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A Study on Aero-dynamic Performances of a Small Ship with a Different Hull Form

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Abstract: *Aero-dynamic performance of a ship is important for the ships and other vehicles in transportation. Aero-dynamic performances of a ship affected on service speed of the ship, air resistance acting on the ship, power energy as well as roll, pitch, yaw and stability of the ship. More ever, it also directly effects on health of the passengers, captains or employers who works on the ship and safety of the ship. If aero-dynamic performance of ship is not good, it may be making accident. In this paper, the authors present a study on aero-dynamic performances of a small passenger and the effects of hull shape on aero-dynamic performance of the ship. By using a commercial Computation Fluid Dynamic (CFD) code, several hulls form of the ships which are designed with Auto-Ship tool are computed to show out their aero dynamic performances. By compared at other results of the ships run at several service speeds, service conditions the effects of hull form on aero dynamic performances of the ships to be shown clearly. From the results of comparison on aero-dynamic performances among different hull form and services condition, the best aero-dynamic performances hull form for a small passenger is found. From the results of the paper may be useful for optimum ship design or user guide for safety of a ship in transportation too.*

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I. Introduction

In recent studies on ship specific aero-dynamics, there are many studies related to conventional cargo ships, such as Ngo.VH et al. (2013, 2014, 2015). In the study, the authors conducted a study to reduce wind resistance acting on a hull of a cargo ship by used a commercial numerical simulations and model experiments at towing tank. These results show the effects of the hull shape on the aero-dynamic performances of the ship and the accommodation, the position of an accommodation on deck has significantly effect on aero-dynamic resistance as well as the aero-dynamic performances of the ship [1, 4, 5]. K. Mizutani et al. (2013, 2014) investigated the effects of hull form above the deck of a chip carrier on the aero-dynamic characteristics acting on the ship by used numerical simulations and experimental model test. The results of the research have shown that the arrangement of loading equipment affects the aero-dynamic resistance on the ship and offers solutions to reduce air resistance [2, 3].

In the studies on hydrodynamic performances of a small shipin recent years [6-9], there are some representative studies such as E. Begovic et al. (2012), an experimental research on impact resistance on small high speed ship in wave conditions. In the study, the author determined the impact resistance acting on the ship in the range of relative speed at the Froude number is from 0.56 to 3.92 through experimental ship model. In there, the authors presented the figures of experimental images determine the tangle and wave created when the ship moves. On the basis of a comparison of the different ship models, the authors provide an overview of resistances optimization for the ship. K. I. Matveev et al. (2015) investigated the reduction of hull resistance with the method of using tank cavitation. I. M. Viola et al., (2014) studied on air resistance acting on a sail ship. The authors proposed some hulls shapes with the different dimension ship and draft. In the study, the authors determined the resistance of the ship in the speed range with the Froude from 0.3 to 1.03. The study also demonstrated the influence of the crew member on the vessel to the aero-dynamic resistances while provided solutions to improve reliability and criticality requirements in the experimental design of the high speed range. E. Becgovic et al., (2016) investigated ship hydrodynamic performances through model test in wave conditions, the effects of oscillation amplitude when the ship was in motion. A review of the study as shown that the most studies focus on the optimization of aero-dynamic performances acting on the cargo ships and other research intensive research on high speed ships, small air ship to find the optimal solution hydrodynamic resistance for the ship.

In this study, the authors investigated the effect of hull form and ship operating condition on ship's aero-dynamic performances by using a commercial numerical simulation CFD (Computational Fluid Dynamics). Based on the analysis of the computed and compared results, the effects on the aero-dynamic performances of the small ship and the small passenger ship will be clarified. At the same time, the results of this study may be useful in research on safety recommendations for the operation of small passenger ships.

II. Model used for computation

In this study, a small passenger ship is used as a referenced model. The ship was designed as following a small cruise ships, rescue vessels. Figure 1 shows body plan of the ships. The main parameters of ships are detailed in Table 1.

Table no 1: The principal particulars of the ships.

Name	N1	N2	N3	N4	Unit
Length of ship, L	6.0	6.0	6.0	6.0	m
Breadth of ship, B	1.85	1.85	1.85	1.85	m
Height of ship, D	0.80	0.80	0.80	0.80	m
Draft of ship, d	0.20	0.20	0.20	0.20	m
Displacement, Δ	0.19	0.75	0.39	1.11	ton
Frontal projected area of ship, S_x	1.15	2.44	2.38	1.57	m^2

Figure no 1: Body plan of the ships used for computation

III. CFD computed aero-dynamic performances of the ships

In this study, the aero-dynamic performances of the ships are investigated by using the CFD, Ansys V.14.5, the copyright license is registered by the authors's school, School of Transportation Engineering, Hanoi University of Science and Technology. The method used in most numerical computational programs in general and the Ansys program in particular is often based on the theory of fluid dynamics computation using the finite element method. Where the basic equations are used and solved by different methods. This section introduces some basic equations in CFD [10, 11].

- The continuous equation:

$$\frac{1}{\rho}\frac{d\rho}{dt} + div\vec{u} = 0 \qquad (1)$$

where: ρ is density of fluid, kg/m3.
u is velocity, m/s.

- The Navier-Stockes equation:

$$\begin{aligned}
\frac{du_x}{dt} &= X - \frac{1}{\rho}\frac{\partial p}{\partial x} + v.\Delta u_x + \frac{1}{3}v\frac{\partial}{\partial x}div\bar{u} \\
\frac{du_y}{dt} &= Y - \frac{1}{\rho}\frac{\partial p}{\partial y} + v.\Delta u_y + \frac{1}{3}v\frac{\partial}{\partial y}div\bar{u} \\
\frac{du_z}{dt} &= Z - \frac{1}{\rho}\frac{\partial p}{\partial z} + v.\Delta u_z + \frac{1}{3}v\frac{\partial}{\partial z}div\bar{u}
\end{aligned} \qquad (2)$$

where: p is pressure at current point, N/m^2
u_x, u_y, u_z are the velocities as flow the axis of the ox, oy and oz
X, Y, Z are the forces of mass acceleration in terms of ox, oy, oz

- The convective equation for k-ε standard model:

Kinetic turbulent energy k equation:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\right] + P_k + P_b - \rho\varepsilon - Y_M + S_k$$

Dissipated turbulent energy ε equation:

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial x_i}(\rho\varepsilon u_i) = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\frac{\partial\varepsilon}{\partial x_i}\right)\right] + C_{1\varepsilon}\frac{\varepsilon}{k}(P_k + C_{3\varepsilon}P_b) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} + S_\varepsilon$$

Represents eddy viscosity equation:

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon} \quad (5)$$

where:

P_k is represents the generation of turbulent kinetic energy due to the mean velocity gradients:

$$P_k = -\rho\overline{u_i' u_j'}\frac{\partial u_j}{\partial u_i} \qquad P_k = \mu_t S^2 \quad (6)$$

S is the modulus of the mean rate of strain tensor:

$$S = \sqrt{2S_{ij}S_{ij}}$$

P_b is the generation of turbulent kinetic energy due to buoyancy:

$$P_b = \beta g_i \frac{\mu_t}{\Pr_t}\frac{\partial T}{\partial x_i} \quad (7)$$

The Prandtl number: P_{rt}= 0.85

The coefficient of thermal expansion:

$$\beta = -\frac{1}{\rho}\left(\frac{\partial\rho}{\partial T}\right)_p$$

The models constant:

$$C_{1\varepsilon} = 1.44 \quad C_{2\varepsilon} = 1.92 \quad C_\mu = 0.09 \quad \sigma_k = 1.0 \quad \sigma_\varepsilon = 1.3$$

- Aero-dynamic resistance: In computation of resistance acting on a ship, the resistance is usually divided into two components, the part of ship that underwater and the part of ship above water. The resistance component that impacts the above water line part of the ship is commonly referred as aero-dynamic resistance component. The aero-dynamic resistance acting on the ship is characterized by the aero-dynamic resistance coefficient that determined by the following equation.

$$C_x = \frac{R_x}{0.5\rho S V^2} \quad (8)$$

where: C_x is the resistance coefficient
R_x is the resistance acting on the hull, N
S is the frontal projected area, m^2
V is the velocity of fluid, m/s

In computation of ship performances by using CFD, the process of performing problem usually consists of steps such as designed problem model, design computed fluid domain and meshing, setup conditions and boundary conditions, compute the problem, calculate and process the results. Each step effects on the calculated results, the effects on results depend on the calculation requirements and the ability of the user. In computation of CFD, the calculation results are often compared with the results of experiment to evaluate the reliability of the used CFD. In this study, the calculation steps were carried out in accordance with the guidelines issued by international organizations and simultaneously carried out according to the results obtained with the comparison with the empirical test which published in the world [1-5], [12, 13].

In this study, the problem model is designed to compute the aero-dynamic performances of the small passenger ships as shown in Figure 1. The scale model with ratio of 1/10 model is used. The computed domain is designed with a length of 3.6 m; width 1.2m and height 0.6m corresponding to 0.6m length model ship. Meshing the computed domain with unstructured mesh generates 1.326 million T grid. Figure 2 shows the computed domain and meshing of the problem.

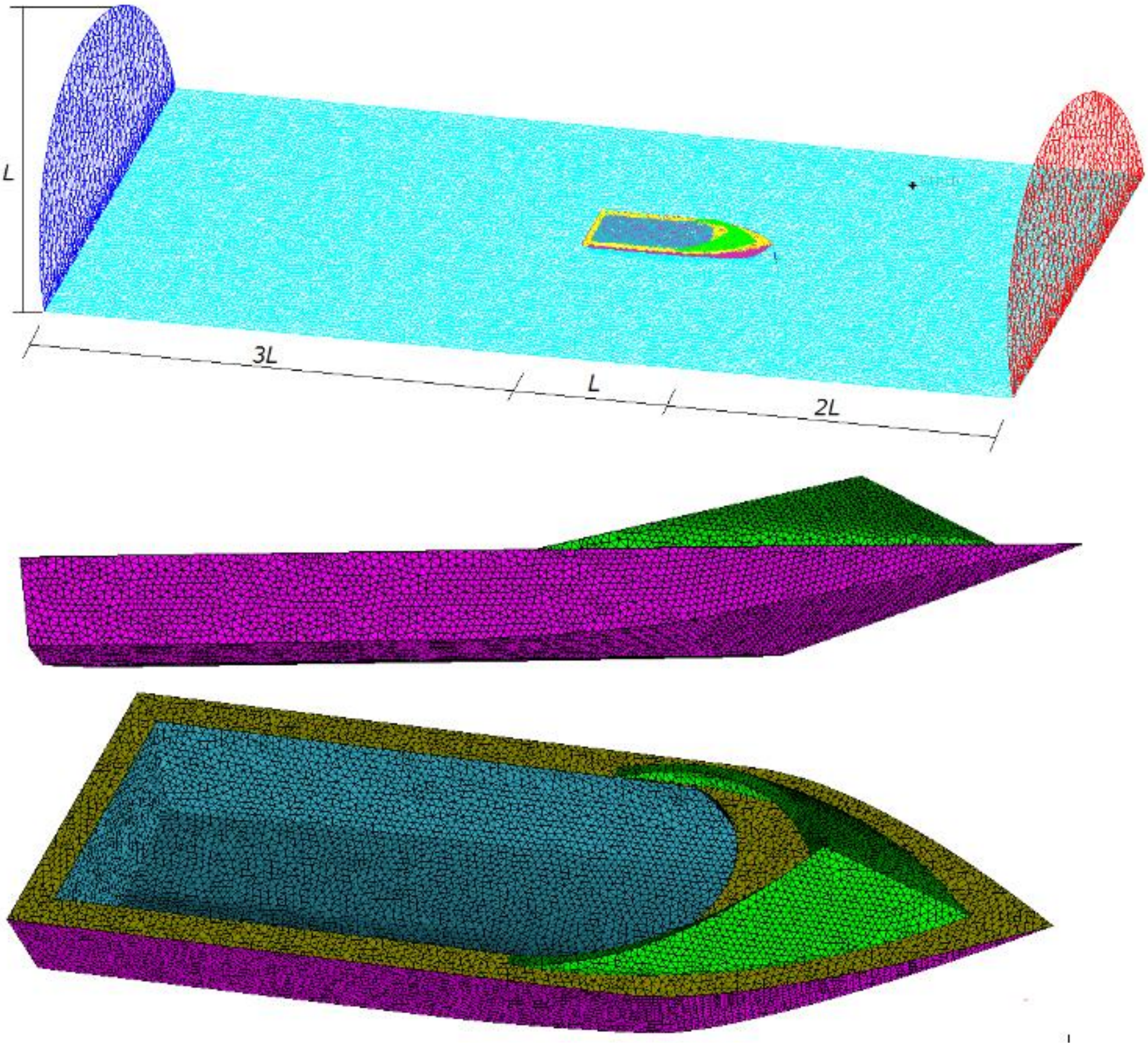

Figure no 2: Computed fluid domain and mesh

In this study, the k-epsilon tangle model for nonlinear flow is chosen to use, the input is conditioned with the input velocity, the output set conditions with the output pressure, the cone is applied condition hard wall. Table 2 shows input parameters for numerical simulation.

Table no 2: The conditional setup for the computed problems

Name	Valuate	Unit
Velocity inlet, V_∞	0 - 7	m/s
Pressure outlet, p_{out}	1,.025	$10^5 N/m^2$
Air density, ρ	1,225	kg/m^3
Kinetic viscosity, υ	1,789	10^{-5}kg/ms
Reynolds number, R_n	$0{,}2 - 5.10^6$	

IV. Effects of hull shape on aero-dynamic performances of the ships

In this section, the all models are computed by the CFD to investigate the aero-dynamic performances. From results of comparison among CFD results of the ships, the effects of hull form on aero-dynamic performances of the ships are shown. From Figures 3 to 7 show the comparison of the pressure and velocity distribution around the shipswith the different shapes and varying posture.

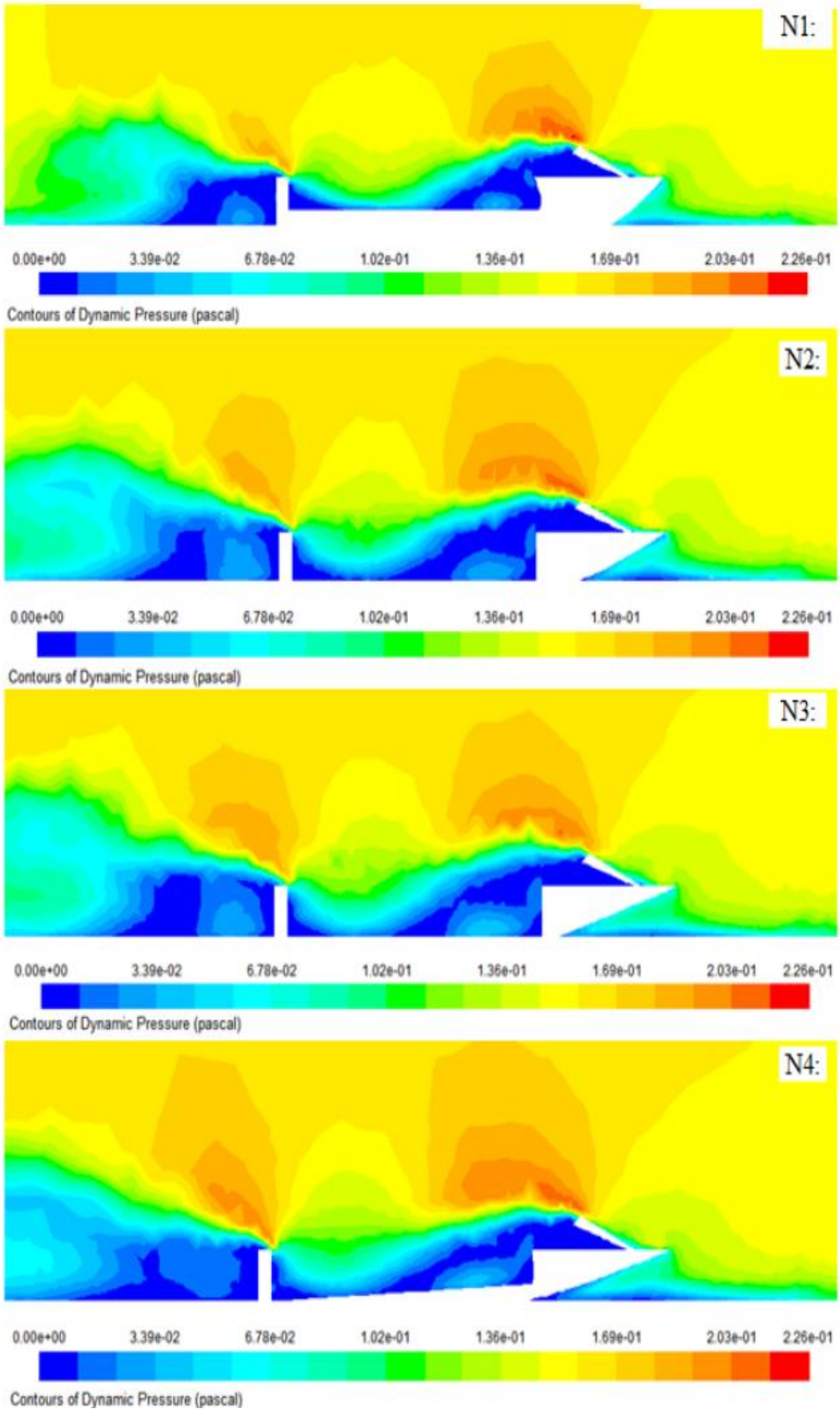

Figure no 3: Pressure distribution around hull at the centre plan of the ships, at heeling angle of zero degree, $R_n=0,2.10^6$

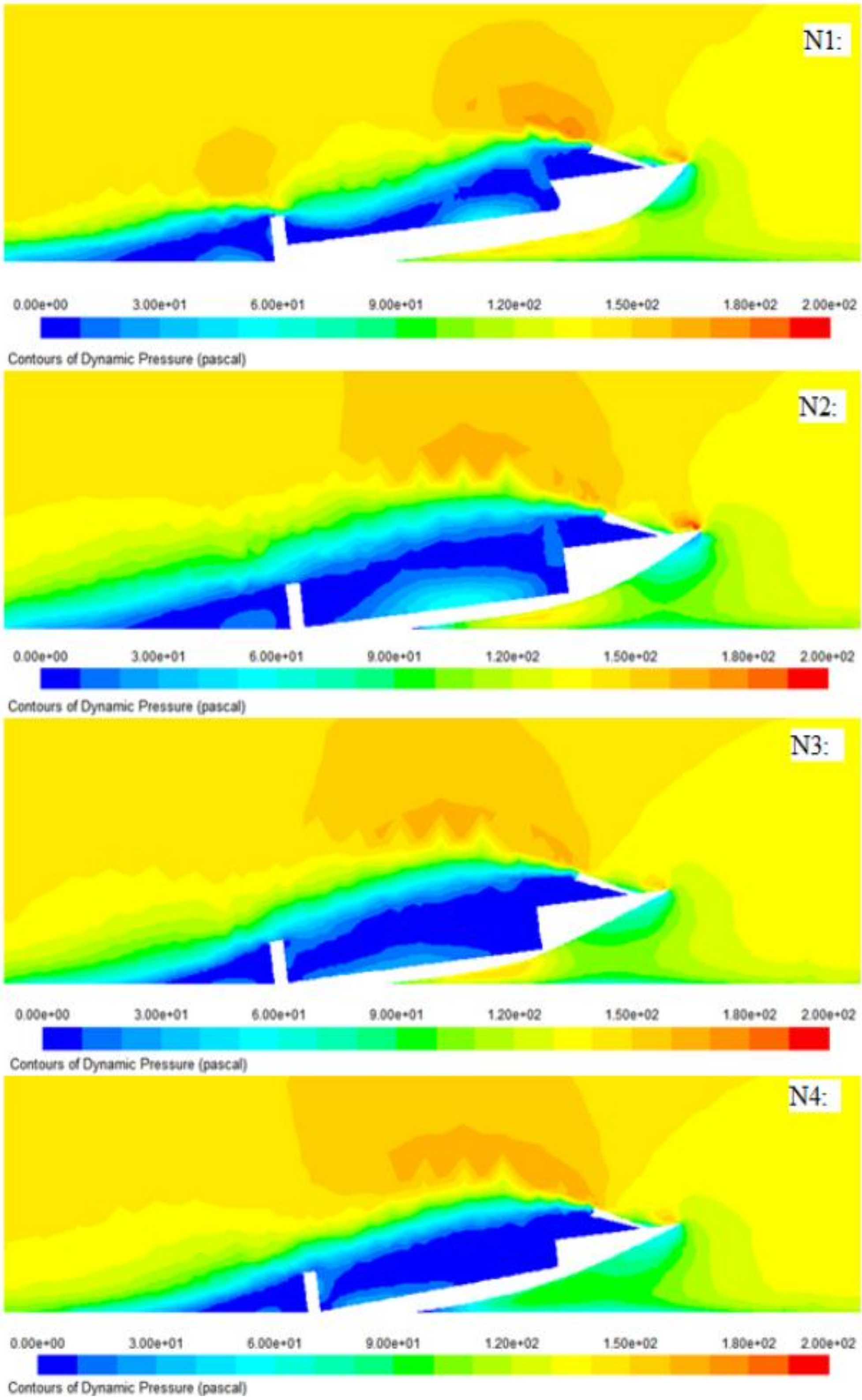

Figure no 4: Pressure distribution around hull at centre plan of the ships at heeling angle of 7 degrees, $R_n=5.10^6$

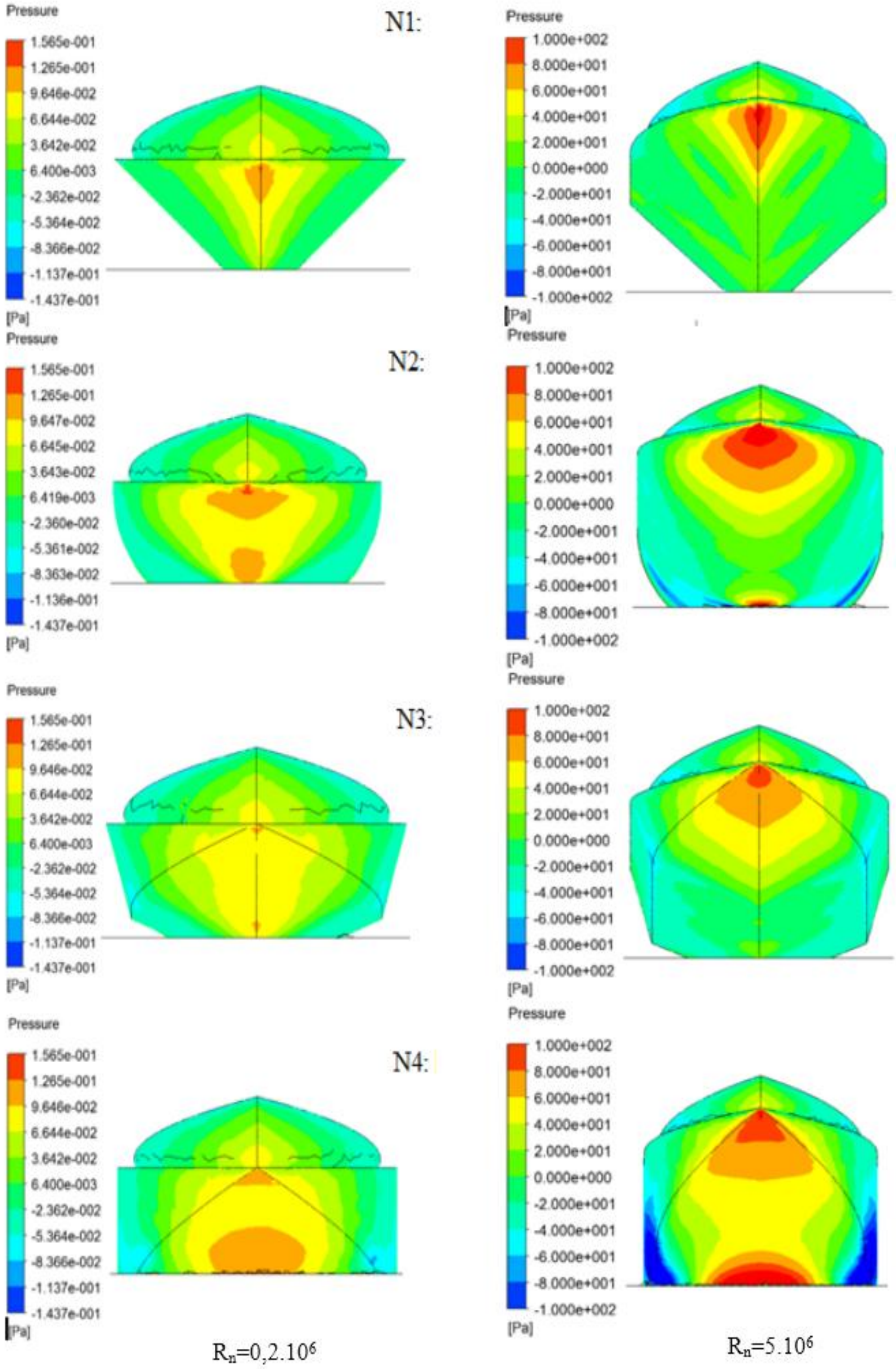

Figure no 5: Pressure distribution over half front of hull surface of the ships at heeling angle of zero and 7 degrees

The results as shown in the figures 3, 4 and 5 show the dynamics pressure distribution around and over hull surface of the hulls. In the figures, red colour area region shows high pressure and blue colour area region is low pressure region acting on the hulls. Clearly changing high pressure area region acting on the hulls by changed hull form of the ships and at the different heeling angle of the ships can be seen in these figures.

Figures 6 and 7 show velocity distribution around hull of the ships at the two different heeling angles of zero and 7 degrees. The results show clearly different of separated flow regions around hull at the centre plan of the computed domain when the ships change heeling angle from zero to 7 degrees.

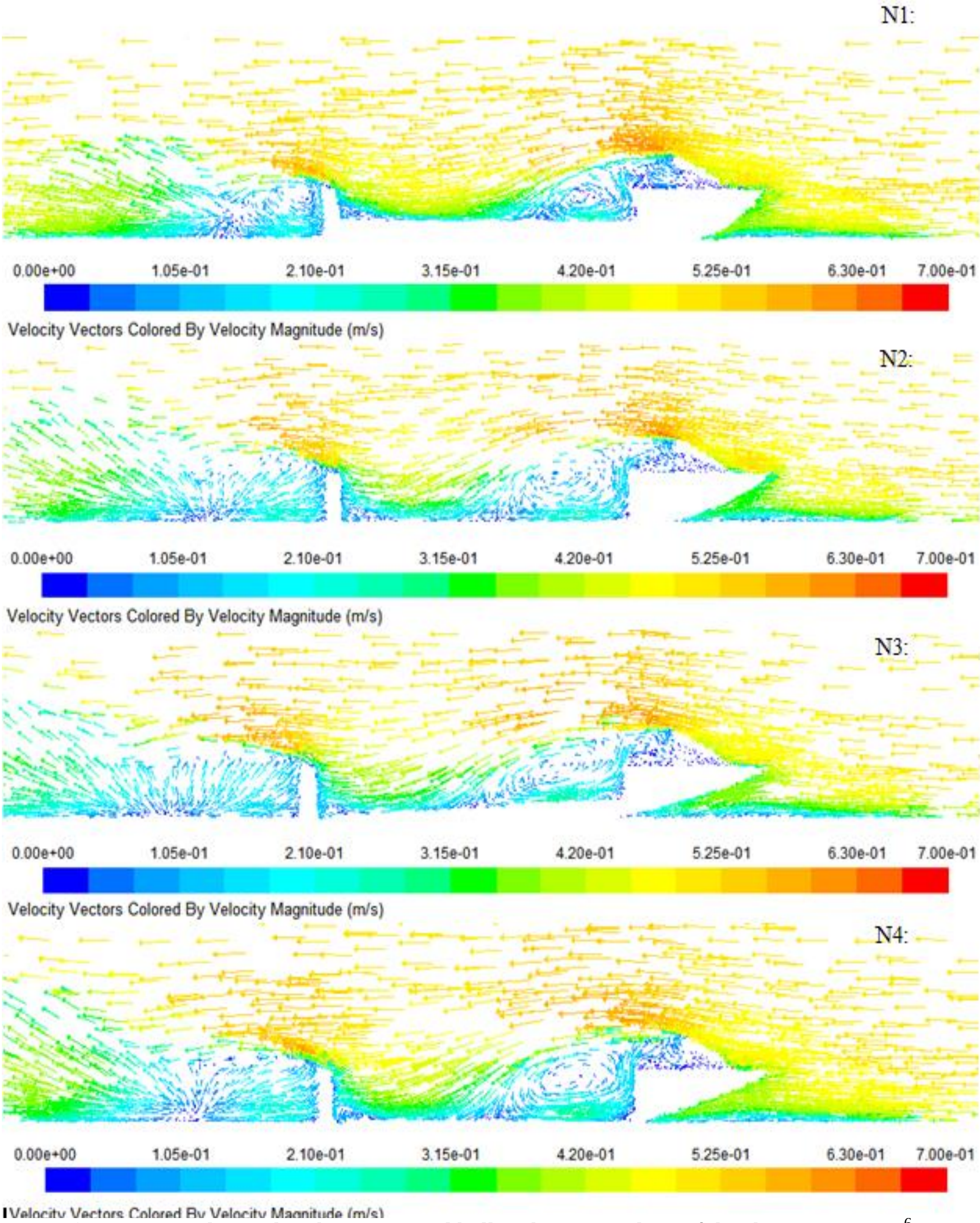

Figure no6: Velocity distribution around hull at the centre plane of the ships, $R_n=0,2.10^6$

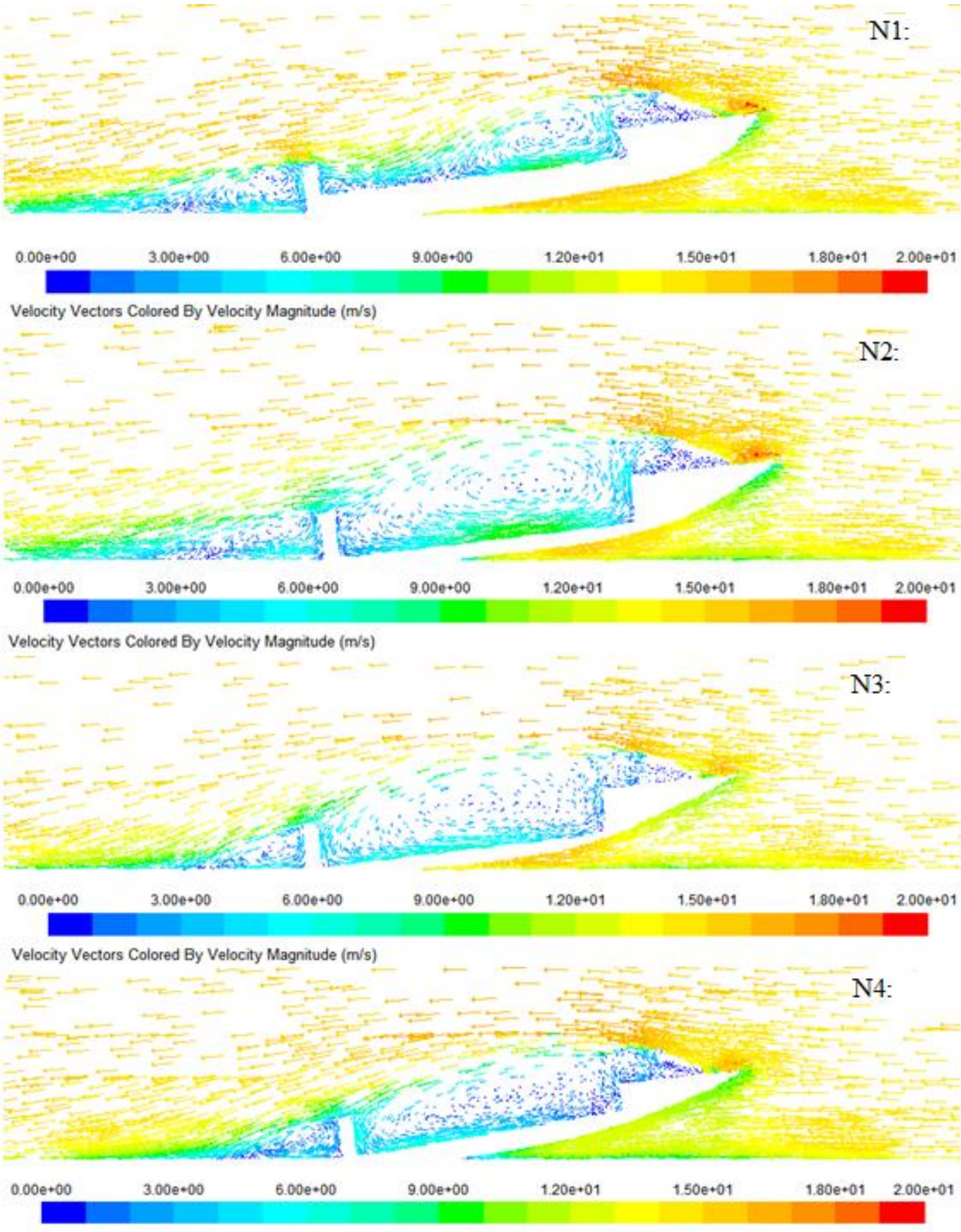

Figure no7: Velocity distribution around hull of the ships at the heeling angle of 7 degrees, R_n=5.10^6

The results of pressure and velocity distribution around the ships as shown clearly effects of hull form and heeling angle of the ships on the aero-dynamics performances. The results demonstrate that the aero-dynamic resistances acting on the ships are effected following as the different hull form and heeling angle of the ships.

Figures 8 and 9 show the CFD results of the aero-dynamic resistances acting on the ships corresponding to the Reynold number at the different of heeling angle of zero and 7 degrees.

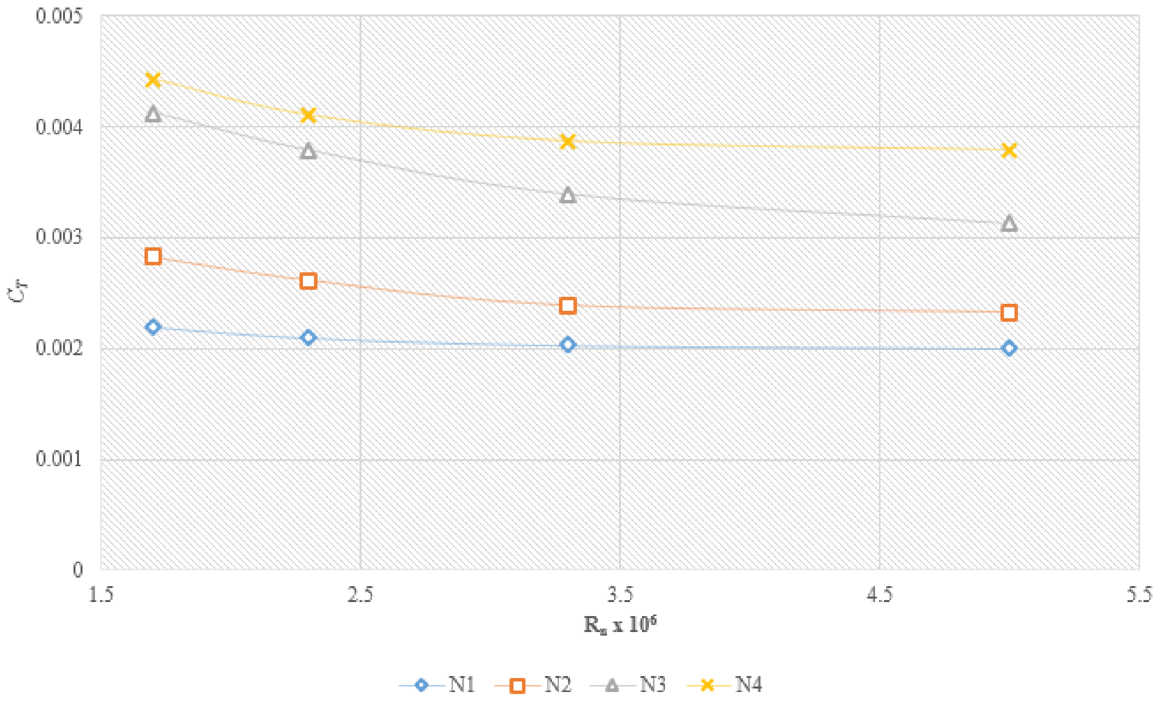

Figure no 8: Aero-dynamic resistance coefficient of the ships with the different hull form at the heeling angle of 0 degree

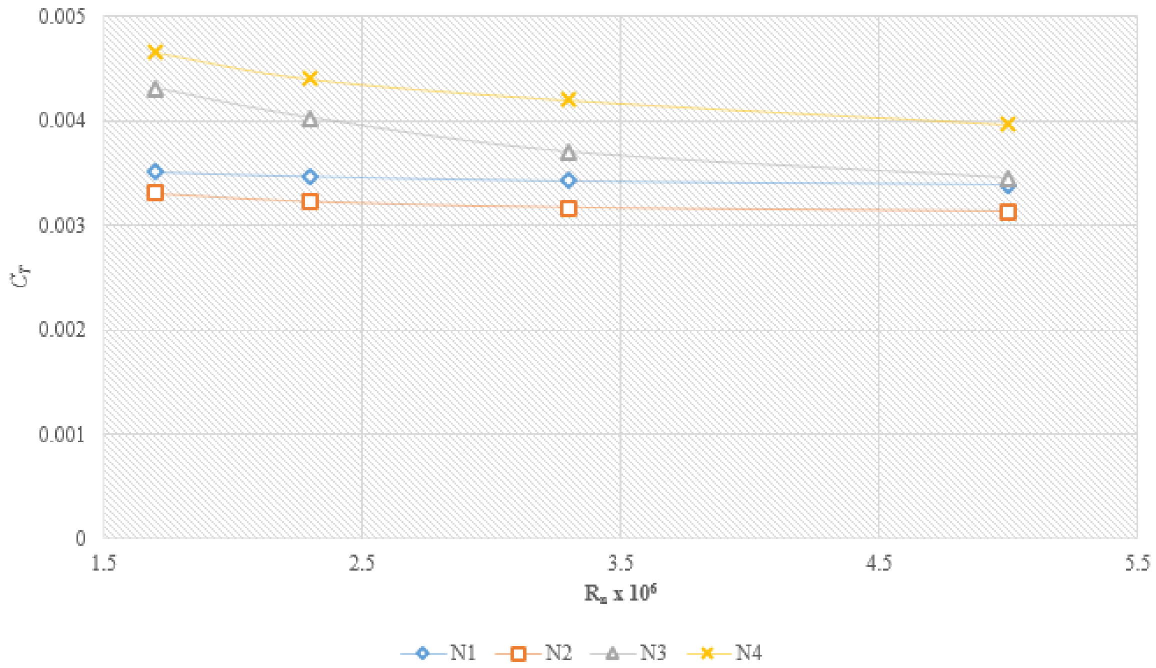

Figure no 9: Aero-dynamic resistance coefficient of the ships with the different hull form at the heeling angle of 7 degrees

The results as shown in the figures 8 and 9 show the aero-dynamics resistances acting on hull of the ships in the different heeling angles and different hull form. The different aero-dynamics resistances acting on the ships are clearly shown in the figures. At heeling angle of zero degree, the model N1 with the tri-angle hull form has small frontal projected area is the lowest aero-dynamic resistance coefficient hull form. The model N2 is the larger frontal projected area, also the aero-dynamic resistance coefficient acting on it is less than other models in both of the two heeling angle zero and 7 degree. The results as show that, when the Reynold number is higher than 3.5 x 10^6, the aero-dynamic resistances coefficient acting on the ships is coming to constant and it has different belong to the hull form and heeling angle of the ships. The detailed aero-dynamic resistances coefficients of the ships are shown in Table 3 and 4. Table 5 shows comparison results of aero-dynamic resistances coefficients of the ships between the two heeling angle of zero and 7 degrees.

Table no 3: Aero-dynamic resistance coefficient of the ship at the heeling angle of 0 degree

R_n x 10^6	C_T			
	N1	**N2**	**N3**	**N4**
1.7	0.00219	0.002824	0.004124	0.004426
2.3	0.002094	0.002612	0.003786	0.004104
3.3	0.002029	0.002387	0.003389	0.003869
5.0	0.002001	0.002325	0.003126	0.00379

Table no 4: Aero-dynamic resistance coefficient of the ship at the heeling angle of 7 degree

R_n x 10^6	C_T			
	N1	**N2**	**N3**	**N4**
1.7	0.003508	0.003308	0.004305	0.004657
2.3	0.003466	0.003227	0.004025	0.004400
3.3	0.003422	0.003168	0.003700	0.004200
5.0	0.003386	0.003128	0.003450	0.003967

Table no 5: Different of the aero-dynamic resistance coefficients of the ships with the different hull form at the different heeling angle of 0 and 7 degrees

R_n x 10^6	Difference of the aero-dynamic resistance coefficient of the ships between the two heeling angle of 0 and 7 degrees, %			
	N1	N2	N3	N4
1.7	60	17	4	5
2.3	66	24	6	7
3.3	69	33	9	9
5.0	69	35	10	5

The results as shown in the table 5 shows clearly different of aero-dynamic resistance coefficients among the four models at the two heeling angle. The most different of the aero-dynamic resistance coefficients belong to the tri-angle hull form N1, up to 69%, and the squared hull form N4 and N3 are the smallest different aero-dynamic resistance coefficient when the ship changing heeling angle from zero to 7 degrees, less than 9%.

V. Conclusion

In this paper, the aero-dynamic performance of a small passenger ships is studied by used the commercial CFD code. From the results of the survey and comparison among the aero-dynamic performances of the ships as shown, the effects of hull form and heeling angle of the ships on the aero-dynamic performances as well as the pressure, velocity distribution around hull and the aero-dynamic resistances coefficient acting on the hulls are shown. In the fourth kind of the hull forms, the tri-angle hull form N1 is the smallest displacement and frontal projected area, also it has low aero-dynamic resistance coefficient hull form. The model N2 has the largest displacement and frontal projected area, but it is too small aero-dynamic resistance coefficient hull form as shown. When the ships change heeling angle, the aero-dynamic resistance acting on its increase, therefore, the squared hull form N4 and N3 have the smallest changing aero-dynamic resistance hull form. In this research, the corresponding speed of the ships used in the computation as the Reynolds numbers is from 0.2 x 10^6 to 5 x 10^6. The results obtained through CFD simulationmay be the basis data for optimal aero-dynamic shape for the small passenger ships, also it can provide the basis theory for the research on optimal status and operational posture for the ships with the full effects of hull form and heeling angle.

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References

[1]. Ngo. V.H, Y. Ikeda.A Study on Interaction Effects between Hull and Accommodation on Air Resistance of a Ship. Proceeding of the JASNAOE, Hiroshima, Japan, 2013, Vol.16, ISSN: 2185-1840, pp.278-281.

[2]. K. Mizutani, D. Arai, Ngo. V.H, Y. Ikeda. A Study on Reduction of the Wind Resistance Acting on a Wood Chip Carrier. Proceeding of the JASNAOE, Hiroshima, Japan, 2013, Vol.16, ISSN: 2185-1840, pp.282-285.

[3]. K. Mizutani, Y. Akiyama, Ngo. V.H, Y. Ikeda. Effects of cargo handling equipment on wind resistance acting on a wood chip carrier. Proceeding of the JASNAOE, Hiroshima, Japan, 2014, Vol.18, ISSN: 2185-1840, pp.421-424.

[4]. Ngo. V.H, K. Mizutani, Y. Ikeda. Reducing air resistance acting on a ship by using interaction effects between the hull and accommodation. Proceeding of the 7th AUN/SEED-Net RCMME 2014, Hanoi, Vienam, 2014, pp.497-501.

[5]. Ngo. V.H, Phan. A.T, Luong. N.L, Y. Ikeda. A Study on interaction Effects on air resistance acting on a ship by shape and location of the accommodation. Journal of Science and Technology, Vietnam, 2015, Vol 27, pp. 109-112.

[6]. E. Begovic, C. Bertorello. Resistance assessment of warped hull form. Journal of Ocean Engineering, 2012, Vol.56, pp. 28-42.
[7]. K. I. Matveev. Hydrodynamic modeling of semi-planing hulls with air cavities. International Journal of Naval Architure and Ocean Engineering, Koen, 2015, p-ISSN: 2092-6782, pp.500-508.
[8]. I. M. Viola, J. Enlander, H. Adamson.Trim effect on the resistance of sailing planning hulls. Ocean Engineering, 2014, Vol.88, pp.187-193.
[9]. E. Becgovic, C. Bertorello, S. Pennino, V. Piscopo, A. Scamardella. Statistical analysis of planning hull motions and accelerations in irregular head sea. Ocean Engineering, 2016, Vol. 112, pp. 253-264.
[10]. Versteeg H. K., Malalasekera W. An Introduction to Computational Fluid Dynamics: The Finite Volume Method, 2nd Edition, Pearson Education, 2007.
[11]. Mohammadi B., Pironneau O. Analysis of the K-epsilon turbulence model, Wiley & Sons, 1994.
[12]. ITTC, The proc. of the 25th International Towing Tank Conference, Fukuoka, Japan, 2008, Website: http://ittc.sname.org/proc25/assets/documents/VolumeI/Proceedings-Vol-01.pdf.
[13]. ANSYS Inc. ANSYS FLUENT User's Guide, Theory Guide and Software Tool, Release 13.0, 2010. Website: http://www.ansys.com/.

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