STUDY OF FAST PATROL BOAT MODELS WITH AND WITHOUT TUNNELS ON THE EFFECT OF RESISTANCE USING COMPUTATIONAL FLUID DYNAMICS

Sutiyo[1], Ali Munazid[1], Gde A. Prabhawatya Poundra[1], Bagiyo Swasono[2]

[1]Department of Naval Architecture, Universitas Hang Tuah, Surabaya, Indonesia
[2]Department of Ocean Engineering, Universitas Hang Tuah, Surabaya, Indonesia

E-mail: sutiyo@hangtuah.ac.id

Received: January 29, 2023 | **Accepted:** April 6, 2023 | **Published:** April 6, 2023
DOI: 10.12962/j27745449.v4i1.586 | **Issue:** Volume 4 Number 1 2023 | **E-ISSN:** 2774-5449

ABSTRACT

Archipelagic countries need modern ships for maritime security, so it is necessary to create effective fast patrol boats. This research is focused on designs with and without a tunnel at the bottom to determine the design with the least resistance. CFD offers accurate findings to compare the problems faced by two different types of fast patrol boats. Calculation of the use without tunnels, the use of tunnels on fast patrol boats reduces the average drag of 5.4%. According to the CFD simulation results, the use of tunnels can greatly reduce the high pressure at the bottom in interaction with the water flow. Utilization of using tunnels is a solution that can be used more successfully for fast patrol boat operations.

Keyword: Fast Patrol Boat, CFD, Resistance, With Tunnel, Without Tunnel

Introduction

Convention on the Law of the Sea (UNCLOS) of 1982 recognized Indonesia as an archipelagic nation [1]. Indonesia is comprised of 17,504 islands, of which two-thirds are water/seas. As the world's biggest archipelago with the fourth-longest coastline, Indonesia boasts an abundance of marine resources. However, these resources cannot be efficiently managed to promote the welfare of the populace. Even the protection of the maritime ecosystem has not received sufficient consideration.

The Indonesian seas are experiencing a decline in quality due to rampant activities that have a negative impact on sea conditions, such as illegal fishing, destruction of coral reefs and environmental pollution [2]. This is a challenge for the Indonesian nation in the future, how can this enormous wealth be utilized for the greatest possible benefit of society in a sustainable manner. Like other developing countries in the world, Indonesia is also still facing problems in managing, conserving and protecting marine areas and their ecosystems and natural resources [3].

The defence and security of Indonesia are heavily impacted by global and regional strategic factors. Indonesia is the only archipelagic state to have identified archipelagic sea lanes in connection with the determination of the rite of passage through archipelagic sea lanes. There are three north-to-south and reverse archipelagic sea lanes that cross through Indonesia.

The Indonesian Archipelagic Sea Lanes (ALKI) can be used for global and regional purposes. With this access, it makes the territory of Indonesia vulnerable to attacks [4]. There are many different kinds of threats in the maritime world, and most of the time, each country or party decides what kind of threat it is based on the threat itself and how vulnerable the party that feels threatened is. Some people think that disputes between countries, maritime terrorism, piracy, narcotics smuggling, people smuggling, weapons enrichment or proliferation, illegal fishing, pollution, maritime accidents, and natural disasters are all threats in the maritime field. With this threat, the law enforcement agencies that are in charge of keeping the Indonesian seas safe need to take action.

For this reason, Indonesia needs competent fast patrol boats.

The efficiency and effectiveness of a ship's operations are greatly enhanced by its hull's design [5]. In addition, the use of tunnels on the bottom of fast patrol boats also affects operational performance [6]. The distribution of pressure around the tunnel area changes with tunnel area ratio, and all three design conditions studied showed a consistent reduction in resistance [7]. The usage of tunnel at high-speed planning vessels have aero-hydrodynamic qualities to decrease drag, good sea-keeping behaviour, reduce slamming, and prevent purposing [8],[9]. A new parameter called tunnel efficiency has been introduced. The tunnel efficiency is the range of speeds where a planning hull's tunnel is most effective at reducing drag [10].

This research was conducted with the aim of knowing and studying the performance of fast patrol boats in bottom variations, with and without tunnels. A computational fluid dynamics approach is used in this study to determine the effect of bottom variations on fast patrol boats on resistance. Simulation and data verification are carried out according to ITTC regulations.

Methodology

Numerical Governing Equation

Computational Fluid Dynamics (CFD) technique was used to predict the resistance of models. Utama [11] have carried out research on calculating the hull resistance of slender catamaran by using CFD, and showed good results compared to experiments. The Reynolds-averaged Navier-Stokes (RANS) method is a three-dimensional equation developed and used in the CFD model. The flow problems in the walls of ship are solved using unsteady incompressible flow such as provided by ANSYS-CFX [12].

In the modeling of wake fields, it is discovered that the selection of turbulence models is very important. This study makes use of the SST (Shear Stress Transport) turbulence model created by Menter [13][14]. The SST model has been utilized and verified by many researchers, all of whom have had positive findings using the model [15][16][17]. The RANS solver, which is implemented in ANSYS CFX, is used to solve the fluid flow field. Equations (1), (2), and (3) describe the continuity, RANS, and SST turbulence equations, respectively, as follow:

Continuity equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}\left(\rho U_j\right) = 0 \qquad (1)$$

The continuity equation was defined that ρ is fluid density, *t* is time, U_j is the flow velocity vector field.

RANS equation:

$$\rho \bar{f_i} + \frac{\partial}{\partial x_j}\left[-\bar{p}\delta_{ij} + \mu\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right) - \overline{\rho u_i' u_j'}\right] - \rho \bar{u}_j \frac{\partial \bar{u}_i}{\partial x_j} = 0 \qquad (2)$$

The left side of RANS equation represents the change in mean momentum of fluid element to the unsteadiness in the mean flow. This change is balanced by the mean body force ($\bar{f}$), the mean pressure field ($\bar{p}$), the viscous stress, $\mu\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right)$, and apparent stress ($\rho u_i' u_j'$) to the fluctuating velocity field.

Menter's SST equation

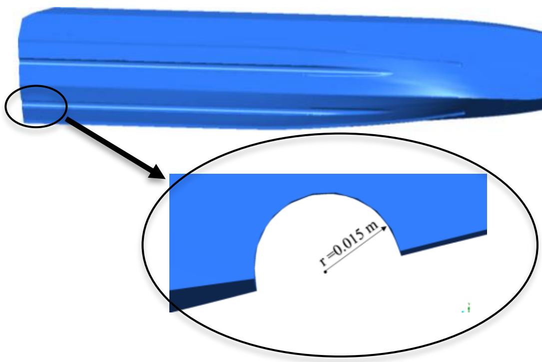
$$\frac{\gamma}{v_t}P - \beta\rho\omega^2 + \frac{\partial}{\partial x_i}\left[(\mu + \sigma_\omega \mu_t)\frac{\partial \omega}{\partial x_i}\right] + 2(1-F_1)2\rho_{\omega 2}\frac{1}{\omega}\frac{\partial k}{\partial x_i}\frac{\partial \omega}{\partial x_i} - \left(\frac{\partial(\rho\omega)}{\partial t} + \frac{\partial\left(\rho u_j \omega\right)}{\partial x_i}\right) = 0 \qquad (3)$$

The Menter's SST model combines the advantages of the k-ω model to achieve an optimal model formulation for a wide range of applications. For this, a blending function F1 is introduced which is equal to one near the solid surface and equal to zero for the flow domain away from the wall. It activates the k-ω wall region and the k-ε model for residual flow. By this approach, the attractive near-wall performance of the k-ω model can be used for the free stream sensitivity.

Geometry Model

As shown in Figure 1, the hull geometry of fast patrol boat with no axe-bow, semi axe-bow and axe-bow modification. The main dimensions of the models are listed in Table 1.

(a) Without Tunnel



(b) With Tunnel; r = 0.015 m

Figure 1. Fast Patrol Boat Model

Table 1. Main dimension of fast patrol boat models

Dimension	Unit	With Tunnel	Without tunnel
Length Over All (L_{OA})	m	2	2
Length Water Line (L_{WL})	m	1.823	1.823
Breadth (B)	m	0.356	0.356
Heigh (H)	m	0.265	0.265
Draft (T)	m	0.692	0.690
Wetted Surface Area (S)	m^2	0.628	0.566
Displacement (Δ)	kg	20.98	20.98
Coefficient Block (C_B)		0.529	0.532

Boundary Condition

The proposed computational domain is 2L forward, perpendicular to the front, at the velocity inlet, and 5L towards the rear, perpendicular to the outlet pressure. By adjusting the transverse and vertical directions to 2L-3L [30], we were able to prevent the negative impact of reverse flow on the borders of the area. Both the domain size and the boundary conditions are shown in Figure 5. Inlet flow velocity is defined as Fr = 0.3 to 0.8, and outlet hydrostatic pressure is defined as a function of water level; the hull body is identified as a fixed boundary and a no-slip condition; the bottom is given a free-slip condition; the top wall is given an opening condition; and the side walls are given a symmetry condition, as shown at Figure 2.

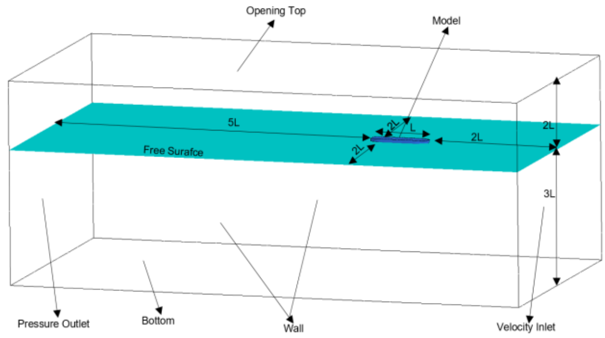
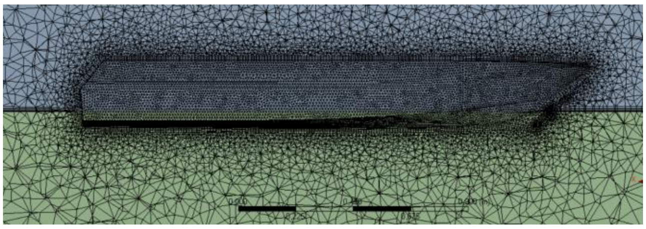


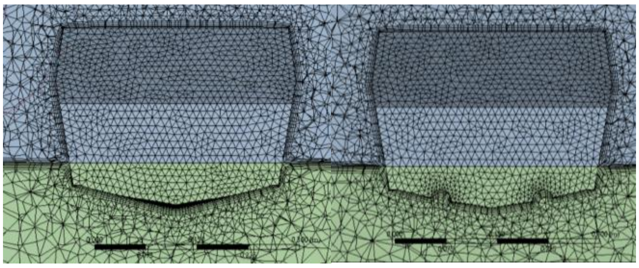
Figure 2. Boundary Condition Setting

Meshing and Grid Independence Study

The use of Design Modeler was required to complete the process of mesh construction for this investigation. A combination of structured and unstructured meshes are used in order to discretize the computation domain. In consideration of the intricate geometrical features of the hull, a mesh consisting of triangle elements is constructed on the surface of the hull. Subsequently, the boundary layer is refined using prism elements that are generated by expanding the surface mesh node. Inflated tetrahedral elements are used to populate the area close to the boat, while an unstructured mesh with grid generation is used to reduce the total number of components in the distant field (as illustrated in Figure 3).



(a) Side view



(b) Without tunnel mid-section (c) With tunnel mid-section

A fine mesh may always deliver reliable results in ANSYS CFX, but at the same time, it increases the computational cost and time consumption owing to the huge element number. The mesh size plays a significant part in the calculation operation. Mesh convergence experiments are performed on both the fast patrol boat model with a tunnel and one without a tunnel at a Froude number of 0.4. This is done so that the mesh size may be determined with an acceptable level of numerical accuracy and the total number of elements, as shown in Figure 4, which presents the results of the grid independence study. The number of elements used in the fast patrol boat model with a tunnel was approximately 1.9 million, while the number of elements used in the fast patrol boat model without a tunnel was approximately 1.7 million.

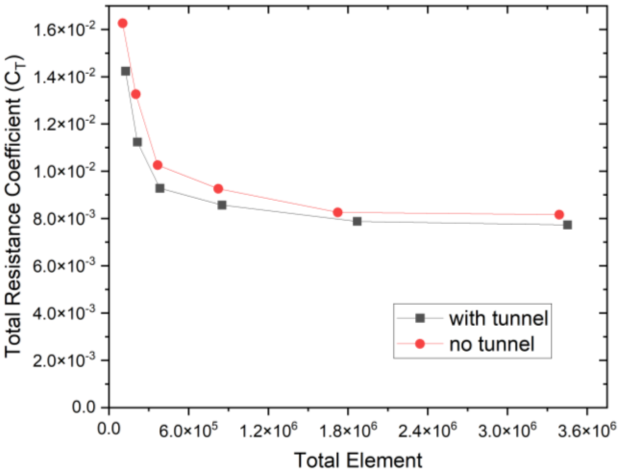


Figure 4. Grid Independence Study

Result and Discussion

Figure 5 illustrates the computation used to determine the resistance of the two models. Although the difference is not statistically significant, the fact that it exists has a beneficial impact on the process of tunnel construction on rapid patrol boats. As can be seen in Figure 5, the resistance differential is at its lowest with a value of 3.2% when Fr is equal to 0.3, while it is at its greatest value when Fr is equal to 0.8 with a value of 7.2%.

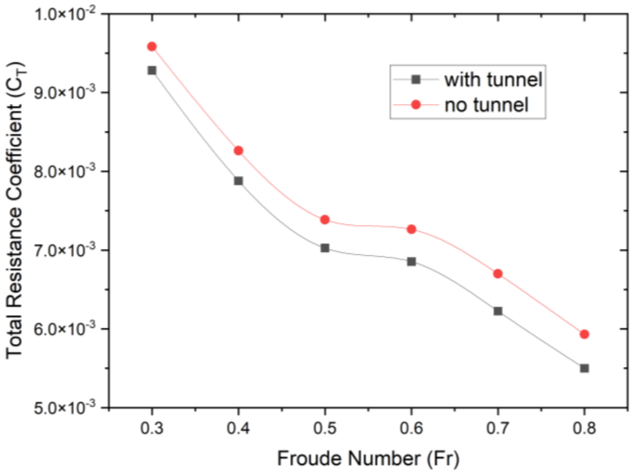
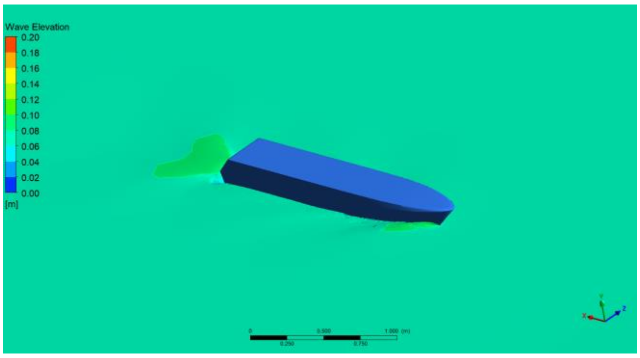
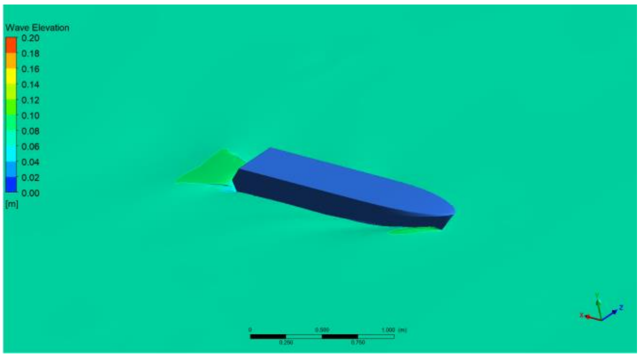


Figure 5. The differences CT at Fast Patrol Boat Models

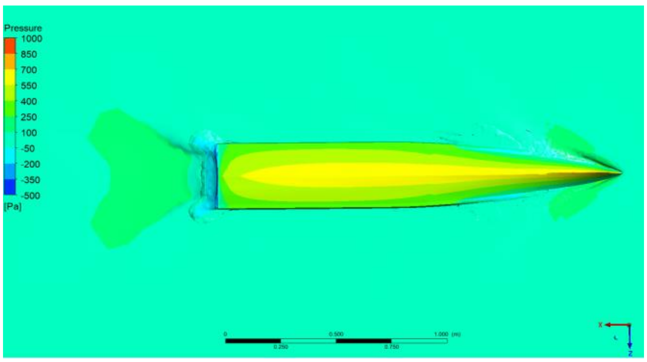


(i) with without tunnel

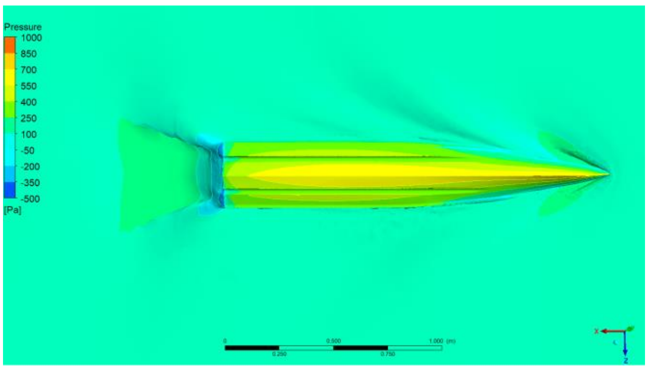


(ii) with tunnel

(a) Wave generation



(i) with without tunnel



(ii) with tunnel

(b) Pressure distribution at bottom

Figure 6. Wave elevation and Pressure distribution of Fast Patrol Model at High Speed (Fr=0.8)

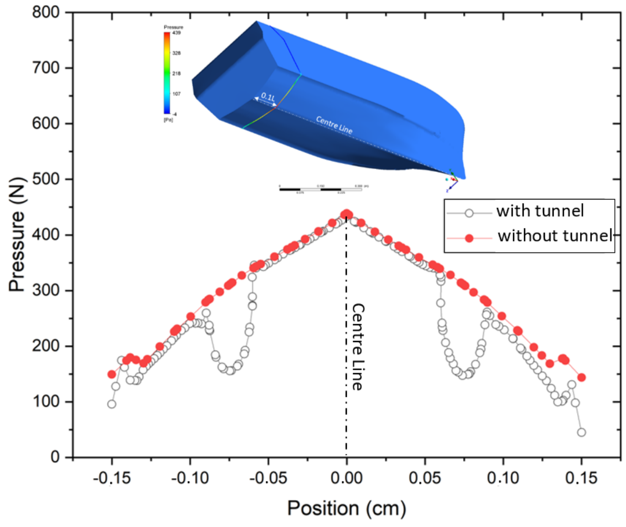
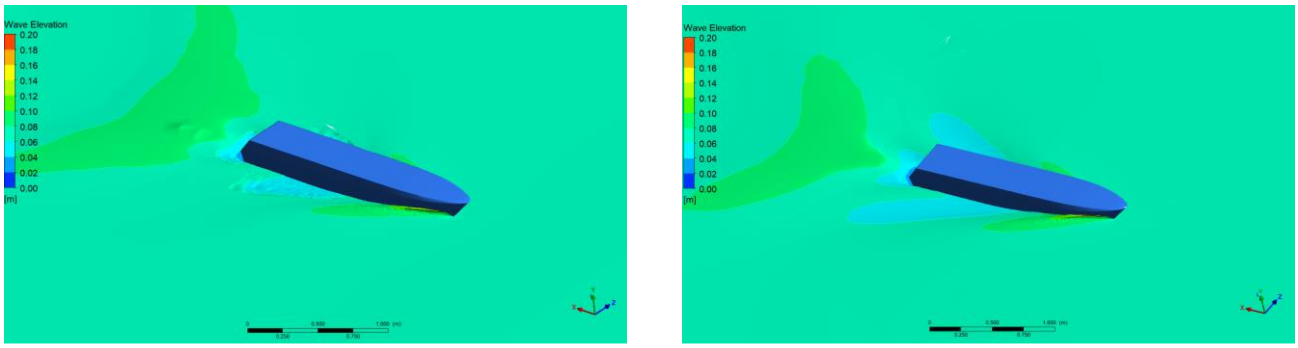


Figure 7. Lateral pressure distribution at 0.1L from stern of bottom at Fr = 0.3

An interesting appearance emerges while comparing the two different models of fast patrol boats, one of which has tunnels and the other of which does not. Both of these models were analysed, one with a low speed of Fr = 0.3, one with a medium speed of Fr = 0.5, and one with a high speed of Fr. 0.8. This study was performed on the difference in pressure on the bottom of the ship as a result of the use of tunnels and their influence on resistance. Tunnels are an effect of the use of tunnels. This phenomenon is clearly illustrated as shown in Figure 6-11.

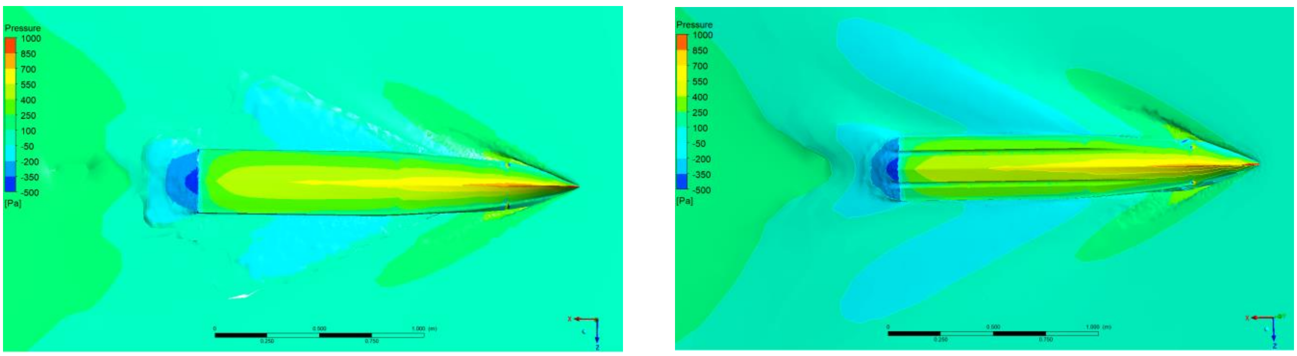
Figure 6.ai demonstrates wave forming on the two models' fronts. The model scale height of 0.09 m makes little effect. This occurrence does not explain the two models' resistance differences. The details are there for the taking, the model without a tunnel (Figure 6.a.i) has a pooled flow that increases the hull pull, while the model with a tunnel (Figure 6.a.ii) has a more pointed flow pattern that reduces the drag of the fluid against the model ship's hull.

The bottom pressure of the two swift patrol boat variants increases as resistance decreases. Figures 6.b and 7 show that the rapid patrol boat model with tunnels has a pressure distribution value of 3.25% higher than the one without tunnels. Figure 11 shows that the tunnel pressure dropped 5.34%, corroborating the considerable drag reduction reported. The tunnel on this quick patrol boat reduces drag by 3.2% at Fr 0.3.



(i) with without tunnel (ii) with tunnel

(a) Wave generation



(i) with without tunnel (ii) with tunnel

(b) Pressure distribution at bottom

Figure 8. Wave elevation and Pressure distribution of Fast Patrol Model at High Speed (Fr=0.5)

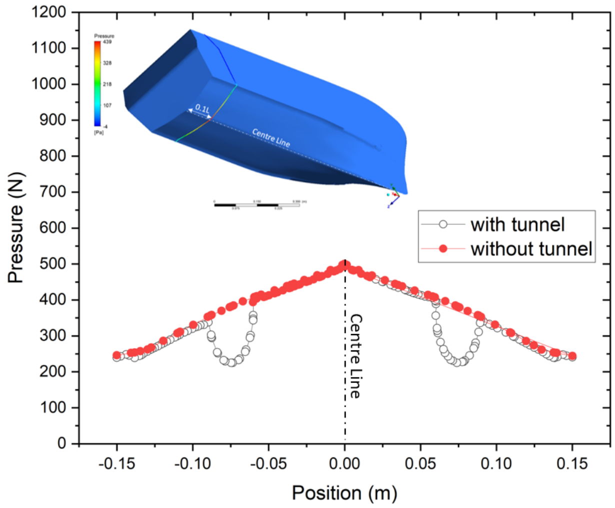
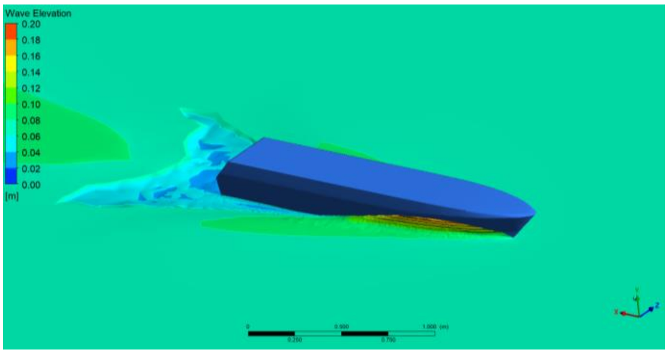


Figure 9. Lateral pressure distribution at 0.1L from stern of bottom at Fr = 0.5

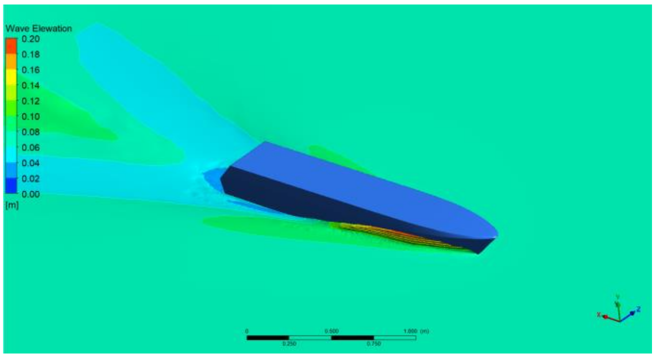
Wave generation of side front hull is seen in Figure 8.a for both models. With a height of around 0.05 m at the model scale, there is no discernible change in the usual case. The discrepancy in resistance between the two models is not due to this occurrence. However, if you look closely, you can see that the flow pattern behind the model is quite different, with the model without a tunnel exhibiting a pooled flow that causes the hull pull to be greater, and the model with a tunnel exhibiting a more pointed flow pattern that shows a more directed fluid flow and provides a reduced drag of the fluid against the hull of the model ship.

Both types of fast patrol boats experience a rise in pressure underneath their hulls as a result of a decrease in resistance. Figures 8.b and 9 show that the pressure distribution trends of the fast patrol boat model with and without tunnels are similar, but that the pressure distribution value is different by around 3.27% between the two models. Figure 11 displays the average percentage drop in tunnel pressure, which at 6.51% lends credence to the significant reduction in drag reported. As an added bonus, at a speed of 0.5 Fr, the tunnel installed on this fast patrol boat reduces total drag by 4.68%.

The drag reduction is quite significant at Fr=0.8 as mentioned in Figure 5. Figure 10 (a.i) shows the occurrence of wave making on the front side of the two models. In general, there is no significant difference with a height of about 0.13 m at the model scale.

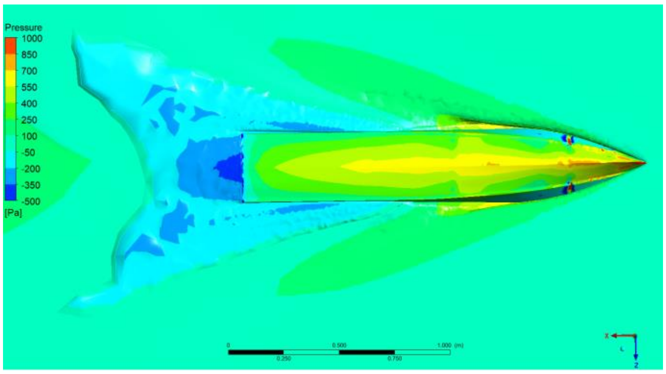


(i) with without tunnel

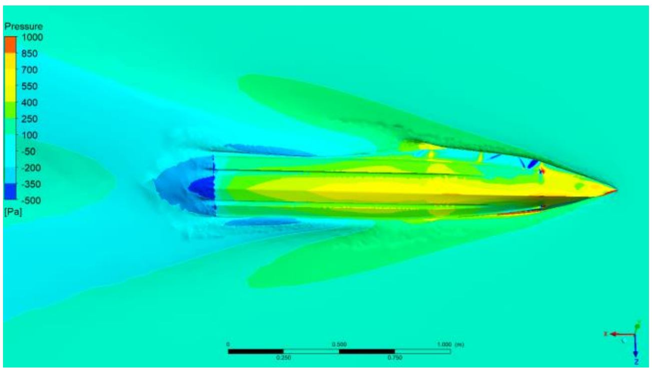


(ii) with tunnel

(a) Wave generation



(i) with without tunnel



(ii) with tunnel

(b) Pressure distribution at bottom

Figure 10. Wave elevation and Pressure distribution of Fast Patrol Model at High Speed (Fr=0.8)

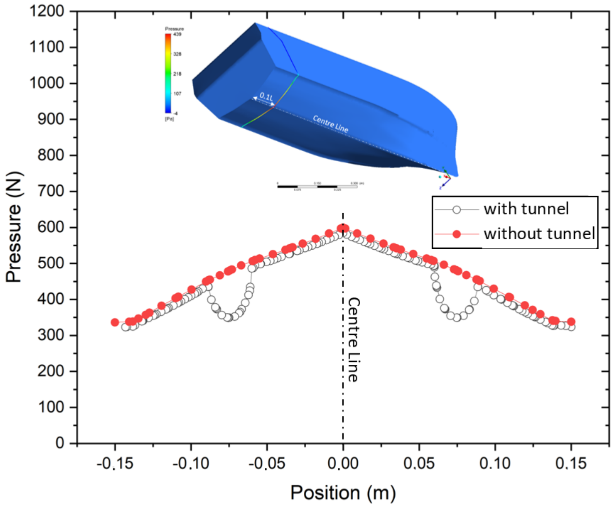


Figure 11. Lateral pressure distribution at 0.1L from stern of bottom at Fr = 0.5

This event is not the cause of the difference in resistance in the two models. However, if you pay close attention, there are differences in the flow pattern behind the model which are quite different, in which the model without a tunnel (Figure 10.a.i)) has a pooled flow which causes the hull pull to be greater while in the model with a tunnel (Figure 10.a.i)) 10.a.ii) the flow pattern behind the model is more pointed which shows a more directed fluid flow and provides a reduced drag of the fluid against the hull of the model ship.

The increase in pressure that builds up on the bottom of the two different models of fast patrol boats is proportional to the decline in resistance that takes place there. Both models exhibit a pressure distribution trend that is comparable to one another, but there is a difference of approximately 4.23% between the fast patrol boat model with tunnels and the fast patrol boat model without tunnels in terms of the pressure distribution value, as demonstrated in Figures 10.b and 11. The decrease in pressure in the tunnel, which has an average value of 9.71% as shown in Figure 11, is supporting evidence for the large reduction in drag that was observed. Additionally, the utilization of the tunnel on this rapid patrol boat results in a 7.2% overall reduction in drag when measured at a Fr of 0.8.

Conclusion

Numerical CFD research on the impact of tunnel changes on the Fast Patrol Boat model's resistance reduction has been conducted. The studies were conducted on a model of a rapid patrol boat with and without a tunnel. It is clear that CFD offers a significant contribution to the modelling and simulation of swift patrol boats. According to the calculations, rapid patrol boats with and without tunnels had a 5.4% reduction in resistance at CFD modelling findings. Load distribution trends are similar in both models, although the fast patrol boat model with tunnels has somewhat higher values than the fast patrol boat model without tunnels. The average pressure decrease in the tunnel is 7.71%, hence, this is supporting evidence for the reported resistance reduction.

Acknowledgements

The author would like to express the appreciation to the Design Laboratory of Universitas Hang Tuah for the facilities provided so that research can be completed.

References

[1] UNCLOS, Overview - Convention & Related Agreements, 1982. Available from: https://www.un.org/depts/los/convention_agreements/convention_overview_convention.htm (accessed Jan. 28, 2023).

[2] H. Ayu, Government Policy Directions on Illegal Unreported Unregulated (IUU) Fishing in Indonesia, in Internationalization of Islamic Higher Education Institutions Toward Global CompetitivenessSemarang, Indonesia – September 20th - 21th, 2018, 2018, pp. 106–114.

[3] Amkieltiela et al., The rapid expansion of Indonesia's marine protected area requires improvement in management effectiveness, *Mar. Policy*. **Vol. 146** (2022), p. 105257. DOI: 10.1016/j.marpol.2022.105257.

[4] Y. Listiyono, B. Pramono, L. Prakoso, K. Prihantoro, and D. Sianturi, Marine defense strategy in securing Indonesian archipelagic sea lanes (Alki) to realize maritime safety and maintain Indonesian soility, *Int. J. Educ. Soc. Sci. Res*. **04** (2021) 224–237. DOI: 10.37500/IJESSR.2021.4313.

[5] A. Lajeunesse, Canada's Arctic Offshore and Patrol Ships (AOPS): Their history and purpose, *Mar. Policy*. **124** (2021) p. 104323. DOI: 10.1016/j.marpol.2020.104323.

[6] F. Roshan, A. Dashtimanesh, and R. N. Bilandi, Hydrodynamic characteristics of tunneled planing hulls in calm water, *Brodogradnja*. **Vol 71, no. 1** (2020) 19–38. DOI: 10.21278/brod71102.

[7] V. A. Subramanian and P. V. V Subramanyam, Effect of tunnel on the resistance of high-speed planing craft, *J. Nav. Archit. Mar. Eng.* **Vol. 2, no. 1** (2005) 1–14 DOI: 10.3329/JNAME.V2I1.2025.

[8] M. Ghassabzadeh and H. Ghassemi, Automatic generation of the planning tunnel high speed craft hull form, *J. Mar. Sci. Appl.* **Vol. 11, no. 4** (2012). 453–461, Dec. 2012,
DOI: 10.1007/S11804-012-1155-9/METRICS.

[9] M. Ghassabzadeh and H. Ghassemi, An innovative method for parametric design of planing tunnel vessel Hull form, Ocean Eng. **60** (2013) 14–27.
DOI: 10.1016/J.OCEANENG.2012.11.015.

[10] F. Roshan, A. Dashtimanesh, and R. N. Bilandi, Hydrodynamic Characteristics of Tunneled Planing Hulls in Calm Water, *Brodogradnja*. **Vol. 71, no. 1** (2020) pp. 19–38.
DOI: 10.21278/brod71102.

[11] I. K. A. P. Utama, W. D. Aryawan, A. Nasirudin, Sutiyo, and Yanuar, Numerical investigation into the pressure and flow velocity distributions of a slender-body catamaran due to viscous interference effects, *Int. J. Technol.* Vol. 12, no. 1 (2021) 149. DOI: 10.14716/ijtech.v12i1.4269.

[12] ANSYS, ANSYS CFX-Solver Theory Guide. Canonsburg, PA, USA: Ansys Inc, 2020.

[13] F. R. Menter, Zonal two equation κ-ω turbulence models for aerodynamic flows, in AIAA 23rd Fluid Dynamics, Plasmadynamics, and Lasers Conference, 1993, 1993.

[14] F. R. Menter, Two-equation eddy-viscosity turbulence models for engineering applications, *AIAA J*. **Vol. 32, no. 8** (1994) 1598–1605.
DOI: 10.2514/3.12149.

[15] J. E. Bardina, P. G. Huang, and T. J. Coakley, Turbulence modeling validation, testing, and development, *Nasa Tech. Memo.* (1997),
DOI: 10.2514/6.1997-2121.

[16] A. F. Molland, S. R. Turnock, and D. A. Hudson, Ship Resistance and Propulsion, Cambridge University Press, 2017.
DOI: 10.1017/9781316494196.

[17] I. K. A. P. Utama, Sutiyo, and I. K. Suastika, Experimental and numerical investigation into the effect of the axe-bow on the drag reduction of a trimaran configuration, *Int. J. Technol.* Vol. 12, no. 3 (2021) 527–538.
DOI: 10.14716/ijtech.v12i3.4659.