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Maneuvering Simulation of Two Ships During Meeting and Passing

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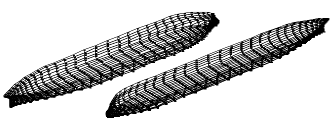
Graphical abstract



Hydrodynamic interaction occurs between two ships in close proximity

Abstract

Motion equations of two ships maneuvering in close proximity are solved in consideration of the interaction between hulls. The interaction forces are calculated by a 3D panel method as a function of the ship position in the time step and considered as external forces in maneuvering. Four kinds of ships are prepared and the maneuvering motions are simulated with variation of the combination of ships, water depth, ship speed and draft. The effect of those parameters on the interaction forces and two ships behaviors are investigated.

Keywords: Ship to Ship interaction; maneuvering; added mass; 3D panel method

1.0 INTRODUCTION

When two ships moves in close proximity, there is the large potential hazard of collision each other. So it is required to understand the hydrodynamic force characteristics acting on those ships in order to avoid any severe accidents.

Yasukawa [1] who is one of authors presented the motion equations for two ships maneuvering in close proximity based on the potential theory under the assumption of the rigid wall free surface. In his method, the hydrodynamic interaction forces can be calculated by a 3D panel method as a function of the ship position in the time step. So the two ships behaviors in close proximity are expected to be realistically demonstrated. However he showed only a few examples of the results of simulation.

In this paper, more case studies on ship to ship interaction are analyzed by Yasukawa's method and the characteristics of hydrodynamic forces are evaluated. Several kinds of ships are selected as the subjects. The maneuvering motions in the case of meeting and passing are simulated with variation of the ship combination, water depth, ship speed and draft. The effect of those parameters on the interaction forces acting on each hull is discussed associating with the motion trajectory.

2.0 MANEUVERING MOTION EQUATIONS

2.1 Coordinate System and Assumptions

The coordinate system fixed in the space o-xyz and fixed at the midship of Ship i (=1,2) $o^{(i)}$-$x^{(i)}y^{(i)}z^{(i)}$ are employed as shown in Figure 1. The $x^{(i)}$-axis is defined in the longitudinal direction to bow, $y^{(i)}$-axis in the lateral direction to port and $z^{(i)}$-axis vertically upward. The $x^{(i)}y^{(i)}$ plane is the same as xyplane and coincides with the still water surface. The sea bottom is positioned at $z= -h$. The relative distance between midships in the x direction is defined as $|x_{MM}|$.

Ship i is assumed to move with surge velocity $U_{1+3(i-1)}$, sway velocity $U_{2+3(i-1)}$ and yaw angular velocity $U_{3+3(i-1)}$. These component velocities are represented as a function of time t. Note they can be redefined as $u^{(i)}$,$v^{(i)}$ and $r^{(i)}$ respectively.

For simplicity of the treatment, the free surface effect and shed vortices are neglected.

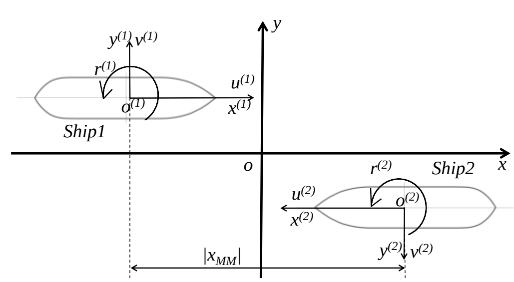


Figure 1 Earthfixed coordinate system and ship fixed coordinate systems

2.2 Motion Equations of Two Ships

Motion equations of two ships in close proximity without propeller and rudder are expressed as follows.

$$m^{(i)}\left\{\dot{U}_{1+3(i-1)}-U_{2+3(i-1)}U_{3+3(i-1)}\right\}=F_{D1}^{(i)}+F_{A1}^{(i)}+F_{V1}^{(i)} \tag{1}$$

$$m^{(i)}\left\{\dot{U}_{2+3(i-1)}+U_{1+3(i-1)}U_{3+3(i-1)}\right\}=F_{D2}^{(i)}+F_{A2}^{(i)}+F_{V2}^{(i)} \tag{2}$$

$$I_z^{(i)}\dot{U}_{3+3(i-1)}=F_{D3}^{(i)}+F_{A3}^{(i)}+F_{V3}^{(i)} \tag{3}$$

Where m denotes the ship's mass and I_z the moment of inertia around $z^{(i)}$ axis.

F_D and F_A in the right-hand side represent the interaction forces and added masses calculated by a 3D panel method. F_D means the quasi-steady pressure with respect to the square of the velocity potential. The definition of F_D should refer to Yasukawa [1]. F_A means the time derivative of the potential and expressed as follows.

$$F_{A1}^{(i)}=-\sum_{k=1}^{6}\left[\dot{U}_k m_{1+3(i-1),k}+U_k\dot{m}_{1+3(i-1),k}-U_kU_{3+3(i-1)}m_{2+3(i-1),k}\right] \tag{4}$$

$$F_{A2}^{(i)}=-\sum_{k=1}^{6}\left[\dot{U}_k m_{2+3(i-1),k}+U_k\dot{m}_{2+3(i-1),k}+U_kU_{3+3(i-1)}m_{1+3(i-1),k}\right] \tag{5}$$

$$F_{A3}^{(i)}=-\sum_{k=1}^{6}\Big[\dot{U}_k m_{3+3(i-1),k}+U_k\dot{m}_{3+3(i-1),k} \\ +U_kU_{1+3(i-1)}m_{2+3(i-1),k}-U_kU_{2+3(i-1)}m_{1+3(i-1),k}\Big] \tag{6}$$

Where $m_{j,k}$ is the added mass and moment of inertia with respect to the j^{th} force induced by motion of the k^{th} mode.

F_V is the damping forces due to viscous fluid and assumed to be expressed as follows.

$$F_{V1}^{(i)}=0 \tag{7}$$

$$F_{V2}^{(i)}=1/2\rho LdU^2(Y_v'v'+Y_r'r'+Y_{vv}'v'|v'|+Y_{vr}'v'|r'|+Y_{rr}'r'|r'|) \tag{8}$$

$$F_{V3}^{(i)}=1/2\rho L^2dU^2(N_v'v'+N_r'r'+N_{vvr}'v'^2r'+N_{vrr}'v'r'^2+N_{rr}'r'|r'|) \tag{9}$$

Where

$$U^{(i)}=\sqrt{U_{1+3(i-1)}^2+U_{2+3(i-1)}^2},\ \ v^{(i)'}=U_{2+3(i-1)}/U^{(i)},\ \ r^{(i)'}=U_{3+3(i-1)}L^{(i)}/U^{(i)} \tag{10}$$

Equation (7) indicates the ship resistance and thrust are always balanced. L and d are the ship length and draft. Y_v',…,N_{rr}' are the hydrodynamic derivatives. Note the discrimination of ships denoted by the superscript (i) is omitted in the right-hand side of Equations (7)-(9) for simplicity.

■3.0 OUTLINE OF CALCULATION

3.1 Subject Ships

Four kinds of ships such as Bulk carrier (C), container ship (D), large and small tanker ships (E and K) were selected as the subjects. Ship C, D and E are the same subjects as Vantorre *et al.* [2]. The principle dimensions of their full ships are listed in Table 1. In the calculation, 768 panels for every hull surface were arranged. Figure 2 shows the example of panel arrangement of Ship E and C.

Table 1 Principle dimensions of subject ships

Symbol	C	D	E	K	
Type	Bulk	Container	Tanker	Small tanker	
L(m)	298.8	289.8	286.8	206.33	
B(m)	37.8	41.25	46.8	27.64	
d(m)	13.50	13.50	15.53	11.67	16.62
C_b	0.843	0.588	0.816	0.796	0.830
Disp	128539	94893	170038	52969	78650

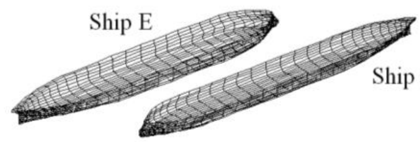


Figure 2 Panel arrangements of Ships E and C when meeting

3.2 Hydrodynamic Derivatives

The hydrodynamic derivatives are estimated by Hirano's method [3] in conjunction with Kobayashi's method [4] in order to consider the shallow water effect on them. Table 2 shows the list of linear derivatives in deep water. The derivatives in shallow water used in the following simulation are also listed in Table 3. Note N_v^{*}' includes the Munk moment term and N_v' is estimated by excluding it from N_v^{*}'. It is understood that the damping sway force and yaw moment increase with decrease of water depth.

■4.0 SIMULATION RESULTS–MEETING–

The hydrodynamic forces in the case of meeting in deep and shallow water are discussed. Three ship combinations i.e. Ship E-C, E-D and E-K (d=16.62 m) are studied where Ship E corresponds to Ship 1 (i=1). The initial lateral clearance between hulls is 0.5 times larger than the width of Ship 2. The surge speed of both ships is 7 knot. The sway force was non-dimensionalized by $1/2\square L^{(1)}d^{(1)}U_0^{(1)2}$ and the yaw moment was made by $1/2\square L^{(1)2}d^{(1)}U_0^{(1)2}$ where U_0 is the initial ship speed. The variables with primesignify the non-dimensional ones.

4.1 Effect of Ship Combination

Figure 3 and 4 show the results of sway force Y' and yaw moment N' when two ships meet each other in deep water. They can be decomposed into F_D', F_A', and F_V'. The component forces of sway force acting on Ship C in the case of Ship E-C meeting and on Ship K in the case of Ship E-K meeting are shown in Figure 5. Those of yaw moment are also shown in Figure 6. $x_{MM}/L^{(1)}$ is taken as the horizontal axis where 0 means the two ships stand side by side. Figure 7 shows the ship trajectories.

Table 2 Hydrodynamic linear derivatives in deep water

	$^{(i=1)}$E	$^{(i=2)}$C	$^{(i=2)}$D	$^{(i=2)}$K
d(m)	15.53	13.50	13.50	16.62
Y_v'	-0.3555	-0.2893	-0.2623	-0.4098
Y_r'	0.0758	0.0633	0.0653	0.1127
N_v^{*}'	-0.1083	-0.0904	-0.0933	-0.1610
N_r'	-0.0424	-0.0370	-0.0379	-0.0546

Table 3 Hydrodynamic linear derivatives in shallow water

h(m)	**18.63**		**[A][C]20.0**	
Symbol	**$^{(i=1)}$E**	**$^{(i=2)}$C**	**$^{(i=1)}$E**	**$^{(i=2)}$K**
d(m)	15.53	13.5	15.53	16.62
h/d	1.20	1.38	1.29	1.20
Y_v'	-1.1867	-0.6924	-1.0899	-0.8977
Y_r'	0.1927	0.1233	0.1815	0.2166
$N_v^{*}{}'$	-0.2753	-0.1761	-0.2592	-0.3095
N_r'	-0.0931	-0.0647	-0.0887	-0.0984

h(m)	**[B]20.0**	
Symbol	**$^{(i=1)}$E**	**$^{(i=2)}$K**
d(m)	15.53	11.67
h/d	1.29	1.71
Y_v'	-1.0899	-0.4738
Y_r'	0.1815	0.1027
$N_v^{*}{}'$	-0.2592	-0.1468
N_r'	-0.0887	-0.0541

※[A][B][C] is referred in Chapter 5.

According to Figure 3, when both ships are close each other, the lateral forces in the repulsion side increases and the peak of the repulsion force appears around x_{MM} =0. Figure 4 shows both ships experience the bow-out, bow-in and bow-out moment again while meeting each other. Figure 5 shows Ship K takes the larger sway force due to the damping force at the meeting side by side. The authors see F_A' is the main component of the yaw moment from Figure 6. Such interaction force and moment cause the ships to deviate from the original course. Note $Y',N'\neq 0$ after meeting indicates the sway and yaw motions is still being developed. Ship K, on the other hand, appears to reduce the motions and sail on the new straight course because Y' and N' tend to converge.

4.2 Effect of Water Depth

The case of meeting between Ship E and C is simulated in shallow water $h/d^{(1)}$ =1.2. Figure 8 and 9 show the results of Y' and

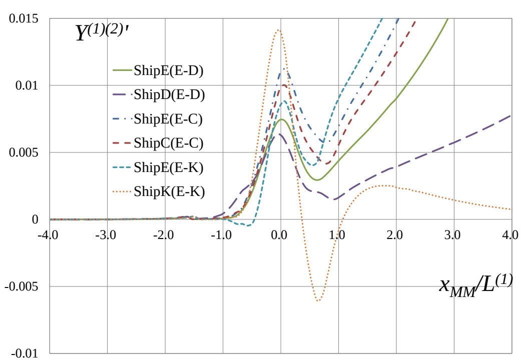


Figure 3 Sway force acting on each ship when meeting each other in deep water versus x_{MM} / $L^{(1)}$

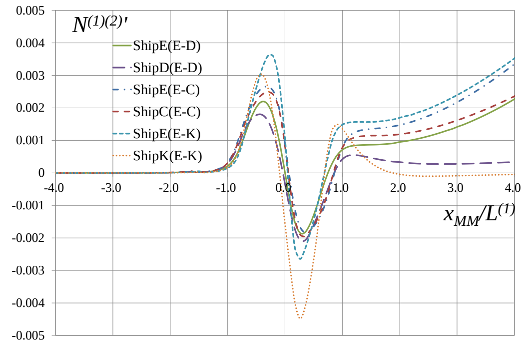


Figure 4 Yaw moment acting on each ship when meeting each other in deep water versus x_{MM} / $L^{(1)}$

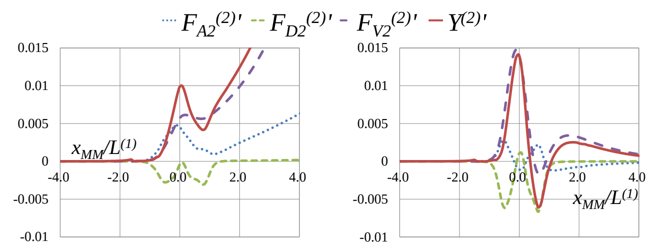


Figure 5 Components of sway force acting on Ship C in the case of E-C meeting (left) and Ship K in the case of E-K meeting (right)vs.x_{MM} / $L^{(1)}$

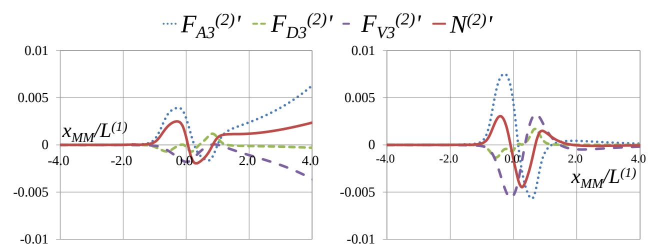


Figure 6 Components of yaw moment acting on Ship C in the case of E-C meeting(left) and Ship K in the case of E-K meeting(right)vs.x_{MM} / $L^{(1)}$

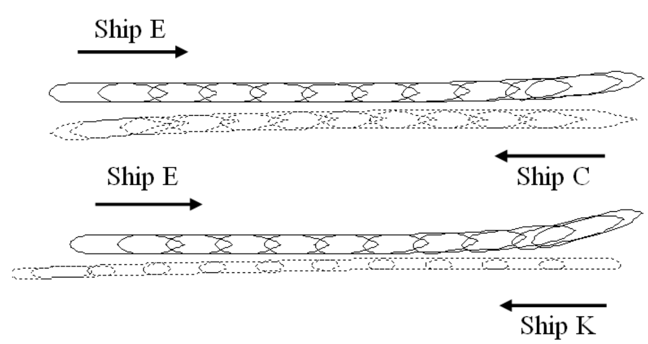


Figure 7 Ship trajectories in the case of E-C meeting (upper) and E-K meeting (lower) in deep water

N'versus $x_{MM}/L^{(1)}$.The non-dimensional sway velocity $v'$and yaw angular velocity r' are shown in Figure 10. The results of the deep water case discussed in 4.1 are also plotted for comparison.

Although Y' and N' change depending on the relative position each other in a similar way as deep water case, their magnitude increases much in shallow water i.e. about 5 times larger than that in deep water around x_{MM}=0 for Y' and 3 times larger for N'. The authors see the interaction between hulls becomes significant with decrease of water depth. As the results, it is supposed to trigger the ship motions and Ship C especially seems to move dynamically according to Figure 10. The trajectory while meeting is shown in Figure 11. In the case of shallow water, Ship C deviates from her course greatly.

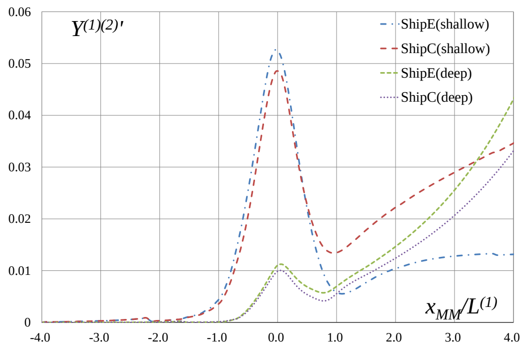


Figure 8 Sway force acting on each ship in the case of E-C meeting in deep and shallow waterversus x_{MM} / $L^{(1)}$

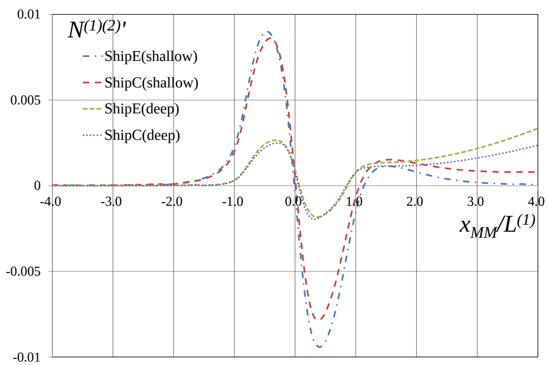


Figure 9 Yaw moment acting on each ship in the case of E-C meeting in deep and shallow waterversus x_{MM} / $L^{(1)}$

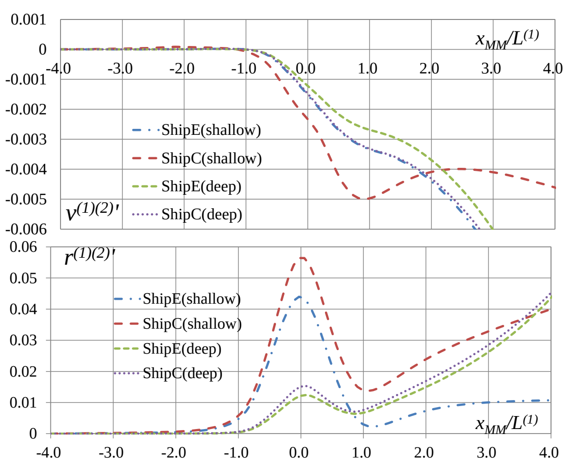


Figure 10 Sway velocity (upper) and yaw angular velocity (lower) of each ship in the case of E-C meeting in deepand shallow waterversus x_{MM} / $L^{(1)}$

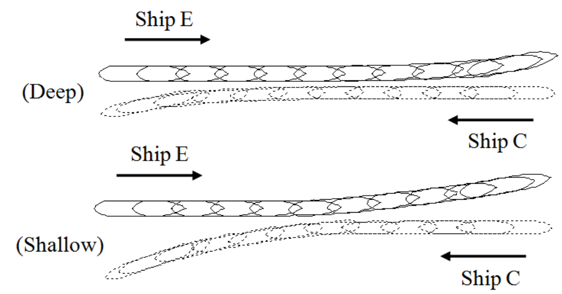


Figure 11 Ship trajectories in the case of E-C meeting in deep water (upper) and in shallow water (lower)

■5.0 SIMULATION RESULTS - PASSING -

Ship experiences running alongside in the crowded sea area and when two tanker ships are engaged in ship-to-ship transfer operation. In this chapter, Ship E (i=1) and K (i=2) are subject ships. Two shallow water cases [A] and [B] were simulated where Ship K sailing at 9 knot was supposed to pass Ship E whose speed was 7 knot. Only the difference of them is thedraft of Ship K i.e. 16.62 m in the case [A] and 11.67 m in the case [B].

In addition, the case [C] which has the same condition as [A] except for the speed of Ship E i.e. 3knot was simulated. The lateral clearance between hulls was set initially at 0.5 times larger than the width of Ship K.

5.1 Effect of Water Depth

Figure 12 shows the results of Y' and N' of shallow water cases [A] and [B]. The deep water case with the same condition as [A] except for the water depth was also plotted for comparison. The component forces are shown in Figures 13 and 14. $x_{MM}/L^{(1)}$ is taken as the horizontal axis.

In the case of deep water, the suction force and bow-out moment acts on each hull as Ship K catches up with Ship E. According to Figures 13 and 14, the increase of the amount of F_D'would be a main factor of that. In the case of shallow water [A], Y' and N' increase with decrease of the relative distance between hulls. F_A' seems to increase much compared with the deep water case, which denotes the increase of added masses in shallow water. Since the magnitude of F_V' also increases, the authors guess the ships experienced the large sway and yaw motions.

Figure 15 shows the ship trajectories until both ships touch each other. In the case of shallow water [A], Ship K seems to be attracted strongly and crashes against Ship E in the earlier stage.

5.2 Effect of Ship Draft

Comparing the results of [A] with [B], the absolute values of component forces in the case of [A] arelarger than those of [B] since Ship K has the deeper draft in the former case. From Figure 15, Ship K with shallow draft i.e. [B] appears to yaw more than the case of [A] before touching Ship E due to the lower damping forces.

5.3 Effect of Ship Speed

Figure 16 shows the results of the case [A] and [C] where the speed of Ship E (3knot) is only different from [A]. Note the values were non-dimensionalized by using the speed of Ship K i.e. 9 knot.

When Ship K passes Ship E which sails at 3 knot, the interaction forces doesn't become significant. As the results, Ship K doesn't' deviate much from the initial course and can pass Ship E without crash as shown in Figure 17. Since the relative speed of Ship K to Ship E in the case of [C] is larger than that of [A], the period of running in parallel is shorter. It is one reason for safe passage.

■6.0 CONCLUSION

Ship to ship interactions between hulls in close proximity were studied by simulating several meeting and passing cases. The effects of ship combination, water depth, ship draft and speed on the interaction forces and ship behaviors were discussed. Understanding the change of component forces according to the relative position of two ships would be helpful to figure out the mechanism of ship to ship interaction well.

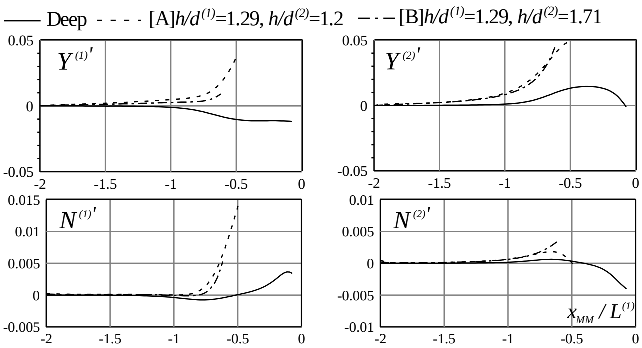


Figure 12 Sway force and yaw moment acting on each ship in the case of E-K passing in deepand shallow water([A] and [B])versus x_{MM} / $L^{(1)}$

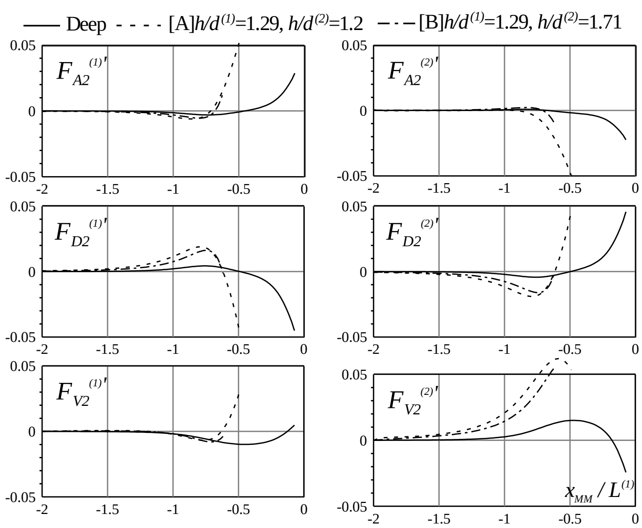


Figure 13 Components of sway force acting on each ship in the case of E-K passing in deep and shallow water([A] and [B])versus x_{MM} / $L^{(1)}$

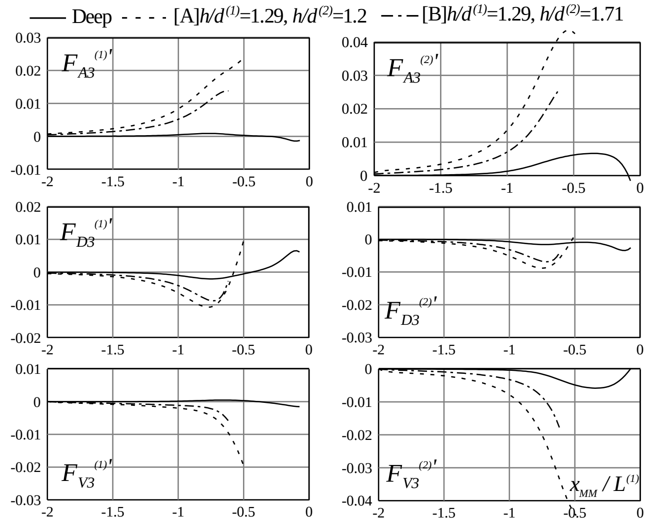


Figure 14 Components of yaw moment acting on each ship in the case of E-K passing in deep and shallow water ([A] and [B])versusx_{MM}/ $L^{(1)}$

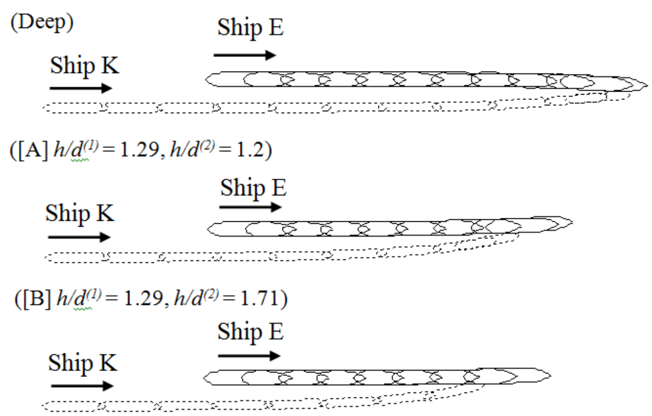


Figure 15 Trajectories when Ship K (9knot) passes Ship E (7 knot) in deep and shallow water ([A] and [B])

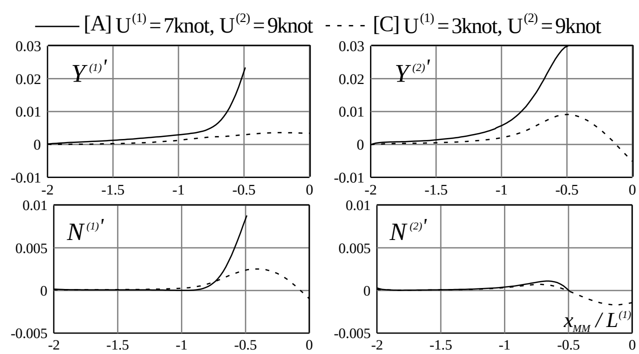


Figure 16 Sway force and yaw moment acting on each ship in the case of shallow water ([A] and [C])

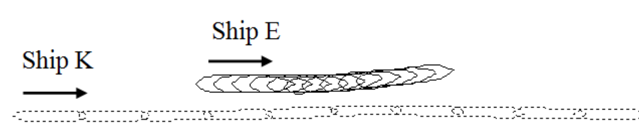


Figure 17 Trajectories when Ship K (9knot) passes Ship E (3 knot) ([C])

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References

[1] Yasukawa, H. 2003. Proc. Int. Conf. on Marine Simulation and Ship Maneuverability. Kanazawa.pp.RC-34-1– RC-34-10.
[2] Vantorre, M., Verzhbitskaya, E. and Laforce, E. 2002. *Ship Technology Research.* 49: 124–141.
[3] Hirano, M. 1980. *J. Society of Naval Architects of Japan.* 147: 144–153. (in Japanese).
[4] Kobayashi, E. 1995. Proc. 6th Int. Symp. on Practical Design of Ships and Mobile Units (PRADS'95). Seoul. 1.712.