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Design and Analysis of a Micro Class UAV Integrating Zimmerman Configuration

K Harshavardhan[1]; AM Sanjana[2]; P Shyam Raja[3]; Dileshwar Rao[4]; A Neha[5]; P Karthik Reddy[6]; J H S D Anoohya[7]
Aeronautical Department, MLR Institute of TechnologyHyderabad

Abstract:- This document describes the design and analysis processes followed by team to build a micro class UAV. Through this opportunity our team has gotten a chance to test and enhance our skills by developing a design and fabricate flying wing UAV of Zimmerman configuration. Integrating this flying wing into the blended body micro classed UAV, allowed the team members to push limits further and work extra hard to make the ends meet, with the final design of a lightweight UAV following all the constrains for the SAE ADC 2020.

Keywords:- *UAV; Zimmerman; Lightweight.*

I. INTRODUCTION

The objective of the team was to design and fabricate a micro class UAV that can be quickly deployed which is light weight. The design, analysis and testing of the fabricated model should give a brief idea of the effects of blended wing of Zimmerman configuration on overall performance, providing a base to the proposed design.

The evolution of aircraft design has witnessed numerous iterations and breakthroughs, each surpassing its predecessor. Amidst this progress, the Zimmerman wing stands out as a particularly promising avenue for advancement. Characterized by its distinctive and exceptional design, it offers ample opportunities for further refinement and innovation.

A. *Vought V-173*

The Vought V-173, affectionately dubbed the "Flying Pancake," is an iconic experimental aircraft renowned for its distinctive appearance and innovative aerodynamic design. Originating during World War II, the V-173 was commissioned by Chance Vought to explore the unconventional concepts of designer Charles H. Zimmerman. Despite its peculiar look, the Flying Pancake not only captivates with its unique aesthetics but also astonishes with its exceptional flight performance.

Earning various nicknames, including the "Flying Pancake," this aircraft became one of the pioneering examples of vertical short takeoff and landing capabilities. Developed under a U.S. Navy contract, the V-173 took to the skies for the first time on November 23, 1942. Its propulsion was provided by two 80 HP Continental A-80 engines, contributing to its experimental prowess and historical significance.


Fig 1: Vought V-173

B. *Vought XF5U*

The Vought XF5U is also known as “Flying Flapjack”. It was also experimental aircraft by U.S Navy which was a developed version of V-173 which is 5 times heavier with two 1,600 HP Pratt &Whitney R- 200 radial engines. It was designed with low aspect ratio with low take-off and landing but with great high speeds up to 550mph and also promised high maneuverability, but it was the time Navy was switching from propeller to jet engines during development. By the time project was over it was of high budget, and the project was dropped off.


Fig 2: Vought XF5U

C. *Boeing X-48*

The Boeing X-48 is U.S experimental unmanned aerial vehiclewhich has a blended wing and flying wing design. The Blended Wing Body concept was developed in the collaboration of NASA Langley Research Centre and Boeing Phantom Works. It is made of composite material. Boeing designed two versions of X-48 built by Cranfield Aerospace in UK. X-48B was modified into X-48C which was flight tested between 2012 and 2013. Boeing and NASA tend to develop larger aircrafts of this type.

Fig 3: Boeing X-48C

II. DESIGN PROCESS

To consider all the constraints of the competition and accommodate all the desired objectives of the final design wasa demanding process. An iterative design process method ensured an optimal result which geared and triggered us.

Table 1: Design Constraints and Target

Parameter	Constrain	Target
Dimension	Maximum volume combining length, width and height (L*W*H) Less than or equal to $3ft^3$	Required as per given dimensional and weight requirements
Empty Weight	Less than or equal to 1.5 kg	1.0kg-1.2kg
Gross Weight	Less than equal to 5kg	2kg
Material	FRP & Pb are prohibited	Is to use Metals, PLA, Wood
Battery	3 cell lithium polymer battery pack	Prioritize power plant during Weight estimation and design structure accordingly.
Propulsion Requirements	Electric propulsion only with one motor	Electric propulsion
Propeller	Metal propellers are prohibited, safety nut or spinners are must	Commercially available plastic propeller
Landing	200ft	Must land in the same direction as take-off within landing zone
Controllability	No excessive sloppy surface & FAA safety criteria must be satisfied. No gyro assistance.	Good controllability for all flight conditions at low altitude.
Take-Off	Launch circle (Distance from start before initial turn 100ft)	Hand launched to so aircraft attains stall velocity
Payload bay	$5×1.5×1.5\ in^3$ +tolerance made of any material with uniform mass distribution	To fit in the internal member of the fuselage

A. Weight Build Up

Total weight of the aircraft is the "Design take-off gross weight" for which it was designed as the mission of the aircraft begins. "Maximum take-off weight" may or may not be same as the "Design take-off gross weight". As the aircraft is overloaded beyond the design weight the aircraft will suffer by reducing its maneuverability. The take-off gross weight can be taken as empty weight of aircraft, crew weight and payload. The aircraft structure (made of balsa, plywood and other material, fixed equipment, propulsive system (electric motor) and anything apart payload as per the design requirements.

Table 2: Weight Build-up of the aircraft

S. No	COMPONENT	QUANTITY	WEIGHT (grams)
1	1000 mAh 3s Battery	1	110
2	Motor (Racerstar BR2814)	1	100
3	Propeller (10×4.5) in	1	20
4	Esc (Hobbywing Skywalker 50A)	1	80
5	Servo	4	80
6	Other	-	90
7	Structural Weight	-	900
	Total		1400
	Payload	-	600
	Total with Payload		2000

The initial weight build-up of the complete model is shown in the table above that is weight of model without pay load 1.4 Kgs and weight of model with payload 2 Kgs.

B. Configuration Selection

➢ *Wing Layout*

One of the vital factors affecting the overall aircraft performance is “Aircraft Wing Configuration”. Configuration of an aircraft wing is possible in many numerous ways. Our configuration of the aircrafts wing is a Monoplane having a Low Aspect Ratio which is causing the wing to have large surface area producing high lift even under low speeds of take.Zimmerman is the shape of the wing that has been selected which has low aspect ratio and very high aerodynamic efficiency and aerodynamic nature. The entire aircraft body contributes to lift production. Zimmerman's blended wing body aircraft features a uniquely flattened and seamlessly integrated fuselage, resembling a central airfoil-shaped body that primarily generates lift, with the wings complementing this function for balance.

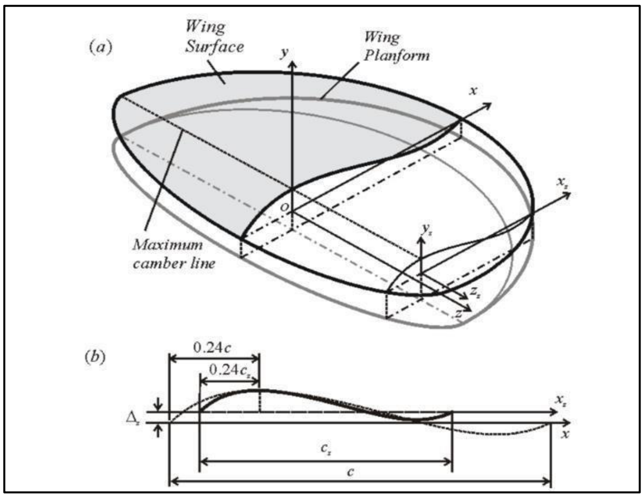

Fig 4: (a) Zimmerman Wing and
(b) Representative Cross Section

➢ *Tail Layout*

Flying Wing aircrafts are also known to be tail less aircrafts. As per our design requirements the tail less problem is solution is given by providing large elevator or elevons surfaces. Elevons are a combination of elevators and ailerons which controls the rolling and pitching moment. Yawing moment is produced by the tail fin placed at the end of the wing trailing edge. But by any tail configuration the main functions to be satisfied are given below:

- Stability
- Control

Through this type of configuration, we can attain both themain functions of tail.

➢ *Motor Placement*

Motor placement selected for the design of the aircraft is tractor installation. The propeller in front of its attachment point that is the motor is known as the tractor installation where a single motor is installed at the nose of the aircraft. This type of installation provides a ready source of cooling air and places the propellers in undisturbed air.

C. Wing Sizing

➢ *Airfoil Selection and Optimization*

An Airfoil is the heart of the wing and it is the cross section ofthe wing in the lateral of the aircrafts wing. Airfoil is placed in an airstream in order to produce a useful aerodynamic force in the most effective manner possible.

As per our design configuration of the unmanned aerial vehicle the following are the criteria to be attained.

- Airfoil which has maximum coefficient of lift CL max.
- Enough lift to drag ratio must be present.
- To prevent laminar separation bubble and drag reduction the thickness of the selected airfoil must be thin as possible. Yet it needs a thickness between 8% and 11%.
- The stall AOA (αstall) must be more than 10°.
- Drag coefficient of airfoil must be low.
- Provided the lift required lift.

After comparing many airfoils, we have concluded that - The very close airfoils for our requirement are as follows.

Table 3: Airfoils with Required Parameters

Airfoil	α	CL	CD	CL/CD	CL max	αStall
MH20	3.5	0.1432	0.0143	10	0.92	8
S5010	3.3	0.1403	0.0142	9.89	1.33	13
S3	3.3	0.1426	0.0147	9.67	0.89	8
EH2510	3.5	0.1416	0.0155	9.12	1.04	12.5

The final Airfoil selected for our design of the unmannedaerial vehicle is S5010. It was worth mentioning that along with the selection of Airfoil with CL/CD being equal to 9.98.

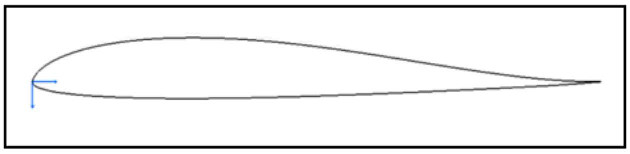

Fig 5: S5010 Airfoil

Table 4: S5010 Airfoil parameters

Ncrit	**9**
Re	3,12000
Cl at AOA 11	1.1964
CD at AOA 11	0.02652
CL max	1.0767
Cd0	0.00768
Max CL/CD	9.98

➢ *Design of Wing*

Throughout the entire design process, the wing assumes a pivotal and central role, functioning as the cornerstone of the aircraft. Serving as the primary source of lift generation, wings significantly influence the performance of any airborne vehicle. Circulation around the wing tips contributes to lift production while simultaneously increasing drag. The spacing of wing tips varies with aspect ratio, directly impacting stalling angles. Lower aspect ratio wings tend to stall at higher angles compared to their high aspect ratio counterparts.

Considering all factors, the Zimmerman planform was chosen to optimize performance. In addition, the aircraft's weight buildup totals 2 kilograms. The stall speed required for lift off is determined to be 8 meters per second.

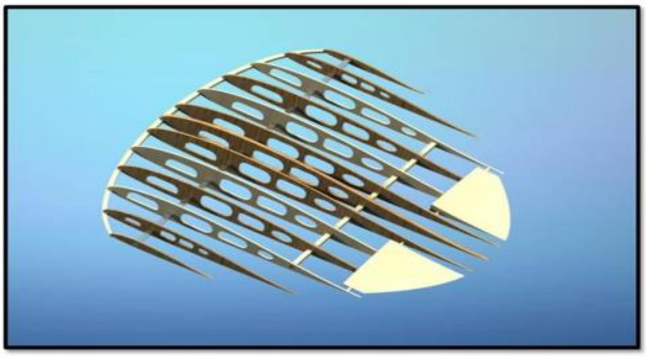

Fig. 6: Design of Wing

Table 5: Wing Parameters

	AR	**b**	**c**	**Sref**	**Swet**	**Vs**	**L**
Wing	1.45	0.8m	0.702	0.44m^2	0.89m^2	7.944m/sec	20.6N

➢ *Design of Fuselage*

In contrast to micro aerial vehicles, our unmanned aerial vehicle incorporates a fuselage based on our design configuration. However, we ensure adaptability, allowing for bespoke body design when necessary. Crafting the fuselage demands meticulous attention, adhering to the fundamental principles of aircraft fuselage design. Our primary focus lies in accommodating motor placement and payload within our design framework.

Various factors dictate fuselage design, including the installation angle, planform type, dimensions of equipment, battery positioning, centralization of the aircraft, tail configuration, and other pertinent parameters. For instance, if the planform necessitates the aerodynamic center of the wing to be positioned forward, aligning the center of gravity requires items to be placed ahead of the aircraft, necessitating the consideration of body length.

The design of the fuselage structure must adhere to several key objectives:

- Minimization of drag to enhance aerodynamic efficiency.
- Elimination of sharp angles to promote smooth airflow.
- Mitigation of any adverse effects on wing lift distribution.

Fig 7: Design of FuselageTable

Table 6: Fuselage Data

Parameter	
Fuselage body	Bluff body
Cross-section geometry	Circular
Fuselage length	0.4m
Frontal cross-section area	6.911×10^{-3} m^2
Payload bay cross-section area	5×1.5 m^2
Fuselage Structure	Ribbed structure

- *Payload Bay*

The following dimensions of pay load is final payload constraints. The above dimensional constraint of payload bay dimension is the internal dimensions of the boxthat should be equal to that of payload which must be fitted into the payload box.

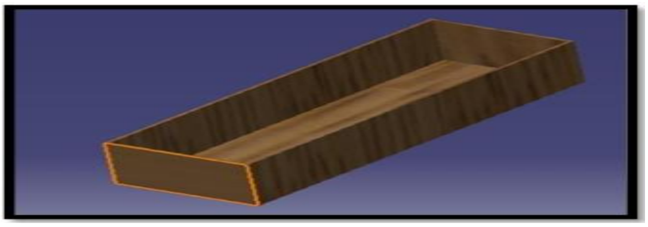

Fig 8: Pay Load Bay

D. *Design of Tail Section*

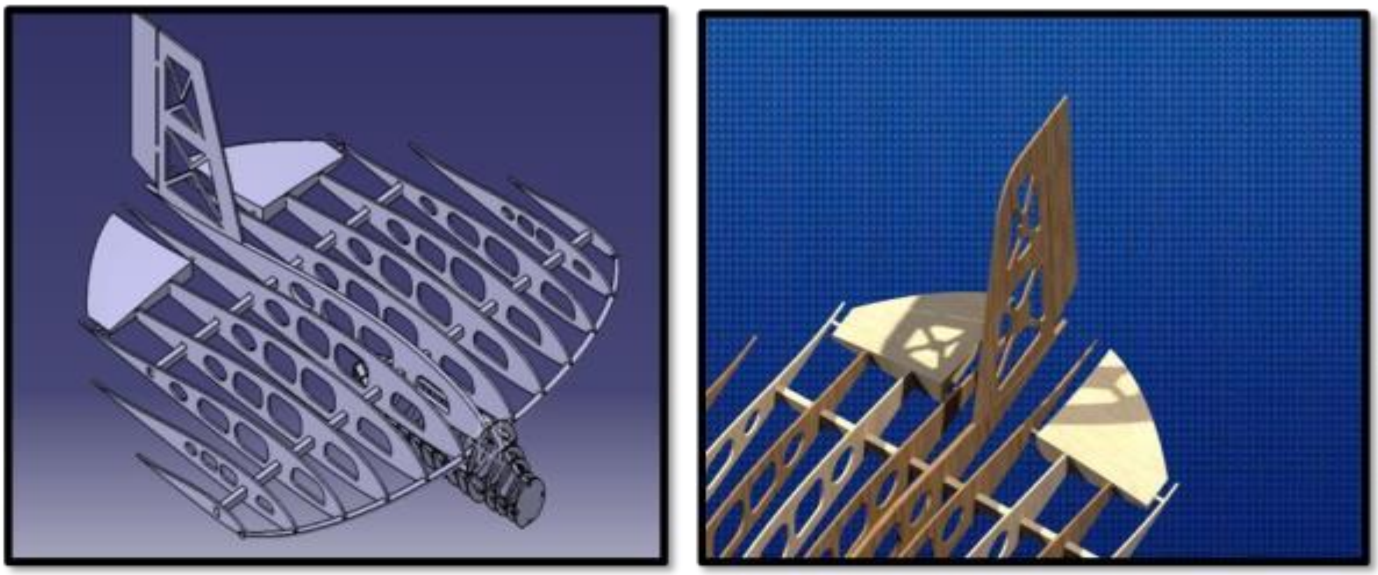

Fig 9: Design of Tail Section

- *Vertical Tail Design*

Aircraft configurations vary, featuring anywhere from one to three vertical tails, or even none at all. When designing the vertical tail, a critical consideration is its surface area, a key variable in tail design. In our design, the vertical tail takes the form of a fin positioned at the trailing edge of the wing. Serving as a stabilizing element, the vertical stabilizer is a fixed wing section tasked with ensuring aircraft stability and maintaining straight flight. Its primary function is to counteract side-to-side yawing motions of the aircraft nose, thereby enhancing overall control and maneuverability.

Table 7: Tail Dimensions

	AR	**b**	**c**	**St**	**Ct**	**Lt**
Vertical tail	*1.45*	*0.211m*	*0.1457m*	*0.0352*$_m2$	*0.04m*	*0.54m*

E. *Control Surface Sizing*

To determine the stability and maneuverability it is essential tohave an appropriate control surface sizing. Since the horizontal tail is not present the elevator and ailerons are on the same control surface and the rudder is set on tail fin.

- *Elevons Sizing*

A very fundamental and primary function of elevators and ailerons is to establish safe flight in longitudinal and lateral direction respectively. Elevons are also known as tailerons. The combination of functions of elevator and the aileron through the same control surface forms the name elevons. At the trailing edge of the aircrafts wing elevons are installed on each side. The elevons of the aircraft are controlled by the transmitter as though the pilot has separate aileron and elevator surfaces at his disposal. Elevon span is 15-25% of wingspan and 5 to 10% of root chord.

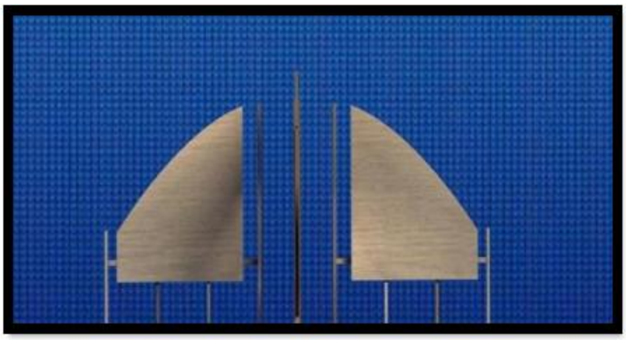

Fig 10: Elevon Sizing

Table 8: Elevon Sizing

	% of wingspan	**% of wing chord**	**b**	**c**	**S**
Elevons	*21*	*8.6*	*0.168m*	*0.0602m*	$17.58\times10^{-3}m^2$

➢ *Rudder Sizing*

Situated at the trailing end of the vertical stabilizer, the rudder connects to the fixed section via hinges. Functioning as the primary control surface for flight management, the rudder rotates around the vertical axis. Its main purpose is to regulate and induce yaw motions in the aircraft. Notably, the rudder does not directly facilitate turning during flight; rather, it adjusts the orientation of the aircraft's nose. Typically, banking the aircraft to one side, achieved through ailerons or spoilers, initiates a turn.

Ensuring proper alignment along a curved flight path is the role of rudder input. Without this adjustment, the aircraft risks encountering additional drag or potential adverse yaw conditions, where increased drag from control surfaces causes the nose to deviate further from the intended trajectory.

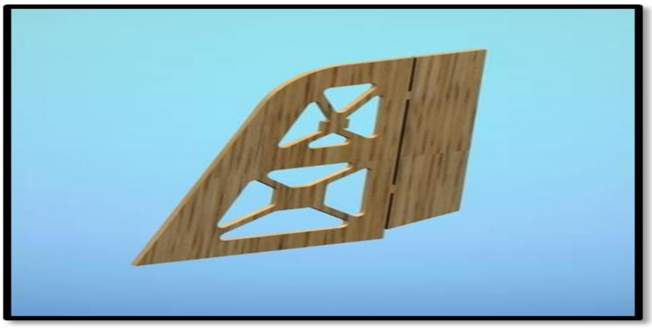

Fig 11: Rudder Sizing

Table 9: Rudder Sizing

	% of VT span	**b**	**c**	**S**	**Tr**
Rudder	*34*	*0.15m*	*0.051m*	$0.00765m^2$	*0.5*

F. *Drag Estimation*

As we know drag is an aerodynamic force which is along the direction of flow of the aircraft. From all the different types of drag, it is cut down to mainly two different types. They are parasite and induced drag. The drag force directly affects the power requirements, as the drag increases the thrust required increases by the overcome the drag force. Not only that higher thrust means larger propulsive system means more weight, hence drag is a huge factor. Since in our case we don't have horizontal tail, it reduces weight compared to other aircrafts with tail. Due to the aerodynamic nature of our aircraft, it decreases parasite drag.

Table 10: Drag Estimations

	Induced drag (C di)	**Parasite drag (Cdf)**
Wing	*1.406*	*1.85259*
Fuselage	-	*0.0161*
Vertical tail	-	*0.00683*
Total	*1.406*	*1.87552*
Total Sum	*3.28152*	

III. PERFORMANCE & STABILITY

A. *Servo Sizing*

The servo size depends upon the force exerted by the flow onto the control surface and the distance between the control surface and push rod. The above two parameters give us the approximate amount of torque required to deflect the control surface.

Table 11: Servo Sizing

Control Surface	**Force Generated**	**Control Arm Length**	**Torque Required**
Elevons	0.2 Kgs	1.5cm	1.58 Kg-cm
Rudder	0.17Kgs	1.5cm	0.1008 Kg-cm

B. *Take-Off Performance*

The aircraft can be held at the fuselage belly and can be hand tossed by troughing the aircraft. One of the members of the team vaayuputra remains inside the

Launched zone before and after releasing the aircraft. The unmanned aerial vehicle can be tossed while running for gaining the required airstream velocity. The aircraft needs minimum of 8m/sec velocity to be air borne and has velocity for cruise 11 m/sec.

C. *Level Turn*

Effective turning performance is crucial for aircraft navigating confined spaces or executing agile maneuvers. Key parameters defining turning performance, often stipulated in design requirements, include turn rate and turn radius, both of which can be characterized as either instantaneous or sustained capabilities. A sustained turn refers to the ability of an aircraft to maintain a consistent turn rate or radius over an extended duration, spanning minutes or even hours. In contrast, an instantaneous turn denotes a momentary capability where the aircraft can swiftly alter its direction, albeit with the potential for a subsequent decrease in maximum performance.

One of the most common turning maneuvers executed by aircraft is the level turn, wherein the aircraft maintains a constant altitude while altering its velocity vector to change direction within a horizontal plane. In a coordinated turn, the aircraft experiences zero sideslip, ensuring that the level turn remains primarily a longitudinal challenge.

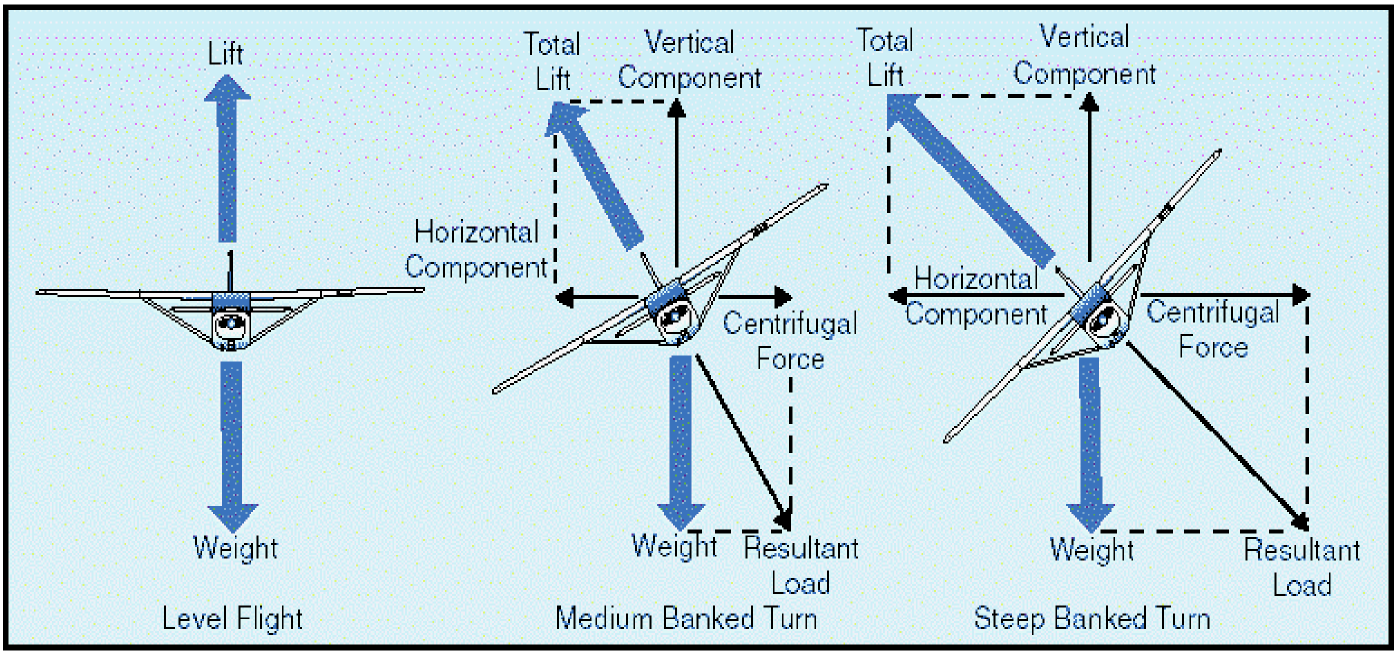

Fig 12: Level Turn Performance

D. *Stability*

The stability of the aircraft depends upon the location of the Center of Gravity from the Mean Aerodynamic Chord and it is recommended to maintain the CG of the aircraft at 25% of MAC which provides the most stable flight possible with better controllability of the aircraft.

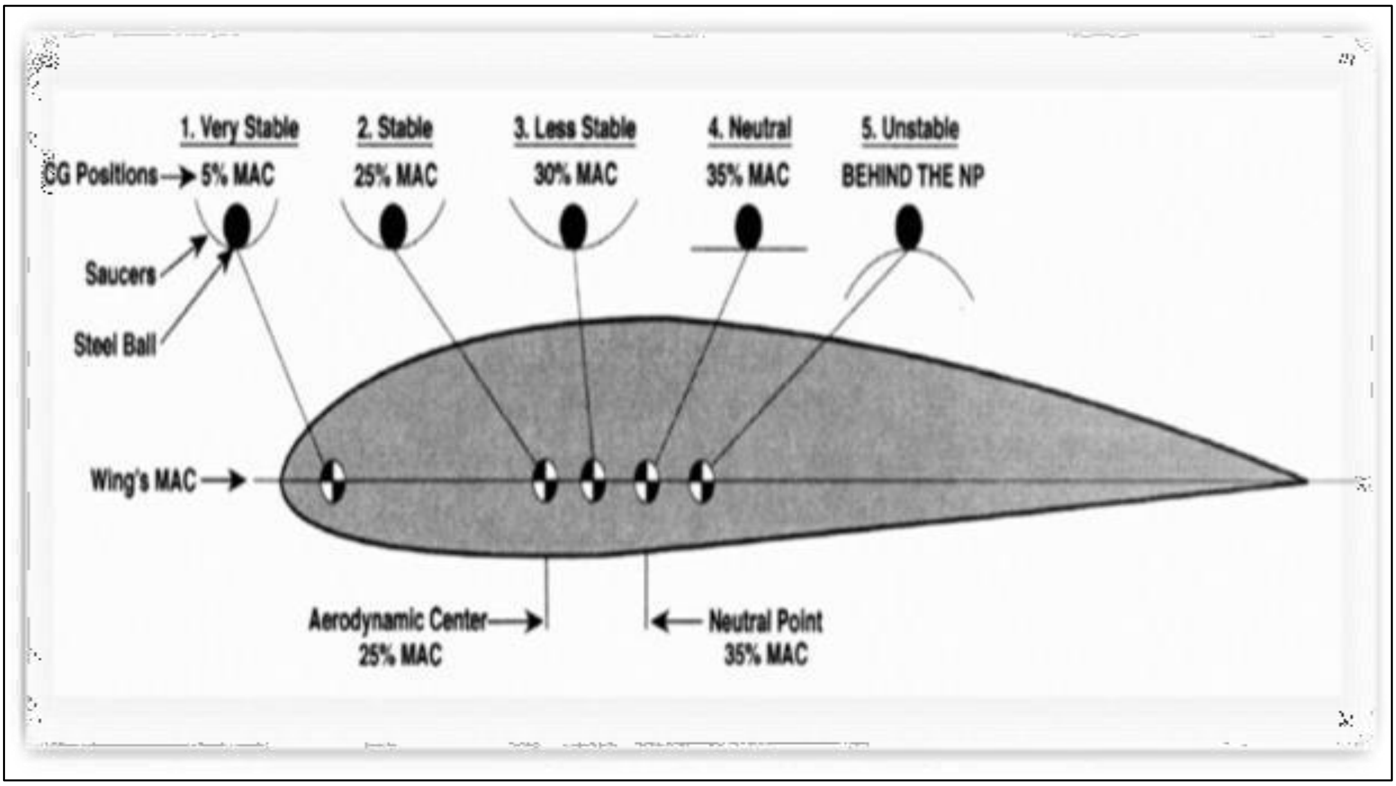

Fig 13: cg Location on the Mac

E. Power Plant Performance

Powerplant in our configuration is an electric motor which produces a trust of 2 kgs. Thrust to weight ratio directly affects the performance of the Aircraft. Higher t/w of the aircraft, more quickly the aircraft accelerates, climb more rapid, reaches higher maximum speed and sustain higher turn rates. As the aircrafts weight is constant throughout the flight, the thrust to weight ratio is constant.

IV. MODELING AND ANALYSIS

Our team has selected CATIA V5 for modelling for the required unmanned aerial vehicle and for the analysis has been done in Ansys and xflr5. These software's have helped gather engineering data for the given model.

A. Modeling

The designed model is the actual size of the aircraft not the scale down model of the aircraft. The complete design, the aero dynamic model and the structural model has been done using CATIA V5.

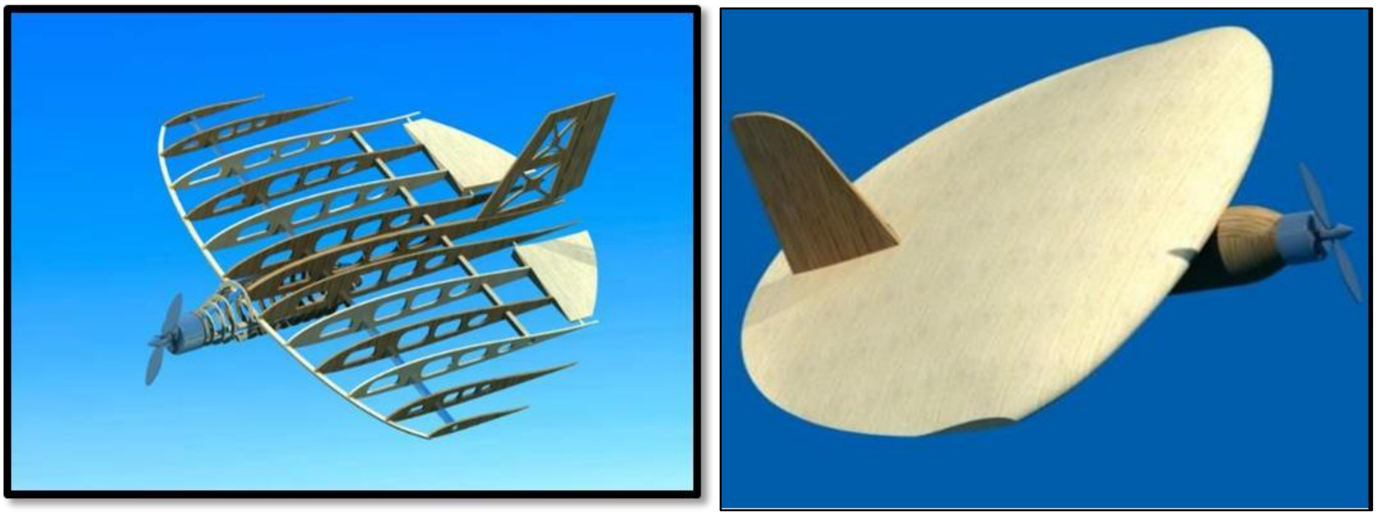

Fig 14: Structure of the Aircraft

B. Aerofoil Analysis

We can see from contours that there is a region of high pressure at the leading edge that is the Stagnation points and region of low pressure on the upper surface of airfoil. We know from Bernoulli equation that whenever there is high velocity, we have low pressure and vice versa. The simulation outcomes of static pressure at angle of attack 0° with spalart Almaraz model. The pressure on the lower surface of the airfoil was greater than that of the incoming flow stream. The result it effectively "pushed" the airfoil upward, normal to the incoming flow stream.

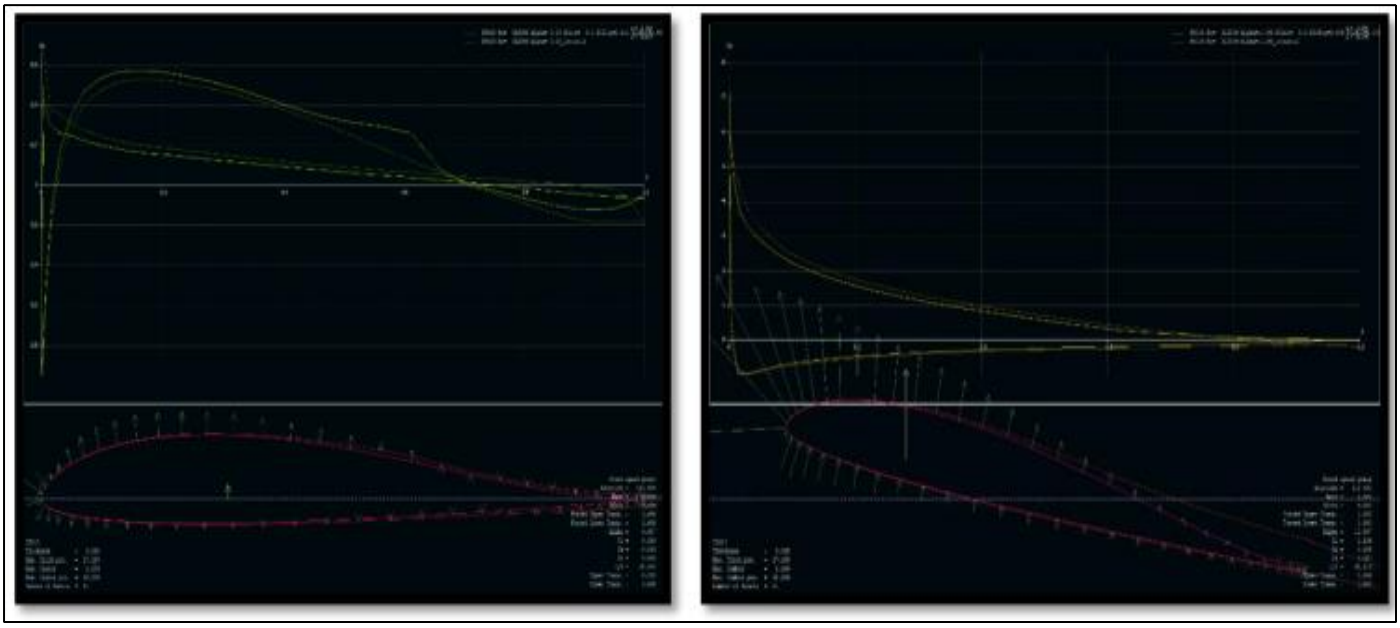

Fig 15: Analysis of Airfoil at 0° & 11°

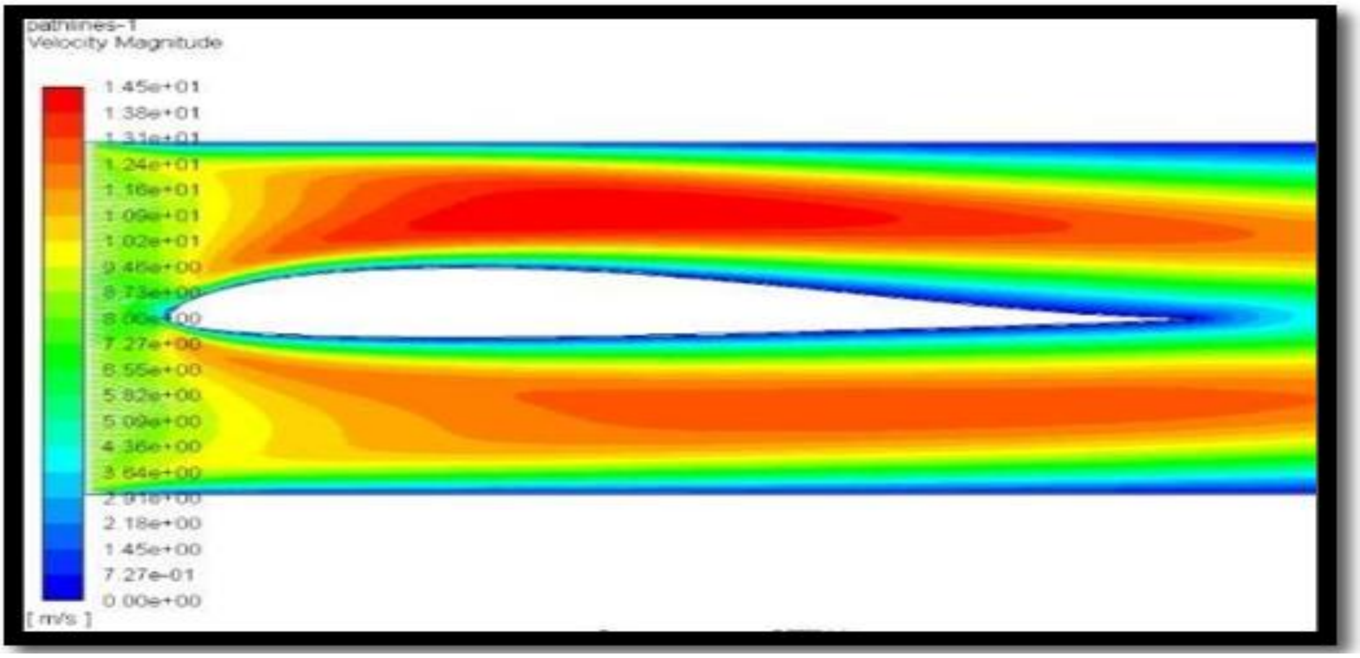

Fig 16: Flow Velocity Over the Airfoil

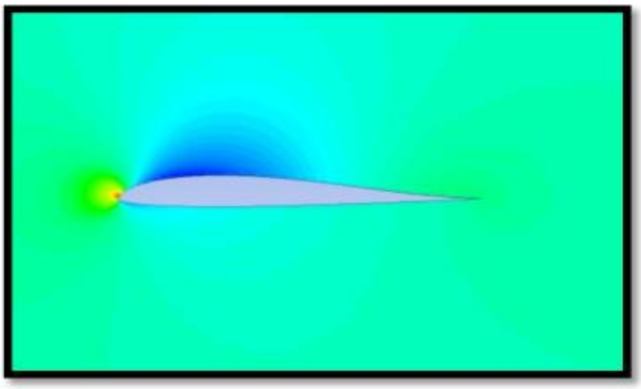

Fig 17: Pressure Contour of Airfoil

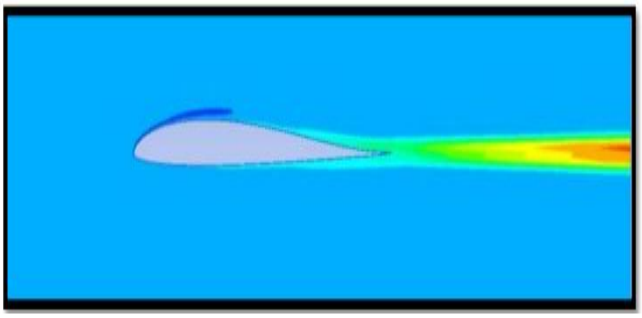

Fig 18: Eddy Vorticity Flow

C. Wing Analysis

The focus is to study and to understand wing design. A standard 3D wing validation has been completed before the designed wing analysis is performed. wing geometry has been modelled and full viscous flow has been calculated for the velocity 8 m/sec at angles of attack 0 to 11 at the same Reynolds number 3,12,000. The wing analysis has been done with xflr5 software and CFD ANSYS.

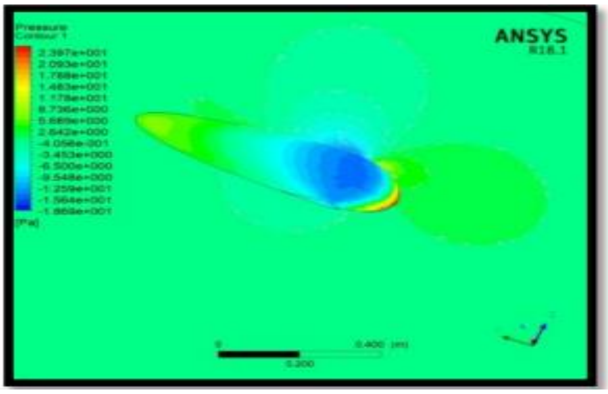

Fig 19: Pressure Contour of flow over wing

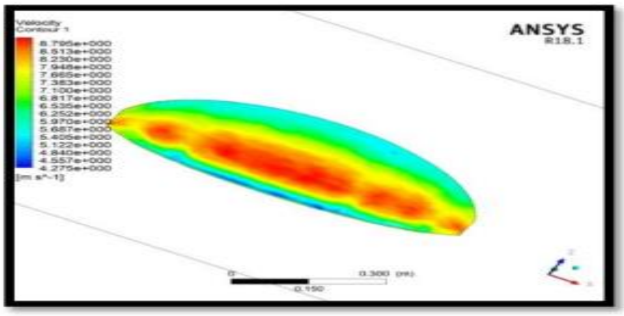

Fig 20: Velocity Contour of Flow Over Wing

The unmanned aerial vehicle CFD analysis has been done in Solid Works and ANSYS. To provide the aircraft an ideal design CFD analysis plays a vital role, qualitative and quantitative information congregated which helped us to verify airfoil selection wing and fuselage design prior to the time of consuming fabrication process. The lift, drag, stall angle and lift to drag ratio have been determined.

Since shape and design of an aircraft influences aircraft handling and controls. From the CFD analysis we can observe that the body is streamlined and has low drag with high lift. compared to other aircrafts with different wings.

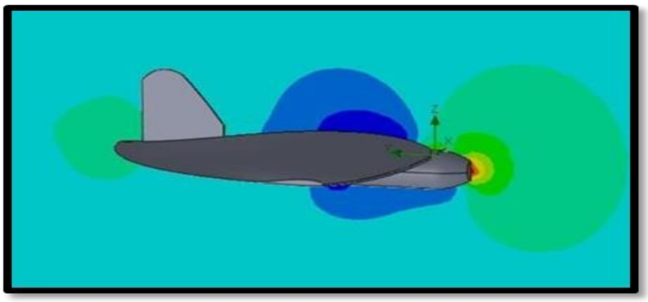

Fig 21: Pressure Contour of Flow

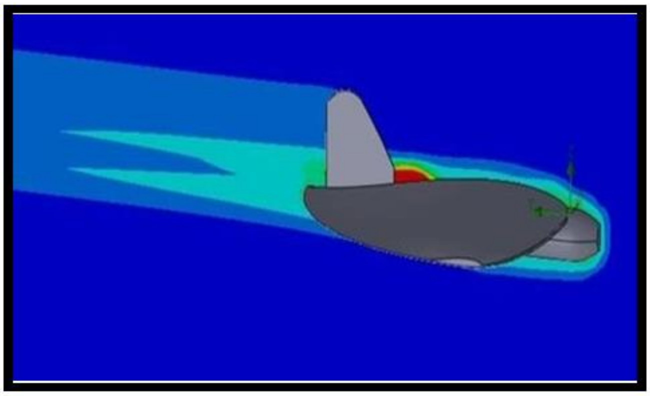

Fig 22: Velocity Contour of Flow

D. Structural Analysis

Structural analysis is the determines loads effecting the structure of the aircraft. Any structure subjected to external loads, it tends to develop internal loads and displacement due to deformation, these are determined through structural analysis. The main objective is to verify that 'unsafe' structural failure does not occur.

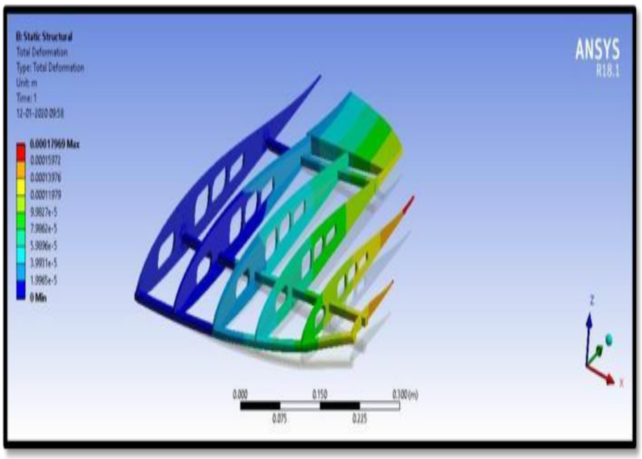

Fig 23: Structural Deflection of Aircraft

V. CONCLUSIONS

The conceptual, preliminary and detailed design phases have been finished and finalized by performing all engineering analysis. Since all the required data has been achieved with all performance estimations, the model has been fabricated. The following are brief overview of the design.

- Dimension (L+B+H) 3ft3
- Empty weight =1.2 Kg
- Aerofoil S5010
- Wing Zimmerman
- Payload 0.4 Kg
- Material Balsa, Plywood and Aluminum

The final model has achieved all the design objectives of team and SAE ADC 2020 and won championship in the event.

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