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Kayıcı Teknelerde Minimum Direnç için Optimum Trim Açılarının Savitsky Yöntemi ile Belirlenmesi

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ÖZET

Bu çalışmada, kayıcı bir teknenin toplam direncinin minimizasyon problemi geniş bir Froude sayısı aralığı için incelenmiştir. Optimum boy-en oranı ve dolayısıyla teknenin dinamik trim açılarını hesaplamak için Savitsky yönteminden yararlanılmıştır. İlk olarak, Savitsky yöntemi ile tekneye ait boy-en oranları, dinamik trim açıları ve toplam dirençler hesaplanmıştır. Daha sonra, her bir tekne hızı için boy-en oranları kademeli olarak değiştirilerek minimum direnç kuvvetleri ve dolayısıyla dinamik trim açıları hesaplanmıştır. Ardından, optimum trim açılarını bulmak için gereken trim momentleri hesaplanmıştır. Bütün hesaplamalar, Python programı kullanılarak yapılmıştır. Sonuçlar, trim tab kullanımının toplam direnci takriben 20% oranına kadar düşürebileceğini göstermektedir. Minimum direnç için elde edilen trim tab açıları şekillerle ve tablolarla gösterilmiştir.

Anahtar kelimeler: Kayıcı Tekneler, Savitsky Yöntemi, Trim Tab, Python

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Research Article

Determination of the Optimum Trim Angle of a Planing Hull for Minimum Drag Using Savitsky Method

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ABSTRACT

In this paper, the minimization problem of the total resistance of a planing hull is studied for a wide range of Froude numbers. The Savitsky method is utilized to calculate optimum aspect ratios and dynamic trim angles of the hull. First, the aspect ratios, dynamic trim angles, and the total resistances of the hull are calculated with the Savitsky method. Then, the minimum drag forces are computed for each vessel speed by changing the aspect ratios systematically. Then, the required trim moments are calculated to find the optimum trim tab angles. The entire calculations are performed by using a Python program. The results showed that trim tabs can reduce the total drag up to 20% approximately. The obtained trim tab angles for minimum drag are demonstrated with figures and tables.

Keywords: Planing Hull, Savitsky Method, Trim Tab, Python

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1. Introduction

Conventional displacement forms could not match the requirements of planing hulls due to their high resistance and inefficiency, during the 19th century. Therefore, Reverend C. M. Ramus has taken one of the first steps to solve this phenomenon by designing a flat-bottomed model that was just under 1 m (3 ft 3 in.) in length but had one step in 1873 [Clark, 2009]. This model was submitted to Royal Admiralty and tested at the Ship Model Testing Tank at Torquay by William Froude (Cane, 1951). Also, Froude has derived expressions for the forces developed on a flat plate. Figure 1 shows normal force (F_1), tangential force (F_2), lift (L), drag (D), weight (W), velocity (V), due to the movement of the flat plate with planing trim (θ) on the surface of the water.

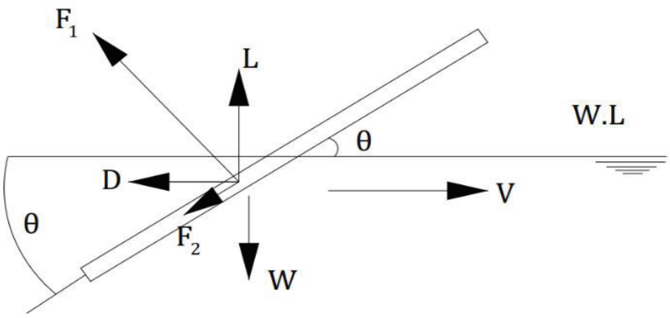

Figure 1. Forces on a planing surface with trim

Primary experiments on planing crafts were carried out by Baker for Hydro-Aeroplanes in 1910 (Baker, 1912). Following experiments were done in Germany by Sambraus and Sottorf, in order to find out the characteristics of planing crafts (Sambraus and Sottorf, 1938). After these works, the cornerstone study of this phenomenon was conducted by Savitsky in USA. He joined Davidson Laboratory in 1947 as a project engineer and following through his career, he would rise to director of the laboratory. During his productive career, he directed research on high-speed marine crafts and was active in expanding analytical techniques and developing unique capabilities for testing a variety of marine vehicles, especially planing crafts. He published a significant technical report which is known as the "Savitsky Method" which predicts the horsepower requirements for planing crafts in 1964 (Savitsky, 1964). The report includes and describes the aspects of the Savitsky Method such as fundamental hydrodynamic characteristics of planing surfaces and definition of planing surface lift, drag, wetted area, pressure distributions and center of pressure, trim angle, deadrise angle, aspect ratio, and wake shape.

Additional studies on planing surfaces with trim flaps, on both experimental and theoretical analysis were conducted by Brown in the Davidson Laboratory as well (Brown, 1971). Furthermore, Savitsky and Brown's study about the effects of controlling trim tabs was published in 1976 (Savitsky and Brown, 1976). Thence, the field of trim control systems became reputed and many other experiments and studies were conducted on planing crafts.

When the very recent literature is surveyed on the trim tabs and their usage on planing hull design, it is seen that the number of numerical studies is numerous. For example, the parametric study with two different models, was carried out on the effects of trim tabs on running trim and resistance of planing hulls by Ghadimi et al (2014). Ertogan et al. (2017) presented an optimal trim control study utilizing dynamic modelling of trim of the craft with the help of sea trial data. In their study, they used system identification techniques and artificial neural network modelling. Amoroso et al. (2018)

investigated the optimum trim curve for minimum resistance for sailing yachts numerically. Ghassemi et al. (2019) proposed a mathematical model based on the Savitsky method to find the optimum trim angle in terms of the total resistance by using trim tab mechanisms. In the study of Jokar et al. (2020), the dynamic stability problem of a planing hull was solved by a pneumatically driven trim tab applied to the transom of the vessel. The linear quadratic regulator (LQR) control approach was used to control the boat. Ashkezari and Moradi (2021) presented the evaluation of the hydrodynamic effects of stern wedges on the stability of a planing hull. In their study, a high-fidelity computational fluid dynamics method was used to examine the effects of stern wedges on resistance and stability.

In the present paper, the phenomenon of reducing the total drag of planing vessel is studied for a wide range of Froude numbers. Firstly, minimum drags are calculated at each hull speed by finding the optimal hull aspect ratio and dynamic trim angle. Then the trim tab direction and angle are obtained according to calculated trim moments for optimal dynamic trim angles. The Savitsky method is utilized to calculate the optimum parameters of the vessel for resistance. The effects of trim tabs on the performance of a planing vessel are investigated.

2. Planing Hull Model and Trim Tab

This study is conducted on the planing hull model with a constant deadrise angle and a trim tab with a constant length of span and chord. Also, the hull form is investigated in detail by the lecture notes of David Clarke (2009). The main specifics of the planing vessel and trim tab are listed in Table 1, the deadrise angle of a planing hull is shown in Figure 2 and a 3D view of the vessel is shown in Figure 3.

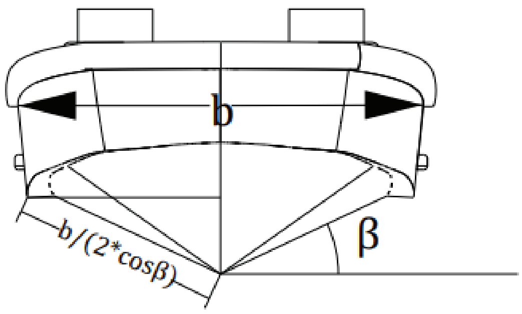

Figure 2. Deadrise angle (β) of a planing hull

Figure 3. 3D model of the planing vessel

3. Savitsky Method

Savitsky method is a widely used approach to predict the planing hull resistance. For this reason, the formulae used in this study are based on the Savitsky method (Savitsky, 1964). The first assumption is the fact that the planing hull is in a condition of a steady-state which implies there is no acceleration in any direction. The total resistance values of the model for 12 different constant vessel speeds are calculated. The speed range is changing between 4 m/s and 26 m/s with an interval of 2 m/s. Therefore, the analyses are done between 0.303 and 1.964 Froude numbers (Fn) with the equations stated below.

Table 1. Dimensions of the planing hull &trim tab

Parameter	Definition	Value	Unit
L	length of the hull	17.678	m
∇	displacement volume	26.515	m^3
LCG	longitudinal center of gravity from the transom	8.839	m
b	beam	4.267	m
σb	length of the trim tab span	4.267	m
β	deadrise angle	10	deg
L_f	length of the trim tab chord	1.067	m

Froude number used in the study is based on the length and the total lift coefficient ($C_{L\beta}$) is as given:

$$Fn = \frac{V}{\sqrt{g * L}} \quad (1)$$

$$C_{L\beta} = \frac{\Delta}{\frac{1}{2} * \rho * V^2 * b^2} \quad (2)$$

where: Δ = displacement force, ρ = density of water, V = hull speed and g = gravity constant.

The speed coefficient (C_V) (Equation 3) is the significant factor to calculate the resistance of the hull. The total lift coefficient of a hull without deadrise angle (C_{L0}) is the sum of the dynamic lift coefficient and buoyant lift coefficient as proposed in Savitsky method. So, C_{L0} can be found iteratively with the help of Equation 4:

$$C_V = \frac{V}{\sqrt{g * b}} \quad (3)$$

$$C_{L0} = C_{L\beta} + 0.0065 * \beta * C_{L0}^{0.6} \quad (4)$$

where β in degree.

The trim angle (τ) and aspect ratio (λ) are required to calculate the total resistance of the planing hull. Throughout the study, the longitudinal center of gravity (LCG) is constant, so, the longitudinal center of pressure (LCP) is constant as well at the equilibrium state for each hull speed, therefore LCG = LCP. According to the Savitsky method, the aspect ratio of planing hull at each speed can be calculated iteratively by following formula Equation 5:

$$\frac{LCG}{b} * \frac{1}{\lambda} = 0.75 - \frac{1}{\frac{5.236 * C_V^2}{\lambda^2} + 2.40} \tag{5}$$

On the other hand, the dynamic trim of planing hull can be readily computed by Equation 6:

$$C_{L0} = \tau^{1.1} * \left(0.0120 * \lambda^{0.5} + \frac{0.0055 * \lambda^{2.5}}{C_V^2}\right) \tag{6}$$

The total friction coefficient (T_{Cf}) (Equation 10) can be calculated after the friction coefficient (C_f) (Equation 9) of the hull which is based on the ITTC-1957 friction line is found and the surface roughness correction ($\Delta * C_f$ =0.0004) is applied. The friction coefficient of the hull is obtained with the use of average bottom velocity (V_1) (Equatiın 7) and Reynolds number (R_n) (Equation 8).

$$V_1 = \left(1 - \frac{0.012 * \tau^{1.1}}{\lambda^{0.5} * \cos\tau} * \left(1 - \frac{0.0065 * \beta}{C_{L0}^{0.4}}\right) * \cos\beta\right)^{0.5} * V \tag{7}$$

$$R_n = \frac{V_1 * \lambda * b}{v} \tag{8}$$

$$\frac{1}{\sqrt{C_f}} = 3.46 * \log(R_n) - 5.6 \tag{9}$$

$$TC_f = \Delta * C_f + C_f \tag{10}$$

where the kinematic viscosity is $(\nu) = 1.356 * 10^{-6}\ m^2/s$.

The total resistance of the planing hull (D) (Equation 12) can be calculated after friction drag (D_f) (Equation 11) is obtained.

$$D_f = \frac{\frac{1}{2} * \rho * V_1^2 * \lambda * b^2}{\cos\beta} * (C_f + \Delta C_f) \tag{11}$$

$$D = \Delta * \tan\tau + \frac{Df}{\cos\tau} \tag{12}$$

3. Optimization Study and Finding Required Trim Tab Moments and Angles

Trim tabs are functional to reduce the total resistance of the planing hull and change the running trim especially for better seaworthiness and avoide a state of porpoising. In the study, the planing model with trim tab is analyzed for this purpose and entire calculations are performed by using a code developed in Python program.

Figure 4 shows the side view of the planing hull with trim tab deflection angle (δ), trim angle (τ), length of the trim tab chord (L_f). On the optimization process, Savitsky method is used in the code for the planing hull with trim tab.

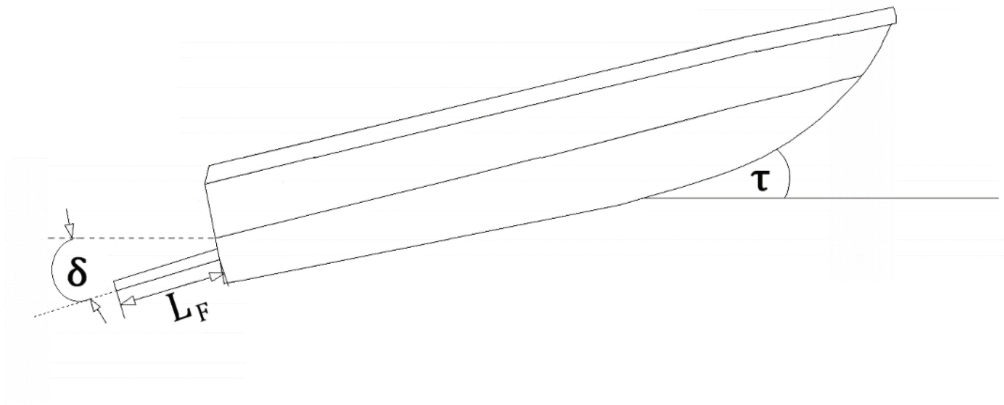

Figure 4. Side view of planing hull

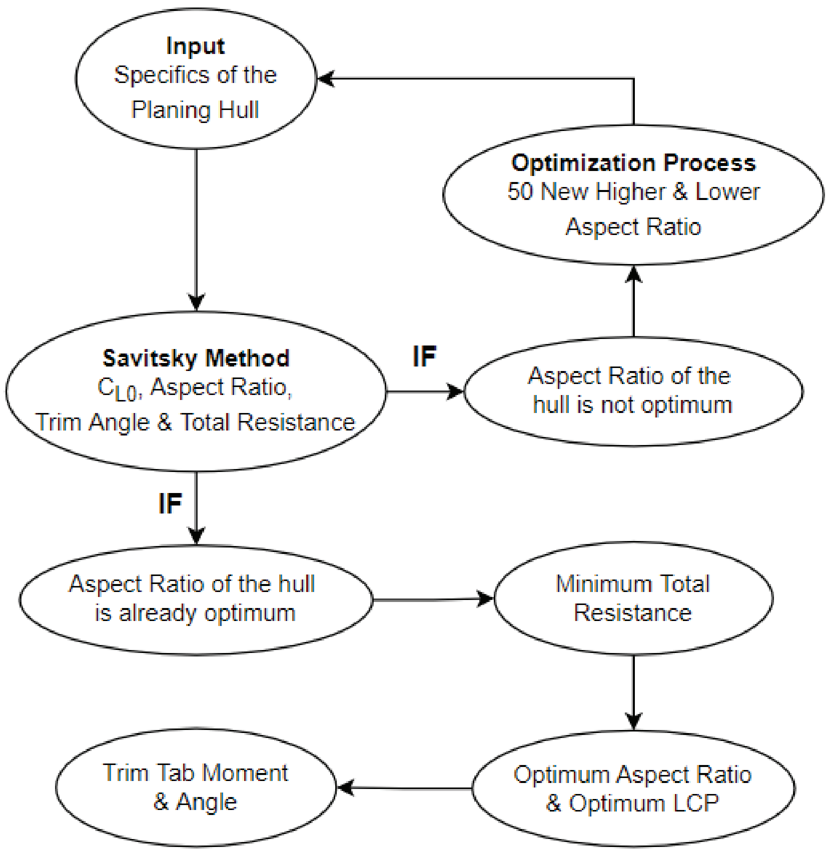

Figure 5. Flowchart of the computational process

The longitudinal center of pressure of the hull (LCP) can be changed with trim tab moment. When the equilibrium is stated with the same location for the longitudinal center of gravity and longitudinal center of pressure, the planing hull does not require a moment by the trim tab. However, this situation is unusual in practice. A flowchart of the computational process is given in Figure 5. As seen from Figure 5, for each planing hull speed the optimum aspect ratio is calculated for minimum hull resistance. Then, the corresponding trim angle and optimum LCP of the hull are found. Therefore, at each hull speed, the optimum location of (LCP_{opt}) is known. In Figure 5, if the aspect ratio of the hull is already optimum then the process answer will be 'no' then it will be terminated. On the other hand, if the aspect ratio of the hull is not optimum then the process answer will be 'yes' then the optimization process will start.

The detailed process is given as follows. The aspect ratios for each speed are changed gradually and this modification is analyzed for the maximum range of solutions. The new aspect ratios are varied within the range of 50 higher and 50 lower values around the original aspect ratios. For minimum drag, this range is searched since the required direction of the trim tab lift is not known at this stage. Then, all values such as the dynamic trim angles and the total drag of the hull are calculated with Savitsky method. The minimum total resistance for each hull speed is selected. Next, optimum LCP is found. The same calculation process is repeated for the defined hull speed range.

The required moment of the trim tab (M_F) (Equations 13 and 15) can be obtained by multiplying the lift of the trim tab (L_T) (Equation 14) with the center of the lift force. The location of the lift force center (x_{cp}), assumed to be x_{cp} = 0.25 * L_f from the leading edge of the trim tab. For this study 2D trim tab lift coefficient ($C_{L,2D}$) (Equation 17) which is the ratio of 3D trim tab lift coefficient ($C_{L,3D}$) (Equation 16) is included in the calculation (Cakici et al., 2018).

$$M_F + \Delta * \left(LCP_{opt} - LCG\right) = 0 \quad (13)$$

$$L_T = \frac{1}{2} * \rho * V^2 * L_f * C_{L,3D} * b * \delta \quad (14)$$

$$M_F = L_T * \left[x_{cp} + LCG\right] \quad (15)$$

$$C_{L,3D} = \frac{C_{L,2D}}{1 + \frac{2}{AR}} \quad (16)$$

$$C_{L,2D} = \frac{\pi^2}{90} \quad (17)$$

where: $AR = \frac{\sigma b}{L_f}$

It should be noted that if LCP_{opt} is greater than LCG, M_F becomes negative (clockwise direction, negative direction) and the trim tab produces lift downwards, so dynamic trim of the hull is increased. If LCP_{opt} is lower than LCG, M_F becomes positive (counter-clockwise direction, positive direction) and the trim tab produces lift upwards, so dynamic trim of the hull is decreased.

3. Results

The optimum trim angles for planing hull with trim tab and the standard trim angles for planing hull without trim tab, within hull speed limits are calculated and presented in Figure 6.

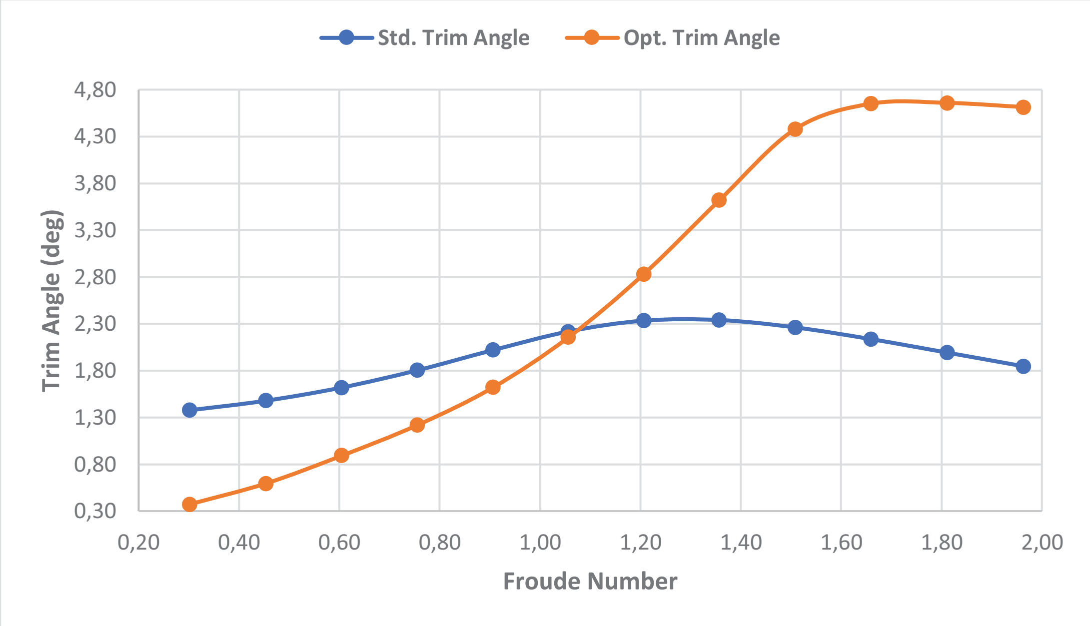

Figure 6. Trim angle vs. Froude number

It is found that optimum longitudinal center of pressure from the transom (LCP_{opt}) for the planing hull speeds less than approximately 15 m/s (Fn = 1.132) are decreased in value while they are increased for the hull speeds more than 15 m/s.

Table 2. Trim tab moments, deflection angles, standard and optimum trim angles of the planing hull in different hull speeds

Direction of Trim Tab Force	Hull Speed (m/s)	Froude Number	Trim Tab Moment (kN*m)	Trim Tab Deflection Angle (deg)	Std. Trim Angle of Planing Hull (deg)	Opt. Trim Angle of Planing Hull (deg)
↑	4.0	0.303	1,777	71.38 (+)	1.377	0.374
	6.0	0.454	1,084	19.36 (+)	1.479	0.595
	8.0	0.605	624	6.26 (+)	1.620	0.892
	10.0	0.756	367	2.36 (+)	1.804	1.219
	12.0	0.906	191	0.85 (+)	2.019	1.621
	14.0	1.057	25	0.08 (+)	2.218	2.156
↓	16.0	1.207	197	0.49 (-)	2.334	2.832
	18.0	1.358	570	1.13 (-)	2.340	3.621
	20.0	1.509	1,079	1.73 (-)	2.261	4.381
	22.0	1.660	1,425	1.89 (-)	2.135	4.651
	24.0	1.812	1,638	1.83 (-)	1.991	4.659
	26.0	1.964	1,793	1.70 (-)	1.846	4.614

With this study, the required optimum trim tab moment values with trim tab force directions, required trim tab deflection angles, standard trim angles and optimum trim angles of the planing hull are analyzed through various hull speeds and showed in Table 2. In Eqs. 13, the optimal position of the pressure center is found with optimum dynamic trim angle and hull aspect ratio. According to Eqs. 13, the required trim tab moments at each vessel speed are calculated and given in Table 2.

According to the optimal center of pressure whether toward to fore or aft of the hull, the direction of the trim tab is determined.

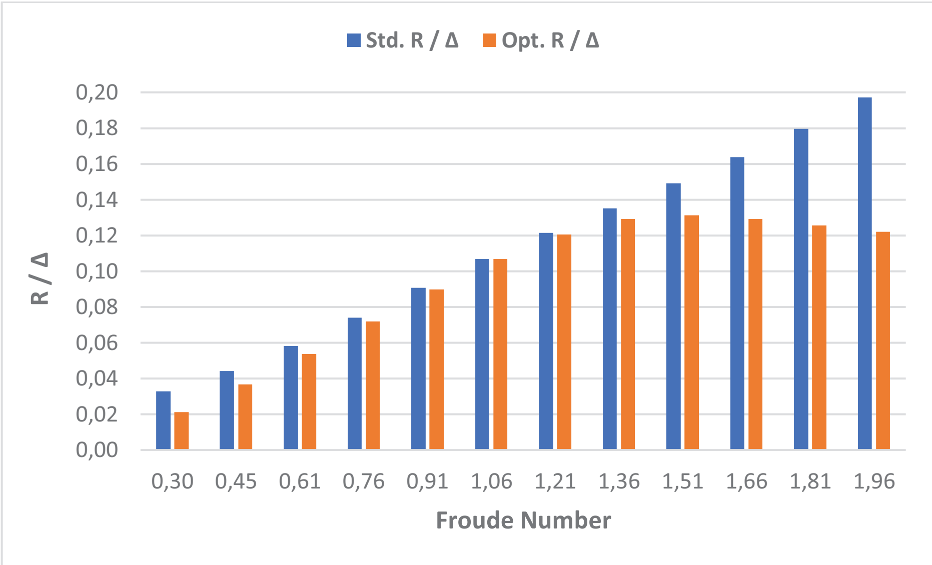

Figure 7. R/Δ vs. Froude number

4. Conclusion

In this paper, the determination of optimum trim angle of a planing hull form for minimum drag with is studied and programemed with the Python language. The model is analyzed with and without a trim tab. First, aspect ratios, dynamic trim angles, and the total resistances of the hull are calculated within the range of planing hull speed limits (from 4 m/s to 26 m/s). Then, optimum aspect ratios are found by choosing the calculated minimum total resistance of the planing hull within the range of a hundred new aspect ratios. Finally, required trim moments are calculated and optimum trim angles of the planing hull are found. The optimum (with trim tab) and standard (without trim tab) trim angle of the planing hull are observed (Please see Figure 6 and Table 2).

For very high speeds (Fn > 1.509), the optimum trim angle is observed at more than 4.5 degrees. Although the trend of drag reduction seems attractive, it is not a good sign when the other parameters such as porpoising, lack of visibility are taken into consideration. The total resistance reduction of the planing hull is varied between the maximum value of 38.2% (Fn = 1.96) and the minimum value of 0.021% (Fn = 1.06) (please see figure 7). Therefore it is concluded that the use of the trim tab is found effective for the entire speed range. Overall, the results showed that trim tab usage for planing hulls is adequate to reduce the total drag up to 20% approximately. This study is performed by using Savitsky method that is known as a low fidelity method since it is semi-empirical. In future works, it is planned to use high fidelity computational fluid dynamics to solve the flow around the planing hull.

5. References

Amoroso C.L, Liverani A., Caligiana G. (2018). Numerical investigation on optimum trim envelope curve for high performance sailing yacht hulls. Ocean Engineering, Vol. 163, PP. 76-384.

Ashkezari A.Z., Moradi M. (2021). Three-dimensional simulation and evaluation of the hydrodynamic effects of stern wedges on the performance and stability of high-speed planing monohull craft. Applied Ocean Research, Vol.110, 102585.

Baker G. S., (1912). Some Experiments in Connection with Design of Floats for Hydro-Aeroplanes, ARC (British) R & M, no. 70.

Brown P., (1971). “An Experimental and Theoretical Study of Planing Surfaces with Trim Flaps”, Davison Laboratory Report 1463, Stevens Institute of Technology, Hoboken, NJ, USA.

Cane Du P. (1951). “High Speed Small Craft”, Temple Press, London.

Cakici F., Yazici H., Alkan A. D., (2018). Optimal control design for reducing vertical acceleration of a motor yacht form.

Clarke D., (2009). High Speed and Advanced Craft Lecture Notes by David Clarke.

Ertogan M., Wilson P.A., Tayyar G. T., Ertugrul S, (2017). Optimal trim control of a high-speed craft by trim tabs/interceptors Part I: Pitch and surge coupled dynamic modelling using sea trial data. Ocean Engineering, Vol. 130, PP. 300-309.

Ghadimi P, Loni A, Nowruzi H, Dashtimanesh A, Tavakoli S, (2014). Parametric Study of the Effects of Trim Tabs on Running Trim and Resistance of Planing Hulls, Advanced Shipping and Ocean Engineering, Vol. 3 Iss. 1, PP. 1-12.

Ghassemi H., Bahrami H., Vaezi A., Ghassemi M.A., (2019). Minimization of Resistance of the Planing Boat by Trim-tab, Int. J. Phys., vol. 7, no. 1, pp. 21–26.

Jokar H., Zeinali H. Tamaddondar M.H., (2020) Planing craft control using pneumatically driven trim tab. Mathematics and Computers in Simulation, Vol. 178, PP 439-463.

Sambraus A., (1938). Planing Surface Tests at Large Froude Numbers – Airfoil Comparison, NACA TM No. 848, February.

Savitsky D., (1964). Hydrodynamic Design of Planing Boats, Marine Technology 1.

Savitsky D., Brown P., (1976). Procedures for hydrodynamic evaluation of planing hulls in smooth and rough water, Marine Technology vol. 13, pp. 381-400.