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Research Article

Hydrodynamic investigation of wet swimming platform problem for semi-planning motor yachts

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ABSTRACT

One of the main optimization problems for the performance and comfort of yachts is the wet swimming platform problem, also known as the rooster-tail phenomena .And this research presents an investigation using Computational Fluid Dynamics (CFD) method for a real case of an 88 ft. semi-planning motor yacht hull form that encountered this phenomena. First of all, the original hull form was analyzed to define the problem at cruising and maximum speeds, 14 knots, and 24 knots respectively. To solve this problem, modifications to the stern form of the hull were made in a two-step iteration. Initially, the size of the current interceptor was increased with a tunnel wedge. Results of the CFD analysis show that this modification eliminated the wet platform problem and increased the top speed of the yacht. Since the applicability of the wedge to mount is complex and costly, a second analysis with only enlarged interceptors was performed. As a result, the wet platform problem is solved, however, the resistance reduction was slightly lower.

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INTRODUCTION

As naval architecture knowledge advances, optimization and improvement levels are also increasing, especially in the pleasure craft industry, where both performance and comfort demands are at their utmost limits. As a result of the high speed and comfort demand for yachts, different hull form types were developed such as planing, and semi-planing hull types, which are the main interests of customers and designers in the pleasure craft industry. The most important advantage of the semi-planing hull form is that it can reach high speeds with relatively low engine power due to the geometrical features of the form, as well as providing high comfort. The underwater behavior of these hulls is directly affected by pressure distribution and trim angle. The trim angle of the hull is a performance indicator and also a decisive factor for the comfort level of the yacht.

In this study, as a specific problem, the wetness of the aft swimming platform of a motor yacht, known as the rooster-tail phenomena, is investigated both performance and comfort-wise. The wet platform can be explained by the ingression of water to the transom or to swimming platforms, which is caused by the hydrodynamic behavior of the hull. As the ingression of water creates an uncomfortable

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habitat in a yacht, it is also an indication of excessive drag force affecting the yacht.

Adjusting trim angle is the main criteria to eliminate the chance of this phenomenon occurring and could be done by means of creating an extra force to lift the platform out of water or modifying underwater hull form to achieve waveforms that leave the platform dry. Increasing the hydrodynamic performance of yachts will need hull form optimization studies and this is not suitable for existing yachts. Besides, by using trim regulating devices, such as interceptors, the trim angle of the yacht can be adjusted to leave the platform dry, however, it may have a negative effect on seakeeping properties, thus reducing the comfort of the yacht. So, in this study, various interceptor arrangements and additional geometries were investigated to find an optimal solution for this problem on a hull form of an existing motor yacht.

LITERATURE REVIEW

Hydrodynamic performance investigation and optimization of planning and semi-planning hulls are studied widely in the literature. There are also studies on trim regulators, such as interceptor, trim tab, with a relatively small number. Martin[1] tried to adapt a mathematical model for optimizing heave and pitch motions. Also, numerical models are used to understand planing behavior of crafts. One method for optimizing heave and pitch motions is to use lift producers like interceptors, trim tabs, and wedges. Mansoori and Fernandes [2] performed a numerical study and verified that heave and pitch motions can be controlled by interceptors. De Luca [3] showed that if the interceptor blade height extension percentage is around 0.15% and 0.40% LWL, interceptors can create positive pressure and change trim. Avci and Barlas [4] researched interceptors' efficiency and states that for Froude numbers around 0.85 and 1.0 interceptors can decrease drag resistance to 6%. Brizzolara and Villa [5] numerically investigated altitude control of a high-speed vessel in various conditions by using lift creating devices such as trim tabs and flaps, study showed that flaps were better at lower deflection angles, and for higher deflection angles interceptors were more useful.

De Luca and Pensa (2017) [6] created setups for model tests to investigate improving the resistance performance of new systematic series of planning hull models. All model results, wetted surface area, waterline length, dynamic trim, and resistance data were added to the literature for validation of numerical simulations.

Savitsky 2003 [7] shared information about operational characteristics of a 50 knot top speed hull form and his study was one of the first in the literature to investigate small extensions of the lower surface of the aft transom as "stern flaps" to reduce resistance. Research also prioritized the height extended from transom means of interceptors, flaps, and wedges to determine the appropriate height. Alexander H, Day N and Christopher [8], Schlichting H. [9] concluded extension height should be within the boundary layer. Mansoori et al. [10] also studied the length of the wedge. Savitsky and Brown [11] investigated wedge types and hydrodynamic effects on a high-speed craft and developed a formula including the angle and length of the wedges.

Effects of wedges and interceptors simultaneous usage were also studied in the literature, for instance by Tsai and Hwang [12], Jang et al. [13] included underwater appendages to this concept to investigate lift and drag force with transom extensions and shared findings of a numerical study.

METHODOLOGY

Original Hull Geometry and Stern Modifications

An 88 ft. semi-planing motor yacht hull form, that has encountered wet swimming platform problem, was used for the analyses as a real case study. All analyzes have been performed at real size. The geometry of the hull and geometrical properties are given in Figure 1 and Table 1, respectively. Firstly, the original hull form was analyzed to define the problem at cruising and maximum speeds, 14 knots, and 24 knots respectively.

The results were studied and modifications in the tunnel and on the interceptors were made to avoid the wet platform. The center 30 mm depth 750 mm length interceptors were swapped to 2 x 50 mm depth 750 mm length interceptors and a small addition to the hull bottom was added in order to maximize the efficiency of the interceptors as shown in Figure 2.

A wedge was designed in the tunnel to generate a lift force to compensate the squat effect (low pressure suction effect in the aft due to rocker), as shown in Figure 2(c).

As new interceptors were bigger in dimensions, edges of interceptors filled with wedges on hull to increase interceptor effectiveness. Wedges have been formed to match the surface form of the hull to minimize drag forces. Interceptor edge wedges are shown red in Figure 3.

Due to application of the wedge, process required a refit process. In the second study, only enlarged interceptors (2x75 mm depth at the keel) were thought, as shown in Figure 4.

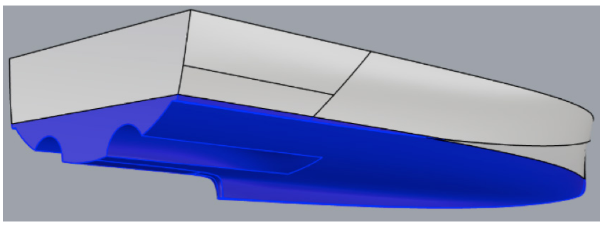

Figure 1. Semi-planing hull form of 88 ft. motor yacht with propeller tunnels.

Table 1. General Properties of the Hull

Properties	Abb.	Value	Units
Length Overall	L_{oa}	26.81	m
Length Waterline	L_{wl}	23.95	m
Breadth, max	B_{max}	7.1	m
Draught	T	1.84 m	m
Depth	D	3.83 m	m
Displacement	Δ	110 tons	tons
Block coefficient	c_B	0.33	
Longitudinal center of gravity	LCG	9.8	m (from AP)
Vertical center of gravity	VCG	2.5	m (from BL)
Cruising speed	V_{cr}	14	knots
Maximum speed	V_{max}	24	knots

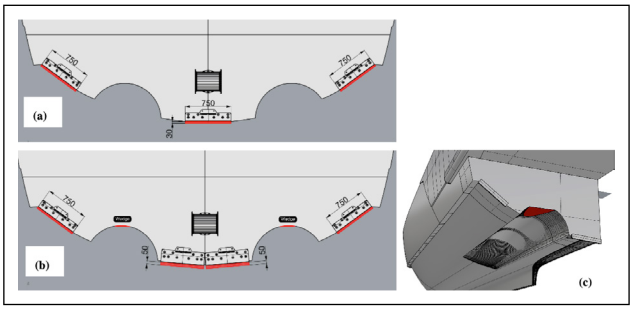

Figure 2. (a) Original interceptor setup, **(b)** Center 2 x 50 mm depth interceptor + Tunnel Wedge setup, **(c)** Tunnel wedge.

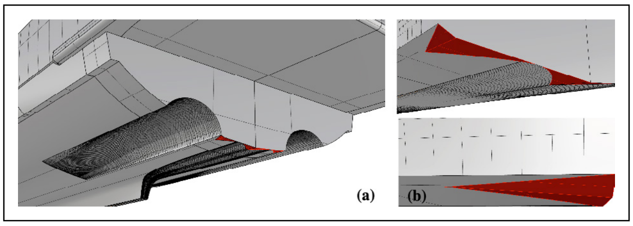

Figure 3. (a) Overview of added wedges (in red) to maximize interceptor performance, **(b)** Close-up views of added wedges.

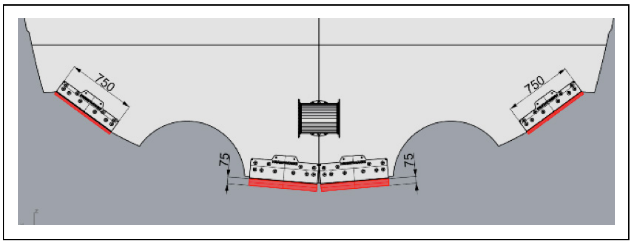

Figure 4. Center 2 x 75 mm depth interceptor setup.

Mathematical Formulation

To analyze the hydrodynamic performance of the hull form in a turbulent flow, a commercial CFD software based on RANS equations have been used. The governing equations are the RANS equations and the continuity equation for mean velocity of the unsteady, three-dimensional, incompressible flow. The continuity equation and momentum equations in Cartesian coordinates can be given as;

$$\frac{\partial U_i}{\partial x_i} = 0 \tag{1}$$

For the continuity;

$$\frac{\partial U_i}{\partial t} + \frac{\partial (U_i U_j)}{\partial x_j} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\nu\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\right] - \frac{\partial u_i' u_j'}{\partial x_j} \tag{2}$$

for the momentum equations, where Ui and ui′ express the mean and fluctuation velocity components in the direction of the Cartesian coordinate xi, P the mean pressure, ρ the density and ′ the kinematic viscosity.

The well-known k-′ model has been used to simulate the turbulent flows. The Reynolds stress tensor is then calculated by the Boussinesq model;

$$\mu_i' \mu_j' = -\nu_t\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right) + \frac{2}{3}\delta_{ij} k \tag{3}$$

The eddy viscosity vt is expressed as vt =C, k2, where C, is an empirical constant (C, =0.09), k the turbulent kinetic energy and ′ the dissipation rate of k. The use of standart k-′ two equation turbulence model formulation is reasonably robust, reliable near solid boundaries and recirculation regions like ship boundary layers. The pressure field is solved by using the well-known SIMPLE algorithm [14].

Computational Domain

CFD models using fully viscous three dimensional formulations are typically of the finite volume formulation, which need the computational domain to be discretized into a finite number of three dimensional volumes.

In this study, an unstructured hexahedral mesh was generated to create the solution domain. An unstructured hexahedral grid is used to permit for flexibility in grid generation and local mesh refinement for free surface waves. In general, grid points are gathered around the calm water plane in the vertical range of expected wave heights to provide adequate resolution at the free surface interface. It should be noticed that for the viscous flow simulation, the prismatic layer mesh is applied around the hull. Local mesh refinement is achieved by means of volumetric controls of predefined geometrical shapes.

In order to resolve the boundary layer accurately and provide desired levels of wall y+ prismatic cells are placed along the hull surface. The stretching factor of prism layers is 1.5. As a practical application technique, the turbulence model approach uses empirically developed velocity profiles, which is widely known as wall-function, near the no-slip wall according to the dimensionless wall y+ values. In the present study, y+ values are set to be in the range of 30-300 for all the analyses.

The volume of control was selected to be of rectangular prism shape. The height of the computational domain is 2.0 LWL and its width is taken to be of 1.5 LWL due to the symmetry of the problem. The domain inlet boundary is at a distance of 2.0 LWL ahead of the ship, while the outlet boundary is located at 3.0 LWL from the ship stern. The dimensions of the computational domain satisfies ITTC procedure. General view of computational domain and the mesh structure can be seen in Figure 5.

Uniform flow condition has been chosen at the upstream and a hydrostatic pressure profile is chosen for the outflow. The center plane is specified as a symmetry plane and the hull surface as a no-slip wall. The top surface, bottom and far-field boundaries are modeled as free slip walls. An initial velocity boundary condition is used at the beginning of the flow domain. The unsteady flow around the hull is computed at using 2 M cells grid system. The surface mesh on hull surface was given in Figure 6.

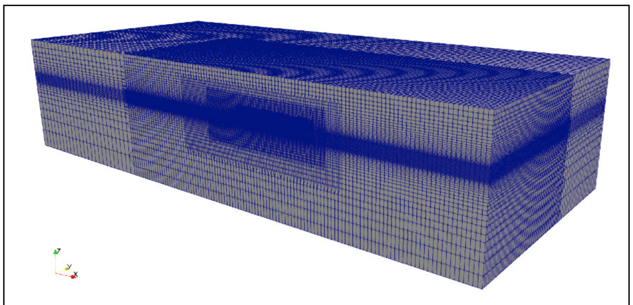

Figure 5. The general view of the computational domain and mesh structure.

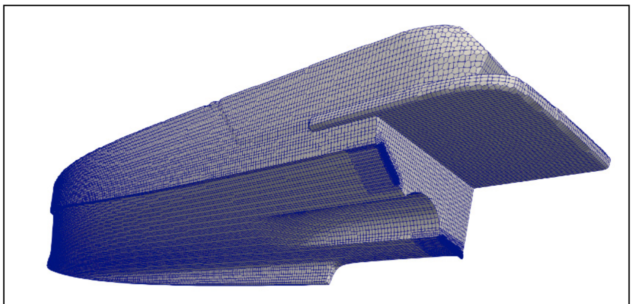

Figure 6. Surface mesh on hull.

Table 2. Analyze Scenarios

#	Interceptor size	Tunnel wedge	Speed
A0-0	-	-	14 knots
A0-1	-	-	24 knots
A1-0	50 mm	+	14 knots
A1-1	50 mm	+	24 knots
A2-0	75 mm	-	14 knots
A2-1	75 mm	-	24 knots

RESULTS

Analyze Scenarios

As a result of the CFD analysis of the original hull form, a large rooster tail was observed just behind the hull creating wetness on the swimming platform. In order to solve this problem, two alternative solutions at two different speeds were considered and analyzed. Analysis scenarios are given in Table 2 below.

Results of the Scenario A1-0

The modifications eliminated this problem completely by delaying the rooster tail top, resulting in a dry platform. But rooster tail is still big due to the squat effect of the hull which is a result of the high rocker hull design. Figure 7 shows the rooster tail on the original hull (left/green) and on the modified hull (right/purple). The color scheme represents wave heights.

The improvement can also be seen comparatively through the fish-eye view, Figure 8. In the Figure, the red color indicates water, and the blue color indicates air. As can be seen from the Figure, the swimming platform is dry after the modification.

From a performance point of view, lifting the stern has a positive effect on overall resistance and the changes resulted in a resistance reduction of 7.9%.

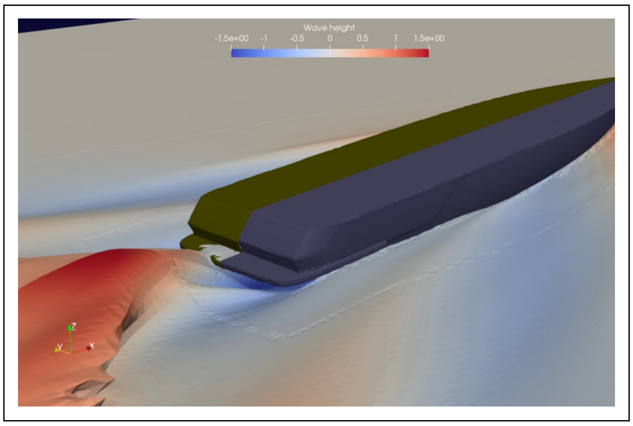

Figure 7. Wave height distribution on the free surface @14 knots: Original hull (left/green), modified hull (right/purple).

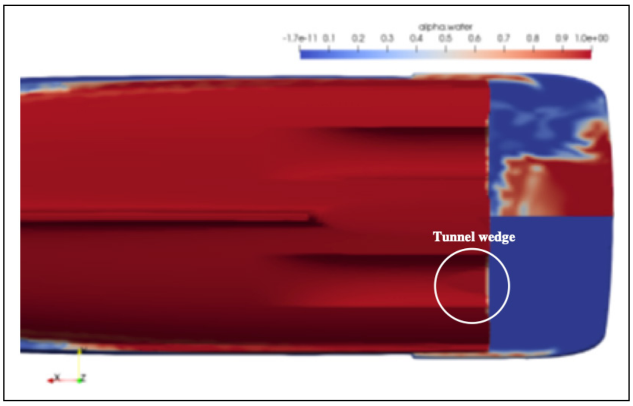

Figure 8. Wetted area: Original hull (top) and modified hull (bottom).

Results of the Scenario A1-1

At 24 knots, it was investigated that, as a result of the modifications the trim angle was reduced, thus the hydrodynamic performance have been improved. It was determined that the resistance was reduced 7.0% (Fig. 9).

Results of the Scenario A2-0

A new analysis was made by increasing the size of the interceptor, considering that no modifications would be applied to the hull form. The wedge was not applied and the interceptor depth was increased to 75mm, compensating for the loss of lift. Figure 10 shows the rooster tail on the original hull (left/green) and on the modified hull (right/purple).

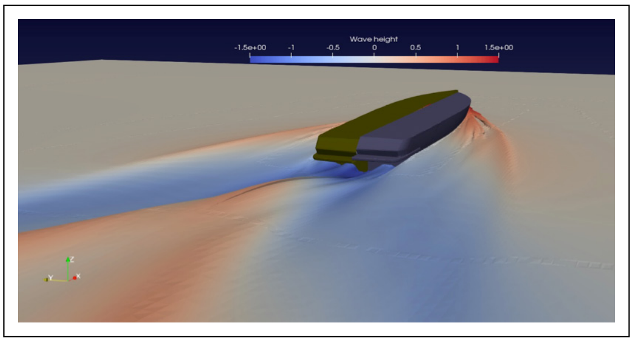

Figure 9. Wave height distribution on the free surface @24 knots: Original hull (left/green), modified hull (right/purple).

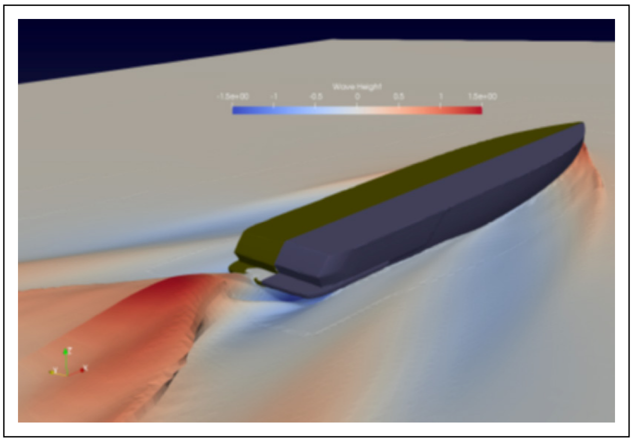

Figure 10. Wave height distribution on the free surface @14 knots: Original hull (left/green), modified hull (right/purple).

Similar to the first version, it was observed that the rooster tail behind the hull moved away from the stern and the swimming platform remained dry. However, there was a reduction in the improvement in the overall resistance of the hull in this version (Fig. 11).

Results of the Scenario A2-1

At 24kn, the performance was better than the original, yet slightly worse than the first study. The resistance was reduced 6,1%. As can be seen from the Figure 12, swimming platform still remained dry.

The results obtained in the analyzed scenarios are given in the table below in comparison with the analysis results of the existing hull form Table 3.

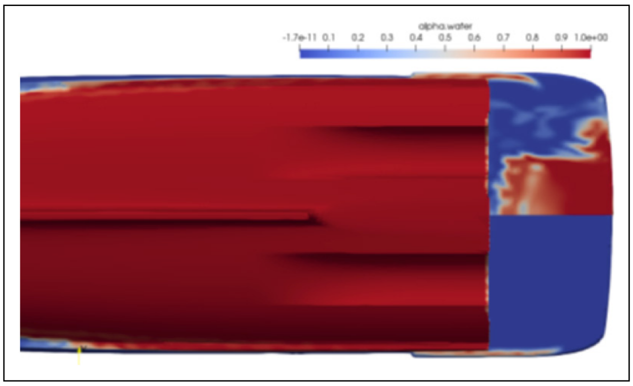

Figure 11. Wetted area: Original hull (top) and modified hull (bottom).

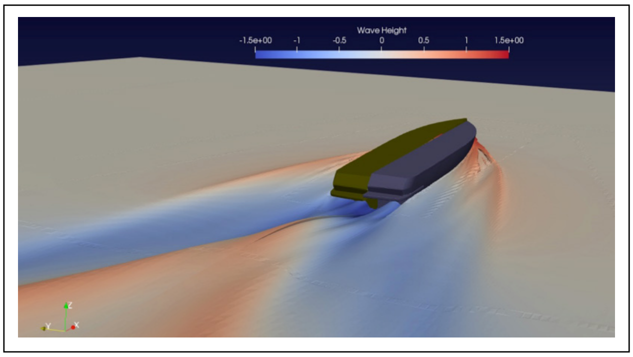

Figure 12. Wave height distribution on the free surface @24 knots: Original hull (left/green), modified hull (right/purple).

Table 3. Resistance Improvement Compared to Original Hull

#	HULL VERSION	14 knots	24 knots
A0	Original	Ref	Ref
A1	50 mm interceptors + tunnel wedge	7.9%	7.0%
A2	75 mm interceptors	7.0%	6.1%

CONCLUSION

In this paper, a real problem observed in an 88 ft. semi-planning motor yacht is discussed and the methods considered to solve the problem are analyzed. First of all, the original hull form was analyzed and the rooster tail formed behind the boat and thus the wetting of the swimming platform were observed. To solve this problem, two alternative solutions were considered and both scenarios were analyzed at cruising and max speeds. Initially, an increased interceptor setup (2x50 mm depth at the keel) was applied with a tunnel wedge. This study eliminated the wet platform issue, and increased the top speed. However due to application of the wedge need a refit process a second study with only enlarged interceptors (2x75 mm depth at the keel) were simulated.

As a result of the analyzes, it was determined that both alternatives eliminate the observed problem. However, it was determined that the improvement in hull resistance decreased somewhat in the method proposed as the 2nd alternative. Which of the proposed alternatives will be implemented should be decided by considering the improvements it brings, as well as the difficulty of implementation and cost.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work

DATA AVAILABILITY STATEMENT

The published publication includes all graphics and data collected or developed during the study.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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