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Comparative Study of Rudder Performance of Single Plate and Fishtail of SPOB Ship Using CFD Method

Amalia Ika Wulandari[1,*], Mukhtar Prabu Dewanagara[1], Muhammad Uswah Pawara[1], Syerly Klara[2]

[1] Naval Architecture Program, Kalimantan Institute of Technology, Balikpapan 76127, Indonesia
[2] Departement of Marine Engineering, Faculty of Engineering, Hasanuddin University, Gowa 92171, Indonesia

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ABSTRACT

Rudder is the most important hydrodynamic control surface on a ship to control horizontal movement. An important function of the rudder is to develop a force concerning orientation and motion relative to the water. The widely used type is the conventional type. However, the other types of rudders, other than the conventional type, are the single plate and fishtail types. This study aims to analyze the difference in performance between the single plate rudder on the Adeline 01 spob (self propeller oil barge) ship and the fishtail rudder on the value of lift force and drag force as well as find out the comparison of the two Rudders on the maneuvering force of the Adeline 01 spob ship. The method used was the Clark equation with the help of a CFD-based application to determine the performance of the ship lifts force and drag force by varying the turning angle by 5°, 10°, 15°, 20°, 25°, and 30°. The results obtained from this study was the Fishtail has better maneuverability at 5° and 10° angle variations with lift coefficient values of 0.0398 and 0.0522, and with Steady Turning Diameter (STD) values of 1882.9 m and 717.83 m. On another hand, the Single Plate rudder has better maneuverability at angle variations of 15° and 20° with lift coefficient values of 688.30 m and 330.77 m, and with STD values of 688.30 m and 330.77 m. At the angle variations of 25° and 30°, Rudder Fishtail has better maneuverability with lift coefficient values of 0.7712 and 0.9993, and with Steady Turning Diameter (STD) values of 53.40 m and 35.92 m

1. Introduction

A ship is designed by taking into account the regulations that apply both nationally and internationally. Standards for Ship Maneuverability is one of the international maritime standards (IMO) regulations [1]. Ship maneuvering performance can be predicted from the beginning of the design in order to meet the requirements because ship maneuvering is important to determine ship safety [2, 3]. Problems in the system cause ship collision accidents that often occur. So the ability to maneuver is needed by improving the ship's motion, namely optimizing the performance of the steering wheel.

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[*] *Corresponding author.*
E-mail address: amaliaikaw@lecturer.itk.ac.id (Amalia Ika Wulandari)

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Ship maneuvers are influenced by the design of the hull, propulsion system, and steering system [4, 5]. The rudder or commonly called the rudder is a control on the hydrodynamic surface of the ship which has a function to control horizontal movement [6]. The rudder has a function to develop forces related to orientation and relative motion in the air [7].

The magnitude of the steering force is determined by the size of the steering wheel and operating speed [8]. The force due to the ship's bend forms an angle of attack to the centerline [9] angle of attack to the centerline.

Good steering conditions will produce a good response for the ship so that it can position itself well. Rudder single plate is a simple plate with a two-dimensional square shape. One of the steering plates has a smaller angle compared to the others. The advantage is that it can achieve high efficiency with straightforward conditions [10]. To improve the ship's capabilities, various innovations were found in the steering system, one of which is the rudder fishtail. This steering is based on the basic shape of the existing steering wheel, both hanging and sitting like a fishtail. With excellent maneuverability, this innovation was developed based on the principle of flow behind the propeller which concludes that the top flow velocity of the propeller is the largest and will approach zero at the propeller boss [11]. This study will compare the performance of Rudder single plate and fishtail. We will find out which rudder is good to use in SPOB Ship's.

1.1 Barge

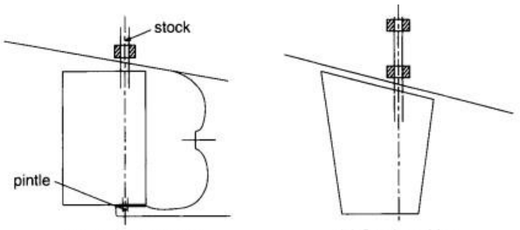
Barge is a ship with a flat hull or large pontoon. Barges are used for river and canal transportation to transport large quantities of goods. On the island of Borneo, barges are one of the most popular means of transportation to transport various mineral products, such as solid cargo (coal, wood, sand) and liquid cargo (crude oil and palm oil). The structure of a barge that carries solid cargo is different from that of a barge that carries liquid cargo. Barges carrying solid loads usually use the deck as cargo hold, whereas barges carrying liquid cargo have cargo hold and a hull design and structure similar to that of a tanker [12].

However, there are also several barges that are designed and built with self-propelled engines, and are equipped with the same safety and transportation equipment as ordinary ships which are commonly referred to as SPOB (self-propelled barge) and SPOB (self-propelled oil barge)

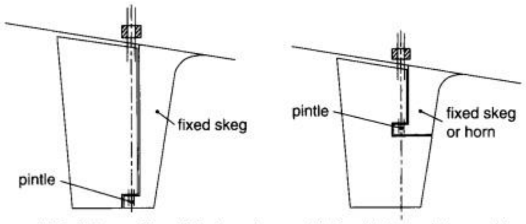
1.2 Rudder

In principle, the driving force of the ship's rudder is strongly influenced by the design, propulsion system, and steering system. Many of these factors directly affect the fluid power and torque acting on the steering blades [13]. Another situation that will have an impact is the condition of the rudder that is too large, causing the rudder propulsion engine to not match the rudder when the ship turns in direction. When a ship moves at a certain speed in free flow, various forces are generated, including the ship's resistance and the ship's thrust. To make the ship turn, the direction of the rudder angle changes to an angle with the centerline (angle of attack), and the resultant hydrodynamic force F is generated. The resultant force consists of a lift component whose direction is usually always perpendicular to the direction of the lift, the lift force whose direction is always perpendicular to the flow is a drag component. In determining the magnitude of the rudder force with the size of the rudder and the speed of the ship's journey varies.

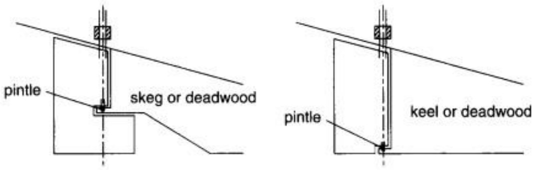
The type of rudder, its location, and placement relative to the propeller aim to affect the effectiveness of the ship's steering and controllability [14]. The rudder should be located near the stern and should be positioned in the blade flow for good handling. Its performance characteristics are very important for ship control as shown in Figure 1.



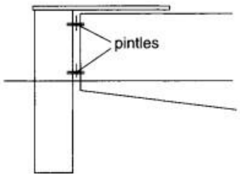
(a) Balanced rudder (b) Spade rudder



(c) Full skeg rudder (Unbalanced) (d) Semi-balanced skeg rudder



(e) Semi-balanced, aft of skeg or deadwood (f) Aft of keel or deadwood (unbalanced)



(g) Transom hung-surface piercing

Fig. 1. Rudder Variations

A ship can move with a certain speed (U) in a free flow, various forces are generated, including the ship's resistance and the ship's thrust. To make the ship turn, the direction of the rudder angle changes to an angle with the centerline (angle of attack), and a resultant force F is triggered. This force acts at a point called the center of pressure (CP) [15].

The figure 2 shows some of the components of the force acting on the steering wheel. Using different sizes of the steering area and operating speed to determine the size of the steering force, we can use the Lewis equation.

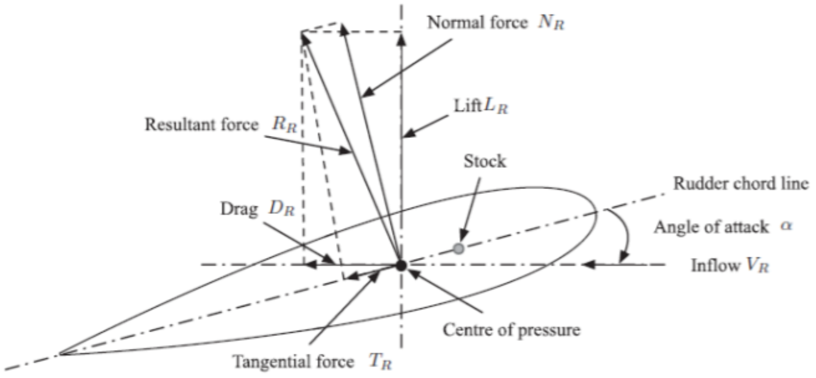


Fig. 2. Force Component on Rudder

According to “RULES FOR HULL” Vol. II, BKI rudder dimension on Figure 3

$$C_L = \frac{L}{(\rho/2)\ \mathrm{Ar}\ \mathrm{U}^2}$$

$$C_D = \frac{D}{(\rho/2)\ \mathrm{Ar}\ \mathrm{U}^2}$$

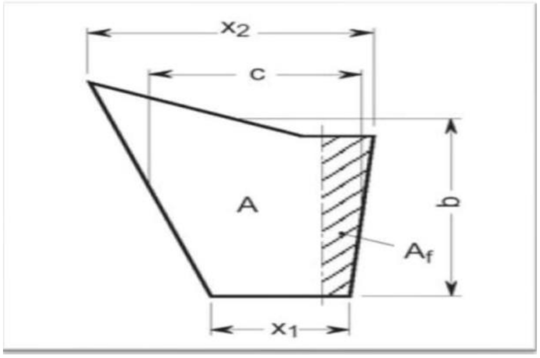


Fig. 3. Rudder Dimension

Where:
A = Rudder Area behind a shaft
Af = Rudder Area in front of a shaft
C = Rudder Width
B = Rudder Height
X1 = Rudder Bottom Width
X2 = Rudder Top Width

In the Rules FOR HULL Part II, BKI (Indonesian Classification Bureau) has made design rules for the ship's rudder so that it has good maneuverability. One of them is the rule that contains or sets the zone from the ship's rudder

$$A = C_1 . C_2 . C_3 . C_4 \frac{1{,}75 .L.T}{100} \quad [\mathrm{m}^2]$$

Where:
C1 = Ship TF Factor of ship type
= 1.0 types of common ships
= 0.9 types of bulk carriers and oil tanker with DWT more than 50,000 tons
= 1.7 for tugs and trawlers
C2 = rudder type factor
= 1.0 common rudder type
= 0.9 Steering Spade Spring
= 0.7 Steering with high lift
C3 = common rudder type factor
= 1.0 types of NACA profiles and common plates
= 0.9 types of hollow and mixed profiles
C4 = factor of the type of rudder design
= 1.0 type of rudder inside the propeller
= 1.5 types of rudder outside the propeller

Fluid is a substance that can flow in the form of liquid or gas and changes shape according to the location or container. Fluids can easily change their shape, so that their volume is equal to the volume of the container that limits the fluid. Application of mechanics in continuous media (solids and liquids). Flow can be distinguished or divided into 3 types of flow, namely, laminar flow, turbulent flow, and transitional flow [16].

2. Methodology

In modeling the ship's rudder, the initial step that is usually used to determine the size and data of the ship's rudder, in this modeling is a 3D software application to model the ship's rudder according to the data obtained and for the fishtail rudder itself, it follows the size of the single plate rudder whose data has been obtained [17].

In the process of simulation and analysis of Computational Fluid Dynamic (CFD) of Rudder Single Plate and Rudder Fishtail using several variations of angle of attack, namely 5°, 10°, 15°, 20°, 25°, 30°. The flow velocity from the inlet angle is given the value of Va which is 5.14444 m/s.

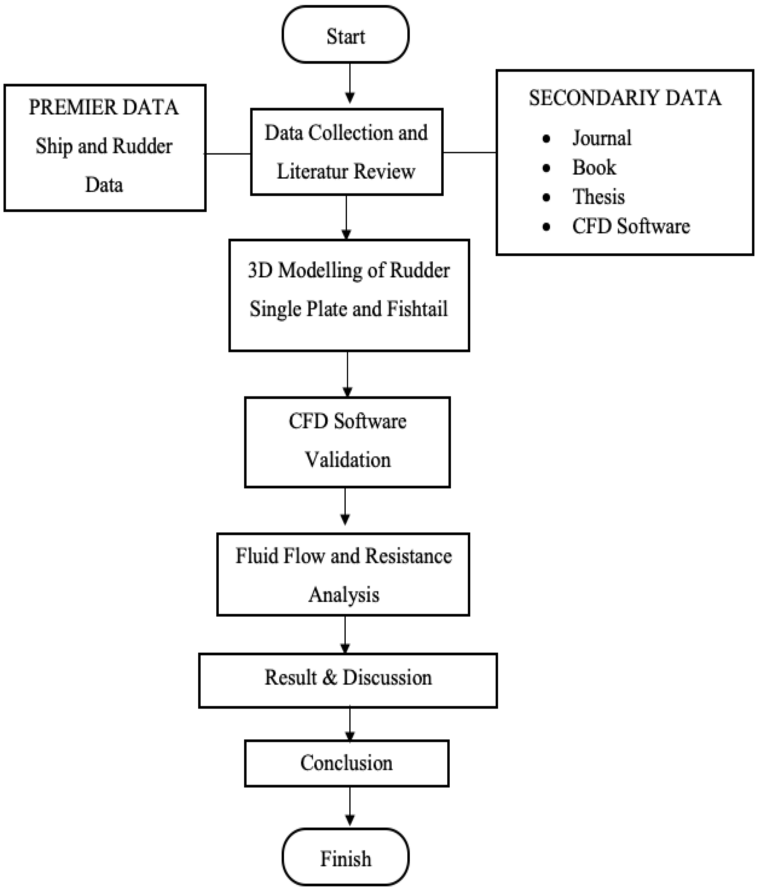


Fig. 4. Flowchart

3. Result and Discussion

In this study, ship and rudder data were obtained from a SPOB ship owned by PT. Sinar Alam Corporation which had been built in its shipyard and had data. Can be seen in Table 1, Table 2, and Table 3

Table 1
Ship Data

Ship Name	**ADELINE 01**
Type	Self-Propelled Oil Barge
LOA	71.40 m
Breadth	16.80 m
Depth	4.40 m
Draft	3.60 m
Engine	2 x Mitsubishi S6R2-MTK 610 PS / 1500 RPM
Gearbox	HCD 400 A Ratio 4 : 1

Table 2
Main Dimension of Rudder Single Plate

Notation	**Component**	**Value**	**Unit**
A	Cross-sectional area of Rudder	8.52	m^2
c	Rudder Width	1.8	m
b	Rudder Height	2.7	m
X1	Rudder Bottom Width	0.25	m
X2	Rudder Top Width	0.25	m

Table 3
Main Dimension of Rudder Fishtail

Notation	**Component**	**Value**	**Unit**
A	Cross-sectional area of Rudder	7.18	$m2$
c	Rudder Width	1.8	m
b	Rudder Height	2.7	m
X1	Rudder Bottom Width	0.2	m
X2	Rudder Top Width	0.2	m

After the running results are complete, the next stage is the post-processor process. At this stage, various simulation results will be presented, such as water pressure, water flow velocity, geometric pressure, etc. Simulation data is a phenomenon of pressure in the fluid that occurs in the steering blade, so that the resultant workforce in the form of drag and lift is obtained. The following are the results of contour visualization of various angle changes between the Single Plate rudder model and the Fishtail rudder model using the CFD method [18].

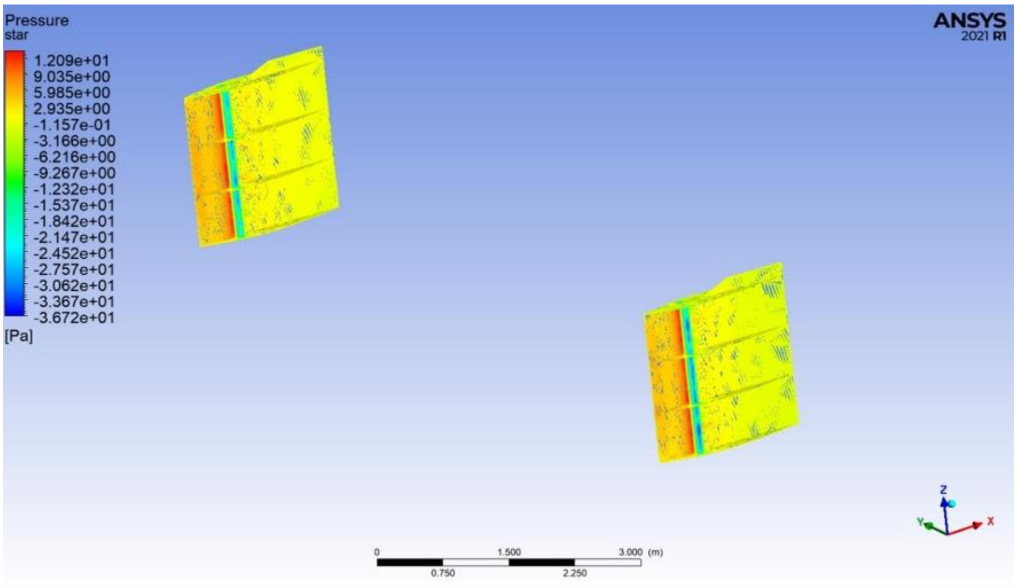


Fig. 5. Pressure distribution on 5˚ rudder single plate

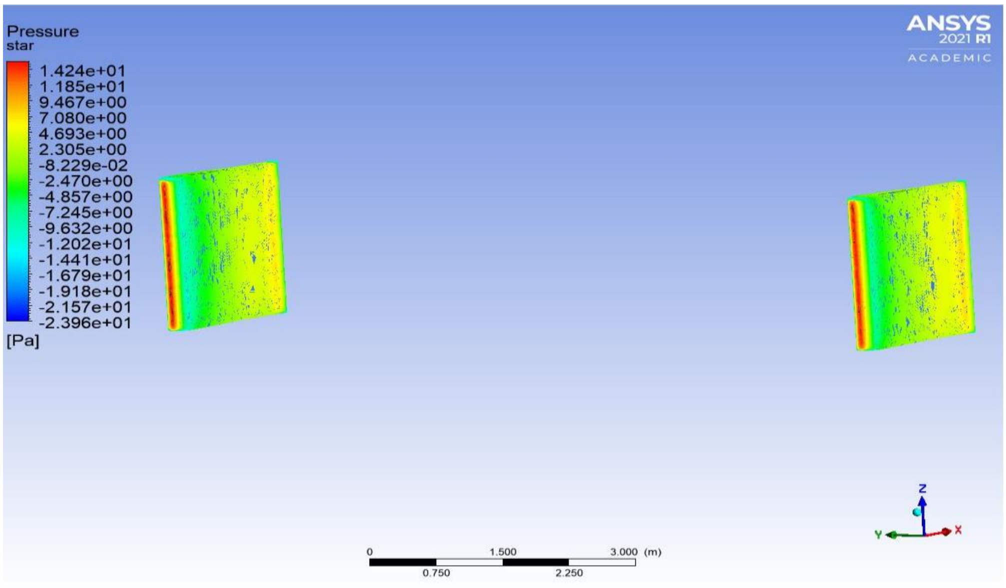


Fig. 6. Pressure distribution on 5˚ rudder fishtail

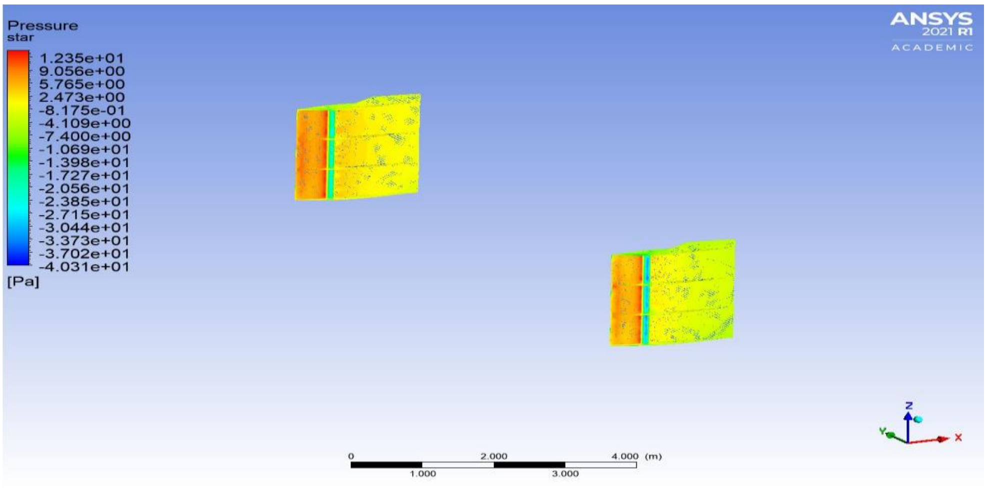


Fig. 7. Pressure distribution on 10˚ rudder single plate

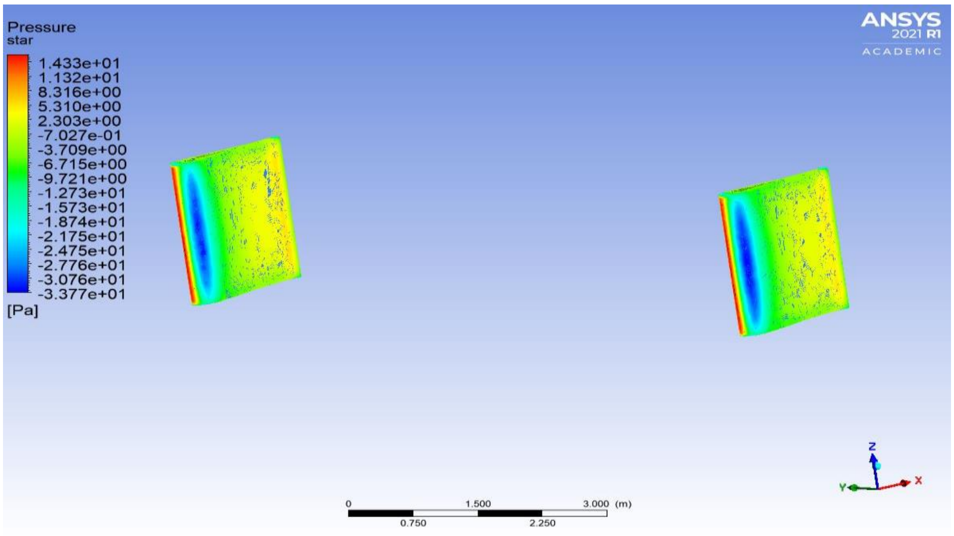


Fig. 8. Pressure distribution on 10˚ rudder fishtail

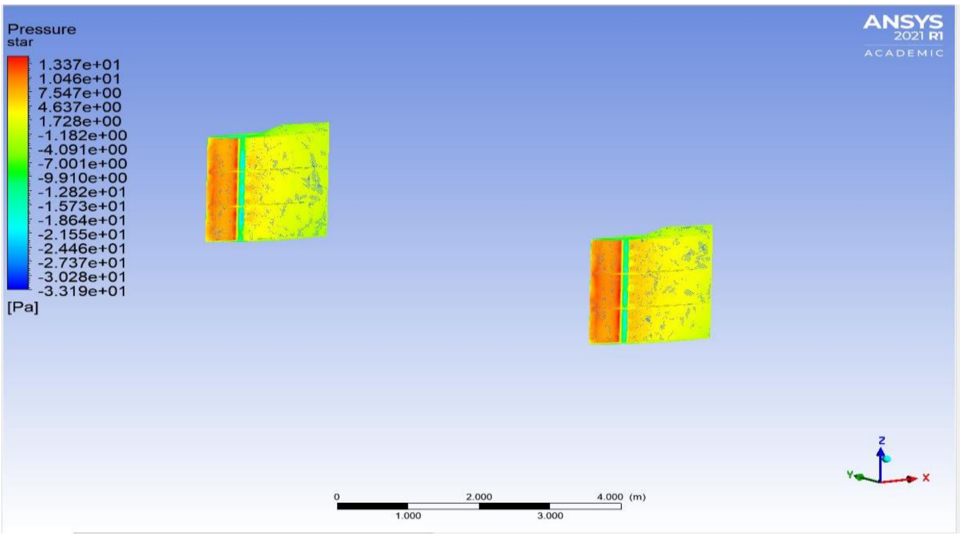


Fig. 9. Pressure distribution on 15˚ rudder single plate

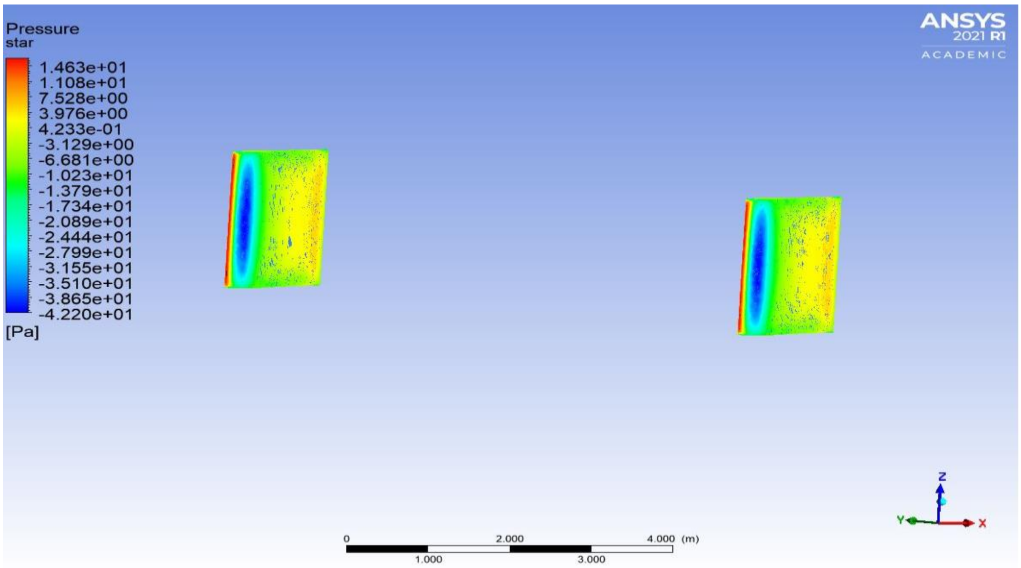


Fig. 10. Pressure distribution on 15˚ rudder fishtail

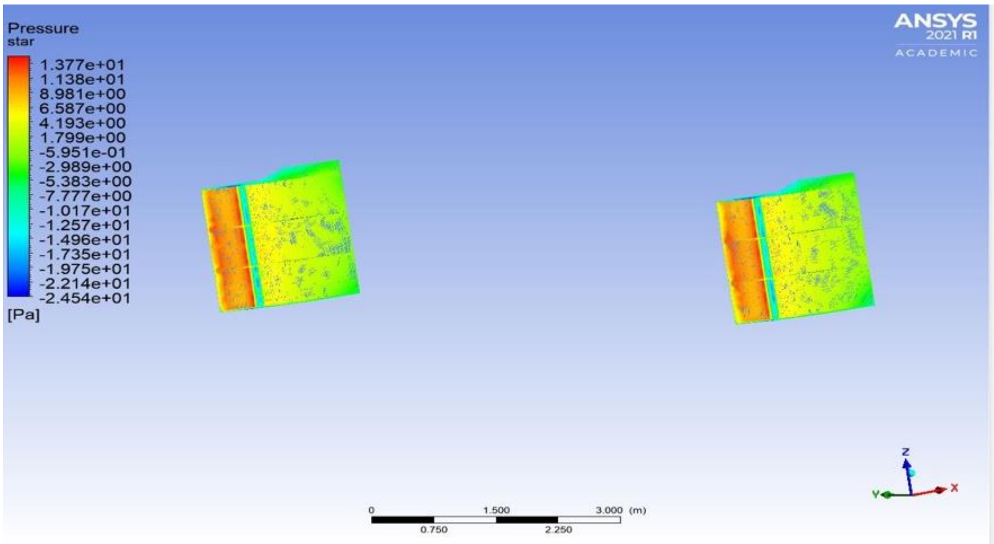


Fig. 11. Pressure distribution on 20˚ rudder single plate

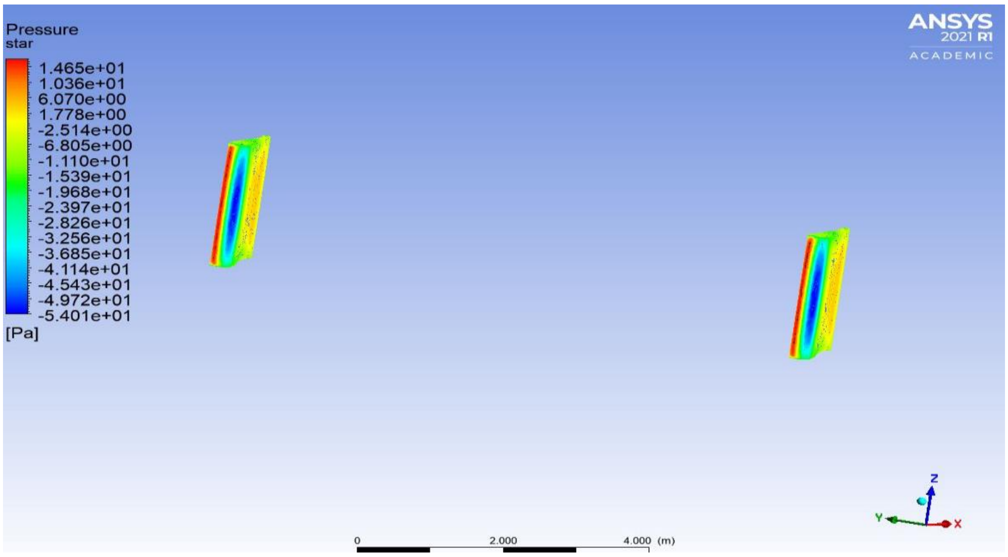


Fig. 12 Pressure distribution on 20˚ rudder fishtail

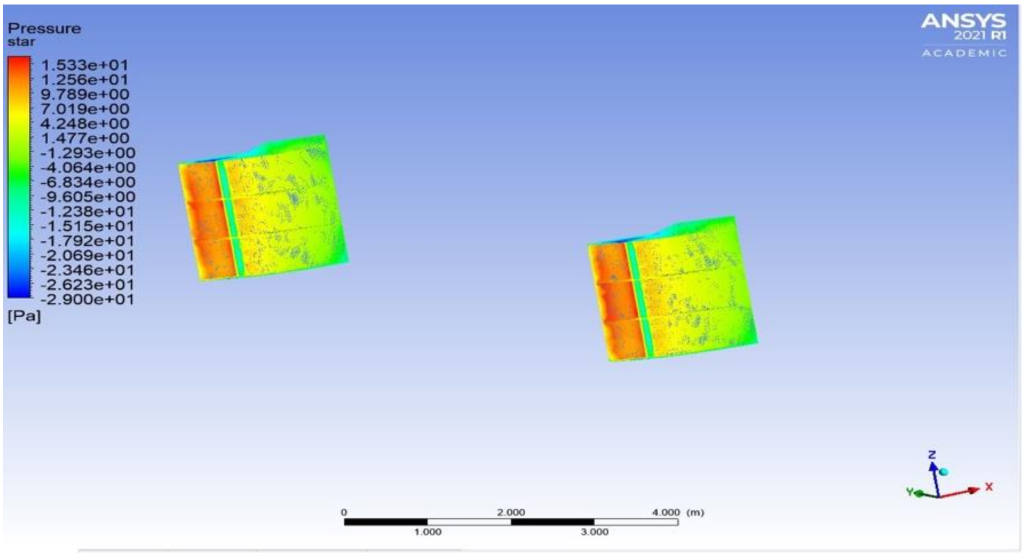


Fig. 13. Pressure distribution on 25˚ rudder single plate

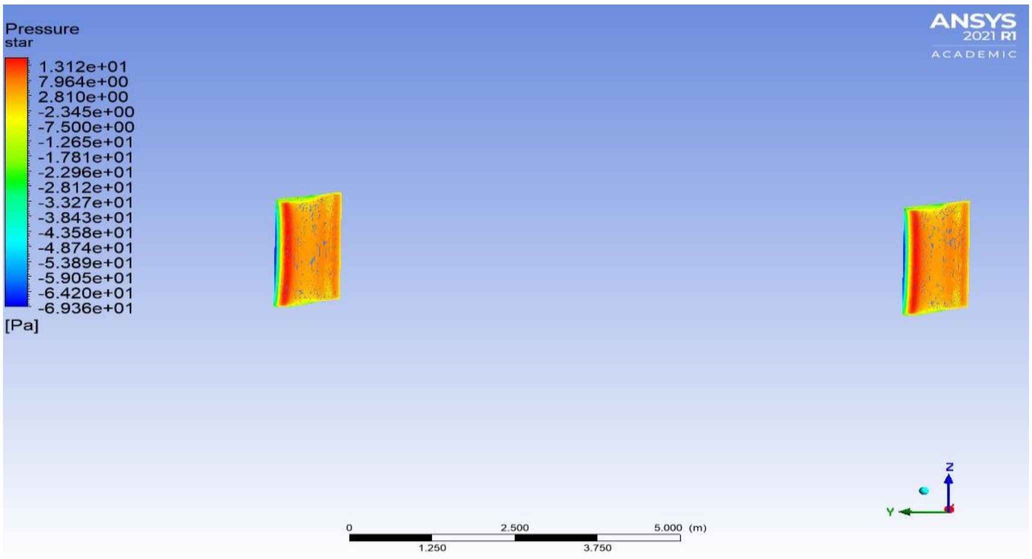


Fig. 14. Pressure distribution on 25˚ rudder fishtail

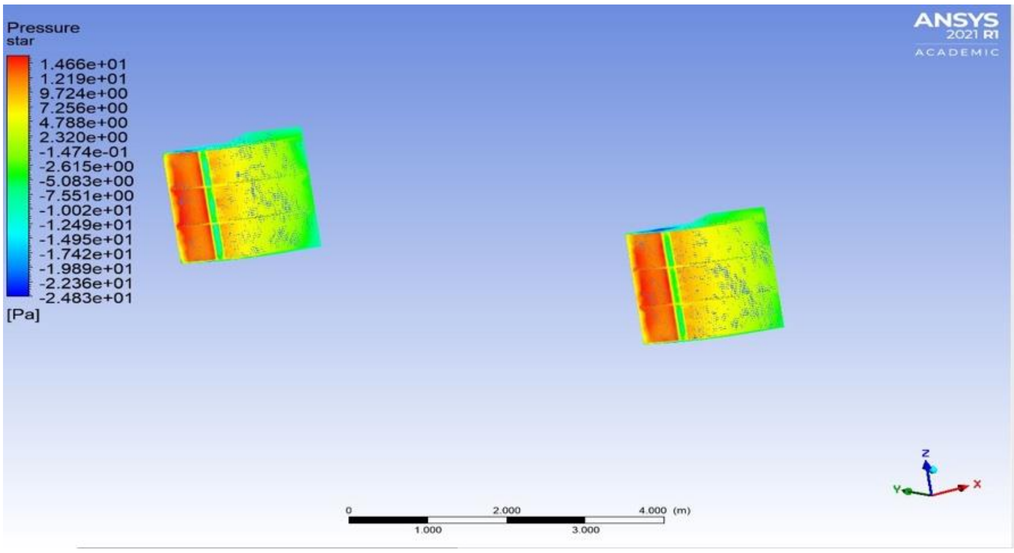


Fig. 15. Pressure distribution on 30˚ rudder single plate

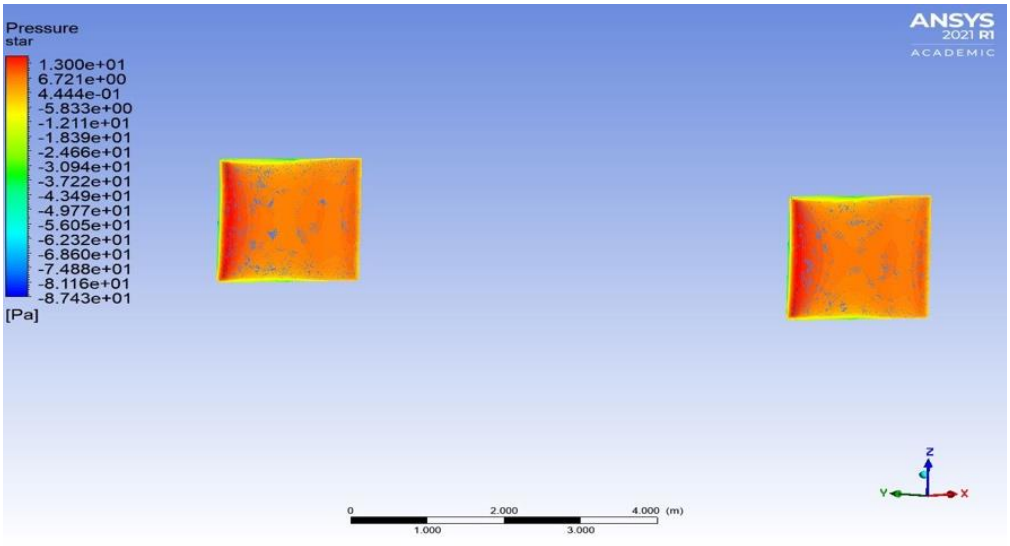


Fig. 16. Pressure distribution on 30˚ rudder fishtail

In addition to using CFD software to obtain the results of the pressure profile visualization from the simulation, the force acting on the steering blade is also obtained. On the x-axis is expressed as drag, and on the y-axis is expressed as lift. The simulation results on CFD software are shown in the Table 4.

Table 4
Lift and drag force data

Angle of attack (δ)	***Drag Force (N)***	***Lift Force (N)***
Single Plate		
5	0.0501	0.0170
10	0.0103	0.0245
15	0.2023	0.0274
20	0.3299	0.0433
25	0.4724	0.9117
30	0.6121	1.9881
Fishtail		
5	0.0927	0.0244
10	0.1357	0.0319
15	0.2157	0.0647
20	0.3415	0.0897
25	0.5144	0.1719
30	0.7396	0.2130

The drag coefficient and lift coefficient values are also obtained from the simulation results on CFD software, which can be seen in the following Table 5.

Table 5
Drag and lift coefficient

Angle of attack (δ)	**Coefficient Drag (Cd)**	**Coefficient Lift (Cl)**
Single Plate		
0	0.0823	0.0141
10	0.1683	0.0274
15	0.3304	0.0455
20	0.5386	0.0653
25	0.7712	1.4885
30	0.9993	3.2459
Fishtail		
0	0.1514	0.0398
10	0.2215	0.0522
15	0.3522	0.0623
20	0.5576	0.0730
25	0.8399	0.2807
30	1.2075	0.3477

The interpretation of the ship's turning capability in IMO regulations is that the Advance (Ad) value must not exceed 4.5 times the length of the ship, and the Tactical Diameter (TD) value must not exceed 5 times the length of the ship. in a circular motion. The following Table 6 shows the maneuverability and lift coefficient of each steering blade obtained using the above calculation formula.

Table 6
Result of maneuver performance analysis of single and fishtail rudders

Angle of attack (δ)	**TD (m)**	**Satisfied**	**Ad (m)**	**Satisfied**
Single Plate				
5	2622.31	X	1419.05	X
10	1158.32	X	666.56	X
15	697.36	X	429.62	X
20	339.83	√	245.86	√
25	69.29	√	106.80	√
30	55.43	√	99.67	√
Fishtail				
5	1892.02	X	1043.68	X
10	726.89	X	444.80	X
15	449.63	X	302.29	√
20	356.01	X	254.17	√
25	62.46	√	103.28	√
30	44.98	√	94.30	√

4. Conclusion

Based on the research that has been done above, it can be concluded that:

I. At an angle of 5˚ and 10˚, the Single Plate rudder has a lower lift coefficient of 0.0241 and 0.0272 compared to the Fishtail rudder, which is 0.0398 and 0.0522. At the angle variation of 15˚ and 20˚, the Single Plate rudder has a lower lift coefficient value of 0.0305 and 0.0476 compared to the Fishtail rudder which is 0.0567 and 0.0540. At an angle of 25˚ and 30˚, the Single Plate rudder has a higher lift coefficient value of 1.4885 and 3.2459 compared to the Fishtail rudder which is 0.2807 and 0.3477.

II. At 5˚ and 10˚ angle variations, the Fishtail rudder has better maneuverability as evidenced by the lower turning radius or STD values of 1882.9 m and 717.83 m compared to the value of the turning radius or STD on the Single Plate rudder which is equal to 2613.2 m and 1149.26 m. At an angle of 15˚ and 20˚, the Fishtail rudder has better maneuverability as evidenced by the lower turning radius or STD values of 440.58 m and 346.95 m compared to the value of the turning radius or STD on the Single Plate rudder which is 688.30 m and 330.77 m. At angle variations of 25˚ and 30˚, Fishtail steering leaf has better maneuverability as evidenced by the lower turning radius or STD values of 53.40 m and 35.40 m compared to the value of turning radius or STD on Single Plate steering leaf which is 60.23 m and 46.92 m.

REFERENCES

[1] Singh, Yogang, S. K. Bhattacharyya, and V. G. Idichandy. "CFD approach to modelling, hydrodynamic analysis and motion characteristics of a laboratory underwater glider with experimental results." *Journal of Ocean Engineering and Science* 2, no. 2 (2017): 90-119. https://doi.org/10.1016/j.joes.2017.03.003

[2] Harvald, Svend Aage. *Resistance and propulsion of ships*. 1992.

[3] Nair, Vinod V., and S. K. Bhattacharyya. "Water entry and exit of axisymmetric bodies by CFD approach." *Journal of Ocean Engineering and Science* 3, no. 2 (2018): 156-174. https://doi.org/10.1016/j.joes.2018.05.002

[4] Rumapea, Marsaut Maurit, Deddy Chrismianto, and Parlindungan Manik. "Pengaruh Penambahan Fin Pada Rudder Untuk Mengurangi Hambatan Kemudi Kapal Dengan Metode Cfd (Studi Kasus Kapal Kriso Container Ship)." *Jurnal Teknik Perkapalan* 4, no. 2 (2016).

[5] Sulisetyono, Aries. "Development of a 'Fish Tail'Rudder to Improve a Ship's Maneuverability in Seaway." *IPTEK Journal of Proceedings Series* 1, no. 1 (2014). https://doi.org/10.12962/j23546026.y2014i1.376

[6] Doustdar, M. Mehdi, and Hamid Kazemi. "Effects of fixed and dynamic mesh methods on simulation of stepped planing craft." *Journal of Ocean Engineering and Science* 4, no. 1 (2019): 33-48. https://doi.org/10.1016/j.joes.2018.12.005

[7] Hutapea, Reinhard Fernando, Parlindungan Manik, and Untung Budiarto. "Analisa Pengaruh Penambahan Fin Pada Rudder Terhadap Kemampuan Manuvering Kapal Dengan Menggunakan Metode Computational Fluid Dynamic (Studi Kasus Kriso Container Ship)." *Jurnal Teknik Perkapalan* 5, no. 4 (2017).

[8] Zheng, Yisong, Xiuguo Zhang, Zijing Shang, Siyu Guo, and Yiquan Du. "A decision-making method for ship collision avoidance based on improved cultural particle swarm." *Journal of Advanced transportation* 2021 (2021). https://doi.org/10.1155/2021/8898507

[9] Badshah, Mujahid, Saeed Badshah, and Sakhi Jan. "Comparison of computational fluid dynamics and fluid structure interaction models for the performance prediction of tidal current turbines." *Journal of Ocean Engineering and Science* 5, no. 2 (2020): 164-172. https://doi.org/10.1016/j.joes.2019.10.001

[10] Bi, Xiu-ying, and XianJie Liu. "Research on double collision avoidance mechanism of ships at sea." *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation* 9, no. 1 (2015): 13-16. https://doi.org/10.12716/1001.09.01.01

[11] U. Budi, “Peranan Baling Baling pada Gerakan Kapal,” *Teknik*, vol. 33, no. 2, pp. 106–111, 2012.

[12] Klaas Van Dokkum, “Ship Knowledgea Modern Encyclopedia.” p. 400, 2016.

[13] Riesner, Malte, and Ould el Moctar. "Assessment of wave induced higher order resonant vibrations of ships at forward speed." *Journal of Fluids and Structures* 103 (2021): 103262. https://doi.org/10.1016/j.jfluidstructs.2021.103262

[14] W. W. Massie, “OFFSHORE HYDROMECHANICS First Edition,” *Currents*, no. January, 2001.

[15] Birk, Lothar. *Fundamentals of Ship Hydrodynamics: Fluid Mechanics, Ship Resistance and Propulsion*. John Wiley & Sons, 2019. https://doi.org/10.1002/9781119191575

[16] Subramaniam, Thineshwaran, and Mohammad Rasidi Rasani. "Pulsatile CFD Numerical Simulation to investigate the effect of various degree and position of stenosis on carotid artery hemodynamics." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 26, no. 2 (2022): 29-40. https://doi.org/10.37934/araset.26.2.2940

[17] Abobaker, Mostafa, Sogair Addeep, Lukmon O. Afolabi, and Abdulhafid M. Elfaghi. "Effect of Mesh Type on Numerical Computation of Aerodynamic Coefficients of NACA 0012 Airfoil." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 87, no. 3 (2021): 31-39. https://doi.org/10.37934/arfmts.87.3.3139

[18] Ali, Jaffar Syed Mohamed, Mohd Farid Amran, and Nurul Aziz Mohamad. "Experimental Study on the Effect of Boundary Layer Control on the Aerodynamics Characteristics of NACA 0021 Aerofoil." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 94, no. 1 (2022): 129-137. https://doi.org/10.37934/arfmts.94.1.129137