High Speed Planing Hulls Resistance Prediction Methods and Comparison

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Abstract

In this study, a brief history and basic information have been provided and the following, starting from planing hull resistance prediction methods, prismatic equations, planing hull series and numerical methods and finally empirical methods are explained. Several prediction methods have been researched and are provided herein. These are Savitsksy's method, which is the best for planning speed ranges, Radojcic's method which is series 62/65 regression, Blount-Fox method, Clement's series 62 model tests, and Clement's simplified method which is also derived from model tests. These methods have been examined, represented, and plotted. The results are presented here.

Keywords: Planing hulls, Savitsky, Clement, high speed, series 62

1. Introduction

Significant research into high speed planing hulls and their resistance prediction methods were begun about 90 years ago. When those studies are examined, it is clear to see that the first experiments had been done on sea planes. Following experiments and studies have been carried out on prismatic planing surfaces and later on planing hulls. The first experiments on planing surfaces were Baker's studies in 1910 (Savitsky, 1964). More comprehensive studies on planing surfaces were carried out by Sottorf. In addition to those studies, there were more experiments conducted by Shoemaker, Sedov, Sambraus and Locke. These studies help us understand hydrodynamic characteristics of different planing surfaces. Empirical equations have been created for practical use by using the relations and variables of hydrodynamic lift force, drag force, pitching moment and wetted area (Savitsky, 1964).

2. High Speed Vessels

The speed-length ratio for high speed vessels is stated as 2 ($V/\sqrt{L} > 2$) (Kafalı, 1981). V is vessel speed in knots and L is waterline length in feet. Another definition was given by

Baird in 1998, states that high speed vessels including all monohulls, catamarans, and trimarans having speeds greater than 30 knots the Froude number will be greater than 0.4. It can be stated that there are two different pressure types acting on the hull. These are known as hydrostatic pressure and hydrodynamic pressure. Hydrostatic pressure is known as buoyancy which is proportional to displacement of the vessel. Hydrodynamic pressure is dependent on the flow around hull and proportional to the velocity square. In general, when the Froude number is less than 0.4, hydrostatic forces (buoyancy) are more predominant than the hydrodynamic pressure forces. Vessels in this speed zone are called displacement vessels. When Froude number is between 0.4 and 1.0 (likewise 0.5 and 1.2), vessels in this speed zone are called semi-displacement vessels. Finally, when the Froude number is greater than 1.0 (likewise 1.2) hydrodynamic forces have an impact on hull and creates lift; these vessels (in this speed region) are called planing hulls.

According to Archimedes, a vessel's underwater volume displacement is equal to the force applied by water to the hull. When the vessel speed is equal to zero (V = 0), the force applied by water to the hull structure is hydrostatic pressure, and will be equal to the floating weight. Conversely, as the body begins moving (speed is greater than 0), water particles are put into motion by the force applied to them. The effect of the force in the opposite direction creates another force known as hydrodynamic pressure. Hydrodynamic pressure forces can cause two different drags. The first one is known as viscous pressure drag, the second is known as wave drag. The component of a pressure through the body results in frictional drag, and the vertical component of the pressure leads to an elevation of the hull (if the effect is in the opposite direction, it may cause the body sink) and trim. As the speed increases, the vertical pressure component, which is known as lift force, is increasing and the hydrostatic forces (buoyancy) will cause the vessel to be lifted out of the water. When hydrodynamic forces are dominant, these vessels are known as planing hulls (Blount & Fox, 1976). Hydrodynamic and hydrostatic pressure forces can vary and subject to the Froude number. Generally, the planing regime starts for Froude number Fn > 1.2 and Fn = 1.0 being the lower limit for the planing regime (Faltinsen, 2005). For this reason, it is possible to categorize high speed vessels with respect to the Froude number, as well as hull forms and their resistances.

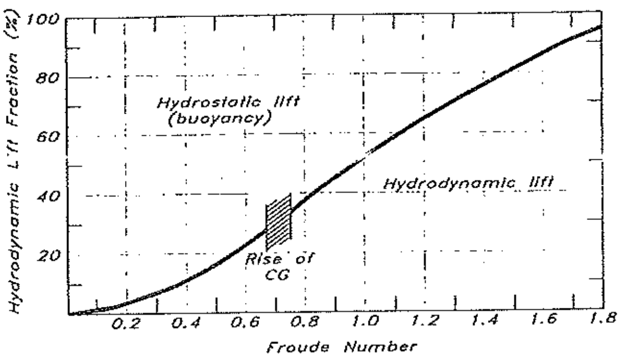

Fig. 1. According to Froude Number, Variation of Effectual Forces on Hull (Larrson & Eliasson, 2000)

3. High Speed Planing Hulls Resistance Prediction Methods

There are some variables which are use to predict resistance of hulls. These are speed and displacement, length and beam, deadrise angle and LCG (Almeter, 1993). Although these parameters show main dimensions and loading of the vessel, they are not capable of specifying the hull form. For this reason, it is necessary to identify hull form subject to beam taper, hull wrap, concave/convex form or straight sections. Nevertheless, it is difficult to include all these variables to the prediction method. Therefore the planing hull series aim is to predict resistance by fixing hull form but changing one dimension of that form. The most accurately matched resistance predictions are based on methods which are developed by planing hull forms (Almeter, 1993).

There is abundant information regarding hull form, therefore it is possible to choose the best prediction method for known hull form. Additionally, any similar hull forms having similar main dimensions and speed ranges may have very close resistance predictions. As explained previously, fundamental speed ranges are shown below;

- Pre-Planing
- Semi-Planing
- Fully-Planing

4. Resistance Prediction

Resistance prediction methods are categorized in the following:

- Planing Hull Series
- Prismatic Equations
- Numerical Methods
- Empirical Calculations
- Theoretical

All prediction methods mentioned above are based on the same data, experiments, and observations of planing hull models tests. The observed data and produced graphics are described the experiment that was conducted (Almeter, 1993).

5. Planing Hull Series

Resistance of planing hull can be predicted from the testing of scale models. In systematic series, forms are generally created by changing dimensions in one parameter. The predicted resistance obtained by using scale laws. It is possible that different prediction methods can lead to different resistance values for same models, it is important for the designer to know how to tests have been carried out for that model (Almeter, 1993).

It is necessary to explain systematic series.

- *Series 50* (Almeter, 1993): This was the first of all planing hull series and was developed in the late 1940's, and designed for the semi-planing region. However, Series 50 is no longer used for modern planing hull forms. The main characteristics of Series 50 are high warp, high beam taper, concave hull. This series was developed for displacement vessels, and tests carried out as such.
- *Series 62* (Almeter, 1993): This series was developed in the early 1960's, and based on pure-planing. The main differences being narrow transom, blunt bow, maximum chine beam forward of midship. This series has been tested on small deadrise angle, and fixed at 13 degrees. Model tests have been made for wide range of speeds, loading and LCG locations. It is adequate and easy to use for a small deadrise angle but blunt bow may lead to high friction force.
- *Series 65* (Almeter, 1993): Series 65 has been developed in the early 1970's to test hull forms for possible hydrofoil applications. This series is suitable for pre-planing regime. Series 65 is actually two series: Series 65A and 65B. Series 65A has exceptionally narrow stern and for this reason its application range is limited. Series 65A is not normally used. Series 65B is more useful in that it is applicable to deep vee hull forms. This series was developed for pre-planing regime and semi-planing regime. Additionally, the models have no beam taper unlike the other series.

  These series has been tested at fixed loading conditions and trim. The resistance was presented in graphical forms as a function of dynamic trim and weight.
- *Naval Academy Series* (Almeter, 1993): The United States Naval Academy tested three systematic round bilge models and three systematic hard chine models. These series were too small to do effective resistance prediction.
- *Dutch Series 62* (Almeter, 1993): This series was developed in the late 1970's, but with low deadrise angle. The Dutch has the same characteristics as Series 62 mentioned above. Although, series 62 has been designed for fully-planing speed ranges, this series has been tested on pre-planing and semi-planing stages.
- *BK Series* (Almeter, 1993): BK series is a semi-planing series was developed in the early 1960's by the Soviets. This series was designed for patrol boats and small warships.
- *MBK Series* (Almeter, 1993): This series is very similar to BK series developed in the early 1970's. MBK series has been oriented towards small, semi-planing hulls.
- *Norwegian Series* (Almeter, 1993): This series was developed in Norway in1969, and was oriented towards semi-planing and pure-planing designs. Norwegian series hull shapes are similar to modern forms. Also, there has been testing to investigate aft beam taper and forebody hull shape.

6. Prismatic Equations

Prismatic bodies have constant cross section and straight buttocks through length. Most of planing hulls can be examined as a prismatic because during planing stage, the sections of hull underwater are constant. The primary variables of prismatic hulls are beam, deadrise angle, LCG, and weight of vessel. Length and hull form cannot be considered in the calculations. Another advantage of prismatic planing hulls is resistance that can be considered as a tangent of a trim angle and the vessel's weight plus frictional drag. Prismatic shapes can be investigated for lift and torque or longitudinal moment. The equations are based on lift and longitudinal moment to trim, and speed and wetted planing area (Almeter, 1993).

There are three prismatic resistance prediction methods (Almeter, 1993).

- Savitsky Method
- Shuford Method
- Lyubomirov Method

The resistance difference between these methods is usually less than 10%. Savitsky's method gives the highest prediction and the other two give a lower prediction. For more detailed information about these methods and other prismatic equation is given in reference (Almeter, 1993).

7. Numerical Methods

Numerical methods can be very useful in the preliminary design stage for resistance prediction. Since numerical methods were developed from model tests, the correct results cannot always be obtained (Almeter, 1993). For this reason, when a designer decides to use numerical methods, it should be considered how correctly the method reflects its database.

There were some numerical methods developed but very few of them are being used today.

- U.S Naval Academy Series Regression (Almeter, 1993)
- Series 62/65 Regression (Hubble) (Almeter, 1993)
- Japan Regression (Almeter, 1993)
- Series 62/65 Regression (Radojcic Regression) (Almeter, 1993)
- Empirical Calculations (Almeter, 1993): Empirical calculations are developed based on graphics and model test data. These graphics are usually developed by designers, mechanical engineers, shipbuilders and naval architectures. If the calculations are correct, it is possible to get proper results. However, in order to get proper results, it is crucial to use similar type of hull forms which are used for developing graphics.

8. Other Methods

There are some other resistance prediction methods different from methods mentioned above. First, Blount-Fox method which is a multiplying factor for Savitsky's method. The second method is Lahtiharju's regression method which was developed in the Technical Research Center of Finland (VTT). Additionally, Soviet BK and MBK methods, along with some other methods have been developed. Finally, there are model tests which have been carried out by Clement based on systematic series.

9. Conclusion

In this study, several resistance prediction methods have been applied on a given planing hull form. These methods are Savitsky's method (Savitsky, 1964), Radojcic's regression method (Radojcic, 1985), Clement's systematic series model tests (Clement and Blount, 1963) and Blount-Fox method (Blount & Fox, 1976).

As shown in Figure 2, one planing hull has been chosen. The deadrise angle is 12.5 degrees, resistance predictions made, and graph plotted against speed (Figure 3).

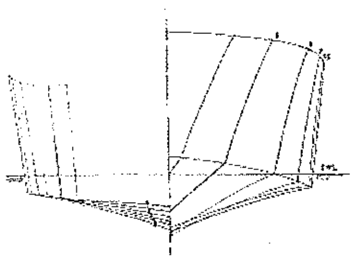

Figure 2. Planing hull.

After the calculations and resistance predictions were done, the comparisons between resistance have been made and illustrated in figure 3 and also given in table 1. When the results were examined, it can be seen that at low speeds (pre-planing and beginning of semi-planing stage) Savitsky's method gives lower resistance values. However, in semi-planing and planing stages Savitsky's method gives better and more acceptable results. The results were compared to the Blount-Fox method, and were found that this method was compatible with Savitsky's method. Blount-Fox is a multiplying factor for Savitsky, and this factor makes a difference of around 20% at low speed ranges. Hence, it can be concluded that using the Blount-Fox method results in better resistance values at low speed ranges than Savitsky's method.

On the other hand, Radojcic's method is a regression analysis of series 62/65. Therefore, it may result incorrect values since the hull is not belonging to series 62/65. After considering this situation, results illustrate that Radojcic's method results in higher values within the lower speed ranges. Conversely, at semi-planing and planing region, Radojcic gives better results but its regression analysis is limited by the volume of the Froude number. So, with the Radojcic's method it is not possible to get results within a wide range of speeds. Also, it is crucial to mention that Radojcic's method is based on A_p value (projected planing bottom area) and this must be taken into account.

Another method is Clement's method, which is based on a systematic series of model tests giving the most literal results. Clement's simplified method is based on $C_{L\beta}$ and gives very acceptable result for very high speeds only.

In conclusion, when designing a high speed planing vessel, the designer must choose the design speed appropriate for that hull. Clement's tests give very good results as they are based on model tests results. For high speed ranges planing stages and semi-planing hulls, Savitsky's and/or Blount-Fox methods would be a good choice. If a series 62/65 is chosen, the designer may employ Radojcic's method. Result comparisons are shown below.

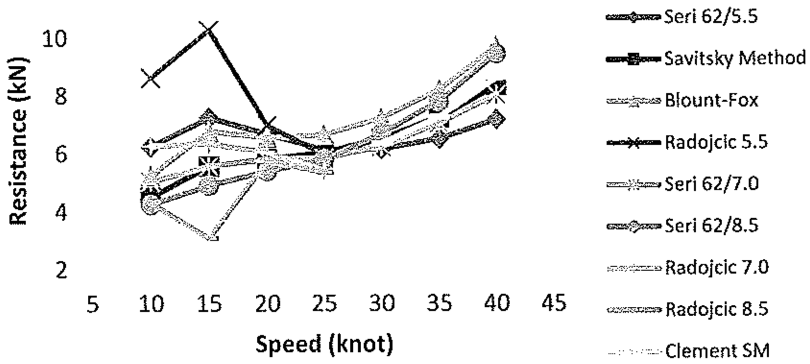

Figure 3. Comparison of Resistance Prediction Methods

Table 1. Resistance Predicion Methods Comparison

F_∇	V / R	Clement S. 62 (5.5**)	Clement S. 62 (7.0**)	Clement S. 62 (8.5**)	Savitsky	Blount Fox	Radojcic (5.5**)	Radojcic (7.0**)	Radojcic (8.5**)	Clement SM*
1.28	10	6.233	5.031	4.229	4.484	5.230	8.616	6.254	4.304	-
1.92	15	7.234	5.565	4.897	5.558	6.762	10.261	6.332	3.072	-
2.56	20	6.678	5.787	5.387	5.800	6.548	6.969	6.049	5.723	-
3.19	25	6.099	5.832	5.787	6.022	6.640	5.953	5.392	5.344	-
3.83	30	6.144	6.233	6.678	6.502	7.218	-	-	-	6.340
4.47	35	6.500	7.034	7.791	7.235	8.194	-	-	-	7.257
5.11	40	7.167	8.013	9.438	8.338	9.689	-	-	-	8.610

* Clement's Simplified Method

** Fixed $A_p / \nabla^{2/3}$ = Values

All values are in kN

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