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CFD ANALYSIS ON COURSE STABILTY OF AN ASYMMETRICAL BRIDLE TOWLINE MODEL OF A TOWED SHIP

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ABSRACT

Ship towing system has been widely used in order to move the unpropelled ship at sea. However, employing improper towing configuration can cause towing instability with the present of large slewing motion which can lead to towing accidents. Therefore, a comprehensive investigation on the course stability of towed ship is important to ensure ship's safety navigation. This paper proposed the asymmetrical towing configuration of towline model by using Computational Fluid Dynamic. Several towing parameter such as tow angle and tow speed have been taken into account. The results revealed that the increase of tow angle and tow speed had improve the stability in term of slewing motion period of the towing barge at sea. The results of this research are very useful for the ship towing system that is mainly needed for a better course stability of the towed ship.

Keywords*: slewing motion, Computational Fluid Dynamics, tow angle, tow speed*

1.0 INTRODUCTION

Maritime accidents during ship towing such as ship collision are bounded to occur when there are lack of course stability which is dangerous for its safety navigation. The towing instability with large amplitude of slewing and yaw motion period had cause serious towing accidents. It is important to ensure the course stability of barge for its safety [1]. Since the towed ship has no active surface control to ensure its stability [2], it is important to have a comprehensive towing analysis to ensure its stable during towing.

Several researchers has been investigate the course stability of towed ship performance incorporating with single and bridle towline model configuration. Few studies on single towline model were done by [3] [4] whom predicting the course stability of barge by considering the hydrodynamic forces acting on it. [5] simulated the surge, sway and yaw motions and study the stability of a towed vessel by a non-linear elastic rope. Symmetrical bridle towline model has been investigated by [6] [7] studied the effect of towline lengths on the bridle towline model for the unstable towed ship. The results showed that the course stability of barge had been gradually improved through significant attenuation of the sway motion. [8] studied the stability of the symmetrical towed ship towed by two tug boats with different types of cables used as towing lines. However, the results from the single and symmetrical bridle towline configuration still need improvement. [9] [10] has done the investigation on the symmetrical bridle towline model and the results show better sway motion of towed ship compared to symmetrical bridle towline. Therefore, a more proper analysis on course stability of towed ship is need to deal with better course stability.

Few research methods were used in order to analyze the course stability such as numerical methods which have been used by [2] [11] [12]. Besides, the experimental method was used by [9] who did the experiment using the towing tank to investigate the effect of sway motion of barge. Besides, [3] had use the experimental method to estimate the hydrodynamic force acting on the towed ship before validating it using Computational Fluid Dynamic(CFD). CFD is a reliable and practical tool to solve maritime problem such as ship towing, seakeeping and analyzing the ship resistance. There are researchers such as [6] [13] [14] [15], [1] [16] [17] [9] using the CFD since it can capture the hydrodynamic force and non-linear phenomenon during the simulation [3] [1].

This paper proposes an analysis on course stability of a towed ship using an asymmetrical bridle towline model by using CFD. The CFD software give more advantages compared to numerical and analytical method as it can capture the non-linear phenomenon during the computation. Besides, it also reduces the computation time and provides more accurate results for this study on course stability of ship towing system. Tow angle and tow speed of the barge is taken into account during the simulation to investigate the course stability of the barge using asymmetrical bridle towline configuration.

2.0 GOVERNING EQUATION

FAVOR technique has been applied in Flow3D simulation. In this technique, the computational domain can have multiple moving object which must be in term of solid with no porosity. The tug and barge are both moving object which allow it to be in the same computational domain. Besides, the FAVOR technique treats the complex geometries very efficiently.

A body system (x, y, z) has been set up for each moving object where the coordinate axes parallel with the space system at time=0. The origin of the six degree of freedom (6DOF) objects have been set up at the object mass center, G. the coordinate transformation between space system (x,y,z) and body system (x’, y’, z’) is

$$\overrightarrow{x_s} = [R] \cdot \overrightarrow{x_b} + \overrightarrow{x_G} \tag{1}$$

where and are position vectors of a point in space and body systems, respectively, is position vector of the mass center in space system, and $[R]$ is an orthogonal transformation tensor,

$$[R] = \begin{bmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{bmatrix} \tag{2}$$

where $R_{ij}, R_{jk} = \delta_{ik}$ and δ_{ik} is the Kronecker δ symbol. It is a property of [R] that its inverse and transposed matrices are identical. For a space vector Ar, the transformation between the space and body systems is

$$\overrightarrow{A_s} = [R] \cdot \overrightarrow{A_b} \tag{3}$$

where $\overrightarrow{A_s}$ and $\overrightarrow{A_b}$ denote the A expressions in space and body systems, respectively. [R] is calculated by solving

$$\frac{d[R]}{dt} = [\Omega] \cdot [R] \tag{4}$$

where

$$[\Omega] = \begin{bmatrix} 0 & -\Omega_z & \Omega_y \\ \Omega_z & 0 & -\Omega_x \\ -\Omega_y & \Omega_x & 0 \end{bmatrix} \tag{5}$$

and Ω_x, Ω_y and Ω_z are the x-, y- and z-components of the angular velocity of the object in space system, respectively.

FLOW-3D solves Navier-stokes type equations embedded with various turbulence models. This simulation used the RNG turbulence model since it consider the low Reynold number effects. [18,19,20]. Applying the double averaging strategy to the transport equations for TKE and its dissipation rate produces the turbulence model for the flow. The resulting equations are:

$$\frac{\delta k}{\delta t} + U_j \frac{\delta k}{\delta x_j} = \frac{\delta}{\delta x_j}\left[\left(v + \frac{v_t}{\sigma_k}\right)\frac{\delta k}{\delta x_j}\right] + P_k + B_k + W_k - \varepsilon \tag{6}$$

$$\frac{\delta \varepsilon}{\delta t} + U_j \frac{\delta \varepsilon}{\delta x_j} = \frac{\delta}{\delta x_j}\left[\left(v + \frac{v_t}{\sigma_\varepsilon}\right)\frac{\delta \varepsilon}{\delta x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}(P_k + B_k)(1 + C_{3\varepsilon}R_f) + W_\varepsilon - C^*_{2\varepsilon}\frac{\varepsilon^2}{k}$$
(6)

$$P_k = v_t S^2 = v_t\left(\frac{\delta U_i}{\delta x_j} + \frac{\delta U_j}{\delta x_i}\right)\frac{\delta U_i}{\delta x_j} \tag{7}$$

$$B_k = \beta g_i \frac{v_t}{\sigma_s}\frac{\delta s}{\delta x_i} \tag{8}$$

where P_k is the shear production term of TKE, $S = \sqrt{2S_{ij}S_{ji}}$ is the modulus of the mean rate of strain tensor and $S_{ij} = \frac{1}{2}\left(\frac{\delta U_i}{\delta x_j} + \frac{\delta U_j}{\delta x_i}\right)$, B_k is the buoyant production term of TKE, W_k

is the wake production tern of TKE, W_ε is the wake production term in ε, σ_k and σ_ε are the turbulent Prandtl numbers for k and ε, and $C_{i\varepsilon}$, $C_{3\varepsilon}$ and $C^*_{2\varepsilon}$ are model coefficients.

3.0 SIMULATION CONDITION

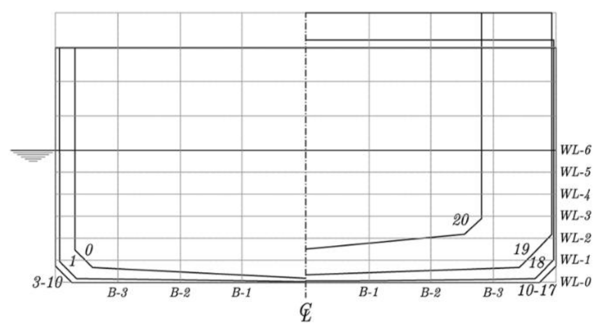
3.1 Principle Data of Ship

The dimension of the barge is presented in Table 1 while the barge model used in the CFD simulation is shown in Figure 1.

Table 1: Barge dimension

Description	Dimension
Length *l*,(m)	1.221
Breadth *b*, (m)	0.213
Draft *d*, (m)	0.0548
Volume *V*,(m^3)	0.02634
L/B	2.86
Block coefficient C_b	0.92

a) Barge model



b) Barge body plan

Figure 1: Barge model and body plan used in CFD simulation

3.2 Simulation Parameter

Figure 2 shows the towing condition of the towed barge. The tug is replaced with the sphere by using similar characteristics of tug. This is to reduce the computational time during simulation. The simulation parameters used in this analysis are shown in Table 2 and 3. The tow angle used are 5 degree, 15 degree, 25 degree and 35 degree at constant speed 0.509 m/s while various tow speed from 0.582 m/s to 0.728 m/s simulated for constant tow angle 25 degree.

Table 2: Barge towing parameter in various tow angle

Tow angle, α	Tow speed (m/s)
5◦	
15◦	0.509
25◦	
35◦	

Table 3: Barge towing parameter in various tow speed

Towline speed (m/s)	Tow angle, α
0.509	
0.582	25◦
0.655	
0.728	

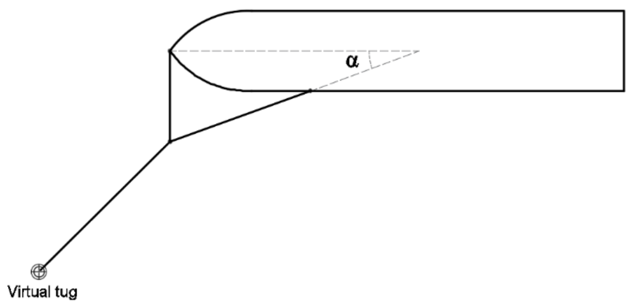
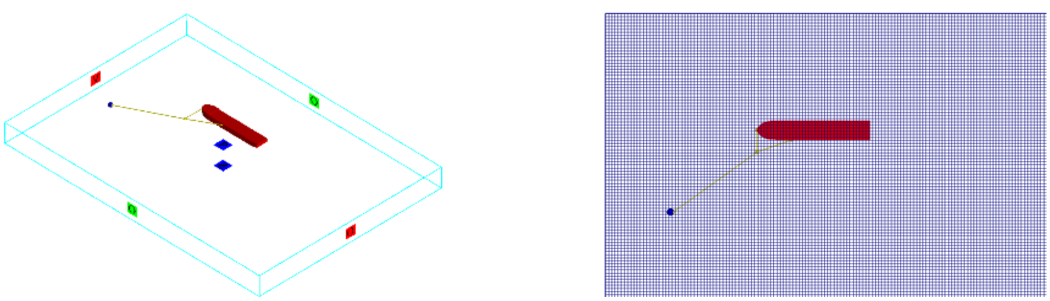


Figure 2: Simulation condition of barge

3.3 Computational Domain and Meshing Generation

The computational domain of the barge associated with the number of meshing cell in the CFD. The total number of cells used in the simulation is 1 million cells.



a) Boundary condition b) Meshing generation

Figure 3: Meshing boundary condition of barge

Referring to Figure 3, the boundary conditions are mark in the mesh block. The boundary condition at X-max boundary is specified velocity so that there is flow of water in the boundary. The velocity used in the simulation is constant by 0.509 m/s for the sphere model. For X-min, Y-max and Y-min use outflow boundary to absorb the wave motion which will reduce the reflection from the boundary while Z-min using symmetry boundary which it applies zero-gradient condition at the boundary and Z-max using specified pressure to create a uniform pressure in the boundary. The boundary conditions for this simulation are as shown in Table 4.

Table 4: Boundary Conditions

Boundary	Mesh block 1
X_{min}	Specified Velocity
X_{max}	Outflow
Y_{min}	Outflow
Y_{max}	Outflow
Z_{min}	Symmetry
Z_{max}	Specified pressure

The barge is coupled through a towline. Sphere model which acted as the tow ship is assigned as prescribed motion while barge as towed ship is set as coupled motion in X translational, Y translational and Z rotational motions (surge, sway and yaw as this simulation is considering 3 degree of freedom. The towline is set as massless elastic rope with spring coefficient of 7.347 kg/s^2.

Based on the applications of FLOW3D v11.0.4, the average duration of every simulation was about 70-80 hours (4 parallel computations) on a HP Z820 workstation PC with processor Intel (R) Xeon (R) CPU ES-2690 v2 @ 3.00 GHz (2 processors) associated with the installed memory of 32.0 GB and 64-bit Operating System.

4.0 RESULTS AND DISCUSSION

Simulation of tow angle at 0 degree has been done by using Flow3D as a benchmark in simulation for the asymmetrical bridle towline model configuration of barge. The results of sway, yaw and towline tension of tow angle 0 degree is shown in Figure 4 while the CFD visualization is shown in Figure 5. The sway motion of tow angle at 0 degree is larger as the time increase. The simulation of asymmetrical bridle towline model in various tow angle is presented to show that it has better course stability compared to the tow angle at 0 degree. The average yaw motion for tow angle at 0 degree is 0.105 rad/s while it towline tension is 1.10 N. These results will be compared with the simulation by using asymmetrical bridle towline model in various tow angle.

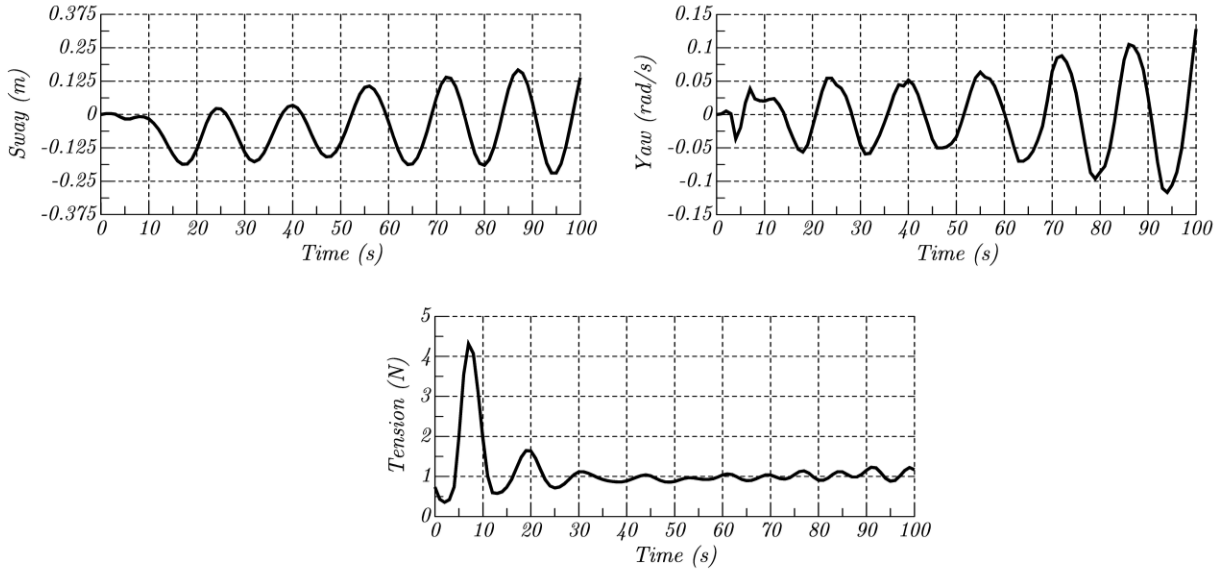


Figure 4. Effect of sway, yaw and towline tension at tow angle 0 degree

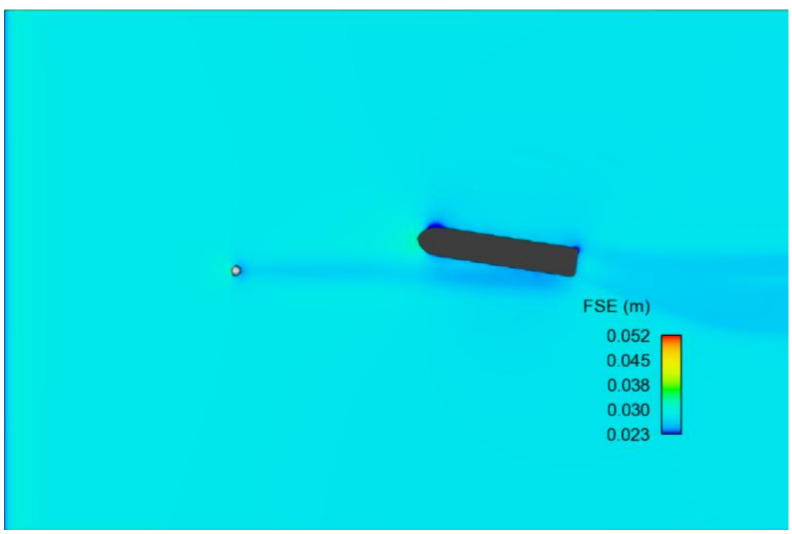


Figure 5. CFD visualization of asymmetrical towing simulation at tow angle, α 0 degree

4.1 Effect of tow angle on course stability of barge

The analysis on course stability of asymmetrical bridle towline model has been done using the CFD simulation approach. The simulation results are presented with the discussion of the analysis.

The increment of sway motion on straight tow is higher compared to the sway motion of the asymmetrical bridle towline model. This can be validated by a research which stated that straight tow has large sway motion during the towing of barge [9].

The sway and yaw motion of the barge in various tow angle are shown in figure 6. Sway motion of the asymmetrical bridle towline at tow angle 5 degree to 35 degree had drifted to starboard side since the towline is located at its port side. The sway motion of the barge had decrease as the tow angle increase from 5 degree to 35 degree. During tow angle

5 degree, the sway motion at 30 s is still significance compared to the sway motion at 35 degree which shows almost zero sway motion. Besides, the decreasing of sway motion as tow angle increase from 5 degree to 35 degree indicate that the course stability of barge increasing. A research from [21] had revealed that the asymmetrical bridle towline of a towed ship has better course stability because the sway motion reduce when the tow angle increase.

The increase of tow angle had reduce the yaw motion of the barge during towing. However, tow angle at 0 degree show highest yaw motion at t=86 s with 0.105 rad/s compared to tow angle 5, 15 degree, 25 degree and 35 degree that give 0.023 rad/s, 0.054 rad/s, 0.085 rad/s and 0.088 rad/s respectively.

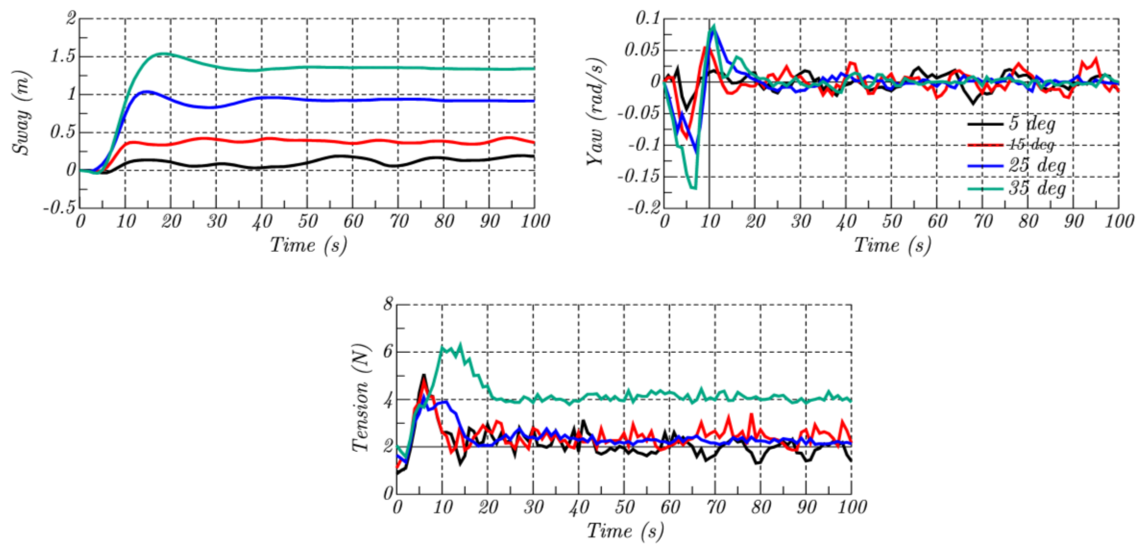


Figure 6. Effect of sway, yaw and towline tension of barge in various tow angle

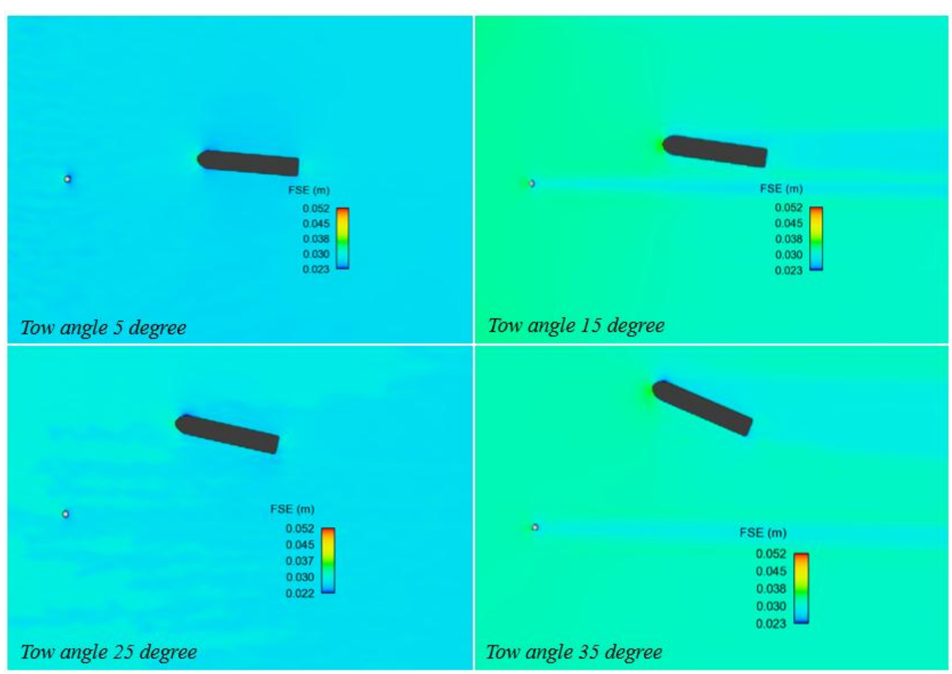


Figure 7. CFD visualization of asymmetrical towing simulation in various tow angle, α

Different tow angle on barge during towing had effect the towline tension. The increase of tow angle has decrease the towline tension of barge during towing [9]. Larger tow angle at tow angle 35 degree has the highest towline tension with the average 4.14 N while 0 degree has the minimum towline tension compared to other angle which is 1.10 N. Higher towline tension at the beginning of the towing may due to the rapid increase in the slewing motion of barge [21]. It can be conclude that the increasing of tow angle had increase the towline tension. This possibly occur due to high acceleration of barge surge motion. Figure 7 shows the CFD visualization of asymmetrical towing simulation in various tow angle from 5 to 35 degree. The further increase of tow angle resulted in having less effect of wave trough (blue colour) on the fluid around the barge. Tow angle at 5 degree shows higher wave crest at bow.

4.2 Effect of tow speed on course stability of barge

The effect of tow speed on course stability of barge in term of sway motion is shown in figure 8. This tow speed is simulated using 25 degree tow angle of barge. The sway motion of the barge increase as the tow speed increase. The average sway motion for 0.509 m/s, 0.582 m/s, 0.655 m/s and 0.728 m/s are 0.84 m, 1.00 m, 1.06 m and 1.20 m. Referring to the sway motion graph, tow speed at 0.728 m/s has the highest sway motion than 0.509 m/s and 0.655 m/s.

The yaw motion of the asymmetrical towing are simulated in different tow speed from 0.509 m/s to 0.728 m/s. As the tow speed increase from 0.509 m/s to 0.728 m/s, the yaw motion decrease. Tow speed 0.728 m/s shows the highest average yaw motion by 0.0029 rad/s compared to 0.509 m/s, 0.582 m/s and 0.655 m/s which show 0.0024 rad/s, 0.0025 rad/s and 0.0026 rad/s respectively.

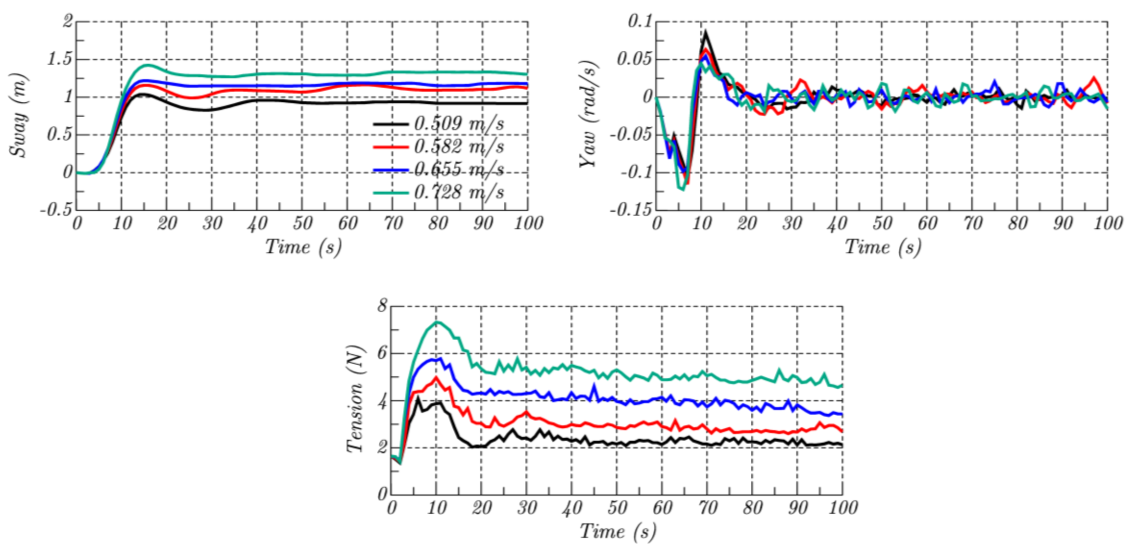


Figure 8. The effect of towline tension in various tow speed

Figure 8 also shows the graph on the effect of towline tension of asymmetrical ship towing in various tow speed. The results show that tow speed at 0.728 m/s has the highest towline tension by 5.16 N compared to 0.509 m/s, 0.582 m/s and 0.655 m/s which have 2.4 N, 3.05 N and 4.06 respectively. The towline tension decrease as the tow speed increase. Figure 11 shows the visualization of asymmetrical towing simulation in various tow speed from 0.509 m/s to 0.728 m/s. As shown in Figure 9, the further increase of tow speed resulted in having more effect of wave crest on the fluid around the barge. This due to higher resistance around the barge.

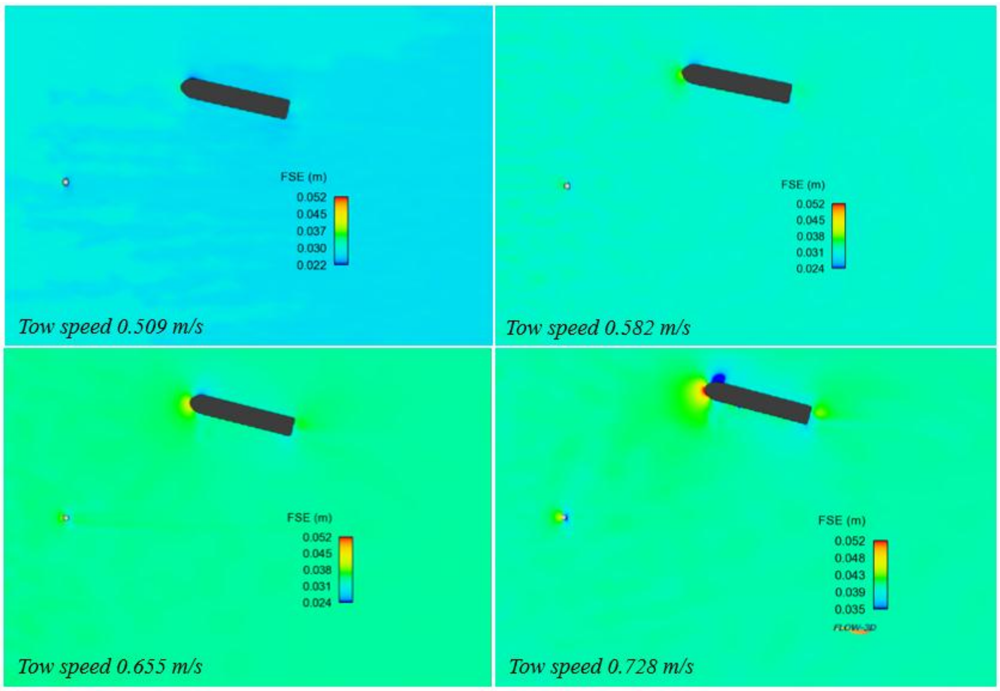


Figure 9. CFD visualization of asymmetrical towing simulation in various tow speed

CONCLUSION

The CFD investigation on the effect of course stability of towed ship using asymmetrical bridle towline was successfully performed. The effect of sway and yaw motion were examined accordingly at a wide range of tow angles and tow speed. The computation results are drawn as follows:

- The asymmetrical bridle towline model in towing system has improve the towing stability compared to straight tow at 0 degree which resulting in decreasing of sway and yaw motion as the tow angle increase 0 degree to 35 degree.
- However, increasing of tow speed had reduce the course stability of barge since the sway motion and the towline tension increase as tow speed increase from 0.509 m/s to 0.728 m/s.
- Increasing of tow angle and decreasing of tow speed dealt with decrement of sway motion period which provide better course stability of the towed ship.

In addition to this CFD simulation, these results are very useful as the preliminary data of the ship's course stability, which is primarily required to ensure a safety navigation of a towed ship at sea.

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