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Design and Analysis of High Endurance Fixed Wing Multirotor UAV

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ABSTRACT

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Current work emphasis on research, design and development of a fixed wing multirotor Unmanned Ariel Vehicle (UAV) which operate under V - TOL configuration. In this investigation an effort is made to develop a high endurance and high payload capacity UAV which can have a payload capacity of 15 Kg and which can serve with the endurance of 2 hrs per cycle.

Keywords : UAV, V-TOL, Fixed wing UAV, Solar Hybrid, High Endurance

I. INTRODUCTION

Aerial vehicles have proved their capability in both military field such as patrolling, surveillance as well as reconnaissance, and civil areas including transport, rescue and agriculture of various applications over a hundred years, while enhancing their capabilities over time, and fulfilling ever-changing mission requirements. By means of smaller, safer and lighter platforms, UAVs propose an exclusive set of advantages compared to piloted aircrafts [1]. Military and civil operations are the main areas where these advantages are effectively utilized. In addition, future UAVs are expected to perform much more extended missions with higher aerodynamic performance and higher degrees of automatic flight. There are two prominent categories of mini UAVs; fixed-wing UAVs and multi-rotors. Fixed-wing UAVs are mini UAVs with propelled electrical batteries with longer ranges than UAVs with similar sizes of multi-rotor systems that require a runway or launcher for landing and knockout [2] [1].

The Fig.1 illustrates the mission profile choosen for the UAV. The multi-rotor UAVs have rotor systems generally carrying three or four propellers that are capable of vertical take-off and landing (VTOL) and hovering over an area while carrying sufficient payload. In addition, they are more maneuverable than fixed wing UAVs with the ability of quickly transition from hover to cruise flight. However, the horizontally mounted rotor system is placed at the wings or the body that results in an enormous increase in drag force opposing the cruise flight. As a result of this decrement in the aerodynamic performance, fixed wing UAVs are more logical to be used to fulfil the missions needed high speed, long range and endurance flight The fixed-wing UAVs has longer flight time and duration, but it is not simple to secure a safe landing space, especially in the city and rugged train areas. VTOL systems make more sense in operations such as mountainous and rural areas where there is no landing and take-off runway. In addition, VTOL systems must be used to operate like a helicopter in the required tasks such as hovering. However, if endurance is of first priority then a fixed wing type will most likely be preferred due to the efficiency of the cruise flight. If both of these features are demanded in a single operation then a fixed wing vertical and take-off landing (VTOL-FW) with level flight capability becomes the best option.

II. Mission Profile

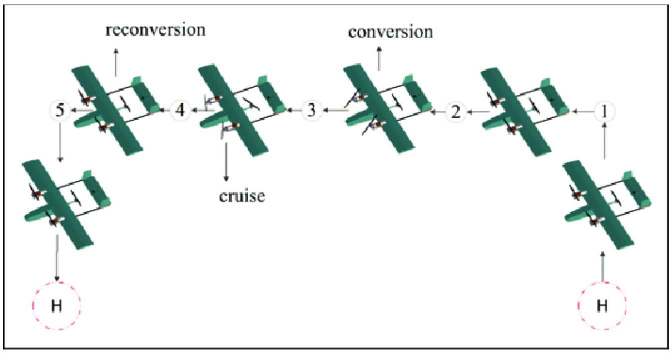


Fig.1 Mission Profile

III. Design Statement

Sl. No	Requirements
1	Minimum Endurance – 2Hrs
2	Maximum Payload – 15 KG
3	Maximum Speed – 150Km/Hr
4	Maximum Altitude – 6000m
5	Operational Temperature - 60^0 C

IV. Design Methodology

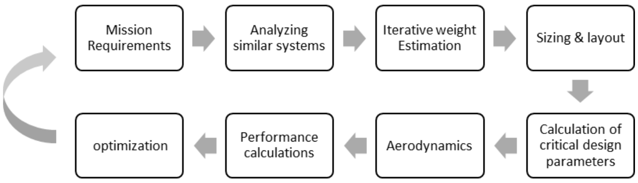


Fig. 2 Design Methodology

The design methodology illustrated in fig. 2 represents a iterative design process. As per the mission profile and operational requirements, the possible take-off weight of the UAV is estimated based on the historical data for general aircraft conceptual design i.e. (W_e/W_{To} = **0.85**). Knowing the minimum aerodynamic characteristics for the given operational range helps us to predict the preliminary sizing of major aircraft components and lifting devices required to sufficiently satisfy the mission requirements. Analyzing these initial sizing parameters at give operational conditions will help us to know more aerodynamic parameters to check for optimization and iterative calculations were considered to optimize the performance of the UAV [3].

V. Assumptions for the design

1. T/W = 1.5 (thrust to weight ratio)
2. Considered UAV as a light aircraft.
3. UAV will be powered with a hybrid power system. i.e. (Li-ion battery + Solar PV arrangement to increase the endurance)

VI. Design Process

A. Weight Estimation

$$\frac{W_{TO} - 15}{W_{TO}} = 0.85 \qquad \text{Eq. 1}$$

Considering estimating the possible take-off and empty weight of an aircraft is the very first step in sizing of the UAV. The ratio of We /WTo can be obtained from the historical data for conceptual aircraft design. It can be stated as W_e/W_{To} is about

0.85. One of the design requirements of the UAV is to carry a payload of 15 Kg weight. As We=WTO ratio is about 0.85 at Eq. (1), then WTO can be found as **100 Kg**. [1]

In order to continue further, knowing the dimensions of the wing is very much important as wing plays major role to lift the aircraft in to the air. In order to know the dimensions of the wing a market study is been carried out considering the payload capacity and endurance that is relevant to our design statement. And we found that the average wing span for a UAV of carrying max. Payload of 15 Kg. with an endurance of 2 hrs in the range of 4.5 Km to 5 Km.

As the larger aspect ratio reduces the power consumption to keep the given weight in the air and results in less induced drag wing span of 4.8 m is for preliminary sizing of the UAV.

B. Wing loading

With the wing span of 5 m and max. Take-off weight of the UAV i.e. 100 Kg got the wing loading as 40 Kg/m^2.

C. Initial sizing of the wing

Calculating the required lift co-efficient of the UAV at cruise velocity

With the basic understanding of aerodynamic forces, for steady state flight we know that

Lift = Weight

$$L = \frac{1}{2} \times V^2 \times \rho \times S \times C_L$$

As per one of the design requirement, the maximum flight speed as 150 Km/hr (i.e. velocity of 41.66 m/s) and flying altitude as 6000 m ASL. We found that the density of air is 0.661Kg/m^3 @ 6000 m.

We know that the basic lift co-efficient formula as,

$$C_{L_C} = \frac{2 \times \left\lfloor \frac{W}{S} \right\rfloor}{{V_C}^2 \times \rho} \qquad \text{Eq. 2}$$

Where;

B. C_L = Lift Co-efficient
C. W/S = Wing Loading in, Kg/m^2
a. V_c = Cruise Speed of the UAV, in m/s
b. ρ = Density of air at flying altitude, in m
c. W = Max. Take-off weight of the UAV in Kg
d. S = Wing span in m

We found that the lift co-efficient required as =0.861

In order to find the lift coefficient for the wing & airfoil alone at cruise velocity;

$$C_{L@\text{Wing}} = \frac{C_{L_C}}{0.95} \qquad \text{Eq. 3}$$

$$C_{L@\text{airfoil}} = \frac{C_{L@\text{ wing}}}{0.9} \qquad \text{Eq. 4}$$

We found that;

$C_{L@\text{Wing}}$	0.9071
$C_{L@\text{airfoil}}$	1.0779

Based on the $C_{L@\text{airfoil}}$ the selection of airfoil is made, considering the ability of the airfoil to produce sufficient lift with lesser angle of attack and larger stalling angle makes the airfoil suitable to use in the aircraft or UAV.

b. Selection of airfoil

As selection of an airfoil for any aircraft is always depends on the operational flight regime. Fig. 3 illustrates the various airfoil shapes for different flight regimes.

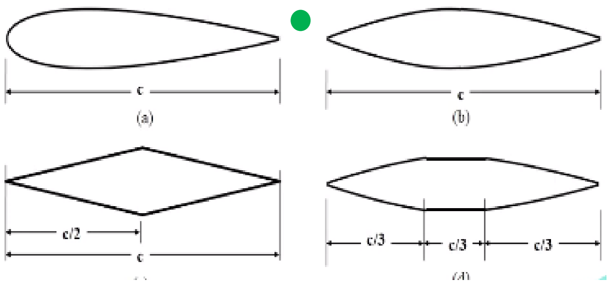


Fig. 3 Airfoil shapes for different flight regimes

And as our flight regime is subsonic a general use airfoil is selected. For low speed general light aircraft max. t/c of 15% to 18% is recommended.

Selected t/c as 15%

Airfoil selected: NACA 23015

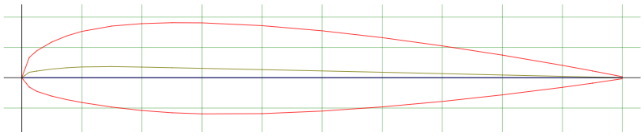


Fig. 4 NACA 23015 Airfoil

Performance characteristics of the airfoil are;

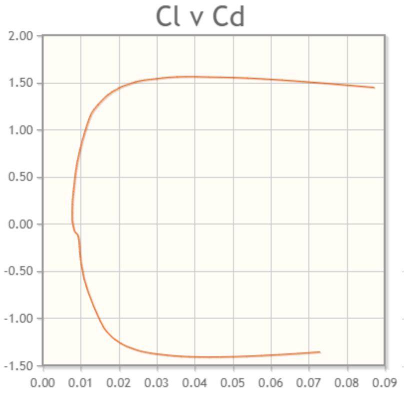


Fig. 5 C_l vs C_d

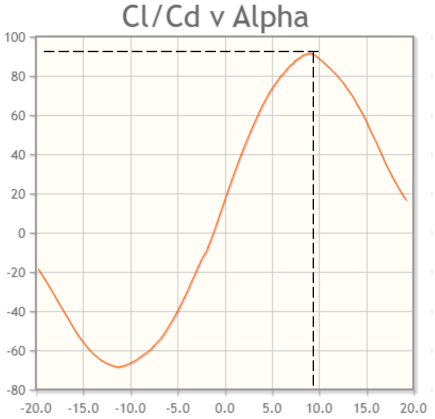


Fig 6 C_l/C_d vs Alpha

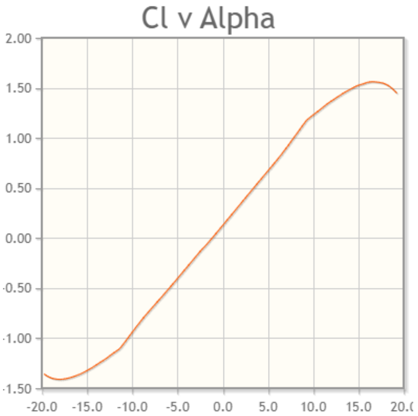


Fig.7 C_l vs Alpha

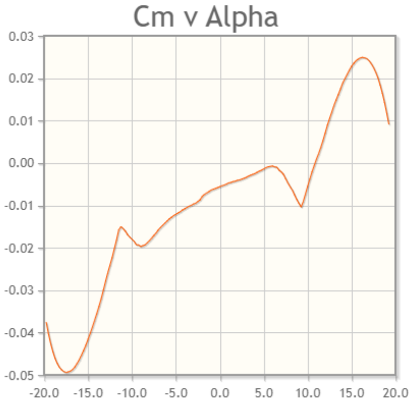


Fig. 8 C_m vs Alpha

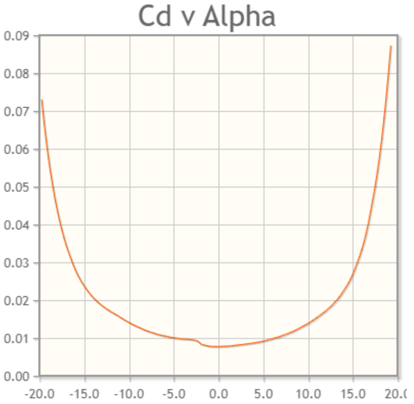


Fig.9 C_d vs Alpha

Analysis prerequisites;

Reynold's number = 10,00,000

Mach number = 0.12

Observations from Fig. 7;

- Max. C_l = approx. 1.7
- Stalling α = approx. 17^{o}

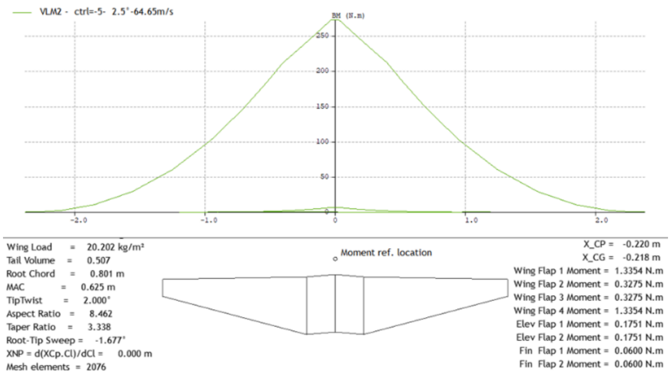
Since the maximum C_l and stalling angle α is within the operating range.

NACA 23015 airfoil is selected. [9] [1]

Preliminary wing analysis

Parameters	Values	units
Maximum cruise speed	41.6	m/s
Max. Wing loading	40	Kg/ m^2
Airfoil	NACA23015	
Aspect ratio	8.46	
Wing area	2.72	m^2
Wing span	4.8	m
Taper ratio	0.3	
Root chord, C_r	.6	m
Tip chord, C_t	.2	m
Sweep angle	0 ^{o}	
Twist angle	2 ^{o}	
Dihedral angle	1 ^{o}	

Bending Moment



Wing Load = 20.202 kg/m²
Tail Volume = 0.507
Root Chord = 0.801 m
MAC = 0.625 m
TipTwist = 2.000°
Aspect Ratio = 8.462
Taper Ratio = 3.338
Root-Tip Sweep = -1.677°
XNP = d(XCp.Cl)/dCl = 0.000 m
Mesh elements = 2076

X_CP = -0.220 m
X_CG = -0.218 m
Wing Flap 1 Moment = 1.3354 N.m
Wing Flap 2 Moment = 0.3275 N.m
Wing Flap 3 Moment = 0.3275 N.m
Wing Flap 4 Moment = 1.3354 N.m
Elev Flap 1 Moment = 0.1751 N.m
Elev Flap 2 Moment = 0.1751 N.m
Fin Flap 1 Moment = 0.0600 N.m
Fin Flap 2 Moment = 0.0600 N.m

Fig. 10 Bending Moment of Preliminary wing

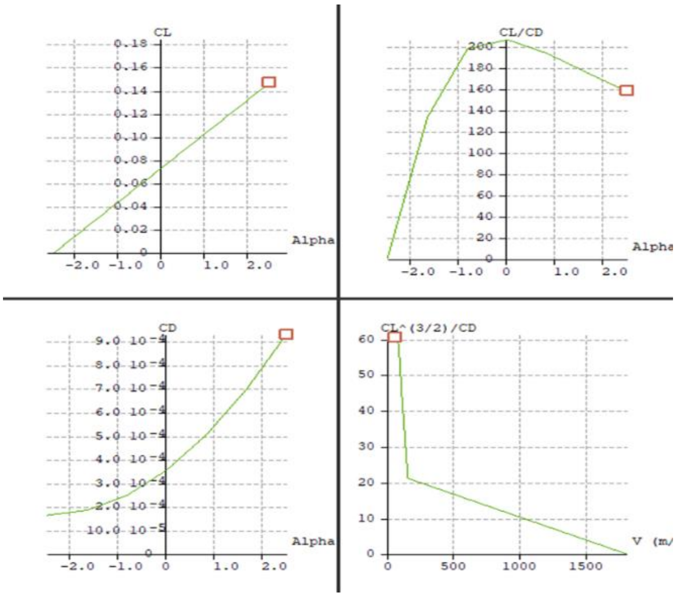


Fig. 11 Aerodynamic Performance of 4.8 m span wing

With the basic understanding of aerodynamic principles, in order to get maximum endurance, the UAV must fly in a condition such that it is experiencing least drag and should produce maximum lift in order to keep the UAV in air. At the same time flying in C_l (3/2) / C_d maximum condition reduces the power consumption in order to produce thrust in cruise condition. After the iterative performance analysis over the market available UAV wing characteristics, from fig. 11 it's been observed that going for larger aspect ratio and increasing wing area for the given operating condition, will substantially makes the UAV statically and dynamically stable and aerodynamically safe design . [1]

VII. Wing Sizing

Main wing

i. Span & Wing area

$$AR = \frac{b\,^{\wedge}2}{S}$$

Since, higher aspect ratio results in reduced wing loading and produces more lift, the aspect ratio of 10 is chosen for initial calculations. And by iterating for the better performance we found that the aspect ratio of 10.75 gives a better performance & span of 6 m is suitable for the wing loading of 40 kg/m^2 with the wing area of 3.347 m^2 [1].

ii. Taper ratio

$$\lambda = \frac{Ct}{Cr} \quad (0 \text{ to } 1)$$

Taper ratio plays a very important role to reduce induce drag, with the reference below found that the taper ratio of 0.3 can be used for most practical & good performative results [2].

iii. Mean aerodynamic Chord, Root & Tip Chord

Root Chord:

$$\mathbf{C_{root}} = \frac{\mathbf{2S}}{\mathbf{b(1+\lambda)}}$$

Up on substituting the span of 6m, wing area of 3.47 m^2 & taper ratio λ of 0.3, found that the suitable root chord length as 0.88 m.

Tip Chord:

$$\mathbf{C_{tip} = \lambda \times C_{root}}$$

And with the root chord length of 0.88 m got the wing tip chord as 0.266 m.

Mean aerodynamic chord:

$$\bar{C} = \frac{2}{3} \times C_r \times \left[\frac{(1+\lambda+\lambda^2}{1+\lambda}\right]$$

With the C_r & C_t of 0.88 m & 0.26 m found the mean aerodynamic chord length as 0.571 m.

iv. Sweep angle

Initially we considered the wing as a rectangular box with 0^0 sweep angle wing, due to the lift force produced by the wing it is assumed that the wing is experiencing a bending and shear load. And in reality addition to the normal load, the wing experiences a tangential forward force which equals the leading edge suction force minus the wing drag.

Typically sweep angle has a major contribution and corresponding effects on maximum lift produced, Drag co-efficient, critical MACH no. , Structural weight & Stability.

Selection of sweep angle can be made on the flight regime, as our flight regime is subsonic and with the MACH no. of 0.12 the sweep angle is chosen as 0^0[7].

v. Twist angle

As we all know **Wing twist** or **Twist angle** is an aerodynamic feature added to aircraft wings to adjust lift distribution along the wing. And with the two categories of wing twist (i.e. geometrical twist and aerodynamic twist) aerodynamic twists are most commonly used in most of the monoplanes and light aircrafts to avoid the tip stalling [7].

Considering our UAV as a light aircraft the aerodynamic twist is assumed as 2^0

vi. Dihedral angle

As our selective wing type is a high wing type, and 2^0 of dihedral angle is been used to as it affects the roll movement of the UAV proportional to the amount of sideslip. The effect produced by the above condition is also known as Dihedral effect. Dihedral effect is also a critical factor in the stability of an aircraft about the roll axis (the spiral mode). It is also pertinent to the nature of an aircraft's dutch roll oscillation and to maneuverability about the roll axis [7] .

vii. Selection of high lifting devices

High lift devices are movable surfaces or, in some cases, stationary components that are designed to increase lift during some phases or conditions of the flight. The most common high lift devices are flaps, slats and Krueger flaps, but the category also includes less common installations such as lead-edge root extensions.[7]

The main purpose of using the high lifting devices are:

- To allow a steeper approach without increasing the speed of the aircraft
- Reduces the distance required to take-off and land
- Reduces the speed at which the aircraft will stall
- They increase the pilot's visibility of the runway

Effects of using Flaps

- **Relation with Centre of pressure:**

Flap movement, up or down, will cause a change of pitching moment. This is due to Centre of Pressure (CP) movement.

Centre of pressure is a point where all the lift of the aircraft is considered to be concentrated.

- **Relation with lift and drag:**

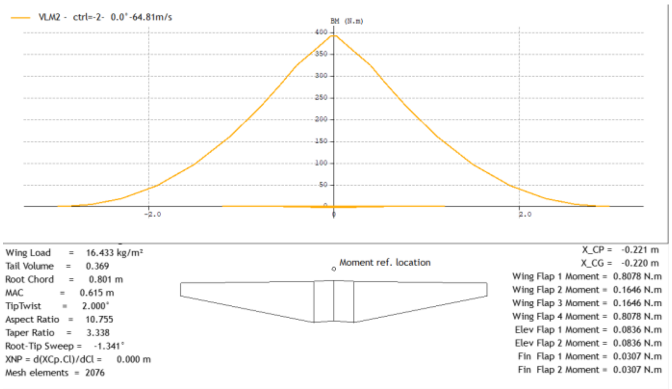
Lowering flap increases both lift and drag, but not in the same proportion. Although the lift is a larger force, and proportional increase in the drag is greater, so the maximum lift/ drag ratio decreases.

In our case **fowler type flaps are used** as it is most widely used in all the military, modern aircrafts which allows our UAV will have a suitable and appropriate function to maintain the operational requirements. [7]

viii. Final design Parameters of Wing

Parameters	Values	units
Maximum cruise speed	41.6	m/s
Max. Wing loading	40	Kg/ m^2
Airfoil	NACA23015	
Aspect ratio	10.75	
Wing area	3.347	m^2
Wing span	6	m
Taper ratio	0.3	
Root chord, C_r	.88	m
Tip chord, C_t	.26	m
Sweep angle	0^{0}	
Twist angle	2^{0}	
Dihedral angle	1^{0}	
Material of the wing	**Polyethylene terephthalate - PET**	

Bending Moment Diagram



Wing Load = 16.433 kg/m²
Tail Volume = 0.369
Root Chord = 0.801 m
MAC = 0.615 m
TipTwist = 2.000°
Aspect Ratio = 10.755
Taper Ratio = 3.338
Root-Tip Sweep = -1.341°
XNP = d(XCp.Cl)/dCl = 0.000 m
Mesh elements = 2076

X_CP = -0.221 m
X_CG = -0.220 m
Wing Flap 1 Moment = 0.8078 N.m
Wing Flap 2 Moment = 0.1646 N.m
Wing Flap 3 Moment = 0.1646 N.m
Wing Flap 4 Moment = 0.8078 N.m
Elev Flap 1 Moment = 0.0836 N.m
Elev Flap 2 Moment = 0.0836 N.m
Fin Flap 1 Moment = 0.0307 N.m
Fin Flap 2 Moment = 0.0307 N.m

Fig. 12 Bending moment plot of 6 m span wing

Comparison of aerodynamic characteristics of 4.8 m Span wing & 6 m Span wing

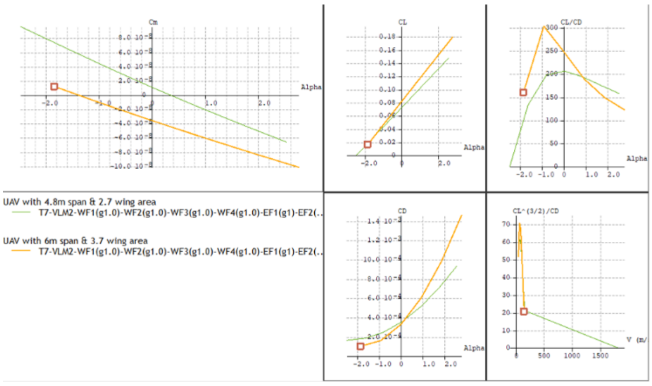


Fig. 13 Comparison of aerodynamic characteristics

From Fig 13 (C_m vs Alpha plot) we can observe that the co-efficient of moment of the wing got reduced which increases the lateral and longitudinal stability of the wing. And the minimum C_l of the wing is increased along with the decreased C_d. Cl / Cd max improved and we can get max. Lift with lesser cruise speed compared to 4.8 m span wing.

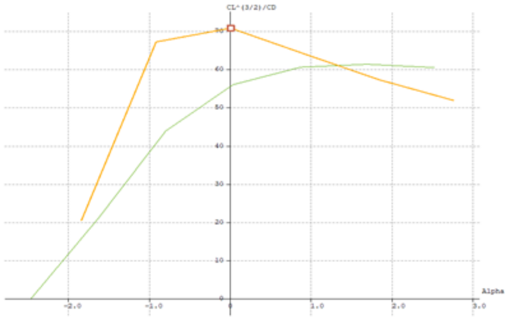


Fig. 14 $C_l^{(3/2)} / C_d$

From Fig. 14 we can observe that Cl / Cd max improved at 0^{0} AOA. Therefore we can get maximum lift at lower flight speed at cruise flight. And results in less power consumption to produce forward thrust.

Sizing of the control surfaces

Elevators or Horizontal stabilizers

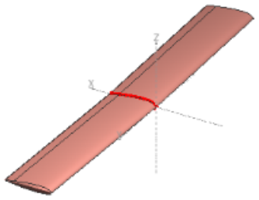


Fig. 15 Elevator

Rudders or vertical stabilizers

Parameters	values	Units
Span	0.9	m
Root chord	0.24	m
Tip chord	0.24	m
Airfoil	NACA 23015	
Position of elevator	1.5 m **(from leading edge of the root chord of the wing)** and 0.3 m from the neutral axis of the fuselage	
Material	Polyethylene terephthalate – PET	

Fig. 16 Rudder

Parameters	values	Units
Span	0.3	m
Root chord	0.28	m
Tip chord	0.2	m
Airfoil	NACA 23015	
Position of elevator	1.5 m **(from leading edge of the root chord of the wing)** at both sides of the elevator.	
Material	Polyethylene terephthalate - PET	

Sizing of the fuselage

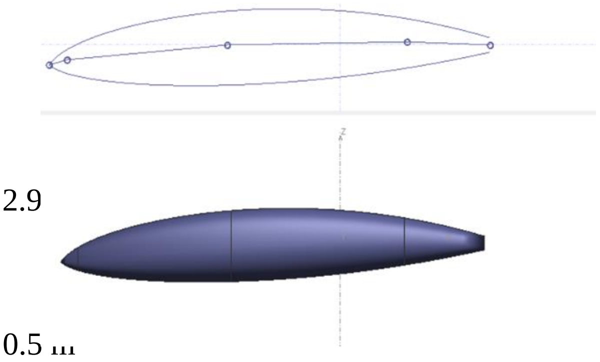
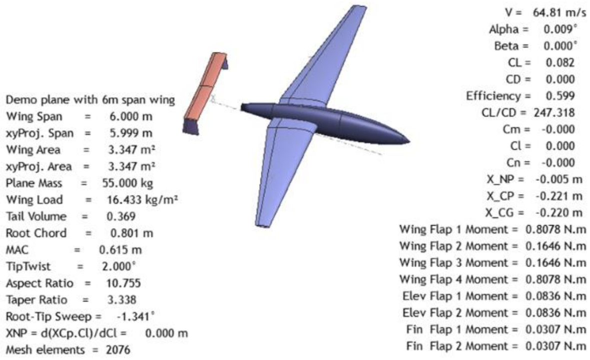


Fig. 17 Fuselage Sizing

VIII. Aerodynamic & stability analysis

Developed blended wing and body configuration

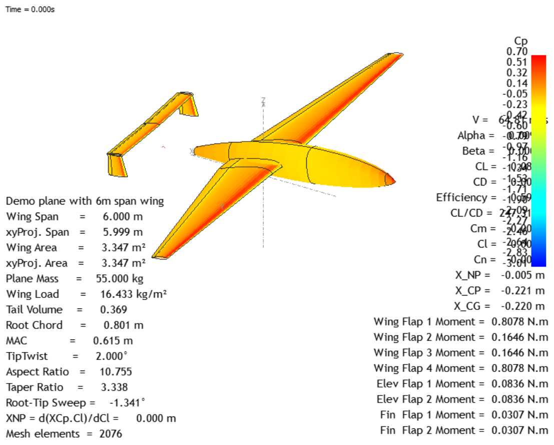


```
Demo plane with 6m span wing
Wing Span     =   6.000 m
xyProj. Span  =   5.999 m
Wing Area     =   3.347 m²
xyProj. Area  =   3.347 m²
Plane Mass    =   55.000 kg
Wing Load     =   16.433 kg/m²
Tail Volume   =   0.369
Root Chord    =   0.801 m
MAC           =   0.615 m
TipTwist      =   2.000°
Aspect Ratio  =   10.755
Taper Ratio   =   3.338
Root-Tip Sweep =   -1.341°
XNP = d(XCp.Cl)/dCl =   0.000 m
Mesh elements =  2076
```

```
                  V =   64.81 m/s
              Alpha =    0.009°
               Beta =    0.000°
                 CL =    0.082
                 CD =    0.000
         Efficiency =    0.599
              CL/CD =  247.318
                 Cm =   -0.000
                 Cl =    0.000
                 Cn =   -0.000
               X_NP =   -0.005 m
               X_CP =   -0.221 m
               X_CG =   -0.220 m
Wing Flap 1 Moment =  0.8078 N.m
Wing Flap 2 Moment =  0.1646 N.m
Wing Flap 3 Moment =  0.1646 N.m
Wing Flap 4 Moment =  0.8078 N.m
Elev Flap 1 Moment =  0.0836 N.m
Elev Flap 2 Moment =  0.0836 N.m
Fin  Flap 1 Moment =  0.0307 N.m
Fin  Flap 2 Moment =  0.0307 N.m
```

Fig.18 Preliminary UAV model

i.Pressure distribution over the UAV configuration



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```

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                  V =   64.81 m/s
              Alpha =    0.009°
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                 CL =    0.082
                 CD =    0.000
         Efficiency =    0.599
              CL/CD =  247.318
                 Cm =   -0.000
                 Cl =    0.000
                 Cn =   -0.000
               X_NP =   -0.005 m
               X_CP =   -0.221 m
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Wing Flap 1 Moment =  0.8078 N.m
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Wing Flap 3 Moment =  0.1646 N.m
Wing Flap 4 Moment =  0.8078 N.m
Elev Flap 1 Moment =  0.0836 N.m
Elev Flap 2 Moment =  0.0836 N.m
Fin  Flap 1 Moment =  0.0307 N.m
Fin  Flap 2 Moment =  0.0307 N.m
```

Fig. 19 Presure Plot

ii.Trimmed conditions

Modal results

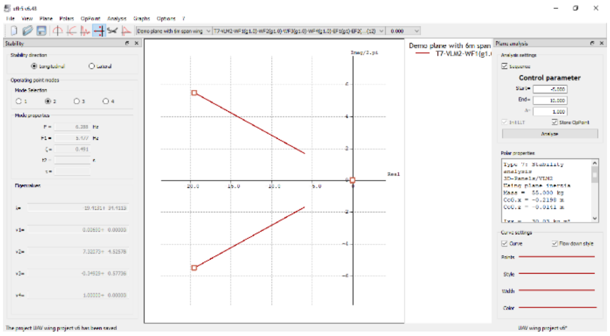


Fig. 22 Longitudinal Stability

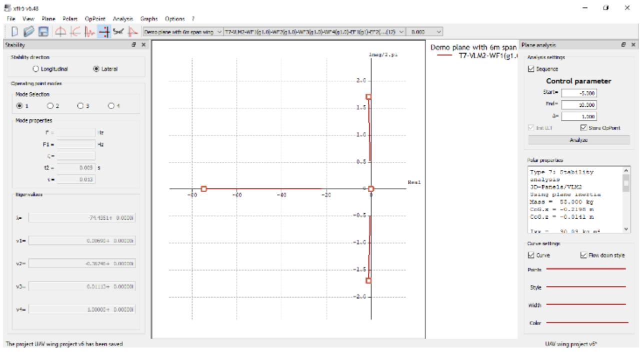


Fig. 23 Lateral Stability

Propulsion system

No. of motors: 4 + 1 (4 – VTOL & 1- cruise)

Propeller size: 30 in propeller

Power consumptionbreakdown

Mission Conditions	Power consumption
Take-off	648.58 W
Climbing	689.62 W
Cruise	2400 W
Descending	689.62 W (conservative)
Landing	640 W
Total power consumption	**5100 (aprox.)**

Batteryspecifications

Battery type: Li-po

Output voltage = 44.4 V

Power = 6000 W

C-rate = 0.5

Current 136 Ah

Weight breakdown

Components	mass (g)	Qty.	Tot. Mass (g)
motors (X-Team BLDC 100 kv 8320)	618	5	3090
ESC (Ready to sky 80A)	100	5	500
80A 200A Large current PDB	15	1	15
Battery 6s 16000 mAh	1900	4	7600
FCU, GPS, Power module, Receiver	800	1	800
propeller	200	5	1000
servo	60	5	300
Fuselage (including frame and consumables like nuts & bolts)	6000	1	6000
Main wing	15000	1	4000
Elevator	4000	1	4000
Fins	400	2	800
Landing gears (Main landing gear & Nose landing gear)	2100	1	2100
Solar charging setup	1500	1	1500
Payload	15000	1	15000
Total weight in KGs.			**46.70**

Solar charge control system

In order to get the maximum endurance the UAV, a solar charge control system is used.

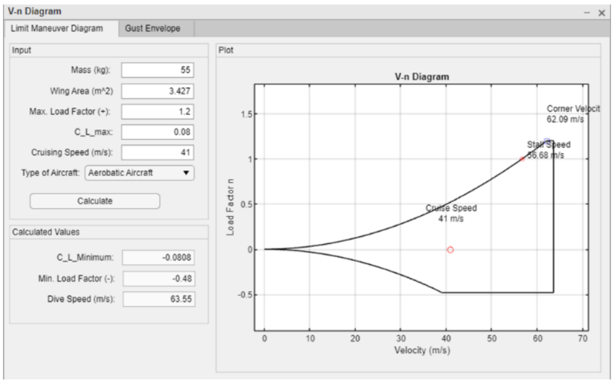
Solar PV panels choosen: : Sun Power C-60
Mono crystalline PV cells No. of cells used: 48
(in series)

Voltage produced from each cell: 0.6 V

By connecting 48 PV cells in series we get a output voltage of 28.8 V. and to maintain the required power at a constant rate a MPPT charge controller in used and which acts in between the solar PV cells and the battery system. And this configuration helps us to increase the endurance of the UAV[5].

Performance of the UAV

V-n Diagram



Mass (kg): 55
Wing Area (m^2) 3.427
Max. Load Factor (+): 1.2
C_L_max: 0.08
Cruising Speed (m/s): 41
Type of Aircraft: Aerobatic Aircraft
C_L_Minimum: -0.0808
Min. Load Factor (-): -0.48
Dive Speed (m/s): 63.55

Fig. 25 V-n diagram

Gust Envelope

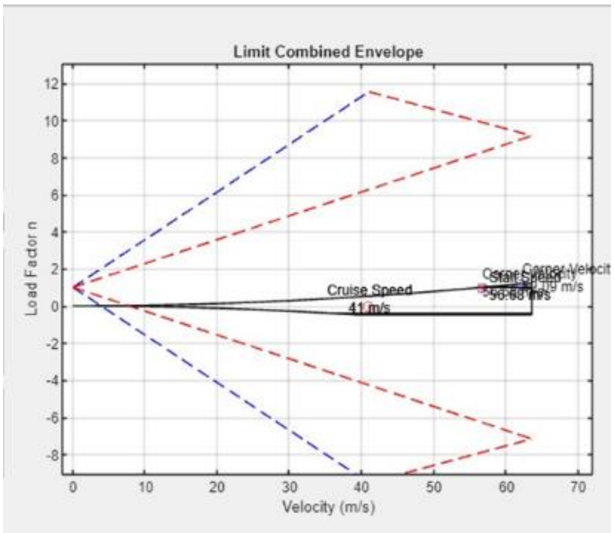


Fig. 26 Gust Envelope

IX. CONCLUSION

In this work, an approach to design a high endurance and high payload capacity unmanned air vehicle is made. This course work demonstrates the various steps to be followed in designing of a fixed wing multirotor V-tol Configuration UAV, a CAD model is developed using X-flr software to evaluate the characteristics & performances of the generated CAD model. In order to have a high endurance and flight time along with the batteries and approach to use Solar-Hybrid method is used by using solar PV modules as discussed above.

It is been found that the developed UAV model will satisfy the operational requirements mentioned in the design statements during our system level development.

X. REFERENCES

[1]. R. Austin, Unmanned Aircraft Systems: UAVS Design, Development and Deployment, WILLEY, 2010.
[2]. "unmannedsystemstechnology.com," Aug 2019. Online. Available: https://www.unmannedsystemstechnology.com/company/elevonx/.
[3]. G. o. I. DGCA, "Drone Rules 2021," 2021.
[4]. K. A. K. a. K. E. V, "Trends in the development of the global civil drones," Eastern State Transport University, 2018.
[5]. Liebeck, Design of the Blended Wing Body Subsonic Transport, Journal of Aircraft, Vol. 41(1), 2004, pp. 10–25.
[6]. "The Global Drone Regulation Landscape 2018," Business Insider Intelligence, 2018.
[7]. M. H. Sadraey, Design of Unmanned Aerial Systems, WILLEY, 2020.
[8]. xflr, "Stability Analysis with XFLR," 2017.
[9]. xflr, "Aerodynamic Analysis with XFLR," 2018.

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