Vietnam Journal of Marine Science and Technology 2022, 22(3) 299–308

Vietnam Academy of Science and Technology

Vietnam Journal of Marine Science and Technology

journal homepage: vjs.ac.vn/index.php/jmst

Estimating Hull Resistance of a Pontoon by using CFD

Ngo Van He*, Hoang Cong Liem, Ngo Van Hien

Hanoi University of Science and Technology, Hanoi, Vietnam

Received: 20 May 2022; Accepted: 29 July 2022

ABSTRACT

This paper presents our estimated results of hull resistance acting on a full-scale pontoon by a commercial Computational Fluid Dynamic (CFD). The results have been compared with those obtained by using various well-established valuable empirical formulae introduced by the International Towing Tank Conference (ITTC). The differences between the empirical formulae and the CFD results have been found and discussed.

Keywords: Hull, resistance, CFD, pontoon, empirical formulae.

*Corresponding author at: Hanoi University of Science and Technology, 1 Dai Co Viet Road, Hai Ba Trung, Hanoi, Vietnam. *E-mail addresses:* he.ngovan@hust.edu.vn

https://doi.org/10.15625/1859-3097/17157

ISSN 1859-3097/

INTRODUCTION

The hull resistance acting on the ship is essential in the ship design process. Prediction of hull resistance working on hull of a vessel is critical at the first step in ship design to achieve its designed efficiency. A model test is the most popular method to estimate hull resistance acting on a ship. Using experimental results, researchers have proposed empirical formulae to estimate the hull resistance for the same series of hull form [1–9]. The hull resistance of a ship has been evaluated in the fundamental calculation. Up to now, empirical formulae have been defined for almost all popular vessels; they have become a powerful designed tool. However, the accuracy of the calculated results given by the empirical formulae is also an important topic that many researchers are interested in [10–15].

In recent years, Computational Fluid Dynamic (CFD) has gained high popularity for predicting the hull resistance of the ship because of its high efficiency and economy. The accuracy of the CFD results has improved significantly; many studies being done on validating the CFD results showing how to predict the hydrodynamic performances and hull resistance of a ship, and so on [11, 14, 16–22]. Others works have developed new hull forms with various attached devices to improve hydrodynamic performances and to reduce resistance of hull forms by using CFD [11, 12, 14, 19, 22, 23].

Pontoons are being used to support floating bridges across rivers, where water flows are relatively small; in other words: pontoons are working in calm water regions. Nevertheless, from a bridge point of view, estimating a pontoon hull resistance and its hydrodynamic performances are as important as those of a ship. In this study, firstly, resistance acting on a full scale hull of a pontoon in calm water has been investigated by the different valuable empirical formulae such as the Froude, Schoenherr, ITTC1957, and Holtrop formulae. Secondly, the CFD ANSYS-Fluent has been used to compute the hydrodynamic performances and resistance woring on the pontoon. The obtained results have been compared with each other to find how different resistances acting on the hull of the pontoon behave and find out the reasons for those.

FULL SCALE MODEL OF THE PONTOON

In this study, a full-scale model of a pontoon is used as a referenced model. Figure 1 shows the body plan of the selected pontoon, and detailed principal dimensions of the pontoon are shown in Table 1.

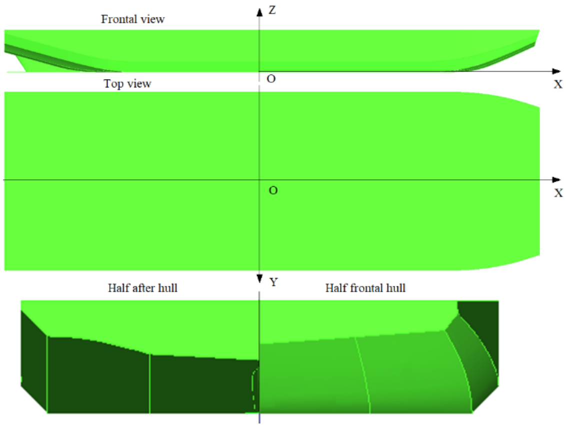


Figure 1. Model of the pontoon used for computation

Table 1. The main particulars of the pontoon

Name	Value	Unit
Length over, L	23.40	m
Width, B	8.10	m
Height, H	1.90	m
Design draft, d	0.90	m
Displacement volume, D	138.6	m^3
Block coefficient, C_B	0.812	-
Wetted surface area, S_w	207.2	m^2
Froude number, F_n	0.356	-

EMPIRICAL FORMULAE MOTHED ESTIMATES HULL RESISTANCE

In the research field of hull resistance, understanding the components of hull resistance and their behavior is essential. That is why researchers have used many methods as well as using many scaled hull forms. Scaling the obtained resistance results of the experimental model at towing tank to get actual results for the full-scale model, using both empirical formulae and CFD predicted methods [1, 2, 4, 5, 10]. Observation of a ship moving through water indicates two flow features, namely the wave pattern of turbulent flow and wake after the hull of the vessel. Both of these features are affected by hydrodynamic performances and increasing resistance on the ship considerably. The total hull resistance (R_T) acting on the ship is defined as the two components: viscous pressure resistance (R_p) and viscous friction resistance (R_f) acting on the hull of the ship [4–6, 8, 24].

$$R_T = R_p + R_f \qquad (1)$$

The total hull resistance coefficient is defined by:

$$C_T = C_p + C_f \qquad (2)$$

where: C_T is the total resistance coefficient; C_p is the viscous pressure resistance coefficient; C_f is the viscous friction resistance coefficient.

The resistance coefficients is defined as follows:

$$C_T = \frac{R_T}{0.5\rho V^2 S};\ C_p = \frac{R_p}{0.5\rho V^2 S};\ C_f = \frac{R_f}{0.5\rho V^2 S} \qquad (3)$$

In this study, hull resistance of the ship is investigated by using empirical formulae methods. The first systematic experiments to determine friction resistance in water of thin flat planks were carried out by W. Froude, and R. E. Froude re-examined the results obtained to considerate that the results of planks having surfaces corresponding to those of clean ship hulls or to paraffin wax models could be expressed as the following [2, 3, 5, 24, 25]:

$$R_f = fSV^{1.825} \qquad (4)$$

in there: f depends on length, and gets from R. E. Froude's skin friction f values; S is wetted surface area, m^2; and V is velocity, m/s.

Schoenherr had reported all the available experimental data from plank experiments both in air and water attempting to determine a formula suitable with the available data. He determined by the following formula [5, 24, 25].

$$C_F = \frac{1}{\left(3.5\lg_{10} R_e - 5.96\right)^2} \qquad (5)$$

The friction resistance coefficient in accordance with the ITTC1957 formula is defined by [1, 5]:

$$C_F = \frac{0.075}{\left(\lg_{10} R_e - 2\right)^2} \qquad (6)$$

An approximate power prediction method presented by J. Holtrop and G. G. J. Mennen, the total hull resistance of a ship is defined as follows [4]:

$$R_T = R_F\left(1 + k_1\right) + R_{APP} + R_W + R_B + R_{TR} + R_A \qquad (7)$$

where: R_F is viscous frictional resistance according to the ITTC1957 friction formula (6); $(1 + k_1)$ is form factor describing the viscous resistance of hull form in relation to R_F; R_{APP} is resistance of appendages; R_W is wave making and wave breaking resistance; R_B is additional pressure resistance of bulbous bow near the water surface; R_{TR} is additional pressure resistance of immersed transom stern; R_A is model ship correlation resistance.

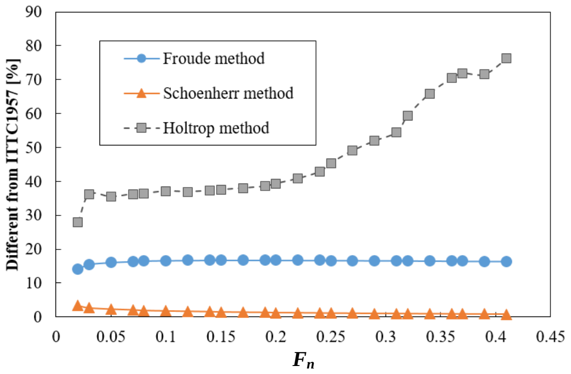


Figure 2. Comparison results of resistance coefficient from the ITTC1957 method

For the pontoon in full scale model as shown in Figure 1, resistance coefficient acting on the hull of the pontoon in calm water is calculated by the empirical formulae as shown in Table 2.

Table 2 shows the detailed resistance coefficient of the pontoon in the range of the Froude number from 0.02 to 0.41. Figure 2 shows the results of the comparison as per the ITTC1957 method. The results shown that viscous frictional resistance calculated by the Schoenherr formula and ITTC1957 are the same values; however, small differences between them can be seen. The results of viscous frictional resistance calculated by the Froude method are higher than those from ITTC1957 up to 17% in range of Froude number from 0.02 to 0.41, as shown.

Table 2. Calculated results of hull resistance of the pontoon by empirical formula

F_n	Resistance coefficient			
	Froude, C_F	Schoenherr, C_F	ITTC1957, C_F	Holtrop, C_T
0.020	0.00367	0.00305	0.00315	0.00438
0.030	0.00331	0.00272	0.00280	0.00438
0.050	0.00312	0.00256	0.00262	0.00405
0.070	0.00299	0.00245	0.00250	0.00392
0.080	0.00289	0.00237	0.00241	0.00379
0.100	0.00281	0.00230	0.00235	0.00373
0.120	0.00275	0.00225	0.00229	0.00363
0.140	0.00270	0.00221	0.00225	0.00358
0.150	0.00265	0.00217	0.00221	0.00353
0.170	0.00261	0.00214	0.00217	0.00350
0.190	0.00257	0.00211	0.00214	0.00348
0.200	0.00254	0.00209	0.00211	0.00349
0.220	0.00251	0.00207	0.00209	0.00353
0.240	0.00248	0.00204	0.00207	0.00362
0.250	0.00246	0.00203	0.00205	0.00375
0.270	0.00243	0.00201	0.00203	0.00398
0.290	0.00241	0.00199	0.00201	0.00418
0.310	0.00239	0.00198	0.00200	0.00438
0.320	0.00237	0.00196	0.00198	0.00488
0.340	0.00235	0.00195	0.00197	0.00577
0.360	0.00234	0.00193	0.00195	0.00660
0.370	0.00232	0.00192	0.00194	0.00690
0.390	0.00231	0.00191	0.00193	0.00678
0.410	0.00229	0.00190	0.00192	0.00805

In the range of Froude numbers lower than 0.2, the total resistance coefficient calculated by the Holtrop method are different from other methods by about 38%. When the Froude number increases higher than 0.2, the different coefficients increase fast and up to 76%, as shown in Figure 2. The different values indicate the number of other resistance components included in to the Holtrop method.

INVESTIGATING HULL RESISTANCE OF THE PONTOON BY USING CFD

Computational fluid domain and mesh

In this section, the hull resistance of the pontoon has been investigated by using commercial CFD code ANSYS-Fluent will be presented. The computation case has been done step by step following the schema for using CFD as well as useful guidlines and many published experiences in useing CFD to solve hydrodynamic ship problems reported by the International Towing Tank Conference (ITTC) [5, 10, 12, 19, 21–23]. The computational fluid domain has been designed in the limited dimension of 6 L × 1.5 L × 1.5 L instead of 140 m length, 35 m calculating the width, and 35 m height. Meshing the computed domain in the structured H-grid is of 2.83 million grids. The turbulent viscous model k-ω is applied to unsteady flow, and the Volume of Fluid (VOF) multiphase model has been used. The inlet and outlet of the computed domain have been set up with a velocity inlet and pressure outlet. Figure 3 shows the mesh of the computational fluid domain.

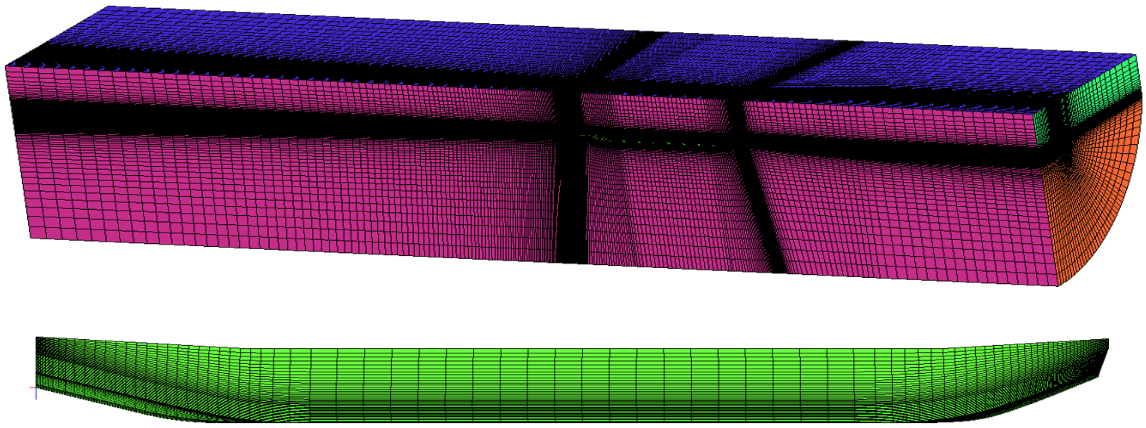


Figure 3. Mesh of the computational fluid domain

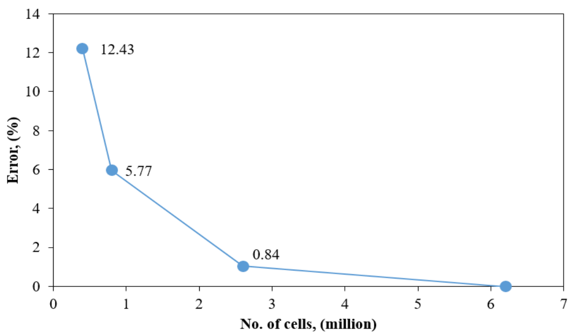


Figure 4. Effect of mesh on CFD results of total resistance coefficient of the pontoon

The effects of a mesh of the computed domain on the CFD results have been reported in many previous papers [7, 11, 12, 14, 16, 18–23]. This study uses several different meshes of the computed domain to simulate the pontoon in calm water at the Froude number of 0.36. Table 3 shows a detailed mesh of the computed domain and the computed hull resistance coefficients of the pontoon in the different caculated cases. Figure 4 shows the curves of the mesh effect on the computed hull resistance coefficient of the pontoon in calm water at the Froude number of 0.36.

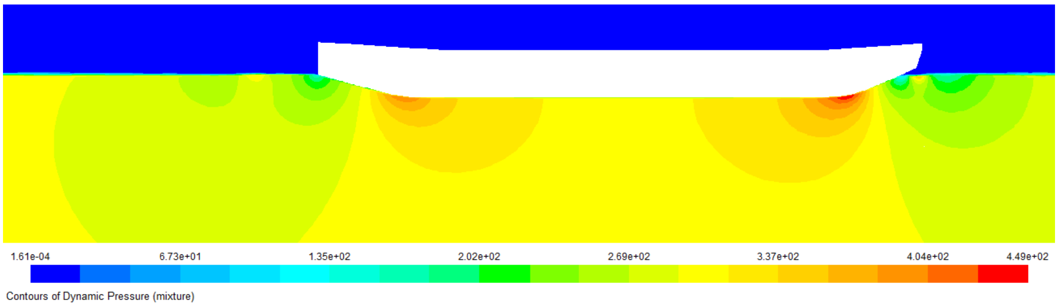
Figure 4 shows the results of the different hull resistance coefficients in the different computed cases, as shown in the Table 3. The error between the calculated results was less than 12.43% when the value of Y^+ was less than 8.325, and the resistance coefficient was the same for all computed cases when the mesh number was over 2.626 million instead of a Y^+ value below 0.897, as shown.

Table 3. Mesh of computed domain and the CFD results of hull resistance

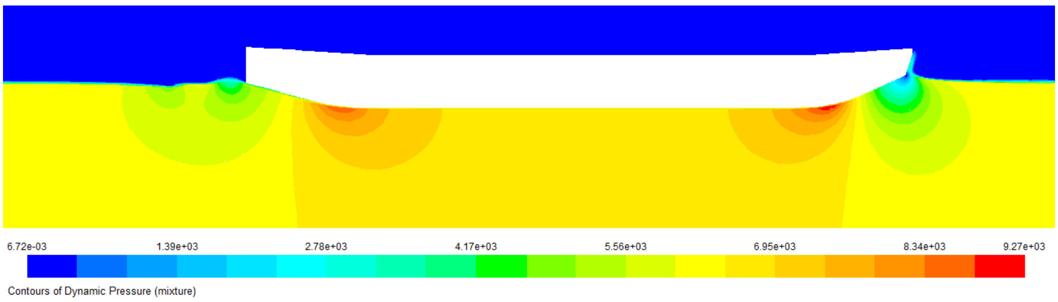
Y^+	Total elements ($\times 10^6$)	Minimum face area, ($\times 10^{-8}$ m^2)	Maximum face area, ($\times 10^{-4}$ m^2)	Minimum volume, ($\times 10^{-6}$ m^3)	Maximum volume, ($\times 10^{-2}$ m^3)	C_T ($\times 10^{-2}$)
8.3251	0.4235	1.9521	12.2825	5.0682	7.2656	0.01112
5.8823	0.8366	1.6223	9.26285	2.6352	2.9372	0.00932
0.8972	2.6269	0.0519	2.01281	0.3267	1.8098	0.00981
0.2436	6.2321	0.0162	1.89285	0.0563	1.5219	0.00991

CFD results of hull resistance acting on the pontoon

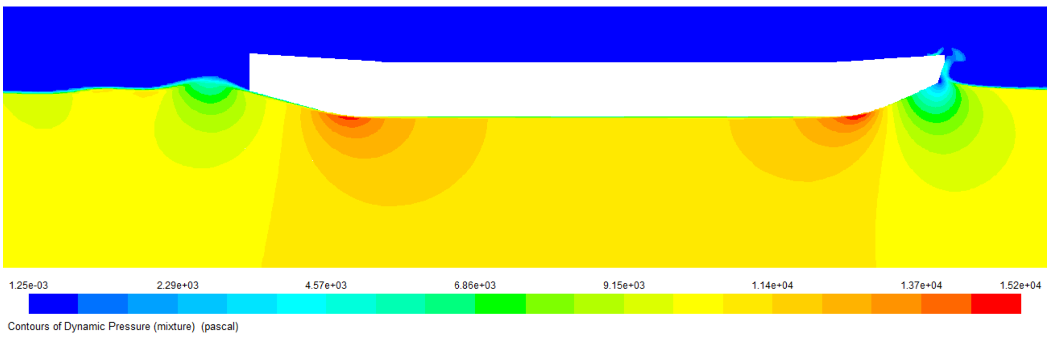
In this section, the hydrodynamic performance and hull resistance of the pontoon investigated by using the CFD is presented. Figures 5–6 show pressure distribution around the hull of the pontoon at the center plane of the computed domain and over the hull surface of the pontoon in different Froude numbers.



a) $F_n = 0.05$

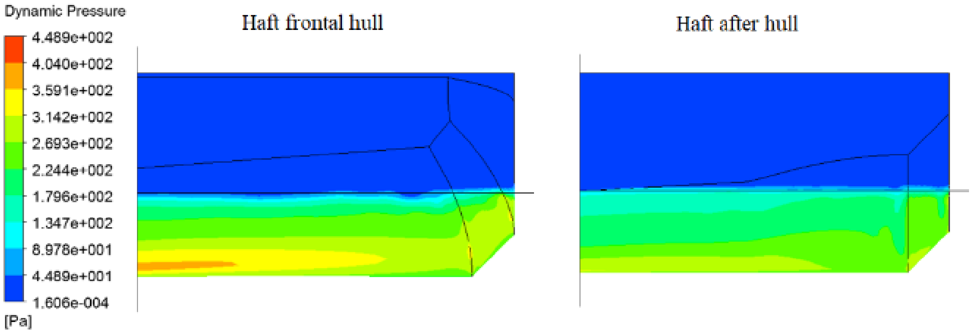


b) $F_n = 0.24$

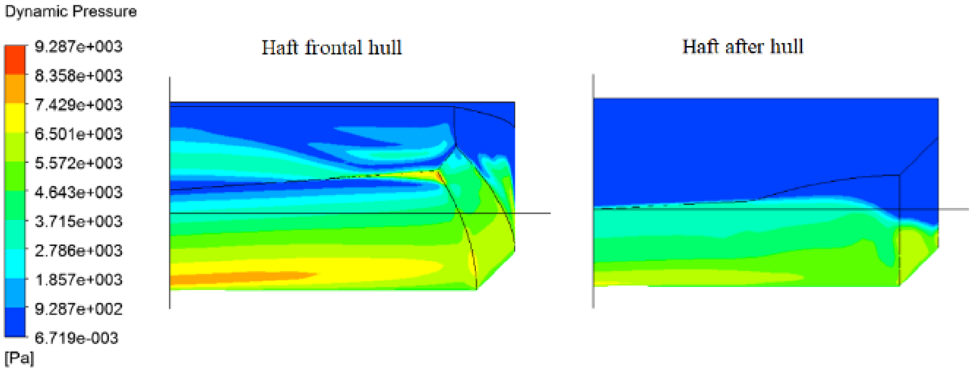


c) $F_n = 0.41$

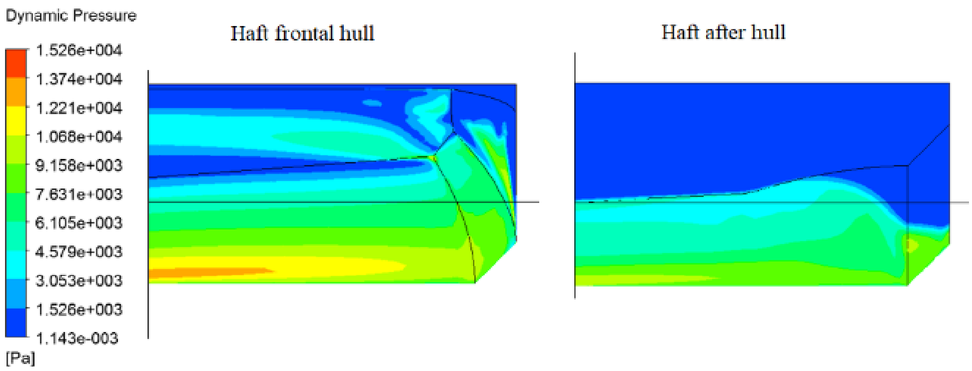
Figure 5. Dynamic pressure distribution around the hull of the pontoon at the center plane of the computed domain



a) $F_n = 0.05$



b) $F_n = 0.24$



c) $F_n = 0.41$

Figure 6. Dynamic pressure distribution over the hull surface of the pontoon

The results, as shown in Figures 5–6, clearly show the effect of the Froude number on dynamic pressure distribution around the pontoon and over the hull surface of the pontoon. In the results, the red and yellow regions indicate that the dynamic pressure around and over the hull surface is high, and the blue area indicates a lower dynamic pressure region over the surface of the pontoon's hull. In high Froude number, the bow waves are high and increase a larger dynamic pressure region over the bow surface of the pontoon. Figure 7 shows the results of the resistance coefficient of the pontoon investigated by the different methods. The detailed results are shown in Table 3, and the CFD results of the hull resistance coefficient of the pontoon are shown in Table 4.

In the results shown, the viscous frictional resistance coefficient acting on the pontoon computed by the CFD is in good agreement with those of the Froude, Schoenherr, and

ITTC1957 methods. The total resistance coefficient calculated by the CFD compared with the Holtrop way is higher than 25% in the range of Froude number lower than 0.24 and increasing fast up to 50% at the high Froude number. The results agree with those of the pressure distribution around the pontoon, as shown.

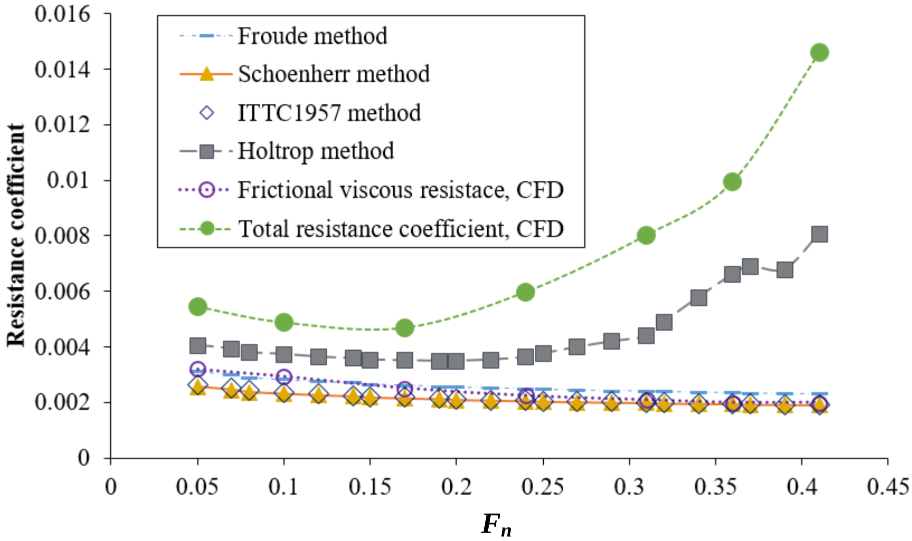


Figure 7. Investigated hull resistance coefficient of the pontoon

Table 4. Resistance acting on the pontoon investigated by the CFD

F_n	Resistance, (N)			Resistance coefficient		
	R_f	R_p	R_T	C_f	C_p	C_T
0.05	198.090	138.236	336.326	0.00320	0.00223	0.00543
0.10	736.021	476.103	1,212.124	0.00298	0.00193	0.00491
0.17	1,731.001	1,480.324	3,211.325	0.00253	0.00216	0.00469
0.24	3,001.981	5,008.131	8,010.112	0.00223	0.00373	0.00596
0.31	4,630.088	13,175.127	17,805.215	0.00208	0.00593	0.00802
0.36	6,007.112	24,089.003	30,096.115	0.00199	0.00797	0.00996
0.41	7,856.321	49,754.910	57,611.231	0.00199	0.01260	0.01459
0.44	9,856.025	61,679.088	71,535.113	0.00213	0.01331	0.01544

CONCLUSION

This study investigated the hull resistance of the full-scale pontoon in calm water using the different empirical formulae methods such as the Froude, Schoenherr, ITTC1957, and Holtrop methods and using the CFD simulation. The obtained results show the restrictions of the empirical formulae applied to calculate the hull resistance of the ship have been found. The empirical formulae have given close results of viscous frictional resistance acting on the hull of the pontoon in comparison between the different methods. However, the viscous pressure resistance component calculated by the empirical formula is much less than the CFD results at a lower Froude number of 0.24. The error is up to 25% and increases fast up to 50% at Froude number of 0.44. The results suggest that a pontoon’s body plane is the only concerned variable at a low Froude number.

REFERENCES

[1] Clements, R. E., 1959. An analysis of ship model correlation data using the

1957 ITTC line. *National Physical Laboratory, NPL, Published by: The Institution of Naval Architects, 101(4), London, RINA Transactions 1959-19*.

[2] Froude, W., 1872. Experiments on the surface-friction experienced by a plane moving through water. *British Association for the Advancement of Science*, *42*, 118–124.

[3] Froude, W., 1874. Report to the lords commissioners of the admiralty on experiments for the determination of the frictional resistance of water on a surface, under various conditions, performed at Chelston cross, under the authority of their lordships. *Taylor & Francis*. 14 p.

[4] Holtrop, J., and Mennen, G. G. J., 1982. An approximate power prediction method. *International Shipbuilding Progress*, *29*(335), 166–170.

[5] ITTC, R. P., 2002. Guidelines: Testing and Extrapolation Methods: Resistance-Uncertainty Analysis, Example for Resistance Test. *ITTC Recommended Procedures and Guidelines, Procedure*, 7-5.

[6] Lackenby, H., 1954. On the presentation of ship resistance data. *British Shipbuilding Research Association, The Royal Institution of Naval Architects, RINA Transactions: 1954-19, Written Discussion*.

[7] Liu, S., and Papanikolaou, A., 2019. Approximation of the added resistance of ships with small draft or in ballast condition by empirical formula. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment*, *233*(1), 27–40. doi: 10.1177/1475090217710099

[8] Peck, R. W., 1976. The determination of appendage resistance of surface ships. *Admiralty Experiment Works, Haslar, AEW Technical Memorandum 76020*.

[9] Shaher Sabit, A., 1971. Regression analysis of the resistance results of the BSRA series. *International Shipbuilding Progress*, *18*(197), 3–17. doi: 10.3233/ISP-1971-1819701

[10] Feng, D., Ye, B., Zhang, Z., and Wang, X., 2020. Numerical Simulation of the Ship Resistance of KCS in Different Water Depths for Model-Scale and Full-Scale. *Journal of Marine Science and Engineering*, *8*(10), 745. https://doi.org/10.3390/jmse8100745

[11] Mikkelsen, H., and Walther, J. H., 2020. Effect of roughness in full-scale validation of a CFD model of self-propelled ships. *Applied Ocean Research*, *99*, 102162. https://doi.org/10.1016/j.apor.2020.102162

[12] Niklas, K., and Pruszko, H., 2019. Full-scale CFD simulations for the determination of ship resistance as a rational, alternative method to towing tank experiments. *Ocean Engineering*, *190*, 106435. https://doi.org/10.1016/j.oceaneng.2019.106435

[13] Samuel, S., Iqbal, M., and Utama, I. K. A. P., 2015. An investigation into the resistance components of converting a traditional monohull fishing vessel into catamaran form. *International Journal of Technology*, *6*(3), 432–441. http://dx.doi.org/10.14716/ijtech.v6i3.940

[14] Seo, J. H., Seol, D. M., Lee, J. H., and Rhee, S. H., 2010. Flexible CFD meshing strategy for prediction of ship resistance and propulsion performance. *International Journal of Naval Architecture and Ocean Engineering*, *2*(3), 139–145. https://doi.org/10.2478/IJNAOE-2013-0030

[15] Tu, T. N., Kraskowski, M., Chien, N. M., Anh, V. T., Luu, D. L., and Phuong, N. K., 2018. Numerical study on the influence of trim on ship resistance in trim optimization process. *Naval Engineers Journal*, *130*(4), 133–142.

[16] Rahaman, M. M., Islam, H., Islam, M. T., and Khondoker, M. R. H., 2017. Calm water resistance prediction of a bulk carrier using Reynolds averaged Navier-Stokes based solver. In *AIP Conference Proceedings*, 1919(1), 020038). https://doi.org/10.1063/1.5018556

[17] Seok, J., and Park, J. C., 2020. Comparative study of air resistance with

and without a superstructure on a container ship using numerical simulation. *Journal of Marine Science and Engineering*, *8*(4), 267. https://doi.org/10.3390/jmse8040267

[18] Ngo, V. H., and Le, T. T., 2020. Effect of mesh on CFD aerodynamic performances of a container ship. *Vietnam Journal of Marine Science and Technology*, *20*(3), 343–353. https://doi.org/10.15625/1859-3097/20/3/15249

[19] Van He, N., and Ikeda, Y., 2013. Optimization of bow shape for a non ballast water ship. *Journal of Marine Science and Application*, *12*(3), 251–260. doi: 10.1007/s11804-013-1196-8

[20] He, N. V., and Ikeda, Y., 2014. Added resistance acting on hull of a non ballast water ship. *Journal of Marine Science and Application*, *13*(1), 11–22. doi: 10.1007/s11804-014-1225-2

[21] Van He, N., Mizutani, K., and Ikeda, Y., 2016. Reducing air resistance acting on a ship by using interaction effects between the hull and accommodation. *Ocean Engineering*, *111*, 414–423. https://doi.org/10.1016/j.oceaneng.2015.11.023

[22] Van, H. N., and Van, T. T., 2021. CFD investigation of interaction effect between hull and accommodation on wind drag of a container ship in head wind. *Vietnam Journal of Marine Science and Technology*, *21*(1), 37–46. https://doi.org/10.15625/1859-3097/16050

[23] Le, T. K., He, N. V., Hien, N. V., and Bui, N. T., 2021. Effects of a bulbous bow shape on added resistance acting on the hull of a ship in regular head wave. *Journal of Marine Science and Engineering*, *9*(6), 559. https://doi.org/10.3390/jmse9060559

[24] Molland, A. F., Turnock, S. R., and Hudson, D. A., 2017. Ship resistance and propulsion. *Cambridge university press*.

[25] Schoenherr, K. E., 1932. Resistance of flat surfaces moving through a fluid. *Trans. Soc. Nav. Archit. Mar. Eng.*, *40*, 279–313.