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ASSESSMENT OF MOTOR YACHT HYDRODYNAMIC PERFORMANCE

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ABSTRACT

This study presents a comprehensive Computational Fluid Dynamics (CFD) analysis of an 18-meter motor yacht featuring a trawler hull design with a swim platform. The investigation explores the hydrodynamic performance of the yacht across three distinct drafts and six varying speeds.

Keywords: CFD, RANSE, motor yacht.

1. INTRODUCTION

The pleasure craft industry is driven by the desire to create unique and custom-made vessels that meet the high expectations of their owners. These expectations can range from top-notch performance in terms of speed to ultimate interior design, quality, and comfort for extended navigation at moderate speeds. While the interior and exterior design of these vessels play a major role in pleasing the buyer's eyes, other engineering tasks must be taken into account to integrate these requirements and create a high-end product. As the industry continues to flourish and improve with each passing year, it is essential to understand the importance of hydrodynamic performance in designing these vessels.

Studying the hydrodynamic performance of a motor yacht is necessary to ensure that it can achieve the desired speed while consuming less engine power. This not only allows the vessel to travel longer distances but also reduces noise and vibration [1], ensuring a comfortable experience on board.

This article embarks on an ambitious exploration, endeavoring to comprehensively investigate the intricate fluid dynamics enveloping a motor yacht distinguished by its 18 meters trawler hull shape. The study delves into the profound influence of varying the draft, a critical parameter intricately

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linked with considerations of interior quality and weight distribution on board.

Through systematic variations in both draft and speed of the yacht's hull at full scale, this study aims to observe the interaction of its distinctive hull features with the surrounding fluid.

2. Motor Yacht hull particularities

Tailored for a semi-displacement navigation regime, the motor yacht's hull shape aligns with the characteristics of a trawler. Therefore, the table below provides an overview of its dimensions.

Tab. 1. Hull dimensions

L_{OA}	18.25	m
L_{WA}	17.10	m
B_{OA}	5.35	m
B_{WA}	5.14	m
T	1.20	m
∇	52.38	m^3

To comprehensively grasp the hydrodynamic performance of the hull geometry, various analysis scenarios were taken into consideration. Therefore, the hull underwent a systematic examination across three draft variations, 0.8, 1.0 and 1.2 m illustrated in Figure 1, and six different speeds ranging from 8 to 13 knots.

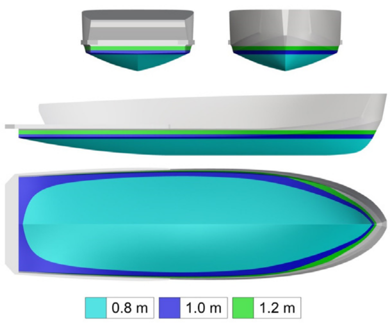

Fig. 1. Hull geometry and drafts

One notable feature of the hull is the presence of a swim platform positioned in the transom. As revealed in the results regarding the chapter of this study case, this characteristic has the potential to significantly impact overall performance through its interaction with the generated wake and waves.

For a better understanding of the hull geometry particularities, the measured displacement and wetted area are tabulated in Table 2.

Tab. 2. Displacement and wetted area

T [m]	*Displacement [m3]*	*Wetted area [m²]*
0.8	23.28	66.66
1.0	37.31	82.63
1.2	52.38	91.48

3. Numerical approach

The analysis of the fluid flow around the ship's hull was meticulously executed, employing the commercial software Cadence/Fine Marine. This sophisticated program's solver integrates the Reynolds-Averaged Navier-Stokes (RANS) equations through the finite volume method, involving a spatial discretization approach to the transport equations. To model Reynolds stresses, the k-ω SST turbulence model was adeptly employed, complemented by the incorporation of wall functions for enhanced accuracy. The turbulence model incorporates components derived from existing two equations models, as outlined in [2], [3]. The treatment of the free surface is rooted in a robust "surface capturing" method, utilizing the Volume of Fluid (VOF) technique [4], [5]. This comprehensive approach ensures a thorough examination of the hydrodynamics, allowing for precise insights into the fluid dynamics surrounding the ship's hull under various conditions.

To increase the numerical solution accuracy, the analysis simulation domain was scaled as follows: 3 x Lpp aft, 1 x Lpp fore, 1.5 x Lpp side, 0.5 x Lpp top and 1.5 x Lpp for bottom. In Figure 2 is given an illustrated form of the domain scale. Another factor

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which increases the accuracy of the solution is the domain discretization. The analysis cells were defined as a hexahedral shape, with a grid topology of H-H type using the grid generator HEXPRESS^{TM} from Cadence – Fine Marine software package.

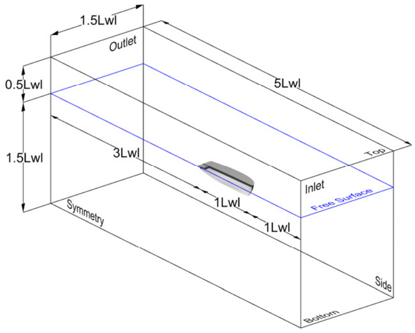

Fig. 2. Domain size

With the purpose of having a good quality of wave and wake development, the free surface around the hull had a higher level of refinement. The Figures 3 and 4 are sections of domain which shows the cell local refinement and distribution.

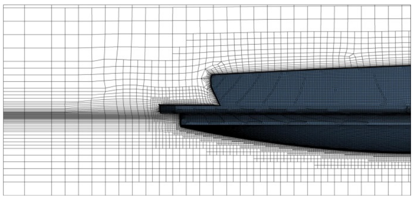

Fig. 3. Mesh refinement - aft

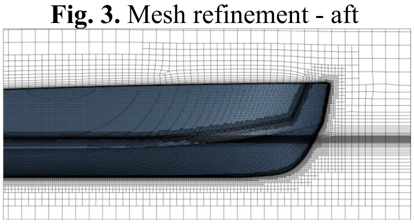

Fig. 4. Mesh refinement - fore

4. Results

The motor yacht hull geometry was analyzed for a total of 18 cases, corresponding to drafts of 0.8m, 1.0m and 1.2m. The speed for each draft ranged from 8 to 13 knots, with a step of 1 knot for each simulation case.

In Figure 5 is presented the fluid domain, development in contact with the hull for the configuration of the draft 0.8m and the given six speeds.

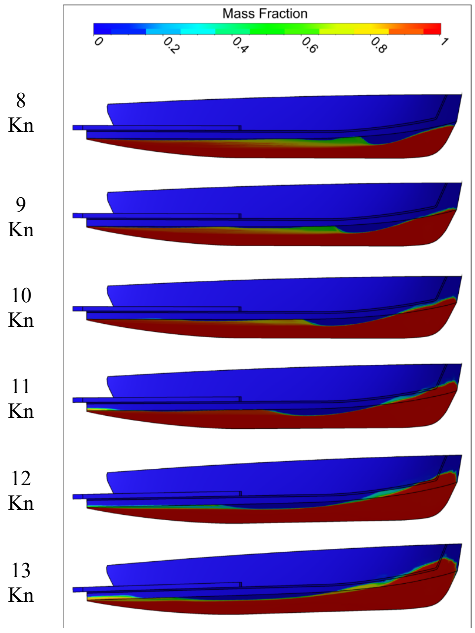

Fig. 5. Mass fraction - draft 0.8m

Viewing the bow, an increase in speed is concomitant with a discernible rise in the crest of the generated bow wave. Furthermore, the progressive change in trim angle is observable as the fluid ascends the bow of the ship, giving rise to an upward force. Additionally, looking in Table 4, during the decrease in trim angle from the speed of 11 knots till the maximum speed, Figure 5 depicts the transom becoming immersed.

Tab. 4. Total resistance, sinkage, and trim for draft 0.8m

v [Kn]	*Fn*	*Fn ∇*	*Rt [kN]*	*z [m]*	*θ [°]*
8	0.32	0.77	4.17	1.62	0.16
9	0.36	0.87	6.34	1.60	0.17
10	0.40	0.97	8.99	1.58	0.11
11	0.44	1.06	12.72	1.56	-0.34
12	0.48	1.16	15.42	1.56	-1.10
13	0.52	1.26	17.40	1.56	-1.76

Shifting the observation point to the development of the free surface from Figure 6, one can notice that toward the aft hull, the wave crest is characterized by height and narrowness at the speed of 8 knots. As the transom protrudes into the water, it widens, concurrently reducing its height. Moreover, along the ship length, the through of the wave attains full development at the speed of 13 knots.

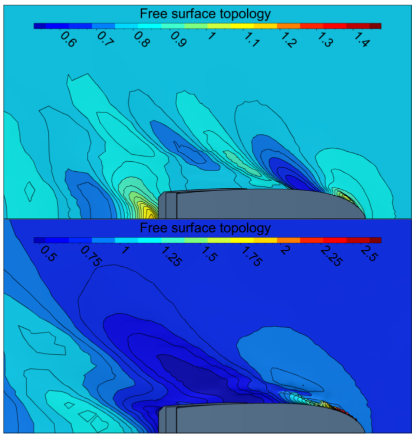

Fig. 6. Free surface - draft 0.8m

Continuing with the next six analysis datasets for the hull draft of 1.0m, in Figure 7 are layered the fluid domain interactions with the geometry for each speed, and in Table 4 are tabulated the total resistance, sinkage and trim angle.

Tab. 4. Total resistance, sinkage, and trim for draft 1.0m

v [Kn]	Fn	Fn ∇	Rt [kN]	z [m]	θ [°]
8	0.31	0.72	6.20	1.60	0.17
9	0.35	0.80	9.70	1.58	0.14
10	0.39	0.89	13.84	1.55	0.12
11	0.43	0.98	20.20	1.52	-0.37
12	0.47	1.07	26.94	1.51	-1.24
13	0.51	1.16	31.44	1.51	-2.14

Analyzing the geometry and the free surface for this draft, the transom is partially submerged. Comparable to the dataset with a 0.8m draft, the bow generates a prominent wave crest that extends over a larger area. With the augmentation of speed, the wave crest produced in the aft section of the model extend slightly above the hard chine.

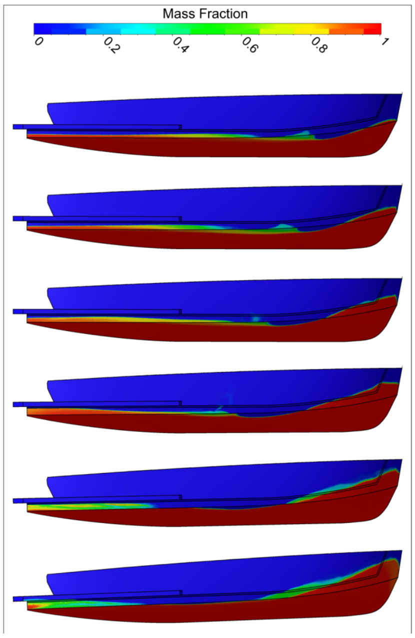

Fig. 7. Mass fraction – draft 1.0m

At maximum speed, in Figure 7 and in Figure 8, it is noticeable that the water makes contact with the swim platform. A closer examination of the swim platform discloses that its side longitudinal strip remains free of water until reaching a speed of 13 knots. Additionally, the chine in the first third length of the ship redirects the flow of water to outside.

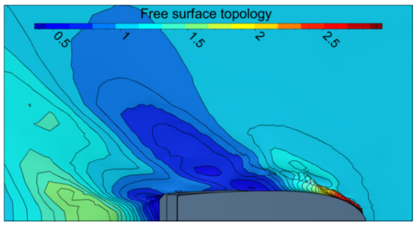

Fig. 8. Free surface – draft 1.0m – 13 knots

For the last six analysis datasets calculated for the higher draft of 1.2m, the fluid

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domain interaction with the hull is represented in Figure 9.

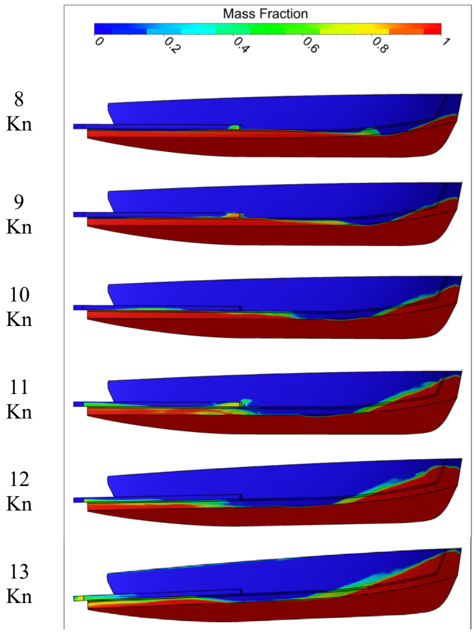

Fig. 9. Mass fraction – draft 1.2m

For this draft, the front wave is much more developed, having an increased value of crest height and a larger contact area when compared with the last two datasets corresponding to draft 0.8 and 1.0m.

Tab. 5. Total resistance, sinkage, and trim for draft 1.2 m

v [kn]	*Fn*	*Fn ∇*	*Rt [kN]*	*z [m]*	*θ [°]*
8	0.32	0.68	8.08	1.59	0.23
9	0.36	0.76	13.39	1.56	0.29
10	0.40	0.85	19.95	1.53	0.34
11	0.44	0.93	28.26	1.49	0.10
12	0.48	1.02	40.44	1.46	-1.19
13	0.52	1.10	49.53	1.45	-2.39

With a draft of 1.2m, the model transom is predominantly submerged, bringing the swim platform near in close proximity to the free surface. Even slight adjustments in trim could result in its submersion, consequently expanding the wetted area and changing the aft free surface topology, presented in Figure 10.

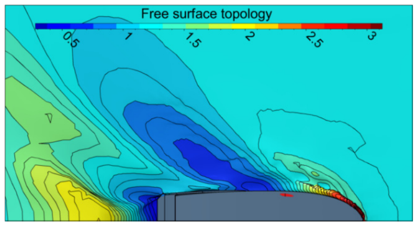

Fig. 10. Free surface – draft 1.2m – 13 knots

Also, Figure 10 revealed that the swim platform is subjected to green water phenomena.

Contrary to the earlier datasets where the swim platform's side longitudinal strip remained predominantly dry, this scenario with the specified draft rendered that condition unattainable. For the speeds of 8 and 9 knots, a subtle splash is noticeable at the fore end of the strip, a consequence of the succeeding wave crest. With the escalating speed and the corresponding increase in wavelength, the wetted surface translates towards the aft section of the strip. Eventually, at a speed of 13 knots, the aft end of the platform becomes substantially wet.

For a thorough analysis of the cases subjected to this study, bringing the values for total resistance in Figure 11, sinkage in Figure 12 and trim in Figure 13, altogether gave more insights into the hydrodynamic performance of the geometry.

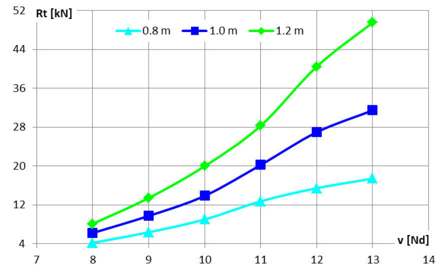

Fig. 11. Comparison between the total resistance curves

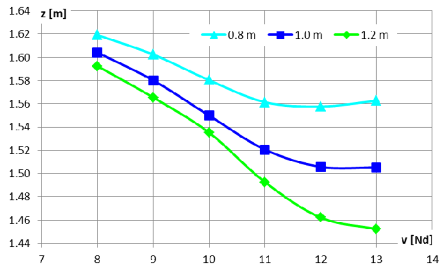

Fig. 12. Comparison between the sinkage curves

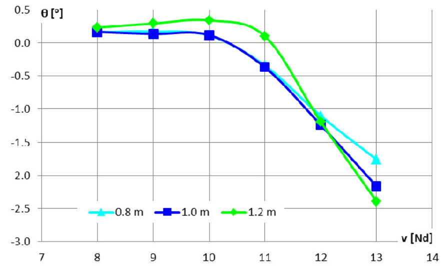

Fig. 13. Comparison between the trim angle curves

Throughout the analysis of the total resistance, a notable observation arises when examining the curve for the case with a draft of 0.8m. A distinctive change in curvature occurs at the speed of 11 knots, as depicted in Figure 5, coinciding with the moment when the transom begins to slightly submerge. For the 1.0m draft, speeds of 12 and 13 knots deviate from the expected curve trajectory, aligning with the water flow modeled by the chine in the aft first 1/3 length of the hull. Furthermore, in all three cases of the drafts, Froude values nearing 0.5 and beyond indicate a transition in the navigation regime. This observation is substantiated by the ship altering its trim and sinkage values, initiating at a speed of 11 knots. In the third draft case, marked by greater displacement and the swim platform near the free surface, the transition in trim values is delayed when compared to the other two scenarios. However, this delay results in a more abrupt change when it does occur.

5. CONCLUDING REMARKS

The article presented a comprehensive overview of a Computational Fluid Dynamics (CFD) study, conducted on a motor yacht geometry characterized by a trawler hull design. The investigation encompassed three different drafts and six speeds.

The geometry of the yacht was examined through the CFD analysis, unraveling details of its fluid domain. The study particularly focused on the free surface topology, elucidating the effects of the swim platform on the surrounding fluid dynamics. This insight into the interaction between the yacht's geometry and the free surface provides valuable knowledge for optimizing design and functionality.

Furthermore, the CFD study identified critical points where the hull undergoes a transition to another navigation regime, offering practical insights into the performance of motor yachts with trawler hull characteristics.

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