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To cite this article: M Hasbullah *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **676** 012023

IOP Conf. Series: Materials Science and Engineering **676** (2019) 012023 doi:10.1088/1757-899X/676/1/012023

Study on the Characteristics of Maneuvering Ferry Vessel as Effect of the Sea Waves

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Abstract. Wave is one of the natural phenomena that gives effect to the cruise ship. The energy produced by the wave is very large that makes the ship turn directions. Therefore the turn has an error coordinates of the starting point of a ship. Deviation of the coordinates has made a further distance and increase fuel consumption, so the operational costs being higher. The research would predict the drift angle, the ship speed and rudder angle to be used after the ship got the influence of wave by taking into account the motion of surge, sway, yaw. Simulations are performed by using Delphi software, with variations of the wind height of 0.5 m, 1 m, 1.5 m, and 2 m, the wave flatness of 0.01, the speed of the wind of 0 and 10 m/s and incoming wave direction 0° - 180° on the side of the ship. It is obtained that the biggest of drift angle happened on 50° wave direction. The biggest of rudder angle happened on 110° wave direction while that fastest ship speed happened on 160° wave direction.

1. Introduction

Ship maneuvering characteristics are influenced by several external factors which include sea state. This needs to be understood in view of the limited ability of the vessel to face the weather and sea waters as well as the movement of the ship in the water which also requires sufficient space. One of the external factors that influence the ship maneuvering is the sea wave. Meanwhile, influencing internal factors (ship) is the weight of the vessel, the dimensions of the vessel, hull, engine (propeller), and rudder system (steering system). They are instrumental in steering the ship when doing different movements (maneuver) in water [1].

Moreover, the influence of the waves against the yaw motion stability is very important to be analyzed, especially while the ship to be operating in wave conditions at far greater length than the length of the ship and the ship's position is on the slopes of the wave. This condition is known by the phenomenon of surf – riding [2, 3]. In this condition, the yaw motion of the vessel can be unstable despite steering control is given. The vessel will turn and move with the waves, the ship's position will ultimately sideways against the waves and eventually sink or reversed.

2. Theoretical Basis

2.1. Ships motion

On the principle of the motion, behavior of the ship is divided into six-degrees of freedom (six-degree of freedom), namely surge, sway, yaw, heave, roll, and pitch which are shown in Figure 1.

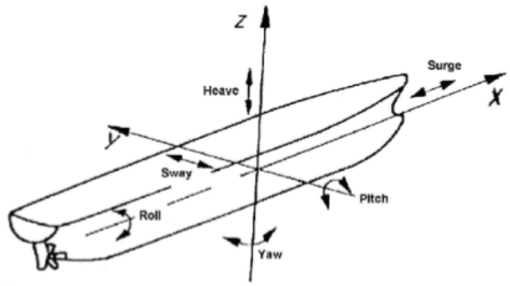

Figure 1. Six degrees of freedom of movement of ships

From Fig. 1, it can be understood as follows

1) *Surge* is one of the translational motion where the vessel experiences displacement on the *x*-axis (*x*-axis direction moving). The motion is not the case of mass change of the vessel, so there is no point bouyancy protection force.
2) *Sway* is one of the translational motion of the ship experienced displacement in the *y*-axis (move sideways), on the motion of the ship's center of gravity has not changed so there is no change of the mass of the ship and the bouyancy point is also does not move and no protection force.
3) *Yaw* is one of the rotational motion of a moving ship spinning on the *z*-axis so that if observed from the above, it can be seen that ship rotation moving.
4) *Heave* is the ship movement up and down vertically.
5) *Roll* is the rotational motion of the ship on the *x*-axis.
6) *Pitch* is the angular movement of the rotating fore and aft of the transverse axis of the ship, along the *y*-axis.

2.2. Steering ship

The rudder is a device to change direction ship by changing the direction of fluid flow that results in changes of ship direction. The steering wheel is placed at the threshold of the back hull (stern). The propeller is driven mechanically or hydraulically from the bridge by moving steering wheel. Because of the important role of steering in sailing, then SOLAS International Convention set rules in Chapter II-1 Construction regarding subdivision and stability, machinery and electrical installations [4, 5].

Rudder has the ability to maintain direction in accordance with the command. Since the requirements for passenger ships, steering wheel which is widely used is the type of Van Amorengen with specifications between -35° to 35° and rudder employment rate of 2.3° - 7° each second. The minimum requirement for an average rate of rudder is determined by the classification society. It is required that the rudder can be moved 35° from the port towards 35° to starboard in no more than 30 seconds.

Table 1. Standard maneuverability ship by IMO (Resolution MSC 137 (76) 2002)

Ability	Test	Criteria
Turning ability	Turning test with max. Rudder Angle (35 deg.)	Advance <4.5 L Tactical diameter <5.0 L
Initial turning ability	10^0 / Z-test10^0	Distance ship rudder run before execution <15 L2^{nd}

The maneuver used in the experiments at sea following a recommendation from the trial maneuvering code of ITTC (1975) and the IMO circular MSC 389 (1985). IMO also determine the appearance of some of the results on posters, bucklet and maneuvering bucklet in IMO Resolution A.601 (15) (1987) [6-8].

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3. Methodology

3.1. Location and Research Time

This research was conducted in the laboratory of hydrodynamics, Naval Architect Department, Faculty of Engineering, University of Hasanuddin.

The vessel which was used as a sample of this research is Ro-Ro Ferry KMP SULTAN Murhum 300 GT. With the primary measure of data as shown in Table 2.

Table 2. Dimensions of the vessel

Main Dimensions			Form Coefficients			Propulsion System Parameters		
LOA	=	36.4 m	Cb	=	0.63	Hr	=	1.559 m
LWL	=	35.73 m	cm	=	0.986	IR	=	1.331 m
LBP	=	31.5 m	Cw	=	0.886	$N_{propeller}$	=	2
B	=	8.7 m	cp	=	0.804	n	=	8.578
H	=	2,65 m				xr	=	-15.75 m
T	=	1.65 m				D	=	1.1 m
V	=	10.5 Knot				N_{blade}	=	4

Source: PT IKI (Shipbuilding Industry Indonesia)

4. Results and Discussion

4.1. Coefficient of hydrodynamics

For calculating the coefficient of hydrodynamic hull according to Yoshimura and Ning Ma with a semi-empirical method, which considered three (3) movement of ships that are surge, sway, and yaw. To run the program, required input data are the main parameters of the vessel which is the object of research. The steps or display the data input on the Delphi program is as follows:

- Input ship's main dimensions

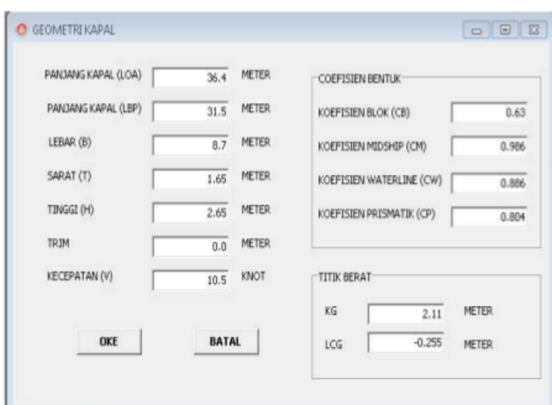

Figure 2. Display form of input data of the ship's main dimensions

- Once the input data is completed, then input the data section (section width, height and breadth section) as well as waveform data (height and flatness of the wave)

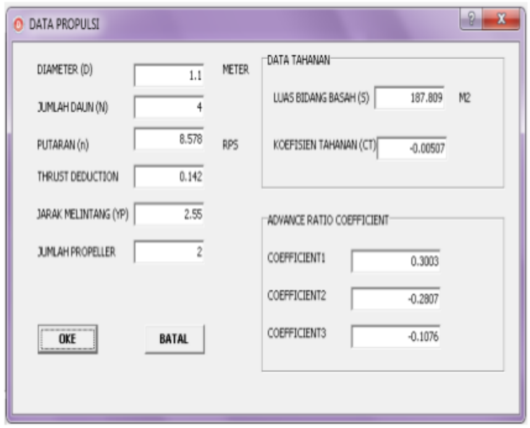

Figure 3. Display form of input data of section and wave

- The next step is propulsion data input

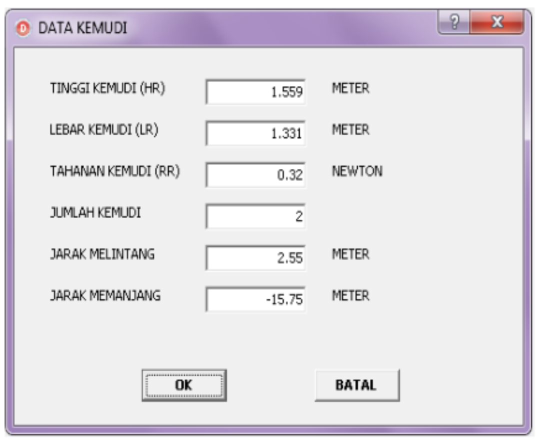

Figure 4. Display form of input data of propulsion and ship resistance

- Furthermore, the input data of the steering of the boat

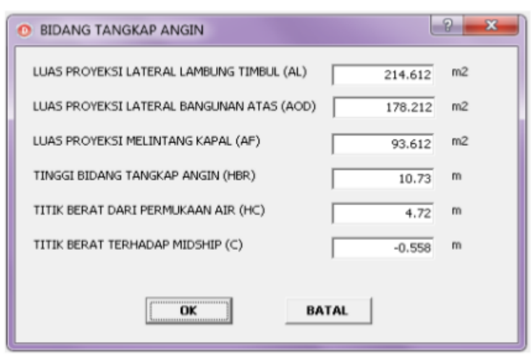

Figure 5. Display form of input data of steering of the boat

- Input field catch of the wind

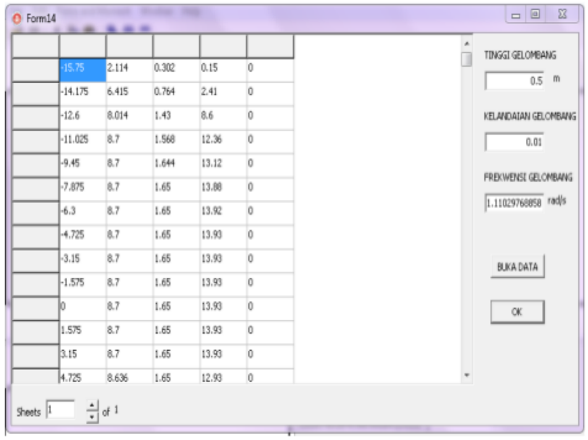

Figure 6. Display form of input data of capture wind field

- To get the predictions of the hydrodynamic coefficients, the used formulas are according to Yoshimura and Ning Ma which are conducted by a semiempirical method. At Delphi software, open window of hull hydrodynamic coefficients, press okay then the Fig. 7 should be filled.

Figure 7. Display form of calculation results of hydrodynamic forces and moment of hull coefficients

- The result of the calculation of force and moment coefficients in the direction of the wind surge, sway, and yaw as a function of the direction the wind comes against the hull are given in the form of a curve as shown in Figure 8.

Figure 8 shows the curve of the relationship between the direction of the incoming wind with the wind force and moment coefficients. The coefficients in question are the coefficient of wind forces and moments on the motion surge (CAX), coefficient of wind forces and moments on the motion sway (GEO) and the coefficient of wind forces and moments on the motion of yaw (CAN). They were calculated using the equation of Fujiwara with a higher degree of accuracy than previous methods. Using physical components, the flow resistance longitudinal, cross flow resistance, lift, and induced obstacles.

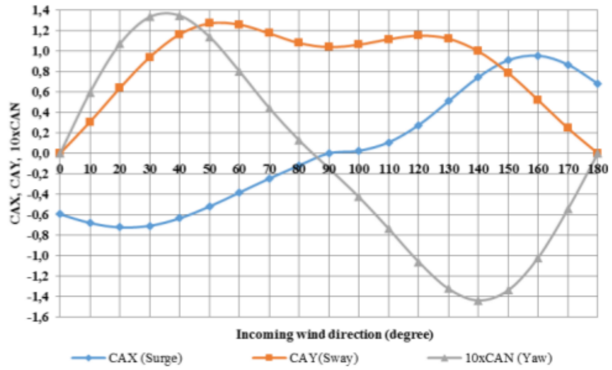

Figure 8. Relationship of incoming wind direction with wind force and moment coefficients on the motion of surge, sway, and yaw.

4.2. Wave effects against drift angle

Based on the purpose of this study which is to know the effect of the waves against the ship maneuvering characteristics and get the value of drift angle and rudder angle which affect the speed of the ship. To obtain these results, wind speed and wave height are varied and simulations using the Delphi program are carried out. Wave height (Hw) used were 0.5 m, 1 m, 1.5 m, and 2 m. The wind speeds used are 0 m/s and 10 m/s while the direction of the incoming wind together with the wave direction ranges from 0º-180º with 10º intervals.

The values of drift angles are obtained by simulation with the results shown in Figure 9.

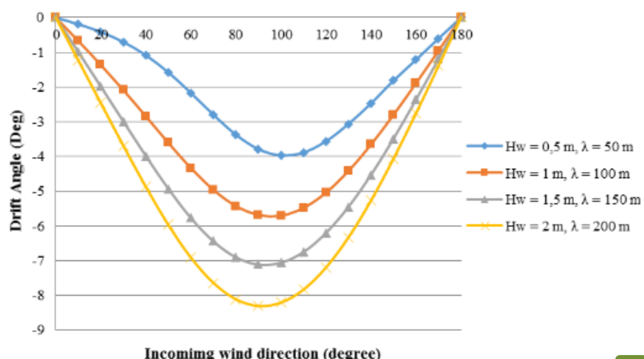

Figure 9. Drift angle at a various incident angle of wind for a wind speed of 0 m/s

Figure 9 compares the magnitude of the drift angle and incoming wind angle ranging from 0 - 180° for a wide variety of wave height and wind speed of 0 m/s. The blue curve illustrates the wave height (Hw) of 0.5 m and the flatness of 0.01 wave.

Drift angle changes because of the influence of the surge, sway, and yaw moment can be seen in Figs. 10-12.

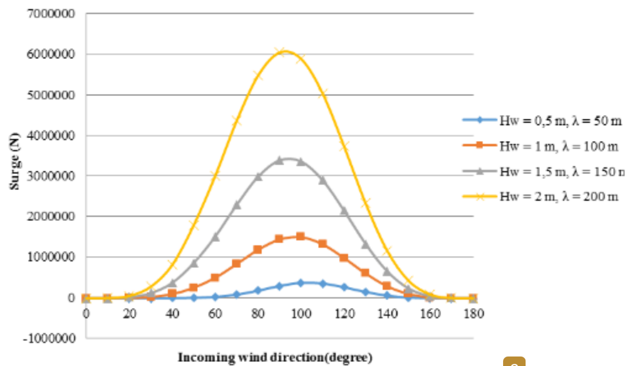

Figure 10. Surge force at various angles of wind for a wind speed of 0 m/s

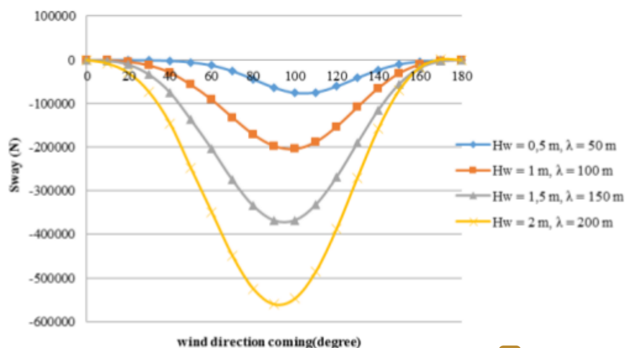

Figure 11. Sway force at various angles of wind for a wind speed of 0 m/s

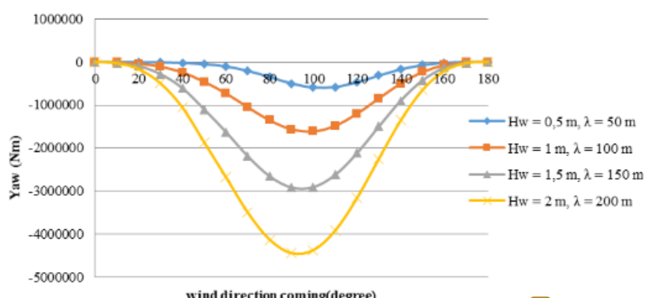

Figure 12. Yaw moment at various angles of wind for a wind speed of 0 m/s

Figures 10-12 indicates that the value of the surge, sway and yaw moments which have influence to change the drift angle on the ship. Sway force and yaw moments have an enormous influence on the change of angle of drift that consists of several elements of the hull, steering, wind, and waves. The greater the value of the sway force and yaw moment of the magnitude of drift angle deviation is also getting larger. This can be seen in a value of sway force and yaw moment when the wave heights are 0.5 m and 1 m primarily at an incidence wave angle of 100°.

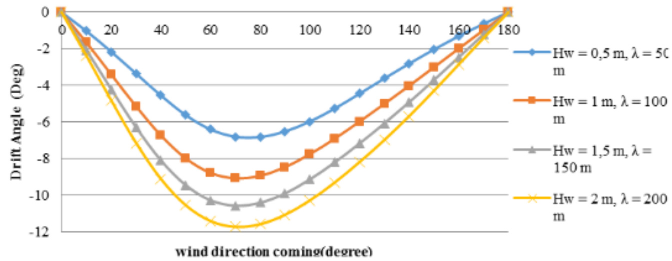

Figure 13. Drift angle at various incident wins angles for a wind speed of 10 m/s

Figure 13 shows that the effect of high waves against the ship drift angles is greater. The higher the waves, the vessel drift angle will be even greater. At the time of wave height (Hw) of 0.5 m and at an 80° angle of incidence, wind drift angle is -6,803°. For the wave height of 1 m, the drift angle when the angle of incidence of wind is 70°, is -9,059°. Drift angle changes because of the influence of the surge, sway, and yaw moment when the wind speed is 10 m/s, can be seen in Figs. 14 – 16.

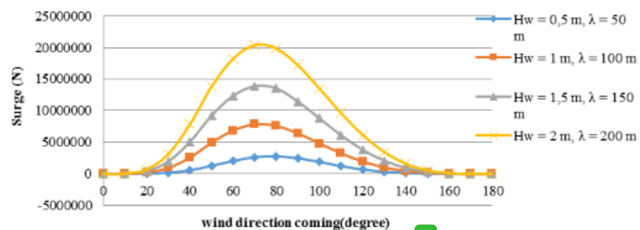

Figure 14. Surge force at various incident wind angles for a wind speed of 10 m/s

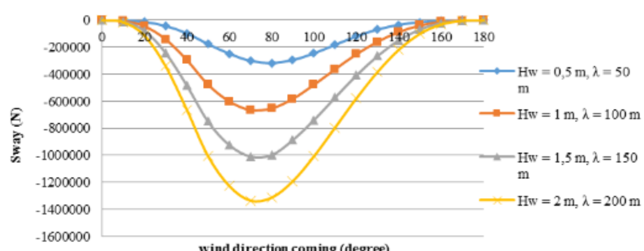

Figure 15. Sway force at various wind angles for a wind speed of 10 m/s

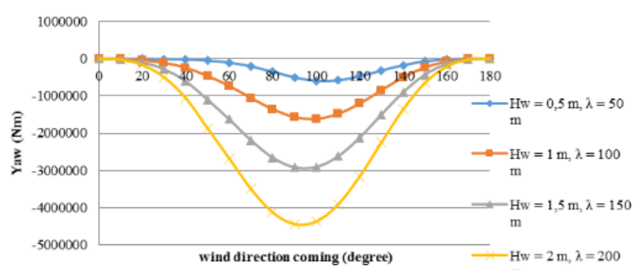

Figure 16. Yaw moment at various wind angles for the wind speed of 10 m/s

Figures 14-16 indicates that the value of the sway force and yaw moment of the direction of the wave direction, when the force of sway and yaw moment consists of elements (hull, propeller, rudder, wind, and waves). Sway force and yaw moments affect the drift angle is evident from the above picture is good value sway force and moments yaw, the greater the incidence angle of the wind against the ship, then the value of the sway force and moments yaw getting bigger until the angle of incidence of wind equal to 800 for the high waves of 0.5 m. In the incident angle is greater than 900 wind and wave height of 1 m, 1.5 m, and 2 m, the value sway force and yaw moment is getting smaller with increasing incidence angle of the wind against the ship. When the wind incidence angle equal to 180°, the value sway force and yaw moment is equal to 0. And the value of sway force and yaw moments occur in the largest wave direction 80° to wave height of 0.5 m. While the greatest value sway force and yaw moment to wave height of 1 m, 1.5 m, and 2 m occurs when the incident angle of 70° wind. So it can be concluded that the value of drift angle and value sway force and yaw moment proportional. The greater the value of the sway force and yaw moments then drift angle will also increase and vice versa the smaller the value sway force and yaw moments then drift angle will also be smaller.

4.3. Effect of waves against rudder angle

The amount of rudder angle obtained by simulation performed in the Delphi program. As a result of the simulation rudder angle when the wind speed of 0 m/s is shown in Figure 17.

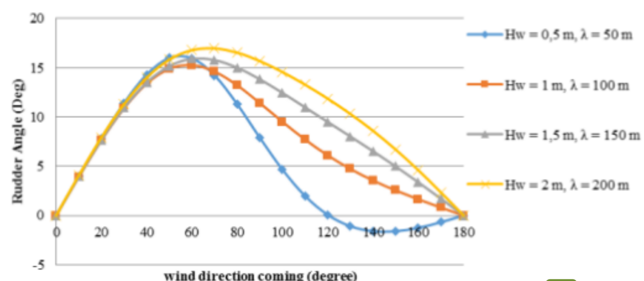

Figure 17. Rudder angle at different angles to the incoming wind speed of 0 m/s

To maintain the trajectory of the ship due to the drift angle that occurs due to the waves, the wheel should be tilted up to certain angle so that the movement of the ship remains on the specified track or path. Figure 17 shows the comparison of the amount of rudder angle and wind incidence angle ranging from 0 - 180° degrees for varying wave height of 0.5 m, 1 m, 1.5 m, and 2 m and at a constant wind speed which is equal to 0 m/s. The blue curve illustrates the wave height of 0.5 m, then red 1 m, green and purple 1.5 m and 2 m, respectively and the wave flatness of 0.01. From Fig. 17, it can be seen that the larger the incident angle of the wind, the greater the value of rudder angle ranging from 0-60°. For the incoming wind direction of 70-180°, rudder angle values tend to be smaller. For the wave height of 1 m, 1.5 m and 2 m, the direction of the rudder and the direction the incoming wind of 0-180° have an opposite direction to the incoming wind.

From Figure 18, it can be seen that the larger the incident angle of the wind, the greater the value of rudder angle ranging from 0-60° for a wave height of 0.5 m. For the wave direction of 70-180°, rudder angle values tend to be smaller. For the wave height of 1 m, 1.5 m, and 2 m, rudder angle direction coming from the direction of wind 0-80° has been larger. Meanwhile, when the direction of the wind coming from angle 90-180°, rudder angle direction gets smaller.

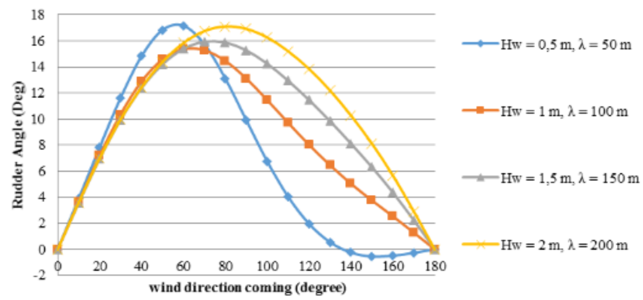

Figure 18. Rudder angle at various angles to the incoming wind speed of 10 m/s

4.4. Effect of waves against ships free

The speed and wave direction have a very significant influence on the operational speed of the ship.

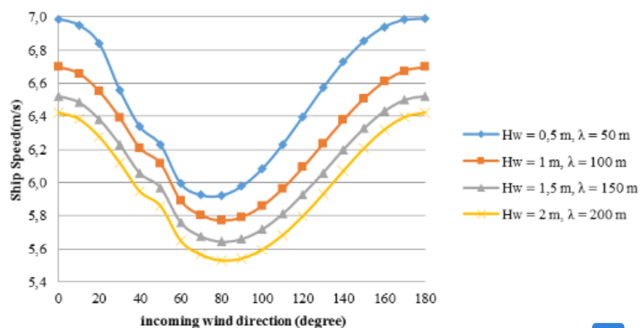

Figure 19. Vessel speed at various incoming wind angles for the wind speed of 0 m/s

Figure 19 illustrates that on the wind direction comes from angle 0 - 80°, the greater the incidence angle of the wind, the speed of the ship will be smaller. For the incoming wind direction greater than 80°, the speed of the ship was also greater with increasing incidence angle of the wind. When the wind speed ratio and the speed of the ship are equal to 0, the ship's speed increases from the with 5.4 m/s. When there is a change in the drift angle, the speed of the vessel decreased where the gradient of the decline getting smaller. The speed reduction occurs because when the ship began to turn, drift angle and vessel speeds increase, so the velocity of the ship in the direction of sway also increases.

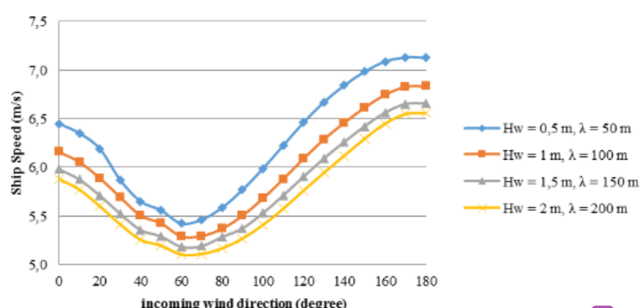

Figure 20. Vessel speed at various incoming wind angles for the wind speed of 10 m/s

Figure 20 depicts the wind speed ratio and the speed of the vessel which result in the drift angle and yaw rate is never stable. Changes of drift angle and yaw speeds cause the vessel speed will always vary in each direction of the incoming wind direction towards the ship. When the wind direction is less than 60^o or in other words the ship operates on the bow wave, ship resistance increases due to surges that can cause the ship speed is significantly reduced. Meanwhile, when the incoming wind direction is greater than 60^o, the ship's speed greater with increasing incidence angle of the wind on the ship. Ship resistance reduces due to the diminishing waves so that the ship's speed increases with increasing angle of incidence of the wind.

Factors that affect the speed of the ship are surge and sway forces arising from the hull, propeller, rudder, wind, and waves. The value of the surge and sway forces is inversely proportional to the speed of the ship. In this case, if the value of surge and sway forces are large, the speed of the ship will be smaller, and if the value of surge and sway forces are small, the speed of the ship will be even greater. The values which have a great influence on the value of the surge force are the values of the forces caused by the hull, while the forces and moments due to the propeller, rudder, wind, and waves.

5. Conclusions

From analysis results, it can be concluded that:

- Wave height and length wave gives the influence to characteristics of maneuvering of ferry ship. Large length and height of wave result in the small value of surge. On the contrary, the motion of sway and yaw are bigger because of the larger wave length.
- The largest change of drift happened on the incoming wave direction of 50° and high of wave 2 m. Angle corner happened on the incoming direction of the wave of 110^o and wave height of 2 m, where angle corner gyrates 22.382° or more.

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