model experience from an industrial perspective", *International Journal of Computational Fluid Dynamics*, Vol. 23, No. 4. pp 305–316. https://doi.org/10.1080/10618560902773387

Park, S., Oh, G., Rhee, S.H, Koo, B.Y., and Lee, H. (2015). “Full scale wake prediction of an energy saving device by using computational fluid dynamics”, *Ocean Engineering*, Vol. 101, pp 254–263. doi:10.1016/j.oceaneng.2015.04.005

Purnamasari, D., Utama, I.K.A.P., Suastika, I.K. (2017). CFD Simulations to Calculate the Resistance of A 17.500-DWT Tanker", *The 3rd International Seminar on Science and Technology, Postgraduate Program Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia*. pp 112-116.

Takekuma, K., Tsuda, S., Kawamura, A., and Kawaguchi, N. (1981), "Development of Reaction Fin as a Device for Improvement of Propulsive Performance of High Block Coefficient Ships", *Journal of the Society of Naval Architects of Japan*, Vol. 150, pp 74–84.

Xing-kaeding, Y., Streckwall, H. and Gatchell, S. (2017), "ESD design and analysis for a validation bulk carrier ", *International Shipbuilding Progress*, Vol. 63, No. 3-4, pp. 137–168. DOI:10.3233/ISP-170126

Zondervan, G., Holtrop, J., Windt, J. and Van Terwisga, T. (2011), "On the Design and Analysis of Pre-Swirl Stators for Single and Twin Screw Ships", *Proceedings of the Second International Symposium on Marine Propulsors - SMP’11.*

corresponding author: andi_haris@ft.unhas.ac.id
DOI: 10.12962/j27745449.v2i1.73