Design and Analysis of Passenger RC Airplane

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***Abstract*- A radio-controlled aircraft is an unmanned aerial vehicle operated through a trans-receiver module – one located at the controller's end, other inside the aircraft. The following section discusses an RC aircraft mirroring a miniature cargo aircraft, The RC aircraft is equipped to perform tasks simulating payload and carrying stationary cargo. A RC aircraft poses similar engineering problems as involved in designing large scale aircraft, albeit at lower speeds. The airworthiness of a RC aircraft is established during the conceptualization, design and modeling, construction, assembly, and testing phases. Software's such as NX Cad 12, ANSYS-Fluid, and XFLR5 were used while developing an airworthy aircraft. Reinforcements of Carbon-fiber during assembly were integrated to make the structure light and sturdy.**

Index terms- RC Aircraft, lift, drag, Aspect ratio, Angle of attack, wing loading, passenger, payload

I. INTRODUCTION

The RC model aircraft resembles a passenger aircraft, expected to carry passengers (tennis balls) as well as their luggage (plates) & use motor for propulsion. The aircraft is powered by a 6-cell 22.2V Li-Po battery. The aircraft has to be designed optimally by considering subsequent weight & maximum power output from battery. Successive modifications were made wherever necessary to improve the design. The team's philosophy was to collect maximum revenue by designing an aircraft capable of carrying optimum number of passengers & the corresponding luggage. Recommended electronic components are installed in UAV to ensure safety of the aircraft & spectators.

The team's philosophy about building a radio controlled aircraft is instrumental in deciding a strategy to work with from the start. The team started with a crystal clear vision of developing an airworthy RC aircraft, nearly capable of enacting a commercial airplane. As pre-specified, it had to carry passengers along with their luggage. The team devised a project plan by evaluating the pros & cons, & then arriving at a preferable strategy, meanwhile dealing with competition restrictions, budget constraints, & various other environmental & technical factors. The following sums up the philosophy of team that consists of all the objectives taken into consideration while building the aircraft.

Design Objectives-

- To build a passenger/commercial model aircraft
- To successfully take-off, cruise, & land the aircraft
- To provide a safe & sound journey for the passengers
- To generate maximum possible revenue from the aircraft

II. PRELIMINARY DESIGN

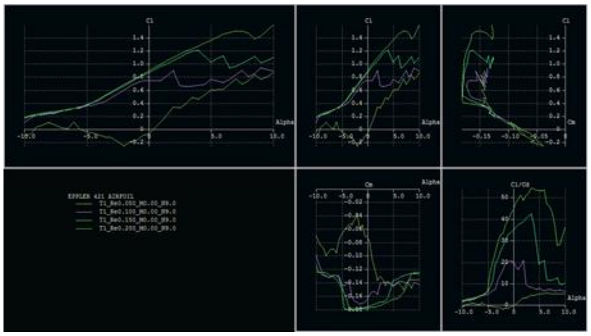
A. Wing Estimation:

Wings are used to generate lift. To estimate the wing parameters, a value for wing loading needs to be chosen. This is one of the most important parameters that not only decides the wing parameters but also plays an important role in the performance of the airplane. An initial estimate of 1.8g/cm2 is considered for wing loading as this is the approximate standard value for RC aircrafts. It is advisable to have an infinite aspect ratio as it provides enough surfaces to generate the necessary lift. From aerodynamic considerations, the aspect ratio should probably be in the range of 6-7. However, structural considerations dictate a moderate value for it.

- Wing loading = 0.256 lbs/in2, Aspect Ratio = 6 to 7
- Lift =CL * 1 / 2 * ρ * v2 * S= 31.81 lbs; where CL = 1.69
- Drag = CD *1 / 2 *ρ*v2 * S = 0.37 lbs

B. Airfoil selection:

Airfoil selection is very important step while the designing since the overall aerodynamic efficiency during all phases of flight depends on this factor. The airfoils are compared on the basis of CL, CD, CP, CG, thickness, range of angle of attack, etc. The comparison gives us an idea about the performance of the airfoils under different parameters &circumstances. The airfoils E423, E421, S1210 were considered for comparison purposes.



Graph. Airfoil Comparison

C. Fuselage Estimation:
Fuselage consists of components viz. payload bay, passenger cabin, motor, battery, etc. inside it. Fuselage should be compact in size but also have sufficient volume to accommodate the cargo & avionic components. The passenger cabin is designed to accommodate exactly 25 passengers (tennis balls) weighing 3.13 lbs. & their corresponding luggage weighing 12.5 lbs. The seats accommodate the passengers in the cabin whereas the cargo bay is located below the passenger cabin.
A monocoque design was thought to suffice the mentioned criteria. However, the truss structure would have an edge over the monocoque design in terms of ease of design. As the centre of gravity lies in the fuselage, the aircraft moments are about the fuselage& therefore, it has to be strong at the attachment points.

D. Landing Gear:
An ideal landing gear has to have a main landing gear carrying about 80% of the total weight. The landing gear has to be designed considering the total take-off weight force & landing impact force on each wheel. The landing gear has to take the entire load, & should dampen the impacts. The under-carriage provides strength against bending & should be strong enough to survive heavy impact loads. If possible, a suspension should be installed in the landing gear to bear the load while taking-off & sustain the shocks while landing. Tricycle, tail dragger, multi-bogey etc. are some prospects which could suffice the above specifications.

E. Empennage Estimation:
It is also known as the tail or tail assembly of the aircraft. Empennage is the rear section of the body of the aircraft. It trims& stabilizes the aircraft longitudinally & directionally. The empennage has a vertical section - stab & rudder, & a horizontal section - stab & elevator. The flight dynamics of yaw & pitch are controlled by these control surfaces. The tail area (horizontal & vertical) is dependent upon the wing area & tail arm moment. Larger the distance between wing aerodynamic centre & tail aerodynamic centre, lesser is the tail area, & vice-versa.

III. DETAILED DESIGN:

The final design is based on modifications made to the preferred configurations.

Components	Parameters		Dimensions
Wing	Span		100 in
	Root Chord		18 in
	Tip Chord		10 in
	Planform Area		1432 in^2
Empennage	Horizontal Tail	Span	30
		Root chord	12
		Tip chord	5
		Planform area	255 in^2
	Vertical Tail	Height	8.75
		Root chord	12
		Tip chord	7
		Planform area	83.12 in^2
Fuselage	Length		27 in
	Width		9 in
	Height		7 in
	Volume		3352 in^3
Landing gear	Wheel base		21.5 in
	Track width		12 in
	Height (from C_G)		11.5 in

Table. Detailed Design Overview

A. Wing:
The selected tapered wing has optimum cross sectional area for required lift. The tapered section

generates decreasing lift from root to tip & provides adequate roll stability to the aircraft. The high winged placement provides maximum stability. The wing has a safety margin of 0.16.The wing spans for 100in& the taper reduces the chord from 18in at root to 10in at tip. The wing's control surface viz. ailerons & flaps are 20in & 16in long, & 2in wide, respectively& are included within the wing chord. The controls provide adequate manoeuvre performance without risking the aircraft's stability. The following table depicts the wing parameters in detail.

Wing Parameters	Values
Wing loading	0.22lbs/in^2
Aspect ratio	7
Taper ratio (tip : root)	0.555
MAC	14.38 in.
Centre of pressure	10 in.
Wing C_G (from leading edge)	7.11 in.
Aerodynamic centre	3.575 in.

B. Empennage:

The T-tail configuration provides a stable option for the tail. It places the horizontal stabilizer above the wing wake region, thus keeping it out of oncoming turbulent air flow. Inverted Clark Y airfoil is selected for the horizontal stabilizer. Inverted airfoil provides nose up movement for the aircraft. It generates negative lift to stabilize the aircraft in cruise flight.

Horizontal stab - span 30in, root chord 12in, tip chord 5in, rib thickness 1.4in. Elevator - 30*2 in.

Vertical stab - height 8.5in, root chord 15in, tip chord 7in, thickness 0.5in. Rudder - 9*2 in.

The following table depicts other empennage parameters

Empennage Parameters	Values
Horizontal Aspect ratio	4.5
Vertical Aspect ratio	1
Vertical taper ratio	0.45
Horizontal taper ratio	0.5
Aerodynamic centre	2.245 in
Tail arm moment	45.5 in
Pitching moment coefficient	0.036

C. Fuselage:

Fuselage has monocoque structure (cylindrical).Use of formers & stringers results reduction in drag, &also no presence of sharp corners. The former radius is 4.5in & is made using balsa wood &aeroply sandwich. The fuselage has two bays one for tennis balls as passengers & another for payload plates as luggage. The passenger tray provides seating arrangement for the passengers & is 27.3in long & 7in wide. The seat (hole) diameter measures 2in in diameter. The tray can accommodate 25 passengers in 3 rows. The following table contains fuselage-related characteristics. The motor is mounted on top of the nose, to generate maximum speed through available thrust in the free air region.

Fuselage Parameters		Values
Skin friction		0.006677
Young's modulus	Balsawood	4.2GPa
	Aeroply	7.8GPa

D. Landing Gear:

The landing gear consists of nose gear & main gear. The total weight of the aircraft is supposed to be distributed so that 80% is barred by main gear & 20% is supported by the nose gear. This phenomenon is efficiently satisfied by the tri- cycle configuration. The material properties also play a key role in the efficient functioning of the landing gear. The materials that are used for the main gear is a composite of commercial grade aluminum tube, reinforced with balsa. The nose gear is made up of stainless steel alloy rods.

E. Avionics:

The team focused on finding light weight electronic components that would still provide the necessary power & performance characteristics. The following table summarizes the electronic components selected by the team.

Components	Specifications
Motor	420kV, Out-runner, BLDC
Propeller	15*8 APC propeller, 2-blade
Servos	8lbs torque @ 6V, 180^o throw
ESC	100 amp
Battery	6200mAh, 35C constant discharge, 70C burst current
Transmitter/Receiver	2.4GHz, 6 channel

IV. ANALYSIS

A. Analytical Tools:

The team used XFLR5 & ANSYS for the analysis of the aircraft. XFLR5 compares the airfoils & generates characteristic graphs, thus giving an idea about the lift & drag v/s AOA, coefficients of lift, drag, pressure, etc. It also gives a rough idea about the flow model & aircraft static & dynamic stability to some extent. ANSYS was heavily relied on during the design optimization process. CFD analysis is performed using ANSYS Fluent. It simulates fluid flow models in a virtual environment to generate specific results. Fluent results showed fluid flow & static & dynamic pressure graphs. Structural analysis is performed on the landing gear & fuselage using ANSYS Static Structural. It uses a finite element analysis tool to solve mechanical design problems, & predict model behavior during diverse flight conditions.

B. Developed Models:

The developed mathematical model is based on Navier-Stokes equation.

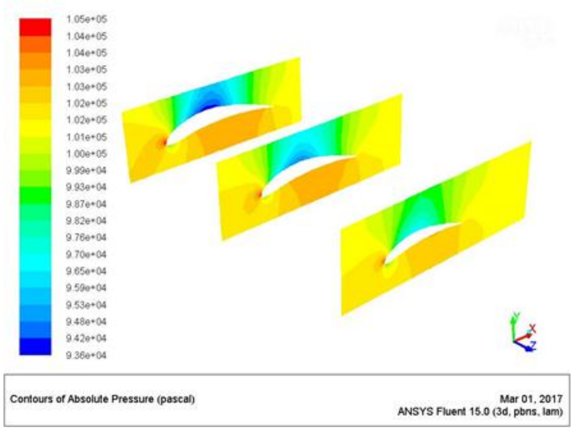


Fig. Absolute Pressure at root, taper root, tip

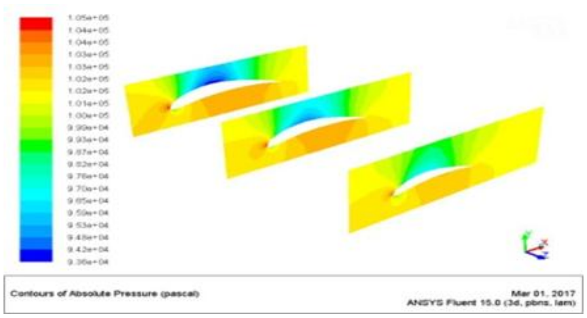


Fig. Velocity Vector at root, taper root, tip chord

C. Performance Analysis:

a. Avionics:

- No load current - 3A
- Maximum continuous current - 35A
- Maximum continuous power - 1000W

b. 5.3.2 Runway/Launch/Landing Performance:

- Take of Distance= 42.65 ft.
- Landing Distance = 35.1 ft.
- Take off Acceleration = 4.1 ft/s2
- Take off Velocity = 28.64 ft/s

c. 5.3.3 Flight & Maneuver Performance:

- Static Thrust = 11.9 lbs.
- Lift = 37.5 lbs.
- Drag = 1.75 lbs.

D. Dynamic & Static Stability

Stability of an aircraft is one of the most vital parameters of an airworthy aircraft. Static stability is the ability of an aircraft to remain upright when at rest, or under acceleration or deceleration. Static margin is a concept used to characterize the static stability & controllability of an aircraft. Dynamic stability is a characteristic of an aircraft body when disturbed from an original state of steady motion that causes it or when disturbed from an original state of steady motion in an upright position, to damp the oscillations set up by restoring moments & gradually return to its original state.

Static Margin = $(X_{Np} - X_{Cg})/MAC * 100$

$= 7.36\%$

The static margin defines the stability of the aircraft. Greater the static margin, more stable is the aircraft. However, it makes the aircraft less responsive to acrobatic maneuvers.

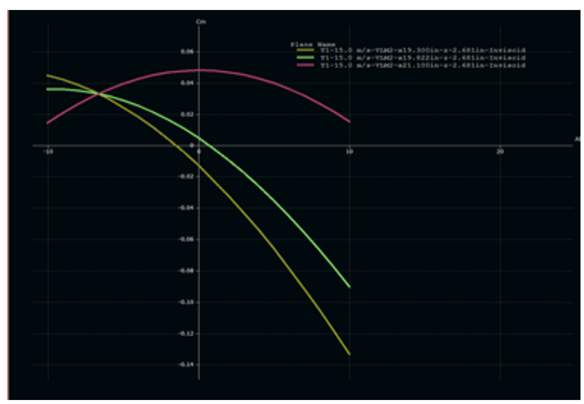


Fig. Static Margin

E. Lifting Performance, Payload Prediction, & Margin

The aircraft is designed to lift a load of 31.5 lbs. It maintains a safety margin of 0.2 which is crucial in deciding the safety of the aircraft. The aircraft has to operate under different circumstances depending upon the environmental factors. The lift generated varies with air density, moisture, etc. The calculated take-off lift approximately equals37.8 lbs.

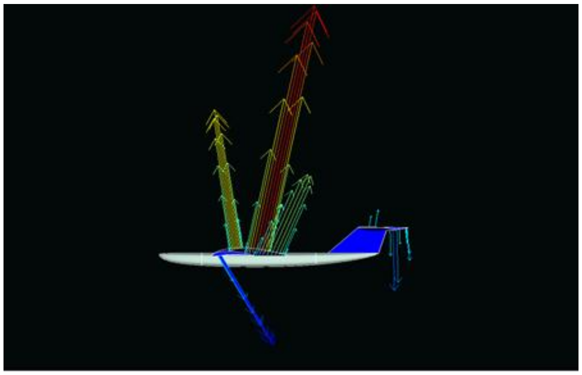


Fig. Panel Forces

F.Applied Loads & Critical Margins Discussion

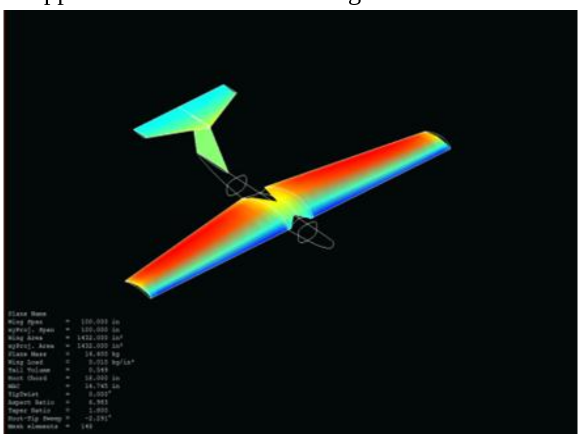


Fig. Load Analysis.

The load analysis of the aircraft is shown above with a series of assumptions; namely, wind velocity, inviscid fluid, angle of attack, etc.

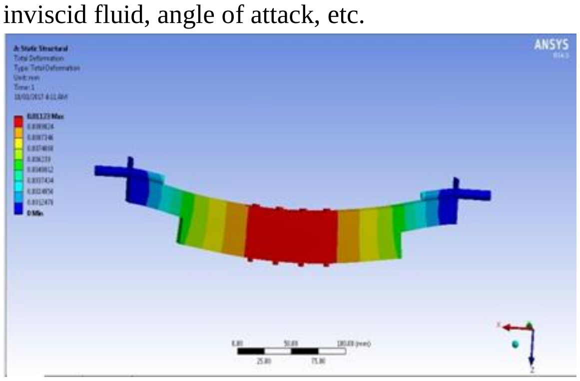


Fig. Main landing gear Load Analysis

The main gear is manufactured out of aluminum square tubes reinforced with balsa. Nylon wheels with rubber covering makes the wheels strong light weight& also provide necessary damping. Stainless steel 304 nuts & bolts are used to attach the wheels. The figure above shows the deformation of the main gear which is approximately 0.02 mm for the applied load of 34 lbs after applying a factor of safety of 1.5.

V. MANUFACTURING:

Material selection is of paramount importance while considering build up weight & cost. Materials are selected on the basis of properties, availability, manufacturability, & cost. The above mentioned components are manufactured after comparing every aspect of the potential choices.

A. Wing:

The wing is manufactured in three parts using balsa ribs. The cross section of the wing, i.e. airfoil is laser cut for high precision of the camber. To get the required profile accurately, the wing frame has 14 ribs on each part aligned &fixed on the wing spars using cyano acrylate adhesives. Two rectangular balsa spars are used to align & support the ribs on each part. The two wings are attached with the help of a balsa dowel of 1.10in diameter attached to the central wing part & passing through guiding pipes of 1.18in on each side part. The dowel has the central wing part attached to with the bottom edge flat & made of plywood. Moreover the dowel is covered by monokote to reduce wear. The leading part has a delta structure covered by balsa sheets & a spar of side 0.47in to avoid tearing due to excessive pressure of the oncoming air. The leading & trailing edges are burnished to curve the sharp edges. The ailerons & flaps are adjacently hinged on the trailing edge.

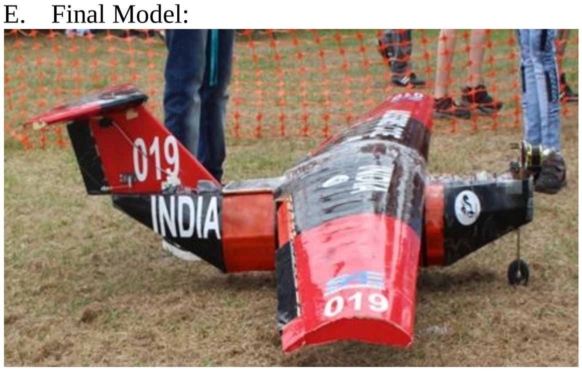
B. Fuselage:

The fuselage consists of 4 formers & 2 firewalls each of thickness 0.24in which are made of a composite structure of balsa wood & aero ply. 6 balsa spars are used to align these formers& firewalls. In order to reduce weight, the sides of the fuselage are covered by monokote sheet. Spars of sides 0.47x0.39in around the formers are on the circumference of the formers. The passenger tray having 30 holes in a single bay is placed above the cargo bay in the fuselage. Tennis balls (passengers) are placed in the tray in their respective holes (seats). It is attached using cyano acrylate adhesive to hold it in place. The top side of the fuselage is covered by aeroply sheet which is detachable to access the passenger bay. The cargo bay is at the bottom of the fuselage. A separate compartment is manufactured for the avionics in the nose of the fuselage to avoid electromagnetic interference & proper heat dissipation.

C. Empennage:
The T-tail configuration which comprises of horizontal stabilizer mounted on vertical stabilizer. Horizontal stab has an inverted airfoil frame & is manufactured in a single part with 12 ribs of balsa. On the other hand, vertical stab has a truss structure of 0.47in. Gussets hold the vertical stab through a notch at the aft section. The root rib of the horizontal stabilizer is clamped to the vertical stabilizer from both sides. Rudder & elevator are made of balsa wood & hinged using nylon ribbons to the end of vertical & horizontal stab respectively.

D. Landing Gear:
Aluminium, balsa & stainless steel are used to manufacture the landing gear. Nose gear, mounted below the fuselage's nose, made from Stainless steel& main gear uses aluminium tube reinforced with balsa. The nose gear has a spring like structure for damping the landing impact. The main gear is made of 20 mm side square aluminium reinforced with balsa to restrict bending moment. This ensures that the main gear does not deform under heavy loads. The wheels are nylon covered with rubber having diameter 5in. The wheels are directly attached to the landing gears using bushes & fasteners.

E. Final Model:



VI. CONCLUSION

The project concluded with successful flight tests of the aircraft, which tested its integrity & capability in standard environmental conditions. Along the course of the project, the team encountered a number of complications which taught us a lot more about aerodynamics, aviation & project management. As every aspect is crucial during designing & fabrication of a radio controlled aircraft, a scrutinized study was performed on every trait to ensure a thorough & full proof model with utmost stability. The project completed within a time period of 9 months with an approximate budget of Rs 100000. Through material selection & design optimization, it was possible to build the aircraft on a limited budget. The team was successful in replicating the design & function of a commercial passenger aircraft. To earn profit, it has to have low operating & maintenance costs & generate high revenue from the passengers.

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