

Table 1. Principal particulars of ship model

Name	Model	Unit
Length, L	1.60	m
Breadth, B	0.282	m
Depth, H	0.171	m
Draft, d	0.0485	m
Block coefficient, C_b	0.774	-
Wind velocity, V	14.50	m/s
Wind attack angle	0-180	degree

Computation domain, meshing and boundary condition for CFD simulation

In CFD simulation, computational fluid domain, meshing and boundary condition setup can affect the simulation results. In this study, all of step for designed simulated fluid domain, meshing and set the boundary condition has done follows as International Towing Tank Conference (ITTC) used guider for using CFD [8] and many experience in application CFD of the authors [9]. For a ship model of 1.6m of length the calculated fluid domain is limited in 15m of length, 3.6m of breadth and 1.2m of height. Meshing of the calculated fluid domain in unstructured mesh is generated in 3.8 million T-grids. For the CFD simulation, the turbulent viscous model k-ε for unsteady flow is used. The pressure inlet is setup at the inlet, the pressure outlet is setup at the outlet of the calculating domain. Figure 2 shows the fluid domain for calculations.

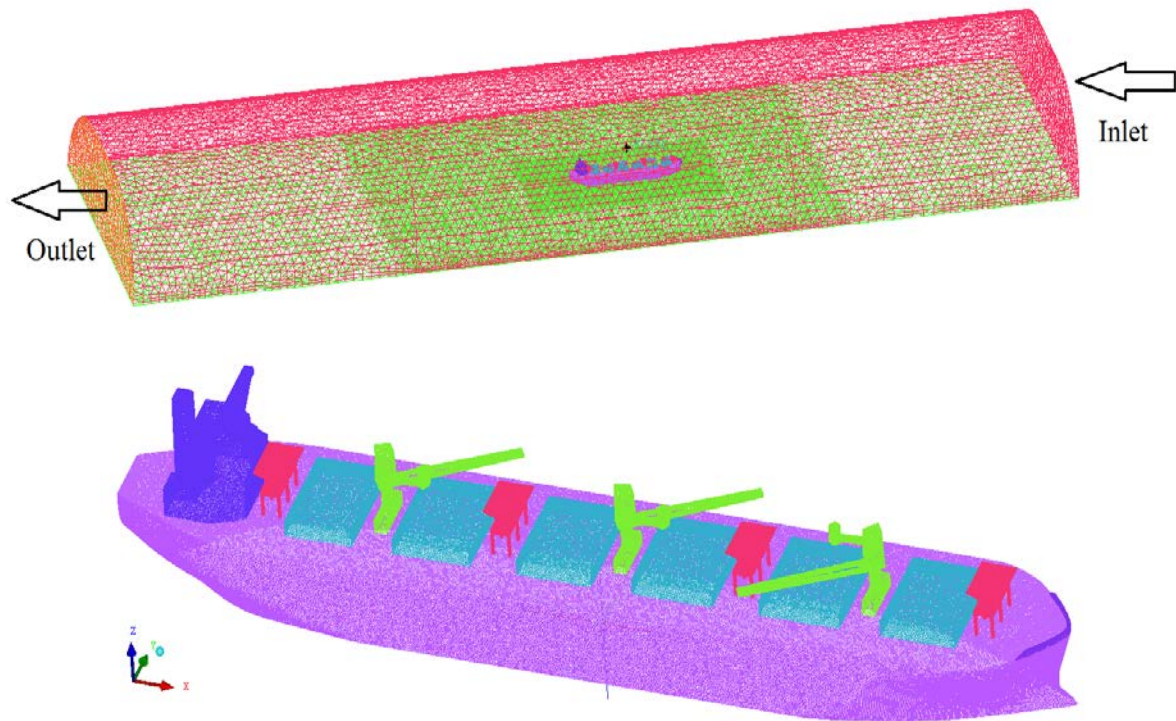


Figure 2. Computational fluid domain and meshing

Validation of CFD results

For validation of CFD results, results of air resistance acting on the ship are compared with those of the experimental data. The experiments are carried out at a towing tank of Osaka Prefecture University in Japan [5, 7]. Figure 3 shows a comparison between the CFD results and the experimental data of ship in air resistances acting on the ship. The blue line shows the coefficient of air resistance acting on the ship given by the CFD, C_x corresponding to wind attack angle, (Figure 1). The red dots show the experimental data. Agreement between them is fairly good as can be seen in the figure.

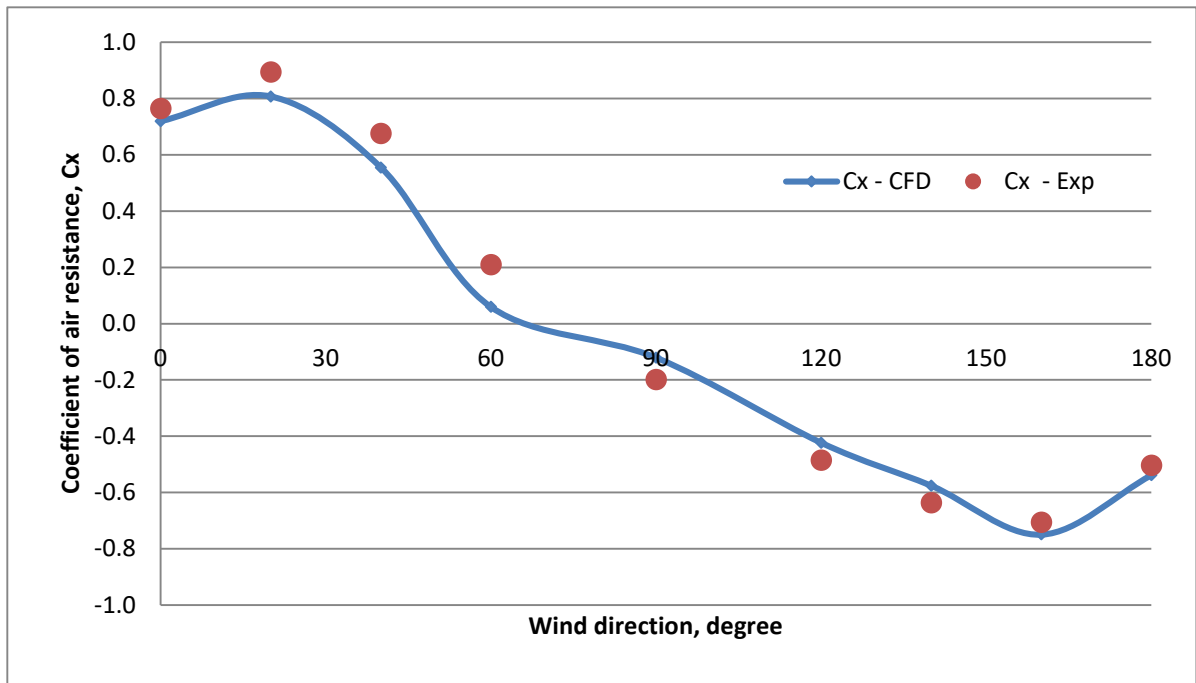


Figure 3. Comparison between CFD and experimental data

Interaction effects between a hull and an accommodation house on air resistance acting on the ship

Air resistance acting on accommodation

In this section, air resistances acting on several types of accommodations of a ship are calculated by using the CFD. The first type accommodation named as Box, has cube shape. The dimensions of Box were taken from the accommodation of the Chip Carrier as shown in Figure 1. The second kind of shapes, M1 and M2 are optimized box shapes accommodation which contain only plat plates. And new streamlined accommodation is proposed. These accommodations M1, M2 were developed in our previous paper N.V. He *et al.* (2013) [6]. All kinds have the same floor area. The shapes of the accommodation and their frontal projected area S_{FPA} are shown in Figure 4.

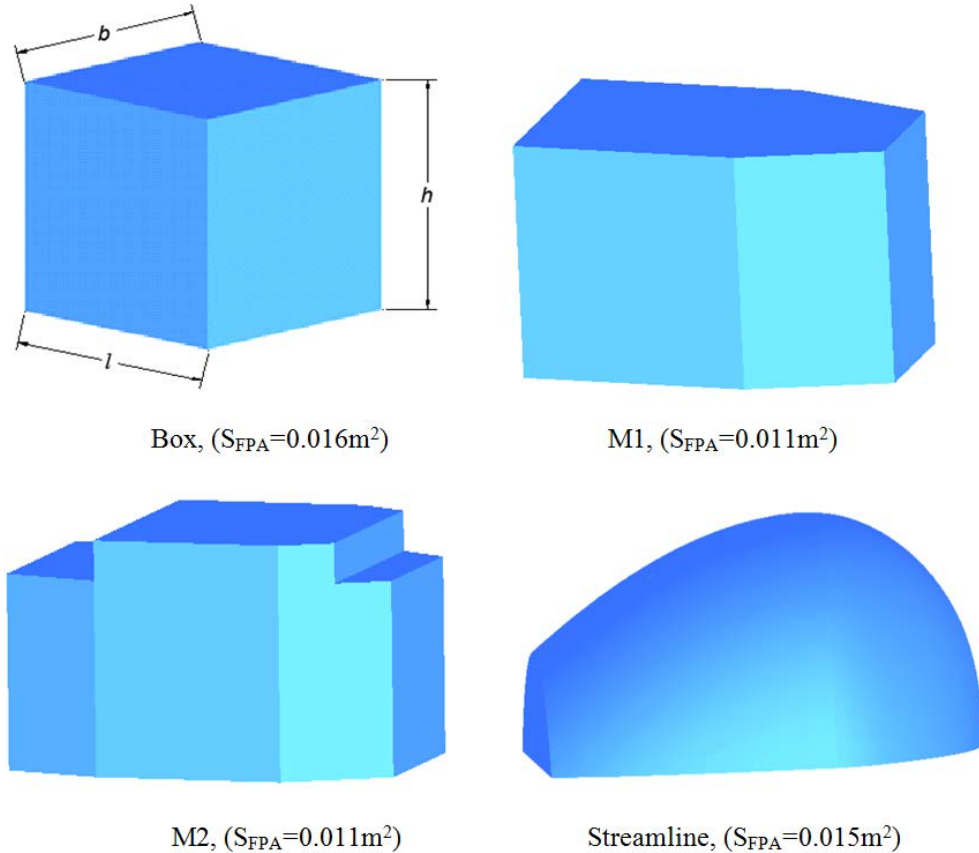


Figure 4. Shape and frontal projected area of the accommodation house

Table 2 shows the computational result of air resistance acting on the original box shape accommodation and experimental data measured in the towing tank at Osaka Prefecture University. The wind velocity is set at 14.5m/s and wind direction 0 degree. The calculated result of the drag coefficient C_d for the accommodation Box is almost 1 and is in good agreement with the experimental results.

Table 2. A comparison of air resistance between CFD and experimental results

Name	Coefficient of air resistance, CFD	Experimental result	Difference %
Box	1.07	1.09	-2

Figures 5 and 6 show computational results of dynamic pressure distribution at center plane and horizontal plane of computational fluid domain. In the figure, the blue area region indicate shows low dynamic pressure where static pressure is high. Red area region indicates high dynamic pressure and low static pressure. The region with high static pressure attached on the accommodation will strengthen air resistance. In the results, clearly differences among dynamic pressure distribution around accommodation can be seen. Low dynamic pressure area behind the streamlined accommodation is drastically reduced because of flow separation become small.

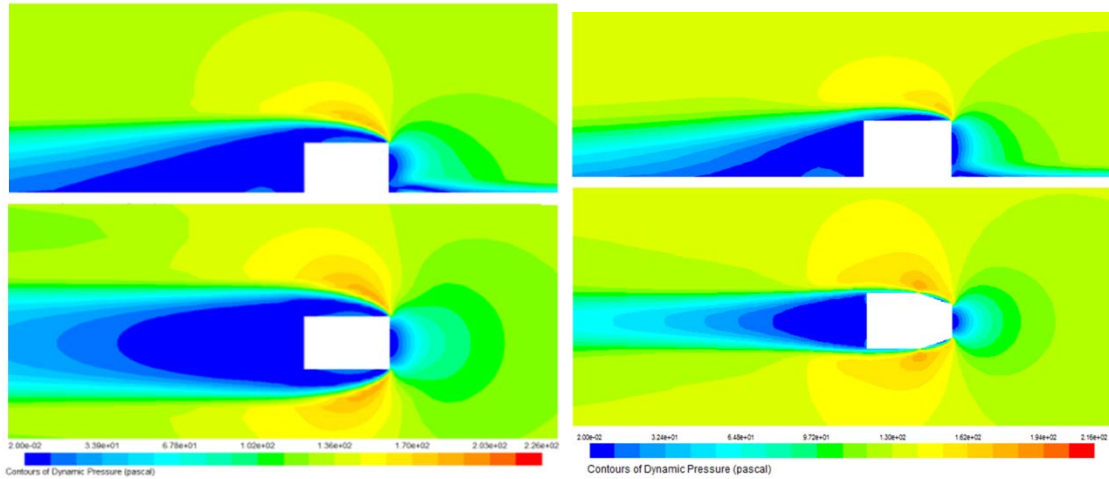


Figure 5. Dynamic pressure around Box shape, M1 (upper: side view, lower: top view)

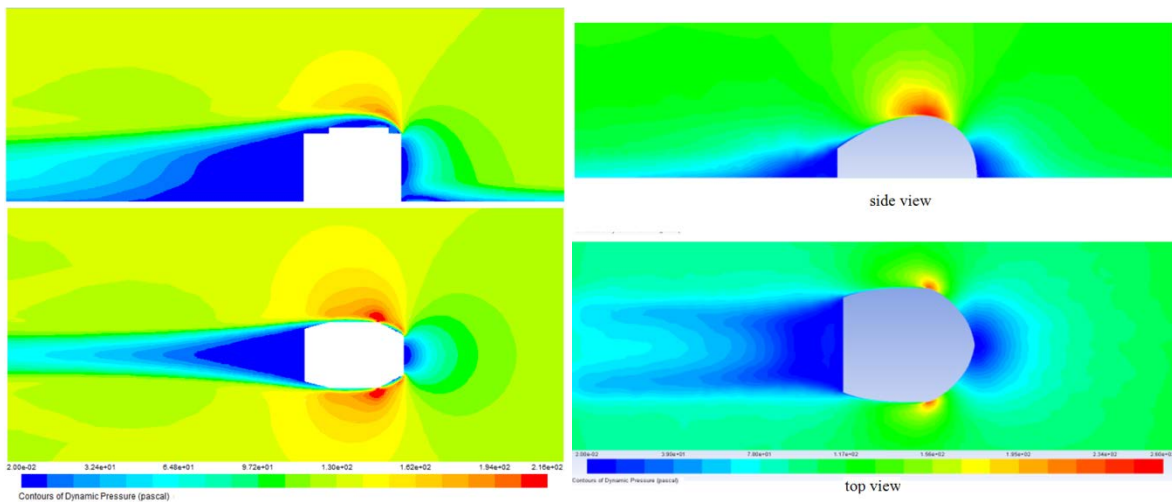


Figure 6. Dynamic pressure around M2 and Streamline (upper: side view, lower: top view)

In common of the effects on hydrodynamic force by shape, we can see that the streamlined shape is the best one in reduction of air draft. However, in the industrial ship building, it takes a high cost to manufacture a streamlined accommodation house. Therefore, an accommodation which made of only flat plates and optimum resistance is the best chosen for a ship building.

Figure 7 shows the air resistance acting on each accommodation. Drastically reductions of air resistance by the developed accommodations, M1, M2 and Streamlined accommodation can be seen. We can see that 72% reduction can be achieved for the streamlined one, but large reductions can be also obtained for simple shapes made from flat plates, M1 and M2. These results of drag forces are in agreement with the results of dynamic pressure as shown in Figures 5 and 6.

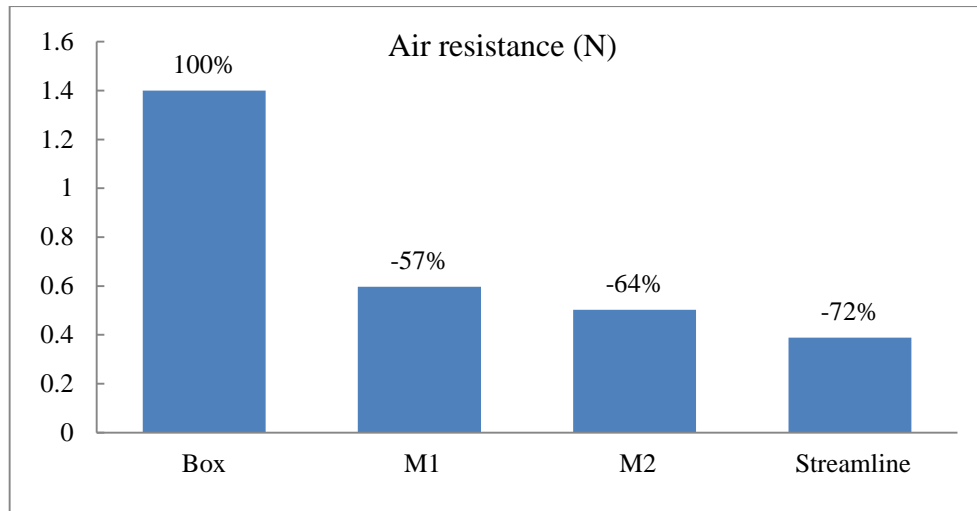


Figure 7. Air resistance acting on independent accommodation on hull

Air resistance acting on a hull with a box-type accommodation house on deck

In this section, air resistance acting on the ship hull with an accommodation on its deck is investigated. The hull of the chip carrier with a box shape accommodation on the deck is used in the studied. The shape of the accommodation is shown in Figure 8. To find optimum position of accommodation on deck, position of the accommodation is changing from aft to fore of the ship, and comparisons of the calculated air resistances are carried out to find the best one. Figure 9 shows the position of the box shape accommodation on the deck of the ship. Following locations of the accommodation on deck, models are named as well as from P1 to P11, N.V. He. *et al* (2013) [6], [9]. Figures 10, 11 and 12 show examples of dynamic pressure distributions at centre plane of the ship with the accommodation located at aft, mid and fore decks of the ship.

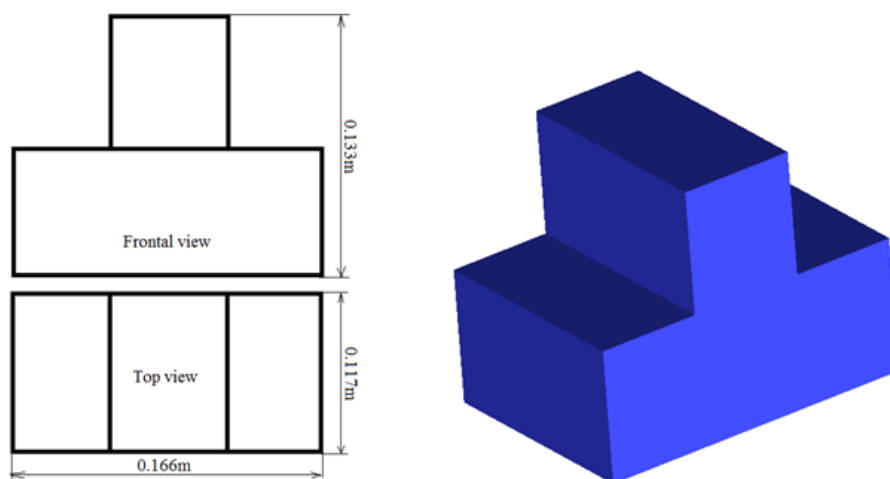


Figure 8. Box shape accommodation P1 to P11

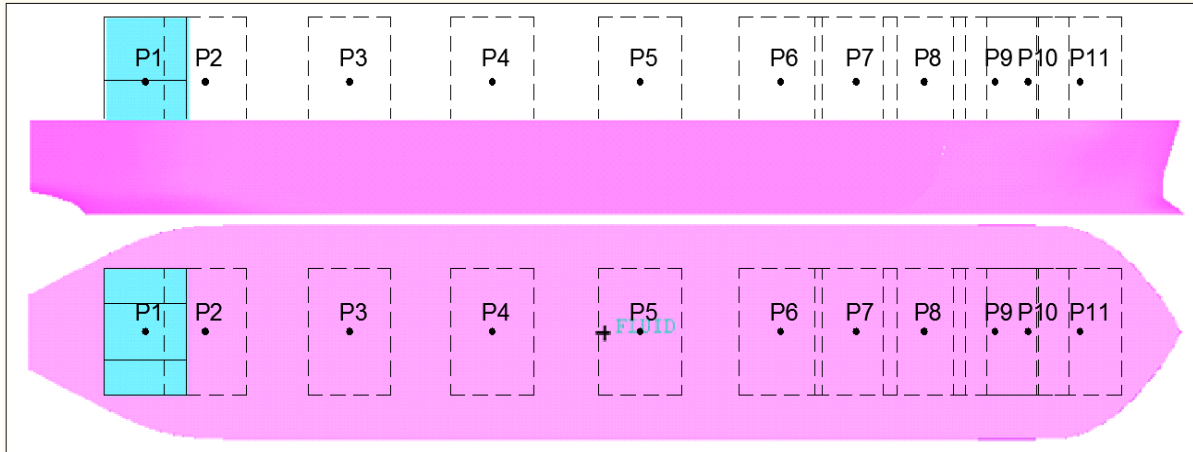


Figure 9. Location of accommodation on deck, P1 to P11

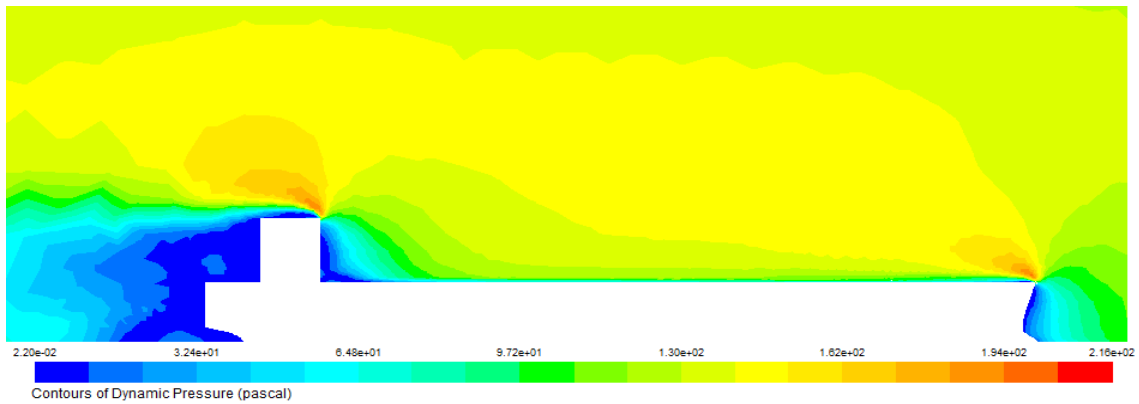


Figure 10. Dynamic pressure distribution at centre plan of calculating domain, P1

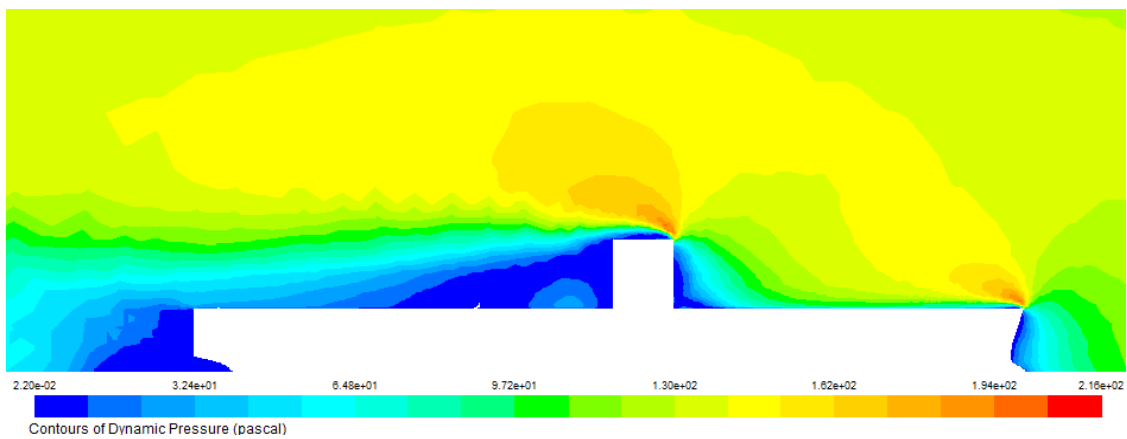


Figure 11. Dynamic pressure distribution at centre plan of calculating domain, P5

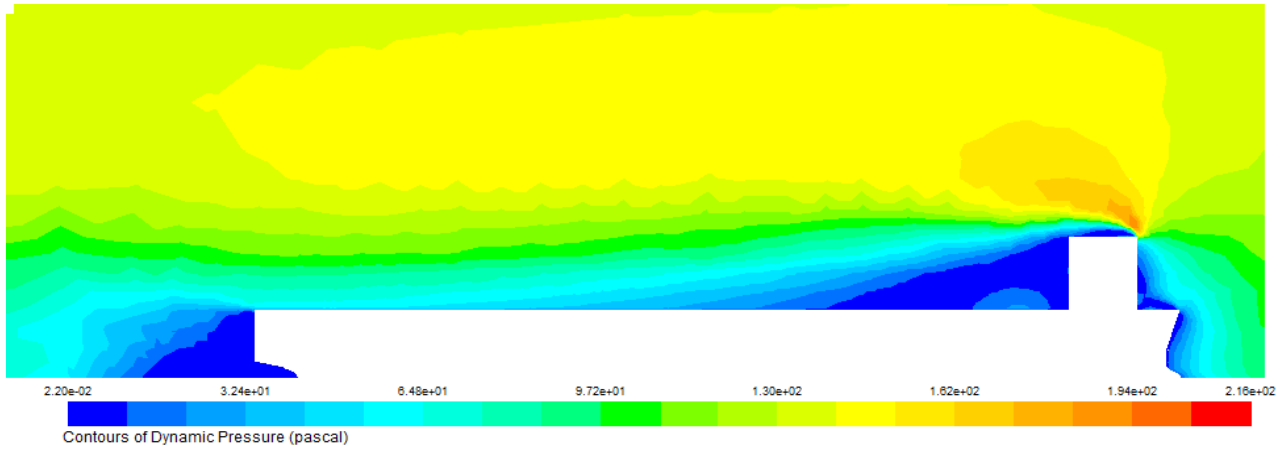


Figure12. Dynamic pressure distribution at centre plan of calculating domain, P11

Table 3 shows the computational air resistance acting on the ship according as position of accommodation on deck, from P1 to P11. The results as shown in the table demonstrate that the air resistance is smaller when accommodation which is located at the fore of the ship.

Table 4 shows the calculated results of interaction effect on the air resistance between the hull and the accommodation on deck. The interactions effects are comparing by subtract the air resistance on a whole ship, or an accommodation from the sum of the resistances acting on the independent hull and accommodation. The results demonstrate that the interaction effect cause increases in air resistance accept the position of P11. These results suggest that for the box type accommodation reduction of the air resistance by using interaction effects between a hull and an accommodation may be difficult to achieve.

Table 3. Effect of position of accommodation on air resistance acting on ships

No	Air resistance (N)	Difference from P1, %	C_d	Difference from P1, %
P1	4.794	0	0.736	0
P2	4.372	-9	0.672	-9
P3	4.041	-16	0.621	-16
P4	4.027	-16	0.619	-16
P5	4.043	-16	0.621	-16
P6	4.089	-15	0.628	-15
P7	4.103	-14	0.630	-14
P8	4.034	-16	0.620	-16
P9	3.900	-19	0.599	-19
P10	3.745	-22	0.575	-22
P11	3.664	-24	0.563	-24

Table 4. Interaction effects between accommodation and hull on air resistance

No	Independent Hull and Accommodation		Ship Hull with Accommodation		Interaction effect, %
	Hull	Acc	Hull	Acc	
P1	1.682	1.968	2.682	2.110	+31
P2	1.682	1.968	2.200	2.172	+20
P3	1.682	1.968	1.887	2.154	+11
P4	1.682	1.968	1.895	2.132	+10
P5	1.682	1.968	1.934	2.108	+11
P6	1.682	1.968	1.983	2.106	+12
P7	1.682	1.968	1.990	2.112	+12
P8	1.682	1.968	1.931	2.101	+10
P9	1.682	1.968	1.785	2.115	+7
P10	1.682	1.968	1.658	2.087	+3
P11	1.682	1.968	1.466	2.198	0

Reducing air resistance acting on a ship by using Interaction effects between hull and accommodation

In this section, interaction effects on air resistance between a hull and an accommodation of a ship are used to reduce air resistance by the developed accommodations, M2 and streamlined accommodation as shown in Figure 4. The accommodations M1, M2 and Streamline are located at fore deck of the ship as shown in Figures 13, 14 and 15.



Figure 13. Ship with plating box shape accommodation M1 on the fore deck



Figure 14. Ship with plating accommodation M2 on the fore deck



Figure 15. Ship with Streamlined accommodation on the fore deck

The three models ship with the accommodation located at force are calculated air resistance acting on hull by the CFD. Figure 16 and 17 show the calculated results of air resistance acting on the ship in two cases: with and without interaction effects between a hull and an accommodation house on it deck. The detail air resistance acting on the hull and the accommodation are shown in the Tables 5 and 6.

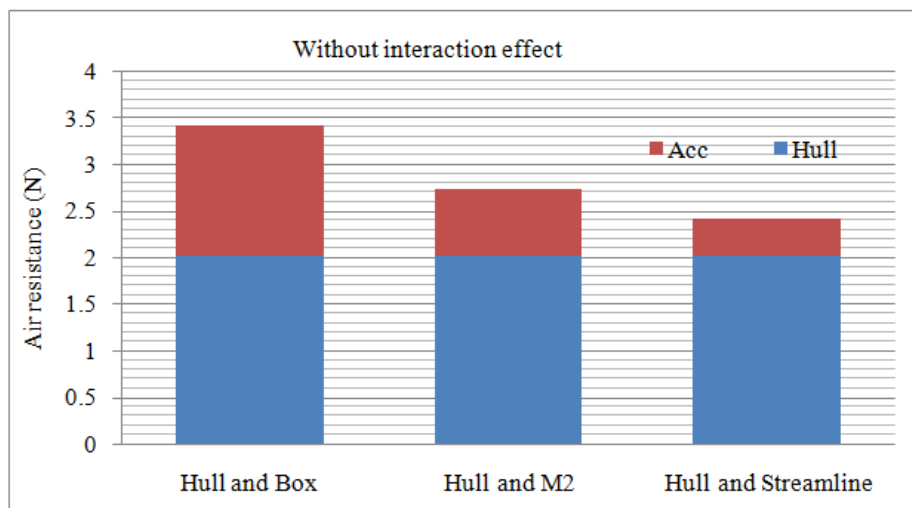


Figure 16. Computed air resistance by summing up that acting on independent hull and accommodation

Table 5. Calculated results of air resistance acting on independent hull and accommodation

Independent Hull and Accommodation			
Name	Hull and Box	Hull and M2	Hull and Streamline
Hull	2.03	2.03	2.03
Acc	1.4	0.716	0.389

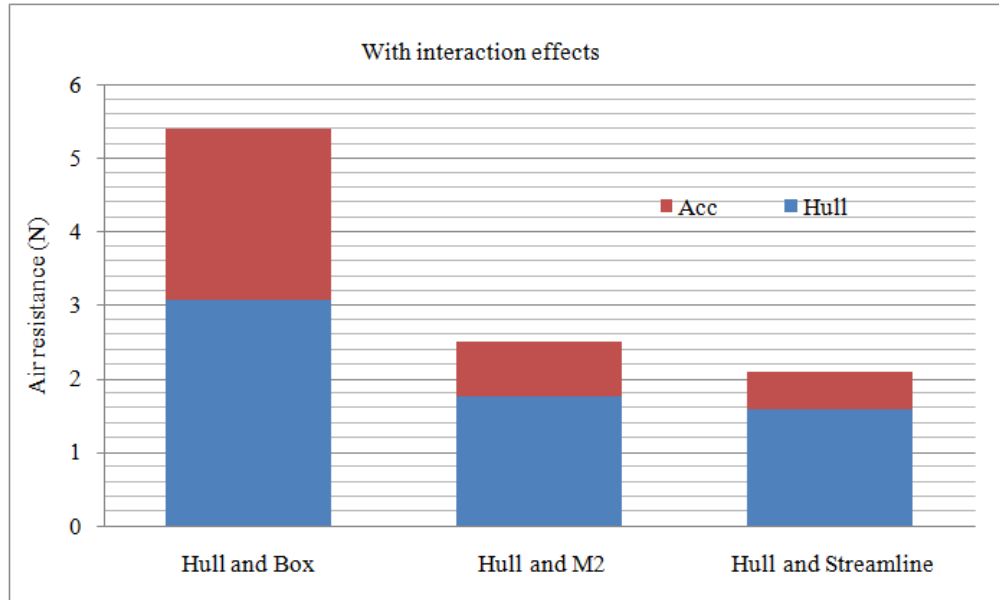


Figure 17. Calculation air resistance acting on a ship with a hull and an accommodation

Table 6. Calculated results of air resistance acting on hull and accommodation

Hull and Accommodation			
	Hull and Box	Hull and M2	Hull and Streamline
Hull	3.064	1.751	1.578
Acc	2.333	0.754	0.521

Table 7. Interaction effects between accommodation and hull on air resistance

Name	Independent Hull and Accommodation		With Hull and Accommodation		Interaction effect, %
	Hull	Acc	Hull	Acc	
Hull and Box	2.03	1.4	3.06	2.33	36%
Hull and M2	2.03	0.716	1.75	0.75	-10%
Hull and Streamline	2.03	0.389	1.58	0.52	-15%

The results shown in Figs.16 and 17 shows that the air resistance can be reduced by using the interaction effects for the accommodation M2 and the streamlined accommodation which are located at force of the ship. Table 7 shows interaction effects on air resistance between hull and accommodation. It should be noted that the box shape accommodation increases the air resistances acting on the hull and accommodation by about 50-60% due to interaction effect, however M2 and the streamlined accommodations decrease the air

resistance acting on the hull. The reason can be seen in the results of dynamic pressure distribution and flow velocity vector around ship. Figures 18 and 19 show drastically reduced separation flow after the streamlined accommodation on the deck.

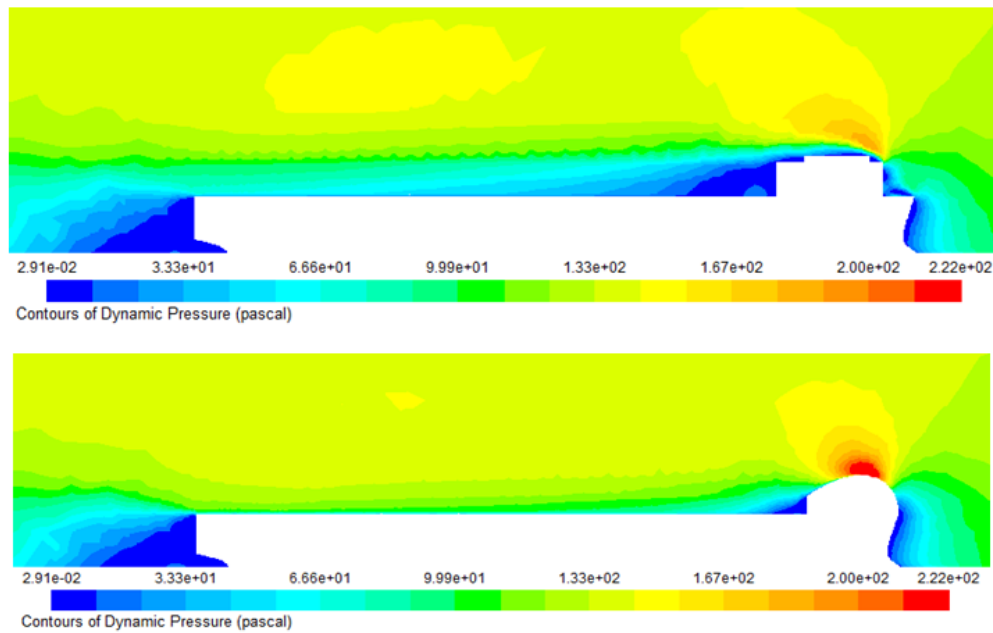


Figure 18. Dynamic pressure distribution at centre plan of calculating domain

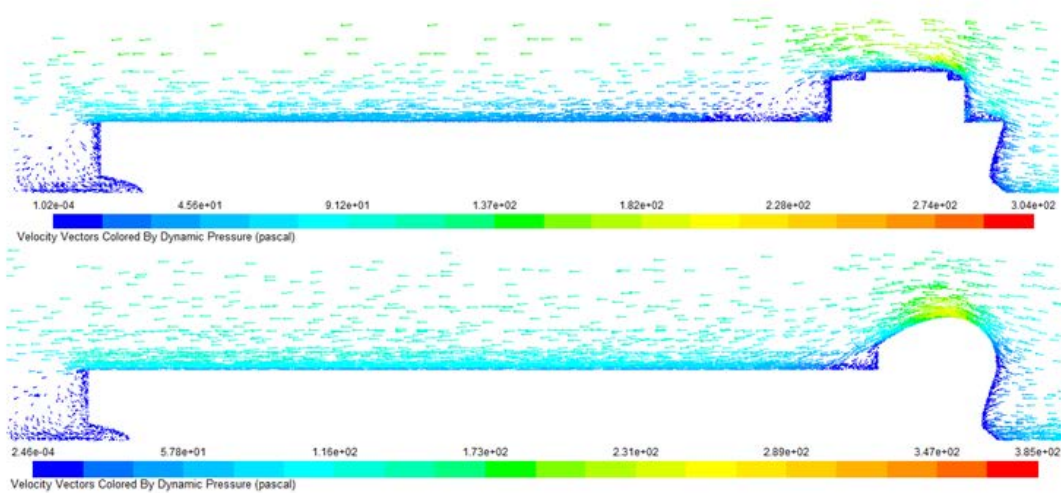


Figure 19. Velocity vectors distribution at centre plan of calculating domain

Conclusions

The paper has presented study on interaction effects of a hull and an accommodation on air resistance in detail. To find a method to reduce air resistance acting on a ship by using

interaction effects between hull and accommodation on deck. The conclusions of this paper are summarized as follows:

- The air resistances acting on independent accommodations are calculated by CFD, and small resistance accommodations are developed.
- The CFD calculations show that location of an accommodation significantly affects the air resistance acting on a whole ship. A box-shaped accommodation located on fore deck give the smallest air resistance but no reduction of the resistance is obtained by interaction effect.
- A streamlined accommodation and a small resistance accommodation built of only flat plates located on fore decks can reduce the air resistance by using interaction effects between a hull and an accommodation.
- The reduction of the air resistance is caused by reduction air resistance acting on the hull by the interaction effects. The shape and location of an accommodation plays an important role in the reduction.

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