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# Stability and Computational Flow Analysis on Boat Hull

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***Abstract* :** *A boat is a water craft of any size designed to float on water to provide passage across water. Boats are extensively used for short distance transportation, trading and fishing etc. This paper describes modeling and CFD (computational fluid dynamics) analysis of boat hull. In the present work, Metacenter height and stability was calculated for a boat hull made of three different materials like wood, aluminum and S-glass/Epoxy composite. The composite materials are being extensively used in varieties of engineering applications because of their superior properties over other conventional materials, the advantages include high strength to weight ratio, high specific strength, high corrosion resistance and high fracture toughness etc. In order to reduce the weight and to increase the performance S-glass/Epoxy composite are used for the boat hull. Theoretical calculation of metacenter height and stability for boat hull is calculated using Simpson's* $\frac{1}{3}^{rd}$ *rule for the three different boat materials. Modeling and CFD analysis was done for the boat hull made of S-glass/Epoxy composite. To simplify the analysis wind force opposite to the boat hull was taken in to consideration. Flow characteristics like drag and lift forces for different wind and boat speeds were obtained by using Computational Fluid Dynamics (CFD) software by keeping the water speed constant at 5 Km/h. The boat hull geometry is modeled using PRO – E 4.0 and meshing was done using GAMBIT software. Analysis is carried out by using a commercial CFD package of FLUENT.*

*Keywords* – Boat hull, Metacenter, CFD, Aluminum, S-glass/Epoxy composite, Wood.

## I. INTRODUCTION

Boat is generally used in sea and ponds. The boats are used for short-distance transportation of people and goods and also for fishing. However many boats are used exclusively for sports. Boats can be made in different shapes and sizes.

They are able to float on water and move due to various propulsion systems (engines, oars, paddles and sails). Boats has been a long fascination, that how to move a boat faster and more safe on the water. Boats have developed from simple rafts to enormous ships that can carry thousands of people.

Boats are made of materials like wood, steel and metal. There are five contributing factors that help to keep a boat afloat and prevent it from sinking. They are buoyancy, stability, waterproofing, air capacity and shape.

Buoyancy is an object's ability to float in water. When an object floats in a liquid, the weight of the volume of liquid displaced by the object is equal to the weight of the object.

The stability of a boat ensures that it does not tip over or become unstable. This means all passengers are able to stay in the boat and not get wet.

The boat shape, pointed at one end and wider at the other, is also a design element that helps to move the boat through the water at a faster rate. At the pointed end of boat water and air resistance is minimum. The schematic diagram of boat hull shown in figure: 3.

## II. SPECIFICATION OF THE PROBLEM

The objective of the present work is to determine metacenter height and stability of a boat hull made of three different materials viz., Wood, Aluminum and S-glass/Epoxy composite. The structure of the hull varies depending on the vessel type. The material commonly used for the manufacturing boat is steel or wood. If steel is used as the material then weight of the boat increases and wood was less weight and effective corrosion resistance. Modeling and CFD analysis was done for the boat hull made of S-glass/Epoxy composite. 3D model of boat hull geometry is modeled using PRO – E 4.0 and mesh is done using GAMBIT software. Analysis is carried out by using a commercial CFD package of FLUENT. Stability, metacenter height calculations have done by using Simpsons $\frac{1}{3}^{rd}$ rule. The 3D view of a boat hull is show in figure:1 and its specifications are listed in table:1.

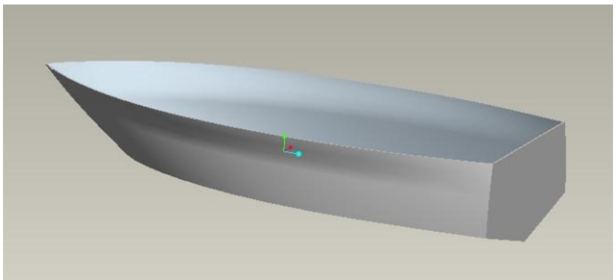

Figure1: 3D view of Boat hull.

## III. SPECIFICATION OF BOAT HULL

Table1: Specification of boat hull.

| S.NO | PERAMETERS | VALUE (m) |
|---|---|---|
| 1 | Boat hull length | 6 |
| 2 | Boat hull height | 2.5 |
| 3 | Beam | 1.2 |
| 4 | Draft | 0.30 (Assumed) |
| 5 | Material | Aluminum, Wood and S-Glass/Epoxy composite. |

## IV. COMPOSITE MATERIAL

Composite materials are formed by combining two or more materials that have quite different properties. The different materials work together to give the composite unique properties. Most composites are made up of just two materials. One material, which is called matrix or binder, surrounds and binds together a cluster of fibers or fragments of a much stronger material, which is the reinforcement. Humans have been using composite materials for thousands of years. Composite materials have extraordinary strength, stiffness, chemical and temperature resistance.

1. E-glass (electrical) - lower alkali content and stronger than A glass (alkali). Good tensile and compressive strength and stiffness, good electrical properties and relatively low cost, but impact resistance relatively poor.
2. C-glass (chemical) - best resistance to chemical attack. Mainly used in the form of surface tissue in the outer layer of laminates used in chemical and water pipes and tanks.
3. R, S or T-glass – manufacturers trade names for equivalent fibers having higher tensile strength and modulus than E glass, with better wet strength retention. Developed for aerospace and defense industries.

## V. THEORITICAL CALCULATIONS FOR METACENTER HEIGHT

Simpson's $\frac{1}{3}$ rd rule may be used to find the areas and volumes of irregular objects. When applied to ships they give a good approximation of areas and volumes. The accuracy of the answers obtained will depend upon the spacing of the ordinates.

This rule assumes that the curve is a parabola of the second order. A parabola of the second order is one whose equation, reffered to co-ordinate axis, is of the form $y = a_0 + a_1y + a_2y^2$, where $a_0$, $a_1$ and $a_2$ are constants.

The coefficients of the ordinates are reffered to as Simpson's Multiplires (SM) and they are in the form: 1424241. There had been nine ordinates, the multiplires would have been: 142424241. Simpson's multiplier begin and end with 1.

Let the curve in Figure:2 be a parabola of the second order. Let $y_1$, $y_2$, $y_3$ and $y_4$, represents four ordinates equally spaced at 'h' units apart.

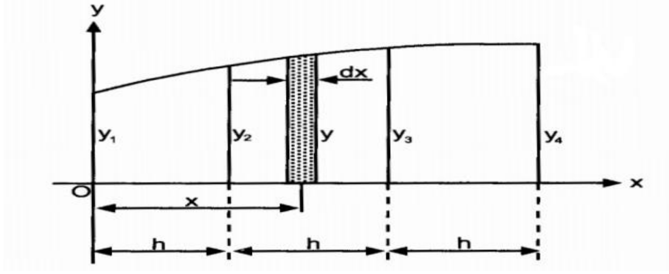

Figure:2 Parabola of the forth order.

**Area of the figure** $= \frac{h}{3}\,(y_1 + y_2 + y_3 + y_4)$

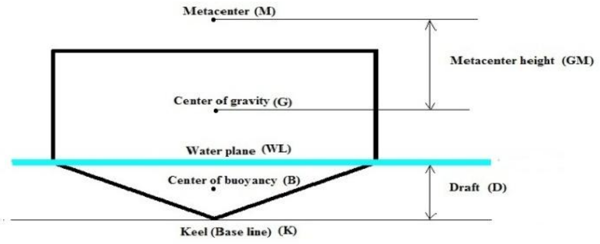

Figure3: Skematic diagram of boat hull.

### V.I. AREAS BY USING SIMPSONS RULE

### V.1.1 Area of the water plane at 0.30 m draft.

For the purpose of calculation of area of water plane half of the water plane (wp) is considered at the draft of 0.30m. There are six ordinates($y_1$, $y_2$, $y_3$, $y_4$, $y_5$, $y_6$) were taken and multiplied with simpson multiplires (SM). Table 2 shows the area of the water plane at various ordinates at 0.30m draft.

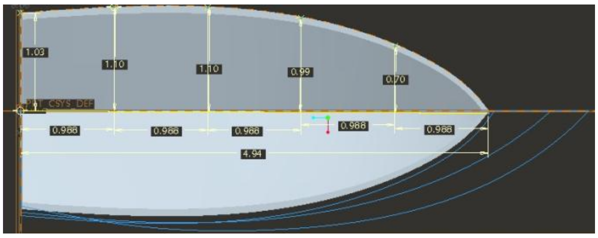

Fig 4: ½Area of the water plane at 0.30 m draft

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Table 2: ½Area of the water plane at 0.30 m draft.

| ½ Ordinate (y) | SM | ½ Area Of Water plane |
|---|---|---|
| 1.03 | 1 | 1.03 |
| 1.10 | 4 | 4.4 |
| 1.10 | 2 | 2.2 |
| 0.99 | 4 | 3.96 |
| 0.70 | 2 | 1.4 |
| 0 | 1 | 0 |
| | | ∑ = 12.99 m |

Common interval (h) = 0.988
½ area of water plane = 1/3 * h * ∑
= 1/3 * 0.988 *12.99
= 4.278 $m^2$
Area of the water plane (∑A) = 1/3 * h * ∑ * 2
= 8.566 $m^2$

### V.1.2 Area of the water plane at 0.20 m draft.

For the purpose of calculation of area of water plane half of the water plane (wp) is considered at the draft of 0.20m. There are six ordinates($y_1$, $y_2$, $y_3$, $y_4$, $y_5$, $y_6$) were taken and multiplied with simpson multiplires (SM). Table 3 shows the area of the water plane at various ordinate at 0.20m draft.

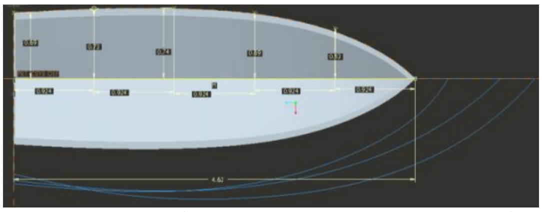
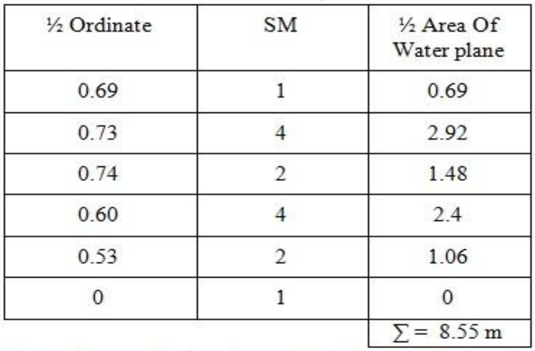


Fig 5: ½Area of the water plane at 0.20 m draft

Table 3: ½Area of the water plan at 0.20 m draft.



| ½ Ordinate | SM | ½ Area Of Water plane |
|---|---|---|
| 0.69 | 1 | 0.69 |
| 0.73 | 4 | 2.92 |
| 0.74 | 2 | 1.48 |
| 0.60 | 4 | 2.4 |
| 0.53 | 2 | 1.06 |
| 0 | 1 | 0 |
| | | ∑ = 8.55 m |

Common interval (h) = 0.924

½ area of water plane = 1/3 * h * $\sum$
= 1/3 * 0.924 *8.55
= 2.633 m$^2$

Area of the water plane ($\sum$A) = 1/3 * h * $\sum$ * 2
= 5.26 m$^2$

### V.1.3 Area of the water plane at 0.10 m draft.

For the purpose of calculation of area of water plane half of the water plane (wp) is considered at the draft of 0.10m. There are six ordinates($y_1$, $y_2$, $y_3$, $y_4$, $y_5$, $y_6$) were taken and multiplied with simpson multiplires(SM). Table 4 shows the area of the water plane at various ordinate at 0.10m draft.

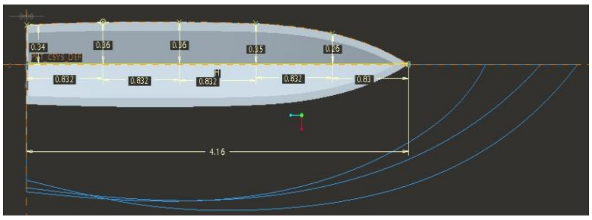
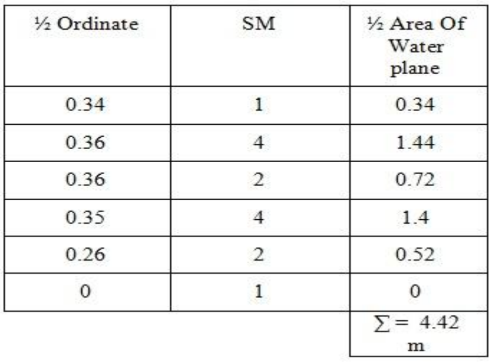


Fig 6: ½Area of the water plane at 0.10 m draft.

Table 4: ½Area of the water plane at 0.10 m draft



| ½ Ordinate | SM | ½ Area Of Water plane |
|---|---|---|
| 0.34 | 1 | 0.34 |
| 0.36 | 4 | 1.44 |
| 0.36 | 2 | 0.72 |
| 0.35 | 4 | 1.4 |
| 0.26 | 2 | 0.52 |
| 0 | 1 | 0 |
| | | ∑ = 4.42 m |

Common interval (h) = 0.832

½ area of water plane = 1/3 * h * $\sum$ (½ area)
= 1/3 * 0.832 * 4.42
= 1.22 m$^2$

Area of the water plane ($\sum$A) = 1/3 * h * $\sum$ * 2
= 2.44 m$^2$

## V.2. VOLUME OF WATER DISPLACED:

For the purpose of calculation of volume of water displaced of boat hull at the draft of 0.30m for different maerials.

**V.2.1 For S-glass/Epoxy composite:-** (density = 2000 Kg/m$^3$):

Weight of boat hull = volume of boat hull * density of boat hull material * g
= 1.077 * 2000 * 9.81
= 21130.74 N

For equilibrium weight of water displaced = weight of boat hull

Volume of water displaced = weight of water displaced / water density
= 21130.74 /(1025*9.81)
= 2.10 m$^3$

**V.2.2 Wood :-** (density = 700 Kg/m$^3$)

Weight of boat hull = volume of boat hull * density of boat hull material * g
= 1.077 * 700 * 9.81
= 7395.75 N

For equilibrium weight of water displaced = weight of boat hull

Volume of water displaced = weight of water displaced / water density
= 7395.75 /(1025*9.81)
= 0.735 m$^3$

**V.2.3 Aluminum :-** (density = 2730 Kg/m$^3$)

Weight of boat hull = volume of boat hull * density of boat hull material * g
= 1.077 * 2730 * 9.81
= 28843.46 N

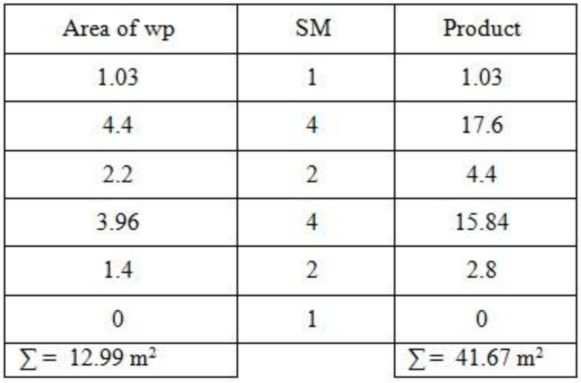
For equilibrium weight of water displaced = weight of boat hull

Volume of water displaced = weight of water displaced / water density
= 28843.46 /(1025*9.81)
= 2.86 m$^3$

## V.3 CENTER OF BUOYANCY:

For the purpose of calculation of center of buoyancy at the draft of 0.30m the area of the half of the water plane multiplied with simpson multiplires (SM). Table 5 shows the center of buoyancy at the draft of 0.30m.

Table 5: Center of buoyancy.



| Area of wp | SM | Product |
|---|---|---|
| 1.03 | 1 | 1.03 |
| 4.4 | 4 | 17.6 |
| 2.2 | 2 | 4.4 |
| 3.96 | 4 | 15.84 |
| 1.4 | 2 | 2.8 |
| 0 | 1 | 0 |
| ∑ = 12.99 m$^2$ | | ∑ = 41.67 m$^2$ |

**CB = $\Sigma$ ($A_{WP}$ ( SM )* Z / $\Sigma$ (product)**

Where,

$A_{WP}$ = water plane area Z = vertical distance b/w the base line to water plane

CB = (12.99 * 0.30) / 41.67

= 0.09

### V.4 SECOND MOMENT OF THE WATER LINE AREA ABOUT THE CENTERLINE

For the purpose of calculation of second moment of water line area about the centerline six ordinates ($y_1$, $y_2$, $y_3$, $y_4$, $y_5$, $y_6$) were taken and there cubic value was multiplied with simpson multiplires (SM). Table 6 shows the second moment of the water line area about the centerline.

Table 6: Second moment of the water line area.

| ½ ordinate | (½ ordinate)$^3$ | SM | Product |
|---|---|---|---|
| 1.03 | 1.092 | 1 | 1.092 |
| 1.10 | 1.33 | 4 | 5.32 |
| 1.10 | 1.33 | 2 | 2.66 |
| 0.99 | 0.97 | 4 | 3.88 |
| 0.70 | 0.34 | 2 | 0.68 |
| 0 | 0 | 1 | 0 |
| | | | ∑=13.632 $m^3$ |

**$I_{cl}$ =2/9 *h *$\Sigma$ (product )**

=2/9 *0.988 *13.632

=2.99 $m^4$

### V.5 TO FIND THE DISTANCE OF " BM " :

$$\mathbf{BM} = \frac{I}{V}$$

I = Second moment of the water plane area about the centerline

V = The volume of water displacement

### V.5.1 For S-glass/Epoxy composite:

BM = 2.99 /2.10

= 1.42 m

**Distance of " KM " :**

KM = KB + BM

= 0.09 + 1.42

= 1.51 m

### V.5.2 For Aliminium:

BM = 2.99 /2.86

= 1.045 m

**Distance of " KM " :**

KM = KB + BM

= 0.09 + 1.045

= 1.135 m

### V.5.3 For Wood:

BM = 2.99 /0.735

= 4.06 m

**Distance of " KM " :**

KM = KB + BM

= 0.09 + 4.06

= 4.15 m

### V.6 STABILITY IN THE UPRIGHT CONDITIONS

### V.6.1 For S-glass/Epoxy composite:

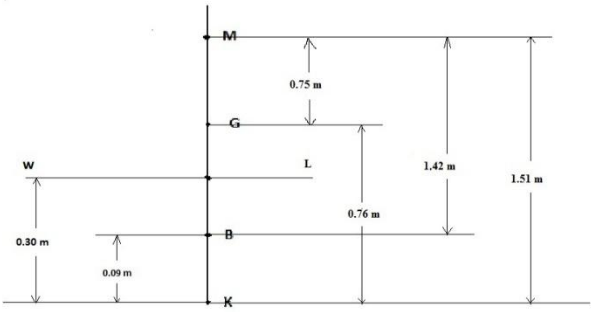


Fig 7: Stability in the upright conditions for S-glass/epoxy.

### V.6.2 For Aluminium:

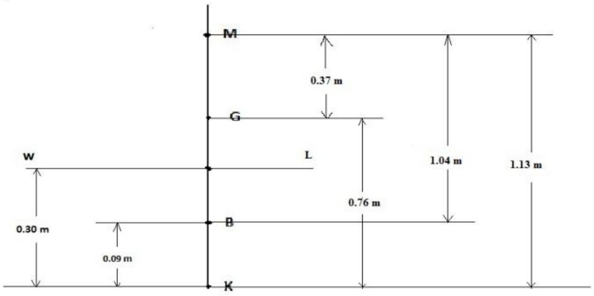


Fig 8: Stability in the upright conditions aluminum.

### V.6.3 For wood:

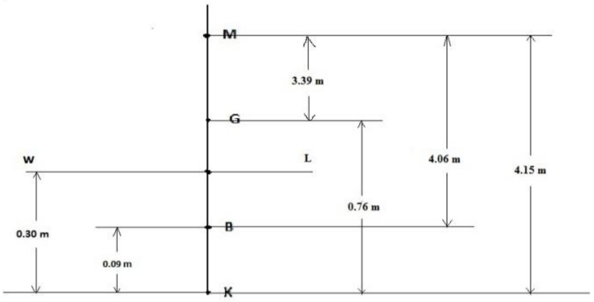


Fig 9: Stability in the upright conditions wood.

1. If G is below M, the boat in stable equilibrium.
2. If G is above M, the boat in unstable equilibrium.
3. If G is coincide with M, the boat is in neutral.

## VI. DRAG AND LIFT FORCES ACTING ON BOAT

<u>**Drag**</u> is the force parallel to the relative wind.

<u>**Lift**</u> is the force perpendicular to the relative wind.

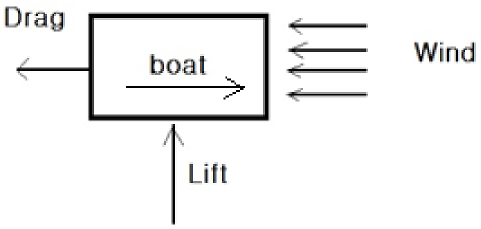


Fig10: Drag and Lift forces acting on boat.

## VII. COMPUTATIONAL FLUID DYNAMICS (CFD) RESULTS

### VII.1 Analysis of Boat with speed of 35 Km/h, Wind speed as 20 Km/h, by keeping Water speed as 5 Km/h. Static pressure, velocity, drag, lift history as shown below

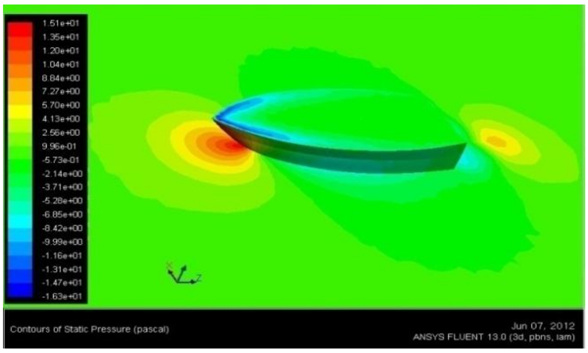


Fig11: Static Pressure on boat hull.

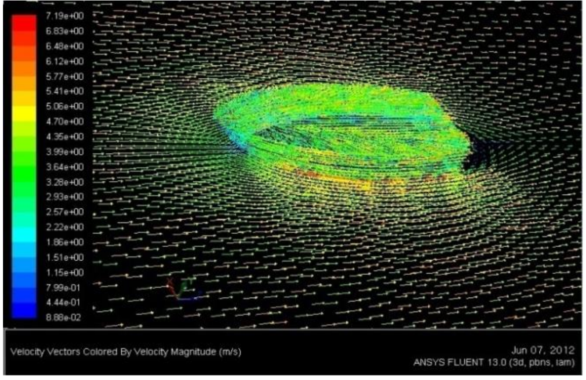


Fig12: Velocity on boat hull.

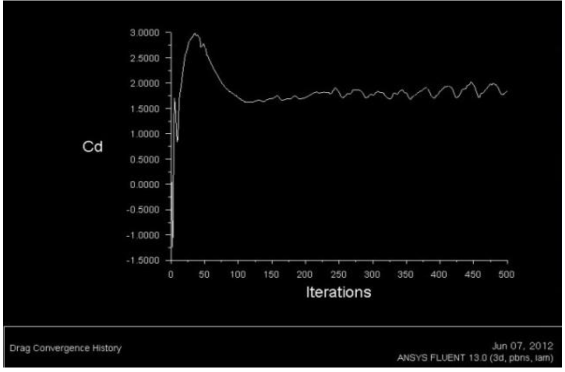


Fig13: Drag History.

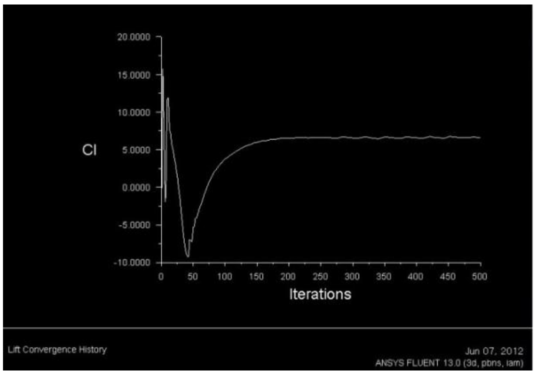


Fig14: Lift History.

## VIII. THEORITICAL FORMULAS FOR DRAG AND LIFT FORCES

$$\text{Drag force} = \frac{1}{2} * \rho * V^2 * C_D * A$$

$$\text{Lift force} = \frac{1}{2} * \rho * V^2 * C_L * A$$

Where $\rho$ = Density of water
$V$ = Water velocity in m/s
$C_D$ = Drag coefficient
$C_L$ = Lift coefficient
$A$ = Area of the boat (28.633 $m^2$)

Similar analysis was carried out for different wind speeds (30, 40 and 50 Km/h) and boat speeds (45, 55and 65 Km/h), by keeping water speed as 5 Km/h. Results for Drag, Lift coefficients are tabulated in tables from 7 to 10 and the respective drag and lift forces are tabulated in tables 11 to 14

## IX. CFD RESULTS FOR DRAG AND LIFT COEFFICIENTS

Drag and lift coefficients are vary depend upon boat speed.

| S. No | Boat speed (Km/h) | Water speed (Km/h) | Wind speed (Km/h) | Drag Coefficient | Lift Coefficient |
|---|---|---|---|---|---|
| 1 | 35 | 5 | 20 | 1.84 | 6.58 |
| 2 | 45 | 5 | 20 | 1.91 | 6.57 |
| 3 | 55 | 5 | 20 | 1.92 | 6.62 |
| 4 | 65 | 5 | 20 | 2.01 | 6.56 |

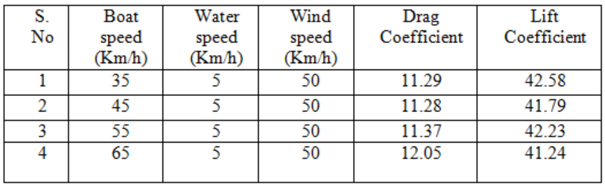
**Table:7**

| S. No | Boat speed (Km/h) | Water speed (Km/h) | Wind speed (Km/h) | Drag Coefficient | Lift Coefficient |
|---|---|---|---|---|---|
| 1 | 35 | 5 | 30 | 4.03 | 14.99 |
| 2 | 45 | 5 | 30 | 3.99 | 14.94 |
| 3 | 55 | 5 | 30 | 4.19 | 14.82 |
| 4 | 65 | 5 | 30 | 4.22 | 14.79 |

**Table:8**

| S. No | Boat speed (Km/h) | Water speed (Km/h) | Wind speed (Km/h) | Drag Coefficient | Lift Coefficient |
|---|---|---|---|---|---|
| 1 | 35 | 5 | 40 | 6.79 | 26.58 |
| 2 | 45 | 5 | 40 | 7.61 | 27.19 |
| 3 | 55 | 5 | 40 | 7.88 | 26.94 |
| 4 | 65 | 5 | 40 | 6.87 | 26.25 |

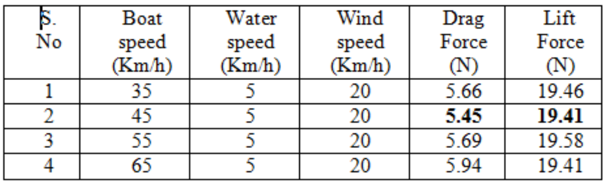
**Table:9**



| S. No | Boat speed (Km/h) | Water speed (Km/h) | Wind speed (Km/h) | Drag Coefficient | Lift Coefficient |
|---|---|---|---|---|---|
| 1 | 35 | 5 | 50 | 11.29 | 42.58 |
| 2 | 45 | 5 | 50 | 11.28 | 41.79 |
| 3 | 55 | 5 | 50 | 11.37 | 42.23 |
| 4 | 65 | 5 | 50 | 12.05 | 41.24 |

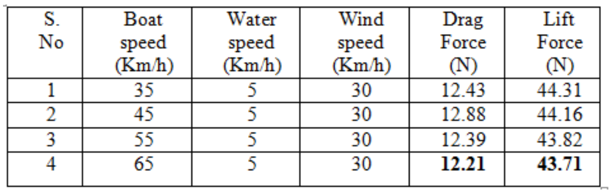
**Table:10**

## X. CFD RESULTS FOR DRAG AND LIFT FORCES



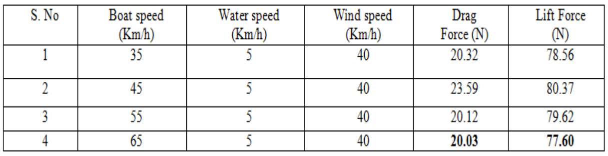
| S. No | Boat speed (Km/h) | Water speed (Km/h) | Wind speed (Km/h) | Drag Force (N) | Lift Force (N) |
|---|---|---|---|---|---|
| 1 | 35 | 5 | 20 | 5.66 | 19.46 |
| 2 | 45 | 5 | 20 | **5.45** | **19.41** |
| 3 | 55 | 5 | 20 | 5.69 | 19.58 |
| 4 | 65 | 5 | 20 | 5.94 | 19.41 |

**Table:11**



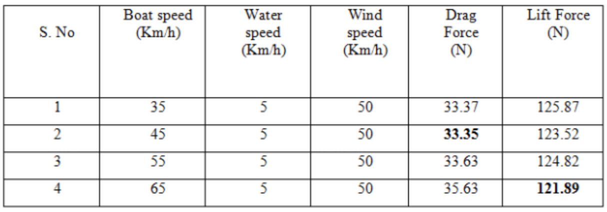
| S. No | Boat speed (Km/h) | Water speed (Km/h) | Wind speed (Km/h) | Drag Force (N) | Lift Force (N) |
|---|---|---|---|---|---|
| 1 | 35 | 5 | 30 | 12.43 | 44.31 |
| 2 | 45 | 5 | 30 | 12.88 | 44.16 |
| 3 | 55 | 5 | 30 | 12.39 | 43.82 |
| 4 | 65 | 5 | 30 | **12.21** | **43.71** |

**Table:12**



| S. No | Boat speed (Km/h) | Water speed (Km/h) | Wind speed (Km/h) | Drag Force (N) | Lift Force (N) |
|---|---|---|---|---|---|
| 1 | 35 | 5 | 40 | 20.32 | 78.56 |
| 2 | 45 | 5 | 40 | 23.59 | 80.37 |
| 3 | 55 | 5 | 40 | 20.12 | 79.62 |
| 4 | 65 | 5 | 40 | **20.03** | **77.60** |

**Table:13**



| S. No | Boat speed (Km/h) | Water speed (Km/h) | Wind speed (Km/h) | Drag Force (N) | Lift Force (N) |
|---|---|---|---|---|---|
| 1 | 35 | 5 | 50 | 33.37 | 125.87 |
| 2 | 45 | 5 | 50 | **33.35** | 123.52 |
| 3 | 55 | 5 | 50 | 33.63 | 124.82 |
| 4 | 65 | 5 | 50 | 35.63 | **121.89** |

**Table:14**

## XI. CONCLUSIONS

The following conclusion were drawned from the CFD analysis performed on a boat hull of S-glass/Epoxy composite.

For stability, the center of gravity (G) is below the metacenter (M). This condition was validated for the three different materials considered for the analysis.

Minimum drag force of 5.45 N and minimum lift force of 19.41 N was obtained for the boat speed of 45 Km/h, when the water and wind speeds are 5 Km/h, 20 Km/h respectively.

Minimum drag force of 12.21 N and minimum lift force of 43.71 N was obtained for the boat speed of 65 Km/h, when the water and wind speeds are 5 Km/h , 30 Km/h respectively.

Minimum drag force of 20.03 N and minimum lift force of 77.60 N was obtained for the boat speed of 65 Km/h, when the water and wind speeds are 5 Km/h , 40 Km/h respectively.

Minimum drag force of 33.35 N and minimum lift force of 121.89 N was obtained for the boat speed of 45 Km/h and 65 Km/h , when the water and wind speeds are 5 Km/h , 50 Km/h respectively.

Drag and lift forces increases with increase in wind speed as well as with boat speed.

For various wind speeds (20,30,40,50 Km/h ). Minimum drag force and Minmum lift force was obtained at 45 Km/h, 65 km/h of boat speeds , when water speed is 5 Km/h.

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