All Sciences Proceedings
All Sciences Proceedings
http://as-proceeding.com/

2nd International Conference on Scientific and Academic Research
March 14-16, 2023 : Konya, Turkey

ICSAR

A Fast Empirical-Based Methodology to Calculate Added Resistance

Emre Kahramanoglu *[1] and Gokhan Budak[1]

[1]*Faculty of Naval Architecture and Maritime, Izmir Katip Celebi University, Turkey*

* *(emre.kahramanoglu@ikcu.edu.tr) Email of the corresponding author*

Abstract – The resistance characteristics of ships are one of the most important concepts in the hydrodynamic field. This characteristic is very important not only in calm water but also in waves since it is directly related to the ship's speed. Therefore, these characteristics should be determined accurately, especially in the design stage. In the present study, a program based on empirical formulas presented in the literature is developed to calculate the resistance characteristics of ships both in regular and irregular waves. The computed results show that the developed methodology is capable to represent the resistance characteristics of ships which have large C_B values. Thus, the methodology can be useful, especially in the preliminary design stage.

Keywords –Added Resistance, Irregular Waves, KVLCC, DTC, Regular Waves

I. Introduction

One of the most important parameters in marine hydrodynamics is ship resistance since this parameter directly affects the economic performance of the ships. Moreover, a badly designed ship in terms of resistance needs more power which means more emissions. From this point of view, this characteristic is very important not only for ecological but also for economic reasons. Therefore, the resistance characteristics of the ships should be determined accurately, especially in the design stage.

An extra resistance which is called added resistance occurs when the ship sails in regular or irregular wave conditions. Thus, the resistance characteristic of it is directly affected by this condition. From this point of view, the added resistance characteristics of the ships should be determined appropriately in waves as well as in calm water. The added resistance values of the ships can be calculated experimentally, empirically or numerically. Hwang et al. [1] and Lee et al. [2] performed experiments to obtain the added resistance for conventional hull forms in regular head waves. Recently, de Luca et al. [3] conducted experiments to calculate added resistance of a planing hull for various Froude numbers. However, experimental studies need comprehensive facilities, qualified personnel, and expensive materials. Therefore, numerical studies especially using CFD tools were used frequently to obtain the added resistance of the ships. The added resistance of S-175 containership in regular head waves for different wavelengths was predicted by Ye et al. [4]. El Moctar et al. [5] obtained the added resistance of DTC hull form in regular head waves both experimentally and numerically. Kim et al. [6] calculated the added resistance values in regular head waves for the KVLCC2 hull form. Cakici et al. [7] carried out a numerical analysis to calculate not only the vertical motions of a surface combatant but also the added resistance of it. Similarly, Lee et al. [8] and Chen et al. [9] calculated the added resistance of different vessel types numerically by using the CFD approach. Kobayashi et al. [10] present a calculation guideline for the added resistance of ships by using the CFD approach. Although the CFD approach is useful to calculate the added resistance, it is also time-consuming and has high computational costs since it needs high computing capacity. Therefore, especially in the preliminary design stage, the researchers use the empirical approaches which are fast while they have limitations. Liu et al. [11] offered an empirical formula to calculate the added resistance of the ships. After this, Liu et al. [12] proposed a fast approach to the added resistance problem. Then, a valid empirical approach was presented by Liu and Papanikolaou [13] and it was modified by Liu and Papanikolaou [14]. Recently, Budak [15] showed that this method can be used in maneuvering simulations in waves as well as the validity of the empirical approach.

In the present study, a fast empirical-based program was developed on MATLAB which can be useful in the preliminary design stage to calculate the added resistance of ships for regular and irregular waves. The present paper is organized as follows: The second section includes the selected hull forms and their properties while it also includes the solution strategy. The third section gives the numerical results obtained from the developed program and it shows the comparison with experiments both in regular and irregular waves. In the last section, the general conclusions were given.

II. Methodology

A. *Hull forms used in the present study*

In the present study, to show the validity of the empirical approach for a wide range of conventional hull types, 4 different benchmark hull forms were selected. The block coefficients (C_B) of the selected hull forms were between 0.57 and 0.84 while the selected Froude numbers were between 0.092 and 0.2. All data obtained from the presented methodology and the data used for comparison were evaluated for the model scales. The main parameters of the selected hull forms were listed in Table 1.

Table 1. Main particulars of the selected hull forms

Main Dimensions		**DTC**	**JBC**	**KVLCC2**	**S175**
Length	m	5.500	4.828	3.200	4.375
Beam	m	0.790	0.776	0.580	0.635
Draught	m	0.225	0.285	0.208	0.238
Displacement	m^3	0.646	0.916	0.313	0.337
C_B	-	0.640	0.844	0.810	0.572
Fn	-	0.154	0.141	0.092	0.200

B. *Equations and solution strategy*

Figures and tables must be centered in the column. Large figures and tables may span across both columns. Any table or figure that takes up more than 1 column width must be positioned either at the top or at the bottom of the page.

$$R_{AW} = R_{AWR} + R_{AWM} \tag{1}$$

$$R_{AWR} = \quad 1.125\rho g B \zeta^2 \alpha_T sin^2 E \ldots$$
$$\ldots \left(1 + 5\sqrt{\frac{L}{\lambda}} Fn\right)\left(\frac{0.87}{C_B}\right)^{1+4\sqrt{Fn}} \tag{2}$$

$$R_{AWM} = 4\rho g \zeta^2 \frac{B^2}{L} \bar{\omega}^{\,b_1} \ldots$$
$$\ldots exp\left[\frac{b_1}{d_1}(1 - \bar{\omega}^{\,d_1})\right] a_1 a_2 a_3 \tag{3}$$

For a regular head wave, the components of the added resistance can be calculated by using Equation (2) and Equation (3). Here, ρ depicts the water density, and g depicts the gravitational acceleration. B and L depict the beam and the length of the vessel while λ and ζ refer to the wavelength and wave amplitude, respectively. The other parameters which are directly related to the ship and the incoming wave can be calculated by using the formulas explained deeply by Liu and Papanikolaou (2016).

After calculating the added resistance for various regular head waves, the total added resistance for a given spectrum ($\overline{R_{AW}}$) can be calculated by using Equation (4) and Equation (5) where $S(\omega_e)$, $S(\omega)$ and V depict the spectral density of a given spectrum for encounter frequency, the spectral density of a given spectrum for wave frequency and the forward speed of the ship, respectively.

$$\overline{R_{AW}} = 2 \int_0^\infty S(\omega_e) \frac{R_{AW}(\omega_e)}{\zeta^2} d\omega_e \tag{4}$$

$$S(\omega_e) = {S(\omega)}\Big/{1 + \frac{2\omega V}{g}} \tag{5}$$

To calculate the added resistance for a given spectrum, a code was developed on MATLAB by following the flow chart given in Figure 1 and an example of the developed program is shown in Figure 2. It should be noted that the non-dimensionalization of the added resistance is obtained by using Equation (6).

$$C_{AW} = {R_{AW}}\Big/{(\rho g \zeta^2 B^2 L^{-1})} \tag{6}$$

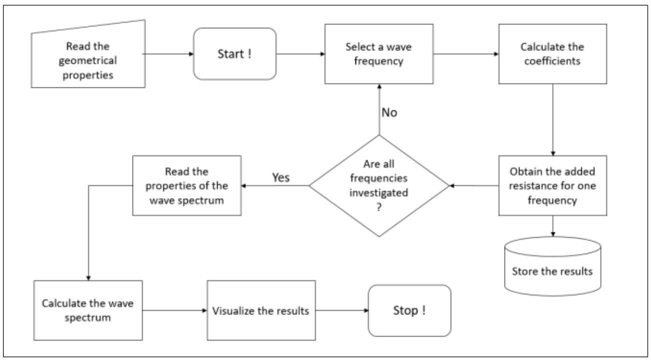


Fig. 1. The flow chart of the developed program

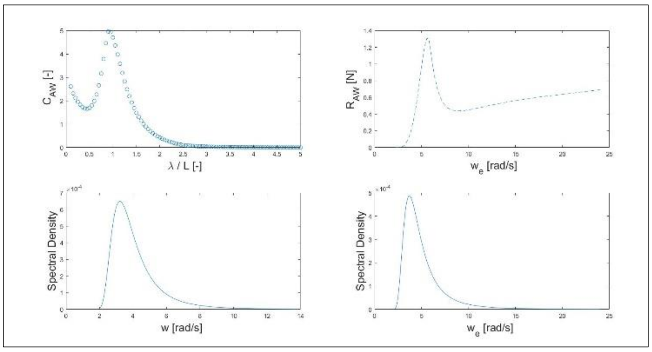
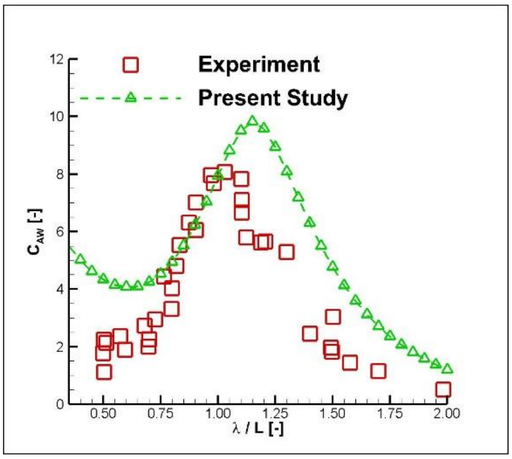


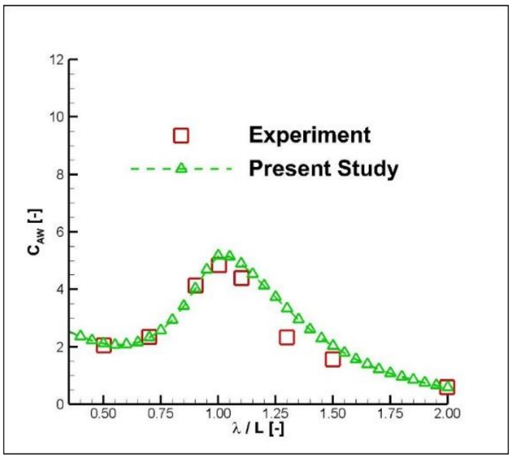
Fig. 2. An example of the output of the program

III. RESULTS

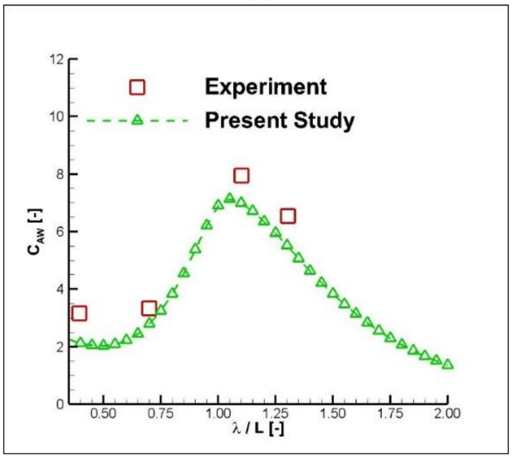
As explained in the previous part, four different hull forms were selected for validation purposes. Therefore, before performing the added resistance calculation for an irregular wave spectrum, the numerical model should be validated.



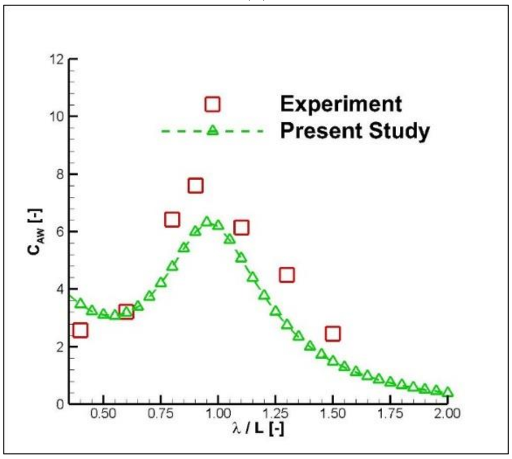
(a)



(b)



(c)

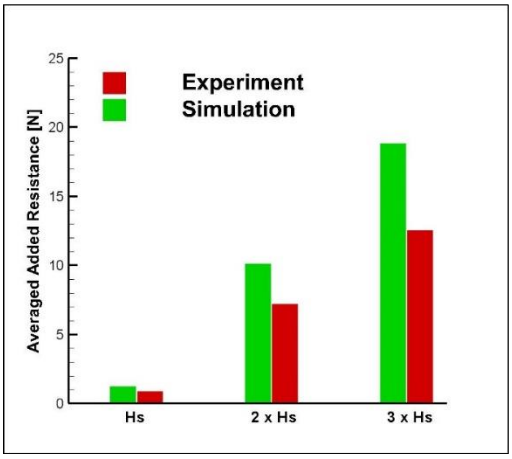


(d)

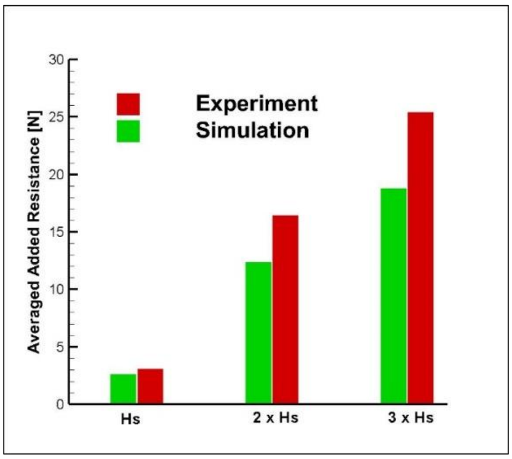
Fig. 3. Comparison of the obtained results with experiments for different hull forms (a: S175, b: KVLCC2, c: JBC, d: DTC)

The numerical data obtained from the developed numerical code are compared with the available experimental data for all hull forms in Figure 3. It should be noted that the experimental data for S175 and KVLCC2 were measured by Liu and Papanikolaou [13] while the rest of the data was obtained from Kobayashi et al. [10]. As can be understood from Figure 3, the added resistance values are generally calculated lower than experiments for JBC and DTC hull forms while the numerical results are higher than experimental values for KVLCC and S175 hull forms. According to the results presented in this figure, the numerical method can be used for all hull forms in the present study for a wide range of regular head waves.

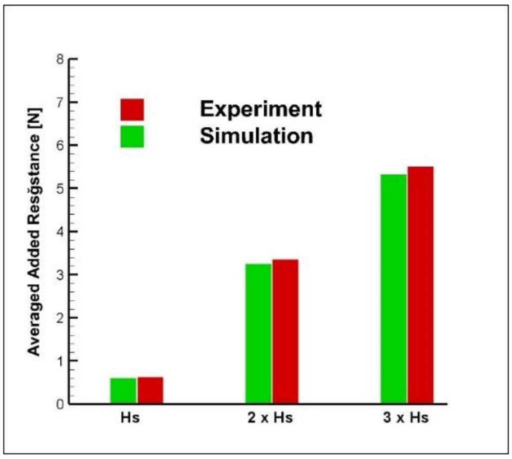
After calculating the added resistance values for regular head waves, the averaged added resistance values for a given irregular wave spectrum are calculated by using Equation (4) and Equation (5). In the present study, the Pierson Moskowitz wave spectrum was used to calculate averaged added resistance. The comparison of the simulation results with the experimental ones is shown in Figure 4. It should be noted that the experimental averaged added resistance values in terms of different significant wave heights (Hs) were obtained following the superposition principle explained in Equation (4) and Equation (5). For a fair comparison, the simulation results for regular head waves are limited considering the wavelengths of the experimental scenarios. Since there are only 4 experimental data for JBC hull form, the averaged added resistance value of it could not be calculated.



(a)



(b)



(c)

Figure 4. Comparison of the averaged added resistance in terms of different significant wave heights (a: S175; b: DTC; c: KVLCC)

According to Figure 4, since the results of the S175 hull form are higher than the experimental ones, as expected the simulation results are higher than that of the experimental ones. The relative difference between simulation results and experimental ones is about 44%. However, the order of the results seems similar. When the DTC hull form is examined, the relative differences between the results are around 20% which can be acceptable order. However, satisfactorily good agreement is observed for KVLCC hull form for all significant wave heights. The relative average difference between them is around 3%. As expected from the added resistance characteristics obtained from the regular head wave analysis, the averaged added resistance values of the simulations are higher than the experiments for S175 while the opposite situation is observed for the DTC hull form.

IV. CONCLUSION

In the present study, to calculate the added resistance for a given irregular wave spectrum, a program based on the empirical method offered by Liu and Papanikolaou [13] is developed on MATLAB by using the linear superposition technique. The numerical results are obtained for different significant wave heights for 4 different hull forms whose experimental results were presented in the literature.

According to the numerical results, the added resistance values for regular head waves have similar trends for all hull forms, except for S175. For this hull form, the resonance wave frequency has a prominent difference from the experiments. Similar observation isn't made for other hull forms. Since the relative difference for lower wave lengths are high, this causes a remarkable difference for averaged added resistance for a given wave spectrum. The differences for DTC hull form can be acceptable level while the numerical results for KVLCC hull form has satisfactorily good agreement with the experiments.

REFERENCES

[1] Hwang, S., Kim, J., Lee, Y-Y., Ahn, H., Van, S-H., Kim, K-S., (2013). Experimental Study on the Effect of Bow Hull Forms to Added Resistance in Regular Head Waves. 12th International Symposium Practical Design of Ships and Other Floating Structures. 20-25 October, CECO, Korea.

[2] Lee, J-H., Seo, M-G., Park, D-M., Yang, K-K., Kim, K-H., Kim, Y., (2013). Study on the Effects of Hull Form on Added Resistance. 12th International Symposium Practical Design of Ships and Other Floating Structures. 20-25 October, CECO, Korea.

[3] de Luca, F., Pensa, C., and Pigazzini, R., (2023). Experimental Assessment of Planing Hulls Added Resistance in Regular Waves. Journal of Marine Science and Engineering. 11. 141. 10.3390/jmse11010141.

[4] Ye, H., Shen, Z., and Wan, D-C., (2012). Numerical prediction of added resistance and vertical ship motions in regular head waves. Journal of Marine Science and Application. 11. 10.1007/s11804-012-1150-1.

[5] el Moctar, O., Sigmund, S., Ley, J., Schellin, T., (2016). Numerical and Experimental Analysis of Added Resistance of Ships in Waves. Journal of Offshore Mechanics and Arctic Engineering. 139. 10.1115/1.4034205.

[6] Kim, M., Hizir, O., Turan, O., and Incecik, A., (2017). Numerical Investigation on Added Resistance with Wave Steepness for KVLCC2 in Short and Long Waves.

[7] Cakici, F., Kahramanoglu, E., and Alkan, A.D., (2017). Numerical Prediction of Vertical Ship Motions and Added Resistance. Transactions of the Royal Institution of Naval Architects Part A: International Journal of Maritime Engineering. 159. 10.3940/rina.ijme.2017.a4.450.

[8] Lee, Y-G., Kim, C., Park, J-H., Kim, H., Lee, I., and Jin, B., (2019). NUMERICAL SIMULATIONS OF ADDED RESISTANCE IN REGULAR HEAD WAVES ON A CONTAINER SHIP. Brodogradnja. 70. 61-86. 10.21278/brod70204.

[9] Chen, S., Zou, B., Han, C., and Yan, S., (2022). Comparative Study on Added Resistance and Seakeeping Performance of X-Bow and Wave-Piercing Monohull in Regular Head Waves. Journal of Marine Science and Engineering. 10. 813. 10.3390/jmse10060813.

[10] Kobayashi, H., Kume, K., Orihara H., Ikebuchi, T., Aoki, I., Yoshida, R., Yoshida, H., Ryu, T., Arai, Y., Katagiri, K., Ikeda, S., Yamanaka, S., Akibayashi, H., Mizokami, S., (2021). Parametric study of added resistance and ship motion in head waves through RANS : Calculation guideline, Applied Ocean Research, Volume 110, 102573, ISSN 0141-1187, https://doi.org/10.1016/j.apor.2021.102573.

[11] Liu S, Papanikolaou A and Zaraphonitis G., (2011) Prediction of added resistance of ships in waves. Ocean Eng; 38: 641–650.

[12] Liu S, Papanikolaou A and Zaraphonitis G., (2015). Practical approach to the added resistance of a ship in short waves. In: Proceedings of the 25th international offshore and polar engineering conference, Kona, HI, 21–26 June 2015, vol. 3, pp.11–18, Cupertino, USA: International Society of Offshore and Polar Engineers.

[13] Liu, S. and Papanikolaou, A., (2016). Fast approach to the estimation of the added resistance of ships in head waves. Ocean Eng; 112: 211–225.

[14] Liu, S., and Papanikolaou, A. (2017). Approximation of the added resistance of ships with small draft or in ballast condition by empirical formula. Proc. IMechE Part M: J Engineering for the Maritime Environment 1-14.

[15] Budak, G. (2023). The Added Resistance Calculations of a Ship in Regular Head Waves. Karadeniz 2nd International Conference on Applied Sciences. March 3-5, 2023. Rize, Türkiye