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Interceptor Impact on the Step Planing Hull: A Computational Investigation

[1] Serliana Yulianti, [2] Iqbal Hibni Riqwan, [3] Jefri Tanjung Wibisono, [4] Sunho Park

[1] [2] [3] Department of Naval Architecture, Faculty of Engineering, Universitas Diponegoro, Semarang Indonesia
[4] Department of Ocean Engineering, Korea Maritime and Ocean University, Busan, Taejong-ro, Yoengdo-gu, South Korea
Corresponding Author Email: [1] serliana.yuliantii@gmail.com, [2] hibniiqbal@gmail.com, [3] irfejwibisono@gmail.com, [4] spark@kmou.ac.kr

Abstract*— Studies have shown that step modifications support the planing hull's ability to accelerate quickly; nevertheless, it also produces excessive drag and creates the hump area extremely trim. Engaging integrated with the interceptor will improve the efficiency of the step hull. Planing hull interceptors are placed at the transom stern to regulate the trim angle and reduce movements caused by seas. This study is focused on the effects of step hulls with interceptors on pressure distribution and how they affect the planing hull's drag, heave, and trim. The environment was modeled according to the two-degree of freedom condition to simulate trim and heave. A combination of an overset mesh and the Finite Volume Method (FVM), the Reynolds-Averaged Navier-Stokes equation, was used to evaluate this study. The water and air phases are represented by the turbulent K- and VOF (Volume of Fluid) models. The errors driven by grid spacing and time-step have been estimated using grid convergence studies. The numerical approach was tested experimentally by Park et al. to ensure accuracy. It has been determined through calculations of the drag, trim, and heave results that adding an interceptor to a step vessel is extremely valuable for minimizing drag and controlling trim.

***Keyword*— interceptor, numerical simulation, step hull.**

I. INTRODUCTION

A planing hull is a type of highspeed craft with quite extreme ship behavior. Changes in trim angle caused a significant effect on increasing ship drag.

Several studies have modeled additional equipment to improve ship performance while reducing ship resistance, one of which is using a step hull. The step hull can reduce the ship's wetted surface area and increase pressure toward the maximum level in a particular area. Wake profile resulted from empirical equation compared with Computational Fluid Dynamic (CFD) method illustrated a perfect consistency concluding using step hull [1]. A step planing hull can also reduce ship resistance when compared to ships without a step hull.

By contrast, in another conditions, step hull created excessive drag dan extremely trim [1] [2]. They also showed a small effect of step on a dynamic trim angle [3]. The conventional step planing hull because it is prone to showing instability[4]. When the high speed the ship will experience porpoising and potentially experience capsizing. The craft will turn abruptly and perhaps capsize when the speed reduces quickly. Engineers provide enormously on several occasions, and a select few additionally offer air pathways through ducts stretching to the rear vertical edge of the steps and inlets to the areas behind the steps [5][6][7]. They showed less drag from step hulls compared to bare hull condition.

Research on interceptors applied to highspeed craft preserve improve ship resistance and increase stability while reducing cases of fast boat porpoising. Several studies on interceptors have discovered. In the research explained that the interceptor reduce heave and pitch by 41.3% and 33.4%, respectively[8].

Hydrodynamic analysis with numerical calculations using two transverse step with different heights invented using ANSYS CFD with the k epsilon model. The study found that the ship can reduce drag and pressure distribution and created moderate performance [9].

The lift generated is primarily used in static conFigureurations and impacts the vessel's trim. By dynamically adjusting the interceptor's height, it is also used to regulate the speed of the high-speed craft in waves actively [10]. Their study recommended using two distinctive, alternative interceptors that offer significant results in drag reduction and the increased velocity range where the interceptors are especially effective [11].

This study uses of the step hull conFigureuration to determine the drag, heave and trim behavior on the bottom of the ship. This study uses the overset mesh method with free heave and trim conditions. Validation of bare hull conditions has induced by comparing the results between the experiment [8] with the CFD simulation. Validation and verification had analyzed with ITTC recommendation and grid independence studies.

II. METHOD

A. Research Object

This research uses an Aragon-2 type deep v planing hull. Experimental testing has been obtained by Park [8] at the Seoul National University towing tank. The main dimensions of the Aragon-2 and modification of step hull had shown in table 1. The size of the appendages consisting of the interceptor and step hull can has shown in Figure 1.

B. Research Method

This study was performed according to the International Towing Tank Conference (ITTC), which attempted to evaluate the degree of CFD accuracy. The following are a few of the ITTC [12] recommendations in this situation for predicting high-speed craft resistance:

Table 1. Main dimensions of the ship and the interceptor

Dimension	Model scale 1/5.33	Unit
Length overall (L_{OA})	1.5	m
Length waterline (L_{WL})	1.4	m
Breadth overall	0.4	m
Draft	0.08	m
Weight	19.77	Kg
Interceptor height (hi)	0.09	m
Interceptor span (s)	0.56	m
Chine breadth	4	m
Longitudinal step-A (from rear)	0.85	m
Longitudinal step-B (from rear)	0.65	m
Height of step (Hs)	0.008	m
Center of gravity from transom (L_{CG})	0.5	m
Center of gravity from baseline ($\overline{KG}$)	0.014	m
Deadrise angle	16 at transom, 24 at midship	deg

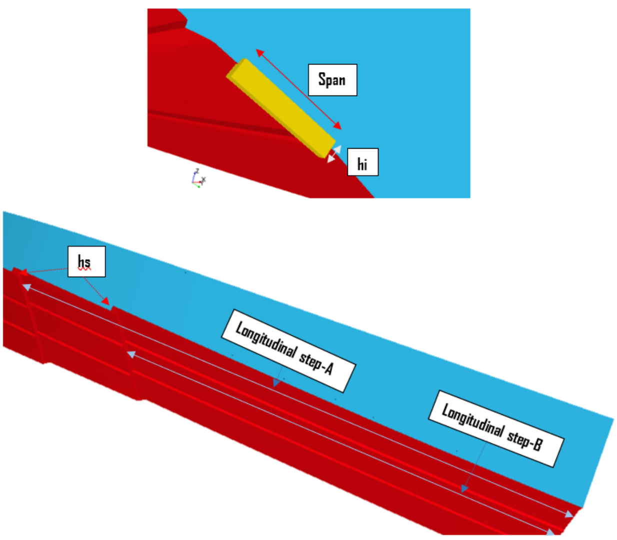

Figure 1. Main Objective Research

1. Size of the computational domain
2. Mesh density
3. Convergence
4. The time step
5. The ship's wall grid (y+)

Verifying the geometry's accuracy is essential to guaranteeing that the surface definitions are reasonably smoot within a predetermined tolerance. The geometry tolerances should be determined based on the length between perpendiculars (L_{PP}), with a suitable range being 1 L_{PP} 10. Figure 2 shows the representation of computational regions and boundary conditions. Between 2.5 and 1 were the domain lengths that we measured. The visualization, as stated above, displayed turbulent flow behind the ship's transom using coordinates of the zero point at the ship's stern and the ship's draught. The sea was two and one ship in depth. The input velocity condition was found to be in the x-negative direction. The positive x-direction was simulated as an outlet pressure to find the static pressure at the outlet. In order to represent the existence of limitless air, the input velocity was adjusted to the optimum number. However, the lower limit was chosen as the no-slip wall to justify the sea boundaries' existence. The ship's symmetry allowed for the modeling of only half of it, which cut down on processing time.

The time increment served as a representation of the interval between iterations. The time step was calculated from the Courant-Friedrichs-Lewy number, which indicates the number of sites the fluid particles visited during the time interval. The time step used in this research had a physical time range of 0.008 to 10 s.

The main challenge conducting a numerical study was verified the analytical results of the experimental method. To ensure that the numerical simulation steps are correct, we perform each CFD set-up based on the recommendations of the ITTC (International Towing Tank Conference) and a grid independence study.

It is Figured that the fluid is viscous and incompressible. The RANS equation functions with the principle of conservation of mass and velocity.

Two-phase flow resolution was using the VOF technique. Calculating the ratio of the volume function F between two distinct phases is the fundamental principle for the VOF method. It can be formulated as follows:

$$F = \frac{\delta F}{\delta t} + u\frac{\delta F}{\delta x} + v\frac{\delta F}{\delta y} + w\frac{\delta F}{\delta z} = 0$$

With u,v, and w are velocity components.

In this study, DFBI is set to define two degrees of freedom of the ship including heave and trim in calm water conditions. Mathematically it can be formulated as follows:

$$\vec{F} = m\frac{d^2\vec{X}}{dt^2}$$

$$\vec{M} = \frac{d}{dt}\left(I\frac{d\vec{\theta}}{dt}\right)$$

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where $\vec{X}$ the linear and $\vec{\theta}$ is angular displacement. It is the inertia mass matrix of the hull around the gravity centre.

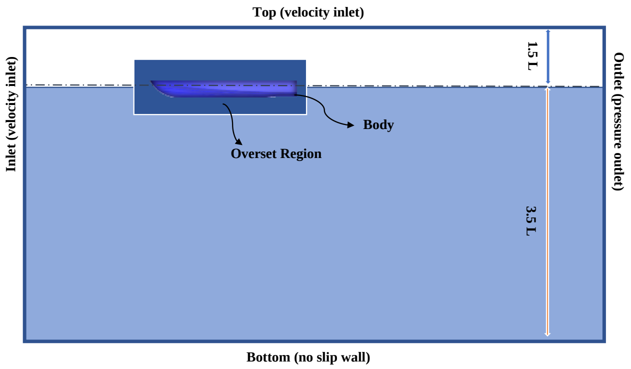

Figure 2. Computational Domain and Boundary Condition

Variations in mesh density were used, as shown in Figure 3. Mesh size variations were made to observe the challenging area. Due to the wash waves produced by the ship's speed, the density level of the mesh was concentrated on the available surface water and the stern of the vessel. The donor-acceptor mesh failure may also be influenced by the mesh density degree. Exceptionally high mesh densities need lengthy computations, so it is necessary to investigate mesh densities to be used appropriately.

The overset grid is used to express the movement of the ship that involves fluid-structure interaction. Overset domain were used as described in Figure 4. Overset require a lot of grids to ensure the donor-acceptor cell can run properly. At least there is background as a donor and an overset as an acceptor. The information transfer process is carried out in the overlapping area between the background-overset. Therefore, this method takes a lot of time for the required grid. However, overset is more effective in terms of calculation accuracy than other available methods.

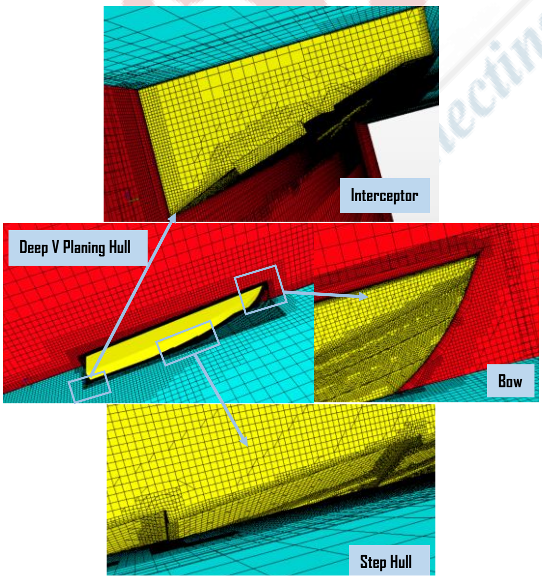

Figure 3. Mesh Density

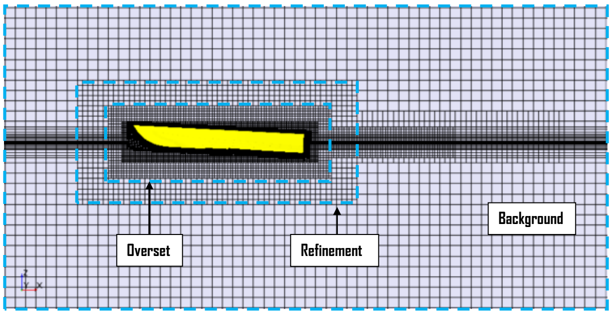

Figure 4. Overset domain

III. RESULT AND DISCUSSION

A. Study of Grid Independence

To choose the best mesh amount for each simulation, grid independence research was carried out. To ensure the accuracy of VOF definition in capturing fluid on the free surface, the mesh is analyzed with the help of volumetric control with an anisotropic refinement scheme. Grid study compared five different mesh sizes to the ship's drag, trim, and heave values. ITTC-based time step was used for the analysis [12]. Each grid generated a highly convergent number due to the analysis, with grids 4 and 5 producing the most convergent outcomes. Because it needs an extended amount of time to complete one simulation calculation on grid number 5, grid number 4 was used for all simulations. The simulation's outcomes for observing.

B. Verification

The CFD simulation involves compared with the Park et al. experiment to obtain results with an adequate degree of accuracy [8]. In both the CFD and the experiment, the trim, heave, and drag values follow the same pattern. The effectiveness of the CFD method is shown in Figure 6. The calculation assumes a discrepancy of 7.5% to 9.9%.

C. Simulation results

Figure 7 shows drag value by step hull with and without interceptor, and bare hull condition of the planing hull. The simulation was tracked between Froude number 0.29 and 1.74. It can be seen that the usage of step hull with interceptor has been the highest drag value at planing phase.

Trim can be reduced by modification of step hull with interceptor in the condition of the hump region. However, this condition does not have a significant impact on changes in the drag value of this research variation. Meanwhile, the improvement of the heave value occurs in the pre-planing, hump region, and planing phases.

Figure 8 shows the pressure that the interceptor and step hull influenced on the ship's bottom. The impact of the Froude number on the pressure the opponent generates was depicted. The increase in the ship's Froude number was contrary to a rise in pressure.

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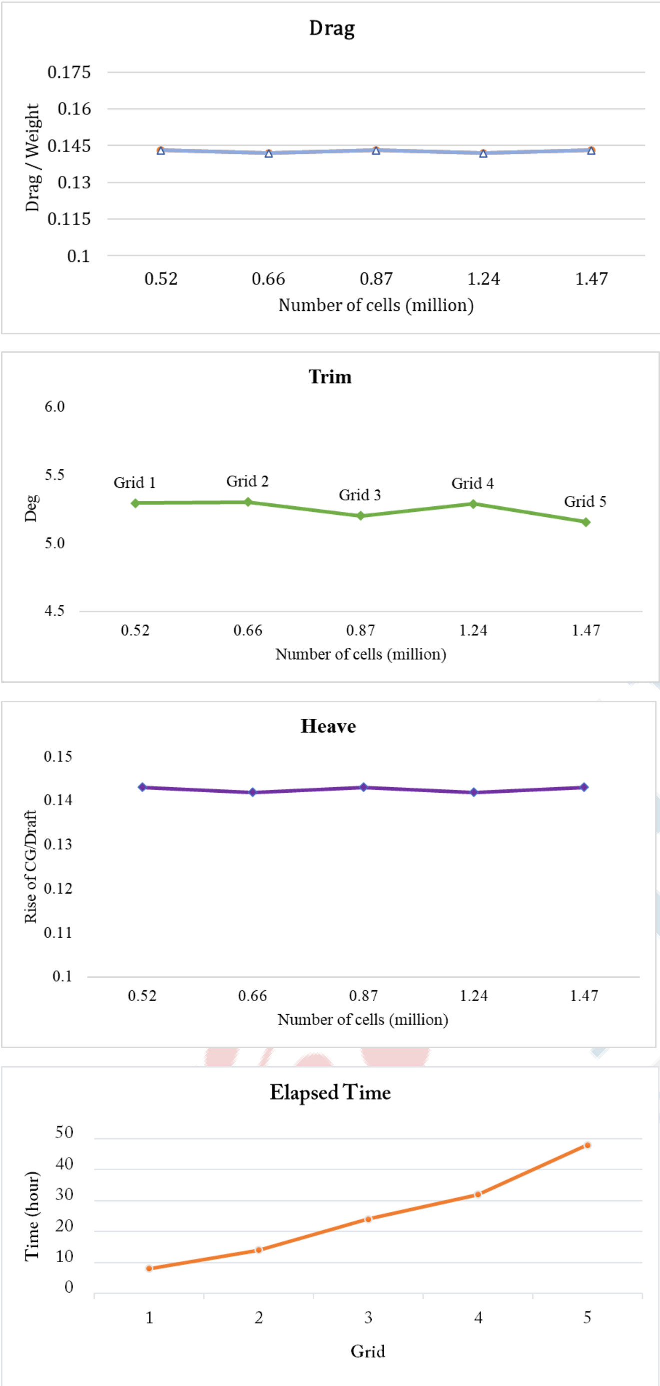


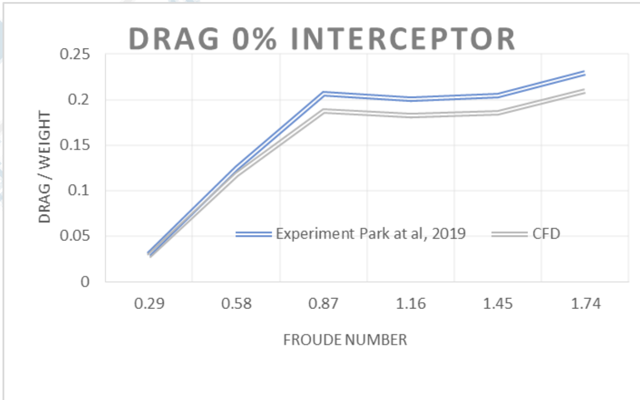
Figure 5. Grid Independence Study

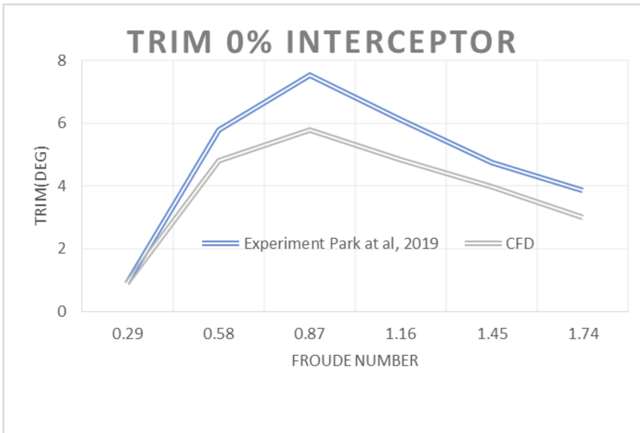
Table 2. Convergence at grid 4

Physical Time	drag/W	heave/T	trim
0.0	0.020	0.000	0.0
0.1	0.178	0.000	0.0
0.2	0.165	0.000	0.0
0.3	0.162	0.000	0.0
0.4	0.161	0.000	0.0
0.5	0.150	-0.016	0.0
0.6	0.135	0.004	1.1
0.7	0.141	0.024	2.6
0.8	0.140	0.051	3.8
0.9	0.132	0.071	4.3
1.0	0.132	0.077	4.5
1.1	0.136	0.074	4.8
1.2	0.140	0.074	4.9
1.3	0.144	0.077	5.3
1.4	0.145	0.077	5.3
1.5	0.147	0.079	5.4
1.6	0.146	0.079	5.4
1.7	0.145	0.079	5.4
1.8	0.146	0.079	5.4
1.9	0.146	0.079	5.4
2.0	0.146	0.079	5.4

IV. CONCLUSION

Information on the step hull modifications on the planing hull was the primary goal of this study. This study examined how step hulls with and without interceptors and naked hull conditions affected trim, heave, and drag.





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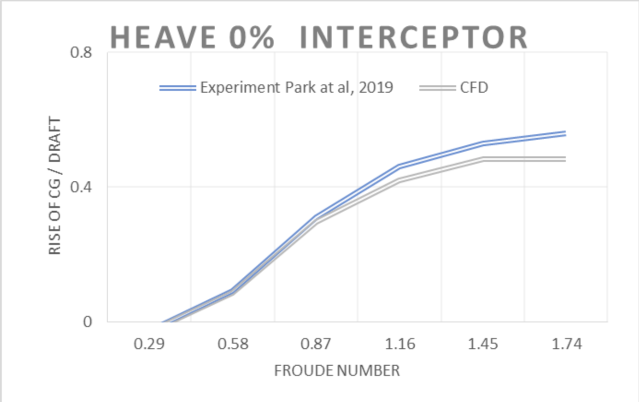

Figure. 6 Evaluation of the experimental data over drag, trim, and heave Park at al [8] and numerical simulations

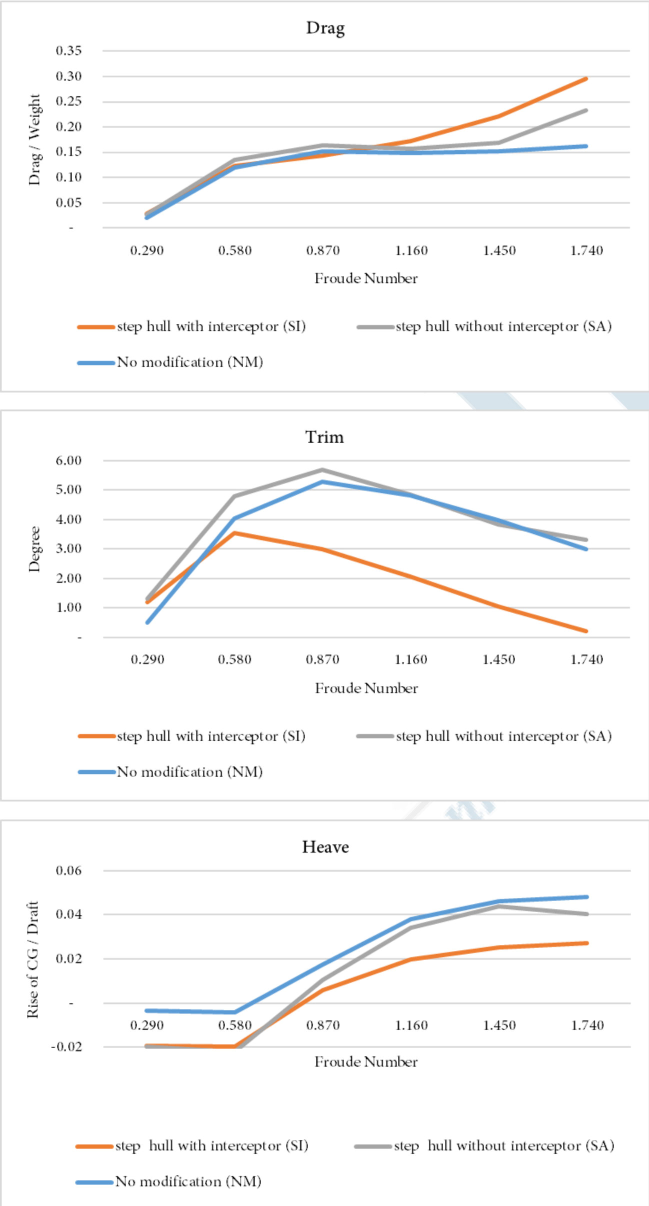

Figure 7. Analyzed Result

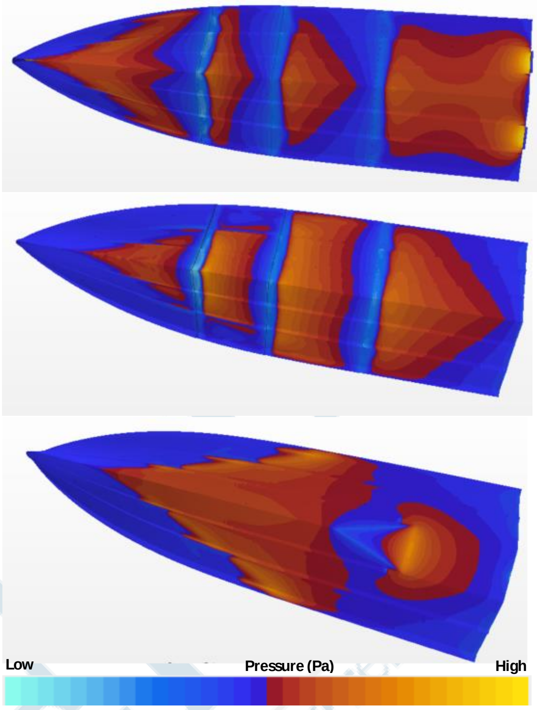

Figure. 8 Pressure Distribution at Froude Number 1.45

Through displaying the grid independence study, this investigation revealed a numerical study. It compared the experimental data with the outcomes of the numerical simulation research. In addition to a maximum difference of 10.7%, the accuracy of CFD provided findings that applied to the experiment.

Typically stated, installing an interceptor on a step hull vessel could decrease the trim angle of the vessel, lowering the draught height but having little impact on drag force. Implementing the interceptor would immediately alter the created moment and the pressure on the ship's bottom. Considering increased ship speed, the pressure in the interceptor region would also rise.

This research reported that step hull with interceptors positively affected reduce trim at the 0.29 to 1.16 Froude number. The comparison of step hull with interceptor, step hull without interceptor and no modification (bare hull condition) did not significantly change the ship's performance.

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