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Analysis of Resistance and Flow Velocity on Barge Skeg Variations Using Computational Fluid Dynamics Method

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ABSTRACT

The maritime sector utilizes various technologies, including barges, which rely on tugboats for propulsion due to lacking their propulsion system. To enhance sailing efficiency, stern modifications through skeg additions can optimize performance, though these affect drag force and velocity. This study analyzed 12 skeg variations using Computational Fluid Dynamics (CFD) simulation via ANSYS Workbench software to determine optimal design configurations. At 4 knots, the analysis revealed variation 3 as the most efficient design, producing a drag force of 17,775.80 N and velocity-u of 2.07198 m/s. Similarly, at 8 knots, variation 3 maintained optimal performance with a drag force of 67,405.60 N and velocity-u of 4.1430 m/s. Results demonstrated that variation 3 consistently provided the most stable and optimal performance across low and high speeds. These findings provide valuable insights for future barge design considerations, offering a reliable reference for selecting optimal skeg configurations.

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INTRODUCTION

The use of ships in the maritime world supports technology that helps facilitate human work (Kyaw 2024), one of which is barges used to transport goods (Shobayo & van Hassel 2019). The maritime industry relies heavily on barges for transporting goods (Hasmi & Nurcholik 2020). This type of vessel does not have a propulsion system and requires a tugboat to move (Yasim & Abdul Ghofur 2018; Lee et al. 2022), which necessitates that the barge be designed with efficient performance for sailing (Ivanov 2021; Duldner-Borca et al. 2024). The selection of an efficient stern design for barges can be achieved by adding a skeg (Yu et al. 2021), which helps enhance the barge's performance during navigation (Lee & Lee 2020).

Various studies have investigated skeg design optimization to improve barge efficiency. A study about stern designs for barges have been developed to achieve optimal performance, with different skeg design variations (Lin, He & Li 2018). The result shows hull form optimization for twin-skeg fishing vessels, emphasizing minimum resistance through surrogate modeling. Other research analyzed skeg's influence on ship maneuverability at different speeds, focusing on optimizing appendage placement (Ferrari et al. 2021). Others examined the resistance characteristics of twin-skeg Ro-Ro ferries, highlighting the impact of skeg shape and position (Maulana et al. 2023). However, in this process, resistance becomes a major influencing factor (Hasmi & Nurcholik 2020) have performed CFD simulations on barge skegs, revealing the significance of skeg geometry in resistance reduction, particularly affecting the flow speed generated (Pacuraru & Domnisoru 2017).

Despite these contributions, prior studies primarily focus on fishing vessels, Ro-Ro ferries, and general ship maneuverability, with limited investigations on barge skeg design optimization using CFD simulations across multiple design variations. This research fills that gap by analyzing 12 skeg variations through Computational Fluid Dynamics (CFD) simulations in ANSYS Workbench, identifying the most efficient skeg configuration for resistance and velocity optimization under varying operational speeds.

The objective of this study is to determine the most optimal skeg design for barges by analyzing resistance and flow velocity patterns. The findings offer valuable insights for barge designers in selecting effective skeg configurations to enhance navigational efficiency.

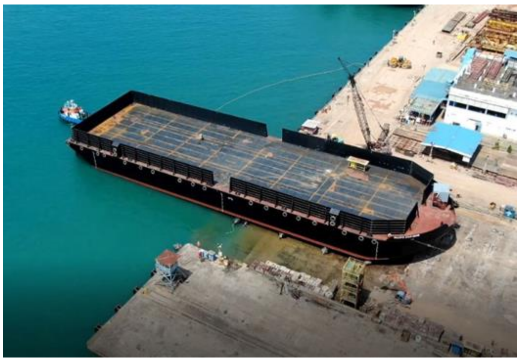

Figure 1. Barge

The barge, also known as a pontoon, is characterized by a large box-shaped hull that floats on the water’s surface (Igwe & Ajoko 2020). It is commonly used as a floating dock and a means for transporting cargo or goods. An example of a barge can be seen in Figure 1. The barge’s hull shape resembles a block, resulting in a block coefficient (Cb) close to 1 (Zhang & Lin

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2024). Barges are generally not equipped with support systems such as propulsion, electricity, or piping systems. Consequently, barges require assistance from tugboats to move (Freeman et al. 2022). The barge used in this study is a model measuring 220 x 64 x 14 feet, equipped with two skegs, each with an angle of 150° and a width of 200 mm. The barge operates at an average speed of 4 knots and a maximum speed of 8 knots.

Figure 2. Skeg on Barge

A skeg is an additional component installed at the stern of a vessel's hull (Maulana et al. 2023). Shaped like a fin, it is designed to improve the vessel's stability at high speeds and to streamline the fluid flow past the hull and propeller (Choi et al. 2021). Figure 2 depicts the type of skeg used in the barge. There are two types of skegs: the first type is positioned inboard alongside the propeller shaft and serves two functions—streamlining fluid flow and supporting the shaft. The second type is mounted on the outer shaft, making it more effective at directing fluid flow smoothly toward the propeller (Ferrari et al. 2021).

Fluid is a substance, either liquid or gas, that can flow. Flow can be classified into three types: laminar, transitional, and turbulent. Distinguishing between these flow types involves a value known as the Reynolds Number (Uruba 2019). Laminar flow has a steady flow rate, with a velocity that does not vary over time and a Reynolds Number below 2000. Transitional flow represents the shift from laminar to turbulent, with a Reynolds Number between 2000 and 4000. In turbulent flow, particle movement is irregular relative to one another, with a Reynolds Number above 4000 (Rónaföldi, Roósz & Veres 2021).

The drag force arising from interaction with fluid is referred to as ship resistance (Deshpande, Das & Sundsb 2020). This resistance is a fluid force that acts parallel to the vessel’s axis of movement. When this resistance equals the applied force, it is termed hydrodynamic force, which occurs due to the relative motion between the ship and water (Winarno et al. 2023). Total ship resistance comprises three main components. First, frictional resistance is caused by friction between water and the ship's outer surface. Second, residual resistance includes surface friction resistance. Third, additional resistance results from factors such as hull surface roughness, air resistance, appendages, and rudders.

METHOD

This research focuses on the effects of various skeg designs on the resistance and fluid flow velocity around the barge (Yang et al. 2024). In general, this study includes the following stages:

a. Determining the ship parameters and skeg variations to be used.
b. Creating 3D models of the barge and skeg variations in 3D software.
c. Validating the ship model according to BKI (Biro Klasifikasi Indonesia) standards.
d. Running Computational Fluid Dynamics (CFD) simulations.
e. Validating simulation results against

previous research.

f. Obtaining values for resistance and flow velocity.
g. Identifying the most optimal skeg design variation.

Barge Model and Skeg Design Specifications

The material for this research is defined and analyzed based on a reference barge model. The designated barge is a 220-foot barge with the following main specifications:

- LOA (Length Over All): 220 feet
- Beam (B): 64 feet
- Height (H): 14 feet
- Draft (D): 11 feet
- LCB (Longitudinal Center of Buoyancy): 1.0802% L
- Displacement: 5,091 tons
- Block coefficient (Cb): 0.89

Object Parameters of the Study

This research aims to find the most optimal skeg design variation for the barge. Therefore, the parameters used in this study are as follows:

a. Fixed Parameters
The study uses the main data of the 220-foot barge as the fixed parameter.
b. Variable Parameters
The skeg design variations in this study are derived from field analysis. Based on this analysis, the variable parameters include two variations in the number of skegs, two variations in skeg cross-sectional width, and three variations in skeg angle. A one-to-one correspondence method is then applied to these parameters, resulting in 12 skeg design variations. Each design will be simulated at two different ship speeds: 4 knots and 8 knots. A summary of the variations is shown in Table 1 and Figure 3 below.

Table 1. The performance of skeg variation data

No	Skeg Quantity	Skeg Cross-sectional Width	Skeg Angle Variation	A (mm)	B (mm)	C (mm)
1	2	200 mm	120°	200	870	170
2	2	200 mm	150°	200	870	90
3	2	200 mm	180°	200	870	-
4	3	200 mm	120°	200	870	170
5	3	200 mm	150°	200	870	90
6	3	200 mm	180°	200	870	-
7	2	300 mm	120°	300	870	169
8	2	300 mm	150°	300	870	91
9	2	300 mm	180°	300	870	-

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No	Skeg Quantity	Skeg Cross-sectional Width	Skeg Angle Variation	A (mm)	B (mm)	C (mm)
10	3	300 mm	120°	300	870	169
11	3	300 mm	150°	300	870	91
12	3	300 mm	180°	300	870	-

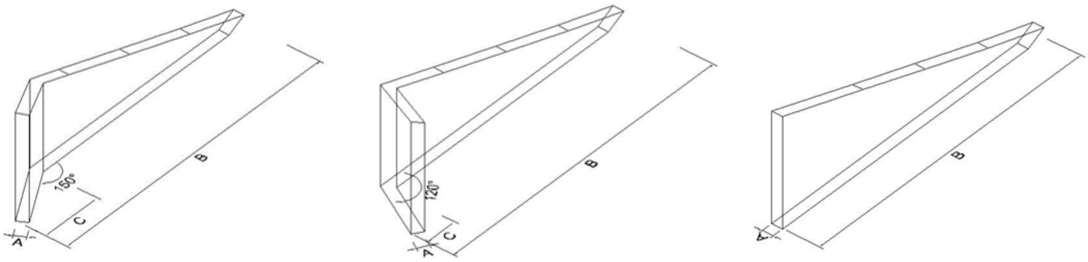

Figure 3. Skeg Dimension

RESULTS AND DISCUSSION

Ship Hull Modeling

The modeling for resistance analysis and flow velocity on this 220-foot barge vessel uses 3D software assistance. From the data established in the research methodology, the following 3D modeling of the 220-foot barge hull was produced.

Before proceeding to the analysis software, the geometry in 3D software must be converted so it can be read in the next simulation software, namely Ansys software. The step that must be taken is to export the file into *.iges format. The *.iges format is a digital modeling format that can be read by Ansys software. The barge ship hull model can be seen in Figure 4 below.

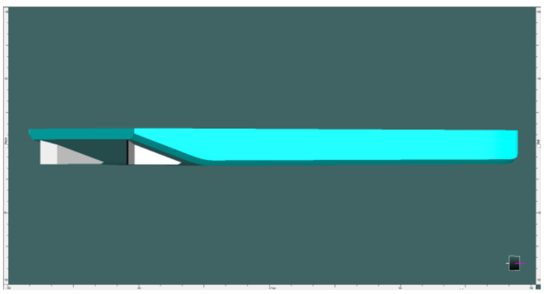

Figure 4. Barge Ship Hull Modeling

Model Validation against BKI

From the ship hull design modeling results, according to the predetermined main barge data, several data points were obtained that can be used as model validation parameters. This validation is done by checking whether the results obtained from barge hull modeling in the application are appropriate and acceptable based on BKI Guidelines for Certification of Loading Computer System. Table 2 below shows the correction results in the modeling validation stage against BKI.

Table 2. Model Validation against BKI

Parameter		Value (Ton)	Correction Result	BKI Correction Limit	Status
Displacement	Ship	5091,72	1,36%	2%	Compliance
	Model	5161,00			
LCB form AP	Ship	34,25	0,83%	1%	Compliance
	Model	33,965			

Skeg Variation Modeling on Ship Hull

Skeg variation modeling is a stage carried out after the modeling validation has met BKI requirements. This variation modeling is done according to the variation data established in the research methodology. The picture of skeg variations can be seen in Figure 5.

Computational Fluid Dynamics (CFD) Simulation

The simulation process using the Computational Fluid Dynamics method begins after the 3D hull modeling has been exported in .iges format. This process uses Ansys Workbench software using Fluent analysis, and the model used must be solid. This analysis is divided into 5 stages.

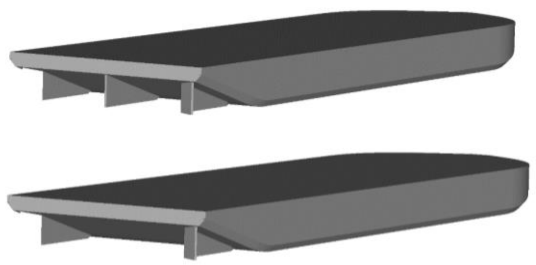

Figure 5. Skeg Variation Modeling

Geometry

The geometry stage is the modeling stage, so that model creation can be done directly at this stage or can be done in other 3D programs, which can then be imported as seen in Table 3. The geometry stage is a stage to check whether a model is solid. If the model can be used and is ready, a ready statement will appear and have volume information.

Table 3 . Geometry Modeling

Details View	
Details of the Body	
Volume	1.7193e+05 m^3
Surface Area	35424 m^2
Faces	36
Edges	91
Vertices	60
Fluid/Solid	Fluid
Shared Topology Method	Automatic
Geometry Type	Design Modeler

The next step is creating a "test pool" as a testing place. Based on previous research in making test pools, determining the size of the test pool must consider the speed and capability of the computer being used, as shown in Figure 6. With the largest speed in this study being 8 knots, the overall length of the domain in the test pool will be 3 times the size of the ship.

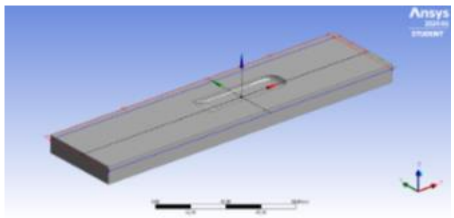

Figure 6. Geometry Stage Test Pool Domain Size

Mesh

The meshing stage is the initial stage to determine if the simulation results can run well. Because at the mesh stage, determining the number of meshing elements can affect the meshing results. Therefore, the selection of body sizing and face sizing must be calculated as well as possible. Therefore, mesh convergence is carried out to compare simulation results from loose to tight mesh. This aims to check if the number of meshes used is appropriate for data collection.

In this study, 7 meshing trials were used. It was found that 0.8 m mesh has the smallest error value (less than 2%) and not many changes compared to other meshing sizes. The results can

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be seen in Table 4 below.

Table 4 . Mesh Convergence

Size mesh (m)	Nodes	Element	Force (N)	Percentage
1,50	48768	257503	17654,50	-
1,00	53456	282462	15589,10	13,249%
0,90	54987	290081	15295,20	1,922%
0,80	57635	304587	15175,30	0,790%
0,70	61988	327658	14248,50	6,505%
0,60	68744	363333	14060,20	1,339%
0,50	79954	423313	13701,30	2,619%

Setup

The setup stage is a stage that contains the determination of matters relating to the model being analyzed. Some settings used at this stage include general setup, viscous model, materials, and boundary conditions.

Solution

In the solution stage, the calculation process (running) is carried out in the form of iterations of the basic equations of fluid dynamics in CFD until it produces convergent results or finds results from simulations at one same or similar point.

Result

This result stage becomes the final stage of CFD simulation. This stage displays the results that have been run. The results obtained can be in the form of numerical and visual data. In this study, the desired results are in the form of resistance value (drag force) and flow velocity (velocity-u) produced from each variation.

Simulation Results Validation

Results validation is a stage carried out to ensure the results from the CFD simulation that has been carried out are appropriate. In validating this simulation, it is done by comparing the results of running CFD fluent simulation with the results of previous research (Dwitara, Santoso & Amiadji 2014). The result can be seen in Figure 7 below.

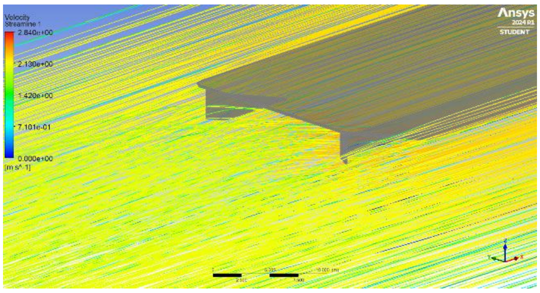


Figure 7. Velocity Distribution Validation Result

It was found that the results of both CFD running analyses have units that are not significantly different. Therefore, the results of running CFD conducted in this study are considered appropriate, and we can proceed to the next stage for analysis on all variations with the same setup. The following Table 5 shows the setup that will be used for all variations in this study.

Table 5. Setup Parameters

Parameter		Input
Mesh	Size (m)	0.9 m
Models	Viscous	k-epsilon (2 equation)
Material	Water Liquid	ρ: 1025 kg/m³ v: 0.0008318 kg/ms
Boundary Conditions	Inlet	Velocity Inlet Velocity 2.05778 m/s (4 knots) Velocity 4.11556 m/s (8 knots)
	Outlet	Pressure Outlet
	Water Surface	Wall – Specified Sher
	Bottom	Wall
	Wall	Wall
	Hull	Wall
Solution	Report Plots	Force Report: Drag Report Output: Drag Force Zones: Hull Force Vector: x,y,z: 1, 0, 0
	Initialize	Standart Intialization Compute from: Inlet

Run Calculation	Time Scale Factor: 1 Number of Iteration: 1000

Analysis of Drag Force and Velocity u on Ships at 4 knots Speed

After analyzing each skeg design variation at 4 knots speed, the optimum variation from all skeg design variations can be known. The selection of this type of skeg variation is based on analysis results, including the smallest drag force value and the largest fluid velocity u value. The following Table 6 is a summary of several main points in selecting the optimum skeg variation.

Table 6. Analysis Results of Drag Force and Velocity u on Ships at 4 Knots Speed

No	Variation	Nodes	Elements	Drag Force (N)	Velocity (m/s)	Reynold Number
1	Variation 1	57992	306105	40010	2,06622	2424865
2	Variation 2	58116	306879	34609	2,07038	2466418
3	Variation 3	58008	306294	17776	2,07198	2455174
4	Variation 4	58382	308085	44532	2,06155	2367687
5	Variation 5	58191	307241	35565	2,06811	2467235
6	Variation 6	58275	307664	18737	2,07018	2433562
7	Variation 7	58115	306862	43725	2,06162	2394534
8	Variation 8	57879	305592	34661	2,06897	2333334
9	Variation 9	57903	305557	17881	2,07161	2426674
10	Variation 10	58169	307054	44244	2,06270	2430946
11	Variation 11	58311	307959	36329	2,06642	2387463
12	Variation 12	58266	307722	19310	2,07046	2377658

The summary results in the table above can be converted into a graph in Figure 8. With the help of graphs in reading, it becomes easier to determine the most optimum variation from other variations.

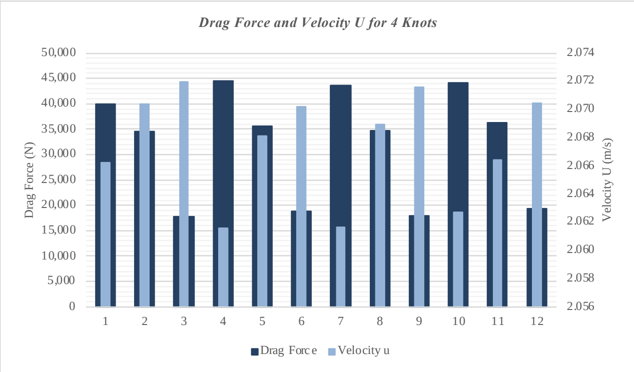
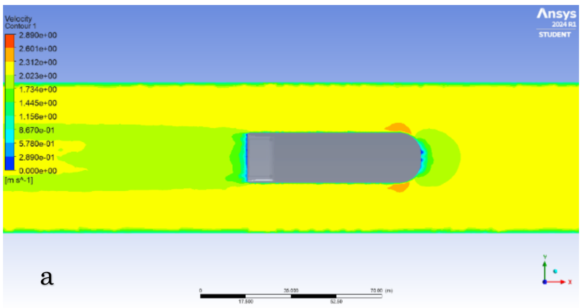


Figure 8. Drag Force and Velocity U on Ships at 4 Knots

The selection of optimal skeg variation based on drag force value is the skeg variation that has the smallest drag force value, while the optimal skeg variation based on velocity-u value is the skeg variation that has the largest velocity-u value. Thus, based on the graph above, variation 3 is the optimal variation with the smallest drag force value of 17775.8 N and the largest velocity u value of 2.07198 m/s. The image below is the visual result of variation 3, which was chosen to be the optimal variation from the other variations. The velocity contour (a), velocity streamline for the whole body (b), velocity front view (c), and velocity streamline for the skeg (d) could be seen in Figure 9.



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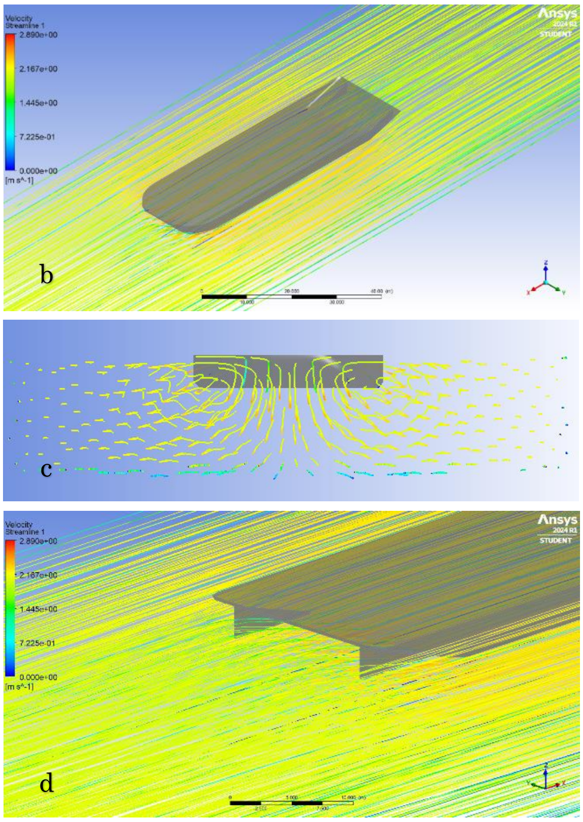

Figure 9. Velocity Distribution for Variation 3 at 4 Knots

Analysis of Drag Force and Velocity on Ships at 8 knots Speed

In the analysis of each skeg design variation at 8 knots speed. The following is a summary of several main points in selecting the optimum skeg variation shown in Table 7.

Table 7. Analysis Results of Drag Force and Velocity u on Ships at 8 Knots Speed

No	Variation	Nodes	Elements	Drag Force (N)	Velocity (m/s)	Reynold Number
1	Variation 1	57992	306105	158091	4,13192	5079462
2	Variation 2	58116	306879	135668	4,13988	5174719
3	Variation 3	58008	306294	67406	4,14320	5162909
4	Variation 4	58382	308085	175819	4,12196	5014825
5	Variation 5	58191	307241	139390	4,13483	5182291
6	Variation 6	58275	307664	71692	4,13986	5112527
7	Variation 7	58115	306862	172146	4,12243	5029376
8	Variation 8	57879	305592	135858	4,13706	4896463
9	Variation 9	57903	305557	68359	4,14246	5111002
10	Variation 10	58169	307054	174843	4,12462	5135664
11	Variation 11	58311	307959	142792	4,13171	5009152
12	Variation 12	58266	307722	74159	4,14028	5010518

The summary results in the table above can be converted into a graph in Figure 10. With the help of graphs in reading, it becomes easier to determine the most optimum variation from other variations.

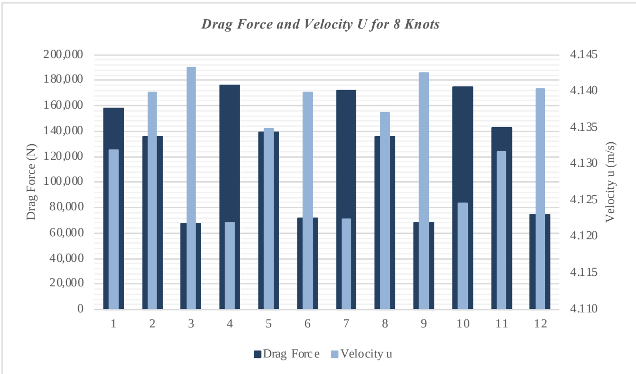

Figure 10. Drag Force and Velocity U on Ships at 8 Knots

The selection of optimal skeg variation based on drag force value is the skeg variation that has the smallest drag force value, while the optimal skeg variation based on velocity-u value is the skeg variation that has the largest velocity-u value. Thus, based on the graph above, variation 3 is also the optimal variation with the smallest drag force value of 67405.60 N and the largest velocity-u value of 4.14320 m/s. The image below is the visual result of variation 3, which was chosen to be the optimal variation from the other variations. The result of velocity contour (a), velocity streamline for the whole body (b), velocity front view (c), and velocity streamline for the skeg (d) can be seen in Figure 11 below.

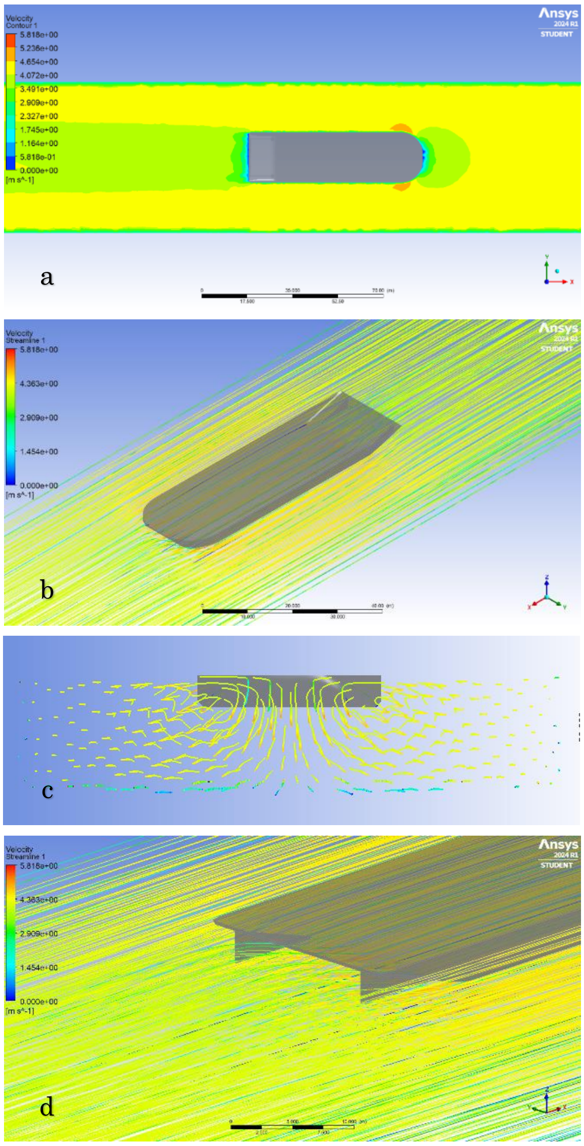

Figure 11. Velocity Distribution for Variation 3 at 8 Knots

CONCLUSION

Based on the results of this study, the following conclusions can be drawn: 1) The most optimal variation obtained from the analysis at a ship speed of 4 knots is variation 3, with a drag force value of 17,775.80 N and a velocity-u value of 2.07198 m/s. 2) The most optimal variation obtained from the analysis at a ship speed of 8 knots is also variation 3, with a drag force value of 67,405.60 N and a velocity-u value of 4.14320 m/s. 3) From the analysis at both 4 knots and 8 knots, stable increases or decreases in drag force and velocity-u were observed for each variation. Therefore, regardless of whether the speed is 4 knots or 8 knots, variation 3 consistently emerges as the most optimal design.

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