Hydrodynamic Performance of A Patrol Vessel

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ABSTRACT

The objectives of this study are to assess the hydrodynamic performance in terms of stability, seakeeping and resistance of patrol vessel hull and analyze the performance based on suitable regulations. Righting Lever (GZ) curve was plotted according to the three loading conditions and the obtained results were compared with the 2008 Intact Stability (IS) Code. In terms of the stability, the patrol vessel passes all the criteria and therefore indicate a good intact stability condition. The seakeeping regulation utilized in this study is NATO STANAG 4154 with the criteria used are the Root Mean Square (RMS) roll angle, RMS pitch angle, RMS vertical acceleration, RMS lateral acceleration and Motion Sickness Incidence (MSI). The vessel passes all the required criteria when operating at the Straits of Malacca but failed to meet certain criteria of the regulation when operating at the South China Sea. Lastly, the resistance data was compared with resistance test that was carried out in the towing tank at the Marine Technology Centre (MTC), Universiti Teknologi Malaysia (UTM). Both results show a good agreement in terms of the resistance and effective power with small percentage difference of only 11.324% and 11.226%, respectively.

Keywords: *Stability, seakeeping, resistance, patrol vessel, Malaysian water*

1.0 INTRODUCTION

There are many types of vessels or boats utilized by the patrolling agency in order to eradicate smuggling, excessive fishing, influx of illegal migrants [1], illegal fishing [2] and terrorist or pirate threats [3]. A Malaysian Maritime Enforcement Agency (MMEA) patrol vessel as shown in Figure 1 is a relatively small naval vessel generally designed to meet the nation's defence base in Malaysian water.

Therefore, important aspects such as stability, seakeeping and resistance should not be taken lightly and are of major concern, i.e., these factors have to be seriously taken into account when designing the vessel. For stability, the vessel might capsize when the vessel is not in upright condition [4] while for seakeeping, the vessel cannot operate effectively even though in low sea state [5]. Lastly, for the resistance, the engine requires a high-power system to resist the ocean wave [6]. However, some patrol vessels in Malaysia does not fulfil the requirements or standards that are recommended by the International Maritime Organization (IMO) or other related organization [7].

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Figure 1: MMEA patrol vessel

2.0 LITERATURE REVIEW

2.1 Stability

Righting lever (GZ) curve as shown in Figure 2 is generated taking into consideration multiple conditions for one ship during the design process. Though the values traced by the curve may be different in each loading case, the shape or curvature of the curve will hardly change, because it typically depends on the geometry of the hull. Thus, the hull designer must always study the initial curvature of the GZ curve once it has been generated for a single load case [8].

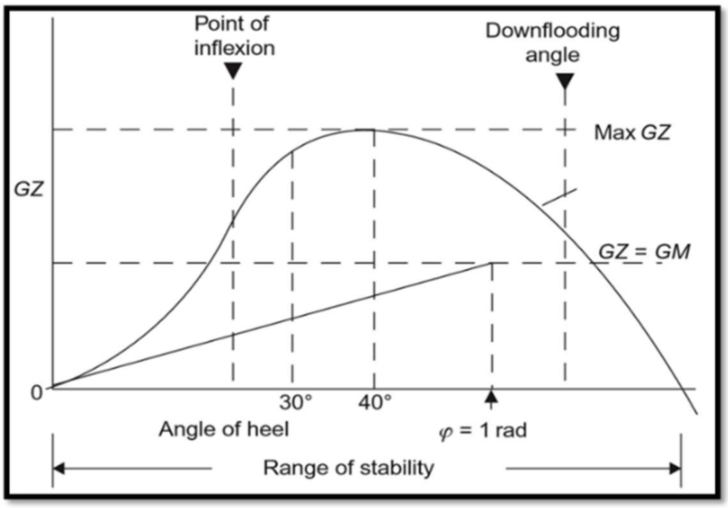

Figure 2: The GZ curve [9]

To determine the stability of a vessel, a number of characteristics of the GZ curve need to be considered including [10]:

i The slope lies at the origin. Righting lever is proportional to the angle of inclination at small angles of the heel and metacentre effectively becomes a fixed point. This means that the metacentric height represents the tangent of the GZ curve at the origin point.

ii Maximum GZ or also known as GZ Max. Both values and the angle at which it occurs are very crucial. This is proportional to the largest steady heeling moment that the ship can survive without capsizing.

iii Range of stability. At a certain angle, the GZ value decreases to zero at times the value greater than 90 degrees and also the larger inclinations become negative. At this angle, it is better known as the vanishing angle of stability. The vessel will return to the upright position at an angle less than this when the heeling moment is removed.

iv Area under the curve. All abilities to absorb the energy of a ship being hit by wind, waves or any external forces represented by the area under this curve.

2.2 Seakeeping

Seakeeping ability or seaworthiness is a measure of how well-suited a watercraft is to the sea conditions when it is navigating. A ship or boat which has a good seakeeping ability is said to be very seaworthy and is able to operate effectively even in the high sea states. Therefore, these aspects should not be taken lightly and should be considered especially in terms of the strength, stability, endurance and the direct wave that can influence these factors.

A floating body as shown in Figure 3 has a six degree of freedom (DOF) configuration. The term motion is defined as the movement of the center of gravity (CG) and the rotation based on a set of orthogonal axes through the CG.

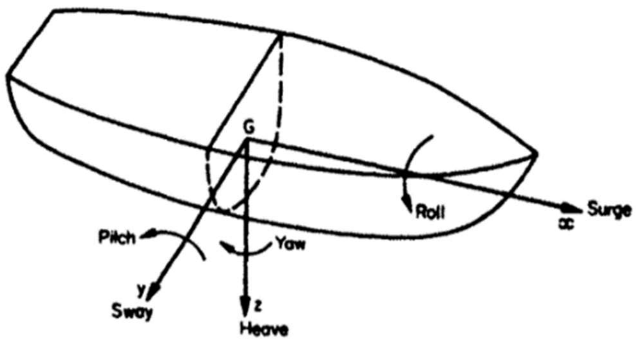

Figure 3: A six DOF configuration of a floating body [10]

2.3 Resistance

The resistance of a ship at a given speed is the fluid force acting on the ship in such a way as to oppose its motion. The faster it moves, the higher the resistance encountered by the ship. As shown in Figure 4, the higher the speed of the ship, the higher the total hull resistance. Air and water have their own masses that are always in motion that in turn cause the occurrence of currents for water and wind for air [11]. For initial study, the resistance is subjected to calm water with the absence of wind factor. Except for the presence of a strong wind, air resistance will be taken into account in determining the resistance.

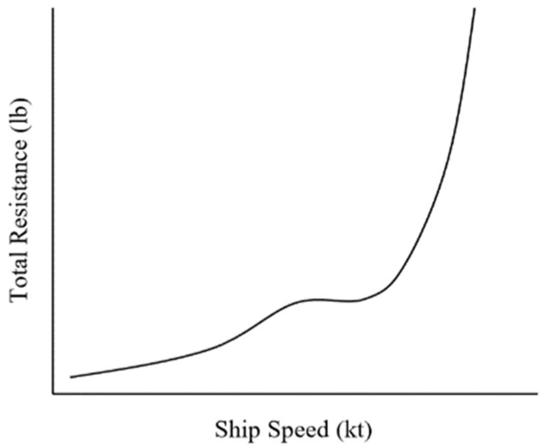

Figure 4: Curve of total hull resistance [12]

Although a ship travels through a calm water, the vessel is also suffering from forces acting in opposite direction to its movement. The force that is exerted is water resistance against the movement of the ship or referred to as total hull resistance, R_T. The ship resistance is influenced by several important factors:

i. Water viscous effect and friction acting on the ship hull
ii. Energy requirements in order to create and maintain characteristic of the wave produced by the ship's bow and stern
iii. The resistance that air provides to the ship motion

3.0 RESULTS AND DISCUSSIONS

It is the objective of this research to evaluate the performance of the patrol vessel in terms of its stability, seakeeping and resistance. After the simulation was conducted, the performance of the vessel in terms of stability, seakeeping and resistance were evaluated according to the requirements and criteria recommended to enhance the productivity and effectiveness of the vessel.

3.1 Stability

The intact stability assessment of the ship shows good agreement whereby the ship is stable based on the three loading conditions which are full load departure, full load arrival and ballast departure conditions. All of the evaluations were conducted with the aid from *Maxsurf Stability Advanced* software package. The GZ curve generated from the software was validated with the recommended stability criteria. In order to get more accurate results, the number of stations can be increased so that the area become more accurate and precise. As tabulated in Table 1, the final stability assessment for all the loading conditions passes all of the entire minimum requirements of the 2008 Intact Stability Code provided by the International Maritime Organization (IMO) [13].

Table 1: Stability assessment for full load departure, full load arrival and ballast departure based on IMO criteria [13]

Criteria	Limit	Full load Departure	Full Load Arrival	Ballast Departure
Initial GM at 0° (m)	≥ 0.150	1.687	1.477	1.533
Area under GZ from 0°-30° (m-rad.)	≥ 0.055	0.205	0.191	0.173
Area under GZ from 0°-40° (m-rad.)	≥ 0.090	0.312	0.298	0.256

Area under GZ from 30° - 40° (m-rad.)	≥ 0.030	0.107	0.107	0.082
Highest GZ in the range of 30° to down flooding (m)	≥ 0.2	0.631	0.625	0.490
Max. angle of GZ (°)	≥ 25	30.5	32.3	28.2

In terms of confidence and accuracy of the results, the results are deemed as acceptable because most part the analysis were performed by using *Maxsurf Stability Advanced* which is a well proven software in executing the stability analysis.

3.2 Seakeeping

For seakeeping, the vessel passes all the required criteria when operating at the Straits of Malacca but failed to meet certain criteria of the regulation when operating at the South China Sea as can be seen in Table 2. This may be due to the wave height and period at the South China Sea which are typically quite high compared to those of the Straits of Malacca. The maximum sea state for the Straits of Malacca is 3 with a characteristic height of 0.875 m while they are 4 and 2.040 m, respectively for the South China Sea. The analysis was done at the highest sea state when the vessel was travelling at the highest velocity assuming that this is the critical state of the ship and hence, this case was evaluated.

The RMS lateral acceleration conformed to the minimum limitation of seakeeping which is 0.1 g for a sea state of 3. However, for a sea state of 4, the RMS lateral acceleration failed to meet the requirement. Meanwhile, the RMS roll angle failed the regulation when heading for the South China Sea due to the high wave condition in the sea state condition. For the RMS pitch angle, the vessel can survive the sea state 3 condition in the Straits of Malacca whereas, the patrol vessel failed to meet the criteria for the South China Sea. The RMS vertical accelerations for both sea states are found to meet the limitation of the seakeeping requirement at 0.2 g. This indicates that as the largest frequency occurs, it results in correspondingly high RMS vertical accelerations due to, different values of the vertical accelerations that are dependent on the exposure time and frequency of oscillation.

Table 2 also presents the MSI at various sea state conditions based on the computational analysis with the limiting values of the MSI at the maximum speed of 26 knots is 20% in 4 hours. The MSI value for sea state 3 at the Straits of Malacca did not exceed the limiting MSI of 20% occurrence after 4 hours while the MSI for sea state 4 at the South China Sea did not meet the criteria. Thus, it can be concluded that the patrol vessel was only able to operate well in sea state 3 while for sea state 4, the vessel cannot travel smoothly due to the fact that sea state 3 represents the coastal zone which experiences short wave heights and low period waves.

Table 2: Seakeeping assessment for the Straits of Malacca and South China Sea

Default criteria	Limit	Malacca Straits	South China Sea
Roll Angle (°)	4	3.78	6.87
Pitch Angle (°)	1.5	0.99	1.93
Vert. Acc. (g)	0.2	0.102	0.181
Lateral Acc. (g)	0.1	0.064	0.111
MSI (%)	20	11.880	33.116

3.3 Resistance

Table 3 summarizes the resistance and effective power for difference speeds (*Vs*) of the patrol vessel. For the purpose of this research, the speeds of patrol vessel were set from 8 knots to 26 knots with an increment of 2 knots. The resistance analysis agreed with the results from the resistance test conducted at the Marine Technology Centre, Universiti Teknologi Malaysia. The total resistance was found to be directly proportional to the ship speeds. The increase in the resistance may be attributed to the viscous pressure drag underneath the vessel's hull. With an average error of 0.02, the results further convince that the *Maxsurf Stability Advanced* software used in this research is reliable.

Knowing the ship's total hull resistance and its speed through the water, the ship's effective power can be determined. Similarly, the effective power increases as the speed of the ship is increased due to the corresponding increase in the resistance. The power required to propel a ship through the water is the product of the total hull resistance and ship speed and hence, the engine power increases even more rapidly than the resistance. This implies that for the ship operator to plan a voyage, getting from one destination to another at high speed requires a lot more power than traveling the same distance at a slower speed. This increase in power adversely and directly affects the amount of fuel burned during traveling.

Table 3: Resistance and effective power data for different speeds

Vs (Kn)	Resistance (kN)		Effective Power (hP)	
	MTC	*Maxsurf*	MTC	*Maxsurf*
8	13.59	14.2	55.92	58.544
10	24.00	24.3	123.43	124.961
12	35.49	37.5	219.07	231.257
14	53.57	47.5	385.76	342.455
16	78.78	76.8	648.38	631.9
18	108.45	106.5	1004.15	986.273
20	136.95	133.5	1408.96	1373.261
22	160.81	157.3	1819.86	1780.063
24	184.02	177.9	2271.80	2196.306
26	207.57	196.4	2776.08	2627.134

4.0 CONCLUSION

The hydrodynamics performance of the patrol vessel hull in terms of its stability, seakeeping and resistance have been successfully assessed and analyzed. according to the standard rules or regulations. It is essential for patrol vessel to meet all the requirements that has been set by specific organization in order to increase the efficiency and effectiveness when operating in open seas. Other than that, good performance also affects the safety and comfort of the crews on board the vessel during the operations. If the patrol vessel has poor hydrodynamic performance, it may cause undesirable accidents or harms to the crews and can severely affect the mission in safeguarding the security and sovereignty of a nation.

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