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SMALL SHIPS MANOEUVRING ESTIMATION IN DISPLACEMENT DOMAIN

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ABSTRACT

The manoeuvring performance estimation of the small ships is an important issue starting with the preliminary design stage. In this paper, a synthetic description of the mathematical model proposed by Mordvinov is presented, in order to calculate the turning circle characteristics of the small ships in displacement domain. On the basis of this model, a computer code was developed in the Research Centre of the Naval Architecture Faculty from “Dunarea de Jos” University of Galati and was integrated in the PHP (Preliminary Hydrodynamics Performance) software platform. A practical demonstration is performed, by using a small ship with about 15 m in length. This computer code is used for didactical applications at the Naval Architecture Faculty.

Keywords: small ships, displacement domain, turning circle characteristics, computer code

1. INTRODUCTION

The initial ship design stage is very important in order to obtain the desired hydrodynamics performances, including the manoeuvring characteristics ([4], [5]).

Different mathematical models can be applied [2] to estimate the manoeuvring characteristics of the typical merchant ships.

A complex software platform was developed in the Research Centre of the Naval Architecture Faculty in “Dunarea de Jos” University of Galati ([7], [8]) in order to compute the manoeuvring performances of the merchant ships, based on the Abkowitz model [1].

The manoeuvring performance estimation of the small ships is also an important issue, starting with the preliminary design stage.

Typical mathematical models were developed in order to describe the small ship trajectory during the turning circle manoeuvres. This paper presented the theoretical model proposed by Mordvinov [3] for the case of a small ship in the displacement domain.

A computer code based on this method was developed and integrated in the PHP (Preliminary Hydrodynamics Performance) software platform [6].

A practical application was performed to estimate the steady turning diameter of a small ship in displacement domain, having about 15 m in length.

A synthetical description of the Mordvinov method is presented in the next chapter.

2. THEORETICAL METHOD

The manoeuvring performance of a small ship is influenced by the main dimensions, fineness coefficients, propeller characteristics and rudder geometry.

In order to estimate the turning circle characteristics, the Mordvinov method is based on the hydrodynamics characteristics of the hull and of the rudder.

The hydrodynamics derivatives of the hull can be estimated by using the following relations [3]

$$C_Y^{\beta} = \pi \cdot \frac{T}{L} \cdot \left(\frac{0{,}65}{C_P}\right)^{5/2} \cdot \left(\frac{L}{6 \cdot B}\right)^{1/3} + \sigma_D - 0{,}96 \quad (1)$$

$$C_Y^{\omega} = 2 \cdot \frac{B}{L} \cdot \frac{C_B}{\sigma_D} \quad (2)$$

$$C_m^{\beta} = 1{,}8 \cdot \frac{T}{L} + 0{,}06 \cdot (0{,}7 - C_P) + (0{,}97 - \sigma_D) \quad (3)$$

$$C_m^{\omega} = \sigma_D^4 \cdot (0{,}05 + 0{,}58 \cdot T / L) \quad (4)$$

$$C_2 = 0{,}72 \cdot \left(\frac{3T}{B}\right)^{1/2} \cdot \left(\frac{0{,}73}{C_P}\right)^{3/2} + 1{,}25 \cdot (\sigma_D - 0{,}95) \quad (5)$$

where L is the ship length, B is the breadth, T is medium draught, C_P is prismatic coefficient, C_B is block coefficient and σ_D is the fineness coefficient of wetted lateral surface aria.

For the case of an open water rudder, the derivative of the lateral force coefficient due to the rudder deflection angle may be determined by using the relation [3]

$$C_{Y_R}^{a} = K_0 \cdot 2\pi / (1 + 2/\lambda) \quad (6)$$

where K_0 depends of the rudder type (suspended or semi-suspended) and λ is the geometric aspect ratio.

For the real case of a rudder placed behind the propeller jet, the derivative of the lateral force coefficient becomes

$$C_{Y_{Rp}}^{a} = C_{Y_R}^{a} \cdot (1 - K_i) \quad (7)$$

where K_i is an induction coefficient due to the propeller action.

The hydrodynamics coefficients of the turning circle manoeuvre can be determined by using the expressions [3]

$$q = q_{21} \cdot r_{31} - q_{31} \cdot r_{21} \quad (8)$$

$$s = r_{21} \cdot s_{31} - r_{31} \cdot s_{21} \quad (9)$$

The coefficients q_{21}, r_{21}, s_{21}, q_{31}, r_{31}, s_{31} can be calculated on the basis of the following expressions

$$q_{21} = C_{YRp}^{a} \cdot k_E \cdot \overline{v}_{cp}^2 \cdot A_R \cdot n_R / F_D + C_Y^{\beta} \quad (10)$$

$$r_{21} = C_{YRp}^{a} \cdot k_E \cdot \overline{\ell}_R \cdot \overline{v}_{cp}^2 \cdot A_R \cdot n_R / F_D - C_Y^{\omega} \quad (11)$$

$$s_{21} = -C_{YRp}^{a} \cdot \overline{v}_{cp}^2 \cdot A_R \cdot n_R / F_D \quad (12)$$

$$q_{31} = C_{YRp}^{a} \cdot k_E \cdot \overline{\ell}_R \cdot \overline{v}_{cp}^2 \cdot A_R \cdot n_R / F_D - C_m^{\beta} \quad (13)$$

$$r_{31} = C_{YRp}^{a} \cdot k_E \cdot \overline{\ell}_R^2 \cdot \overline{v}_{cp}^2 \cdot A_R \cdot n_R / F_D + C_m^{\omega} \quad (14)$$

$$s_{31} = -C_{YRp}^{a} \cdot \overline{\ell}_R \cdot \overline{v}_{cp}^2 \cdot A_R \cdot n_R / F_D \quad (15)$$

where k_E is a coefficient of the hull-propeller influences, $\overline{v}_{cp}$ is the medium speed of the flow on the rudder, under nondimensional form, obtained by using the ship speed v. Also, A_R is the rudder area, n_R is number of the rudders, F_D is wetted lateral surface area and $\overline{\ell}_R$ is the nondimensional value of the turning moment arm, obtained by using the ship length.

The main characteristics of the turning circle manoeuvre of a small ship in displacement domain can be calculated on the basis of the following relations [3]:

- Drift angle measured in radians, depending by the rudder deflection angle δ_R

$$\beta_g = -q + \left(q^2 + 4 \cdot C_2 \cdot r_{31} \cdot s \cdot \delta_R\right)^{1/2} / (2 \cdot C_2 \cdot r_{31}) \quad (16)$$

- Nondimensional angular speed

$$\overline{\omega} = -(s_{31} \cdot \delta_R + q_{31} \cdot \beta_g) / r_{31} \quad (17)$$

- Nondimensional steady turning diameter

$$\overline{D} = 2 / \overline{\omega} \quad (18)$$

- Ship speed measured in [m/s], during the steady turning motion, depending by the steady turning radius $\overline{R}$

$$v_g = v \cdot \overline{R}^2 / (\overline{R}^2 + 1{,}9) \quad (19)$$

- Maximum heeling angle during the turning circle manoeuvre, measured in degrees

$$\phi_{\max} = 1{,}4 \cdot v^{2} \cdot \left(z_g - \frac{T}{2}\right) / (h \cdot L) \quad (20)$$

where h is the initial metacentre height and z_g is the vertical centre of gravity.

Also, the lateral force developed due to the deflected rudder may be computed by using the relation

$$Y_0 = C_{YRp}^{a} \cdot \frac{\rho \cdot v_{cp}^2}{2} \cdot A_R \cdot \alpha \quad (21)$$

where ρ is the water density.

The attack angle α is obtained by using the relation

$$\alpha = \delta_R - k_E \cdot \left(\beta_g + \bar{\ell}_R \cdot \overline{\varpi}\right) \tag{22}$$

On the basis of the mathematical model proposed by Mordvinov, a new computer code was developed in the Research Centre of the Naval Architecture Faculty in "Dunarea de Jos" University of Galati (PHP NM-MAN-D [6]).

The computer code was integrated in the PHP (Preliminary Hydrodynamics Performance) software platform. A practical application is described in the next chapter.

3. PRACTICAL EVALUATION

The new computer code can be used in order to determine the main characteristics of the turning circle manoeuvre of a small ship in displacement domain.

A practical evaluation for a small ship with about 15 m in length is presented in this chapter.

The input data module comprises: the main dimensions of the ship (L, B, T), fineness coefficients (C_B, C_P), ship speed, the coordinates of the centre of gravity (x_G, z_G), initial metacentre height, propeller thrust, propeller diameter and the wake fraction (Table 1).

Table 1. Main dimensions of the small ship

Main characteristics	Value
Length, L [m]	15.1
Breadth, B [m]	3.14
Medium draught, T [m]	0.78
Design speed, v [Km/h]	20
Block coefficient, C_B	0.65
Prismatic coefficient, C_P	0.72
Longitudinal center of gravity from midship section, x_G [m]	0
Vertical center of gravity, z_G [m]	1.15
Initial transverse metacentric height, h [m]	0.5
Propeller diameter, D_P [m]	0.6
Propeller thrust, T_p [kN]	6.5
Wake fraction, w	0.14

Also, the input data module contains the rudder characteristics: type of the rudder (suspended or semi-suspended rudder), rudder profile (NACA 0012, 0015, 0018 or 0021), aspect ratio of the rudder, rudder area, rudder area situated in the propeller jet, the height of the rudder, the turning moment arm, number of the rudders and the distance between the propeller shaft and the lower plan of the rudder (Table 2).

Table 2. Rudder characteristics

Main characteristics of the rudder	Value
Geometric aspect ratio, λ	1.5
Rudder area, A_R [m^2]	0.216
Rudder area situated in the propeller jet, A_{RDp} [m^2]	0.172
Height of the rudder, b_R [m]	0.38
Turning moment arm, l_R [m]	7.24
Number of the rudders, n_R	1
Distance between the propeller shaft and the lower plan of the rudder, a_1 [m]	0.18

The output data are presented in Table 3. Figures 1 … 4 depict the diagrams of the drift angle, angular speed, steady turning diameter and final ship speed, depending by the rudder deflection angle.

Table 3. Turning circle results

Rudder angle δ_R [degs.]	Drift angle β_g [degs.]	Angular speed $\overline{\varpi}$	Steady turning diameter $\overline{D}$	Ship speed v_g [m/s]
0	0.1	0	1516.5	5.6
5	8.5	0.138	14.5	5.4
10	12.0	0.216	9.3	5.1
15	14.7	0.283	7.1	4.8
20	17.0	0.345	5.8	4.5
25	19.0	0.404	4.9	4.2
30	20.8	0.461	4.3	4.0
35	22.5	0.516	3.9	3.7
40	24.0	0.569	3.5	3.4

The growth of the rudder deflection angle determines the drift angle and angular speed increase. Also, the steady turning diameter and final ship speed decrease, when the rudder deflection angle increases.

The maximum heeling angle during the turning circle manoeuvre was estimated by using the relation (20). A relative small value was determined

$$\phi_{\max} = 4.4\,[\text{degs.}] \tag{23}$$

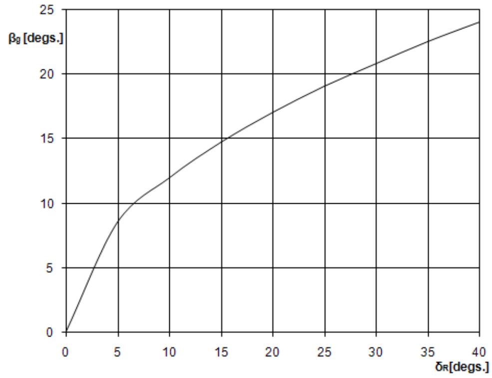

Fig.1. Drift angle

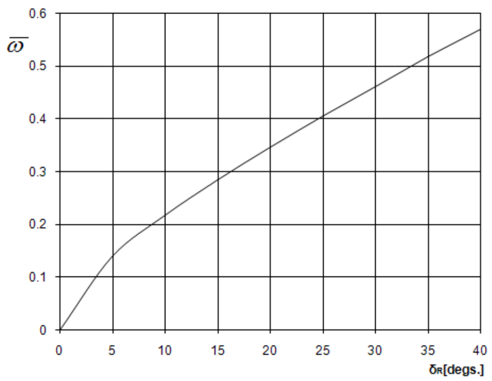

Fig.2. Nondimensional angular speed

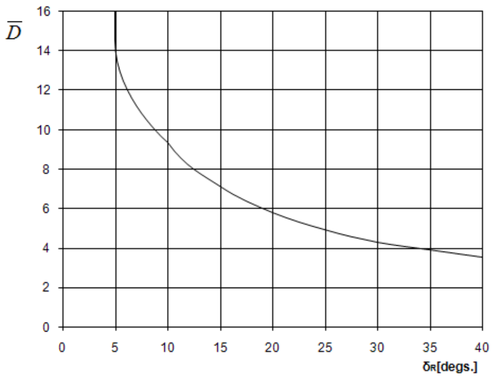

Fig.3. Nondimensional steady turning diameter

The computer code can be used to study the influence of the input data on the turning circle characteristics.

For example, in the mentioned application, the rudder area placed in the propeller jet represents about 80% from the total rudder area. If the total rudder area will be placed in the propeller jet, the steady turning diameter decreases with about 7.7% in the case of rudder deflection angle δ_R=35 degs.

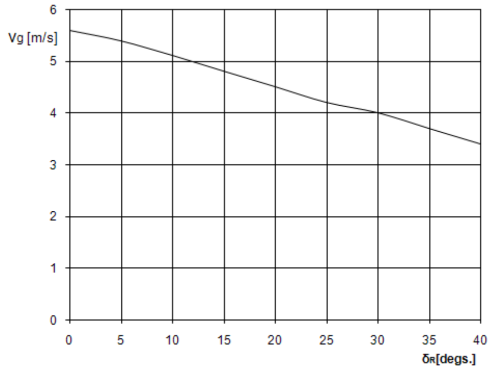

Fig.4. Final ship speed in turning circle manoeuvre

Fig. 5 depicts the comparative evolution of the steady turning diameter, when the rudder area placed in the propeller jet represents 80% (curve I) and 100% (curve II) from the total rudder area. If the rudder area placed in the propeller jet increases, the steady turning diameter decreases.

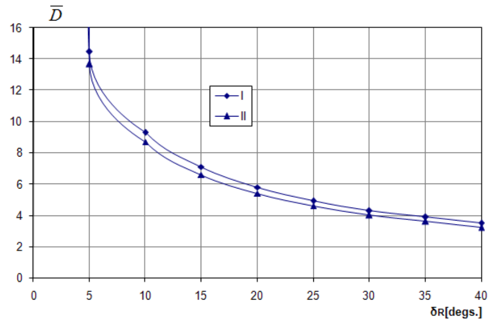

Fig.5. Nondimensional steady turning diameter
(I: A_{RDp}= 80% A_R; II: A_{RDp}=100% A_R)

In order to determine the ship speed influence on the steady turning diameter, a decrease value of the initial ship speed was considered (v=18 Km/h).

Fig. 6 depicts the comparative values of the steady turning diameter, for the initial ship speed v=20 Km/h (curve I) and for the case with initial ship speed v=18 Km/h (curve II). In the second case, the steady turning diameter decreases.

If the rudder deflection angle is δ_R=35 degs., the decrease of steady turning diameter is about 15.4% for the case of initial ship speed v=18 Km/h.

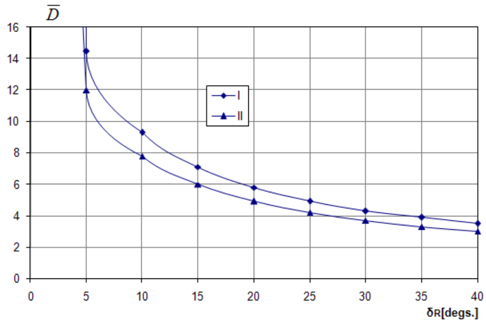

Fig.6. Nondimensional steady turning diameter (I: v=20 Km/h; II: v=18 Km/h)

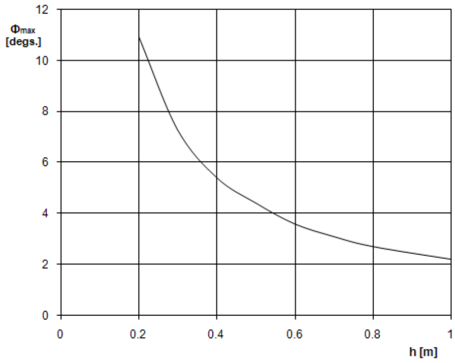

Fig.7. Maximum heeling angle

Also, the influence of the initial transverse metacentre height on the maximum heeling angle can be studied by using this computer code.

If the initial transverse metacentre height increases, then the maximum heeling angle decreases (Fig. 7).

This computer code is used for didactical applications at the Naval Architecture Faculty at "Dunarea de Jos" University of Galati [6].

The students have the possibility to increase your knowledges refer to the manoeuvrability performances of the small ships, in initial ship design stage.

4. CONCLUDING REMARKS

Starting with the preliminary ship design stage, the manoeuvring performance estimation of the small ships is an important issue.

The theoretical model proposed by Mordvinov was used in this paper in order to develop a new computer code, to describe the trajectories of the small ships in displacement domain, during the turning circle manoeuvres.

The following main characteristics of the turning circle manoeuvre can be estimated: steady turning diameter, drift angle, angular speed, maximum heeling angle and final ship speed.

In this paper, a practical application was performed on the basis of a small ship with about 15 m in length.

It has been shown that the steady turning diameter and final ship speed decrease, when the rudder deflection angle increases.

The computer code can be used in order to study the influence of the input data on the turning circle characteristics.

In this way, it was shown that the steady turning diameter decreases if the rudder area placed in the propeller jet increases, or if the initial ship speed decreases.

Also, the maximum heeling angle decreases, if the initial transverse metacentre height increases.

This computer code was integrated in a complex PHP (Preliminary Hydrodynamics Performance) software platform, developed in the Research Centre of the Naval Architecture Faculty from "Dunarea de Jos" University of Galati.

The software platform is in current use for didactical applications.

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