International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-11, September 2019

On Experiment of Determining the Relationship between Ship Maneuverability and Gravity of Metacenter using Ship Model

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***Abstract*: Understanding of ship maneuverability and factors effecting to ship maneuverability is important to naval architectures and marine navigators. In ship control problems, the ship maneuvering characteristic must be considered before designing the controllers. With the development of science and technology, it allowed the studies of ship maneuvering to be performed in computation simulations. However, there are always the different results between computation simulation and the fact. For that purpose, this article presents an experiment to establish the quantitative relationship between metacentric height and ship maneuverability using scaled model ship.**

***Keywords*: Ship maneuverability, metacentric height, ship model, heeling angle, turning circle.**

I. INTRODUCTION

Ship maneuverability is one of the most important features, of which, the navigators need to be master in order to effectively operate a ship. As for naval architectures, ship-designing is conditional upon purpose of use so that it could meet the requirements of maneuvering features. Besides that, in ship control problems, the ship maneuvering characteristic must be considered before designing the controllers. For this reason, it can be seen that understanding of ship maneuverability is really necessary and meaningful,

According to IMO, the ship maneuvering ability needs to be satisfied requirements which can be referred in [5, 6, 7, 8]. Therefore, some researchers studied on this problem such as [1, 2, 3, 4, 9]. However, there are not any experimental study on the relationship of the ship maneuvering and gravity of metacenter with model ship.

In the world, the use of scaled ship models to determine the factors of ship maneuverability as well as the experiments in solving the problems of automatic ship navigation, which has been widely used. In this article, the author presents the experimental process to establish the quantitative relationship between metacentric height and ship maneuverability using a scaled ship model. This research was carried out during the time when the authors worked at Mokpo National Maritime University, Korea.

Manuscript published on 30 September 2019.
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II. THE EXPERIMENTAL EQUIPMENTS

A. Ship Model

In this research, the authors used a scaled ship model, which was simulated from a very large crude carrier (VLCC). This model was also used in the test-tank to determine the different hydrodynamic factors affecting the hull in various situations to solve various problems. The shape of the ship model is shown in Fig. 1 and its particulars as well as the VLCC's are shown in the Table 1.

Fig. 1. The model of ship (KVLCC1)

Table 1. Ship particulars

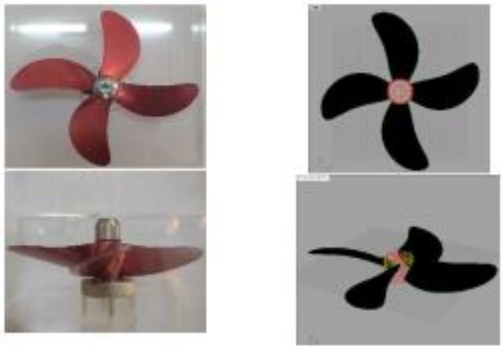
	Real Ship	Ship Model
Scale	1	1/100
Ship type	Tanker	Tanker
Speed (m/s)	7.97	0.79
LBP	320 (m)	3.2 (m)
Bread (m)	58	0.58
High (m)	30	0.3
Draft (m)	20.8	0.2
Displacement (Ton)	312937.5	0.3127
Block coefficient (C_B)	0.8101	0.81001

B. Rudder and propeller

The model is fitted with Horn rudder, which has a blade area of 273.3 (cm^2) and rational speed of 23.4 (degrees/second). The rudder is connected with a servo-motor for port to starboard helm. The propeller is a right-handed fixed screw with 4 blades, which has the diameter of 9.86 cm. The detail of the used rudder and propeller is shown as the Table 2.

Table 2. The specifications of the rudder and the propeller

Rudder	
Rudder type	Horn
Rudder Area (cm^2)	273.3
Rotation Rate (degs/second)	23.4
Propeller	
Propeller type	Fixed blade
Blade number	4
Diameter (cm)	9.86
Scale P/D (0.7R)	0.721
Scale Ae/Ao	0.431



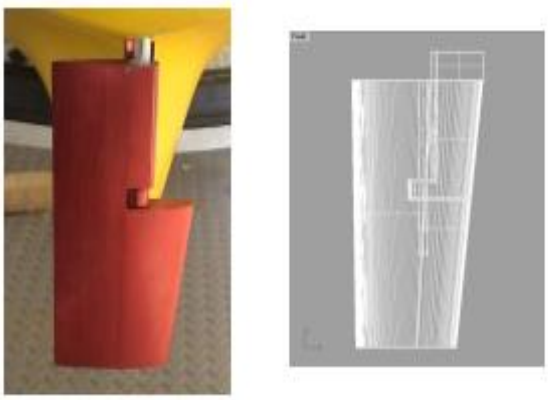


Fig. 2. Rudder and propeller

C. General block diagram of the ship model

On this model, the rudder and the propeller are controlled by servo-motors, which are connected to the signal-receiving units in the control box. The control box is to transmit the parameters of steering angle, steering speed and propeller speed to the server. On the other hand, the onshore handheld controller connected to the control box on the model that executes remote controls of changing steering angle and speed of propeller. On this model, a GPS receiver and an Inertial Measurement Unit (IMU) are also installed and connected to the server for continuous parameters of ship position, speed, course and some states like heeling angle, trim by stern or bow, speed change. All parameters of the model are transmitted to the server, this computer is also connected to another located on shore via a wifi connection to conveniently monitor the experimental process. The overview of experimental equipment is presented as in Fig. 3.

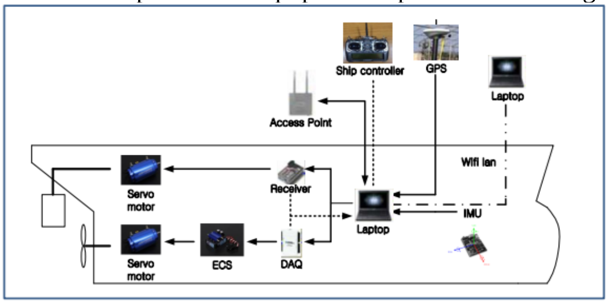


Fig. 3. Overview of experimental equipment

LABVIEW software is used as the communication language between computers and electronic devices, as shown in Fig. 4.

Fig. 4. Interface of LABVIEW software and indicators

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D. Location & weather conditions

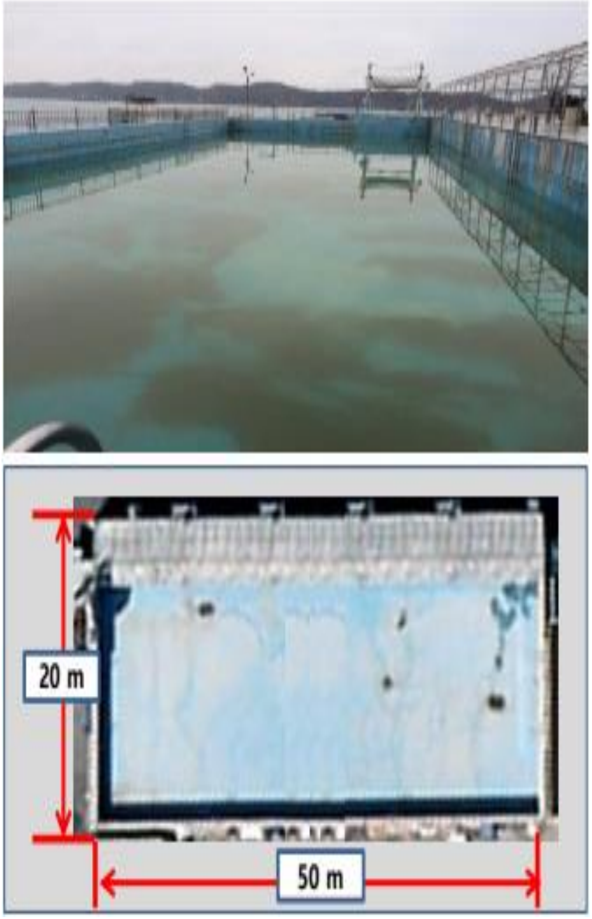

Fig. 5. The location for experiment

The experimental site was located at the pool of Mokpo National Maritime University, with the two dimensions of 50m and 20m, a depth of 80 cm, and the weather conditions, wind speed from 1.8 to 2 knots, air temperature of 17.5 degrees Celsius.

III. EXPERIMENT & RESULTS

Before carrying out the experiment on the pool to record the quantitative relationship between metacentric height and ship maneuverability, values such as center of gravity, draft, displacement and weights placed on the model to determine the initial metacentric height. In this study, four different cases of initial metacentric height were employed for testing as shown in the Table 3. The experimental process is shown in Fig. 6.

Table 3. The particular of experimental cases

	First case	Second case	Third case	Fourth case
GM	0.004	0.015	0.009	0.003
K_{zz}	L/4	L/4	L/4	L/4
Draft	0.135	0.135	0.135	0.135
Froude	0.164	0.164	0.164	0.164
Displacement	186.17	186.17	186.17	186.17

Fig. 6. The experimental process in pool

Fig. 7 shows the turning circles of the various experiments corresponding with the initial metacentric height (GM) shown in the Table 4.

In Fig. 7, it can be seen that the advance distances and the tactical diameters tend to decrease when the initial metacentric heights downs.

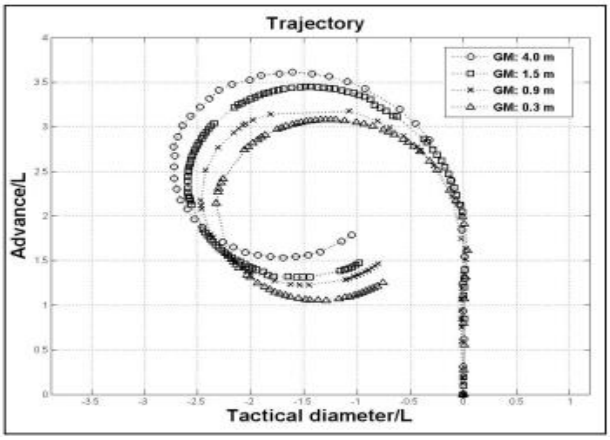

Fig. 7. The turning circles and diameters of the various experiments corresponding to the initial metacentric height

Table 4. The particular of experimental cases

Metacentric High-Gravity of Metacenter (GM)		Tactical Diameters	Advance Distances
Model Ship	**Real Ship**		
0.040	4.0	2.78L	3.43L
0.015	1.5	2.5L	3.28L
0.009	0.9	2.25L	3.03L
0.003	0.3	2.12L	2.90L

The data collected from the server are processed and displayed on the graphs as shown in Fig. 8, Fig. 9 and Fig. 10 below. Different regression methods are also used to establish the relationship between the tactical diameters, the advance distances and the maximum heeling angle with the initial metacentric heights.

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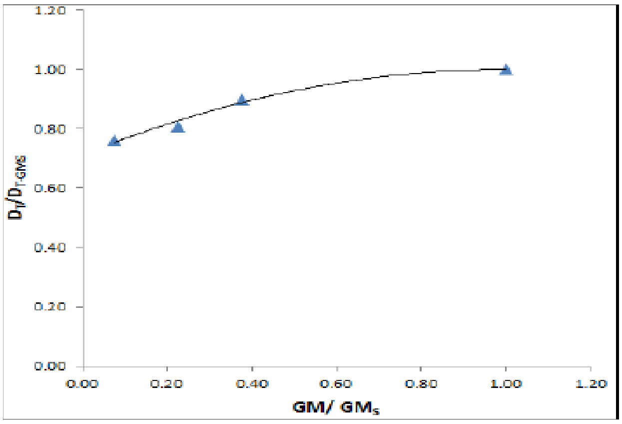

Fig. 8. The tendency of tactical diameters according to metacentric height

The relationship between tactical diameter and metacentric height are shown in the equations below:

Linear regression:

$$\frac{D_T}{D_{T-GM(4.0)}} = 0.25\frac{GM}{GM_{4.0}} + 0.76 \quad (1)$$

Logarithmic regression:

$$\frac{D_T}{D_{T-GM(4.0)}} = 0.99\ln\left(\frac{GM}{GM_{4.0}}\right) + 0.99 \quad (2)$$

Polynomial regression:

$$\frac{D_T}{D_{T-GM(4.0)}} = -0.28\left(\frac{GM}{GM_{4.0}}\right)^2 + 0.57\left(\frac{GM}{GM_{4.0}}\right) + 0.71 \quad (3)$$

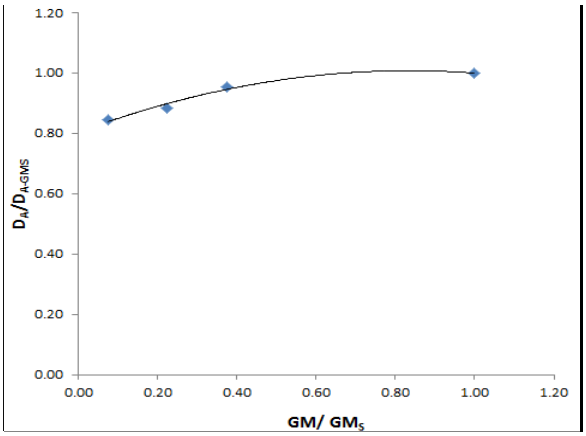

Fig. 9. The tendency of advance distance according to metacentric height

The relationship between advance distance and metacentric height are shown in the equations below:

Linear regression:

$$\frac{D_A}{D_{A-GM(4.0)}} = 0.16\frac{GM}{GM_{4.0}} + 0.85 \quad (4)$$

Logarithmic regression:

$$\frac{D_A}{D_{A-GM(4.0)}} = 0.06\ln\left(\frac{GM}{GM_{4.0}}\right) + 1 \quad (5)$$

Polynomial regression:

$$\frac{D_A}{D_{A-GM(4.0)}} = -0.29\left(\frac{GM}{GM_{4.0}}\right)^2 + 0.49\left(\frac{GM}{GM_{4.0}}\right) + 0.8037 \quad (6)$$

The relationship between maximum heeling angle and metacentric height are shown in the equations below:

Linear regression:

$$\frac{\phi}{\phi_{GM(4.0)}} = -3.76\frac{GM}{GM_{4.0}} + 4.4 \quad (7)$$

Logarithmic regression:

$$\frac{\phi}{\phi_{GM(4.0)}} = -1.61\ln\left(\frac{GM}{GM_{4.0}}\right) + 0.79 \quad (8)$$

Polynomial regression:

$$\frac{\phi}{\phi_{GM(4.0)}} = 9.27\left(\frac{GM}{GM_{4.0}}\right)^2 - 14.29\left(\frac{GM}{GM_{4.0}}\right) + 6.04 \quad (9)$$

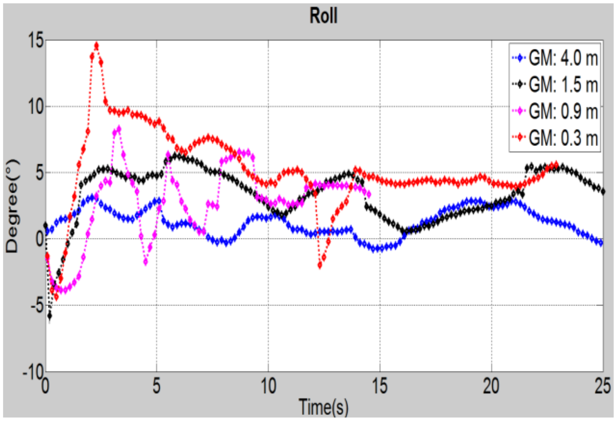

Fig. 10. The relationship between maximum heeling angle and metacentric height

IV. CONCLUSION

The article provides the experimental process of determining the relationship between initial metacentric height and ship maneuverability, in particular, the equations expressing the relationship between tactical diameter, advance distance and maximum heeling angle with initial metacentric height. From these equations, we have a quantitative basis to explain the downward trends of the tactical diameter, advance distance and maximum heeling angle when metacentric height decreases. Nevertheless, the experiment only applies to a specific model, in subsequent studies, the authors will continue to study with other kinds of ships and in the future we will establish a general equation to apply for various ships.

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