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# *Effect Of Stepped Hull On Wing In Ground Effect (WIG) Craft During Take Off*

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*Abstract* - **Power efficiency of a system is one of the important criterions to achieve a green society as an efficient system lessens harmful emissions considerably, thus to find ways to reduce power is very significant. A noteworthy fraction of harmful emission is done by various transport systems, WIG craft is relatively new concept of transportation, can have a fruitful future as it is more efficient than equivalent aircraft and quicker than equivalent marine vessels, like any other modes of transportation, power efficiency of a WIG is very important, especially today when achieving a greener society is not an option but the only way for a sustainable human civilization. The aerodynamic force of a specific WIG depends on a certain minimum take off speed which is directly related with thrust power , so to reduce the amount of required energy, it is necessary to reduce the drag resistance during take off , In this paper the effect of steps bellow hull on resistance of a 2 seated WIG is discussed and analyzed by changing position and dimension of steps later it is compared with resistance hull without steps .finally how it can reduce the amount of harmful emission through reducing power is investigated.**

***Keywords: WIG trimaran; Planing Hull; Savitsky Method; stepped hull; power efficiency; drag reduction***

## I. INTRODUCTION

Moving marine vehicles at high speed has been one of the biggest challenges faced by naval architects and hydrodynamic researcher over the years especially after the invention of aircraft, much thought have been given to find different methods that can move ships quickly, Wing In Ground Effect (WIG) Craft is the most successful one in terms of gaining high speed. One of the major difficulties in designing a WIG is to find a method to reduce drag during take off. As a WIG needs to run at high speed to lift itself from the surface of the water, it faces significant amount of hull resistance, that requires a considerable amount of energy thus contributes to Carbon emission .So to get a solution of this problem (reducing drag) is a worthy effort.

Planing hull has been chosen for the Wig as high speed is necessary to take off .In October 1964, a comprehensive paper that summarized previous experimental studies on the hydrodynamics of prismatic planing surfaces was presented by Savitsky [3]. He presented a method for application of these results for the design of moving ships. Besides, many laboratories and research centers have conducted hydrodynamic studies on several fundamental planing hull phenomena. The underlying principles of high speed planing craft resistance have been treated by DuCane, Clyaton and Bishop. Viscosity and free surface effects, including spray and overturning waves, play significant roles, making both experimental and numerical predictions of suitable hull parameters very difficult

One of the approaches of reducing resistance hull of a planing surface is using steps, Eugene P. Clement [7] had done several research on it .In this paper a concentrated effort has been taken to investigated the effect of step on hull resistance by adopting sweep-back of the steps At the end how it can reduce the amount of harmful emission through reducing power is investigated.

## II. NUMERICAL FORMULATION

### A. *Planing Hull*

The planing hull is a kind of hull that is specifically designed for a craft to achieve relatively high speed on the surface of water. A planing hull makes the water to be pushed down and to the sides as the hull moves forward. By the wake depression behind the hull, the downward motion of the water is observed. The pushing of the water sideways can be observed by the spray produced to the sides of the hull. This downward and sideways movement of water builds pressure under the hull (Savander, Brant R).

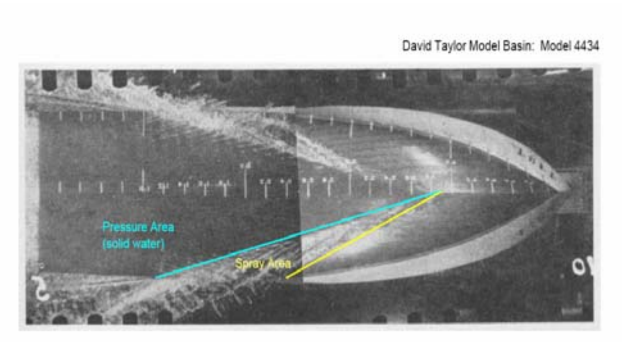


Figure 1

Centre of pressure for a flat planing surface is given as ([3]J.B. Hadler):

$$C_p = \frac{L_{CP}}{L_M} - 0.75 - \left(\frac{1}{5.21 + \frac{Cv^2}{\lambda^2} + 2.39}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

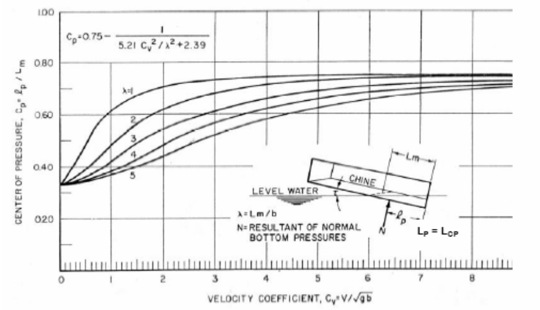


Figure 2

Planing hull also has Hydrodynamic Lift, Savitsky Method involves the following empirical equations:

For speed coefficient or "Breadth – froude Number" is given by the following equation D. Savitsky [3]:

$$C_v = \frac{V_s}{\sqrt{g * b}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The lift coefficient for flat planing hull (zero dead rise) is given by the following equation D. Savitsky [3]:

$$C_{Lo} = \frac{Displ}{0.5x\rho xV^2xb^2} \quad (3)$$

with parameter angle of trim and speed coefficient ([3]D. Savitsky):

$$C_{Lo} = \tau^{1.1}x(0.012\lambda^{0.5} + \frac{0.0055\lambda^{2.5}}{C_v^{\,2}}) \quad (4)$$

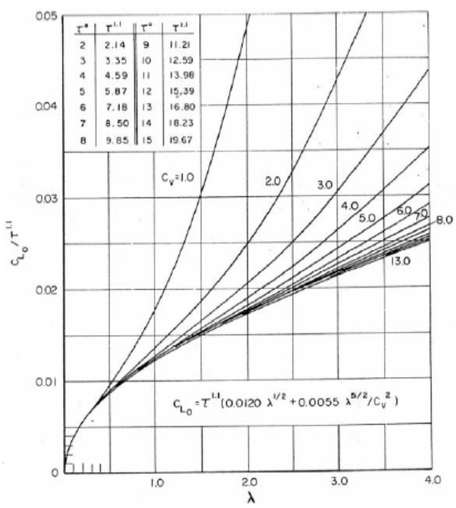


Figure 3

For Vee-surface (prismatic), the lift Coefficient has developed by D. Savitsky [3] as:

$$C_{L\beta} = C_{Lo} - 0.0065\beta C_{Lo}^{\ 0.6} \tag{5}$$

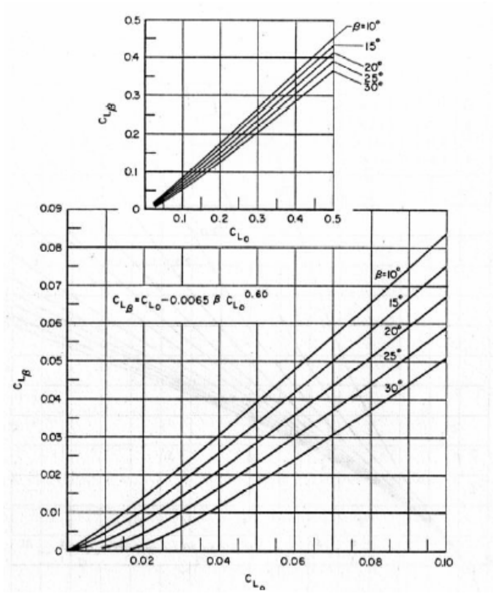


Figure 4

The total hydrodynamic drag of a planing surface is composed of pressure drag developed by pressure acting normal to the inclined bottom and viscous drag acting tangential to the bottom in both of pressure area and spray area D. Savitsky [3]:

$$D = \Delta \tan\tau + \frac{D_f}{\cos\tau} \tag{6}$$

$$D_f = \frac{C_f \rho V_1^2 (\lambda b^2)}{2\cos\beta^4} \tag{7}$$

Where $C_f$ is applied according ITTC, 1959 friction line, and is given by the following:

$$C_f = \frac{0.075}{(LogR_e - 2)^2} \tag{8}$$

The Reynold’s Number can be solved by applying the formula:

$$R_e = \frac{V_M x L_M}{\nu} = \frac{\lambda x b x V_s}{\nu} x \left(\frac{V_M}{V_S}\right) \tag{9}$$

Where average bottom velocity for planing surface easily developed for given service speed, equation can be expressed ([3] J.B.Hadler):

$$\frac{V_M}{V_S} = \left[1 - \frac{0.012\lambda^{0.5}\tau^{1.1} - 0.0065\beta(0.012\lambda^{0.5}\tau^{1.1})^{0.6}}{\lambda\cos\tau}\right]^{0.5} \tag{10}$$

*B. Effect of Stepped Hull*

The strategy behind the design of stepped planing hull is reducing the viscous resistance by decreasing the wetted hull surfaced area while maintaining a high hydrodynamic lift force. The numerical equation wetted surface can be expressed Eugene P. Clement [1]:

$$S_w = \frac{L_M x b}{\cos\beta} = (\lambda + \Delta\lambda) x \frac{b^2}{\cos\beta} \tag{11}$$

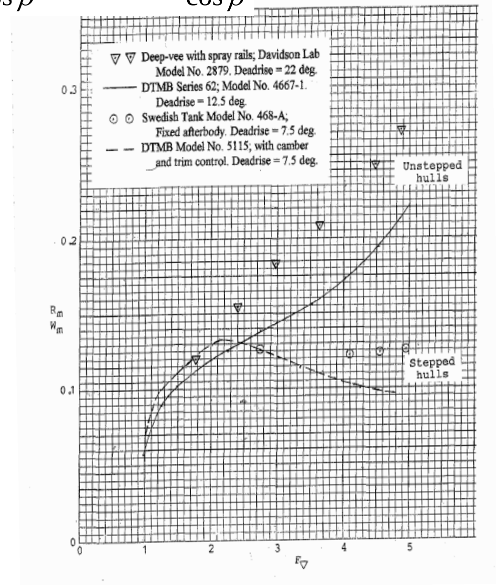


Figure 5

The potential problem for stepped hull is spray wetting the bottom of after body. In designing a stepped hull care must be taken to prevent a particular type of spray produced from the fore body that wetting the after body, and causing a large drag rise.

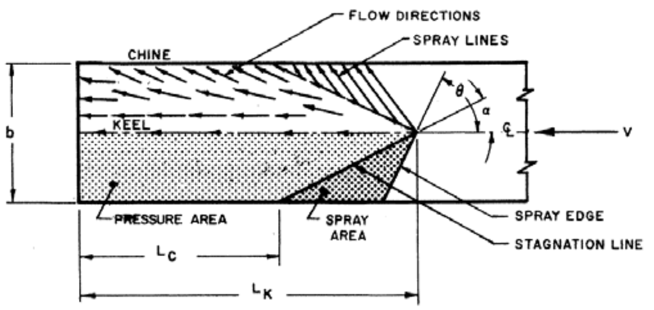


Figure 6

The area of spray can be predicted with D. Savitsky [6]:

$$A_s = \frac{b^2}{4\sin 2\alpha} \tag{12}$$

Thus the contribution of the spray on viscous drag can be written as D. Savitsky [6]:

$$D_{fs} = \tfrac{1}{2}\rho V^2 \Delta\lambda b^2 C_f \tag{13}$$

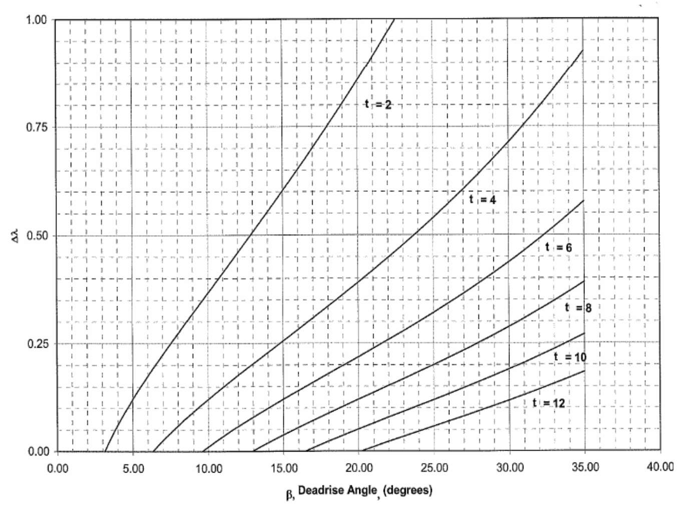


Figure 7

With arrange step position can be reducing spray produced. Eugene P. Clement [7].

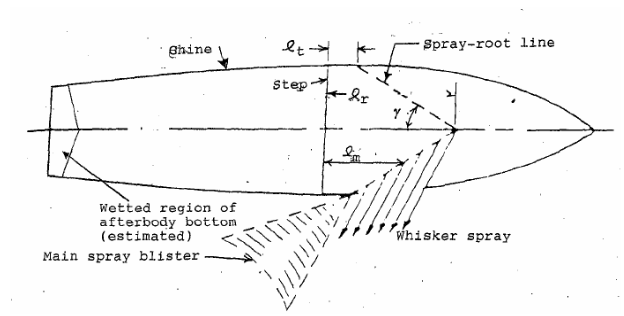


Figure 8

Where :

$$l_r = l_m + \frac{b}{(4\tan\gamma)} \tag{14}$$

$$l_m = l_t + \frac{b}{(4\tan\gamma)} \tag{15}$$

Spray problem can be overcome by adopting swept-back of the step, good planing efficiency can be maintained up to very high speeds Eugene P. Clement [7].

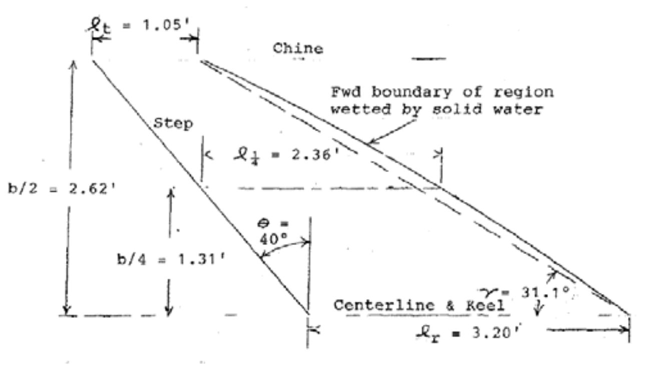


Figure 9

Numerical Equation can be expressed with Brown's Equation [7]:

$$A = \frac{0.5}{({}^{l_r}\!/_{b} + {}^{l_t}\!/_{b} + 0.06)} \tag{16}$$

$$l_m = 0.5(l_r + l_t) + 0.03b \quad (17)$$

$$C_D = C_L \tan\tau + C_f \sec\beta. \quad (18)$$

$$C_L = C_{L\beta} x A \quad (19)$$

*C. Thrust Specific Fuel Consumption (TSFC) and $Co_2$ Emission*

Thrust specific fuel consumption (TSFC) or sometimes simply specific fuel consumption, SFC, is an engineering term that is used to describe the fuel efficiency of an engine design with respect to thrust output. It allows the efficiency of different sized engines to be directly compared. Empirical equation can be written as NASA Website [8]:

$$TSFC = \frac{m_f}{F} \quad (20)$$

We can assume thrust (F) equal with total drag (D), so equation (20) can be written as:

$$TSFC = \frac{m_f}{D} \quad (21)$$

To calculate the $CO_2$ emission from a fuel the carbon content of the fuel must be multiplied with the ratio of molecular weight $CO_2$ (*44*) to the molecular weight Carbon 12 -> *44 / 12 = 3.7*. Carbon Dioxide emission can be calculated as Eng Tools Website [9]:

$$qCO_2 = \frac{c_f}{h_f} + \frac{C_{CO2}}{C_m} \quad (22)$$

**III. COMPUTATIONAL RESULT AND DISCUSSION**

Below a comparison between hull without steps and with step (clement steps) is shown Figure 10 shows the plan view of these two types of hull, from the simulation (Figure 11) it is clear clement step hull produce lesser wake compare to the hull without step which indicates clement hull's efficiency in terms of reducing hull resistance. From Figure -12 we can see by using step hull resistance can be reduced to a significant margin, about 8 %.

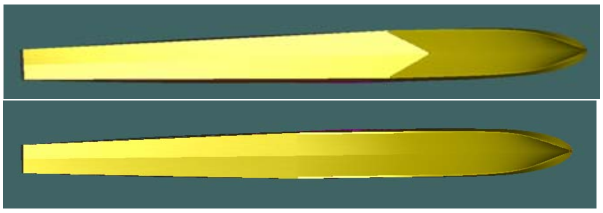

Figure 10

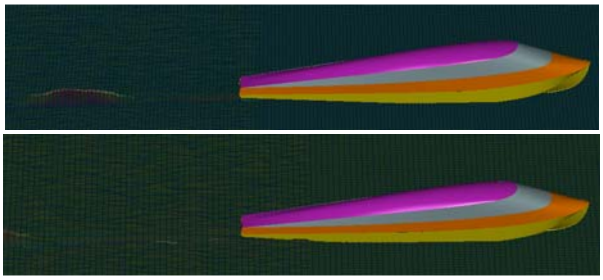

Figure 11

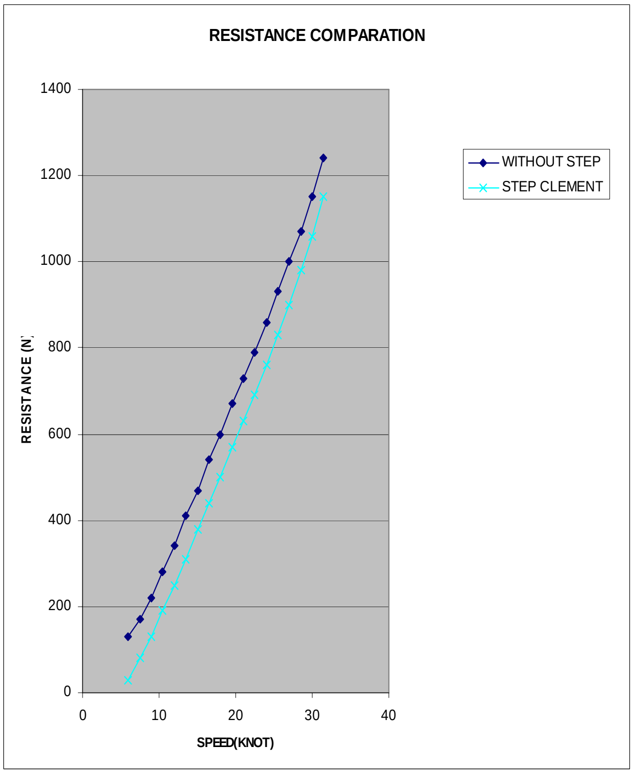


Figure 12

The estimated speed needed to take off for this particular WIG is 30 knots at which clement step hull consumes about 0.575 ton gasoline par hour whereas without step hull consumes about 0.62 ton of gasoline par hour, which means more than 100 kg of fuel per hour can be saved (see Figure 13).

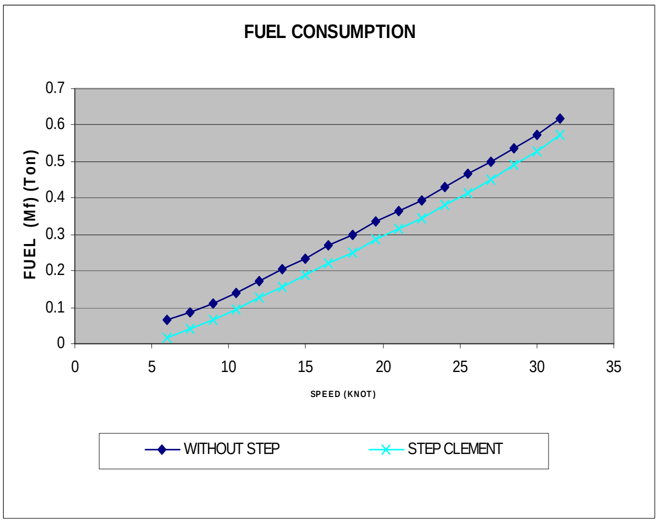


Figure 13

At the end from fig 14 we can find that a clement step is able to reduce the $CO_2$ emission up to 10 % which is a significant improvement .

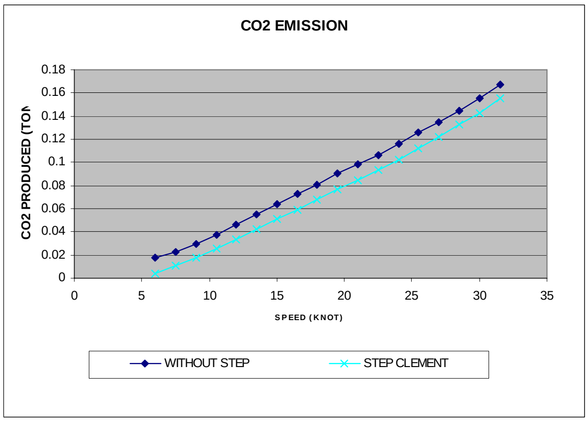


Figure 14

## IV. CONCLUSION

In this paper the problem of drag faced by WIG during take off has been tried to be solved by adopting sweep-back steps, and by doing so how it can affect the environment has been investigated .Results show about 8 % of drag reduction can be possible which is going to reduce similar percentage of $CO_2$ emission that a WIG of this kind is able to emit without using step. Though there further experimental investigations are needed the result of this paper can be used in the preliminary design stage for choosing the step type for the planing surface of a WIG.

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