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A Systematic Approach for Designing, Analyzing and Building a Model RC Plane

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***Abstract* - A radio controlled plane (RC Plane) is a small flying machine i.e. controlled by an operator on the ground using a hand held transmitter. The plane is controlled using a transmitter communicating with a receiver sending signals to servos onboard the plane. The aerodynamics governing these aircrafts is the same as those governing large aircrafts. The aircraft considered in this study was designed to have optimum lift and drag characteristics. This was achieved by choosing the optimum values of fuselage length, wingspan, elevator, rudder dimensions and the all up weight determined by a series of iterative analysis. In addition, the optimum angle of attack such that a stall condition doesn't occur was also determined. The modelling was done using commercial software CATIA V5R18. The analysis for determining the parameters of the plane was done using XFLR-5.The lifting line theory method was used in XFLR-5. This was also confirmed by the method of computational fluid dynamics using commercial software ANSYS (FLUENT) 15.**

Keywords - RC plane, Fuselage, Wingspan, Elevator, Rudder, Drag, Lift, All up weight, stall, and angle of attack.

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I. INTRODUCTION

The main aim of this project was to design, analyze and build an RC plane. This involves understanding the various aerodynamic forces and moments acting on the plane, choosing the right motors, controllers for its operations and hence making it fly. Hence this project involved optimization of various parameters for an enhanced flight. In order to achieve the stated objective, extensive literature review was done in determining the various parameters for building of the plane. Authors in [1] suggest development of a Canard type aircraft, with the mission of aerial reconnaissance and surveillance. Ryan et al [2] provide insight into flapping flight configuration that provided an insight into improved aerodynamic performance, improved maneuverability, and hover capabilities. Luca et al [3] provide a review of state of art with respect micro and nano aerial vehicles, which helped better understanding of different design and engineering principles for such vehicles. Reference [4] provided detailed information on RC controlled aircrafts design and build.

Based on all the literature review and available knowledge, it was decided to systematically design, analyze and build an RC plane. In addition it was decided to develop such a plane, to maximize the aspect ratio, minimize the wing loading and optimize the weight.
Basic terms like lift coefficient, tip, root chord, taper ratio etc help understand the aerodynamics of flight while movement of air over the airfoil help understand the behavior of flight in air. Keeping these considerations in mind the design and optimization were done.

The aim of this paper is therefore to explain the systematic methodology followed for designing, analyzing and building the RC plane including details of optimization. The following are the major steps in this process:-

- Selecting various design targets
- Selecting the type of geometry
- Optimization of parameters to obtain the best performance
- Determining the stress points, critical points on the wing and fuselage (for example - neutral point on the wing)
- Designing the fuselage, wing, elevator etc (using the appropriate airfoil)
- Analyzing the structure for its parameters
- Analyze and reiterate as appropriate

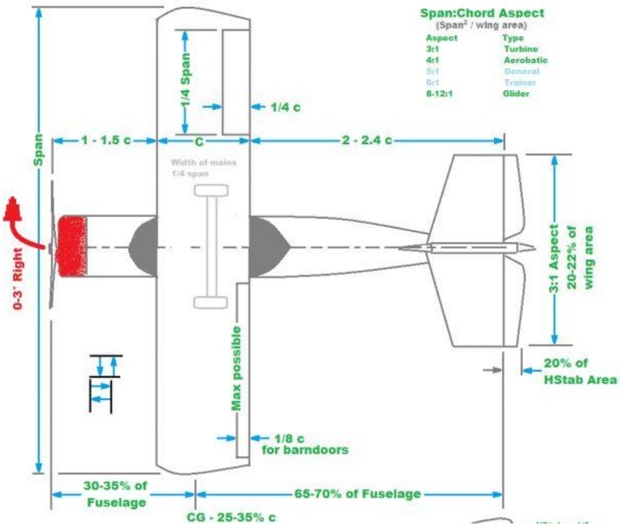

Fig 1 Basic Configuration of the RC plane [6]

Figure 1 shows the basic configuration of the RC plane and the various proportions of parameters which have to be used in order to ensure a balanced flight.

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II. CONCEPT OF STABILITY AND TAIL SIZING

Longitudinal static stability is the stability of an aircraft in the longitudinal, or pitching, plane under steady-flight conditions. If an aircraft is longitudinally stable, a small increase in angle of attack will cause the pitching moment on the aircraft to change so that the angle of attack decreases and vice versa. The nature of stability may be examined by considering the increment in pitching moment with change in angle of attack at the trim condition. The moment equilibrium condition is called trim, which is of general interest for considering the longitudinal stability of the aircraft. In principle trim limits could determine the permissible forward and rearward shift of the centre of gravity. Usually it is only the forward Cg limit which is determined by the available control, the aft limit is usually dictated by stability. A mathematical analysis of the longitudinal static stability of a complete aircraft yields the position of center of gravity at which stability is neutral. This position is called the neutral point. The larger the area of the horizontal stabilizer, and the greater the moment arm of the horizontal stabilizer about the aerodynamic center, the further aft is the neutral point. The static center of gravity margin (c.g. margin) or static margin is the distance between the center of gravity and the neutral point. It is usually quoted as a percentage of the Mean Aerodynamic Chord. The center of gravity must lie ahead of the neutral point for positive stability/ If the center of gravity is behind the neutral point, the aircraft is longitudinally unstable .This concept is used to find the neutral point and also the tail sizing.

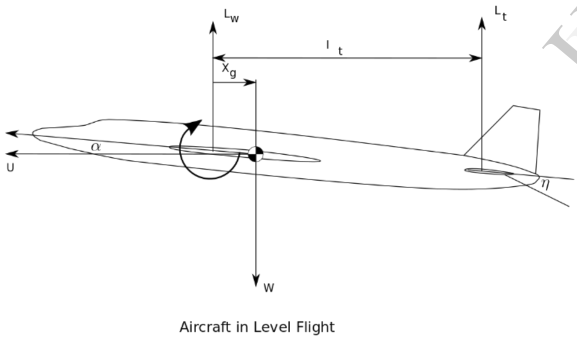

Fig 2 Concept Of Stability [8]

Equation (1) relates the moment with the Cg

$$M = L_w x_g - (l_t - x_g) L_t \quad (1)$$

Here x_g is location of center of gravity with respect to the aerodynamic center and L_t is the tail moment arm. Under trim condition equation (1) equals to zero and thus we can obtain the value of tail moment arm.

III DETAILS OF DESIGN

A. WING

Initially the parameters were chosen using the basic formulae of aspect ratio, taper ratio and then analyzed and validated using ANSYS15. The aspect ratio was chosen to be in the range of 6-6.5, the wing loading .46 - .55g/cm^2, surface area of the wing 1250 - 1350cm^2 and weight of the wing to be 500g.The all up weight, lift and drag forces, lift and drag coefficients etc were optimized on the basis of these design parameters. The aim was to maximize lift. The free stream velocity of operation was chosen to be 1500cm/s. Based on this the stall speed was also determined. Since it was chosen to make it an aerobatic plane a symmetric airfoil had to be chosen. Also in the region of the ailerons and wingtip a symmetric airfoil would help increase the range of angles of attack to avoid spin and stall. Thus relatively a large range of angles can be used without boundary layer separation. Hence NACA0016 wing configuration was considered. Here, the number16 indicates that the airfoil has a 16% thickness to chord length ratio. With this, the wing length was fixed at 90cm having a fixed chord length of 15cm.
Figure 3 shows the particular airfoil considered for the purpose of this study.

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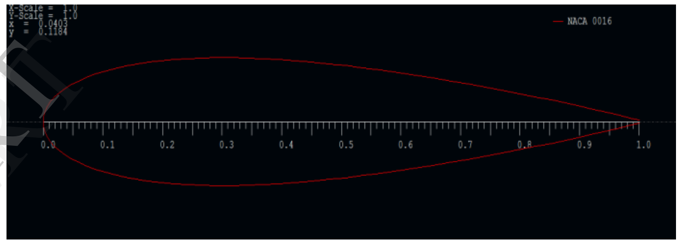

Fig 3 NACA0016 Airfoil

Further, an analysis of the airfoil was done and the neutral point (i.e. where the coefficient of moment is 0) was found to be at 3.47 cm from the tip of the airfoil. Neutral point is basically the point where coefficient of moment is 0 and it coincides with the centre of lift for a symmetric airfoil. Also, the centre of gravity must lie ahead of the neutral point for positive stability. This was since stability was required as explained earlier under stability.

The neutral point was found using XFLR-5 and validated using ANSYS15

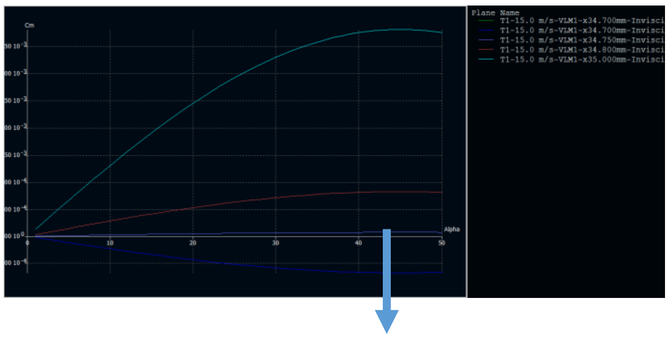

Fig 4: Graph of the coefficient of moment v/s alpha tending to a straight line

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Figure 4 shows the variation of the coefficient of moment v/s alpha. The neutral point was found to be 3.47cm.

Figure 5 shows the validated data from an ANSYS run confirming the location of the neutral point at 3.47cm.Since ansys is a more accurate software and values are obtained by the use of k-w turbulence module and good meshing procedures this value is used for all further calculations. Also the neutral point is found to lie between 3.47 and 3.48 since the moment changes its value from the current to +.00328.Hence 3.47 is taken as the approximate value

Moments -Moment Center (1 3.47 0) Moment Axis (1 3.47 0)

Moments

Zone	Pressure	Viscous	Total
Airfoil region	-0.028518209	-0.012876024	-0.041394233

Fig 5 Data from ANSYS run

The pressure forces acting on the airfoil were also analyzed in order to place the wing in such a way that maximum lift were to be obtained.

Figures 6 and 7 below show the pressure contours on the wing

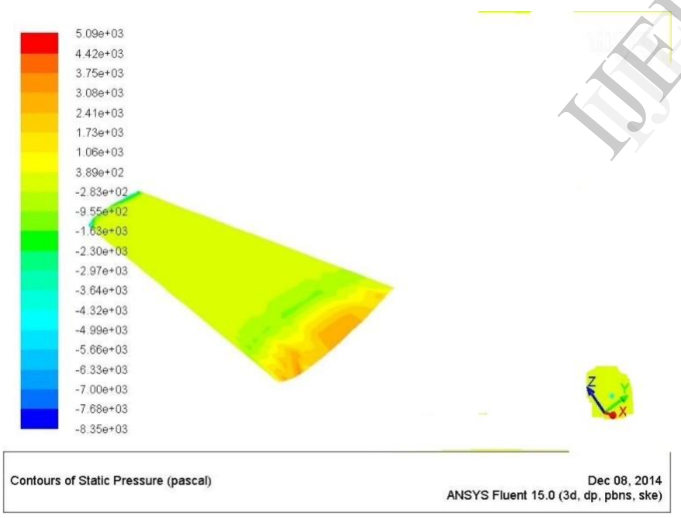

Fig 6 Pressure contour on the wing

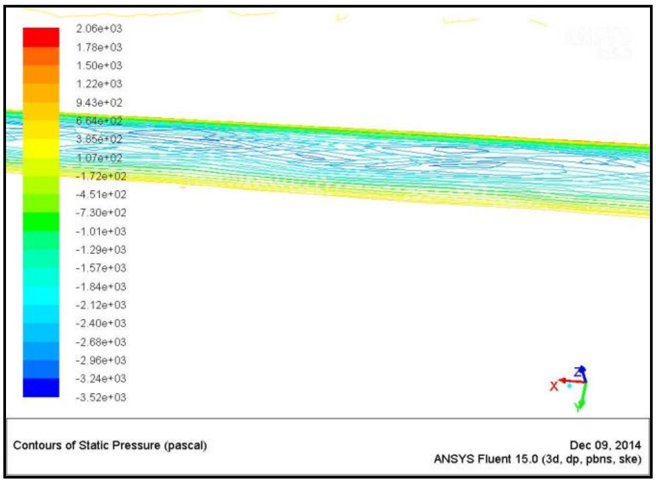

Fig 7 Pressure contour on the wing

The other parameters were chosen after a more detailed analysis of wing which involved batch analysis and determination of lift and drag forces which were all done with the help of ANSYS and XFLR-5 [5].

Figure 8 shows the static pressure distribution on the wing surface.

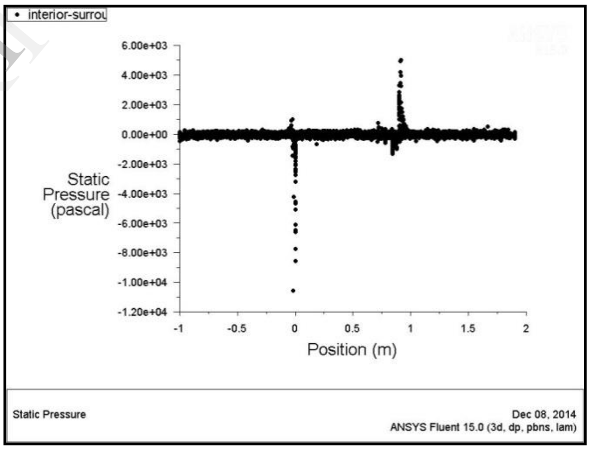

Fig 8 Static pressure on the wing surface

Figures 9 and 10, show the distribution of pressure and velocity of airflow on the wing surface. The velocity on the lower surface is lower than the velocity of air on the upper surface. This confirms that the pressure of air on the lower surface of the wing is higher and on upper surface is lower. Thus by Bernoulli's theorem this would help lift the aircraft.

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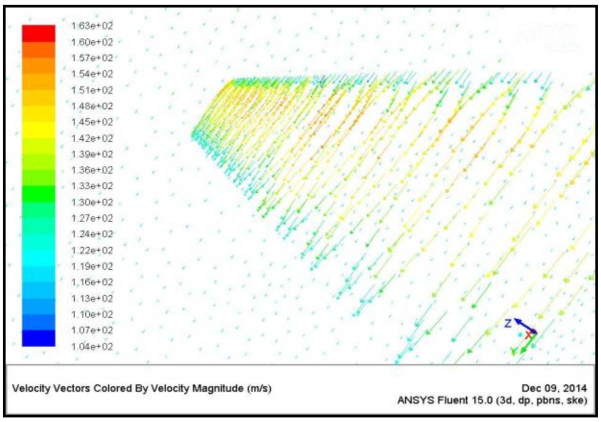

Fig 9 Wing analysis and airflow over the wing

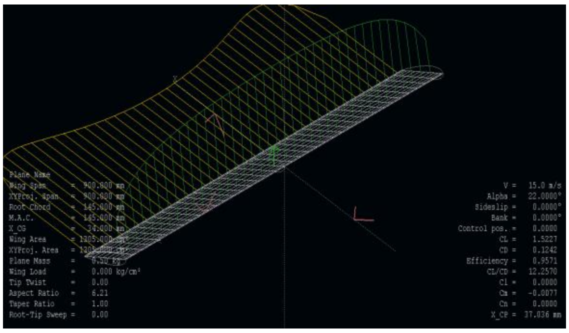

Fig 10 Wing analysis (C_L and C_D)

Figure 10 shows the wing analysis which helped to determine the lift coefficient (C_L) and drag coefficients (C_D) using XLFR-5. From this the lift and drag forces are estimated using equations 2 and 3 below.

$$F_L = (1/2)*\rho*v^2*C_L \quad (2)$$

$$F_D = (1/2)*\rho*v^2*C_D \quad (3)$$

Where, F_L – Lift force, F_D – Drag force, ρ – Density, v - velocity, C_L- lift coefficient, C_D – drag coefficient

Thus the lift and drag forces were found to be 129.375kN and 12.79kN respectively by using the above formulae. These were then validated in ANSYS software.

Figure 11 shows the data generated from ANSYS validating the values of lift and drag forces. (1 0 0) and (0 1 0) represent the direction of drag and lift forces. The data obtained for the lift and drag forces from ANSYS, 137.9kN and -11.364kN (negative sign due to opposite direction of force) validate the results from the formulae. Since XFLR-5 produces approximate values and ANSYS (Fluent) produces more accurate values due to the use of better models such as k-e turbulence model etc, the values obtained from ANSYS were considered for further calculations.

Forces - Direction Vector (1 0 0)

Forces (kN)

Zone	Pressure	Viscous	Total
Airfoil-region	-6.354	-5.009	**-11.364**
-------------------------	---------------	---------------	-----
Net	-6.354	-5.009	**-11.364**

Forces - Direction Vector (0 1 0)

Forces (kN)

Zone	Pressure	Viscous	Total
Airfoil-region	137.932	0.001	**137.934**
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Net	137.932	0.001	**137.934**

Fig 11 ANSYS Output of Forces

Based on all the above analysis, the wing was then designed for a lift coefficient of 1.15 and a wing of NACA0016 airfoil configuration having a wing span of 90cm and chord length of 15cm was considered. Then the same values were confirmed once again by a batch analysis.

Figure 12 from batch analysis confirms all the parameters related to the wing and its design.

Taking all these parameters into consideration the wing design was completed.

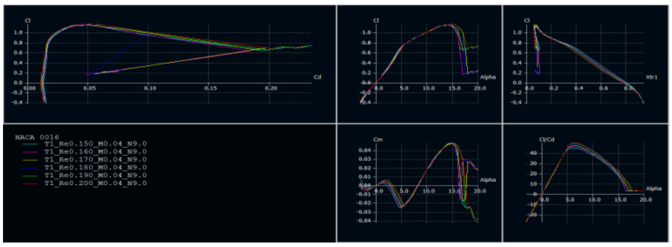

Fig 12 Results from batch analysis (analysis at a range of parameters)

B. *FUSELAGE*

Next the fuselage design and related parameters were to be determined. Extensive literature review and analyzing of various designs were done. The elevator and rudder dimensions were determined subsequently and the plane was modeled with the exact values in CATIA to determine the centre of gravity i.e. at which the entire mass is assumed to be concentrated.

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The concept used in determining the fuselage, elevator and rudder dimensions are as shown in figure 1 i.e. conventions to be followed for a balanced plane. Also the stall angle was obtained from the graph of C_L versus alpha and was found to be at 15^0 and hence the safe angle of operation was taken to be 10^0 - 12^0. The following were the additional parameters considered.

- Horizontal Stab: 20% - 25% of the wing area
- Elevator: 20% - 25% of the horizontal stab chord
- Vertical Stab: 7% -12% of the wing area
- Rudder: 30% - 50% of the vertical stab chord
- Fuse Length: 70% of wing span (measured from nose/thrust washer to rudder hinge line).

From this analysis the following dimensions were obtained. The length of the fuselage was optimized to be 65cm. The breadth of the fuselage was 7cm. From front till 40 cm along the length of the fuselage, the cross section is rectangular and then it converges to a trapezoidal cross section. The wing was mounted at 21cm from the tip of the motor mount. The battery was placed at the centre of gravity which was required for stability and balancing of forces of the plane. At the aft part of the fuselage the elevator and rudder were attached, dimensions of which were as follows.

C. ELEVATOR

The total length of the elevator was 25cm and width 4.5. The V shaped portions were found to be 14cm on both side and the last side of the trapezium to be 9.3cm.It was mounted in such a way that its centre coincided with fuselage centre line.

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D. TAIL SIZING

For tail sizing the concept of longitudinal stability was used. From this the dimensions were obtained. The moving part of the rudder was found to be 12cm in length and 4cm in width. 0.5cm was cut in order to allow its movement by the servo mechanism. The hinged part was of length 15cm and width varying from 7 cm at the bottom to 2 cm at the top. The attaching part was joined at a distance of 3cm from the base.

E. AILERONS

The ailerons were 6cm in width and 23cm in length. They were attached to the wing as per conventions in figure 1 i.e. at a distance of 8cm from the tip of the wing.

F. MOTOR MOUNT AND LANDING GEAR

The motor mount dimensions were 11 cm x 7cm i.e. same as the fuselage and 1cm on each side was bent in a near perpendicular manner so as to act as a mount on the fuselage. The landing gear was 11cm wide and 25cm long with the bent part bent at an angle of 120^0. The rear landing gear was made of 2 perpendicular strips of length 4cm and width 7cm. Figure 12 below shows the complete plane model in CATIA with the above parameters. This was then analyzed to obtain the coordinates of centre of gravity of the resulting plane configuration.

After determining the various forces acting on the plane, the plane was modeled to full scale parameters and then the prototype was built.

Figure 13 shows the full scale CATIA model of the resulting aircraft.

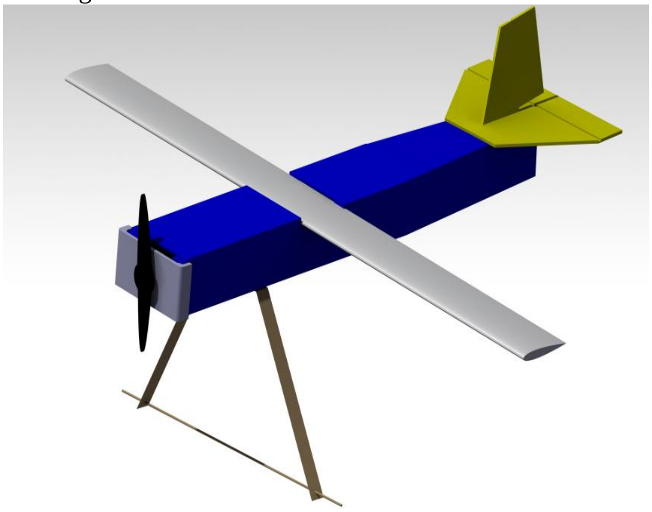

Fig 13 CATIA model of the plane

Component	Area [m^2]	Volume [m^3]	Mass [kg]	Gx [cm]	Gy [cm]	Gz [cm]
Fuselage	0.360	0.003	0.06	12.229	2.60933	-44.498
Motor mount	0.024	6.39363e-005	0.064	18.343	-46.188	-40.631
Landing gear	0.025	6.08716e-006	0.006	-109.908	93.036	-49.155
Elevator	0.066	0.000122566	0.123	53.653	6.24184	-36.649
Rudder	0.028	4.93731e-005	0.049	106.768	5.9531	-30.077
Wing	0.130	0.000548569	0.549	49.020	18.8569	-32.087
Propeller	0.009	1.6498e-005	0.016	22.243	-56.564	-43.627
Wheel axle	0.004	3.18086e-006	0.003	-229.629	89.668	-60.125
Plane	0.662	0.003	.87=870g	20.782	25.9370	-41.940

Fig 14 Centre of mass coordinates

Figure 14 shows centre of mass co-ordinates as generated by CATIA

Thus the position of centre of gravity was found to be at 20.782 cm (i.e. right below the wing) and the total mass of the plane to be 870g.

Thus the final parameters of the plane were as follows:-

- Length of half wing = 45.0cm
- Wing span = 90.0cm
- Breadth =14.5cm
- Aspect ratio = 6.21
- Total weight = 870g
- Weight of wing = 500g
- Surface area of wing = 1305cm^2
- Neutral point(with respect to the leading edge)= 3.47cm
- Stall angle = 12^0
- Velocity of plane = 1500cm/s

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- Stall speed = 880cm/s
- Airfoil used is NACA 0016
- Coefficient of lift=1.15
- Length of fuselage 65.0cm
- Drag force =12.79kN
- Leading edge of wing =21cm from motor tip
- Reynolds number range =100000 to 150000
- Mean aerodynamic chord (Ac) =25% of chord behind leading edge.

III. MANUFACTURING OF THE PLANE

After finalizing upon the parameters the process of building the prototype was started. These were the procedures adapted in building of various parts of the model

A. *WING*

Since the lift force was 137kN, a material which could withstand that force and was light weight had to be a chosen. Hence high density thermocol (of density 0.03g/cm3) was a considered a good option. Initially the wing was cut to 90cm using the technique of hot wire cutting and then sanded using high and low grade sandpaper to perfection to obtain the final shape. A spar made of metal was inserted (as shown in the final model at the end) in order to witstand impact forces.

B. *FUSELAGE*

The fuselage was primarily made of Corox a material like plastic. It was 4mm in thickness. The bonding was achieved using high strength glue. In order to provide additional stiffness or strength at stress point's thin strips of galvanized metal sheets about 1mm in thickness were cut and placed at stress points. These were the points where the landing gear was connected and the point that would be held during launch. A section (horizontal) was cut out to fix the wing in place.

C. *ELEVATORS RUDDER AND AILERONS*

The elevators, rudder and ailerons were made of the same 4mm thick Corox, since it had high toughness and could be rigid throughout the flight

D. *LANDING GEAR AND MOTOR MOUNT*

The front and rear landing gear were made of aluminum strips since they were proven to be light weight and sturdy to withstand the impact forces during landing. They were first bent at 120^0 to a length of 25cm as specified earlier .A motor mount was made of sheet metal (galvanized) and holes were driven to screw in the landing gear as well as motor mount onto the fuselage using nuts and bolts. It was bolted so as to prevent its movement and withstand the thrust produced by the motor basically to ensure that it didn't detach from the fuselage at any point in time.

IV. ELECTRONICS USED ONBOARD THE PLANE

A. *MOTOR*

The motor used was 110g in weight and worked on an 11V battery. A motor mount was made of sheet metal (galvanized) and holes were driven to fasten the motor onto it. It was bolted so as to prevent it movement and withstand the thrust produced by the motor. The battery was in turn connected to the ESC which was connected further to servos. The propeller was11''/7'' in dimension (made of carbon fiber) and was mounted onto the motor using a domed nut provided. The thrust required were calculated and the motor was chosen accordingly. Some of the specifications were as follows:-

Rotational Speed: 1050(kV) RPM/V
Motor Weight (Motor only): 110g
Motor shaft Diameter: .4cm

B. *ELECTRONIC SPEED CONTROLLERS (ESC)*

The ESC's are used to control the speed or thrust produced by the motor. It has 3 ends 2 of which are connected via Deans' plug to the battery and the other end to the receiver. The other 3 ends of the ESC are connected to the motor by soldering it using connectors of 2mm. This was then run to maximum throttle and the effect was noted.

C. *BATTERIES*

The battery used has a rated voltage of 11V and 2200 mah current. This was chosen depending on the time the plane could be airborne given the thrust produced by the motor which was the major current drawing factor apart from servos. It was found that the flight could last for 4-5 minutes with the use of 2200mah Lithium polymer batteries and was hence chosen.

D. *TRANSMITTOR AND RECIEVER*

To control the movement of elevators for takeoff and landing and also the throttle of the motor a 2.4 GHz transmitter and 6 channel receiver was used. In particular, 1channel was used for the ailerons, 1 for the rudder, 1 for the elevators and other for the motor. Two other channels were left free.

V. FLIGHT TEST AND PERFORMANCE

Extensive flight testing was done in different conditions which included different tail wind velocities. It was found that the plane didn't have major problems for designed flight duration of about 4-5 minutes. Also crash test was performed and it was seen that the motor mount detached as per requirement and the motor and propeller were saved. The wing due to a metal spar being used didn't suffer damage as more of the impact was observed by the spar. The corox material used for the fuselage was also saved due to its impact strength .The symmetric airfoil provided good maneuverability and not a very high lift (provided good lift upto stall condition and no stall occurred. The overall lift wasn't very high) as expected. The electronics combinations of motor, ESC, Servos also proved to be the right combination

VI. CONCLUSIONS

An attempt has been made to systematically design, analyze, build and fly a prototype RC plane. This project provided the team an insight into basics of aircraft design, engineering, building and testing albeit on a small scale. The team also could learn aircraft technology fundamentals and use design and analysis tools. The project also provided an opportunity for multi-disciplinary team to work together and understand the interactions. The teams also have been able to document the lessons learnt to be further used in the upcoming aerospace projects by the same team

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VII. ACKNOWLEDGEMENT

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The final plane - as built prototype model

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