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An UAV with Twin Propellers Driven by Single Motor

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Abstract: ***As the technology is looping and far applications of UAV is improving so there is need to develop an UAV with optimum propulsive efficiency and also producing high thrust. So our mission is to build an UAV with twin propellers propelled by single motor. A fixed wing UAV which has a unique type of propulsion system. In this fixed wing UAV, two propellers are driven by single motor to enhance the propulsive efficiency. The bevel gear mechanism is the most important. This is the propulsion system for the aircraft model which runs the two propellers with a single motor. Bevel gears are used to transfer the power from the motor to the propeller. The bevel gear train is 80cm long through which a long shaft is passed that holds the bevel gears. Totally six bevel gears are housed inside the box which connects the motor shaft to the propeller shaft. The bevel gears are arranged in such a way that the when motor shaft rotates the propeller connected rotates both in opposite direction.***

Keywords : Unmanned aerial vehicle (UAV), Bevel gear, Twin propeller and fixed wing.

I. INTRODUCTION

The document provides an overview of design, analysis and manufacturing techniques of our final design. The objective is to design and fabricate an aircraft that complete all competition missions and is capable of lifting maximum payload as much as possible within the requirements specified by.

II. REQUIREMENTS AND CONCLUSION

Requirements and constrains laid down for regular class tabulated in Table 1.1 and criteria to select configuration for conceptual design.

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Table- I: SAE ADC -2018 Requirements and Constrains

S.No	Parameter	Requirement/Constrain	Remarks
1	Aircraft Type	fixed wing aircraft only	Good aerodynamic ratio (L/D)
2	Dimension	maximum combined length, width, and height (L+W+H) of 170 inches or 431.8 cm	required as per given dimensional and weight requirements
3	Wing Span	Maximum - 6 ft /1.8 m	High wing configuration
4	Empty Weight	Permissible - 2 to 5 Kg	for better clearance and
	Gross Weight	Maximum - 8 Kg	easy assembly
5	Material Restriction	FRP & Pb are prohibited	Metals, PLA, Wood shall be used as per availability
6	Propulsion Requirements	Electric propulsion only with 1 motor	
7	Battery	Required: Li-Po battery 4cell(14.8 Volt-6 cell(22.2 volt) i.e. Commercially available only	PrioritizePower plant during weight estimation and design structure accordingly.
8	Propeller	Metal Propellers Prohibited ,Safety nut or spinners are must	Commercially available plastic or wooden propellers
9	RC Transmitters	6 Channel 2.4 GHz radio must be used & properly powered	
10	Controllability	No excessive sloppy surfaces & FAA safety criteria must be satisfied.No Gyro assistance	Good controllability & manoeuvrability for all flight conditions at low altitude.
11	Landing	Ground roll- 122 m	Conventional configuration.
12	Take-Off	Ground roll- 61 m Time-out=180 sec	As lot of historical data is available to compare design and analyse it for evaluation
13	Payload	$4\times4\times10$ in^3 $+\frac{1}{8}$ tolerance made of any material with uniform mass distribution	For more internal volume rectangular fuselage cross section -4×6 in2

III. DESIGN PROCESS

The data mentioned in Table1 and mission profile shown in Figure 1 provided basic requirements for the design to initialize the design process. The Design is developed by increased payload capabilities as much as possible and maximizing the aerodynamic lift without compromising on performance.

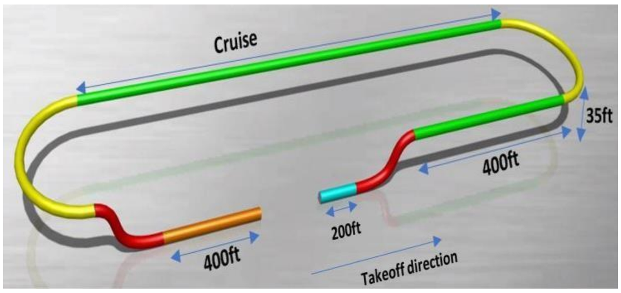


Fig. 1. Mission Profile

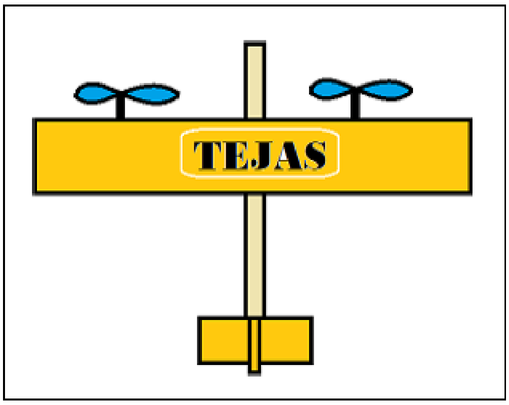


Fig. 2. Conceptual sketch

The preliminary source for the design stages of the project was decided after literature survey by referring various aerodynamic textbooks, course notes, and publications in the design of RC model planes and flight theory. In general design process starts with brainstorming and critical thinking by determining what configuration aircraft would be best for the specified requirements. A pull type twin propeller single motor aircraft with mono wing is selected for the competition.

IV. AIRCRAFT SHAPING AND SIZING

The following section describes about the engineering design selection process and several trade studies performed based on the research to achieve the objective.

A. WEIGHT ESTIMATION

An approximate weight of the total aircraft with respect to each component are tabulated in below table 1-2. An estimated gross weight of 5 kg is used to design the wing that will generate sufficient lift to lift aircraft.

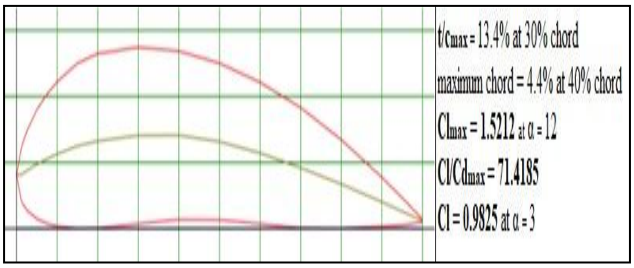
Table- II: Weight build up

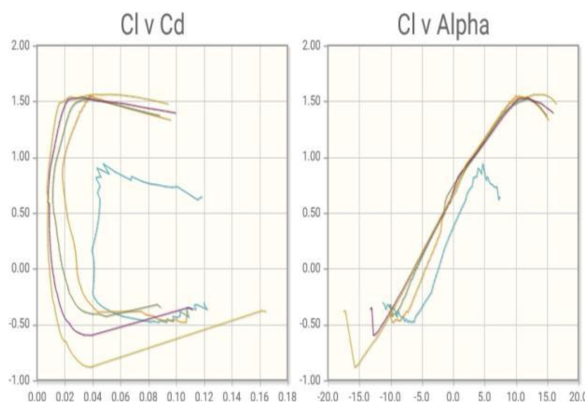
Weight of Components		
S.NO	***COMPONENT***	***WEIGHT (gr)***
1	Motor	600
2	Propeller	70
3	Servos	200
4	Servo Extensions	10
5	empty weight(full structure)	2000
6	Adhesive	100
7	Payload	500
8	landing gear	250
9	Hinges	10
10	R/C Receiver with Antenna	10
11	bevel gears SETUP	600
12	Li Battery 6-cell including ESC	600
	TOTAL	4950

B. AIRFOIL SELECTION

The selection of the Airfoil for an aircraft's wings is a crucial component to ensuring the aircrafts performance is good. Team researched and analysed the available Airfoil databases selected Daytonwright-t1 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 much higher lift at low Reynolds number (200000-300000). The Reynolds number is estimated Restall =1.43105E+05 and Recruise = 3.57105E+05. Characteristics curves are plotted for Re=200000.





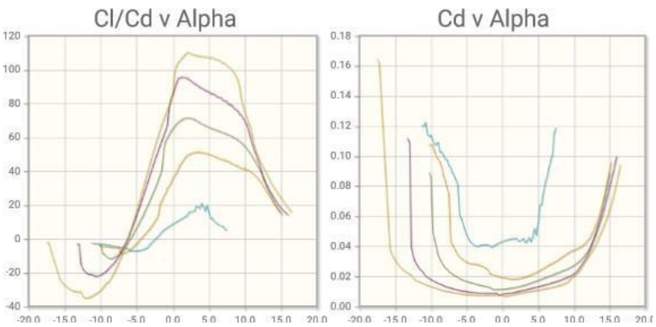


Fig. 3. DAYTONWRIGHT-T1 Airfoil characteristics and Profile

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.

D. ASPECT RATIO

Historical data states that aerodynamic efficiency is directly proportional to aspect ratio of the body and flow can be considered to 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 is considered for high aerodynamic efficiency and good landing performance. And the wing span is 6 ft. (1.8283m)

E. LIFT

Among several types of airplane configuration, it was decide to implement monoplane design with rectangular wing for ease in achieving the mission profile and precision in fabrication techniques. A high wing is suitable as it produces more lift than symmetric wing and has more stability. Maximum lift generated at cruise velocity at 18.62 is 58.86N.

$$L = 1/2 \times \rho \times v^2 \times S \times Cl$$

Table- II: Wing geometry and aerodynamic specifications

AR	6	
Cl	0.88425	α=3
Clmax	1.36908	
Airfoil	Daytonwright-t1	
bw	1.8288	m
Cw	0.3	m
Sw	0.54864	m²
Vstall	11.35	m/s
Vapp	13.62	m/s
Vcruise	18.62	m/s
L	58.86	N

F. EMPENNAGE DESIGN

Tejas decided to utilize a conventional tail for the empennage for the reason that it provides adequate stability and control and is minimum in weight when compared with other tail arrangements (H tail, T tail etc.). Thumb rules and volume coefficient method was used to size both the vertical and horizontal portions of the empennage.

G. HORIZONTAL AND 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 0.7315m.

$$Svt = \frac{Cvt\ bw\ Sw}{Lvt} \qquad Sht = \frac{Cht\ Cw\ Sw}{Lht}$$

Table-III: Horizontal and Vertical tail design specification.

HORIZONTAL TAIL		
Horizontal Surface area (SHT)	0.1125	m²
Span (bh)	0.4107	m
Chord (ch)	0.2738	m
Aspect ratio(ARH)	1.5	
SHT/Sw	0.2	
Vh	0.5	
Moment arm length(LHT)	0.7317	m

VERTICAL TAIL		
Vertical Surface area (SVT)	0.0411	m²
Span (bv)	0.2484	m
Chord (cv)	0.1656	m
Aspect ratio(ARV)	1.5	
SVT/Sw	0.07	
Vv	0.03	
Moment arm length(LVT)	0.7315	m

H. CONTROL SURFACE SIZING AILERON SIZING

The aircraft has a conventional control surface configuration with ailerons in front and an elevator in back. To determine an 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- IV: Aileron sizing

Span (ba)	Chord (ca)	Plan view area (Sa)	Sa/Sw	Ca/Cw	Ba/bw
0.914 m	0.075 m	0.068	0.12	0.25	0.5

I. 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- V: Rudder sizing

Span (br)	Chord (cr)	Plan view area (Sr)	Sr/Sv	Cr/Cv	Br/bv
0.2484 m	0.066 m	0.0164 m²	0.4	0.4	1.0

J. ELEVATOR SIZING

The chosen span for the elevator was the entire span of the horizontal tail. 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- VI: Elevator sizing

Span (be)	Chord (ce)	Plan view area (Se)	Se/Sh	Ce/Ch	Be/bh
0.410 m	0.068 m	0.028 m²	0.25	0.25	1.0

K. FUSELAGE DESIGN

Fuselage was designed in such a way that it can implement all the instruments and payload as well as to support all the components such as wings, engines etc. A rectangular fuselage constructed from balsa wood is permanently attached to the tail boom. The trussed structure was selected for its desirable structural strength and ease of construction. The fuselage of 5 x5 inch, which 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 75% of the wing span.

Table- VII: fuselage specifications

S.No	Parameter	
1	Fuselage body	Bluff body
2	Cross-section geometry	Rectangular
3	FRL(fuselage reference line)	1.24 m
4	FRL in % of wing span(bw)	75%
5	Frontal Cross-section area	2 * 2in2
6	Fitness Ratio	3.33
7	Fuselage Structure	Monocoque Structure
8	Internal Volume	0.53939 m3

L. SERVO SIZING

To determine servo capacity all hinging moments and Clcontrol are neglected as they are very low for considered flight geometry and operating Mach number. Objective is to equate servo motor torque to moment generated by control surface deflection

Table- VIII: Servo Sizing

SERVO SIZING			
DYNAMIC PRESSURE			
Dynamic Pressure	Q	352.8	Pa
AILERON			
Surface Area Of Aileron	Sa	0.0686	m²
Distance Of Aileron Form CG	La	0.1	m
Torque	Ta	0.5986	Kg/m³
ELEVATOR			
Elevator Distance from CG	Le	0.6	m
Surface area of elevator	Se	0.0332	m²
Torque	Te	0.4059	Kg/m³
RUDDER			
Distance of rudder from CG	Lr	0.6	m
Surface area of rudder	Sr	0.0255	m²
Torque	Tr	0.4887	Kg/m³

M. LANDING GEAR

Tricycle configuration is opted for this design as it gives more propeller clearance. Landing gears are must be designed to withstand impact load 43 N for 10.24 m impact-height of aircraft. Considering 2 as safety factor landing gear is designed with commercially available parts. Minimum cross-section area and width are determined to with stand these loads. Preliminary studies on tail dragger landing gear gave us some results, which are very near to the conceptual sketch made. The thickness of each wheel should be 0.033 m, and a wheel diameter of 0.073m. The diameter of tail wheel is 0.023m. Once wheel dimensions are determined, components with close resembles are brought and installed. These dimensions are sufficient to fulfil requirements.

Fig. 2. Main landing gear

N. POWER PLANT MATCHING.

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 19N so the minimum thrust required is 1.4 times the drag forces. The model is over powered by70%. In cruise

$$\frac{T}{W} = \frac{1}{(\frac{L}{D})max}$$

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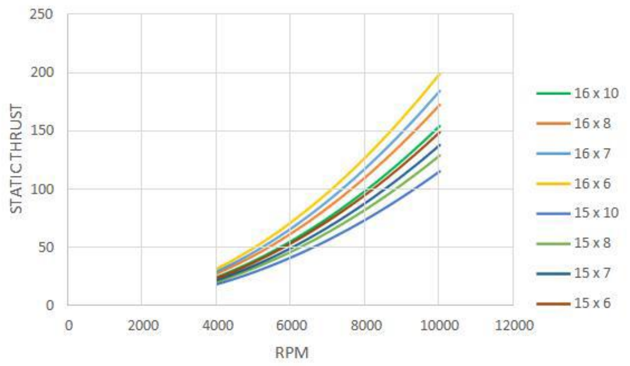
RPM vs STATIC THRUST



RPM vs DYNAMIC THRUST

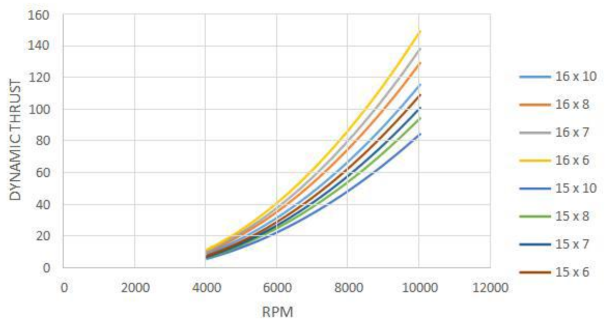


Fig. 5. propeller trade studies for dynamic & static thrust

O. BEVEL GEAR MECHANISM

The bevel gear mechanism is the most important. This is the propulsion system for the aircraft model which runs the two propellers with a single motor. Bevel gears are used to transfer the transfer the power from the motor to the propeller. The bevel gear train is 80cm long through which a long shaft is passed that holds the bevel gears. Totally six bevel gears are housed inside the box which connects the motor shaft to the propeller shaft. The bevel gears are arranged in such a way that the when motor shaft rotates the propeller connected rotates both in opposite direction. Below figure shows the arrangement.

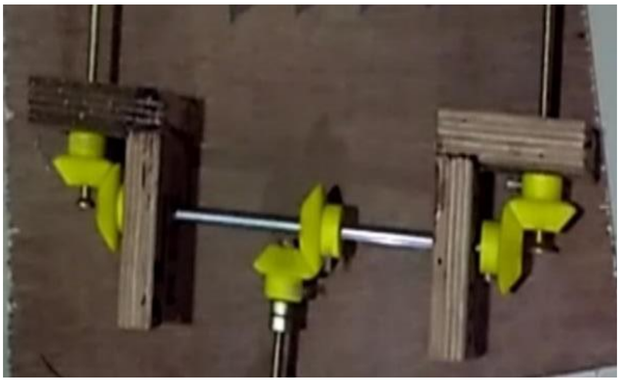


Fig. 6. bevel gear setup

P. SHEAR FORCE AND BENDING MOMENT DIAGRAM

Figure below shows the SFD and BMD of the wing. The estimated deflection of the Al spar of 12 x 12 mm^2 cross section area attached to wing is 7mm. Using the strip theory ribs, skin & spars are designed for each section of wing along wing's span such that optimized wing fulfils requirements just like a solid wing. The wing loading of the aircraft is 90 N which is close to the historical data for home built planes.

Thus has static structural stability.

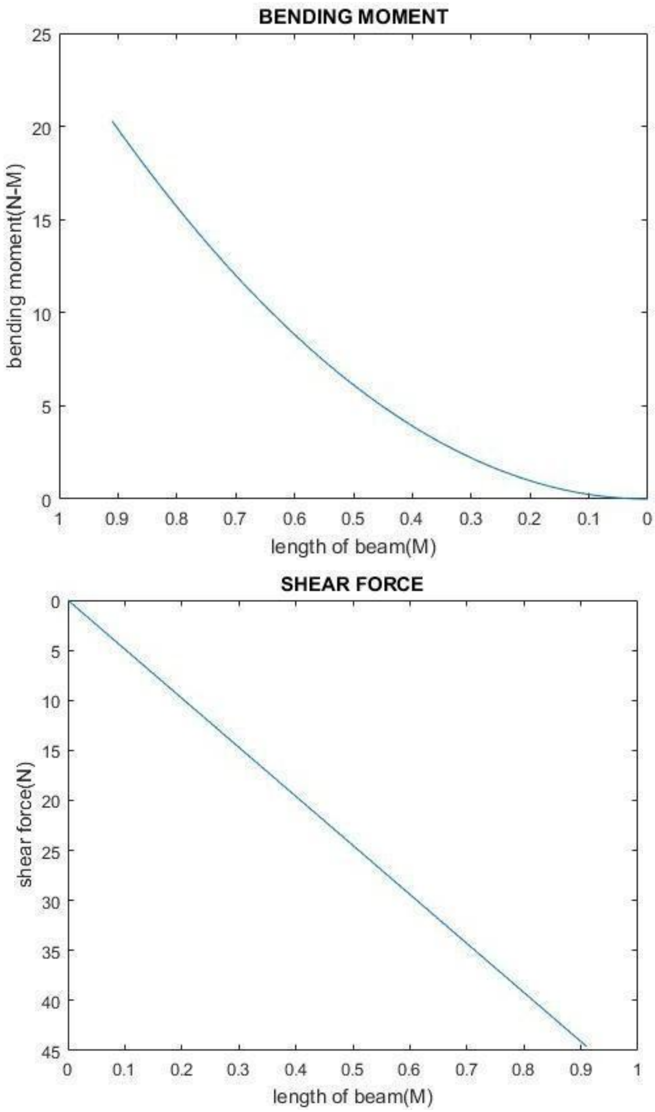


Fig. 7. shear force and bending moment diagram for wing

V. COMPUTATIONAL ANALYSIS

Structural and Computational fluid dynamic analysis of the designed aircraft was performed using ANSYS18.1. 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.

VI. STRUCTURAL ANALYSIS

Structural analysis of individual components of the aircraft are performed. ANSYS was used to analyse the structural integrity of all the components prior to the construction.

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A fine mesh with quad elements of minimum edge length of 1.1354e-003m is considered for accurate results. Static load tests were carried out on wing with ribs, spars and trussed structures by applying a distributed load along the lower portion of the wing, with the innermost rib fixed in place to simulate the effect of fuselage integration... Material selected is balsa wood and aluminium for spar which has isotropic elasticity by nature and its properties are given in table below.

Table- IX: Propertied of materials

Material	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
Aluminium	7.1e+010	0.33	6.9608r+010	2.6692e+010

The most crucial loading conditions were assumed corresponding to total distributed load of about 58N. The results of the study indicated that the wing is fully capable of carrying anticipated flight loads. Also, the maximum stress was distributed over the length of the aluminium Spar, which has a much higher yield strength than the balsa wood components. The wing stress distribution and deflection are shown below.

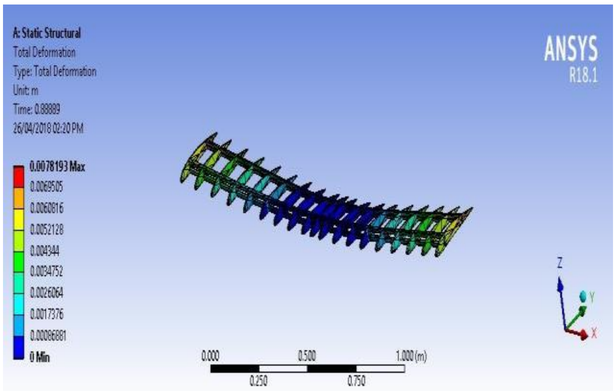

Fig. 8. Analysis of wing under Uniformly Distributed load undergoing deflection

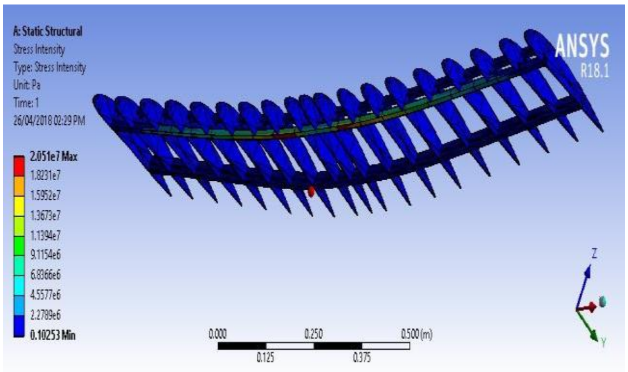

Fig. 9. Stress Intensity over the wing

VII. CFD ANALYSIS

The flow analysis is done on wing which is designed in Catia v5 and exported as an IGS format file to 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. Meshing is done as default meshing with quadrilateral and tetrahedral mesh elements which is unstructured mesh. Input parameters Viscous is set to laminar Cruise Velocity is 17m/s

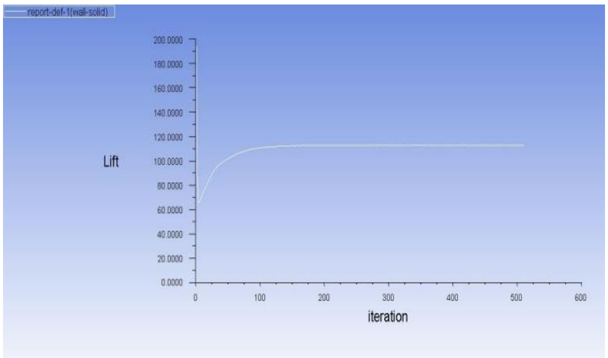

Fig. 10. scale residuals

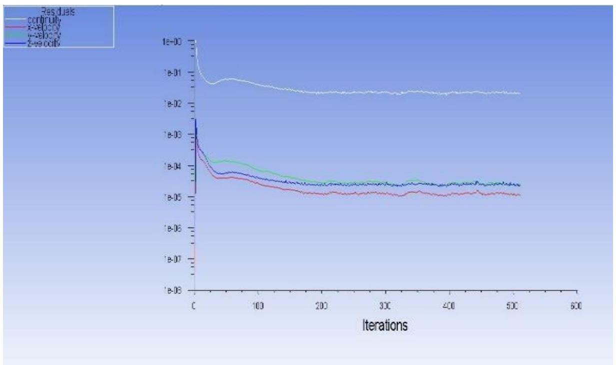

Fig. 11. Lift

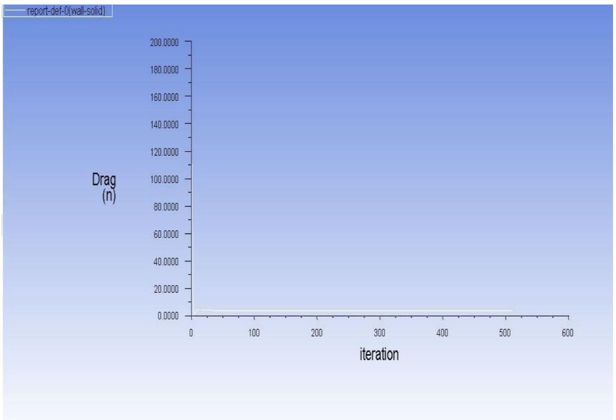

Fig. 12. drag iterations

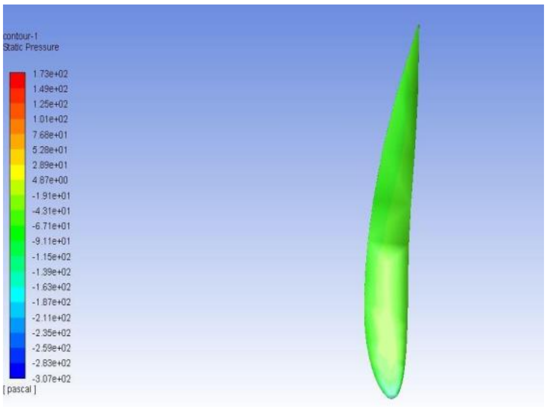

Fig. 13. Pressure distribution around Airfoil

```
Forces - Direction Vector (0 0 1)
                         Forces (n)
Zone                     Pressure        Viscous         Total
wall-solid               69.146609       0.0071589275    69.153768
------------------------ --------------- --------------- ---------------
Net                      69.146609       0.0071589275    69.153768
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Figure 3-11 Lift forces generated on wing

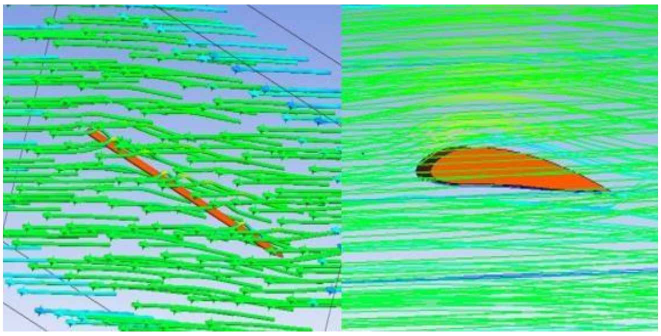

Fig. 15. Flow simulation over wing

The lift and drag and scale residuals are from the CFD results, the drag forces generated by individual components of the aircraft are tabulated below.

Table- X: Drag forces in CFD

S. No	Model	Drag Force (N)
1	Wing	3.53
2	Fuselage	1.84
3	Empennage	0.59
4	Power plant	4.33
5	Landing gear	7.13
	TOTAL	17.42

1. MODELLING & MANUFACTURING OF SUB-ASSEMBLY

Individual parts of the designed in CATIA V5. Manufacturing and construction play a crucial role in the weight and strength of an aircraft design.

The materials used for aircraft is balsa wood and all the parts were handcrafted using cutter. Sand papers were used to smoothen the surface. Glue is used to join the wooden parts with each other. Screws were used to set the bevel gears in a position. To get high stiffness and strength aluminium hollow rods are used. Covering film is used to mono coat the wing. The aircraft is assembled using temporary joints and fasteners.

VIII. PAYLOAD BAY

A payload box of 4 x 4 x 10 inches is made with balsa of 4mm thickness. Such that it can withstand the load. It is mounted just below the wing, so that payload can be removed whenever needed. This bay will be casted with homogeneous and uniform mass distribution. The payload loading and unloading is done from the fuselage top. A simple rectangular design that will fit snugly into the fuselage.

IX. FUSELAGE CONSTRUCTION

Fuselage bottom skin and longerons are designed with higher strength based on ANSYS reports such that they withstand mechanical loading due to landing gear, payload masses as well as the bevel gear propulsion mechanism. The fuselage consist of a rectangular body which will span a total distance of 48 inches from nose to tail. The dimensions of the nose are 2 x 2 inch and 5 x 5 inch at the payload section and begin to taper off roughly at 30 inches to 2 x 5 inch at the empennage. The fuselage is a trussed structure using 10 x 10mm balsa wood blocks. And film cover is used to monocot the structure. This design allow the fuselage to withstand the stress of landing with the load.

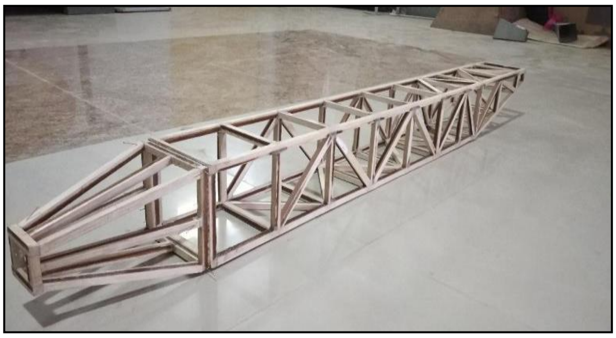

Fig. 16. Trussed fuselage structure

X. WING CONSTRUCTION

A conventional method and materials were used to build the aircraft's wing. Ribs were made out of balsa except for a few in high stress. Balsa sheet of 4mm thickness is used to make the ribs and are spaced 4 inch apart. A total of 18 ribs are used to design the wing. Two Aluminium hollow spar of 12 x 12 mm is assigned as spars as it has high strength when compared to balsa. The aircraft wing is continuous and is mounted on the fuselage using with elastic rubber tubes. The wing is covered with a see through layer of aircraft plastic skin i.e., covering film and the leading edge of the wing is covered with a thin layer of balsa referred to as planking.

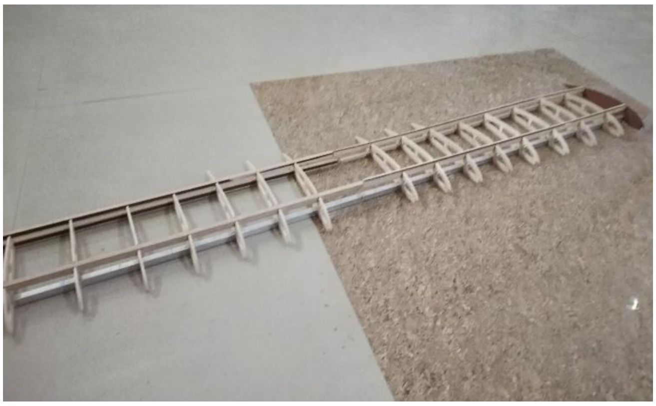

Fig. 17. Wing structure with ribs and spars

LANDING GEAR

Load transferred to fuselage due to landing gear and inertia forces due to payload weight are critical loads and thus margins are derived accordingly. The strength needs to be increased at the lower section of fuselage to sustain loads due to payload along with landing gear effects. Thus more material is added there to increase its strength by allocating more space for structure thickness at that corresponding area. It is evident from the draft to lower surface of fuselage is longer than upper surface unlike streamlined slender body fuselage.

TAIL CONSTRUCTION

A rectangular sheet of balsa is used to construct the horizontal and vertical tail. However it will be fixed relative to the body of the airplane. The vertical tail will be fixed to the horizontal tail. Its bottom will be fixed to the top of the fuselage by glue. The horizontal and vertical tail are made using balsa sheets and mono coated with a thin covering film. The leading edge of the tail is smoothened slightly circular and the trailing edge is to be thin. Such that the profile appears like an airfoil and flow separation is avoided

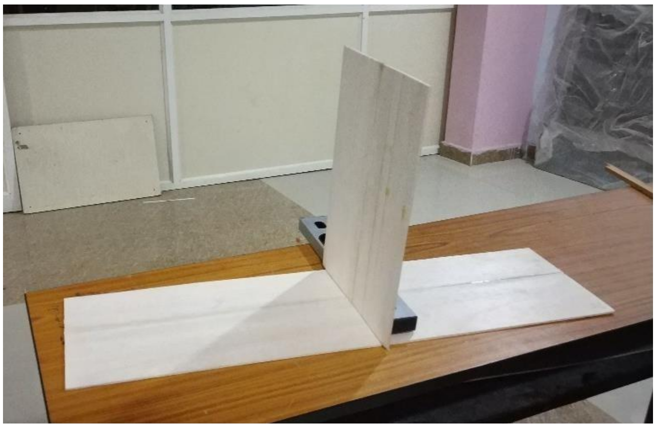

Fig. 18. Conventional tail

BEVEL GEAR TRAIN

The bevel gear train is the most important of all parts that houses the propulsion system of the aircraft. The bevel gear train is 80cm long with a cross section of 5 x 6 cm. because of the moving parts i.e. rotation of shaft at high RPM the body undergoes vibration. To sustain these and minimize the deflection, the box is made of hallow aluminum rods in order to reduce the weight and also increase the structural strength. The bevel gears are attached to the shaft with the help of screw and the shaft is fixed in the box in such a way that there is enough space for bevel gears to rotate freely. The box is fixed to the fuselage.

Fig. 19. Assembled Bevel gear train

XI. ELECTRONICS AND CABLE ASSEMBLY

A total of total of four servos are used to control the airplane's motion on ground as well as in mid-air through the usage of a remote control. Two separate servos will be used to control the ailerons since the ailerons will be deflected in different directions as well as more apart from each other. One servo will be connected to both rudder and the front wheel. Another servo will be connected to the elevators.

XII. MAIN ASSEMBLY

Finally the team mono coated the members to obtain the finest finish minimizing surface drag. Lastly the final preparations will be made in or to prepare 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

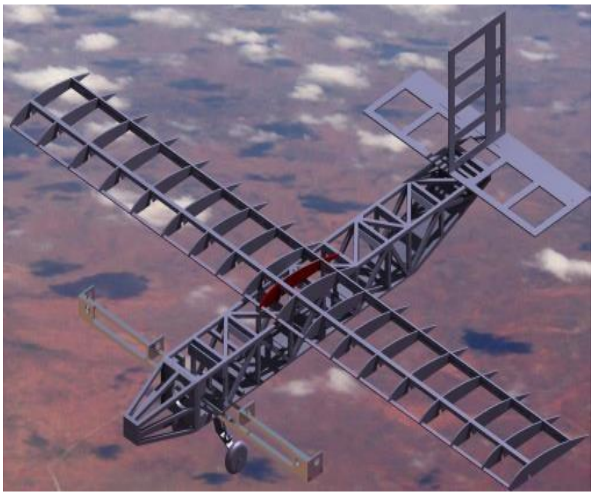

Fig. 20 Assembled model

XIII. CONCLUSION

An regular class aircraft has been designed, fabricated and tested as per requirements specified by the ADC competition. All the calculations are performed at standard atmospheric conditions at low altitude.

S.NO	Parameters	Requirements	Achieved
1	Wing span	<=6ft i.e. 72 in	72 in
2	Dimensional limit	175 in	148 in
3	Total weight	8 kg	Max 5 kg

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