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Numerical Analysis of Hydrodynamic Resistance of a Joubert BB2-Type Submarine

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Abstract

Objective: This study aims to analyze the hydrodynamic resistance characteristics of submarine hull designs suitable for Indonesia's complex maritime environment, which includes shallow waters, strong currents, and deep-sea conditions. Minimizing resistance is essential to enhance operational efficiency, energy consumption, and maneuverability of submarines operating in such diverse waters. **Theoretical framework:** The theoretical framework of this research is grounded in naval hydrodynamics and resistance theory, particularly focusing on viscous and pressure resistance components acting on submerged bodies. The study also adopts the Theory of Change approach in naval design, emphasizing that optimized hull geometry leads to improved performance and operational effectiveness. **Literature review:** The literature review indicates that previous studies on submarine resistance have primarily focused on standard hull forms under idealized conditions, with limited attention to region-specific operational environments such as Indonesian waters. Comparative analyses of hull types such as teardrop, Joubert BB2, and ALFA class have been conducted, but systematic numerical evaluations under consistent submerged conditions remain limited. **Methods:** This research employs a quantitative numerical approach using Computational Fluid Dynamics (CFD). Simulations were conducted on three submarine hull types: teardrop hull, Joubert BB2, and ALFA class under submerged operating conditions at a constant speed of 10 knots. The CFD model analyzes total hydrodynamic resistance by resolving fluid flow behavior around each hull geometry, allowing for a detailed comparison of resistance performance. **Results:** The results reveal that the teardrop hull exhibits the lowest total resistance compared to the Joubert BB2 and ALFA class designs at the specified operational speed and submerged condition. This finding indicates superior hydrodynamic efficiency, reduced energy consumption, and enhanced maneuverability, making the teardrop hull particularly suitable for submarine operations in Indonesian waters. **Implications:** The implications of this study are both practical and strategic. Practically, the findings guide the selection of submarine hull designs that optimize operational efficiency and stability. Strategically, the results support future submarine development tailored to Indonesia's maritime characteristics. **Novelty**: The novelty of this research lies in its comparative numerical analysis of multiple submarine hull types under a uniform submerged condition, specifically contextualized to Indonesian waters, offering design insights that bridge numerical simulation and operational needs. Future studies are recommended to validate these findings through experimental towing tank tests.

Keywords: submarine, hydrodynamic resistance, computational fluid dynamics, joubert bb2, indonesian waters.

INTRODUCTION

Unitary State of the Republic of Indonesia. In addition to being called an agrarian country, it is also referred to as a maritime country because Indonesia is the largest archipelagic country in the world. Submarines also have a very important strategic role. Indonesia has more than 17,000 islands and a very large sea area, so the need for reliable marine technology is very high. In addition, the potential of Indonesia's marine wealth is also huge, ranging from fish resources to seabed mines, all of which require good supervision and protection. In the maritime world, submarines are one of the technological innovations that have a very strategic and multifunctional role. Unlike most ships that can only operate at sea level, submarines are designed to be able to dive to a certain depth and operate for long periods of time without having to come to the surface [1].

This research discusses the resistance of the hull model of the Joubert BB2 type submarine for Indonesian waters by using a model geometry that has (λ) Scale Factor 18.348 which will be carried out Testing the Joubert BB2 submarine model, At depth variation, the depth variable is used Submaege below the surface of the water and uses the submarine speed variable 10 Knot in diving conditions [1].

Joubert BB2 type submarine, is one of the submarine models developed by Joubert which has two types of geometry, namely BB1 and BB2, According to Dogrul this Joubert type submarine is designed for diesel electric attack submarines (SSK) in the BB1 geometry variant, In the BB1 geometry variant it is not accessible for numerical study and research, With that, a Joubert BB2 geometry type submarine was chosen for the model medium in this study, where this type of geometry is open and can be used in numerical studies and research. In this research, the BB2 submarine model was used, using the model scale, and the model's suitability was validated by comparing it with one of the test results from the previous research [2].

With the presence of a large influence on submarine resistance caused by the hydrodynamic pressure of a certain service speed, according to Dogrul, each increase in submarine service speed has an influence on the submarine's resistance. This makes it something that needs to be seriously considered, considering that the condition of the waters in Indonesia certainly affects submarines. Based on previous research by Wibowo H Nugroho and Ahmad S. Mujahid, the analysis of Hydrodynamic pressure on the Joubert BB2 type submarine is very necessary, and comprehensive research is carried out to be able to ensure the feasibility of the submarine model [3].

Novelty and Research Implications. Based on this background description, this research has a significant element of novelty in the study of submarine hydrodynamics, especially in the context of Indonesian waters. The main novelty of this study lies in the analysis of the resistance of the Joubert BB2 type submarine, which is specifically adjusted to the characteristics of Indonesian waters, both in terms of depth of operation and hydrodynamic conditions. In contrast to previous studies that generally focused on deep-sea waters assuming ideal and homogeneous conditions, this research places submarines in a more realistic operational scenario, in accordance with the relatively shallow, dynamic, and complex conditions of Indonesian waters [4].

In addition, this study offers methodological novelty through the use of the Joubert BB2 submarine geometry model with a scale factor (λ) of 18,348, which is validated comparatively with the results of previous research. This approach not only ensures the reliability of the models used but also strengthens the accuracy of hydrodynamic obstacle analysis under diving conditions. The determination of a fixed operating speed of 10 knots at the submerge depth variation provides a new perspective on the effect of hydrodynamic pressure on the total resistance of the submarine, which has not been explored specifically for Indonesian waters [5].

Another novelty lies in the research's focus on the relationship between variations in diving depth and changes in submarine obstacle characteristics. This approach allows for a more comprehensive understanding of the hydrodynamic behavior of submarines' hulls when operating below sea level, particularly under varying water pressure conditions. Thus, this research not only contributes to the theoretical aspect but also provides relevant technical data for the development of future submarine designs [6].

In terms of implications, the results of this study have a wide impact both academically and practically. Academically, this research enriches the treasure of submarine hydrodynamics by presenting contextual data and analysis on the conditions of Indonesian waters. The findings of this study can be a reference for further research in the field of hull design and optimization of submarines, especially those operating in archipelago waters. Practically, the implications of this research are very relevant for the national defense and maritime industries. Information about the characteristics of submarine resistance at various diving depths can be used in the design process, selection of operating configurations, and improvement of submarine energy efficiency. In addition, the results of this research can also support strategic decision-making related to the operation of submarines in Indonesian waters, so as to be able to increase the effectiveness, safety, and durability of the national maritime defense system [7].

LITERATURE REVIEW

The study of submarine resistance is one of the important topics in the field of marine engineering and hydrodynamics, considering that resistance has a direct effect on energy efficiency, operational performance, and maneuverability of submarines. Submarine drag is fundamentally different from surface ships because submarines operate below sea level and are affected by hydrostatic pressure, dynamic pressure distribution, and three-dimensional fluid flow interactions around the hull. Therefore, the design of the hull shape of a submarine is a crucial factor in determining the characteristics of total resistance [8].

Previous studies have shown that the streamlined hull shape, such as the teardrop hull, has lower resistance characteristics than conventional hulls. This is due to the ability of the streamlined shape to minimize flow separation and reduce negative pressure at the stern. In the context of modern submarines, hull design development continues to be geared towards shape optimization to achieve a balance between speed, stability, and energy efficiency. In addition to the main hull shape, external components such as sails and hydrofoils also contribute significantly to increased drag, so they need to be comprehensively analyzed [9].

As computing technology develops, numerical simulation methods based on Computational Fluid Dynamics (CFD) are increasingly used in the analysis of submarine obstacles. This method allows for detailed visualization of flow patterns, pressure distribution, and velocity vectors without always having to perform expensive and time-consuming experimental testing. CFDs also provide flexibility in evaluating various geometric configurations and operating conditions, such as variations in speed, depth of diving, and configuration of additional components [10].

The literature related to CFDs on submarines emphasizes the importance of geometry modeling accuracy and mesh quality in producing reliable simulation results. Geometric inaccuracies or poor mesh discrimination can lead to significant numerical errors, especially in drag analysis. Therefore, the use of three-dimensional modeling software with precise surface modeling capabilities is the main need in submarine hydrodynamics research. In addition, the process of validating numerical models on reference data is a stage that cannot be ignored to ensure the compatibility between the simulation results and the actual physical phenomena [11].

Previous studies have also emphasized the importance of Grid Independence Studies (GIS) in CFD simulations. GIS is used to ensure that the calculation results are no longer affected by the size of the mesh, so that numerical solutions can be considered convergent and stable. This approach became standard in numerical hydrodynamic analysis, particularly for submarine applications that had complex geometries and high-pressure gradients around the hull [12].

In the context of Indonesian waters, the study of submarine resistance has increasing relevance. The characteristics of Indonesian waters, dominated by archipelagos, shallow waters, and complex current dynamics, demand the design of submarines that are able to operate efficiently in various conditions. However, most studies of submarine hydrodynamics still focus on deep-sea water scenarios and ideal conditions, so they do not fully represent operational conditions in Indonesian waters [13].

Some cutting-edge research is beginning to turn attention to the analysis of submarine resistance by taking into account variations in diving depth and different hull configurations. This approach opens up opportunities to understand the influence of hydrodynamic pressure on submarine performance more realistically. In addition, comparative analysis between several hull types, such as the teardrop hull, Joubert BB2, and ALFA class, is important to determine the design that best suits operational needs. Overall, the literature review shows that a combination of precise geometry modelling, validated CFD simulations, and grid independence analysis is an effective approach in the study of submarine resistance. However, there is still a need for research that specifically links the results of numerical analysis to the characteristics of Indonesian waters. This gap is the basis for this research to make a scientific and practical contribution to the development of submarine designs that are more efficient and adaptive to national maritime conditions [14].

METHODOLOGY

The method used is a literature study by collecting references from journals, theses, books, and electronic sources relevant to the topic of submarine resistance. The research object was determined in the form of a model of the hull of the BB2 type Joubert, with a focus on obstacle analysis using a numerical simulation approach. The research process begins with the determination of research specifications, including objects, variables, analysis methods, and research limitations, which are compiled based on literature review and research objectives. Modeling of the submarine's geometry was carried out using Rhinoceros (Rhino) software to produce a precise three-dimensional hull model according to the main size of Joubert BB2 based on the Dogrul reference [15].

The next stage is numerical model validation to ensure the compatibility of the simulation results with the reference data. Validation is carried out through resistance analysis using Ansys Fluent with a grid independence approach to obtain optimal meshing size. The validation results showed that the model resistance value at a speed of 10 knots was close to the journal data with a correction rate that was still within the tolerance limit, so the model was declared feasible for further analysis. Once the model is validated, resistance analysis is performed on various variations of submarine speeds. From the CFD simulation, hydrodynamic characteristics in the form of flow patterns, velocity vectors, streamlines, and dynamic pressure distribution were obtained, which became the basis for the evaluation of the hydrodynamic performance of the Joubert BB2 submarine [16].

RESULTS AND DISCUSSION

The modeling of the Joubert BB2 submarine in this study is a fundamental stage that determines the overall accuracy of numerical obstacle analysis. The modeling process is carried out as a first step to obtain a geometric representation that is close to the original shape of the submarine before proceeding to the Computational Fluid Dynamics (CFD) simulation stage. The submarine geometry is built on the main size of the Joubert BB2 that has been available in the open literature, so that the resulting model is able to realistically represent the hydrodynamic characteristics of the submarine. The use of open-source geometric data allows the validation process to be carried out transparently and minimizes bias due to limited design data. The modeling was carried out using the Rhinoceros (Rhino) software, which was chosen for its advantages in producing smooth and precise surface modeling, especially in the hull geometry of submarines, which have streamlined characters and complex curvatures. Smooth hull surfaces are a crucial factor in CFD analysis because geometric irregularities can cause mesh distortion, trigger flow instability, and increase numerical errors in drag calculations [17].

The resulting geometric model is then adjusted to the scale parameters of the research model so that numerical simulations can be carried out efficiently without eliminating the equivalence of fluid flow phenomena with full-scale submarines. After the basic hull modeling stage is completed, this study develops several variations of model configurations, namely hull models only, hulls with the addition of sails, hull + sail + hydrofoil 1, hull + sail + hydrofoil 2, and a complete submarine model that combines all components. This configuration variation is designed to evaluate the effect of the addition of external components on changes in the hydrodynamic resistance of the submarine. With this approach, the research not only focuses on the total resistance value, but is also able to identify the contribution of each component to the increase or decrease in resistance [18].

After the geometry modeling is completed, the next stage is the validation of the model through a comparison of the barrier value with the results of previous research. The reference resistance value of 21 N at a speed of 10 knots is used as the basis for evaluating the suitability of the model. The simulation results showed that the model resistance value was within the correction tolerance range of less than 2% against the reference data, indicating that the hull shape and modeled geometry configuration had accurately represented the original characteristics of the Joubert BB2 submarine. The success of this validation stage provides a strong scientific basis for continuing research to the advanced numerical analysis stage, including grid generation and grid independence study [19].

The grid generation stage is carried out using ANSYS Meshing to build fluid domain differentiation around the submarine model. A grid or mesh is a collection of elements that divide the computing domain into small parts, so that the fluid flow equation can be solved numerically. In this study, the meshing process was carried out while maintaining the original geometric shape without distortion, with a minimum curvature size of 1 mm so that the mesh is able to follow the contours of the hull optimally. The size and number of the mesh are important parameters because they directly affect the level of accuracy, the accuracy of the simulation results, and the computational needs. Meshes that are too rough have the potential to produce less accurate results, while meshes that are too smooth will significantly increase computation time and file size. Therefore, the selection of mesh sizes is carried out systematically to achieve a balance between accuracy and computational efficiency [20].

For each model configuration, ranging from hull, hull + sail, hull + sail + hydrofoil 1, hull + sail + hydrofoil 2, to submarine, complete three variations of the same mesh size were used, namely 0.01234 m, 0.00822 m, and 0.00493 m. This approach aims to maintain analysis consistency and allow for direct comparisons between configurations. With the increase in size of the mesh, the number of cells increases significantly, which indicates an increase in the resolution of the discretization around the surface of the stomach and additional components [21].

Verification of grid independence is performed to ensure that the simulation results are no longer affected by changes in the size of the mesh. The Grid Independence Study (GIS) is an important stage in CFD modeling to assess the sensitivity of results to grid discretization and estimate numerical uncertainty. In this study, GIS was carried out by evaluating the change in the total resistance value (RT) at each level of mesh fineness. The results show that an increase in the number of meshes results in a smaller change in the barrier value, with the difference being below the 2% threshold as recommended in various CFD literature and

ITTC guidelines. This indicates that the numerical solution has reached a convergent and stable state [22].

In the hull model, the best grid independence value is obtained on the smoothest mesh with an RT value of 15.87 and a difference of about 1%. A similar pattern was also found in the configuration of hull + sail, hull + sail + hydrofoil 1, hull + sail + hydrofoil 2, and submarine complete, where all configurations showed smaller differences in results as the number of mesh increased. Thus, a mesh with a size of 0.00493 m was chosen as the optimum mesh because it provides the most stable results with a minimum error rate. This mesh selection ensures that the numerical barrier analysis performed at a later stage truly reflects the physical phenomenon of fluid flow, not an artifact of numerical dissection [23], [24].

Based on the calculation of the resistance that has been simulated in the CFD-CFX method using Ansys Software, the value of the ship resistance has been obtained.

Table 1. Barriers

Barriers (N)	Speed (m/s)	Model variations/Component Additions				
		Hull	Hull+ Sail	Hull+ Sail+ Hydrofoil 1	Hull+ Sail+ Hydrofoil 2	Hull Complete
	1,4351	15,65	14,54	15,38	16,46	20,53

Table 2. Barrier Difference

Differences	Hull+M 1 -Hull		Hull+M 2-Hull		Hull+M 3-Hull		Hull+M 4-Hull	
Speed	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
1,4351	-0,27	-2%	0,27	2%	-0,81	-5%	-4,88	-31%
Average	-0,27	-2%	0,27	2%	-0,81	-5%	-4,88	-31%

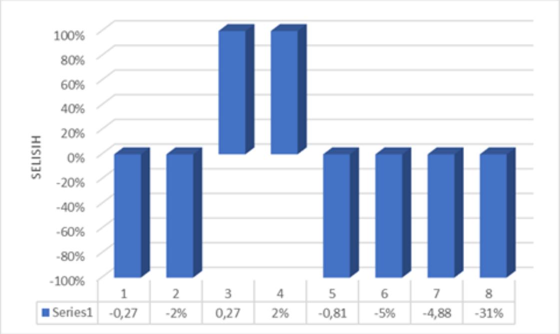

Figure 1. Obstacle Difference Diagram

The analysis of the resistance of the Joubert BB2 submarine using the Computational Fluid Dynamics (CFD) method was carried out to determine the effect of the addition of external components on the total resistance value of the submarine when moving at a depth of 300 meters. The simulation was carried out on five variations of the ship's configuration, namely Hull, Hull + Sail, Hull + Sail + Hydrofoil 1, Hull + Sail + Hydrofoil 2, and Hull Complete, which represents the stages of the submarine's geometric construction from basic shape to full operational configuration [25], [26].

The simulation results showed that the resistance value (RT) increased along with the addition of external components to the hull. The pure hull model produces the lowest resistance of 15.65 N, which corresponds to the characteristics of a streamlined hull without fluid flow interruptions. In this condition, the flow of fluid surrounds the hull more regularly so that the shear stress and stern pressure are at a minimum. The base model (hull only) produces the lowest drag compared to other configurations. This is due to the shape of the Joubert BB2 hull, which has a streamlined contour with a smooth and elongated cross-section, so that the fluid flow can follow the surface of the body stably without causing significant flow separation [27].

In the absence of additional components, *Skin Friction Drag* and *form drag* are at the minimum level. This value is the main reference for assessing the change in resistance due to the addition of external components. When the sail was added, the drag decreased to 14.54 N. This phenomenon appears non-linear compared to the base model, but hydrodynamically can be explained as a result of changes in flow patterns around the hull that cause pressure redistribution. The contour of the sail can smooth the flow separation so that it delays the flow separation point, which has an impact on reducing the drag force under certain conditions [28]–[30].

The simulation results show that this configuration produces lower drag than pure hull models. This phenomenon can be explained hydrodynamically:

1. The addition of sails modifies the flow pattern in the center of the ship.
2. Sails can direct flow (flow reattachment), thereby reducing flow separation in certain areas.
3. The contour of the sail causes a change in pressure that delays the occurrence of wake on the stern side.

As a result, *the form drag* decreases slightly so that the total drag becomes smaller. This is in line with several studies of submarine hydrodynamics, which show that sails in certain proportions can act as *a flow stabilizer* at low to medium speeds.

It is different when Hydrofoil 1 and Hydrofoil 2 are added. The resistance increases to 15.38N and 16.46 N. The addition of a hydrofoil changes the distribution of hydrodynamic forces at the stern, increases the wetted surface area, and creates local turbulence, resulting in additional resistance. Nonetheless, the presence of hydrofoils plays an important role in the stability of submarine motion, so the increase in drag that occurs is a form of design compromise between hydrodynamic control and drag efficiency. The addition of hydrofoil 1 caused the resistance to rise back to 15.38 N. This increase occurred due to:

1. Hydrofoil adds wetted surface area, so skin *friction drag* increases.
2. Hydrofoil creates local disturbances in fluid flow that cause increased turbulence around the structure.
3. There is an increase in stern pressure at the stern due to the interaction of the flow with the hydrofoil [31]–[33].

A hydrofoil has the function of controlling the direction and vertical stability of the submarine, so the increase in resistance is a consequence of that function. The final configuration, the Hull Complete, produced the highest drag of 20.2 N. This value increased by about 27% over the base model, indicating that the complexity of the external structure contributed significantly to the increase in form drag. Components such as sails, hydrofoils, as well as additional contours on the hull increase the fluid-structure interaction, which directly impacts the total resistance value Overall, the trend of increasing resistance in each configuration proves that the addition of external components of the submarine not only affects maneuver performance and stability, but also on the hydrodynamic efficiency of the ship [34], [35].

Therefore, the final design of the submarine must consider the balance between minimizing drag and the operational needs of the submarine, particularly when sailing at significant depths. The drag limit increases drastically to 20.20 N, or about 27% larger than the pure hull model. This huge increase is influenced by:

1. Increase in the total wet surface of all components.
2. Increasingly complex fluid flow interactions around sails, front hydrofoil, aft hydrofoil, and other detailed contours.
3. Increased backpressure that enlarges *the drag form*.
4. The wake flow pattern becomes more turbulent and unstable.

The highest resistance value on the complete model indicates that each external component contributes to the increase in total resistance, even though they are necessary for the stability and maneuver control of the submarine.

Table 3. Comparative Hydrodynamic Resistance Characteristics of Hull Configurations under Progressive Sail and Hydrofoil Integration in Operational Flow Conditions

Hull	**15,65**	**Minimum resistance, stable flow**
Hull+Sail	14,54	Pressure distribution changes, drag decreases
Hull+Sail+Hydrofoil 1	15,38	Resistance to climb due to increased wet surfaces
Hull+Sail+Hydrofoil 2	16,46	Increased flow turbulence
Hull Complete	20,53	Maximum resistance, full operational configuration

Results Analysis

Based on the results of numerical simulations using the Computational Fluid Dynamics (CFD) method, it can be analyzed that the hydrodynamic resistance of the Joubert BB2 type submarine is greatly influenced by the configuration of the hull geometry and the addition of external components. The analysis was carried out on diving conditions with an operating speed of 10 knots and a depth of 300 meters, which represents the operational conditions of submarines in Indonesian waters. The pure hull configuration shows a resistance value of 15.65 N and is the configuration with the most geometrically efficient hydrodynamic performance. This indicates that the basic shape of the Joubert BB2 hull has good streamlining characteristics, so that the fluid flow can follow the contours of the hull stably without producing significant flow separation. In this condition, skin friction drag and form drag are at a minimum level because the wet surface area is relatively small and there is no flow disturbance from additional components [36], [37].

Interestingly, the addition of sails actually resulted in a reduction in drag to 14.54 N or about 2% lower than a pure hull. This phenomenon suggests that sails do not necessarily increase resistance but can rather serve as a flow controller under certain conditions. Hydrodynamically, sails can modify the pressure distribution along the hull, delay the flow separation point, and reduce the wake at the stern. This causes a decrease in form drag even though the wet surface area increases. These findings suggest that a proportionate sail design can provide hydrodynamic advantages at medium operating speeds [38].

In contrast, the addition of hydrofoil 1 and hydrofoil 2 caused an increase in resistance to 15.38 N and 16.46 N, respectively. The interaction between the main flow and the hydrofoil structure increases the shear stress and return pressure in the stern area, resulting in additional resistance. Nonetheless, this increased drag is an acceptable design consequence as hydrofoils play an important role in the vertical stability and maneuver control of submarines [39], [40].

The complete submarine configuration resulted in the highest drag of 20.53 N, an increase of about 27–31% compared to the pure hull model. This value reflects the complexity of the fluid's interaction with all the external components of the submarine. An increase in the total wet surface, increased return pressure, and a more turbulent wake pattern are the main factors in increasing resistance. These findings confirm that each external component carries a significant resistance contribution, even though they are essential for the operational functioning of submarines. Overall, this analysis suggests that the design of the Joubert BB2 submarine must consider the balance between hydrodynamic efficiency and stability and control needs. The results of the study prove that the optimization of geometric configurations, especially sail and hydrofoil designs, has a crucial role in minimizing obstacles without sacrificing operational performance, especially for complex and diverse Indonesian water conditions [41], [42].

CONCLUSION

Based on the results of the numerical analysis that has been carried out, it can be concluded that the hydrodynamic resistance of the Joubert BB2 submarine is greatly influenced by the geometric configuration and the addition of external components to the hull. CFD modeling and simulations that have been validated through the independence grid study show that the pure hull model produces the lowest drag values, reflecting the effectiveness of the Joubert BB2 hull streamlined shape in minimizing drag under diving conditions. The validation process showed that the simulation results had a good degree of conformity to the reference data, with a difference of less than 2%, so that the numerical model used could be declared reliable and accurate. The addition of sails to the hull of the submarine actually results in a decrease in drag compared to the pure hull model, which is caused by changes in the flow distribution and pressure around the hull, so that it is able to delay the flow separation. In contrast, the addition of hydrofoil 1 and hydrofoil 2 led to increased drag due to increased wet surface area and increased flow turbulence, although these components play an important role in the stability and control of submarine motion. The complete submarine configuration results in the highest resistance as a consequence of the complexity of fluid flow interaction with all external components. Overall, this study confirms that submarine design must consider the balance between hydrodynamic resistance efficiency and operational needs, particularly to support submarine performance in diverse and challenging Indonesian water conditions.

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Author's Contributions

Abiyyu Nafis Edfian conceived and designed the research framework for the numerical analysis of hydrodynamic resistance of the Joubert BB2-type submarine. The author conducted the computational simulations, including geometry preparation, mesh generation, boundary condition setting, and numerical validation. Data processing, analysis of resistance components, and interpretation of flow behavior were carried out independently by the author. In addition, the author prepared all visualizations, discussed the results in relation to submarine hydrodynamic theory, and drafted the manuscript. The final version of the paper was reviewed, revised, and approved solely by the author.

Conflicts of Interest

The author declares that there are no conflicts of interest associated with this study. The research was conducted independently and was not influenced by any financial, institutional, or commercial relationships that could be perceived as a potential conflict. No external funding, sponsorship, or personal affiliations affected the design, execution, analysis, or reporting of the results. All numerical simulations and interpretations were performed objectively based on established scientific and engineering principles. The author affirms that the findings presented in this paper are solely for academic and scientific purposes.

REFERENCES

[1] Dogrul, A., Aydogdu, B., Cakici, F., 2021. Resistance Analyses of Joubert BB2 Benchmark Submarine.

[2] Mujahid, A.S., Utina, M.R., 2017. Analisa Pengaruh Variasi Laju Kecepatan Pada Model Kapal Selam Dengan Menggunakan Simulasi Numerik. Wave: Jurnal Ilmiah Teknologi Maritim 11, 61–68. https://doi.org/10.29122/jurnalwave.v11i2.3061

[3] Ramírez-Macías, J.A., Brongers, P., Rúa, S., Vásquez, R.E., 2016. Hydrodynamic modelling for the remotely operated vehicle Visor3 using CFD. IFAC-PapersOnLine 49, 187–192. https://doi.org/10.1016/j.ifacol.2016.10.341

[4] Renilson, M., 2018. Submarine Hydrodynamics. Springer International Publishing, Cham. https://doi.org/10.1007/978-3-319-79057-2

[5] Wibowo H Nugroho, Ahmad S. Mujahid, 2023. Prediksi Umur Kelelahan Struktur Badan Tekan Kapal Selam Karena Pengulangan Perubahan Beban Hidrostatik = On The Fatigue Life Prediction Of Submarine Pressure Hull Due To Alternating Hydrostatic Loads. Majalah Ilmiah Pengkajian Industri 9, 139–146. https://doi.org/10.29122/mipi.v9i3.1644

[6] Utina, M. Ridwan, Syafiul, A., dan Ali, Baharuddin. (2016). Numerical and Experimental Investigation of Lift Performance Over the Hydroplane of a Submarine. Journal of Subsea and Offshore, Vol. 5: 1-16.

[7] Tuakia, Firman. (2008). Dasar - Dasar CFD Menggunakan Fluent. Bandung: Penerbit Informatika.

[8] A. Federici, "Design and analysis of non-conventional hybrid high speed hulls with hydrofoils by CFD methods," University of Genoa, 2014.

[9] Aditya Purwoadikusumo, & Ali Munazid. (2023). Studi Compuutational Fluid Dynamic Penambahan Bulbousbow Tipe Axe Bow dan Wave Piercing pada kapal katamaran NPL 4a.

[10] Khairatunnisa, "Analisis Qs. Al-Baqarah/2: 283 Terhadap Tradisi Mappasanra Di Kecamatan Sinjai Selatan Kabupaten Sinjai," 2020, https://core.ac.uk/download/pdf/235085111.pdf%250Awebsite: http://www.kemkes.go.id%250Ahttp://www.yankes.kemkes.go.id/assets/downloads/PMK No. 57 Tahun 2013 tentang PTRM.pdf%250Ahttps://www.kemenpppa.go.id/lib/uploads/list/15242-profil-anak-indonesia_-2019.pdf%25

[11] R. E. Barr and D. Juricic, "From Drafting to Modern Design Representation: The Evolution of Engineering Design Graphics," *J. Eng. Educ.*, vol. 83, no. 3, pp. 263–270, 1994, https://doi.org/10.1002/j.2168-9830.1994.tb01114.x.

[12] R. E. Barr, D. Juricic, T. J. Krueger, L. S. Wall, and B. H. Wood, "The freshman Engineering Design Graphics course at the University of Texas at Austin," *J. Geom. Graph*, vol. 2, no. 2, pp. 169–179, 1998, [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85011681041&partnerID=40&md5=95aded7ae2f671e901be8bf203633238

[13] S. T. Maulia, H. Hendra, and M. Ichsan, "Jejak Perkembangan Islam Pada Kerajaan-Kerajaan Islam Di Indonesia," *JEJAK J. Pendidik. Sej. Sej.*, vol. 2, no. 2, pp. 77–84, 2022, https://doi.org/10.22437/jejak.v2i2.22477.

[14] Nasional, "Undang-Undang Dasar Negara Republik Indonesia 1945," *Nasional*, vol. 105, no. 3, pp. 129–133, 1945, [Online]. Available: https://webcache.googleusercontent.com/search?q=cache:BDsuQOHoCi4J:https://media.neliti.com/media/publications/9138-ID-perlindungan-hukum-terhadap-anak-dari-konten-berbahaya-dalam-media-cetak-dan-ele.pdf+&cd=3&hl=id&ct=clnk&gl=id

[15] Setiyowati, "Design/methodology/approach: This is an exploratory qualitative research, employing a thematic analysis approach. Six Muslim Wills (State) Enactments [Enakmen Wasiat Orang Islam (Negeri)] in Malaysia, Islamic Law Compilation (Kompilasi Hukum Islam) in Ind," *Croat. Int. Relations Rev.*, vol. 28, no. 89, pp. 136–149, 2022, https://doi.org/10.2478/CIRR-2022-0008.

[16] S. Gustiani, "Research and Development (R&D) Method as a Model Design in Educational Research and its Alternatives," *Holistics J.*, vol. 11, no. 2, pp. 12–22, 2019.

[17] D. G. J. and F. U. Noor Mahmudah1, Iswanto1, Dian M Setiawan1, "Analysis Demand and Supply Parking

Lot of Motorcycle Abu Bakar Ali Yogyakarta," in *International Conference of Sustainable Innovation*, 2019, pp. 37–39.

[18] C. N. Castel-Branco, N. Massingue, and C. Muianga, "Questions on productive development in Mozambique," no. May 2017, pp. 1–410, 2015.

[19] UU No.9 Tahun, "Presiden Republik Indonesia Peraturan Presiden Republik Indonesia," *Demogr. Res.*, pp. 4–7, 2018.

[20] I. Sánchez-Queija, I. García-Moya, and C. Moreno, "Trend Analysis of Bullying Victimization Prevalence in Spanish Adolescent Youth at School," *J. Sch. Health*, vol. 87, no. 6, pp. 457–464, 2017, https://doi.org/10.1111/josh.12513.

[21] M. H. Makarim, "Analysis of the Effect of Halal Supply Chain Management and Green Supply Chain," 2019, [Online]. Available: https://revistas.ufrj.br/index.php/rce/article/download/1659/1508%0Ahttp://hipatiapress.com/hpjournals/index.php/qre/article/view/1348%5Cnhttp://www.tandfonline.com/doi/abs/10.1080/09500799708666915%5Cn

[22] K. Breivik and D. Olweus, "An item response theory analysis of the Olweus Bullying scale," *Aggress. Behav.*, vol. 41, no. 1, pp. 1–13, 2015, https://doi.org/10.1002/ab.21571.

[23] K. L. Chester, N. H. Spencer, L. Whiting, and F. M. Brooks, "Association Between Experiencing Relational Bullying and Adolescent Health-Related Quality of Life," *J. Sch. Health*, vol. 87, no. 11, pp. 865–872, 2017, https://doi.org/10.1111/josh.12558.

[24] C. E. Lister, R. M. Merrill, D. L. Vance, J. H. West, P. C. Hall, and B. T. Crookston, "Victimization Among Peruvian Adolescents: Insights into Mental/Emotional Health From the Young Lives Study," *J. Sch. Health*, vol. 85, no. 7, pp. 433–440, 2015, https://doi.org/10.1111/josh.12271.

[25] K. R. Case, A. Pérez, D. L. Saxton, D. M. Hoelscher, and A. E. Springer, "Bullied Status and Physical Activity in Texas Adolescents," *Heal. Educ. Behav.*, vol. 43, no. 3, pp. 313–320, 2016, https://doi.org/10.1177/1090198115599986.

[26] J. Vessey, T. D. Strout, R. L. Difazio, and A. Walker, "Measuring the Youth Bullying Experience: A Systematic Review of the Psychometric Properties of Available Instruments," *J. Sch. Health*, vol. 84, no. 12, pp. 819–843, 2014, https://doi.org/10.1111/josh.12210.

[27] A. W. A. Muhadri, Ali Imran Sinaga, "Imam Al-Ghazali's Thoughts On The Competence Of Professional Teachers In The Ayyuhal Walad Book," vol. 1, No 4, pp. 104–111, 2020.

[28] J. Meisner *et al.*, "Mapping hotspots of zoonotic pathogen emergence: an integrated model-based and participatory-based approach," *Lancet Planet. Heal.*, vol. 9, no. 1, pp. e14–e22, 2025, https://doi.org/10.1016/S2542-5196(24)00309-7.

[29] D. Stojmenovska, "Gender Differences in Job Resources and Strains in Authority Positions," *Gend. Soc.*, vol. 37, no. 2, pp. 240–267, 2023, https://doi.org/10.1177/08912432231159334.

[30] A. Serdari, A. Gkouliama, G. Tripsianis, H. Proios, and M. Samakouri, "Bullying and minorities in secondary school students in Thrace-Greece," *Am. J. Orthopsychiatry*, vol. 88, no. 4, pp. 462–470, 2018, https://doi.org/10.1037/ort0000281.

[31] E. Cirves, A. Vargas, E. E. Wheeler, J. K. Leach, S. I. Simon, and T. Gonzalez-Fernandez, "Neutrophil Granulopoiesis Optimized Through Ex Vivo Expansion of Hematopoietic Progenitors in Engineered 3D Gelatin Methacrylate Hydrogels," *Adv. Healthc. Mater.*, vol. 13, no. 14, 2024, https://doi.org/10.1002/adhm.202301966.

[32] J. M. Colston *et al.*, "Use of earth observation-derived hydrometeorological variables to model and predict rotavirus infection (MAL-ED): a multisite cohort study," *Lancet Planet. Heal.*, vol. 3, no. 6, pp. e248–e258, 2019, https://doi.org/10.1016/S2542-5196(19)30084-1.

[33] D. Sarah, E. Soebowo, N. A. Satriyo, T. Wirabuana, and R. Widyanmgrum, "Urgent Need for Land Subsidence Education in Indonesia to Increase Community Awareness and Preparedness," *AIP Conf. Proc.*, vol. 2468, no. November 2020, 2022, https://doi.org/10.1063/5.0102454.

[34] E. M. Djafar, T. F. Widayanti, M. Zulfan Hakim, and S. S. Rivannie, "Analysis of law enforcement on Marine Debris in Indonesia," in *IOP Conference Series: Earth and Environmental Science*, Constitutional Law Department, Faculty of Law, Hasanuddin University, Makassar, Indonesia: Institute of Physics, 2022. https://doi.org/10.1088/1755-1315/1119/1/012065.

[35] A.-N. Mubin *et al.*, "Retracted: Managing the invisible threat of microplastics in marine ecosystems: Lessons from the coast of the Bay of Bengal," *Sci. Total Environ.*, vol. 889, p. 164224, Sep. 2023, https://doi.org/10.1016/j.scitotenv.2023.164224.

[36] I. Caamaño-Franco, A. Pérez-García, and M. Andrade-Suárez, "Female entrepreneurship and marine tourism: Innovative practices on the coastline," in *Innovation and Entrepreneurial Opportunities in*

Community Tourism, Universidade da Coruna, Spain: IGI Global, 2020, pp. 172–190. https://doi.org/10.4018/978-1-7998-4855-4.ch010.

[37] A. D. Rini, S. D. Handy, and I. Hidayah, “Blue Economy-Based Fisheries and Marine Business Model Development,” *J. Entrep. Dan Entrep.*, vol. 10, no. 1, pp. 43–56, 2021, https://doi.org/10.37715/jee.v10i1.1848.

[38] B. B. Hering and H. Feith, *The Decline of Constitutional Democracy in Indonesia*. 2007. https://doi.org/10.2307/40198726.

[39] J. E. Sirait, N. A. Soraya, and H. Alrasyid, “Penguatan Model Bisnis Badan Usaha Milik Swasta (BUMS) Dalam Mendukung Kemandirian Industri Pertahanan,” *J. Kewarganegaraan*, vol. 6, no. 4, pp. 7273–7283, 2022, [Online]. Available: http://journal.upy.ac.id/index.php/pkn/article/view/4493

[40] C. Maharani and R. Matthews, “The Role of Offset in the Enduring Gestation of Indonesia’s Strategic Industries,” *Def. Peace Econ.*, vol. 00, no. 00, pp. 1–22, 2022, https://doi.org/10.1080/10242694.2022.2065423.

[41] Z. Abuza, A. Ft, and L. J. McNair, “The Ongoing Insurgency in Southern Thailand : Trends in Violence, Counterinsurgency Operations, and the Impact of National Politics,” *Strateg. Perspect.*, no. 6, 2011, https://doi.org/10.21236/ADA577624.

[42] B. W. P. Muhammad Diaz Arda Kusuma, “Deconcentration Funds: Redistribution and Economic Growth in Indonesian Provinces,” in *The 19th Malaysia Indonesia International Conference on Economics, Management and Accounting (MIICEMA)*, 2018, pp. 1689–1699.