SMALL SHIPS HYDRODYNAMICS SOFTWARE PLATFORM

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ABSTRACT

The hydrodynamics performances prediction of the small ships represents an important issue in the initial design stage. The Preliminary Hydrodynamics Performances (PHP) software platform was developed at the Research Centre of the Naval Architecture Faculty from "Dunarea de Jos" University of Galati, in order to calculate the ship resistance, as well as the powering and manoeuvring performances of the small ships. The description of the most important software modules and corresponding theoretical aspects is presented in this paper. The software platform is used for the didactic applications and research activities dedicated to the estimation of the hydrodynamics performances of the small ships, in the preliminary design stage.

Keywords: small ships, resistance, powering, manoeuvring, software platform.

1. INTRODUCTION

The estimation of the resistance, powering and manoeuvring performances of the small ships in the initial design stage is a very important problem.

Specific theoretical methods were developed depending on the number of hulls and operating domain (displacement, transient or planning), in order to solve the above mentioned hydrodynamics performances.

The operating mode depends on the value of the Froude number Fn_∇, calculated by means of the relation

$$Fn_\nabla = \frac{v}{\sqrt{g \cdot \nabla^{1/3}}} \qquad (1)$$

where g is the gravity acceleration, ∇ is the volumetric displacement and v is the ship speed.

Depending on the Froude number Fn_∇ value, the following operating domains may be defined:

- Displacement domain, if $Fn_\nabla < 1$;
- Transient domain, if $1 < Fn_\nabla < 3$;
- Planning domain, if $Fn_\nabla > 3$.

From the small ship resistance performance point of view, specific methods can be used for mono-hulls and catamarans, in displacement, transient and planning domains [2], [3], [22], [23], [24], [25], [26].

By means of the ship resistance and selection of the optimum propeller characteristics based on the B-Wageningen propeller series, the powering performance of the small ships can be calculated [4], [5].

In the last step of the hydrodynamic analysis, the manoeuvring performance of the small ships must be estimated, including the hydrodynamics characteristics of the rudder. The specific computational methods can be applied depending on the ship operating domain [3], [4], [5].

A fast investigation software platform (PHP-Preliminary Hydrodynamics Perform-

ances) was generated at the Research Centre of the Naval Architecture Faculty from "Dunarea de Jos" University of Galati, in order to estimate the resistance, powering and manoeuvring performances of the small ships, in the preliminary design stage.

A synthetical description of the specific theoretical methods applied in order to solve the small ships resistance problem both for mono-hulls and catamarans is presented in the next chapter.

2. SMALL SHIPS RESISTANCE PERFORMANCE

The ship resistance problem can be solved on the PHP platform for the following types of small ships: mono-hulls (for displacement, transient and planning domains), catamarans (both with rounded bilge and hard chine forms) and sailing vessels.

The small ship resistance estimation in the case of the *mono-hulls in displacement or transient domains* was performed by means of the Mordvinov method ([3], [4], [5], [6], [18]). The total ship resistance R_T may be calculated using the relation

$$R_T = R + R_{APP} + R_A \qquad (2)$$

where R is the bare hull resistance notation, R_{APP} is the appendage resistance and R_A is the aerodynamic resistance.

The bare hull resistance is given by the expression

$$R = R_F + R_{PV} + R_W \qquad (3)$$

where R_F is the frictional resistance, with R_{PV} representing the viscous pressure resistance and R_W is the own wave resistance.

The frictional resistance is calculated on the basis of the ITTC 1957 formula, depending on the Reynolds number

$$Re = \frac{v \cdot L_{WL}}{\upsilon} \qquad (4)$$

where L_{WL} is the length of the waterline and υ is the kinematic viscosity of the water.

The viscous pressure resistance may be calculated with the following relation

$$R_{PV} = R_F \cdot (\eta - 1) \qquad (5)$$

depending on the viscous pressure resistance coefficient, noted with η.

The own wave resistance R_W is determined by using the Papmel relations [3], depending on the critical ship speeds v_1 and v_2.

- If $v > v_2$

$$R_W = 20 \cdot k \cdot \frac{g \cdot \varDelta}{L_{WL} \cdot 10^3} \cdot v_2^2 \cdot (v / v_2)^{1/2} \qquad (6)$$

- If $v_1 < v < v_2$

$$R_W = C_{B0} \cdot k \cdot \frac{g \cdot \varDelta}{L_{WL} \cdot 10^3} \cdot v^2 \qquad (7)$$

where $\varDelta$ represents the ship displacement. The critical speeds, the coefficient C_{B0} and the coefficient k may be determined in accordance to reference [3].

The appendages resistance R_{APP} may be calculated as a fraction of the bare hull resistance and depends on the complexity of the appendages and the ship speed [3]

$$R_{APP} = k_{APP} \cdot R \qquad (8)$$

where k_{APP} represents the appendages coefficient.

The aerodynamic resistance is given by the relation [3]

$$R_A = C_A \cdot \frac{\rho_a \cdot (v + v_v)^2}{2} \cdot S_e \qquad (9)$$

where C_A is the aerodynamic coefficient, ρ_a is the air density, v_v is the wind speed and S_e is the aerodynamic surface area (projected on the midship section).

The computer code PHP-NM-RI-DT was developed at the Research Centre of the Naval Architecture Faculty from "Dunarea de Jos" University of Galati, in order to compute the small ship resistance in displacement or transient domains [6], [18] by using the described procedure.

In the case of the *mono-hulls planning domain*, the resistance performance may be estimated according to the Mordvinov method [3], by means of the relation (2).

The bare hull resistance R is determined by using the following relation [3]

$$R = R_F + R_P \qquad (10)$$

where R_F is the frictional resistance of the equivalent plane plate and R_P is the pressure resistance.

The frictional resistance of the equivalent plane plate R_F is calculated by means of the Prandtl-Schlichting coefficient, given by the formula

$$C_{F_0} = \frac{0.455}{\left(\log \mathrm{Re}_{l_w}\right)^{2.58}} \qquad (11)$$

The Reynolds number Re_{lw} is determined by using the relation

$$\mathrm{Re}_{l_w} = \frac{v \cdot l_w}{\upsilon} \qquad (12)$$

where l_w is the wetted length of the equivalent plane plate.

The pressure resistance R_P may be estimated by means of the formula [3]

$$R_P = g \cdot \varDelta \cdot tg\alpha \qquad (13)$$

where α is the attack angle.

The appendages resistance R_{APP} and the aerodynamic resistance R_A may be estimated by using the relations (8) and (9).

The computer code PHP-NM-RI-G was developed at the Research Centre of the Naval Architecture Faculty from "Dunarea de Jos" University of Galati, in order to calculate the small ship resistance in the planning domain [7], [19] by using the described method.

Different methods can be used in order to solve the catamaran resistance problem, depending on the hull forms.

In the case of the *hard chine catamarans* forms, the method based on the series generated by Pham, Kantimahanthi and Sahoo [22] was selected.

The total resistance of the catamaran may be calculated on the basis of the following relation

$$R_{Tcat} = \frac{1}{2} C_{Tcat} \cdot \rho \cdot v^2 \cdot S_w \qquad (14)$$

where ρ is the water density, S_w is the wetted surface area of the catamaran and C_{Tcat} is the coefficient of the total resistance, calculated by means of the formula

$$C_{Tcat} = \left(1 + \gamma \cdot k\right) \cdot C_F + C_{wcat} \qquad (15)$$

C_{wcat} is the wave resistance coefficient of the catamaran and C_F is the frictional resistance coefficient of the demi-hull. The form factor of the catamaran $(1 + \gamma \cdot k)$ may be determined by using the multiple regression analysis of Molland, Wellicome and Couser [2].

The frictional resistance coefficient C_F may be determined using ITTC'57 ship model correlation line

$$C_F = \frac{0.075}{\left(\log \mathrm{Re} - 2\right)^2} \qquad (16)$$

The wave resistance coefficient C_{wcat} can be estimated using the following regression relation proposed by Pham et al. [22]

$$C_{wcat} = e^\alpha \cdot \left(\frac{L}{B}\right)^{\beta 1} \cdot \left(\frac{B}{T}\right)^{\beta 2} \cdot \left(C_B\right)^{\beta 3} \cdot \left(\frac{s}{L}\right)^{\beta 4} \qquad (17)$$

and depends on the regression coefficients β_i (i=1…4). L is the waterline length of the catamaran, B is the catamaran demi-hull beam, T is the draught, C_B is the block coefficient and s is the distance between the demi-hull centre planes.

The computer code PHP Hard Chine Catamaran Resistance was developed at the Research Centre of the Naval Architecture Faculty from "Dunarea de Jos" University of Galati, in order to determine the total resistance of the catamarans with hard chine forms [8], [14] by using the described procedure.

In the case of the *round bilge catamarans* forms, the method proposed by Sahoo et al. [23], [24] was selected. The wave resistance coefficient of the catamaran C_{wcat} was estimated using the following regression formula

$$C_{wcat} = e^{c1} \cdot \left(\frac{L}{B}\right)^{c2} \cdot \left(\frac{B}{T}\right)^{c3} \cdot \left(C_B\right)^{c4} \cdot F_1$$

$$F_1 = \left(\frac{L}{\nabla^{1/3}}\right)^{c5} \cdot \left(i_E\right)^{c6} \cdot \beta^{c7} \cdot \left(\frac{s}{L}\right)^{c8} \qquad (18)$$

where i_E is the half angle of entrance and β is the deadrise angle at amidships. The volumetric displacement of the demi-hull was noted with ∇. The regression coefficients c_i (i=1…8) are given in references [23], [24].

On the basis of this method, the computer code PHP Round Bilge Catamaran Resistance was developed at the Research Centre of the Naval Architecture Faculty from "Dunarea de Jos" University of Galati [9], [15].

Also, a specific module is dedicated to the *sailing vessels (including the yachts)*, in order to estimate the ship resistance *in displacement and semi-planning domains*.

According to the reference [1], the total yacht resistance may be determined using the following formula

$$R_T = R_F + R_R + R_H + R_A \qquad (19)$$

where R_R is the residuary resistance and R_H is the heel resistance.

The frictional resistance of the yacht R_F may be obtained by summing the frictional resistance of the hull, keel and rudder

$$R_F = R_{Fhull} + R_{Fkeel} + R_{Frudder} \qquad (20)$$

These components may be determined by means of the ITTC'57 ship model correlation line.

The residuary resistance in the displacement domain (in the low speed range, with the Froude number F_n between 0.125 - 0.45) or in the semi-planning domain (F_n between 0.475 - 0.75) may be calculated by using the regression relations obtained on the basis of the Delft series, generated by Gerritsma and extended by Stadt and Partners [1]. The Froude number F_n is defined by the following relation

$$F_n = \frac{v}{\sqrt{g \cdot L}} \qquad (21)$$

The heel resistance component R_H may be determined on the basis of the Froude number, using the expression [1]

$$R_H = 0.5 \cdot C_H \cdot \rho \cdot v^2 \cdot S_{Whull} \cdot F_n^2 \cdot \varphi \qquad (22)$$

where φ is the heeling angle of the yacht and C_H is the heel coefficient [1].

The aerodynamic resistance of the yacht R_A depends on the following three components: the aerodynamic resistance of the hull R_{AH}, mast R_{AM} and rig (shrouds and stays) R_{AR} [1]

$$R_A = R_{AH} + R_{AM} + R_{AR} \qquad (23)$$

On the basis of this method, the computer code PHP Yacht Resistance was developed at the Research Centre of the Naval Architecture Faculty from "Dunarea de Jos" University of Galati [10], [16].

The mentioned modules of the PHP software platform were used to compute the ship resistance performance of the specific small ships.

Some examples of the ship resistance evaluation for small mono-hulls (including the sailing vessels) and catamarans were presented in the references [14], [15], [16], [18] and [19].

3. SMALL SHIPS POWERING PERFORMANCE

In order to determine the powering performance of the small ships, the following procedure was applied, based on the calculation of the effective power, the delivered power and the brake power.

The effective power may be determined using the relation

$$P_E = R_T \cdot v \cdot (1 + M_D) \qquad (24)$$

where M_D is the power design margin.

The delivered power is calculated on the basis of the following expression

$$P_D = \frac{P_E}{\eta_D \cdot n_p} \qquad (25)$$

where η_D is the propulsive coefficient and n_p is the propellers number.

The propulsive efficiency may be determined using the formula

$$\eta_D = \eta_0 \cdot \eta_H \cdot \eta_R \qquad (26)$$

where η_0 is the open water propeller efficiency, η_H is the hull efficiency and η_R is the relative rotative efficiency.

The selection of the optimum propeller characteristics is based on the B-Wageningen propeller series.

The brake power of the main engine at full rating (100% MCR-Maximum Continuos Rating) can be determined using the following expression

$$P_B = \frac{P_D}{\eta_{ax} \cdot \eta_{red} \cdot (1 - M_S)} \qquad (27)$$

where η_{ax} is the line shaft bearing efficiency, η_{red} is the reduction gear box efficiency and M_S is the power service margin.

The brake power of the main engine at service rating can be calculated on the basis of the following relation

$$P_B^{SR} = \frac{P_B}{SR} \qquad (28)$$

where *SR* is the service rating coefficient.

On the basis of the brake power value, the main engine necessary to be installed on board of the small ships is selected from the specific data catalogue.

4. SMALL SHIPS MANOEUVRING PERFORMANCE

The small ships manoeuvrability represents an important preliminary hydrodynamic subject and can be determined on the basis of the turning circle test.

The rudder is the usual passive control device, used on the ships in order to convert the water energy into control forces and moments in the horizontal plane. The manoeuvring performance depends on the geometry and the hydrodynamic efficiency of the rudder [17].

The PHP software platform dedicated to the small ships, developed at the Research Centre of the Naval Architecture Faculty from "Dunarea de Jos" University of Galati, includes some specific modules used to determine the hydrodynamics characteristics of the rudder and to estimate the manoeuvring performance in the displacement or planning domain [5].

The estimation of the *hydrodynamics characteristics of the rudder* was performed by means of the Mordvinov method [3], [4].

The hydrodynamic moment on the rudder stock is determined using the following relation

$$M = C_{mRHp} \cdot \frac{\rho \cdot v_{cp}^2}{2} \cdot A_R \cdot b_R \qquad (29)$$

where C_{mRHp} is the coefficient of the hydrodynamic moment (with the hull and propeller influences), v_{cp} is the water speed on the deflected rudder, A_R is the rudder area and b_R is the rudder chord.

The following problems can be solved on the basis of this method:
- the optimum position of the rudder stock;
- the calculation of the total torque (adding the frictional component to the hydrodynamic moment);
- the selection of the steering gear from specific data catalogue;
- the calculation of the rudder stock diameter.

The computer code PHP-NM-MAN-HC was developed at the Research Centre of the Naval Architecture Faculty from "Dunarea de Jos" University of Galati [11], in order to calculate the hydrodynamics characteristics of the rudder by using the Mordvinov method.

In order to estimate the *turning circle characteristics of the small ships in the displacement domain*, the Mordvinov method can be used, based on the hydrodynamics characteristics of the hull and of the rudder [3], [4], [20].

The following characteristics of the turning motion can be determined: the steady turning diameter, the angular speed, the drift angle, the ship speed and the maximum heeling angle during the steady turning motion.

The computer code PHP-NM-MAN-D was developed at the Research Centre of the Naval Architecture Faculty from "Dunarea de Jos" University of Galati [12], in order to calculate the manoeuvring characteristics of the small ships in the displacement domain, by using the Mordvinov method.

The *manoeuvring performance problem in the case of the planning small ships* was also solved by means of the same Mordvinov procedure [3], [4], [21].

The computer code PHP-NM-MAN-G was developed at the Research Centre of the Naval Architecture Faculty from "Dunarea de Jos" University of Galati [13], in order to determine the manoeuvring characteristics of the planning of small ships, using the Mordvinov method.

The above mentioned manoeuvring modules of the PHP software platform were applied to determine the hydrodynamics characteristics of the rudders and the turning circle performance of the small ships, in the displacement and planning domains.

Some practical evaluations of the small ships manoeuvring characteristics, in the displacement and planning domains were presented in the references [20] and [21].

4. CONCLUDING REMARKS

The resistance, powering and manoeuvring performances estimation of the small ships is an important preliminary design problem. istinct theoretical methods can be applied in order to solve the mentioned hydrodynamics problems, depending on the number of the hulls and the operating domain (displacement, transient or planning).

In this paper, a software platform dedicated to the evaluation of the resistance, powering and manoeuvring performances of the small ships was described.

A synthetical description of the main theoretical aspects was presented.

The PHP (Preliminary Hydrodynamics Performances) software platform was developed at the Research Centre of the Naval Architecture Faculty from "Dunarea de Jos" University of Galati.

The following small ships hydrodynamics problems may be solved:
- mono-hulls resistance estimation in displacement or transient domains;
- mono-hulls resistance estimation in planning domain;
- sailing vessels resistance estimation in displacement and semi-planning domains;
- catamarans resistance estimation with rounded bilge forms;
- catamarans resistance estimation with hard chine forms;
- powering performance estimation;
- evaluation of the hydrodynamics characteristics of the rudders;
- determination of the optimum position of the rudder stock;
- estimation of the total torque on the rudder stock and selection of the steering gear;
- estimation of the turning circle characteristics of the mono-hulls in the displacement domain;
- estimation of the turning circle characteristics of the mono-hulls in the planning domain.

The software platform can be used for didactic applications and applied research activities, dedicated to the hydrodynamics performances estimation, in the preliminary design stage of the small ships.

Acknowledgements

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