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AUTOMATION OF SAVITSKY'S METHOD FOR POWER CALCULATION OF HIGH SPEED VESSEL AND GENERATING EMPIRICAL FORMULA

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ABSTRACT

The design of High speed craft has recently become one of the most active areas of naval architecture. Speed increase makes these vehicles more efficient and useful for military, economic or leisure purpose. The planing hull is designed specifically to achieve relatively high speed on the surface of the water. Speed on the water surface is closely related to the size of the vessel and the installed power. The Savitsky method was first presented in 1964 for application to non-monohedric hulls and for application to stepped hulls. This method is well known as a reliable comparative to CFD analysis of hull resistance. A computer program based on Savitsky's method has been developed using MATLAB. The power of high speed vessels has been computed in this research. At first the program reads some principal parameters such as displacement, LCG, Speed, Dead rise angle, inclination of thrust line with respect to keel line etc. and calculates the resistance of the hull using empirical planning equations of Savitsky. However, some functions used in the empirical equations are available only in the graphical form, which are not suitable for the automatic computation. We use digital plotting system to extract data from nomogram. As a result, value of wetted length-beam ratio and trim angle can be determined directly from the input of initial variables, which makes the power calculation automated without manually plotting of secondary variables such as p/b and other coefficients and the regression equations of those functions are derived by using data from different charts. Finally the trim angle, mean wetted length-beam ratio, frictional coefficient, resistance and power are computed and compared with the results of Savitsky and good agreement has been observed.

Keywords: *Planing hull, nomogram, principal parameters, regression, resistance.*

1.0 INTRODUCTION

Resistance calculation is significant in order to calculate required power of a high speed vessel. Existing methods follow rigorous steps to determine parameters based on initial particulars and finally give the output in form of resistance and power. Power of a high speed vessel is a function of the principal particulars, speed, dead rise angle, trim angle etc. Obtaining power requirements is prerequisite for ship design as space available, engine and auxiliary machinery selection and performance at sea highly depend on this.

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The Savitsky method was first presented in 1964 [1]. Since then the method was well documented by J. B. Hadler in 1966 [2], D. L. Blount and D. L. Fox 1976 [3], D. Savitsky and P. W. Brown in 1976 [4] and L. J. Doctors in 1985 [5]. The method was interrogated for accuracy by Clarke et al 1997 [6] and was found satisfactory for design purposes. Savitsky later developed a procedure for the calculation of the whisker spray resistance [7] and a procedure for estimating the resistance of warped planing hulls [8]. The Savitsky method was developed for application to non-monohedric hulls by C. Bertotello and L. Oliviero [9] and for application to stepped hulls by D. Svahn [10] and Loni et al 2013 [11]. The Savitsky method was also used as a significant standard for comparison with CFD calculations of planing hull resistance by M. Caponnetto [12], S. Brizzolara and F. Serra [13] and by O'Shea et al 2012 [14] and Fu et al 2012 [15].

Savitsky has derived formulas for the lift and drag forces on planning hulls. These formulas are based on a large number of resistance tests with prismatic or wedge-type surfaces, in which the trim angle, dead rise angle, wetted length and length-beam ratio were varied systematically.

Hadler presented a method to predict the performance of a planning hull. He used Savitsky's formulas to determine the hydrodynamic forces on hull and an open water diagram to evaluate propeller forces. The solution if the three equations of equilibrium yields the three unknowns- trim angle, wetted length and rate of revolutions.

The main purpose of the present study is the automation of Savitsky's Method to obtain power of high speed vessel directly with the input of initial parameters. This will simplify the process of calculation by exclusion of intermediate calculations and obtaining of data from nomogram. Also with the help of large data set, empirical formulas have been generated for determining mean wetted length-beam ratio, trim angle, friction coefficient and finally resistance of high speed vessel.

2.0 METHODOLOGY

The initial piece of work is solely based on Savitsky's formula for power calculation of high speed vessel. In the beginning, an enhanced study was done and different parameters were calculated based on the initial ones. These intermediate parameters were equivalent flat lift coefficient, lift coefficient for finite dead rise, mean wetted length-beam ratio, trim angle, average bottom velocity & friction coefficient. Among these, trim angle & mean wetted length-beam ratio have been derived from the nomogram.

3.0 AUTOMATION OF SAVITSKY'S METHOD

The whole process was then coded using MATLAB and the nomogram was digitally plotted by using Plot Digitizer to simplify the working procedure. All the curves on the nomogram were plotted by extracting their values first and then regenerating them in a readable digital form. When this digital nomogram was attached to the main code, it provided the final value of resistance.

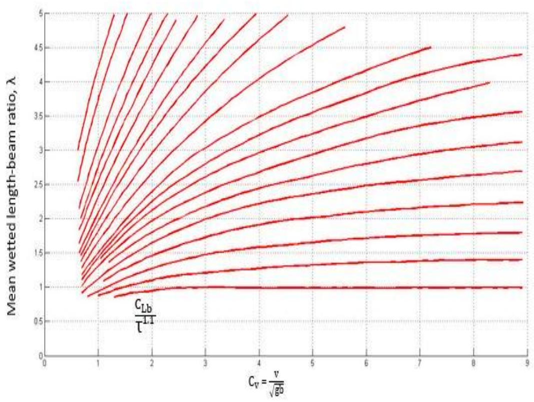

Figure 1: Digital Plotting of curves for $C_{Lb} / \tau^{1.1}$.

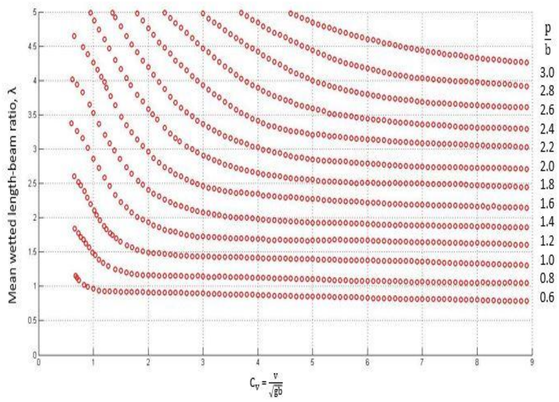

Figure 2: Digital Plotting of curves for p/b.

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To digitally obtain the values in between the curves, method of digital interpolation was applied. This made it possible to deduce exact corresponding values for given Speed Coefficient (C_v) and p/b even if they are in between the curves. In this study, the linear interpolation was taken as a metric of calculation. After this function of interpolation was added to the central calculation system, the final resistance is determined directly. As the whole procedure became automated, it was possible to generate a large set of data within range easily. Furthermore a proper approximation was made on the empirical formula for power calculation of high speed vessel through regression analysis based on this set of data.

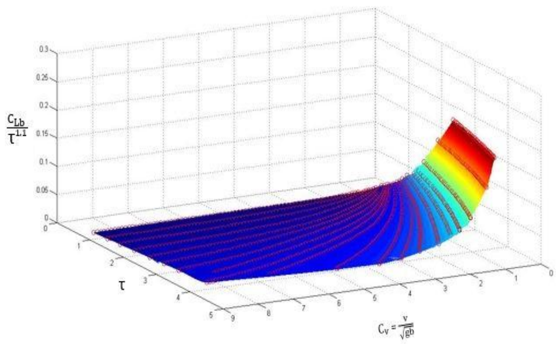

Figure 3: Digital interpolation of curves for $C_{Lb} / \tau^{1.1}$.

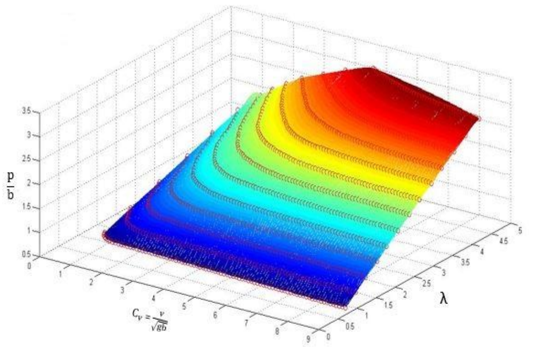

Figure 4: Digital interpolation of curves for p/b.

4.0 GENERATION OF EMPIRICAL FORMULA FOR POWER CALCULATION

The data set was used for approximate equations of intermediate parameters. In order to generate empirical formulas, regression for large data set was made and to set a proper equation that perfectly fit the plotted curves, certain assumptions were made.

From the data set, range of individual parameters was obtained. At first equation for Mean wetted length-beam ratio (λ) was obtained by curve fitting and then Trim angle (τ) was obtained from Savitsky's method.

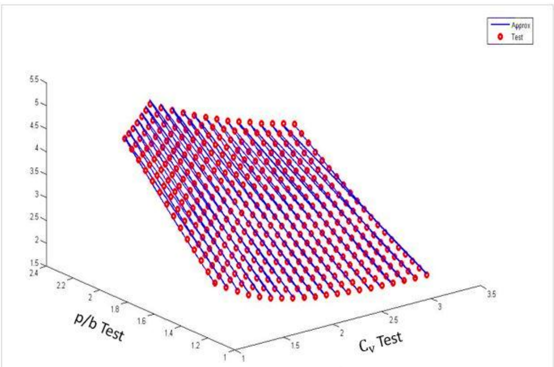

Figure 5: Approximation for the value of λ within range.

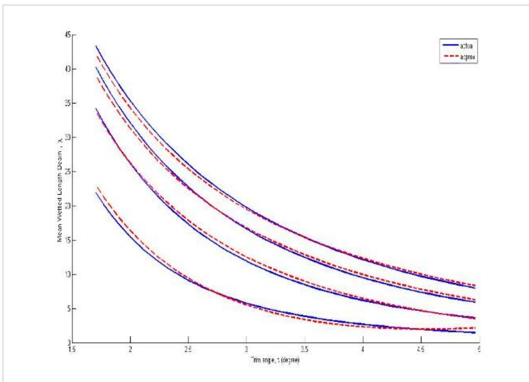

Figure 6: Approximation for the value of τ within range.

The impact of average bottom velocity (V_{1}) on the resistance was analyzed and it was found that it can be assumed as equal to velocity (V) with minimum error. That contributed to the simplification of the regression model and the terms in the final equation were reduced to a good number.

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Then a curve was linearly fitted for deriving empirical formula for C_{FO} which yielded maximum error of about 5%. The approximations were then used to generate formula for Resistance by combining equations for λ, τ and $C_{FO.}$

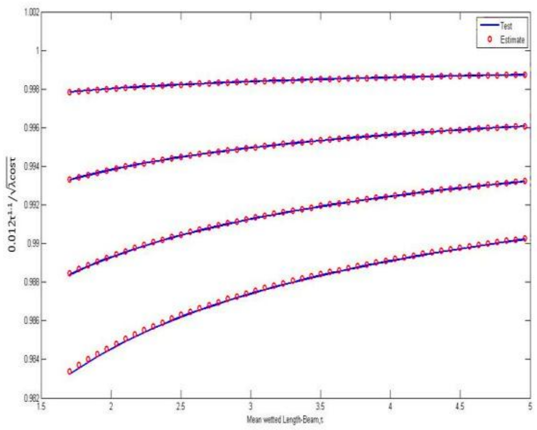

Figure 7: Approximation for V_1 using parameter τ and λ.

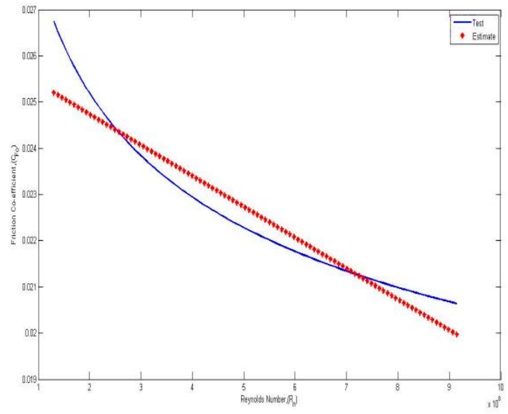

Figure 8: Linear curve fitting for approximation of $C_{FO.}$

Table 1: Range of Input Parameters

Input Parameter	Values	Input Parameter	Values
Length, l [m]	17.74 - 40.04	Mean Wetted Length-Beam Ratio, λ	1.7035 – 4.9624
Speed, v [m/s]	8.52 - 22.74	Trim angle, τ (degree)	1.1452 – 4.0874
Dead rise angle, β [degree]	10°, 15°, 20°	Reynolds Number	1.3015e+08 – 9.1076e+08

5.0 RESULT AND DISCUSSION

The result of the study, through regression analysis of the obtained data set, provided empirical formula for Mean Wetted Length-Beam Ratio (λ), Trim Angle (τ), Frictional Coefficient (C_{FO}) and finally the Resistance (R_T) of high speed vessel. The generated formulas are as followed.

$$\lambda = 0.34952 \times C_v^2 + 0.40036 \times \left(\frac{p}{b}\right)^2 - 0.72402 \times C_v^2 \times \frac{p}{b} - 1.08875 \times C_v^2 + 2.97164 \times \frac{p}{b} + 0.30039 \quad (1)$$

$$\tau = \sqrt[1.1]{\left(\frac{C_{L\beta}}{0.0012\times\sqrt{\lambda}+0.0055\times\frac{\lambda^{2.5}}{C_v^2}}\right)} \quad (2)$$

$$C_{FO} = 0.075 \times (2.6071 \times 10^{-2} - 5.61911 \times 10^{-6} \times b \times v \times \lambda) \quad (3)$$

$$R_T = \rho^2 \times g \times \nabla \times \tau \times \frac{\pi}{180} \times \frac{1}{2} \times v^2 \times \lambda \times C_{FO} \times \frac{b^2}{\cos\beta} \quad (4)$$

$$P = v \times R_T \quad (5)$$

Where, [16]

$$\frac{p}{b} = \frac{LCG}{b} \qquad C_v = \frac{v}{\sqrt{gb}} \qquad C_{Lb} = \frac{2g\nabla}{v^2 b^2} \quad (6, 7, 8)$$

$$C_{L\beta} = C_{Lb} - 0.0065 \times \beta \times {C_{Lb}}^{0.6} \quad (9)$$

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Comparison between the obtained values from the empirical formulas and the actual values from Savitsky's method are illustrated in Figure 7, 8, 9 & 10. In these figures, obtained values and actual values of different parameters for individual data points have been graphically plotted and differences between them was observed.

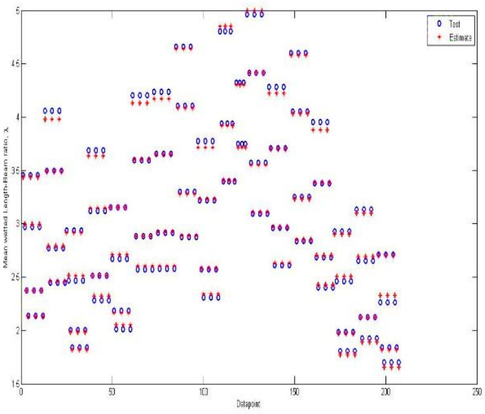

Figure 9: Error checking for value of λ

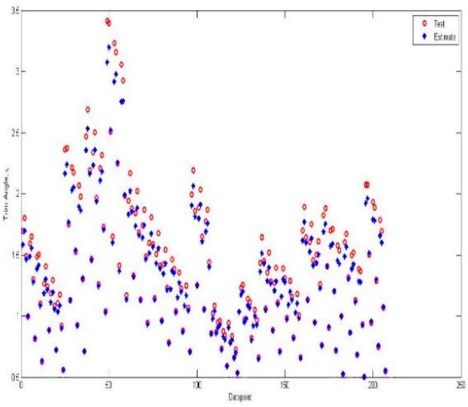

Figure 10: Error checking for value of τ.

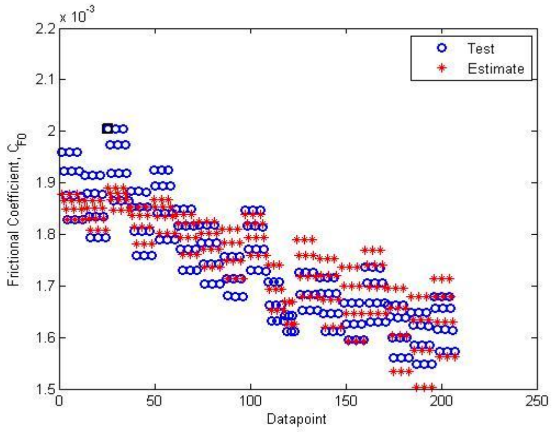

Figure 11: Error checking for value of $C_{FO.}$

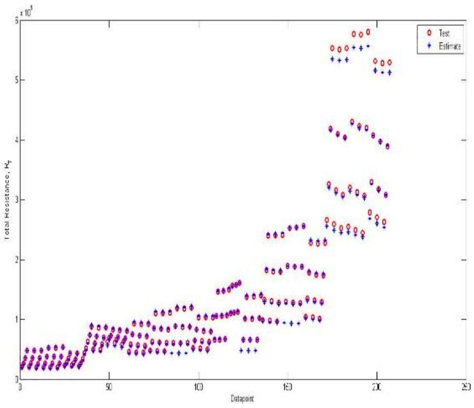

Figure 12: Error checking for value of $R_{T.}$

The obtained results show a good range of similarity with the actual values. With minimal error throughout the data point range, the maximum error of mean wetted length-beam ratio is 2.9%, trim angle is 9% and frictional coefficient is only 0.2%. For most of the data points, the difference between actual values & obtained values of Resistance is negligible. For vessels with higher resistance the maximum error is about 8%. In most of the cases, error increases as the value approaches towards the boundary of the range.

6.0 CONCLUSION

In this paper, approaches were made to generate empirical formula for calculating power of high speed vessel. Also to generate the data set in an automated way, Savitsky's method was put in form of computer program by digital plotting of nomogram for directly obtaining intermediate parameters and finally the resistance. The basic purpose of this paper was to make the power calculation easy.

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The end results were validated by comparing the obtained data and the actual date derived from existing method. The error is negligible throughout most of the data points. The study can be improvised for more accuracy by using a larger data set and fitting curve of higher order. Nonetheless these empirical formulas can be used for study of resistance and power calculation of high speed vessels.

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