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Study on Resistance of Stepped Hull Fitted With Interceptor Plate

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ABSTRACT

The application of appendages or trim control mechanisms such as the interceptor plate, stern flap and trim tabs have been widely used in recent years most notably on high speed planning hulls including stepped hulls. With the popular use of stepped hulls in the current market, it is of upmost importance to investigate and predict the resistance of these hulls in order elongate and diversify the lifespan and function of the planning hull. It is also important in a sense to increase the effectiveness of the hulls during operation at various speeds. Eventhough the use of interceptor plates has been catching up in recent years, there had been only a handful of studies investigating the impact of interceptors on the performance of planning hulls. In the present study, a scaled down design of a bare hull used by the Royal Malaysian Customs is used. The bare hull design will be analysed in the CFD software COMSOL Multiphysics with various speeds ranging from 0 to 35.9 m/s. The results that are going to be analysed and discussed later are the total resistance and the pressure contours around the hull. Next, a stepped hull design is analysed using step height of 50 mm to 80 mm. Finally, the optimum step height will be used to be fitted with various interceptor plate height of 18 mm, 22 mm, 26 mm and 30 mm. The effect of appendage, which is the interceptor on the performance of the hull will be analysed and compared to other hull configurations. Based on literature reviews and past studies, it is found that the interceptor plates are able to reduce the total resistance by 15% to 19%. However certain parameters were not taken into account for this study, including the trim angle which is assumed to be zero for all cases. This may cause a slight error in the results, but is deemed allowable for academic purposes.

KEYWORDS: *Appendages, Interceptor Plate, Planning Hull, CFD, Stepped Hull, Total Resistance Analysis*

1.0 INTRODUCTION

Planing hulls have been used widely around the world for recreation and other purposes. Amongst the many types of vessels includes motor yachts, fast ferries and even patrol boats. But the problem arises operating at low speeds, in which the vessel experiences high drag force and wave resistance. The resistance of a planing hull compared to a displacement hull, such as a tanker is somewhat different. For a planing hull its primary resistance is wave resistance, while for a displacement hull its primary resistance is surface friction. Therefore, the approach to counter the resistance must acknowledge and adhere to the specified resistance components. This has led to many studies and solutions leading to the application of appendages to be fitted onto the hull surface of a planning hull, including stern flap, trim tab, stern wedge and interceptor plate.

This paper will be discussing a method to reduce and observe resistance in planing hull, which is by fitting an interceptor plate onto a stepped hull. Among the topics that will be covered includes early development, basic principle of operation and the limitation of the method used. A computational fluid dynamic (CFD) software will be used to analyse the resistance of the stepped hull fitted with interceptor plate.

2.0 STEPPED HULL

In the context of stepped hull, it can be classified into one of two groups of hull. Namely, it is in the category of planing hull. It is designed for high speed operations and skims the surface of the water. This is totally different with another category of hull, which is the displacement hull, that displaces water equal to the weight of the vessel and is operated at relatively slow speeds. The idea behind a planing hull is to increase the speed by reducing resistance to forward motion due to the contact with the water. According to Savitsky & Morabito [1], (2010) a stepped hull is an alternative high speed planing hull configuration.

In order to achieve this feat, the wetted surface area of the hull has to be reduced, by introducing lateral breaks or steps midway between the bow and the stern. The steps divides the wetted surface area into several smaller areas. This in turn will allow the hull to plane on two or more high-aspect planing surfaces. Other purpose of the stepped hull is to develop high speeds whilst operating efficiently at low and high speeds, reducing the surface friction of water on the hull and drag resulting from the steps. Operating speeds of a stepped hull is relatively high, around 30 – 50 knots.

Based on the literature review on stepped hulls, Savitsky and Morabito [1], (2010) had suggested that the steps should not be intersected by the stagnation line. Also, that the step height is approximately 5% of the beam. In order to determine the stagnation line, both the length of wetted keel, L_K and alpha which is the angle between L_K and stagnation line has to be obtained first. From the CFD model, the value of L_K is 3.183m. After both the values are determined, they can then be used to determine the value of L_C, length of wetted chine. This study has identified the value of L_C to be 1.394m.

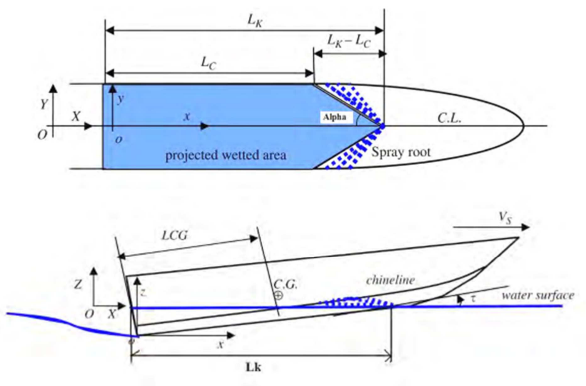

Figure 1: Length of wetted keel and chine (L_K & L_C) (Hassan Ghassemi, et.al, 2008)

The step height is then calculated by taking 5% of the total beam length, which is 1.27m. The obtained step height is 63.5 mm or roughly 64 mm. However, for this study we are going to use several values of step height in order to determine the best value. The step height ranges from 50 to 80 mm, with an increment of 10 mm

3.0 INTERCEPTOR PLATE

The use of interceptor plates have been in place since the 1970's for purpose of trim and ride control of recreational and fast boats such as planing hull and semi-planing hull vessels, motor yachts and even on patrol boats. The application of interceptor plates have been steadily rising throughout the years, and even applied on larger vessels such as merchant ships. Other notable functions of the interceptor plate are for motion control and steering of high speed craft. However, as application of the interceptor plates continue to grow, there have been relatively few published studies concerning interceptor plate, whether it be studying about the impact of interceptor plates or the overall performance when using an interceptor plate.

An interceptor plate is basically a metal plate which is fitted vertically to the transom of the ship, normal to the flow direction and covering the main breadth of the transom protruding with its lower edge several centimetres below the transom, Jaap Allema [2]. The configuration of the interceptor plate which is placed normal to the flow direction causes a stagnation flow region near the blade. The resultant pressure acts on the hull bottom creating an effect which is known as 'trim moment'. This effect adds lift and controls the attitude of the craft, M.H.Karimi [3], (2013). The main principle behind the interceptor plate is to create pressure underneath the hull, at the stern part of the vessel. Pressure is created when the interceptor plate is deployed into the water flow underneath the hull. Minor deployment of the interceptor plate is needed to create a huge lift force under the hull. This lift will change the running trim of the vessel which ultimately results in a lower wave resistance.

Many researchers had studied the optimal height of interceptors in order to improve its effectiveness and had widely adopted the idea that the main factor in selecting the interceptor height is the boundary layer thickness at interceptor location. Based on past experiments conducted on interceptors fitted onto various types of vessel, Alexander H. Day [4] had plotted the interceptor height values against Reynolds number. From this graph, he had found that the interceptor height varies from 0.4% to 0.6% of the waterline length for mono hull model. As for the span of the interceptors, the full beam of the mono hull was used. The stern interceptor's position is located at the transom of the mono hull. Based on the CFD model, the calculated interceptor height of 0.4% to 0.6% of the waterline length is 18.2 mm to 27.3 mm. Therefore, the optimum height should be within the calculated range. Therefore, several height values are used to determine the best interceptor height. These values range from 18 mm to 30 mm, with an increment of 4 mm.

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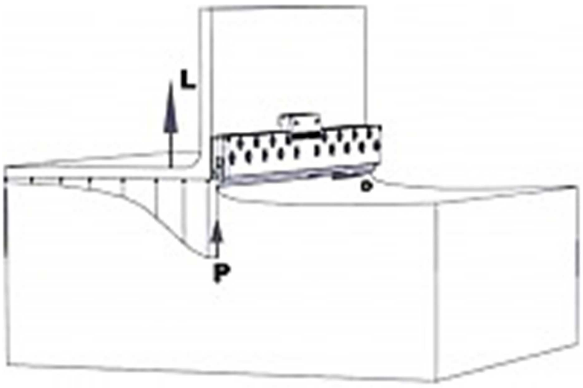
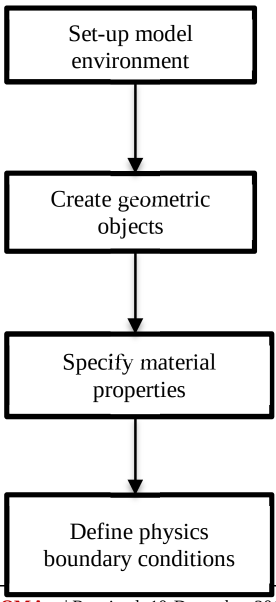


Figure 2: An interceptor plate protruding the water surface

4.0 SIMULATION ANALYSIS USING CFD

The simulation in COMSOL Multiphysics will follow different tasks which is different from one another. The first step in the simulation process is the physics selection where different types of physics such as heat transfer and fluid flow can be selected. Afterwards, is the model orientation, whether it is in one, two or three dimension. Afterwards, is the geometry which can be created in COMSOL Multiphysics or imported from a different file. The materials will be specified and selected for the object, and the physics boundary conditions are defined clearly. The physics boundary includes the walls, inlet and outlet which is important. Then the mesh is generated for the whole geometry and boundary, the mesh size will vary depending on the location. Areas located near the waterline will have much more elements than that found elsewhere. After all the tasks are undergone, the simulation is run. The simulation time will vary depending on the mesh size and the number of physics selected.



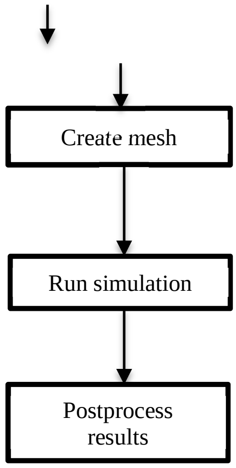


Figure 3: COMSOL Multiphysics simulation workflow

5.0 RESULTS AND DISCUSSION

The first model to be analysed is the bare hull. The bare hull will be subjected to speeds ranging from 0 to 35.98 ms^{-1}. The boundary of the geometry to be simulated is stated clearly, with one inlet and one outlet as well as fixed walls. The initial velocity for every speed is set at 0 ms^{-1}. For the simulation, it is run with a trim angle of zero.

Figure 4: Resistance of the bare hull at various speeds ranging from 0 to 35.9 ms^{-1}

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The second hull configuration is the stepped hull, which is based on the bare hull. The stepped hull will be fitted with various step heights ranging from 60 to 80 mm. The speeds will also be run from 0 to 35.9 ms^{-1}. For the simulation, it is run with a trim angle of zero.

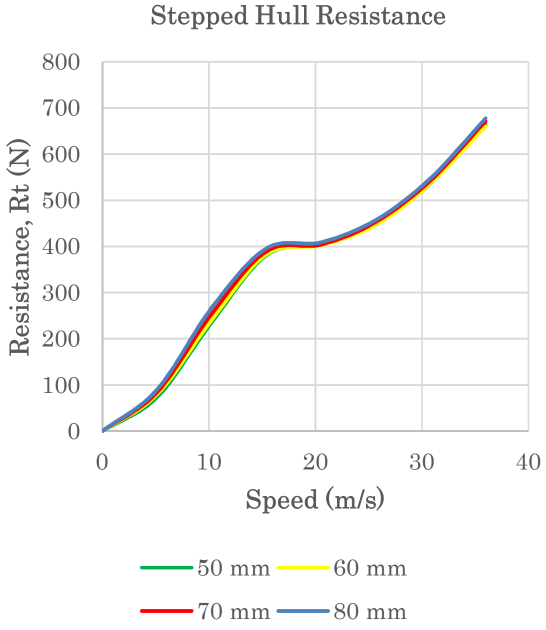

Figure 5: Stepped Hull Resistance at various speeds ranging from 0 to 35.9 ms^{-1}

The final hull configuration to be analysed is the stepped hull fitted with an interceptor plate. The optimum step height of 60 mm was chosen to be fitted with various interceptor height ranging from 18 to 30 mm. These interceptors were fixed at the transom of the model.

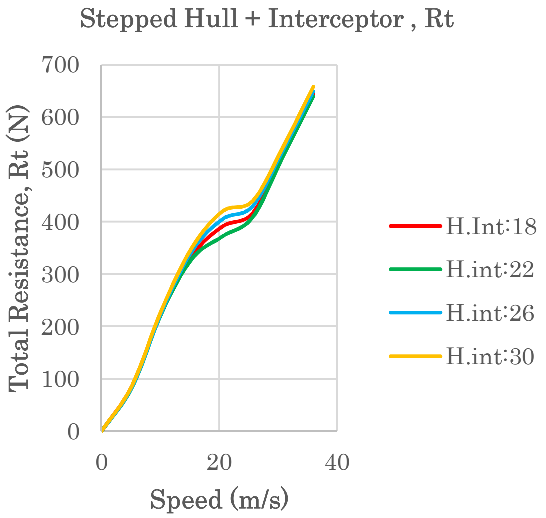

Figure 6: The total resistance for the stepped hull fitted with interceptor plate of heights (18-30) mm

From figure 6, there is a considerable amount of resistance reduction at speeds of 15 to 25 ms^{-1}, thus complying to theory that the interceptor's function at certain speeds. The percentage of resistance reduction at speed of 20.56 ms^{-1} for interceptor height of 30mm and 22 mm is 11.43 %. When comparing the maximum resistance values with the stepped hull, results show a 2.85 % reduction. From the results obtained, it has shown the effectiveness of fitting an interceptor plate to reduce the total resistance acting on the hull. However, during the simulation was done, there might have occurred an error. This error includes external error from the user, during the process of inputting initial information. These may include the selection of boundary, mesh size or initial velocity. Therefore, under these pretenses the results obtained may be subject to error. But this error can be assumed to be negligible as the percentage is very low.

6.0 CONCLUSION

The results obtained for all three hull configurations shows a reduction in terms of total resistance, whether it would be small or big. For the stepped hull with step height of 60 mm, it achieved a 7.47 % reduction in total resistance at a speed of 20.56 〖ms〗^(-1) compared to the bare hull. For the stepped hull of 60 mm height fitted with 22 mm interceptor plates, a 13.84 % reduction in total resistance was obtained when compared to the stepped hull of 60 mm height at 15.42 〖ms〗^(-1). The comparison of this hull against the bare hull resulted in a 17.9 % reduction in total resistance when run at 15.42 〖ms〗^(-1).

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7.0 RECOMMENDATION

The study of the interceptor plate has to be diversified in the future, in order to get a much clearer view on its behaviour and characteristics. The current study on interceptor plates is rather low, and focuses on certain types of planing hull such as the catamaran or the monohull. These are some of the suggestions and recommendations that may be useful for future studies;

1. The use of more than one interceptor to be placed at various location other than the transom, for example the midship.
2. Combination of appendages, such as the interceptor coupled with a stern flap.
3. Simulation of interceptor plate in various other environment conditions.
4. Performing experimental studies on retractable interceptor plates for various types of hull to analyse its effectiveness.

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