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EFFECT OF HULL AND ACCOMMODATION SHAPE ON AERODYNAMIC PERFORMANCES OF A SMALL SHIP

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Abstract. In marine transportation, aerodynamic performance is important for the ships, especially for the small passenger fast ships. It has affected the service speed, air resistance acting on hull, power energy as well as roll, pitch, yaw and stability of the ships. Moreover, the aerodynamic performance also directly affects the passengers, captains or employments who work on the ships. For a bad aerodynamic performance hull shape, it may make an accident in marine transportation. In this paper, the authors present a study on effect of hull shape on aerodynamic performance of a small passenger fast ship by using a commercial Computational Fluid Dynamics (CFD). Several hull forms with different shapes are proposed and computed to show their aerodynamic performances. From the comparison between different CFD results of the ships, the effects of hull shape on aerodynamic performances of the ships are understood.

Keywords: Aerodynamic, small ship, air resistance, hull, CFD.

INTRODUCTION

In the field of study on aerodynamic ship, there are many published studies that are related to conventional cargo ships. In Ngo V. H. et al., (2013, 2014, 2015), the authors presented a study to reduce wind resistance acting on a hull of a cargo ship by using commercial numerical simulations and model experiments at towing tank. These results showed the effects of hull shape on the aerodynamic performances of the ship; the accommodation and the position of an accommodation on deck have significantly affected aerodynamic performance of ship as well as the air resistance acting on hull [1–3]. Mizutani, K. et al., (2013, 2014) investigated the effects of hull form above the deck of a chip carrier on the aerodynamic characteristics acting on the ship by using numerical simulations and experimental model test. The results of the research have shown that the arrangement of loading equipment affected the aerodynamic resistance acting on the ship and offered solutions to reduce air resistance [4, 5].

In others studies on hydrodynamic performances of a small ship [6–9], there are some representative studies such as that presented by Begovic, E. 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 from 0.56 to 3.92 through experimental ship model. The authors presented the figures of experimental images determining the tangle and wave created when the ship moved. On the basis of a comparison of the different ship models, the authors provide an overview of resistance optimization for the ship. Matveev, K. I. et al., (2015) investigated the reduction of hull resistance with the method of using tank cavitation. Viola, I. M. et al., (2014) studied air resistance acting on a sailing. The authors proposed some hull shapes with the different ship dimensions and drafts. 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 on the aerodynamic resistances, simultaneously provided solutions to improve reliability and criticality requirements in the experimental design of the high speed. Becgovic, E. et al., (2016) investigated ship hydrodynamic performances through model test in wave conditions, the effects of oscillation amplitude when the ship moved.

In this study, the authors investigated the effect of hull shape on aerodynamic performances of a small ship by using the CFD, Ansys-Fluent v.14.5. Based on the analysis of the CFD results, the effects on the aerodynamic performances of the small passenger fast ship are clarified. The results may be useful in research on optimal hull shape and safety recommendations for the ship in operation.

MODEL OF A SMALL SHIP USED FOR COMPUTATION

In this paper, a small passenger fast ship is used as a referenced model. The ship was designed as follows: A small passenger ship, rescue vessel [6, 7]. Fig. 1 shows the body plan of the ship, the detailed main parameters of the ship are shown in table 1.

Table 1. The principal particulars of the small ships, N3

Name	Full scale	Unit
Length of ship, L	6.0	m
Breadth of ship, B	1.85	m
Height of ship, D	0.80	m
Draft of ship, d	0.20	m
Displacement, Δ	0.39	ton
Frontal projected area of ship, S_x	2.38	m^2

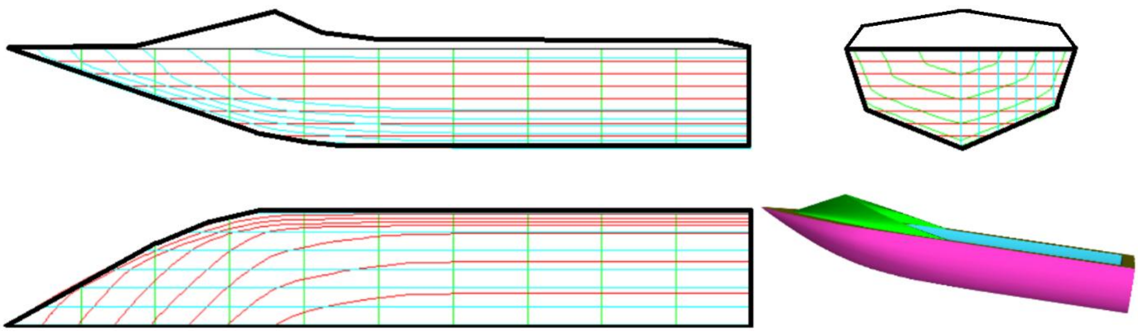

Fig. 1. Body plan of the small ships used for computation, N3

CFD COMPUTED AERODYNAMIC PERFORMANCES OF THE SHIPS

In this paper, the aerodynamic performances of the ships are investigated by using the CFD, Ansys V.14.5, the copyright license is registered by the author’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 computational fluid dynamics using the finite element method [10–13]. In computation of ship performances by using CFD, the process of performing problem usually consists of steps such as designing problem model, designing computed fluid domain and meshing, setting up conditions and boundary conditions, computing the problem, calculating and processing the results. Each step affects the calculation results, the effects on results depend on the calculation requirements and the ability of the user. The calculation results are often compared with the results of experiment to evaluate the reliability of the used CFD. In this paper, 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 was published in the world [1–5, 10–13].

In computation of resistance acting on a ship, the resistance is usually divided into two components, the part of ship under water and the part of ship above water. The resistance component that impacts the above water line part of the ship is commonly referred to as aerodynamic resistance component. The aerodynamic resistance acting on the ship is characterized by the aerodynamic resistance coefficient that is determined by the following equation.

$$C_x = \frac{R_x}{0.5\rho S V^2} \tag{1}$$

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 this paper, the problem model is designed to compute the aerodynamic performances. The scale model with ratio of 1/10 is used. The computed domain is designed with a length of 3.6 m (6 l); width 1.2 m (2 l) and height 0.6 m (l) corresponding to 0.6m length model ship (l). Meshing the computed domain with unstructured mesh generates 1.326 million T grid. Fig. 2 shows the computed domain and meshing of the problem. The turbulent viscous model k - ε is used, the inlet is set up with velocity inlet, the outlet is set up with pressure. Table 2 shows the computed condition.

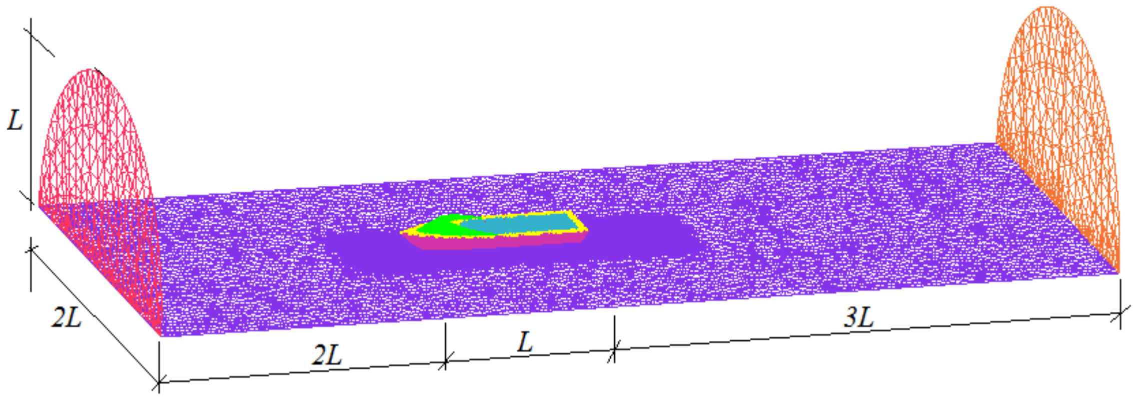

Fig. 2. Computed fluid domain and mesh

Table 2. Computed condition set up for the problems

Name	Value	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	

EFFECTS OF HULL FORM ON AERODYNAMIC PERFORMANCES OF THE SHIPS

In this section, the fourth models with different body plan proposals for the small ship named as N1, N2, N3 and N4 are computed by the CFD to investigate the aerodynamic performances. All the body plans are the same main dimension as the length, breadth and height of the original small ship as shown in the fig. 1 (N3). Fig. 3 shows the body plan of the ships and the principal particulars of the ships are shown in table 3.

All the models are computed by the CFD to investigate aerodynamic performance and air resistance acting on the hull. Fig. 4–6 show the pressure distribution over hull surface of the ships, velocity flow around the ships and air resistance coefficient acting on hulls in wind with the Reynolds number from 1.7 × 10^6 to 5.0

× 10^6. The CFD results show aerodynamic performances of the ships in the different heeling angles of zero degree and 7 degrees.

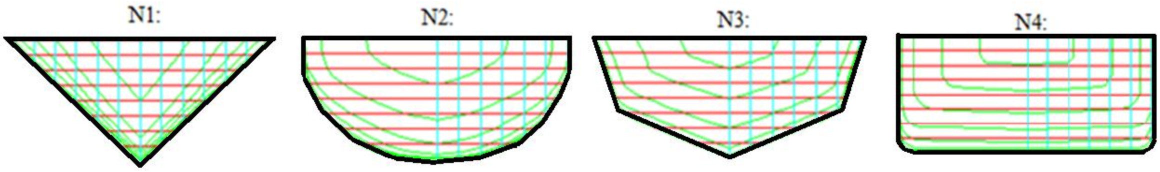

Fig. 3. Different body plan proposals for the small ship

Table 3. The principal particulars of the ships with different body plans

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

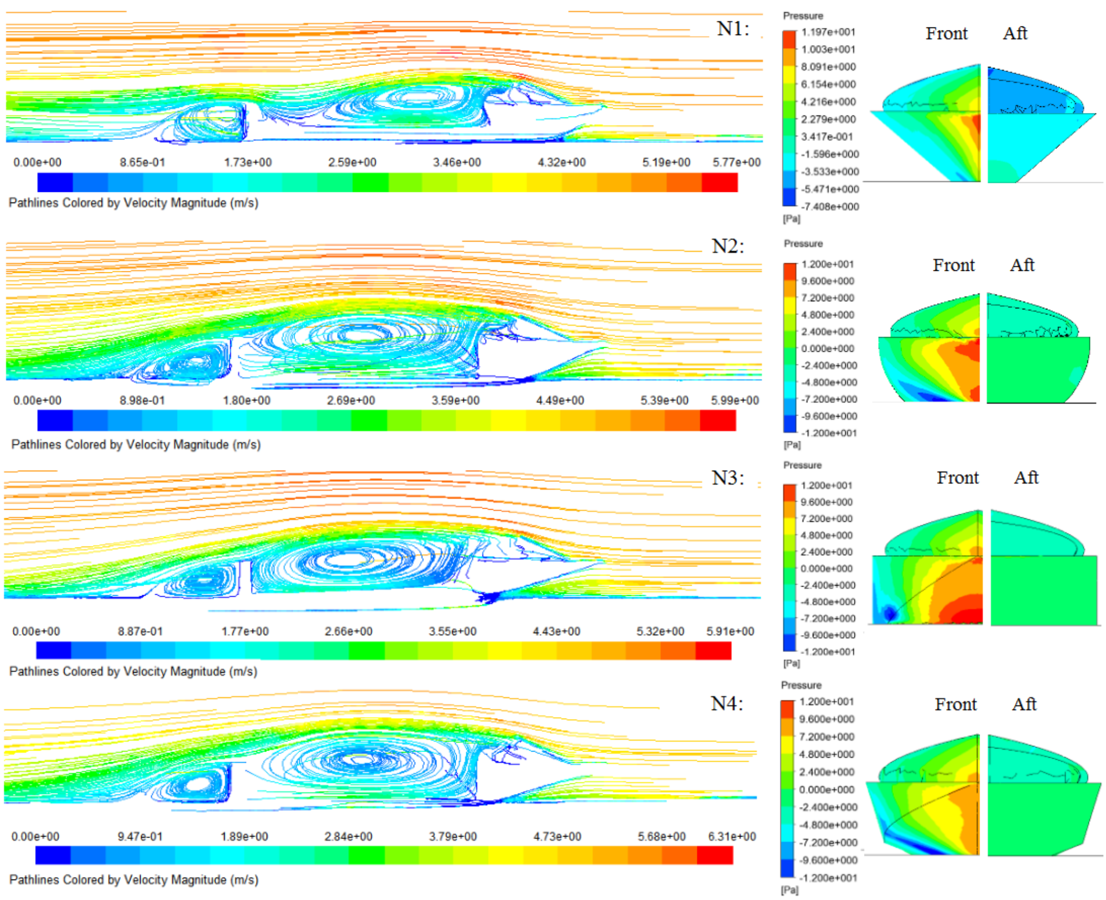

Fig. 4. Pressure distribution over hull surface and velocity flow around hull of the ships, at heeling angle of 0 degree, R_n= 1.7 × 10^6

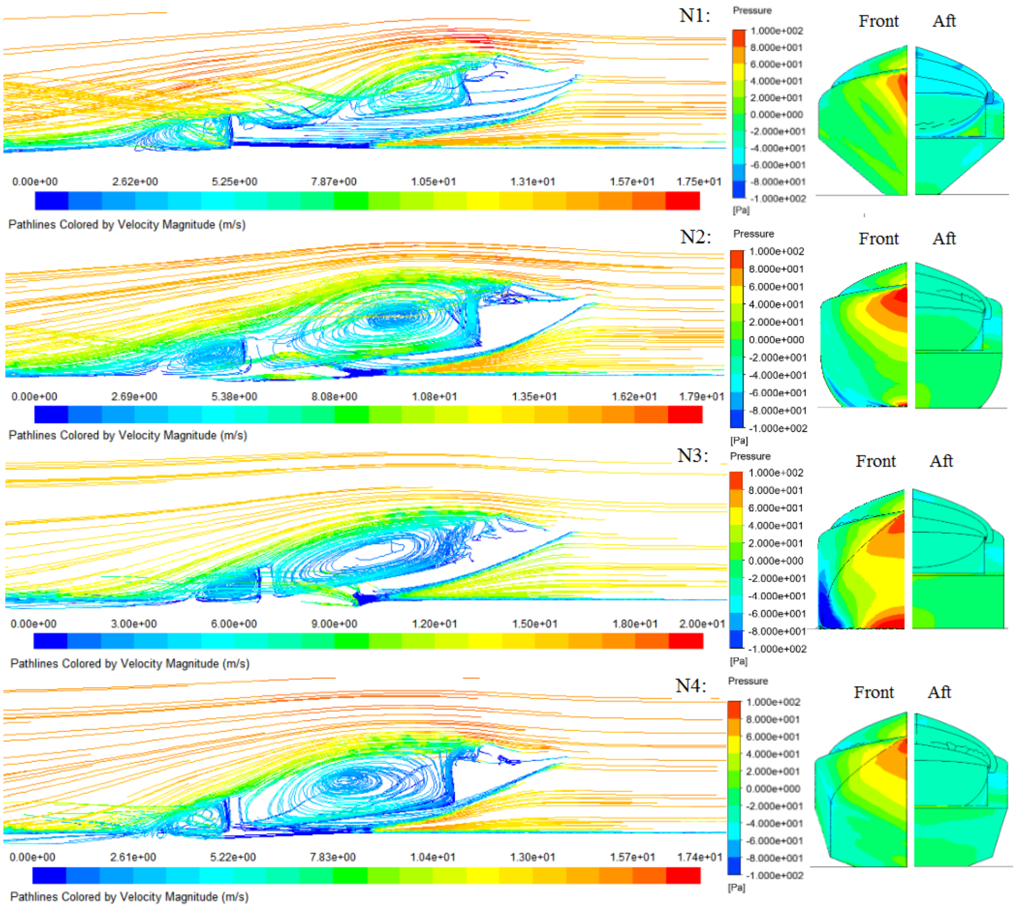

Fig. 5. Pressure distribution over hull surface and velocity flow around hull of the ships at heeling angle of 7 degrees, $R_n = 5 \times 10^6$

The results as shown in fig. 4–5 show pressure distribution and velocity flow around hull of the ships. In the figures, red colour area shows high pressure and blue colour area is low pressure region acting on the hulls. Clearly changing high pressure area acting on the hulls for the different body plans of the ships and at the different heeling angles can be seen in the results as shown.

From the results as shown in the fig. 4–5, we can clearly see effects of hull form and heeling angle of the small ship on its aerodynamic performances. The results demonstrate that air resistances acting on the ships are affected by the different body plans and heeling angles of the ships in transportation.

Fig. 6 shows the CFD results of air resistances acting on the ships corresponding to the Reynolds number, at the different heeling angles of 0 and 7 degrees. The different air resistances acting on the ships are clearly found in the figure. At heeling angle of zero degree, the model N1 with a tri-angle hull form has small frontal projected area and the lowest air resistance coefficient. The model N2 with a circle hull form has the largest frontal projected area, also the air resistance coefficient acting on it is less than that of other models at both heeling angles of zero and 7 degrees. This results show that the higher Reynolds number than 3.5×10^6 is the coming constant of the air resistance coefficients acting on the ship, and it has different values depending on the hull form and the heeling angle of the ships. The detailed air resistance coefficients of the ships with different body plans and at the different heeling angles are shown in table 4.

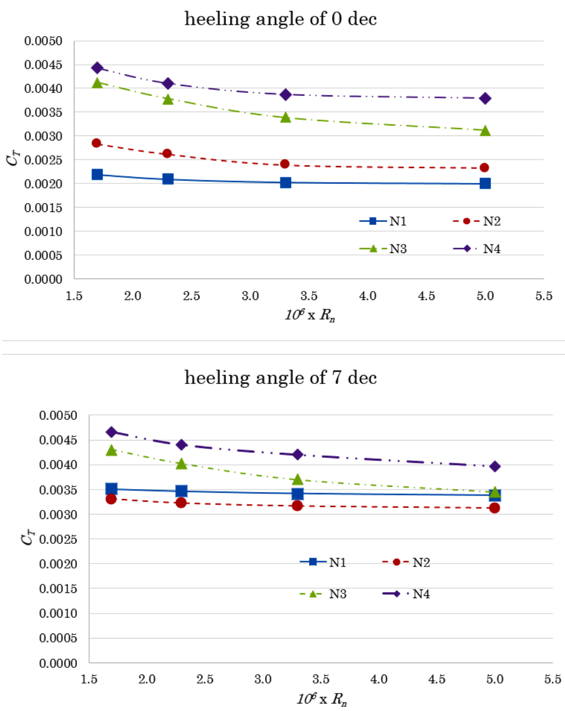

Fig. 6. Air resistance coefficient of the ships at the different heeling angles

Table 4. Air resistance coefficient of the ships

$R_n \times 10^6$	C_T (at heeling angle of 0 degree)			
	N1	N2	N3	N4
1.7	0.002190	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	0.003790
$R_n \times 10^6$	C_T (at heeling angle of 7 degrees)			
	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

The results as shown in the table 4 show clearly different air resistance coefficients among the models at the two heeling angles of 0 and 7 degrees. The most different air resistance coefficient belongs to the tri-angle hull form N1, up to 69%. The model N3 has the smallest different air resistance coefficient when the ship changes heeling angle, it is less than 9%.

EFFECTS OF ACCOMMODATION SHAPE ON AERODYNAMIC PERFORMANCES OF THE SHIPS

In this section, a new hull form with a different accommodation shape has been proposed for the small ship to improve aerodynamic performance. As shown in the results on aerodynamic performance of the ships with different hull form, the model N3 has the smallest different air resistance when the ship changes heeling angle. A new model N5 that has the same body plan but different accommodation shape from the model N3 is proposed for the ship to improve aerodynamic performance. Fig. 7 shows body plan of the model N5. The principal dimensions of the model N5 are the same as those of the model N3.

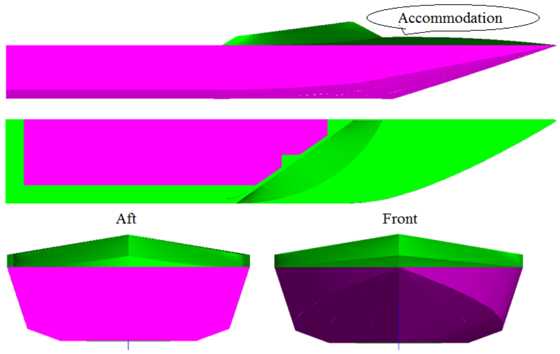

Fig. 7. Body plan of the new model N5

The model N5 is computed by using the CFD to obtain the aerodynamic performances in the same computational conditions with those of the model N3. Fig. 8 shows the CFD results on aerodynamic performance of the model N5 and comparison with those of the model N3.

From the figure that presents pressure distribution over hull surface and velocity flow around hull of the model N5 in comparison with those of the model N3, clearly changing pressure and separation region around hull at other models can be seen. Fig. 9 shows air resistance acting on hull of the model N5 in comparison with that of the model N3. The detailed air resistance acting on the hull of the model N5 is shown in table 5.

The results as shown in the fig. 8 and table 5 show drastically reduced air resistance acting on hull of the ship with new accommodation shape and without heeling angle, N5. In comparison with the model N3, it can be reduced up to 51% of total air resistance at low Reynolds number of 0.2×10^6 and 40% at high Reynolds number of 2.3×10^6. Also, in the field of ship design on behalf of reducing resistance acting on hull we must remark on ship stability and other ship performances too.

Table 5. Air resistance coefficient of the model N5

10^6 x R_n	R_a, N		C_T		% Different
	N3 (0dec)	N5	N3 (0dec)	N5	
0.2	0.00245	0.00132	1.11096	0.6559	-46
1.0	0.03306	0.02988	0.41716	0.4118	-10
1.7	0.08491	0.07922	0.38576	0.3929	-7
2.3	0.16552	0.15170	0.38365	0.3839	-8
10^6 x R_n	N3 (7dec)	N5	N3 (7dec)	N5	%
0.2	0.160855	0.07922	0.44118	0.39296	-51
1.0	0.294738	0.15169	0.80838	0.38391	-49
1.7	0.494332	0.30690	0.33895	0.38059	-38
2.3	1.128398	0.67909	0.77371	0.37429	-40

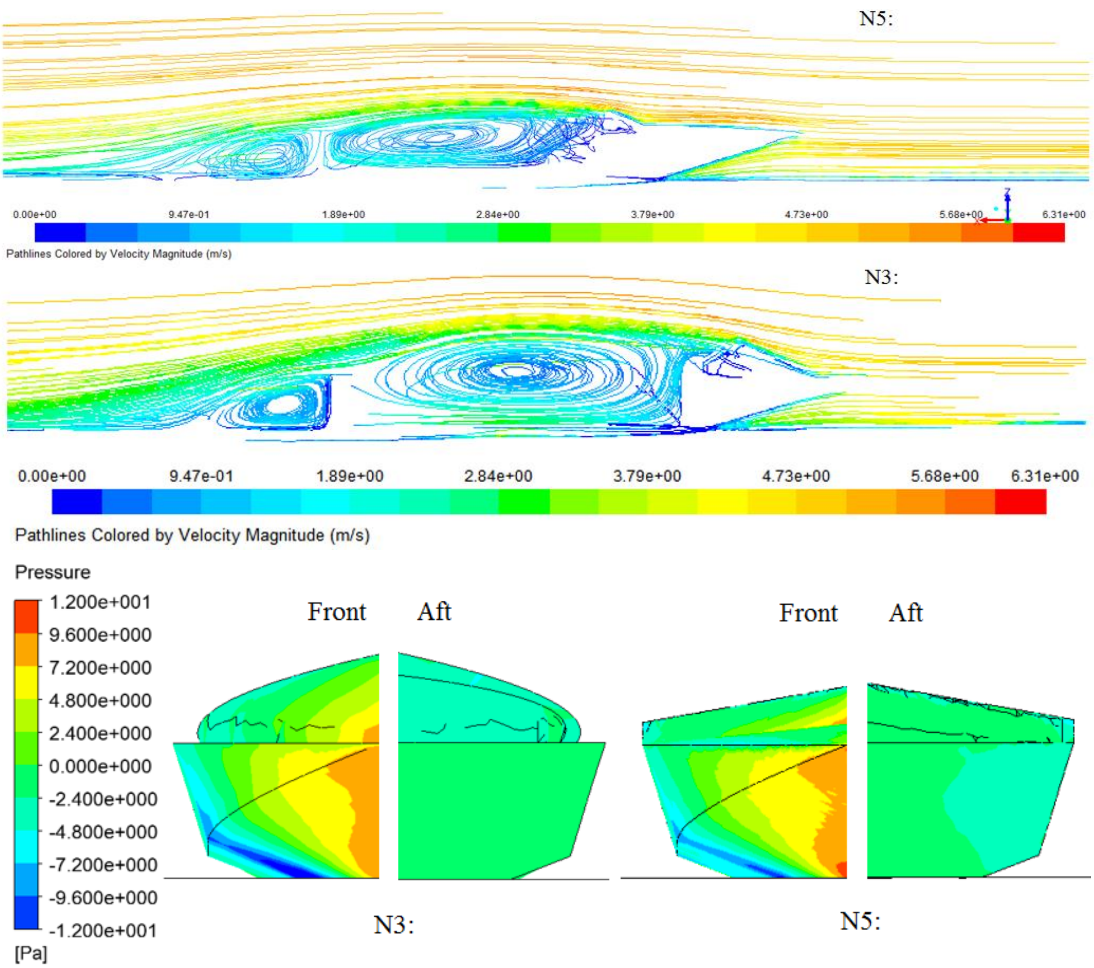

Fig. 8. Pressure distribution over hull surface and velocity flow around hull of the ships, at R_n=1.7×10^6

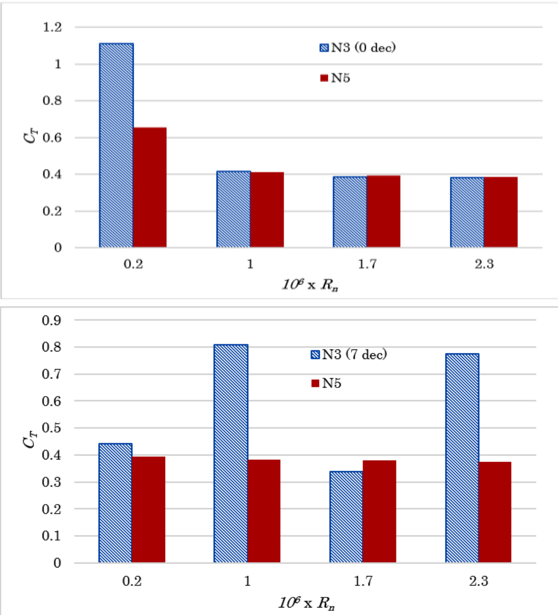

Fig. 9. Air resistance acting on hull of the new model N5

CONCLUSION

In this paper, the aerodynamic performance of a small ship is investigated by using the commercial CFD, Ansys-Fluent. From the comparison of different CFD results of the ships with different body plans, different heeling angles and changed accommodation shape the aerodynamic performances of the ships are shown, the effects of hull form and heeling angle of the ships on the aerodynamic performances can be seen.

In the fourth types of body plan as shown, the tri-angle hull form N1 has the smallest displacement and frontal projected area, also it has lower air resistance coefficient than that of other ones. The model N2 has the largest displacement and frontal projected area, but it has too small air resistance coefficient. When the ships change heeling angle, the air resistances acting on hulls are increased. The most changing air resistance acting on hull belongs to the models N1 and N2, it is increasing up to 69% in comparison with that of the ship at heeling angle of 0 degree. The knuckle hull form N3 has the smallest changing air resistance, it is less than 10%.

The model N5 with a newly proposed accommodation and without heeling angle can reduce air resistance up to 51% at low Reynolds number and 40% at high Reynolds number in comparison with those of the model N3. The obtained results as shown may be useful to optimal aerodynamic shape for the small ships, and can also provide the basis 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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