Design and construction of high speed, hard chine planing hull

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Abstract— *With the development of the tourism in the country, there will be potential demand for water sports and leisure boating industry as in Maldives Island and other developed countries. Export development board and other related industries are in a process of development of industry related yachting, pleasure boating and marina in the country. Aim of this research project was establishing ground works in design and development of such craft and commences the same industry locally.*

When considering vessel in its motion, the force exerted by the propulsion system and the resistance that opposes it, would determine the speed a vessel could attain. The propulsion power is opposed by various kinds of resistance, or drag. Form drag results when the hull travels through the water, with its shape and frontal area relative to its direction of motion determining its total resistance. Hull beam at the chines and hull depth, as well as drag from appendages such as struts and rudders, create form drag.

In order to plane (move on the water surface) a hull at higher speed, hull size, hull shape, design displacement, and the trim, or running angle are important parameters. Such a planing hull has to climb over its own bow wave. This needs a great deal of power because of variation of angle of attack of the hull relative to the water surface. When the vessel on plane, efficiency increases as the hull rises and trims decreases, flattening the wake and reducing form drag. With less hull bottom in contact with the water, frictional drag also decreases. In order to arrives at such a design, the fundamental principles of planing hull designs are to be used. This project involves use of such theories and development of a high speed hull.

The paper presents the work carried out by the author in related to the above investigation in the following stages.

i. Designing the planing hullform using principles of Naval Architecture to optimise the performance with respect to speed, seakeeping and stability.

ii. Development of the plug and mould for the construction the boat in fibre glass.

iii. Speed trial and performance test to verify the estimated power and seakeeping of the constructed boat.

I. INTRODUCTION

Hulls are classified into three different types depending on the achievable speed for reasonable power input. Namely, Displacement, Semi displacement and Planing hulls. When a displacement hull passes through the water, hull must push the water out of the way and when doing this energy is lost to the water creating waves. The quicker the water is moved the bigger the waves will be and the more energy is used in creating them.

The speed of a wave is given by $v = \sqrt{\frac{g\lambda}{2\pi}}$, where *v* is the wave speed and *L* = λ is the wave length. The limiting speed for a displacement hull is given when the wave length is same as the vessel length or otherwise crests at bow and stern. If *L* is the vessel length, limiting speed is given when L=λ or in other words $v = \sqrt{\frac{g\lambda}{2\pi}}$. This was discovered by the W. Froude [1860] and presented as hull speed formula $v = 1.34\sqrt{L}$ with *v* in knots and *L* in feet. Displacement hull service speed is well below the above limit for economical operation and the maximum service speed is proportional to the square root of the length of the vessel.

Semi displacement hull ride over bow wave and can attained a speed beyond the above limit with the expense of more power [Fig.1}

The planing hull evolved to overcome the inherent hydrodynamic limitation associated with high speed operation of the displacement hull. The basic principle behind a planing hull theory is that of the generation of sufficient hydrodynamic lift to the bottom of the hull to support the vessel weight. The lift force is created when the hull bottom surface is faced with the incoming water at correct angle of attack.

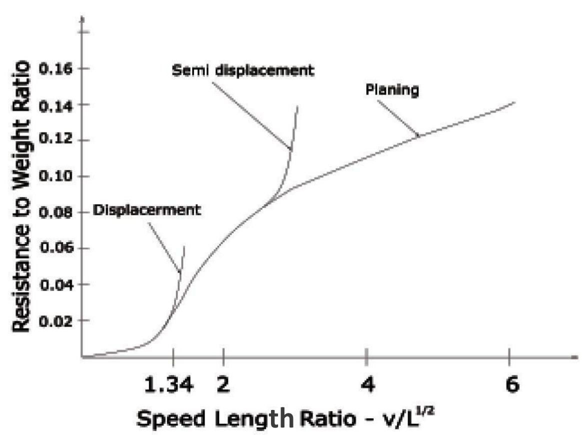

Fig. 1. Resistance to weight ratio for different hull types

Planing hull's bottom is generally a V-shape. A correctly designed planing vessel is thus able to overcome the majority of the drag experienced by the hull in terms of wetted surface area (the surface area of the vessel's hull immersed at rest), by lifting out of the water. This results in, not allowing vessel create, much of the wave making resistance as the vessel is now riding on the surface of the water, rather than having to push through it. This allows rapid acceleration and high maximum speeds. The compromise here is that relatively large power is required in order for the vessel to achieve a planing attitude and the total engine power is being used to create the manly lift rather than to propel the vessel.

II. FACTORS INFLUENCING PERFORMANCE

An excellent summary of development of planing hull from has been given by Gore [1979] and Savitsky [1964]. Accordingly, the principal parameters affecting the performance of a planing hull form are:

i. Length beam ratio $\frac{L_p}{B_{PA}}$ where the mean beam over chines $B_{PA} = \frac{A_P}{L_P}$. (Fig.2)

ii. Size weight ratio define by coefficient $A_p / \nabla^{2/3}$ Where ∇ is volume of displacement

iii. Deadrise angle β and its variation along the length

Iv. Longitudinal position of centre of gravity –LCG

iv. Longitudinal curvature of buttock line at $\frac{B_{pA}}{4}$ from centerline

v. Shape of chine in plan and shape of sections

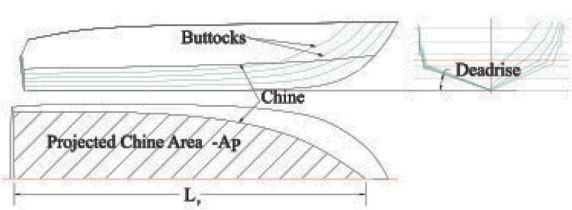

Fig 2. Principal design parameters

When the length beam ratio is low, the hull needs significantly higher power to weight ratio at pre-planing stage but once the hull is in full planing mode the power to weight ratio is of the same order with other hulls of higher length beam ratio.

Size weight ratio indicates the projected chine area supporting a unit volume of the boat. As this quantity is high, vessel is light in weight and hull plain easily with less power input. Wider transom would help in case of OBM boats to increase the above factor and lift the boat easily during planing stage.

Deadrise is the angle a hull bottom makes with the horizontal plane as shown in Fig.2. The correct amount of deadrise to be decided based on the operating water (calm water or rough water) Deadrise gives a boat dynamic and directional stability, a softer ride and reduces wetted surface drag as the boat rises on a plane. With some design deadrise is constant from midship to transom. If it gradually decreases to transom from midship is called variable deadrise. Smaller the deadrise less power is needed but can be used for calm water or as inshore craft. Larger the deadrise power consumption is more but can be a soft rider even for rough water or higher sea state. So the selection of the deadrise angle would depend on the purpose and application of the boat. High speed naval craft may have deadrise angle of above 25 degree. The variation of deadrise angle is very important because angle of attack of the hull with the water will depend on this variation and hence planing ability of the hull.

Performance of a planing hull is very dependent upon the location of the longitudinal center of gravity of the boat. Initial trim angle would depend on the location of the longitudinal centre of buoyancy and the longitudinal centre of gravity.

Initial trim angle has a major effect of planing ability of a hull and also resistance per weight ratio is minimum for trim angle of 3-4 degrees. [Savitsky 2003]

The buttocks are always parallel to the centerline and longitudinal curvature set the correct angle of attack with water in order to develop positive pressure and also the separation of flow from the hull at the transom. Spray rails that produces additional lift are usually set along the buttock lines.

Shape of the chines in plan determines the projected chine area and the distribution of the area. Location of the resultant hydro dynamic lift force would depend on the shape of the chines as well.

The above factors should be taken into account with analysis when considering a new design.

III. DESIGN METHODOLOGY

Taking above factors into account three dimensional hullform was developed using Delftship software. The overall length of the hull was limited to 5.95m (19'-6"). Design process involves use of the knowledge and visualization of the hull shape to achieve the correct design parameters. Design hydrostatics, cross sectional area curve, profile plan, body plan and waterline plan are displayed during the design process. Stability of the hull is being assessed while developing the hull. Perspective view (Fig.3) and lines plan (Annex, Fig.a) of the hull is shown and the derived design particulars are in table 1.

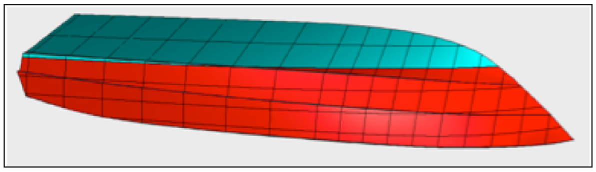

Fig 3. Perspective view of the hull

Length overall	= 5.95m
Length of waterline	= 5.23m
Maximum Breadth (transom)	= 2.15m
Breadth of waterline	= 1.85m
Design draft	= 0.35m
Displacement	= 1.20t
Longitudinal center of buoyancy	= -19.5%
Block coefficient	= 0.35m
Prismatic coefficient	= 0.93
Wetted surface area	= 8.0m2
Transverse metacentric height	= 1.43m
Deadrise at amidships	=19 deg.
Entrance angle	=25 deg

Table 1. Basic particulars of the designed hull

III. RESISTANCE AND POWER PREDICTION

There had been several approaches to power prediction of planing hull form and these methods have been analyzed and discussed by Kukner(2008). Some of these methods are numerical approaches applicable for particular hull shape of different standards hull series. Most of the methods deviate from each other with less than 10% in resistance prediction. The method develop by Savitsky is adopted by the most designers and it would gives slightly lower estimation to the power at pre-planing stage. The power estimates at higher speeds or full planing stage very well acceptable (savitsky,1964). Therefore Savitsky method is used in this case to predict the power. Annex (Fig.B) describes the above method with relevant diagrams.

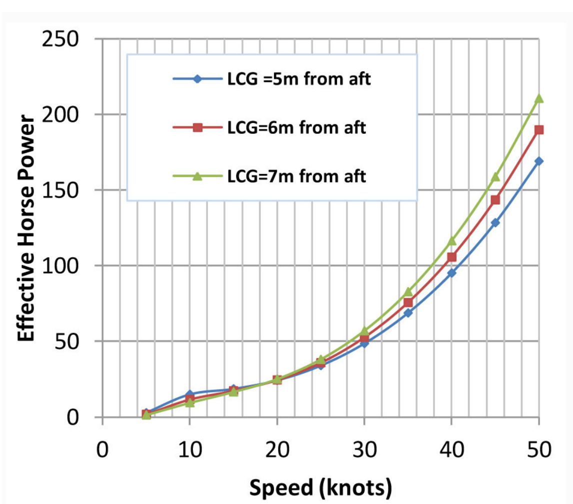

Fig 4. Estimated effective power

The effective power was estimated for three different values of LCG and the above Fig. 4 shows the predicted effective power. As the LCG tend to be more toward aft, the initial trim become higher and boat needs slightly higher power to attained planing mode. Planing commences at a speed of around 18 knots.

V. CONSTRUCTION

A boat is to be built in fiber glass and therefore plugs and moulds are to be constructed to the exact dimensions of the design. All frame sections were produced using CNC milling machine to the exact dimension of the hull form using MDF board and then the plug of the boat is constructed very accurately with excellent craftsmanship under author's advices and supervision. Figure C in the annex shows the picture of the completed hull plug before finishing the surface. Plug surface was finished to mirror finish with special painting and polishing.

Constructions of moulds and boat in fibre glass are a lengthy process for the discussion with relevant scientific and technical requirement to be satisfied to achieve a good quality product. Author's intention is not to give detail production process in this paper. In the manner described above plug of the deck are designed taking aesthetic and ergonomics aspects into account and then the mould of the deck is taken.(Fig. D in Annex).

The purpose of this project was to design and develop a speed boat for water sports in Sri Lanka and also as product to be marketable anywhere.

Author's aspiration was to achieve innovative design in all aspects with amazing and robust features that excite boaters and improve their desire on water sports. Two deck models were developed for the same hull 1.Bow rider and 2. Center console with attractive features. Fig. F in the annex shows a completed Bowrider model ready for installation of the engine. Both models were tested for speed one with 90hp out board motor (OBM) and the other with 250hp OBM.

IV. SPEED TRIAL AND PERFORMANCE

Both models were tested for speed, maneuvering and dynamic stability. The boat displacement was 1.35 tonne with the OBM and LCG was estimated to be 5.9 m aft of midship. The performance was demonstrated with videos at the symposium. In all aspects, performances were excellent and records of speed trail are as follows (Annex Fig.G)

Speed (knots)	25	29	33	36	40	45	49
Delivered hp	50	70	90	115	150	200	250

Table 2. Engine horse power and attained speed

Boat speed and engine RPM were measured and the Engine horse power was estimated from the engine characteristics curves at the relevant RPM. The overall propulsive efficiency of the OBM was exactly not known and was a brand new engine. With overall propulsive efficiency of 68% the utilized effective power is almost same as the estimated effective power for LCG of 6m.

Figure 5 shows the comparison of estimated and utilized effective power which is in very good agreement for assumed propulsive efficiency.

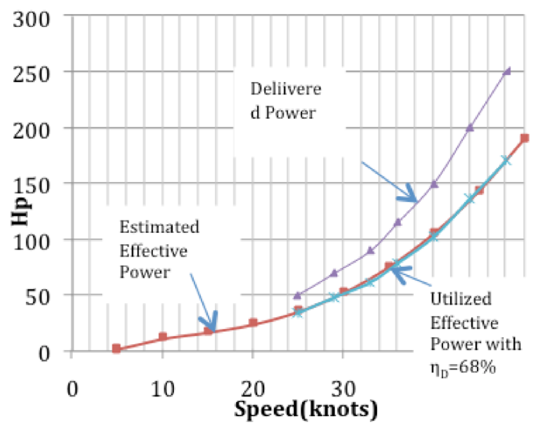

Fig 5. Comparison between utilized and estimated effective power.

V. CONCLUSION

It was a very successful project from the point of the design of high speed planing craft. All theoretical estimates and assessment with the designer's experience and judgment lead to a successful completion of construction of such a boat. Savitsky method of power estimation of planing hulls proved to be fairly accurate for real life power prediction for planing hulls. At present there are few boats used by srilankan boat riders for water sports.

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BIOGRAPHY OF THE AUTHOR

Author, Dr WK Wimalasiri is a Senior Lecturer in the Department of Mechanical Engineering, University of Moratuwa, Sri Lanka. His research interests are hull design for small vessel and stability analysis of vessels and preparation of stability booklet.

ANNEX

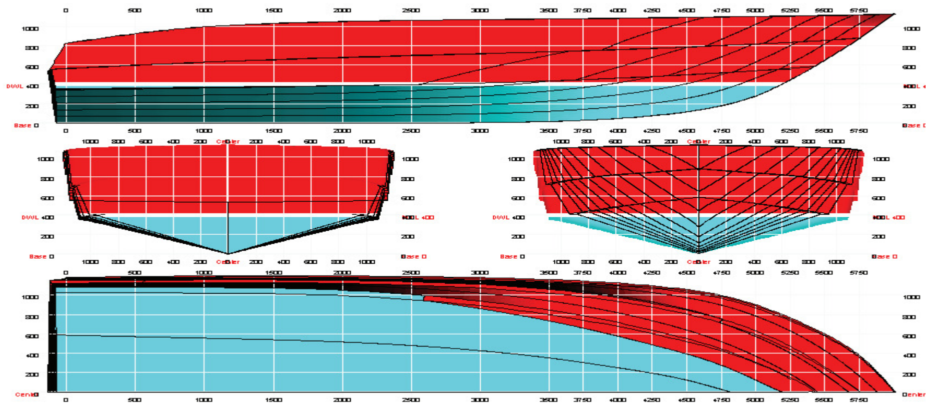

Fig A. Lines Plan of the Design

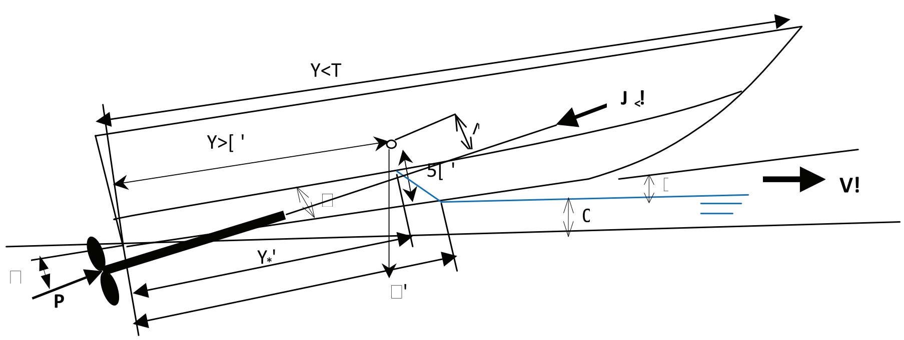

Fig B. Forces and relevant design data for Savitsky method

<u>Nomenclature</u>

LOA – Length overall

LCG – Longitudinal centre of gravity

KG – Height to vertical centre of gravity

T – Thrust

Df – Drag force

Δ - Weight or Displacement

α - Angle between thrust line and the keel

V - Speed

θ - Angle between keel and main chine

f – Distance between thrust line and center of gravity

h – Transom draft

τ - Trim angle

Lk – Keel wetted length

Lc - Chine wetted length

<u>Mathematical summery of power estimation</u>

The displacement Froude number $\boldsymbol{Fn_V = \frac{V}{\sqrt{\nabla^{1/3} g}}}$

The Froude number based on maximum beam over chine, b $\boldsymbol{C_v = \frac{V}{\sqrt{gb}}}$

The equivalent flat plate lift coefficient, $C_{Lb} = \frac{\rho g \nabla}{1/2\, \rho b^2 V^2}$

Trim angle for equilibrium conditions is given by Savitsky formula

$$C_{Lb} = \tau^{1.1}(0.0120\sqrt{\lambda} + 0.055\lambda^{\frac{5}{2}}/{C_v}^2)$$

Where λ is mean wetted length beam ratio : Lm/b

The lift coefficient for deadrise angle β can be found by

$$C_{L\beta} = C_{Lb} - 0.0065\beta {C_{Lb}}^{0.6}$$

Total resistance is given by $R_T = \Delta \tan\tau + \frac{1}{2}\rho\lambda V^2 b^2 C_{FO} /(\cot\tau\, \cos\beta)$

Where $C_{FO} = \frac{0.075}{(Log\, Rn - 2)^2}$ ITTC friction coefficient and $Rn = V_1 \lambda b/\nu$

V1 is the average bottom velocity which is less than forward planing velocity V and given by

$V_1 = V\left(1 - \frac{0.0120\tau^{1.1}}{\sqrt{\lambda}\cos\tau}\right)^{1/2}$ for zero deadrise. There is graphical relationship given by Savitsky for other deadrise angles.

Fig C. Plug of the Boat Hull

Fig D. Plug of the Deck

Fig E. Mould of the Deck

Fig F. Completed Boat

Fig G. Maneuvering when fully planing