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Maneuvering Performance of Indonesian Ro-Ro Ferries under Action of Wind

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Abstract: Maneuvering performance is one of the most important aspect in ship operation especially when the ship operating in rough weather. Ships with large windage area may have large drift angle. In order to maintain the ship direction or heading angle, a significant rudder angle is necessary. The ship speed may significantly decreases due to high wind speed. This paper discusses maneuvering performance of Indonesian ro-ro ferries under action of variation wind speed. The wind speed variation was determined using the ratio between the wind speed and the ship speed. The wind direction is also simulated from 0 degree (head wind) and 180 degrees (following wind). The results show that the drift angle significantly increases due to increases the wind speed. The maximum drift angle occurs when the angle of wind direction relative to the ship is 60 degrees. The same phenomena occur in case of the rudder angle. However the necessary rudder angle in order to maintain the ship direction is larger than the drift angle of the ship mainly in low wind speed.

Keywords: maneuvering，ro-ro ferries，wind

1. Introduction

As an archipelago country with more than one thousand islands, the ro-ro ferries play an important role for inter-island transportation in Indonesia. The ro-ro ferries are mostly used to transport passenger, goods and vehicles from one island to the other island with short distance or operation time not longer than 8 hours even for some certain routes, the time operation are longer than 12 hours. Recently more than 170 ro-ro ferries are operated to serve inter-island transportation in Indonesia. Some of them were the second hand ships imported from foreign countries especially from Japan with age more than 25 years. The others were build in national shipyard with similar geometry characteristics such as large breadth and small draught. Most of ferry terminals have shallow water front, therefore the draught was designed as small as the water deep. The ship breadth was designed to be large in order to accommodate the goods and vehicles as main payload of the ro-ro ferries. The Indonesian ro-ro ferries are identified with small freeboard in order to easily load in and load out the vehicles. This is because tidal is very large in some location of the ro-ro ferry terminals.

Even the distance between the islands is not too long, condition of sea environment in some water area may become stronger for a certain period of time. The wind speed could reach 20 m/s or more and the wave height more than 4.0 meters [1]. The current velocity is also sometime become faster due to position of Indonesia located between two continents and two oceans. Several collision accidents of ro-ro ferries have been occurred such as collision between ro-ro ferry Bahuga Jaya and a chemical tanker in Sunda Street two years ago. The ro-ro ferry Bahuga Jaya sunk with passenger loss more than 10 persons and some vehicles as well as goods. This accident shows that maneuvering characteristics of ro-ro ferries under action of wind and wave is important in order to avoid such accident in the future especially in traffic route such as Sunda

Street. The wind may excite significant drift motion for ships with large windage area. Significant drift motion may also occur when the ship operating in rough sea. Fujiwara et., al. [2] investigated effect of wind and wave on maneuvering performance of a large passenger ship. Their results show that drift angle of the passenger ship significantly increase when the wind velocity increases. The ship speed also drastically decreases due to wind and waves. Direction stability of the ship may also become unstable when the ship operating in windy condition [3]. This means that the heading angle also be able to significantly change due to wind. In order to maintain the ship direction, a large rudder angle is necessary depends on the wind speed and direction relative to the ships.

The Indonesian ro-ro ferries have large windage area for both lateral and transverse direction. This large windage area induces forces and moments so that the ships experience drift, heeling and yawing. With small draught, the hydrodynamic forces and moments induced by ship hull could be smaller than those induced by the wind. As a result, drifting motion, roll angle and heading angle due to wind is larger than the ship with larger draught. This interaction of wind and ship hull forces and moments may affect the direction stability of the ship become unstable. In order to maintain direction of ship in windy condition, rudder angle should be changed oppositely contrary to the forces and moments due to wind. The changing of rudder angle depends on the wind speed and direction as well as the windage area.

This paper discusses effect of wind on maneuvering performance of Indonesian ro-ro ferries. This is important in operation to avoid misdirection relating to collision accident. Under a certain wind speed and direction, drift angle, actual ship velocity and rudder angle for maintaining the ship direction can be estimated. The actual ship velocity can be used to estimate time to destination for estimating fuel consumption. Results in this paper may be in advance used to develop maneuvering control to avoid collision.

2. Ship Maneuvering Under Action of Wind

Ship maneuvering is usually modeled using three degree of freedom equation namely surge, sway and yaw. Some researchers use four degree of freedom including the roll motion equation in order to investigate effect of some maneuvering factor on roll motion [2]. The mathematic model of maneuvering equation is developed based on the local and global coordinate systems as shown in Figure 1. The original of the local coordinate system was in the ship center of gravity and the global coordinate system is fixed relative to the earth. Here, u and v are the surge and sway velocity respectively. U and β are the ship speed and drift angle. The heading angle of the ship is measured on the global coordinate system designated as ψ. U_T is the wind velocity and the wind direction relative to the ship is indicated by ψ_T.

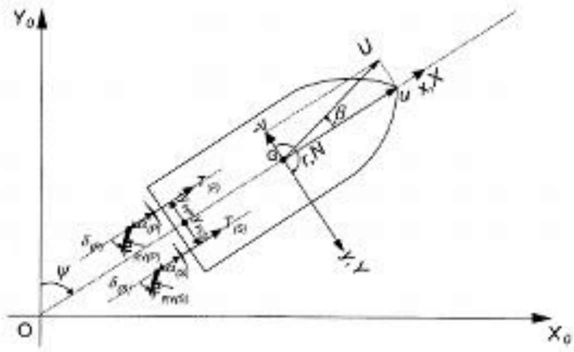

Fig. 1. The coordinate system of ship maneuvering.

The equation of ship motion for three degree of freedom using the MMG model proposed by Hirano, et., al [4] and Kijima, et., al. [5] as follows:

$$m(\dot{u} - vr) = X$$
$$m(\dot{v} - ur) = Y \qquad (1)$$
$$I_{zz}\dot{r} \qquad = N - x_G Y$$

where m and I_{zz} are the ship mass and moment of inertia of ship in yaw motion, respectively. $\dot{u}$ and $\dot{v}$ are the surge and sway acceleration and x_G is the longitudinal position of ship center of gravity. X, Y and N are the resultant of external force in surge, the resultant of external force in sway and the resultant of external moment in yaw motion, respectively. These external forces and moments consist of hull hydrodynamic forces and moments as well as forces and moments induced by the propeller, rudder and wind. The total external forces and moments in surge, sway and yaw motion therefore can be written as follows:

$$X = X_H + X_P + X_R + X_A$$
$$Y = Y_H + Y_P + Y_R + Y_A \qquad (2)$$
$$N = N_H + N_P + N_R + N_A$$

The hull hydrodynamic forces and moment consist of the calm water resistance and the forces acting on the underwater hull due to drift angle which can be obtained from the hydrodynamic derivative as the following equation [6]:

$$X_H = \frac{\rho}{2}LTU^2\left(X'_{HO} + X'_{\beta\beta}\beta^2 + \left(X'_{\beta rr} - m'_y\right)\beta r' + X'_{rr}r'^2 + X'_{\beta\beta\beta r}\beta^3 r' + X'_{\beta\beta\beta\beta}\beta^4\right)$$
$$Y_H = \frac{\rho}{2}LTU^2\left(Y'_{\beta}\beta + (Y'_r - m'_x)r' + Y'_{\beta\beta\beta}\beta^3 + Y'_{\beta\beta r}\beta^2 r' + Y'_{\beta rr}\beta r'^2 + Y'_{rrr}r'^3\right) \qquad (3)$$
$$N_H = \frac{\rho}{2}L^2TU^2\left(N'_{\beta}\beta + N'_r r' + N'_{\beta\beta\beta}\beta^3 + N'_{\beta\beta r}\beta^2 r' + N'_{\beta rr}\beta r'^2 + N'_{rrr}r'^3\right)$$

In case of steady condition, the ship has constant surge velocity, sway velocity and heading angle. It means that the yaw velocity becomes zero when the ship in steady condition. Component yaw rate (r’) therefore can be neglected from the above equation.

The propeller thrust is estimated in a manner consistent with the MMG model using the following equation [5]:

$$X_P = (1 - t_P)n^2 {D_P}^4 K_T(J) \qquad (4)$$

Here, t_P is thrust deduction factor. N and D_P are the rotational velocity of propeller and the propeller diameter, respectively. K_T is the thrust coefficient depending on advance coefficient, J. In case of twin propeller, yaw moment induced by the propeller may exist due to different rotation velocity between the starboard and portside propeller. Therefore, the propeller thrust and the yaw moment due to the propeller thrust for twin propeller may be mathematically written as follow:

$$X_P = \left(1 - t_{P(S)}\right)n^2 {D_P}^4 K_{T(S)}(J) + \left(1 - t_{P(P)}\right)n^2 {D_P}^4 K_{T(P)}(J)$$
$$N_P = y_{P(S)}\left(1 - t_{P(S)}\right)n^2 {D_P}^4 K_{T(S)}(J) + y_{P(P)}\left(1 - t_{P(P)}\right)n^2 {D_P}^4 K_{T(P)}(J) \qquad (5)$$

where subscribe s and p indicates the starboard and portside propeller, respectively. y_P is the transverse position of the propeller.

The rudder forces and moments are estimated following Kijima empirical equation [5] for single propeller single rudder. In cases of ship with twin propeller twin rudder, the rudder forces and moments may be estimated by using the following formula.

$$X_R = -\left(1 - t_{R(S)}\right)\left(F_{RN(S)} \sin\delta_{(S)} + F_{RN(P)} \sin\delta_{(P)}\right)$$
$$Y_R = -(1 + a_H)\left(F_{RN(S)} \cos\delta_{(S)} + F_{RN(P)} \cos\delta_{(P)}\right) \quad (6)$$
$$N_R = -(x_R + x_H a_H)\left(F_{RN(S)} \cos\delta_{(S)} + F_{RN(P)} \cos\delta_{(P)}\right)$$

where t_R, x_R, x_H and a_H are reduction coefficient of rudder resistance in surge direction, longitudinal position of rudder measured from the midship section, position of the interaction force induced by ship hull and normal rudder force and coefficient of interaction force on ship hull induced by rudder normal force, respectively. F_{RN} is the rudder normal force depends on the rudder area, rudder coefficient, inflow velocity to the rudder, effective rudder angle and the rudder angle. Δ is the rudder angle and the subscribe s and p indicate the starboard and portside rudder respectively.

3. Methodology

The above mathematic model of maneuvering equation is applied to investigate effect of wind on an Indonesian ro-ro ferry with principle dimensions shown in Table 1 and the propeller and rudder characteristics are shown in Table 2. The ship resistance was estimated using Holtrop method. The coefficients of hydrodynamic derivative of ship hull are estimated using Yoshimura empirical equation [4].

Table 1. Main particulars

Length overall (L_{OA})	36.40 m
Length between perpendicular (L_{BP})	31.50 m
Breadth (B)	8.70 m
Height (H)	2.65 m
Draught (T)	1.65 m
Ship speed (V_S)	10.5 knot
Block coefficient (C_B)	0.63
Midship coefficient (C_M)	0.986
Waterline coefficient (C_W)	0.886
Prismatic coefficient (C_P)	0.804
Lateral projected windage area (A_L)	36.40 m^2
Transverse projected windage area (A_F)	93.61 m^2
Lateral projected area of superstructure (A_{OD})	187.21 m^2
Center of windage are from midship (C)	-0.558 m
Vertical center of A_L (H_C)	0.720 m
Vertical center of A_{OD} (H_L)	4.930 m
Height of transverse projected area (H_{BR})	10.73 m

Table 2. Propeller and rudder dimension

Number of propeller	2
Propeller blade (Z)	4
Propeller diameter (D_P)	1.10 m
Propeller revolution (n)	8.58 rps
Transverse position propeller (y_P)	±2.55 m
Long. position propeller (x_P)	15.50 m
Rudder area (A_R)	2.08 m^2
Rudder coefficient (f_Λ)	2.10
Transverse rudder position (y_R)	±2.55 m
Long. Rudder position (x_R)	15.75 m

The thrust coefficient was statistically estimated using the following polynomial equation:

$$K_T(J) = \sum_{n=1}^{39} C_n(J)^{s_n} \left(P/_D\right)^{t_n} \left(A_E/_{A_0}\right)^{u_n} Z^{v_n} \tag{7}$$

Here, s_n, t_n, u_n and v_n are determined based on statistical data of B series propeller as function of the advance coefficient, J, respectively. Using the equation (7), the thrust coefficient for each advance coefficient can be obtained which can be modeled as a third order polynomial equation as function of advance coefficient as the following equation:

$$K_T(J) = a_0 + a_1 J + a_2 J^2 \tag{8}$$

Maneuverability of the ro-ro ferries under action of wind will be investigated in variation of wind speed and direction. The wind speed was decided from 5 m/s up to 20 m/s. The maximum speed was based on the wind speed data of Indonesia. The wind coefficients in surge, sway and yaw direction are estimated using Fujiwara empirical equation as function of wind direction relative to the ship [8]. These three coefficients were estimated from angle of 0 degree up to the angle of 180 degrees. The wind direction relative to the ship hull is shown in Figure 2.

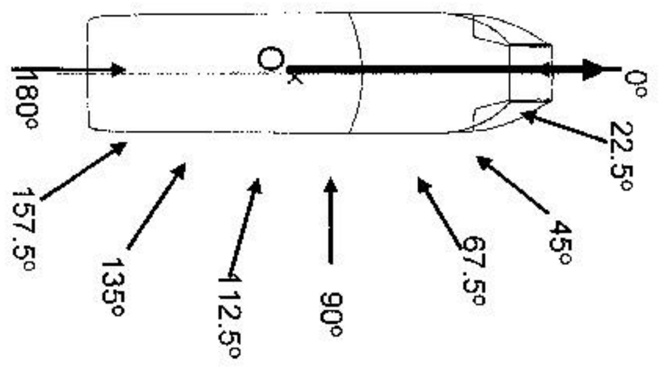

Fig. 2. Wind direction relative to the ship

The drift angle induced by the wind forces and moments will be calculated in steady state of ship motion and direction. This condition occurs when the resultant of external forces and moment acting on ship hull the same as zero. The yaw rate is also assumed to be zero in order to maintain the heading angle as requirement of steady state of ship direction. The drift angle then can be obtained by solving the equation of resultant of external forces and moments. The necessary rudder angle is finally obtained using the equation of external forces and moments.

4. Results and Discussion

Numerical simulations of turning and zig-zag maneuvers with and without wind have been performed with results shown in Figure 3 for then turning maneuver and Figure 4 for the zig-zag maneuver. Here, the wind speed was 20 m/s and the wind direction of 30 degrees for the turning maneuver. The rudder angle for the zig-zag maneuver is 10 degrees without wind.

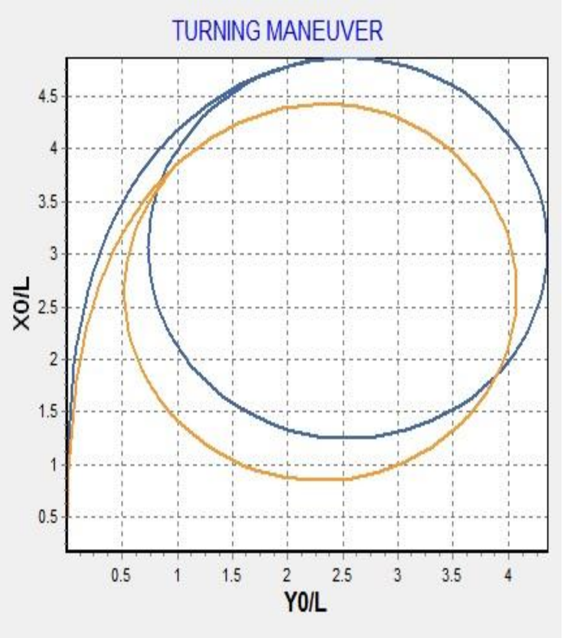

Fig. 3. Turning maneuver with and without wind with rudder angle of 35 degrees. The wind velocity of 20 m/s and direction of 30 degrees.

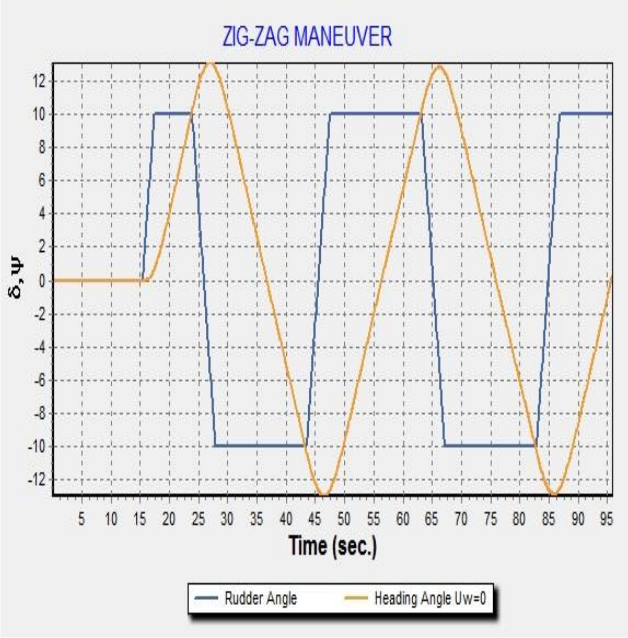

Fig. 4. Zig-zag maneuver without wind with rudder angle of 10 degrees.

The tactical diameter and advance of the ship with wind are smaller than those with wind. The tactical diameter and advance characteristics may different for different wind speed and direction. The over shoot angle for zig-zag maneuver without wind for rudder angle of 10 degrees is 2.50 degrees. The zig-zag maneuver is very difficult to simulate in windy condition especially for high wind speed. The time period for each over shoot can be different depends on the wind speed and direction. The maneuvering performance of ships with and without wind is different because the wind direction relative to the ship changes due to the alteration of ship heading angle. The windage area also changes due to relative direction of wind as well as the forces and moment coefficients of wind. Therefore, the forces and moment acting on the ship hull fluctuate depends to the wind direction and heading angle. The variation of the wind forces and moments coefficients in each wind direction relative to the ship is shown in Figure 5. These coefficients depend on the characteristic of the ship windage area. The maximum coefficient in surge direction occurs in the wind angle of 120 degrees and the minimum coefficient occurs in the wind angle of 90.0 degrees.

The force coefficient in sway direction and the moment coefficient for yaw are smaller than the coefficient for surge direction. For the other ship type and configuration of the windage area may have different characteristics of the wind forces and moment coefficients [1]. For passenger ship investigated by Fujiwara, et. al. [1], the wind moment coefficient for yaw is the largest coefficient. This could be because of the ratio lateral and transverse projected area of the windage area.

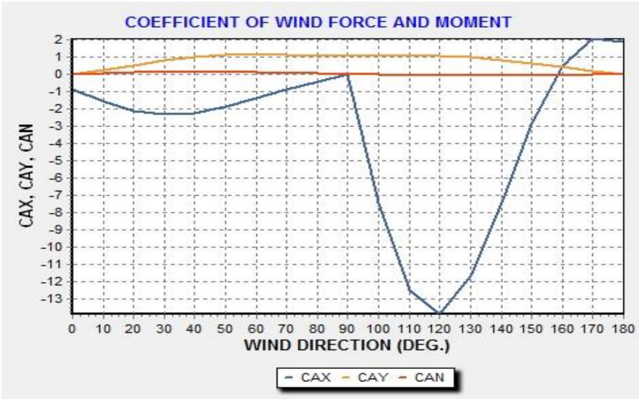

Fig. 5. The coefficient of wind forces and moments

Figure 6 show the drift angle under action of wind with wind direction from 0 degree (head wind) up to 180 degrees (following wind) and the wind speed was determined as ratio between the wind speed and the ship speed. The variation of wind speed and ship speed ratio means that the ship speed may significantly decreases when the wind speed increases.

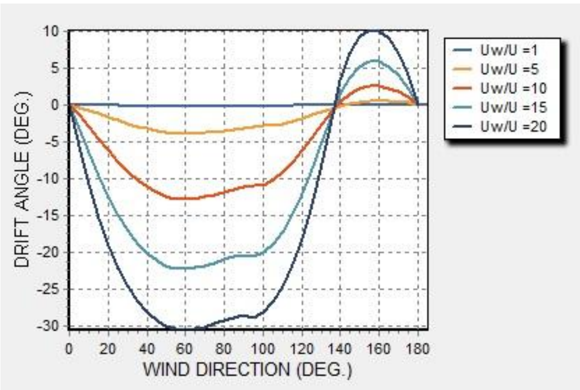

Fig. 6. The drift angle for the ratio of wind speed and ship speed of 1.0 up to 20.0.

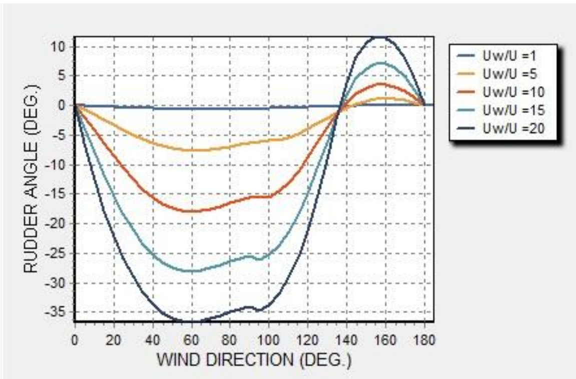

Fig. 7. The rudder angle for the ratio of wind speed and ship speed of 1.0 up to 20.0.

The drift angle increases due to increases the ratio of wind speed and ship speed and the maximum drift angle occurs in wind direction relative to the ship of 60.0 degrees. The occurrence of maximum drift angle may be affected by the center of the windage area laterally and transversally. Therefore, configuration of the ship super structure may have significant effect on the maneuvering performance in windy condition. The necessary rudder angle in order to maintain the ship direction is also increases due to increases the wind speed as shown in Figure 7. The forces and moments induced by the wind become larger when the wind speed increases for the same windage area. Therefore, larger forces and moments of rudder are needed to avoid the changing of the ship direction due to large drift angle. The necessary rudder angle is larger than the drift angle for all ratio of wind speed and ship speed even the difference is not too significant in all wind direction.

Assuming the maximum rudder angle of ships is 35.0 degrees, it can be concluded that the ship cannot be controlled under action of wind when the ratio of wind speed and ship speed more than 20.0. In case of wind speed is 20.0 m/s and the ship speed decreases lower than 1 m/s, the ship will experience drift angle more than 35.0 degrees in wind direction of 60 degrees. In this condition, the necessary rudder angle is also larger than 35.0 degrees which is the maximum rudder angle for conventional rudder system. The actual ship speed during operating in windy condition is important not only to control ship maneuver but also to estimate actual fuel consumption during operation. Therefore, advance researches regarding the decreasing of the ship speed and to determine the optimum route of the ship is important in the future.

5. Conclusions

The maneuvering performance of an Indonesian ro-ro ferry under action of wind has been investigated. Based on the numerical simulation results and discussions, some conclusions can be remarked as follow:

1. The turning radius and advance of the ship with wind is different with those without wind. The alteration depends on the wind direction relative to the ship, configuration and area of the windage. In a certain wind speed, the ship cannot perform zig-zag maneuver because the necessary rudder angle to control the ship direction is larger than the requirement rudder angle for meaning of zig-zag maneuver test.
2. The drift angle significantly increases when the ratio of wind speed and ship speed increases. As a result, the necessary rudder angle in order to avoid alteration of the ship direction becomes larger. The maximum drift and rudder angle occurs in the wind direction of 60.0 degrees and the necessary rudder angle is larger than drift angle in the same of wind speed and ship speed ratio as well as the same wind direction.
3. The maximum ratio of wind speed and ship speed for safely operating the ship is 20.0 in which the necessary rudder angle is larger than the maximum rudder angle if the wind direction relative to the ship is 60.0 degrees. However, in other wind direction, the necessary rudder angle still smaller than the maximum rudder angle.

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References

[1] Paroka, D., (2014), "Sea Environment Condition : The Basic for Developing of the Intact Stability Criteria for Non Convention Ships in Indonesia" (in Indonesia), Bulletin of Indonesian Classification Society (PT. BKI), Jakarta, Indonesia (Accepted for published).

[2] Fujiwara, T., Ueno, M. and Ikeda, Y., (2006), "Cruising Performance of a Large Passenger Ship in Heavy Sea", Proceedings of the 16th International Offshore and Polar Engineering Conference (ISOPE), San Fransisco, USA, pp. 304 – 311.

[3] Yasukawa, H., Hirano, T., Nakayama, Y. and Koh, K.K, (2011), "Course Stability and Yaw Motion of a Ship in Steady Wind", Journal of Marine Science and Techology, Japan.

[4] Hirano, M. and Takashima, J., (1982), "A Calculation of Ship Turning Motion Taking Coupling Effect Due to Heel into Consideration", Journal of West Japan Society of Naval Architects, vol. 59, pp. 71 – 81.

[5] Kijima, K., Katsuno, T., Nakiri, Y., et., al, (1990), "On the Maneuvering Performance of a Ship with The Parameter of Loading Condition", Journal Society of Naval Architect of Japan, vol. 168, pp. 141 – 148.

[6] Yoshimura, Y. and Sakurai, H., (1988), "Mathematical Model for the Maneuvering Ship Motion in

Shallow Water (3rd Report)",Translated from the Journal of Kansai Society of Naval Architects of Japan, vol. 211, pp. 115 – 126.
[7] Carlton, J., (2007), "Marine Propellers and Propulsions", Second Edition, Elsevier, Ltd.
[8] Fijiwara, T., Ueno, M. and Ikeda, Y., (2006), "A New Estimation Method of Wind Forces and Moments Acting on Ships on the Basis of Physical Component Models (in Japanese)", Journal of the Japan Society of Naval Architects and Ocean Engineers, vol. 2, pp. 243 – 255.