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Investigating the Performance Characteristics of a Semi-Planing Ship Hull at High Speed

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Abstract. Nowadays, the monohull and catamaran design as the high-speed vessel (HSV) become the convenient ships in sailing for the use of civilians, cars, buses, large trucks, and freight. However, some accidents by this kind ship due to its performances at high speed still occurred and required serious attention. The resistance and stability of a semi-planing hull must be reasonably considered because sometimes these are contradictory in making decisions for proper design. Therefore, this study has investigated the performance characteristics of a semi-planing ship hull at high speed. The semi-planing hull was modeled into three trim by stern conditions. The trim by stern of the semi-planing hull increases air cavity length and effects on resistance reduction. The decreased resistance is significant in FnV > 1.5 and the resistance reduction was averaged 34%. The powering requirement of the semi-planing hull would reduce due to trim by stern to then shifts on higher FnV. On the other hand, the stability range of semi-planing hull for all trim conditions is reduced due to the increase of trim by stern. Also, the maximum righting arm (GZ) shifts due to trim by stern as well where the increase of maximum GZ was averaged 3.72%. The GM decreases in increasing the angle of stern trim averaged 9.12%.

1. Introduction

Nowadays, convenient sailings using high-speed vessels are still popular for the use of civilians, cars, buses, large trucks, and freight. As known, in the 1990s, monohull and catamaran designs as a high-speed vessel (HSV) become widely used. However, some accidents due to performance still occurred and required serious attention.

The HSVs, hull shape underwater surface, are classified into semi-planing hull and planing hull. The performance and hydrodynamic characteristics of the HSVs have been interesting to be studied. Some studies have attempted various approaches to investigate the performance of the HSV. The modeling of vertical plane motion of an air cavity ship was modeled [1], and then artificial cavitation for reducing ship drag was applied [2]. However, these researches were continued to investigate more [3-6], then the steady hydrodynamic of semi-planing air cavity hulls was modeled based on linearized potential-flow theory [7]. However, the result had not validated yet with experimental results. These all research has shown that interaction between planing hull-water-air cavity contributes complex hydrodynamics matter. Moreover, the surface wave contours associated with the forebody wake of stepped planing hulls was investigated where the longitudinal surface wake profiles aft of prismatic hulls was defined and empirical equations are that quantitatively was developed as well [8].

This study has introduced to the concept of stepped planing hull that could contribute hydrodynamic advantages and then it was highlighted that the stepped planing hull was firstly studied and introduced. Correspondingly, the stepped planing hull was continuously studied [9-11]. Nevertheless, both the planing hull without stepped and the stepped planing hull are still used for the designs of monohull, catamaran, and trimaran.

On the other hand, the performances of the HSVs have been studied as well. The resistance variations related to different hull forms, slenderness ratio and other hull characteristics along with suggested design criteria for forecasting the threshold of dynamic transverse stability [12]. However, the semi-planing hull is sometimes sailing at high speed until 30 knots. The characteristic of resistance and hull form of high-speed trimaran planing hull were investigated [13], where the two auxiliary side hulls increased aerodynamic lift at high-speed motion, which improves the hydrodynamic performance. The trimaran planing hull also has excellent longitudinal stability and low wave-making action. The calm-water resistance of hard chine hulls in the pre-planning regime was predicted by using mathematical model [14], and the model could be used in the concept design phase. The hydrodynamic of the stepped planing hull was investigated by using both experimental and numerical analyses [15]. This study focused on the vertical flow phenomena featured by planing hull.

On the other hand, the related studies focused on the stability of the ship at high speed had been discussed [16-18]. Correspondingly, the mechanism of a transverse stability loss of planing craft was investigated [19]. The towing tank test was used for investigation and then estimation method of stability criteria was proposed. Therefore, the stability of a ship at high speed becomes important concern to study more detail.

Based on the discussion above, there are two understanding points of hydrodynamics view that are resistance and stability of a semi-planing hull at high speed. Those points are important matters in ship design for semi-planing hull. However, the proper resistance and good stability at high speed are sometimes contradictory in decision making for ship design. The speed of semi-planing hull increases in decreasing resistance due to increasing the angle of stern trim, however, this condition decreases absolutely stability. Regardless, the studies of the performance and hydrodynamic characteristics of semi-planing hull at high speed are still devoted widely to obtain some interpretations and knowledge for proper ship design. Therefore, this present study has investigated resistance and stability of a semi-planing hull at high speed.

2. Methods

Here, the semi-planing hull which was investigated has the main dimensions as provided in Table 1 and the body lines plan shown in Figure 1. The semi-planing hull probably shifts to high speed and then trim by stern is resulted. Therefore, the semi-planing hull was modeled and set into three trim by stern conditions, i.e. 1 degree, 2 degrees, and 3 degrees as shown in Figure 2. Those trim conditions were kept during computation process. Firstly, the semi-planing was modeled by using Maxsurf Modeller application [20] as shown in Figure 2. The investigation of resistance and stability of the semi-planing hull was conducted by using Maxsurf Resistance and Maxsurf Stability application [20].

The resistance was computed by using the Wyman method. The speed of the semi-planing hull was set until higher volume Froude number (FnV) around 4.0 with efficiency 60%. Ship water depth (T) is similar to the displacement given by the sum of Lwt and Dwt in even keel conditions.

Table 1. The main dimensions of the semi-planing hull

Length Over All (LOA)	19.06 m
Length Between Perpendicular (LBP)	17.72 m
Length Water Line (LWL)	17.77 m
Breadth (B)	4.51 m
Height (H)	1.80 m
Draft (T)	0.45 m

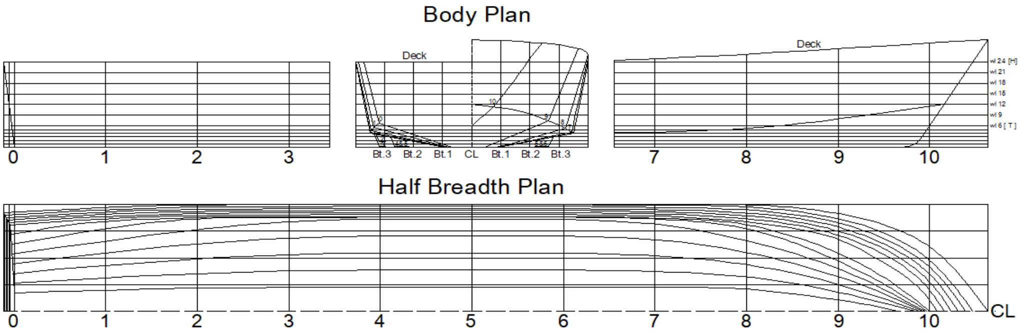


Figure 1. The main dimensions of the semi-planing hull

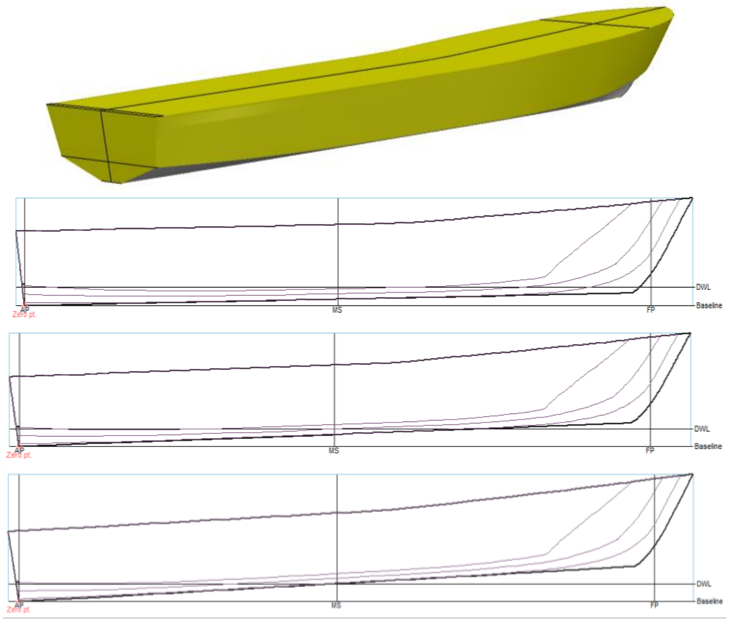


Figure 2. The model of semi-planing hull and their conditions in trim by the stern 1 degree, 2 degrees, and 3 degrees

For stability investigation, the center gravity point of the semi-planing hull was considered by calculation of weight moment. The deadweight ton (Dwt) of the semi-planing hull included passengers, luggage, fuel oil, fuel diesel oil, freshwater. Then, the lightweight ton (Lwt) included overall hull, outboard engine, outfitting component, accommodation equipment, navigation equipment, deck machinery, and lifesaving appliance and equipment. The weight distributions of Dwt and Lwt components were accorded to general arrangement. Then, the weight distributions were input in load case of Maxsurf Stability. The stability parameters were then corrected by using the criteria of IMO–HSC 2000 provided by Maxsurf Stability application.

3. Results and Discussion

The semi-planing hull was modeled successfully using Maxsurf Modeller. Then, the model was computed using Maxsurf Resistance and hereafter, it was computed using Maxsurf Stability. The followings are the discussion of the obtained results of the resistance and stability of the semi-planing hull.

3.1. Resistance Analysis

The several parameters of hydrostatic for each trim by the stern condition are shown in Table 2. The water displaced of the semi-planing hull decreased in increasing the angle of trim by stern due to shifting FnV where immersed depth was similar each trim condition. Water length also decreased in increasing the angle of trim by stern, therefore, the length air cavities of trim by stern 1 degree, 2 degrees, and 3 degrees resulted approximately 0.31 m, 4.75 m, and 9,04 m respectively.

Hereafter, the resistance of the semi-planing in increasing FnV for each trim by stern is shown in Figure 3. The resistance seems an increase in increasing FnV, however, the resistance increases significantly in FnV more than 1.5 for each stern trim condition. However, the effect of trim by stern could be reduced resistances and then results different resistance in increasing the angle of stern trim.

Table 2. The hydrostatic parameters of the semi-planing hull in each trim by the stern condition

Parameter	Trim by stern (degree)			
	Even keel	1	2	3
Displacement (ton)	20.19	11.78	6.271	3.979
Volume displaced (m^3)	19,696	11,495	6,118	3,882
Draft Amidships (m)	0.45	0.45	0.45	0.45
Immersed depth (m)	0.45	0.45	0.45	0.45
WL Length (m)	17.7	17.392	12.953	8.661
Wetted Area (m^2)	68,232	57,706	37,794	24,376
Waterplane Area (m^2)	62,898	55,231	36,243	23,052
Prismatic coefficient (Cp)	0.835	0.661	0.522	0.95
Block coefficient (Cb)	0.619	0.372	0.286	0.297

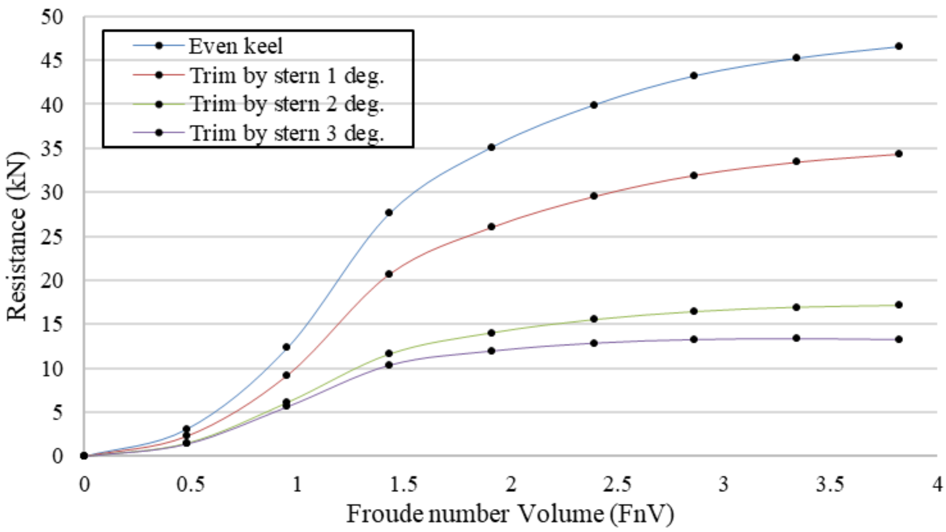


Figure 3. The resistance of the semi-planing hull in increasing Froude number volume (FnV); even keel, 1 degree, 2 degrees, and 3 degrees

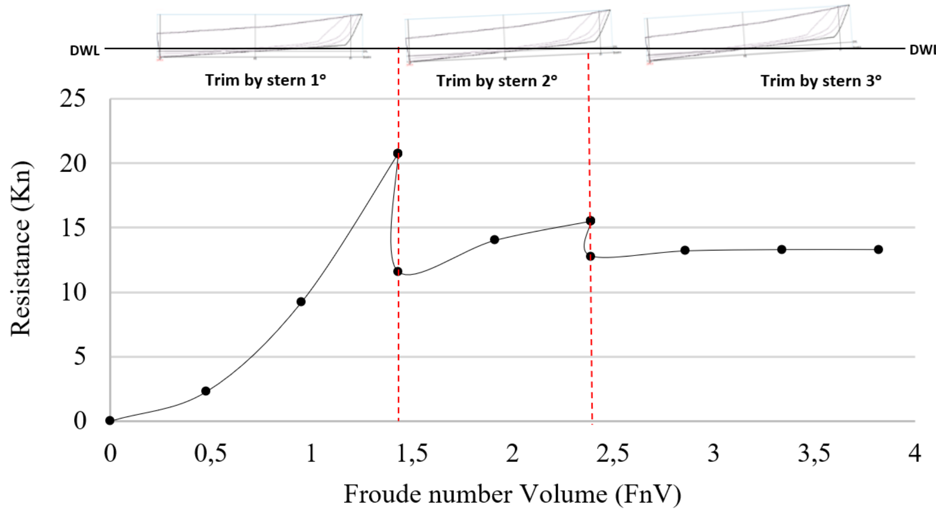


Figure 4. The resistance of the semi-planing hull in each trim by stern and fluid flow regime based on Froude number volume

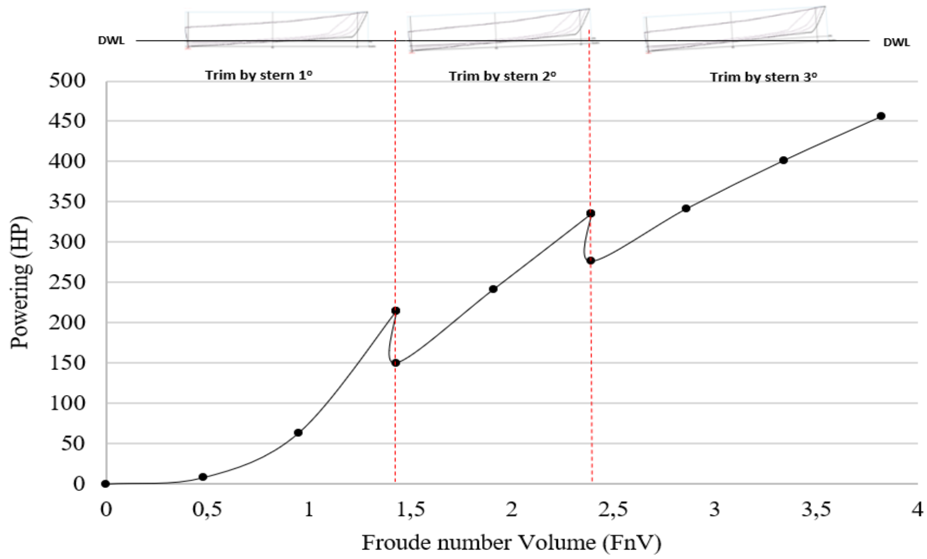


Figure 5. The powering of the semi-planing hull in each trim by stern and flow velocity regime based on Froude number volume

Figure 4 shows the resistance and shifting speed (FnV) of the semi-planing hull in each trim by stern. Correspondingly, Figure 4 describes the effect of trim by stern on resistance and speed contribution through the water. The resistance of the semi-planing hull by stern trim 1 degree reached approximately 13 kN in FnV around 1.15 and it reached 20 kN in FnV around 1.43. However, the stern trim 2 degrees reached 11.6 kN in FnV around 1.43 and the resistance 15 kN reached FnV 2.39 but it was only 12.5 kN by stern trim 3 degrees. Moreover, the resistance approximately 12.5 kN contributed FnV 1.2 by stern trim 1 degree, FnV 1.7 by stern trim 2 degrees, and FnV $\geq$ 2.39 by stern trim 3 degrees. This means the increased stern trim angle or the increased air cavity length effects on resistance reduction or increase of FnV.

On the other hand, the resistance and FnV as discussed previously effects on resulted powering and then it could be used could decide properly powering taking into account economical operation and performance safety. Figure 5 shows the powering of the semi-planing hull in each trim by stern and flow velocity regime based on Froude number volume. The powering semi-planing hull by stern trim 1 degree is required approximately 214 Horse Power (HP) when FnV reaches 1.43, however, it is only required approximately 150 HP by stern degree 2. In addition, the reached FnV 2.39 is required powering approximately 334 HP by stern trim 2 degrees but it is only required approximately 276 HP by stern trim 3 degrees. Similarly, the required power 214 HP reaches FnV 1.43 by stern trim 1 degree and shifts FnV around 1.78 by stern trim 2 degrees.

3.2. Static Stability Analysis

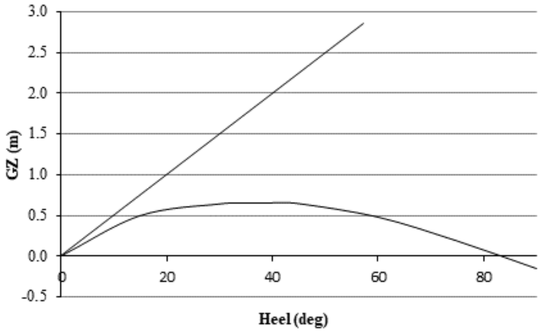
The stability of the semi-planing hull was analyzed successfully using Maxsurf Stability in full loading condition. Figure 6 shows examples of the statical stability curves in still water that were produced for even keel condition and stern trim 1 degree by measuring the righting arm or arm lever (GZ) for each heel angle.

The stability range for all trim conditions seems the same from 0 degrees to 82 degrees, In fact, it has a different because the vanishing stability angles that were obtained are small different magnitude. The righting arm (GZ) of the semi-planing hull instability range each stern trim condition is provided in Table 3. The maximum righting arm (GZ) of even keel condition was given 0.663 meter which was in 40 heeling degrees but it moved to 35 degrees for all stern trim conditions that were 0.656 m, 0.640 m, and 608 m respectively. Those seem little increase averaged 3.72%.

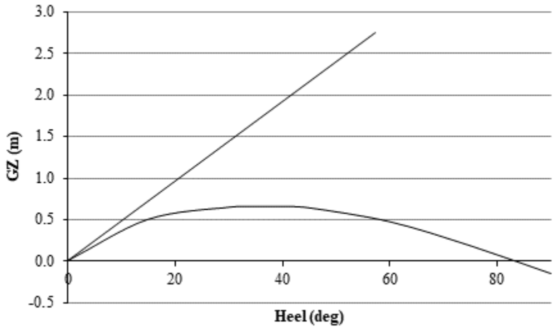
The heel angel larger after the maximum point is strong decrease of righting arm to zero. Also, those seem the stability range reduction where the trim by stern 3 degrees has the lowest stability range. Then, the stable upside-down seems in overall trim conditions and the highest negative stability is in stern trim 3 degrees as shown in Table 3.

As discussed the righting arm in range stability, the intact stability of the semi-planing hull in each stern criteria hull was corrected to fulfill stability criteria as shown in Table 4. The intact stability criteria were given by the code of High-Speed Craft Monohull 2000 which is provided into the Maxsurf application. Overall criteria requirements were accepted for all trim conditions. The metacentric height (GM) is the most vital parameter for intact stability where the GM decreases in increasing the angle of stern trim of semi-planing hull averaged 9.12%. Then, overall stern trim conditions describe positive GM or GM> 0.

The GM of the semi-planing hull is affected by body form or shape underwater surface.



(a)



(b)

Figure 6. Example static stability curves; a). even keel condition, b). trim by stern 1 degree

Table 3. Righting arm of the semi-planing hull in stability range each stern trim condition

Heel degree / Conditon	Righting arm (GZ) in meter								
	0	15	30	35	40	45	60	75	90
Even Keel	0.000	0.504	0.649	0.661	0.663	0.653	0.486	0.189	-0.155
1 Degree	0.000	0.501	0.646	0.656	0.655	0.639	0.471	0.181	-0.155
2 Degree	0.000	0.486	0.628	0.640	0.638	0.617	0.455	0.179	-0.143
3 Degree	0.000	0.454	0.596	0.608	0.603	0.581	0.428	0.171	-0.131

Table 4. The stability criteria requirements of the semi-planing hull in each stern trim condition

Code	Criteria	Value	Trim by stern (degree)			
			Even Keel	1	2	3
HSC 2000 Annex 8 Monohull Intact	1.1 Weather criterion from IMO A.749(18) Angle of steady heel shall not be greater than (<=)	16	2	2.1	2.3	2.7
	Angle of steady heel/Margin line immersion angle shall be less than (<)	80	5.21	5.71	6.9	9.35
	1.2 Area 0 to 30 or GZmax	3.15	12.42	12.36	11.99	11.27
	1.3 Area 30 to 40	1.71	6.58	6.53	6.36	6.03
	1.4 Max GZ at 30 or greater	0.2	0.663	0.656	0.64	0.60
	1.5 Angle of maximum GZ	15	40	35	35	35
	1.6 Initial GMt	0.15	2.86	2.75	2.48	2.14

The above discussion highlighted that resistance and stability are important considerations for the design of semi-planing hull. The body form of semi-planing hull underwater surface affects its performances, therefore, a good understanding of the performance characteristics would be produced proper design of semi-planing hull.

4. Conclusions

The performance characteristics of the semi-planing hull at high speed, resistance dan stability, were successfully investigated using Maxurf Resistance and Stability application. The investigations of performance characteristics are obtained as follows: 1). The resistance of the semi-planing hull increases in increasing FnV for each stern trim. In high speed, the different increase of resistance is significant in FnV > 1.5. The trim by the stern of the semi-planing hull increases air cavity length, therefore, it affects resistance reduction when shifting FnV. 2). The powering requirement of the semi-planing hull would reduce due to the increased trim by stern. For instance, the required power 214 HP reaches FnV 1.43 by stern trim 1 degree and then shifts to FnV around 1.78 by stern trim 2 degrees. 3). The stability range of the semi-planing hull for all trim conditions is reduced due to the increased trim by stern. The vanishing stability angle in each stern trim condition has a small different magnitude. The maximum righting arm or arm lever (GZ) shifts due to trim by stern where the maximum GZ of even keel condition is in 40 heeling degrees, other conditions move to 35 degrees. The increase in maximum GZ is averaged 3.72%. 4). The intact stability of the semi-planing was corrected to fulfill stability criteria given by the code of High-Speed Craft Monohull 2000. The GM decreases in increasing the angle of stern trim averaged 9.12%. 5). The resistance and stability are important considerations for the design of the semi-planing hull. The performance characteristics of the semi-planing hull could be improved depending on body form underwater surface. Therefore, a good understanding of the performance characteristics would be produced proper design of semi-planing hull.

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