CHARACTERISTICS OF MANEUVERING MOTIONS OF PHILIPPINE OUTRIGGER CRAFT IN WIND

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Abstract: Most fishing craft of the Philippines are constructed in the double outrigger form with a main hull and floats at both sides. Generally, a float and its beam are made of bamboo. The craft has met with a sea accident such as a collision or aground in a strong seasonal wind. A great deal effort has been made on the issue, little is known about maneuverability under the wind forces for the craft.

In this paper, a prediction method of the maneuverability for the craft is proposed to investigate the maneuvering motions under the wind forces. The point about the development of this method is divided into different parts of the hull and the outriggers. Furthermore, the model of hydrodynamics forces on outriggers is described as a simple mathematical formula. The accuracy of the method is checked by model tests. From these simulation studies, a safer and more efficient craft could be designed.

1. INTRODUCTION

When considering the maneuvering motions of outrigger craft under the wind forces, field survey provides a starting-point. Aguilar (1997)[1)2)] has conducted field surveys to measure and record the technical characteristics of the craft and to build a database that can be used for analyses. Furthermore, Aguilar and Shigehiro (2002) [3)4)] have conducted the sea trials of an outrigger craft to investigate the ship's speed and turning ability in the Philippines. However, there is not enough data to apply the other outrigger craft in generally. From these remarks, it is clear that the simulation study is useful method to improve the performance for the craft. As the craft is constructed in the double outrigger form, it is important to take account into the effect of hydrodynamics forces on outriggers.

The purposes of the studies are to develop a prediction method to estimate the maneuvering motions and to clarify the effect of outriggers and wind forces on maneuvering motions for the craft. In this prediction method, the mathematical model of hydrodynamics forces is divided into different parts of the hull and the outriggers. Firstly, the accuracy of the method is checked by comparing between the results of numerical simulation and turning motions of model tests in a calm condition. Secondly, the simulation studies are applied to investigate the maneuvering motions for the craft under the wind forces. From these simulation studies, the effects of outriggers and the wind forces for the craft are able to discuss quantitatively.

2. PREDICTION METHOD

The prediction method of maneuvering motions for the craft is based on numerical simulation. The mathematical model for the simulation is the typical modular type that is called MMG model[5) 6)] in Japan, and it is described as follows:

$$\begin{aligned} m(\dot{u} - vr) &= X_H + X_P + X_R + X_E \\ m(\dot{v} + ur) &= Y_H + Y_P + Y_R + Y_E \\ I_{zz}\,\dot{r} &= N_H + N_P + N_R + N_E \end{aligned} \tag{1}$$

where m : mass of the craft, I_{zz} : moment of inertia at the center of gravity of the craft, u, v : velocity of x-direction and y-direction and r: angular velocity of yawing. The notation of X, Y and N represent the hydrodynamics forces and moments acting on the center of gravity of the craft.

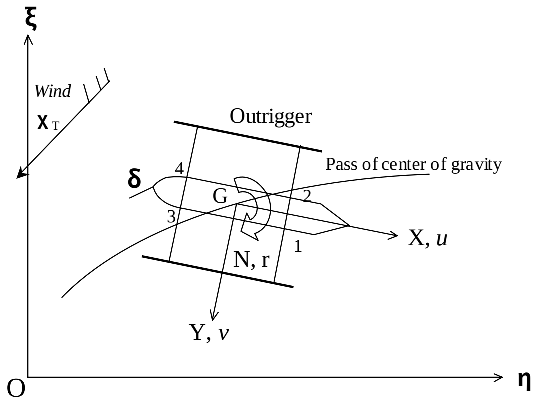

Fig. 1 Co-ordinate systems.

The subscripts of H, P, R and E refer to the hull, the propeller, the rudder and the external forces, respectively. The co-ordinate systems are shown in Fig. 1.

2.1 Mathematical Model of Forces and Moments Acting on the Hull

X_H, Y_H and N_H include the effect of outriggers and are expressed by the following polynomials of u', v' and r'.

$$\begin{aligned}
X_H &= \frac{1}{2}\rho L d U^2 \{ X'_o + X'_{vv}v'^2 + (X'_{vr} + m'_y)v'r' \\
&\qquad + X'_{rr}r'^2 - m'_x \dot{u}' \} \\
Y_H &= \frac{1}{2}\rho L d U^2 \{ Y'_v v' + (Y'_r - m'_x u')r' + Y'_{vvv}v'^3 \\
&\qquad + Y'_{vvr}v'^2 r' + Y'_{vrr}v'r'^2 + Y'_{rrr}r'^3 - m'_y \dot{v}' \} \\
N_H &= \frac{1}{2}\rho L^2 d U^2 \{ N'_v v' + N'_r r' + N'_{vvv}v'^3 + N'_{vvr}v'^2 r' \\
&\qquad + N'_{vrr}v'r'^2 + N'_{rrr}r'^3 - J'_{zz}\dot{r}' \}
\end{aligned} \tag{2}$$

where ρ: density of water, L: length between perpendiculars, d : the mean draft and U : resultant velocity of u and v. $v' = v/U \cong -\beta$, $r' = r(L/U)$.

A thing worth of note is that the derivatives of the craft are largely different from those of a mono-hull ship. Detailed account of the influence of outriggers is given in the next section (3. INFLUENCE OF OUTRIGGERS).

2.2 Propeller

X_p, Y_p and N_p are expressed by the following formulas:

$$\begin{aligned}
X_p &= (1-t)\rho n^2 D_p{}^4 K_T \\
Y_p &= \frac{1}{2}\rho u_p{}^2 \frac{\pi}{4} D_p{}^2 \frac{C_T}{\sqrt{1+C_T}} \beta_p \cong 0 \\
N_p &= x_p \cdot Y_p
\end{aligned} \tag{3}$$

where

$$\begin{aligned}
C_T &= \frac{8K_T}{\pi J_s{}^2} \\
\beta_p &= \beta - x'_p r' \\
J_s &= \frac{u_p}{nD_p} \\
u_p &= (1-w_p)u \\
w_p &= w_o e^{c\beta_p{}^2} \quad (c = -4.0)
\end{aligned} \tag{4}$$

and where t : coefficient of thrust reduction, n : speed of rotation per seconds, D_p : diameter of the propeller, K_T : coefficient of thrust, x_p : location of the propeller $(x'_p = x_p / L)$ and w_o : hull wake fraction in straight motion.

2.3 Rudder

X_R, Y_R and N_R are expressed by the following formulas:

$$\begin{aligned}
X_R &= -(1-t_R)F_N \sin\delta \\
Y_R &= -(1+a_H)F_N \cos\delta \\
N_R &= -(x_R + a_H x_H)F_N \cos\delta \\
&\cong -(1+a_H)x_R F_N \cos\delta
\end{aligned} \tag{5}$$

where δ is the rudder angles, x_R represents the location of the rudder and t_R, a_H are interactive coefficients among the hull, the propeller and the rudder. F_N is the rudder normal force and is expressed by the following forms:

$$\begin{aligned}
F_N &= \frac{1}{2}\rho f_\alpha A_R u_R{}^2 \sin\alpha_R \\
\alpha_R &= \delta - \delta_o + \gamma_R (v' + \ell_R r')/u'_R \\
f_\alpha &= \frac{6.13\Lambda}{2.25+\Lambda} \\
u_R &= \varepsilon u_p \sqrt{1 + \kappa 8K_T / \pi J_s{}^2}
\end{aligned} \tag{6}$$

where δ_o: neutral angles of the rudder, γ_R: flow straightening factor around the rudder, Λ : aspect ratio of the rudder, A_R: movable area of the rudder and ℓ_R, ε, κ are interactive coefficients among the hull, the propeller and the rudder.

2.4 External Force

As for external force, the wind force is considered in this study. X_E, Y_E and N_E are expressed as follows:

$$\begin{aligned}
X_E &= C_X(\chi_a)\frac{1}{2}\rho_a A_X U_a{}^2 \\
Y_E &= -\mathrm{sgn}\{\chi_a\} C_Y(\chi_a)\frac{1}{2}\rho_a A_Y U_a{}^2 \\
N_E &= -\mathrm{sgn}\{\chi_a\} C_N(\chi_a)\frac{1}{2}\rho_a A_Y L U_a{}^2
\end{aligned} \tag{7}$$

$$\text{where} \quad \mathrm{sgn}\{\chi_a\} = \begin{cases} 1 & (\chi_a \ge 0) \\ -1 & (\chi_a < 0) \end{cases} \tag{8}$$

$$U_a{}^2 = W_T{}^2 + U^2 + 2W_T U \cos(\beta + \chi_T - \psi) \tag{9}$$

$$\chi_a = \begin{cases} \sin^{-1}\left\{\dfrac{W_T}{U_a}\sin(\beta + \chi_T - \psi)\right\} - \beta & (U_a \ne 0) \\ \pi - \beta & (U_a = 0) \end{cases} \tag{10}$$

where ρ_a : density of air, A_X : transverse projected area above-water hull, A_Y : longitudinal projected area above-water hull, W_T : true wind velocity, χ_T : true wind direction and ψ : heading of ship. $C_X(\chi_a)$, $C_Y(\chi_a)$ and $C_N(\chi_a)$ are the coefficients of wind forces and moments, obtained from a wind tunnel test or estimated from the databases of Isherwood (1970)[7] or Tsuji (1971)[8].

3. INFLUENCE OF OUTRIGERS

As mentioned above, outriggers are so slender and these are located a far distance from the hull to maintain the transverse stability. It seems to be a very little interacted force between the hull and outriggers in maneuvering motion. On this assumption, the derivatives of the hydrodynamics forces due to outriggers could be described as follows:

$$F(y) = F_H + \Delta F + \Delta f \cdot \left\{ \frac{y}{L} - \frac{1}{4} \right\} \quad , \; y \geq \frac{B_H}{2} \qquad (11)$$

where F_H : effect of the hull, ΔF : effect of the outriggers and Δf : effect of the distance between outriggers.

Circular Motion Test (CMT) was conducted to investigate the effect on these terms in the National Research Institute of Fisheries Engineering (NRIFE), using a 1/4 scale model as shown in Fig. 2. Type-H is a hull without outriggers. Type-A is a standard type in the Philippines, and distance between outriggers is about half ship's length. Type-C is a wide model to examine the effect of the distance between outriggers. The model arrangements of the craft are shown in Fig. 3, and its principal dimensions are shown in Table 1.

Table 1 Principal dimensions.

Items		Ship	Model
Scale		1	1/4
L_{pp}	(m)	10.940	2.735
B_H	(m)	1.260	0.315
d_m	(m)	0.468	0.117
W	(kg)	3702.4	57.850
$\otimes G$	(m)	aft 0.196	aft 0.049
K_{yy}/L_{pp}		0.242	0.242
$F_n \; (= V / \sqrt{L_{pp} g})$		0.298 (6.0 knots)	0.298 (1.543 m/s)

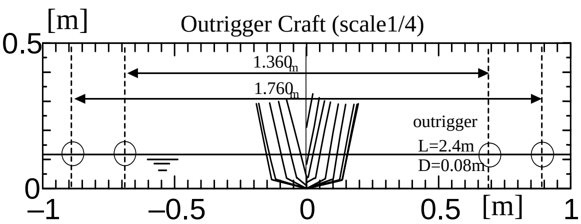

Fig. 2 Body plan of the outrigger craft.

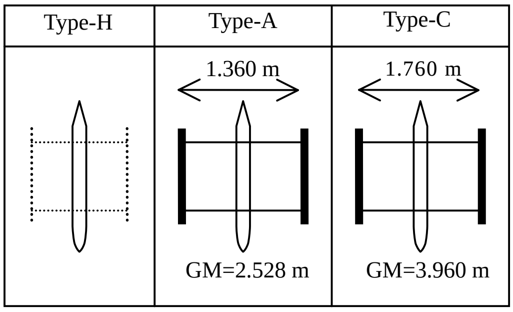

Fig. 3 Schematic illustration of model arrangements.

3.1 Resistance

The results of CMT are shown in Fig. 4. Furthermore, Fig. 5 shows the increased resistance due to the angular velocity of yawing. From these results, the increasing resistance due to outriggers can be observed, but the influence of the distance between outriggers is rather slight.

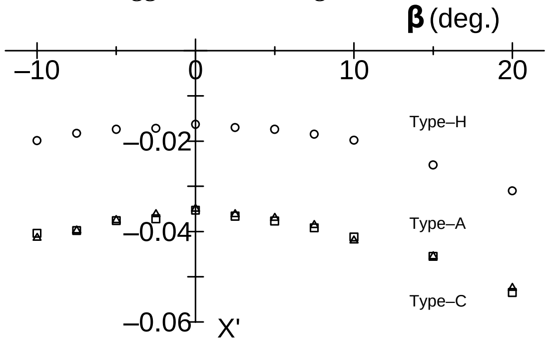

Fig. 4 Non-dimensional resistance acting on the outrigger craft.

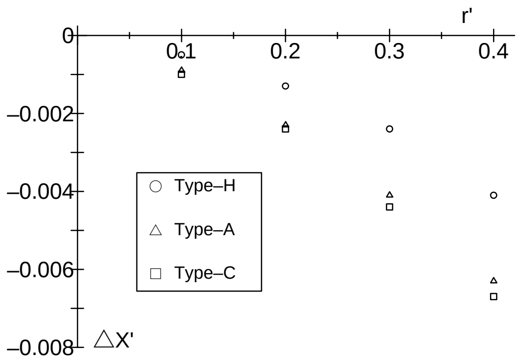

Fig. 5 Increased resistances due to the angular velocity of yawing.

3.2 Lateral Forces and Yaw Moments

The results of the oblique tests on type-H, type-A and type-C are shown in Fig. 6 and Fig. 7. The hydrodynamic forces and moments on the craft have a non-linear effect in a large range of drift angles (β). In order to investigate the influence of the angular velocity of yawing, the hydrodynamic forces and moments are shown in Fig. 8 and Fig. 9.

Hydrodynamic forces and moments due to pure yaw motions have a linear effect within the range of $0.4\,(r'=0.4)$.

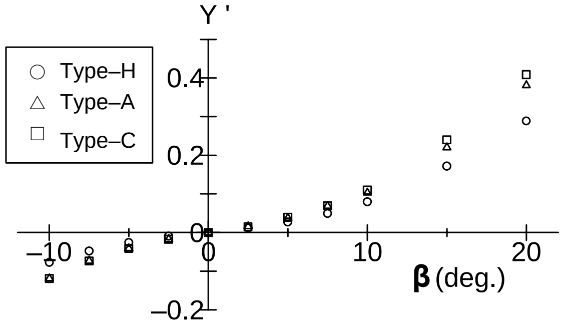

Fig. 6 Lateral forces of the outrigger craft due to oblique motions.

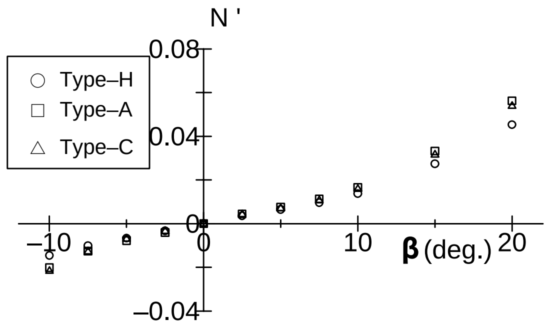

Fig. 7 Yaw moments of the outrigger craft due to oblique motions.

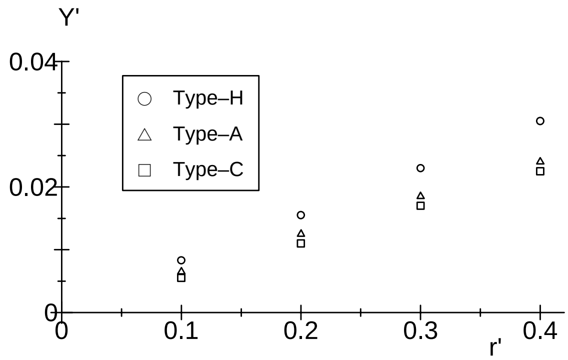

Fig. 8 Lateral forces of outrigger craft due to pure turning motions.

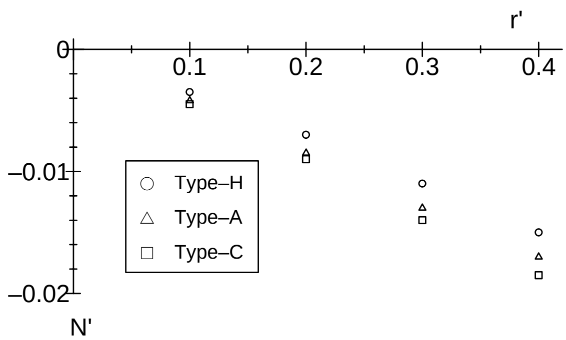

Fig. 9 Yaw moments of outrigger craft due to pure turning motions.

3.3 Results and Discussion

The derivatives of hydrodynamic forces are obtained from fitting by polynomials of v' and r'. The derivatives of resistance are shown in Table 2. The static derivatives of lateral force and moment are shown in Table 3. The dynamic derivatives are shown in Table 4. Furthermore, the each vale of terms in formula (11) with respect to the linear derivatives is shown in Table 5. On the other hand, $\ell_v (= N'_v / Y'_v)$ is representing the point of force due to the oblique motion from the center of gravity in the craft, and $\ell_r (= N'_r /(Y'_r - (m' + m'_x))$ is also representing the point force due to the pure turning motion. $D\,(= \ell_r - \ell_v)$ is the stability discriminate as shown in Table 6. If D would be positive $(D \geq 0)$, the craft would have a stable characteristic on course keeping ability. As can be seen, the craft is adequate to the course keeping ability (see Table 6).

Table 2 Derivatives of resistance.

Type	X'_o	X'_{vv}	X'_{rr}	$X'_{vr} + m'_y$
H	-0.0163	-0.122	-0.028	0.059
A	-0.0350	-0.180	-0.045	0.059
C	-0.0353	-0.180	-0.045	0.059

Table 3 Static derivatives of lateral force and moment in oblique motions.

Type	Y'_v	Y'_{vvv}	N'_v	N'_{vvv}
H	-0.315	-4.318	-0.068	-0.511
A	-0.458	-0.5271	-0.084	-0.573
C	-0.467	-5.893	-0.086	-0.614

Table 4 Dynamic derivatives of lateral force and moment in turning motions.

Type	Y'_r	Y'_{rrr}	N'_r	N'_{rrr}
H	0.078	-	-0.038	-
A	0.061	-	-0.043	-
C	0.056	-	-0.045	-

Table 5 Effect of outriggers with respect to linear derivatives.

	F_H	ΔF	Δf
Y'_v	-0.315	-0.143	-0.126
Y'_r	0.078	-0.017	-0.070
N'_v	-0.068	-0.016	-0.028
N'_r	-0.038	-0.005	-0.028

Table 6 Stability discriminate.

Type	ℓ'_r	ℓ'_v	$D = \ell'_r - \ell'_v$
H	0.611	0.216	0.395
A	0.543	0.183	0.360
C	0.534	0.184	0.350

The derivatives of the hydrodynamics forces on a part of outrigger could be discussed in this study. As an outrigger is made of bamboo, its hydrodynamics derivative seems to be a little variation for most of fishing craft. In the near future, if the hydrodynamics derivatives of main hull could be built a database, the prediction method would be applied to a great many outrigger craft in the Philippines.

4. NUMERICAL SIMULATIONS

The main hull of the craft is so slender, and the propeller and the rudder are located far distance from the hull as shown in Photo1. It seems to be a little interaction among the hull, the propeller and the rudder. Accordingly, the interactive parameter of rudder (t_R) is negligible, and the other interactive parameters are estimated from the published database as shown in Table 7.

Meanwhile, the model of diameter of propeller is 0.150 m and the number of blade is 2. The rudder area is 0.015 m^2 (A_R/Ld=1/21.3) and the aspect ratio is 0.67.

Table 7 Coefficients with respect to propeller and rudder.

Propeller		Rudder	
t	0.100	γ_R	0.80
w_o	0.200	a_H	0.35
ε	1.000	ℓ_R	-1.00
κ	0.135	t_R	0.0

Photo. 1 Rudder and propeller of outrigger craft

Photo. 2 Outrigger craft in the Philippines

4.1 Accuracy

The accuracy of the prediction method is discussed by comparing the predicted motions with results of free running model tests in calm condition. The trajectories of turning motion of type-A and type-C are shown in Fig. 10 and Fig. 11, and compared with the measured results of free running model tests. The rudder angles are 35 degrees and 20 degrees. The results of the prediction agree well with the results of the measurements made at each rudder angles. The trajectories of type-A and type-C are almost equivalent. Accordingly, the influence of the distance between outriggers is slight in the turning motions.

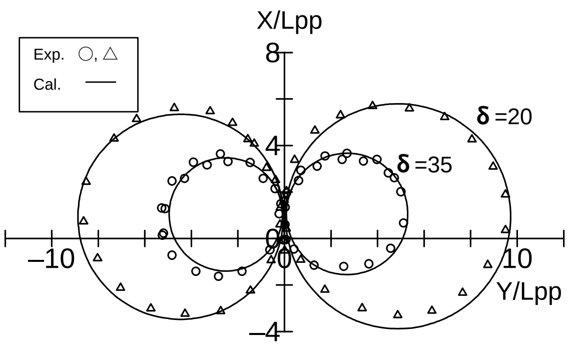

Fig. 10 Turning trajectories on the outrigger craft with a 1.36 m beam in length (Type-A).

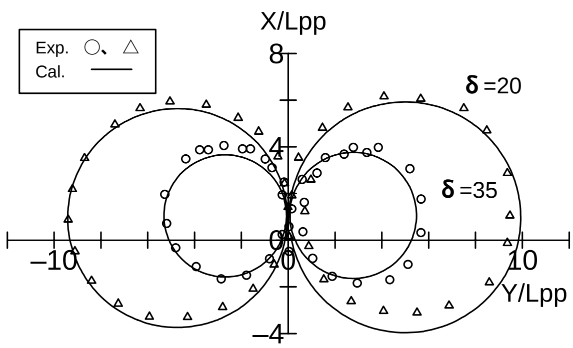

Fig. 11 Turning trajectories on the outrigger craft with a 1.76 m beam in length (Type-C).

4.2 Effect of Wind Force

In this study, because the superstructure of the craft is a simple shape as shown in Photo. 2, the coefficients of wind force and moment are obtained from database of Isherwood as shown in Fig. 12. The simulation studies are carried out to obtain the basic characteristic of maneuvering for the outrigger craft in wind. Accordingly, the turning and the zig-zag maneuver are selected for the simulation studies.

The effect of the wind force is a very large for the craft in the turning motions because of the draft is shallow. The maximum deviations (SD/L_{pp}) in the turning motions are shown in Fig. 13. SD is denoted the deviation from trajectory of calm condition as shown in Fig. 14. True wind direction is zero and the model is type-C in this simulation studies. Also, example for simulation results, trajectories are shown in Fig. 14, and the time histories of ship's speed u, yaw rate r and drift angle β are shown in Fig. 15. In this case, wind speed of the simulation is six times as large as ship's speed (WT/U=6) and the rudder angle is 35 degrees. As can be seen, the craft is pushed down the wind about two ship's length, also, yaw rate and drift angle are strongly influenced of wind force in turning motion. The effect of wind is getting more strongly as the rudder angles are less than 10 degrees.

On the other hand, the effect of wind is rather slight in 10-10 zig-zag maneuver as shown in Fig. 16. The main reason is that the craft has an excellent course keeping ability in the main because the hull is so slender, and the outriggers are large damping of yaw moment. Meanwhile, the true wind direction is –90 degrees in this simulation studies.

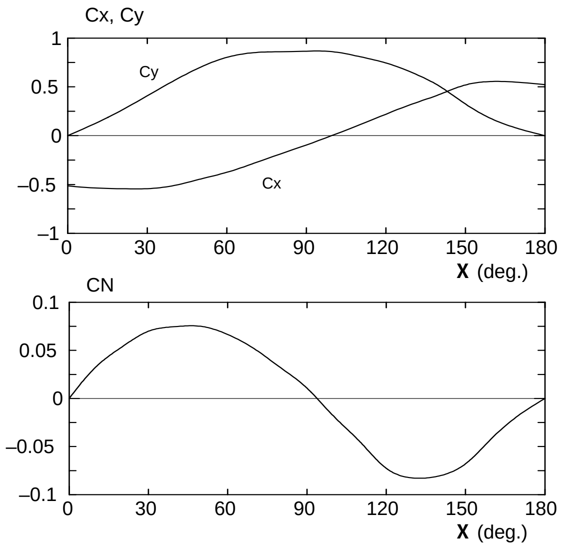

Fig. 12 Coefficients of wind force and moment.

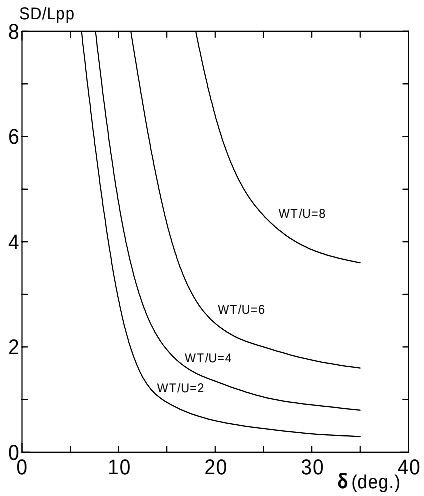

Fig. 13 Maximum deviation in turning motions from trajectories of calm condition

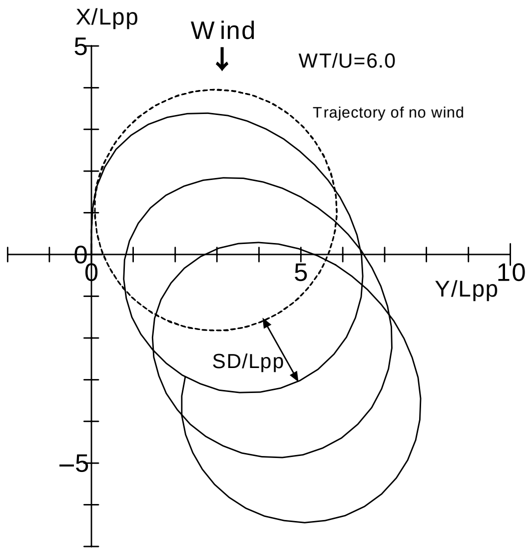

Fig. 14 Example of simulation results of turning trajectories under wind force (type-C, rudder angles of 35 degrees).

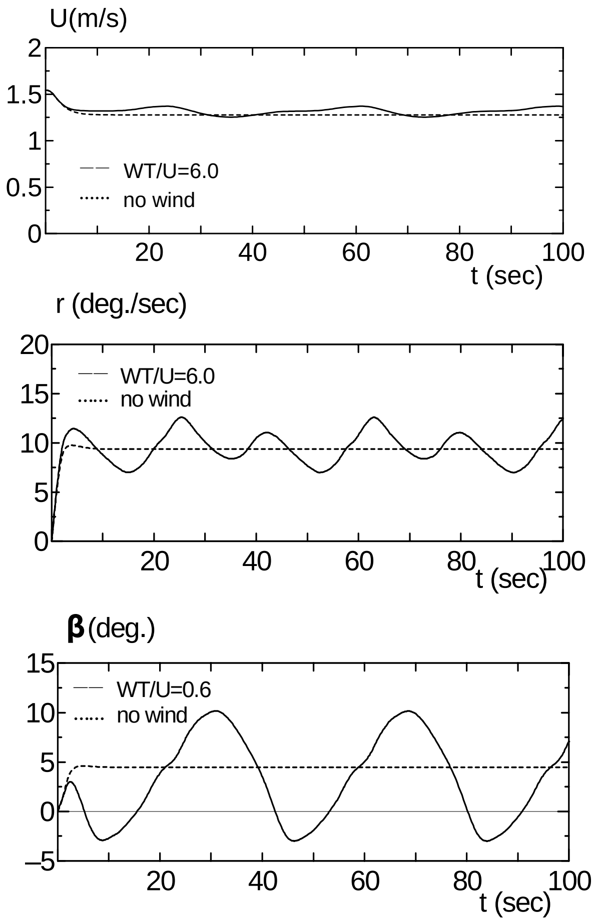

Fig. 15 Time histories of ship's speed u, yaw rate r and drift angle β in turning motion under wind force (type-C, rudder angles of 35 degrees).

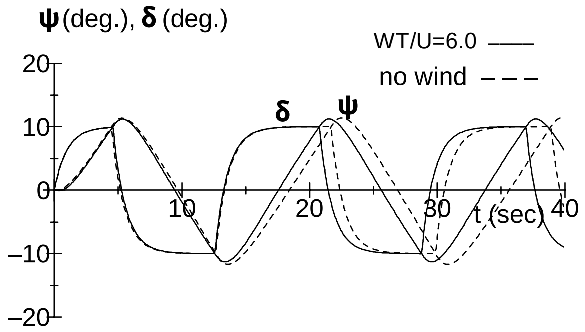

Fig. 16 Simulation results of 10-10 zig-zag maneuver under wind force (type-C).

5. CONCLUSIONS

On the basis of this simulation studies, the effects of wind force in maneuvering motion are discussed quantitatively for Philippine outrigger craft. Meanwhile, free running model tests were conducted to check the accuracy of the prediction method. The following conclusions are drawn:

1) The prediction method of maneuverability for Philippine outrigger craft is proposed, and the accuracy of the prediction method is adequate to consider safety of navigation.
2) The outriggers have influence on increasing resistance as much as resistance of a hull, but the influence of the distance between outriggers is rather slight.
3) The maximum deviations in the turning motions are quantitatively obtained from the simulation studies for the craft with wind conditions.
4) As the draft of outrigger craft is shallow, yaw rate and drift angle are strongly influenced of wind force in turning motion.
5) The hull of Philippine outrigger craft is so slender and outriggers are large damping of yaw moment. Accordingly the craft has an excellent course keeping ability.

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