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SOFTWARE PLATFORM FOR MANOEUVRABILITY PERFORMANCE ESTIMATION IN INITIAL SHIP DESIGN

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ABSTRACT

Starting with the initial ship design stage, cost-effectiveness in manoeuvring and course keeping performance is a major objective. In this context, a software platform was developed in the Research Centre of the Faculty of Naval Architecture, of "Dunarea de Jos" University of Galati, in order to evaluate the ship manoeuvring abilities in deep water conditions, the squat in shallow water, the rudder hydrodynamics including the cavitation check and bowthruster powering. The present paper is a synthetical description of the specific methods and computer codes used to solve the manoeuvring problems mentioned above. The software platform PHP-Manoeuvrability is currently being used at the Faculty of Naval Architecture , both for didactical applications and research activities related to the manoeuvring domain.

Keywords: manoeuvrability, software platform, initial design.

1. INTRODUCTION

Manoeuvrability deals with the ship motion in the horizontal plane and represents a very important hydrodynamic subject. Ship manoeuvrability comprises the following concepts: manoeuvring (controlled course change), course keeping or stability on route and speed changing (including stopping manoeuvres).

The manoeuvring requirements are a standard part of the regulations imposed by maritime organizations and also by the contract between the shipyard and the ship owner. According to the IMO regulations [4], the manoeuvring performance may be determined on the basis of the following standard manoeuvres: turning circle, zig-zag, spiral test and stopping manoeuvres (crash stop and inertia test). The turning ability is measured by the advance (less than 4.5 ship lengths) and tactical diameter (which should not exceed 5 ship lengths). The yaw checking ability is determined on the basis of the overshoot angles and the stopping performance by tracking the reach distance of the crash stop test (less than 15 ship lengths).

The control devices convert energy into control forces and moments. The rudder is a passive control device, a hydrofoil pivoting on a vertical axis, in order to control the ship motion in the horizontal plane [2]. The body line plan is usually developed by ship design companies without particular regard to the rudder location. As a consequence, the rudder dimensions depend on the shape of the aft part, the draught and the position of the propeller which is located in the propeller jet, in order to increase the flow speed on the rudder surface [6]. On a straight course, the rudder needs to have minimum influence on the speed loss. The manoeuvring performance depends on the area, geometry and hydrodynamic efficiency of the rudder.

According to the strategic directions of the Research European Association "Vessel for the Future" [3], aiming towards zero accidents in vessels is one of the most important objectives. The ships are complex products delivering specialized services, based on dedicated technologies. As a consequence, the reduction of the accident frequency (collision, grounding, fire, explosion, etc.) will determine the decrease of the sea pollution problems and a more efficient and safer maritime transport.

In this context, the investigation of the manoeuvring performance is an important objective of the ship design, starting in the early design stage. In order to estimate the hydrodynamic characteristics of the rudder, the manoeuvring performance and course keeping ability of the ship, the software platform PHP-Manoeuvrability was developed in the Research Centre of the Faculty of Naval Architecture, "Dunarea de Jos" University of Galati. A synthetical description of the specific methods used to solve these manoeuvring problems in the initial design stage is discussed in the followig chapter.

2. HYDRODYNAMICS OF THE RUDDER AND MANOEUVRING PERFORMANCE

The hydrodynamic performance of the rudder is influenced by the type of rudder, the shape of the hydrodynamic profile, the aspect ratio, the rudder inflow velocity, the angle of the stall, the rudder ventilation or the cavitation phenomena [8]. Fig. 1 shows the rudder forces generated by the dynamic pressure distribution on the deflected rudder with an incident angle α, in free stream condition: the drag component P_x, the lift component P_y, the normal force P_n and the tangent component P_t [8]. v is the flow velocity. The hydrodynamic moment on the leading edge is calculated by the following relation:

$$M = P_n \cdot e \tag{1}$$

where e is the distance from the pressure centre to the leading edge. The hydrodynamic moment on the stock rudder is determined by the expression:

$$M_r = P_n \cdot (e - d_0) \tag{2}$$

where d_0 is the distance from the rudder stock to the leading edge.

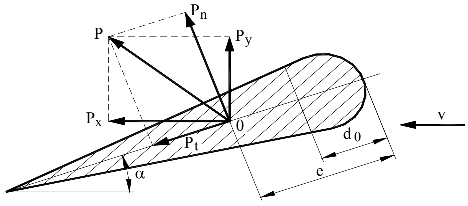

Fig.1. Rudder forces

The following hydrodynamic coefficients may be defined by means of the relations:

$$\begin{aligned}
C_y &= P_y / \left(0{,}5 \cdot \rho \cdot v_R^2 \cdot A_R\right) \\
C_x &= P_x / \left(0{,}5 \cdot \rho \cdot v_R^2 \cdot A_R\right) \\
C_m &= M / \left(0{,}5 \cdot \rho \cdot v_R^2 \cdot A_R \cdot \bar{c}\right) \\
C_{m_r} &= M_r / \left(0{,}5 \cdot \rho \cdot v_R^2 \cdot A_R \cdot \bar{c}\right) \\
C_n &= P_n / \left(0{,}5 \cdot \rho \cdot v_R^2 \cdot A_R\right) \\
C_t &= P_t / \left(0{,}5 \cdot \rho \cdot v_R^2 \cdot A_R\right)
\end{aligned} \tag{3}$$

where ρ is the water density, v_R is the rudder inflow velocity, A_R is the rudder area and c is the medium chord of the hydrodynamic profile.

Various rudder types have been designed (Fig. 2) depending on the rudder attachment mode (simplex, semi-spade or spade) and the rudder stock position (non-balanced, semi-balanced or balanced). The rudder profile shape influences the magnitude of the lift and drag forces. Greater profile thickness produces greater maximum lift at the stall angle, but it increases the drag force and the danger of cavitation.

The ventilation of the rudder along the suction side decreases the hydrodynamic performance. Also, the rudder cavitation will decrease the lift force due to the separation of the flow from the suction side.

On the basis of the hydrodynamic forces and the moments generated on the deflected rudder, the following issues may be solved in the initial design stage [7]:

- determination of the optimum position of the rudder stock;
- determination of the total torque (adding the frictional component to the hydrodynamic moment) and selection of the steering gear from a specific data catalogue;
- calculation of the rudder stock diameter based on the equivalent bending moment or equivalent torque;
- checking the rudder cavitation;
- estimation of the manoeuvring performance.

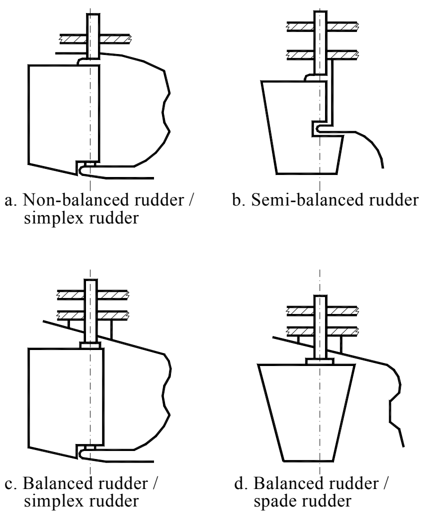

Fig.2. Main types of rudder

In order to compute the optimum position of the rudder stock and the total torque, a method proposed by Y.I. Voitkounski was used [11]. In principle, the hydrodynamic moment is calculated for ahead and astern ship running. The influence of the hull and propeller on the rudder hydrodynamics is taken into consideration, and the following characteristics are calculated, both for ahead and astern ship motions: the wake coefficient, the total flow deviation angle, the inflow velocity on the rudder, the hydrodynamic coefficients of the rudder in free stream [10], the optimal distance from the rudder stock to the leading edge, the hydrodynamic moment on the rudder stock, the frictional torque, and the total torque. The total torque in ahead ship running is compared to the astern motion, the maximum value being used to select the steering gear.

The checking of the rudder cavitation is performed by means of a theoretical method proposed by Brix [2], which may be applied in the domain $0.7\,D < h_0 < D$, where D is the propeller diameter and h_0 is the immersion of the rudder point used for the cavitation study. The influence on the rudder flow due to the wake and the propeller is estimated by computing the maximum axial velocity on the rudder, the inflow angle depending on the mean and local wake fraction, the maximum local lift coefficient and the extreme negative pressure. If the total pressure on the suction side is negative, then the side plating of the rudder is prone to cavitation. For a right turning propeller, cavitation will occur at starboard in the upper part of the rudder (relative to the propeller axis) and at portside in the lower part.

In order to estimate the manoeuvring performance in the initial design stage, the linear mathematical model proposed by Abkowitz [1] was used. The system of the differential equations of the ship motion in horizontal plane, in deep water conditions, may be written under this form

$$\begin{aligned}
&X_e + X_u u + X_{\dot{u}} \dot{u} = m\dot{u} \\
&Y_e + Y_v v + Y_r r + Y_{\dot{v}} \dot{v} + Y_{\dot{r}} \dot{r} = \\
&m(\dot{v} + rU + \dot{r} x_G) \\
&N_e + N_v v + N_r r + N_{\dot{v}} \dot{v} + N_{\dot{r}} \dot{r} = \\
&I_{zz} \dot{r} + m x_G (\dot{v} + rU).
\end{aligned} \tag{4}$$

where X_e and Y_e are the control longitudinal and lateral forces generated by the deflected rudder. N_e is the control yaw moment. The hydrodynamic derivatives X_u, $X_{\dot{u}}$, Y_v, Y_r, $Y_{\dot{v}}$, $Y_{\dot{r}}$, N_v, N_r, $N_{\dot{v}}, N_{\dot{r}}$ were estimated by means of the relations proposed by Clarke, Gedling and Hine [6]. The components of the speed in the origin of the coordinates system are $v_O(u,v,w)$, and the components of the angular speed are $\omega(p,q,r)$, w, p and q being neglected. U is the notation for the ship speed, m is the displacement and I_{zz} is the inertia moment of the ship around the vertical axis. The components of the acceleration in the origin of the coordinates system are $\dot{u}, \dot{v}$, and $\dot{r}$ is the angular acceleration in the horizontal plane.

By separating the equation of the longitudinal motion and solving the coupled equations for lateral and yaw motion, it is possible to obtain the steady turning radius R and the drift angle β, by means of the following relations

$$R = \frac{UC}{\delta\left(N_v Y_\delta - Y_v N_\delta\right)} \tag{5}$$

$$\beta = \frac{\delta}{UC}\left[\left(mx_G U - N_r\right)Y_\delta + \left(Y_r - mU\right)N_\delta\right] \tag{6}$$

where C is the parameter of stability on route, δ is the rudder deflection angle, and x_G is the longitudinal position of the centre of gravity.

Moreover, the relations proposed by Lyster and Knights [6] were used to estimate the steady turning diameter, the tactical diameter, the advance and transfer (Fig. 3), in order to determine the manoeuvring performance of the ship in the initial design stage, in deep water conditions.

Some particular aspects may be observed in the case of a ship operating in shallow water conditions (h/T=1.2 … 1.5, where h is the water depth and T is the mean draught of the ship). The squat is defined as the combined effect of sinkage and trim due to the forward speed of the ship in restricted water conditions. Close to the critical value of the Froude depth number $F_{nh} = 1$, the ship substantially changes the trim and sinkage. In order to check the squat in the initial design stage, several authors proposed practical methods to calculate mean, stern and bow sinkage ([2], [5]). The maximum values of the bow sinkage were estimated on the hydrodynamic platform PHP-Manoeuvrability using the relations of Brix, Barras and Millward. In this case, the power of the bowthruster and the minimum value of the submersion of the cylindrical tunnel may be estimated, using a practical method proposed by Brix [2], based on the design diagrams of the factor F and the tunnel submersion (to avoid air ventilation).

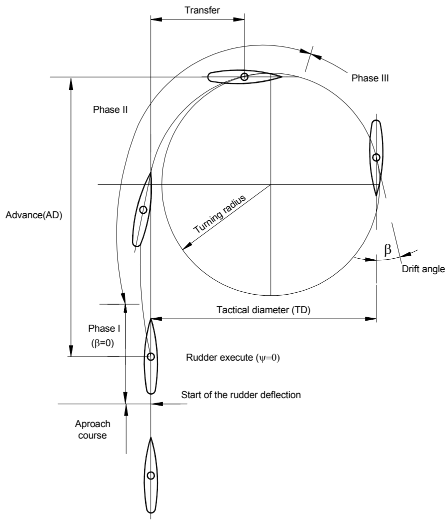

Fig.3. Turning circle characteristics

A short presentation of the software platform PHP-Manoeuvrability developed in the Research Centre of the Faculty of Naval Architecture, of "Dunarea de Jos" University of Galati, in order to estimate the rudder and bowthruster hydrodynamics and the ship manoeuvring abilities in the initial design stage, is shown in the following chapter.

3. PHP-MANOEUVRABILITY SOFTWARE PLATFORM

A preliminary hydrodynamic platform PHP-Manoeuvrability was developed in order to determine the optimum position of the rudder stock, to check the rudder cavitation, to estimate the ship manoeuvring performance in deep water conditions or the sinkage in shallow water, and to calculate the Bowthruster powering.

PHP-Manoeuvrability contains five distinct software modules (Fig. 4): PHP-Rudder Hydro, PHP-Rudder Cavitation, PHP-Manoeuvrability Performance, PHP-Squat, and PHP-Bowthruster.

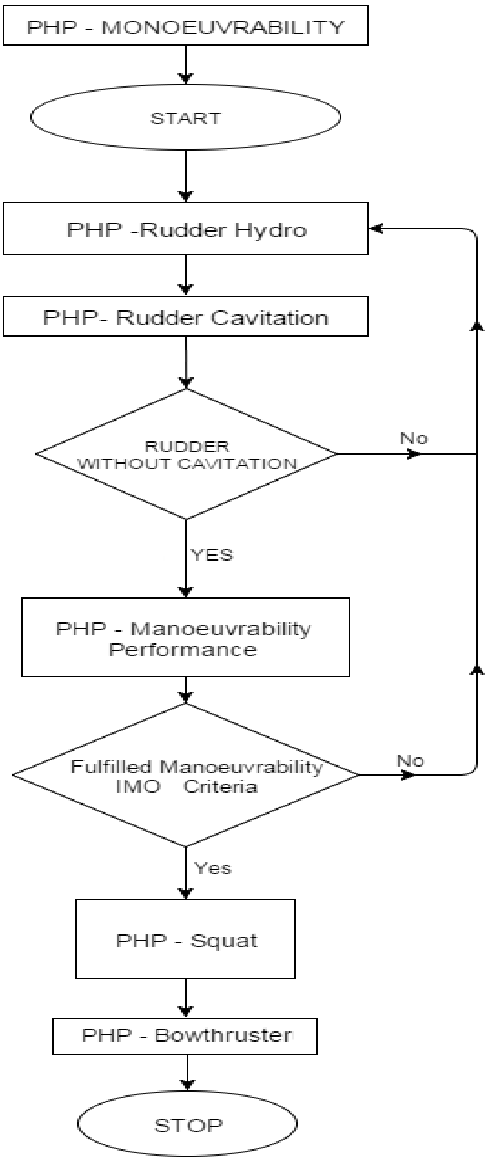

Fig.4. PHP-Manoeuvrability flow chart

The first module calculates the position of the rudder stock and provides the total torque by means of the Voitkounski method, in order to select the steering gear.

The second module applies the Brix method to check the rudder cavitation.

The third module is developed to compute the manoeuvring and course keeping abilities of the ship, based on both the linear hydrodynamic form of the Abkowitz manoeuvring model and the relations of Lyster and Knights.

In the case of shallow water applications, the module PHP-Squat may be used to compute the maximum values of the bow sinkage.

If a Bowthruster solution is used to increase the manoeuvring performance at low speed, then the final module will be performed to estimate the power of the Bowthruster and the tunnel submersion.

The software platform PHP-Manoeuvrability is currently used at the Faculty of Naval Architecture, both for didactical applications at the Ship Manoeuvring Numerical Laboratory [9] and research activities related to the ship manoeuvring performance in the initial design stage.

4. CONCLUDING REMARKS

"Towards the zero accident vessel" is one of the most important strategical directions of the European Research Association "Vessel for the Future", with a huge impact on safer maritime transport and decrease of sea pollution. Starting in the initial ship design stage, achieving the cost-effectiveness of the manoeuvring performance is an important objective.

In this context, a software platform dedicated to evaluating the manoeuvring and course keeping abilities was developed in the Research Centre of the Faculty of Naval Architecture of "Dunarea de Jos" University of Galati. The following problems may be solved on the basis of the PHP-Manoeuvrability software platform:

- determination of the optimum position of the rudder stock;

- estimation of the total torque on the rudder stock, in ahead and astern motions, and selection of the steering gear;
- checking the rudder cavitation;
- estimation of the ship manoeuvring and course keeping performance in deep water conditions;
- estimation of sinkage in shallow water conditions;
- estimation of the powering and selection of the Bowthruster type.

Using the PHP-Manoeuvrability, the students will develop their abilities and knowledge related to the rudder design process and the manoeuvring performance estimation, in the initial ship design stage.

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REFERENCES

[1]. **Abkowitz, M.A.**, *"Lectures on Ship Hydro-dynamics-Steering and Manoeuvrability"*, Report No. Hy-5, Hydro- and Aerodynamics Laboratory, Lyngby, 1964.

[2]. **Brix, J.**, *"Manoeuvring Technical Manual"*, Seehafen Verlag, Hamburg, 1993.

[3]. **Greaves, P.**, *"Vessel for the Future"*, European and International Technical and RDI Session, Sedef Shipyard, Istanbul, 2015.

[4]. **IMO**, *"Resolution MSC 137 (76)"*, 2002.

[5]. **ITTC**, *"The Manoeuvring Committee"*, Proceedings of 23rd ITTC, Vol. 1, 2002.

[6]. **Lewis, E.V**, *"Principle of Naval Architecture"*, Second Revision, Vol. III (Motions in Waves and Controlability), SNAME, 1989.

[7]. **Molland, A.F., Wellicome, J.F., Couser, P.R.**, *"Resistance experiments on a systematic series of high speed displacement catamaran forms: variation of length-displacement ratio and breadth-draft ratio"*, Ship Science Report, No. 71, University of Southampton, UK, 1994..

[8]. **Obreja, C.D., Crudu, L., Pacuraru, S.**, *"Ship Manoeuvrability"*, Galati University Press, 2008 (in Romanian).

[9]. **Obreja, C.D., Crudu, L., Pacuraru, S.**, *"Ship Manoeuvrability. Numerical Laboratory"*, The University Foundation "Dunarea de Jos" Publishing House, Galati, 2015 (in Romanian).

[10]. **Obreja, C.D., Jagite, G., Marcu, O.**, *"Analysis of the NACA Hydrodynamic Coefficients in Free Stream"*, The Annals of "Dunarea de Jos" University of Galati, Galati University Press, pp. 53-62, 2012.

[11]. **Voitkounski, Y.I**, *"Spravocinic po teoria korablea"*, Sudostroenie, Sankt Petersburg, 1998 (in Russian).

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