A study of interceptor performance for deep-v planing hull

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Abstract. The acting on the planing hull is the most complex hydrodynamics simulation. Therefore, an analysis was done to evaluate drag, lift force, and seakeeping in two degrees of freedom (2-DOF) which is heave and trim. It was fundamental aspects of the overall high-speed vessel. This article focused on the hydrodynamic performance of a complete interceptor configuration that could control the motion behavior of deep-V planing hull in calm water conditions. The benchmark study was undertaken by comparing numerical results with experimental study by Park at al. Models with and without interceptors had been analyzed by numerical simulation performed using Reynold Averaged Navier Stokes (RANS) to describe turbulence model with k epsilon based on computational fluid dynamic (CFD). In this study, the interceptor proper applies at a speed of less than Froude number 0.87. Interceptor reduce by 21% drag at Froude number 0.87 and also reduce by 16% trim and 6% heave at Froude number 0.58. Nevertheless, applied interceptor in high Froude number such as more than Froude number 1.16 caused interceptor lose effectiveness due to producing a decisive moment which made negative trim (bow-down) and increase total drag.

Keywords: CFD, drag, full interceptor, heave, lift force, planing craft

1. Introduction

The interceptor is a thin rectangle mounted on the vessel's transom to modify local flow near the stern. The interceptor generates substantial additional pressure towards the vessel's stern. This concept is adopted from an aerodynamic device called a gurney flap on race cars to increase down-force on the car's rear wing. The interceptor mechanism aims to increase the lift to drag ratio pressure on the vessel, which is slightly different from the situation on race cars. The aerodynamic aspect of a racing car does not affect drag friction. However, drag friction is significantly affected even in steady flow on the vessel. The interceptor will modify the pressure distribution in the same way as the gurney flap. However, the interceptor can affect the balance, which impacts the generation of the stern wave system and the resistance due to the waves. In addition, the increase in lift force also reduces sinkage and wetted surface areas as well as frictional resistance to the hull.

An experimental study conducted by Day and Cooper reported that the interceptor could reduce drag on sailing yachts [1]. Furthermore, Van Oossanen conducted a 45 m motor yacht with an interceptor dimension of 50 mm using the CFD approach. The study resulted in a reduction in the trim of 1 degree and decrease in drag of 7% at Froude number 0.6 [2].

In recent years, the interceptor has become increasingly recognized as a trim controller on medium to high-speed vessels, especially for semi-planing and planing hulls. The complexity of the hydrodynamics of planing hull often causes the vessel to move coarse when it is operated. Excessive trim and drag when the vessel is at high speed is a challenge for architects to improve performance of the vessel.

Interceptors can reduce trim and drag on high-speed planing craft [3]. The interceptor system can reduce pitch motion up to 32.4% and heave motion 12.1% on irregular waves at a certain speed [4]. The hydrodynamic performance of the transom-interceptor configuration can control the movement of speed boats on waves. The transom-interceptor configuration experiment resulted in a positive and negative lifting force as a controlled force in the opposite direction so that the vessel's motion became better [5]. Another study also compared trim tabs and interceptors of the same size on a planing hull. The study reported that the interceptor provided better trim control [6].

This research used numerical simulation to get the vessel's resistance. The research of Yousefi discussed the numerical method using Computational Fluid Dynamics (CFD) related to planing hull. The research was divided into three methods, namely Finite Volume Method (FVM), Finite Element Method (FEM), and Boundary Element Method (BEM). It was reported that FVM was the most accurate method compared to other methods [7]. In 2015, research on CFD was successfully carried out to predict catamaran ship drag by ignoring ship movement [8]. The research was continued by using a numerical method to modify the addition of a center bulb to reduce the total drag [9]. Furthermore, the numerical simulation was also carried out to reduce the drag by applying a spray strip to the Fridsma hull [10]. In another analysis also compared experimental and numerical method to give a reliable and fairly accurate prediction of the flow around the ship[11]. The growing world of computing made numerical methods an efficient choice.

2. Method

In this study, the Aragon 2 vessel tested experimentally by Park [4] was used, and the interceptor size was selected based on the vessel's dimensions. Table 1 shows the main dimension of the vessel that would be used as this research topic. Table 2 as shown data of interceptor's dimension. The simulation was performed in the scaled model (1: 5.33) . Figure 1 represents the lines plan on the deep-V planing hull, such as side view 1(a), front view 1(b) and bottom view 1(c). Figure 2 represents dimension of interceptor. Figure 3 as shown position of interceptor toward of the ship.

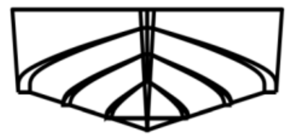
Table 1. The main dimension of deep-V planing hull [4]

Dimension	Full-scale	Model scale 1/5.33	Unit
Length overall (LOA)	8.00	1.50	Meter
Length waterline (LWL)	7.54	1.41	Meter
Breadth overall	2.30	0.43	Meter
Draft	0.45	0.08	Meter
Weight	3000	19.7	Kg
LCG	2.64	0.49	Meter
C.G from baseline	0.80	0.15	Meter
k	21.5	27.2	degree

Table 2. Dimension of interceptor

Dimension	Rectangular Interceptor (full scale)	V-Shape Interceptor (full scale) for Current Study	Unit
Span	300	450	mm
Height	50	Ha: 115 Hb: 200.5	mm
Thickness	20	20	mm

(a)



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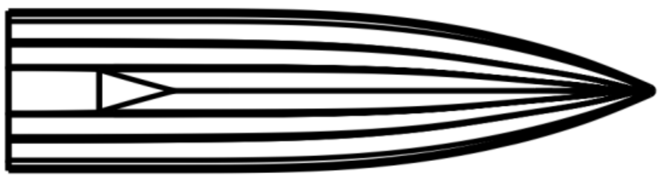

(c)

Figure 1. (a) Side view, (b) front view, and (c) bottom view of Aragon 2

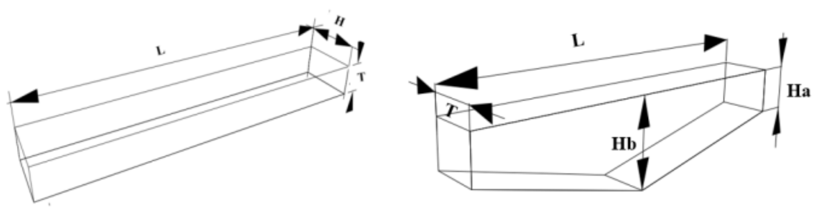

Figure 2. Dimension of (a) rectangular interceptor, (b) v-shape interceptor

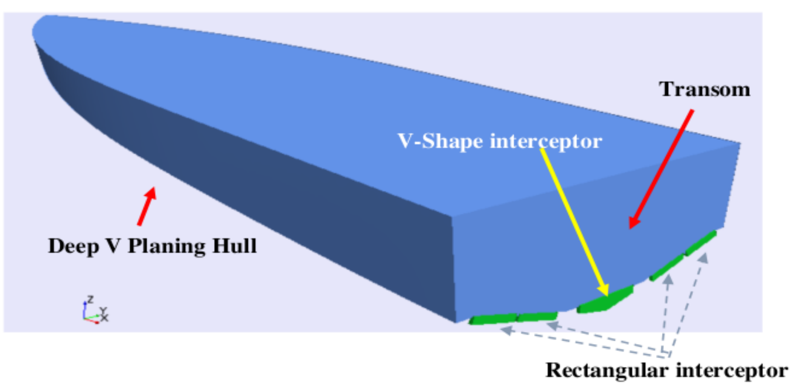

Figure 3. Position of interceptor toward of the ship

The fluid flow modeling used the RANS equation to carry out a predictor-corrector approach that connected the continuity and turbulence equations with the standard k-epsilon model according to the ITTC recommendation [12]. The RANS equation consisted of three main steps, namely:

1. Integration of equations governing fluid flow overall control volumes of the solution domain.
2. Discretization of integral equations into a system of algebraic equations.
3. Solving algebraic equations using an iterative method with the RANS equation and numerical turbulence. The discrete equations were derived using the volume method until then solved by the SIMPLE method and the Implicit Pressure-Correction method, which were used for flow and pressure equations, respectively.

Free surface effects are represents using that called the "Volume-of-Fluid" approach: the solution domain is assumed to be filled by a sufficient fluid whose properties vary according to volume fraction. In CFD, assumed that the volume fraction of fluid in each cell is represented by a function, F, and its value is unity in a cell full of water, and zero value represents no water. Hence, each fluid which has a value between 0 and 1 must contain a free surface. The free surface field can be represented by the transport equation in conservative form as follow:

$$\frac{\delta F}{\delta t}+\frac{\delta uF}{\delta x}+\frac{\delta vF}{\delta y}+\frac{\delta wF}{\delta z}=0 \tag{1}$$

This study referred to the ITTC as an international standard that provides recommendations for predicting ship hydrodynamics using numerical and experimental methods. As for the case of speed vessel, ITTC recommends several things, including [12]:

1. The size of the computational domain and boundary condition
2. Grid sizing
3. Convergence
4. Time-step
5. Grid on the ship wall (y+)

Figure 4 illustrates the size of the computational domain and boundary conditions. Domain length was calculated from -2.5 LOA to 1 LOA with the coordinates of the zero point at the stern and vessel's draft. The width was set to 1.5 LOA vessel. The next was the definition of boundary conditions. The inlet velocity condition was set in the negative x-direction, where the wave was simulated. The positive x-direction was modeled as outlet pressure to show the static pressure at the outlet. The upper limit was chosen as the inlet velocity to represent the infinite air condition, while the lower limit was selected as the inlet velocity. The simulation was carried out on half the hull. It was to reduce time consumption.

The grid size is shown in Figure 5 to see the effect of installing the interceptor. The grid size on the vessel's hull was shown with more mesh to measure the dynamics of the vessel's movement to be more accurate. Figure 5 (a) shows grid size on the side view, and figure 5 (b) shows grid size on the top view. The same thing was done on the water surface.

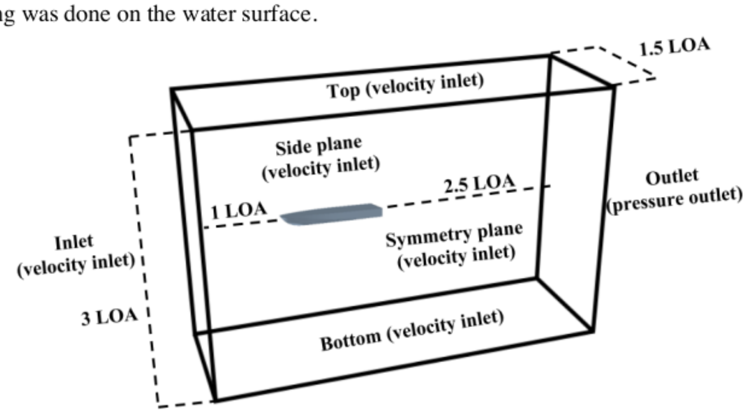

Figure 4. Computational domain and boundary condition

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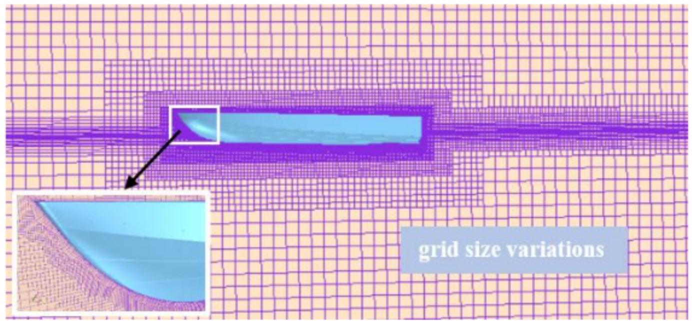
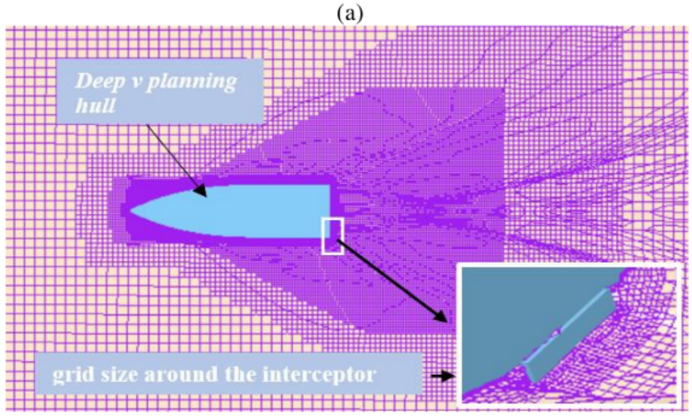


(a)



(b)

Figure 5. Variation of grid size (a) side view, (b) top view

In some cases, the dispersion error often resulted in an oscillating solution due to coarse mesh quality. The result was that the residual plot could show that the solution was not convergent. Based on this reason, it was essential to do a grid study to find the best mesh to use for each simulation. In this study, a grid independence test was conducted. The test was carried out using a five-level grid. In Table 3, it was reported that the higher the cells, the higher the time required in one test simulation. The simulation selection was determined based on the drag, heave, and trim values. On grids 1 to 3 produce fluctuating values and illustrate that the results are not good. Grids 4 and 5 produce better values with the drag, trim, and heave stable. But grid 5 takes a relatively long time to generate data. So that grid 4 is selected with good results and does not require relatively much time. It taken 2 seconds to get a convergent iteration. The drag, trim and heave, as shown in figure 6 (a), 6 (b), 6 (c) results showed stable results at 2 seconds. Simulations were carried out on Froude number 1.072. Drag and heave are non-dimensional by the weight and draft after perpendicular, respectively.

Table 3. Grid independence

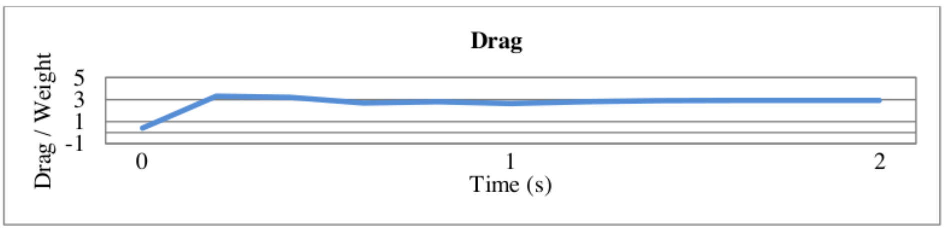
No	Number of cells (Million)	Time processing (hours)	Drag	Heave	Trim (deg)
Grid 1	0.52	8	0.143	0.081	5.29
Grid 2	0.66	14	0.141	0.086	5.30
Grid 3	0.87	24	0.143	0.083	5.20
Grid 4	1.24	32	0.141	0.085	5.29
Grid 5	1.47	48	0.143	0.082	5.15

The time step was the interval period for each iteration. The time step was determined based on the CFL (Courant-Froderichs Lewy) number, which showed the number of points travelled by the fluid particles in the time interval. The time step value was inversely proportional to the speed of the vessel so that the higher the speed of the vessel, the smaller the time step used. In this study, the time step value used was 0.008.

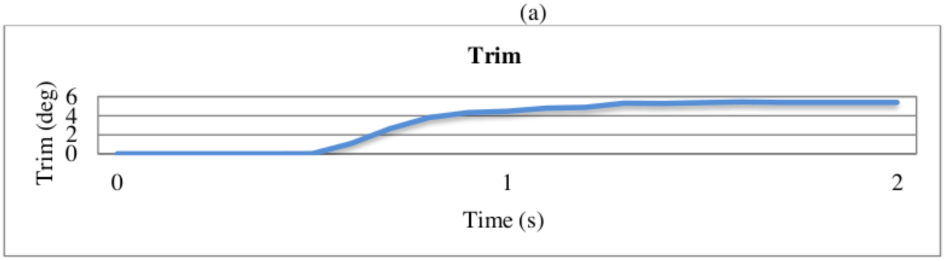
Another parameter to validate the CFD analysis was the value of y+. The value of y+ (wall function) was expressed in dimensionless units to capture the boundary layer phenomenon. The presence of y+ made it easier to predict the thickness of the first layer of the mesh and reduced numerical simulation inaccuracies. Figure 7 describes the value of y+ between 1 to 6. Based on the ITTC guide [12], the value of y+ can be formulated as follows:

$$\frac{y}{L} = \frac{y^{+}}{Re\sqrt{\frac{C_f}{2}}} \tag{2}$$

Meanwhile, Y was the thickness of the first layer, L was the vessel's length. Then, Re was the Reynolds number, and C_f was the coefficient of friction.



(a)



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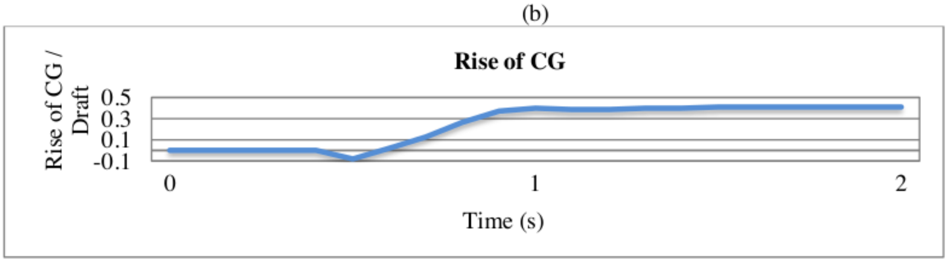


(c)

Figure 6. A sample of convergence of (a) drag, (b) trim, (c) heave parameters, showing how a CFD model calculates the equilibrium condition for the deep-V hull operating in planing mode at Froude number of 1.072

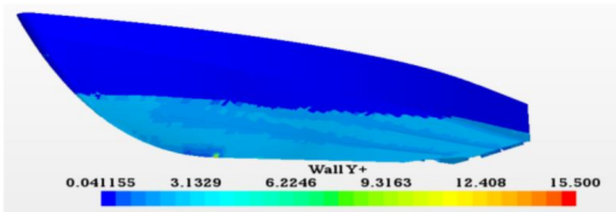


Figure 7. Wall y+

3. Results and Discussion

3.1 CFD verification

The vessel's motion was assumed to heave and trim motion as two degrees of freedom (2-DOF). The study focused on the hydrodynamic performance of a interceptor configuration that could control the motion of deep v planing hull in condition of calm water.

In this study obtained a maximum difference of 10.7%. Figure 8 shows the drag, trim, and heave patterns using the CFD and comparison with experimental approaches[4]. The same pattern had obtained between the results of numerical simulation analysis and experiments. However, there have slightly differences value of the CFD calculation and the experimental results due to the limitations of CFD in modeling according to actual conditions. This also has a similar study in Brizzola and Serra. They investigated the accuracy of numerical simulations by predicting ship planning. They obtained the variation of drag values and compared it with the experimental data of Savitsky[13] and resulting in an average error of 10% in predicting barriers[14]. The percentage difference between Park's experimental results and CFD analysis is shown in table 4.

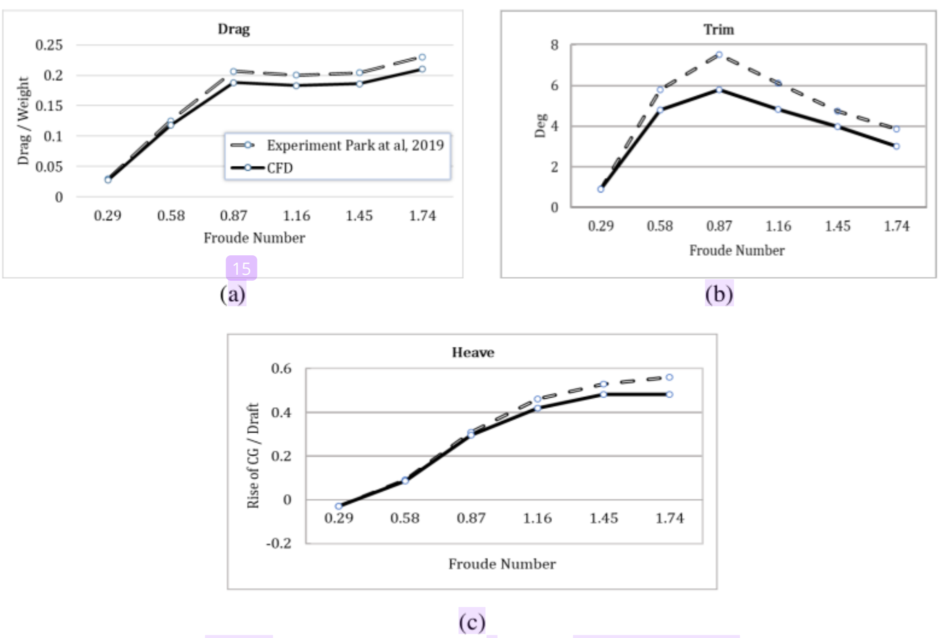


Figure 8. Validation results (a) drag, (b) trim, (c) heave

Table 4. CFD analysis and experiment Park at al 2019

Froude Number	Drag	Heave	Trim
0.29	6.1	3.2	0.9
0.58	7.5	4.6	7.5
0.87	9.9	5.7	10.7
1.16	9.5	9.6	9.5
1.45	9.9	9.8	6.9
1.74	9.5	10.0	7.4

3.2 Numerical simulation

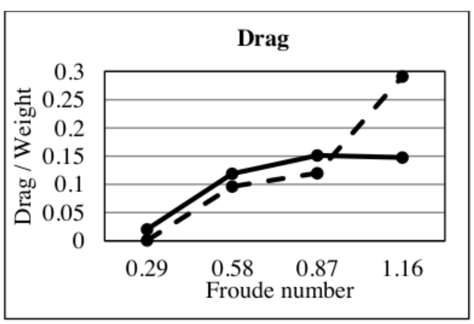
The line graph compares the study analyzed variation with and without an interceptor. The results of this study as shown in Figure 9. Overall figure 9 (a) had represented both with and without interceptor had increased from their initial values by the end of the Froude number. Interestingly that using of an interceptor showed improvement in drag for Froude numbers 0.29, 0.58 to 0.87. Although, the drag increased significantly at the Froude number 1.16.

Figure 9 (b) shows that with the interceptor, the trim value increased even at Froude number 0.29, but at Froude number 0.58, there was an improvement in the trim. Along with the increase in the vessel's speed from Froude number 0.87, there was a significant decrease in the trim value.

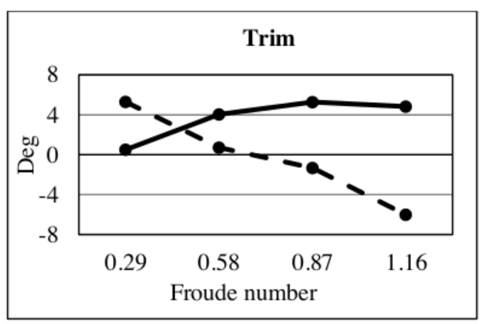
Figure 9 (c) shows that the value of lift force on the vessel without an interceptor decreased as the Froude number increased. The lowest lift value was at Froude number 0.29 and experienced the lowest lift force at Froude number 1.74. However, when the vessel was applied to the interceptor, the lift force value decreased at Froude number 0.29. Then, the vessel experienced an increase in the value of the lift force at Froude number 0.58 to Froude number 1.16.

Furthermore, from figure 9 (d) the vessel experienced an increase in the heave value at Froude number 0.29. However, the vessel experienced an improvement in the heave value at Froude numbers 0.58 and 0.87. Then, there was a negative heave on Froude number 1.16.

The vessel 's characteristics can be seen in figure 10. This figure explains the vessel's condition with and without using interceptor for each Froude number variation. On a vessel without using an interceptor, it can be seen that the trim increases as the Froude number increases. However, on the vessel using an interceptor, it is found that the trim value improvement at the Froude number was low and effective at the Froude numbers were 0.58 and 0.87. However, when the vessel was in the planing phase, namely at Froude number 1.16, there was excessive trim due to the interceptor moment being more significant than the pressure moment of the fluid while causing a change in the pressure distribution as described in figure 11.



(a)



(b)

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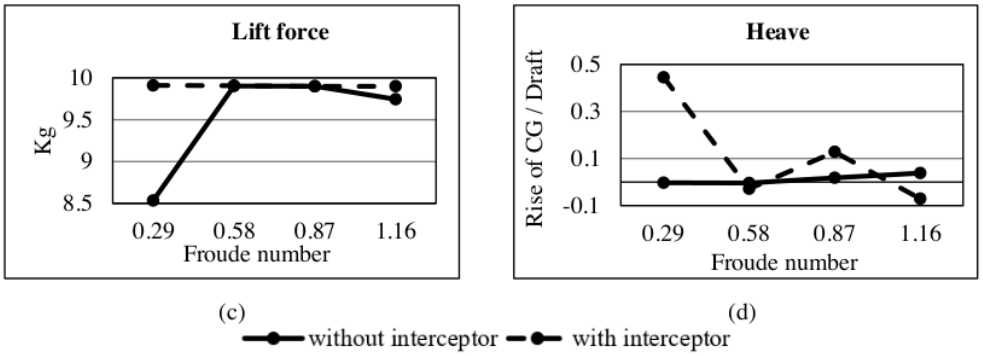


Figure 9. Result analysis (a) drag, (b) trim, (c) lift force, (d) heave

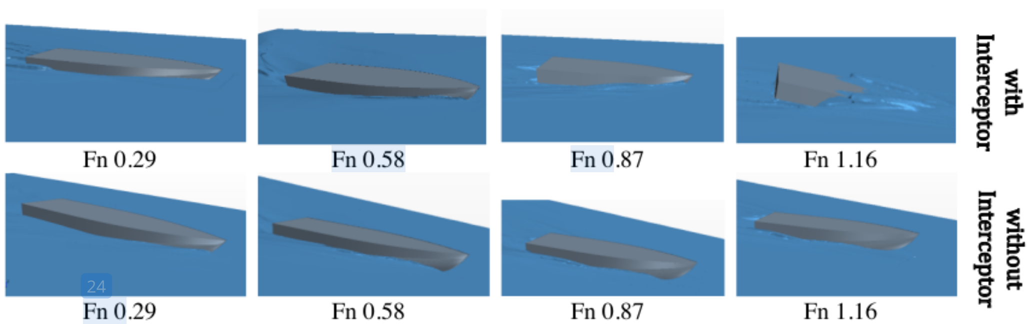
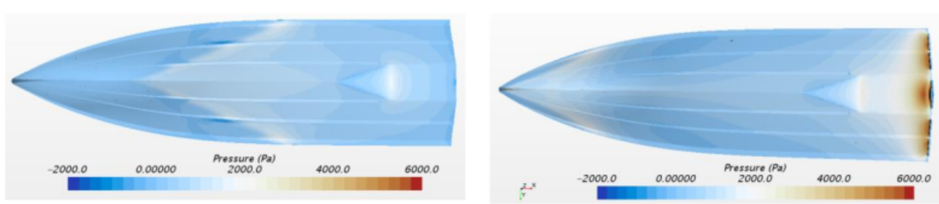


Figure 10. Snapshot interceptor performance



(a) (b)

Figure 11. Pressure distribution at Froude number 1.16 (a) without interceptor, (b) with interceptor

4. Conclusion

A vessel without an interceptor experienced pressure in the bow area resulting in trim. Vessel using interceptors experienced moments at the stern and bow. The interceptor became ineffective if the aft moment was more significant than the bow moment. However, the interceptor was not needed at Froude numbers more than 1.16 because it could create a big enough moment at the vessel's stern to result in negative trim. The interceptor could be used at a certain speed. In this study, the interceptor suggestion applies at a speed of less than Froude number 0.87. Interceptor can decrease 21% drag at Froude number 0.87, 16% trim and 6% heave at Froude number 0.58.

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