CFD Letters 12, Issue 4 (2020) 35-42

CFD Letters

Journal homepage: www.akademiabaru.com/cfdl.html
ISSN: 2180-1363

Study on the Resistance Reduction on High-Speed Vessel by Application of Stern Foil Using CFD Simulation

Open Access

Muhammad Arif Budiyanto[1,*], Muhammad Aziz Murdianto[1], Muhamad Fuad Syahrudin[1]

[1] Department of Mechanical Engineering, Universitas Indonesia, Kampus Baru UI Depok, Jawa Barat, Indonesia

ARTICLE INFO

Article history:
Received 19 February 2020
Received in revised form 16 April 2020
Accepted 21 April 2020
Available online 28 April 2020

Keywords:
High-speed vessel; Hydrofoil; Stern Foil; Ship Resistance

ABSTRACT

Stern foil is an innovation that can be used on high-speed vessel craft. This innovation uses the same principles as interceptor but using hydrofoil. Interceptor are used to reduce the wetted surface area of the transom by making vortex under the transom, this kind of change will increase speed and reduce the total resistance of the ship. The mechanism on how the stern foil reduces the total resistance is an interesting question in term of ship hydrodynamics. This study aims to analyse the resistance reduction on high-speed patrol vessel by application of stern foil using simulation model. The study was carried out using computational fluid dynamics (CFD) with hydrodynamic parameters using a variation of the angle of attack 3˚ and 0˚ on Froude number range 0.6 - 1.3 with service load at 2 kg. The simulation result was obtained the optimal work for stern foil is at service load (2 kg) is a reduction in the total resistance of about 26,70% with the angle of attack is 0˚ in Froude number 0.9.

1. Introduction

In terms of vehicle design, fuel efficiency is the main problem, both in terms of land, air and even sea vehicles. The ship's resistance affects the efficiency of marine vehicles, especially the ship, where the way to minimize the resistance is to optimize the shape of the hull [1-3]. Decreasing ship resistance could be done in various ways, such as decreasing wave resistance or friction resistance by using stern flaps [4], and/or using hydrofoils that can raise the hull above the surface of the water, thus reducing resistance and increasing efficiency more than designing hulls [5]. There is also a lift interceptor, like hydrofoil, but with a different concept [6], Called vortex and the use of thick foil under the transom hull. Van Oossanen invented this technology and it was named Hull Vane. In a survey of 64 m Holland Class OPV yachts and 108 m Holland Class OPV, Hull Vane was able to reduce ship barriers by 26.5% and 15.3% respectively [7-8]. The study also stated that the Holland Class 108 m OPV had a fuel reduction of 15.3% with a speed of 17.5 knots.

* *Corresponding author.*
E-mail address: arif@eng.ui.ac.id (Muhammad Arif Budiyanto)

https://doi.org/10.37934/cfdl.12.4.3542

Hull Vane also influences the pitch motion and wave resistance of the vessel as well as increasing the resistance [9]. In experiments using a 167 m Ropax Vessel Norbank and 167 m Container Vessel Rijinborg vessel with simulation and testing process, this was shown to decrease pitch motion by 9.7% and 4.9% respectively, with 2 m wave height, decreasing wave resistance by 17.3% and 4.46%. With the same vessel as Andrews *et al.,* [10] which is AMERC Series # 13 Patrol Vessel, Uithof *et al.,* [11] is carrying out a comparative study of the use of Hull Vane, trim wedges, interceptors, and ballasting, showing that the Hull Vane has the greatest reduction in resistance on Fr 0.35, exactly 32.4 percent. In other experiments with different series, namely # 3, # 4, # 8, # 11, and # 13 in Avala's Fr 0.5-0.7 using Hull Vane, showing a 4% reduction in resistance, -10%, 18.3%, 21.3%, and 12.3% [12].

Based on the available literature, there is still an interesting research gap to study, which is a very limited study on the effect of stern foil in the range of Fr above 0.7 both through simulations and experiments. Thus, the research on the effect of stern foil with a Fr above 0.7 will be a significant result for the hydrodynamics field of ships. This work is aimed at measuring the application of stern foil to patrol boats using NACA foil asymmetry to produce lifting power. Displacement was defined as a separate load of operation. In order to prove additional translation force on the x-axis, researchers set the stern foil parallels to the keel at the 3 ° counter clockwise angle to x-axis. In addition, this research conducted Froude number simulation ranging from 0.6 to 1.3 and validated with experimental data. This value of the Froude number is based on the class of high speed ships above 0.5.

2. Design of Ship Model and Simulation Method

2.1 Particular Dimension of Ship Model with Stern Foil

The model used in this study is the Mark VI Patrol Vessel with a high-speed model and a unique slender body model, with principle dimension are Length overall 25.8 m, Beam 6.2 m, Draught 1.2 m and Fn >1 [13-14]. The simulation was conducted on Froude Number 0.6-1.3 with ANSYS (Fluent) Student Version, which is different from other studies before Froude Number was used below 1. The model used uses a scale of 1:25.8, displaying the ship's dimensions and plan on Table 1 and Figure 1.

Table 1
Scaled ship’s dimension

Model		
Length Overall (LoA)	1	Meter
Beam (B)	0.24	Meter
Draught (T)	0.04	Meter
Displacement	3.25	Kg
Block Coefficient (Cb)	0.37	
Model scale	1:25	

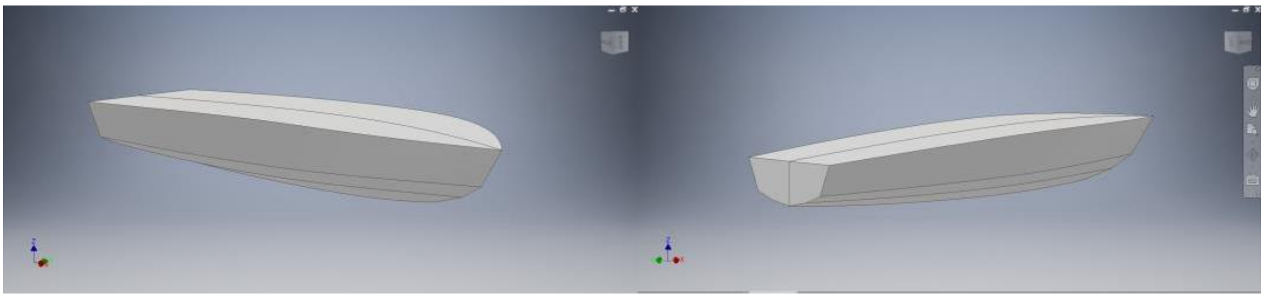


Fig. 1. Patrol hull design without stern foil

Stern foil used was asymmetric NACA 4412 [15] because researchers are most commonly using and studying this type of NACA, besides that the lifts produced at NACA are built to hit 80 percent of ship load. The hydrofoil was designed with the section of NACA 4412 and the chord length 4cm, span 20cm by this requirement as shown in Figure 2. Also used in this analysis is symmetrical NACA 0010 as a strut linking the stern foil and vessel.

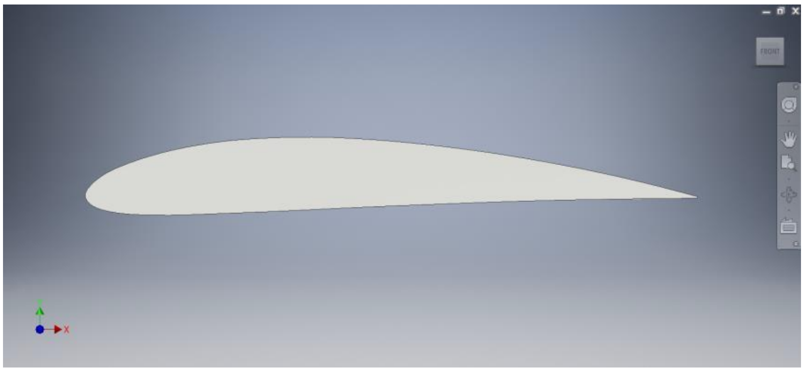


Fig. 2. Side view hydrofoil NACA 4412

The stern foil was equivalent to transom under the keel with trailing edge. Therefore, the depth of the stern foil is 1.5 inches (6 cm) from the based water surface, with an angle of attack 3 as well as 0 as the x-axis. The defined configuration is shown on Figure 3.

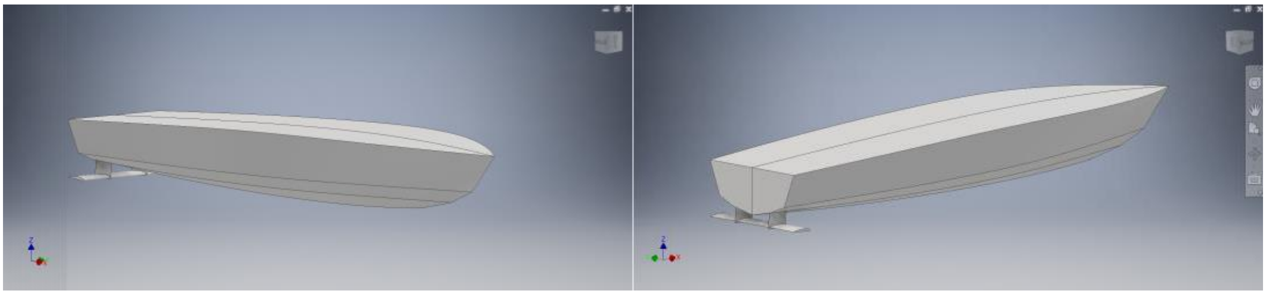


Fig. 3. Configuration of stern foil on the transom of Patrol hull

2.2 Simulation Method

Researchers used Ansys Fluent in this analysis as a multi-fluid computational fluid dynamics media [16]. The equation of Reynold's Averaged Navier Stokes (RANS) became the basis of this simulation, using k-bis SST as a turbulent and incompressible flow medium, the formula goes down to Eqs. (2) and (3) [17]:

$$\frac{\partial(\rho k)}{\partial_t} + \frac{\partial(\rho u_j k)}{\partial x_j} = P - \beta^* \rho \omega k + \frac{\partial}{\partial x_j}\left[\left(\mu + \sigma_k \frac{\rho k}{\omega}\right)\frac{\partial k}{\partial x_j}\right] \quad (1)$$

$$\frac{\partial(\rho k)}{\partial_t} + \frac{\partial(\rho u_j \omega)}{\partial x_j} = \frac{\gamma \omega}{k} P - \beta \rho \omega^2 + \frac{\partial}{\partial x_j}\left[\left(\mu + \sigma_\omega \frac{\rho k}{\omega}\right)\frac{\partial k}{\partial x_j}\right] + \frac{\rho \sigma_d}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial \omega}{\partial x_j} \quad (2)$$

Where β, β*, γ, σk, and σd are closure constant coefficient and $P = \tau_{ij}\frac{\partial U_i}{\partial x_j}$, this simulation was incompressible flow, so P = 0. Model boundary conditions in Figure 4 Followed ITTC [18-19] standard for simulation. Inlet is 1-L from the model ship's bow (where L is Length waterline), with input fluid velocity equal to ship velocity (because the vessel is stationary and pushes liquid towards the ship). The outlet is 2-L with an incompressible flow option from the ship's transom.

The wall's top and bottom are 0.25 L from the deck and 1-L from the keel, respectively. And from the longitudinal axis the side of the wall is 1-L. The model and wall are defined as conditions of no-slip but with the addition of the option of numerical beach to damp wave near the outlet [20-21]. The ship model is free to move pitch and heave using User Define Function (UDF), where inertia moment (IYY) and inertia item (IXZ) are specified as shown in Eqs. (3) and (4). However, the ship's weight is also defined by the draft (2 kg).

$$z = z_a \cos(\omega_e t + \varepsilon_z \varsigma) \neq 0 \tag{3}$$

$$y = y_a \cos(\omega_e t + \varepsilon_y \varsigma) \neq 0 \tag{4}$$

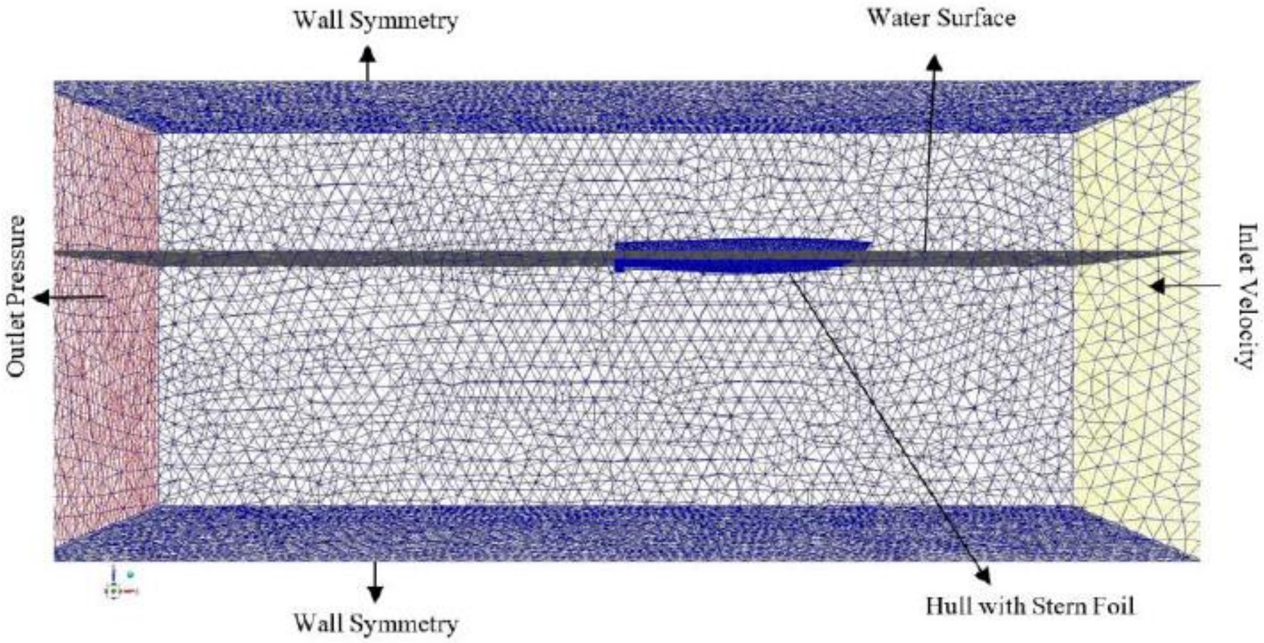


Fig. 4. Boundary condition of simulation model

The grid independence test to check the quality of the mesh simulation model was evaluated by cell skewness. If the skewness value is getting better 1, it indicates that the meshing made is of poor quality and higher error increases if simulations are carried out with this mesh, vice versa. Table 2 shows the obtained mesh quality and skewness results. Validation has been carried out by comparing the total resistance from the simulation results with experiments conducted in previous studies [22]. Validation results can be seen in Figure 5.

Table 2
Mesh skewness results

Mesh Quality	
Node	1254080
Elements	905087
Target Skewness	0.5
Average Skewness	0.23343
Skewness (Min)	4.03E-04
Skewness (Max)	0.66934

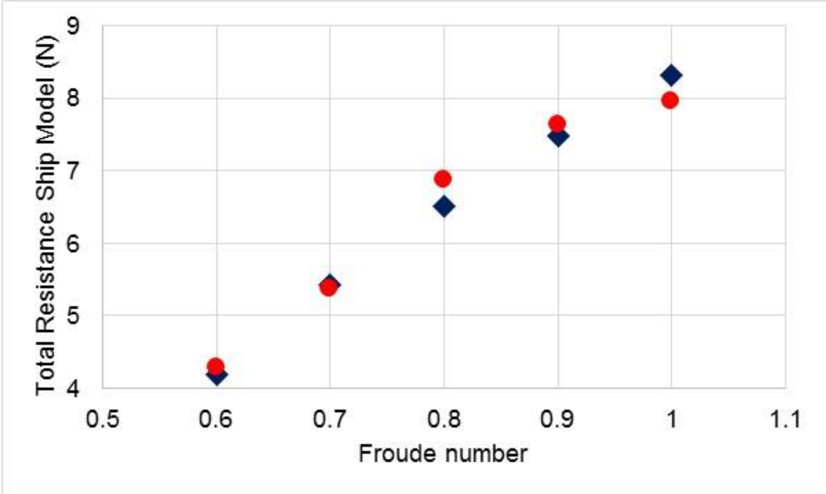
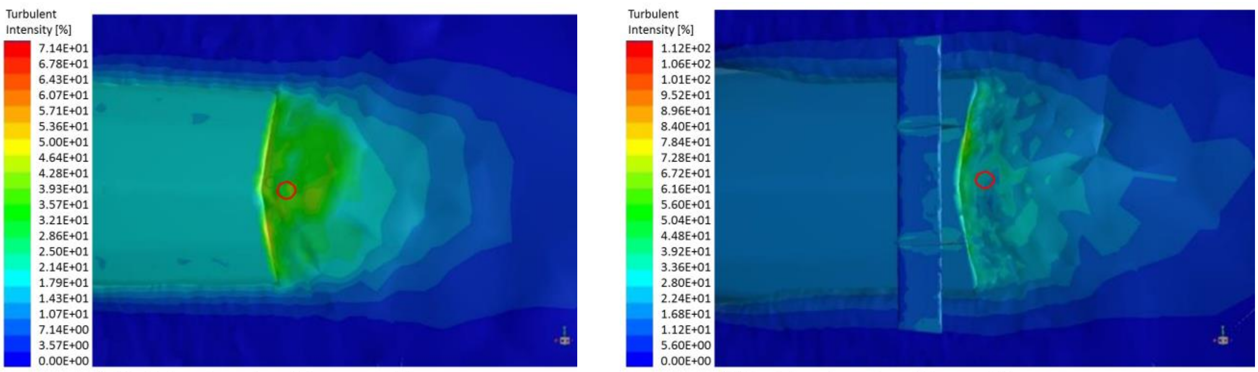


Fig. 5. Validation of simulation results with the previous experimental results

3. Result and Discussion

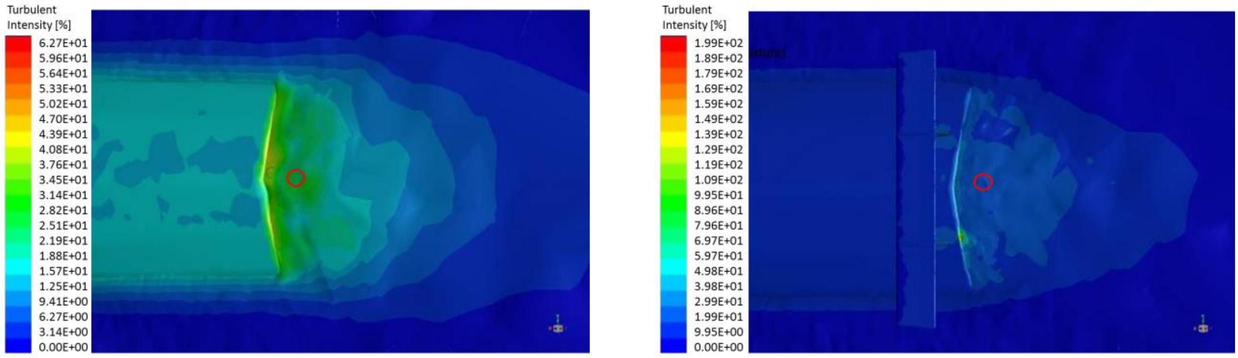
3.1 Turbulent Intensity

Figure 6 shows the turbulent intensity at the same Froude Number that is 0.9 with half-full loading, which in this Froude Number has the greatest reduction of resistance among other Froude Numbers with stern foil 0˚. As shown in the red circle, the greatest turbulent intensity when not using stern foil 0˚ based on the scale in the figure ranged from 34.5% - 37.7% and when using stern foil 0˚ ranged from 30% - 40%. However, the turbulent intensity far behind the transom when using stern foil 0˚ is in the range of 20% -30%, this certainly affects the magnitude of the ship resistance. Figure 7 illustrates the difference when using and not using stern foil 3˚ during Froude Number 1.1 with a loading of 2 kg which in this condition stern foil can reduce resistance by 23.268%. The greatest turbulent intensity shown by the red circle according to the color and scale that exists when not using and using stern foil respectively around 39.3-42.9% and 33.8-39.4%, and also the flow far behind the transom has an intensity of turbulence that is smaller is around 22.6-28.2%. This difference also affects the wetted surface area where there are differences in the waves created by hull when using and not using stern foil 3˚. This is illustrated in Figure 8 which shows that the conditions under the back of the transom are very dry and uniform when using stern foil 3˚.



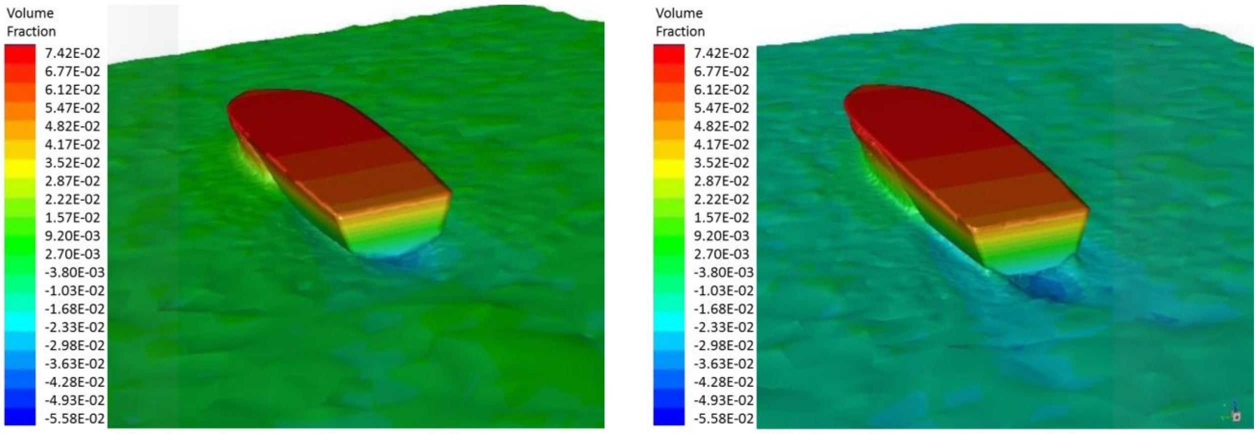
(a) Turbulent intensity without stern foil (b) Turbulent intensity with stern foil

Fig. 6. Turbulent intensity stern foil 0˚ with 2 kg loading condition on Froude Number 0.9



(a) Turbulent intensity without stern foil (b) Turbulent intensity with stern foil

Fig. 7. Turbulent intensity stern foil 3˚ with 2 kg loading on Froude Number 1.1



(a) Volume fraction without stern foil (b) Volume fraction with stern foil

Fig. 8. Volume of Fraction comparison without and using stern foil 3˚ (stern view)

3.2 Effective to Reduce Total Resistance

Figures 9 and 10 show that the stern foil 0˚ and 3˚ are quite optimal in a half-full vessel condition or with a load of 2 kg. Seen in the trend line referred to starting Froude Number 0.7 shows a significant difference from when not using stern foil 3˚. Reduction of total resistance occurred around 3.218% - 23.268% compared to the model of the ship without a 3˚ stern foil. The total reduction occurred at Fr 1.1 around 23.268% which is in accordance with the experimental results. Furthermore, a total decrease of 20% occurred in the compilation of Froude Numbers above 1, 23.268%, 21.86%, and 21.455% in Froude Numbers 1.1, 1.2, and 1.3, which showed that stern foil 3 ˚ works more effectively on Froude number above 1. This proves about which increases the power produced in the stern foil Compared to the effective stern foil 3˚ at Fr> 1, with an angle of attack 0˚, the effectiveness of the total resistance reduction occurs at around Fr < 1, Further Froude Number 0.7 - 0.9 when related to corresponding reductions reached 7.795%, 18.865%, and 26.705%. In addition, the reduction of total resistance is less effective at Fr≥1 compared to stern foil 3˚. And also, the reduction of total resistance occurs around 7.795% - 26.705% with the highest reduction value occurring at Froude Number 0.9, then increasing due to the increase in Froude Number respectively about 17.338%, 16.554%, 13.305%, and 14.743% at Fr 1, 1.1, 1.2 and 1.3. The difference is that due to the ship planning or trimming the rear the greater the angle, the thing that affects the angle of attack on the stern of the foil becomes greater with respect to the x axis which causes obstacles to be higher by 3˚.

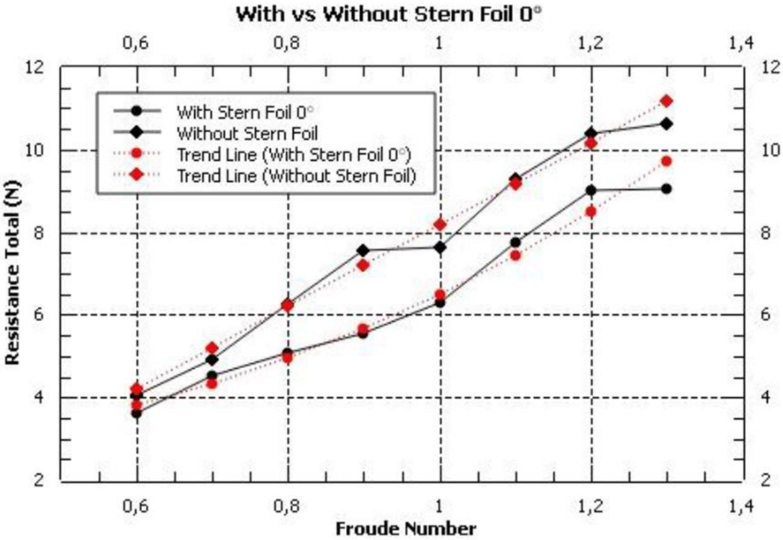


Fig. 9. Comparison application of stern foil using 0 ˚ angle

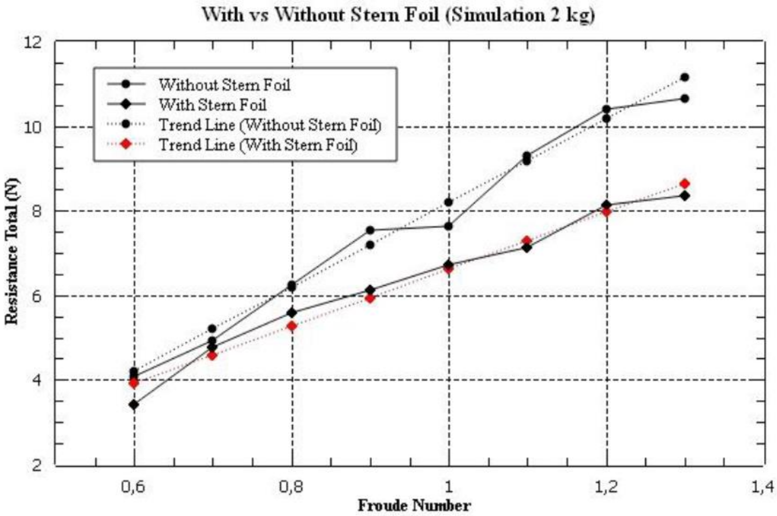


Fig. 10. Comparison application of stern foil using 3 ˚ angles

4. Conclusion

Simulations with the CFD method have been carried out on patrol vessels using stern foil. Based on the data and analysis of the research, the following conclusions can be concluded from the model simulated with different loading, stern foil works optimally at a load of 2 kg, either by using 3˚ stern foil or 0 ˚ stern foil. In 3˚ stern foil, the optimum resistance reduction occurred in Froude Number 1.1 - 1.3 with the reduction of successively 23.26%, 21.86%, and 21.45% where in Froude Number 1.1 had the largest reduction. Whereas at 0˚ stern foil, the reduction of optimal resistance occurs in Froude Number 0.7 - 0.9 with the reduction of successively 7,79%, 18,86%, and 26,70% where in Froude Number 0.9 has the largest total resistance reduction.

Acknowledgement
Authors would like to thanks to Directorate of Research and Community Engagements (DRPM) Universitas Indonesia for providing grant PITTA B contract number NKB 0761/UN2.R3.1/HKP.05.00/2019. Authors also thanks to Department of Mechanical Engineering, Faculty of Engineering, Universitas Indonesia for supporting facility equipment.

References

[1] Campana, Emilio Fortunato, Matteo Diez, Giampaolo Liuzzi, Stefano Lucidi, Riccardo Pellegrini, Veronica Piccialli, Francesco Rinaldi, and Andrea Serani. "A multi-objective DIRECT algorithm for ship hull optimization." *Computational Optimization and Applications* 71, no. 1 (2018): 53-72. https://doi.org/10.1007/s10589-017-9955-0

[2] Diez, M., A. Serani, E. F. Campana, and F. Stern. "CFD-Based Stochastic Optimization of a Destroyer Hull Form for Realistic Ocean Operations." In Proc. FAST. 2017.

[3] Budiyanto, Muhammad Arif, Jansen Novri, Muhammad Idrus Alhamid, and Ardiyansyah. "Analysis of convergent and divergent-convergent nozzle of waterjet propulsion by CFD simulation." In *AIP Conference Proceedings*, vol. 2062, no. 1, p. 020066. AIP Publishing LLC, 2019. https://doi.org/10.1063/1.5086613

[4] Song, Ke-wei, Chun-yu Guo, Jie Gong, Ping Li, and Lian-zhou Wang. "Influence of interceptors, stern flaps, and their combinations on the hydrodynamic performance of a deep-vee ship." *Ocean Engineering* 170 (2018): 306-320. https://doi.org/10.1016/j.oceaneng.2018.10.048

[5] Vellinga, Ray. *Hydrofoils: Design, Build, Fly*. Peacock Hill Publishing, 2009.

[6] Avci, Ahmet Gultekin, and Baris Barlas. "An experimental investigation of interceptors for a high speed hull." *International Journal of Naval Architecture and Ocean Engineering* 11, no. 1 (2019): 256-273. https://doi.org/10.1016/j.ijnaoe.2018.05.001

[7] Bouckaert, B., K. Uithof, PG van Oossanen, N. Moerke, B. Nienhuis, and J. van Bergen. "A life-cycle cost analysis of the application of a Hull Vane to an Offshore Patrol Vessel." In *13th International Conference on Fast Sea Transport (FAST), Washington DC*. 2015.

[8] Uithof, K., P. van Oossanen, N. Moerke, P. G. van Oossanen, and K. S. Zaaijer. "An update on the development of the Hull Vane." In *9th International Conference on High-Performance Marine Vehicles (HIPER), Athens*. 2014.

[9] Uithof, K., B. Bouckaert, P. G. van Oossanen, and N. Moerke. "The Effects of the Hull Vane® on Ship Motions of Ferries and RoPax Vessels." *RINA Design & Operation of Ferries & Ro-Pax Vessels, London* (2016).

[10] Andrews, V. K. Avala, P. Sahoo, and S. Ramakrishnan. "Resistance Characteristics For High-Speed Hull Forms with Vanes. " In *13th International Conference on Fast Sea Transport (FAST), Washington DC*. 2015.

[11] Uithof, K., N. Hagemeister, B. Bouckaert, P. G. van Oossanen, and N. Moerke. "A systematic comparison of the influence of the Hull Vane®, interceptors, trim wedges, and ballasting on the performace of the 50m AMECRC series# 13 patrol vessel." *Proc. Warship* (2016).

[12] Avala, Venkata Karthik. "CFD Analysis of Resistance Characteristics of High-Speed Displacement Hull Forms fitted with Hull Vane®." PhD diss., 2017.

[13] HamiltonJet. "MK VI Coastal Riverine Force' JetBrief. " Woodinville WA, USA: HamiltonJet INC. 467, p. 651.

[14] U. S. N. E. C. Command. "MK V a t r o l o a t a c t h e e t a t r o l o a t a c t h e e t."

[15] AirfoilTools.com. (2019). NACA 4412. Retrieved from http://airfoiltools.com/airfoil/details?airfoil=naca4412-il

[16] ANSYS Inc. (2011). *Tutorial: Heave and pitch simulation of ship hull moving through head sea waves introduction setup and solution preparation* (pp. 1–17).ANSYS FLUENT 13.0 Tutorial Guide.

[17] Budiyanto, Arif, Bambang Sugiarto, and Bagus Anang. "Multidimensional CFD simulation of a diesel engine combustion: A comparison of combustion models." In *Proceedings of the FISITA 2012 world automotive congress*, pp. 879-893. Springer, Berlin, Heidelberg, 2013. https://doi.org/10.1007/978-3-642-33750-5_5

[18] ITTC - Recommended Procedures and Guidelines. (2011). Practical guidelines for ship CFD. 26th Int. Towing Tank Conf. International Towing Tank Conference 7.5-02-03

[19] ITTC. (2014). Practical guidelines for ship resistance CFD. ITTC – Recomm. Proced. Guidel. 27th (pp. 1–9). International Towing Tank Conference 7.5-03-03-01

[20] Ali, Arifah, Adi Maimun, and Yasser Mohamed Ahmed. "Analysis of Resistance and Generated Wave around Semi SWATH Hull at Deep and Shallow Water." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 58, no. 2 (2019): 247-260.

[21] Dorozhko, Veniamin M., Victor G. Bugaev, and Maksim V. Kitaev. "CFD Simulation of an Extreme Wave Impact on a Ship." In *the Twenty-fifth International Ocean and Polar Engineering Conference*. International Society of Offshore and Polar Engineers, 2015.

[22] Budiyanto, Muhammad Arif, Muhamad Fuad Syahrudin, and Muhammad Aziz Murdianto. "Investigation of the effectiveness of a stern foil on a patrol boat by experiment and simulation." *Cogent Engineering* 7, no. 1 (2020): 1716925. https://doi.org/10.1080/23311916.2020.1716925