

# Minimization of Resistance of the Planing Boat by Trim-tab

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**Abstract** Trim-tab is a device for controlling the trim and improves the performance of the planing boat. It is installed at the stern of the hull to adjust the longitudinal center of pressure (LCP). This paper is presented to minimize the resistance of the planing boat using trim-tab. Savitsky's method is employed to calculate the resistance. The chord of trim-tab is defined constant but the span is changed. The longitudinal center of gravity (LCG) is constant but LCP is varied at each speeds. By using the trim-tab, the LCP and LCG are adapted and the optimum trim angle and minimum resistance are calculated. The results of optimum trim angle, total resistance and angle of trim-tab at different speeds are presented and discussed.

**Keywords:** trim-tab, minimum resistance, planing boat, savitsky's method

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## 1. Introduction

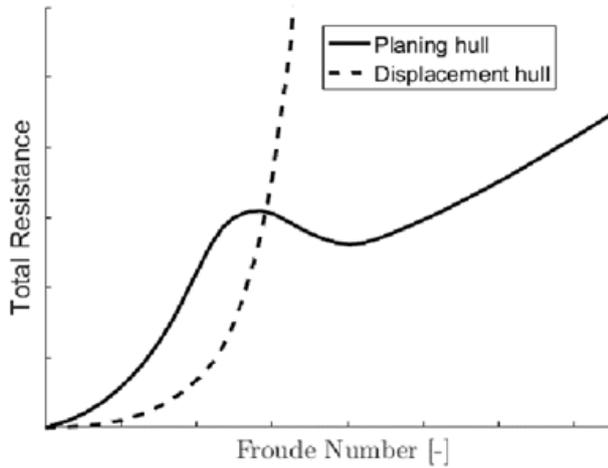
Reaching to higher speed is an important factor for the owner of the fleet. Designer should provide this requirement of the owner by good design of the boat and diminish the resistance and increase the propulsion efficiency. Trim-tab is an active tool to control the operating condition. It adjusts the trim and LCP to find the minimum resistance. When the speed of the boat is increased the LCP and trim are changed. So, it is required to use the trim-tab to control the required trim. It can be said that the trim-tab is an active control surface to make longitudinal stability of the boat. At the hump speed, the both trim and the resistance are high that is complex and the worst conditions. If the thrust of the propulsion system is sufficiently generated to overcome the resistance, the boat can pass this condition. After passing the hump speed, the boat is raised up and total resistance is slightly decreased. When the speed is increased more (Froude number is bigger than 1.2), it may be said the boat is at planing condition. Dynamic lift is increased at this condition [1]. Figure 1 shows the total resistance ( $R_T$ ) and hydrodynamic lift versus ( $v$ ) Froude number ( $F_n$ ).

The initial work on the planing boats was presented by Baker [2]. Then, it was extended wide attention by other researchers like Sottorf [3] Shoemaker [4] and Samba [5]. The first important study of planing phenomenon took place in Davison Laboratory at Steven institute of technology in 1964 by Savitsky [6]. This study resulted in several technical reports including definition of planing surface lift, wetted area, pressure distribution, wake shape

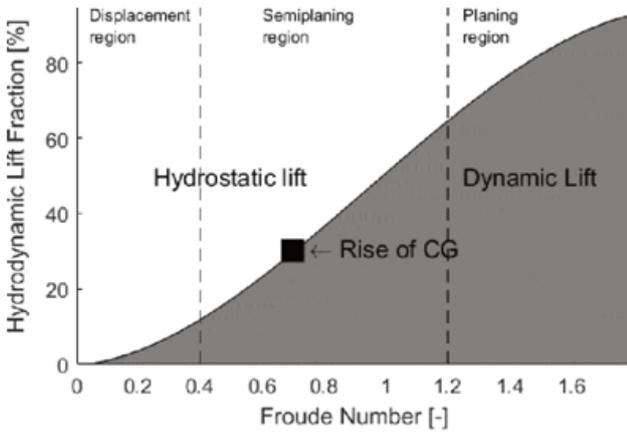
and etc. Brown [7], Brawn and Savitsky [8] worked on the experimental and theoretical of planing surfaces with trim flaps. Humphree [9] studied effect of trim-tab on planing hulls and suggested that the basic principle of the interceptor trim-tab is to create pressure underneath the hull, at the stern of the boat. The pressure is created when the blade is deployed into the water flow underneath the hull.

Metcalf et al [10] conducted an experimental research for analyzing the U.S. Coast Guard planing boats. They presented trim angle and resistance of four models in various conditions including different displacements, various center of gravity and etc. Taunton et al [11] further developed a new series of planing boats including six models. These models consisted step and step-less crafts. They also presented their experimental data. Begovic and Bertorello [12] study the effect of variation of deadrise angle and introduced four hulls. In three models, deadrise angle varied from the stern to the bow of craft. Their observation indicated the complex behavior of the wetted area and the stagnation line angle. They also showed that keel wetted length increases by an increase in the speed of the warped hulls, while it decreases in the prismatic body. On the other hand, three different planing boats were introduced by Kim et al. [13] for improving the performance and sea keeping of the planing boats. Performance of the planing trimaran was also considered as a subject of research by Ma et al. [14] and they presented experimental results related to the trim angle and resistance for the craft. They also examined the effect of step on the performance of trimaran. Step is another parameter which affects the performance of planing hulls experimentally studied by Lee et al [15] and the best

height of the step for decreasing the resistance was achieved. Here, also additional research on planing boat carried out by other researchers. A very comprehensive textbook of hydrodynamics on the high-speed marine vehicles published by Faltinsen in 2005 [16].



A)  $R_T$ - $F_n$  for planing and displacement hulls.



B) Hydrodynamic lift vs.  $F_n$

Figure 1.  $R_T$  and hydrodynamic lift against  $F_n$  [1]

During 2008~2017, a comprehensive research on the planing boat carried out by Ghassemi and his colleagues. They worked on various planing hull and tunnel hull using boundary element method (BEM) and CFD solvers. They have presented the hydrodynamics of the planing hull using BEM to find pressure resistance, induced resistance and many related to hydrodynamic characteristics [17-21]. Ghassabzadeh and Ghassemi employed a NURBS to design the hull of tunnel ship [22,23,24,25]. Also, many numerical results on the planing hull carried out by CFD solver [26,27,28,29].

In the present paper, prediction of the performance of planing boats with trim-tabs is undertaken as a field of study and effect of the trim-tabs on running trim and resistance is investigated.

## 2. Mathematical Formulas

These formulas are based on Savitsky's method with some modified and additional formulas for the trim-tab. The first assumption is the fact that the planing boat is moved at steady condition which implies there is no

acceleration in any direction. Figure 2 is shown the planing boat with trim-tab.

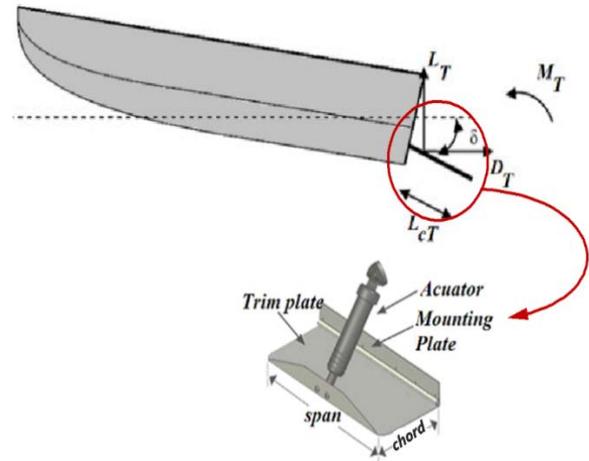


Figure 2. Trim-tab geometry and its acted forces

At  $F_{nL} > 1.2$ , weight of the boat is almost equal to the dynamic lift. Here, we defined three Froude numbers (based on length, beam and volume) and the lift coefficient  $C_{L\beta}$  as follows:

$$F_{nL} = \frac{V}{\sqrt{gL}}, F_{nB} = \frac{V}{\sqrt{gB}}, F_{nV} = \frac{V}{\sqrt{gV^{1/3}}} \quad (1)$$

$$C_{L\beta} = \frac{F_{L\beta}}{0.5\rho V^2 B^2} \quad (2)$$

where:  $F_{L\beta} = W = \text{weight of the boat}$ .

### Step 1:

Estimate trim angle ( $\tau$ ), obtain the mean wetted length-beam ratio ( $\lambda_w$ ) by the Eqs. (3) and (4):

$$C_{L\beta} = C_{L0} - (0.0065\beta C_{L0}^{0.6}) \quad (3)$$

$$C_{L0} = \tau^{1.1} (0.012\lambda_w^{0.5} + 0.0055\lambda_w^{2.5} / F_{nB}^2). \quad (4)$$

Then, find the LCP by following formula:

$$\frac{LCP}{\lambda_w B} = 0.75 - \frac{1}{\left[ \frac{5.21 F_{nB}^2}{\lambda_w^2} + 2.39 \right]} \quad (5)$$

### Step 2:

Calculate the frictional resistance by ITTC-57 and pressure resistance:

$$R_f = 0.5\rho(c_F + \Delta c_F) S_{tot} V^2 \quad (6)$$

where:

$$c_F = C_{F.ITTC} + \Delta C_F \quad (7)$$

$$C_{F.ITTC} = \frac{0.075}{(\log Rn - 2)^2} \quad (8)$$

$$10^3 \Delta C_F = 44 \left[ \left( \frac{AHR}{L} \right)^{\frac{1}{3}} - 10R_n^{-\left(\frac{1}{3}\right)} \right] + 0.125 \quad (9)$$

where:

$$R_n = \frac{VL_K}{v}. \quad (10)$$

And the following data:

Allowance hull roughness =  $AHR = 150e - 6$  [ $\mu$ ] and  $AHR = 150 * 10^{-6}$  Kinematic viscosity =  $v = 1.19e - 6$  [ $v = 1.19 * 10^{-6} \text{m}^2/\text{s}$ ].

After finding the Reynolds number and wetted area,  $s_{tot}$ , the frictional resistance can be calculated as follows:

$$s_1 = \frac{\tau}{\sin \beta \frac{\pi}{2} x_s^2} \quad (11)$$

$$s_2 = \frac{BL_C}{\cos \beta} \quad (12)$$

$$s_{tot} = s_1 + s_2. \quad (13)$$

In the calculation the wetted length  $L_K$  and  $L_C$  can be obtained as follows.

$$L_K - L_C = x_s \quad (14)$$

$$L_K = \lambda_w B + 0.5 x_s \quad (15)$$

$$L_C = \lambda_w B - 0.5 x_s \quad (16)$$

$$x_s = \frac{B \tan \beta}{\pi \tau}. \quad (17)$$

Thus

$$L_K = \lambda_w B + 0.5 \frac{B \tan \beta}{\pi \tau} \quad (18)$$

$$L_C = \lambda_w B - 0.5 \frac{B \tan \beta}{\pi \tau} \quad (19)$$

Pressure resistance is calculated by:

$$R_P = W \tau = F_{L\beta} \tau. \quad (20)$$

So, the total resistance is defined by

$$R_{tot} = R_f + R_P. \quad (21)$$

### Step 3:

Find minimum resistance and optimum trim angle by using trim-tab. For each speed, the steps 2 and 3 are repeated for many trim angle, then draw the resistance against trim angle. We found  $\tau$  and  $\lambda_w$  which the resistance is minimum value. Then, obtain the  $LCP$  by Eq. (5).

### Step 4:

If  $LCP$  is equal to  $LCG$ , the boat does not need the trim-tab. But when the  $LCP$  and  $LCG$  are not equal, the boat needs trim-tab. The required moment by trim-tab ( $M_T$ ) is found as follows:

$$M_T + F_{L\beta} (LCP - LCG) = 0. \quad (22)$$

The lift of the trim-tab ( $L_T$ ) is obtained by

$$L_T = 0.5 \rho U^2 l_{cT} \pi \alpha B. \quad (23)$$

where  $l_{cT}$  is the chord of the trim-tab,  $\alpha$  is the trim-tab angle. We know that there is air on the top of the trim, so the lift coefficient for the trim-tab is:

$$C_L = 0.5(2\pi\alpha). \quad (24)$$

If we assumed the center of the lift force locates  $x_{cp} = 0.75 l_{cT}$  from the trailing edge. So, the distance from the center of the lift to center of gravity is:

$$x_l = (l_{cT} - 0.75 l_{cT}) + LCG. \quad (25)$$

Thus, the trim-tab moment:

$$M_T = L_T x_l. \quad (26)$$

So, the final equation for  $M_T$  is expressed as:

$$M_T = 0.5 \rho U^2 l_{cT} \pi \alpha B (0.25 l_{cT} + LCG). \quad (27)$$

The process of using these equations for the purpose of intended analyses has been automated by MATLAB programs. In order to clarify the process clearly, a computational flowchart is provided in Figure 3. In this approach, the input variables ( $B$ ,  $LCG$ ,  $V$ ,  $\beta$ ,  $\Delta$ ) are given as input data. The outputs are minimum resistance and trim-tab effect on the results.

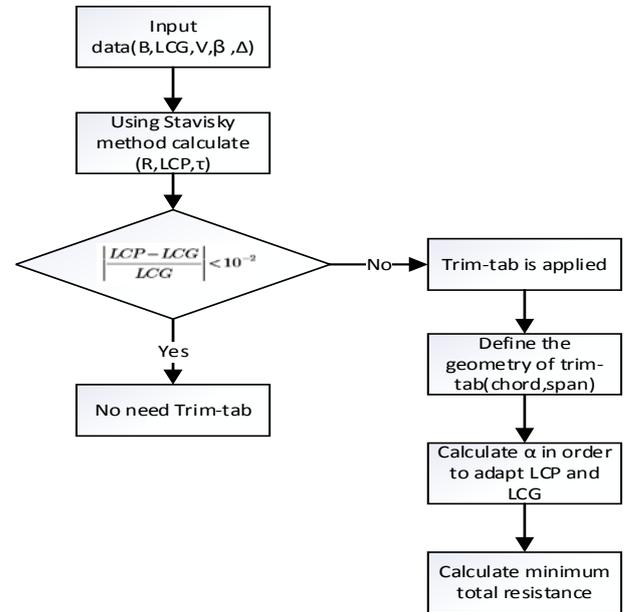


Figure 3. Flowchart of the computational process

## 3. Results

The main dimensions of the selected planing boat are given in Table 1. The results of the resistance and trim angle are presented and discussed.

Table 1. Dimensions of the planing boat and its trim-tab.

| Parameter               | Value  |
|-------------------------|--------|
| Length [m]              | 22.5   |
| Beam [m]                | 4.27   |
| LCG [m]                 | 8.84   |
| Mass [kg]               | 27000  |
| Deadrise angle [degree] | 10     |
| Chord [m]               | Beam/4 |
| Span of flap1 [m]       | Beam   |
| Span of flap2 [m]       | Beam/2 |
| Span of flap3 [m]       | Beam/3 |
| Span of flap4 [m]       | Beam/4 |

The total resistance at different velocities against trim angle is calculated and presented in Figure 4. It is found that by increasing the trim angle, the resistance is slightly decreased and then increased with more rate.

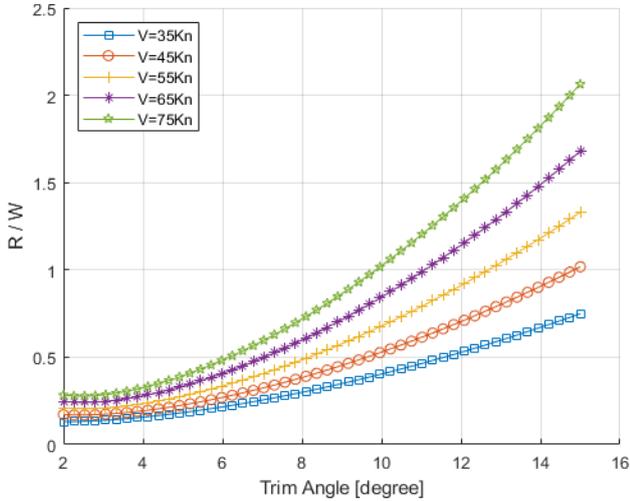


Figure 4. R/W vs. trim angle

Figure 5 is shown the zoom of R/W from 2 to 4 degrees of trim angle. We can find the optimum trim angle is found where the resistance is minimized. For example at velocity of 35 knots, the optimum trim angle is 2.24 degrees. Table 2 is given the optimum trim angle and minimum resistance at various speeds and volume Froude numbers ( $F_{nV}$ ).

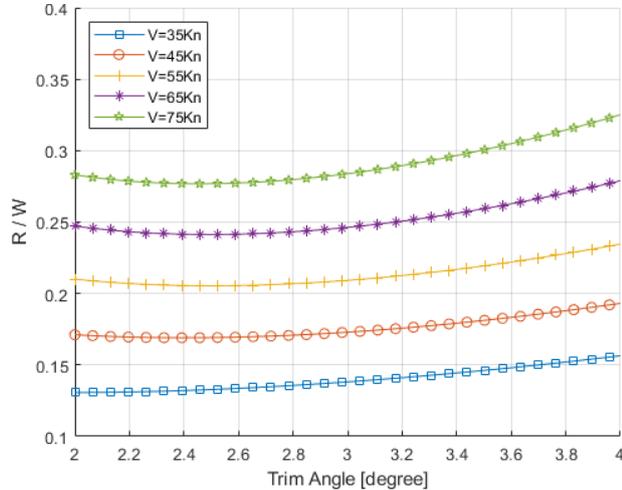


Figure 5. The zoom of the R/W vs. trim angle of 2~4 degrees

Table 2. Optimum resistance and trim angle in different velocities

| Velocity [knot] | $F_{nV}$ [-] | Optimum Trim Angle [deg] | Minimum Resistance [N] |
|-----------------|--------------|--------------------------|------------------------|
| 35              | 3.33         | 2.24                     | 34630                  |
| 45              | 4.29         | 2.39                     | 44772                  |
| 55              | 5.24         | 2.52                     | 54415                  |
| 65              | 6.19         | 2.52                     | 63915                  |
| 75              | 7.14         | 2.46                     | 73310                  |

Figure 6 is shown optimum trim angle against  $F_{nV}$ . It is also given the polynomial formula as a second order function of  $F_{nV}$  as found by  $\tau = -0.0432F_{nV}^2 + 0.5118F_{nV} + 1.0076$ .

+ 1.0076. By increasing  $F_{nV}$  from 3.33 to 5.24, the trim angle is increased. Then, from  $F_{nV} = 5.24$  and 6.19 is constant and after that is decreased. Minimum trim angle is 2.24 degree in  $F_{nV}$  of 3.33.

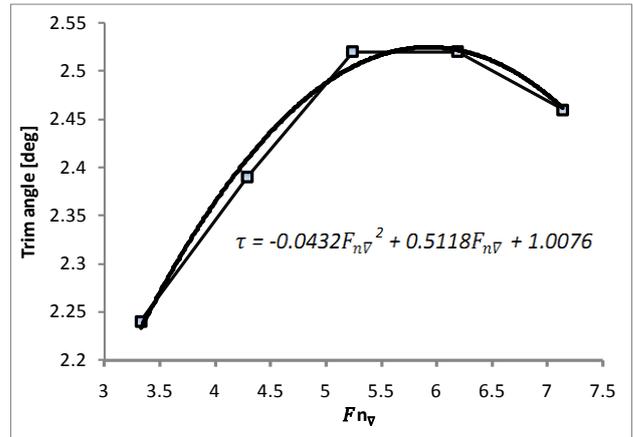


Figure 6. Optimum trim angle vs.  $F_{nV}$

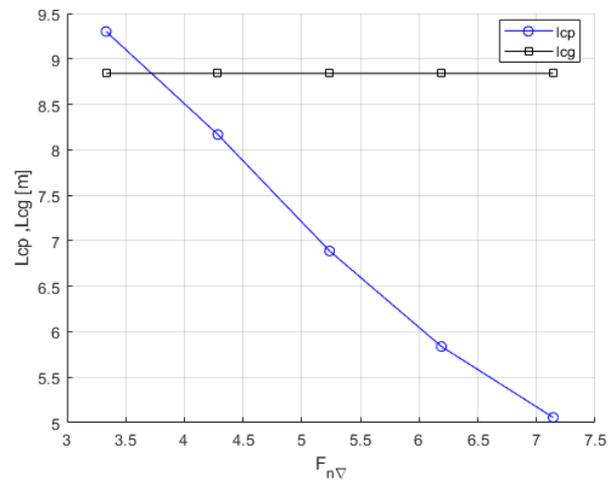


Figure 7. LCP and LCG vs.  $F_{nV}$

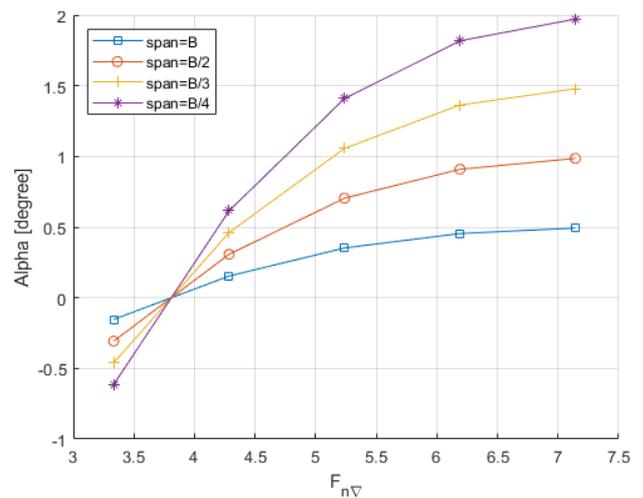


Figure 8. Trim-tab angle vs.  $F_{nV}$

Figure 7 presents the LCG and LCP against  $F_{nV}$ . LCG is constant while LCP decreases when the  $F_{nV}$  is increased. When the LCP is equaled to LCG no need the trim-tab, but when these two points are not equaled trim-tab is required. Figure 8 is presented the angle of trim-tab in

order to adjust the LCP to the LCG. It is shown with different size of span. When the span is large, so, the angle of trim-tab is to be small. Four different sizes of span are considered ( $\text{span}=0.25, 0.33, 0.5, 1$ )\*B are considered and the results are shown in this figure. The resistance of trim-tab is also shown in Figure 9. Bigger span gives more resistance. The percentage of trim-tab resistance to the total resistance is presented in Figure 10. When the span is  $0.25B$ , this percentage is less than 3% at all speeds. When the span is equal to  $B$ , the percentage is between (4~ 10)% .

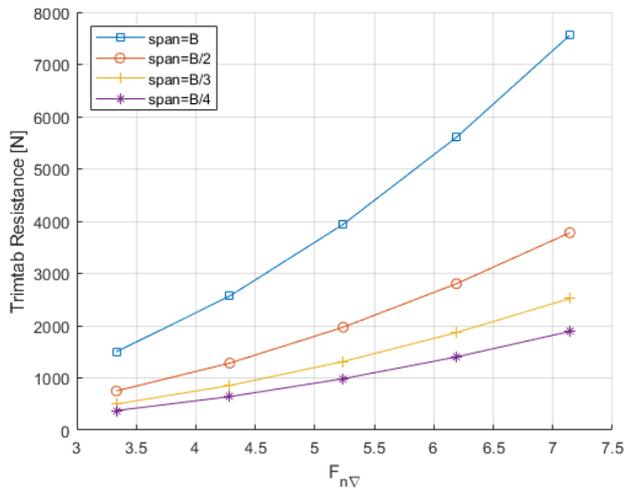


Figure 9. Resistance of trim-tab vs  $F_{n\nabla}$

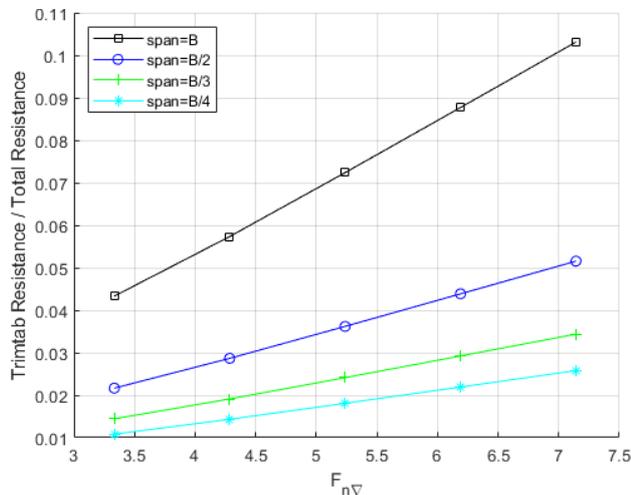


Figure 10. Resistance of trim-tab to total resistance ratio vs.  $F_{n\nabla}$

## 4. Conclusion

This paper is presented to obtain the minimum resistance by using the trim-tab. Different sizes of trim-tab are selected and some results are presented and discussed. Based on the results, the following conclusion can be drawn:

- Trim-tab is required when the LCP is not adapted to the LCG. It is useful to adjust the trim of the boat in order to minimize the resistance.
- Bigger span of trim-tab is given more resistance but small angle of trim-tab is required.

- Minimum resistance is found when the trim angle is about 2~3 degrees at all speeds.

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