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IN SHALLOW AND CONFINED WATER

Conference proceedings

3rd International Conference on Ship Manoeuvring in Shallow and Confined Water:

with non-exclusive focus on

Ship Behaviour in Locks

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Third International Conference on Ship Manoeuvring in Shallow and Confined Water:

with non-exclusive focus on

Ship Behaviour in Locks

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Ghent, Belgium

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Third International Conference on
Ship Manoeuvring in Shallow and Confined Water:
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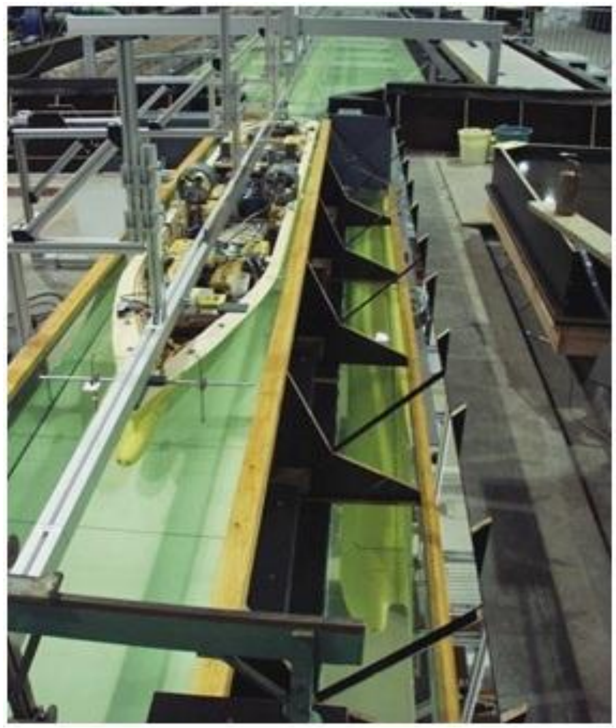
Preface

Scale enlargement in the shipping industry appears to be an ever-lasting trend. Particularly in container transport, the limit is not yet in sight. When the successful Second International Conference on Ship Behaviour in Shallow and Confined Water was being organised in Trondheim two years ago, the largest container carrier afloat had a capacity of 14 500 TEU. The limit of 16 000 units has been reached since then, and 18 000 TEU giants will be launched in the very near future. These new vessels will not only distinguish themselves by their overall dimensions; their propulsion system and speed characteristics will be essentially different compared to their predecessors', driven by concerns about fuel prices and emissions.

These evolutions are scrupulously watched by harbour and waterways authorities, who experience the continuous need to evaluate whether new and larger types of ships will still be able to make use of their infrastructure in the – even near – future. In order to guarantee an acceptable safety level, they continuously have to adapt their acceptance policy, reconsider operational limits and nautical procedures, have more sophisticated aids to navigation developed and have tug fleets extended. If these measures are assessed to be insufficient, widening and deepening of port areas and their access channels must be taken in consideration, which generally implies decisions with important financial and environmental consequences. In some cases, adapting the dimensions of existing infrastructure is no option at all. This is particularly the case when the access to a terminal requires the passage through a lock or a lock complex.



The construction of locks implies important investments with public and/or private funding. The final decision on the characteristics of the lock and on the maximum dimensions of the ships which will be allowed is irreversible and will determine the degree of economic success of the infrastructure for the next decades. The last few years have seen a growing interest in lock design and construction, both for maritime and inland traffic, in Europe, as well as in the Far East and, of course, in Panama. In many cases, new locks are being planned, designed or built with the purpose of replacing existing lock systems or increasing their capacity. As a consequence, a lock designer mostly needs to take account of many constraints imposed by the present situation, the existing shipping traffic and environmental considerations, so that the location of locks and the layout of their access channels are seldom optimized from the ship handling point of view. The design of new locks therefore not only creates new challenges with respect to the hydraulic and civil engineering aspects, but it must always be borne in mind that a new infrastructure can only be successful if ships are able to approach, enter and leave the lock in a safe and efficient way. The importance of a profound knowledge of the hydrodynamic effects to which ships are subjected throughout the complete locking process has been recognised by PIANC, evidence of which is given by the formation of InCom Working Group No. 155, “Ship behaviour in locks and lock approaches”.

This international interest certainly justifies the selection of the topic “Ship Behaviour in Locks” as the main focus for the Third International Conference on Ship Manoeuvring in Shallow and Confined Water. Moreover, it is hard to find any environment where a more intense interaction occurs between a ship under way and the navigation area. Shallow and confined water effects cannot be experienced more extremely than during lockage manoeuvres.

It is perhaps not appropriate to speak of traditions when discussing a series of conferences that only started four years ago, but the Knowledge Centre *Manoeuvring in Shallow and Confined Water* tries to keep in mind a few basic principles. Along with the call for papers for each conference, benchmark model test data obtained at the experimental facilities of Flanders Hydraulics Research have been made available for the validation of simulation models and numerical calculation tools. For the present conference, a number of tests with self-propelled models carried out to investigate the behaviour of vessels transiting the Panama Canal Third Set of Locks has been chosen, as well as a selection of captive model tests conducted in the towing tank for manoeuvres in shallow water in a scale model of the Pierre Vandamme Lock in Zeebrugge. Several research groups have again made use of this opportunity and will present their findings during this conference.

Secondly, all conferences so far have been organised with a focus on one particular topic without excluding other subjects related to the behaviour of ships in shallow and confined waters and keeping in mind that in daily practice most hydrodynamic effects do not occur separately. As a result, the conferences offer a forum for recent developments in research on shallow water manoeuvring, bank effects, ship-ship interaction, squat and other phenomena ships are subjected to in harbours and their approaches. A continuous and ever increasing international interest in these specific aspects of ship hydrodynamics and nautical practice can be observed in international organisations. For example, the present ITTC Manoeuvring Committee explicitly mentions the study of possible criteria for manoeuvring at low speed and in shallow waters. The best-selling PIANC report appears to be “Approach Channels – A Guideline for Design”, of which a long-expected updated version entitled “Horizontal and Vertical Dimensions of Fairways” will be issued shortly. A similar effort is being carried out for inland waterways by PIANC Working Group InCom 141, “Design Guidelines for Inland Waterways”.

Finally, the organisers wish to create a meeting place for both researchers and nautical experts. Problems concerning ship behaviour in shallow and confined water cannot be reduced to merely academic questions. Scientific research can only contribute effectively to practical solutions if researchers have a clear idea about the daily practice, while providing pilots and masters with a more thorough insight into the physical phenomena dominating a ship’s reaction in confined water may contribute to safer manoeuvres.

The first conference, with focus on bank effects, was organised in 2009 in Antwerp, the home base of Flanders Hydraulics Research. NTNU and Marintek organised the second edition in Trondheim in 2011 within the framework of a successful project studying ship-to-ship operations. The third conference will offer a busy technical program: 35 presentations, two keynote speakers and a visit to locks in operation and under construction in the Port of Antwerp. For several reasons, the Knowledge Centre has selected

Ghent as the venue for the third Conference. Not only because this city is the seat of the academic partner of the Knowledge Centre, but also because of the strong link between Ghent and the main topic of the conference. Safe and smooth lock operations are of the utmost importance for the Port of Ghent, both for the maritime and the inland shipping traffic. For both transport modes, important infrastructure works including extension or replacement of lock complexes are presently being studied, planned and executed. Lastly, the venue – Ghent University's Convention Centre "'t Pand", with its unique location in the historic heart of Ghent – allows the organisers to offer the delegates a well-balanced combination of a busy technical program with a selection of social activities offering the opportunity to catch a glimpse of the highlights of Ghent's cultural heritage and establish personal and professional relationships.

On behalf of the Royal Institution of Naval Architects, Flanders Hydraulics Research and Ghent University, we wish all participants a pleasant and fruitful conference.

Welcome to Ghent!

Prof. Marc Vantorre

SHIP MANOEUVRING BEHAVIOUR IN CROSSING CURRENT

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SUMMARY

Ship behaviour in a current is one of the classical problems in ship manoeuvrability. However, it is not yet fully investigated. The study is motivated by an assessment study on the ship navigation near-by a river lock where a relatively strong current exists, and simulations are done to demonstrate how the ship behaves in a current. As a result, relatively large drift angles are obtained, where the ship is around perpendicular to the current and the current speed is relatively large. In normal ship speed, the drift angle is almost less than 20° where a normal mathematical model based on lift theory can be applied, but even if the ship speed is not low, in presence of current, a mathematical model for low speed should be considered. The phenomena should more frequently occur, if the current is not uniform, and the way to calculate in such case is discussed.

NOMENCLATURE

A_R	Rudder area (m^2)
B	Breadth of ship (m)
b_R	Rudder breadth (m)
C_B	Block coefficient of ship (-)
D_P	Propeller diameter (m)
d	Draft of ship (m)
F_N	Rudder normal force (N)
F_{Na}	Apparent rudder normal force (N)
h_R	Rudder height (m)
I_{zz}	Yaw moment of inertia (kg m^2)
m	Ship mass (kg)
m_x	Added mass in surge (kg)
m_y	Added mass in sway (kg)
N	Yaw moment (N m)
N_H, N_P, N_R	Yaw moment components of hull, propeller and rudder (N m)
n	Propeller revolutions per minute (rpm)
P	Propeller pitch (m)
r	Angular velocity in yaw(deg/s)
$\dot{r}$	Angular acceleration in yaw(deg/s^2)
r'	Non-dimensional angular velocity (-)
t	Thrust deduction factor (-)
U_c	Current speed (m/s)
U_d	Drifting speed due to current (m/s)
U_R	Rudder inflow velocity (m/s)
U_{Ra}	Apparent rudder inflow velocity (m/s)
U'	Non-dimensional ship speed (-)
u	Speed in surge (m/s)
u_a	Apparent speed in surge (m/s)
u_{Ra}	Apparent speed of rudder in surge(m/s)
u_c	Current speed in surge (m/s)
$\dot{u}_a$	Apparent acceleration in surge (m/s^2)
v	Speed in sway (m/s)
v_a	Apparent speed in sway (m/s)
v_{Ra}	Apparent speed of rudder in sway (m/s)
v_c	Current speed in sway (m/s)
$\dot{v}_a$	Apparent acceleration in sway (m/s^2)
X	Surge force (N)
X_H, X_P, X_R	Surge force components of hull, propeller and rudder (N)
x_G	Centre of gravity in x-axis direction (m)
Y	Sway force (N)
Y_H, Y_P, Y_R	Sway force components of hull, propeller and rudder (N)
Z	Number of propeller blades (-)
α_R	Rudder inflow angle (deg)
α_{Ra}	Apparent rudder inflow angle (deg)
β	Drift angle of ship (deg)
δ	Rudder angle (deg)
Λ	Aspect ratio of rudder height to chord length (-)
ψ	Ship heading (deg)
ψ_c	Current direction (deg)
ψ_d	Drifting angle due to current (deg)

1. INTRODUCTION

In a narrow water channel/river where there is fast current/stream exists, ship cannot be operated in high speed and the ship motion has relatively large drift angle. To assess the safety of ship operation in such circumstances, it is important to simulate the ship motion in current/stream accurately. If there are some obstacles in waterway such as islands, shallow bottom/water splash, a lock or flood gate etc., the ship behaviour is quite complicated because of the current/stream near-by the obstacles. This paper aims to predict ship behaviour in such case. There are already some researches [1-6] mostly done in 1970s in Japan, because in Japan there are many strong current waterways mostly in an inland sea called "Setonaikai", due to the fact that there are strong ocean current as well as strong ocean tidal, there exists large difference of sea surface at the orifices between outer area and inland sea. This area is called as "Seto" in Japanese and from the ancient time, it is terrified by seamen. Therefore these researches [1-6] were done to analyze/prevent the accidents happened at such places. In these researches, they [2,3,4] treat mathematical model using apparent velocity due to the current. Even though they did not quote, this concept is probably first proposed by Crane [7]. He has also proposed to use cross flow model which can be applied for the calculation of ship motion in a non-uniform current, although he did not apply it for simulation.

Ogawa [4,5,6] used the shear flow model instead of the cross flow model. He [4] researched about the shear flow model numerically, and for validation of the model, he [5] conducted experiment. Then, the model is applied to actual problem [6]. Honda, *et al.* [1] studied the research based on real ship observation/measurement, and heading angle distribution between simulation and observation/measurement is compared. Iwai *et al.* [3] studied about the influence of current around the bridge pier for safe course-keeping of ship, and they [3] showed the dangerous zone is wide and the ship manoeuvring is rather effective to the reverse current. However, as their [1-6] research aim is to estimate a ship's motion in such a place, they did simulation based on the measured current distribution, and they did not draw general conclusion on the influence of the current.

Kashiwagi [8] used cross flow model for simulation of ship motion in a non-uniform current, following Crane's [7] concept.

Yang and Fang [9] have also worked for this subject, and proposed new distribution forms of hydrodynamic force and moment on the basis of wing theory. Their model is expressed following Ogawa [6] and Kashiwagi's [8] expression way, and Crane's [7] apparent speed concept is used.

In this paper, the basic behaviour of ship motion in a current will be discussed using apparent speed concept proposed by Crane [7]. For the main purpose of this paper, ship behaviour near-by a lock should be calculated using cross flow model, but at the same time, the importance of low speed manoeuvring model is pointed out. Actual simulation of the ship motion near-by a lock will be done based on the measured/estimated current distribution with mathematical model for low speed, although in this paper, it is not yet done.

2. SHIP MANOEUVRING MOTION IN CURRENT

2.1 MATHEMATICAL MODEL UNDER UNIFORM CURRENT

In this chapter basic mathematical model treating uniform current will be summarized.

Coordinate system and definition of symbols and their positive directions are shown in Figure 1. There are several expressions to express external forces and moment (X, Y and N) in eq. (1), but here they are generally described in terms due to hull (H), propeller (P) and rudder (R) as shown in eq. (2).

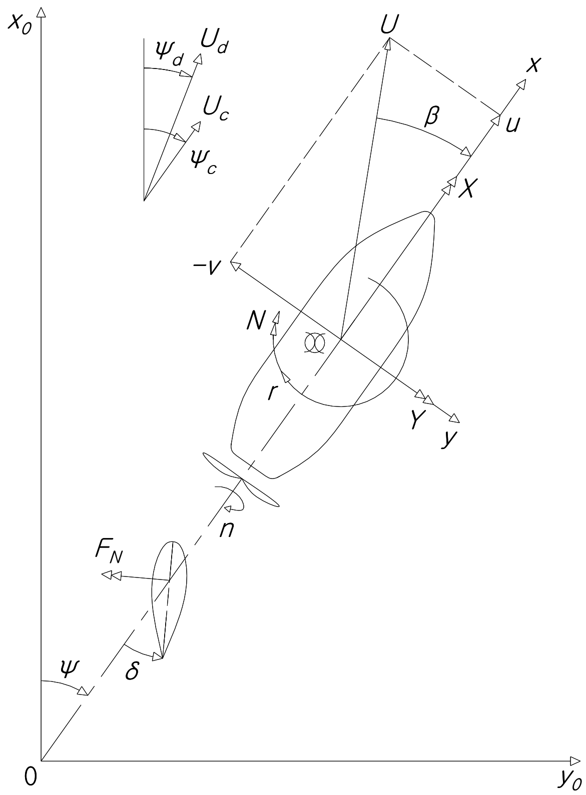


Figure 1: Coordinate system.

$$\left.\begin{aligned} m(\dot{u}-vr-x_G r^2) &= X \\ m(\dot{v}+ur+x_G\dot{r}) &= Y \\ (I_{zz}+mx_G^2)\dot{r} & \\ +mx_G(\dot{v}+ur) &= N \end{aligned}\right\} \quad (1)$$

$$\left.\begin{aligned} X &= X_H + X_P + X_R \\ Y &= Y_H + Y_P + Y_R \\ N &= N_H + N_P + N_R \end{aligned}\right\} \quad (2)$$

In the expressions of each external force and moment, apparent speeds u_a and v_a are used as shown in eq. (3), instead of u and v respectively, when a current exists.

$$\left.\begin{aligned} u_a &= u + U_c\cos(\psi_c - \psi) \\ v_a &= v + U_c\sin(\psi_c - \psi) \end{aligned}\right\} \quad (3)$$

where U_c is current speed, ψ_c and ψ are the current directions and ship heading angle respectively. It is described, as shown in *e.g.* eq. (4). The detail expression is based on MMG model [10,11], but it is not unique and not necessary to be the same expression.

$$
\left.\begin{aligned}
X &= -\dot{u}_a m_x + v_a r m_y + X_{vv} v_a^2 \\
&\quad + X_{vr} v_a r + X_{rr} r^2 + X_{vvvv} v_a^4 \\
&\quad + (1-t)T - R \\
&\quad - (1-t_R) F_N \sin\delta \\
Y &= -\dot{v}_a m_y - u_a r m_x + Y_v v_a + Y_r r \\
&\quad + Y_{vv} v_a |v_a| + Y_{rr} r |r| \\
&\quad + Y_{vvr} v_a^2 r + Y_{vrr} v_a r^2 \\
&\quad - (1+a_H) F_N \cos\delta \\
N &= -\dot{r} J_z + N_v v_a + N_r r \\
&\quad + N_{vv} v_a |v_a| + N_{rr} r |r| \\
&\quad + N_{vvr} v_a^2 r + N_{vrr} v_a r^2 \\
&\quad - (x_R + a_H x_H) F_N \cos\delta
\end{aligned}\right\} \qquad (4)
$$

where t is thrust deduction factor, T is thrust, and R is resistance of a ship. In the term of rudder force, t_R is effective wake coefficient, δ is rudder angle. F_N is rudder normal force as shown in eq. (5).

$$
\left.\begin{aligned}
F_N &= \frac{\rho}{2} A_R f_\alpha U_R^2 \sin\alpha_R \\
U_R &= \sqrt{u_R^2 + v_R^2} \\
\alpha_R &= \delta - \tan^{-1}\left(\frac{-v_R}{u_R}\right)
\end{aligned}\right\} \qquad (5)
$$

where A_R and f_α are rudder area and the gradient of the lift coefficient of rudder respectively, U_R is inflow velocity of rudder, and α_R is inflow angle. u_R and v_R are surge and sway speed at rudder. For more detail of u_R and v_R, refer [10,11]. In order to treat current, the concept of apparent speed which is shown in eq. (6), must be used for the U_R and α_R.

$$
\left.\begin{aligned}
u_{Ra} &= u_R + U_c \cos(\psi_c - \psi) \\
v_{Ra} &= v_R + U_c \sin(\psi_c - \psi)
\end{aligned}\right\} \qquad (6)
$$

As a result, eq. (5) is transformed as eq. (7), the subscript N, a and R of F_{Na}, U_{Ra} and α_{Ra} means normal, apparent and rudder respectively.

$$
\left.\begin{aligned}
F_{Na} &= \frac{\rho}{2} A_R f_\alpha U_{Ra}^2 \sin\alpha_{Ra} \\
U_{Ra} &= \sqrt{u_{Ra}^2 + v_{Ra}^2} \\
\alpha_{Ra} &= \delta - \tan^{-1}\left(\frac{-v_{Ra}}{u_{Ra}}\right)
\end{aligned}\right\} \qquad (7)
$$

2.2 MATHEMATICAL MODEL IN NON-UNIFORM CURRENT

2.2 (a) Hydrodynamic Force and Momnet Acting on a Hull

In non-uniform current situation, lateral hydrodynamic force cannot be calculated properly using MMG model. Because of this problem, Ogawa [4,5,6] proposed the shear flow model as shown in eqs. (8,9,10). The lateral force Y_H and yaw moment N_H acting on a ship due to a current can be expressed as shown in eq. (8), if it is expressed in the distribution component.

$$
\left.\begin{aligned}
Y_H &= \int_{-L/2}^{L/2} y_H(\xi) d\xi \\
N_H &= \int_{-L/2}^{L/2} n_H(\xi) d\xi
\end{aligned}\right\} \qquad (8)
$$

where the lateral force and moment distribution alongside longitudinal direction $y_H(\xi)$ and $n_H(\xi)$ can be expressed as eq. (9).

$$
\left.\begin{aligned}
y_H(\xi) &= h(v_a, r) f(\xi) \\
n_H(\xi) &= h(v_a, r) f(\xi)\xi
\end{aligned}\right\} \qquad (9)
$$

where $h(v_a, r)$ is the lateral force distribution for given v_a and r, and $f(\xi)$ is defined as eq. (10).

$$
\int_{-L/2}^{L/2} f(\xi) d\xi = 1 \qquad (10)
$$

On the other hand, Kashiwagi [8] proposed to use cross flow model originally proposed by Crane [7] for the lateral force and moment, which can be applied for a non-uniform current directly. The non-linear terms in Y and N expressions in eq. (4) are replaced with the cross flow models which are expressed as $Y_{NL}(v_a, r)$ and $N_{NL}(v_a, r)$ as shown in eq. (11), where v used in normal, cross flow model are replaced with v_a.

$$
\left.\begin{aligned}
Y_{NL} &= -C_D \int_{-1/2}^{1/2} |v_a(\xi) + \xi r| (v_a(\xi) + \xi r) d\xi \\
N_{NL} &= -C_D \int_{-1/2}^{1/2} |v_a(\xi) + \xi r| (v_a(\xi) + \xi r) \xi d\xi
\end{aligned}\right\} \qquad (11)
$$

where C_D is drag coefficient of hull at drift angle is 90°.
Yang and Fang [9] proposed a similar expression of $y_H(\xi)$ based on wing theory.

2.2 (b) Hydrodynamic Force Acting on a Rudder

In non-uniform current situation, U_c and ψ_c are different according to the position in space fixed coordinate system. Moreover, for hull and rudder, different two concepts of apparent speed are required. The apparent speed at hull have to be calculated using eq. (3), and the apparent speed for rudder have to be calculated using eq.

(6), where U_c, the current speed and ψ_c, the current direction is the function of the coordinate of the rudder in the space-fixed coordinate system 0-x_0y_0.

3. SIMULATION OF SHIP MANOEUVRING MOTION IN CURRENT

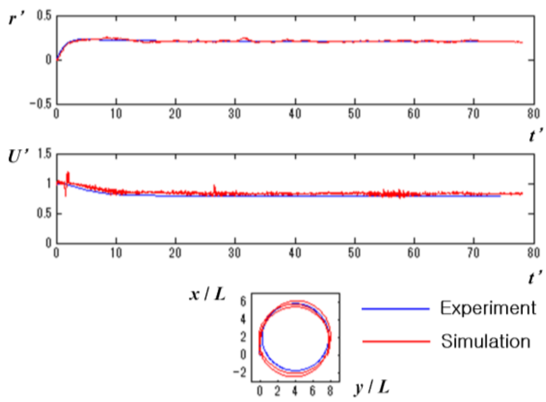
For the estimation of ship manoeuvring motion in a current, simulation studies are carried out. As the subject ship, Esso Osaka model is used, and the principal particulars are listed in Table 1. The simulation is conducted at ship speed is 0.495 m/s with various current speed.

Table 1: Principal particulars of subject model.

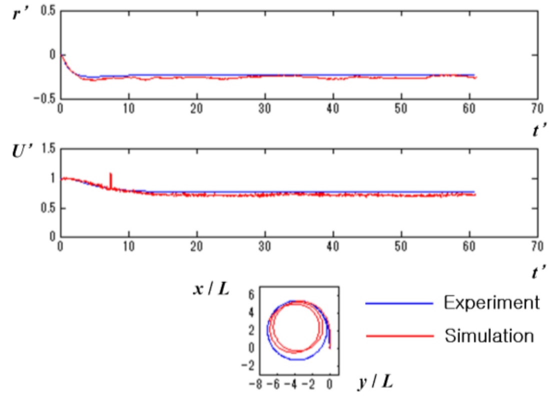
Hull	Length, L (m)	3.000
	Breadth, B (m)	0.489
	Depth, d (m)	0.201
	Block Coefficient, C_B	0.831
Propeller	Propeller Diameter, Dp (m)	0.084
	Pitch, P (m)	0.060
	No. of Blades, Z	5
Rudder	Rudder Breadth, b_R (m)	0.080
	Rudder Height, h_R (m)	0.128
	Rudder Area, A_R (m^2)	0.010
	Aspect Ratio, Λ	1.54

3.1 SIMULATION IN VARIOUS CURRENT CONDITIONS

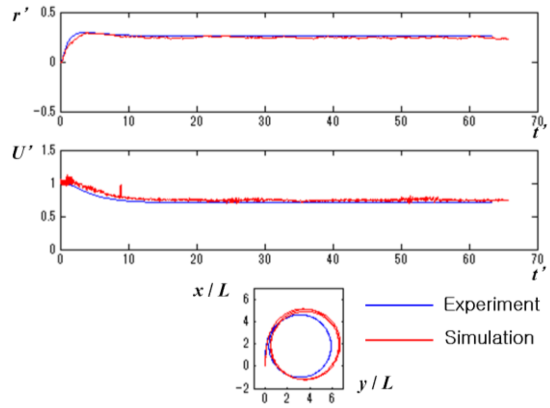
Before conducting the simulation in current, in order to validate the mathematical model and its coefficients, turning simulation is conducted in several rudder angle conditions without current, and results are compared with the free running experiment data as shown in Figure 2. They match well respectively, so the model and its coefficients are validated.



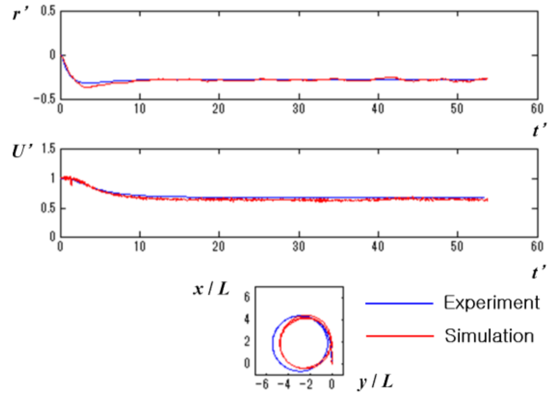
(a) 10° turning



(b) -10° turning



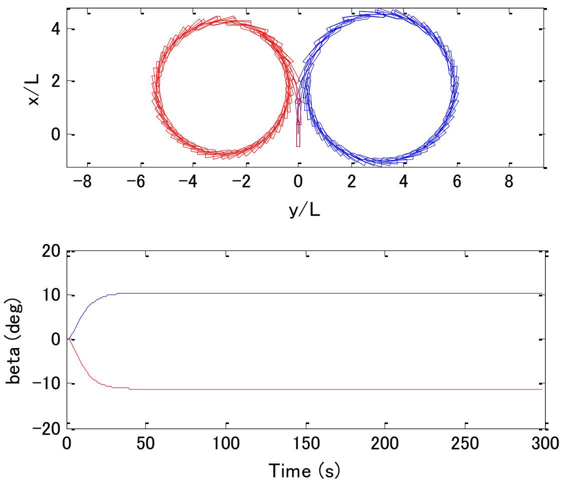
(c) 15° turning



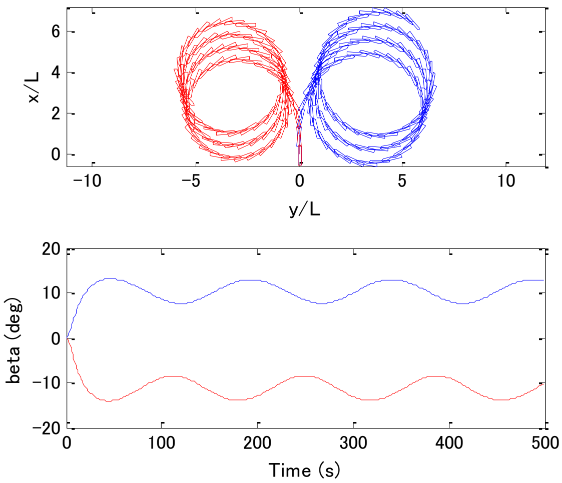
(d) -15° turning

Figure 2: The comparison of several turning motions between experiment and simulation.

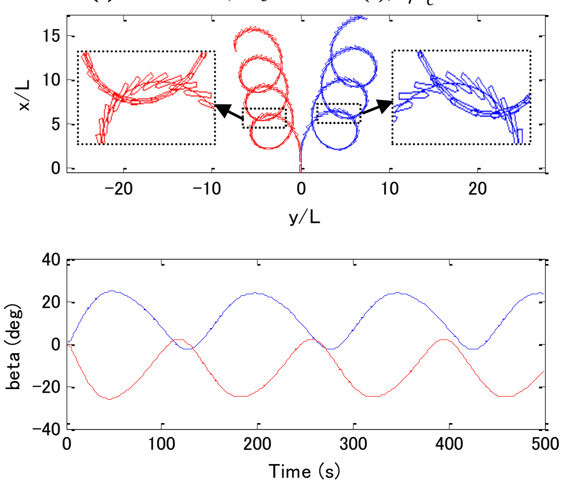
The simulation is conducted for rudder angle is 15° in various current conditions and the results are shown in Figure 3. Figure 3(e) is the result without a current for the comparison with others (f-h). The upper graph is the ship's trajectory and the lower graph is the time history of drift angle (β) respectively. The upper graph of Figure 3(e) is same with the trajectories of Figure 2(c-d), but drift angle is added for the comparison between others (f-h). It is found that the drift angle is saturated to around +/-10° in steady turning. In case of Figure 3(f-h), turning circle radius is almost same but drifting down stream side with slightly starboard side for starboard turning and vice versa for port turning. Looking inside the time history of the drift angle and enlarged part of the trajectories, it is also found that the drift angle fluctuates around the saturated value of the case (e) and the degree of the fluctuation is proportional to the current speed ratio to the ship speed. Due to this fluctuation, the ship has larger drift angle in down stream side (12 O'clock direction, if the turning trajectory is regarded as a clock) of a turning circle and vice versa in the upper stream side (6 O'clock direction) of a turning circle. On the other



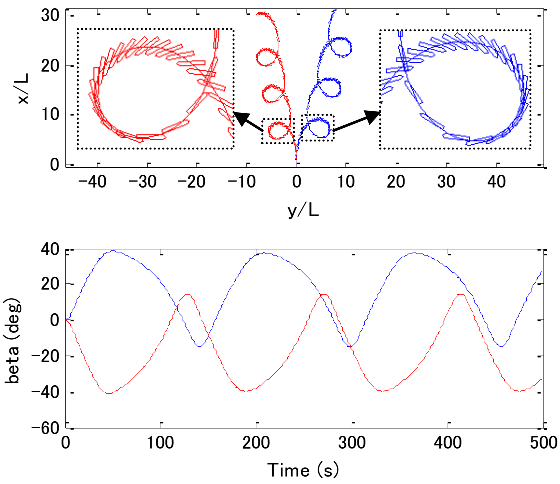
(e) δ= +/-15°, U_c/U = 0.0 (-), ψ_c = 0.0°



(f) δ= +/-15°, U_c/U= 0.1 (-), ψ_c = 0.0°



(g) δ= +/-15°, U_c/U = 0.5 (-), ψ_c = 0.0°



(h) δ= +/-15°, U_c/U = 1.0 (-), ψ_c = 0.0°

Figure 3: Simulation results in various current speed ratio conditions with current direction is 0°.

hand around 3 O'clock direction and 9 O'clock direction the drift angle is almost same with the value of the case (e). This asymmetry of the drift angle makes the *trajectory* to *drift* (which is not the same terminology of the ship drift angle and to be defined as *trajectory drift* [12]) starboard side for starboard turning and port side for port turning. Figure 4 shows the relation of the *trajectory drift* angle in term of $|\psi_d|$-ψ_c, where ψ_d is the *trajectory drift* angle and the current speed ratio to the ship speed. Figure 5 shows the relation of the *trajectory drift* speed of the trajectory defined as U_d in ratio to U_c and the current speed ratio to the ship speed.

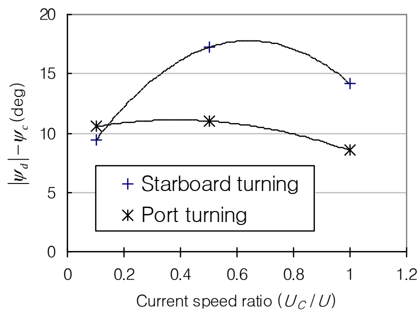


Figure 4: The relation between current speed ratio and drifting angle.

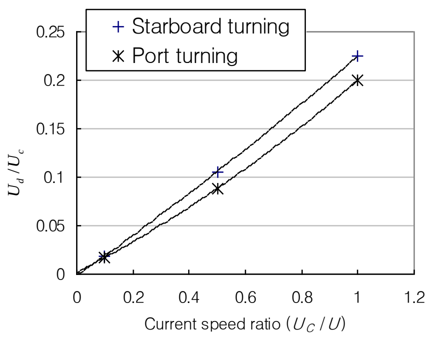


Figure 5: The relation between current speed ratio and drifting speed ratio.

From Figures 3-5, the following general descriptions of current influence to a ship motion in case of turning can be drawn.

(1) The ship *trajectory drifts* to the down stream side, when a ship makes turning in a uniform current, but slightly starboard side for starboard turning and vice versa for port turning. This tendency is also obtained by You and Rhee [13].

(2) The *trajectory drift* angle has not clear tendency, and different between starboard and port turnings with the current speed ratio to the ship speed, but roughly speaking, the difference of this value is not so large and around 10-17º.

(3) Contrary, the *trajectory drift* speed is almost proportional to the current speed ratio to the ship speed and not much different between starboard and port turnings.

(4) In a single turning circle, even if the *trajectory drifts*, the ship drift angle is different with the ship position in the circle. Around 12 O'clock, if the circle will be regarded as a clock, there exists larger drift angle and the value is almost proportional to the current speed ratio to the ship speed, while around 6 O'clock, the value is smaller than that of no current condition. If the current speed ratio to the ship speed exceeds 0.5, the maximum drift angle exceeds 20º. It suggests that in such large drift angle range due to current/stream, a normal mathematical model such as eq. (4) cannot be applied, but a low speed manoeuvring model should be used, because the normal mathematical model expresses the hydrodynamic forces and moment acting on a ship only within the drift angle range of about +/-20º.

For the detail of the low speed manoeuvring model Oh and Hasegawa [14, 15] summarized several models and compared their applicability. Calculating ship motions in non-uniform current and applying a low speed manoeuvring model, more preside ship behaviour in sophisticated current/steam condition can be obtained.

4. CONCLUSIONS

In the present study, ship manoeuvring in a current is reviewed and simulated. In various current speed ratios to ship speed, the influence of current is studied, and the obtained results are summarized below.

1) In most cases, if the current speed ratio to ship speed is not high, conventional mathematical model can express ship motion in current well.

2) Even if the ship speed is not so low, there are some current conditions where hydrodynamic forces/moment have to be treated considering low speed model.

3) The influence of low speed mathematical model and non-uniform current should be studied in the future for the case in river or in strong shear current.

4) The method can be also utilized for ship motion analysis under tsunami or some ship accident analysis in a river.

5) The influence of ship drifting in a current at turning motion is shown respective to current ship speed ratio.

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