Amphibious Aircraft Design

Requirements:

- Hybrid amphibious aircraft to be designed
- Mangalore to Mundra/Surat by sea (ground effect preferred)
- Further from Mundra/Surat it flies to Bikaner and Ladhakh over land.
- Payload 1500 to 2500 kgs

The payload here was taken as 2000kgs

1. Similar Aircrafts:

The first step in designing an aircraft is to find similar aircrafts that fit the requirements.

The one I used here were:

- Metro III

- Dassult Falcon 20 Cargo

- Dornier 228

- Cessna Grand Caravan Ex Amphibian

- Canada Air C215

2. Research and selection

Based on the requirement that the aircraft has to fly over sea and land while being an amphibious vehicle, a design that would amplify/utilise the ground effect would be a useful choice. Having ground effect over the entire water journey is definitely more efficient as it reduces the induced drag, therefore designing a hybrid vehicle as a Wing in Ground (WIG) was the approach, similar to the C215 aircraft which is inherently a seaplane.

3. Mission profile

a. Payload Capacity = 2000kgs
b. Number of crew = 2
c. Cruise speed over sea = 100knots (Mach 0.2)
d. Range = 1100kms

The mission is classified into eight phases.

They are:

1. Acceleration from standstill at sea level at the port of mangalore with Gross takeoff weight of 8500 kgs.

2. Climb to a cruise altitude of 20 m above sea level to utilise the ground effect

3. Cruise at 20 m altitude until mudra/surat

4. descent and land.

5. Refuel and Take off from surat for Bikaner at an altitude of 5000m

6. Cruise at mach 0.3 until Bikaner, descent and land

7. Refuel again at Bikaner and take off from Bikaner heading towards Ladakh at an altitude of 5000 m, and eventually climbing to 6500 m to ensure safety from the mountain peaks of the region.

8. Descent and land at Ladakh

4. Calculations

4.1 Weight Calculation:

From Table 1 in [1]

Typical take – off wing loading for a general aviation – twin engine = 127 kg / m^3

Weight constraint analysis :

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

Considering payload + W_{crew} to be 2000kgs

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

According to [1], the overall weight can be assumed using :

$$W_o = W_p / k_p$$

Where,

Wo = Weight overall of the craft
Wp = Payload weight
Kp = Coefficient of payload, usually this factor is assumed to be 0.2 – 0.3

Considering $k_p = 0.235$

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

The empty weight fraction is estimated using

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

Where,
We = Empty weight of craft
From Table 3 in [1], for a flying boat , A = 1.09 & c = –0.05
Kvs = variable sweep constant = 1.00 for fixed sweep
∴ We = 5893 kg

4.2 Wing Area Calculation

From Chapter 3 [2]

$$S = \frac{W_o}{\text{take – off wing loading}}$$

$$\therefore S = \frac{8500}{127} = 67\ \text{m}^2$$

Aspect Ratio (AR) is taken as 7.8 based on [1]

∴
Wingspan = 22.86 m
Root chord = 2.93 m

4.3 Fuselage Sizing

The internal and external dimensions of the fuselage are calculated using the steps and parameters presented by [3].

The Dornier 228 is used as the reference aircraft here because it has a similar payload, which has a 1.5m wide cabin

$$\therefore D_f = 1.5$$

Nose length ratio is between 1.7 – 2

$$\frac{L_N}{D_f} = 1.7$$

$$\therefore L_N = D_f \times 1.7 = 2.55\text{ m} \approx 2.6\text{ m}$$

Rear length ratio is between 2.6 – 3.5

$$\frac{L_R}{D_f} = 2.6$$

$$\therefore L_R = D_f \times 2.6 = 3.9\text{ m} \approx 4\text{ m}$$

Cabin length (L_C) can be assumed from the Dornier, which has a 6.3 m long cabin

$$\therefore L_C = 6.3\text{ m}$$

Length of the fuselage (L_f) $= L_C + L_R + L_N = 12.9\text{m}$

4.4 Horizontal Tail

Horizontal tail arm optimum equation from [3]

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

V_H = Horizontal tail volume = 0.44

D_f = diameter of fuselage = 1.5 m

$\therefore L_{opt} = 8.65\text{ m}^2$

Area of horizontal stabilizer equation from [3]

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

Where, S_h = Area of horizontal tail

$\therefore S_h = 10.28\text{ m}^2$

4.5 Vertical Tail

Assuming $\frac{S_v}{S} = 0.08$, reference [3]

Where, S_v = Area of vertical tail

$\therefore S_v = 5.36\text{ m}^2$

Vertical span of airfoil (b_v) from [3]

$$b_v = \sqrt{S_v * Ar} = 4\text{ m}$$

4.6 Design of Propeller

According to the Chapter 4 [3], the lift coefficient (CL) is given by,

$CL = Wo / (0.5\rho\ V^2\ S)$

$CL = 8500 / (0.5 * 1.225 * 51.4^2 * 66.9)$

$\therefore\ CL = 0.0784$

And the drag polar is calculated by,

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

where,

SWet = Wetted Area

WTo = Take – off weight of craft

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

$\therefore\ SWet = 1840.772\ m^2$

$\log10\ f = a + b*\log10\ SWet$

Where,

f = the equivalent parasite area $a = -2.3979$ & $b = 1$

$\therefore\ \log10\ f = 0.8671$

$\therefore\ f = 7.3687\ m^2$

$CD = C_{D,O} + (CL^2 / \pi Ae)$

Where,

$CD,O = f / S = 7.3637 / 667$

$\therefore\ CD,O = 0.1104$

$\therefore\ CD = 0.1104$

From Chapter 4 [3]

Thrust Horse Power,

$THP = 0.5 * \rho * Vc^2 * C_D * S$

$\therefore\ THP = 615232\ W = 615.232\ KW$

max power at 2000 rpm = N

Assuming efficiency, np = 0.8

$BHP = THP / np$

Where,

BHP = Braking horsepower = 615232 / 0.8

$\therefore\ BHP = 769040\ KW$

N = 2000 max power
$\therefore$ n = 5000 / 60 = 33.33 rps

C_S = Vc (ρ / BHP∗ n²)$^{1/5}$

$\therefore$ CS = 0.87

For CS according to the graph on page no. 5, Chapter 4 [3]
, the value of Advance ratio was found out to be,

J = 0.5

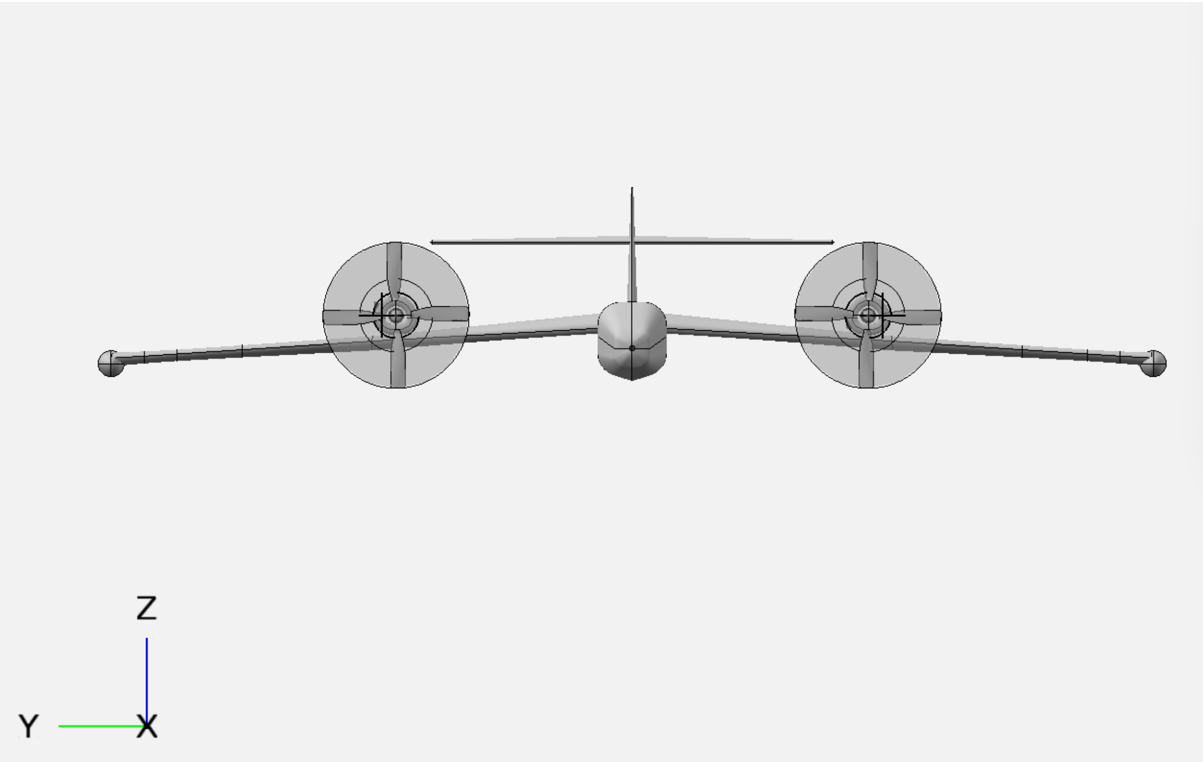
Also, J = Vc / n∗d

Estimate diameter of propeller (d)
, $\therefore$ d = 3.084 m

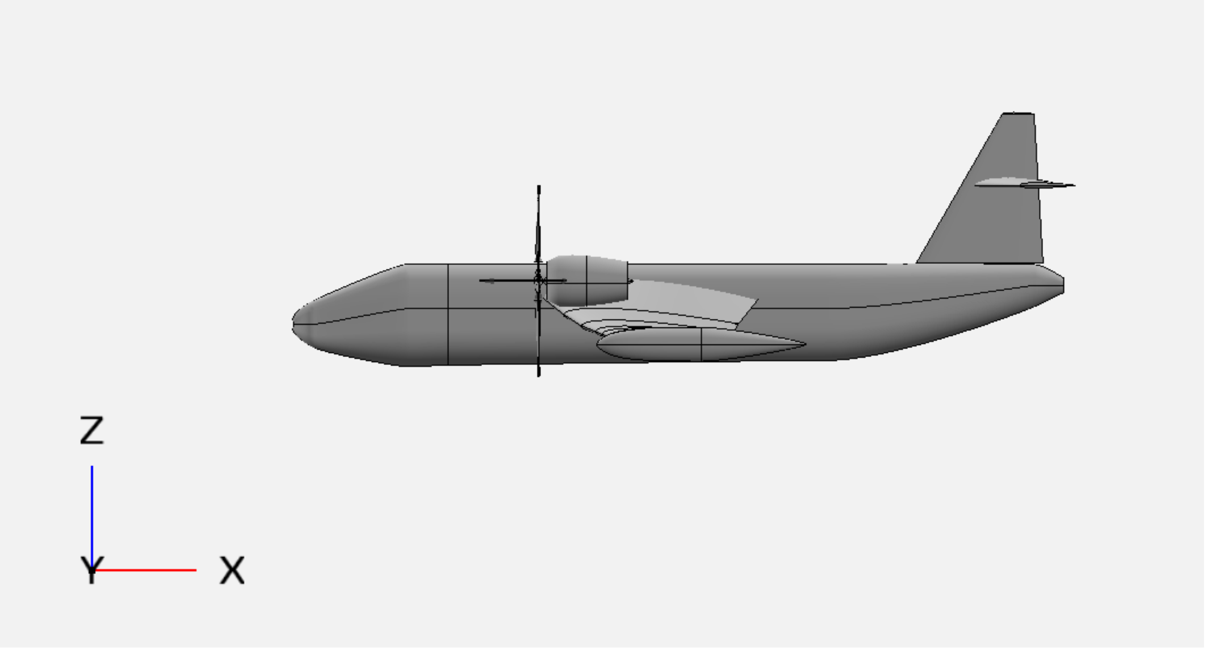
Since power required is more, we make use of 4 blade propellers.
For maximum efficiency, angle of attack of propeller should between 2° to 4°.
Hence, we select 3° angle of attack

5. Modeling in OpenVSP

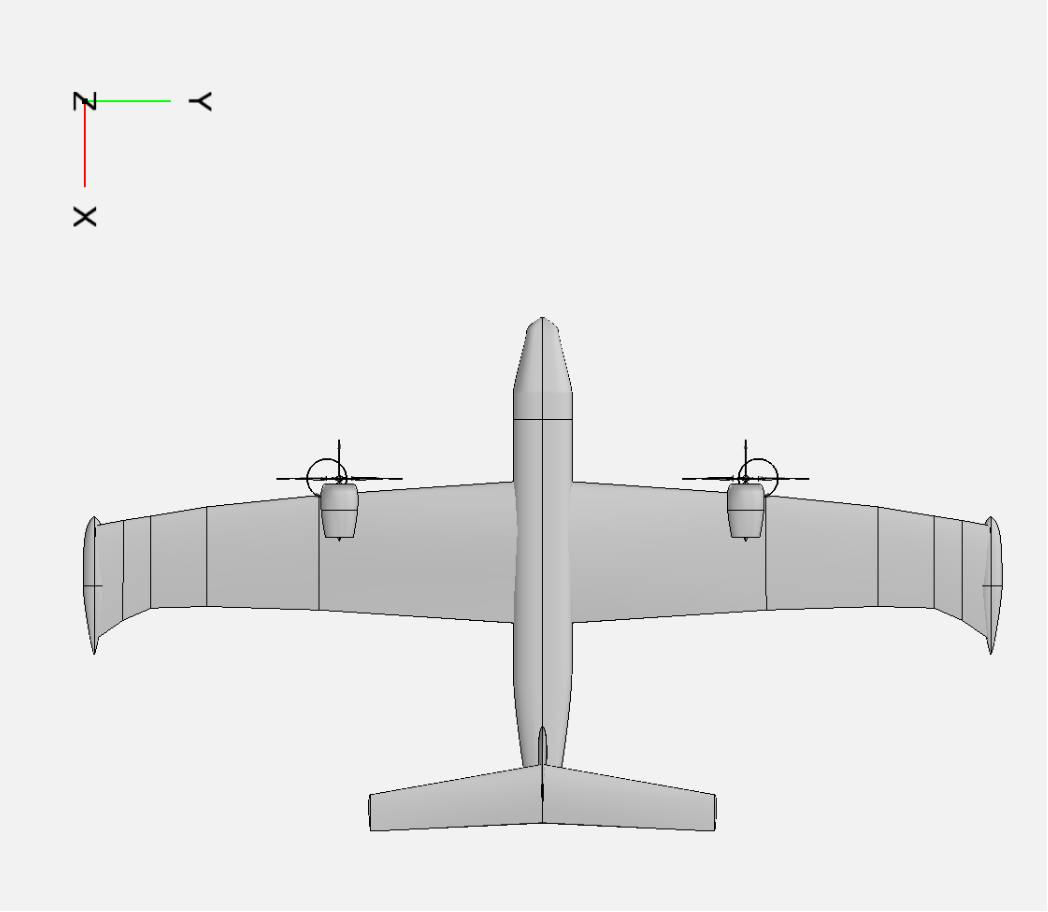
Front View:



Side View:



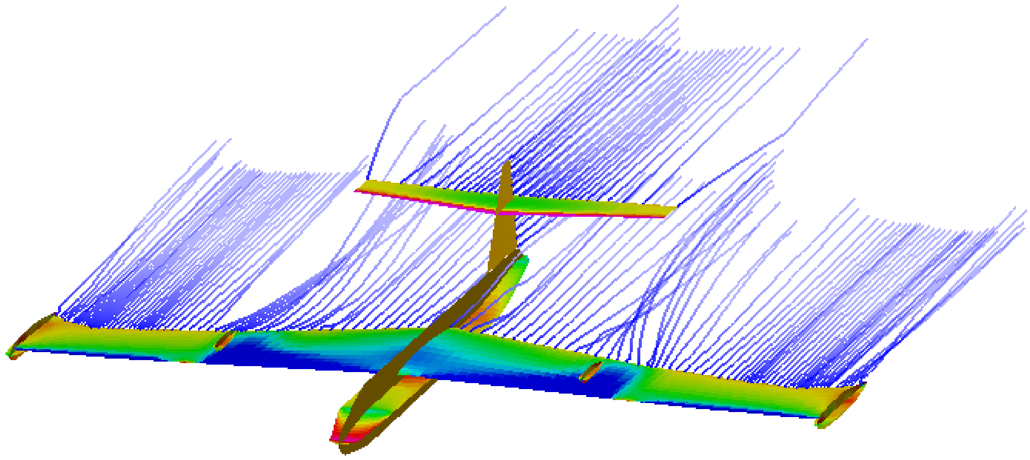
Top View:



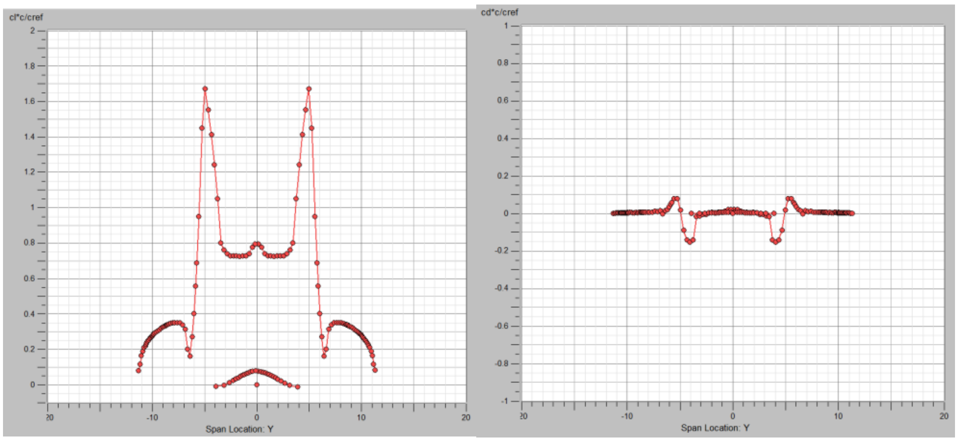
Here, an anhedral wing was used as it is a lot more efficient to create ground effect. The pods on either side of the wings help as floats when the aircraft is on water.

There is a boat structure on the underside of the aircraft as well to create the amphibious effect of the aircraft

Analysis:



Based on an earlier analysis, the horizontal tail was being influenced by the main wing wake, and hence was moved upwards. The twirling trails at the centre of the wing are from the propeller engine.



CL and CD curves

SL No	Parameter	Value
1	Wing span	$22.86\ m$
2	Wing area	$67\ m^2$
3	Total mass of UA	$8500\ kg$
5	AR	7.8

References:

I. Badis, Abderrahmane 2017, "Subsonic aircraft wing conceptual design synthesis and analysis." International Journal of Sciences: Basic and Applied Research.
II. Nita B Shah , 2011, “Design of a Hoverwing Aircraft”.
III. Tulapurkara, E. G. 2014, "Airplane design (Aerodynamic). AIP