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DESIGN AND FABRICATION OF 150MM FIXED WING MICRO AERIAL VEHICLE

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Abstract —

A Micro Aerial Vehicle (MAV) is a class of unmanned aerial vehicles (UAV) that has a size restriction and may be autonomous. Since, the size of an MAV is restricted; the lift generated is very small. So, the design must provide sufficient lift, which has to be greater than the total weight of the aircraft. The weight of the model is estimated by combining the weights of each component and the structural weight of the assumed Planform. Selection of airfoil is done by comparing the aerodynamic performance of nearly 30 low Reynolds number airfoils. The characteristics of various Planforms have been calculated theoretically and appropriate Planform is selected according to the design requirement to generate sufficient lift. The design is then analyzed in XFLR5 software for characterization of aerodynamic performance. Results are compared with the theoretical values. The Planform is then fabricated according to the conceptual layout. The MAV Planform is then processed further to integrate the avionics components for the RC fly configuration. Later according to its performance the additional surveillance setup is integrated in the model.

Key Words: MAV, Airfoil, Planform, XFLR5, design, VLM, 3-D panels, fixed wings

Nomenclature

C_d= Sectional drag coefficient (2D-Airfoil)

C_l=Sectional lift coefficient (2D- Airfoil)

C_D= Drag coefficient (3D-Wing)

C_L= Lift coefficient (3D- wing)

C_{dmin}= Minimum drag Coefficient

C_{Lmax}= Maximum lift coefficient

C_{Lmin}= Minimum lift Coefficient

C_m= Pitching moment coefficient

$C_{mo/4}$= Zero Angle Pitching moment coefficient

C_{mC}= pitching moment about the quarter-chord

$C_{L\alpha}$= Lift-Curve slope

L/D= Lift-to-Drag Ratio

CG= Center of Gravity

t/c= Thickness to Chord Ratio

α= Angle Of Attack

I. INTRODUCTION

Micro aerial vehicles (MAV) are a new type of remotely controlled aircrafts. Most MAVs today target a length of about six inches. The application of this device is mostly for observational purposes. Therefore, it can be used to unveil hazardous environments, new terrain or any areas that aren't easily assessable by ground.

Micro Air Vehicle (MAV) is defined as a small, portable flying vehicle which is designed for performing useful work. They have the potential to revolutionize our sensing and information gathering capabilities in areas such as environmental monitoring and homeland security. MAVs can be broadly categorized into:

- Ornithopter (inspired by birds)
- Entomopter (inspired by insects)
- Fixed wing
- Rotary wing

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As the size of a vehicle becomes smaller than a few centimeters, fixed wing designs encounter fundamental challenges in lift generation and flight control. Hence, researchers are slowly arching towards bio mimicking flapping wing MAVs. They offer great potentials for various civil and military applications, especially for surveillance and sensing at remote and hazardous locations.

It is been always challenge in make small scale fixed wings aerial vehicles. Due to their size and weight, there are many different factors affecting in its making. The need to better understand fundamental aspects of flight for small vehicles has spawned a surge in high quality research in this area. Extensive research is being done to get a deeper biological insight, create new mathematical models, come up with a physical interpretation, figure out new experimental techniques and design concepts.

II. WORKING METHODOLOGY

The desired MAV is limited to size of 150mm with a maximum weight of 75grams. It should carry a minimum load of 10grams.

Working methodology involves weight estimation and then designing of Planform which could generate a lift greater than the weight of the MAV. The procedure involves the selection of airfoils with minimum pitching moment and considerable lift. Later, Planform is designed such that it could lift the estimated load. This may involve modifications of airfoils and planform to attain optimum performance characteristics.

III. DESIGN PROCEDURE

Design is an iterative effort, as shown below. Requirements are set by prior design trade studies. Concepts are developed to meet requirements. Conceptual design is made to check whether it is possible to meet the requirements otherwise requirements are revised.

Three phases of design-

- Conceptual Design
- Preliminary Design
- Detailed Design

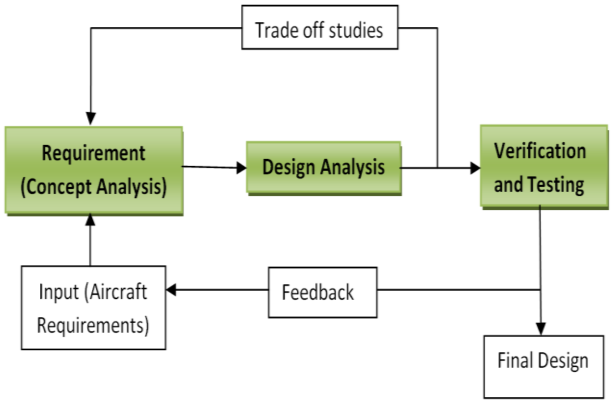

Fig. 1 Block Diagram of Design Procedure

III-1. Conceptual Design Process

Conceptual design process is the initial stage of designing process. In this stage model is designed through reviewing concepts to initialize the required data of Planform into work form. Every aerial vehicle before modeling conceptual review is taken down to get the performance and the various working conditions of the model. Later on those working conditions are modified accordingly and are incorporated in the designing of model.

Though the rectangular planform is having high lift co-efficient, it is dynamically inefficient and cannot be used for flying wing configuration. Hence, we have chosen the cropped delta wing Planform for the design with root chord of length 125mm and tip chord of length 100mm.

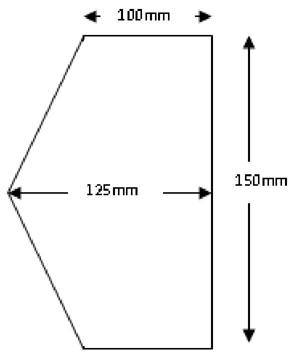

Fig. 2 Expected wing Planform

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III-2. Working Conditions:

Velocity (v)= 15 ms^{-1}
Density (ρ) = 1.225 kgm^{-3}
Pressure (P) = 1 atm

III-3. Initial Calculations:

Assumed weight that must be lifted by aircraft is 75 grams. So, minimum lift that must be generated by the aircraft is 75 grams

Weight (W)= 75 g = (75/1000)9.81= 0.735 N
Area (S) = 0.01875 m^2

Wing Loading (W/S) = 0.735/.01875= 39.2

$L=W=0.5\ \rho v^2 S C_l$

C_l = 0.28(min)

IV. PRELIMINARY DESIGN

IV-1. Weight estimation

The initial weight of the total aircraft is calculated by component weight method in which the individual weights of each components have been add to calculate total weight of the aircraft

S No.	Components	Weight(g)	Percentage weight (%)
1.	Structure	10	20
2.	Motor	6	12
3.	Propeller + mount	2	4
4.	Battery	10	20
5.	Servos (2)	4	8
6.	Speed controller	2	4
7.	Receiver	5	10
8.	Wires, servo connecting wires	1	2
9.	Payload	10	20
	Total	**50**	**100**

TABLE I. WEIGHT ESTIMATION

IV-2. Airfoil selection

Selection of an airfoil is the critical aspect of the design for an aircraft, as the co-efficient of lift for an airfoil is an index of total lift generated by the wing. Since all the MAV's operate at low Reynolds number, nearly 40 low Reynolds number airfoils have been analyzed for aerodynamic performance at various angles of attacks and at a velocity of 15 ms^{-1} and Reynolds number 80000 to 120000. This zone is mostly avoided because of the high fluctuations in lift and drag. In this zone the coefficient of lift reduces and drag increases rapidly as the Reynolds number decreases and respectively vice versa. Generally MAV's don't fly in this region. Since chord length and velocity are restricted to the desired limits, Reynolds number of the design falls into this region. So, there is no other option than to operate the MAV in the Forbidden Region.

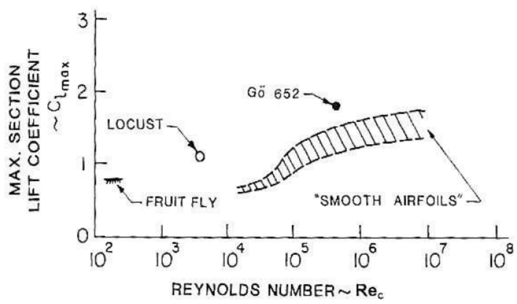

Fig.3 (A)

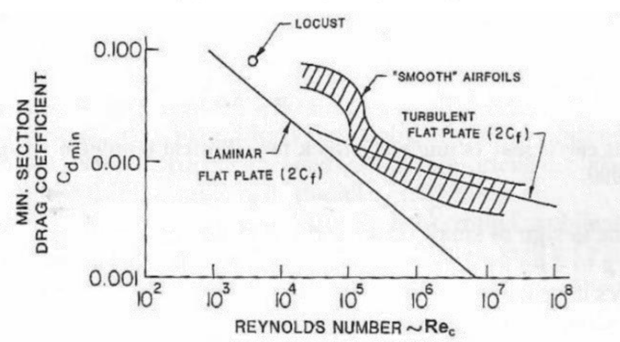

Fig.3 (B)

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Airfoil	AOA	C_L	C_D	$-C_m$	X_{cp} (mm)
Ah 7476	6	0.402	0.0753	0.168	43.43
Bw3	8	0.410	0.0731	0.131	35.62
E61	5	0.417	0.0810	0.204	49.02
E62	7	0.404	0.0668	0.152	40.10
E58	5	0.422	0.0789	0.210	49.65
E471	3	0.397	0.0632	0.206	51.42
E63	3	0.414	0.0700	0.222	54.19
E71	5	0.420	0.0665	0.191	46.49
GOE 79	6	0.402	0.0799	0.144	38.67
S1223	0	0.392	0.1045	0.292	69.73
S3021	12	0.393	0.0608	0.046	19.71
S4083	11	0.406	0.0586	0.075	25.066
S5010	15	0.410	0.0697	0.004	11.06
S5020	15	0.420	0.0710	0.008	11.76
S6061	14	0.410	0.0642	0.030	16.27
S6062	14	0.406	0.0616	0.027	15.895
S6063	14	0.403	0.0590	0.026	15.699
ESA 40	13	0.415	0.0570	0.095	24.181
Falcon	11	0.404	0.0518	0.140	36.766

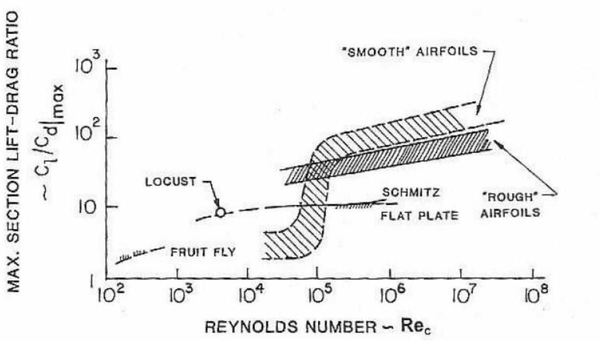

Fig.3(C)

Fig. 3 A) Coefficient of lift variation along forbidden range; B) Coefficient of drag variation in forbidden range C) Max CL/CD variation along forbidden region

According to the above charts very few airfoils can withstand economically in this zone according to coefficients variations with respect to alpha. The shortlisted airfoils with the aerodynamic characteristics are mentioned below in the table.

TABLE II. AIRFOIL AERODYNAMIC PERFORMANCE CHARACTERISTICS

All the airfoils have been modified to meet the requirements i.e. at 75% of chord flaps are provided with a deflection angle of -3^0.

According to the obtained results from the XFLR5, four airfoils are having better aerodynamic performance. They are

- S5010
- ESA40
- FALCON
- S1223
- Modified E61

The E61 is modified to the desired vales so that we can decrease the pitching moment and to generate high lift. This also enables to accommodate the avionic system inside the wing.

Parameter	Initial Value	Modified Value
Maximum Thickness	5.6% at 23.8% of Chord	7.81% at 23.8% of Chord
Maximum Camber	6.4% at 51% of Chord	4.11% at 32.4% of Chord

TABLE III. MODIFICATION IN E 61 AIRFOIL

V. PLANFORM DESIGN

The main design consideration for the MAV's is the weight and dimension i.e. the chord and span of the wing. The calculations were performed for different aspect ratio velocity, lifts coefficient, etc., and optimized result

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was chosen as the design requirement specification of the MAV. Increasing the aspect ratio could lead to a very low wing area permitting the MAV to carry only less weight, so the aspect ratio was varied between 1 and 1.5. The various planform like Zimmerman, Inverse Zimmerman, Modified 3-Circle, Delta Planform, cropped Delta; elliptical and Rectangular were analyzed to choose optimally best planform for the MAV. But, all the Planforms found to be inefficient to generate sufficient lift.

The cropped delta with extended rectangular planform with different airfoil section at 25 mm from root chord was selected to obtain the required amount of lift coefficient with less pitching moment. Three vertical fins are used to increase the stability along longitudinal axis. The planform is selected with certain amount of sweep to reduce the structural strain to make the planform rigid enough to withstand high maneuvers.

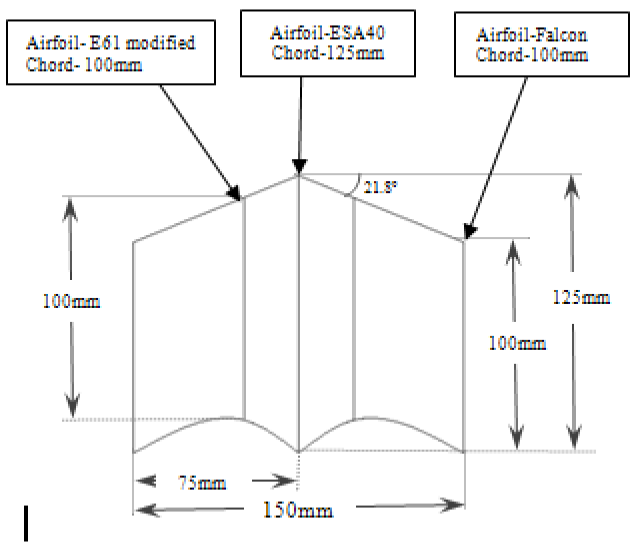

Fig. 4 Finalized Planform

VI. Aerodynamic Center Calculation

The aerodynamic center is the point at which the pitching moment coefficient for the airfoil does not vary with lift coefficient (i.e. angle of attack), so this choice makes analysis simpler.

$$\frac{dC_m}{dC_l} = 0$$

It is fundamental in the science of stability of aircraft in flight. It lies on the longitudinal symmetrical axis the mean aerodynamic center of the finalized planform is obtained by AC Calculator software. It takes the planform specifications as input and displays the calculated aerodynamic center as output.

Later the configuration is analyzed with different airfoils at the specified locations. The results of few analyses are given below Geometric properties of designed MAV

Property	Value
Span	150mm
Area	156.250cm^2
Aspect Ratio	1.44
Mean Aerodynamic Chord	104.667mm
Root Chord	125mm
Tip Chord	100mm
Taper Ratio	1.25
Sweep Angle	21.8^o
CG Location	20mm
Aerodynamic Center	37.04mm
Winglet Area	5000mm^2
Height of Winglets	50mm
Height of the Vertical tail	75mm
Vertical tail area	5625 mm^2

TABLE IV. Airfoil Aerodynamic performance Characteristics

VI-1. Modeling Of Wing in XFLR5

The designed MAV is modeled in XFLR5with the help of 3-D panel method. In 3-D panel method wing is defined by a set of panels and each panels is defined by its length, root and tip chord, leading edge offset at root and tip, mesh for VLM/3-DPanels analysis. The 1000 numbers of VLM Panels and2000 numbers of 3D Panels can be

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modeled in XFLR5.The span wise length of a Panel should be at least equal to the minimum length of the VLM elements on other panels which can be seen in figure

MAV is modeled in XFLR5 with the help of 3-D panel method which include VLM mesh also. The airframe has been modeled by giving the hypothetical sections in X and Y direction respectively. The spacing between the hypothetical sections is filled by 3-D panels and VLM panels as shown in Fig.-6.The spacing between the panels can be defined either linearly or using a sinusoidal function. The cosine function is generally used to resolve the flow accurately at all the desirable points by increasing the density of mesh at the root, tip, leading and trailing edge. As panel distribution is consistent with the wing geometry so the density of the mesh can be increased at the geometrical breakdown points and at the root and tip of the wings. The wing is "meshed" into a number of panels distributed over the span and the chord of the planforms, and a vortex is associated to each panel. The MAV wing is meshed with VLM panels as well as 3-D panels with the help of XFLR5.

In the first case, the root airfoil is ESA40, at 25 mm from root the airfoil is S5010 and at the tip FALCON. The planform for the first case is Planform-1.

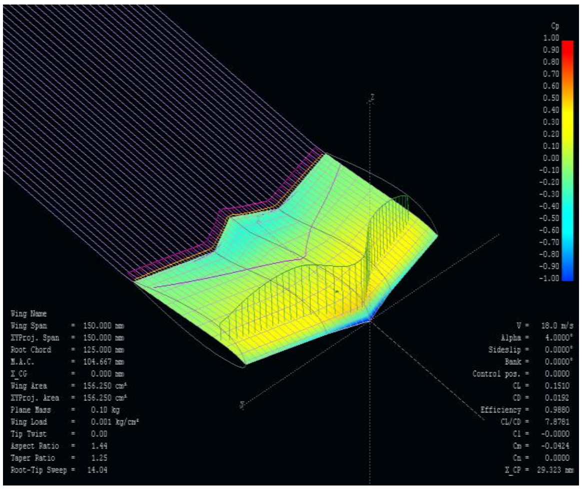

Fig. 5 Results of Planform with high lift airfoils

In the second case, the root airfoil is ESA40, at 25 mm from root the airfoil is S1223 and at the tip FALCON. The planform for the first case is Planform-2

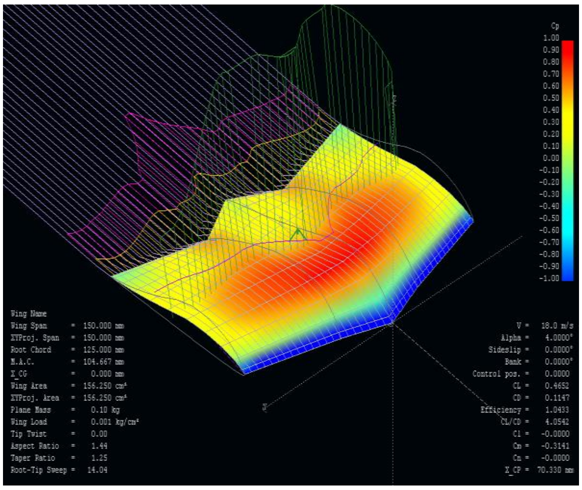

Fig. 6 Results of Planform with low pitching moment airfoils

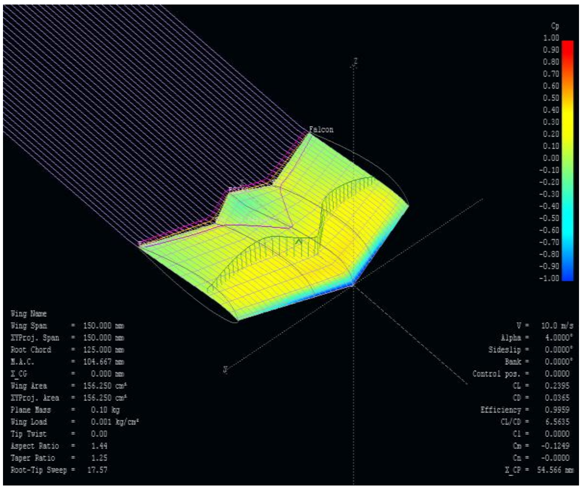

Fig. 7 Results for Planform with low pitching moment and high lift

In the third case, the root airfoil is ESA40, at 25 mm from root the airfoil is E61 is modified and at the tip FALCON. The planform for the first case is Planform-3

VI-2. *Selection of planform*:

Out of the three models the planform having low pitching moment and better lift co-efficient is selected. Since, the static margin of stability of the aircraft is based on the pitching moment. For the stability of the aircraft the C_m pitching moment must be less.

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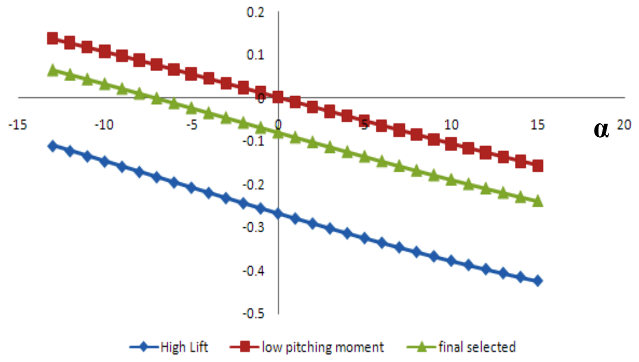

Fig. 8 (A)

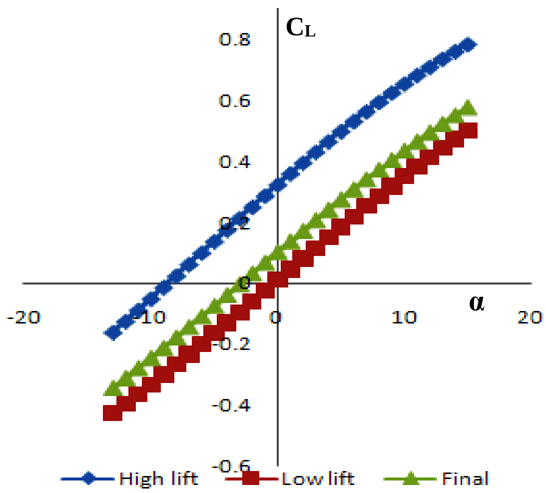

Fig. 8 (B)

Fig. 8 A) Comparison of Cm for Planforms at different angle of attacks of airfoils ; B)Comparison of Cl for Planforms at various angle of attacks of airfoils

But, low pitching moment is achieved with less lift co-efficient or vice versa. Hence, the final planform is selected as a compromise between the co-efficient of pitching moment and the co-efficient of lift.

Aerodynamic characteristics of designed MAV

Parameter	**Values**
C_{Lmax}	0.8
C_{Dmin}	0.02
C_{mo}	-0.075
Stall Angle	24^0
$(C_L/C_D)_{max}$	8.1
$C_{L\alpha}$	0.022/deg
Cruise Speed	15-18m/s

TABLE V. AERODYNAMIC CHARACTERISTICS OF DESIGNED OF MAV

VII. PROPULSION SYSTEM

Propulsion system must generate required thrust to accelerate the aircraft to the required velocity. The selection of propulsive system includes the selection of the components such as

- Motor
- Propeller
- Electronic Speed Controller (ESC) etc.

VII-1. Motor:

The engine along with its components must be less in weight and with better performance. Hence, we selected AP05 3000kv Brushless Micro motor because of:

- Less weight along with its other accessories
- Compact size.

The dimensions of motor are:

Parameter	Specification
Kv (rpm/v)	3000
Weight (g)	5.4
Max Current (A)	4
Resistance (mh)	0
Max Voltage (V)	7
Power(W)	0
Shaft A (mm)	2
Length B (mm)	12
Diameter C (mm)	13
Can Length D (mm)	8
Total Length E (mm)	19

TABLE VI. DIMENSIONS OF MOTOR

VII-2. Motor Specifications:

The Factory specifications are:

Parameter	Specification
Kv	3000rpm/v
Battery Range(Li-po)	1~2S(3.7~7.4V)

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Suggested propeller	5030
Max Current	3A
Burst Current(5s)	4A
Weight (including mount and wire)	5.4g
Shaft	1.5mm

TABLE VII. MOTOR SPECIFICATIONS

VII-3. Propeller:

Propeller is mounted on the motor which rotates to increase the momentum of the air and push it on the wings at increased velocities. Since the recommended propeller is 5030 which stands for 5 inch diameter and 3 inch pitch.

The thrust generated by the motor and propeller combination is 110g.

VIII. FABRICATION AND TESTING

The fabrication of the model has been carried out for the designed planform. The structural frame was made with BALSA WOOD, which is covered with NYLON cloth as Skin of the structure. Care is taken while arranging the internal components So that the CG of the wing lies very close to the AC of the wing at Zero AoA. This is the criteria for high stability. After construction flight tests have been conducted.

IX. CONCLUSION

An MAV with a flying wing configuration is designed with a span of 150 mm according to the required problem statement. When analyzed in XFLR5, the modified planform exhibited low influence of the wing tips vortices over the wing for the operational conditions. Hence, the design is dynamically stable.

Flight testing of the Designed model has been carried out and found to be good. The Performance of the model is compatible with the flight conditions.

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