

## **Design And Analysis of Wing In Ground Effect Vehicle**

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### **Abstract**

A wing-in-ground effect vehicle is the one that controls the flight levels near the Earth's surface due to aerodynamic interaction between the surface and the wings. The ground effect phenomenon occurs when the airplane wing flies under a close proximity to one particular surface. Here, the presence of the surface deforms the downwash from the wing and impedes the development of vortices. This results in an increased lift and a reduction in drag in comparison to something achieved by a conventional wing in flight. The application of Ground effect vehicles commonly used were to carry tonnes of goods over a long distance. The speed of these vehicles was far greater compared to ships at the same time, being more efficient. The Ekranoplan, was one such ground effect vehicle which was developed during the cold war as an experiment to achieve a faster means of transportation while staying out of enemy's radar. The DACC type of WIG craft consist of, one or two small aspect ratio lifting wings in tandem formation. A configuration comparable with ram air cushion supported platform along with ability to take off into surface effect flight is observed in DACC type. There are a lot of sceptics who assume there isn't a lot to attain from this technology in comparison to a conventional hovercraft. However, in this current era of sustainability, due to advancements in aerodynamics and flight control along with the use of newer methods of propulsion, ground effect vehicles can hold good as a more efficient means of water transportation. The core intention of this paper is to reintroduce the ground effect vehicles as a newer, faster and more efficient means of water to land transportation in remote areas or places which are separated by huge water bodies.

**Keywords:** aerodynamic, WIG craft, DACC, sustainability, preliminary, ground effect, aerofoil, chord.

## 1. INTRODUCTION

The delicate balance of the world's ecosystem is seriously threatened by humanity's wasteful ways. Taking into account the seriousness of the greenhouse effect, drastic measures must be taken to prevent carbon dioxide emission from transport system. At some point the future generation will once again be forced to rely on trains, trams, buses, aircrafts and ships. The world of transportation has recently seen a paradigm shift in private vehicles. Car companies have diverted their attention to more sustainable and environmentally economical means to propel the vehicles. Regardless of these advancements, it is quite surprising that this paradigm shift hasn't took place in public transportation [1-3]. Moreover, the problems of connectivity are still faced by public transportation over long distances. Recently, due to the increase in environmental problems, research and development of transport systems cannot be carried out without considering energy efficiency and environmental impact. Hence, there is a need for a type of transportation which would help reach remote sections of a region with ease while addressing the current environmental issues.

The Wing in ground effect vehicle is a type of a plane that exploits the ground effect phenomenon to achieve faster speeds of travel by hovering at some proximity to the ground. Due to the craft flying under the ground effect, the power required to fly the vehicle is considerably lesser than a ship that might possibly be used in its case [4]. Also, the speed achieved from this vehicle is quite comparable to that of some planes. This results into an immense scope especially for intercontinental travel. So, it was decided to perform a preliminary design of a ground effect vehicle which would be future proof in the sense that with the advent of new means of propulsion. Technologies like electric motor, hydrogen fuel cells can be retrofitted in the aircraft when developed in the future.

## 2. METHODOLOGY

Since the wing in ground effect craft is essentially a plane, a lot of calculation and research were brought about by comparing the data and dimensions of several aircrafts having similar specifications. First, we were required to assume a mission profile upon which the design was to be made. We had to select the cruising speed, range of operations and payload capacity for starters. The design calculations were initiated with weight sizing.

This was followed by selecting an appropriate aerofoil for the craft. The aerofoil design involved calculation of wing loading, wing span, wing area, taper ratio, dimensions of root chord and tip chord. Similar calculations were involved in the design of the empennage.

Design of the propeller was made with respect to the lift and drag values followed by thrust horsepower and brake horsepower figures from engine selection. This helped us determine the propeller diameter.

Further the calculations for fuselage were done by using the references from various papers which set the standards for design and hence the suitable parameters were considered. The fuselage or the main body is observed to be a mixture of the layout of commercial aircrafts and ships. Hence, the fuselage related dimensions were calculated using the standards specified for the comfort of the passengers. The lower body of craft has a shape similar to hull of boats, for displacing the water flow during take-off and landing. The buoyancy factor is considered to examine, whether the vehicle floats on sea water. Which further helps determine the height of the part submerged in water.

To maintain the reserve buoyancy and to fulfil the criteria of DACC craft design, floats were added at the wingtips of the vehicle; for which dimensions were calculated using various formulas corresponding to the conditions. Thus, it helped maintain the stability; and handling of the craft becomes easier.

Based on these calculations the initial design was obtained and further changes were made according to the results acquired through analysis. After certain iterations the final design required results of analysis were secured.

## **2.1. Perspective:**

### **Solution for transportation problems faced by government:**

A unique problem of connectivity in between urban and rural areas has resulted due to the presence of large water bodies between two regions. Given to increasing the economic advancement of the nation, there is need of faster means of interstate transportation; which is also economical to construct over long distances and the operational cost is less. Hence, the WIG effect Vehicle is a good fit for:

- Long distance travel for passengers with a sustainable approach.
- High speed international transportation also possible at much cheaper rates.
- Navy applications for carrying soldiers and weapons and for other emergency services.

### **Benefits for common people:**

- Small ground effect vehicles can be used as an alternative to speed boats.
- Water bikes can also be manufactured; and can achieve higher speeds compared to regular bikes.
- If significant development is made in improving stability of ground effect vehicles in operation at rough seas, intercontinental high-speed travel would become possible and cheaper than airplanes.
- They can also be used for travelling in desert areas as the problem of getting sunk in desert mud is eliminated because the vehicles travel above ground.

- Because of their amphibious nature, they can be used on land as well as water bodies.

All of these can be manufactured and used at a reduced cost, due to the sustainable approach. And also reduce the carbon footprint through transportation systems.

### 3. DESIGN AND ANALYSIS

Certain Design Parameters, as mentioned in [1] , are to be selected in order to set requirements for the overall form, shape and compartmentation of the WIG effect Vehicle for its primary stage of Design. Once the prerequisites are fulfilled the influence of IMO and the Classification Society Criteria can be assessed.

#### 3.1. Design Calculations:

##### Step 1- Determination of Mission Profile:

Number of crew members =2

Payload Capacity = 2000 kg

Number of Engine = 2

- General Aviation Twin  
Engine

Cruise Speed =100 knots

= 51.4 m/s

Range = 480 km

##### Step 2- Take-off Wing Loading Estimation:

From Table1 [15] ,

Typical take off wing loading for general aviation- Twin Engine

=127 kg/m<sup>2</sup>

Also, from equation (8) [15] ,

$$\left(\frac{W}{S}\right)_{To} = (34.66) e^{\left(\left(\frac{4}{10}\right)*a\right)}$$

Where,

W= Take off weight of craft

S= Total wing area

a= Loading index,  $0 \leq a \leq 8$

For incident angle  $3^\circ$

$$\left(\frac{W}{S}\right)_{T_0} = 115 \text{ kg/m}^2$$

For incident angle  $4^\circ$

$$\left(\frac{W}{S}\right)_{T_0} = 170 \text{ kg/m}^2$$

### Step 3- Aircraft Weight Constraint Analysis:

With the reference of the mission profile mentioned above the overall weight can be calculated as,

$$W_o = W_{\text{crew}} + W_{\text{payload}} + W_{\text{fuel}} + W_{\text{empty}}$$

Let us consider, Mission payload +  $W_{\text{crew}}$  to be 2000 kg

$$\therefore W_{\text{crew}} + W_{\text{payload}} = 2000 \text{ kg}$$

According to [1] crafts overall weight assumed to be,

$$W_o = W_p / k_p$$

Where,

$W_o$  = Weight overall of the craft

$W_p$  = Payload weight

$K_p$  = Coefficient of payload, in general, take  $K_p = 0.2 - 0.3$

Considering  $k_p = 0.235$ ,

$$\therefore W_o = 8500 \text{ kg}$$

Empty weight fraction, from 4.5.1. [15] is given by,

$$\left(\frac{W_e}{W_o}\right) = A \cdot W_o^c \cdot K_{vs}$$

Where,

$W_e$  = Empty weight of craft

For flying boat, reference Table 3 [15] ,

$A = 1.09$  &  $c = -0.05$

$K_{vs}$  = variable sweep constant = 1.00 for fixed sweep

$$\therefore W_e = 5893 \text{ kg}$$

### Step 4-Determination of total Wing Area:

From Chapter 3 [3]

$$S = W_o / \text{take-off wing loading}$$

$$\therefore S = \frac{8500}{127} = 66.9 \text{ m}^2$$

Wingspan = 15 m

Mean Aerodynamic Chord = 5.71 m

Root Chord = 3.5 m

**Step 5- Aero-foil Selection:**

The WIG craft will be fitted with Clark y Airfoil, reference Chapter 6 [3] , with a thickness ratio of 18%.

**Step 6- Fuselage sizing:**

According to parameters specified in chapter 6 [16] , the internal and external dimensions of the fuselage are calculated in the following steps. Which further help set-up the layout of the payload.

For 20- 45 passenger's 3 abreast is preferred according to FAR.

No. Of passenger's = 20

Seat width = 0.45 m

Seat Pitch / Legroom ( $P_s$ ) = 0.8m

Diameter of fuselage ( $D_f$ ) = Cabin Width + 2 (Cabin Wall Thickness)

$$= [(No. of Seats in a row * Seat Width) + (No. Of Aisle * Aisle Width) + (2*Cabin Wall Thickness)]$$

$$D_f = (3*0.45) + (1*0.50) + (2*0.1)$$

$$\therefore D_f = 1.87 \text{ m}$$

Nose length ratio is between 1.7-2 for 3 abreast.

$$L_N / D_f = 1.7$$

Where,

$L_N$  = Nose length of the fuselage

$$L_N = D_f * 1.7$$

$$\therefore L_N = 3.179 \text{ m}$$

Rear length ratio is between 2.6-3.5 for 3 abreast.

$$L_R / D_f = 2.6$$

Where,

$L_R$  = Rear length of the fuselage

$$L_R = D_f * 2.6$$

$$\therefore L_R = 4.86\text{m}$$

Nose Cone Angle ( $\alpha$ ) can be determined by,

$$\tan\left(\frac{\alpha}{2}\right) = (D_f/2) / L_N$$

$$\therefore \alpha = 32.78^\circ$$

Cabin Length ( $L_C$ ),

$$L_C = (\text{no. of rows} * P_S) + (\text{No. of doors} * \text{door width})$$

$$= (7 * 0.8) + (1 * 8)$$

$$\therefore L_C = 6.4 \text{ m}$$

Length of fuselage ( $L_f$ ),

$$L_f = L_C + L_N + L_R$$

$$\therefore L_f = 14.439 \text{ m}$$

### Step 7- Design of Horizontal Tail:

Horizontal tail arm optimum, equation (2) [17] .

$$L_{opt} = k_c \sqrt{\frac{4 \bar{c} S V_H}{\pi D_f}}$$

$$V_H = \text{Horizontal tail volume} = 0.44$$

$$D_f = \text{diameter of fuselage} = 1.9\text{m}$$

$$\therefore L_{opt} = 10.54$$

Area of horizontal stabilizer, equation (3) [17] .

$$S_h = \frac{V_H * S * c}{L_{opt}}$$

Where,

$$S_h = \text{Area of horizontal tail}$$

$$\therefore S_h = 15.7 \text{ m}^2$$

NACA4412 Air-foil is selected for Horizontal Stabilizer.

### Step 8- Design of Vertical Tail:

Assuming  $\frac{S_v}{S} = 0.08$ , reference [17] .

Where,

$$S_v = \text{Area of vertical tail}$$

$$\therefore S_v = 5.28 \text{ m}^2$$

Vertical span of airfoil ( $b_v$ ) from [17] ,

$$b_v = \sqrt{S_v * A_r}$$

$$= 2.71 \text{ m}$$

$L_v$  = Vertical tail arm

$$\therefore L_v = 9 \text{ m}$$

NACA 0012 Airfoil is selected for Vertical stabilizers.

### Step 9- Power Required to Cruise:

From reference [18] , we have,

$$P = \frac{1}{2} \rho V^3 S C_D + \frac{\omega^2}{0.5 \rho V S} \left( \frac{1}{\pi e A} \right)$$

Where,

P = Power required to cruise

V = Velocity in knots

$C_D$  = Drag coefficient

$\rho$  = Density of sea water

For V = 120 knots

$$\therefore P = 1050 \text{ hp}$$

### Step 10- Design of Propeller:

According to the Chapter 4 [16] , the lift coefficient ( $C_L$ ) is given by,

$$C_L = W_o / (0.5 \rho V_c^2 S)$$

$$C_L = 8500 / (0.5 * 1.225 * 51.42^2 * 66.9)$$

$$\therefore C_L = 0.0785$$

And the drag polar with reference to Chapter 3 [3] is calculated by,

$$\log_{10} S_{Wet} = c + d * (\log_{10} W_{To})$$

where,

$S_{Wet}$  = Wetted Area

$W_{To}$  = Take-off weight of craft

$$\therefore \log_{10} S_{Wet} = 3.265$$

$$\therefore S_{Wet} = 1840.772 \text{ m}^2$$

$$\log_{10} f = a + b \cdot \log_{10} S_{Wet}$$

Where,

f = the equivalent parasite area

$$a = -2.3979 \text{ \& } b = 1$$

$$\therefore \log_{10} f = 0.8671$$

$$\therefore f = 7.3687 \text{ m}^2$$

From equation (16) [3],

$$C_D = C_{D,0} + (C_L^2 / \pi A e)$$

Where,

$$C_{D,0} = f / S$$

$$= 7.3637 / 66.9$$

$$\therefore C_{D,0} = 0.1101$$

$$\therefore C_D = 0.123$$

From Chapter 4 [16] we have,

Thrust Horse Power,

$$THP = 0.5 \cdot \rho \cdot V_c^2 \cdot C_D \cdot S$$

Where,

$$V_c = 51.4 \quad S = 66.9 \text{ m}^2$$

$$C_D = 0.123 \quad \rho = 1.225 \text{ kg/m}^3$$

$$\therefore THP = 684426.23 \text{ W} = 684.426 \text{ KW}$$

LS3 max power at 5000 rpm = N

Assuming efficiency,  $n_p = 0.8$

$$BHP = THP / n_p$$

Where,

BHP = Braking horsepower

$$= 684.426 / 0.8$$

$$\therefore BHP = 855.53 \text{ KW}$$

$$\text{Hub dia.} = 0.17 \cdot 7.2 = 1.224 \text{ m}$$

For LS3,

N = 5000 max power

$$\therefore n = 5000 / 60 = 83.33 \text{ rps}$$

$$C_s = V_c (\rho / \text{BHP} * n^2)^{1/5}$$

$$\therefore C_s = 0.594$$

For  $C_s$  according to the graph on page no. 5, Chapter 4 [16], the value of Advance ratio was found out to be,

$$J = 0.25$$

Also,

$$J = V_c / n * d$$

Estimate diameter of propeller (d),

$$\therefore d = 2.46\text{m}$$

Since power required is more, we make use of 4 blade propellers.

$$\text{No. Of blade} = 4$$

Reason for selection is the stability, larger engine and more powerful engine requires more no. of blades.

Air-foil Selection: According to reference [19],

For maximum L/D ratio which is the case for obtaining ground effect, we selected air-foil from NACA 4-digit family. Since, the available Air-foils in Software Java Prop is Clark Y, it is assumed to be ideal for our propeller.

According to reference [20],

For maximum efficiency, angle of attack of propeller should be between  $2^\circ$  to  $4^\circ$ . Hence, we select  $3^\circ$  angle of attack.

### **Step 11- Buoyancy, Centre of Buoyancy and Float dimensions:**

Amphibious aircraft use a boat hull as their primary water operation method. Hence, according to [21] a reserve buoyancy of 150% is considered for the craft to float.

Using Archimedes principle for floating bodies,

$$1.5 W_o = \rho V$$

Where,

$W_o$  = overall weight of the craft

$\rho$  = density of sea water =  $1025 \text{ kg/m}^3$

$V$  = volume of water displaced

$$\therefore V = 12.439 \text{ m}^3$$

The centre of mass of the submerged part of the craft is considered to be the centre of buoyancy (CB). Hence, the distance between the CG and CB ( $h_{CB}$ ) is obtained from the initial design of craft.

$$h_{CB} = 0.434\text{m}$$

The metacentric height is obtained from equation (C3-13) [13] ,

$$h_{MC} = K^3 \sqrt{W_o}$$

Where,

$h_{MC}$  = metacentric height

$K$  = constant according to the type of seaplane

=1.0 (for flying boat with wingtip floats)

$W_o$  = overall weight of craft = 8500 kg

$$\therefore h_{MC} = 17.6\text{m}$$

Calculation for float dimensions: -

From Chapter 3.1.3 of [22] , the breadth of the float (B) is given by,

$$B = \sqrt[3]{\frac{D_s}{2}}$$

Where,

$D_s$  = water displaced by single float in  $\text{ft}^3$ .

Since the float will not be the main floating device of the wig craft, it is assumed that total buoyancy forces the float will account to is 10%.

$$\therefore D_s = 0.1 * (W_o / \rho)$$

$$= 29.28 \text{ ft}^3$$

$$\therefore D_s = 0.8 \text{ m}^3$$

Hence,

$$B = 2.44 \text{ ft}$$

$$\therefore B = 0.7437\text{m}$$

The distance between the floats ( $S_f$ ) is considered to be 15m.

$$S_f = 15\text{m}$$

From equation (C3-16) [13]

$$S_f = (0.2679 * W_o^{2/3}) / \sqrt{L * B}$$

Where,

$L$  = Length of float

$$\therefore L = 1.842\text{m}$$

From [13] recommended heel angle ( $\theta$ ) is between  $1^\circ$ - $4^\circ$ . We consider,

$$\therefore \theta = 2^\circ$$

Height of float from the bottom of the craft (h) can be obtained by,

$$h = S_t / \cot \theta$$

$$\therefore h = 0.2346\text{m}$$

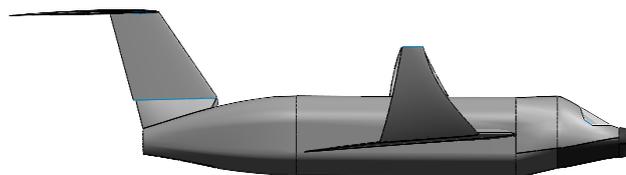
### 3.2. List of Materials:

1. High-performance riveted Aluminium plate.
2. Magnesium Alloy.
3. Titanium.
4. 60-series Aluminium Alloy.
5. 304 grade Stainless Steel.
6. Composite material

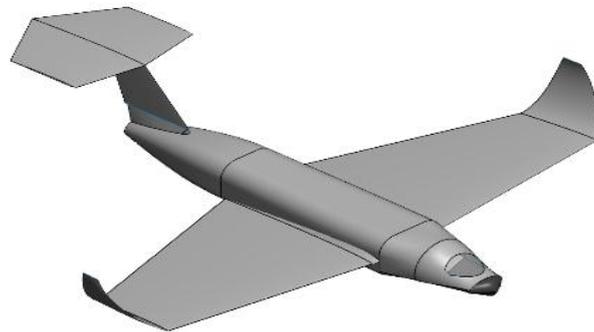
### 3.3. Stages of Design of WIG Effect Vehicle:



**(a) Front view**



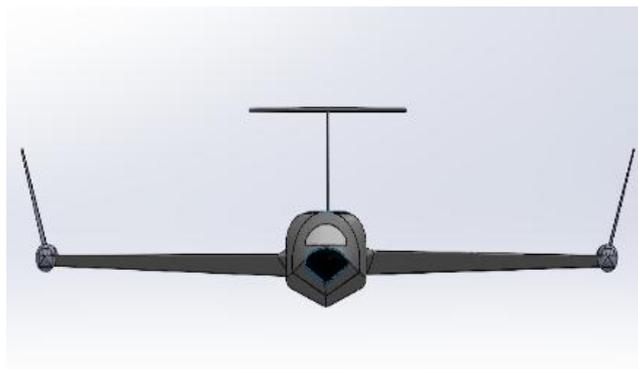
**(b) Side view**



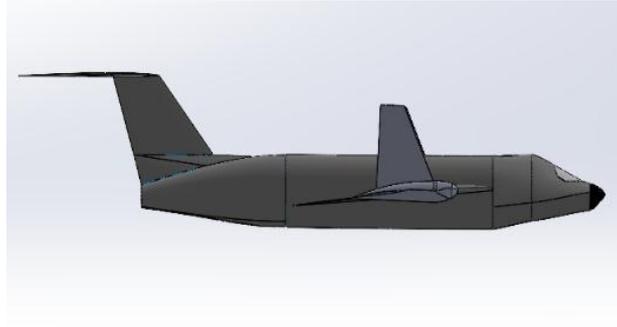
**(c) Isometric view**

**Figure. 1:** Initial design of the WIG effect vehicle based on the calculations.

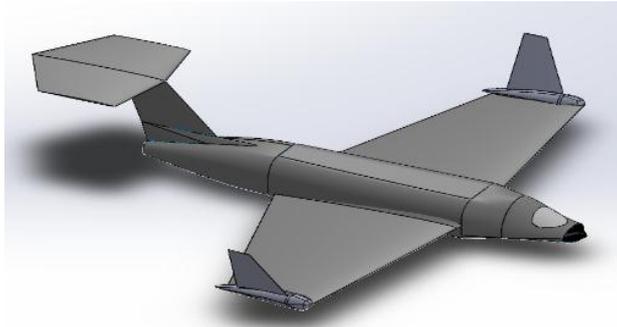
The Fig 1, shows the initial design of the WIG effect vehicle, for which the parameters and dimensions obtained from the calculations mentioned in 3.2. In further stages addition of components was done.



**(a) Front view**



(b) Side view

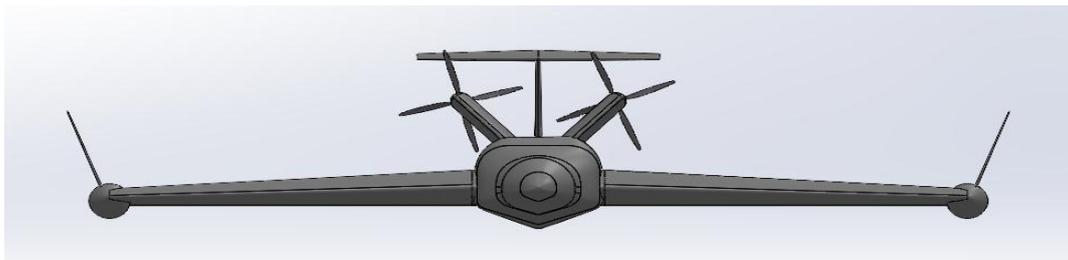


(c) Isometric view

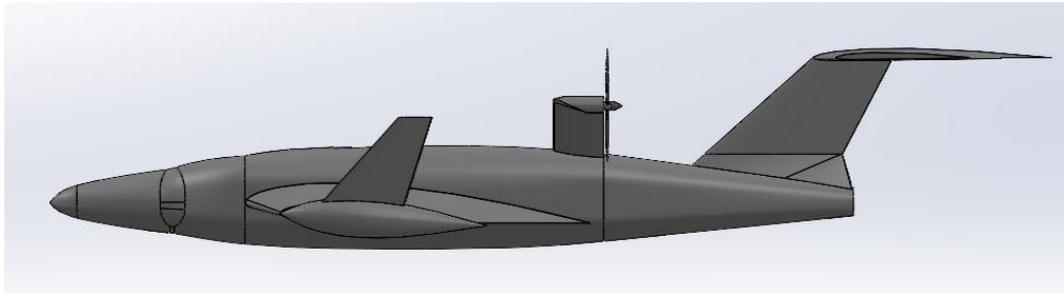
**Figure. 2:** Advancement according to analysis and floats added at wingtips of the WIG effect vehicle.

As shown in Fig 2, the changes in design of the outer body were craft were made according to the analysis obtained from the initial stage of design. Fig 2 also depicts the floats added at the wingtips for increasing the safety and stability of the WIG effect vehicle.

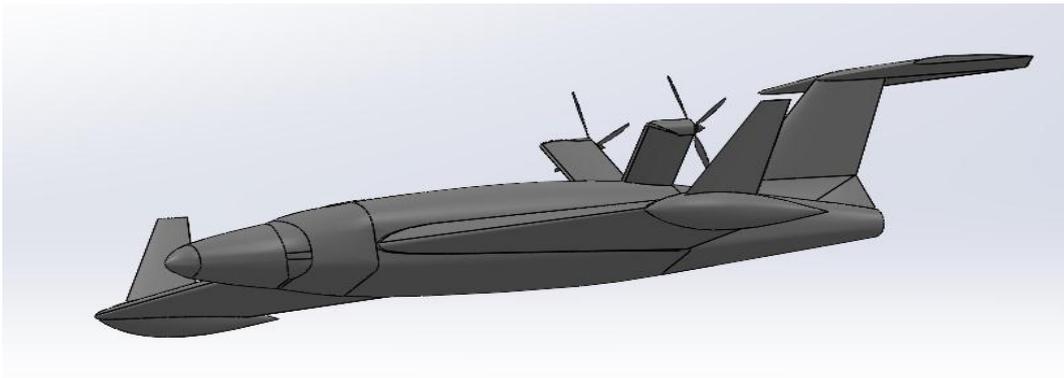
After the optimization of the design shown in Fig 2 and addition of propellers, the final design of the WIG effect vehicle is acquired which is shown in Fig 3.



(a) Front view



(b) Side view



(c) Isometric view

**Figure 3:** Optimized design of WIG effect vehicle with propellers.

Final analysis was conducted on the design shown below in Fig 3 and corresponding results were obtained. The process of analysis of the vehicle is explained in detail in the following part.

#### **3.4. Analysis:**

Ansys was the software selected for analysis, as it offered us values of lift and drag; in order to determine whether ground effect was produced or not. Ground effects occurs at a close proximity to the ground. As an aircraft is flying closer to the surface, the lift increases with reduced drag. The induced drag which is perpendicular to the lift increases. This phenomenon is termed as ground effect. Thus, the closer the plane to the ground, the maximum ground effect is produced. This means that at some ground clearance, the plane would operate at highest efficiency. Based on that parameter, the objective of our analysis was decided.

##### **Objective:**

The values of lift and drag coefficients were calculated in at two  $h/c$  ratio. The  $h/c$  ratio is also termed as ground clearance which is the distance from the lowest point on the aircraft to the ground surface. By varying the values of the ground clearance, we would get an idea regarding the amount of lift generated and drag produced and we can

compare the values between the two cases. Hence, it was decided to do the analysis at 2 h/c ratios, namely: 0.25 and 1.64

1<sup>st</sup> case:

$$h/c = 0.25$$

Here c= chord length

$$c = 6.1$$

Therefore, h= 1.525 m

2<sup>nd</sup> case:

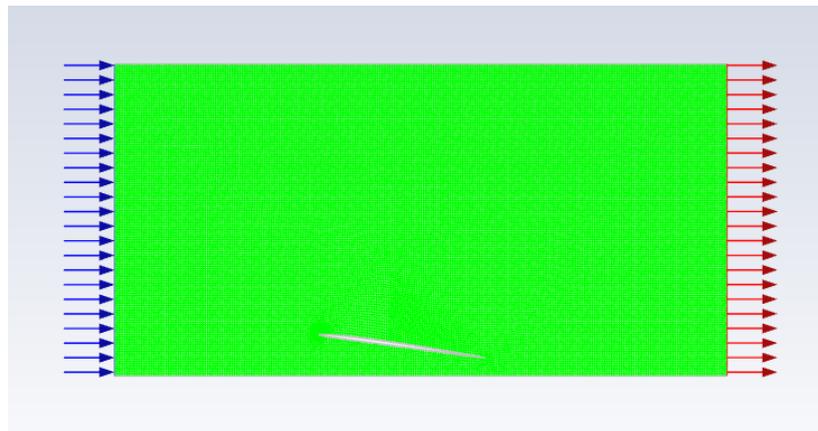
$$h/c = 1.64$$

$$C = 6.1$$

Therefore, h= 10 m

**Methodology:**

The aerofoil used for our craft were placed in the DesignModeler. The aerofoil was enclosed in a rectangular boundary. Then, the edge on the left-hand side was subjected to an inlet velocity of 41 m/s and the aerofoil was placed at distances 1.525m and 10m respectively in two cases. The right-hand side edge was defined for the outlet air. And analysis was carried out. The aerofoil spline parameters were imported from a text file after specifying the chord length, thickness ratio and angle of attack under normal operation. Below in Fig. 4 the boundary conditions for case (1) i.e. h= 1.525m was defined.



**Figure. 4:** Definition of boundary conditions for case 1.

**Meshing:**

The meshing is the process of splitting the domain into discrete number of elements in order to obtain solution. Meshing is the key towards obtaining accuracy from CAE analysis.

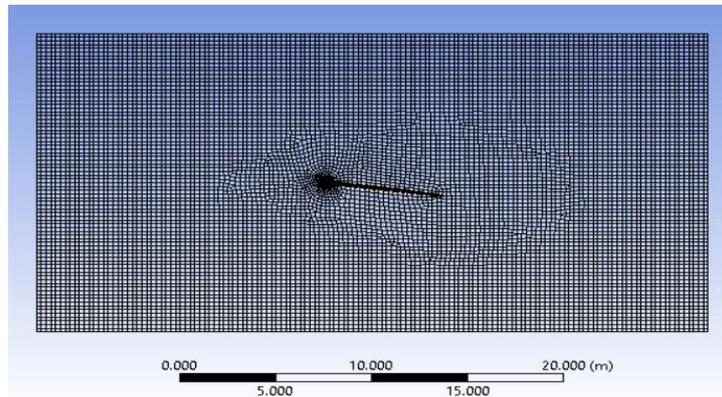
The meshing used for our model includes the parameters mentioned in Table 1 mentioned below:

Table 1: Parameters considered for analysis of the final design.

Physics preference	CFD
Solver preference	Fluent

Element order	Linear
Element size	9.e-002 m

The remaining parameters were set to default. Fig. 5 below shows the meshing of aerofoil of case (2) i.e.  $h=10\text{m}$  according to the parameters considered from the table mentioned above.



**Figure. 5:** Meshing for aerofoil at height 10m.

**Solver parameters:**

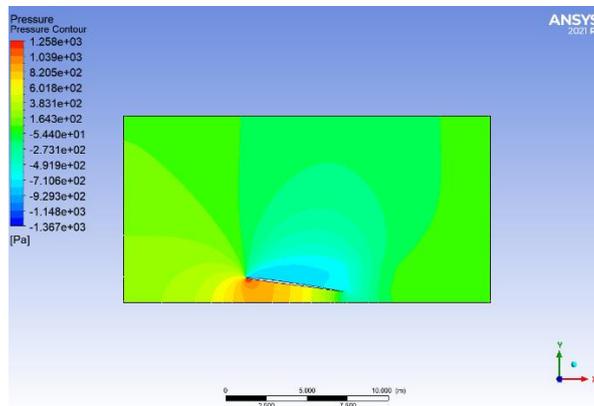
Solver used: Ansys fluent

Model used: k- epsilon viscous

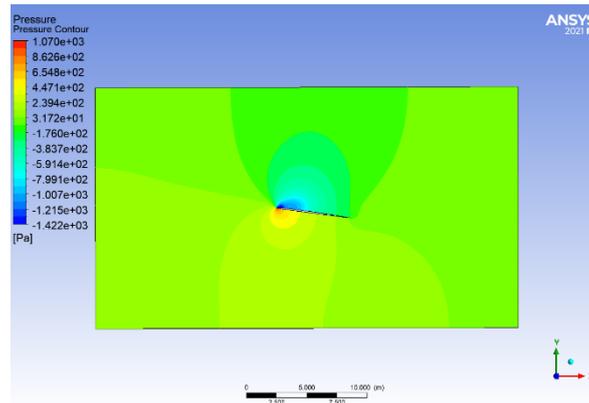
Medium: Air

Inlet velocity: 41 m/s

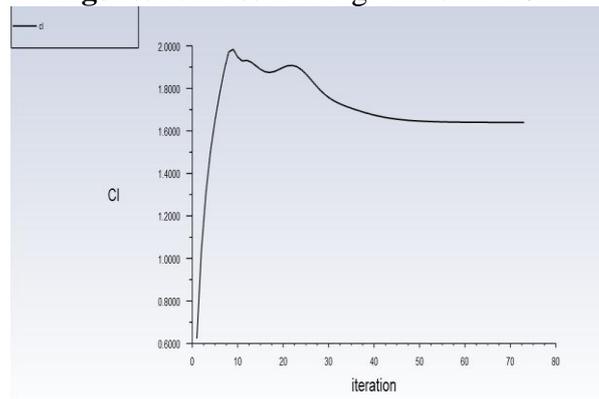
Results definition: Coefficient of lift and coefficient of drag.



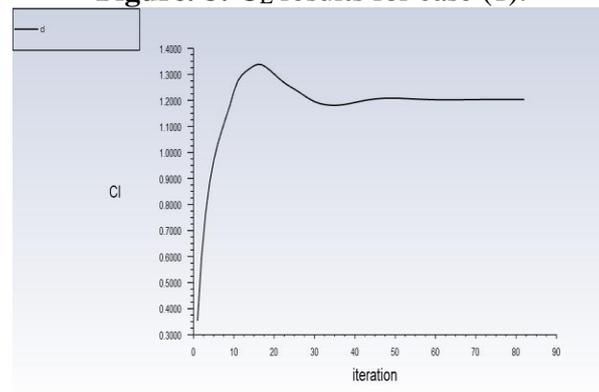
**Figure. 6:** Pressure diagram for  $h=1.525\text{m}$



**Figure. 7:** Pressure diagram for  $h=10m$ .



**Figure. 8:**  $C_L$  results for case (1).



**Figure. 9:**  $C_L$  results for case (2).

### **Results and Analysis:**

The results of the analysis are shown in the figures above. It can be seen from the Fig. 6, that in the 1st case, that is, at height 1.525m above the ground surface, the pressure distribution is more on the extreme end. In simpler words, one can actually observe the high pressure developed along the lower section of the aerofoil while low pressure formation can be seen on the upper section of the aerofoil. This is a prerequisite for achieving ground effect. The coefficient of lift generated in the first case can be seen

from Fig. 8. This is a graph which shows the approximations considered in 500 iterations. The final value of lift coefficient turned out to be 1.64.

In the second case of height 10 metres above the ground surface, it can be seen from Fig. 7 that the pressure distribution is significantly sparse in comparison to the 1st case. The high-pressure formation at the lower section is less even if we compare to the upper section of the aerofoil in case 1. The graph shown in the Fig. 9 denotes the lift coefficient values under 500 iterations on ANSYS Fluent solver. The lift coefficient achieved is significantly less at 1.2 in comparison to case 1.

#### **4. CONCLUSION:**

Hence, this paper provided a detailed procedure of preliminary design of a wing in ground effect craft. Considering the fact that the craft is essentially a combination of a boat and a plane, a lot of parameters were needed to be considered. Finally, analysis was performed in order to determine whether ground effect can be achieved with our aerofoil selection. Given to the fact that the power train used is essentially twin car engines, it can be said that the craft has relatively less fuel consumption than a conventional airplane or a ship which might be used for similar application and for similar payload requirements.

WIG craft offer a lot of advantages over ships. WIG crafts may be difficult to detect by mines or sonar, making them suitable for crossing minefields and mine clearance. WIG crafts allow for high speed marine transportation at 100 knots in comfort, without water contact, slamming shock, stress, wake, wash or seasickness. These crafts are extremely fuel efficient. The ability of WIG crafts to handle sea state opens the potential usage to coastal, inter island, and major rivers. There are benefits of zero water contact such as no sea motion or sea sickness. Low fatigue for passengers. There is a tremendous potential for this technology to be developed further using modern sustainable means of propulsion. Further improvement in this technology can bring about massive leaps in long distance oceanic transportation as it would be considerably cheaper than a plane while being faster than a conventional ship. We believe that this paper had been fruitful as a means to guide others for their research in this field of Aerospace.

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