Analysis of the effect of hull vane on ship resistance using CFD methods

Kiryanto¹, U Budiarto¹ and A Firdhaus¹
¹Department of Naval Architecture, Faculty of Technology, Diponegoro University, Indonesia

e-mail: kiryanto@lecturer.undip.ac.id

Abstract. The development of technology in the ship industry is remarkable with many new innovations in the effort to improve ship performances. Ship resistance is one of the aspects that is very important to be comprehended the ship's characteristics. One of the innovations to reduce ship resistance is by adding hull vane to the ship hull. Hull vane is a fixed foil placed under the water line at the stern of the ship. This study is aimed to determine the effect of ship resistance after the addition of the hull vane and the location of the hull vane on the ship hull. This study utilizes a computer application program Computational Fluid Dynamic (CFD). The foil used is NACA 2415 type with s parameters angle of attack 5°, span foil 9.76 m, and chord hull vane length 1.15 m. Investigations are further carried out on the variation of the vane hull at 2 different positions and implementation of single foil and double foil configurations. The results of this study indicate that the installation of a single foil hull vane on a ship can reduce vessel resistance and in contrast for the installation of double foil. In the case of single foil and its position at 50% of T = 2.9 m the resistance is found to be most optimally reduced when the vessel is operated at Froude number Fr = 0.342. The reduction in the total vessel resistance is 20.135% in comparison to the ship without a hull vane.

1. Introduction
At present, the mode of transportation is an important aspect in the development of an area or country. No exception to sea transportation, which has an important function in various fields, such as defence, tourism and the economic sector. To meet these needs, a high-speed ship is needed to fulfil these fields. One of the primary problems which are always faced by ships when sailing in the sea is resistance. Ship resistance analysis is an important aspect of ship design. The research area considering fuel efficiency of ships can be divided into four main themes: engine and propulsion efficiencies, alternative renewable resources and ship resistance reduction [1].

Regarding the ship resistance reduction because of hull vane, which is the focus of this study, many innovations have been made, among others those utilizing appendages. A considerable amount of research has been conducted in the past on stern appendages Karafiath and Fisher (1987) conducted a study on stern wedges by, it was shown that a reduction of running trim of up to 2.0 degrees could result in a 2% of saving in fuel consumption [2]. Cusanelli and Cave (1993) investigated the application of stern flaps as a retrofit on US Navy vessels. They found a reduction in power which resulted in reduced fuel consumption and increased top speed [3]. Karafiath and Cusanelli (1997) later study on the integrated wedge-flap design, a reduction in power of 11.6% was observed, while a wedge-only configuration leads to a power reduction of 6.2% [4]. Tsai and Hwang (2004) studied interceptors and found that these can be used to reduce the resistance of planning hulls [5].
The most successful application is the so-called Hull Vane®, invented by van Oossanen in 1992 and patented in 2002. When applied to a ship, the Hull Vane® can generate an additional thrust, thereby reducing the bow-up trim and reducing the generation of waves. Furthermore, it can reduce the vessel’s motions in waves, leading to a higher comfort level for the crew and passengers. Successful applications were reported when a Hull Vane® was applied to a 108 m Holland-Class OPV. Beside resistance reduction, other benefits include lower vertical acceleration, and increased sailing range and increased top speed [6,7]. Better seakeeping performances were also reported due to Hull Vane®’s applications to ferries and ro-pax vessels [8]. Comparing the performances of the Hull Vane®, interceptors, trim wedges and ballasting utilizing CFD simulations, the Hull Vane® was found to be the most efficient device in reducing the ship resistance and in improving the seakeeping performance [9]. The resistance reduction reached 32.4% in the Froude-number range 0.2 < Fr < 0.6 while in the higher Froude-number range (0.6 < Fr < 0.8), the resistance reduction was approximately between 10-12%.

Based on this analysis, the operational limits of a ship can be determined. One innovation to reduce ship resistance is the addition of hull vane. Hull Vane is a fixed foil located below the water line at the stern of the ship. The function of the addition of hull vane is to reduce the height of the waves generated from the rotation of the ship's propeller. Besides, the lift force of the hull vane can reduce the running trim, which is a trim that occurs when the ship is advancing at high speed, where the bow lifts up while the stern sinks further [10].

2. Methodology
The preparation of the study has been arranged as follows. The main dimension of vessels used in this study are as shown in Table 1 and the hull configuration is depicted in Figure 1. The foil used for hull vane is the NACA 2415 series, with specifications of maximum thickness is 15% at 29.5% chord and the maximum chamber is 2% at 39.6% chord, as exhibited in Figure 2 [11]. In this analysis, the hull vane resistance is analyzed for speed variations of 12 to 16 knots, as listed in Table 2. In addition, for this model variations are also made on the position and the number of foil as contained in Table 3 and illustrated in Figure 3.

| No | Item            | Measurement |
|----|----------------|-------------|
| 1  | Length Over All (LOA) | 64.00 m     |
| 2  | Length of Waterline (LWL) | 58.96 m     |
| 3  | Length of Perpendicular (LPP) | 57.00 m     |
| 4  | Breadth (B)      | 11.60 m     |
| 5  | Draft (T)        | 2.90 m      |
| 7  | Depth (H)        | 4.50 m      |
| 8  | Displacement (Δ) | 1,164.00 ton|

Table 1. Main dimensions of the ship

![Figure 1. Ship hull form for the research](image-url)
Table 2. Speed variation

| Fr | V     |
|----|-------|
|    | m/s   | knot |
| 0.25 | 1.45  | 12   |
| 0.27 | 1.57  | 13   |
| 0.29 | 1.69  | 14   |
| 0.32 | 1.81  | 15   |
| 0.34 | 1.94  | 16   |

Table 3. Model variation

| Model | Position | Foil |
|-------|----------|------|
| 1     | As per Calculation | 1    |
| 2     | 50% towards top of draught from model 1 | 1    |
| 3     | 4% LWL to the back of model 1 | 1    |
| 4     | according to model 1 | 2    |
| 5     | 50% towards top of draught from model 1 | 2    |
| 6     | 4% LWL to the back of model 1 | 2    |

Figure 2. Foil NACA 2415 series [11]

The hull as well as hull vane modelings as presented in Figure 1 and 3 are conducted by employing a CAD modeler. The results of the CAD modeling are scaled at 1:100 and then exported into a .iges file and further opened in the CFD software.

2.1 Variation of Hull Vane

In accordance with the research methodology, the corresponding hydrofoil parameter values are as given in Table 4.
Table 4. Variation of hull vane

| Model | Layout of foil from LWL (m) | Number of Foil |
|-------|-----------------------------|-----------------|
|       | Foil dimension | x | z | Chord | Span |
| Origin | - | - | - | - | - |
| 1      | -1.15 | -1.74 | 1.15 | 9.76 | 1 |
| 2      | -1.15 | -1.45 | 1.15 | 9.76 | 1 |
| 3      | -2.36 | -1.74 | 1.15 | 9.76 | 1 |
| 4      | -1.15 | -1.74 | 1.15 | 9.76 | 2 |
| 5      | -1.15 | -1.45 | 1.15 | 9.76 | 2 |
| 6      | -2.36 | -1.74 | 1.15 | 9.76 | 2 |

2.2 Computational Fluid Dynamics Simulation

The Computational Fluid Dynamic (CFD) software used in this research is Tdyn version 12.2.3. The numerical simulation process in the CFD starts from creating a hull model in the form of an .Iges file that comes from the export program file Rhinoceros v 5.0. The CFD computations utilize the Reynolds-averaged Navier-Stokes method to solve the viscous flow field. The turbulence model used in the present study is the SST k-ω model [12], which gives accurate predictions of the onset and the amount of flow separation [13]. This is a combination of the k-ω model for the flow in the inner boundary layer and the k-ε model for the flow in the outer region of and outside of the boundary layer.

Figure 4. Meshing of domain and ship

Pre-processor phase in Tdyn software 12.2.3 is divided into 4 stages, namely materials and properties, initial condition data, modules data and meshing data. Meshing of domain and the ship as shown in Figure 4. The remaining boundary conditions of the computational domain are as follows [14]. The inlet boundary, located at 1-L upstream from the ship (where L is the ship’s length at the water line), is defined as a uniform flow with velocity equaling the ship’s velocity. (In the simulations, the
ship is at rest, but the water flows.) The outlet boundary, at a location 4-L downstream from the ship, is also given as a uniform flow with velocity equaling that of the ship. The boundary conditions on the surface of the ship’s hull, foil and struts are defined as no-slip condition. Meanwhile, the boundary conditions on the bottom wall, at approximately 1-L below the mean water surface, and on the top wall, at approximately 0.2-L above the mean water surface, are defined as free-slip condition. The boundary conditions on the side walls (0.4-L away from the side of the model) are defined as symmetric pressure condition. This means that the pressure inside the wall is equal to the pressure outside the wall; there is no wave-reflection due to the side walls.

The Solver Manager stage can be done after the Pre-processor stage is completed. In this stage the calculation process is done in the form of iteration from the basic equation of fluid dynamics in CFD. To determine the optimum grid size (number of elements), tests were carried out such that the numerical results complied with the grid-independence criterion [15]. The rms error criterion with a residual target value of $10^{-4}$ was used as the criterion for the convergence of the numerical solutions.

3. Results and Discussions

Computation of the resistance in original condition or without hull vane has been carried out by considering the model that has been tested at the Indonesian Hydrodynamics Laboratory (LHI), which has a scale of 1:18 to the ship size contained in Table 1. Further, the results of the current research by employing Tdyn are compared to the model test results from LHI [16], as presented in Table 5 and Figure 5. The comparison is performed to attain the validation of the resistance values from the current investigation.

| Fr  | RT LHI (N) | RT Tdyn (N) | Correction (%) |
|-----|-----------|-------------|----------------|
| 0.257 | 11.37    | 11.630      | 2.236          |
| 0.278 | 14.29    | 14.012      | -1.984         |
| 0.299 | 18.54    | 19.240      | 3.638          |
| 0.321 | 22.96    | 23.455      | 2.110          |
| 0.342 | 28.06    | 27.383      | -2.472         |

Figure 5. Validation value graph

Calculation of Meshing in Hydrodynamic Diffraction using element sizing 1/40 LOA. This is done with the aim to provide better density in the meshing process and more accurate results. By examining Table 5 and Figure 6, it is found results from the current computation using Tdyn are quite close to the model test from LHI. The highest difference is only in the order of 3.638%. This could be considered reasonably low, and hence the validation is achieved. This validation is used to adjust the meshing size convergence accordingly. So the meshing size of 0.032 for the underwater area, 0.032 for freesurface, 0.327 for all remaining components and 0.0016 for the hull vane has been used.
In numerical simulations on CFD Tdyn 12.2.3.0, the value of resistance can be seen after running data on the "Force on Boundaries" menu. Simulation has been conducted for Froude number \( (Fr) \) 0.257, 0.278, 0.299, 0.321 and 0.342. The results from resistance simulation for the ship model are presented in Table 6, and subsequently scaled up for the full size ship resistance as displayed in Table 6.

**Table 6.** Total model resistance (in N) for each Froude number

| Model | Fr 0.257 | Fr 0.278 | Fr 0.299 | Fr 0.321 | Fr 0.342 |
|-------|----------|----------|----------|----------|----------|
| Origin| 11.37    | 14.29    | 18.54    | 22.96    | 28.06    |
| 1     | 11.33    | 13.52    | 16.50    | 19.43    | 23.81    |
| 2     | 11.71    | 13.77    | 15.99    | 19.21    | 22.41    |
| 3     | 11.25    | 13.98    | 17.01    | 20.39    | 24.58    |
| 4     | 12.99    | 15.28    | 18.48    | 22.25    | 27.83    |
| 5     | 12.59    | 15.32    | 19.05    | 22.92    | 27.57    |
| 6     | 13.20    | 15.39    | 19.34    | 23.61    | 27.92    |

**Table 7.** Total ship resistance (in kN) for each Froude number

| Model | Fr 0.257 | Fr 0.278 | Fr 0.299 | Fr 0.321 | Fr 0.342 |
|-------|----------|----------|----------|----------|----------|
| Origin| 66.30    | 48.83    | 108.05   | 125.44   | 163.61   |
| 1     | 66.10    | 78.96    | 96.17    | 106.18   | 138.87   |
| 2     | 68.29    | 80.43    | 93.22    | 104.98   | 130.67   |
| 3     | 65.64    | 81.66    | 99.49    | 111.42   | 143.35   |
| 4     | 75.75    | 89.28    | 96.17    | 106.18   | 138.87   |
| 5     | 73.43    | 89.49    | 111.06   | 125.23   | 160.76   |
| 6     | 76.99    | 89.94    | 112.75   | 129.04   | 162.82   |

**Figure 6.** Total resistance of model ships on each Froude number

Based on the data in Table 7 and graphs in Figure 7 above, the resistance value from CFD for the case of single foil positioned with variation of 50% \( T \) eventually has the lowest resistance. The total resistance of the ship with aforementioned foil configuration and position can be reduced by as much as 20.135% from the resistance of the original configuration. This value occurs at the Froude number \( Fn = 0.342 \) as the vector of velocity shown below.
4. Conclusions
Based on experiments and simulations that have been carried out, it can be concluded that simulation results using CFD shows that of the six variations of the model, the smallest resistance value occurs in the second model variation (50% laden) which is 20.135% of the original ship's resistance. The CFD simulation results show a reduction in total resistance from 28,060 N to 22,410 N. From the above data with the addition of hull vane can reduce ship resistance in model 1, model 2, and model 3, whereas in model 4, the model 5 and model 6 did not decrease significantly.

References
[1] Manik, P. (2007). “Analisa gerakan seakeeping kapal pada gelombang reguler”. Kapal: J. Ilmu Pengetahuan dan Tekno. Kelautan 4:1–10.
[2] Karafiath, G. and Fisher, S.C. (1987). “The effect of stern wedges on ship powering performance”. J. of Naval Engineers.
[3] Cave, W.L. and Cusanelli D.S. (1993). Effect of Stern Flaps on Powering Performance of the FFG-7 Class 30(1). Marine Technology and SNAME News.
[4] Cusanelli, D.S. and Karafiath, G. (1997). “Integrated Wedge flap for enhanced powering performance”. 4th Int. Conf. on Fast Sea Transportation FAST’97, Sydney, Australia.
[5] Tsai, J.F., Hwang, J.L. and Chou, S.K. (2004). ”Study on the compound effects of interceptor with stern flap for two mono-hulls with transom stern”. Oceans 2004, MTTS/IEEE Techno-Ocean 2:1023-1028.
[6] Uithof, K., van Oossanen, P., Moerke, N., van Oossanen, P.G. and Zaaier, K.S. (2014). “An update on the development of the Hull Vane”. 9th Int. Conf. on High-Performance Marine Vehicles (HIPER), Athens.
[7] Bouckaert, B., Uithof, K., van Oossanen, P.G. and Moerke, N. (2016). “Hull vane on Holland-Class OPVs–A CFD analysis of the effects on seakeeping”. 13th Int. Naval Eng. Conf. and Exhibition (INEC), Bristol.
[8] Bouckaert, B., Uithof, K., van Oossanen, P.G., Moerke, N., Nienhuis, B. and van Bergen, J. (2015). "A life-cycle cost analysis of the application of a hull vane to an offshore patrol vessel". In 13th Int. Conf. on Fast Sea Transport (FAST), Washington DC.
[9] Uithof, K., Hagemeister, N., Bouckaert, B., van Oossanen, P.G. and Moerke, N. (2016). “A systematic comparison of the influence of the Hull Vane®, interceptors, trim wedges, and ballasting on the performance of the 50m AMECRC series 13 patrol vessel”. Proc. Warship: Advanced Tech. Naval Design, Constr. Operation, Bath, UK.
[10] Iqbal, M. and Rindo, G. (2015). “Optimasi bentuk semihull kapal katamaran untuk meningkatkan kualitas seakeeping”. Kapal: J. Ilmu Pengetahuan dan Tekno. Kelautan 12:19–24.
[11] Airfoil Tools (2017). NACA 2415. Apr. 4 23:25, retrieved from: http://airfoiltools.com/airfoil/details?airfoil=n2415-il
[12] Menter, F.R. (1994). “Two-equation eddy-viscosity turbulence models for engineering applications”. AIAA J. 32(8):1598–1605.
[13] Bardina, J.E., Huang P.G. and Coakley T.J. (1997). Turbulence Modeling Validation, Testing, and Development, NASA Technical Memorandum 110446, Ames Research Center, Moffett Field, California, USA.
[14] Versteeg, H.K. and Malalasekera, W. (2007). An Introduction to Computational Fluid Dynamics: The Finite Volume Method. Pearson education, UK.
[15] Anderson, J.D. (1995). Computational Fluid Dynamics: The Basics with Applications. McGraw-Hill, New York.
[16] Anonim. Pengujian Kapal Perintis 750 DWT. Laboratorium Hidrodinamika Indonesia, Surabaya