

CFD investigation of interaction effect between hull and accommodation on wind drag of a container ship in head wind

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Abstract

In this paper, we present a research on applying a commercial Computational Fluid Dynamics (CFD) code to determine interaction effect between hull and accommodation on wind drag of a container ship. For the high superstructure and large windward area ships such as container, wind drag acting on hull accounts for a large amount of total resistance. To clearly find aerodynamic performance and interaction effects on wind drag of a container ship, a full scale 1,200 TEU container has been used as a reference model. From results of comparison in the two computed cases of hull with and without accommodation, the interaction effects between hull and accommodation on aerodynamic performance and wind drag have been investigated. The targets of the paper has proposed a new solution to improve aerodynamic performances and reduce wind drag acting on the ship by reducing interaction effects between hull and accommodation.

Keywords: CFD, hull, accommodation, container ship, wind drag.

INTRODUCTION

A study on reducing resistance acting on the ships is still important in marine transportation. For the type of ships which has a high superstructure and large windward area such as container ship, wind drag acting on hull accounts for a large percentage of the total resistances. Therefore, study on reducing wind drag acting on the container ship and other high superstructure and large windward ship has been more important. Until now, there are many publications in the field of aerodynamic performances and reducing wind drag acting on the ship, however a study on interaction effects between hull and accommodation of the ship is still attractive problem. The most important previous publications in the field of aerodynamic performances and wind drag acting on the ship have been listed as follows:

There are many publications in the field of applying a commercial Computational Fluid Dynamics (CFD) to solve the aerodynamic performances of a container ship. The most important point of these papers is that the authors have used both commercial CFD code and wind tunnel test model to compute and measure the aerodynamic performances and wind drag acting on hull of the container ships [1–9]. The steady Reynolds Averaged Navier Stokes (RANS) equations and turbulent viscous model have been used to solve the problems. The authors have concluded that CFD results were in fairly good agreement with the experimental results shown previously and the CFD could be used to develop new hull shape with reduced wind drag acting on the ship [1, 3–5, 7, 9–10].

Others authors has proposed a modified hull or accommodation shape to reduce wind drag acting on the ships [2, 3, 5]. The slender ship hull instead of the blunt ship hull decreased total wind load up to 5.9%. Taking into account wind tunnel blockage following the approach of the Engineering Sciences Data Unit showed an underestimation of up to 17.5% for the lateral wind load, as evidenced by comparing the CFD results in the narrow domain with those in wider domain [2]. Others authors had presented a study on using CFD and experimental test to develop a modified

hull shape with reduced wind drag acting on a container ship. The authors proposed modified hull shape with attaching a side cover, a center wall, a T center wall and a dome at the bow deck of the container ship. By using side covers and the center wall, the container ship could reduce up to 40% of the total wind drag acting on ship at wind direction of zero degree. A dome at the bow ship could reduce up to 30% of total wind drag acting on the container ship at the wind direction angle less than 30 degrees [9, 10]. A paper presented a study on designing new concepts and device on the superstructure of a container ship to reduce wind drag. Gap protectors between container stacks and visor in front of upper deck had been found to be most effective for reducing wind drag acting on the ship. The authors concluded that CFD results agreed with the experimental measurements and the wind drag acting on the modified ship could reduce up to 56% in the wind direction angle from zero to 50 degrees [11]. Other authors presented results of wind loads on post-panamax container ship. By using model test in wind tunnel, the wind forces acting on the ship had been investigated. The authors applied a purely experimental approach to provide directly applicable results for container ship operators and to provide benchmark for development of new computational methods [5, 12]. For other types of ship, some authors had presented a study on the numerical analysis of the wind forces acting on a LNG carrier model performed with CFD and experiment in wind tunnel. Others authors presented the results on aerodynamic performances of the carrier ship such as the research on reducing interaction effect between hull and accommodation on wind drag acting on hull of the ship. The authors proposed a new hull form with different accommodation position and accommodation shape on deck to reduce interaction effects between hull and accommodation. By using CFD and experimental test in towing tank, drastically reduced wind drag acting on the ship had been found. The total wind drag acting on hull could reduce up to 60% [13–15]. Others research on effects of side guards on aerodynamic performance of a wood chip carrier was

presented. By using CFD and experimental test in towing tank, the authors developed a side guard for the wood chip carrier. The CFD results clearly showed effects of side guards on aerodynamic performance of the ship and wind drag acting on hull drastically reduced up to 50% of total wind drag [16].

In this paper, interaction effects between hull and accommodation of a container ship has been investigated by using a commercial CFD code ANSYS-Fluent. By applying CFD, the aerodynamic performances and wind drag acting on a 1,200 TEU container ship have been computed. The aerodynamic performances and wind drag acting on the hull with accommodation on its deck and on the independent hull without accommodation have

been investigated to determine the interaction effects between hull and accommodation of the ship. From the results of interaction effects between hull and accommodation of the container ship, several ideas about reducing wind drag acting on hull by reducing interaction effect between hull and accommodation have been proposed in this paper.

MODEL OF 1,200 TEU CONTAINER SHIP

A full scale 1,200 TEU container ship has been used as a reference model. The ship has been designed with an accommodation located aft of the ship. Figure 1 shows the full scale model ship used for computation. The detailed principal dimensions of the ship are shown in table 1.

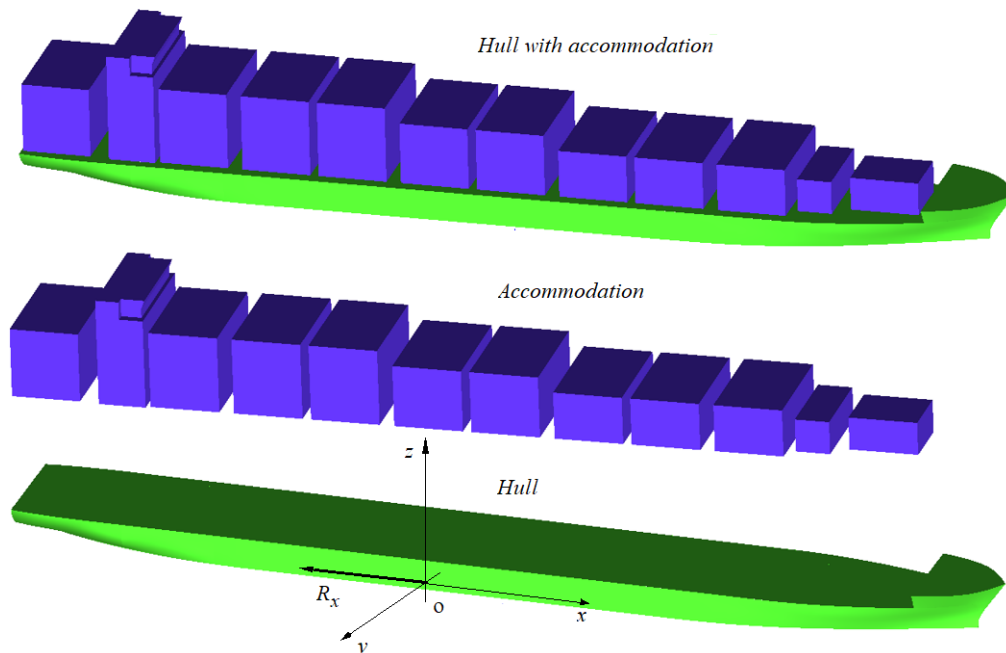


Figure 1. Model of the 1,200 TEU container ship with and without accommodation

Table 1. Principal particulars of the container ship

Name	Description	Value	Unit
L	Length	176.20	m
B	Breadth	24.90	m
H	Depth	13.70	m
d	Draft	8.30	m
S_x	Frontal projected area of ship	541.29	m ²
C_b	Block coefficient	0.68	-
R_n	Reynolds number	5.8–8.7	$\times 10^7$

Computed domain and setup conditions

In applying CFD code to solve the ship hydrodynamic problems as well as the aerodynamic performances of the container ship, computed domain, mesh, and the boundary condition have affected the CFD results. Therefore, we must solve the problem according to user guide line for applying CFD which has been published by the International Towing Tank Conference (ITTC) [18] or the CFD manufacturer. Moreover, the researcher’s experiment is very important in using CFD to solve the same problems [7, 13, 14, 16, 18, 19]. In this study, computed domain has been designed in 1,200 m of length ($6.5 \times L$), 300 m of breadth ($1.5 \times L$) and 150 m of height ($0.75 \times L$) as limited dimensions. Mesh of the computed domain in unstructured mesh contains about 2.6 million elements. Figure 2 shows detailed mesh in computed domain and over hull surface of the ship. For calculation, the turbulent viscous model $k-\epsilon$ for unsteady flow has been used

[16, 17, 20]. The velocity inlet is set up for the inlet, the pressure outlet is set up for the outlet of the computation domain. The bottom and side of the computed domain are set up in the wall condition. After finishing condition setup, the problem has been computed by the CFD. For this problem, the time size step is of 0.005 sec and 5000 time steps. The problem has been computed by a computer core i7 intel 3.6 GHz with 12 GB of RAM. The detailed computed condition setup for the computation is shown in table 2.

Table 2. Computational condition setup for the problems

Name	Value	Unit
Turbulent viscous model	$k-\epsilon$	-
Velocity inlet, V_∞	6.2–9.3	m/s
Pressure outlet, p_{out}	1.025	10^5 N/m^2
Air density, ρ	1.225	kg/m^3
Kinetic viscosity, ν	1.789	10^{-5} kg/ms

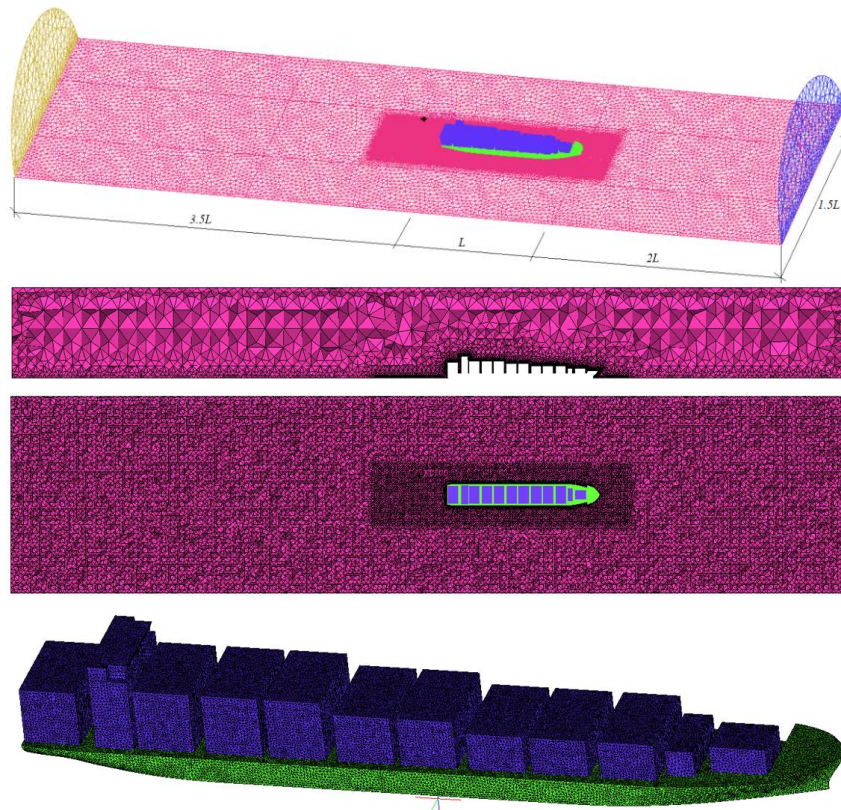


Figure 2. Mesh of the computational domain

Interaction effects on aerodynamic performance of ship

In this section, the CFD results of aerodynamic performance of the ship have been shown in the different cases of hull with accommodation and hull without accommodation. By comparing the results

between the two cases, interaction effects on aerodynamic performance of hull and accommodation have been found. Figure 3 shows dynamic pressure distribution around the ship in the two computed cases of the hull with and without accommodation on its deck.

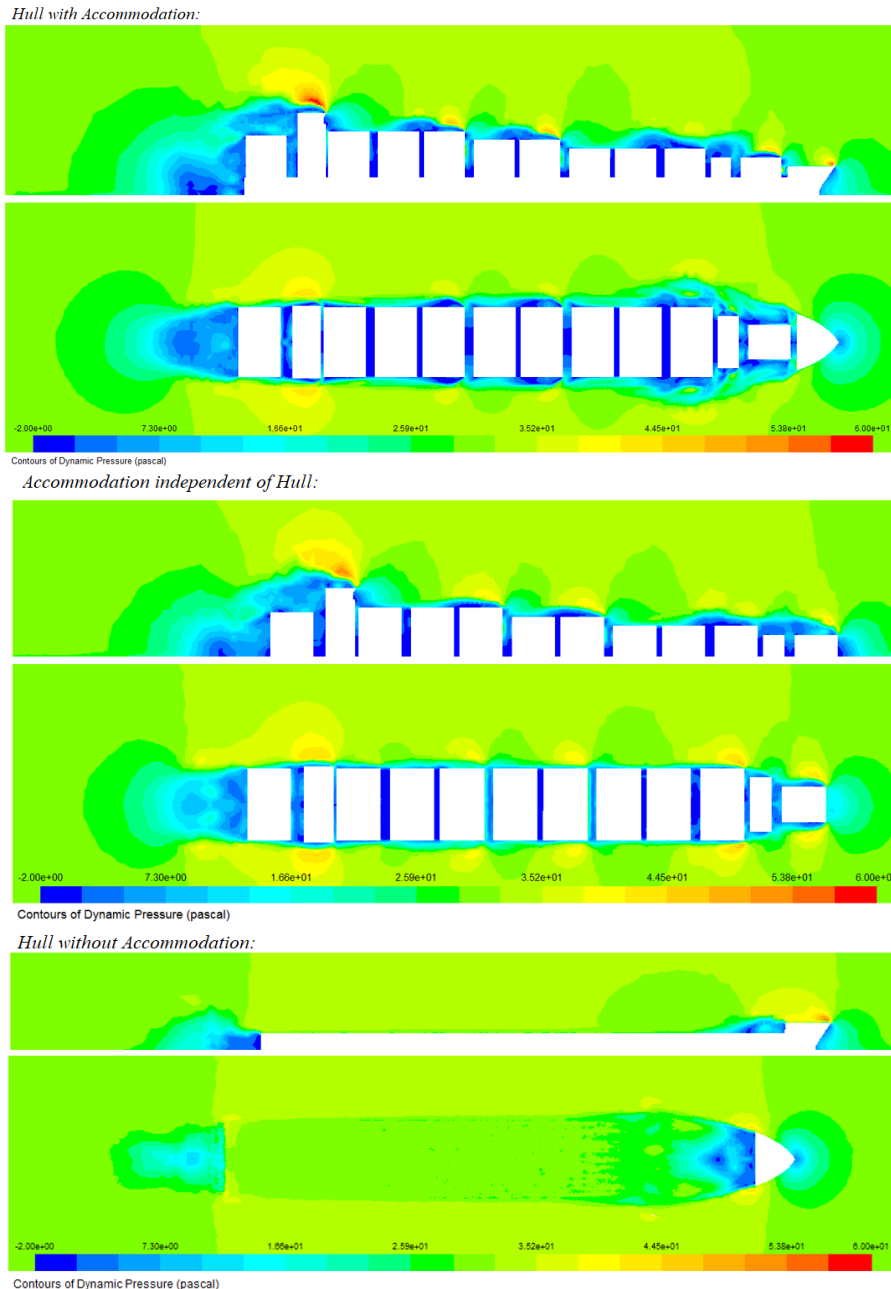


Figure 3. Dynamic pressure distribution around ship in the two computed cases at central plan and horizontal plan of the computed domain, at Reynolds number of 6.73×10^7

The results in the figure 3 clearly show the difference in pressure distributions around hull in the two different cases. In the case of hull with accommodation on its deck, the separation flow around accommodation seems larger than

that of the case with accommodation independent of hull. Figure 4 shows pressure distribution around hull at several cross sections in computed domain at Reynolds number of 6.73×10^7 .

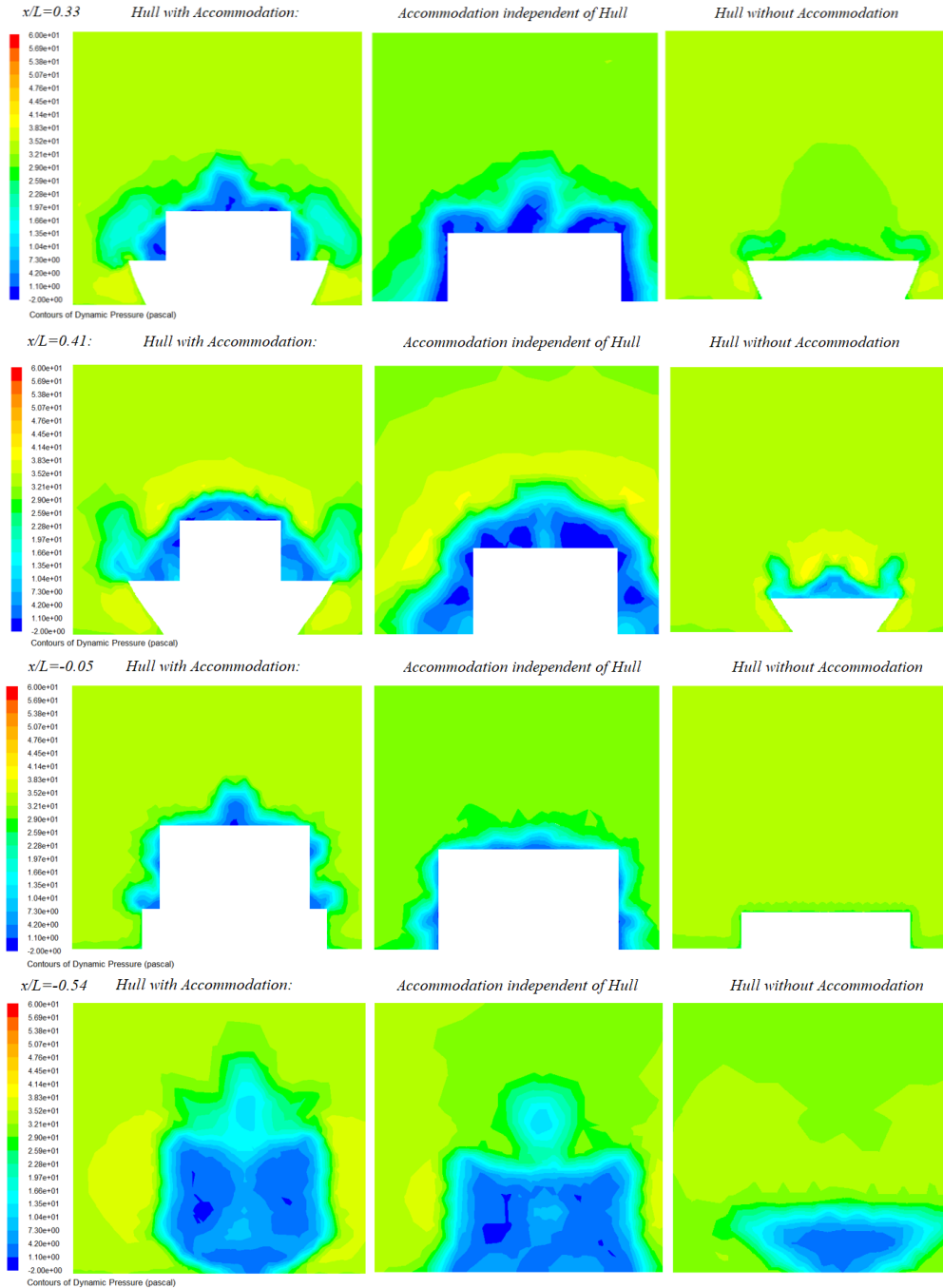


Figure 4. Dynamic pressure distribution around ship in the two computed cases at several cross sections, at Reynolds number of 6.73×10^7

Figure 4 clearly shows effects on pressure distribution around hull in the two computed cases. The interaction effects between hull and accommodation as shown in the results of

pressure distribution may affect wind drag acting on hull of the ship. Figure 5 shows comparison of pressure distribution over hull surface of the ship in the two computed cases.

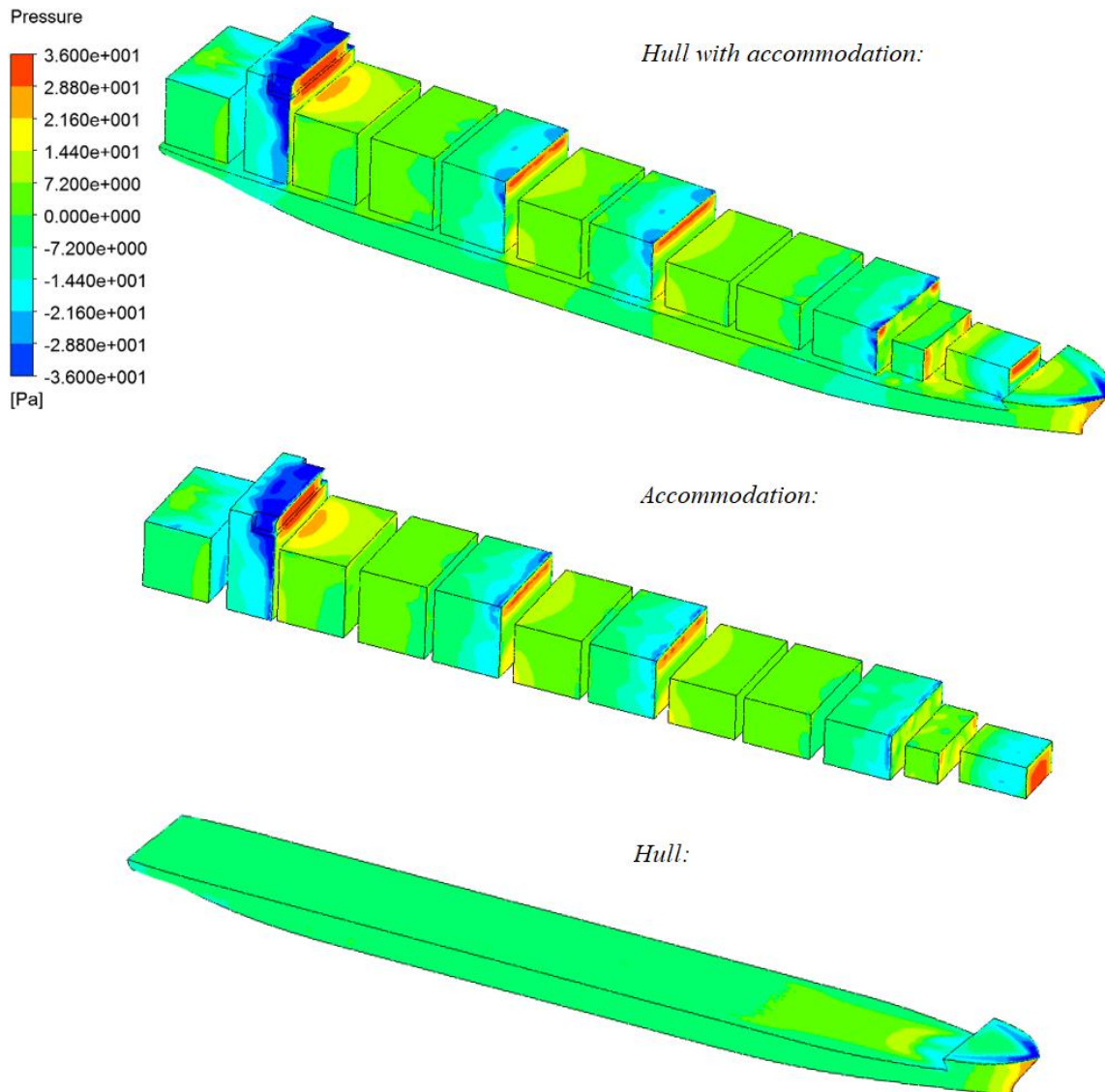


Figure 5. Pressure distribution around ship in the two computed cases at several cross sections, at Reynolds number of 6.73×10^7

In the results shown in figure 5, the red and yellow colours show high pressure area, the blue colour shows lower pressure area. In these figures, we can see the effects of hull and accommodation on pressure distribution over hull surface of the ship. The interaction effects between hull and accommodation will be

determined by comparison of the wind drag acting on hull and accommodation in both computed cases.

Interaction effects on wind drag

In this section, interaction effects between hull and accommodation on wind drag acting

on the ship have been investigated. The interaction effects between hull and accommodation are determined by the equation (1):

$$\%IE = \frac{C_d(\text{Hull with Acc}) - C_d(\text{Independent Hull and Acc})}{C_d(\text{Independent Hull and Acc})} 100\% \quad (1)$$

Where: %IE is interaction effects between hull and accommodation; $C_d(\text{Hull with Acc})$ is total wind drag coefficient acting on hull with accommodation; $C_d(\text{Independent Hull and Acc})$ is total wind drag coefficient acting on independent hull.

Tables 3, 4 and 5 show detailed wind drag acting on the hull, accommodation and interaction effects between hull and accommodation on wind drag acting on the ship.

Table 3. Wind drag acting on hull with accommodation

$R_n \times 10^7$	Wind drag, R_x (N)			Wind drag coefficients, C_x		
	Acc	Hull	Total	Acc	Hull	Total
5.77	10058	1506	11564	0.797	0.119	0.916
6.73	13116	1878	14994	0.763	0.109	0.872
7.69	17536	2448	19984	0.781	0.109	0.889
8.65	22512	3171	25683	0.792	0.112	0.903

Table 4. Wind drag acting on independent hull and independent accommodation

$R_n \times 10^7$	Wind drag, R_x (N)			Wind drag coefficients, C_x		
	Acc	Hull	Total	Acc	Hull	Total
5.77	10262	2372	12634	0.8126	0.1878	1.0004
6.73	13606	3180	16786	0.7912	0.1849	0.9761
7.69	17805	4099	21905	0.7924	0.1825	0.9749
8.65	22478	5145	27623	0.7902	0.1809	0.9711

Table 5. Interaction effect between hull and accommodation on wind drag

$R_n \times 10^7$	Wind drag, R_x (%)			Wind drag coefficients, C_x (%)		
	Acc	Hull	Total	Acc	Hull	Total
5.77	-2	-37	-8	-2	-37	-8
6.73	-4	-41	-11	-4	-41	-11
7.69	-2	-40	-9	-2	-40	-9
8.65	0	-38	-7	0	-38	-7

In the results shown in the tables 3–5, the wind drag acting on hull and accommodation in the case of hull with accommodation on its deck is less than that in the case of independent hull and accommodation up to 11%. For the wind drag acting on hull and accommodation, the interaction effect is about 41% and 4% following Reynolds number. Figures 6 and 7 show the comparison of wind drag acting on the ship in the two computed cases and the

interaction effect between hull and accommodation on wind drag.

In the results, the wind drag coefficient and interaction effect between hull and accommodation are determined by Reynolds number. From the results, we can see that wind drag acting on the ship in the case of hull with accommodation is less than that in the case independent hull and accommodation about 11%. However, interaction effect of

independent hull on wind drag is up to 41%. The same results have been given in the different Reynolds number.

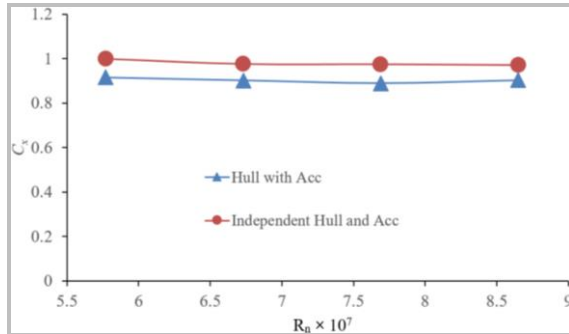


Figure 6. Wind drag acting on the ships in the two cases of hull with and without accommodation

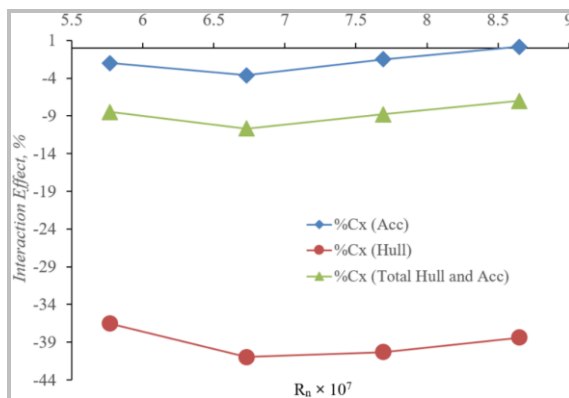


Figure 7. Interaction effects between hull and accommodation on wind drag acting on hull, accommodation and the ships

CONCLUSIONS

In this research, the interaction effect between hull and accommodation of the container ship has been studied. The aerodynamic performances and wind drag acting on hull of the 1,200 TEU container ship in the two different cases of hull with accommodation and hull independent of accommodation have been investigated. The following are some conclusions based on obtained results:

1) By using the CFD, the aerodynamic performances and wind drag acting on the 1,200 TEU container ship in the two computed

cases of hull with accommodation and hull independent of accommodation have been investigated. The obtained results may be useful to design and optimize aerodynamic performances for the container ship or other type of ship with larger above water surface hull and so on.

2) The CFD results of the aerodynamic performances of the ship as well as the pressure distribution around hull and over hull surface of the ship in the two computed cases of hull with accommodation and accommodation independent of hull are important to find the reasons for the interaction effects between hull and accommodation on wind drag acting on the ship.

3) In the range of Reynolds number from 5.77×10^7 to 8.65×10^7 , interaction effect between hull and accommodation on wind drag acting on the ship is around 11%. For the hull only, it is up to 41%.

4) The interaction effect between hull and accommodation follows Reynolds number. The results shown in the paper may be useful for study on reducing wind drag acting on the ship by reducing interaction effect between hull and accommodation.

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