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Study on Strut Effect on Turning Characteristics of LNG Carrier

Mohd Amirul Hamdi Bin Mohd Alwi,[a] Jaswar Koto,[a, b,*] and Zulkarnain,[b]

[a)]*Department of Aeronautics, Automotive and Ocean Engineering,Mechanical Engineering, Universiti Teknologi Malaysia*
[b)]*Ocean and Aerospace Engineering Research Institute, Indonesia*

*Corresponding author: jaswar.koto@gmail.com and jaswar@mail.fkm.utm.my

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ABSTRACT

There are many types of propulsion system used to propel the ship. One of them is podded propulsion system. Up to date, there is still no LNG carrier that was installed with this kind of propulsion system. The idea of installing podded propulsion system onto LNG carrier is till at design and development stage. This paper presents about the study on effect of changing the size of strut of podded propulsor to the turning characteristic of an LNG carrier named Tenaga Satu. The manoeuvring performance of this ship can be predicted by using numerical simulation method. This study is mainly focussing on modifying and developing mathematical model to simulate the turning characteristic of this LNG carrier. Three designs of pod propulsor with different strut length have been made to evaluate the effect to the turning characteristic.

KEY WORDS: *Podded Propulsion; Turning Characteristics; LNG Carrier; Manoeuvring; Mathematical Model; Numerical Simulation.*

NOMENCLATURE

IMO International Maritime Organization
LNG Liquefied Natural Gas
LCB Longitudinal Center Buoyancy

1.0 INTRODUCTION

According to the IMO "Standards for Ship Manoeuvrability", manoeuvring performance of a ship should be predicted during the preliminary design stage. There are two methods that were widely used to predict the ship manoeuvrability. The first method is free-running model test, and the second one is by applying computer simulation using the mathematical method. [1] In this study, mathematical model method was applied. Before applying this method, it is a must to prepare the modelling of the equations describing the manoeuvring motions first. Then, computer simulation is carried out to determine manoeuvring characteristics by the means of the mathematical model.

For this project, an existing LNG carrier named "Tenaga Satu" was chosen. The problem with TenagaSatu is it is a ship that was installed with conventional propulsion system where it uses the common configuration of main engine, rudder, and propeller as it propulsion system but this study requires an LNG carrier with podded propulsion system. Since there is still no LNG carrier that is installed with podded propulsion system in operation today, it is considerable to select this Tenaga Satu LNG carrier for this study and all the prediction on manoeuvring and turning ability will be based on this ship.

Table 1: Technical Information of Tenaga Satu LNG Carrier.

Principle Dimension	
Length overall (Loa) (m)	289.119
Length water line (Lwl) (m)	277.653
Length between perpendicular (Lpp) (m)	266
Breadth moulded (Bm) (m)	41.6
Depth moulded (Dm) (m)	25.448
Hydrostatic coefficient	
Block Coefficient (Cb)	0.726

Prismatic Coefficient (Cp)	0.734
Prismatic Coefficient at after (Cpa)	0.684
MidshipCoefficient (Cm)	0.989
Water Plane Coefficient (Cwp)	0.801
Operational Condition	
Draft moulded (dm) (m)	11.3
Wetted surface (m^2)	14000
Displacement (m^3)	94715

2.0 POD PROPULSOR DESIGN

Three different design of pod propulsor unit was made in order to make comparison between the turning ability of the same LNG carrier but differ in pod propulsor. All three designs of pod propulsor have same dimension of pod body and its strut height, the only difference between them is the strut length. Changing the strut length will change the strut area. The first design has shorter strut length, the second design has normal strut length and the third design has largest strut length.

Pod propulsor-1 has the shortest strut length which is 2.726 metres. The design of pod propulsor-2 is based on the original dimension of pod propulsor unit. The strut length is 7.5 metres. The third design has biggest strut length compared to design 1 and design 2 of pod propulsor unit. The strut length is 8.863 metres which is not much different from design of pod propulsor 2 that has strut length of 7.5 metres. This is due to the limitation of length of pod body. The strut height and pod body diameter for all three designs are 4.229 metres and 4.41 metres respectively.

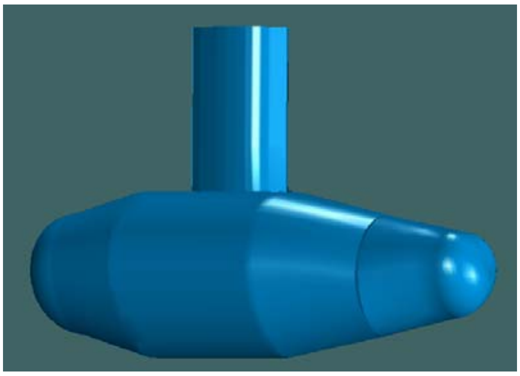

Figure.1: Pod Propulsor-1.

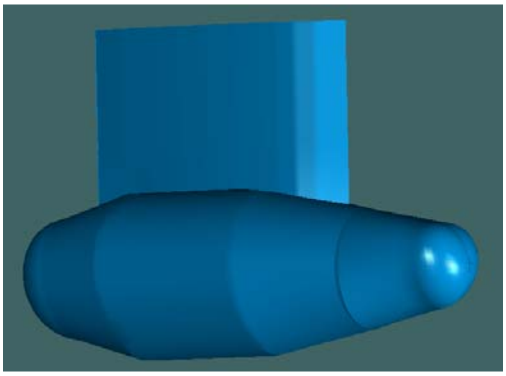

Figure 2: Pod Propulsor-2.

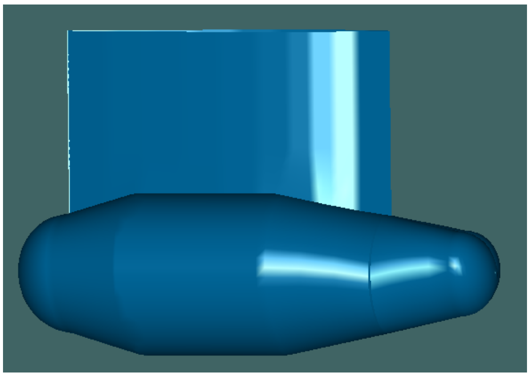

Figure 3: Pod Propulsor-3.

Table 2: Principle dimension of pod propulsors.

ITEM	POD Propulsor-1	POD Propulsor-2	POD Propulsor-3
Strut Height (m)	4.229	4.229	4.229
Strut Length (m)	2.726	7.5	8.863
Strut Area (m^2)	28.326	67.713	80.333
Pod Body Diameter (m)	4.41	4.41	4.41
Pod Body Area (m^2)	156.204	156.204	156.204

3.0 NON-DIMENSIONAL FORCES AND MOMENT ACTING ON THE SHIP

To develop a mathematical model for predicting ship manoeuvrability, only the forces and moment acting on the ship are taken into consideration. In general, the non-dimensional forces for surge and sway, and also yaw moment can be expressed as: [2]

$$X' = (m' + m_x')\left(\frac{L}{U}\right)\left(\frac{\dot{U}}{U}\cos\beta - \dot{\beta}\sin\beta\right) + (m' + m_y')r'\sin\beta$$

$$Y' = (m' + m_y')\left(\frac{L}{U}\right)\left(\frac{\dot{U}}{U}\sin\beta - \dot{\beta}\cos\beta\right) + (m' + m_x')r'\cos\beta$$

$$N' = (I_{zz}' + i_{zz}')\left(\frac{L}{U}\right)^2\left(\frac{\dot{U}}{L}r' - \frac{U}{L}\dot{r}'cos\beta\right)$$

(1)

Where;

$$m', m_x', m_y' = \frac{m, m_x, m_y}{0.5\rho L^2 d},$$
$$I_{zz}', i_{zz}' = \frac{I_{zz}, i_{zz}}{0.5\rho L^4 d},$$
$$X' = \frac{X}{0.5\rho U^2 dL},$$
$$Y' = \frac{Y}{0.5\rho U^2 dL},$$
$$N' = \frac{N}{0.5\rho U^2 dL^2},$$
$$r' = \frac{r}{U}L.$$

L is ship length, d is draft, m is ship mass, m_x, m_y is for x and y-axis components of added mass of ship, I_{zz}, i_{zz} is moment and added moment of inertia of ship, U is ship speed, β is drift angle, r is angular velocity, X' is external surge force acting on ship, Y' is external sway force acting on ship, N' is yaw moment acting on ship, and ρ is density of fluid.

For conventional ship, the non-dimensional surge and sway forces and yaw moment are acting on its hull, propeller, and rudder. But for a ship with podded propulsion system, the component of rudder can be replaced with pod propulsor. The equation of external forces and moment that acting on the pod propulsor will be totally different from the equation of forces and moment that acting on the rudder. Generally the non-dimensional surge and sway forces and yaw moment can be expressed as:

$$X' = X_H' + X_P' + X_R'$$

$$Y' = Y_H' + Y_P' + Y_R'$$

$$N' = N_H' + N_P' + N_R'$$

(2)

3.1 Forces and Moment Acting on the Hull

The longitudinal component of hydrodynamic force (X_H'), the lateral force (Y_H'), and yaw moment (N_H') acting on the ship hull is respectively expressed as follows:

$$X_H' = X_{vrr}' r' \sin\beta + X_{uu}' cos^2\beta$$

$$Y_H' = Y_v'\beta + Y_r' r' + Y_{vv}'\beta|\beta| + Y_r' r'|r'| + (Y_{vvr}'\beta + Y_{vrr}' r')\beta r'$$

$$N_H' = N_v'\beta + N_r r' + N_{vv}'\beta|\beta| + N_r' r'|r'| + (N_{vvr}'\beta + N_{vrr}' r')\beta r'$$

(3)

Where $Y_v', Y_r', Y_{vv}', Y_{vvr}', Y_{vrr}'$ are sway hydrodynamic derivatives and $N_v', N_r', N_{vvr}', N_{vrr}'$ are sway hydrodynamic derivatives.

3.2 Forces and Moment Produced by Propeller

The hydrodynamic forces and moment induced by the propeller are expressed as follow:

$$X_P' = \frac{(1-t_{POD})n^2 D_P^4 K_T \cos\delta_P}{0.5LdU^2}$$

$$Y_P' = \frac{(1-t_{POD})n^2 D_P^4 K_T \sin\delta_P}{0.5LdU^2}$$

$$N_P' = \frac{-x_{POD}'(1-t_{POD})n^2 D_P^4 K_T \sin\delta_P}{0.5LdU^2}$$

(4)

Where t_{POD} is thrust deduction of pod, n is propeller revolution, D_P is propeller diameter, L is ship length, d is is ship draft, U is ship speed, δ_P is pod propulsor angle, and x_P' is the distance from LCB to propeller plane. The propeller thrust coefficient, K_T can be expressed as a function of propeller advance coefficient, J_P.

$$K_T = C_1 + C_2 + C_3 J_P^2$$

(5)

3.3 Forces and Moment Induced by Pod Propulsor

For a podded propulsion ship, there will be no forces and moment induced by the rudder because the ship do not have the conventional rudder. The hydrodynamic forces and moment induced by the rudder are replaced by the hydrodynamic forces and moment induced by the pod propulsor. The main component of a pod propulsor is its strut, pod body, and fin. For this study, the pod propulsor is assumed to not having fin installed on its pod body. So, the hydrodynamic forces and moment acting on the fin is considered to be zero.

$$X_{POD}' = X_{STRUT} + X_{POD} + X_{FIN}$$

$$Y_{POD}' = Y_{STRUT} + Y_{POD} + Y_{FIN}$$

$$N_{POD}' = N_{STRUT} + N_{POD} + N_{FIN}$$

(6)

For strut component, the hydrodynamic forces and moment induced by strut are as follow:

$$X_{STRUT}' = -(1 - t_R)F_S' \sin\delta_P$$

$$Y_{STRUT}' = -(1 + \alpha_{HPOD})F_S' \cos\delta_P$$

$$N_{STRUT}' = -(x_{POD}' + \alpha_{HPOD} x_{HPOD}')F_S' \cos\delta_P$$

(7)

Where the coefficient for additional drag is t_R, F_S' is dimensionless strut normal force, α_H is ratio of additional lateral force, x_{POD}' is the distance of pod to the ship centre of gravity, and x_H' is the distance between the ship centre of gravity and centre of lateral force.

The hydrodynamic forces and moment induced by pod body are expressed as follow:

(8)

4.0 SIMULATION AND RESULTS

The simulation programme to predict the turning ability of the ship was written in FORTRAN language. The programme must be developed based on the mathematical model where it considers the hydrodynamic forces and moment acting on the ship. All the required equations involved in this mathematical model were explained in the previous chapter. A programme flow chart was constructed as a guide to develop the programming coding.

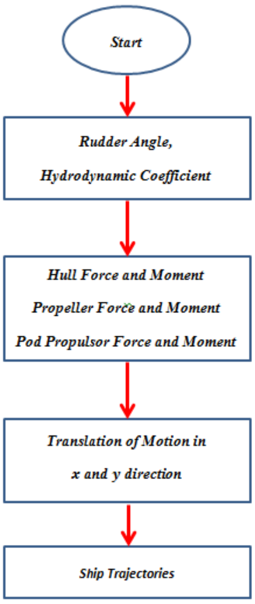

Figure 4: Basic Programme Flowchart.

Figures.5 - 7 show turning circle of three different pod propulsors. The simulation result yields that the ship model with Pod Propulsor-1 has the advance of 6.7251 metres and tactical diameter of 5.4938 metres. The design of Pod Propulsor-2 has the original strut length that is 7.5 metres. The result shows that the turning ability of the ship with this design of pod propulsor has the advance of 6.2159 metres and tactical diameter of 4.7892 metres. Pod Propulsor-3 has the longest strut length and biggest strut area. The simulation result yields that the advance of this ship model during turning circle test is 6.2092 metres and tactical diameter is 4.741 metres.

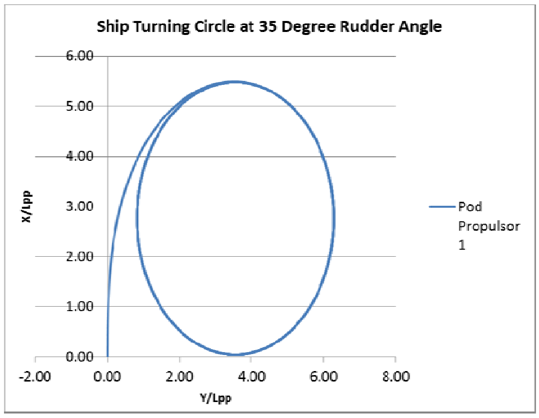

Figure 5: Turning Circle of Pod Propulsor 1.

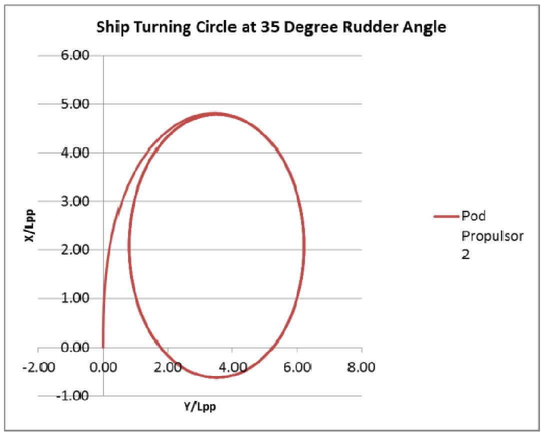

Figure 6: Turning Circle of Pod Propulsor 2.

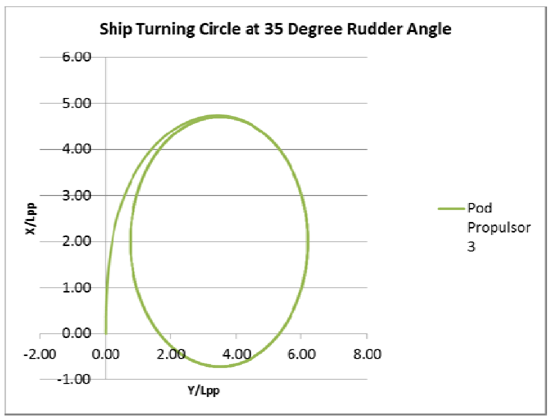

Figure 7: Turning Circle of Pod Propulsor 3.

4.1 Comparison with IMO Criteria

According to IMO "Standard for Ship Manoeuvrability" in 76th

Marine Safety Committee meeting in December 2002, all seagoing ships must comply with the minimum criteria to ensure its safety at seas. The criteria for turning ability of a ship is the ship must shows the advance of not more than 4.5 ship's length and tactical diameter of not more than 5 ship's length during turning circle with rudder angle executed at 35 degrees. Please note that the ship model used in this study is 3.5 metres in length. [3]

Table 3: Comparison with IMO Criteria

Item	Advance	IMO Criteria	Tactical Diameter	IMO Criteria
Pod Propulsor 1	1.921 L	< 4.5L	1.570L	< 5L
Pod Propulsor 2	1.776 L	< 4.5L	1.368L	< 5L
Pod Propulsor 3	1.774 L	< 4.5L	1.354L	< 5L

The results show that Tenaga Satu LNG carrier passes all IMO criteria for advance and tactical diameter during turning circle. The turning circle of the ship with three different designs of pod propulsor fulfils the minimum requirement by IMO.

5.0 CONCLUSIONS

From this study on turning characteristic of an LNG carrier with podded propulsion system, few conclusions can be deducted. They are listed as follow:

- The results for turning circle of Tenaga Satu LNG carrier with podded propulsion system was obtained by the means of changing the strut size of pod propulsor.
- Computer programme was modified and developed based on the previous mathematical model to simulate the turning circle of the ship. The simulation tool used in this study is Visual FORTRAN Professional.
- The results from the simulation programme exhibit that LNG carrier with Pod Propulsor-1 (smallest strut area) has the biggest turning circle and LNG carrier with Pod Propulsor-3 (biggest strut area) has the smallest turning circle.
- Bigger strut area will generates bigger normal force and thus smaller turning circle.
- The turning circle results for the LNG carrier with three different designs of pod propulsors shows that all of them pass the minimum requirement under IMO "Standards for Ship Manoeuvrability" that is the advance should not exceed 4.5 ship's length and tactical diameter not exceed than 5 ship's length.
- Numerical simulation method is very useful tool to predict the ship manoeuvring characteristic (turning ability) of a ship during early design stage.

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REFERENCES

1. Ho Young Lee, and Sang-Sung Shin. (1998); The Prediction of Ship's Manoeuvring Performance in Initial Design Stage, *Hyundai Maritime Research Institute*, Ulsan, Korea.
2. Jaswar and Ikeda, Y. (2002); *A Feasibility Study on Podded Propulsion LNG Tanker in Arun, Indonesia-Osaka, Japan Route.* Osaka Prefecture University, Sakai, Japan.
3. Standards for Ship Manoeuvrability, Report of the Maritime Safety, Committee on its Seventy-Sixth Session-Annex 6 (Resolution MSC.137 (76)), (2002); *International Maritime Organization*, London, UK.
4. Yasuo, Yoshimura. (August, 2005); *Mathematical Model for Manoeuvring Ship Motion (MMG Model)*, Hokkaido University, Japan
5. Jaswar Koto, Amirul Amin, 2014, *Performance of VLCC Ship with Podded Propulsion System and Rudder*, Journal of Ocean, Mechanical and Aerospace -Science and Engineering-, Vol.3, pp: 18-24
6. Jaswar and Yoshiho Ikeda (2002), *Project Report to SHI*: A Feasibility Study of Podded Propulsion Double Acting Oil Tanker, Osaka Prefecture University.
7. Jaswar (2005), Determination of Optimum Hull of Ice Ship Going, *Proceeding of the 5th Osaka Colloqium*, Japan.
8. Jaswar, A.Amin, Agustin, A.Maimun, Munirah, Mufti F.M, Jonathan and C.L.Siow (2012), Study on Powering of Podded Propulsion VLCC, *The 6th Asia-Pacific Workshop on Marine Hydrodynamics*, Johor, Malaysia.