7. A Practical Calculation Method of Ship Maneuvering Motion at Initial Design Stage

Masayoshi HIRANO*, *Member*

(From J.S.N.A. Japan Vol. 147, June 1980)

Summary

This paper presents a practical calculation method to predict the ship maneuverability at the initial design stage. Supposing that principal particulars of ship hull, propeller and rudder are given at the stage of the ship initial design, an attempt is made to calculate the maneuvering motion utilizing these principal particulars as basic input data. The mathematical model which describes the ship maneuvering motion is based on the coupled equations of surge, sway, yaw, roll and propeller revolution. Computations are made for seven typical merchant ships covering various kinds and sizes of ships. In order to examine the validity of the calculation method of this paper for wide range of the maneuvering characteristics, comparisons of the computed results with the results of the full-scale trials are made for three kinds of typical characteristics, namely the turning motion with 35° rudder, the 10° - 10° Z-maneuver response and the steady turning performance. The computed results show satisfactory agreements with the full-scale trial results for various kinds and sizes of ships, and for wide range of the maneuvering characteristics. It can be concluded that the calculation method proposed in this paper is very useful and powerful for the predictions of the ship maneuverability at the initial design stage.

1. Introduction

Recent development of the maritime transportation has produced various types of ships, such as high-speed container carriers, roll-on/roll-off ships, pure car carriers and oil tankers from handy-sized product carriers to ULCCs. In relation to the problems of the maritime traffic safety, the diversification in ship kinds or the growth in ship sizes, mentioned above, has enhanced the significance of the maneuverability as one of the fundamental performances of ships. Namely it has become very important to predict precisely the ship maneuverability at the stage of the ship initial design. In addition, at the time of the ship completion, it has become necessary to provide the maneuvering informations for posting in the wheel house of ships, as is recommended by IMCO[1] and required by Panama Canal Regulations[2].

For these kinds of purposes, the simulation calculation technique of the maneuvering motion may be thought to be the most useful and powerful tool. Paying attention to this point, the author has been making extensive efforts to develop a practical calculation method to predict the ship maneuverability. In the previous papers[3),4)] Inoue and the author proposed estimate formulae of the hydrodynamic forces acting on ship hull which play an important part in the ship maneuvering motion, where the formulae were given as functions of the principal dimensions of ship hull. This paper presents a practical calculation method of the ship maneuvering motion using the principal particulars of ship hull, propeller and rudder, which are usually known at the initial design stage, as basic input data.

The study in this paper consists of two phases. At first the mathematical model of

* Akishima Laboratory, Mitsui Engineering and Shipbuilding Co., Ltd.

the ship maneuvering motion is developed employing the coupled equations of surge, sway, yaw, roll and propeller revolution. Then computations are made for seven typical merchant ships covering various kinds and sizes of ships. Comparing the computed results with the results of the full-scale trials, the validity of the calculation method of the present study is examined for wide range of the maneuvering characteristics. The maneuvering motion treated in this paper is that in calm and deep water condition, and the maneuvering motion with main engine operation such as the crash stop maneuver is not included here.

Nomenclature

A_R = rudder area
a_H = ratio of hydrodynamic force, induced on ship hull by rudder action, to rudder force
B = breadth of ship
C_B = block coefficient
C_P = propeller flow-rectification coefficient
C_S = ship hull flow-rectification coefficient
D = propeller diameter
d = draft of ship (mean draft)
F_N = rudder normal force
$GZ(\varphi)$ = restoring moment lever of roll
H = rudder height
h_H = vertical distance from still water surface to point on which lateral force Y_H acts (see Fig. 2)
I_{xx}, I_{zz} = moment of inertia of ship with respect to x and z-axes respectively
I_{PP} = moment of rotary inertia of propeller-shafting system
J_{xx}, J_{zz} = added moment of inertia of ship with respect to x and z-axes respectively
J_{PP} = added moment of rotary inertia of propeller
L = length of ship (between perpendiculars)
m = mass of ship
m_x, m_y = added mass of ship in x and y-axes direction respectively
$N(\dot{\varphi})$ = roll damping moment
n = number of propeller revolution
P = propeller pitch
r = turning rate
r' = dimensionless turning rate $(= rL/V)$
t_{P0} = thrust deduction coefficient in straight running condition
u = ship speed in x-axis direction
V = ship speed $(=(u^2+v^2)^{\frac{1}{2}})$
V_R = effective rudder inflow speed
v = ship speed in y-axis direction
v' = dimensionless ship speed in y-axis direction $(=v/V)$
W = displacement of ship
w_P = effective propeller wake fraction
w_{P0} = effective propeller wake fraction in straight running condition
w_R = effective rudder wake fraction
w_{R0} = effective rudder wake fraction in straight running condition
x_P = x-coordinate of propeller position
x'_P = dimensionless form of $x_P (= x_P/L)$
x_R = x-coordinate of point on which rudder force Y_R acts
x'_R = dimensionless form of $x_R (= x_R/L)$
$x_{\otimes}$ = x-coordinate of midship
z_H = z-coordinate of point on which lateral force Y_H acts
z_R = z-coordinate of point on which rudder force Y_R acts
α_R = effective rudder inflow angle
β = drift angle $(=-\sin^{-1} v')$
γ = flow-rectification coefficient
δ = rudder angle
δ_0 = rudder angle of zero rudder normal force
λ = aspect ratio of rudder
ρ = density of water
τ = trim quantity
φ = roll angle
ψ = heading angle

2. Mathematical Model

2.1 Equations of 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, assuming that the horizontal motions could be separated from other types of motions. In the derivation of the motion equations of the present study, the following considerations are paid to the equations of the horizontal motions.

(1) The coupling effect due to roll

Some ships such as high-speed container carriers and roll-on/roll-off ships perform considerable roll in their maneuvering motion. The recent study by the author[5] reveals that the maneuvering motion of ships with large roll mentioned above should be calculated taking the coupling effect due to roll into consideration.

(2) The coupling effect due to propeller revolution

In the maneuvering motion of full-scale ships the number of propeller revolution varies due to variation of both the propeller torque and the main engine torque even under the normal running condition of the main engine. This fact may suggest that the variation in the number of propeller revolution should be reflected in the calculation of the propeller thrust and the rudder forces. Namely it may be considered that the coupling effect due to propeller revolution on the horizontal motions can not be ignored.

A set of coordinate axes with origin fixed at the center of gravity of the ship (denoted with G hereinafter), as shown in Figs. 1 and 2, is used to describe the ship maneuvering motion. Longitudinal and transverse horizontal axes are represented by the x and y-axes respectively, and the z-axis is chosen so as to be perpendicular to the xy-plane (downward positive). By reference to this coordinate system G-xyz, the basic equations of the ship maneuvering motion can be written in the following form taking the coupling effects due to both roll and propeller revolution into consideration.

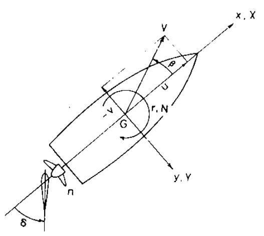

Fig.1 Coordinate system (1)

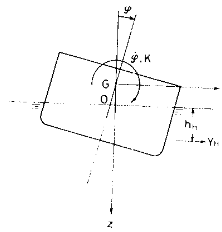

Fig. 2 Coordinate system (2)

$$
\begin{aligned}
&\text{Surge}: \quad m(\dot{u}-vr)=X_H+X_P+X_R\\
&\text{Sway}: \quad m(\dot{v}+ur)=Y_H+Y_R\\
&\text{Yaw}: \quad I_{zz}\dot{r}=N_H+N_R \qquad\qquad (1)\\
&\text{Roll}: \quad I_{xx}\ddot{\varphi}=K_H+K_R\\
&\text{Propeller revolution}: \quad 2\pi I_{pp}\dot{n}=Q_E+Q_P
\end{aligned}
$$

where the terms with subscript H represent the hydrodynamic forces produced by the motion of ship hull (without propeller and rudder) and acting on it, and the terms with subscript R represent the rudder forces including the hydrodynamic forces induced on ship hull by rudder action. The terms X_P, Q_P and Q_E in Eq. (1) represent the propeller thrust, the propeller torque and the main engine torque respecitively.

2.2 Longitudinal Force Acting on Ship Hull, Propeller Thrust and Propeller Torque

The longitudinal force acting on ship hull X_H can be written

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

The added inertia terms in Eqs. (2) and (6), namely m_x, m_y and J_{zz}, can be estimated by making use of the estimate charts proposed by Motora[6]. Rewriting the coefficient of the second term in Eq. (2) as $m_y+X_{vr}=C_m m_y$ then C_m may have approximate value of 0.50 - 0.75[7]. The estimation of the second term can be made by giving an appropriate value to C_m. The third term in Eq. (2) represents ship resistance as a function of u.

The propeller thrust X_P and the propeller torque Q_P can be written

$$X_p=(1-t_{P0})\cdot\rho n^2D^4K_T(J_P)$$
$$Q_P=-2\pi J_{pp}\dot{n}-\rho n^2D^5K_Q(J_P). \qquad (3)$$

The thrust coefficient $K_T(J_P)$ and the torque coefficient $K_Q(J_P)$ can be computed with the propeller characteristic curves as functions of the advance constant J_P, which is expressed as

$$J_P=u(1-w_P)/(nD). \qquad (4)$$

The effective propeller wake fraction w_P, which is defined with the concept of the propeller thrust identity, may generally vary in the maneuvering motion from that in the straight running condition. The following estimate formula is made based on some model experimental results [8),9),10)] shown in Fig. 3.

$$w_P=w_{P0}\exp(K_1\beta_P{}^2),\ K_1=-4.0 \qquad (5)$$

where the effect of the maneuvering motion on w_P is considered with the geometrical inflow angle at propeller position β_P, which is defined as $\beta_P=\beta-x'_Pr'$.

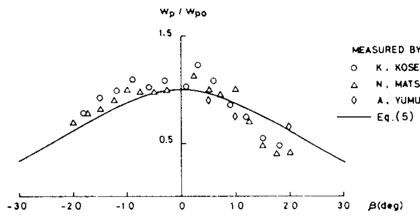

Fig. 3 Effect of drift angle on wake fraction

2.3 Lateral Force and Yaw Moment Acting on Ship Hull

The lateral force and the yaw moment acting on ship hull, namely Y_H and N_H, can be written in the following form.

$$Y_H=-m_y\dot{v}-m_xur+Y_{H0}(v,r)+Y_{H1}(v,r,\varphi)$$
$$N_H=-J_{zz}\dot{r}+N_{H0}(v,r)+N_{H1}(v,r,\varphi)$$
$$+[Y_{H0}(v,r)+Y_{H1}(v,r,\varphi)]x_{\otimes}. \qquad (6)$$

The terms $Y_{H0}(v,r)$ and $N_{H0}(v,r)$ in Eq. (6) represent the fundamental force and moment which play an important part in the ship maneuvering motion. Inoue and the author have developed the estimate formulae of $Y_{H0}(v,r)$ and $N_{H0}(v,r)$, and the results have already been reported in the previous papers[3),4)]. They are summarized briefly as follows. $Y_{H0}(v,r)$ and $N_{H0}(v,r)$ are expressed

$$Y_{H0}(v,r)=\tfrac{1}{2}\rho LdV^2[Y'_vv'+Y'_rr'+Y'_{v|v|}v'|v'|$$
$$+Y'_{v|r|}v'|r'|+Y'_{r|r|}r'|r'|]$$
$$N_{H0}(v,r)=\tfrac{1}{2}\rho L^2dV^2[N'_vv'+N'_rr'+N'_{vvr}v'^2r'$$
$$+N'_{vrr}v'r'^2+N'_{r|r|}r'|r'|]. \qquad (7)$$

The derivatives in Eq. (7) can be estimated by knowing the principal dimensions of ship hull, namely L, B, d, C_B and τ. The estimate formulae for the linear derivatives are given in the form

$$Y'_v=[a_1k+f(C_BB/L)](1+b_1\tau')$$
$$Y'_r=a_2k(1+b_2\tau')$$
$$N'_v=a_3k(1+b_3\tau') \qquad (8)$$
$$N'_r=(a_4k+a_5k^2)(1+b_4\tau')$$

where

$$k=2d/L,\ \tau'=\tau/d \qquad (9)$$

and a_1, a_2, ..., b_1, b_2, ... etc. are the constant. Estimate charts, as functions of the principal dimensions of ship hull, are given for the estimation of the nonlinear derivatives, where the effect of the trim is not considered.

The terms $Y_{H1}(v,r,\varphi)$ and $N_{H1}(v,r,\varphi)$ in Eq. (6) represent the added terms due to inclusion of the roll effect. According to the study by the author [5)], they can be written

$$Y_{H1}(v,r,\varphi)=0$$
$$N_{H1}(v,r,\varphi)=\tfrac{1}{2}\rho L^2dV^2[N'_\varphi\varphi+N'_{v|\varphi|}v'|\varphi|$$
$$+N'_{r|\varphi|}r'|\varphi|]. \qquad (10)$$

The derivatives in Eq. (10) can be

estimated by utilizing the results of the study cited above[5], namely

$$N'_{\varphi}=c_1$$
$$N'_{v|\varphi|}=c_2N'_v \qquad (11)$$
$$N'_{r|\varphi|}=c_3N'_r$$

where c_1, c_2 and c_3 are the constant.

2.4 Roll Moment Acting on Ship Hull

The roll moment acting on ship hull can be written

$$K_H=-J_{xx}\ddot{\varphi}-N(\dot{\varphi})-W\cdot GZ(\varphi)-Y_H\cdot z_H. \qquad (12)$$

The coupling effect due to the horizontal motions on the motion of roll is reflected in the form of $Y_H\cdot z_H$ in Eq. (12). As for the estimation of the vertical distance z_H (from G to the point on which Y_H acts), the estimate chart proposed by Inoue[11], where estimate curves of h_H $(=z_H-OG)$ shown in Fig. 2 are given as functions of C_B, can be utilized.

2.5 Rudder Forces and Moments

The rudder forces and moments including the hydrodynamic forces and moments induced on ship hull by rudder action, namely X_R, Y_R, N_R and K_R, can be written in the following form[12].

$$X_R=-F_N\sin\delta$$
$$Y_R=-(1+a_H)F_N\cos\delta$$
$$N_R=-(1+a_H)x_RF_N\cos\delta \qquad (13)$$
$$K_R=(1+a_H)z_RF_N\cos\delta\ .$$

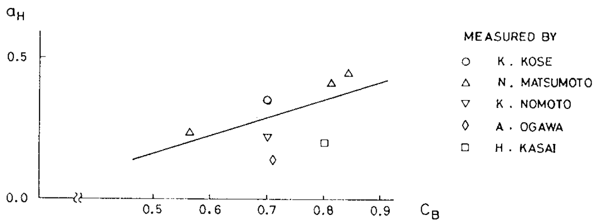

Fig. 4 Ratio of induced force on ship hull by rudder action to rudder force

In Eq. (13), the hydrodynamic force induced on ship hull by rudder action is described in the form of $a_HF_N\cos\delta$. The coefficient a_H can be estimated based on some model experimental results[8] shown in Fig. 4, which suggest that a_H may be expressed as a function of C_B. In the present study the line drawn in Fig. 4 is used to estimate the coefficient a_H. The rudder normal force F_N can be written in the form

$$F_N=\frac{1}{2}\rho\frac{6.13\lambda}{\lambda+2.25}A_RV_R^2\sin\alpha_R. \qquad (14)$$

The effective rudder inflow speed and angle, namely V_R and α_R in Eq. (14), are calculated as follows.

(1) The effective rudder inflow speed V_R

Introducing the effective rudder wake fraction w_R, which is defined with the concept of the rudder normal force identity, V_R can be expressed in the form[7]

$$V_R=V(1-w_R)[1+K_2\,g(s)]^{1/2} \qquad (15)$$

where K_2 = 1.065 for the port rudder and K_2=0.935 for the starboard rudder. The term $K_2g(s)$ in Eq. (15) represents the effect of the propeller slip-stream on V_R, and

$$g(s)=\eta\kappa\{2-(2-\kappa)s\}s/(1-s)^2 \qquad (16)$$

where

$$s=1-u(1-w_P)/(nP)$$
$$\eta=D/H \qquad (17)$$
$$\kappa=0.6(1-w_P)/(1-w_R)\ .$$

The estimation of the effective rudder wake fraction is made assuming that w_R in the maneuvering motion could be computed by

$$w_R/w_{R0}=w_P/w_{P0}=\exp(K_1\beta_p^2). \qquad (18)$$

The effective rudder wake fraction w_{R0} of full-scale ships may be obtained from the results of the model experiments in the same manner as for the effective propeller wake fraction w_{P0} in the area of the ship propulsion, namely making use of the technique to estimate the full-scale value from the model experimental results with the concept of the wake ratio. For the estimation of w_{R0}, some model experimental results on w_{R0}[7),13),14)] may be referred.

(2) The effective rudder inflow angle α_R

Taking the flow-rectifying effect into consideration, α_R can be expressed in the form

$$\alpha_R=\delta+\delta_0-\gamma\beta_R' \qquad (19)$$

where β_R' is defined as $\beta_R'=\beta-2x'_Rr'$. The flow-rectifying effect may be considered to be constituted by two kinds of factors. One is the flow-rectifying effect due to ship hull and the other is due to propeller, then the flow-rectification coefficient γ can be written[10)]

$$\gamma=C_P\cdot C_S. \qquad (20)$$

The propeller flow-rectification coefficient C_P is given in the form

$$C_P=1/[1+0.6\eta(2-1.4s)s/(1-s)^2]^{1/2}. \qquad (21)$$

The ship hull flow-rectification coefficient C_S is given in the following form based on some model experimental results[9),13)]

$$C_S=K_3\beta_R' \text{ for } \beta_R'\leqq C_{S0}/K_3$$
$$C_S=C_{S0} \text{ for } \beta_R'>C_{S0}/K_3 \qquad (22)$$

with K_3 = 0.45 and C_{S0} = 0.5.

2.6 Main Engine Torque

The types of the main engine treated here are the slow-speed diesel engine and the steam turbine, and the following torque characteristics are used.

(1) The slow-speed diesel engine

$$Q_E=|Q_P| \text{ for } |Q_P|\leqq Q_{EMAX}$$
$$Q_E=Q_{EMAX} \text{ for } |Q_P|>Q_{EMAX}. \qquad (23)$$

(2) The steam turbine.

$$Q_E=\mathrm{SHP}/(2\pi n). \qquad (24)$$

3. Numerical Results

3.1 Full-Scale Maneuvering Trials and Ship Selection

At the time of the ship completion, the full-scale sea trials for the maneuverability such as the turning test, Z-maneuver test etc. are conducted. In this paper three kinds of the maneuvering tests, i.e. the turning test with 35° rudder, the 10° - 10° Z-maneuver test and the spiral test, are taken for the comparison purpose of the computed results with the results of the full-scale trials. Namely in order to examine the validity of the calculation method of the present study for wide range of the maneuvering characteristics, computations are made for the turning motion with 35° rudder, the 10° - 10° Z-maneuver and the spiral maneuver.

The ships, of which the comparisons are made, are selected so as to satisfy the following requirements.

(1) The three kinds of the maneuvering tests mentioned above should have been conducted for each ship to be selected.

(2) The full-scale maneuvering trials of each ship to be selected should have been conducted in the environmental condition below the "Slight" sea and below 5.0 m/sec wind speed.

Thus the following seven ships covering the various kinds and sizes of the merchant ships, namely from a general cargo boat of 10,000-DWT class to a ULCC, are selected from ships built in Mitsui Engineering and Shipbuilding Co., Ltd. during the last ten years.

Ship A: High-speed container carrier
Ship B: General cargo boat
Ship C: Roll-on/roll-off ship

Ship D: Pure car carrier
Ship E: Bulk carrier (70,000-DWT)
Ship F: VLCC (270,000-DWT)
Ship G: ULCC (370,000-DWT)

The principal particulars of ship hull, propeller and rudder of these ships are given in Table 1. The steam turbine is mounted as the main engine on ship F and ship G, and the slow-speed diesel engine on the other five ships.

Table 1 Principal particulars of hull, rudder and propeller

SHIP	A	B	C	D	E	F		G
KIND OF SHIP	CONTAINER CARRIER	CARGO BOAT	RO/RO	PURE CAR CARRIER	BULK CARRIER	VLCC		ULCC
LOADING CONDITION	BALLAST	BALLAST	BALLAST	BALLAST	BALLAST	FULL	BALLAST	FULL
HULL								
L (m)	202.00	160.00	212.00	180.00	230.00	318.00		348.00
B (m)	31.20	23.50	32.26	32.00	32.20	56.00		63.40
d (m)	6.93	5.20	6.29	6.80	7.24	20.58	9.64	21.85
τ (m)	1.95	3.78	1.13	1.03	1.05	0.0	3.95	0.0
C_B	0.518	0.600	0.612	0.566	0.820	0.827	0.788	0.826
RUDDER								
A_R/Ld	1/48.1	1/37.7	1/50.6	1/34.8	1/47.9	1/58.6	1/34.5	1/53.5
λ	1.40	1.57	1.22	1.19	1.38	1.55	1.28	1.44
PROPELLER								
D (m)	7.10	5.70	6.60	6.20	6.70	8.90		9.60
P/D	1.04	1.14	0.97	0.95	0.71	0.71		0.71
Z	6	4	5	5	4	5		5

3.2 Numerical Results and Comparisons with Full-scale Trial Results

Computations based on the mathematical model described in the chapter 2 are made for the three kinds of the maneuvering motions mentioned before, and the computed results are compared with the results of the full-scale trials as follows.

(1) Turning motion with 35° rudder

The computed results of the turning motion with 35° rudder (the starboard turning) for all of the ships selected are shown with solid lines in the form of both the turning trajectory and the motion time-histories in Figs. 5-20, where the results of the full-scale trials are also shown with empty circles. It can be mentioned from these figures that the computed results, with respect to both the turning trajectory and the time-histories of the heading angle, the ship speed and the number of propeller revolution, show satisfactory agreements with the results of the full-scale trials for all of the ships.

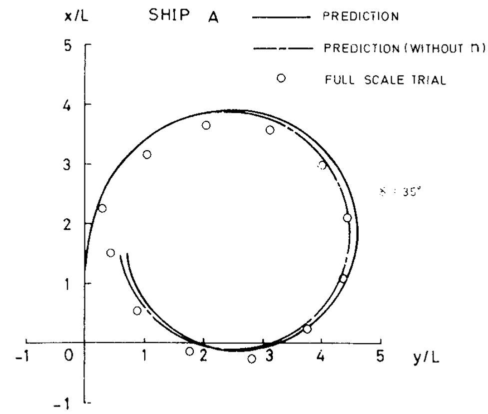

Fig. 5 Turning trajectory (SHIP A)

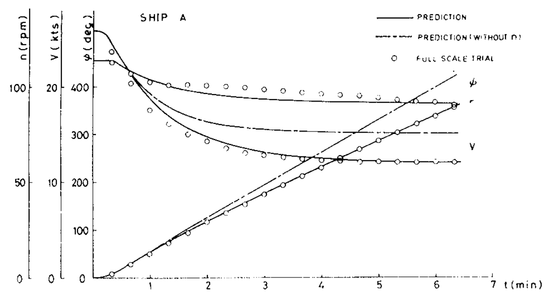

Fig. 6 Time histories of heading angle, ship speed and number of propeller revolution in turning motion (SHIP A)

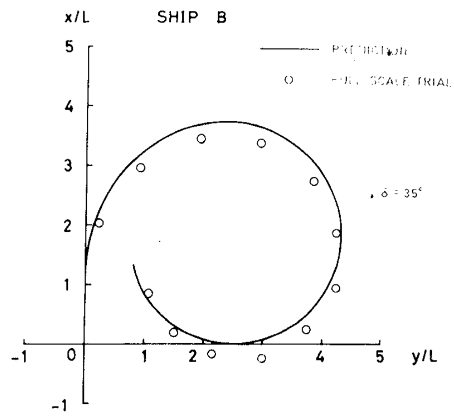

Fig. 7 Turning trajectory (SHIP B)

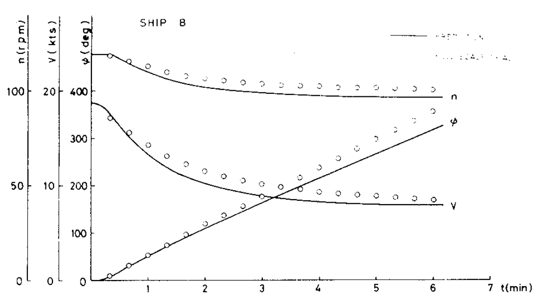

Fig. 8 Time histories of heading angle, ship speed and number of propeller revolution in turning motion (SHIP B)

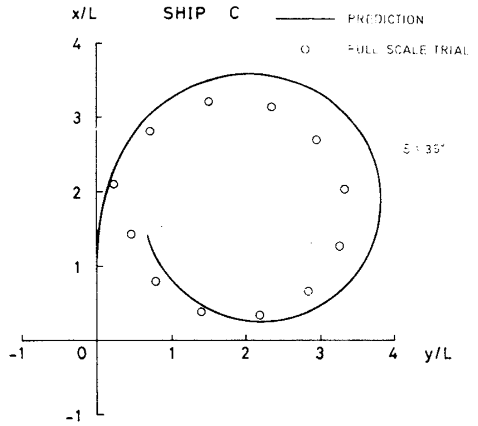

Fig. 9 Turning trajectory (SHIP C)

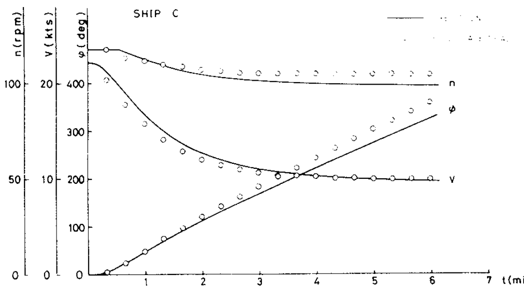

Fig. 10 Time histories of heading angle, ship speed and number of propeller revolution in turning motion (SHIP C)

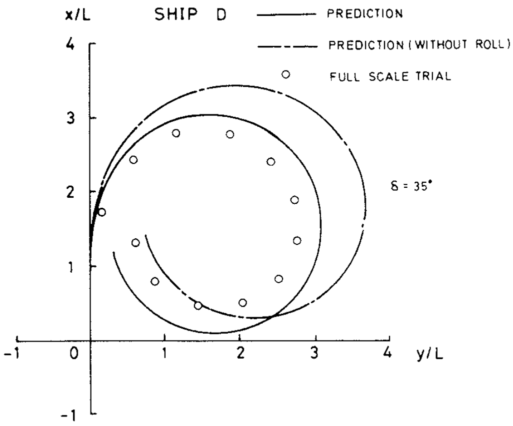

Fig. 11 Turning trajectory (SHIP D)

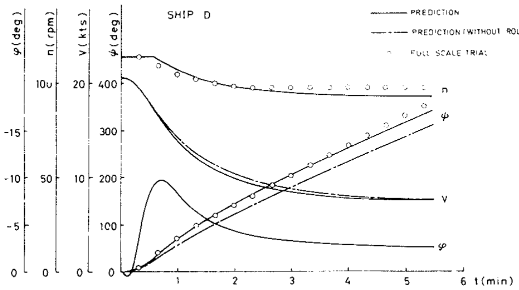

Fig. 12 Time histories of heading angle, ship speed, roll angle and number of propeller revolution in turning motion (SHIP D)

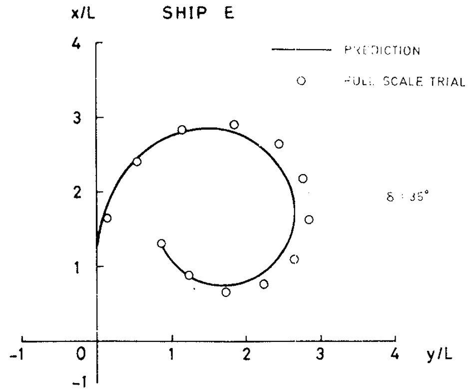

Fig. 13 Turning trajectory (SHIP E)

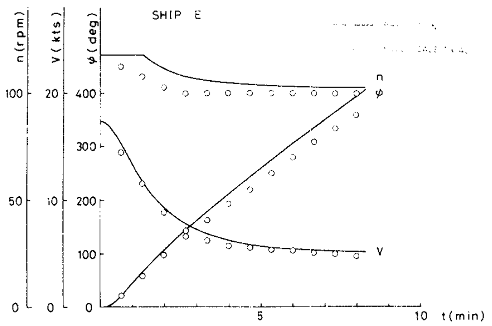

Fig. 14 Time histories of heading angle, ship speed and number of propeller revolution in turning motion (SHIP E)

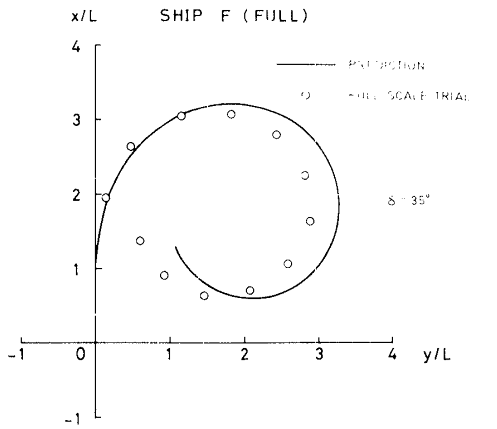

Fig. 15 Turning trajectory (SHIP F FULL)

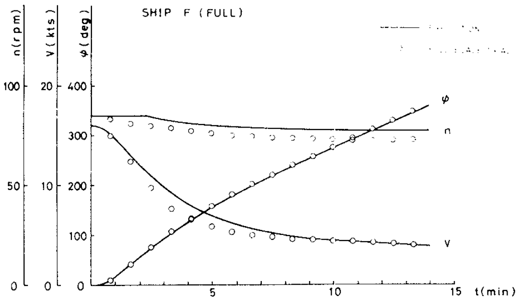

Fig. 16 Time histories of heading angle, ship speed and number of propeller revolution in turning motion (SHIP F FULL)

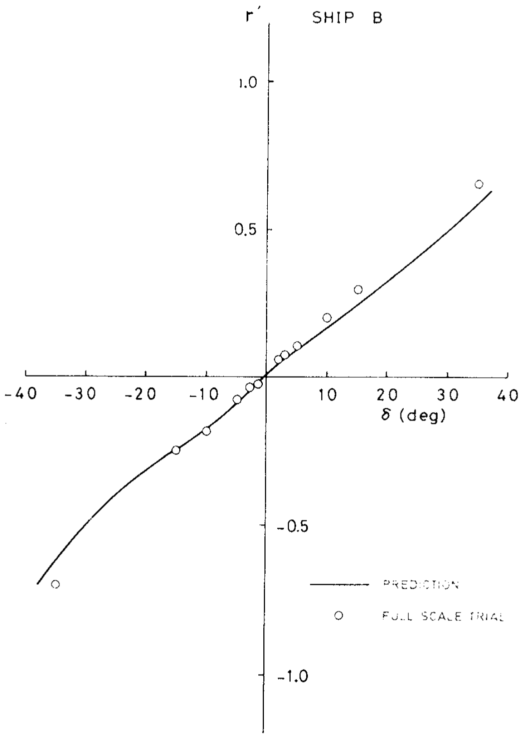

Fig. 27 Steady turning performance (SHIP B)

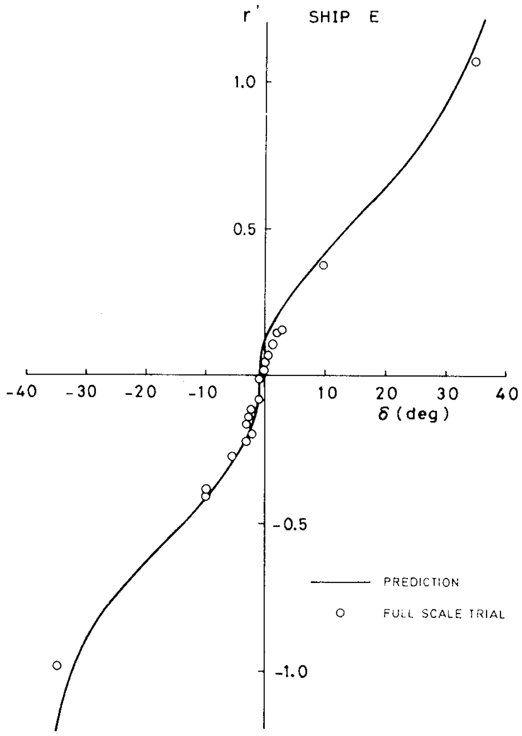

Fig. 29 Steady turning performance (SHIP E)

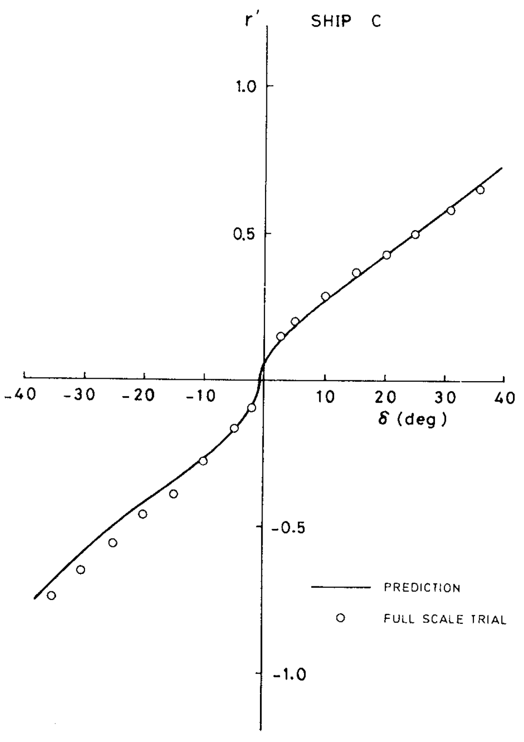

Fig. 28 Steady turning performance (SHIP C)

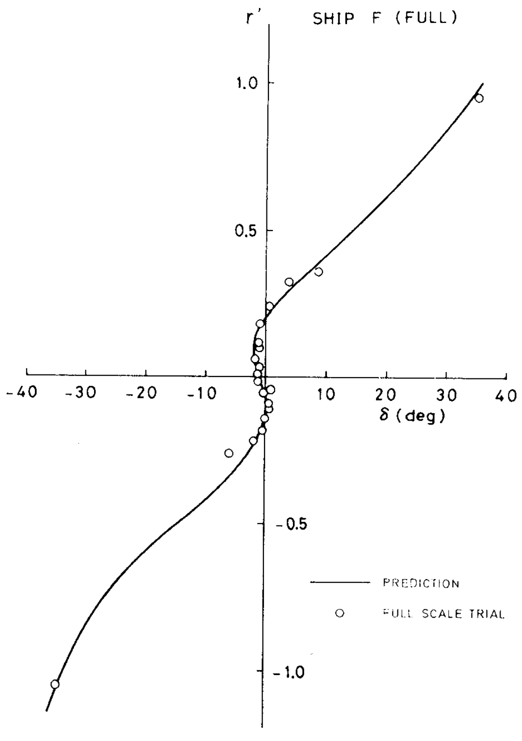

Fig. 30 Steady turning performance (SHIP F FULL)

are made for Ship A, B, C, E and F, where the reversed-spiral maneuver computations are added if necessary. The computed results are shown in the form of the steady turning performance in Figs. 26-30. It can be mentioned from these figures that the computed results are in fairly good agreements with the full-scale trial results. Especially the computed results explain well the sensitive behavior of the steady turning performance of each ship in the region of small rudder angle.

4. Conclusions

It is the purpose of the present study to develop a practical calculation method of the ship maneuvering motion using the principal particulars of ship hull, propeller and rudder as basic input data. The computed results are compared with the results of the full-scale trials, and the validity of the calculation method of the present study is examined. The major results obtained in the study of this paper are summarized as follows.

(1) The computed results show satisfactory agreements with the results of the full-scale trials for various kinds and sizes of the merchant ships, namely from a general cargo boat of 10,000-DWT class to a ULCC, and for wide range of the maneuvering characteristics, namely for the turning motion with 35° rudder, the 10°-10° Z-maneuver response and the steady turning performance.

(2) The maneuvering motion of a ship with large roll should be treated together with the motion of roll simultaneously.

(3) The maneuvering motion of the full-scale ships should be calculated taking the coupling effect due to propeller revolution into consideration even under the normal running condition of the main engine.

(4) Finally the calculation method of the present study is very useful and powerful for the predictions of the ship maneuverability at the initial design stage, when the principal particulars of ship hull, propeller and rudder are known.

Acknowledgements

In the course of the present study, Prof. S. Inoue of Kyushu University has given the author valuable guidances and advices. The author wishes to express his sincere gratitude to Prof. S. Inoue. The author also wishes to express his hearty thanks to Dr. Y. Yamanouchi of Mitsui Engineering and Shipbuilding Co., Ltd. (MES) for his kind encouragements and suggestions. Thanks are also due to Mr. J. Takashina of MES for his fruitful discussions and great helps in carrying out the present study.

References

1) IMCO: Recommendation on Information to be Included in the Manoeuvring Booklets, Resolution A. 209 (VII) adopted on 12. Oct. 1971.
2) Maneuvering Characteristics: Data Required, Code of Federal Regulations, 35 Panama Canal §103. 41 a, 1977.
3) S. Inoue, M. Hirano, Y. Hirakawa and K. Mukai: The Hydrodynamic Derivatives on Ship Maneuverability in Even Keel Condition (in Japanese), Transactions of the West-Japan Society of Naval Architects, No. 57, 1979.
4) S. Inoue, M. Hirano and K. Mukai: The Non-linear Terms of Lateral Force and Moment Acting on Ship Hull in the Case of Maneuvering (in Japanese), Transactions of the West-Japan Society of Naval Architects, No. 58, 1979.
5) M. Hirano and J. Takashina: A Calculation of Ship Turning Motion Taking Coupling Effect Due to Heel into Consideration, Transactions of the West-Japan Society of Naval Architects, No. 59, 1980.
6) S. Motora: On the Measurement of Added Mass and Added Moment of Inertia for Ship Motions (Part 1, 2 and 3) (in Japanese), Journal of the Society of Naval Architects of Japan, Vol. 105 and 106, 1959 and 1960.

7) Y. Yoshimura and K. Nomoto: Modeling of Maneuvering Behaviour of Ships with a Propeller Idling, Boosting and Reversing (in Japanese), Journal of the Society of Naval Architects of Japan, Vol. 144, 1978.
8) K. Kose and T. Saeki: On a New Mathematical Model of Manoeuvring Motions of a Ship (in Japanese), Journal of the Society of Naval Architects of Japan, Vol. 146, 1979.
9) N. Matsumoto and K. Suemitsu: The Prediction of Manoeuvring Performances by Captive Model Tests (in Japanese), Journal of the Kansai Society of Naval Architects, Japan, No. 176, 1980.
10) A. Yumuro: Some Experiments on Flow-Straightening Effect of a Propeller in Oblique Flows (in Japanese), Journal of the Society of Naval Architects of Japan, Vol. 145, 1979.
11) S. Inoue: On the Point in Vertical Direction on Which Lateral Force Acts (in Japanese), Technical Report, SP. 82, Technical Committee of the West-Japan Society of Naval Architects, 1979.
12) A. Ogawa and H. Kasai: On the Mathematical Model of Maneuvering Motion of Ships, International Shipbuilding Progress, Vol. 25, No. 292, 1978.
13) S. Inoue: On the Rudder Force (in Japanese), Technical Report, SP. 77, Technical Committee of the West-Japan Society of Naval Architects, 1978.
14) M. Nakato, K. Kose and T. Saeki: Experimental Study on Accelerating and Decelerating Ship Motions (2nd Report) – on Manoeuvrability – (in Japanese), Journal of the Society of Naval Architects of Japan, Vol. 144, 1978.