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DESIGN OF MICRO SIZED UNMANNED AERIAL VEHICLES OR MAV

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Abstract— **This report mainly presents the concept, design and analysis of a micro class aircraft with maximum lifting capacity which has many applications in different areas for different operations. Pay load carrying capacity has been a key issue for a micro class aircraft. The design mostly concentrated on weight reduction of aircraft. Anything that does not carry load in the structure has been removed from the aircraft. Tandem wing ensured a better lifting capacity compared to conventional aircraft. The removal of horizontal stabilizer reduced the drag by 10% to that of conventional aircraft with same lifting capacity.**

More over the design concentrated on the taper wing with zero leading edge sweep increasing the lift at the same time reducing the drag of aircraft. Aerodynamic devices like stall fences are used to make sure the stalling effect is delayed.

This design can be employed for surveillance aircrafts with huge payloads like multi spectral imagers. They also can be used for payload drops. With a compact size achieving the following things is generally not witnessed.

Keywords—**Aerodynamics, MAV, DRAG REDUCTION**

I. INTRODUCTION

The basic concept of micro sized unmanned aerial vehicles or (MAV) has started increasing interest over the past few years for military applications. In the year 1992, RAND report for DARPA stated that the great use of micro UAVs for the wide range of military applications. Firstly, UAVs are autonomous, the main motto is to remove human for the regular wars and basic human casualty basically, and the MAVs have wide arch range of coverage in military operations including the difficult task like fire control, deflection of intruders, border patrol, traffic surveillance and riot controls

Today's piloted military aircrafts are basically equipped with high end technology in order to protect and safe guard the life of pilot which increases the cost and weight but most UAVs can be easily configured for some particular missions which carries the simple hardware system for the completing the mission. The UAVs can be lighter and cheaper because they don't carry life supporting system. Recent developments in the UAV field like the cargo carrier drone created by BOIENG show that UAV s are capable of doing dangerous, heavier and complex works very efficiently. So, in order to make them more efficient we have incorporated the following features discussed below.

The team decided to fabricate the UAV with an innovative taper, tandem wing aircraft with a 0-degree leading edge sweep. This allowed the team members to push limits further and work extra hard to make the ends meet, with the final design following all requirements. The above-mentioned wing structure helps the aircraft reduced induced drag without losing the lift component compared to that of simple rectangular wing construction.

II. EXECUTIVE SUMMARY

A. PROJECT SCOPE-

The main objective of the team echo is to design and fabricate an aircraft which can achieve the highest payload possible with lowest empty weight fraction. A tandem wing with a taper configuration with 0° leading edge sweep is considered for the model which meets the design requirements and constraints.

A.1. Tandem wing configuration-

A tandem wing aircraft presents two independent lift generating wings which eliminates the need for a conventional horizontal plane on the aircraft's tail. In this design, a taper wing with 0° leading edge sweep is considered with an aspect ratio 7 for both the wings. The main criteria for selecting the tandem wing is that it can achieve more stability compared to the conventional wing as the lift vectors on two wings are spread far apart longitudinally allowing them to act together which contributes to achieve a good stability and control. A conventional airplane tail contributes to 10% of drag which is reduced by tandem and thus achieving the better lift and better ground effect.

A.2. Tapered wing-

We considered a tapered wing with zero-degree leading edge sweep for our design to decrease the drag without compromising on lift. The leading edge with zero leading edge sweep has got an ability to have local velocity component similar to a rectangular wing. While the taper wing can reduce the induced drag. More over taper ratio of 0.4 is assumed to have elliptical lift distribution.

A.3. Stall fences-

Stall fences are small chord wise plates that protrude from the upper wing surface from the leading edge. Their purpose is to disrupt span wise flow, shielding the outboard wing section from a developing inboard stall. By keeping the outboard section from stalling, aileron effectiveness is maintained during a stall.

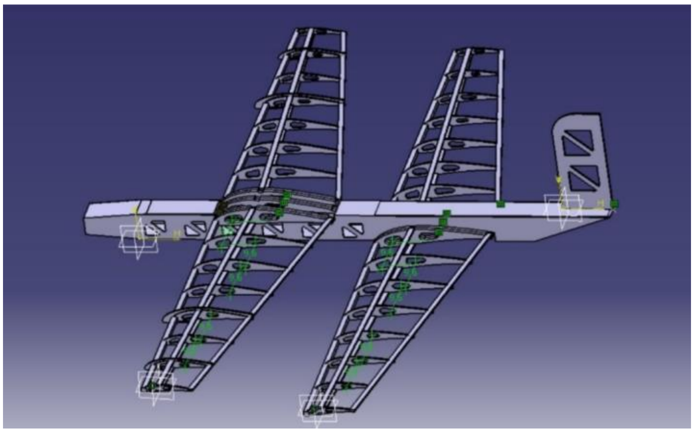

Fig 1: aircraft design

B. Design process-

Design process of the model is as follows. The following series of steps are followed to design out aircraft. Starting from the conceptual design to the final product we have gone through each phase with at most precision.

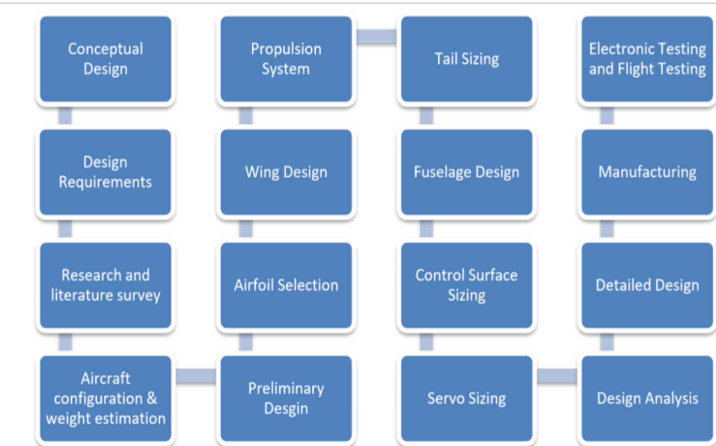

Fig 2: Series of steps involved in design and fabrication of aircraft model

III. AIRCRAFT SHAPING AND SIZING

A. *PRELIMINARY WEIGHT ESTIMATION-*

Approximate weights of the total aircraft with respect to each component are tabulated in below table 1-2. A gross weight of 2.5 kg (although the estimated weight is less than 2.5 kg) is used to design the wing that will generate enough lift to aircraft. The table below describes the weight of each component.

Table 1:

MOTOR	106 grams
ESC	63 grams
BATTERY	90 grams
SERVOS	50grams (10*5)
PROPELLER	20 grams
EMPTY WEIGHT	1100 grams
Payload	700 grams
TOTAL	**2129 grams**

B. *AIRFOIL SELECTION-*

The selection of the Airfoil for an aircraft's wings is a crucial component to ensuring the aircraft's performance is good. Research and analysis of the available Airfoil databases fetched Selig S1223 airfoil based on manufacturability and performance requirements such as moderate stalling angle, high maximum lift coefficient and aerodynamic efficiency. In comparison to other airfoils, this provides a much higher lift at low Reynolds number (50000-200000). The Reynolds number is estimated $R_e$stall =90,800 and $R_e$cruise = 1,08,960.
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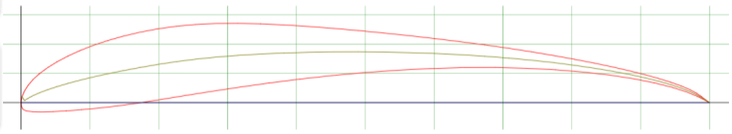

Selig S1223 Low Reynolds number high lift Airfoil Max thickness 12.1% at 19.8%
chord Max camber 8.1% at 49% chord.

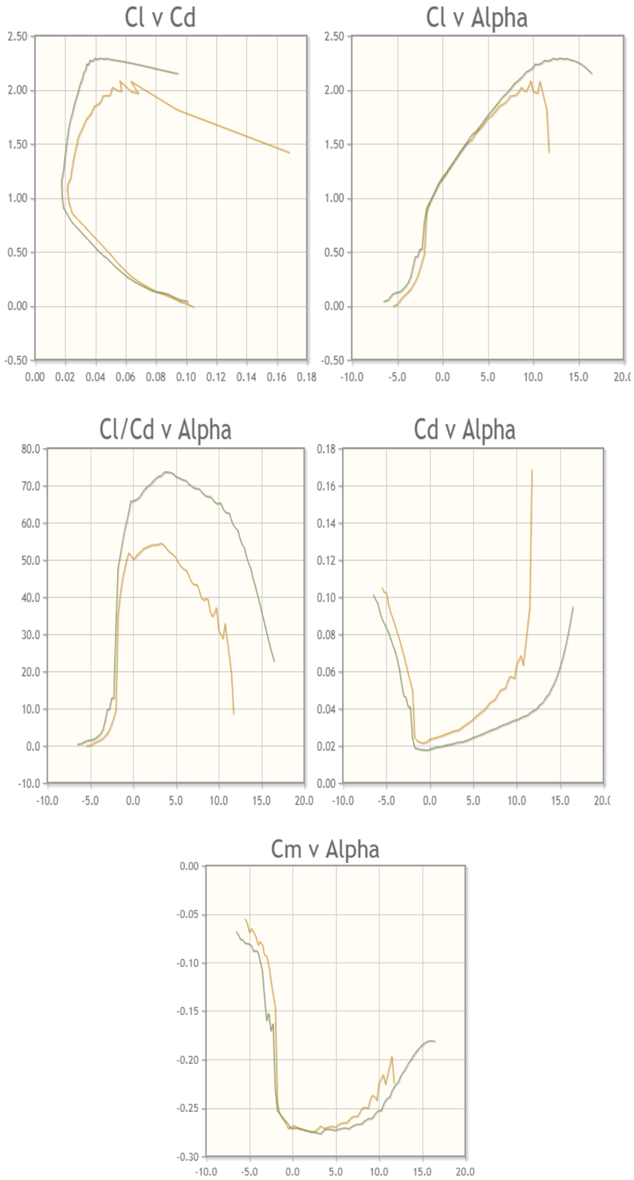

Figure 3: Selig S1223 Airfoil characteristics and Profile.

C. *WING DESIGN-*

After selecting the Airfoil and desired weight range for the aircraft. Using these weights and Cl value of our Airfoil, we calculated wing areas that provided the lift needed to achieve the take-off requirement. Team iterated this analysis and selected a wing area and established the chord dimensions.

C.1. ASPECT RATIO-

Historical data states that aerodynamic efficiency is directly proportional to the aspect ratio of the body and flow can be nearly 2-D if the Aspect ratio is higher than 6. Aspect ratio greater than 8 gives high gliding performance. Aspect Ratio less than 6 gives decreases gliding performance. Thus, Aspect ratio i.e. AR of 6.96 is considered for high aerodynamic efficiency and good landing performance. And the wing span (both wings) is 4.921 ft. (1.5 m) each.

C.2. LIFT-

Among several types of airplane configuration, it was decided to implement tandem wing design with taper wing with 0° leading edge sweep for ease in achieving the mission profile and precision in fabrication techniques. A high wing is suitable as it produces more lift than symmetrical wing and has more stability. Maximum lift generated at cruise velocity at 3◦ angle of attack is as follows.

Table 2:

AR	6.96
C_l (α=3°)	1.36
C_{lmax}	1.8152
Airfoil	Selig S1223
B_w	1.50 m
C_w	0.3 m
S_w	0.645 m²
Vstall	5.25 m/s
Vapp	6.3 m/s
Vcruise	7.5 m/s
L	44.71N

Span (b_a)	**Chord (c_a)**	**Plan view area (S_a)**	**S_a/S_w**	**C_a/C_w**	**B_a/b_w**
1.18	0.05375	0.634 m^2	0.48	0.0017	0.797

D. *EMPENNAGE DESIGN-*

Echo-19 decided to utilize a conventional vertical stabilizer, rear wing (as horizontal stabilizer) because it provides adequate stability and control and is minimum in weight when compared with other tail arrangements (H tail, T tail etc.).

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Thumb rules and volume coefficient method was used to size both the vertical portion of the empennage.

D.1. VERTICAL STABILIZER-

The following equation was used to determine the surface area of the stabilizer and necessary parameters was taken from historical data. From the trade studies, moment arm length is 0.54m.

C_VT=S_VT*L_VT/Bw*Sw

Table 3: Vertical tail design specification

Vertical Surface area (SVT)	0.02838 m^2
Span (b_v)	0.213
Chord (c_v)	0.04
Aspect ratio (AR_v)	1.6
S_{VT}/S_W	0.88
V_v	0.142
Moment arm length (L_{VT})	0.634

E. *CONTROL SURFACE SIZING*

E.1. AILERON SIZING-

The aircraft has a conventional control surface configuration with ailerons in front and an elevator in back. To determine the optimum size for control surfaces on the aircraft. In order to minimize the structural complexity of the wing and aileron for our design, a constant aileron chord was used.

Table 4: Aileron sizing

Materi al	Young's modulus (Pa)	Poisson 's ratio	Bulk modulus (Pa)	Shear modulus (Pa)
Balsa	3.0e + 009	0.38	2.188e +009	0.23 ×10^9

E.2. RUDDER SIZING-

The entire span of the vertical tail was used as the span for the rudder. The chord length of the rudder is typically 25-50% of the vertical tail chord. A constant rudder chord based on 40% of the average rudder chord was chosen for our design.

Table 5: Rudder sizing

Span (b_r)	**Chord (c_r)**	**Plan view area (S_r)**	**S_r/S_v**	**C_r/C_v**	**B_r/b_v**
0.213	0.145	0.030m^2	1.07	3.625	1

E.3. ELEVATOR SIZING-

The chosen span for the elevator was span of the secondary wing. The chord length of the elevator is typically 25-50% of the horizontal tail chord. Just like the ailerons, it was deemed appropriate to use a constant chord for the elevator, and our selected elevator chord length was based on 40% of the average chord length of the horizontal tail.

Table 6: Elevator sizing

Span (b_e)	**Chord (c_e)**	**Plan view area (S_e)**	**S_e/S_h**	**C_e/C_h**	**B_e/b_h**
1.48	0.05375	0.079 m^2	0.24	0.250	0.98

F. *FUSELAGE DESIGN*

Fuselage was designed in such a way that it can accommodate both wings rigidly and payload as well as to support all the components such as wings, engines etc. A rectangular fuselage constructed from balsa wood. The trussed structure was selected for its desirable structural strength and ease of construction. The fuselage carries the payload, is positioned below the wing on the projected center of gravity (CG) to minimize CG shift with payload addition. Its length is 60% of the wing span.

Table 7: fuselage specifications

S.No	**Parameters**	specification
1	Fuselage length	1m
2	Cross-section geometry	square
4	FRL in % of wing span(bw)	60%
5	Frontal cross-section area	20.25 m^2

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7	Fuselage structure	Monocoque
8	Internal Volume	0.0000548 m^3

G. *POWER PLANT MATCHING.*

Thrust or power required is a function of drag. Thrust required is equal to drag whereas power required is drag times velocity.
P=V*D
Total drag is sum of induced drag, skin friction drags and drag due to power plant.
Dtotal=5.05N.
The minimum thrust required for the model is taken from the drag forces that the model creates. But considering the losses and atmospheric conditions, the T/W ratio is chosen in between 1 and 1.3. This excess thrust is helpful at the take-off conditions and while taking turns. The drag forces caused by the model in the cruise is 5.053 N, so the minimum thrust required is 1.4 times the drag forces. The model maximum thrust overpowered drag by 4 times.

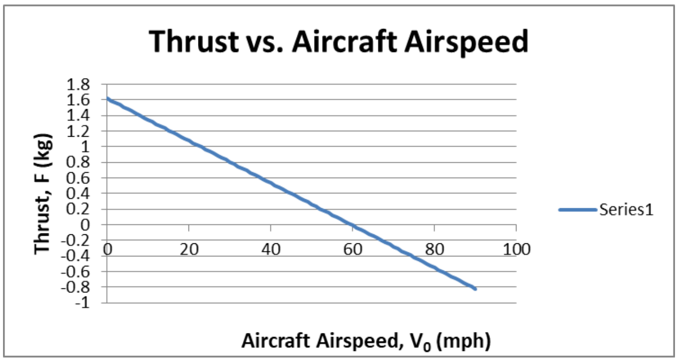

Figure 4: Airspeed vs thrust

IV. AIRCRAFT ANALYSIS

A. ESTIMATION OF CENTER OF GRAVITY-

The location of the center of gravity should be at aerodynamic center of first wing with minimal static margin. Static margin can be assumed up to 10%. Iterations are carried out for estimating the center of gravity by changing the locations of payload. Catia software is used to perform this activity.

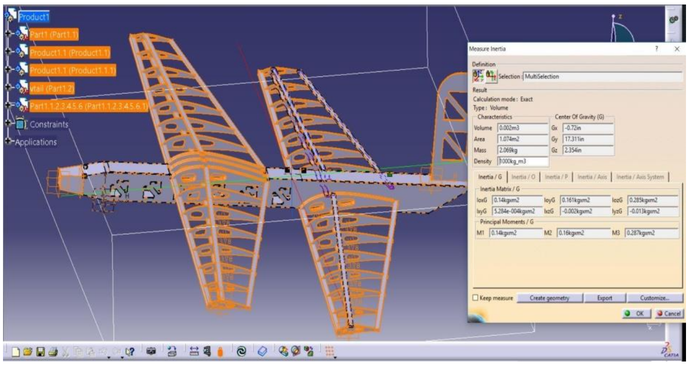

Fig 5: Estimation of center of gravity without any payload

B. COMPUTATIONAL ANALYSIS-

Structural and computational fluid dynamic analysis of the designed aircraft was performed using ANSYS. This analysis allowed us to make necessary changes and aided us to make our design more efficient in both aerodynamically and structural aspects of design.

B.1. STRUCTURAL ANALYSIS-

Structural analysis of individual components of the aircraft are performed. ANSYS was used to analyze the structural integrity of all the components prior to the construction. Static load tests were carried out on wing with ribs, spars and trussed structures by applying a distributed load along the lower position of the wing. The material selected is balsa wood and its properties are given below in the table.

The results of the study indicated that the wing is fully capable of carrying anticipated flight loads. The wing stress distribution and deflection are shown below.

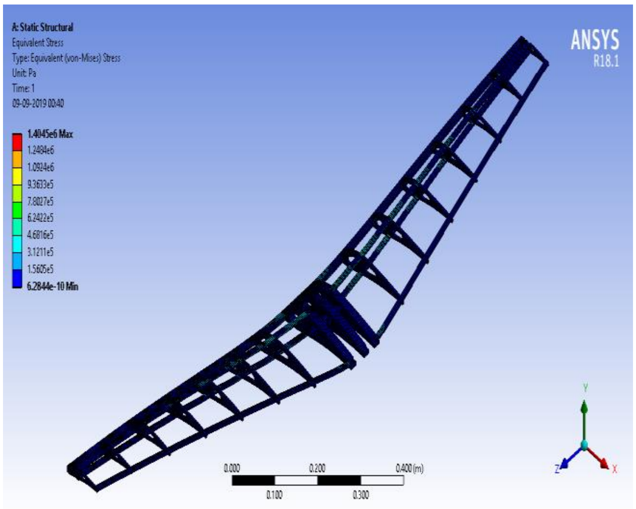

Figure 6: Equivalent stress distribution over wing (ANSYS)

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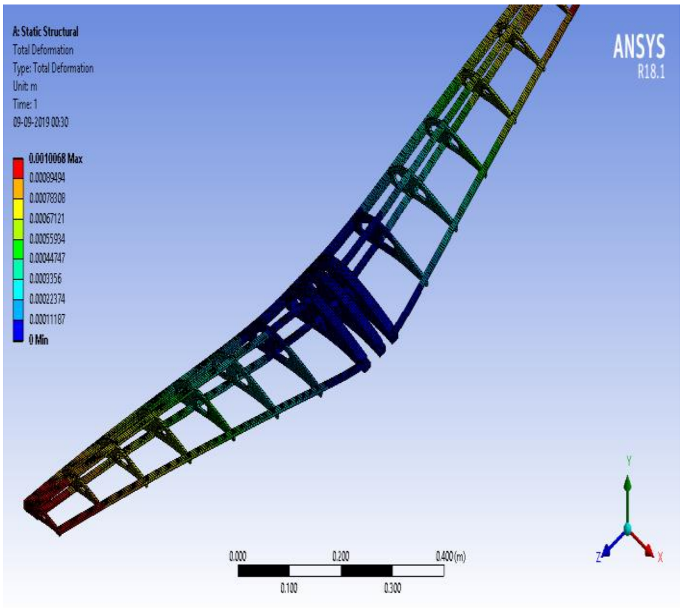

Figure 7: Total deformation over wing (ANSYS)

B.2 CFD ANALYSIS-

The flow analysis is done on airfoil in ANSYS workbench. In ANSYS workbench fluent analysis is taken and model is imported. Domain around the model is taken as 3D rectangle which is of length and breadth and height as 1m × 1m×1m after domain is created Boolean operation is done, to unite all the components

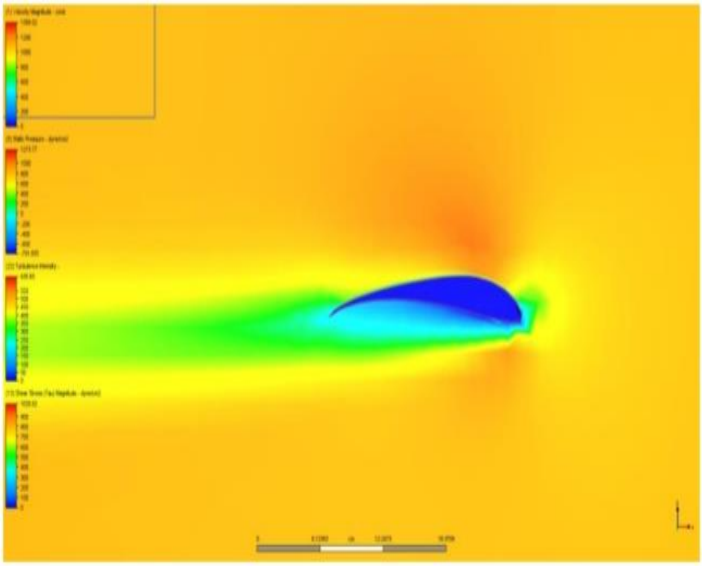

Figure 8: Velocity countour over airfoil

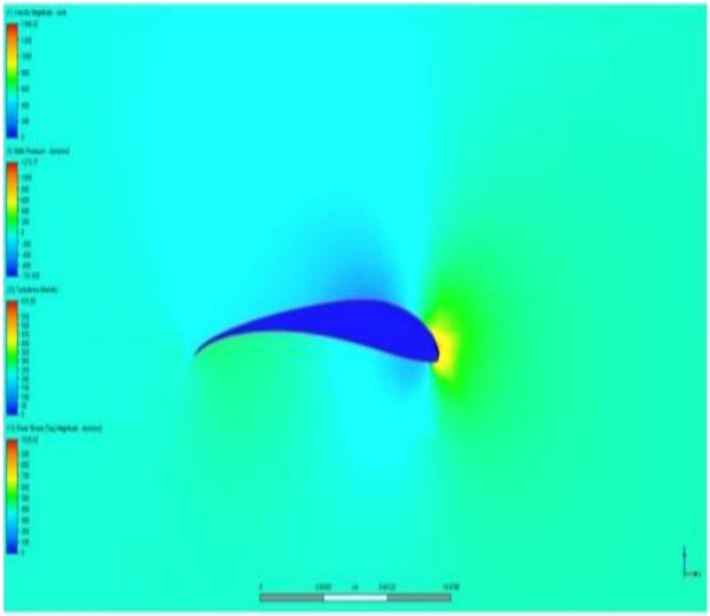

Figure 9: static pressure countour over airfoil

The complete model fluid analysis is performed in xflr 5 . The analysis is performed at 10 m/s at 3 degree angle of attack.

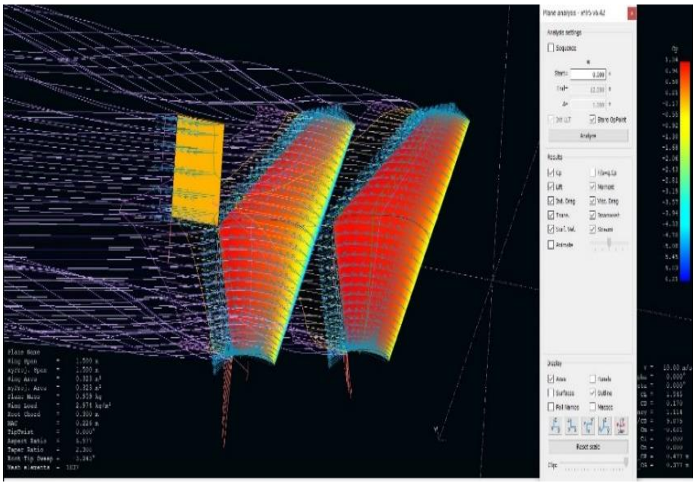

Figure 10:coefficient of pressure countour of the wings

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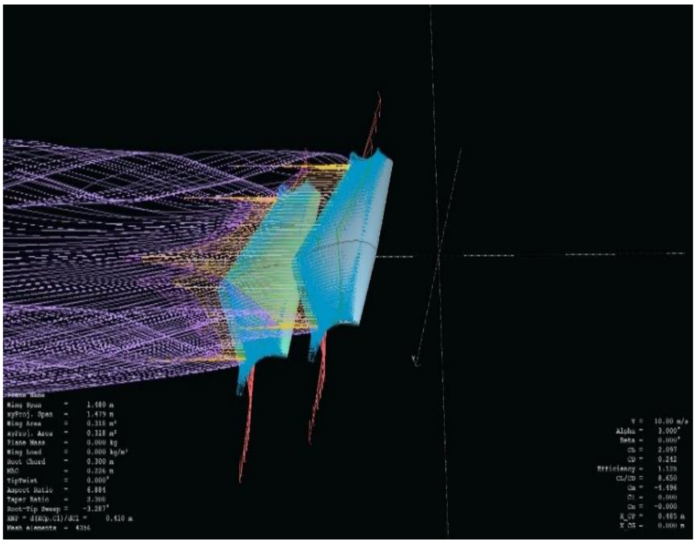

Figure 11: The stream flow over the wings and downwash

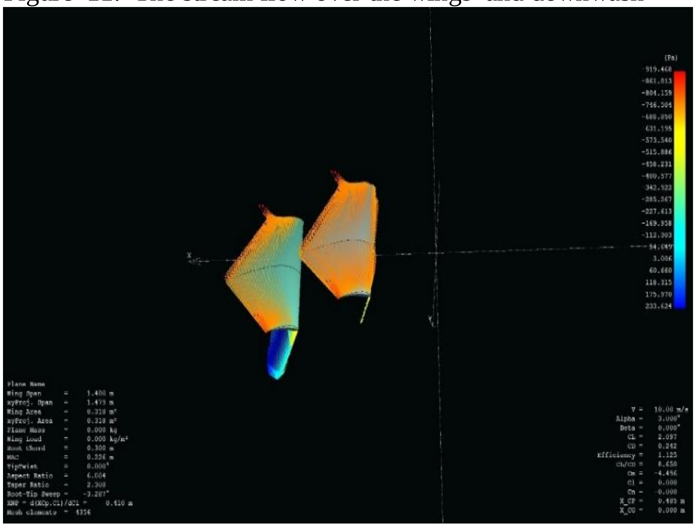

Figure 12: pressure distribution over the wings

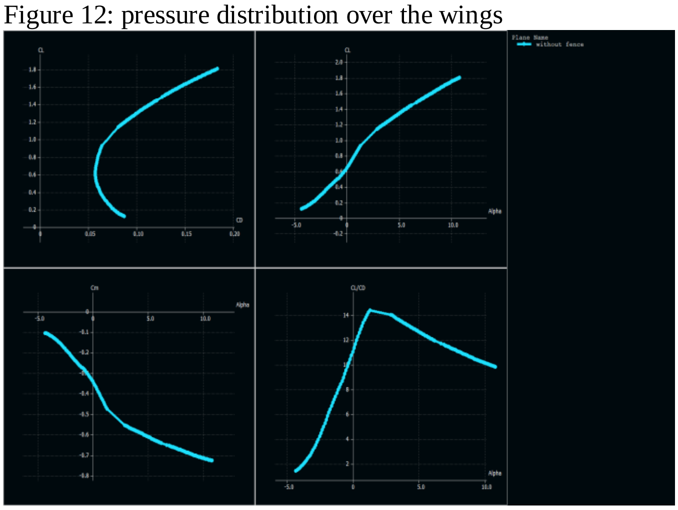

Figure 13: The aerodynamic plots for the tandemn wing

V. MODELLING AND MANUFACTURING OF SUB-ASSEMBLY

The parts are designed in CATIA V5. Manufacturing and Construction plays a crucial role in the weight and strength of an aircraft design. The material used for construction is balsa wood and all the parts were laser cut and then remaining are handcrafted using cutter. Sand papers were used to smoothen the surface. Wood adhesive is used to stick all the parts together. Covering film is used to mono coat the wing finally.

A. FUSELAGE CONSTRUCTION-

The fuselage consists of a rectangular body which will span a total distance of 39.37 inches from nose to tail. The dimensions of the nose are 1.57 x 1.57 inch. The total fuselage is constructed using balsa wood of 4mm with trussed monocoque structure. A covering film is used to monocot the structure. This design allows the fuselage to withstand the stress of landing while landing.

Fig 14: fuselage construction

B. WING CONSTRUCTION-

The tandem wings are constructed using the balsa wood of 4mm and 1.5mm for the upper skin. The parts are constructed using wood adhesive.

Fig 15: Wing construction

C. ELECTRONICS AND CABLE ASSEMBLY-

In total, five servos are used to control the airplane's motion on the ground as well as in mid air with a remote control. Two servos are used at the mid-section of each wing. Another one servo is connected to the rudder situated on vertical stabilizer.

D. MAIN ASSEMBLY-

Finally, the team mono coated the members to obtain the finest finish minimizing surface drag. Lastly final preparations are made and prepared the airplane for test flights. Checks will be made to all servos and their functionality. All the final touches will be conducted in order to ensure success.

VI. CONCLUSION

A micro class aircraft has been designed, fabricated and tested as per requirements. All the calculations are performed at standard atmospheric conditions at low altitude. The aircraft had a successful flight allowing further research into the real time usage of MAV. The design empowered the lifting capacity of a portable micro class vehicle. This enabled wide applications in the aerospace sector considering the compact size of UAV with better lifting capacity.

S.No	Parameters	Requirements	Achieved
1	Wing span	59 inches	58.26 inch
2	Total weight	Max 1.5kg (structural with electronics)	1.12 kg
3	Materials	No FRP or Lead	Balsa wood is used

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