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Parameter study for enhancing the speed of a high-speed craft prototype with adequate maneuverability

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ABSTRACT

The demand for high-speed crafts has grown rapidly due to their strategic importance and quick response capabilities. Governments prioritize their development through research and industry advancements. Designing a high-speed craft exceeding 60 knots requires significant time and cost. This study identifies key factors for optimizing speed and maneuverability through hull modifications, chine positions, indentations, propulsion systems, and initial trim adjustments. The sample craft was 3D scanned, and simulations were conducted using MAXSURF. The hull was modified and uniformly adjusted, followed by hydrostatic and hydrodynamic calculations.
Findings indicate that achieving speeds above 60 knots require a minimum initial trim of 0.4° at the transom. Proper hull line adjustments and equipment placement were essential. Additionally, with a safety factor of 1.25, the craft requires approximately 600 horsepower for the desired speed. These optimizations ensure efficient performance while minimizing costs.

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1. Introduction

Today, with the advancement of technology, the need for time in societies has increased. To meet this need, the pace of life has accelerated, leading to further progress in human life. The maritime transportation industry is no exception to this rule, and significant advancements have been made in the design and construction of high-speed vessels. In this study, based on this perceived need, attention is focused on examining the parameters affecting the increase in speed of a high-speed craft prototype with adequate maneuverability. The ultimate goal of this article is to achieve the maximum speed with the minimum length of the craft, without compromising its stability and maneuverability. This is to be accomplished by utilizing the existing hull, conducting hardware and software analyses, and leveraging the laws and relationships of hydrodynamics and hydrostatics governing the model hull. The aim is to attain the highest speed at the lowest cost, ensuring that no compromise is made on the craft's equilibrium and maneuverability.

The study of planning surfaces and hydrodynamic evaluations has been a subject of extensive research and experimentation over several decades. Brown (1971) conducted both experimental and theoretical investigations into planning surfaces with trim flaps, aiming to understand their behavior in different conditions, which was documented in the Davidson Laboratory Technical Report. Building upon this foundational work, Savitsky and Brown (1975) outlined procedures for hydrodynamic evaluation of planning hulls in various water conditions, presenting their findings in the Proceedings of the Hampton Road Section of SNAME. Similarly, Dawson and Blount (2002) explored trim control mechanisms, discussing their implications in Professional Boat Builder. Further research delved into specific aspects of planning surfaces' hydrodynamics. Bizzolara (2003) analyzed interceptors using Computational Fluid Dynamics (CDF) methods, presented at the 7th International Conference on Fast Sea Transportation. Molini and Brizzolara (2005) conducted a fundamental study on the hydrodynamics of interceptors, which was shared at the International Conference on Maritime Research and Transportation. Advancements in computational methods enabled detailed analysis, as seen in Villa and Brizzolara's (2009) systematic CFD analysis of flaps/interceptors' hydrodynamic performance presented at Fast 2009. Steen et al. (2009) investigated the performance of planning craft with mid-mounted interceptors in Greece. In the pursuit of optimizing high-speed craft performance, Hansvic (2005) explored the resistance of planning catamarans with steps in his Master's thesis. Subsequently, Hansvic and Steen (2006) discussed the utilization of interceptors and stepped hulls to enhance the performance of high-speed planning catamarans at the International Conference on High-Speed Craft. Theoretical frameworks were also explored, such as Fridman's (1969) work on the application of interceptors on high-speed ships, presented at Fast 2007 in Shanghai. Additionally, foundational studies like Chambliss and Boyd's (1953) examination of V-shaped prismatic surfaces' planning characteristics contributed to understanding basic principles. Over the years, research extended to various aspects of planning surfaces' hydrodynamics, including turbulence stimulation (Savitsky & Ross, 1952), wetted area analysis (Savirsky & Neidlinger, 1954), and stability limits (Sottorf, 1949). Additionally, studies focused on related topics like porpoising characteristics (Davidson & Locker, 1943) and the effect of deadrise (Benson, 1942) enriched the understanding of planning hull dynamics. Recent investigations encompassed a wide range of applications, from ship powering performance (Karafitah & Fisher, 1987) to spray rails and transverse steps effects (Teimouri, 2009), showcasing the diverse interests within the field. Specifically, studies by Cuasanelli and Cave (1993) and Cuasanelli and Karafiath (2001) investigated the effect of stern flaps on powering performance, showcasing advancements in design and application techniques. Tsai and Huang (2003) contributed to the understanding of interceptor effects on high-speed craft, providing insights through empirical studies. Furthermore, Karimi (2006) proposed hydrodynamic quality improvement techniques for high-speed planning crafts, emphasizing the continuous pursuit of enhancing performance in the marine industry. This aligns with the efforts of organizations like KSRI, as evidenced by their reports on new systems for ship motion stabilization and speed increase based on interceptors (KSRI, year not provided, 2004). Moreover, advancements in understanding planning surfaces have been facilitated by theoretical frameworks like boundary layer theory (Schlichting, 1979), which provided a deeper understanding of flow dynamics near hull surfaces. Practical applications of such knowledge were evident in studies like Wang's (1980) investigation into the wedge effect on planning hulls. Interdisciplinary research has also been instrumental in advancing the field. Day and Cooper (2011) conducted an experimental study of interceptors for drag reduction on high-performance sailing yachts, bridging the gap between hydrodynamics and yacht design. Additionally, guidance from organizations such as the ITTC

(International Towing Tank Conference) through their recommended practices for model tests (ITTC Recommended 2002) has ensured standardized methodologies across research endeavors. In recent years, there has been a growing emphasis on the practical application of research findings in industry settings. For instance, the Interceptor Guide (2011) serves as a valuable resource for marine engineers and designers, offering guidance on the selection and implementation of interceptors in various vessel designs. This reflects the industry's recognition of the importance of optimizing hull designs for improved performance and efficiency. Furthermore, the utilization of advanced computational tools, such as Computational Fluid Dynamics (CFD), has revolutionized the study of planning surfaces. Studies like Karimi et al. (2013) have leveraged experimental approaches alongside computational simulations to provide a comprehensive understanding of interceptor effectiveness on hydrodynamic performance. Additionally, the exploration of innovative technologies, such as motion stabilization systems based on interceptors (KSRI, year not provided, 2004), highlights ongoing efforts to push the boundaries of performance and safety in high-speed marine operations. These advancements not only improve vessel efficiency but also enhance onboard comfort and safety, thereby addressing broader concerns within the maritime industry. Moreover, the integration of emerging concepts, such as the utilization of stern wedges (Karafitah & Fisher, 1987) and spray rails/transverse steps (Teimouri, 2009), underscores the dynamic nature of research in this field. By exploring novel design elements and configurations, researchers continue to seek innovative solutions to improve vessel performance across diverse operating conditions.

Overall, the background of research on planning surfaces and hydrodynamics reflects a multifaceted approach encompassing experimental, theoretical, and computational methods. This interdisciplinary endeavor has yielded significant advancements in understanding and optimizing hull designs for enhanced performance, efficiency, and safety in high-speed maritime operations. As technological capabilities continue to evolve, ongoing research endeavors are poised to drive further innovations in this critical aspect of marine engineering.

As the maritime industry faces evolving challenges such as environmental concerns and regulatory requirements, research on planning surfaces and hydrodynamics has increasingly focused on sustainability and compliance. Efforts to reduce emissions and fuel consumption have led to studies exploring the impact of hull designs on efficiency and environmental performance. For example, studies by Karimi (2006) and Teimouri (2009) have investigated the effects of various hull modifications, such as spray rails and stern wedges, not only on performance but also on fuel efficiency and emissions. By optimizing hull designs to minimize resistance and improve hydrodynamic efficiency, researchers aim to contribute to the industry's sustainability goals. Furthermore, advancements in materials science and manufacturing techniques have enabled the development of lighter and more durable hull structures, which can enhance vessel performance while reducing environmental impact. Research in this area encompasses not only hydrodynamics but also structural engineering and materials science, highlighting the interdisciplinary nature of modern marine research. In addition to technical advancements, there is a growing emphasis on the human factor in vessel design and operation. Human-centered design principles are increasingly being incorporated into the development of planning surfaces and hull configurations to improve safety, ergonomics, and crew comfort. Moreover, the global nature of the maritime industry has led to collaborative research efforts and knowledge sharing across borders and disciplines. Conferences, symposiums, and publications serve as platforms for researchers from around the world to exchange ideas, collaborate on projects, and disseminate findings. Overall, research on planning surfaces and hydrodynamics continues to evolve in response to changing industry needs and technological advancements. By addressing challenges related to efficiency, sustainability, safety, and human factors, researchers aim to drive innovation and improve the performance and environmental footprint of vessels operating in diverse marine environments. For example, studies by Savitsky and Neidlinger (1954) and Cuasanelli and Cave (1993) have explored the application of planning surfaces and interceptors to improve the powering performance of military vessels, such as the FFG-7 class. By optimizing hull designs and control systems, researchers aim to enhance the maneuverability, stability, and efficiency of naval vessels operating in demanding maritime environments. Similarly, research on planning surfaces has also extended to the recreational boating sector, where there is growing demand for high-performance boats and yachts. Studies by Day and Cooper (2011) and Teimouri (2009) have investigated the use of interceptors and other hull modifications to reduce drag and improve the handling characteristics of sailing yachts and high-performance powerboats. Moreover, the integration of advanced technologies, such as autonomous systems and electric propulsion, is opening up new opportunities for research and innovation in planning surface design. By leveraging these technologies, researchers aim to develop next-generation vessels that are not only more efficient and environmentally friendly but also safer and more autonomous. Furthermore, research on planning surfaces and hydrodynamics is increasingly being driven by real-world applications and industry partnerships. Collaborations between researchers, shipyards, naval architects, and maritime companies are helping to bridge the gap between theory and practice, ensuring that research findings are directly applicable to the design, construction, and operation of modern vessels. Overall, the research on planning surfaces and hydrodynamics continues to evolve and expand, driven by advances in technology, changes in industry needs, and a growing awareness of environmental and safety concerns. By addressing these challenges through interdisciplinary research and industry collaboration, researchers aim to enhance the performance, efficiency, and sustainability of vessels operating in today's maritime environment. In addition to the traditional focus on performance optimization, there is a growing interest in understanding the dynamic behavior of planning surfaces in complex operating environments. This includes studying the effects of waves, currents, and wind on vessel stability, maneuverability, and seakeeping characteristics. For instance, research by Hansvic and Steen (2006) explored the use of interceptors and stepped hulls to improve the performance of high-speed catamarans, taking into account the interaction between the hull and the water surface in various sea states. Similarly, studies by Steen et al. (2009) investigated the performance of planning craft with mid-mounted interceptors, considering the impact of waves and rough water conditions. Furthermore, advancements in numerical modeling and simulation techniques have enabled researchers to conduct virtual testing and optimization of planning surfaces before physical prototypes are built. Computational Fluid Dynamics (CFD) simulations, in particular, have become a valuable tool for predicting hydrodynamic performance, analyzing flow patterns, and optimizing hull designs. Research in this area, exemplified by Villa and Brizzolara (2009), involves conducting systematic CFD analyses to evaluate the hydrodynamic performance of flaps and interceptors under various operating conditions. By simulating different design configurations and operating scenarios, researchers can identify optimal solutions for improving vessel performance and efficiency. Moreover, there is increasing interest in studying the interaction between planning surfaces and other components of the vessel, such as propulsion systems, control surfaces, and stabilizers. This holistic approach to vessel design and optimization considers the integrated performance of all subsystems, aiming to achieve optimal efficiency, maneuverability, and safety. Overall, research on planning surfaces and hydrodynamics is advancing on multiple fronts, driven by the need to improve vessel performance, efficiency, and safety in diverse operating environments. By integrating experimental, theoretical, and computational approaches, researchers aim to develop innovative solutions that address the complex challenges facing the maritime industry.

2. Methodology

In this section of the research, the methodology and the process of determining the parameters affecting the increase in speed and adequate maneuverability of a high-speed craft prototype, whose initial specifications are provided in the table below, are elaborated.

Table 1. Specifications of the high-speed craft prototype

Characteristic	**English Identifier**	**Value**
Length (m)	L	69.8
Width (m)	B	26.2
Height (m)	H	10.71
Draft (m)	D	4.0
Current Speed (kn)	v	45
Total Enclosed Volume (m^3)	V	933.10
Bow Trim Angle (deg)	Ɵ	195.15
Trim Amount (mm/m)		41.3
Transom Heel Angle with the Vertical Axis (deg)	β	6.12

Initially, the high-speed craft prototype is scanned, and then the process of converting the three-dimensional scan of the hull into a format usable in its redesign is considered. Although the geometry of the prototype is precisely scanned in three dimensions, direct and rigid utilization of such geometry may not be accurate. The geometry obtained through scanning is a significant portion of the reality that must be considered in the redesign of the high-speed craft. However, construction errors, minor damages incurred during usage, and ultimately elastic deformations of the hull due to the lack of structural reinforcements are important factors that need to be addressed and appropriately compensated for. On the other hand, potential changes in hull lines, spray rails, buoyancy, and equipment, as well as modifications in the power of the propulsion system and trim, are essential considerations for achieving the minimum design speed of 60 knots, which is the ultimate goal of this project.

The scanning process of the prototype boat was carried out in two stages. In the first stage, marking points were initially placed on the hull of the boat, and in the second stage, scanning of the individual sections of the boat such as the bow, hull, transom, and both sides of the boat were performed. The images below depict parts of the scanning process of the prototype boat:

Figure 1. Marking points on the entire hull of the boat on the first day

Figure 2. Scanning of the front section of the boat

Figure 3. Scanning of the left and right sides of the boat

Figure 4. Scanning of the hull bottom and transom

Figure 5 illustrates the results obtained from scanning the entire boat. After model alignment, discrepancies were observed at the edges of the boat, which were attributed to the float displacement during the scanning process. Therefore, a need for rescanning some parts of the boat arose to obtain more valid results, which was carried out.

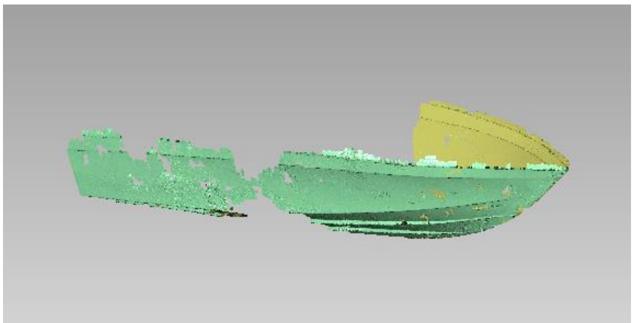

Figure 5. Result obtained from scanning the entire boat

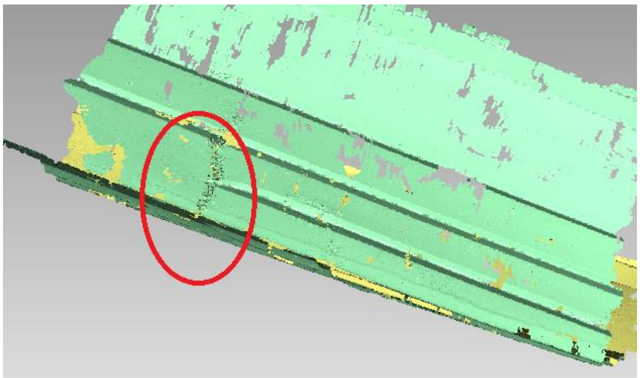

Figure 6. Alignment of scan results with the boat and discrepancies at the edges.

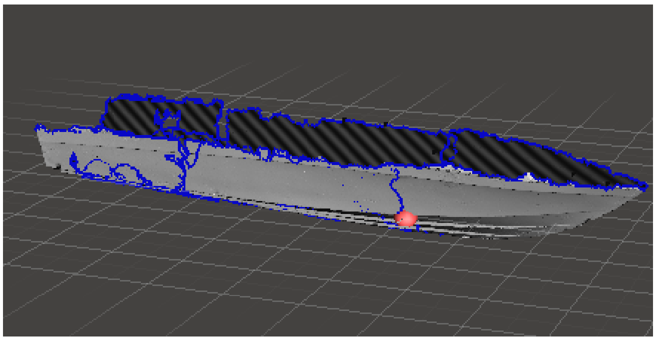

Figure 7. Rescanning of points with discrepancies on the boat and final alignment.

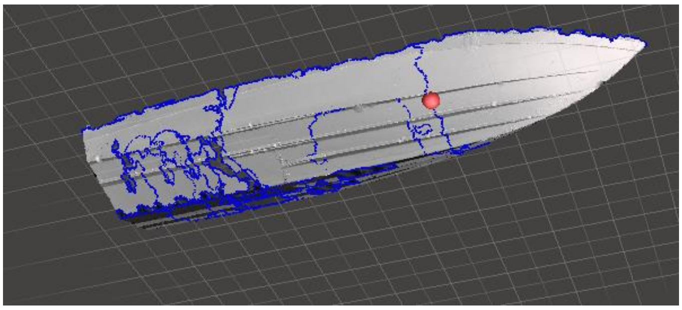

Figure 8. The final boat model obtained from the scan.

In the final model obtained (Figure 8) from the 3D scan, there was a likelihood of discrepancies due to float undulation during the process; hence, there was a need for a metric to correct the model. Accordingly, during the rescanning phase, the boat was launched into the water, and in the waterbed, the main and longitudinal lines were measured to obtain the metrics for model correction. In this situation, the boat's hull was re-marked and then launched into the water. The float was leveled based on the dimensions obtained, and a new scan was performed.

Figure 9. Re-marking of the boat's hull.

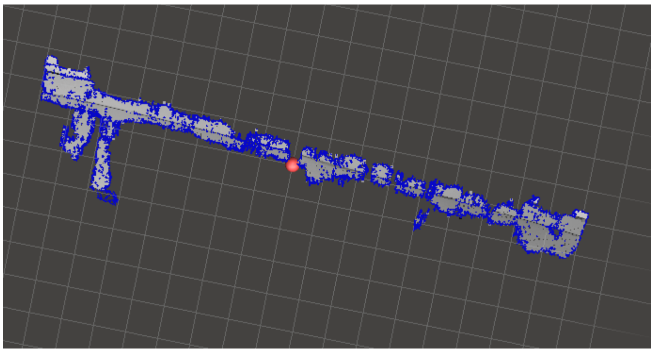

Figure 10. Side view based on the new position for scan correction.

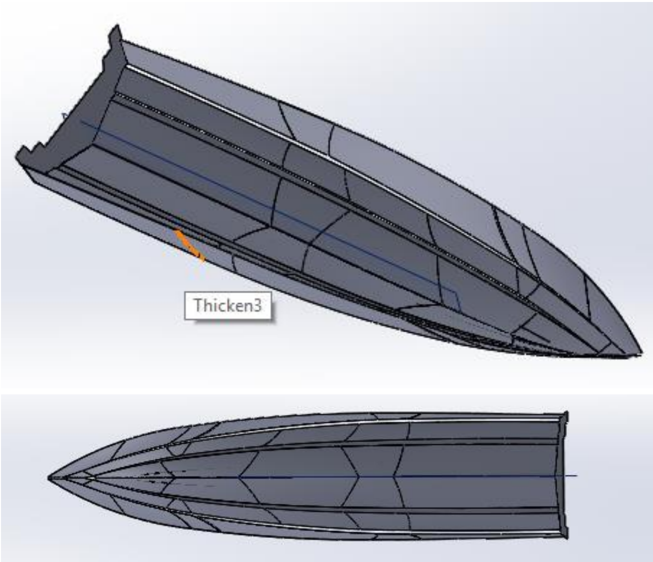

Figure 11. Accurate alignment of models at the end of the 3D scanning process of the boat.

Table 2. General specifications obtained from the 3D scan of the boat

Characteristic	Unit	Value
Overall length (from stem to transom intersection and keel line)	m	690.8
Overall width	m	268.2
Height	m	107.1
Approximate design draft	m	40.0
Total enclosed volume in the hull	m^3	933.10
Trim angle towards the stern	deg	19515.0
Trim value towards the stern	mm/m	41.3
Transom angle with the vertical axis	deg	6.12

The highest spray line height in section 0 from the baseline is approximately 40.0 meters. Considering the significant change in the hull angle in this area, this region is likely the boat's waterline; hence, the boat's design draft in the current conditions is assumed to be 40.0 meters.

To pass suitable editable surfaces from the obtained cross-sections in Maxsurf software, it is necessary to first approximate the existing sections with an appropriate number of points or markers. As evident in Figures 13 and 14, each section has been approximated with a considerable number of markers. Table 3 shows the number of points used in each section. As observed in this table, the average distance between points varies from a minimum of 15.7 to a maximum of 37.4 millimeters in different sections. The highest average point distance is related to section number 3800. An interesting point to note is that this section has the largest perimeter and area compared to other sections, with values of 3.66 meters and 1.74 square meters, respectively.

The point marking process in each section is as follows: first, each section is converted into a continuous line in AutoCAD software, and then points are marked at equal distances around the section's perimeter. Since the corner points (which are essentially the corners of the spray water tapes) play a crucial role in geometric modeling of the float, the nearest marker points to these corners have been directly transferred to their positions.

Figures 15 display the isometric and three-dimensional arrangement of the float sections and the markers on them. The number of points used to replace the float cross-sections is over 4700 points. Finally, these points have been successfully imported into the Maxsurf software to serve as the basis for creating NURB surfaces to form the float skin in the next step.

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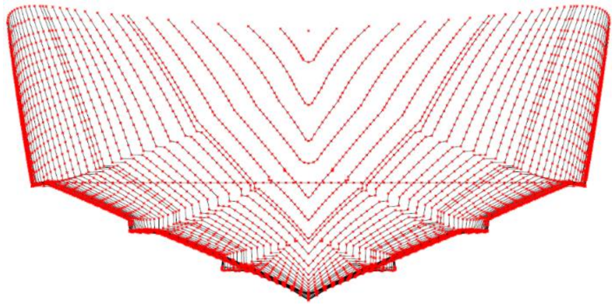

Figure 13. Display of float cross-sections and replacement offset points

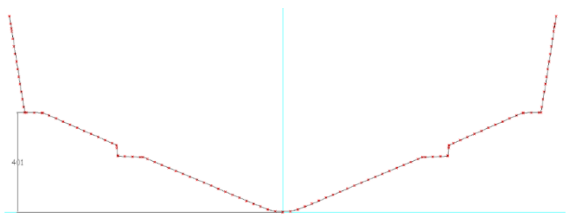

Figure 14. Cross-section 0

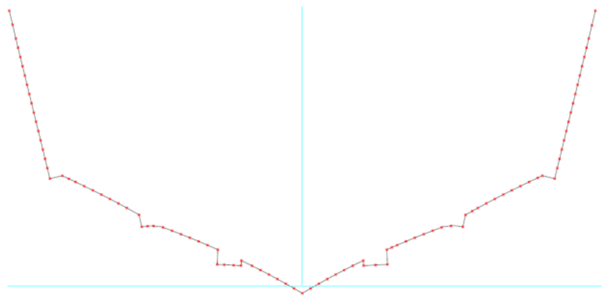

Figure 14. Display of section 4000 as an example (Red dots on the section indicate the offset replacement points)

Table 3 illustrates the longitudinal positions, areas, perimeters, number of points, and average point distances for various scanned sections, alongside replacement offset points.

Section Number	Longitudinal Position (m)	Area (square meters)	Perimeter (m)	Number of Points	Average Point Distance (mm)
-156	-156.3	0.000	2185	2	2184.8
-87	-87	0.805	2839	100	28.7
0	0	1.238	3079	197	15.7
100	100	1.258	3113	99	31.8
...	...	...	...	...	...
8400	8400	0.014	336	20	17.7

Section Number	Longitudinal Position (m)	Area (square meters)	Perimeter (m)	Number of Points	Average Point Distance (mm)
8534	8533.5	0.000	0	1	-

This table offers a comprehensive overview of the aforementioned parameters for each scanned section, along with the inclusion of replacement offset points.

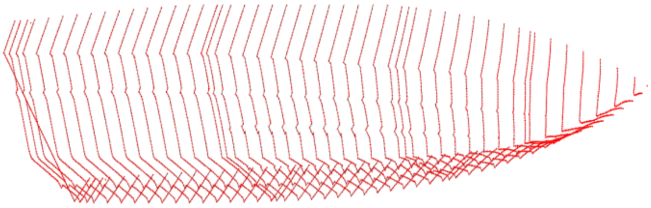

Figure 15. Three-dimensional layout of cross sections and offset points

3. Generation of Floating Three-Dimensional Surfaces

Using the point cloud data obtained from the three-dimensional scan of the floating structure, surfaces were generated to visualize the overall form of the boat hull. Given the errors inherent in the scanning process, it was necessary at this stage of the project to address and rectify issues in the identification of hull lines to achieve a uniform body with regular hydrodynamic lines in a desirable and scientific manner.

The sources of errors in the three-dimensional scanning process are as follows:

- Point cloud scatter resulting from scanning process discontinuities.
- Deformation of the hull due to the lack of a robust longitudinal girder and weak transverse frames.
- Damages to the sample boat hull, which have occurred and persisted over time.

The corrective steps taken to address the aforementioned error sources are outlined as follows:

- A fixed three-dimensional coordinate system was coupled to the bottom point in the zero frame. Consequently, all points resulting from the scan were endowed with their unique coordinates.
- A surface was fitted through each set of points. Surfaces at the connection points exhibit discontinuities.
- To resolve the problem of surface discontinuity at connection points and create uniform and consistent surfaces, a standard criterion (2.5 millimeters) for the maximum deviation of point coordinates from the passing surface was considered.
- Considering the ultimate goal of creating a uniform and integrated body for mold construction, a number of points exceeding the aforementioned criterion were transferred to the passing surface.
- In the final step, to increase the accuracy of the passing surfaces, separate surfaces were defined as follows:
    - Each side wall as a separate surface
    - Each spray rail as a separate surface
    - The final hull surface as a separate surface
    - The bottom surfaces

The figures below encompass all the information regarding various surfaces of the boat hull, which will be utilized in the future for mold construction.

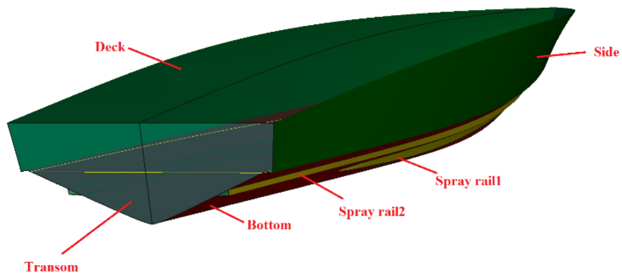

Figure 16. Definition of primary floating surfaces

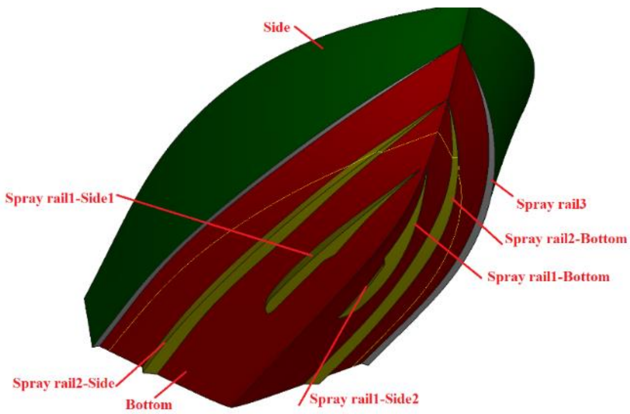

Figure 17. Definition and representation of spray rail surfaces

4. Data Analysis

Hydrostatic calculations and trim equilibrium

Accurate geometric modeling of a boat for the manufacturing process is a precise and somewhat time-consuming task, depending on the project requirements. Figures 18 to 20 depict a precise hull over markers. Essentially, this hull consists of a set of small triangular flat surfaces that connect adjacent markers to each other. These surfaces are referred to as triangular meshes. This hull can be used for advancing calculations of equilibrium, resistance, and seaworthiness.

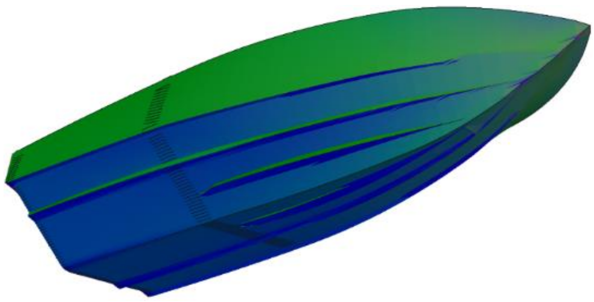

Figure 18. Isometric view of the hull with triangular mesh in the Maxsurf environment.

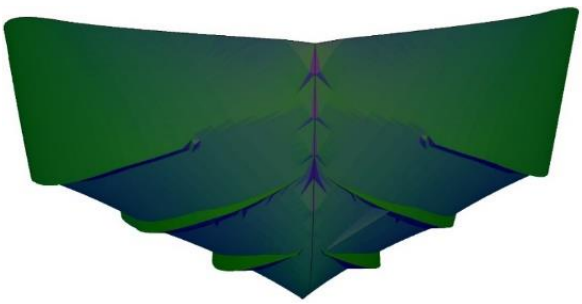

Figure 19. Front view of the hull modeling using triangular mesh in the Maxsurf environment.

Figure 20. Side view of the hull modeling using triangular mesh in the Maxsurf environment.

The description of the origin and direction of the coordinate axes used in this study is as follows:

- Longitudinal axis: Positive towards the bow of the boat, with its origin at frame zero on the baseline at the lowest point of the transom heel.
- Vertical axis: Positive upward, with its origin at the boat's baseline.
- Transverse axis: Positive towards the right side of the boat and on the boat's symmetry line.

The hydrostatic characteristics of the boat in the designed waterline are provided in the table below:

Table 4. Hydrostatic Characteristics at 38.0m Waterline

Unit	Value	Characteristic	Row
t	2.07	Displacement	1
m^3	2.019	Volume (Displaced)	2
m	0.38	Draft Amidships	3
m	0.38	Immersed Depth	4
m	7.682	WL Length	5
m	1.828	Beam Max Extents On WL	6
m^2	15.3	Wetted Area	7
m^2	0.369	Max Sect. Area	8
m^2	10.732	Water pl. Area	9
	0.713	Prismatic Coeff. (CP)	10
	0.378	Block Coeff. (CB)	11
	0.533	Max Sect. Area Coeff. (CM)	12
	0.764	Waterpl. Area Coeff. (CWP)	13
m from zero pt. (+vefwd)	2.924	LCB Length	14
m from zero pt. (+vefwd)	3.026	LCF Length	15
% lwl	38.058	LCB %	16
% lwl	39.396	LCF %	17
m	0.255	KB	18
m	0	KG Fluid	19
m	1.166	BMT	20
m	19.674	BML	21
m	1.421	GMT	22
m	19.929	GML	23
m	1.421	KMT	24
m	19.929	KML	25
tonne/cm	0.11	IMMERSION (TPC)	26
tonne.m	0.048	MTC	27
tonne.m	0.051	RM AT 1DEG = GMT.DISP.SIN (1)	28
	4.203	Length:Beam Ratio	29
	4.81	Beam:Draft Ratio	30
	6.078	Length: VOL^0.333 Ratio	31

In order to achieve the appropriate initial trim angle, all hydrostatic calculations of the boat were conducted in the condition without heel and at various trims. The results of this section greatly assist in determining the installation location of the engine and achieving the optimal point for designing the propulsion system and overcoming hull resistances. One of the important considerations for achieving the desired speed with minimal costs and design alterations is determining the precise location of the propulsion system installation.

However, it should be noted that increasing the initial trim angle is feasible to a certain extent, firstly, if the boat can reach a planing state in hydrodynamic analyses, and secondly, if the boat does not experience repeated pounding or capsizing during motion.

Changes in waterlines of 5 centimeters were considered, ranging from 0 to 75 centimeters for hydrostatic calculations.

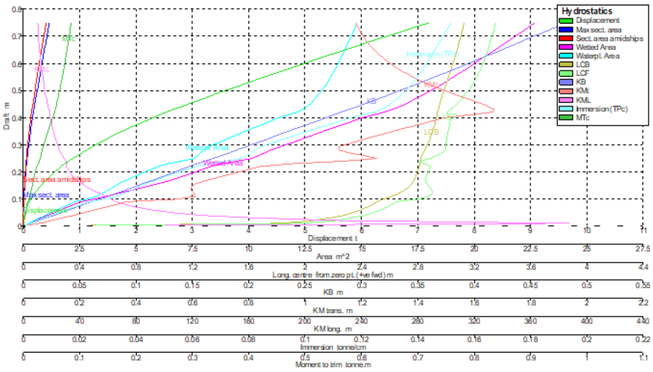

Figure 21. Curves depicting variations in important hydrostatic parameters at various waterlines for the condition without heel and trim.

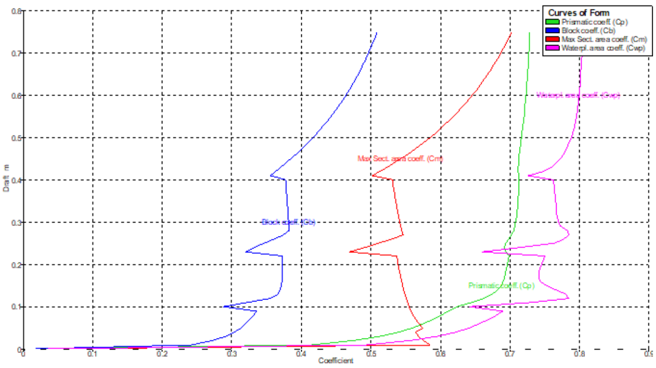

Figure 22. Curve illustrating changes in hull form coefficients at different waterlines for the condition without heel and trim.

The hydrostatic characteristics and parameters of the boat at various waterlines with a trim of 1.0 meter towards the float heel are calculated according to Table 5.

Table 5. Hydrostatic Characteristics of the Boat at Various Waterlines with a Trim of 1.0 Meter Towards the Float Heel

Draf	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Disp	0	0	0	0	0	1	1	1	2	3	3	4	5	5	6	7
Heel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Draf	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Draf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Draf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trim	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WL	4	5	6	6	7	7	7	7	7	7	7	7	8	8	8	8
Bea	0	0	0	1	1	1	1	2	2	2	2	2	2	2	2	2
Wett	0	1	3	5	8	1	1	1	1	1	1	1	2	2	2	2
Wat	0	1	3	4	6	7	8	1	1	1	1	1	1	1	1	1
Pris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bloc	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Max	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LCB	0	1	2	2	2	2	2	2	2	2	2	2	2	2	2	3
LCF	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3
KB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BM	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0
BM	4	5	4	3	2	2	2	1	1	1	1	1	1	1	9	8
GM	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
GM	4	5	4	3	2	2	2	1	1	1	1	1	1	1	1	8
KM	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
KM	4	5	4	3	2	2	2	1	1	1	1	1	1	1	1	8
Imm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Max	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trim	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

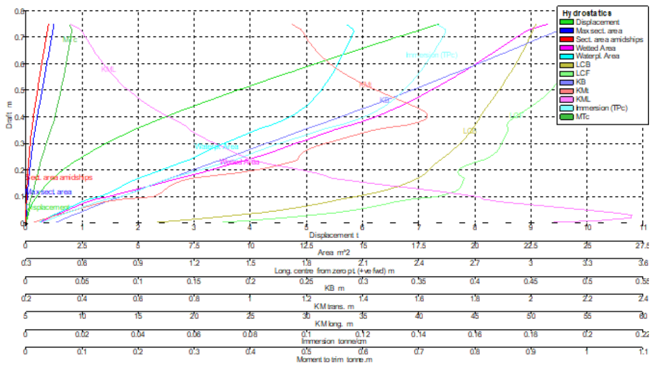

Figure 23. Curves illustrating variations in important hydrostatic parameters at various waterlines with a trim of 1.0 meter towards the float heel.

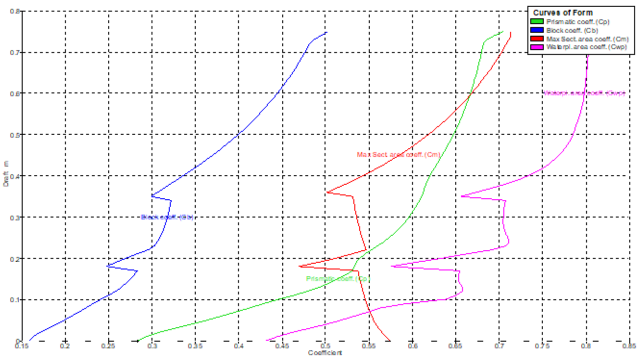

Figure 24. Curve depicting changes in hull form coefficients at different waterlines with a trim of 1.0 meter towards the float heel.

The hydrostatic characteristics of the boat were calculated at different waterlines: at a draft of 3.0 meters, 4.0 meters, and 5.0 meters towards the keel.

The hydrodynamic analysis of the mentioned boat was conducted at various trim angles to determine the optimal installation point of the propulsion system and the required effective power to achieve a speed of over 60 knots based on the data obtained from the hydrostatic and resistance calculations on the hull.

In the figures below, the results of the hydrodynamic analysis of the vessel at different static trim angles are presented:

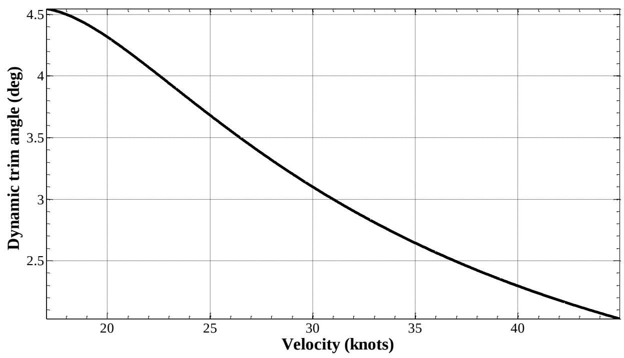

Figure 25: Dynamic trim angle of the vessel at the initial trim angle of zero degrees and LCG=2.924 m.

The figure indicates that the vessel dynamically trims from zero to 4.5 degrees initially and gradually reduces its dynamic trim as the speed increases, moving downward toward the keel.

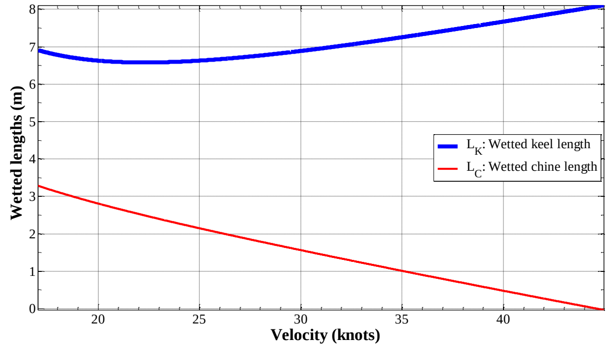

Figure 26: Length of keel line and immersed transom at the initial trim angle of zero degrees and LCG=2.924 m.

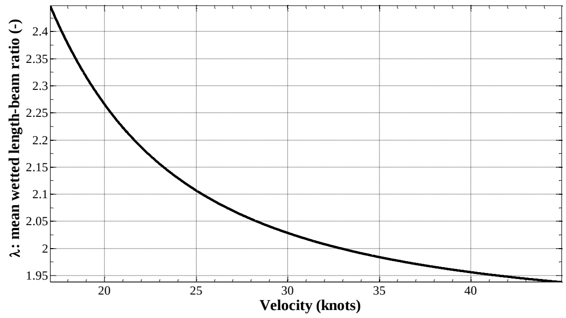

Figure 27: Ratio of average immersed length to beam at the initial trim angle of zero degrees and LCG=2.924 m.

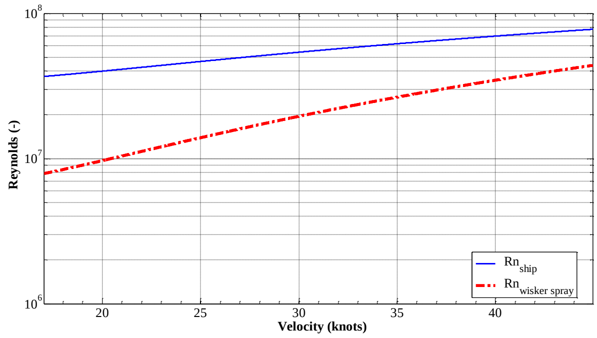

Figure 28: Reynolds number of pressure and spray area at the initial trim angle of zero degrees and LCG=2.924 m.

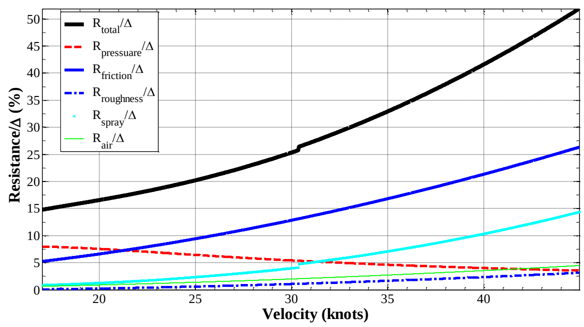

Figure 29: Ratio of resistance components to vessel weight at the initial trim angle of zero degrees and LCG=2.924 m.

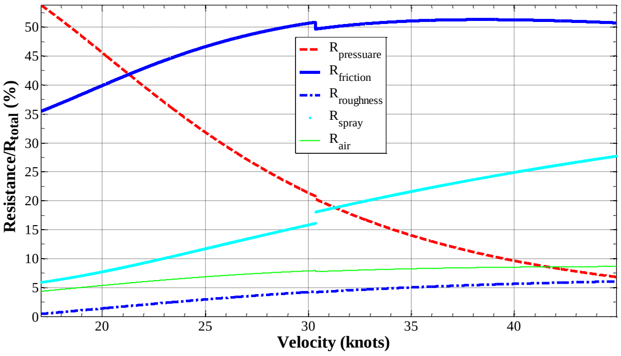

Figure 30: Examination of the contribution of resistance components to total resistance at the initial trim angle of zero degrees and LCG=2.924 m.

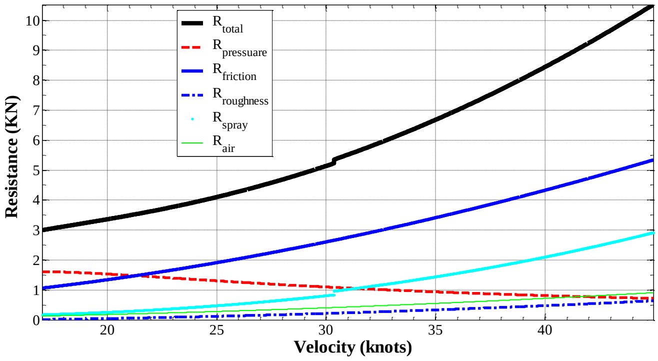

Figure 31: Examination of vessel resistance at the initial trim angle of zero degrees and LCG=2.924 m.

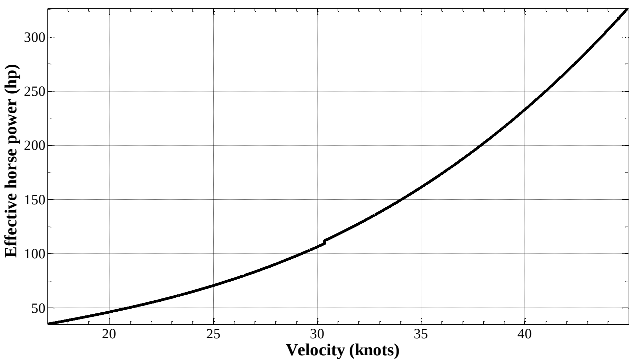

Figure 32: Examination of the effective power required by the vessel at the initial trim angle of zero degrees and LCG=2.924 m.

The results of the hydrodynamic analysis of the vessel at an initial static trim angle of 5.1 degrees are presented in the following figures:

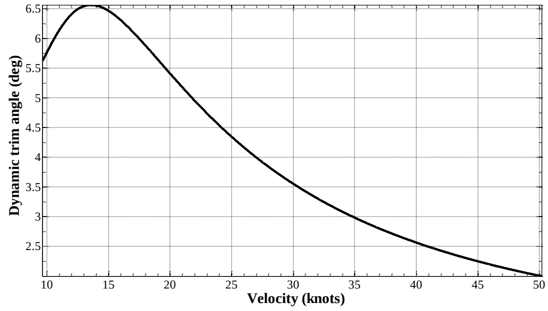

Figure 33: Dynamic trim angle of the vessel at the initial trim angle of 5.1 degrees and LCG=2.441 m.

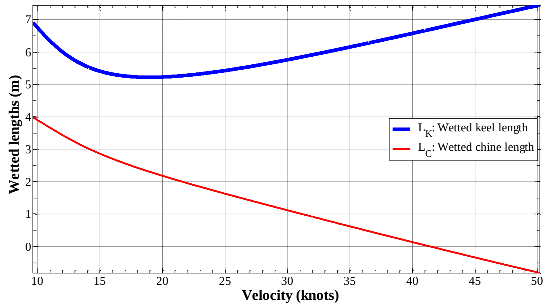

Figure 34: Length of keel line and immersed transom at the initial trim angle of 5.1 degrees and LCG=2.441 m.

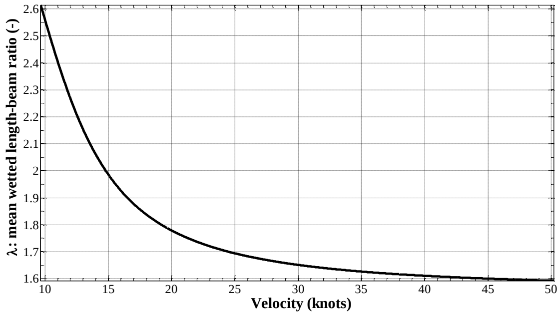

Figure 35: Ratio of average immersed length to beam at the initial trim angle of 5.1 degrees and LCG=2.441 m.

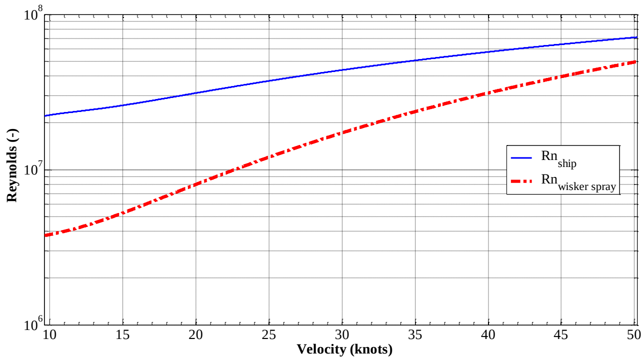

Figure 36: Reynolds number of pressure and spray area at the initial trim angle of 5.1 degrees and LCG=2.441 m.

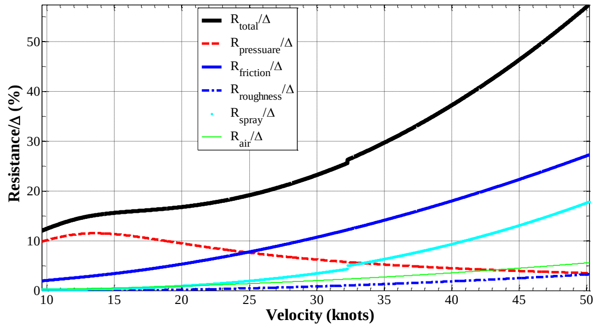

Figure 37: Ratio of resistance components to vessel weight at the initial trim angle of 5.1 degrees and LCG=2.441 m.

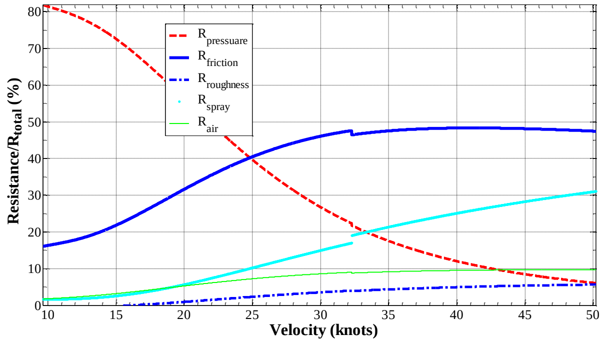

Figure 38: Examination of the contribution of resistance components to total resistance at the initial trim angle of 5.1 degrees and LCG=2.441 m.

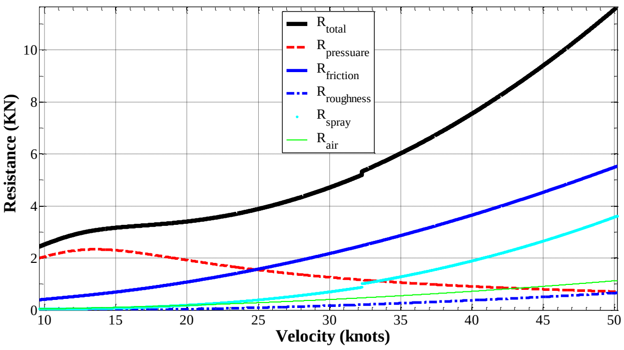

Figure 39: Examination of vessel resistance at the initial trim angle of 5.1 degrees and LCG=2.441 m.

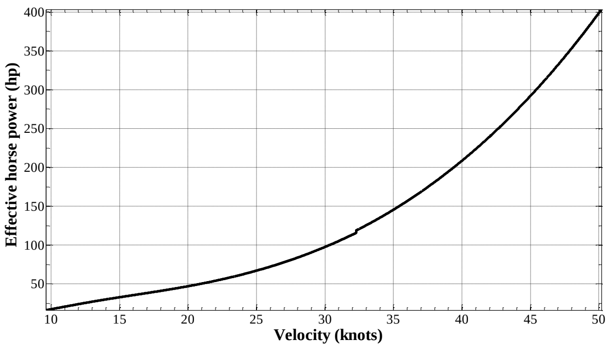

Figure 40: Examination of the effective power required by the vessel at the initial trim angle of 5.1 degrees and LCG=2.441 m.

Similar analyses were conducted at static trim angles of 3.0, 5/4, 5.0, 6.0, and 5/7 degrees, with corresponding figures provided for each angle. These analyses aimed to investigate the hydrodynamic behavior of the vessel at various trim angles and determine the power requirements necessary to achieve desired performance, contributing to optimizing the vessel's design and operation.

5. Academic Analysis of Boat Hydrostatic Characteristics

This analysis aims to explore the hydrostatic characteristics of a high-speed craft prototype, using data from various tables provided.

5.1. Overview of Boat Specifications: The boat prototype has an overall length of 690.8 meters, width of 268.2 meters, and height of 107.1 meters. Its approximate design draft is 40.0 meters, and it possesses a total enclosed volume of 933.10 cubic meters. Notably, it features a significant trim angle towards the stern of 19515.0 degrees and a trim value of 41.3 millimeters per meter.

5.2. Hydrostatic Characteristics at Various Waterlines:

- **Table 5:** These tables present data on displacement, heel, draft at different positions, waterline length, maximum beam extents, wetted area, and coefficients such as prismatic, block, max section area, and waterplane area for conditions with and without heel and trim. These parameters vary with changes in draft and waterline length, affecting the boat's stability and hydrodynamics.

5.3. Hydrostatic Characteristics at 38.0m Waterline:

- **Table 4:** This table provides specific hydrostatic characteristics at the 38.0m waterline, including displacement, volume, draft, immersed depth, waterline length, beam max extents, wetted area, and coefficients like prismatic, block, max section area, and waterplane area. These parameters offer insights into the boat's behavior at a specific waterline.

5.4. General Specifications from 3D Scan:

- **Table 2:** Data obtained from a 3D scan reveals the boat's overall length, width, height, approximate design draft, total enclosed volume in the hull, trim angle towards the stern, trim value, and transom angle with the vertical axis. These specifications contribute to understanding the boat's physical dimensions and structural attributes.

5.5. Sectional Data:

- **Table 3:** This table provides longitudinal positions, areas, perimeters, number of points, and average point distances for various scanned sections. It aids in comprehending the boat's sectional geometry and hull shape, crucial for structural analysis and design optimization.

By integrating these datasets, researchers and engineers can conduct comprehensive analyses of the boat's hydrostatic behavior, structural integrity, stability, and performance under varying conditions, facilitating informed design decisions and optimizations for enhanced efficiency and safety.

6. Conclusion

This section discusses the hydrostatic and hydrodynamic calculations performed on the high-speed boat, focusing on the influence of longitudinal center of gravity displacement and changes in the initial trim angle on hydrodynamic parameters such as forward speed, resistance, and required propulsion power.

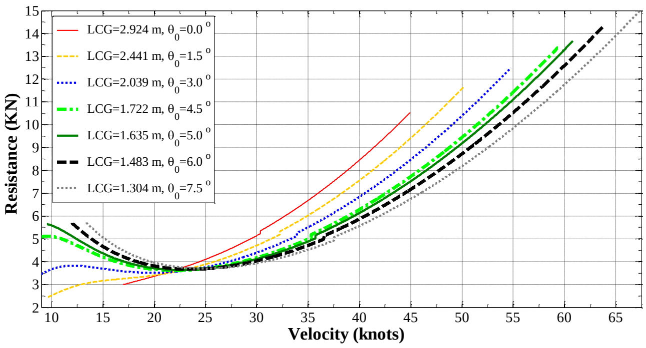

Figure 41 illustrates the effect of longitudinal center of gravity displacement on the total resistance of the boat.

Increasing the static trim angle results in an increase in the vessel's speed, accompanied naturally by an increase in resistance and required effective power. However, a noteworthy point in these calculations is that to achieve a desired speed above 60 knots, a minimum initial trim angle of 5/4 degrees must be established.

From the initial trim angle of 5/4 degrees and above, practically, there was not enough freeboard on the sample boat's body lines, and water entered the boat from the transom. Therefore, modifications were made to the inner keel cover and inner hull walls to increase the height of the sections above the waterline. This prevented water from entering the vessel when trimmed towards the transom. These modifications increased the structure's weight and consequently altered the longitudinal center of gravity, necessitating a recalculation and relocation of some items such as fuel tanks, seating, battery boxes, etc., to achieve the desired outcome.

At a speed of approximately 5.22 knots, the minimum resistance forces are exerted on the vessel. An intriguing point at this speed is that with an increase in the initial trim angle, the hull resistance also increases significantly at the start of motion, making the vessel's skiing conditions harder. To address this issue, outboard motors equipped with manual trim jacks are used to manually adjust the trim.

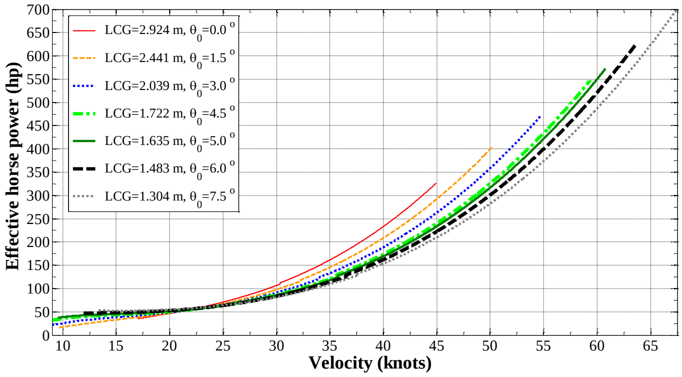

Figure 42 illustrates the effect of longitudinal center of gravity displacement on the required effective power for propulsion.

To achieve a speed of over 60 knots in the target vessel, a minimum effective power of 475 horsepower is required. Considering factors such as losses in the propeller system, resistance, climatic and weather conditions, hull roughness, and cleanliness, a safety factor of 1.25 was applied in the calculations for determining the required effective power. Therefore, the design includes two 300-horsepower engines.

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