Development of A High-Speed Vessel Design Using A Combination of Optimal Shape and Materials Based on 3D Modeling

Veda Fauzan Wardiansah[1], Muhammad Farisan Zhafiri[1], Dandun Mahesa Prabedaowoputra[1]*

[1] Teknik Mesin, Universitas jenderal Soedirman, Purbalingga, Jawa Tengah, Indonesia
*Corresponding author: dandun.mahesa@unsoed.ac.id

Abstract. Indonesia, as a maritime country, has a vast territorial sea that requires efficient sea transportation. Fast boats are an important solution to support sea transportation mobility, patrols, and logistics activities. Fast boat design needs to consider hull shape and the selection of appropriate materials to produce optimal, stable, and efficient structural performance. This study was conducted to analyze the effect of hull geometry and material type variations on the structural strength of fast boats through 3D modeling based on Finite Element Analysis (FEA) in design software. Three hull shapes were analyzed, namely V-shaped hulls, round hulls, and flat hulls. The three shapes were then adjusted to three material options, namely aluminum alloy, AISI 1036 steel, and titanium. Each model was given an external load of 1,000 N as a simulation of the force acting on the structure, so that the stress values, deformation levels, and strains that appeared in each combination of shape and material could be obtained. Based on the simulation results, it was found that the V-shaped hull using aluminum material showed the best performance, with the smallest deformation value and a relatively higher strength-to-weight ratio compared to other combinations. Aluminum was chosen as the best material because it has a lower density, good corrosion resistance in marine environments, and provides higher energy efficiency compared to steel and titanium. In conclusion, the V-shaped hull design and aluminum material can be recommended as a superior fast boat design concept in terms of structural strength, operational stability, and motion efficiency when operating in water.
Keywords: Speedboat, Material Design, FEA, Structural Deformation

How to cite (in APA style):
Wardiansah, V.F., Zhafiri, M.F., & Prabedaowoputra, D.M. (2026). Development of A High-Speed Vessel Design Using a Combination of Optimal Shape and Materials Based on 3D Modeling. *Proceeding of IJC-MaSTEd*, 1(1), 39-47.

DOI: https://doi.org/10.31571/ijcmasted.v1i1.1027

1. Introduction

Indonesia is a maritime nation; this designation was not simply bestowed upon Indonesia. One reason Indonesia is called a maritime nation is that it possesses vast oceans, and geographically, two-thirds of Indonesia's territory consists of oceans. There are several sectors within the maritime economy in Indonesia, namely the shipping sector, the fisheries sector, and the marine tourism sector (Nikawanti, 2021).

Throughout the history of human civilization, ships have played a vital role as the primary means of exploring territorial waters and supporting the advancement of science. As human society has evolved, shipbuilding technology has also advanced rapidly. Today, ships are not only used for regular voyages but are also designed for specialized purposes such as firefighting, rescue missions, and scientific research activities. As an archipelagic nation, Indonesia heavily relies on ships across various sectors. The use of ships in Indonesia has expanded into various fields, including logistics, mass transportation, and military defense. (Oliveira et al. 2020) in the Journal of Marine Science and Engineering demonstrate that the application of high-speed ship designs based on green technology can reduce energy consumption by 20–30% while minimizing environmental impact, thereby enabling maritime transport to contribute more effectively to achieving the SDGs.

The initial stage in the technical process of shipbuilding is determining the ship's dimensions and shape parameters, however, in addition to these, there is one important factor that influences a ship's performance, namely ship resistance or resistance force. The fundamental principle underlying the design calculations for a ship's structural strength is the consideration that the ship's hull functions as an elongated beam resting on a fluid medium in this case, ocean waves which exert fluid pressure and dynamic forces. Based on this, predicting the ship's resistance is crucial before the ship is constructed.

An optimal ship design must have low resistance to move smoothly and consume as little energy as possible, even when carrying a heavy load. This makes the ship more energy efficient, economically efficient, and more environmentally friendly. In addition to efficiency, ship design must also consider stability and maneuverability to ensure the ship remains balanced and capable of navigating effectively in various water conditions. Innovations in design technologycontribute to improved efficiency in the logistics and tourism sectors, and offer new solutions for maritime transportation. To enable a shipto move quickly, the hull design must be engineered so that water flow around it remains smooth. Additionally, the load distribution must be carefully designed to maintain the ship's balance and stability while moving quickly through the water. The combination of an efficient design and proper high-speed maneuverability allows cargo ships to operate optimally without compromising agility while navigating the waters.

The purpose of this study is to compare and test various high speed boat designs. We will examine three high speed boat models with different shapes, then analyze the strength of each design using three types of materials fiberglass, aluminum, and steel. The method used in this study is the Finite Element Analysis (FEA), which emerged in the 1960s. In the field of structural engineering, FEA has been developed to solve static, dynamic, linear, and nonlinear problems. FEA is a numerical procedure accepted by engineers for estimating limit values by determining the stress, displacement, and strain occurring in the vessel (Arifin et al., 2023). The ultimate goal of this analysis is to determine the most optimal combination of design and materials, so that the resulting speedboat has high strength, an attractive appearance, and maximum performance.

2. Method

Design Thinking generally consists of several sequential stages: Empathize, Define, Ideate, Prototype, and Test. The following is a flowchart illustrating the research methodology.

2.1 Empathize

High speed boats aren't just about speed, they're about helping people who need to move quickly across the water to save lives, deliver essential supplies, or connect remote islands. These boats are designed to remain stable and safe even when traveling at high speeds over the waves. Every part of a speedboat serves a purpose, from its streamlined shape to its powerful engine. Everything is designed so the boat can perform at its best in a short amount of time.

2.2 Define

The design of high-speed vessels aims to create ships that can travel at high speeds without compromising stability, safety, and comfort. This is important so that the vessels can be used for various purposes, such as patrols, inter-island transportation, or tourism. In the design process, factors such as speed, the vessel's ability to maintain balance while navigating waves, the use of strong and durable materials, and fuel efficiency must be considered. Additionally, the vessel must be comfortable and meet the needs of its users. By planning all of these aspects from the outset, the high-speed vessel design will be more suitable and effective.

2.3 Ideate

High-speed vessel hull designs come in various types, each designed to meet operational requirements, speed, and vessel stability. One of the most commonly used types is the monohull, known for its simple construction, suitability for high speeds, and relative cost effectiveness in terms of construction. To achieve better stability, especially when operating in rough waters, the catamaran design with a V shaped hull is a preferred choice because it provides superior lateral stability and improved fuel efficiency. As another alternative, the flat-bottomed hull design features a flat hull that provides excellent stability and maximum performance when traveling at high speeds.

2.4 Prototype

A. Form 1 (V Hull High Speed Boat)

The first design features a V shaped hull at the bottom of the ship. This design is intended to cut through waves more efficiently, thereby reducing water resistance when the ship is traveling at high speeds. The advantages of the V shaped hull include good stability when turning and optimal performance in rough waters. However, this shape requires more engine power than other types due to its larger wetted surface area.

B. Type 2 (Round Hulled High Speed Boat)

The second design uses a round hull. This shape is characterized by smooth movement and is efficient at reducing water resistance. Ships with round hulls generally have good cruising speed in calm waters. However, their stability tends to be lower at high speeds and in rough seas, making them more suitable for medium speed cruisers.

C. Type 3 (Flat Hulled High-Speed Boat)

The third design features a flat hull. This design has high buoyancy and is capable of operating in shallow waters. A flat hull provides good lateral stability at low speeds and facilitates maintenance due to the ship's simple underwater structure. However, at high speeds, ships with flat hulls tend to experience harsher wave impacts, thereby reducing comfort.

2.5 Mesh Study

A. Object Diagram and Dimensions

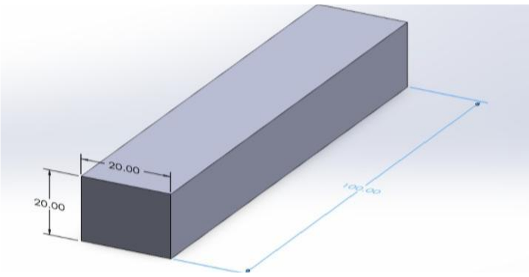


Figure 1. Objects and dimensions

The figure above shows the geometric model of the workpiece used in the simulation process. The object is modeled as a block using CAD software. The figure also displays the main dimensions of the object, namely length, width, and height. These dimensions serve as the basis for the analysis process because they determine the geometric shape and volume of the object to be analyzed. Clear definition of these dimensions is necessary so that the meshing and simulation processes can produce accurate calculations consistent with the actual model conditions.

B. Meshing

a. Material: Aluminium

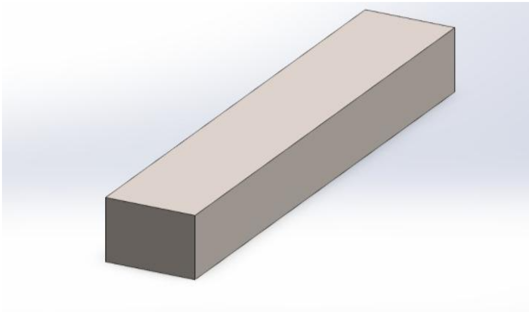


Figure 2. Meshing aluminium

This figure shows that the material used in the simulation model is aluminum. Aluminum was chosen because it is lightweight, has good strength, and is frequently used in various engineering applications, such as frame structures and machine components. In the simulation, the mechanical properties of aluminum such as the elastic modulus, Poisson's ratio, and density are input into the software so that the material's behavior under load can be analyzed numerically.

b. Fixture: Fixed Geometry

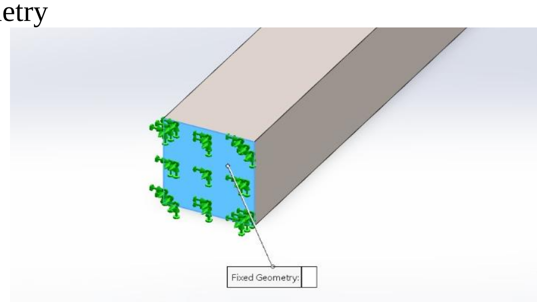


Figure 3. Fixture

This figure shows a fixed geometry boundary condition applied to one of the object's surfaces. The surface marked with a green arrow indicates that this section is locked or constrained so that it cannot undergo displacement or rotation during the simulation process. The application of this boundary condition aims to represent real world conditions where one side of the structure is fixed or attached to a support, allowing for a more realistic calculation of stress, deformation, and structural response.

c. External Load: Force 1.000 N

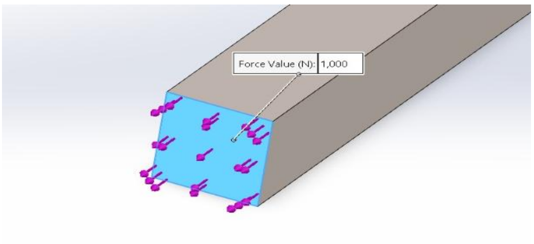


Figure 4. External load

The figure shows the application of an external load to the simulation model. The applied load consists of a force of 1,000 N acting on one of the beam's end surfaces. The direction of the arrow in the figure indicates the direction of the force distribution acting on that surface. The application of this load aims to simulate the structural operating conditions when subjected to external forces, thereby enabling the analysis of the resulting mechanical responses, such as stress, strain, and material deformation. With this external load, the software can calculate the stress distribution throughout the model based on the previously defined boundary conditions.

d. Mesh size: 6–1

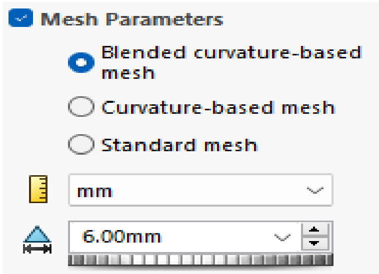


Figure 5. Mesh

This figure shows the meshing parameter settings used in the simulation process. The mesh method used is a blended curvature-based mesh, which allows the mesh elements to follow the model's geometry more accurately. The mesh element size is set from 6 mm to 1 mm to conduct a mesh convergence study. This variation in mesh size aims to determine the effect of element size on the simulation results. The smaller the mesh size used, the greater the number of elements, so the analysis results generally become more detailed and closer to actual conditions.

e. Run

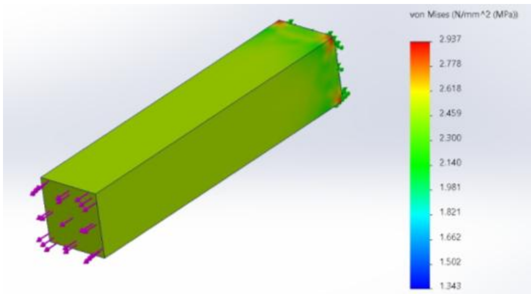


Figure 6. Sample for mesh size 6

This image shows the simulation results after the calculation process has been run. The analysis results are displayed as color contours representing the stress distribution in the model. The color scale on the right side of the image indicates the magnitude of the stress values occurring in each part of the object. Red indicates areas with the highest stress, while blue indicates lower stress. In the example results shown for a 6 mm mesh size, a stress value of approximately 2,500 N/mm² was obtained. This value will then be compared with simulation results for other mesh sizes (5, 4, 3, 2, and 1 mm) to assess the stability of the analysis results in the mesh study (mesh convergence).

3. Results and Discussion

As the ideal material for high-speed boats, aluminum is the best choice compared to steel or titanium. One of aluminum's key advantages is its light weight, which significantly contributes to increased boat speed. With a density of only about one third that of steel, using aluminum reduces water resistance and allows the engine to operate more smoothly and efficiently. Furthermore, aluminum specifically designed for maritime use is known for its high resistance to corrosion caused by the marine environment. Aluminum is also easier to work with, both in terms of forming and welding, which can accelerate and simplify the shipbuilding process. Due to these characteristics, aluminum is highly suitable for high-speed vessels such as passenger ships, patrol boats, and speedboats that prioritize optimal performance over short travel times.

The results of a mesh study conducted on a simulation model with element sizes ranging from 6 mm to 1 mm. Each change in mesh size results in a different number of elements in the analyzed model. In general, the smaller the element size used in the meshing process, the greater the number of elements generated, resulting in a more detailed representation of the model's geometry. This condition can be observed in the data presented in the table, where the use of a 6 mm mesh size resulted in 1783 elements, whereas when the mesh size was reduced to 1 mm, the number of elements increased significantly to 247756 elements. This increase in the number of elements indicates that the model is divided into smaller parts, allowing the numerical analysis to be performed with a higher level of accuracy.

The simulation results show that the stress values for each mesh size variation are relatively consistent, at approximately 2,500 N/mm². This consistency in stress values indicates that the analysis has reached a state of convergence, meaning that changes in element size no longer have a significant effect on the calculation results. In other words, even though the mesh size was gradually refined, the resulting stress values remained stable. This indicates that the simulation model used is capable of accurately representing the loading conditions, and the analysis results can be considered sufficiently accurate to describe the structural response to the applied forces. In addition, an error value of 0% was obtained for each mesh size variation, indicating that there were no significant differences in the calculated stress results. This very small error value indicates that the simulation process exhibits a high degree of consistency across the tested mesh variations.

The study was conducted on three design variations and three material variations, the differences lie in the hull shape and the materials used. The hull design of the speedboat is shown in the following figure.

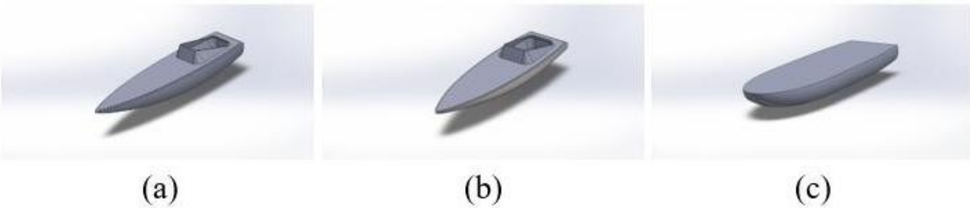


Figure 7. Ship Hull Geometry a) V-shaped, b) Round, c) Flat

On the other hand, steel is still widely used in the shipbuilding industry due to its superior structural strength and impact resistance. This material provides high stability and sturdiness to ships, making it ideal for large vessels or those operating in extreme sea conditions. However, the main drawback of steel is its high weight. This substantial mass adds to the ship's load and directly impacts reduced speed as well as increased fuel consumption. Consequently, steel hulled ships tend to be slower and require greater engine power. Therefore, steel is more commonly used in tankers, large commercial vessels, or cargo ships that prioritize cargo capacity and structural durability over speed.

Meanwhile, titanium offers a combination of superior technical properties. This material boasts exceptional strength, light weight, and extremely high corrosion resistance, even surpassing that of aluminum. Titanium can withstand aggressive marine environments for extended periods without structural degradation. However, titanium also presents several challenges, particularly regarding cost and manufacturing processes. It is significantly more expensive than aluminum and steel, and its fabrication requires specialized technology and expertise not available at all shipyards. Its use is more limited to specialized applications such as high standard military vessels, scientific research ships, or marine vehicles for specialized exploration requiring extreme durability and long-term reliability. The boundary conditions used in the load test are a weight of 1600 N. For the ship's materials and design, equivalent values of 1000 N are applied for the ship's machinery and 600 N for the weight of people on board.

For the first ship design, simulations were conducted using three materials. In the test using aluminum alloy, a deformation scale of 54.671 was obtained. In the test using AISI 1036 steel (ss), a deformation scale of 54.529 was obtained. And for the titanium material, a deformation scale of 54.387 was obtained. The contour results for the V-shaped design are shown in Figure 2 for the stress contour, Figure 3 for the displacement contour, and Figure 4 for the strain contour.

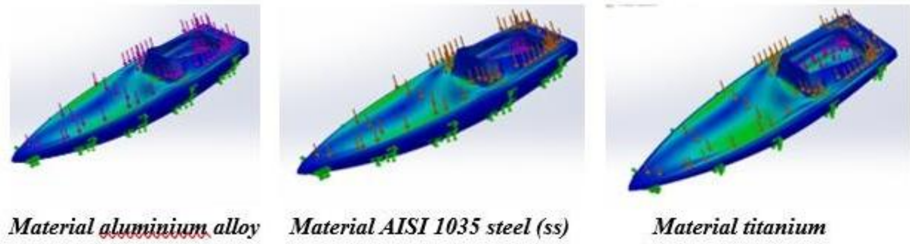


Figure 8. Stress Contours on a V-Shaped Shape

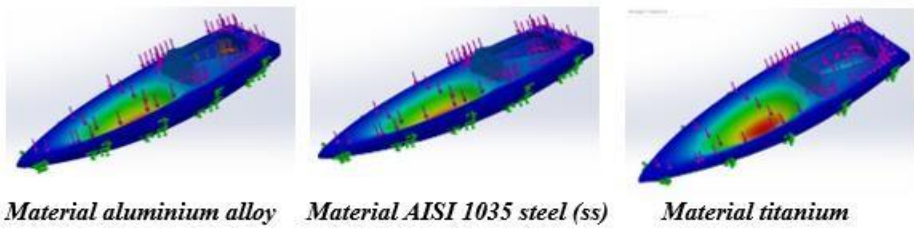


Figure 9. Contour Displacement on a V-shaped form

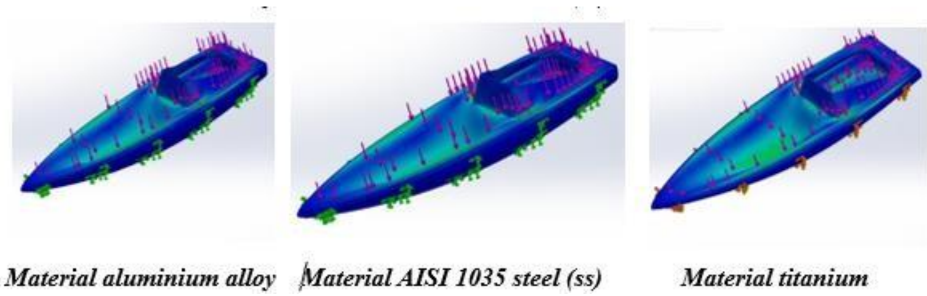


Figure 10. Strain Contour in a V-Shape

For the second ship design, simulations were conducted using three materials. In the test using aluminum alloy, a deformation scale of 50.177 was obtained. In the test using AISI 1036 steel (ss), a deformation scale of 49.967 was obtained. And for titanium, a deformation scale of 49.755 was obtained. The contour results for the circular design in the stress contour are shown in Figure 5, the displacement contour is shown in Figure 6, and Figure 7 shows the strain contour.

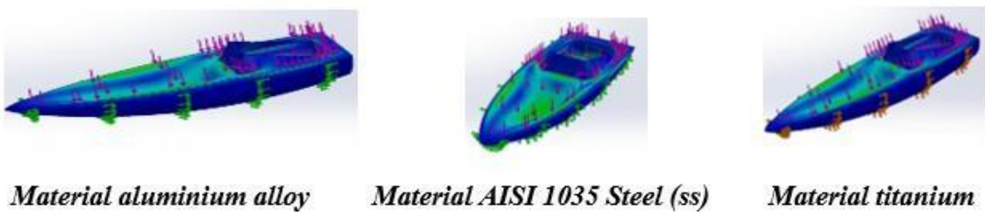
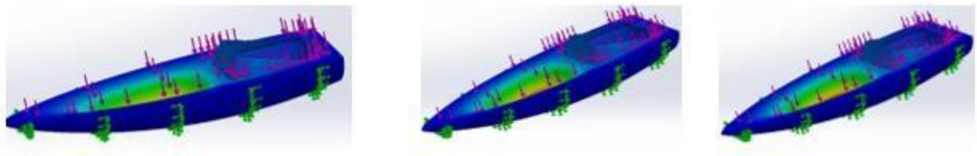
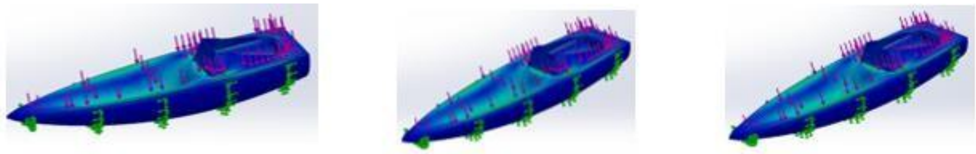


Figure 11. Stress Contours on a Spherical Shape



Material aluminium alloy *Material AISI 1035 steel (ss)* *Material titanium*

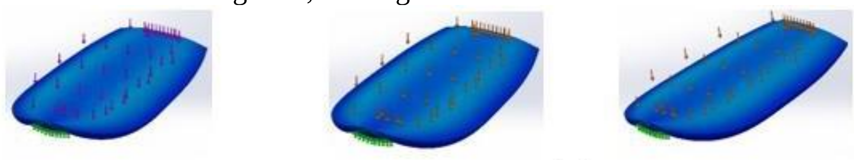
Figure 12. Contour Displacement on a Circular Shape



Material aluminium alloy *Material AISI 1035 steel* *Material titanium*

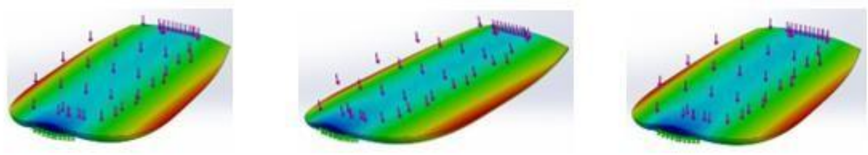
Figure 13. Strain Contour on a Spherical Shape

For the third ship hull configuration, simulations were conducted using three materials. In the test using aluminum alloy, a deformation scale of 0.141 was obtained. In the test using AISI 1036 steel (SS), a deformation scale of 0.142 was obtained. And for titanium, a deformation scale of 49.755 was obtained. The contour results for the flat design in the stress contour are shown in Figure 8, the displacement contour is shown in Figure 9, and Figure 10 shows the strain contour.



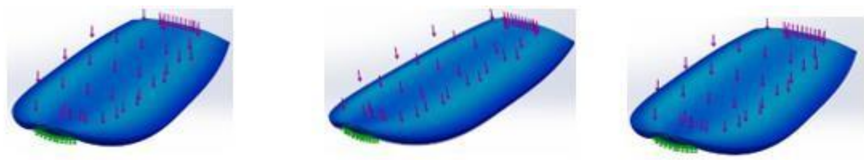
Material aluminium alloy *Material AISI 1035 steel (ss)* *Material titanium*

Figure 14. Stress Contours on a Flat Surface



Material aluminium alloy *Material AISI 1035 steel (ss)* *Material titanium*

Figure 15. Contour Displacement on a Flat Surface



Material aluminium alloy *Material AISI 1035 steel (ss)* *Material titanium*

Figure 16. Strain contours on a flat surface

4. Conclusion

From the analysis and modelling I have carried out, it can be concluded that the choice of materials and design significantly influences how a high-speed vessel performs in terms of speed, safety, stability on the water and resistance to corrosion. Although steel is highly suitable for use in ships, its corrosion resistance in the hull is very poor compared to aluminium and titanium. It is therefore essential to select the most appropriate material for the vessel's requirements. For this high speed vessel, aluminium and titanium are highly suitable materials as they are lightweight and corrosion resistant, enabling the vessel to move at high speeds. In this case, one design variation a V shaped hull made of aluminium achieved the highest score of 451 across the criteria of speed, aesthetics, safety, corrosion resistance, and stability, with the best rating specifically in the corrosion resistance category.

Overall, this report provides comprehensive instructions on all the necessary stages involved in the design modelling of high-speed vessels, ranging from mesh studies and material selection to 3D modelling and structural analysis. By applying the principles of design thinking and the Finite Element Analysis (FEA) methodology, potential issues can be identified at an early stage of the design process. This allows for improvements to be made before the mass production process begins, thereby minimising the risk of errors or production failures.

Reference

Alvin, M. H., Atok, M., & Indiaryanto, M. (2020). Analisis Regresi untuk Memprediksi Tahanan Kapal Cepat. *Jurnal Sains dan Seni ITS*, *9*(1), D87-D94.

Aprilia, L., Wahyudi, D., & Ariani, B. (2018). Analisis teknis sudut fin stabiliser pada kapal patroli cepat dengan simulasi CFD (Computational Fluid Dynamics). *Jurnal Midship*, *1*.

Arifin, F., Azharuddin, Arnoldi, D., Effendi, S., Herlambang, Y. D., Yahya, F., Fadilah, M. A., & Radjiq, A. (2023). Design simulation of upper arm on welding table. *International Journal of Mechanics, Energy Engineering and Applied Science (IJMEAS)*, 1(1), 7–11.

Hakim, P. R., & Utama, I. K. A. P. (2018). Analisa Hambatan dan Pitching Moment Equilibrium Pada Kapal Planing Jenis Monohull with Tranverse Step Pada Perairan Calm Water. *Jurnal Teknik ITS*, *7*(1), G53-G58.

Nugraha, Y. A. (2014). Implementasi Sistem Otomatis pada Robot Kapal Berbasis Komputer Vision Untuk Kontes Kapal Cepat Tak Berawak Nasional (KKCTBN). *Bandung: Universitas Komputer Indonesia*.

Noya, M., & Noya, E. V. (2023). Dampak Gelombang Kapal Cepat Pada Wilayah Pesisir Pantai Yang Mengakibatkan Abrasi. *Balobe Law Journal*, *3*(1), 8.

Romadhoni, A. P. (2024). *Desain Kapal Pengangkut Barang Untuk Unmaned Surface Vehicle (USV) Pada Perairan Tenang Untuk Wisata Bahari* (Doctoral dissertation, Universitas Islam Indonesia).

Wulandari, A. I., Suardi, S., & Ismail, M. Y. (2021). Analisis getaran dan kebisingan pada kamar mesin dan geladak penumpang kapal cepat Aluminium. *Turbo J. Progr. Stud. Tek. Mesin*, *10*(2), 264-271.

Yani, A. R. S. P. A., & Putra, M. A. A. (2025). Pemodelan cerdas disain meja belajar sederhana: Analisis material dengan finite element approach. *Jurnal Teknik Mesin Indonesia*, *20*(2), 19-24.

Zubaer, H. (2018). Analisa Variasi Twin Step Hull pada Kapal Pilot Boat 15 Meter ALU dengan Menggunakan Metode CFD. *Jurnal Teknik Perkapalan*, *6*(1).