Design of Hydrofoil Craft for Balikpapan-Penajam Route

Wira Setiawan, Alamsyah, Suardi, R. Jamal Ikhwani and Luthfi Habibi
Institut Teknologi Kalimantan

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Abstract: The construction of the Balikpapan-Penajam bridge in order to accelerate the mobilization of goods and passengers is a policy that needs to be highlighted from a maritime perspective. In addition to the huge investment costs, this infrastructure work is very likely to turn out sea transportation, which currently consists of Ro-Ro ferry, Speed boat, and traditional wooden boat. One of the innovations in shipping that can respond to the challenge is the hydrofoil craft. This vessel is designed as a fast ship by utilizing the lift force acting on the foil to produce more speed due to the reduced wetted surface area. The design of this fast ship was carried out using max surf software and CFD simulations to determine foil performance. Based on the results of the study, it is obtained LoA: 2.4 m, B: 1 m, H: 0.53 m, T: 0.27 m. The Hydrofoil used is NACA 64 (1) 212 type with Angle of Attack 20 °, Cl/Cd: 1,424, which results in a greater lift force than the weight at a lifting speed of 17 Knots. The stability analysis shows a maximum GZ value of 0.201 at a heel angle of 48.2 °, and an Initial GMt at heel angle of 0 ° is 0.444 m and fulfilled the IMO HSC 2000 criteria in intact stability for monohull and submersed hydrofoil.

1 INTRODUCTION

Balikpapan-Penajam is two cities in East Kalimantan separated by the sea. This condition is used as a source of income for Ferry Ro-Ro crossing vessels managed by the government and, moreover, individual businesses in the form of fast boats and traditional wooden boats. In 2019, it is planned to begin construction of a crossing bridge connecting the two regions at an expensive cost with a length of 7.35 km. The main reason for the building of this bridge is to accelerate the mobilization of passengers and goods that have been able to take between 30-60 minutes by sea transportation.

The challenge experienced so far can be overcome by using a hydrofoil ship. Foil on ships can facilitate the operation of the fast ship in deep or shallow waters. The application is quite simple, namely by adding foil and strut to the underside of the ship's hull to provide lift due to the pressure difference on both sides of the foil (Wonggiawan, 2015). To apply hydrofoil on the ship, an accurate calculation is needed in determining the type of foil, the angle of attack, and the placement of the foil (Slamet and Suastika, 2012). This is needed to ensure that the hydrofoil design has a greater lift force than the weight of the ship. In addition, error calculation can also cause problems in ship performance, particularly stability (Purwanto et al., 2010).

Hydrofoil Crafts' hull shape tends to be V as typical of the other fast speed ships. It can also be combined with single and many hull shapes. The unique advantage of this type of ship is that the resistance can be reduced by 35% (Sunardi et al., 2016). This is because of the hull as a component of the ship is immersed in water so as to cause drag on the ship, raised in such a way by the pressure difference that occurs on the two sides of the foil. The reduced resistance that occurs will result in lower engine power needed to drive the ship.

Lifting force on the ship as the main concept is designed so that the foil used can maximize the life force that is generated greater than the weight of the ship. Hydrofoil effects of increasing lift on the ship when speed is added. After the hull is lifted from the water to the maximum extent, the required lifting force is constant (Slamet and Suastika, 2012). The lift force depends on the coefficient of lift generated by the foil itself.

The coefficient of lift is influenced by the design of the chamber shape of the foil. The coefficient of lift produced by a foil varies linearly with a certain angle of attack (α). To get the maximum lift force,

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the angle of attack parameter and the selected chord foil are those that have the highest lift and drag ratio (L / D) (Slamet and Suastika, 2012).

This cannot be separated from the speed of the ship itself. The greater the speed of the ship, the greater the lift force (Aji et al., 2016). In terms of Froude Number, at relatively low speeds (Fn <1.8), foils actually increase ship resistance while at relatively high speeds (Fn> 1.8), foils reduce ship resistance (Sunardi., 2016).

Another thing to note is that the angle of attack configuration must be precise. Failure to make correct adjustments will cause the hull to collide with sea level, which will affect the stability of the ship (Purwanto et al., 2010). The position of foils supported by strut also greatly affects the resistance and stability of the ship. For a single hydrofoil, the most optimum position is just below the CG of the ship to reduce the resistance (Sunardi et al., 2016). While the position of fore hydrofoil was 3/5 Lpp from LCG (Slamet and Suastika, 2012)

However, besides all the technical aspects described above, it is also important to discover the limit of the angle of attack where the ratio of lift coefficient/drag coefficient still provides an advantage that affects the lifting force of the foil.

2 METHOD

The ship's hull is designed by using max surf modeler software. The dimension of the ship used is the same as the Balikpapan-Penajam crossing fast boat. Before being built, the design is analyzed both related to resistance and stability, also by using the Maxsurf resistance and Maxsurf stability software packages. Ship resistance is obtained by using two Savitsky method to predict the engine power needed at a maximum speed of 30 knots. Whereas stability for the fast boat is calculated based on the criteria of code for the safety of High-Speed Craft (HSC 2000) both for monohull and submersed hydrofoil issued by the International Maritime Organization (IMO).

On the other hand, to determine the appropriate foil to the ship that has been designed, the foil that has the highest Cl / Cd ratio was selected to generate an optimum foil performance. The types of foil compared were NACA 23012, NACA 0015, NACA 2412, and NACA 64A12 with various angles of attack by using Computational Fluid Dynamic simulation.

$$Cl = \frac{L}{\frac{1}{2}\rho . v^2 .AP} \quad (1)$$

Where :
L: Lift Force (N)
ρ: Fluid Density (Kg/m3)
Cl: Lift Coefficient
v : Velocity (m/s)
AP: Plan Area (m2)

$$Cd = \frac{D}{\frac{1}{2}\rho . v^2 .AP} \quad (2)$$

Where :
D: Drag Force (N)
ρ: Fluid Density (Kg/m3)
Cd: Drag Coefficient
v : Velocity (m/s)
AP: Plan Area (m2)

3 RESULT & DISCUSSION

3.1 Design

The dimension of the hydrofoil vessel is created according to the size of the Balikpapan Penajam crossing fast ship. It is needed in order to facilitate the shipbuilding process, which will be carried out in further research.

Table 1: Main Dimension of Hydrofoil Craft

Item	Dimension
Length Overall (LoA)	2.40 m
Breadth (B)	1.00 m
Depth (H)	0.53 m
Draft (T)	0.27 m

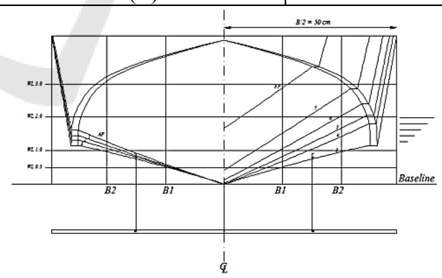

Figure 1: Body Plan of Hydrofoil Craft

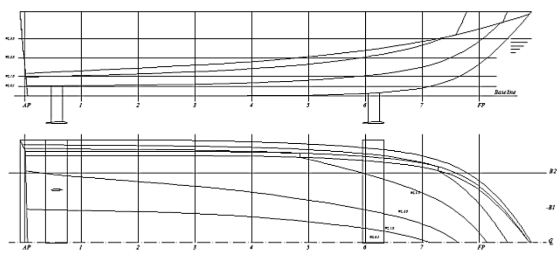

Figure 2: Profile and Plan View of Lines Plan

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Due to the dimension, a V-type fast hull with a hard chine is designed that separates the bottom and side hull with a 14 ° deadrise, and the stern is likely to be raked. The coefficient block is made slim 0.45 but still notice the load capacity, while the coefficient of midship is 0.75. Displacement of ships designed with Fiber Reinforced Plastic (FRP) materials is 0.33 tons with LWT and DWT of 0.06 tons 0.27 tons, respectively. The area of the wetted surface is 2,574 m2, which will be 0 when the ship is in lifting condition. For the starting point of the longitudinal stability, the ship has a stern trim of 0.07 °.

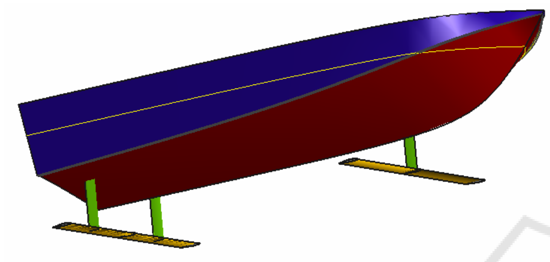

Figure 3: Isometric View of Hydrofoil Craft

3.2 Resistance

Resistance is the most important indicator that can be significantly reduced on hydrofoil craft. The prediction is made by using the Savitsky method up to 100% Maximum Continuous Rating at 30 knots. Based on the Maxsurf Resistance simulation results, the resistance of 0.72 - 0.88 kN is obtained at a service speed of 25-30 knots with engine power requirements of 12.5-18.4 HP, as shown in table 2 and figure 4.

Table 2: Resistance of Hydrofoil Craft

Speed (Knot)	Froude Number	Resistance (N)	Power (HP)
8	1.588	776.18	4.284
10	1.986	752.78	5.193
12	2.383	690.90	5.720
14	2.780	643.36	6.214
16	3.177	618.91	6.832
18	3.574	615.07	7.638
20	3.971	628.92	8.678
22	4.368	657.75	9.983
24	4.765	699.40	11.58
26	5.163	752.27	13.493
28	5.560	815.13	15.746
30	5.957	887.07	18.359

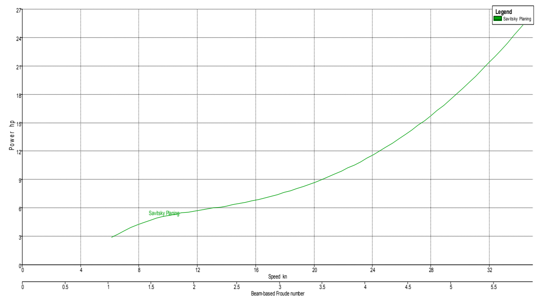

Figure 4: Power v Speed Curve

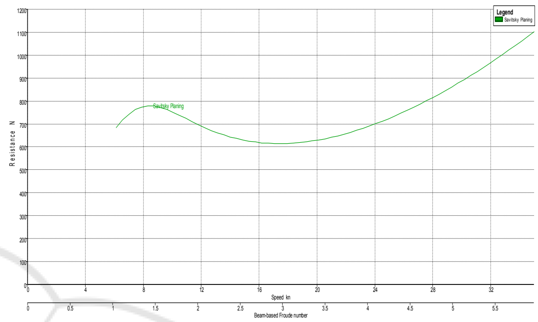

Figure 5: Resistance v Speed Curve

Figure 5 explains that as most ships commonly, a hump occurs at a speed of 8.5 knots and increases sharply in the speed range of 20-30 knots. Humps can occur due to wave patterns that are longer than the length of the ship. Hump is a bad condition to operate the ship because it generates a greater wave-making resistance at low speeds so that it consumes more fuel.

3.3 Stability

Intact stability is calculated by using three criteria, namely High-Speed Craft (HSC) 2000 Annex 8 for a monohull, HSC 2000 Submersed hydrofoils Hull borne mode, and HSC 2000 Submersed hydrofoils Transitional and foil borne modes. The results of the max surf software simulation present stability with displacement of 0.33 tons, LCG = 0.923 m, VCG 0.1 m, and TCG 0.0 m, thus it is obtained data that meet all aspects of safety, for example, maximum GZ 0.201 at a heel angle of 48.2° and Initial GMt at 0° heel angle is 0.444 m. Special for hydrofoil, wind heeling, and angle of equilibrium with passenger crowding also meet the requirements.

Table 3: Intact Stability Result

Criteria	Value	Units	Actual
Code: HSC 2000 Annex 8 Monohull. Intact			
1.1 Weather criterion from IMO A.749(18)			
The angle of steady heel shall not be greater than (<=)	16.0	deg	1.0
The angle of steady heel / Marginline immersion angle shall be less than (<)	80.00	%	15.85
Area1 / Area2 shall not be less than (>=)	100.00	%	261.48
1.2 Area 0 to 30 or GZmax	3.1510	m.deg	3.2567
1.3 Area 30 to 40	1.7190	m.deg	1.9102
1.4 Max GZ at 30 or greater	0.200	m	0.201
1.5 Angle of maximum GZ	15.0	deg	48.2
1.6 Initial GMt	0.150	m	0.444
HSC 2000 Submersed hydrofoils. Hull borne mode			
Criteria: Angle of equilibrium			
Wind heeling (Hw)	10.0	deg	-0.2
HSC 2000 Submersed hydrofoils. Transitional and foil borne modes			
Annex 6 1.2.2.3 Transitional Mode - Angle of equilibrium with passenger crowding			
- The angle of equilibrium with passenger crowding shall not be greater than (<=)	12.0	deg	-0.2

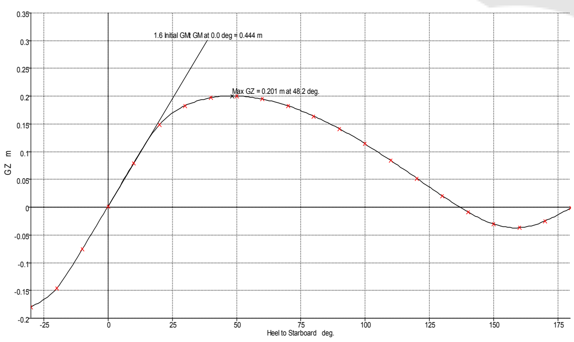

Figure 6: GZ Curve

3.4 Hydrofoil Performance

Four types of hydrofoil were tested to determine the performance of the lift per drag ratio generated. It is known that the displacement of the ship is 0.33 tons or equal to 3237.3 N. The force is charged to the typical two foils so that the load per foil is 1618.65 N.

Based on the CFD simulation results, it is selected NACA 64 (1) 212 foil which shows Cl and Cd by using equations 1 and 2 as the data below:

Table 4: Cl and Cd at Various Angle of Attack

Angle of Attack	Cl	Cd	Cl/Cd
0°	1.01441	0.71942	1.41004
5°	5.48150	3.87586	1.41427
10°	9.23589	6.51238	1.41821
20°	11.97510	8.40703	1.42442
30°	13.32200	9.41710	1.41466

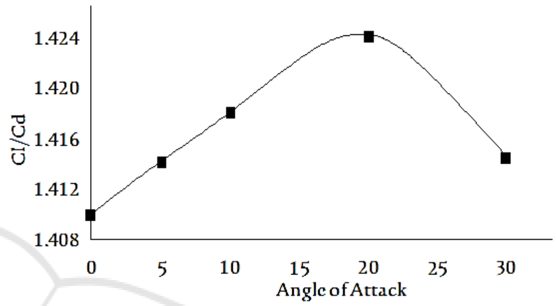

Figure 7: Cl/Cd v Angle of Attack

Figure 7 shows the limit of the advantage point of a foil. It presents that the angle of attack at 20° provides the highest cl/cd ratio and decreases sharply to 30°. Hence, the foil at the angle of attack at 20° is selected to support the hull.

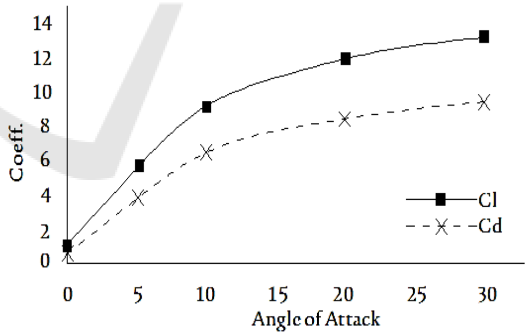

Figure 8: Cl and Cd v Angle of Attack

4 CONCLUSIONS

Based on the results of the study, it is obtained the main size of the hydrofoil craft, namely LoA: 2.4 m, B: 1 m, H: 0.53 m, T: 0.27 m. The foil used is NACA 64 (1) 212 at an Angle of Attack of 20 ° with a span length of 1 m, which results in Cl / Cd 1.42. Whereas the engine power needed at 30 knots speed is 18.4 HP. In addition, stability meets the IMO HSC code criteria for monohull and hydrofoil craft.

To sum up, the hydrofoil as an alternative fast boat crossing Balikpapan Penajam can be declared feasible to proceed to the prototype building stage with FRP material. If the test results are satisfactory, it can be recommended an advanced design of a ro-ro hydrofoil ferry boat that can load passengers and goods in large quantities, including the cost investment calculation.

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