On the interaction effects between ships in confined water including the effect of wind and current

Chun ki-LEE, Il kwon-KANG†*

Kyushu University, Japan, *Pukyong National University

외력의 영향을 고려한 제한수역에서 선박간의 상호작용

이춘기 · 강일권†*

일본 큐슈대학교, *부경대학교

요 약

제한수역에서 바람과 조류와 같은 외력을 받으며 항행하는 선박들 사이에는 대양에서 항행할 때와는 달리 상호간에 여러 가지 작용이 일어나면서 선박의 안전이 위협받는 수가 많다.

본 연구에서는 협수로와 같은 제한수역에서, 해난사고를 피하기 위해 요구되어지는 선박들간의 적절한 안전속도 및 안전거리를 제안하기 위해 선장비, 속도비, 풍향, 풍속, 유향 및 유속 등을 파라메타로 해서 조종운동 시뮬레이션 계산을 행하였다.

시뮬레이션 계산 결과, 두 선박 간의 상호 영향은 대형선박에 비해서 소형선박에 보다 크게 작용하는 것으로 나타났고, 속도비 1.2의 경우가 속도비 0.6, 1.5의 경우보다 매우 크게 나타났다.

한편, 외력하에서 항행하는 두 선박에 있어서, 고속 선박에 비해서 저속 선박에 미치는 외력의 영향은 상당히 크게 작용하기 때문에 조선할 때, 이 점에 유의하여 항행해야 함을 알 수 있었다.

Key words : marine safety(해상 안전), manoeuvrability(조종성능), hydrodynamic interaction(유체역학적 상호작용), bank effect(측벽 영향), safe speed and distance(안전속도 및 안전거리)

Introduction

When a large vessel navigation in restricted waterways should be properly understood, and the works on this part have been reported for the past years. But, the detailed knowledge on maneuvering characteristics for the safe navigation while avoiding terrible collision between ships, particularly under the wind and current, is still being required to prevent marine disasters from the viewpoint of marine safety.

A large number of papers have been described on the hydrodynamic interaction between ships. Thus, some improved results were obtained. Yeung[1] analyzed hydrodynamic interactions acting on a ship moving near the fixed obstacles. Similar works were also reported by Davis[2]. Kijima[3] studied on the interaction effects between two ships in the proximity of bank wall. Kijima[4] studied on maneuvering motion of a ship in the proximity of bank wall. Yasukawa[5] studied on the bank effect on ship maneuverability in a channel with varying width. Meanwhile, Lee[6] obtained the evaluation on the safe navigation including the interaction forces between ships, and between ship and some fixed obstacles under various conditions.

The main subject of this paper is to propose an appropriate safe speed and distance between ships required to avoid marine disasters from the

† Corresponding author : ikkang@pknu.ac.kr

viewpoint of marine safety.

Background

The coordinate systems fixed on each ship and on the earth are shown by $O_i - x_i y_i$ $(i=1,2)$ and $O - xy$, respectively in Fig. 1. Consider two vessels designated as ship 1 and ship 2 moving at speed $U_i (i=1,2)$ in an inviscid fluid of finite water depth h. S_{P12} and S_{T12} represent the lateral and longitudinal distances between ship 1 and ship 2 in Fig. 1. V_W, V_C, ν, α mean the wind velocity, current velocity, wind direction and current direction, respectively. Both calculation methods and theoretical backgrounds related in this were reported in the previous research work[6], but non-dimensional expression for the lateral force, CF_i, and yawing moment, CM_i, affecting upon two vessels is given by

$$CF_i = \frac{F_i}{\frac{1}{2}\rho L_i d_i U_i^2},\ CM_i = \frac{M_i}{\frac{1}{2}\rho L_i^2 d_i U_i^2} \quad \cdots\ (1)$$

where L_i is the ship length of ship i and d_i the draft of ship , i. ρ is the water density.

Results and Discussion

1. Conditions of calculation and hydrodynamic interaction forces between ships in open sea

In case where the wind and current velocity are very small, compared to the advance speed of the ship, it is possible to turn the ship to the left or right with moderate helm angle. However, as the wind or current velocity becomes large, it becomes difficult to turn her to the direction as one demands.

So, the manoeuvering motion between ships while overtaking in congested areas under the current and wind is potentially hazardous. A parametric study on the numerical investigations has been conducted on the general cargo ship as a model vessel as shown in Table 1 and Table 2, which both ship 1 and ship 2 are always similar form. A typical overtaking condition was investigated as shown in Fig. 1.

Provided that the speed of a ship 1 (denoted as U_1) is maintained at 10 *kt*, the velocities of overtaking or overtaken ship 2 (denoted as U_2)

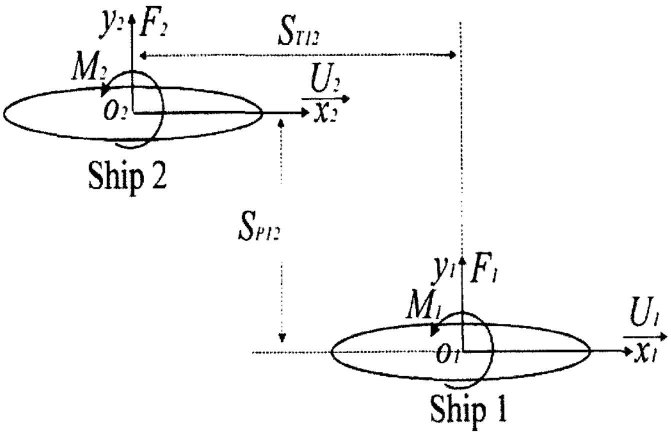

Fig. 1. Coordinate systems.

Table 1 Principal particulars

$L(m)$	2.5
$B(m)$	0.419
$d(m)$	0.140
C_B	0.698
Scale	1/62

Table 2. Types with parameters L_2/L_1 and U_2/U_1

Types	Ratio between ships	
	L_2/L_1	U_2/U_1
Type 1	0.5	0.6, 1.2, 1.5
Type 2	1.0	0.6, 1.2, 1.5
Type 3	1.18	0.6, 1.2, 1.5

were varied, such as 6 *kt*, 12 *kt* and 15 *kt*, respectively. The ratios of ship length selected for comparison were 0.5, 1.0 and 1.18 As shown in Table 3, for the cases of external force, the wind direction (ν) and velocity (V_W) were considered from 0° to 350° and $10m/s$, respectively, and the current direction (α) was considered as 0° and 180°, and also current velocity (V_c) was considered as $4kt$.

Fig. 2 to Fig. 4 show the computed lateral force and yaw moment coefficient acting on two ships while overtaking. In this case, the results for relative position between the vessels are plotted. Fig. 2 shows the result for interaction forces with function of the lateral distance between two ships

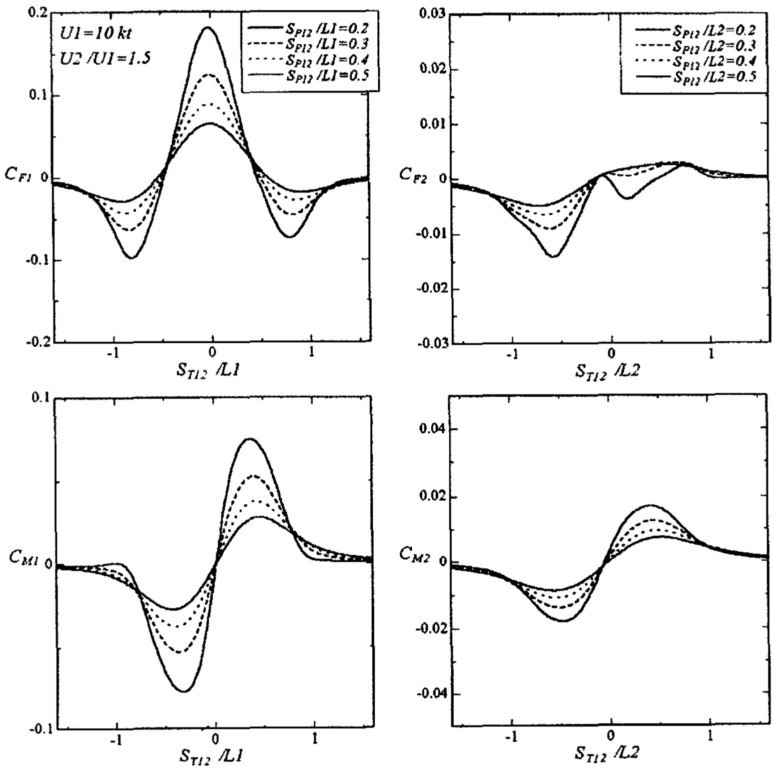

Fig. 2. Lateral force and yawing moment coefficients acting on the ship 1 and ship 2 with function of the lateral distance between ships in open sea ($h/d=1.2$).

Table 3. Conditions of external force

External force	Wind and current	
	direction	velocity
Wind	0°~350°	10m/s
Current	0°, 180°	4kt

for the case of 1.5 in U_2/U_1 .

The separation between two ships was chosen to be 0.2 to 0.5 times of a ship length under the condition of 1.0 in L_2/L_1.

Fig. 2 (a) and (b) show the result for ship 1 and ship 2, respectively. From this figure, it indicates the following result. The overtaken and overtaking vessel experience an attracting force which increases as two vessel approach with each other.

When the bow of overtaking vessel approaches the stern of the overtaken vessel, two ships encounter the first hump of the attracting force and a maximum bow–in moment. The maximum repulsive force value is achieved when the midship of overtaking vessel passes the one cf overtaken vessel.

Then the sway force reverses to attain the steady motion due to the sufficient longitudinal distance between two ships. Two ships experience the maximum bow–out moment when the longitudinal distance between the midship of two ships is about 0.5 times of a ship length in distance, then the bow–out moment acting on two vessels due to the

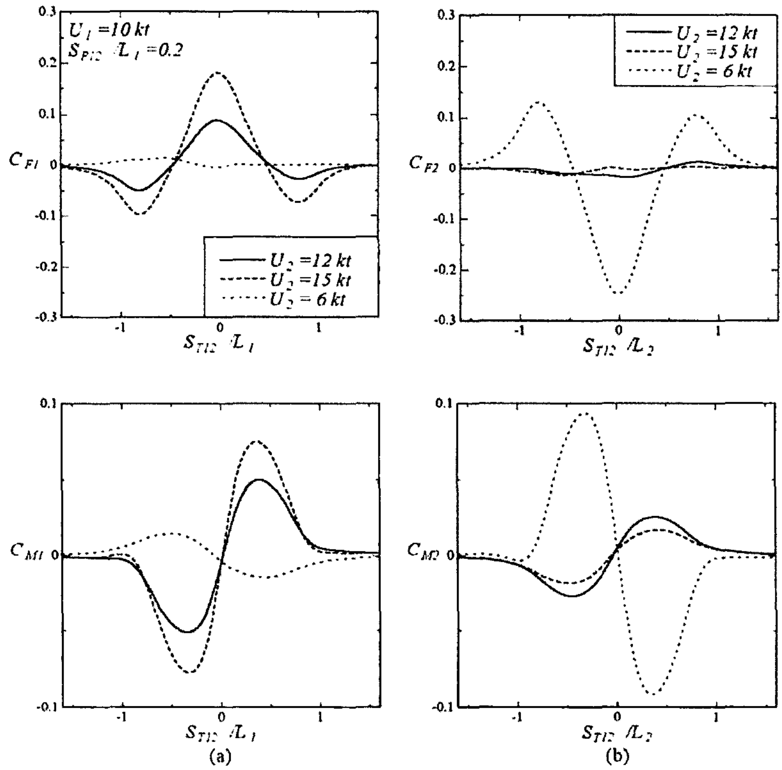

Fig. 3. Lateral force and yawing moment coefficients acting on the ship 1 and ship 2 with function of U_2/U_1 the in open sea(h/d= 1, 2, L_2/L_1=1.0).

sufficient longitudinal distance between two ships are disappeared. For hydrodynamic interaction forces, the effect of ship 1 is quantitatively bigger than the one of ship 2.

Fig. 3 display the result of interaction forces with function of the U_2/U_1, respectively. In this case, the separation between two ships was taken as 0.2 times of a ship length and the ratio of length difference, L_2/L_1, was taken as 1.0. From this figure, it indicates the following result.

The effect of hydrodynamic interaction forces between of Fig. 2. The effect of hydrodynamic interaction forces acting on the overtaken vessel become bigger as the difference of velocity between ships overtaking and overtaken vessel represent almost qualitatively same tendency, compared to the case increases, compared to the case of overtaking vessel.

The hydrodynamic interaction forces between two ships with various L_2/L_1 is shown in Fig. 4. In this case, the separation between two ships was taken as 0.2 times of a ship length 1 and the ratio of velocity difference, U_2/U_1, was taken as 1.5.

From Fig. 4, it indicated that reciprocal effect between two ships become bigger as ship−length increases, compared to the case between two small ship−length.

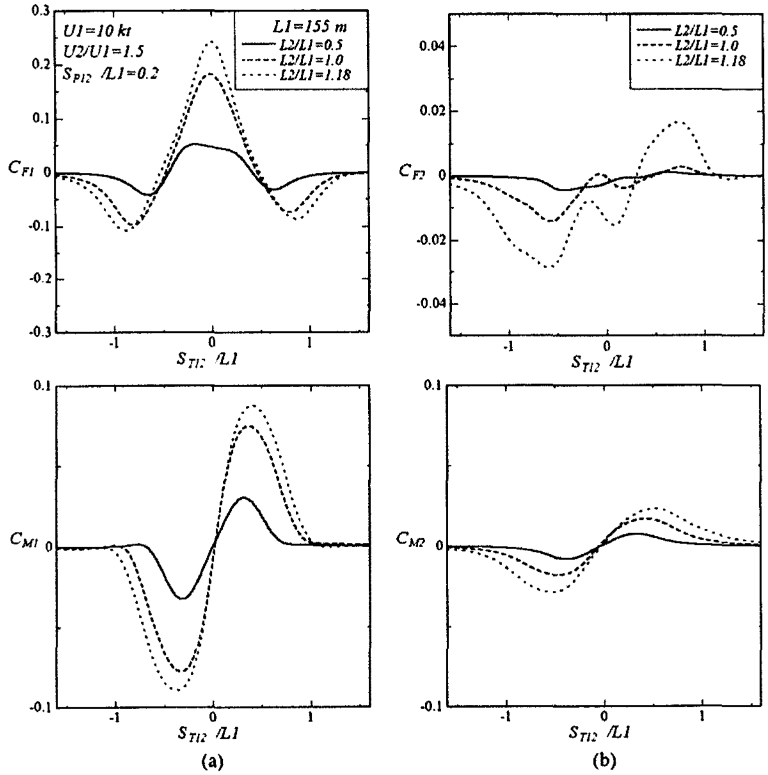

Fig. 4. Lateral force and yawing moment coefficients acting on the ship 1 and ship 2 with function of the L_2/L_1 in open sea($h/d=1, 2$, $L_2/L_1=1.0$).

2. Simulation of ship manoeuvring motions under the influence of the hydrodynamic interaction forces

The ship manoeuvring motions are simulated numerically by using the predicted hydrodynamic interaction forces and using the ship manoeuvering model of Kijima[7], and the external force and moment acting on two ships moving each other in restricted waterways under the condition of current and wind can be expressed as follows :

$$(m_i' + m_{xi}')\left(\frac{L_i}{U_i}\right)\left(\frac{\dot{U}_i}{U_i}\cos\beta_i - \dot{\beta}_i\sin\beta_i\right) +$$
$$(m_i' + m_{yi}')r_i\sin\beta - (m_{xi}' + m_{yi}')\frac{V_{ci}}{U_i}r_i\sin \quad (2)$$
$$(\Psi_i' - \alpha) = X_{hi}' + X_{Pi}' + X_{Ri}' + X_W'$$

$$-(m_i' + m_{xi}')\left(\frac{L_i}{U_i}\right)\left(\frac{\dot{U}_i}{U_iS}\sin\beta_i - \dot{\beta}_i\cos\beta_i\right)$$
$$+(m_i' + m_{xi}')r_i'\cos\beta_i' - (m_{yi}' - m_{xi}') \cdots\cdots\cdots (3)$$
$$\frac{V_{ci}}{U_i}r_i\cos(\Psi_i' - \alpha) = Y_{HI}' + Y_{Ri}' + Y_{Ii}' + Y_W'$$

$$(I_{ZZi}' + i_{ZZi}')\left(\frac{L_i}{U_i}\right)^2\left(\frac{\dot{U}_i}{L_i}r_i' + \frac{U_i}{L_i}\dot{r}_i'\right)$$
$$= N_{Hi}' + N_{Ri}' + N_{Ii}' + N_w' \cdots\cdots\cdots (4)$$

where, m_i' represents non−dimensionalized mass of ship i, m_{xi}' and m_{yi}' represent x, y axis components of non−dimensionalized added mass of ship i, β_i means drift angle of ship i, respectively.

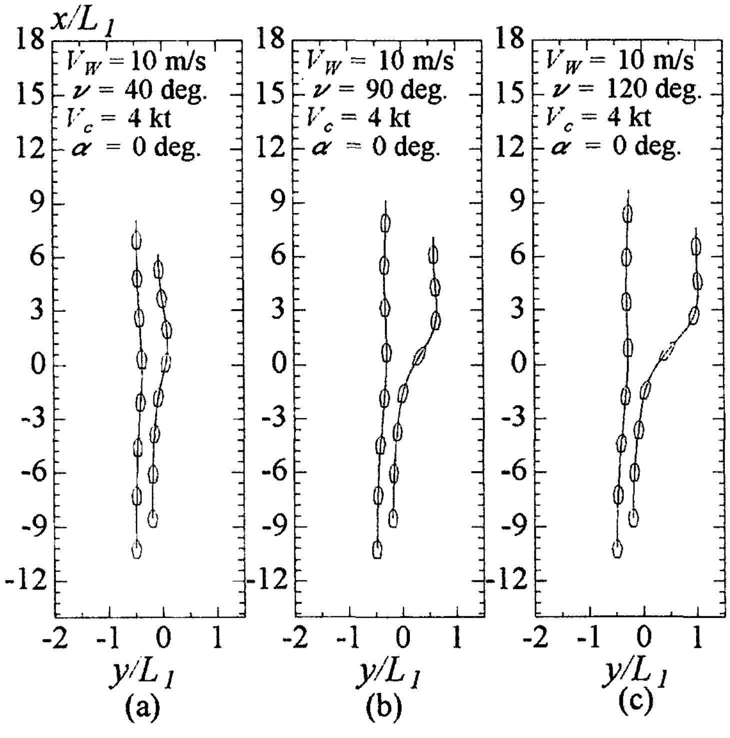

Fig. 5. Ship trajectories under the external forces with rudder control.

The subscript H, P, R, I and W mean ship hull, propeller, rudder, component of the hydrodynamic interaction forces between two ships and wind respectively, and also, V_c, α, Ψ_i mean current velocity, current direction and heading angle of ship i, respectively. X, Y and represent the external force of x, y axis and yaw moment about center of gravity of ship, respectively. Wind forces and moments acting on ships were estimated by Fujiwara *et al.*[8].

A rudder angle is controlled to keep course as follows :

$$\delta_i = \delta_{0i} - K_1(\Psi_i - \Psi_{0i}) - K_2 r_i' \quad \cdots\cdots\cdots\cdots\cdots (5)$$

where δ_i, r_i' represent rudder angle, non-dimensional angular velocity of ship i, respectively. Subscript '0' indicates initial values and also, K_1 and K_2 mean the control gain constants.

Fig. 5 shows the result of manoeuvring simulation for model ship with function of the external force for the case of 1.2 in U_2/U_1. In this case, the wind velocity (V_W), current velocity (V_c) and current direction (α) were taken as $10m/s$, $4kt$ and 0°, respectively. However, the wind direction(ν) were taken 40° as 90° and 120°, respectively.

The separation between two ships, S_{P12}, was taken as 0.3 times of ship 1 and L_2/L_1 was taken as 1.0 in $h/d_1 = 1.2$. The control gain constants used in these numerical simulations are $K_1 = K_2 = 5.0$, and maximum rudder angle, $\delta_{max} = 10°$.

Fig. 5 indicates the following result. When and if one ship passes the other ship, any yawing moments of the overtaken vessel as shown in Fig. 5 show strong motions due to the hydrodynamic interaction forces between ships according to the wind directions.

Then once initiated such a turn would develop rapidly, the rudder force of the overtaken vessel under the condition of $\delta_{max} = 10°$ was not large enough to stop this tendency. In case of 120° of wind direction(Fig. 5(c)), there was a most clear tendency for the overtaken vessel to deviate to starboard, compared to the cases of (a) and (b) in However, in case of (a) in Fig. 5, two ships' courses are not almost deviated from the original direction under the condition of because the effect of external force under the condition of $\delta_{max} = 10°$ of wind direction is not large.

Conclusion

The following conclusions can be drawn from the numerical calculation for hydrodynamic interaction forces between two ships while overtaking in open sea. When compared to the case of overtaking vessel, among other things, the effect of hydrodynamic interaction forces acting on the overtaken vessel is increasingly larger with increase of velocity ratio. Secondly, mutual effect between two ships becomes bigger as the ship length ratio increases. Furthermore, if the lateral distance between two ships is about one times of a ship-length the hydrodynamic interaction forces were disappeared.

From the simulation of ship manoeuvering motions using numerical data, the following conclusions can be drawn. Firstly, lateral distance between ships are required for the velocity ratio of 1.2, compared to the cases of 0.6 and 1.5. Secondly, non-dimensional lateral separation between two ships is necessarily required for the 1.18 in L_2/L_1, compared to the cases of 1.0 and 0.5 regardless of the velocity ratio.

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