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Investigation of The Effect Hullvane and Bow Foil on Flat-Hull Ship Using CFD Approach

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***Abstract*—The flat-hull ship design is an innovative concept that saves costs and speed-up the fabrication of the ship. Even though the flat-hull ship was hydrodynamically inefficient, some shipowners probably experienced an issue with its unusual shape and disadvantages where drag is greater than that of conventional ships. This paper aimed to improve the design of a flat-hull vessel using hull vane and bow foil to reduce ship resistance. The asymmetric foil NACA 4412 and 0012 were used for the hull vane. For bow foil, only NACA 4412 is used. In addition, the angle of the strut of the hull vane was varied to find out the effect to ship resistance. This study was performed in a numerical approach using computational fluid dynamics (CFD). The mesh-based CFD with RANSE solver was used in this study, and numerical analysis will be conducted to determine ship resistance of flat-hull ships with hull-vane and bow foil. It was found that the effectiveness of hull vanes on ships failed to improve resistance for flat-hulled vessels. Because of the addition of the WSA on the ship, the total resistance of the ship increases following the installation of the hull vane. As an alternative, using bow foil can reduce ship resistance at Fn 0.44 and 0.59 by 10% and 24%, respectively.**

Keywords—*Flat-hull ship; hull vane; angle strut; bow foil; resistance; CFD* .

I. Introduction

The flat-hull form ship is one innovation in ship design by the Blohm + Voss AG shipyard in 1968. The first novelty is the flat-hull form, the shell consisting exclusively of a flat-hull, to save costs and speed production designed to eliminate all curves and bending work. Compared with a flat-hull form ship, the conventional ship hulls are smooth, round, and streamlined. It was found that the propulsion power of the flat-hull ship was close to an equivalent round hull. However, in a scaled calculation, the flat-hull model requires about 5-10 percent more power than the round hull. However, in a full-scale model, it was found that the power needed for the flat-hull ship was 15% lower than the scaled calculation. [1]. While hydrodynamically successful, the flat-hull ship probably has an issue with some shipowners despite its unusual shape [2].

Many studies have been carried out for ships with flat-hull form, ship design using the flat-hull method for different types and sizes of ships has become the hallmark of ships in Indonesia [3]. Research on the resistance of the semi-trimaran flat-hull ship by comparing the numerical and experimental methods results in an increase in each method's resistance with a trend of similar resistance values [4]. Apart from increasing drag by about 5%, flat-hull monohull ships also experience a diving effect in the aft trim that occurs when the ship is sailing [5]. Apart from the ship's character, which has slightly higher resistance than conventional models, the stability performance of the semi-trimaran flat-hull hull ship has also been analyzed to show that this ship has good ship stability by meeting IMO standards [6].

Various studies on overcoming losses caused by the form factor of the flat-hull has been carried out by various researchers before; research on analysis with the numerical method of flat-hull form ship resistance by varying the shape of the bow to reduce ship resistance showed that of the several types used, the raked bow model experienced the slightest ship resistance [7]. Nabawi et al. studied ship resistance on the flat-hull ship using hull vane and stern foil [8]. The study revealed that hull vane could reduce ship resistance due to lifting force. A similar study of stern foil to reduce ship resistance was carried out by Budiyanto et al. [9]. The study evidence that stern foil could be one alternative way to reduce resistance and stabilize the ship's motion. Hereafter, Amiadji et al. [10] analyzed the seakeeping of a flat-hull monohull ship and reported enormous turbulence flow around the stern hull. A smoother flow pattern at the bow caused the increase of resistance and bow diving in calm water phenomena.

Based on previous studies, the hull vane technology is often used as an energy-saving device to overcome ship resistance in the flat-hull ship [11-13]. This paper aimed to improve the design of a flat-hull vessel using hull vane and bow foil to reduce ship resistance. The asymmetric foil NACA 4412 and 0012 were used for the hull vane. For bow foil, only NACA 4412 is used. In addition, bow foil was compared with hull vane installation in the flat-hull ship. Numerical computation of ship resistance was carried out with computational fluid dynamics (CFD). The mesh-based CFD with RANSE solver was used to calculate ship resistance. Using the CFD approach, the hull vane and bow foil are expected to overcome the increased drag and bow trim problems that occur on flat-hull monohull ships. The results showed that bow foil can reduce ship resistance due to a change of trim by stern and it was one solution to improve design of flat-hull ship.

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TABLE 1.
PRINCIPAL DIMENSION OF FLAT-HULL SHIP\

Item	Dimension	Unit
Lpp	31.0	m
B	8.0	m
H	7.53	m
T	3.0	m
Δ	292,565	tonnes

II. METHODS

Firstly, a flat-hull ship is designed using so-called the similarity method, which, the ship is designed using an existing ship. Using a regression method principal dimension was obtained, as seen in Table 1. In this paper, the ship was designed for high-speed vessels, for instance, patrol vessels and pilot boats. Lpp, B, H, T, and Cb are the length between perpendiculars, breadth, height, draft, and block coefficient, respectively. Figure 1. shows the lines plan of a flat-hull ship with a bow ship configuration with two different strut angles, namely 45° and 90°, and a flat-hull ship with bow foil. NACA 4412 and 0012 are used in the hull vane configuration, and NACA 4412 is used for bow foil configuration. The angle of attack is set 0^0 for all configurations.

Table 2. shows the numerical setup for the computation domain, including the background domain, as seen in Figure 3. Table 3 displays the numerical setup of overset mesh around the ship. Figure 3. reveals the numerical domain of computational fluid dynamics (CFD) setup. Three Froude numbers are used in the numerical simulation, i.e., 0.295, 0.443, and 0.59. Figure 4 reveals the meshing setup divided into the two-part background and overset mesh. Overset mesh was set near the ship hull to get detailed free surface flow phenomena.

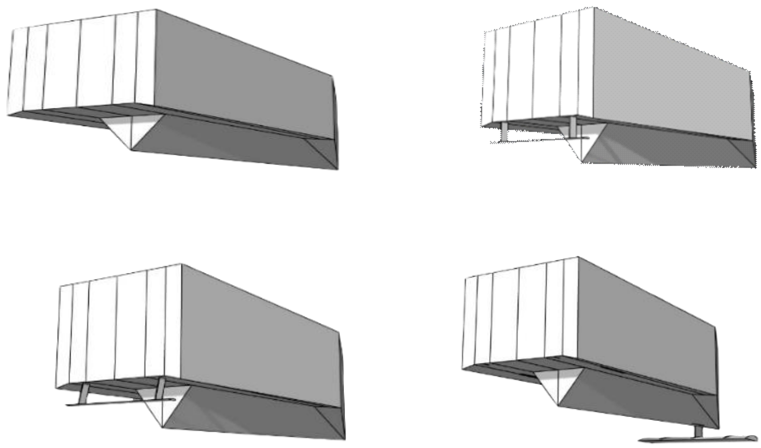

Figure 1. Ship geometry of flat-hull ship with different configuration foil

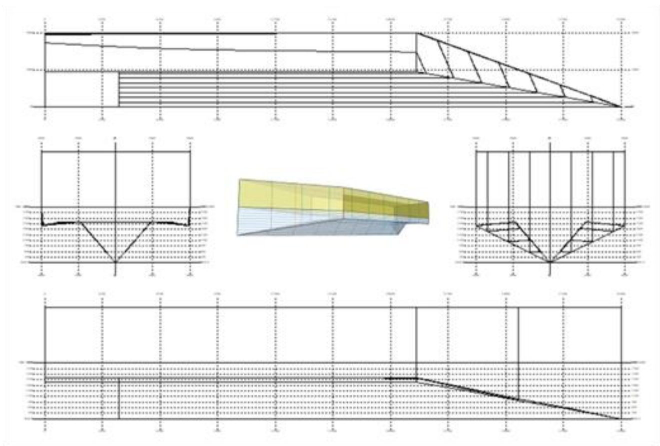

Figure 2. Ship geometry of flat-hull hull form ship

resembling of axe [14]. Although some flat-hull ships are designed with semi trimaran hull, the present study is a carry-out flat-hull ship that generates from a monohull. Figure 2. displays a primary flat-hull ship, a hull vane

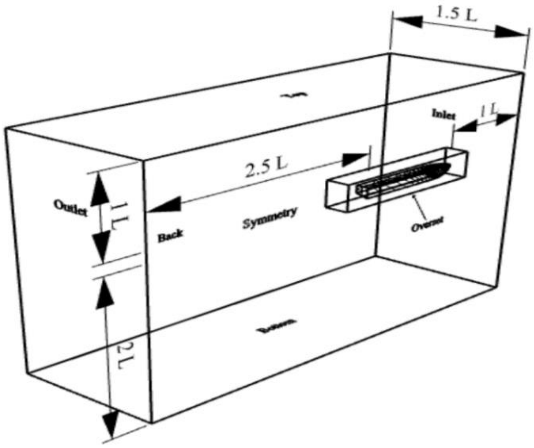

Figure 3. Numerical domain setup

In this computational domain, the boundary conditions are as follows [15]. The inlet boundary, located at 1-L upstream from the ship fore perpendicular (where L is the LPP-length between perpendicular-), an equal-velocity uniform flow corresponds to the ship's speed. In the outlet boundary, at a location 2.5-L downstream from the ship after perpendicular, disturbances do not propagate upstream due to an equal hy-drostatic pressure [16]. The boundary condition on the ship surface is defined as a no-slip condition. The boundary conditions

$$\nabla . V=0 \quad (1)$$

$$\rho \frac{\partial V}{\partial t} = -\nabla P + \mu \Delta V + \nabla . T_{Re} + S_M \quad (2)$$

Where ∇ is volume, V is an average velocity vector, ρ is density, t is time, P is the average compressive field, μ is dynamic viscosity, T_{Re} is a Reynolds stress tensor, Δ is displacement, and S_M is a vector of momentum sources. The T_{Re} component is calculated using the chosen

TABLE 2.
NUMERICAL SETUP

Domain	Boundary Type
Back	Symmetry Plane
Bottom	Velocity Inlet
Inlet	Velocity Inlet
Outlet	Pressure Plane
Symmetry	Symmetry Plane
Top	Velocity Inlet

on the top and bottom walls (at a distance of 2-L above and below the ship, respectively) and on the side walls (approximately 1.5-L away from the side of the model) are defined as a free-slip condition.

The two-phase flow of air and water is modeled using a Fully Eulerian Finite Volume Method. The VOF multiphase model handles problems involving immiscible fluid mixes and free surfaces. The dynamic Fluid Body Interaction (DFBI) module simulates a vessel's motion in reaction to forces. The vessel can move freely in heave and trim, but roll and sway are fixed.

Reynolds-Averaged Navier-Stokes models are used in this study to explain the conservation of mass and momentum in the fluid domain. It's assumed that the fluid is two-phase and incompressible. Thus, the RANS equations can be presented as

turbulence model, according to the Boussinesq hypothesis:

$$\tau_{ij}^{Re} = \left(\frac{\partial V_i}{\partial x_j}+\frac{\partial V_j}{\partial x_i}\right) - \frac{2}{3}\rho k \delta_{ij} \quad (3)$$

Where μ_t the turbulent viscosity, k is is the turbulent kinetic energy. Many turbulence models can be used to cover hydrodynamic problems in the RANS method. The turbulence model commonly used in the hydrodynamics field is the model of the two equations, such as *SST k-ω* and *k-ε* [17].

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TABLE 3.
NUMERICAL SETUP FOR OVERSET MESH

Domain	Boundary Type
Block surface	Overset mesh
Bottom	Wall
Inlet	Wall
Symmetry	Symmetry Plane

The overset mesh technique has two geometries, the background as the donor and the overset as the acceptor. The dimensions used in this study are shown in Figure 4. Where *L* is the ship's length, *H* is the ship's height, and *B* is the ship's width. Numerical simulations were carried out using a half hull to shorten time computation.

Time-step was used in unsteady flow simulation. The time step is an interval period for each iterative calculation. The smaller the value, the more accurate the result obtained, and vice versa. The time-step determination of the CFD calculation depends on the ship's speed. The faster the ship's speed, the smaller the time-step used. The time-step determination recommended by ITTC is found in equation 5. *L* is a ship's length, and *U* is the ship's speed.

$$\Delta t\ ITTC = 0.005 \sim 0.01 \frac{L}{U} \quad (5)$$

strip theory. It can be seen in Table 3 that from the comparison results, it can be concluded that the percentage of relative error is relatively small, which is around 5-7.5 %.

Furthermore, as shown in Figure 5 as a summary of the results of total resistance, at a speed of 10 knots or Fn 0.29, flat-hull ships without any variation have the slightest resistance among other variations. The Base Model flat-hull ship with notation 'BM' has a drag of 49.5 kN. Meanwhile, on the other hand, flat-hull ships with added bow foil (notation 'BF') have the most superior resistance with a value of 57 kN. This is due to the significant addition of foil area to the variation of bow foil, and the ship's speed is insufficient to provide a lifting effect that can lift the ship's hull. For flat-hull ships with hull vane variations, all of them have the effect of increasing speed on flat-hull ships, leading to an average resistance of 52 kN. The value of the resistance between variations of the strut slope is also not significant enough to differ from one another, so it can be said that the variation of the strut slope on the hull vane has not had such a significant effect on the resistance value of flat-hull ships at relatively low speeds.

TABLE 4.
COMPARISON RESULTS OF RESISTANCE CALCULATIONS

Froude Number (Fn)	CFD (kN)	Strip Theory (kN)	Difference (%)
0,295	49.59	52.41	5.68
0,443	208.9	211.31	1.15
0,590	332.6	357.6	7.51

III. Results and Discussion

This section will discuss the results of the analysis of total, frictional, and residual resistance on flat-hull hull ships using hull vanes and bow foil at Froude number speeds of 0.29, 0.443, and 0.59. Table 4 compares the values between the results using CFD and the results of

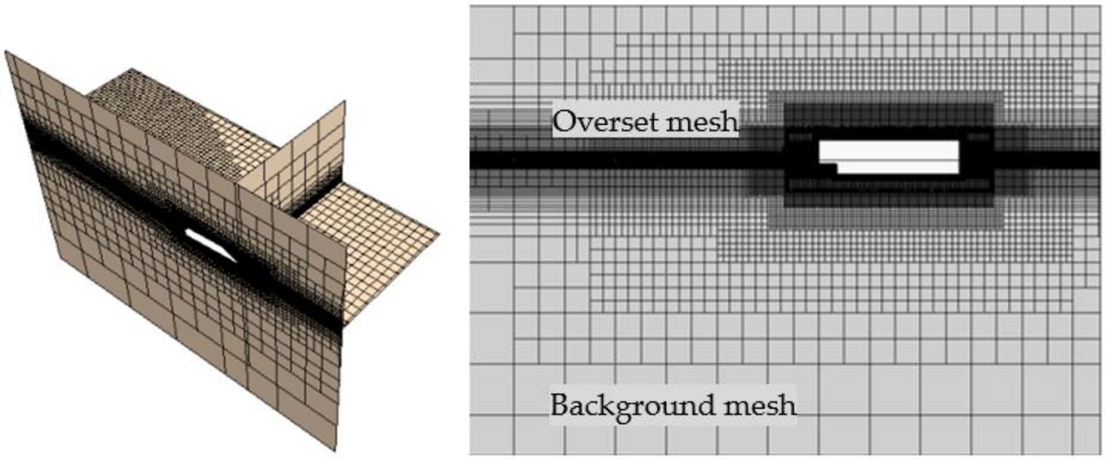

Figure 3. Meshing setup configuration

A flat-hull ship with a speed of Fn 0.59 has the results as shown, where it can be seen that the effect of adding a hull vane on a flat-hull ship still shows an increase in the resistance value of 22% with an average resistance value of 406 kN. However, at a speed of Fn 0.59, it can be seen that it does not coincide as at the previous speed, so it can be said that the variations in the slope of the struts here have quite varied values at a speed of Fn 0.59. For struts angle 45° was rated at 423 kN, up 27% over flat-hull hull vessels without any variation. While on flat-hull ships with variations in the addition of bow foil, it can be seen in Figure 5 that variations in adding bow foil on flat-hull hull ships have a positive effect with a decrease in the resistance value of 24% at 252 kN.

Figure 6 shows a visualization of the wave pattern of a flat-hull hull ship with variations that experience the most significant increase or decrease in the resistance value. It can be seen in the wave pattern in Figure 6. In part 1, flat-hull ships with hull vane variations experience bow trim. The WSA value on ships with these variations was increased. It was linear to increase the value of drag pressure on the faces of flat-hull ships. While in part 2, it can be seen that the variation of the bow foil gives a lifting effect on the bow section of the ship, causing a stern trim condition on the ship, the result is that the WSA value on the flat-hull ship is reduced, as results, the drag pressure value that occurs on the faces of the flat-hull hull ship is drastically reduced.

The analysis results also found that flat-hull ships with additional variations of bow foil had a higher WSA value than other variations; this was due to the different surfaces in the form of a larger foil compared to other variations. In addition, the WSA value that occurs on flat-hull ships with hull vane variations with a strut slope does not change much from one variation to another at Froude numbers 0.29 and 0.443. at the highest speed (Fn 0.59) can be seen in the figure, flat-hull ships with bow foil variations have a smaller WSA value than other variations; because the speed is sufficient for the foil to be able to lift part of the flat-hull so that the WSA value can be reduced significantly and the WSA value is directly proportional to the frictional resistance received by the ship. Moreover, the total resistance value of the ship on a flat-hull ship with a bow foil is the most minor compared to other model variations. The wave created by a flat-hull ship is divergent, and there is no deck wetness. In contrast to hull vane configuration, there is deck wetness, and the flow becomes unstable after passing the stern (see Figure 7.)

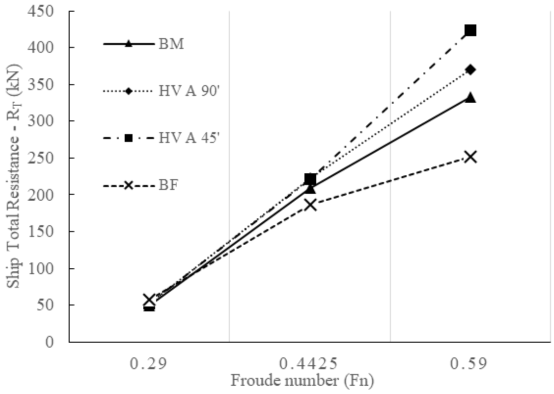

Figure 4. Total resistance (R_T) of 4 different conditions of flat-hull hull ship with a straight line (-) as a base model, dashed line (--) as bow foil model, dash-dot line (-·-) as hull vane model with 90° strut and dot line (···) as hull vane model with 45° strut as a function of 3 different Froude number (0.29, 0.443, 0.59)

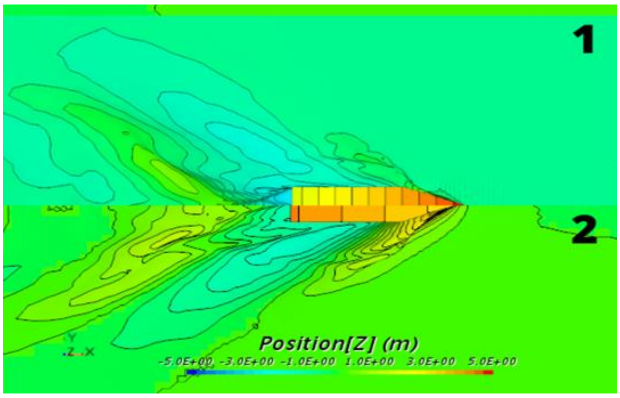

Figure 5. The wave pattern of the base model (1) and bow foil (2)

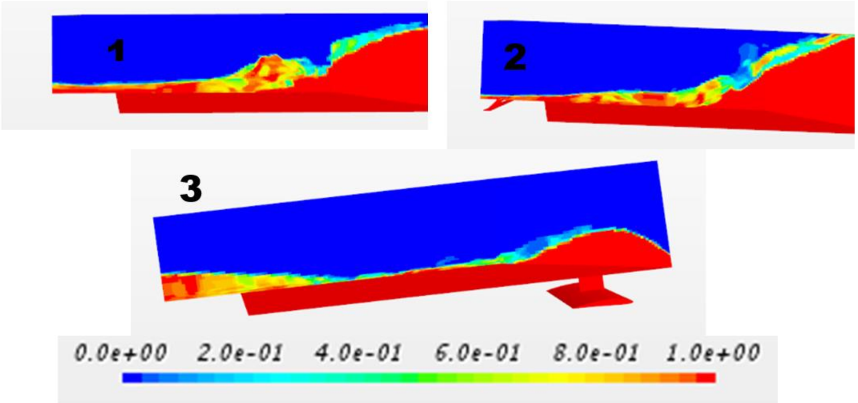

Figure 6. Trim visualization of the three variations of the ship model (1) base model, (2) hull vane model, (3) bow foil model on Froude number 0.59

The trim value that occurs on a flat-hull ship at a speed of Fn 0.59 can be seen in figure 8 and figure 9 as the trim visualization. As a result, it can be seen in the graph in figure 9 that the trim values on flat-hull ships with the addition of hull vane with variations of the strut slope of 45° and 90° have relatively the same trim values at low speeds and only differ at relatively high speeds where the strut slope is 90° lower in numbers. 1.4°. The trim value in the hull vane variation here is the bow trim, while the bow foil variation has a stern trim condition at 7°. The bow trim condition that occurs on flat-hull ships is one of

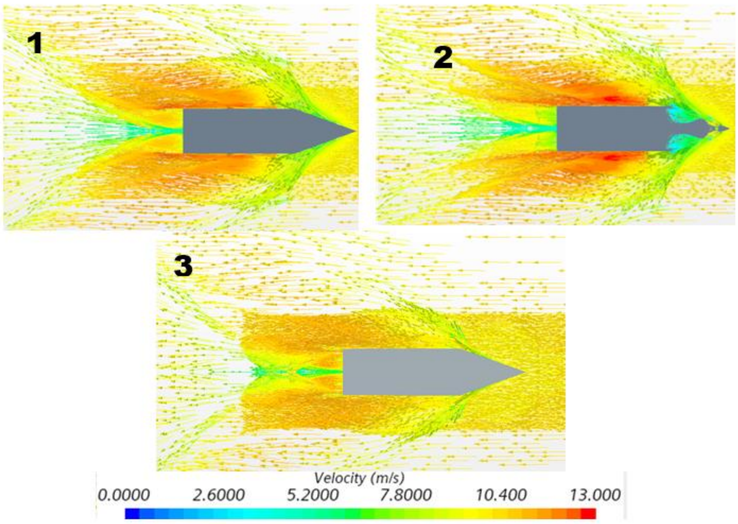

Figure 7. Velocity vector of the base model in three different Froude number model (1) base model, (2) hull vane model, (3) bow foil model on Froude number 0.59bow foil model on Froude number 0.59

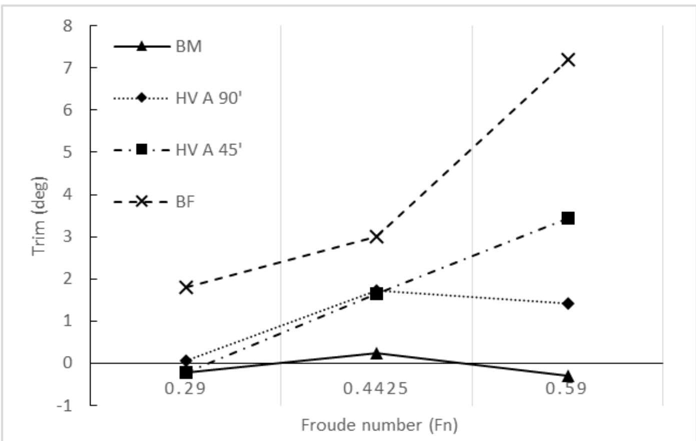

Figure 8. Trim value of 4 different conditions of flat-hull hull ship with a straight line (-) as the base model, dashed line (--) as bow foil model, dash-dot line (-·-) as hull vane model with 45° strut, and dot line (···) as hull vane model with 90° strut as a function of 3 different Froude number (0.29, 0.443, 0.59)

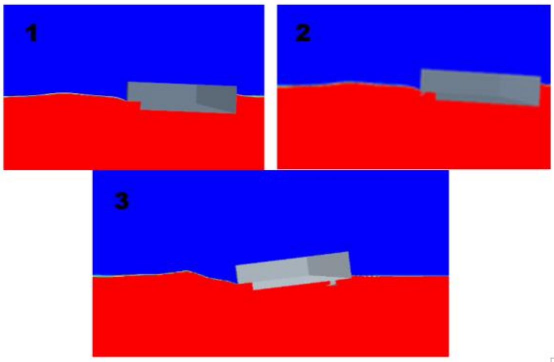

Figure 9. Trim visualization on the three variations of the ship model (1) base model, (2) hull vane model, (3) bow foil model on Froude number 0.59

the causes of the additional resistance on flat-hull ships [18]. Although flat-hull ships with bow foil have the slightest resistance, some consequences are the occurrence of an extensive stern trim compared to other model variations shown in the following figure.

IV. CONCLUSION

Numerical analysis using CFD has been carried out to calculate the resistance of flat-hull ships with variations in the addition of hull vanes and bow foil. The drag analysis results showed that adding a hull vane on flat-hull ships increased slight drag ship resistance more than on ordinary flat-hull ships. In addition to the hull vane vari-ation, it was also found that the strut angle did not significantly affect the ship's re-sistance at relatively low speeds, and the resistance changed slightly. More contrast is obtained at high speed, but the effect is not favorable for the drag of flat-hull ships.

While in the variation of the model with bow foil, flat-hull ships have immensely advantage results at Froude numbers 0.443 and 0.59, namely a reduction in ship re-sistance by 10% and 24%. However, at a speed of 10 knots, ships with bow foil varia-tions experienced an additional 15% resistance value; at that speed, the foil did not have sufficient force to lift the ship's hull. However, the use of bow foil must be paid for by the occurrence of a significant enough stern foil so that it can affect the perfor-mance of other vessels. Apart from the addition of energy-saving devices on flat-hull ships such as hull vanes and bow foils, the hydrodynamic characteristics of this ship model, which tends to experience bow trim, need attention so that this does not hap-pen to get a good ship model. For further research, it is necessary to analyze bow foil on flat-hull ships with the selection of a more suitable type of foil. In addition, experi-mental validation is needed to confirm the results of numerical calculations.

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