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Investigation of Planing Hull Resistance Calculation Using Smoothed Particle Hydrodynamics

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***Abstract* –Over the decades, advancements in computer technology have significantly contributed to the development of numerical methods, including computational fluid dynamics (CFD). CFD encompasses two primary approaches: mesh-based and mesh-free methods. While mesh-based methods are well-established and widely used for analyzing free-surface flows, such as ship resistance, mesh-free methods like smoothed particle hydrodynamics (SPH) have gained traction in real-world engineering applications. Despite its growing use, limited research has explored the application of SPH to ship resistance analysis. This study investigates the total ship resistance of a planing hull using the open-source SPH solver DualSPHysics. The research focuses on analyzing spray patterns and complex flow dynamics around the hull. DualSPHysics typically employs dynamic boundary conditions (DBC) as its standard boundary definition method. However, this study utilizes an advanced implementation of DBC, known as Modified Dynamic Boundary Conditions (mDBC), in conjunction with Project Chrono for enhanced simulation accuracy. The results demonstrate that SPH provides acceptable accuracy when compared to the Strip theory approach. Additionally, key parameters such as total force, sinkage, and trim are effectively reproduced using Project Chrono. This research highlights the potential of SPH, particularly with advanced boundary conditions, for ship resistance analysis and contributes to the growing body of knowledge in this field.**

Keywords: Planing hull, SPH, Resistance, mDBC, Project Chrono

I. INTRODUCTION

Predicting ship performance during the design phase is a critical aspect of ship production, with ship resistance calculation being one of the most important factors. Accurate resistance calculations directly influence the determination of the required propulsion power, which is essential for ensuring the ship's operational efficiency. Various methods are available to predict ship resistance, including analytical, experimental, and numerical approaches. In recent years, the rapid advancement of computer technology has made numerical methods increasingly popular, offering significant advantages over traditional analytical and experimental techniques.

Many studies has been carried out a numerical approach to calculate ship drag by employing computational fluid dynamics (CFD), mostly they used mesh based CFD such as volume of fluid (VOF) methods that However, mesh-based methods face challenges in handling large deformations and free-surface flows, often requiring specialized treatments to achieve accurate results. Beside the mesh based CFD there is a meshfree CFD, one of the major meshfree CFD is smoothed particle hydrodynamics (SPH). There are few researcher employed SPH for calculating ship resistance, though, the CFD mesh-based approach has good accuracy for predicting the free surface flows. The application CFD for the ship resistance and seakeeping were performed for planing and frigate hull [1]–[3] and also for ship propeller performance[4]–[6]. The results indicated the accuracy and the phenomenon are well reproduced by mesh-based CFD. However, the works of SPH approach has been applied to many engineering problems and has good accuracy such as ship resistance and submarine[7], [8], sloshing [9]–[11], water wave propagation [12]–[14] and the progress indicated has promising for free surface flow cases such as ship resistance.

Applying SPH to the aforementioned cases can be more challenging compared to other well-established methods, such as strip theory. This is primarily because SPH, as a particle-based approach, is relatively newer and less established. However, SPH is a significant mesh-free

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CFD method that has gained attention in recent years, particularly with the advent of parallel computing on GPUs, which has substantially reduced computational costs [15, 16]. These advancements suggest that SPH has the potential to become a next-generation CFD method. Despite its promise, there have been limited studies applying SPH in the field of naval engineering, especially for common applications in ship engineering cases [17-19]. This research gap highlights the need for further exploration, which the present study aims to address.

This study focuses on calculating ship drag, or resistance, for a planing hull using smoothed particle hydrodynamics (SPH). The open-source SPH solver DualSPHysics is employed to model the fluid domain, coupled with Project Chrono for enhanced simulation capabilities. The results indicate that the drag calculation for the planing hull exhibits oscillations due to the influence of lifting forces under planing conditions. Additionally, SPH effectively captures the ship's heave and pitch motions. However, further analysis, including validation and verification, is required in future work to achieve more precise and reliable calculations.

II. Method

Smoothed particle hydrodynamics (SPH) was developed for free surface problems by Monaghan for dam break and water wave propagation [20] and became popular for engineering problems. SPH is a mesh-free CFD based on the Lagrangian approach that to determine the physical value and derivatives of the continuous field using discrete evaluation points, employs an interpolation approach. In order to narrow down the range of the neighbor particles' contributions, the quantities are acquired as a weighted average from nearby particles inside the smoothing length (h), for detailed theory and references the reader can be found at https://github.com/DualSPHysics/DualSPHysics/wiki.

Table 1 shows the principal dimension for a planing hull used for SPH simulation based on Tounton et. al [21], where LoA, Lwl, Bwl, and T are length overall, length in the waterline, breadth in the water line, and draft ship, respectively. Fig. 1 illustrates the linesplan of planing hull model C1 based on [21]. Table 2 indicates the numerical setup for SPH computation, some of the setup is default on DualSPHyiscs for instance coefficient of sound (Coefsound) that has an impact on the pressure field in the calculation of impact pressure [22]. Coefh, CFL, and Delta-SPH are the coefficient of smoothing length, Courant Fredrichs Lewiy coefficient, and numerical diffusive terms to suppress pressure fluctuation, respectively. Detailed setup terms for the SPH computation reader can be seen in ref. [23], [24].

TABLE 1.
THE PRINCIPAL PARTICULAR OF PLANING HULL

Main Dimension (units in m)	
Loa	2.611
Lwl	2.400
Bwl	0.743
T	0.167
Displacement	106.07

TABLE 2.
PARAMETERS SETUP OF SPH SIMULATION

Parameters	
Kernel function	Wendland
Time step algorithm	Sympletic
Artificial viscosity coefficient (α)	0.02
Coefsound	20
Particle spacing (mm)	10
Coefh	1.2
CFL	0.2
Delta-SPH (δφ)	0.1
Simulation time (s)	4

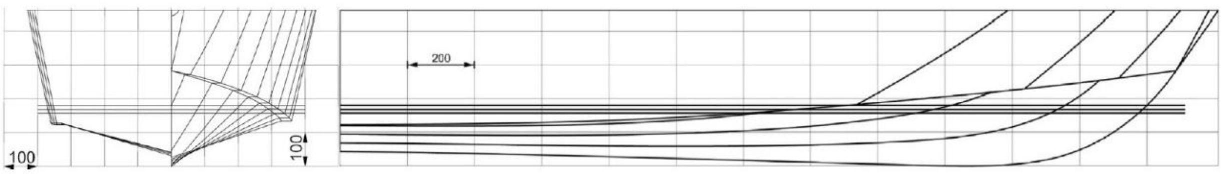

Figure 1. Linesplan of planing hull

III. RESULTS AND DISCUSSION

A planning hull ship is a small craft for high-speed craft that has unique characteristics for the effect of lifting force in high Froude numbers (Fr). This paper carries out the Fr 1.44, where Fr = $v/\sqrt{g*L}$, where, v, g, and L are speed velocity, gravity acceleration, and ship length perpendicular. Because we use Fr in planing mode as a result the ship has a lifting force during this condition.

Fig. 2 indicates the total force in the x-direction showed an oscillation in a positive direction. This phenomenon showed that the position of the center of gravity as a point of calculation force undergoes oscillation during this phase. The total resistance of a planing hull using strip theory in different conditions is shown in Fig. 3, which is Fr from displacement mode to planing condition showed in Fig. 3. The comparison of total drag that force acts in x-direction which is the same as total resistance in strip theory, the results showed SPH is 233 N and strip theory is 233.54 N which is nearly same, which is total resistance for SPH is stable in three cycle drag calculation after time 1.0 seconds. Future works of statistical calculation of SPH results need to be carried out for comprehensive validation and verification.

Fig. 4 indicates of heaving motion in the z-direction, in this paper, we tried to mimic of experimental situation, which is in a vertical direction in project chrono we put an axis that the ship can rotate and translation move. This is to reproduce the lifting force of the planing hull and ship motion during high Fr. It was showed the phenomena well reproduced by SPH and the results showed in Fig. 4 and 5 that heaving and pitch have similar patterns. In addition, the lifting condition illustrated in Fig. 6 clearly showed the spray effect of planing hull well reproduction compared to mesh-based CFD [1]–[3]

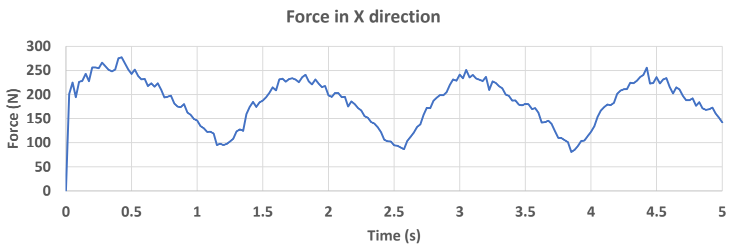

Figure 2. Total force in x-direction

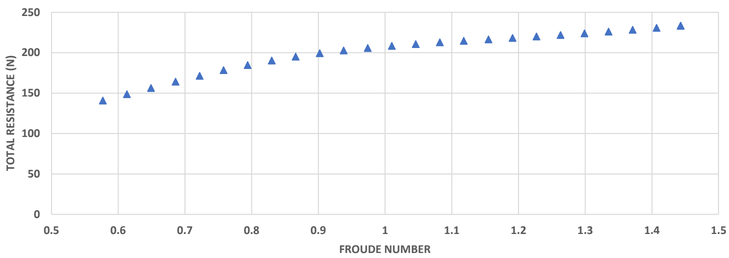

Figure 3. The total resistance of planing hull in different Fr

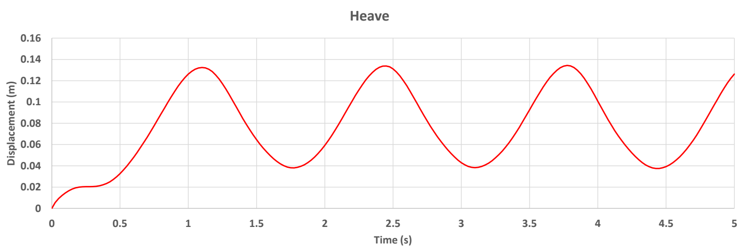

Figure 4. Heave motion of planing hull

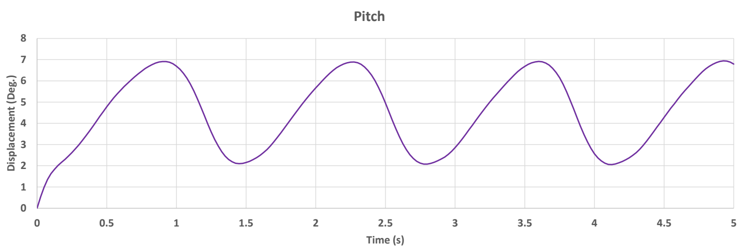

Figure 5. Pitch motion of planing hull

Figure 6. Velocity contour of planing hull

Fig. 7 illustrates the wave pattern of the planing hull using vorticity contour, the wave pattern indicated the nonlinear form of eddy wake compared with displacement ship that turbulence prominent in planing hull wake. Fig. 8 shows the pressure contour of the planing hull in a planing condition in this situation pressure field in the ship hull is caused by water impact in the hull during in lifting condition. The pressure contour clearly showed the pressure noise as a nature of weakly compressible SPH although Delta-SPH has been used. Finally, advanced visualization of CFD-post processing is presented by using VisualSPHysics [25] an add-on in Blender software https://www.blender.org/.

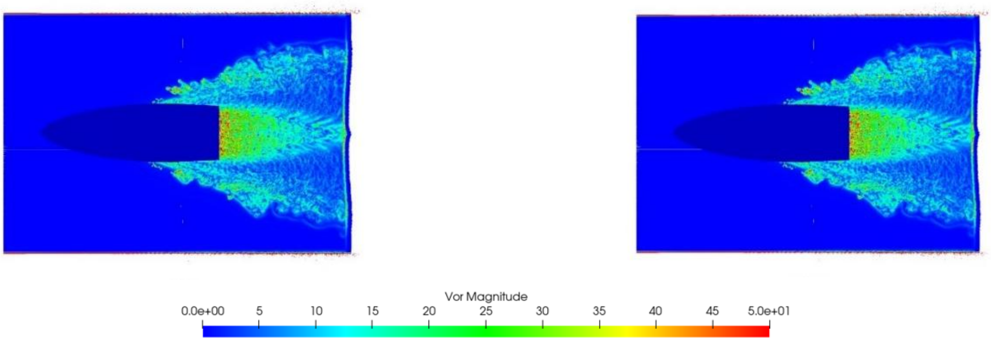

Figure 7. Vorticity contour of planing hull

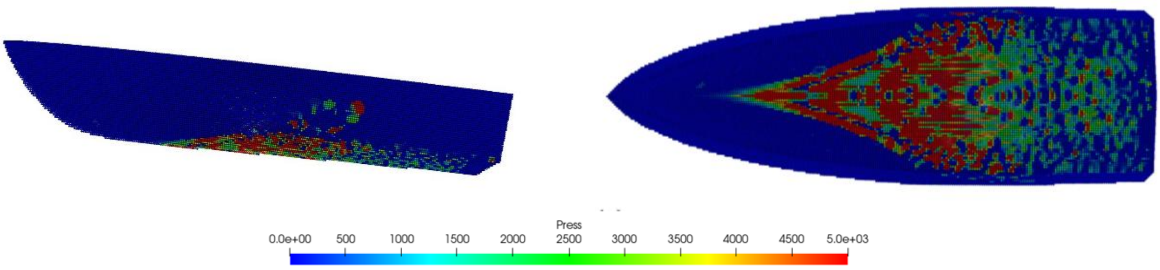

Figure 8. Pressure contour of planing hull

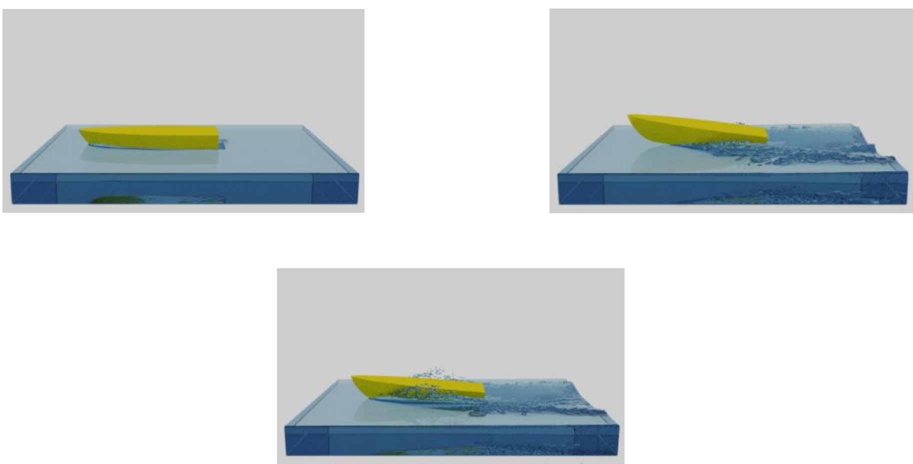

Figure 9. Advanced post-processing with time 0.0 s, 2.0 s, and 3.0 s

IV. CONCLUSIONS

The present study demonstrates that the resistance calculation for a planing hull can be successfully performed using smoothed particle hydrodynamics (SPH), despite some oscillations in the results. These oscillations occur because the planing hull experiences significant lifting forces at high Froude numbers. SPH has shown promising accuracy in ship resistance calculations, as evidenced by benchmarking studies against strip theory. Additionally, SPH effectively captures ship motions and reproduces the spray effects characteristic of high-speed crafts. For future work, further validation and verification of SPH are needed by comparing its performance with other methods to ensure comprehensive accuracy in ship resistance and performance analysis.

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REFERENCES

[1] A. Trimulyono, M. L. Hakim, C. Ardhan, S. T. P. Ahmad, T. Tuswan, and A. W. B. Santosa, "Analysis of the double steps position effect on planing hull performances," *Brodogradnja*, vol. 74, no. 4, pp. 41–72, 2023.

[2] Samuel, A. Trimulyono, P. Manik, and D. Chrismianto, "A numerical study of spray strips analysis on fridsma hull form," *Fluids*, vol. 6, no. 11, 2021.

[3] S. Samuel *et al.*, "Investigation of An Inverted Bow on Frigate Hull Resistance," *J. Appl. Fluid Mech.*, vol. 17, no. 1, pp. 136–147, 2024.

[4] A. Trimulyono, I. P. Mulyatno, and A. F. Rachmat, "The Effect of Mewis Duct Energy Saving Device to Propeller Performance," in *IOP Conference Series: Earth and Environmental Science*, 2022, vol. 1098, no. 1.

[5] A. Trimulyono, A. B. Jatmiko, I. P. Mulyatno, and H. Yudo, "The effect of propeller cap angle and fin size of PBCF on propeller performance," in *IOP Conference Series: Earth and Environmental Science*, 2022, vol. 972, no. 1.

[6] I. E. Sandjaja, I. M. Ariana, E. Erwandi, Mahendra Indiaryanto, M. Muryadin, and B. A. Adietya, "Numerical Analysis of the Effects of Propeller High Thrust Distribution on Propulsion Sytem Performance," *Kapal: J. Ilmu Pengetah. dan Teknol. Kelaut.*, vol. 20, no. 3, pp. 309–319, 2023.

[7] S. R. C. Mogan, D. Chen, J. W. Hartwig, I. Sahin, and A. Tafuni, "Hydrodynamic analysis and optimization of the Titan submarine via the SPH and Finite–Volume methods," *Comput. Fluids*, vol. 174, pp. 271–282, 2018.

[8] S. Capasso *et al.*, "Regular Wave Seakeeping Analysis of a Planing Hull by Smoothed Particle Hydrodynamics: A Comprehensive Validation," *J. Mar. Sci. Eng.*, vol. 11, no. 4, 2023.

[9] A. Trimulyono, D. Chrismianto, H. Atthariq, and Samuel, "Numerical Simulation Low Filling Ratio of Sway Sloshing in the Prismatic Tank Using Smoothed Particle Hydrodynamics," *CFD Lett.*, vol. 14, no. 7, pp. 113–123, 2022.

[10] A. Trimulyono, S. T. M. Owhaamsorrc Gultom, E. S. Hadi, and D. B. Purwanto, "Investigation of Sloshing with Vertical and Horizontal Baffle in the Prismatic Tank using Meshfree CFD," *CFD Lett.*, vol. 15, no. 6, pp. 115–129, 2023.

[11] A. Trimulyono, H. Hashimoto, and A. Matsuda, "Experimental validation of single- and two-phase smoothed particle hydrodynamics on sloshing in a prismatic tank," *J. Mar. Sci. Eng.*, vol. 7, no. 8, 2019.

[12] M. A. Salvikran, A. Trimulyono, and E. S. Hadi, "Validation of multiphase water wave propagation using smoothed particle hydrodynamics," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1166, no. 1, p. 012032, 2023.

[13] A. Trimulyono and H. Hashimoto, "Experimental Validation of Smoothed Particle Hydrodynamics on Generation and Propagation of Water Waves," *J. Mar. Sci. Eng.*, vol. 7, no. 1, p. 17, 2019.

[14] A. Trimulyono and A. Wicaksono, "Simulasi numerik large-deformation surface wave dengan smoothed particle hydrodynamics," *Kapal: Jurnal Ilmu Pengetah. dan Teknol. Kelaut.*, vol. 15, no. 3, pp. 102–106, 2019.

[15] A. C. Crespo, J. M. Dominguez, A. Barreiro, M. Gómez-Gesteira, and B. D. Rogers, "GPUs, a new tool of acceleration in CFD: efficiency and reliability on smoothed particle hydrodynamics methods.," *PLoS One*, vol. 6, no. 6, 2011.

[16] J. M. Domínguez, A. J. C. Crespo, D. Valdez-Balderas, B. D. Rogers, and M. Gómez-Gesteira, "New multi-GPU implementation for smoothed particle hydrodynamics on heterogeneous clusters," *Comput. Phys. Commun.*, vol. 184, no. 8, pp. 1848–1860, 2013.

[17] S. R. C. Mogan, D. Chen, J. W. Hartwig, I. Sahin, and A. Tafuni, "Hydrodynamic analysis and optimization of the Titan submarine via the SPH and Finite–Volume methods," *Comput. Fluids*, vol. 174, pp. 271–282, 2018.

[18] K. Kawamura, H. Hashimoto, A. Matsuda, and D. Terada, "SPH simulation of ship behaviour in severe water-shipping situations," *Ocean Eng.*, vol. 120, pp. 220–229, 2016.

[19] H. Mutsuda, T. Kanehira, K. Kawawaki, Y. Doi, and H. Yasukawa, "Occurrence of stern slamming pressure and its characteristics in following irregular waves," *Ocean Eng.*, vol. 170, pp. 222–236, 2018.

[20] J. J. Monaghan, "Simulating Free Surface Flows with SPH," *J. Comput. Phys.*, vol. 110, no. 2, pp. 399–406, 1994.

[21] D. J. Taunton, D. A. Hudson, and R. A. Shenoi, "Characteristics of a series of high speed hard chine planing hulls – Part 1: Performance in calm water," *Trans. R. Inst. Nav. Archit. Part B Int. J. Small Cr. Technol.*, vol. 152, pp. 55-75., 2010.

[22] A. Mokos, B. D. Rogers, and P. K. Stansby, "A multi-phase particle shifting algorithm for SPH simulations of violent hydrodynamics with a large number of particles," J. Hydraul. Res., vol. 1686, pp. 1–20, 2016.

[23] A. J. C. Crespo *et al.*, "DualSPHysics: Open-source parallel CFD solver based on Smoothed Particle Hydrodynamics (SPH)," *Comput. Phys. Commun.*, vol. 187, pp. 204–216, 2015.

[24] J. M. Domínguez *et al.*, "DualSPHysics: from fluid dynamics to multiphysics problems," *Comput. Part. Mech.*, 2021.

[25] O. García-Feal, A. J. C. Crespo, and M. Gómez-Gesteira, "VisualSPHysics: advanced fluid visualization for SPH models," *Comput. Part. Mech.*, vol. 9, no. 5, pp. 897–910, 2022.