A Study on Reduced Air Resistance Acting on Hull of a Cargo River Ship by Used CFD

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Abstract

Aiming to improvement of the inland water transportation efficiency, this paper presents development of new hull concept for the cargo river ships with reduced air resistance by using a commercial CFD (Computational Fluid Dynamic) method. The CFD results of aero-dynamic performances of the ship as pressure distribution, velocity flow around hull and air resistance acting on hull are investigated by the CFD. By analysing air resistance acting on a conventional cargo river ship which is widely used in Vietnam, a new concept of cargo river ships with drastically reduced air resistance hull form has been developed. A suitable method for application of the obtained research results has been suggested namely gradual replacement the current hull form by the newly developed one.

Keywords: new hull; reduced air resistance; cargo river ship, CFD, accommodation.

1. Introduction

Study on reduction of resistance acting on a ship is important in marine transportation. Reducing resistance acting on hull is a well known way for saving the ship fuel consumption which is an important factor in study on improving economic efficiency of marine transportation. In the field of research on ship hydro dynamics, resistance acting on a hull of ship consists of two components. The first is water resistance including viscous resistance and added wave resistance and the second is air resistance acting on the above water surface hull part of the ship. This paper studies only how to reduce air resistance acting on a cargo river ship, one of the most interesting problem in the field of the current research on ship hydrodynamic performance.

Matumoto *et al.*, 2003, Nihei *et al.*, 2008, 2010 studied on keeping a ship as Pure Car Carrier (PCC) safety in a strong wind and ballast condition with reducing resistance acting on the original ship. A new hull form had been designed achieving its total resistance reduced by 15% at wind speed of 14m/s and 22% at wind speed of 10m/s accordingly [1, 2]. T. Fujiwara *et al.,* 2009, 2001 reported their research results of wind force acting on a container ship by experimental measurement in a wind tunnel. The aerodynamic characteristics of various types of external forms of the container ship had been investigated in the tunnel with a 1.5m block model. A new method for estimating wind force coefficients of container ship had been proposed [3, 4]. Sugata *et al.*, 2010, studied on reduced wind force acting on a non ballast ship, a new model proposed for the non ballast water ship can reduce up to 44% of wind force in full loaded condition and by 33% of wind force in the ballast condition without ballast water [5]. Mizutani *et al.*, 2013 reported on research of reduced air resistance acting on a chip carrier. The total air resistance can reduce from 2% to 15% by experimental measurement at a towing tank. In the studies, He *et al.*, 2013, 2016, Mizutani *et al.*, 2014, effects of hull shape and cargo handling equipment on air resistance had been investigated. The conclusions were that total air resistance can reduce by 10% by experiment and the interaction between hull shape and accommodation shape on deck as well as wind direction have been looked into [7-9].

In this paper, air resistance acting on the above water surface hull part of the ship is reduced by improving its accommodation, changing heel and using bow cover.

Fig. 1. Conventional cargo river ship at Duong River in the north of Vietnam

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2. CFD for computation of ship aero-dynamic performances

For computation of air resistance acting on the ship, in this research a commercial CFD code ANSYS-Fluent v.15.0 has been used, ANSYS Inc 2015. The software license has been registered by the authors' School. The k-ε turbulence viscous model is used to simulate [10, 11]. The computed conditions are set by step and step strictly following CFD simulation methods successfully applied in references or user's guide for using CFD [12-17]. In the current research, the computation fluid domain is limited in *6L* of length, *2L* of breadth and L of height for model length *L* in scale model ratio 1/100. Meshing the calculating fluid domain in unstructured mesh generated in 1.82 million T-grids. The velocity inlet is setup for the inlet, the pressure outlet is setup for the outlet of the calculating fluid domain.

3. Original Conventional cargo river ship used for computation

In this research, the cargo river ship 3400 ton is used as a reference model. Fig. 2 shows the original ship at statement of full load condition (NF2) and ballast conditions (NB2). The principal particulars of the conventional cargo river ship are shown in table 1. In this research, a scale model with scale ratio 1/100 is used for computation.

Table 1. Principal particulars of the ship

No		NF2	NB2
Length, L_{pp} (m)		83.50	83.50
Breadth, B (m)		14.50	14.50
Draft (m)		5.570	1.905
Displacement, Dispt (t)		51280	15120
Frontal projected area, S_{FA} (m^2)	S_x	504.26	703.34
	S_y	1632.15	2825.96

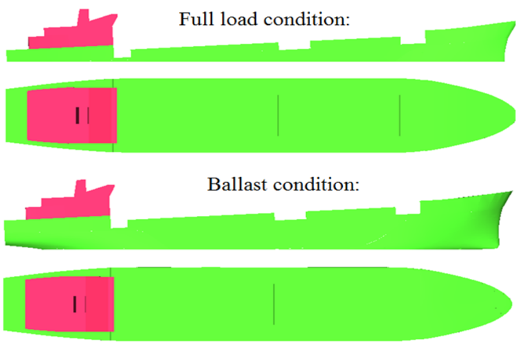

Fig. 2. Original cargo river ship using in computation, NF2, NB2

Fig. 3 shows the computed fluid domain and meshing. Table 2 shows the condition setup for the computed problem.

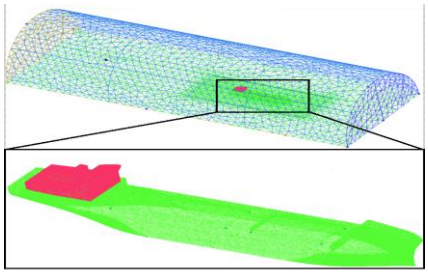

Fig. 3. Computed fluid domain and meshing

Table 2. Condition setup for computation

Name	Valuate	Units
Turbulent viscous model	k-ε	-
Inlet	Velocity inlet	-
Outlet	Pressure outlet	-
Reynolds number, R_n	7.10^6	-
Atmospheric of air, p_a	1.025	$10^5 N/m^2$
Air density, ρ_{air}	1.225	kg/m^3
Air dynamic viscosity, υ	1.789	$10^{-5} kg/ms$

For computation CFD, a high performance computer, Core i7, 2.65GHz, RAM 2Gb is used. Fig. 4 shows the results of pressure and velocity distribution at center plane of the computed domain at wind direction 0 degree.

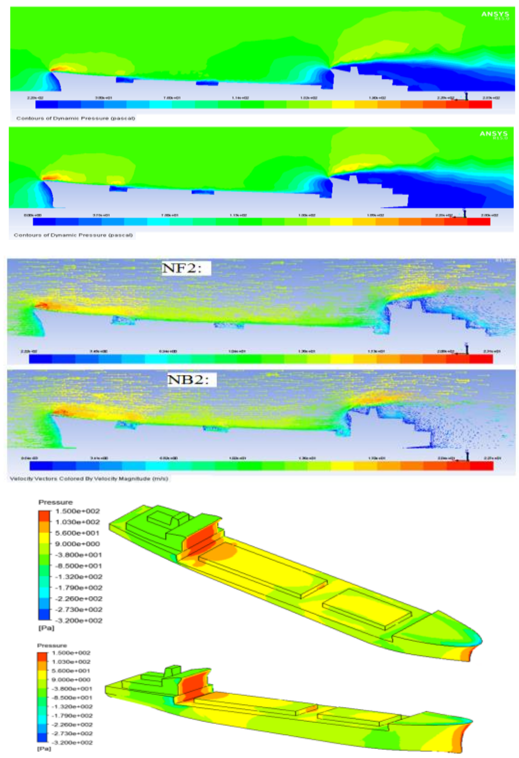

Fig. 4. Pressure and velocity distribution around hulls of the ships in full load and ballast conditions

The results as shown in these figures show clearly different from pressure and velocity flow around and over hull surface of the ships. From the difference of draft, it makes pressure and velocity changing around and over hull surface of the ships. Fig. 5 shows the results of air resistances acting on the ships. Detailed air resistances acting on the ships as shown in the table 3. The results as shown are the important basic theory to develop new hull form for the ship with reduced air resistance.

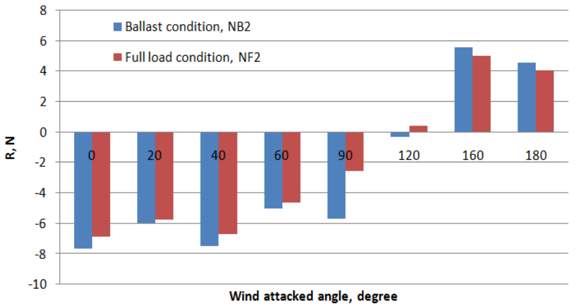

Fig. 5. Air resistance acting on the original ship at full load and ballast conditions

Table 3. Air resistance acting on the ships NF2, NB2

α, dec	C_x, NB2	C_x, NF2	% NF2
0	-0.844	-1.061	+10
20	-0.307	-0.429	+3
40	-0.261	-0.366	+10
60	-0.142	-0.214	+7
90	-0.157	-0.122	+55
120	-0.010	0.019	-19
160	0.287	0.370	+11
180	0.498	0.620	+11

The results as shown clearly different form air resistance acting on the ships in the two different conditions. At the ballast condition NB2, air resistances acting on the ship are higher than those of the full load condition, the different air resistances is up to 55% at wind direction of 90 degree.

4. Developing new hull concept for the cargo river ship with reduced air resistances

In this research, by propose a Non Ballast Water hull with a hybrid diesel electric system for the conventional ship, at ballast condition the new ship can drastically reduce water resistance hull form by eliminating large amount of ballast water [12-15]. More ever, by using a podded propulsion for the new ship, the ship heeling can change up to 5 degrees at ballast condition. Therefore, a new ship has the same draft at bow and stern in both ballast condition and full load condition. Therefore, the original ship has heeling angle of 3 degrees is changed to new condition with a heeling angle of zero degree. In the proposed model, displacements are kept in constant. This is a key point leading to reduction of air resistance acting on the ships. Fig. 6 shows the original ship with the new conditions.

Fig. 6. The new conditions proposed for the cargo river ship with heeling angle of 0 degree

Figs. 7 to 9 show dynamic pressure, velocity flow distribution around and over hull surface of the ships at wind direction 0 degree. A clear change in pressure and flow velocity distribution over regions of the ship can be observed.

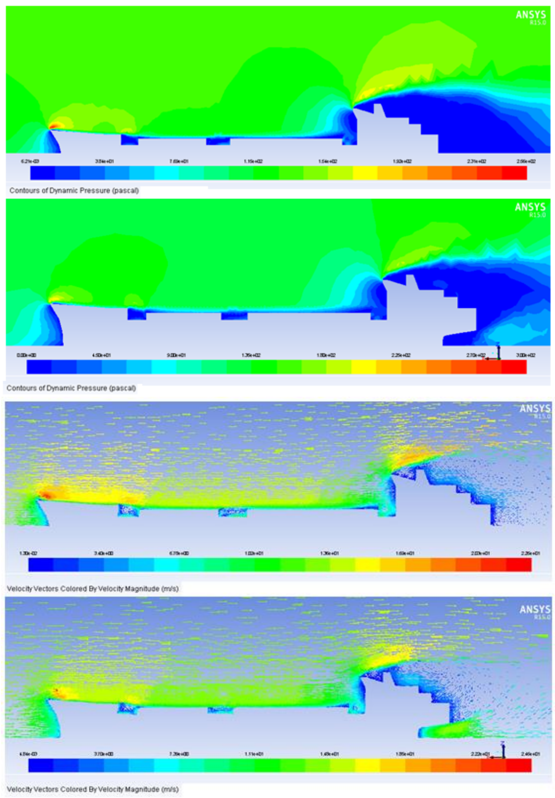

Fig. 7. Dynamic pressure distribution and velocity flow around hull at center plane of computed fluid domain of the ships, NF1, NB1

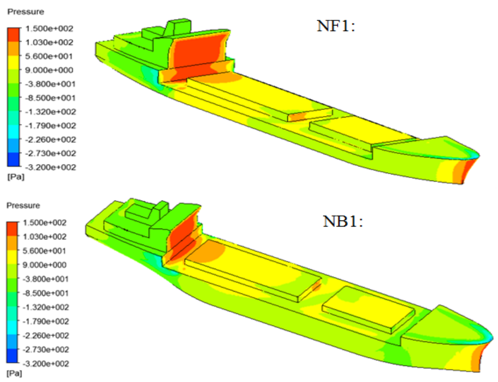

Fig. 8. Pressure distribution over hull surface of the ships, NF1 and NB1

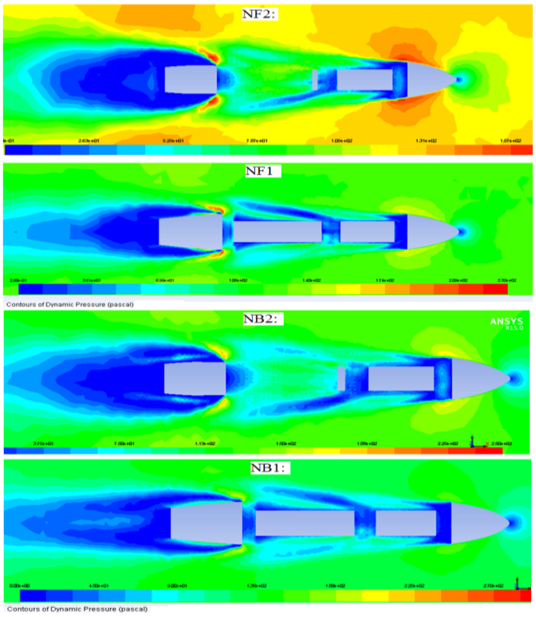

Fig. 9. Dynamic pressure distribution around hull at horizontal plane (z=0.18m) of the computed fluid domain, NF1, NF2 and NB1, NB2

Fig. 9 shows comparison of dynamic pressure distribution acting on the ships at horizontal plane of the computed fluid domain. Clearly different from pressure distribution around the ships can be seen.

Fig. 10 shows comparison of air resistances acting on the ship at different condition. The results show clearly different of air resistances acting on the ships as follows wind attacked angle.

The results as shown in the Fig. 10 show that the air resistances acting on the new ballast condition NB1 is higher than those of the new full load condition NF1 at almost wind direction, up to 53% at wind attacked angle of 120 degree. At the full load condition, model NF1 has smaller air resistances hull form than those of the model NF2. At the ballast conditions, air resistances acting on the two models NB1 and NB2 are closed at other. At wind attacked angle of 40 and 60 degree, air resistances acting on the model NB1 are smaller than those of the model NB2 up to 40% of total air resistance.

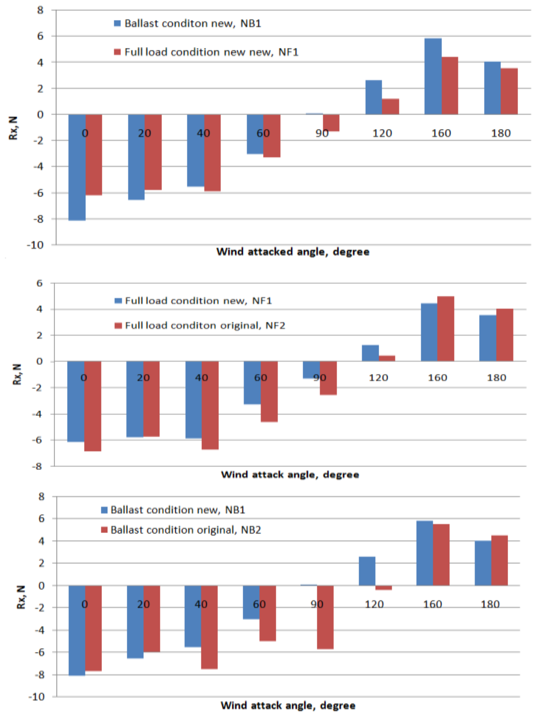

Fig. 10. Air resistance acting on the ships at full load and ballast conditions NB1, NB2 and NF1, NF2

The next proposed new hull concept is modified accommodation and used bow cover for ship. In this section, the conventional ship is developed with a new modified accommodation shape and added bow cover. Firstly, a bow cover is attacked to hull of the original ship. Secondly, the accommodation of the ship is modified at the frontal shape to reduce air resistance acting on the new hulls. Figs. 11 and 12 show the models of the new hulls.

Fig. 11. New hull form proposed for the new concept ship at ballast condition, NB1

Fig. 12. New hull form proposed for the conventional ship at ballast condition, NB2

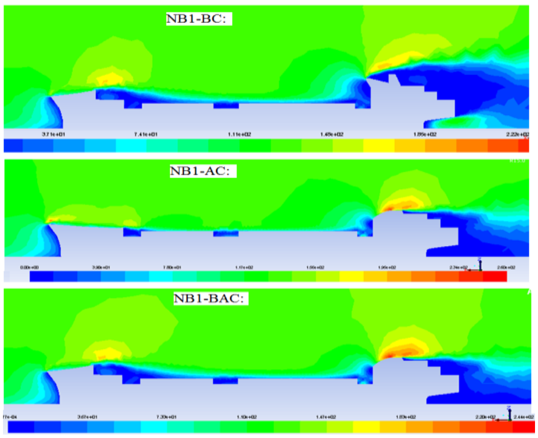

Fig. 13. New hull form proposed for the new concept ship at ballast condition, NB1

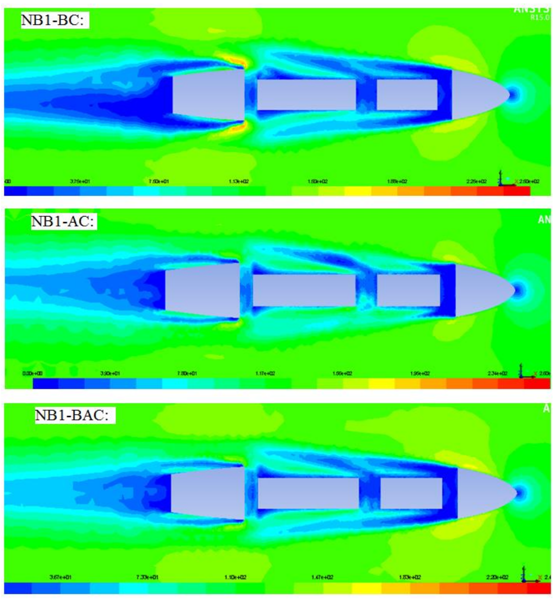

Fig. 14. Dynamic pressure distribution at horizontal plane (z=0.18m) of the computed domain

Figs. 13 and 14 show the results of pressure distribution around hull at center plane and horizontal plane of the computed fluid domain of the new ships at wind direction 0 degree, in the same conditional computed CFD. Clearly different pressure distribution around hull of the ships can be seen in the figures.

The results show clearly different from pressure distribution with those of the original models as shown in the Figs. 4, 7 and 9. The results may make the air resistances acting on the new ship reduced.

Fig. 15 shows pressure distribution over hull surface of the new ship at wind direction 0 degree, in the same conditional computation with those of the original models.

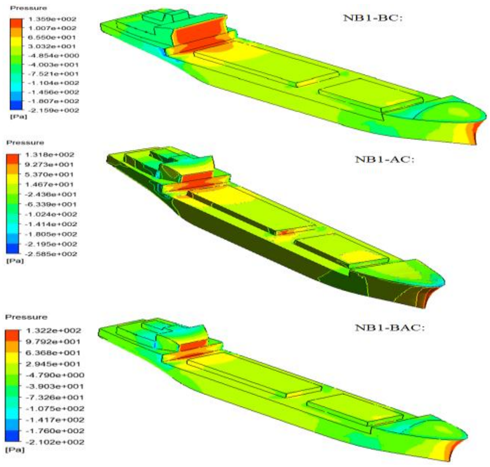

Fig. 15. Pressure distribution over hull surface of the new ships

A larger area of high pressure region (red colour region area) has been reduced by adding a bow cover and modified accommodation for the new ship can be seen in the figures. Fig. 16 shows air resistances acting on the new ships at wind direction 0 degree.

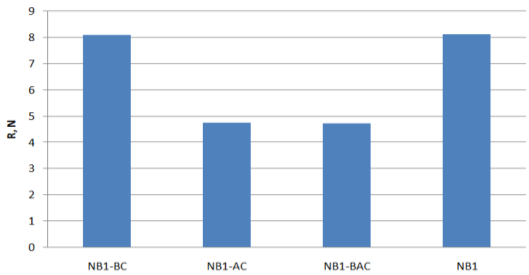

Fig. 16. Air resistances acting on the ships

The results show drastically reduced air resistances acting on the new ship with modified accommodation, a reduction up to 41% of the total air resistance acting on the hull form could be achieved.

Figs. 17 to 19 show the pressures distribution around hull of the new ships at wind direction 0 degree.

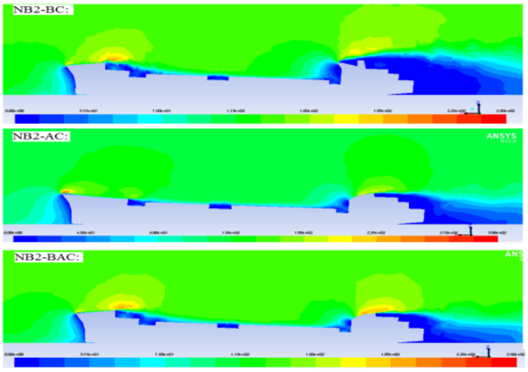

Fig. 17. Dynamic pressure distribution around hull of the new ships NB2 with AC, BC and BAC

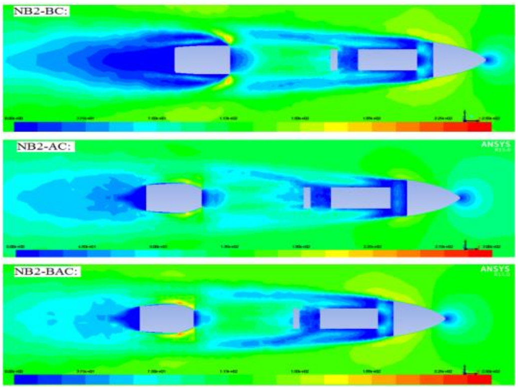

Fig. 18. Dynamic pressure distribution around hull at horizontal plane (z=0.18m) of the new ships

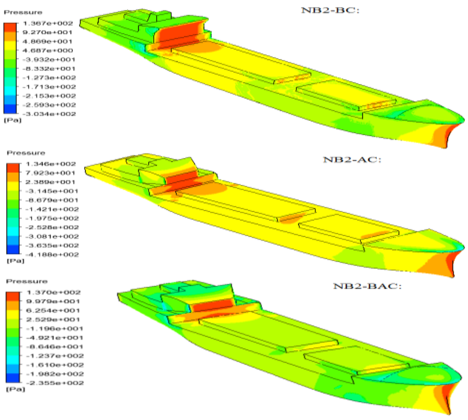

Fig. 19. Pressure distribution over hull surface of the new ships with AC, BC and BAC

The results show remarkable reduction in high dynamic pressure areas (red colour) due to air acting on hull surface of the ship when accommodation has been modified. The low dynamic pressure area (blue colour) has also been drastically reduced by modified accommodation and used of a bow cover as shown in the figures. Fig. 20 shows results of air resistances acting on the ships.

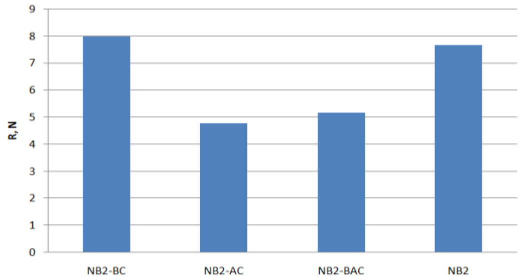

Fig. 20. Air resistances acting on the new ships

The results show drastically reduced air resistance acting on the ship by modified accommodation for the models: NB2-AC and NB2-BAC. Table 4 shows air resistances acting on the ship at wind direction angle 0 degree in detailed.

Table 4. Air resistance acting on the new ships in compared with those of the model NB2

No		R_{vp}, N	R_{vf}, N	R_a, N	% NB2
NB1	BC	7.748	0.317	8.065	+5.5
	AC	4.357	0.381	4.739	-38.0
	BAC	4.381	0.344	4.725	-38.2
NB2	BC	7.665	0.313	7.978	+4.4
	AC	4.381	0.392	4.773	-37.6
	BAC	4.788	0.365	5.153	-32.6

The results show that air resistance acting on the ships by modified accommodation have been reduced up to 38.2% of the total air resistance of hull form. The dynamic pressure resistance component occupies most of the total air resistance acting on the ship as shown in the table 4. Therefore, the results as shown in pressure distribution are important to identify areas affecting on air resistance and to improve hull shape to reduce air resistance for the ship. The results of air resistances acting on hull of the ship are in agreement with the results of the pressure distribution around and over hull surface of the ship as shown.

5. Conclusions

In this paper, a new hull concept above water surface part of the conventional cargo river ship has been improved by proposed a new condition with heeling angle of zero degree, modified accommodation and an added bow cover for the hull. The proposed models have been thoroughly investigated by CFD computation and following conclusions can be made:

- Using the CFD, the best hull shape above water surface part of the cargo river ship can be determined by comparison air resistances acting on each model of the ship.

- The new ship condition with heeling angle of 0 degree is better than that of the original conventional ship. The new model NB1, NF1 and NB1, NB2 with modified accommodation and an added bow cover are confirmed to be good in this research. It could significantly reduce total air resistance as shown by the CFD computed results.

- It is theoretically confirmed that a new concept of cargo river ship with reduced air resistance hull form can be developed by the CFD. An experimental study is however, needed to improve the CFD results and a gradual application of the current research results in marine in general and inland water transportation in particular is highly suggested.

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