Development of a Computer Program for Ship Maneuverability

H. Zeraatgar[§]; E. Davoodi[*]

ABSTRACT

The main purpose of this paper is developing a computer program for prediction of ship maneuverability in deep water in early stage of ship design. The authors have chosen Kijima's model for prediction of ship maneuverability together with some approximate formula for estimating hydrodynamics forces acting on hull, propeller, and rudder in deep water. A computer program has been developed where the results of program show satisfactory agreement with the model tests result. The conclusion is that the calculation method of the present study is very useful and powerful for prediction of ship maneuverability at the initial design stage, when the principle particulars of ship hull, propeller, and rudder are known.

KEYWORDS

maneuvering, course keeping, turning, crash stopping, zigzag test.

1. INTRODUCTION

According to the reports, on marine disaster, there are considerable examples of the casualties such as collision and ramming caused by directly and indirectly inadequate ship maneuverability. The possibility to decrease marine disaster can be expected if the inherent maneuvering motion performance of a ship is improved. There are three methods for predicting ship maneuverability: method based on database of the past record. method based on model test, and method based on mathematical model. The last method is very useful for practical design at the initial stage of design [4].

The simplest mathematical description of ship's maneuverability was originally presented by Nomoto (1975) and consists of a single differential equation. Davidson and Schiff (1946) described the drifting and turning performance by two degrees of freedom. The next extension consists of the influence of the ship's forward speed on the transverse force. These three degrees of freedom system appear to be quite effective to describe the maneuvering performance of a large category of ships (see e.g., Norrbin (1971) and Inoue (1981)) [3].

Despite publication of several mathematical models of maneuvering, none of them presents all hydrodynamic coefficients comprehensively and correctly. In this study, the authors have gathered all required hydrodynamic coefficients among several references, checked and corrected some of them. The Kijima method has been modified and programmed. Having access to model test data [8], the results have been validated by comparing with the test results.

The study in this paper consists of three parts. At first, the Kijima's mathematical model of ship maneuvering motion is developed employing the coupled equations of surge; sway and yaw then computations are made for typical ships. Finally, the computed results are compared with the results of the model test. The maneuvering motion treated in this report is in calm and deep-water conditions.

2. EQUATION OF MANEUVERING MOTION

The ship maneuvering motion has generally been treated as the coupled motions in the horizontal plane, namely, the coupled motions of surge, sway and yaw and the other types of motion are neglected.

A. Main Equation

A set of coordinate axes with origin fixed at the center of gravity of ship (denoted with G herein after), as shown in Figure 1 and 2, is used to describe the ship maneuvering motion. The longitudinal and transverse axes are represented by the x and y axes respectively, and the z axis is chosen so as to be perpendicular to the x-y plan (downward positive). By reference to above coordinate system, the three equation of motion in the standard form are as follows [9]:

$$\begin{cases} m(\dot{u} - vr) = X_H + X_P + X_R \\ m(\dot{v} + ur) = Y_H + Y_R \\ I_{zz}\dot{r} = N_H + N_R \end{cases} \qquad (1)$$

where the terms with subscript H represent the hydrodynamics forces and moments acting on naked

---

[§] Assistant Professor. Amir Kabir University of Technology. hamidz@cic.aku.ac.ir

[*] M.Sc. in Naval Architecture. Amir Kabir University of Technology

ship's hull, terms with subscript R represent forces and moments acting on rudder and terms with subscript P represent propeller thrust.

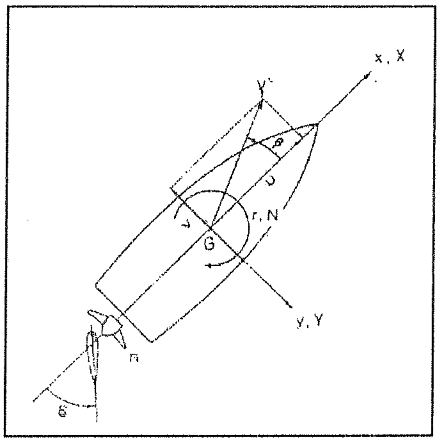

Figure 1: Coordinate Systems

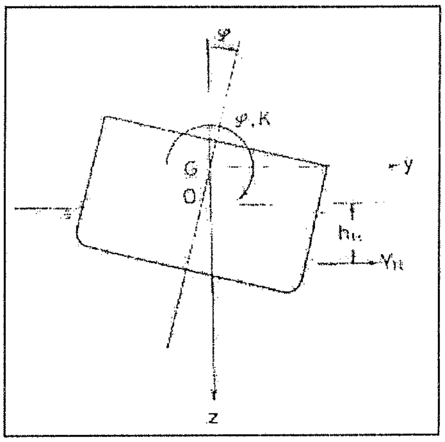

Figure 2: Coordinate Systems

B. Longitudinal Force Acting on Ship Hull, Propeller Thrust and Propeller Torque

The longitudinal force acting on ship hull X_H can be written [8]:

$$X_H = -m_x\dot{u} + (m_y + X_{vr})vr + X(u) \qquad (2)$$

The added inertia terms in above equation namely m_x and m_y can be estimated by making use of the charts proposed by Prof. Motora. He estimated that the added mass would have values of ten percent of the ship's mass in the longitudinal direction and 100 percent of ship's mass moment of inertia in the transverse direction [9]. Rewriting the coefficient of the second term as $m_y + X_{vr} = c_m m_y$ then c_m may have approximate value of 0.50-0.75 [4].

The propeller thrust X_P and propeller torque Q_P can be written [9]:

$$\begin{cases} X_P = (1-t_{P0})\rho n^2 D^4 k_T(J_P) \\ Q_P = -2\pi J_{PP}\dot{n} - \rho n^2 D^5 k_Q(J_P) \end{cases} \qquad (3)$$

The thrust coefficient k_T and the torque coefficient k_Q can be computed with the propeller open water characteristic curves as function of the advance ratio, J_p.

C. Lateral Force and Yaw Moment Acting on Ship Hull

The lateral force and yaw moment acting on the hull are expressed as follows [5]:

$$\begin{cases} Y_H = -m_y\dot{v} - m_x ur + Y_{H0}(v,r) + Y_{H1}(v,r,\varphi) \\ N_H = -J_{zz}\dot{r} + N_{H0}(v,r) + N_{H1}(v,r,\varphi) \\ \qquad + [Y_{H0}(v,r) + Y_{H1}(v,r,\varphi)]x_s \end{cases} \qquad (4)$$

The terms $Y_{H0}(v,r)$ and $N_{H0}(v,r)$ in (4) represent the fundamental force and moment which play an important role in ship maneuvering motion. Based on Taylor's Expansions and modification according to physical behavior of vessel in maneuvering motion they are summarized briefly as follows:

$$\begin{cases} Y_{H0}(v,r) = \frac{1}{2}\rho L d V^2[Y'_v v' + Y'_r r' + Y'_{vv} v'|v'| \\ \qquad + Y'_{v|r|} v'|r'| + Y'_{r|r|} r'|r'|] \\ N_{H0}(v,r) = \frac{1}{2}\rho L^2 d V^2[N'_v v' + N'_r r' + N'_{vvr} v'^2 r \\ \qquad + N'_{vrr} v' r'^2 + N'_{rr} r'|r'|] \end{cases} \qquad (5)$$

The derivatives in (5) can be estimated by knowing the principle dimensions of ship hull, where the non-dimensional lateral force and moment are divided by linear term and non-linear term. Linear terms calculated using formula developed by Inue [9] as function of $k = 2d/L$ and they are as follows:

$$\begin{cases} Y'_\beta = \frac{1}{2}\pi k + \frac{1}{4}(C_B B/L) \\ Y'_r = \frac{1}{4}\pi k \\ N'_\beta = k \\ N'_r = 0.54k - k^2 \end{cases} \qquad (6)$$

The nonlinear term obtained by using the measured results as function of $(1-C_B)/(B/D)$ can be written as follows [9]:

$$\begin{cases} Y'_{\beta|\beta|} = 6.63[(1-C_B)d/B] - 0.1048 \\ Y'_{\beta|r|} = -2[(1-C_B)d/B] + 0.47 \\ Y'_{rr} = -0.54[(1-C_B)d/B] + 0.0021 \\ N'_{rr} = -6.98(\frac{C_B B}{L})^2 + 2.18(\frac{C_B B}{L}) - 0.1804 \\ N'_{\beta\beta r} = -17.455(\frac{C_B B}{L})^2 + 2.807(\frac{C_B B}{L}) - 0.184 \\ N'_{rr\beta} = -0.5(\frac{C_B d}{B})^2 + 0.074 \end{cases} \quad (7)$$

where:

$$Y'_v v' = Y'_\beta \beta$$

$$Y'_{vv} v'v' = Y'_{\beta\beta} \beta\beta$$

$$Y'_{vr} v'v' = Y'_{\beta_r} \beta r$$

$$N'_v v' = N'_\beta \beta$$

$$N'_{vvr} v'v'r = N'_{\beta\beta r} \beta\beta r$$

$$N'_{rrv} rrv' = N'_{rr\beta} rr\beta$$

The terms $Y_{H1}(v,r)$ and $N_{H1}(v,r)$ in (4) represent the added terms due to inclusion of the roll effect. Actually, these terms exist where the tight maneuvering happens. Then a significant roll motion take places which couples with the other maneuvering motions. In this study, tight maneuver is ignored, consequently, the coupled roll motion is negligible. The rudder force and propeller thrust formulas are based on Inue presented in [9].

3. COMPUTER PROGRAM DESCRIPTION

The calculation of maneuvering properties is still a very sensitive matter. The authors have developed a program according to Kijima's model that enables the investigation of maneuverability in a very early design stage. It provides a simulation of the displacement ship's maneuverability including turning ability, ZigZag test in calm water with three degrees of freedom and verifies ship's compliance with the IMO maneuvering standards. The main body of Program is to solve three coupled differential equations as presented by (1). The hydrodynamic coefficients are calculated based on (6) and (7). The propeller force is calculated on the basis of (3). The rudder forces and moments are calculated based on [3].

A. Input Data

The input data consists of three parts where part one is ship main particulars such as ship length, breadth, draught, and block coefficient. Part two concerns ship rudder qualities such as rudder type, rudder profile, and steering gear characteristics. Part three concerns ship resistance and propeller performance such as resistance versus speed, *Kt*, *Kq* versus advance ratio and so on.

After that, user selects the type of maneuvering test and enters appropriate data. Then, the program is executed starting with a change in rudder angle. The forces and moments of right hand side of (1) starts to take some values. Then, the system of differential equations for surge, sway and yaw motions are solved in time domain.

B. Output Data

The output consists of ship yaw rate, sway rate and surge rate. The yaw angle, sway motion and surge motion versus space and state are also tabulated.

IMO standard requirements for maneuvering qualities of ship are discussed in [3]. The calculated maneuvering motions, yaw, sway and surge, are compared with the said requirements and the results are shown in output data.

4. VERIFICATION OF THE COMPUTER PROGRAM

The model test for recording maneuvering performance of a ship is the most accurate method for prediction of ship maneuverability during the design of a ship. Test conditions are very similar to the conditions of modeling. For the testing, geometric similarity, kinematical similarity, and consequently dynamic similarity between the model and the ship are imposed. The model was tested in a lake where the water surface was calm. The calm water was also the environment condition for the computer program calculations.

There is a lake called Slim in Poland which belongs to Technical University of Gdansk. This Lake is designed and equipped for maneuvering tests for ship models. Table 1 show the main particulars and form coefficient of different ship model being tested in RTCSM [8].

TABLE 1
DATA OF TESTED MODELS [8]

The Particular of the model		Model		
		Warta Tanker	Szczecin Bulk carrier	Gdynia Container
Length Overall	L(m)	12.205	8.542	8.313
Breath	B(m)	2.000	1.271	1.292
Draft	T(m)	0.639	0.504	0.396
Displacement	D(t)	12.178	4.518	2.532
Block Coefficient	C_B (-)	0.844	0.504	0.634
Speed	V(m/s)	1.620	1.574	2.202
RPM	N (Rev/Min)	598	671	661

Maneuvering tests of all models were performed at RTCSM on the lake Silm and maneuvering characteristics consisting of:

- Turning circle, 35 ^{0} rudder
- Zig Zag maneuver, 10/10 rudder

The computed and the measured results of turning motion with 35 ^{0} rudder (the starboard turning) for Szczecin and Warta models are shown in Figure 3 and 4. The results are also shown in Table 2. Based on comparison made in Table 2, Figure 3 and 4 the results are quite satisfactory. The maximum difference is 14% in prediction of Szczecin model advance.

A comparison made also for ZigZag maneuver between calculation and model tests. Table 3, Figure 5 and 6 are presenting ZigZag maneuver of 10/10 for Szczecin and Gdynia. Generally, two types of models show very good results in comparison between computer program and model tests. The maximum different is 17%, which is not so bad in early stage of ship design.

If one assumes that the model test result is the accurate result then the maximum difference between model test and computer program is as low as 17%. The main source of this difference is the inaccuracy of hydrodynamic coefficients. The numerical method as well as the equation of motions could also cause the errors. There is some weak coupling between roll motions, propeller and main engine dynamic behavior with the maneuvering motions which are not included in this modeling. However, the maximum error of 17% for prediction of ship maneuverability at early stage of ship design is well within the practical range of accepted errors.

5. CONCLUSIONS

It is the purpose of present study to provide a program using the practical method. The computed results are compared with the results of model tests, and validity of the calculation method of the present study is examined. The computed results show satisfactory agreements with the results of model test for various kinds and types of ship. According to above agreements, the program is a powerful tool for prediction of ship maneuverability in initial design of a ship.

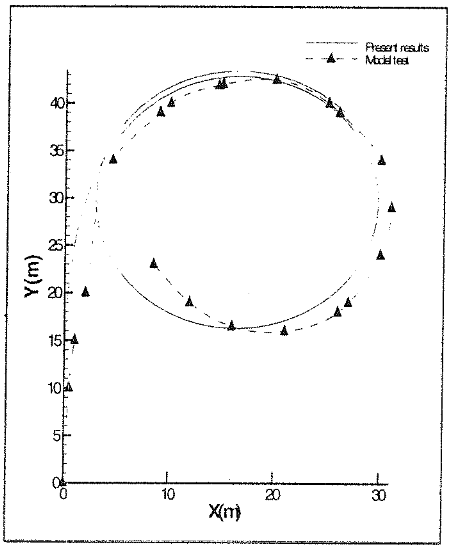

Figure 3: Szczecin model, Turning, Rudder 35SB

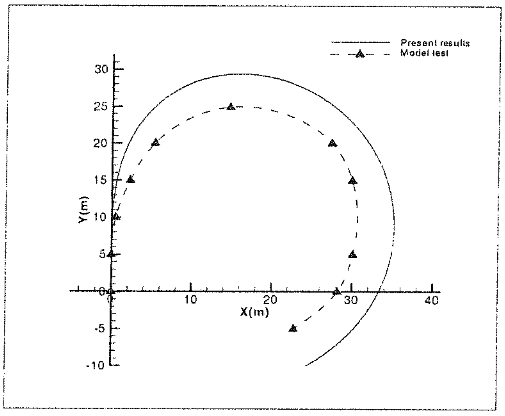

Figure 4: Warta model, Turning, Rudder 35SB

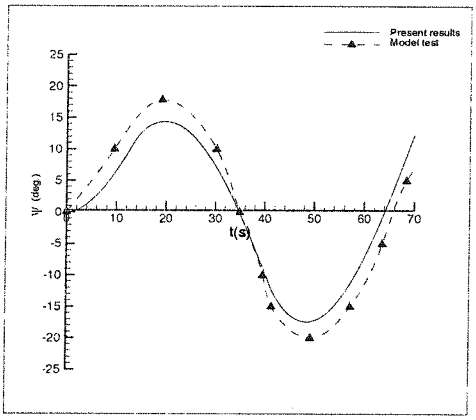

Figure 5: Szczecin model, ZigZag, Rudder 10SB

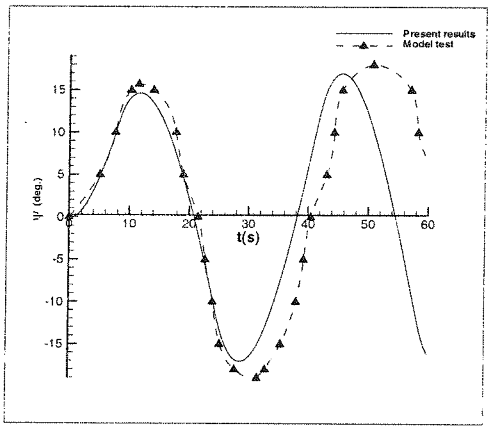

Figure 6: Gdynia model, ZigZag, Rudder 10SB

TABLE 2
PERCENTAGE OF DIFFERENCE BETWEEN MODEL TESTS AND CALCULATION OF TURNING MANEUVER

Model	Predicted Method	Rudder	Program Result (m)		Percentage of difference with model tests (%)	
			Tactical	Advance	Tactical	Advance
Szczecin	Kijima	35SB	35	29	+10.08	+13.7
Warta	Kijima	35SB	29	44	-6.26	+2.22

TABLE 3
PERCENTAGE OF DIFFERENCE BETWEEN MODEL TESTS AND CALCULATION OF ZIGZAG MANEUVER

Model	Predicted Method	Rudder	Program Result (degree)		Percentage of difference with model tests (%)	
			First Overshoot	Second Overshoot	First Overshoot	Second Overshoot
Szczecin	Kijima	10SB	14.90	-17.50	-15.79	-16.67
Gdynia	Kijima	10SB	14.80	-17.00	-10.52	-6.89

6. REFERENCE:

[1] V. K. Ankudinov, E. R. Miller, J. P. Alman and B. Jakobsen, "Ship Maneuverability Assessment in Ship Design-Simulation Concept", *MARSIM*, 1987.

[2] E. Davoodi, "Modification of a Mathematical Model and Development of a Computer Program for Ship Meneuverability", M.Sc. Thesis, Faculty of Marine Technology, Amir Kabir University of Technology, June 2002.

[3] J. P. Hooft, and U. Nienhuis, "The Prediction of Ship's Maneuverability in The Design Stage", *SNAME Transaction*, Vol. 102, 1994.

[4] IMO; "A Proposal of the Maneuvering Standards", *The Panel PR.742 of The Shipbuilding Research Association of Japan*, 1988.

[5] S. Inoue, M. Hirano, K. Kijima, and F. Takashina, "A Practical Calculation Method of Ship Maneuvering Motion", *International Shipbuilding Progress*, Vol. 28, No. 321, 1981.

[6] S. Inoue, M. Hirano, and K. Kijima, "Hydrodynamic Derivatives on Ship Maneuvering", *International Shipbuilding Progress*, Vol. 28, No. 321, 1981.

[7] ITTC; "Report of Maneuverability Committee", in *Proceedings of* 22^{nd} *International Towing Tank Conference*, 1999.

[8] K. Kobylinski, and G. Zolfaghari, "Prediction of Maneuvering Characteristics in Ship Design" *International Shipbuilding Progress*, 1997.

[9] E. V. Lewis, "Principle of Naval Architecture" *The Society of Naval Architectures and Marine Engineering*, Vol. III, 1989.

[10] M. Pourzanjani, H. Zienkiewics, and J. O. Flower, "A Hybrid Method of Estimating Hyrodynamically Generated Forces for Use in Maneuvering Simulation" *International Shipbuilding Progress*, Vol. 34, No. 399, 1987.