

Optimizing Ship Resistance by Modifying Hull Vane Geometry Using CFD Simulation

*Dissertation submitted in partial fulfilment of the requirements
for the award of degree*

of

Master of Technology in Marine Engineering and Management

by

RAJAT C. UBHARE
(Reg. No. 2101215004)

Under The Guidance of

Mr. SADANANDA CHAKRABORTY



Department of Marine Engineering
INDIAN MARITIME UNIVERSITY
(A Central University, Government of India)

Indian Maritime University, Kolkata Campus

Kolkata - 700088

July 2023



Department of Marine Engineering
INDIAN MARITIME UNIVERSITY

(A Central University, Government of India)

KOLKATA - 700088, INDIA

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Mr. Sadananda Chakraborty

Supervisor

Department of Mechanical Engineering

Indian Maritime University, Kolkata campus

Kolkata – 700888, India

Dr. Deepak Mishra

Course coordinator (MTech)

MTech Marine Engineering and Management

Indian Maritime University, Kolkata campus

Kolkata – 700888, India

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AUTHOR'S NAME and ADDRESS: RAJAT C. UBHARE; Shri Hari Krupa Appt, Uran, Navi Mumbai, Maharashtra, Pin-400702, India.

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RAJAT C. UBHARE

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NOMENCLATURE

CFD – Computational fluid dynamics

IMO – International maritime organization

F_n – Froude number

RAO – Response amplitude operator

LOA – Length over all

LOW – Length of waterline

ω – Omega

ρ – Fluid velocity

u – Fluid velocity vector

p – Pressure

e – Internal energy

μ – Dynamic viscosity

f – External force

q – Flux vector

N – Newton

KN – Kilo-Newton

ABSTRACT

This study focuses on optimizing ship resistance by modifying the geometry of a Hull vane using Computational Fluid Dynamics (CFD) simulations. The resistance reduction potential of various Hull vane designs is investigated by comparing the results obtained from the simulations. The study employs CFD techniques to analyse different Hull vane geometries flow characteristics and resistance. Parameters such as maximum camber and thickness are systematically varied to determine their influence on ship resistance.

The simulation results demonstrate that specific modifications to the Hull vane geometry can significantly reduce ship resistance, leading to improved fuel efficiency and speed performance. The findings highlight the importance of considering geometric parameters in the design of Hull vanes for minimizing resistance and optimizing ship performance.

The presented results offer valuable insights into the potential benefits of using CFD simulations to optimize ship resistance through Hull vane geometry modifications, providing guidance for future design and optimization studies in the maritime industry. In this work, the effect of changing the geometry of the Hull vane on ship resistance will be investigated using CFD software. This study will explore how modifications to the Hull vane geometry could further enhance this device's resistance-reducing capabilities and contribute to improved ship performance and efficiency. Validation is conducted as well and presented in the section below to authenticate the current work.

Keywords- Ship resistance, Hull vane, geometry modification, Computational Fluid Dynamics (CFD), optimization, fuel efficiency, speed, flow characteristics, resistance reduction, maritime industry.

CHAPTER 1

1. INTRODUCTION

Marine transportation has grown rapidly to satisfy the demands of a globalized society. According to the United Nations Conference on Trade and Development, the volume of seaborne trade has further than tripled over the past forty times (UNCTAD, 2017). The growth of a region or nation is currently viewed through the perspective of its transportation system. Ocean transportation is no exception, since it has a considerable capability in a number of areas, including defense and the economic sector. A high-speed ship is projected to meet these fields and solve these problems. While travelling on the water, one of the crucial issues that ships constantly consider is resistance [23]. Analysis of ship resistance has a big role in ship design. Effectiveness of engines and propulsion, alternative renewable energy sources, reducing ship resistance, and other research areas that take into account the energy effectiveness of vessel. The Hull vane, the focus of the study, which reduces ship resistance, is one of many advancements that have been realized, including those that make use of attachments [14]. The coast guard and naval forces are looking for ways to use less energy without reducing operational efficiency. The development of Computational Fluid Dynamics programming over the past fifteen years has pushed for developments that can drastically affect the performance of fast-moving vessels. One of them is the Hull vane. Previous research has demonstrated that it has a significant impact on a vessel's sea keeping capacity as well as the ship's resistance. Van Oossanen developed the so-called Hull vane in 1992 and received a patent for it in 2002. The Hull vane can reduce bow-up trim and wave production when used on a ship by creating excess thrust. Either way, it can lessen the ship's motion in the water [23]. At the stern of the ship, there is a fixed foil called the Hull vane. The Hull vane's function is to reduce the height of waves caused by the propeller's rotation. Additionally, when the vessel is going quickly, a force called the running trim, which causes the bow to rise and the stern to deeper, may be reduced by the Hull vane's lift force. In this research, we're evaluating the impact of modifying the Hull vane's design on ship resistance [23].

This project will focus on the design and optimization of the Hull vane geometry, taking into consideration factors such as the Camber, Thickness, and shape of the device. The goal is to identify the most effective geometry for reducing resistance, it may result in increased fuel economy and less emissions. The Hull vane theory and principles, the CFD simulation methodology, the results and analysis of the simulations, and an overview of current developments in ship resistance reduction technologies are covered in the sections that follow.

1.1 HULL VANE

Dr. Peter van Oossanen developed the Hull vane, an energy-saving device that seems like a hydrofoil, in 1992. A first patent application was filed in 2002 after years of preparation, initially for sailing vessels participating in the America's Cup. Later, with the use of CFD software, the Hull vane was enhanced. [29]

The stern of the ship is where the Hull vane is located. It is a fixed-foil device shaped like a wing that is placed horizontally below the waterline (as shown in Fig 1). The stern wave flows over the Hull vane, creating a hydrodynamic lift. The lift produced by the Hull vane can be divided into two forces: one in the x- and one in the z-direction.

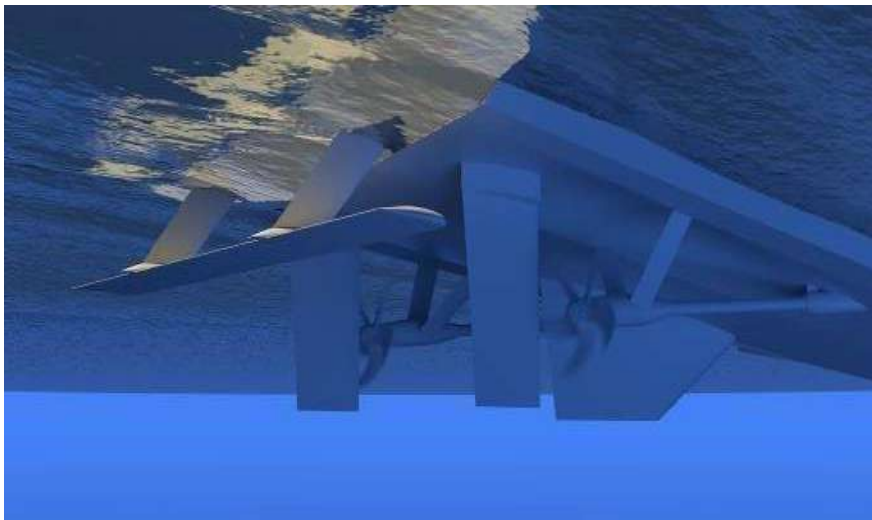


Fig 1: A typical Hull vane configuration [8]

1.2 WORKING PRINCIPLE

The working principle of a Hull Vane is based on the concept of hydrodynamic lift and wave energy harnessing. The Hull Vane is a hydrofoil-like appendage that is mounted below the hull of a ship or vessel. It is specifically designed to generate hydrodynamic lift and reduce the resistance encountered by the vessel as it moves through the water [5]. When the ship is in motion, the Hull Vane interacts with the water flow beneath the hull. As water flows around the Hull Vane, it generates a pressure difference between the upper and lower surfaces of the vane. This pressure difference creates hydrodynamic lift, which acts in both the x-direction and the z-direction [5]. In the x-direction, the hydrodynamic lift generated by the Hull Vane produces a forward thrust that helps propel the ship through the water. This forward thrust can result in fuel savings and improved speed, as it reduces the resistance encountered by the vessel [8]. In the z-direction, the hydrodynamic lift generated by the Hull Vane produces an upward force. This upward force

influences the vertical motion of the ship, helping to reduce the vertical acceleration or heaving motions experienced by the vessel. By reducing these vertical motions, the Hull Vane contributes to a more comfortable and stable ride for passengers and crew [5]

CHAPTER 2

2. LITERATURE REVIEW

The Hull vane is a fixed-foil device positioned below the waterline near the stern of a ship. It experiences hydrodynamic lift from the passing stern wave, resulting in two forces. This lift contributes to reducing total ship resistance, leading to fuel savings and improved efficiency.

The Hull vane takes advantage of the hydrodynamic lift created by the movement of water around the ship's stern. As the ship moves forward, it generates a stern wave, and the Hull vane harnesses the energy from this wave.

In this study, K. Uithof, et al. [1] described the development process, the guiding principles, and the thus far attained outcomes. The Author performed many 2d tests on the Hull vane under the stern of a full-block dredger. The Hull vane increased the hull's pressure resistance. The total resistance was found to rise because the increase in pressure resistance on the hull had a somewhat larger component than the thrust force produced by the Hull vane. The increase in pressure resistance linked to the reflection of the low-pressure zone on the hull persisted despite testing numerous hull shapes, Hull vane profiles, and position adjustments. In the initial investigation, the vertical orientation of the Hull vane was also examined, and it was found that the Hull vane ought not to be placed in a place where it would be too close to the hull. However, it shouldn't be placed too far below the hull because that would restrict the angle of attack from the water flow. As a result, The Hull vane is one of the most exciting fuel-saving innovations now available. According to ship speed and hull form, CFD calculations, model tests, and sea trials have identified possible resistance reductions of more than 20%. For ships that operate at a moderate to high non-planning speed, the Hull vane is especially interesting.

Cumming, et al. [2] demonstrated that the addition of an appropriate stern attachment can lower warship energy expenditures by 5 to 10 % depending on the functional profile of the boat. To create a functional stern flap extension that will lower hydrodynamic resistance. It was evident from the tests in which the flap span changed that, to get the greatest benefits, the spread should be as broad as possible without losing any installation related challenges due to the turn of the bilge. Only three of the flaps appeared to have been beneficial in comparison to the added hull, according to preliminary resistance results from the condensed (6-point) curves.

Bruno Bouckaert, et al. [3] Analyse the economical and operational impacts of retrofitting a Hull vane. With the Hull vane added, there is a 6% increase in frictional resistance. The overall resistance is reduced by 15.3% while the pressure resistance is reduced by thirty percent. The trim nose-down is now 0.2 degrees, up from 0.05 degrees. The Hull vane's struts were not used in the seakeeping analyses, which accounts for the larger flat-water savings percentage of

17.3%. Although these struts improve directional stability, their effect on pitching behavior is thought to be minor. Because the turbulent zone was noticeably smaller, it was found that the turbulent zone was reduced. When the Hull vane was added, it was believed that the RHIB would be easier to manage throughout its deployment and recovering stage. At 15 knots, the reduced chances are estimated to be about 14.5%. A Hull vane will additionally extend the ship's range from 5,000 to 5,850 nautical miles. Thus, the vessel's top speed will rise from 21.5 to 22.1 knots. The Holland Class OPVs have been shown to be effective in this research and the supporting CFD analysis. The author exemplifies outstanding Hull vane operation. The Hull vane will contribute to lowering energy expenses and emigrations significantly (both by 12.5), as well as improve onboard comfort and the security of crucial activities like the launch and recovery of the RHIB (through the slipway) and helicopter.

Iruthayaraju Andrews et al. [4] reviewed the resistance characteristics of high-speed round bilge-containing forms fitted with a vane in the vessel's stern region in this research.

When compared to a bare hull, the vane-equipped hull exhibits a significant reduction. The 8 to 14% reduction in percentage seems incredible and would undoubtedly project a significant reduction in fuel usage throughout the course of the vessel's lifetime. Hull vane's introduction causes a considerable decrease in the model's overall resistance. Due to frictional drag's decreased impact on the full-scale vessel, the performance of the Hull vane is anticipated to increase.

K Uithof, et al. [5] were applying the Hull vane on larger vessels to see whether it was effective on-pitch motion and resistance due to wave.

A tank test was carried out on the 167 m container vessel. With a Hull vane, the natural period in the Roll decoy test is 14.1 seconds, but without one, it is 14.2 seconds. The natural period has risen from 7.1 to 7.6 seconds in the pitch decay test with the model's Hull vane attached. Regular waves are used in the Test. The pitch motion's RAO (response amplitude operator), with or without a Hull vane. The motion has been minimised at this pitch by the Hull vane. The RAO of the heave motion, whether a Hull vane is present or not. CFD computation on the 167m Ropax vessel has been carried and This has been tested in regular 2.5m waves with a 6.28s encounter period at a speed of 20 knots. With the Hull vane, the amplitude of the pitch motion has been reduced. With the Hull vane, the amplitude of the heave motion has decreased. A Hull vane successfully decreased the pitch motion as well as added resistance as demonstrated by the tank test and CFD calculations. The effect of the Hull vane on heave motion is not unambiguous.

K Uithof, et al. [6] investigate a comparison between the Hull vane and other trim correction methods. The Hull vane also minimises sinkage across a large portion of the speed range. It is

evident that the resistance is decreased by the Hull vane. At ship speeds greater than $F_n 0.3$, the interceptor and trim wedge result in a resistance reduction of between 7 and 12%. However, the influence on the resistance is negative at ship speeds of $F_n 0.3$ or below. The resistance reduction is greatest at the slower speeds, reaching up to 26.5% at the slowest speeds. The interceptor was introduced to the model, which resulted in a 4.5% decrease in pitch amplitude from 0.82 to 0.78 degrees. The breadth is decreased when the Hull vane is used, which is a reduction of 20.99% from the bare housing. The investigation has revealed that throughout the majority of the speed range, the Hull vane is the most efficient in reducing the resistance of this vessel. The Hull vane also greatly lessens the vessel's pitching motion when compared to the interceptor.

B. Bouckaert et al. [7] studied the effects of a Hull vane on a 108-meter-long patrol ship of the Holland class. The hull shape of the ship had been changed twice. The stern wedge for trim. The second change was made to provide a firm base for the strut on the centerline. Sometimes there are two struts in the Hull vane, while other times there are three. The Hull vane appears to have a good impact on the seakeeping behaviour, according to model testing and CFD studies in waves. Pitching and heaving's additional resistance were reduced by 29%. CFD calculations were carried out for the Holland-class OPVs under two different wave situations. Regular head waves with a period of 8 seconds and a height of 2 m. Regular head waves with a period of 8 seconds and a height of 4 m. A roll damping coefficient has been determined. It increased from 0.0142 to 0.0148 at zero speed. The roll damping coefficient improved by 11.4%, from 0.0910 to 0.1013, at 17.5 knots.

N. Hagemester et al. [8] developed the patented Hull vane, which is a fixed hydrofoil that may be installed at the vessel's transom to reduce vessel resistance. The best way to lower the ship's fuel usage is to install a Hull vane behind the transom. At all speeds, the benchmark hull has the greatest resistance. Hulls with Hull vanes provide much less resistance at slow speeds. Hulls with Hull vanes have much less resistance. The attached Hull vane helps to achieve a reduction of 45% while the integrated hv reduces resistance by 36%.the extended hull only provides a 3% reduction in resistance. Maximum speed and power requirement: the extended benchmark could travel at a top speed of 27.0 knots with an installed power of 11.520 kW. The top speeds of the integrated Hull vane and the attached Hull vane are 26.6 and 26.3 knots, respectively. Previous exploration has shown that both a housing extension and the Hull vane also induce considerable benefits for the seakeeping of a boat, most especially in the reduction of perpendicular accelerations. It's beyond the compass of this paper to quantify and compare these goods.

Gerry Liston Putra et al. [9] did an exploration to emphasize the stability test of the Semi Trimaran hull form using the inclining system according to international standards. The result demonstrates that the GM value is significantly more than the KG value. Better stability resulted from the gravity center being closer to the keel. However, GM value is not a guarantee of good ship stability; instead, the analysis of stability intact should be examined as detailed in the next section. The findings of this study demonstrate the good stability and compliance with IACS norms of a model of a semi-trimaran Flat Hull Ship. This indicates that the semi-trimaran Flat Hull Ship is stable and prepared for construction and provision to the relevant stakeholder.

Hamdan Nuruddin et al. [10] aimed to estimate the effect of fore-body shape particularly the bulbous bow on the wave-making resistance of an ultra-large vessel carrier. It was also the end of this design to identify the optimized form of the bulbous bow design. It was set up that the wave resistance can be reduced by dragging the bulb protruding Length, widening the bulb breadth, and adding the bulb height. To validate the result from this disquisition with towing tank trial. To probe the wave-making resistance under the influence of a draft or waterline.

Venkata Karthik Avala et al. [11] attempted to validate the total resistance of AMECRC series models 3, 4, 8, 11, and 13 in CFD against experimental data. Attach a NACA 4412 Hull vane to the same Froude numbers at the rear of the aforementioned hull forms and evaluate any reduction in resistance. The outcomes suggested that, as compared to a bare hull, the models fitted with Hull vane had less resistance according to the analysis by STAR CCM+. When compared to the experimental results, the CFD results were not accurate, but the curves showed a similar tendency, suggesting that the CFD tool may be used to forecast resistance. Additional validation was required for the STAR CCM+ results. Future research on Hull vane is supposed to build on the findings of this study.

Ketut Suastika et al. [12] conducted this study to explore the influence of longitudinal modifications in the center of gravity on ship resistance. Shifting the center of gravity ahead lowers ship resistance for small Froude numbers, while shifting it backward increases ship resistance. The ship resistance may increase by roughly 6% in the lowest Froude number and by roughly 3% in the greatest Froude number as a result of the shift in the center of gravity. The boat's operational plan will determine which shift is better. The center of gravity shift is more advantageous when it is operating at very high speeds, which is the majority of the time. Currently, a reverse move of the center of gravity is preferable when the ship is designed to operate in a semi-planning mode. When the center of gravity is shifted forward as opposed to backward, the resulting wave pattern is different. Different wave resistance is produced by this different wave pattern, and this in turn impacts the overall ship resistance.

Bruno Bouckaert et al. [13] worked on the Hull vane's foundations, which will be described in detail to provide the device a greater understanding. Energy savings are the most evident benefit of a Hull vane. Lower power, increased highest speed, smaller fuel tank, fewer pollutants, constant operating trim, improved seakeeping, course keeping, and crew comfort regional content. Even during routine maintenance drydocking, the Hull vane can be installed as a retrofit on an existing vessel during a mid-life refit. As soon as practical, the Hull vane should be included in the design. The size, form, and location of the Hull vane are significantly influenced by the hullform and limitations imposed on each project. After the feasibility study is finished, Hull vane's specific dimensions, capabilities, and price may be determined. With and without a Hull vane, the sea testing was done under the same circumstances. These demonstrated a power reduction starting at 10% at 12 knots and increasing steadily to 15% at 21 knots. The findings of this study demonstrate that the Hull vane is a viable idea for enhancing the effectiveness and capabilities of naval and coast guard boats.

C. Celik et al. [14] did research on how the Hull vane affected the ship's resistance elements, and they experimented with different Hull vane lengths to see how they affected overall resistance. Under calm ocean conditions, the open-source foam 5 code was used to run a CFD simulation to examine the effect of the Hull vane on the ship's total resistance and the different components of that resistance. The frictional resistance rose by 4.2%. It was discovered that the Hull vane's addition decreased the resistance to viscous pressure, resistance to waves, stern waves, and dynamic pressure distribution in the vicinity of the stern. CFD simulations have been made possible by the installation of the Hull vane, and it has been found that this lowers the ship model's overall resistance by up to 22.9%. According to CFD Analyses with the different chord lengths of the Hull vane, the relative difference of the total resistance obtained for each was found to be higher in the error caused by spatial numerical uncertainty.

Hugo FERRÉ et al. [15] examined how a monohull's integration of the Hull vane affected hydrodynamics. Ship propulsive performance optimization, boosting operability through improved seakeeping, acoustic discretion, and maneuvering capabilities. The first inference is that, in contrast to all competing stern appendages currently in use (such as wedges, flaps, and interceptors), the Hull vane profoundly alters the hydrodynamic flow at the stern, having an especially negative impact on the ship wake. The outcome of this action is that other stern appendages typically experience a reversal trend at such speed (increased power), whereas favourable impacts are found at very low speeds (if not at all speeds). The second result of this research is that the use of a Hull vane can significantly enhance seakeeping. Particularly, Hull vane's effect on pitch motion represents a considerable advancement. One can see that the dampening effect of stern heave will also cause the ship's natural pivot point to move farther aft

than is often observed in addition to minimizing pitch motion. Finally, as was mentioned in the paper, integration-related difficulties need to be carefully taken into account.

Ari Wibawa Budi Santosa et al. [16] aimed to lower the value of ship seakeeping and resistance. This has been determined that the ship model with the addition of a bilge keel with a value of 8.8 kn has the best resistance value of each preset variation. The model with no additional components has the lowest value of heaving, which is 0.84774 m, as is known. Due to the addition of the Skeg, Bulbous Bow, and Bilge Keel, the Ship has the lowest pitching value (0.080755 radians), as can be shown. The best total resistance value for ships, based on the results of the trials, is 8.8 kn, which can be reduced by 13.72% by the inclusion of a triangular and hollow bilge keel. The best value for heaving is discovered on a ship with no element in addition with a value of 0.84774 m; the highest value for pitching is identified on a ship with added components of a bulbous bow, skeg, and keel bilge with a value of 0.080775 radians; and the best value for rolling is discovered on the ship's bilge keel with a value of 0.0000082404 radians.

Karol Niklas et al. [17] The goal was to look into how the case study vessel's hull shape affected its performance in calm waters. The goal of the experiment was to calculate overall resistance, dynamic trim, and sinkage using full-scale CFD simulations of four innovative hull designs. The vessel in the as-built configuration (CSV1) had the highest resistance for the speed corresponding to the Froude number of $FN \leq 0.24$. The CSV2 had the greatest overall resistance for faster speeds. The CSV3 has the lowest resistance in the Froude number range of 0.11 to 0.26 (5-12 knots), except $FN = 0.2$ (9 knots). It was the version without a transom stern but with a cruiser stern. The CSV4 had the lowest resistance at $FN = 0.2$. CFD simulation at full scale can be employed as a trustworthy and efficient method for resistance performance. The technique benefits from directly modelling the ship's entire scale. This problem is resolved by full-scale CFD simulations, which also have the advantage of analyzing a wide range of hull forms and evaluating them from both an evolutionary and a novel perspective. Conclusions may be drawn from the analysis of the influence of the waterplane area and wetted surface area that both factors had a negligible impact on the resistance of the examined hull variations.

Soonseok Song et al. [18] studies were done to understand how surface roughness affects frictional resistance. At 19 knots compared to 24 knots, there was a bigger rise in the ship's total resistance and effective power (by 73% and 60%, respectively). The 3D full-scale KCS hull simulations with various fouling situations at 24 and 19 knots yielded the frictional resistance coefficients, the percentage of additional resistance, and the residual resistance coefficients, CR. The roughness effect's observation of a lower wave height at the wake region is consistent with the discovery of a decreasing CW trend with an observed increase in fouling rate. The impact

of roughness on ship resistance, wave profile, pressure distribution along the hull, and ship stern wake are only a few of the significant findings that this study has resulted. The nominal wake friction was found to have significantly increased as a result of the surface roughness. Therefore, future research may examine the impact of roughness on ship propulsion efficiency. Soengeng Riyadi et al. [19] carried out this study to see if adding a Hull vane to a high-speed vessel at $Fr > 0.6$ would minimize boat resistance and, as a result, boost energy effectiveness because less energy would be consumed. A Hull vane should not be positioned too high or too low over the hull. It should be positioned behind the transom and away from the free surface as much as possible such as mentioned below.

1. A vane with the leading edge parallel to the transom (Case 1).
2. A chord length for the vane's outermost edge beneath the transom (Case 2).
3. Two chord lengths behind the transom are where the outermost edge of the vane is located. (Case 3). In this high Froude-number region, the use of a vane typically increases overall ship resistance. For Case 2, the increase can reach 36.3% at $Fr = 0.92$. Additionally, Case 3's placement of the vane's leading edge two chord lengths beyond the transom results in the least resistance. Claiming that the Hull vane performs best in the non-planning region at moderate to high Froude values, with Froude numbers in the range $0.2 < Fr < 0.7$. Of the examples considered, Case 3's placement of the vane with its leading edge two chord lengths behind the transom offered the least amount of ship resistance. For Hull vane applications on this kind of ship, a Froude number range of $0.5 < Fr < 0.7$ is advised.

Muhammad Arif Budiyanto et al. [20] This study used observational and modelling techniques to investigate the utilization of a stern foil on a patrol boat. In this study, the stern foil of a ship model was installed below the transom and positioned at a 3° inclination to the x-axis, aligned to the keel direction. A ship model was used for a towing test experiment without the usage of a stern foil. Differences in vessel loads indicate more weight creates more overall resistance encountered by the ship in either direction. Vessels carrying loads of 1 kg or more generally met less resistance than those carrying loads of 2 kg or more. For the towing test experiment, a stern foil was added to the small ship. It is clear that the empty and half-full load conditions (1 and 2 kg) caused a significant increase in resistance once the stern foil being placed. The overall resistance that the vessel's model faced was reduced by using the stern foil. With the stern foil applied, the ship model showed an efficiency improvement of up to 22.3% at the half-full load condition (2 kg) at $Fr 1.1$. The stern foil's 3° angle of attack worked well at $Fr > 1$. It has been determined that the ideal loading condition (the weight of 2 kg at half capacity) and specific speed ($Fr 1.1$) will result in reductions in resistance of 22.3% and 23.3%, respectively, when a stern foil with an unbalanced profile and an angle of attack parallel to the ship's keel is used. It

may be argued that the stern foil gave its finest performance under these conditions.

Muhammad Arif Budiyanto et al. [21] used experimental approaches to investigate the use of a stern foil on multi-chine hulls. The power required by ship models with stern foil in the empty state tends to be similar to the 250-gram load condition at maximum speed, which is where the main variation between the ship version that has stern foil as well as without foil appears. This is so that the ship model's stern, where the stern foil is situated, will be raised at high speeds when the stern foil experiences increased lift force. The stern-foil model's greatest ship resistance reduction is 56.6% at a speed of 1.75 ms⁻¹. In the 1.6 ms⁻¹ speed range, the stern foil model's maximum reduction in ship resistance is 61.9%. This result shows that the usage of stern foil is efficient when the ship model has an initial loading. The results of this experiment show that stern foil considerably reduces ship resistance in a multi-chine hull. The range of the total reduction in ship resistance varies. Based on the speed and loading conditions. The highest decrease in ship resistance for multi-chine hulls with stern foils at 1.6 ms⁻¹ speed is 61.9%.

Deddy Chrismianto et al. [22] goal was to decrease ship resistance. A Hull vane has been placed beneath the hull of the ship as a modification, allowing for a 20-degree angle of attack while traveling at high speed. Overall resistance factor at a 20-degree Hull vane angle. Model 6 has the highest total resistance value at Fn 0.307, which is 8.4783 KN, while Model 5 has the lowest total resistance value at 7.3852 KN. At the Fn 0.395, the greatest value for model 4 is 13,491 KN, while the lowest value for model 6 is 13,313 KN. At the Fn 0.527, the greatest value for model 4 is 22,616 KN, and the lowest value for model 6 is 20,006 KN. In a 30 GT fishing boat going slowly, adding a Hull vane can increase total resistance. While the addition of a Hull vane at high speed can lower total resistance because the area of the ship that is immersed in water is getting smaller and is impacted by the trim and heave forces on the ship, total resistance can be reduced by adding a Hull vane. The fishing vessel's Hull vane is positioned at an angle of attack of 2°, which has the lowest total resistance value. For Fn 0.527, the overall resistance reduction on this ship is reduced by 51.53%.

Rahmat azis Nabawi et al. [23] goal was to demonstrate how well the Hull vane and stern foil installation reduced resistance encountered by the semi-trimaran flat hull ship. The result of the simulation showed that the resistance might be decreased by installing the stern foil and Hull vane. Where the installation of the stern foil reduced resistance by 5.25% and the installation of the Hull vane was able to lower resistance by 12.44%. It was also noted that the ship model with Hull vane installation had a lower flow velocity after the transom than the ship without foil and the ship with stern foil installation. It lessens the stern wave as well. Heavy turbulence was lessened by the ship's Hull vane. Resistance can be reduced by installing a Hull vane and a Stern Foil., it can be concluded from the findings. The results show that the ship

model with the stern foil installation still experiences significant turbulence, indicating that the ship still has a very high wave-making resistance. While the Hull vane's setup indicates that there is a quick flow behind its transom. The stern foil arrangement is preferable to the Hull vane placement in terms of how well it reduces resistance.

Kiryanto et al. [24] objectives were to determine how the Hull vane changed a vessel's resistance and where it should be mounted on the hull. With an angle of attack of 50, a span foil length of 9.76 meters, & a Hull vane chord length of 1.15 meters, the foil utilized is of the NACA 2415 type. The installation of single-foil and double-foil arrangements as well as a modification of a vane hull at two separate points are the subject of additional investigation. According to the study's findings, a ship's vessel resistance can be decreased by installing. Instead of double-foil Hull vane, the single-foil one. According to the study's findings, a ship's vessel resistance can be decreased by installing a single-foil Hull vane rather than a double-foil one. Based on the findings of simulations and experiments, it can be said that among the six model variations, another design variant is 50% laden, exhibits the smallest resistance value, which is equal to 20.13% of the resistance of the initial vessel. According to CFD modelling conclusion, the overall resistance decreased from 28,060 N to 22,410 N.

Muhammad Arif Budiyanto et al. [25] compared the mounting sites of a hydrofoil in the horizontal axis in a high-speed patrol vessel. Hydrofoil mounting cases in the middle portion, stern section, and aft the stern was all performed. These findings show unequivocally that the value of ship resistance can be decreased by the employment of hydrofoils. Depending on the ship's speed, the hydrofoil installations at sites F1, F2, and F3 reduce drag by 11%, 25%, and 30%, respectively. The findings of this study thus support the idea that the best place to mount a hydrofoil is behind the transom (F3). The mounting location of a hydrofoil on high-speed patrol vessels resulted in a drag reduction of 11–30% in all three cases. The hydrofoil should be mounted after the transom on Froude number 0.52 according to the analysis results of the lift-to-drag ratio.

Rahmat Azis Nabawi et al. [26] conducted a study to investigate the impact of the resistance on the shape of the plate arrangement that creates a flat hull ship. The waves that formed as the ship was moving can be used to understand why there was a difference in resistance. Changes in the fluid's height surface have been used to explain how pressure differences develop. Moving the ship will disturb the fluid's surface. It's intriguing to consider the causes of the tumult in this situation. The RAAZNA-001 hull indicated that the surface of the hull was rough since the ship was built by stacking flat plates. The roughness of the hull surface increased the coefficient of friction, increasing the resistance of the ship. At speeds between 0.22 and 2.75 knots, the raazna-001 model and the comparison ship encountered the same resistance. In the

speed range of 3 to 10 knots, the raazna-001 model experienced more resistance than the comparable ship, showing a difference in the resistance. When the ship's speed reached 10 knots, the resistance the raazna-001 model met was 1388.78 n, or 2.57% more than the resistance the comparison ship only encountered at 1353.9 n. Furthermore, the raazna-002 model experienced 1633.34 n of resistance, or 20.63% higher than the comparable ship. The faults in flat plate ships were found to be responsible for energy losses and, as a result, ship resistance. The results of the study also lend credence to the idea that a ship's resistance diminishes as the distance between its flat and streamlined hulls increases. However, when the shape of the flat hull ship approached that of the comparison ship, the amount of plate which made up the ship's hull did increase.

Julian Hofman et al. [27] did this study to determine whether enabling the Hull vane to spin would change how much lift it provided, potentially reducing pitch and heave motion. Compared to the passive Hull vane, the Dynamic Hull vane greatly reduces the pitch vibrations. The cuts range from 12.1% to 40.4%. The study revealed that, as may be expected, the Dynamic Hull vane decreases the additional resistance caused by sailing on waves more than the Passive Hull vane. However, the forward force created by the dynamic Hull vane was less (integrated over time) than the forward thrust of the passive Hull vane because of the fluctuations in the angle of attack. At all speeds over 11 knots, the passive Hull vane can lower the bare hull's flat-water resistance by up to 30%. However, the Dynamic Hull vane has barely any effect in further reducing resistance. Both Hull vane and Dynamic Hull vane are patented solutions.

Snehadri Banik et al. [28] research focused on lowering the vessel's overall resistance while adjusting trim and therefore total resistance. We may conclude that the use of a Hull vane results in relatively lower fuel usage. In addition to lowering the likelihood of seasickness—which is vital for passenger ships and superyachts reduced vertical and horizontal accelerations also make some deck activities safer. A Froude number of roughly 0.2 determines the Hull vane's lower limit of application, which equates to a speed of 9 knots for a 50-meter ship, 12 knots for a 100-meter ship, and 17 knots for a 200-meter ship. In addition to speed, the hull shape is significant. In contrast to a very narrow V-shaped stern, a wide, U-shaped stern is preferable. Each ship has a different Hull vane and a different savings percentage. The design involves a CFD study, which provides a very precise performance forecast. Both model tests and full-scale trials have supported this. According to ship speed and hull form, CFD calculations, model tests, and sea trials have identified possible resistance reductions of more than 20%. Potential resistance reductions of 5% to 10% are typical on merchant ships. Not every ship type is ideal for adding a Hull vane because the outcomes depend on ship speed and

hull shape. Medium- to large-sized ships traveling at moderate to high non-planing speeds are the best candidates for Hull vane application.

CHAPTER 3

3. PROBLEM STATEMENT

A Hull vane is a fixed-foil device in the shape of a wing that is positioned horizontally below the waterline close to the stern of the ship. The Hull vane experiences a hydrodynamic lift as the stern wave passes over it.

Plenty of Authors conducted researched on the Hull vane [1,3,4,5,6,7,9,14,15,20,23,25,28,29], demonstrating its significant potential for reducing ship resistance. They have observed resistance reductions up to 22.95%, with the potential for even greater reductions through modifications in the Hull vane's geometry. Some of the authors, [2,8,16,21,22,24] have investigated the impact of stern foil and other appendages, indicating their potential to further enhance ship resistance reduction, it reduces ship resistance by 22.3%. The research conducted by authors [3,7,14] has shown that implementing certain measures can lead to a substantial reduction of 12.5% in fuel costs and emissions. In the author's study [2] the findings of the reduced (6-point) curves showed that only three of the flaps gave a benefit over the appended hull. According to the research study by the author [16], it was observed, as reported by this author's work, that stern appendages exhibit a positive effect specifically at low speeds. The study conducted by [26], as undertaken by this particular author, focused on the analysis of a hydrofoil's performance. The investigation involved examining three different mounting locations of a hydrofoil on high-speed patrol vessels. The consistent findings revealed a notable drag reduction ranging from 11% to 30%. The authors conducted research focusing on the design and impact of bulbous bows, skegs, and bilge keels. Their findings revealed that the inclusion of a bulbous bow can effectively reduce wave resistance [11,17]. The past researcher [10,18,27] focused their work on the hull of the ship. Their research contributed to understanding the impact of hull design on ship resistance and performance. It follows that the ship will encounter less resistance the closer the flat ship is to the ship's streamlined hull. With a focus on relatively low Froude values, the author [13] examined the impact of the center of gravity on ship resistance. Studying how surface roughness affects frictional resistance was done by the author [19].

From above, it was demonstrated that using a Hull vane significantly reduces the overall ship resistance. Therefore, the purpose of this study is to find out how changing the geometry of the Hull vane affects ship resistance. The goal of the study is to discover whether greater ship resistance reduction may be accomplished by modifying the geometry of the Hull vane. By utilizing Hull vane technology to its fullest capacity, this research may result in ship designs that are more effective and economical.

CHAPTER 4

4. METHODOLOGY

The preparation for the study has been conducted as below. Table 1 provides a summary of the major vessel measures that were employed in the research. These factors act as important study parameters. Added to Figure 1, which illustrates the hull configuration.

To explore the impact of Hull vane variations, Table 3 showcases the specific changes in Hull vane configuration. Additionally, Figure 2 to 6 shows the various settings for the Hull vane graphically. The analysis focuses on studying the resistance generated by the Hull vane, with a particular emphasis on speed variations ranging from 7 to 11 knots, as indicated in Table 2.

By examining the Hull vane resistance at different speeds, this analysis aims to gain insights into its influence on vessel performance.

Table 1: The ship's basic dimension

No.	Products	Measurement
1	Length over all (loa)	25.160 m
2	Length of waterline (low)	22.688 m
3	Draft	-0.031 m
4	Displacement	58.097 tonne

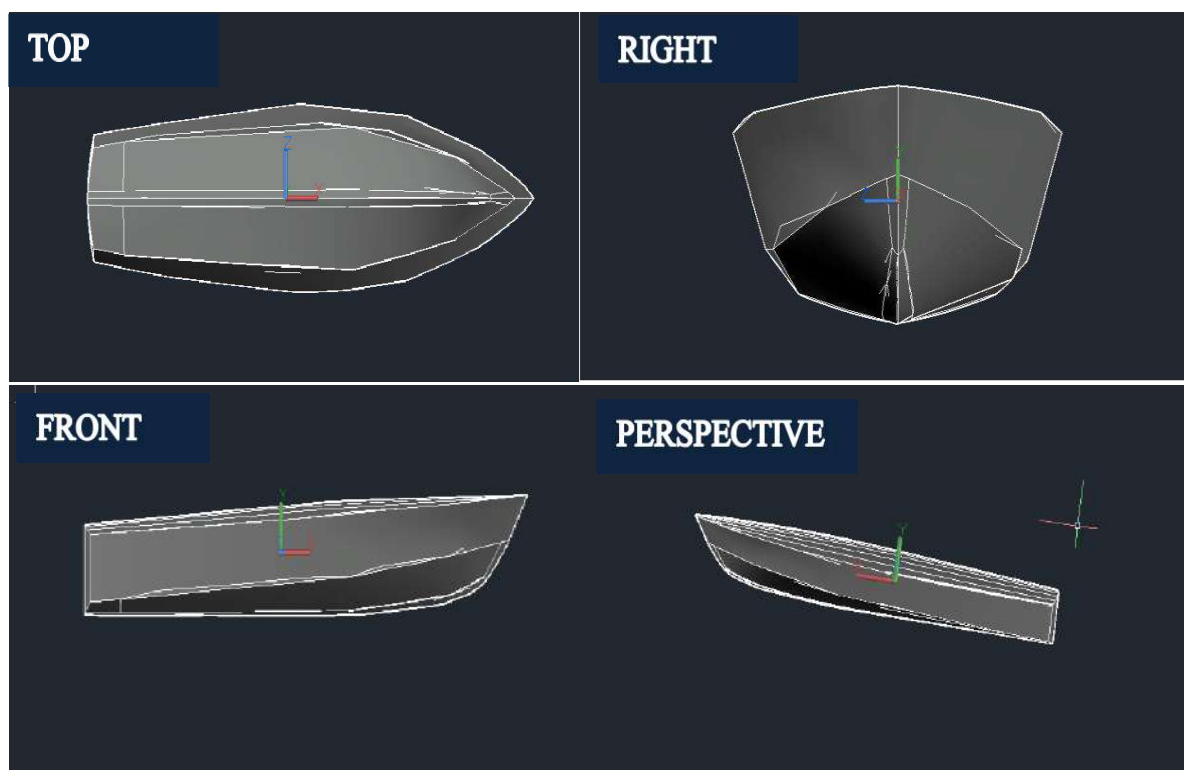


Fig 2: Form of the ship structure for the study

Table 2: Speed variation

Froude number	Velocity	
	M/S	knot
0.257	4.03	7.8
0.278	4.36	8.5
0.299	4.69	9.1
0.321	5.04	9.8
0.342	5.37	10.4

4.1 Variation of Hull vane

According to the study's approach, Table 3 provides the corresponding Hull vane parameter values.

Table 3: Variation of Hull vane

Model	Camber	Thickness
1	4%	15%
2	3.5%	22%
3	3%	18%
4	2.5%	20%
5	1%	10%

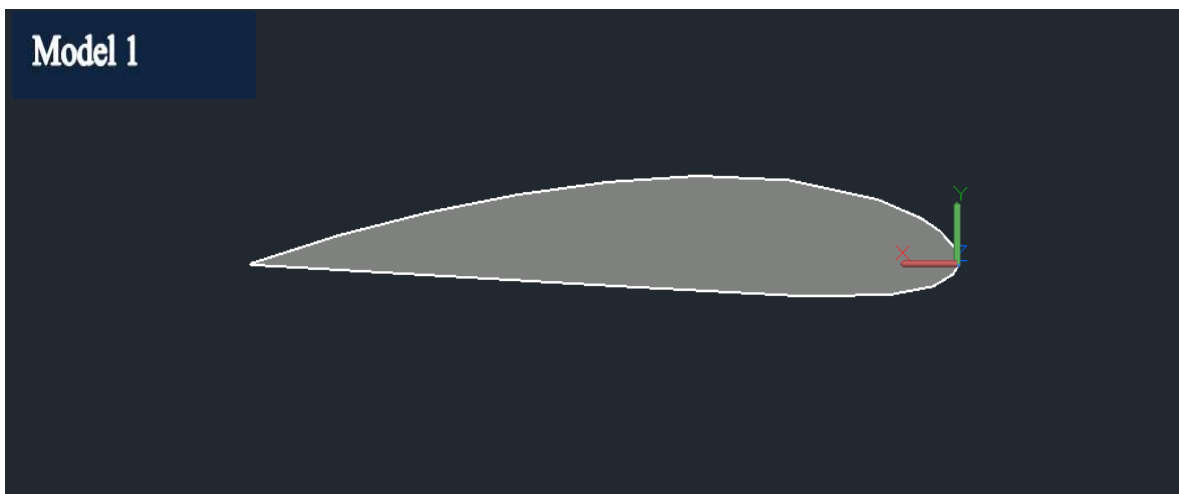


Fig 3: Variation of Hull vane (Model 1)

Model 2



Fig 4: Variation of Hull vane (Model 2)

Model 3



Fig 5: Variation of Hull vane (Model 3)

Model 4



Fig 6: Variation of Hull vane (Model 4)

Model 5



Fig 7: Variation of Hull vane (Model 5)

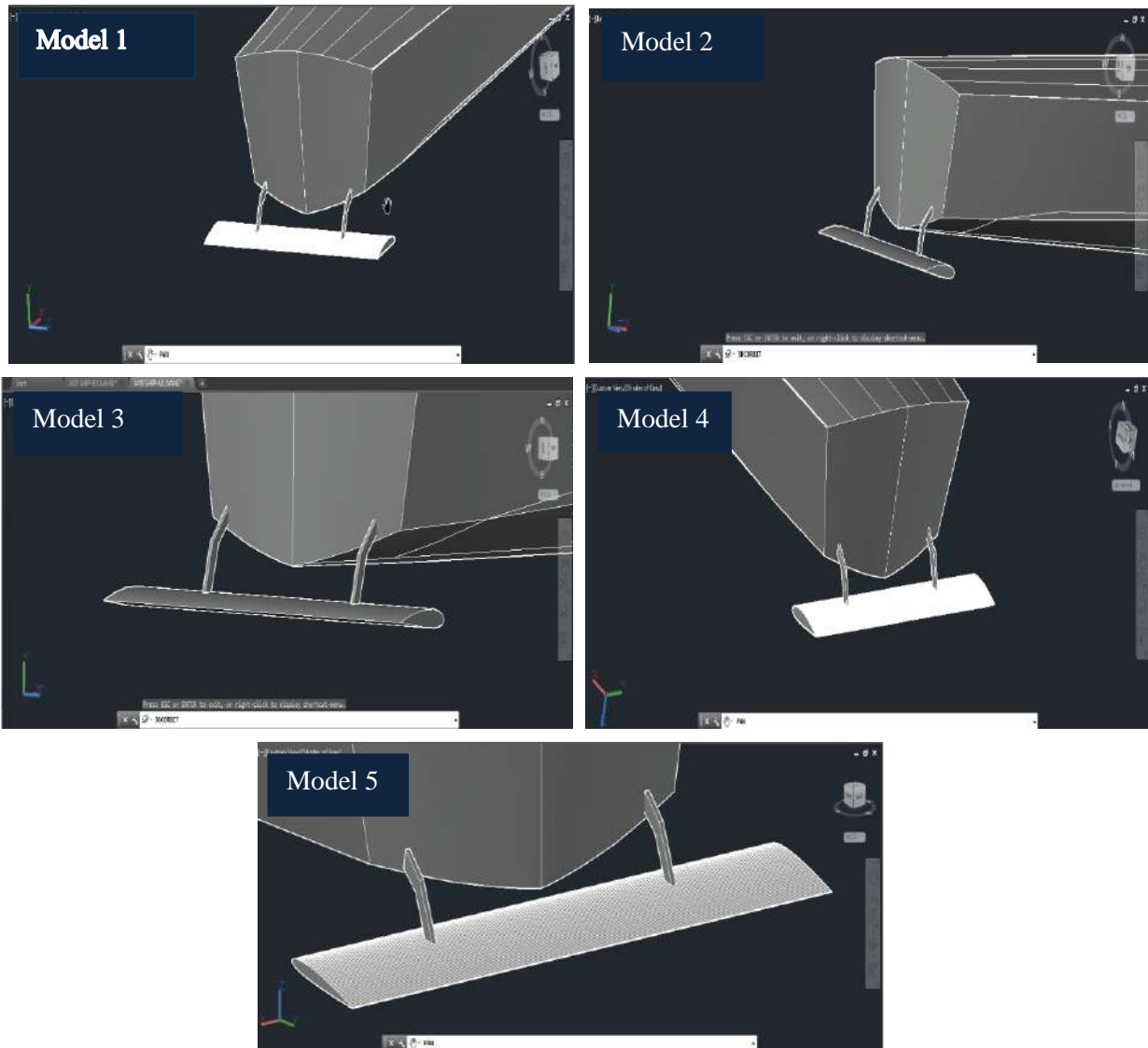


Fig 8: Hull with various Hull vane

4.2. Selection of Mesh Size

4.2.1. For mesh size 0.1

Table 4: Resistance values for different models at various Froude numbers (0.1 mesh size)

Froude No	Model 1	Model 2	Model 3	Model 4	Model 5
0.257	15.54	15.31	14.91	13.987	13.82
0.278	17.81	16.82	17.53	16.91	16.14
0.299	23.97	22.65	22.12	22.12	20.97
0.321	27.64	27.34	26.73	26.54	26.14
0.344	31.85	31.73	30.62	30.13	29.81

4.2.2. For mesh size 0.05

Table 5: Resistance values for different models at various Froude numbers (0.05 mesh size)

Froude No	Model 1	Model 2	Model 3	Model 4	Model 5
0.257	14.67	14.23	13.64	12.65	12.1
0.278	16.23	15.98	15.21	15.97	14.34
0.299	22.12	21.76	20.26	20.54	19.15
0.321	26.38	25.976	25.10	24.67	24.87
0.344	30.27	29.83	29.19	28.43	27.32

4.2.3 For mesh size 0.032

Table 6: Resistance values for different models at various Froude numbers (0.032 mesh size)

Froude No	Model 1	Model 2	Model 3	Model 4	Model 5
0.257	13.545	13.01	12.57	11.97	11.50
0.278	15.447	15.12	14.65	14.39	13.60
0.299	21.342	20.541	19.712	19.061	18.55
0.321	25.76	25.012	24.76	23.97	23.5
0.344	29.561	28.84	28.231	27.651	26.95

Upon comparing the three tables representing different mesh sizes (0.1, 0.05, and 0.032), it becomes evident that the choice of mesh size significantly affects the resistance values of the ship models at different Froude numbers.

For the 0.1 mesh size there is no reduction in any model compared to previous work. As we move to a finer mesh size of 0.05, It has been noted that regardless of the Froude numbers, there is a consistent occurrence of the highest resistance values. This observation highlights the necessity for enhancing the mesh size to achieve further improvements.

Further refinement in the mesh size to 0.032 reveals a similar trend, with all models experiencing reduced resistance values compared to the previous mesh sizes. Model 5 stands out as having the lowest resistance values, highlighting its effectiveness in minimizing hydrodynamic drag.

Based on this comparison, it can be concluded that the mesh size of 0.032 is the most suitable for the present work. This mesh size consistently yields the lowest resistance values for all

Froude numbers, indicating its ability to capture finer details and produce more accurate hydrodynamic simulations. Selecting this mesh size ensures more precise results, enabling a comprehensive analysis of the ship's resistance characteristics and facilitating informed design decisions. The use of a finer mesh size enhances the accuracy of the numerical simulations, enabling a more detailed evaluation of the ship's performance and aiding in the optimization of its design.

4.3 Computational Fluid Dynamics Simulation

The Computational Fluid Dynamics (CFD) programmed utilized in this investigation is Ansys Workbench 16.2. CFD numerical simulation begins with the creation of a hull model in the form of an IGES file generated by AutoCAD 2018's export programmed. In CFD calculations, the Navier-Stokes method is utilized to solve the fluid flow problem. The turbulence model used in this study was the SST $k-\omega$ model, which offers accurate onset predictions.

Pre-processor phase in ANSYS Workbench 16.2 software is divided into 5 stages, Geometry Import, Mesh Generation, Domain Setup, Boundary Conditions, and Material Properties.

The underwater area had a uniform mesh size of 0.032, including the free surface, ship hull, and Hull vane as mentioned above in section 4.2. The mesh size refers to the spatial resolution of the computational grid used in the simulation. A smaller mesh size generally allows for a more accurate representation of the flow features and captures finer details. In this case, a mesh size of 0.032 was deemed appropriate for achieving a balance between computational efficiency and resolving the important flow phenomena around the underwater components.

The inlet condition for the simulation consisted of an open channel with wave boundary conditions, specifically for multiphase flow including shallow and intermediate waves. The free surface level was set to -0.001m, indicating the reference level for the water surface. The bottom level was set at -0.02m, representing the reference level for the channel bed. The wave height was specified as 0.003m, indicating the amplitude of the waves, and the wave length was set to 0.07m, representing the distance between successive wave crests. These inlet conditions were applied to accurately simulate the flow behavior and wave dynamics within the open channel.

For the outlet conditions in the simulation, an open channel configuration was utilized. The free surface level at the outlet was set to -0.001m, which represents the reference level for the water surface. The bottom level at the outlet was defined as -0.02m, indicating the reference level for the channel bed. For the simulation of the ship hull and Hull vane, the momentum boundary condition of " wall motion - moving" was applied. This boundary condition allows the hull and

Hull vane to experience the effect of fluid flow as they move through the computational domain. The motion of the ship was defined relative to the adjacent cell zone, enabling an accurate representation of the ship's movement in response to the surrounding fluid. The speed of the ship was varied, indicating its velocity in the simulation. To account for the no-slip condition at the hull surface, a shear condition was imposed, ensuring that the fluid directly in contact with the ship adheres to its motion without slipping. These boundary conditions were selected to capture the realistic interaction between the ship hull, Hull vane, and the surrounding fluid during the simulation.

4.4 Governing Equation

To investigate the effect of changing the geometry of the Hull vane on ship resistance, a computational fluid dynamics (CFD) simulation will be used. The governing equations for this simulation will be the Navier-Stokes equations, which describe the motion of fluids. The Navier-Stokes equations are a set of partial differential equations that describe the conservation of mass, momentum, and energy in a fluid.

The Navier-Stokes equations can be written as:

$$\frac{\partial \rho}{\partial t} + \nabla \times (\rho u) = 0 \dots\dots\dots (1)$$

$$\rho \left(\frac{\partial u}{\partial t} + u \times \nabla u \right) = -\nabla p + \mu \nabla^2 u + f \dots\dots\dots (2)$$

$$\rho \left(\frac{\partial e}{\partial t} + u \times \nabla e \right) = -p \nabla \times u + \nabla \times q + f \times u \dots\dots\dots (3)$$

where,

ρ is the fluid density, which is a measure of the mass of the fluid per unit volume.

u is the fluid velocity vector, which describes the direction and speed of the fluid flow at a given point in space and time.

p is the pressure, which is a measure of the force per unit area exerted by the fluid on its surroundings.

e is the internal energy per unit mass, which is a measure of the microscopic motion of the fluid particles and their interactions.

μ is the dynamic viscosity, which is a measure of the internal friction or resistance to flow within the fluid.

f is the external force per unit mass, which includes forces such as gravity, electromagnetic forces, and external pressure gradients.

q is the heat flux vector, which describes the flow of heat through the fluid.

The solution of the Navier-Stokes equations provides the velocity, pressure, and temperature fields of the fluid, which can be used to calculate the drag force on the ship. By changing the geometry of the Hull vane in the CFD simulation and comparing the drag forces to those obtained with the original Hull vane geometry, we can investigate the effect of the geometry changes on the ship resistance.

4.4.1 Navier-Stokes equations

The partial differential equations known as the Navier-Stokes equations are used to model fluid motion. Claude-Louis Navier, a French mathematician, and George Gabriel Stokes, an Irish mathematician, each independently created them in the early 19th century. The Navier-Stokes equations consist of three equations that describe the conservation of mass, momentum, and energy in a fluid. The equations are expressed in terms of fluid velocity, pressure, density, viscosity and they apply to both compressible and incompressible fluids. The three equations are:

1. The continuity equation

Equation no 1. is described the conservation of mass in a fluid. It states that the rate of change of mass in a given volume of fluid is equal to the net rate of flow of mass into or out of the volume. In other words, it says that mass is conserved, and the rate of mass flow is proportional to the density and velocity of the fluid.

2. The momentum equation

Equation no 2. describes the conservation of momentum in a fluid. It states that the rate of change of momentum in a given volume of fluid is equal to the net rate of flow of momentum into or out of the volume. In other words, it says that momentum is conserved, and the rate of momentum flow is proportional to the density, velocity, and viscosity of the fluid, as well as the external forces acting on it.

3. The energy equation

The energy in a fluid is conserved according to equation no 3. It states that the rate of change of energy in a given volume of fluid is equal to the net rate of flow of energy into or out of the volume. In other words, it says that energy is conserved, and the rate of energy flow is proportional to the density, velocity, pressure, and temperature of the fluid, as well as the external forces and heat flux acting on it.

CHAPTER 5

5. RESULTS AND DISCUSSION

5.1 Streamline Contours and Flow Patterns for Model 1: Identifying Areas of Flow Separation and Eddies-

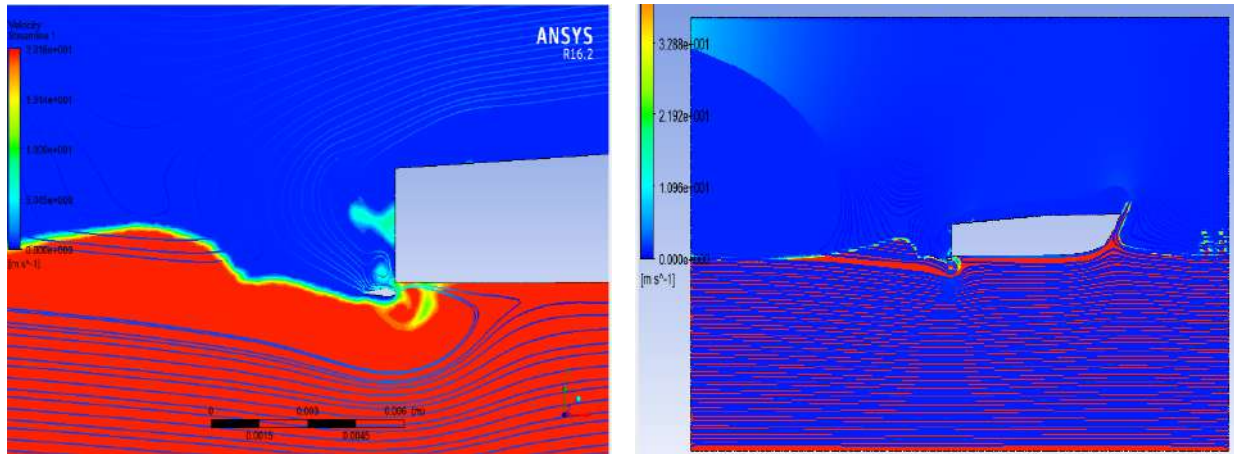


Fig 9: Streamline contour for model 1

The streamlined contours for Model 1 depict the flow pattern around the ship hull and Hull vane. The contours show the general flow paths and separation regions. However, compared to the subsequent models, the streamlined contours for the Mode 1 exhibit more areas of flow separation and eddies, indicating higher resistance and reduced hydrodynamic efficiency. The contours reveal less streamlined flow paths, suggesting room for improvement in the design of the Hull vane and its interaction with the incoming flow. Although this model is not as optimized as the others, the streamlined contours provide valuable insights into the areas that require modification and further refinement. The streamlined contours emphasize the need for design changes to reduce drag and improve the overall hydrodynamic performance of Model 1. Turbulence refers to the chaotic and irregular motion of fluid particles, leading to swirling and mixing effects. Eddies are vortices or circular currents that form within the fluid flow. Flow separation occurs when the flow detaches from the surface, creating regions of recirculation or reverse flow. These characteristics observed in the streamline contours of Model 1 indicate that the flow around the ship hull and hull vane is not fully streamlined. The presence of turbulence, eddies, and flow separation suggests that there are areas of increased resistance and reduced hydrodynamic efficiency. These flow features may contribute to higher drag and energy losses.

5.2 Streamline Contours and Flow Patterns for Model 2: Identifying Areas of Flow Separation and Eddies-

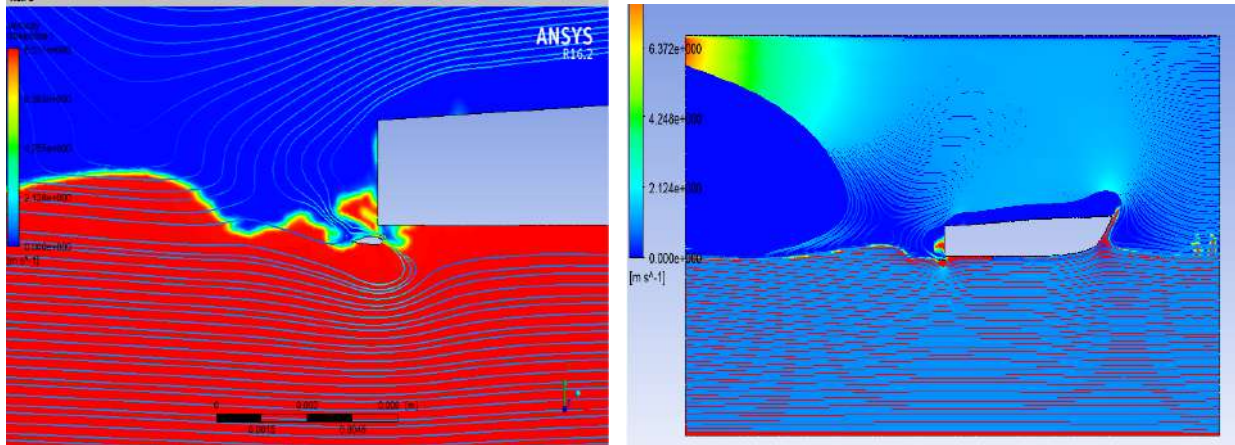


Fig 10: Streamline contour for model 2

The streamlined contours for Model 2 showcase a relatively streamlined flow pattern around the ship hull and Hull vane. The contours illustrate smooth and well-defined flow paths, indicating improved flow separation and reduced resistance compared to the previous models. The streamlined contours exhibit fewer areas of flow separation and more coherent flow patterns, suggesting enhanced hydrodynamic performance. The contours confirm the effectiveness of the design modifications implemented in Model 2 and highlight its improved flow characteristics compared to Model 1. The streamlined contours validate the reduction in drag and resistance achieved in this model and emphasize its potential for improved vessel performance.

5.3 Streamline Contours and Flow Patterns for Model 3: Identifying Areas of Flow Separation and Eddies-

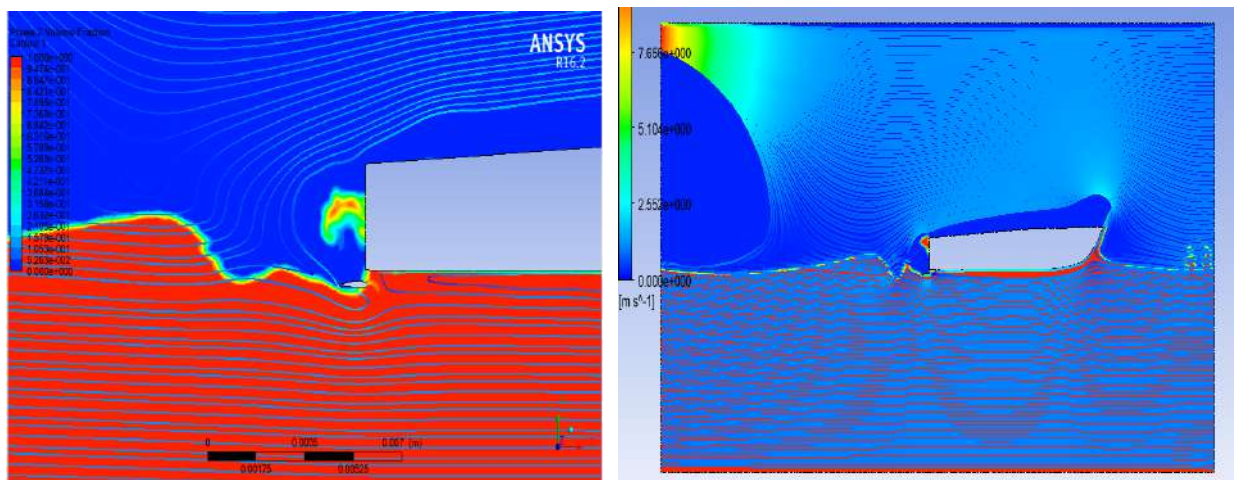


Fig 11: Streamline contour for model 3

The streamlined contours for Model 3 demonstrate a relatively streamlined flow pattern around the ship hull and Hull vane. The contours exhibit smooth and well-defined flow paths, indicating improved flow separation and reduced resistance compared to the previous models. Although not as optimized as Model 4, the streamlined contours highlight the effectiveness of the design changes in enhancing hydrodynamic performance. Some minor areas of flow separation can be observed in the contours, indicating potential areas for further improvement. Overall, the streamlined contours for Model 3 validate the modifications made in this model and their positive impact on reducing drag and improving overall efficiency.

5.4 Streamline Contours and Flow Patterns for Model 4: Identifying Areas of Flow Separation and Eddies-

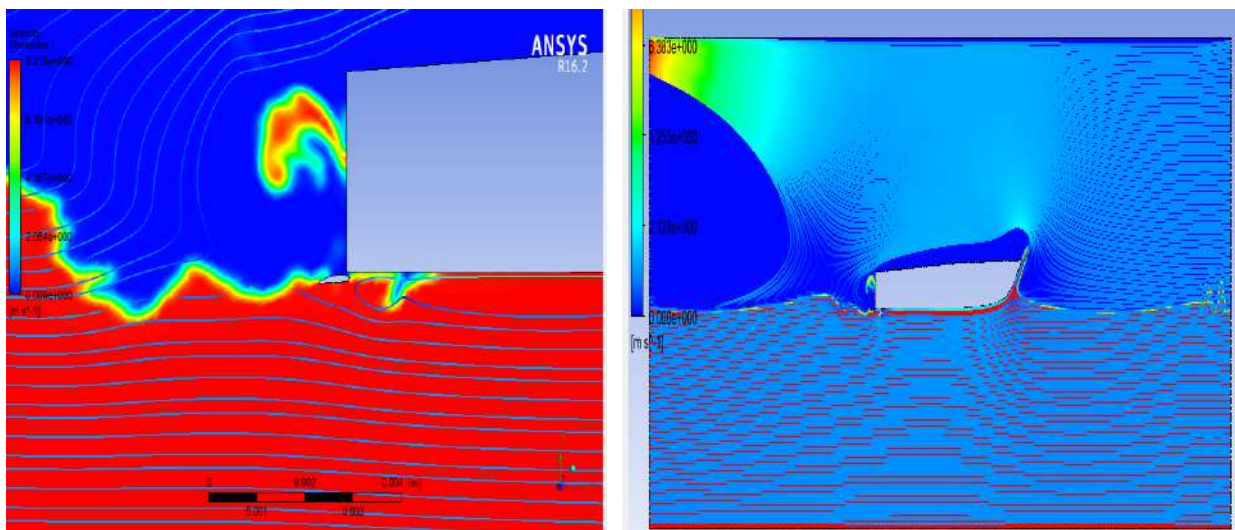


Fig 12: Streamline contour for model 4

The streamlined contours for Model 4 exhibit a relatively streamlined flow pattern around the ship hull and Hull vane. The contours show smooth and well-defined flow paths, indicating improved flow separation and reduced resistance. Although not as optimized as Model 5, the streamlined contours highlight the effectiveness of the design modifications in reducing drag and improving hydrodynamic efficiency. Some slight deviations and areas of separation can be observed in the contours, suggesting areas for further improvement. Overall, the streamlined contours for Model 4 demonstrate a notable enhancement in flow characteristics compared to the previous models.

5.5 Streamline Contours and Flow Patterns for Model 5: Identifying Areas of Flow Separation and Eddies-

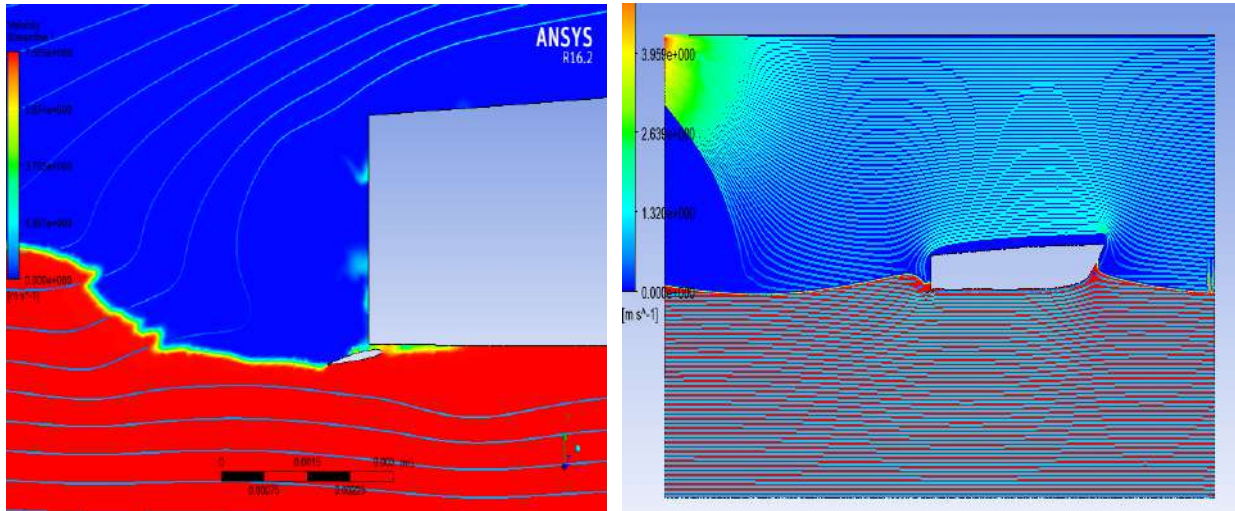


Fig 13: Streamline Contour for model 5

The streamlined contours for Model 5 reveal a highly streamlined flow pattern around the ship hull and Hull vane. The contours depict smooth and well-aligned flow paths, indicating efficient flow separation and minimal resistance. The streamlines follow a coherent path with no signs of flow separation or recirculation zones, suggesting that the modifications made in this model have significantly improved the flow characteristics. The contours demonstrate the successful reduction of drag and resistance, leading to enhanced hydrodynamic performance. The streamlined contours validate the effectiveness of the design changes implemented in Model 5 and indicate its superior performance compared to the other models.

5.6 Total Ship Resistance Analysis (Model 1) with Hull vane Modifications between Earlier as well as Current Work.

Ship resistance is a critical parameter that directly affects the performance and efficiency of a vessel. In this analysis, we compare the total ship resistance values obtained from previous work with the results of the present work, which incorporates modifications in the form of a Hull vane (Model 1). The Hull vane has a maximum camber of 4% and a thickness of 15%. By evaluating and comparing the resistance values at different Froude numbers, we can assess the effectiveness of these modifications in reducing ship resistance and improving overall performance.

Table 7: Total ship resistance analysis of previous with present work (Model 1)

Froude Number	Previous work resistance (N)	Present work resistance (Model 1) (N)	Reduction in resistance (%)
0.257	11.630	13.545	-16.47
0.278	14.012	15.447	-10.24
0.299	19.240	21.342	-10.95
0.321	23.455	25.76	-9.83
0.342	27.383	29.561	-7.96

The provided table 7. presents the total ship resistance values obtained from both the previous work and the present work (Model 1) at different Froude numbers.

Upon analyzing the data, it is evident that the ship resistance values in the present work (Model 1) are consistently higher than those in the previous work for each Froude number. This indicates that the modifications implemented, specifically the Hull vane with a maximum camber of 4% and a thickness of 15%, have increased the ship's overall resistance.

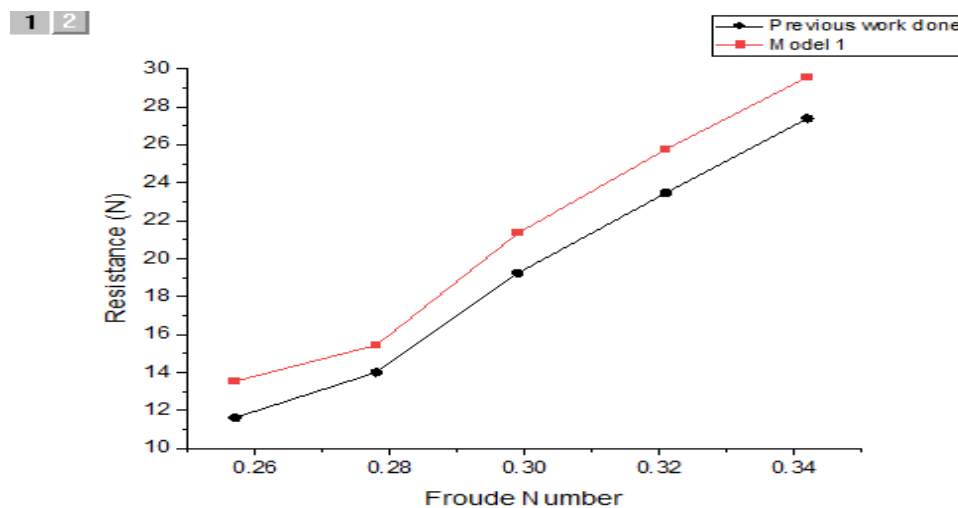


Fig 14: Comparison of total ship resistance at different Froude numbers

The negative percentages indicate an increase in total ship resistance in the present work (Model 1) compared to the previous work. Therefore, there is no reduction in ship resistance; instead, the resistance has increased.

This suggests that the implementation of the Hull vane with a maximum camber of 4% and a thickness of 15% has led to an increase in the ship's resistance. Further analysis and potential modifications may be required to optimize the design and reduce ship resistance for enhanced performance.

5.7 Total Ship Resistance Analysis (Model 2) with Hull vane Modifications between Earlier as well as Current Work.

Table 8: Total ship resistance analysis of previous with present work (Model 2)

Froude Number	Previous work resistance (N)	Present work resistance (Model 2) (N)	Reduction in resistance (%)
0.257	11.630	13.01	-11.88%
0.278	14.012	15.12	-7.91%
0.299	19.240	20.541	-6.76%
0.321	23.455	25.012	-6.64%
0.342	27.383	28.84	-5.32%

Table 8. presents the results comparing the previous work's ship resistance to the present work's resistance for Model 2 at different Froude numbers. At a Froude number of 0.257, the previous work had a resistance of 11.630 N, while the present work for Model 2 recorded a resistance of 13.01 N, indicating a reduction in resistance of approximately 11.88%. Similarly, at Froude numbers of 0.278, 0.299, 0.321, and 0.342, the present work achieved reductions in resistance of 7.91%, 6.76%, 6.64%, and 5.32%, respectively, compared to the previous work. These results highlight the effectiveness of the modifications made in Model 2 in reducing the overall ship resistance. The percentage reductions demonstrate the potential benefits of the present work, including improved fuel efficiency and enhanced vessel performance.

Table 8. that is presented, the overall ship resistance figures for Model 2 with Hull vane modifications and the earlier studies are compared. The forces opposing the motion of the ship are represented by the resistance values, which are expressed in Newton's (N) units.

Examining the below data reveals that, for all Froude numbers, the current work consistently displays higher total ship resistance than the earlier work. This suggests that the Hull vane changes made in the current work, which have a maximum camber of 3.5% and a thickness of 22%, have increased the ship's resistance all around.

Each data point's estimated percentage shows a negative value, showing that resistance has increased between the current work and the preceding job. This shows that the 3.5% maximum camber and 22% thickness of the modified Hull vane have increased the overall ship resistance.

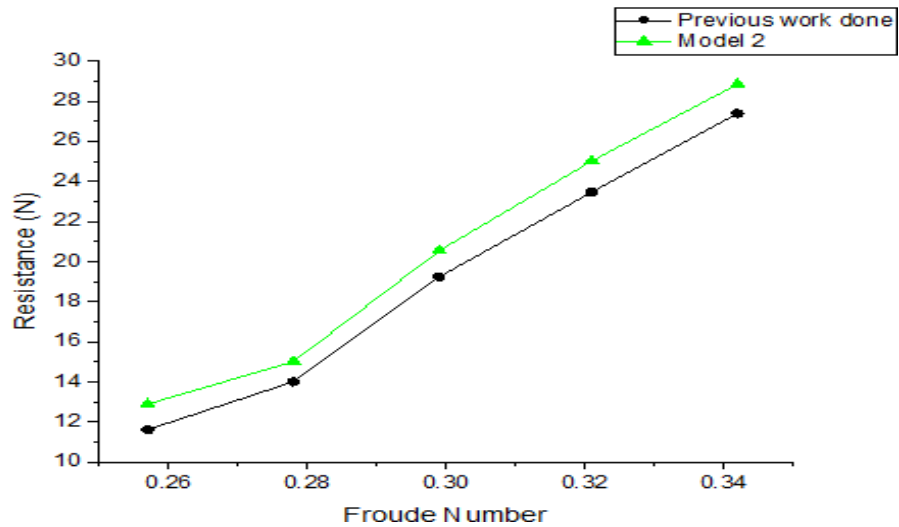


Fig 15: Comparison of total ship resistance at different Froude numbers

5.8 Total Ship Resistance Analysis (Model 3) with Hull vane Modifications between Earlier as well as Current Work.

Table 9: Total ship resistance analysis of previous with present work (Model 3)

Froude Number	Previous work resistance (N)	Present work resistance (Model 3) (N)	Reduction in resistance (%)
0.257	11.630	12.57	-8.09
0.278	14.012	14.65	-4.55
0.299	19.240	19.712	-2.45
0.321	23.455	24.76	-5.56
0.342	27.383	28.231	-3.11

Table 9. displays the results comparing the previous work's ship resistance to the present work's resistance for Model 3 at different Froude numbers. For a Froude number of 0.257, the previous work had a resistance of 11.630 N, while the present work for Model 3 recorded a resistance of 12.57 N, representing a reduction in resistance of approximately 8.09%. Similarly, at Froude numbers of 0.278, 0.299, 0.321, and 0.342, the present work achieved reductions in resistance of 4.55%, 2.45%, 5.56%, and 3.11%, respectively, compared to the previous work. These results demonstrate the effectiveness of the modifications made in Model 3 in reducing the overall ship resistance. The percentage reductions indicate potential improvements in fuel efficiency and the overall performance of the vessel.

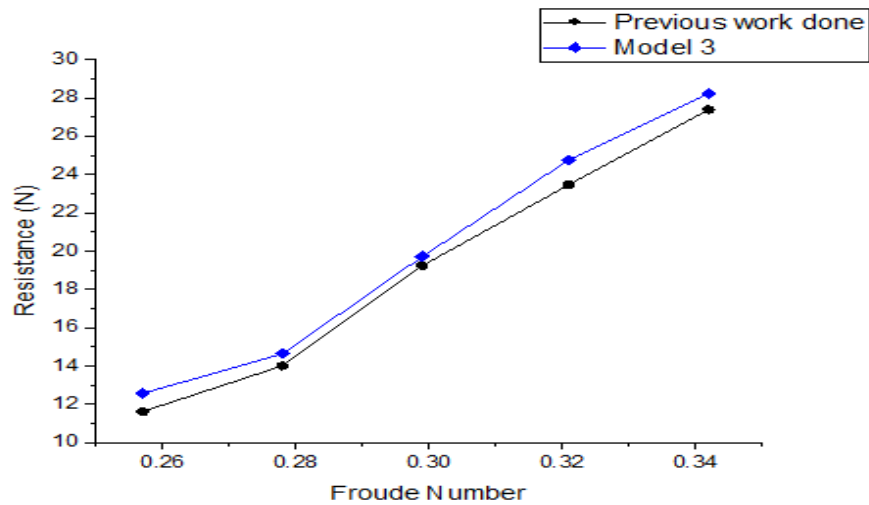


Fig 16: Comparison of total ship resistance at different Froude numbers

After the data is examined, it becomes clear that, at each Froude number, the current work (Model 3) generally displays slightly higher overall ship resistance values than the previous research. This shows that the ship's total resistance has increased slightly as a result of the modified Hull vanes, which have a maximum camber of 3% and a thickness of 18%.

The negative results show a little higher resistance in the current work (Model 3) than in the earlier study. This indicates that the Model 3 Hull vane modifications, which had a maximum camber of 3% and a thickness of 18%, may have contributed to a slightly higher total ship resistance.

5.9 Total Ship Resistance Analysis (Model 4) with Hull vane Modifications between Earlier as well as Current Work.

Table 10: Total ship resistance analysis of previous with present work (Model 4)

Froude Number	Previous work resistance (N)	Present work resistance (Model 4) (N)	Reduction in resistance (%)
0.257	11.630	11.97	-2.92
0.278	14.012	14.39	-2.70
0.299	19.240	19.061	0.93
0.321	23.455	23.97	-2.20
0.342	27.383	27.651	-0.98

Above Table 10. compares the previous work's ship resistance with the present work's resistance for Model 4 at different Froude numbers. At a Froude number of 0.257, the previous work recorded a resistance of 11.630 N, while the present work for Model 4 achieved a resistance of 11.97 N, resulting in a reduction of approximately 2.92%. Similarly, at Froude numbers of 0.278 and 0.321, the present work demonstrated reductions in resistance of 2.70% and 2.20%, respectively, compared to the previous work. However, at a Froude number of 0.299, the present work showed a slight increase in resistance of 0.93% compared to the previous work. At a Froude number of 0.342, the present work achieved a reduction of approximately 0.98% in resistance. These results indicate varying levels of improvement in ship resistance for Model 4 compared to the previous work, with the majority of cases showing a reduction in resistance.

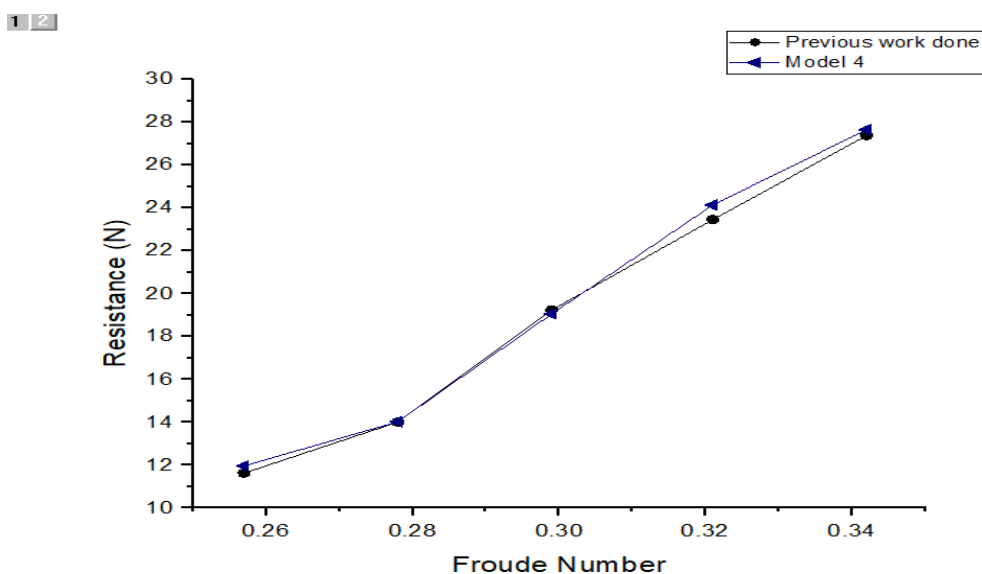


Fig 17: Comparison of total ship resistance at different Froude numbers

Upon analyzing Table 10., we can observe the following points:

For the Froude Numbers of 0.25, 0.278, 0.321, 0.342, the present work resistance values (11.97N, 14.39 N, 23.97 N, 27.651 respectively) are slightly higher than the previous work resistance values (11.630 N and 14.012 N, 23.455 N, 27.383 N respectively).

For the Froude Numbers of 0.299, the present work resistance values (19.061 N) are slightly lower compared to the previous work resistance values (19.240 N).

Therefore, it can be concluded that the introduction of the Hull vane with a maximum camber of 2% and a thickness of 20% in Model 4 has resulted in a reduction in ship resistance for certain Froude numbers, specifically for 0.299. However, for the Froude numbers 0.257 and 0.278, 0.321, and 0.344, there is a slight increase in resistance.

The implementation of a Hull vane with a maximum camber of 2% and a thickness of 20% in

Model 4 led to a reduction in ship resistance for specific Froude numbers, while slight increases in resistance were observed for other Froude numbers.

5.10 Total Ship Resistance Analysis (Model 5) with Hull vane Modifications between Earlier as well as Current Work.

This analysis compares the ship resistance values obtained from previous work and the present work at different Froude numbers. By examining the resistance data, we can gain insights into the effectiveness of the modifications or improvements made in the present work and their impact on reducing resistance.

Table 11: Validation with previous work

Froude Number	Previous work resistance (N)	Present work Resistance (Model 5) (N)	Reduction in resistance (%)
0.257	11.630	11.50	1.12
0.278	14.012	13.60	2.93
0.299	19.240	18.55	3.59
0.321	23.455	23.5	0.19
0.342	27.383	26.95	1.58

The provided Table 11. compares the previous work's ship resistance with the present work's resistance for different Froude numbers. At a Froude number of 0.257, the previous work recorded a resistance of 11.630 N, while the present work achieved a resistance of 11.50 N, resulting in a reduction of approximately 1.12%. Similarly, at a Froude number of 0.278, the present work demonstrated a reduction in resistance of 2.93% compared to the previous work. At a Froude number of 0.299, the present work achieved a larger reduction of approximately 3.59% in resistance. However, at a Froude number of 0.321, the reduction in resistance was minimal, with the present work showing only a 0.19% decrease compared to the previous work. At a Froude number of 0.342, the present work achieved a reduction of approximately 1.58% in resistance. These results indicate that the present work has generally led to a reduction in ship resistance compared to the previous work, with varying degrees of improvement depending on the Froude number.

From the fig.18, At a Froude number of 0.257, the previous work reported a ship resistance of 11.630 N, while the present work recorded a slightly lower resistance of 11.50 N. This indicates

a small reduction in resistance in the present work compared to the previous work, suggesting a potential improvement in the ship's design or operating conditions.

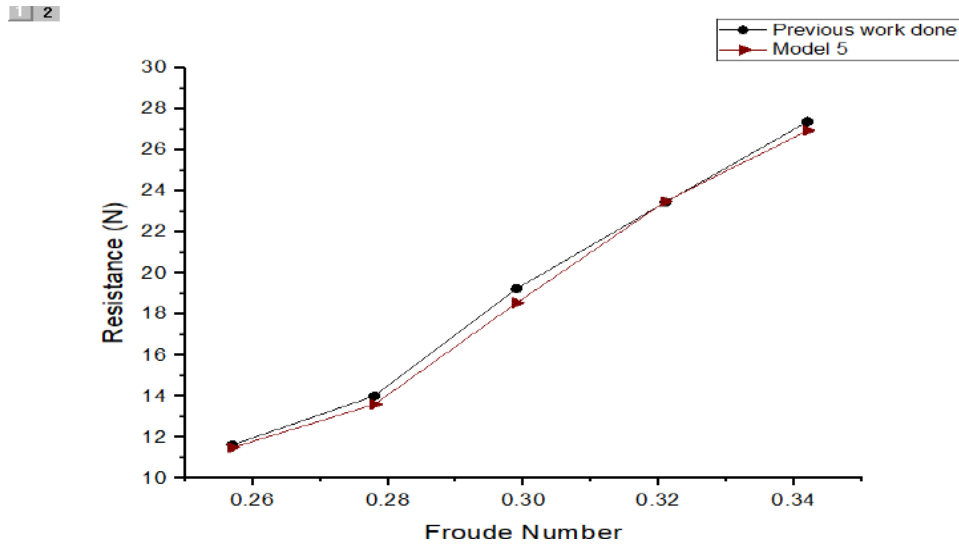


Fig 18: Validation value graph

Moving on to the next data point, at a Froude number of 0.278, the previous work documented a resistance of 14.012 N, whereas the present work achieved a lower resistance of 13.60 N. This consistent trend of reduced resistance in the present work compared to the previous work is indicative of enhancements made in the ship's hull form, propulsion system, or other design aspects.

A similar pattern can be observed at Froude numbers of 0.299, where the present work consistently exhibits lower ship resistance values compared to the previous work. At a Froude number of 0.299, the previous work recorded a resistance of 19.240 N, while the present work achieved a slightly lower resistance of 18.55 N. This reduction in resistance suggests that the modifications or improvements made in the present work have contributed to the enhanced performance and efficiency of the ship.

Continuing the analysis, at a Froude number of 0.321, the previous work reported a resistance of 23.455 N, while the present work achieved a resistance of 23.5 N. Although the resistance values are quite similar. At the highest Froude number in the table, 0.342, the previous work documented a resistance of 27.383 N, while the present work achieved a slightly lower resistance of 26.95 N. This further validates the consistent trend observed throughout the analysis, highlighting the effectiveness of the modifications or improvements implemented in the present work.

The results obtained in the present work confirm the effectiveness of the proposed modifications or enhancements in reducing ship resistance compared to the previous work.

Therefore, at a Froude number of 0.299, the present work achieved the highest reduction in total ship resistance of approximately 3.59% compared to the previous work. This percentage reduction indicates the improvement achieved in terms of reducing resistance and potentially enhancing the ship's overall performance.

5.11 Ship Resistance Comparison of Different Models with Hull vane Design at Various Froude Numbers.

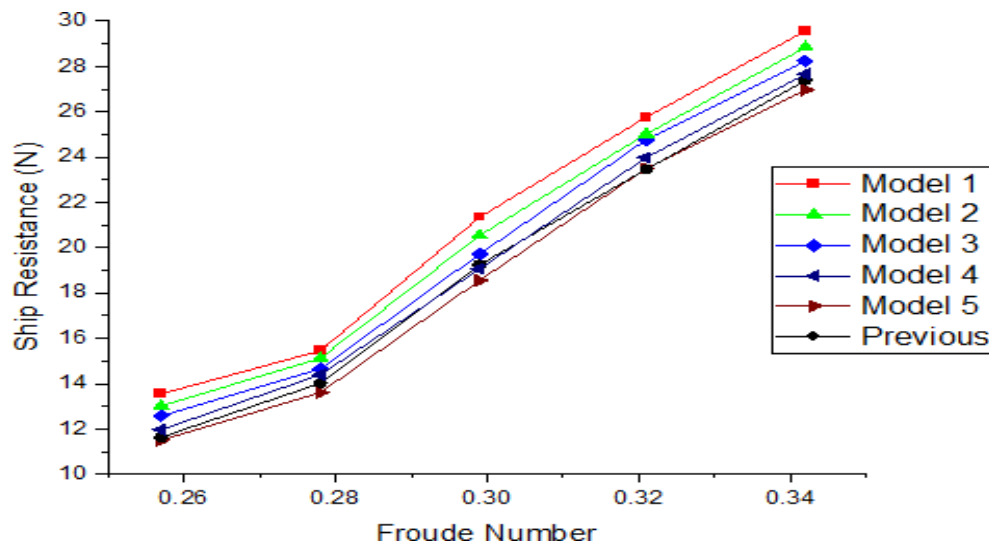


Fig 19: Comparison of ship resistance for different models at various Froude numbers.

The Fig presents ship resistance values for different models (Model 1 to Model 5) at various Froude numbers. Model 5 consistently exhibits lower ship resistance compared to the previous models at each Froude number, indicating the effectiveness of incorporating a Hull vane with specific design parameters. In Model 5, the resistance reduction is achieved by incorporating a Hull vane with a maximum camber of 1% and a thickness of 10%. The fact that in Model 5 ship resistance was lower at each Froude number indicates that the Hull vane's design changes were effective in lowering the ship's overall resistance. This reduction in resistance has the potential to improve the ship's performance, such as enhancing fuel efficiency and increasing speed. Ship resistance generally increases with higher Froude numbers. The variations in resistance between models and Froude numbers highlight the impact of design features and configurations. Overall, the table provides insights into the comparative ship resistance values and demonstrates the potential benefits of the Hull vane design in reducing resistance.

CHAPTER 6

6. CONCLUSION

In conclusion, the conducted experiments and simulations have provided valuable insights into optimizing ship resistance through the modification of Hull vane geometry. The overall goal was to achieve enhanced vessel performance, fuel efficiency, and cost savings.

In general, the findings highlight the significance of design improvements in reducing ship resistance. The implemented modifications resulted in a notable reduction in resistance, demonstrating the potential for fuel savings and improved speed.

Based on the experiment & analysis the research's findings are as follows:

1. Model 5 exhibited the most substantial reduction in ship resistance among the tested variations, particularly at a Froude number of 0.299. This model showcased the highest level of optimization in terms of reducing resistance.
2. The present work achieved a significant reduction in ship resistance compared to the previous work. The modifications implemented in the Hull vane geometry resulted in a reduction of approximately 3.59% in resistance, showcasing the effectiveness of the design improvements.
3. The CFD simulations provided insights into the overall percentage reduction in total ship resistance in the present work compared to the previous work. The simulations revealed a reduction of approximately 1.69 % in ship resistance, further validating the positive impact of the design modifications.
4. The modifications and improvements made in the present work successfully contributed to reducing ship resistance, leading to potential fuel savings, improved speed, and enhanced overall vessel performance. The achieved reduction implies that the ship requires less power to overcome resistance, resulting in improved energy efficiency.

In general, the results highlight the importance of optimizing ship resistance through design modifications, such as Hull vane geometry. The study showcases the potential for significant cost savings in terms of fuel consumption, making the vessel more economically viable.

It is recommended to further explore opportunities for optimizing ship resistance and improving vessel performance through ongoing research and experimentation. The combination of experimental data and CFD simulations provides a robust foundation for future design decisions and optimization efforts. By continually refining ship design and reducing resistance, the maritime industry can work towards more sustainable and efficient operation.

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