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Related Literature Review on the Design of Hull Vane on an Offshore Surfer Vessel for Improved Fuel Efficiency

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I. INTRODUCTION

The increasing demand for fuel-efficient high-speed marine transportation has intensified research into hull-form optimization, energy-saving appendages and computational hydrodynamic design (Bertram, 2012). Offshore surfer vessels, fast crew suppliers, patrol boats and other semi-displacement or high-speed displacement craft often operate under demanding conditions where speed, trim, resistance, seakeeping, operational safety and fuel economy are simultaneously important (Yang & Huang, 2016).

In such vessels, total resistance rises significantly with speed, especially where wave-making resistance, stern-wave generation, transom flow separation and running trim become dominant hydrodynamic issues (Molland et al., 2011). Consequently, recent literature has shifted from conventional empirical hull design toward integrated CAD modelling, NURBS-based surface refinement, CFD prediction, motion analysis and effective-power computation (Papanikolaou, 2014; Molland et al., 2017).

The hull vane has emerged as one of the most promising stern-mounted hydrofoil appendages for reducing resistance and improving vessel performance (Budiarto & Firdhaus, 2021). It is generally described as a fixed submerged wing located near the transom, designed to interact with the upward stern flow, generate a useful forward force component, suppress the stern wave and modify running trim (Bouckaert et al., 2016). Its application has been examined in patrol vessels, yachts, ferries, RoPax ships, semi-displacement vessels and high-speed displacement hulls (Hannan et al., 2018; Hou et al., 2020). More recent research continues to show that hull-vane effectiveness depends on longitudinal position, vertical position, foil section, chord length, span, angle of attack and interaction with the stern flow field (Çelik & Danışman, 2023).

This review is structured around the present study's objectives: designing a hull vane tailored to the aft hull form of an existing surfer vessel using advanced CAD and Maxsurf; achieving resistance reduction through CFD-predicted stern-flow control; improving hydrodynamic performance and running trim through Maxsurf analysis; determining effective power using MATLAB; and comparing the bare hull and hull-vane vessel using resistance and motion simulation results.

1.1 Hull Vane Development and Relevance to Fuel Economy

The hull vane concept developed from earlier hydrofoil and stern-appendage research, where designers sought to recover energy from the aft flow and reduce stern-wave losses (Uithof et al., 2014). Unlike a bulbous bow, which modifies the bow-wave system, the hull vane acts behind or below the stern and uses the local inflow angle to create a lift vector with a forward component (Bouckaert et al., 2015). This forward component can partly offset the hull's resistance, while the vertical component can improve dynamic trim and reduce stern sinkage (Avala, 2017). This makes the device particularly relevant for vessels operating at moderate to high Froude numbers, where stern-wave formation and running trim have strong influence on effective power.

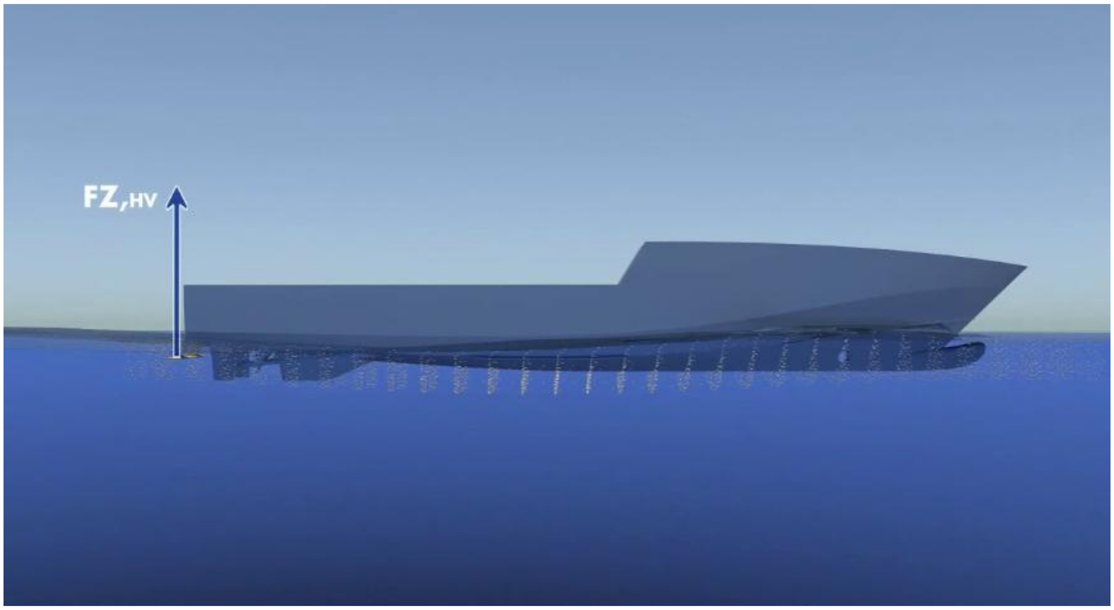

Figure 1: Hull Vane Interaction

Previous studies have reported different levels of resistance and fuel reduction because the device is highly vessel-specific. Uithof et al. (2014) reported that commercial resistance reductions are commonly within the 5–10% range, while larger reductions may occur for suitable hull forms and operating speeds. Bouckaert et al. (2015) and Bouckaert et al. (2016) showed that the hull vane could improve fuel consumption and seakeeping on Holland-class offshore patrol vessels. Uithof et al. (2016a) compared the hull vane with interceptors, trim wedges and ballasting on a 50 m patrol vessel and found that the hull vane produced the highest resistance reduction over much of the tested speed range. Hagemeister et al. (2017) further compared hull vane application with hull lengthening and concluded that a hull vane may provide a more beneficial energy-saving option than simply increasing vessel length (Budiyanto et al., 2020b). Similar conclusions have been supported in later experimental and numerical studies on stern foils and hull vanes (Goutham & Vijayakumar, 2022).

For an offshore surfer vessel, fuel economy is especially important because such vessels often undertake repeated crew-transfer trips, operate under tight schedules and consume considerable fuel at high service speeds (Hannan et al., 2018). The present study's first objective improving the fuel economy of an existing surfer vessel by designing a hull vane tailored to the aft hull form is therefore consistent with the direction of recent hydrodynamic research (Çelik et al., 2019). However, the literature also emphasizes that hull-vane benefits are not automatic; poor placement or unsuitable angle of attack may increase appendage drag and reduce performance (Soma & Vijayakumar, 2023). Therefore, a case-specific design approach using CAD, NURBS refinement, Maxsurf and CFD is necessary.

1.2 CAD Modelling, NURBS Refinement and Aft-Hull Integration

Modern hull-vane design begins with accurate geometric representation of the existing vessel (Yang & Huang, 2016). Traditional ship design relied heavily on lines plans, offsets, body plans and manual fairing (Zhang et al., 2017). Current hydrodynamic optimization requires digital geometry that can be modified, linked to appendages and exported for simulation (Zhu et al., 2024). NURBS-based modelling has become central in ship design because it allows smooth mathematical representation of complex hull surfaces and local shape modification without destroying surface fairness (Walker, 2024; Walker, 2025). In particular, NURBS surfaces are well-suited to hull-form modelling because they can represent curved stern regions, transom details, chine lines, and hydrofoil surfaces with high continuity.

Zhou et al. (2022) noted that NURBS-based parametric ship-hull design supports surface representation, feature-parameter control and geometric deformation. This is important for hull-vane design because the hydrofoil must be matched to the vessel's aft-body flow rather than treated as a detached component. Simulation-based hull optimization requires coordination between geometry modification, hydrodynamic evaluation and optimization algorithms (Zha et al., 2021; Dong et al., 2025). Therefore, the use of advanced CAD followed by Maxsurf Design refinement is justified because it allows the researcher to develop a fair hull-vane model, adjust foil parameters and ensure that the resulting geometry is suitable for resistance and motion analysis.

Recent studies also show growing interest in parametric and data-driven hull modelling. Yu and Wang (2018) used principal component analysis and deep neural networks for hull-form optimization, while Khan et al. (2023), Yonekura et al. (2023), Bagazinski and Ahmed (2023), and Bagazinski and Ahmed (2024) explored generative and diffusion-model approaches for ship-hull generation. Although the present research does not require artificial intelligence-based hull generation, these studies confirm a broader movement toward computational geometry, parametric control and performance-driven hull design. For the present surfer vessel, CAD and NURBS refinement are suitable because the aim is not to create an entirely new vessel but to adapt a hull vane to an existing stern form and assess how it changes resistance, trim and wake behaviour.

1.3 Hull Form Parameters and Resistance Behaviour

Resistance reduction cannot be separated from hull-form parameters. Length, beam, draught, displacement, block coefficient, prismatic coefficient, wetted surface area, transom immersion and stern geometry all influence calm-water resistance and motion behaviour. For high-speed vessels, wave-making resistance and dynamic trim are particularly sensitive to length-displacement ratio, beam-draught ratio, longitudinal centre of buoyancy and stern shape (Papanikolaou, 2014; Babadi et al., 2024). Zha et al (2021), suggest that hull-form optimization often involves trade-offs because a change that reduces resistance at one speed may increase resistance or worsen seakeeping at another speed.

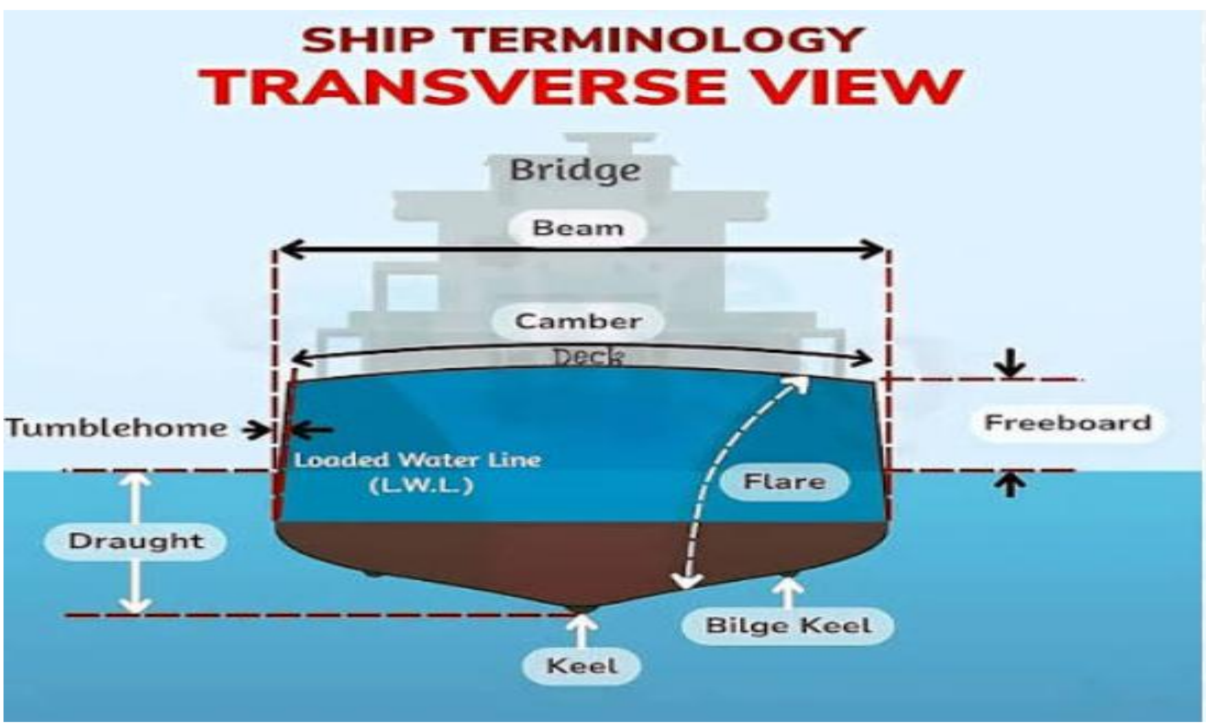

Figure 2: Ship Terminology View

The surfer vessel is expected to operate over a range of speeds rather than at one fixed design speed. Therefore, the hull vane must be optimized across the operational speed range. This aligns with studies showing that hull-vane benefits vary with Froude number. Uithof et al. (2016a) found that hull-vane effectiveness depends strongly on speed and aft-flow condition. Avala (2017) observed that resistance reduction for high-speed round-bilge hulls fitted with hull vanes varies across Froude numbers. Budiyanto et al. (2020a) found that stern-foil performance changed with angle of attack and Froude number. Soma and Vijayakumar (2023) also showed that X and Z positioning of the hull vane affects its hydrodynamic benefit. These studies support the present research objective of targeting resistance reduction across the operating speed range rather than at a single speed point.

Uithof et al (2016a) analysed appendage selection, which considered whether resistance reduction is achieved mainly through trim change, wave suppression or thrust generation. Interceptors and trim wedges influence pressure and trim at the transom, while hull vanes combine trim correction with hydrofoil lift and stern-wave suppression. Thus, the hull vane is suitable for the present study because it directly addresses the surfer vessel’s drag, stern-wave and running-trim challenges.

1.4 CFD Prediction of Stern Flow, Low-Pressure Region and Wake Energy Loss

The second objective of the present study is to optimize motion resistance by achieving a 7% reduction across the operational speed range through creation of a low-pressure region at the stern, suppression of stern waves and minimization of wake energy losses using CFD-predicted results (Shi et al., 2012). CFD is particularly suitable for this objective because it allows detailed examination of pressure distribution, free-surface elevation, wave pattern, wake field, velocity distribution and resistance components (Kleinsorge & Bronsart, 2016). Unlike purely empirical resistance prediction, CFD can show how the hull vane modifies the stern flow and whether the added foil produces net resistance benefit (ITTC, 2024).

The main hydrodynamic mechanism is that the vane interacts with the upward flow behind the hull. When properly positioned, it creates lift whose horizontal component acts in the forward direction (Uithof et al., 2014). At the same time, it redirects flow more horizontally, reduces the stern-wave trough and decreases wave-making losses (Goutham & Vijayakumar, 2022). Ra’uf et al. (2025) demonstrated through SHIPFLOW simulations that hull-vane position and angle of attack strongly influence total resistance, delivered power and propulsive efficiency (Uithof et al., 2016a). This confirms that CFD is not merely a validation tool but a design-optimization tool for selecting the most suitable vane configuration (Bouckaert et al., 2016).

For the present study, CFD should be applied to both the bare hull and the hull-vane configuration under identical speed, displacement and trim assumptions. The target of 7% reduction is realistic when compared with previous findings, but it must be verified through simulation over the operating speed range. Literature shows that stern foils and hull vanes may produce reductions below or above this target depending on geometry and speed (Hannan et al., 2018). A careful CFD workflow must include geometry cleanup, domain definition, free-surface modelling, mesh refinement, turbulence modelling, boundary-condition setting and convergence assessment (ITTC, 2017; Korkmaz et al., 2026).

1.5 Maxsurf Analysis, Trim Optimization and Motion Response

The third objective is to optimize hydrodynamic performance and reduce running trim so that the vessel operates at an optimal angle across different speeds using Maxsurf analysis (Budiyanto et al., 2020a). Running trim is a critical performance indicator for high-speed craft because excessive bow-up trim increases wave-making resistance, while excessive bow-down trim may increase wetted surface, reduce comfort and increase hydrodynamic loading (Suneela et al., 2020). Studies on hull vanes, interceptors and stern foils show that trim correction is one of the main pathways through which stern appendages reduce resistance (Chen et al., 2024).
Maxsurf is relevant because it supports hull modelling, hydrostatic evaluation, resistance

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prediction, powering and motions analysis. In a hull-vane study, Maxsurf can be used to establish baseline resistance and motion behaviour, compare trim across speed points, and evaluate how the appended hull vane affects the vessel's hydrodynamic profile. Ra'uf et al. (2025) used a hull form from the Maxsurf library and validated CFD predictions using Maxsurf and Holtrop–Mennen resistance estimation. This supports the present study's proposed workflow, where Maxsurf analysis provides a bridge between CAD geometry and CFD/MATLAB post-processing.

Seakeeping performance is also important because surfer vessels may operate in offshore environments where pitch, heave and acceleration affect crew comfort and operational safety. Hull-vane studies indicate that the foil may damp pitch motion and reduce added resistance in waves (Bhatia et al., 2023). However, the seakeeping benefit depends on speed, wave condition, vessel form and vane placement. Therefore, the present research should compare pitch, heave, trim and resistance response for the vessel with and without the vane. Such comparison will show whether the hull vane improves both calm-water resistance and motion performance or whether it introduces undesirable trim or motion effects at some speeds.

1.6 Effective Power Estimation and MATLAB-Based Performance Evaluation

The fourth objective is to determine effective power using MATLAB coding. Effective power is the power required to overcome total resistance at a given speed and is expressed as:

$$P_e = R_T \times V$$

Where
P_e is effective power,
R_T is total resistance and
V is vessel speed.

This calculation is central to marine powering because resistance reduction is meaningful only when translated into lower power demand, fuel consumption and operating cost (Larsson & Raven, 2010). Ship resistance and propulsion texts emphasize that effective power links hull hydrodynamics to engine and propulsion requirements (Carlton, 2012). ITTC procedures also emphasize resistance testing, uncertainty control and power prediction as essential components of reliable hydrodynamic performance assessment (ITTC, 2021).

Figure 3: Ship Hull Resistance

MATLAB is useful in this study because it can process resistance outputs from Maxsurf and CFD, calculate effective power for each speed, generate speed-resistance and speed-power curves, and

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compute percentage reductions for the hull-vane vessel relative to the bare hull. This supports objective and repeatable comparison. MATLAB can also be used for interpolation across operational speed points, error checking, numerical plotting and sensitivity analysis. Similar computational post-processing approaches are common in modern ship performance studies, where numerical outputs are converted into design indicators such as resistance coefficient, delivered power, propulsive efficiency and fuel-saving percentage (Korkmaz et al., 2021). For the present surfer vessel, MATLAB-based effective-power calculation should be carried out for the bare hull and the hull-vane hull at each selected speed. The percentage power saving can be obtained as:

Power saving (%) = [(Pe,bare − Pe,hull vane) / Pe,bare] × 100

This will allow the study to evaluate whether the target 7% resistance reduction produces a meaningful reduction in effective power. It will also show whether the hull vane performs better at low, medium or high service speeds. This is important because previous studies show that hull-vane benefits are often speed-dependent (Ra'uf et al., 2025).

1.7 Comparative Analysis of Vessel with and Without Hull Vane

The fifth objective is to compare the performance of the vessel with and without hull vane through resistance model-test results and Maxsurf motion simulation analysis. Comparative evaluation is essential because the hull vane itself introduces appendage drag; therefore, the device is beneficial only when the forward thrust, trim improvement and wave reduction exceed the drag penalty. Literature on hull-vane performance consistently adopts this comparative method, using bare hull results as the benchmark and appended-hull results as the modified case (Budiarto & Firdhaus, 2021).

The comparison should cover total resistance, wave-making resistance, effective power, running trim, sinkage, pitch response and wake structure. In addition, CFD visualization should be used to compare pressure contours and wave profiles. A successful hull-vane configuration should show lower total resistance, smoother stern wake, improved running trim and reduced effective power across the operational speed range. Where motion analysis is included, pitch and heave response should not worsen under typical operating conditions (Babadi et al., 2024).

The comparison also helps identify design trade-offs. A hull vane optimized for one speed may not be optimal at all speeds; an angle of attack that reduces resistance at one condition may increase drag at another; and a foil that improves trim may produce excessive bow-down attitude at higher Froude numbers (Hannan et al., 2018). Therefore, the study should evaluate average performance across the operational speed range rather than selecting a design solely because it performs well at one speed.

II. RESEARCH GAP

Although hull-vane research has expanded, several gaps remain. First, most published studies focus on patrol vessels, yachts, ferries, RoPax vessels, container vessels and generic high-speed displacement hulls, while fewer studies focus specifically on offshore surfer vessels or crew-transfer craft (Ra'uf et al., 2025). Second, many studies evaluate resistance reduction but do not fully integrate CAD modelling, NURBS refinement, Maxsurf analysis, CFD prediction and MATLAB-based effective-power computation into one workflow (Dong et al., 2025).

Third, existing research often emphasizes idealized or newly generated hull forms, while the present study focuses on improving an existing surfer vessel. Retrofitting or adapting a hull vane to an existing stern requires careful consideration of aft geometry, transom flow, structural feasibility and operational profile (Çelik & Danışman, 2023). Fourth, many studies report maximum resistance reduction at selected speeds, but fewer examine a specified reduction target across a defined operational speed range. The present study addresses this by aiming for a 7% reduction across operational speeds, not merely at one design speed.

Finally, there is a need for more studies that connect hydrodynamic improvement to effective power and fuel-economy interpretation. Since fuel economy depends on resistance, power demand and speed profile, MATLAB-based post-processing of Maxsurf and CFD outputs will provide a clearer understanding of whether the proposed hull vane delivers meaningful operational benefit (DeKeyser et al., 2022). This study therefore contributes to the literature by applying an integrated design-analysis-comparison framework to an offshore surfer vessel.

III. SUMMARY OF LITERATURE REVIEW

The reviewed literature shows that hull vanes and stern foils can reduce resistance, improve trim, suppress stern waves and reduce effective power when properly designed and positioned. However, their performance is highly dependent on vessel form, Froude number, foil geometry, longitudinal position, vertical depth and angle of attack. CAD and NURBS-based modelling provide the geometric foundation for accurate hull-vane design, while Maxsurf supports hull refinement, resistance prediction and motion analysis. CFD enables detailed prediction of stern pressure field, wave pattern and wake-energy loss, while MATLAB allows effective-power calculation and performance comparison. Therefore, the proposed study is justified because it integrates these tools to improve the fuel economy and hydrodynamic performance of an existing surfer vessel and compares the bare hull with the hull-vane design using resistance and motion simulation results.

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