Volume 23 (1) 2024 Page 54 - 63

Mekanika: Majalah Ilmiah Mekanika

Analytical Review of Numerical Analysis in Hydrodynamic Performance of the Ship: Effect to Hull-Form Modifications

Aldias Bahatmaka[1*], Deni Fajar Fitriyana[1], Samsudin Anis[1], Achmad Yanuar Maulana[2,3],
Mamad Tamamadin[4,5], Sang Won Lee[6], Joung Hyoung Cho[7]

1 Department of Mechanical Engineering, Universitas Negeri Semarang, Semarang 50229, Indonesia
2 Department of Chemistry, Dong-A University, Busan, 49315, South Korea
3 Association of Indonesian Researchers in Korea (APIK), Seoul 07342, South Korea
4 University Core Research Center for Disaster-free & Safe Ocean City Construction, Dong-A University, Busan 49315, South Korea
5 Atmospheric Science Research Group, Bandung Institute of Technology, Bandung 40132, Indonesia
6 Department of Fluid, Research and Development, Daewoo Shipbuilding and Marine Engineering, Co. Ltd., Geoje 53305, South Korea
7 Interdisciplinary Program of Marine Design Convergence, Pukyong National University, Busan 48513, South Korea

*Corresponding Author's email address: aldiasbahatmaka@mail.unnes.ac.id

Keywords:
Design
Ship hull
Optimization
Numerical analysis
Performances

Abstract

This review paper provides an overview of simulation-based hydrodynamic design optimization for ship hull forms. It also includes a numerical analysis aimed at accomplish early-stage simulation-based design in terms of hydrodynamic performance. A hydrodynamic module, a hull surface modeling module, and an optimization module are the primary components of this numerical analysis. The hydrodynamic module includes both simple design approaches and high-fidelity numeric tools; these integrated tools are used to evaluate hydrodynamic performances at different design stages. The hull surface modeling module offers a variety of techniques for ship hull surface representation and modification. It is also used to automatically create hull forms or change existing hull forms based on hydrodynamic performance and design constraints. The optimization module includes several optimization algorithms and surrogate models used to determine optimal designs in terms of hydrodynamic performance. Numerical findings indicate that the current tool is well suited for hull form design optimization at the early design stage because it can produce effective optimal designs within a short time.

1 Introduction

The multi-objective functions that measure ship hydrodynamic performances are defined to compare the merit of different designs quantitatively. These objective functions can be evaluated using numerical based simulation tools for a particular design, i.e., a hull form associated with a set of design parameters/variables. The optimal hull form that exhibits the best hydrodynamic performance can then be obtained by means of an optimization technique. Hydrodynamic design of a ship involves several stages, from preliminary and early-stage design to late-stage and final design. Hydrodynamic optimization is an essential part of ship design. During the design process, numerical analysis-based simulation tools can be

https://dx.doi.org/10.20961/mekanika.v23i1.83635

Revised 19 February 2024; received in revised version 09 March 2024; Accepted 20 March 2024

2579-3144

used to evaluate the hydrodynamic performance of a design or design alternatives. Therefore, the simulation-based hydrodynamic design/optimization tool usually consists of a numerical module that can be used to compute the flow field and evaluate the objective functions, a hull surface modeling module that can be used to create hull forms using given sets of design variables/parameters, and an optimization module that can be used to minimize the objective functions under given constraints. Hull form optimization has long focused on reducing ship resistance among the many aspects of ship performance. For certain hull forms, it can reduce resistance [1-4]. A self-blending technique for the modification and optimization of a bulbous bow. The shape of the bulbous bow of a fishing vessel was optimized, and the resistance was decreased by 2% [5]. Optimization of propulsion power for different water depths using a parametric stern shape of a ship inland [6]. Optimization of the hull form of a research vessel of the catamaran type using numerical simulation based on the method of successive approximations [7]. genetic algorithms and nonlinear programming to optimize the hull shape and get promising results [8]. A new method of automatic hull surface modification based on Delaunay triangulation is used to perform hull form optimization, which can significantly increase the optimization efficiency [9].

The objective functions can be minimized by using a variety of optimization strategies. Including optimization strategies that can locate the local and/or global minimum for functions with one or more objectives is crucial. The optimization module can incorporate these optimization methods. To satisfy design requirements, an appropriate optimization method can be chosen from the optimization module. Iterative processes, including the evaluation of numerous objective functions, are necessary for preliminary and early hydrodynamic design. High quality model usage can be unaffordable in design optimization, particularly in the early stages of the design process. To minimize the computational expense while maintaining the ability to rank various designs, computational tools that take into consideration pertinent physics that are important (albeit not necessarily all of them) and are robust and highly efficient in terms of Central Processing Unit (CPU) and user input time is necessary. For this design stage, linear potential flow assumptions may be required. Each class of modeling techniques has well-documented benefits and drawbacks in the literature [7-10].

For the purpose of utilizing both parametric and conventional modeling methods, several strategies for the representation and manipulation of the hull-surface have been devised. To be more precise, during optimization cycles, a parametric hull form representation and modification technique linked to the sectional area curve is developed to alter the hull form worldwide. During optimization cycles, a Radial Basis Function (RBF) based approach is created to change the hull form locally or globally. They only need a few design variables specified in terms of the movable control nodes of the radial basis function and the shape parameters. The hull form represented by discrete surfaces or Non-Uniform Rational B-Spline (NURBS) surfaces can be modified using these methods. Another benefit of using these hull form representation and modification approaches is that, prior to optimization, the impact of each design parameter on hydrodynamic performance may be examined. This RBF-based modification technique has recently been further improved for a baseline hull represented by NURBS surfaces. It may be used to automatically construct a bulbous bow or modify an existing bow depending on supplied geometry constraints and hydrodynamic performance throughout the optimization process [14]. To illustrate the usefulness of the current multi-objective hydrodynamic optimization tool in ship design, particularly in the early stages of the design process. A number of new optimal hull-forms were produced in this research review, which used the contrast review method. This method is carried out by finding differences between several research journals to conclude and, in this case, to obtain steps or strategies to improve the design performance of ships which will be explained thoroughly.

2 Hull Form Modification

All objective functions, including resistance, stability, and seakeeping, must be taken into account while optimizing a ship's hydrodynamics. Merely focusing on one of the goals will produce unreal and unworkable outcomes. Optimizing the hull form from the perspective of hydrodynamic performance is a crucial part of the first ship design. Because ship design involves many dynamics and levels of complexity, naval architects strive to employ a variety of dependable and flexible methods to enhance the overall quality of the design. Certain optimization techniques alter the hull shapes of ships by decreasing wave patterns and calm-water drag [12,13].

2.1 Small Waterplane Area Twin Hull (SWATH)

Figure 1 illustrates the SWATH hull design, which reduces the hydrostatic restoration forces by minimizing the waterline level as compared to single-hulls and catamarans. The SWATH water plane area is directly related to sea-induced ship motions and wave-making resistance, and it is stated as a function of volume displacement.

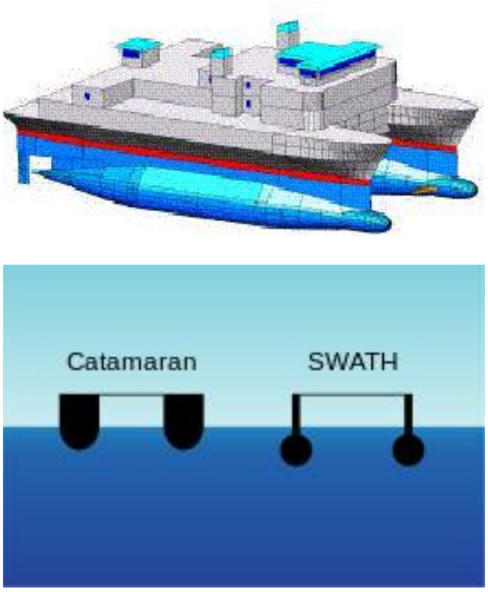


Figure 1. Waterline conditions of different hull forms [17]

2.2 Lifting body ship hybrid

The parent hull's wetted surface area is reduced, which lowers its friction drag, by shifting displacement volume from the parent hull to the lifting bodies. The lifting body has a high lift to drag ratio and is shaped hydrodynamically efficient. As seen in Figure 2, two varieties of marine vehicles with lifting bodies attached beneath the midsection of the vehicle are MIDFOIL and HYSWAC. Results of the research showed a 15-30% reduction in drag over a broad speed range when compared to a traditional mono-hull [18-22].

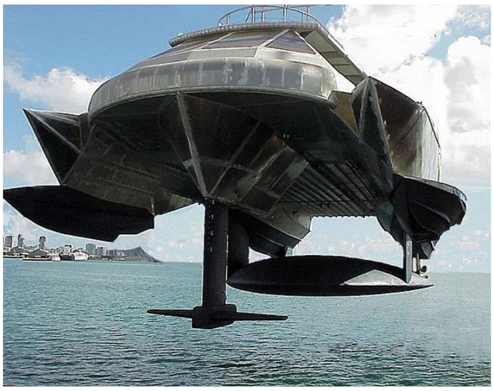


Figure 2. Lifting body of the ship hull [23]

2.3 Deadrise angle on the hull form

The deadrise angle on the boats is typically designed to function in the planning mode at high speeds. Although these boats are often made to be quite light, there are some specific uses for which fast boats may occasionally need to be very laden. The difference in the transverse hull line by comparing the original geometry and new hull geometries of the configuration can be seen in Figure 3.

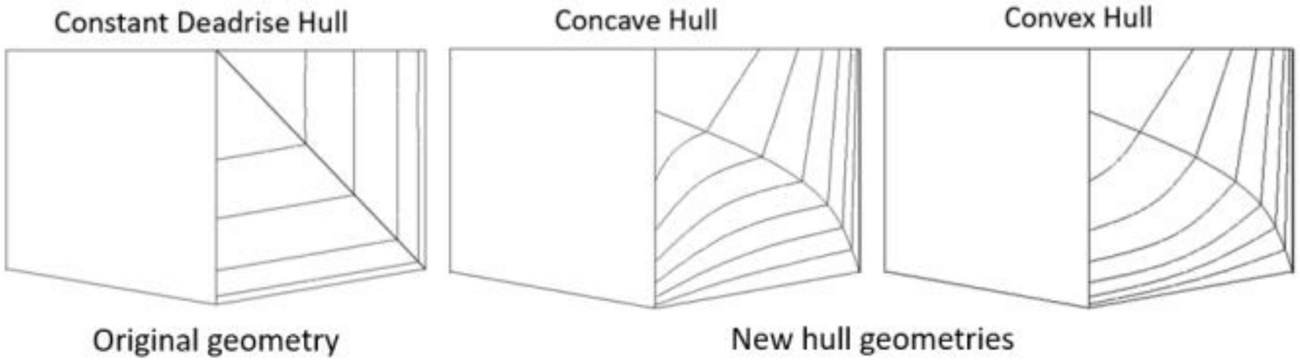


Figure 3. Transverse hull line of the configurations [24]

2.4 Interceptor design on the hull

Figure 4 shows the significant pressure fluctuations were brought about by the interceptor, particularly on the transoms. Lift force, draft height, and resistance were all impacted by pressure changes. Recent studies suggest that the interceptor's height shouldn't exceed 60% ($d/h < 0.6$) of the transom boundary layer. The interceptor's span length needs to be seven times its height when the interceptor's height is 60% of the boundary layer to operate as efficiently as possible [25].

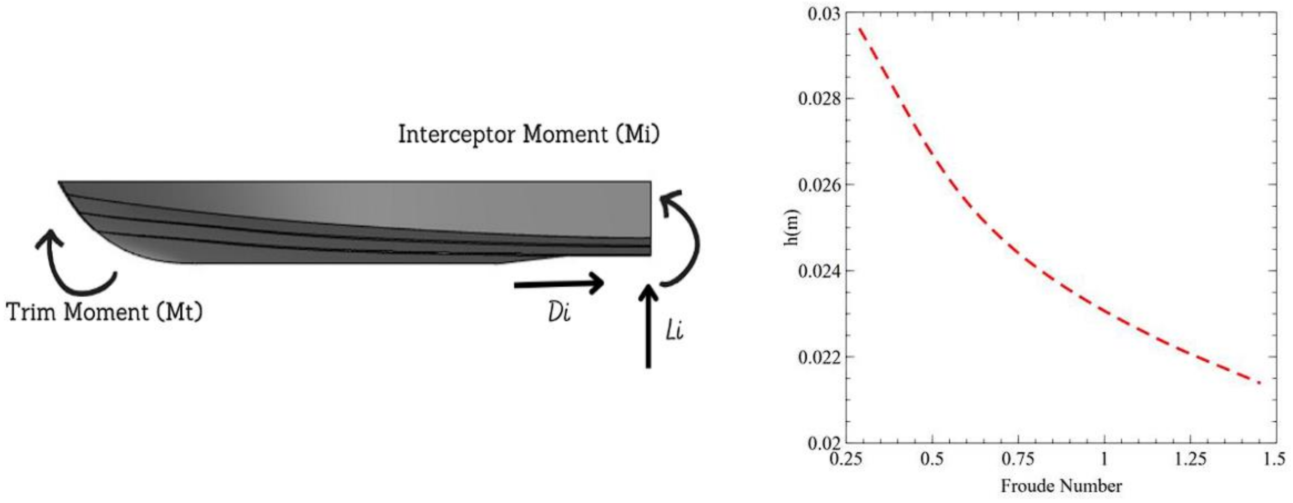


Figure 4. Influence of interceptor design to hull form [26]

3 Optimization on The Numerical Analysis

3.1 Benchmark study of the numerical analysis against the experimental

The participants' background information and references for the applicable methods are provided by the validation of numerical analysis. The following categories generally describe the methodologies that took part in the benchmark study, i.e. Potential methods for strip theory with potential adjustments for viscous flow, potential methods for 3D panels with potential adjustments for viscous flow, field methods based on solving Reynolds-averaged Navier–Stokes (RANS) or Euler equation and also semi-empirical approach [27].

A time-marching method to produce a time series of wind forces and pressures. Time-averaged and unstable flows, where big vortices are occasionally created in the aftermath of simulations, can be simulated with RANS. To put it simply, Large Eddy Simulations (LES) forecasts wind loads on structural frames and claddings. LES calculation and the experiment-related velocity fluctuation at the inflow border [28].

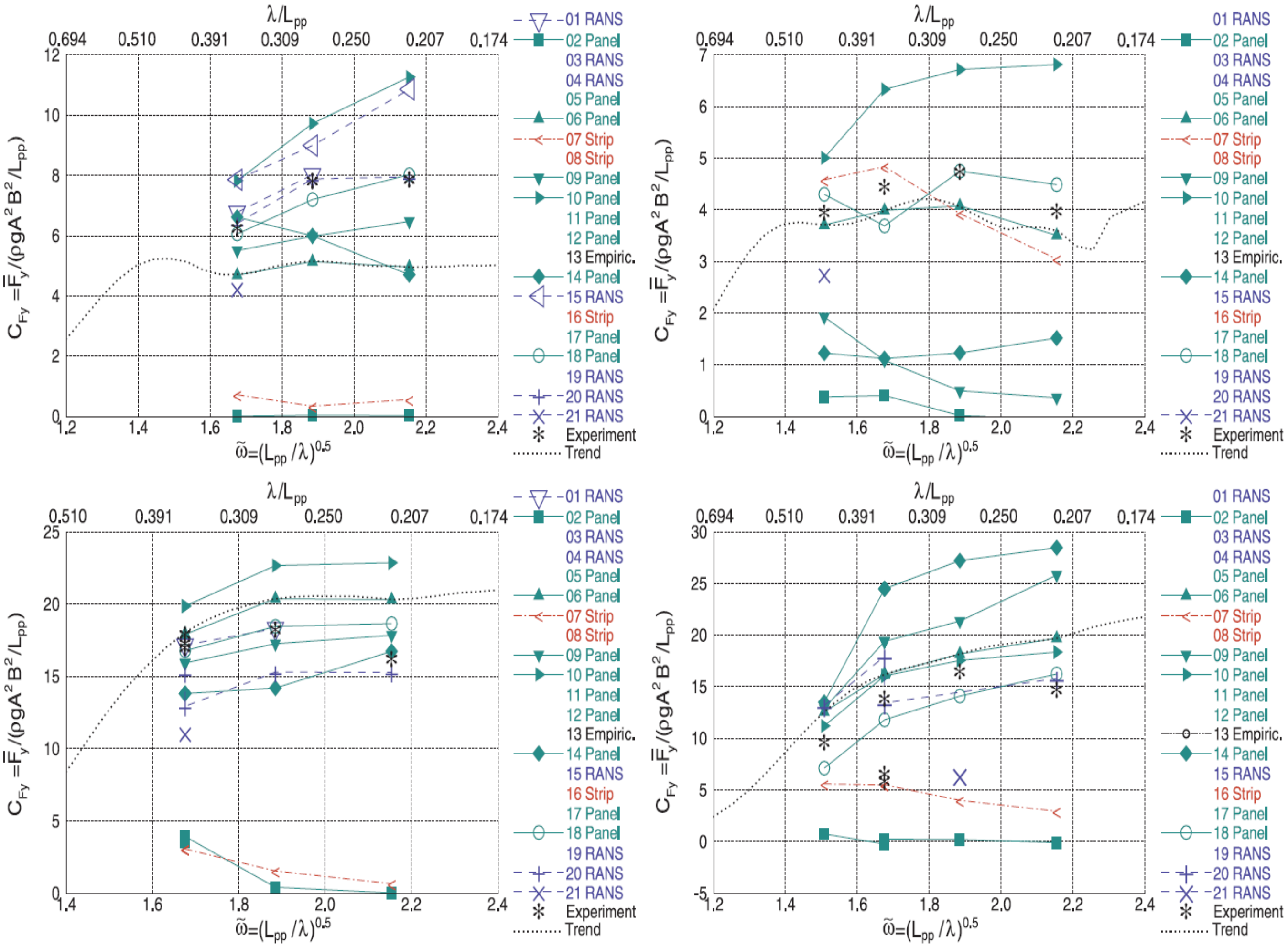


Figure 5. Numerical approach against the experimental by time-average wave-induced [29]

From the Figure 5, The remaining 3D panel routines, especially 02 and 14, show significant departures from both the experiments and the core group of 3D panel techniques. It's interesting to see that, compared to the situations previously discussed, the strip theory approach 07 produces superior results in this more complex case. A portion of the RANS simulations offered for this scenario closely resemble the trials, but they also show notable outliers and variations among various sets of data. The empirical technique 13 consistently over-predicts wave-induced thrust in stern-quartering waves and wave-induced resistance in bow-quartering waves, yielding results that are similar to the core group of 3D panel methods.

In other conditions, a benchmark study of the characteristics was produced with the same trend line by using the Savitsky and Holtrop methods for the analysis the resistance of the hull (see Figure 6). The characteristics of benchmarking study can be seen in Table 1.

Table 1. Data design and characteristics of the benchmark study [30]

Parameters	Value	Unit	Savitsky	Holtrop
Length between waterline	70.03	m	70.03	70.03
Beam	13.50	m	13.50	13.50
Draft	6.70	m	-	6.70
Displacement	4024.16	m^2	4024.16	4024.16

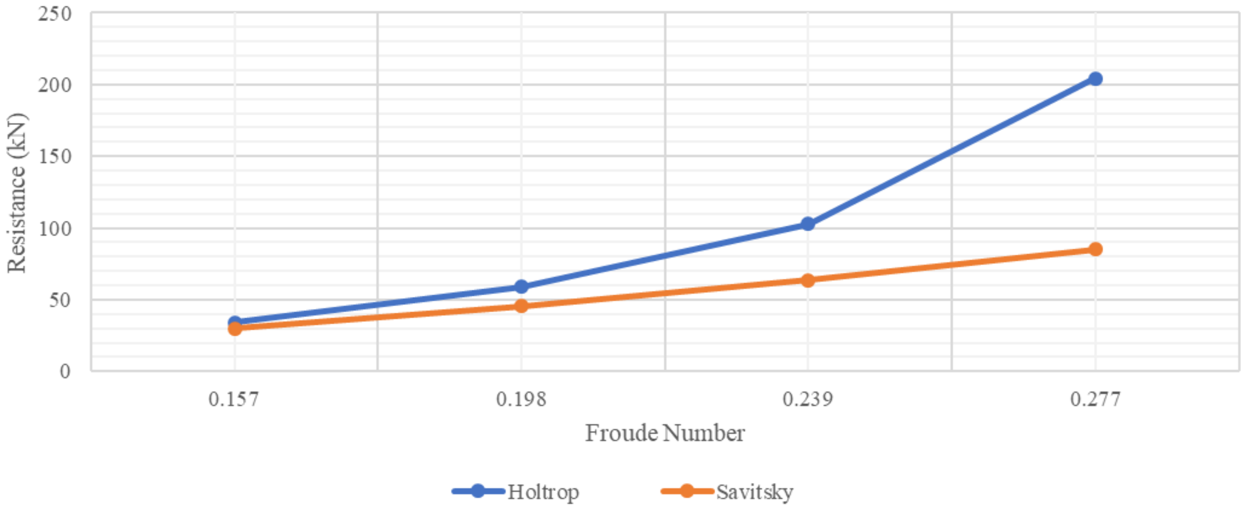


Figure 6. Comparison method of the total resistance [30]

3.2 Influence of scaled model on the simulation

Differences in force ratios between model and full-size ships cause scale effects. Only two dimensionless groups. The Froude and Reynolds numbers need to be identical, assuming one can accurately recreate geometrical and dynamical properties [31] which can be seen in Equations 1 and 2, correspondingly. Figure 7 describes a stronger relationship between the flow's Reynolds number and ΔC_T due to an inflectional roughness function of the steeper.

$$Fn = \frac{V}{(gL)} \tag{1}$$

$$Re = \frac{VL}{v} \tag{2}$$

where L is the ship's length, v is the viscosity, g is the acceleration caused by gravity, and V is the speed. The Froude number, which is connected to wave formation, is a measure of the ratio between gravitational and inertial forces. Conversely, the Reynolds number represents the proportion of viscous to inertial forces. It also indicates whether the flow is turbulent, transitional, or laminar.

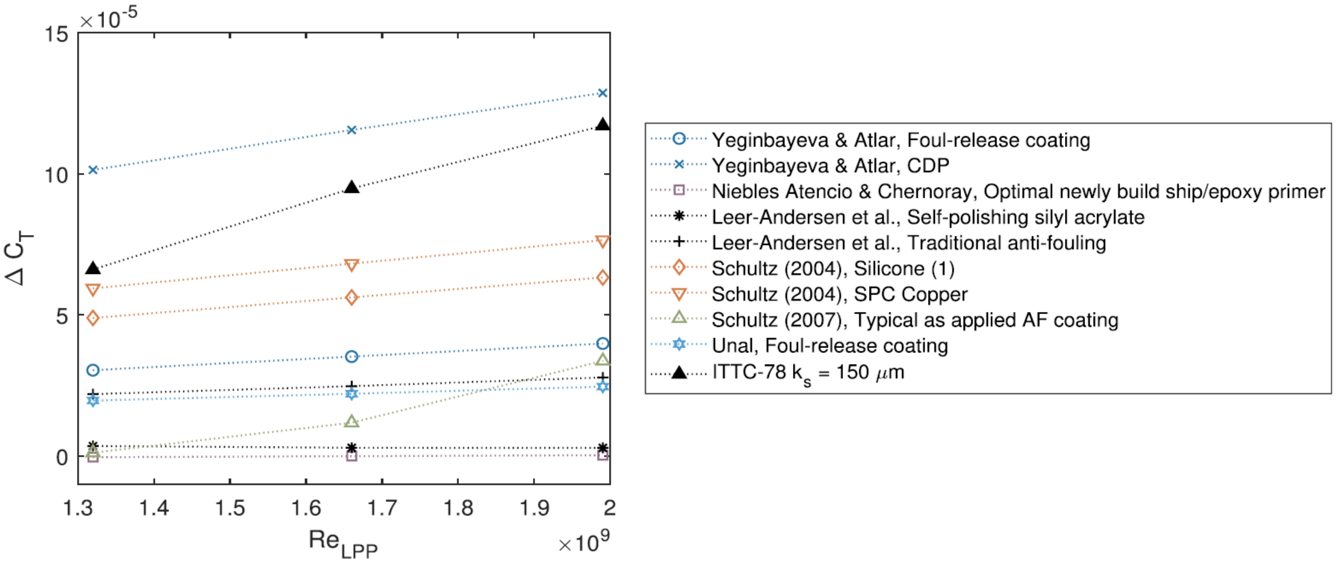
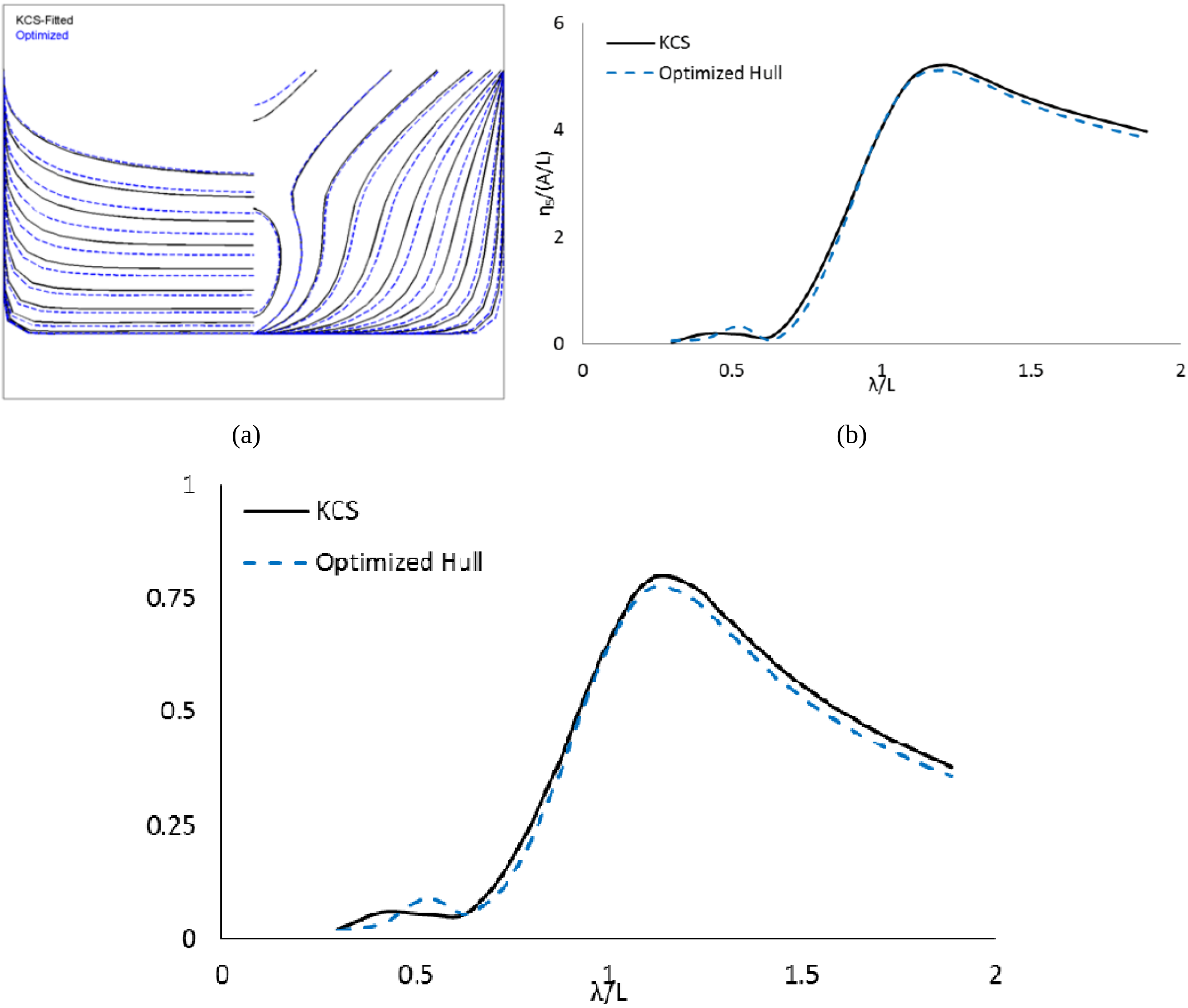


Figure 7. Additional resistance (ΔC_T) as a function of Reynolds number based on L_{PP} [31]

3.3 Optimization method on the simulation

The parameterization of the ship hull is dependent on several parameters. A semi-solid shape that is able to distort in any direction and still conform to a final shape that is perfect for all performance goals and limitations might be the most general situation that can be imagined [32]. It is still not possible to define in a meaningful mathematical form all the limitations pertaining to production capability, operational circumstances, and human-sought aesthetics and comfort. As a result, most researchers choose a very pragmatic approach to define the ship's hull in terms of the specification provided by reputable naval architects and adjust the design variables to ensure that the majority of the ship's basic needs would be met organically. Figure 8 shows the forms, which rely on primary particulars like length, breadth, draft, prismatic coefficient, center of floatation, etc., were used in this example to describe the hull form.



(a) (b)

(c)

Figure 8. Comparison between Korea Research Institute of Ships & Ocean (KRISO) engineering Container Ship (KCS) and optimized hulls; (a) Body plan of initial KCS, (b) Pitch amplitude, (c) Bow acceleration [33]

The other work findings show that the ideal hull form obtained a relative drag that is lower by 8.07% at = 0.27 *Fr*, higher by 14.5% at = 0.32 *Fr*, and higher by 3.8% at = 0.22 *Fr* when compared to the original hull. The outcomes of the basic CFD tool-based optimization tools are in line with the trend that the high-fidelity solver projected. It can be seen in Figure 9.

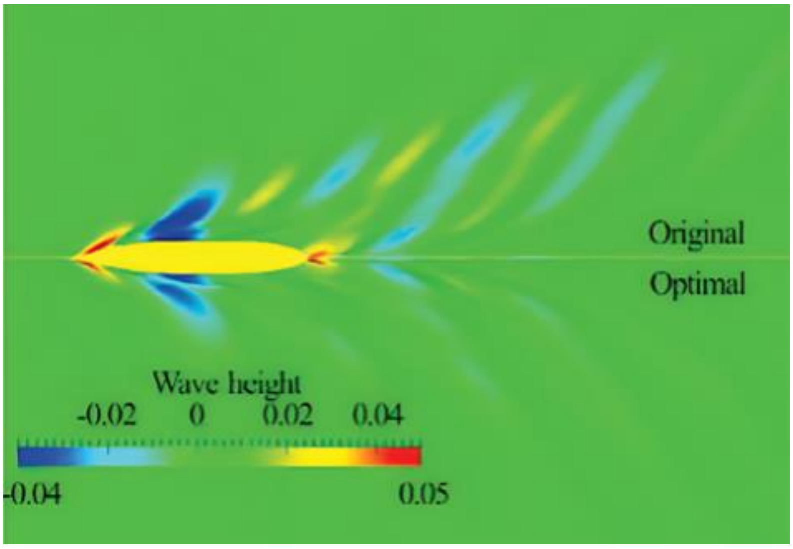


Figure 9. Comparison of wave pattern between the original hull and optimized hull on the *Fr* = 0.32 [34]

4 Conclusions

A number of assessments were carried out regarding how hull-form adjustments affect the hydrodynamics performance using a numerical analysis. The numerical analysis demonstrates robustness in comparison to the experiment. Several strategies have been used as representative cases to discuss the analysis using the numerical approach. It has been demonstrated that the numerical findings closely match the experimental data. Every part of the inquiry was carried out, and the outcomes were generally in agreement. As a result, the numerical technique is slightly different from the experimental result. It can be proven by comparing simulation results with error gaps of less than 5% to experimental data. This means that the validation of the numerical technique's reach is satisfied. Deploying calculation using the ship design selection method, it is found that the factors that significantly influence hydrodynamic performances are the form of the ship's bow. Water flows through a ship differently depending on its stern form. The degree of resistance will vary depending on the flow's form. Designing a stern form that meets the requirements of the crew boat is, therefore crucial. There are numerous stern form variations that can be employed when constructing a ship. The most popular aft design is the aft transom shape. To improve the effectiveness of the propulsion system, a ship trim controller can be fitted in addition to this shape.

5 Acknowledgments

The author would like to thank the Universitas Negeri Semarang, Indonesia, for supporting the research.

References

1. E. Sariöz, "An optimization approach for fairing of ship hull forms," *Ocean Eng.*, vol. 33, no. 16, pp. 2105-2118, 2006.
2. L. Lan, Y. Sun, and W. Luo, *An application of a multi-objective evolutionary strategy to the ship hull form optimization - in Maritime Technology and Engineering 5 Volume 1*, Florida: CRC Press, 2021.
3. Y. Lu, X. Chang, X. Yin, Z. Li, and others, "Hydrodynamic design study on ship bow and stern hull form synchronous optimization covering whole speeds range," *Math. Probl. Eng.*, vol. 2019, article no. 2356369, 2019.
4. D. Villa, F. Furcas, J. O. Pralits, G. Vernengo, and S. Gaggero, "An effective mesh deformation approach for hull shape design by optimization," *J. Mar. Sci. Eng.*, vol. 9, no. 10, article no. 1107, 2021.
5. Z. C. Hong, Z. Zong, H. T. Li, H. Hefazi, and P. K. Sahoo, "Self-blending method for hull form modification

and optimization," *Ocean Eng.*, vol. 146, pp. 59-69, 2017.
6. E. Rotteveel, R. Hekkenberg, and A. van der Ploeg, "Inland ship stern optimization in shallow water," *Ocean Eng.*, vol. 141, pp. 555-569, 2017.
7. J. Čerka, R. Mickevičienė, Ž. Ašmontas, L. Norkevičius, T. Žapnickas, V. Djačkov, and P. Zhou, "Optimization of the research vessel hull form by using numerical simulaton," *Ocean Eng.*, vol. 139, pp. 33-38, 2017.
8. R. Deng, D. Huang, L. Yu, X. K. Cheng, and H. G. Liang, "Research on factors of a flow field affecting catamaran resistance calculation," *J. Harbin Eng. Univ.*, vol. 32, no. 2, pp. 141-147, 2011.
9. X. Cheng, B. Feng, Z. Liu, and H. Chang, "Hull surface modification for ship resistance performance optimization based on Delaunay triangulation," *Ocean Eng.*, vol. 153, pp. 333-344, 2018.
10. K. Suzuki, H. Kai, and S. Kashiwabara, "Studies on the optimization of stern hull form based on a potential flow solver," *J. Mar. Sci. Technol.*, vol. 10, no. 2, pp. 61-69, 2005.
11. X. Liu, W. Zhao, and D. Wan, "Linear reduced order method for design-space dimensionality reduction and flow-field learning in hull form optimization," *Ocean Eng.*, vol. 237, article no. 109680, 2021.
12. D. W. Park and H. J. Choi, "Hydrodynamic Hull Form Design Using an Optimization Technique," *Int. J. Ocean Syst. Eng.*, vol. 3, no. 1, pp. 1-9, 2013.
13. G. J. Grigoropoulos, C. Bakirtzoglou, G. Papadakis, and D. Ntouras, "Mixed-fidelity design optimization of hull form using CFD and potential flow solvers," *J. Mar. Sci. Eng.*, vol. 9, no. 11, article no. 1234, 2021.
14. L. Wang, F. Huang, C. Yang, and R. Datla, *Hydrodynamic optimization of a wedge hull - in SNAME International Conference on Fast Sea Transportation*, New Jersey: Society of Naval Architects and Marine Engineers, 2015.
15. S. Percival, D. Hendrix, and F. Noblesse, "Hydrodynamic optimization of ship hull forms," *Appl. Ocean Res.*, vol. 23, no. 6, pp. 337-355, 2001.
16. K. Hochkirch and C. Fassardi, *Analysis of wave making resistance and optimization of canting keel bulbs - in SNAME Chesapeake Sailing Yacht Symposium*, New Jersey: Society of Naval Architects and Marine Engineers, 2007.
17. A. Bahatmaka, E. S. Hadi, and I. P. Mulyanto, "Studi Perancangan Lambung Small Waterplane Area Twin Hull (SWATH) Kapal Protector Dengan Sistem Unmanned Surface Vehicle (USV) Untuk Perairan Ambalat," *Jurnal Teknik Perkapalan.*, vol. 2, no. 1, pp. 13-20, 2014.
18. M. Ahmadzadehtalatapeh and M. Mousavi, "A Review on the Drag Reduction Methods of the Ship Hulls for Improving the Hydrodynamic Performance," *Int. J. Marit. Technol.*, vol. 4, pp. 51-64, 2015.
19. D. Pan, X. Xu, B. Liu, H. Xu, and X. Wang, "A review on drag reduction technology: Focusing on amphibious vehicles," *Ocean Eng.*, vol. 280, article no. 114618, 2023.
20. S. Kumar, K. A. Verma, K. M. Pandey, and K. K. Sharma, "A review on methods used to reduce drag of the ship hulls to improve hydrodynamic characteristics," *Int. J. Hydromechatronics*, vol. 3, no. 4, pp. 297-312, 2020.
21. F. Pacuraru, A. Mandru, and A. Bekhit, "CFD study on hydrodynamic performances of a planing hull," *J. Mar. Sci. Eng.*, vol. 10, no. 10, article no. 1523, 2022.
22. W. U. Hao, O. U. Yongpeng, and Y. E. Qing, "Experimental study of air layer drag reduction on a flat plate and bottom hull of a ship with cavity," *Ocean Eng.*, vol. 183, pp. 236-248, 2019.
23. J. Todd and P. E. Peltzer, "Lifting Body Technology for Transformational Ship Designs," in *9th Naval Platform Technology Seminar*, Singapore, Singapore, 2003.
24. M. P. Wheeler, K. I. Matveev, and T. Xing, "Numerical study of hydrodynamics of heavily loaded hard-chine hulls in calm water," *J. Mar. Sci. Eng.*, vol. 9, no. 2, article no. 184, 2021.
25. M. Mansoori, A. C. Fernandes, and H. Ghassemi, "Interceptor design for optimum trim control and minimum resistance of planing boats," *Appl. Ocean Res.*, vol. 69, pp. 100-115, 2017.
26. R. K. Praja, D. Chrismianto, M. L. Hakim, A. Fitriadhy, and A. Bahatmaka, "Advancing Interceptor Design: Analyzing the Impact of Extended Stern Form on Deep-V Planing Hulls," *CFD Lett. Int. J.*, vol. 16, no. 5, pp. 59-77, 2024.
27. H. Yasukawa and Y. Yoshimura, "Introduction of MMG standard method for ship maneuvering predictions," *J. Mar. Sci. Technol.*, vol. 20, no. 1, pp. 37-52, 2015.
28. Y. Tominaga, A. Mochida, S. Murakami, and S. Sawaki, "Comparison of various revised k-ε models and LES applied to flow around a high-rise building model with 1:1:2 shape placed within the surface boundary layer," *J. Wind Eng. Ind. Aerodyn.*, vol. 96, no. 4, pp. 389-411, 2008.

29. V. Shigunov, O. E. Moctar, A. Papanikolaou, R. Potthoff, and S. Liu, “International benchmark study on numerical simulation methods for prediction of manoeuvrability of ships in waves,” *Ocean Eng.*, vol. 165, pp. 365-385, 2018.
30. A. Bahatmaka, M. Y. Wibowo, A. A. Ghyfery, M. Harits, S. Anis, D. F. Fitriyana, R. F. Naryanto, A. Setiyawan, R. Setiadi, A. R. Prabowo, and K. D. Joon, “Numerical Approach of Fishing Vessel Hull Form to Measure Resistance Profile and Wave Pattern of Mono-Hull Design,” *J. Adv. Res. Fluid Mech. Therm. Sci.*, vol. 104, no. 1, pp. 1-11, 2023.
31. J. Andersson, D. R. Oliveira, I. Yeginbayeva, M. Leer-Andersen, and R. E. Bensow, “Review and comparison of methods to model ship hull roughness,” *Appl. Ocean Res.*, vol. 99, article no. 102119, 2020.
32. T. C. Smith, D. A. Walden, W. L. Thomas III, *Improvement of destroyer performance through optimized seakeeping design - International Conference on Interaction between Naval Weapon Systems and Warship Design*, London: Royal Institution of Naval Architects, 1990.
33. A. Guha and J. Falzaranoa, “Application of multi objective genetic algorithm in ship hull optimization,” *Ocean Syst. Eng.*, vol. 5, no. 2, pp. 91-107, 2015.
34. F. Huang and C. Yang, “Hull form optimization of a cargo ship for reduced drag,” *J. Hydrodyn.*, vol. 28, no. 2, pp. 173-183, 2016.