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Design & Analysis of a Experimental 4 Channel Unmanned Aerial Vehicle

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ABSTRACT
The ever fast growing information technology is enabling a re-definition of the early stages of aircraft design which has been restricted to mostly statistical and empirical approaches because of lengthy and costly simulation times .The paper basically deals with designing a UAV by considering various parameters such as aspect ratio, taper ratio, power loading etc. During design, electronic components are to be considered and number of channels to be used is taken into account. Based on the above parameters a rough sketch of our aircraft is designed, later detailed calculations for each part of the aircraft is done keeping in mind of our objectives. In basic analysis, the main focus is on how various parameters such as lift, drag, co-efficient of lift v/s angle of attack etc behave on the wing. The basic analysis is performed using design foil software, analysis is done in order to check the theoretical calculated value matches with the nearest value obtained in the software and also to place the wing at desired angle of attack for the aircraft to achieve stable flight, it is also corrected for errors if any. Finally our own prototype manufactured is displayed & tested practically.

Introduction

A radio-controlled (model) aircraft (often called unmanned aerial vehicle/UAV) is a flying machine that is controlled remotely by an operator on the ground using a hand-held radio transmitter. The transmitter communicates with a receiver within the craft that sends signals to servo mechanisms (servos) which move the control surfaces based on the position of joysticks on the transmitter. The control surfaces, in turn, affect the orientation of the plane.

Flying UAV as a hobby has been growing worldwide with the advent of more efficient motors (either electric and miniature internal combustion or jet engines), lighter and more powerful batteries and less expensive radio systems.

Scientific, government and military organizations are also utilizing unmanned aerial aircraft for experiments, gathering weather readings, aerodynamic modeling and testing, and even using them as drones or spy planes.

Aim

1) Building a stable aircraft.
2) It must have good maneuverability
3) Most likely to be a monoplane
4) It should be a high winger with conventional tail design.
5) It should have 4channels
6) The aircraft must have just a basic look and it should have good strength.

Basic Design Concept

Utilizing the idea of a classic airplane along with the above requirements, referring to many classic monoplanes such as cessna skylane, piper cub, Fokker trimoter airliner etc an emperical formula in calculating various dimensions for our own aircraft was derived and computed. We designed our aircraft for experimental purpose and to achieve the above said objectives, hence gave it a basic look.

Design Methodology

The design methodology basically has 5 phases:

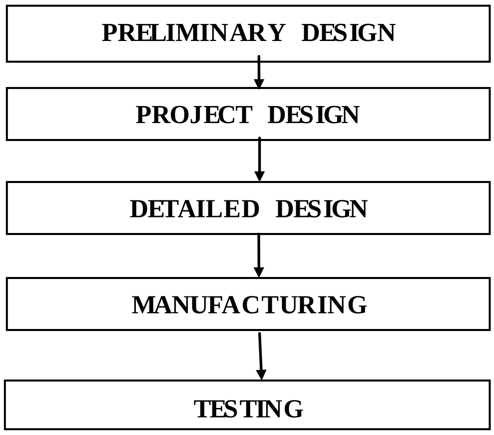

Fig 1. Design flow process chart.

Parameters to Be Considered While Designing an Aircraft

In order to consider different parameters the aircraft must be split into various categories of components, such as:

Wing design

Eighteen parameters must be determined in wing design, they are as follows:

1) Number of wings: It is basically the number of wings to be used in the aircraft. Ex: monoplane, biplane, tri-plane.

2) Vertical position relative to the fuselage (high, mid, or low wing): One of the wing parameters that could be determined at the early stages of wing design process is the wing vertical location relative to the fuselage centerline. This wing parameter will directly influence the design of other aircraft components including aircraft tail design, landing gear design, and center of gravity.

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3) Wing configuration (straight, tapered, delta etc): It is basically how the wing is shaped i.e. whether it is a tapered wing, a straight wing or a delta wing. It basically portrays the top view of the wing.
4) Span (b): wing span or just span is the length of the wing. The wingspan of an aircraft is always measured in a straight line, from wingtip to wingtip, independently of wing shape or sweep.
5) Wing area (SW or Sref or S): the projected area of the planform and is bounded by the leading and trailing edges and the wing tips.
6) Aspect ratio (AR): Aspect ratio (AR) is defined as the ratio between the wing span b and the wing Mean Aerodynamic Chord (MAC). The Aspect Ratio of a wing is defined to be the square of the span divided by the wing area and is given the symbol AR. For a rectangular wing, this reduces to the ratio of the span to the chord length as shown at the upper right of the figure.

AR = s^2 / A = s^2 / (s * c) = s / c

7) Taper ratio (TP): Taper ratio (TP) is defined as the ratio between the tip chord (Ct) and the root chord (Cr). This definition is applied to the wing, as well as the horizontal tail, and the vertical tail. TP= Ct/ Cr
8) Tip chord (Ct): The chord length of the wing near the tip of the wing is called tip chord.
9) Root chord (Cr): The chord length of the wing near the fuselage is called root chord.
10) Mean Aerodynamic Chord (MAC or C): It is the straight line connecting from the leading edge and the trailing edge.
11) Airfoil: The cross-sectional shape obtained by the intersection of the wing with the perpendicular plane is called aerofoil
12) Twist angle (or washout) (TA): If the wing tip is at a lower incidence than the wing root, the wing is said to have negative twist or simply twist (□t) or washout. On the other hand, if the wing tip is at a higher incidence than the wing root, the wing is said to have positive twist or wash-in. The twist is usually negative which means the wing tip angle of attack is lower than root angle of attack.
13) Incidence (IW) (or setting angle): The wing incidence (*IW*) is the angle between fuselage center line and the wing chord line at root. It is sometimes referred to as the wing setting angle (Wset). The fuselage center line lies in the plane of symmetry.
14) Aileron: Ailerons are roll-control control surfaces of the RC Airplanes. Ailerons provide roll by moving in opposite direction to each other. When one aileron moves down the other moves up thus providing more lift on one side as oppose to the other causing the RC Airplane to roll. Ailerons are at the trailing edge of RC Airplane wing and towards the wing tips.
15) Wing loading: wing loading is the loaded weight of the aircraft divided by the area of the wing. The faster an aircraft flies, the more lift is produced by each unit area of wing, so a smaller wing can carry the same weight in level flight, operating at a higher wing loading. Correspondingly, the landing and take-off speeds will be higher. The high wing loading also decreases maneuverability.

Tail design

Tail configuration: It is basically the position of the tail in an aircraft. Ex:

Aft tail and one aft vertical tail, aft tail and twin aft vertical tail etc.

Horizontal tail

1) Planform area (Sh)
2) Tail arm (*T*)
3) Airfoil section
4) Aspect ratio (ARh)
5) Taper ratio (TR)
6) Tip chord (Ch_tip)
7) Root chord (Ch_root)
8) Mean Aerodynamic Chord (MACh or Ch)
9) Span (bh)
10) Sweep angle (SA)
11) Dihedral angle (DA)

Vertical tail

1) Planform area (Sv)
2) Tail arm (*T*)
3) Airfoil section
4) Aspect ratio (ARv)
5) Taper ratio (TR)
6) Tip chord (Ct_v)
7) Root chord (Cr_v)
8) Mean Aerodynamic Chord (MACv or Cv)
9) Span (bv)
10) Sweep angle (SA)
11) Dihedral angle (DA)

Design Calculations

Design of wing

In designing a wing as shown in fig. 2. There is a systematic approach in order to determine various parameters step by step. To start the calculation the minimum data required is the gross weight of the aircraft and the wing span.

So, weight of the aircraft is 1000gm, wing span is 110cm and aspect ratio is 5.5

Table 1. Aspect Ratios for Various Aircrafts

SL NO.	AIRCRAFT TYPE	ASPECT RATIO
1	Hang glider	4-8
2	Glider (sailplane)	20-40
3	Homebuilt	4-7
4	General Aviation	5-9
5	Jet Trainer	4-8
6	Low subsonic transport	6-9
7	High subsonic transport	8-12
8	Supersonic fighter	2-4
9	Tactical missile	0.3-1
10	Hypersonic aircraft	1-3

The aspect ratio selected is 5.5 because ours is a homebuilt aircraft so according to the given table 1, we have chosen it to be in the correct range.

Pre determined data:

Weight of the aircraft =1000gm

Wing span =110cm

Aspect ratio is 5.5

Step1: To determine the plan form area (S_{wing})

AR: b^2/s_{wing}

$S_{wing}=b^2/AR$

$S_{wing} = 110^2/5.5 = 2200\ cm^2$

Step 2: wing loading selection: keeping in mind the structural constraints the wing loading must not exceed 0.6 gm/cm^2

Wing loading= Mass of the aircraft/S_{wing}

Wing loading=1000/2200 =0.45gm/cm^2

Step 3: Taper ratio (TR) = 1 (because we are using a straight wing).

Step 4: $C_{root}=2*S_{wing}/ (b*(1+TR))$

$= 2*2200/ (110*2)$

$=20cm$

Step 5: C_{tip}: $(TR * C_{root}) = (1*20) = 20$ cm

Step 6: To find the value of C_{root}'.

C_{root}' is the chord length at the random position of the wing.

Since the wing we are using is a straight wing the value of $C_{root}=C_{tip}$

Wkt $(C_{root}-C_{tip})/(b/2) = (C_{root}'-C_{tip})/((b/2)-4))$

Therefore $Croot'=C_{tip}=20cm$

Step 7: Determination of mean aerodynamic chord (C').

Mean aerodynamic chord is the width of the wing along the span where the entire lift is assumed to be acting.

$C'=2*C_{root}(1+TR+TR^2)/(3*(1+TR))$

$C'=2*20(1+1+1)/(3*(1+1))$

Therefore $C'=20cm$

Step 8: Determination of aerodynamic center(X)

Aerodynamic center is defined as the point along the width of the wing where the entire lift force is assumed to act.

$X=(C_{root}'-C')+C'/4=(20-20)+20/4$

$X=0+5$

Therefore $X=5cm$

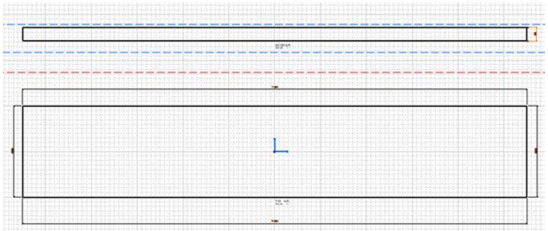

Fig 2. Front, top view of the wing

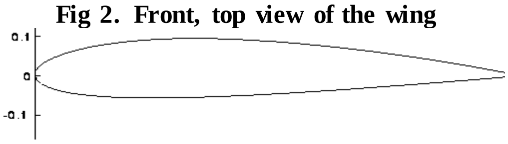

Fig 3. Side view of the wing (NACA 2412)

Step 9: Airfoil Design: the co-efficient of lift is to be obtained and this is determined by equating the lift obtained from the wing to the aircraft weight.

L=W.

$0.5*\rho*V^2*C_L*S_{wing}=M*g$

Where ρ is the density of air = $1.225kg/m^3=1.225*10^{-3}g/cm^3$

g is acceleration due to gravity = $9.81m/s^2 = 9.81*10^2cm/s^2$.

V is the cruise speed = 15m/s = $15*10^2cm/s$

C_L obtained in this calculation is the 3D value.

$S_{wing} = 2200cm^2$

M= 1000g

Therefore $C_{L3D=}0.3235$

The aircraft is generally trimmed at 3 to 5 degrees angle of attack (α). This range of values keeps the aircraft away from stall angle providing a safer flight.

Angle of attack, α=1 (assumed)

So, finally the airfoil used is of "asymmetrical airfoil".

Asymmetrical airfoil used is "**NACA 2412**"

Horizontal stabilizer Design shown in fig.4.

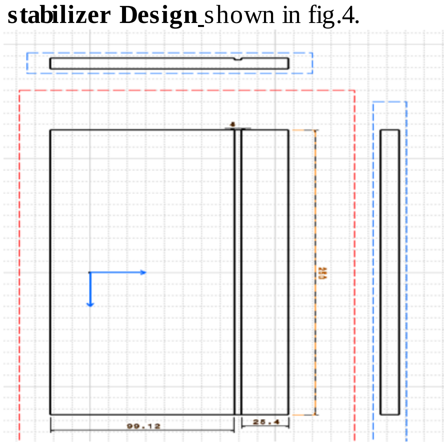

Fig 4. Top view & side view of the tail (horizontal stabilizer).

Step 1: Choose the tail area (S_t) to be around 14-15% of the wing area. (For better stability of the aircraft)

$S_t=319\ cm^2$ (percentage $*S_{wing}/100$)

Step 2: The aspect ratio of tail is chosen to be less than that of the wing so that the stall in tail is delayed with respect to that of the wing

Aspect ratio of tail (AR_t) should be between 3-5

Therefore we have chosen aspect ratio of the tail as 3.

Step 3: Tail span (b_t) = $(AR_t*S_t)^{1/2}$

Therefore $b_t=(3*319)^{1/2}$ [AR_t=3 assumed]

Hence BT=30.935cm

Step 4: Taper ratio of the tail (TR_t) = 1 [assumed]

Step 5: Tail root chord $C_{root\ t}=2*S_t/(b_t(1+TR_t))$

$C_{root\ t}=2*319/(30.935(1+1))$

$C_{root\ t}=10.3119cm$

Step 6: tail tip chord $(C_{tip})=(TR_t*C_{root\ t})=(1*10.3119)$

Hence C_{tip} = 10.3119cm

Step 7: Choose the tail setting angle (i_t) to be 1degree-1.5 degree less than α (angle of attack).

i_t =1-1 =0.

Vertical stabilizer design (rudder)

Rudder is as shown in fig.5.

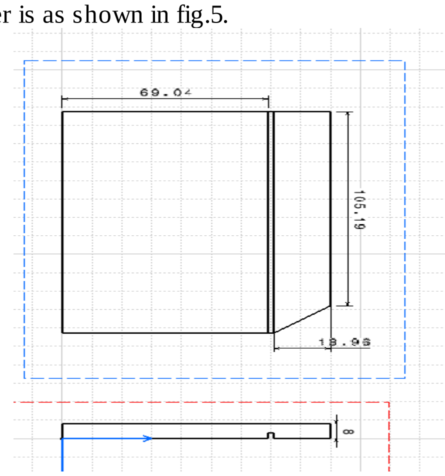

Fig 5. Right side view of the tail (vertical stabilizer)

Step 1: Fin area is the static part of the rudder.

Fin area= 30-35% of stab area

Fin area=32.5*319/100 =103.675cm²

Step 2: to calculate elevator area

Elevator area =15-20% of stab area

= 0.16*319 =51.04cm²

Using this area we can find the geometry.

Design of fuselage

The fuselage is as shown in fig.6.

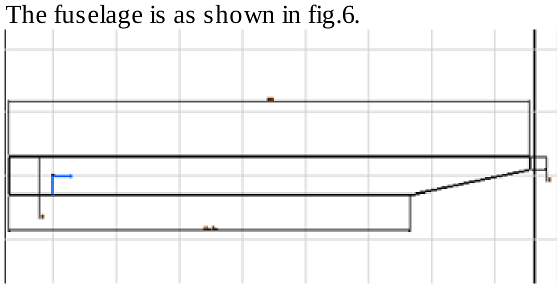

Fig 6. Right side view of the fuselage

The fuselage is mainly designed based on empirical formulae that were developed by comparing various designs of many classic aircrafts like as cessna skylane, piper cub, fokkertrimoter airliner etc. to give an aerodynamic design i.e. a streamlined body.

The length of the fuselage was empirically taken as 75% of wing span

Therefore $L_{fuselage}$= 0.75* wing span= 0.75*110= 82.5cm

The front cross sectional area is 6cm*6cm and the end cross section is 2cm*2cm.

A slot is made at the top of the fuselage in order to accommodate the various electronic components.

Material Used For Manufacturing The Aircraft

The material used in the manufacturing of our unmanned aerial vehicle is “coroplast”. The coroplast material is as shown in the below fig.7.

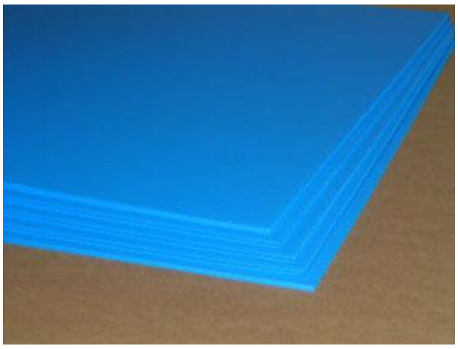

Fig 7. Coroplast

Properties of coroplast material are as follows:

1. It is a plastic material and cannot be mould into desired shape.
2. Coroplast has high strength
3. Easier to cut coroplast compared to other materials.
4. Durability of coroplast is best.
5. Impact resistance is best
6. Coroplast is stiff.
7. Cost is less.

Electronic Components Used

Various electronic components are used in the working of the aircraft. There is a step by step procedure to select each and every electronic component. We select motor and propeller by considering the weight of the aircraft. The first component that we have to consider is

1) Brushless motor: The most popular type of motor being used for model airplanes today is the Brushless Out runner Motor. They provide a greater power-to-weight ratio, but cost a little bit more than the traditional brushed motors. Out runner motors produce a lower rpm, but produce more torque and can drive their propellers directly. This eliminates the weight and complexity of a gear box. The size of the motor is determined by the weight of your model airplane, which determines the size of the propeller. In essence, you need to choose a motor that will be able to generate the required rpm for the propeller. We have used 1100kv brushless electric motor. Brushless motor is as shown in fig.8.

Fig 8. Brushless DC Motor.

2) Propeller: Propellers for RC airplanes are nothing more than vertically mounted rotating wings. Their job is to convert the engine power in to thrust, to pull/push the plane through the air. Thrust is generated in exactly the same way as lift is generated by the wing, and that's why props have a profile airfoil section. Shown in fig.9.

We have used a 10x7E prop.

Fig 9. Propeller-10X7E

3) Esc: The ESC is a device that regulates the amount of power that goes to the electric motor. The device may be separate from (but plugged into) or a part of the receiver. ESC stands for electronic speed controller. The ESC interprets signals from the receiver and works to provide variation in motor speed and direction and may act as a braking mechanism. There are electronic speed controls for brushed and brushless motors. We have used a (30amp esc) shown in fig.10.

Fig 10. Electronic Speed Controller

4) Servo: A servo is a device for moving a part of the model. Shown in fig.11. Usually servos operate the rudder and elevator on a three channel model and the aileron as well on a four channel model. The throttle may be operated by a servo or on electric models it may be operated by a speed controller called an 'electronic speed controller' that plugs into the receiver and it connects the control rods.

We have used a 9g servo.

Fig 11. Servo.

5) Receiver: The receiver is one component which you really cannot choose. It comes along with the radio, and works only with that particular radio on a certain pre-defined frequency. It is connected directly to the “servos”, and has a thin single wire antenna that extends outside the airplane. The receiver gets signals from the transmitter when you move a stick/control. These signals are then passed through to the servos, or ESC, which respond appropriately. We are using a 7ch receiver and transmitter. Receiver is shown in fig.12.

Fig 12. Receiver.

6) Batteries: We used 3 cells, 11.1v Lipo battery of 1800mah.

All the above consideration of the electronic components is done on the basics of the weight of the aircraft and the components are selected by selecting how much thrust is required and which configuration gives that much capacity. Shown in fig.13.

Fig 13. LIPO Battery

7)Ghz Radio Transmitter

A transmitter or radio transmitter is an electronic device which, with the aid of an antenna, produces radio waves. The transmitter itself generates a radio frequency alternating current, which is applied to the antenna. Transmitter is shown in fig.14. When excited by this alternating current, the antenna radiates radio waves.

Fig 14. Transmitter.

8) Control Rods

Control rods are used to transmit power from the servo to the control surfaces of the aircraft such as the ailerons and rudders. The control rod is shown in the fig.15.

Fig 15. Control Rods.

9) Hinges and Clevis

Hinges and clevis are the components that are used to fasten the control rod and control surface. The hinges and Clevis are shown in the fig.16.

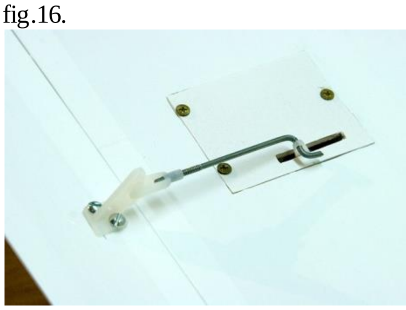

Fig 16. Hinges & Clevis.

Specifications Of Electronic Components

PROP – 10x7E
To get 1600gms Thrust
Lipo – 3cell 11.1V
Operating Voltage – 10.8V
Amp draws at load – 32.7 amps
ESC - 30 amps
Power – 327W

Simulation Of The Model

After the completion of the design, for simulation of the aircraft, a 3D CAD model can be generated using solid edge, or any other modeling software's, this model can be simulated using software called X-PLANE. The X-Plane software also has a 3D modeling software in which we can build our 3-D CAD model of our plane and fly it in a graphical user interface. This software will fly the plane in real time and it can be found out if any errors in the design and re-modify using some tools and redo simulation.

Basic Analysis Of The Wing

Here in this section lift, drag, co-efficient of lift v/s angle of attack etc are found out using software called design foil.

Virtual wind tunnel analysis is done on the airfoil which has been selected in the design process. This option allows you to vary the angle of attack and observe the varying nature of coefficient of lift (CL), coefficient of drag (CD), etc as shown in fig. 17 to fig.21. Thus this analysis is basically conducted to mount the wing at the optimum angle of attack so that required amount of lift is generated.

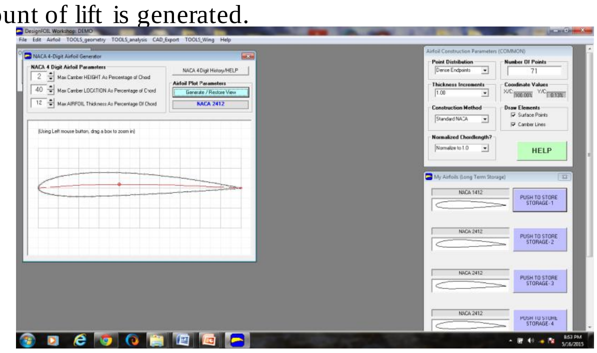

Fig 17. Wing Analysis of the aircraft for NACA 2412.

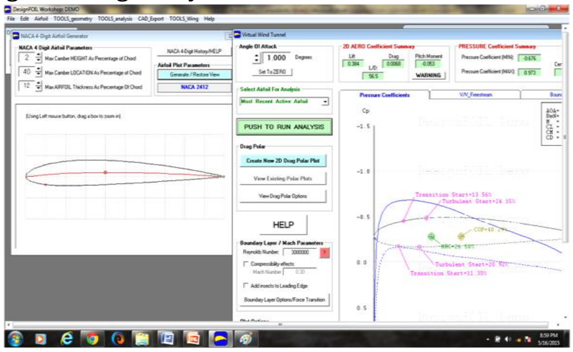

Fig 18. Wing Analysis of the aircraft for NACA 2412

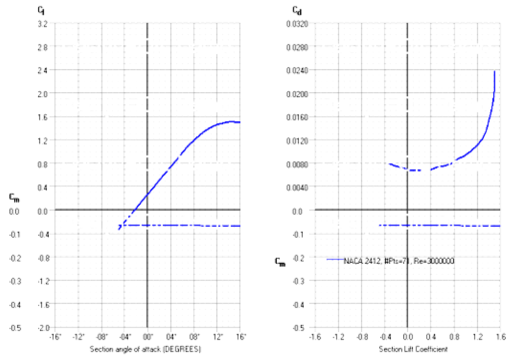

Fig 19. Co-efficient of lift & Co-efficient of drag VS pitching moment

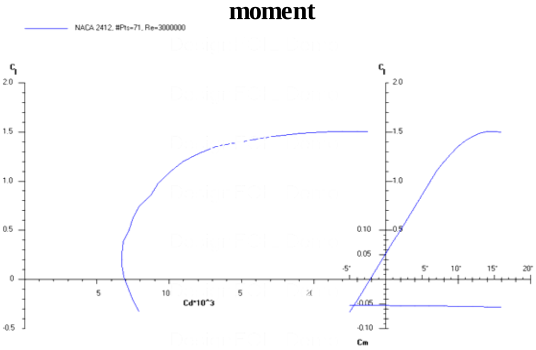

Fig 20. Wing Analysis of the aircraft for NACA 2412

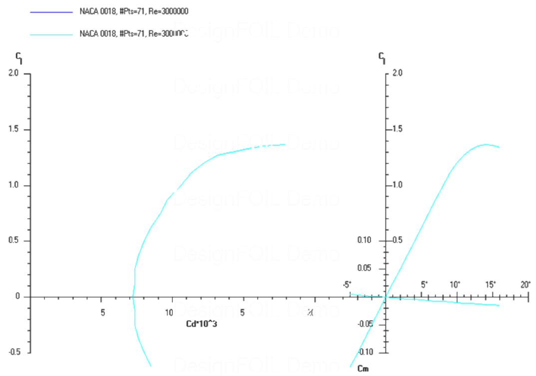

Fig 21. Wing Analysis of the aircraft for NACA 2412

Different value of lift and drag are calculated using “design foil” software. Thus at an angle of attack α= 1 degree the lift obtained from design foil is closely equal to the lift obtained from the calculation. Thus the wing should be mounted on to the aircraft at an angle of attack greater than 1 degree but less than 13 degree as shown in the C_l vs α graph.

Thus the aircraft was fabricated in these methods and was successfully flown.

Completed Views Of Our Experimental 4 Channel Unmanned Aerial Vehicle

The completed views of our final model is as shown in the below fig.22 to fig.26.

Fig 22. Conventional tail 4ch unmanned aerial vehicle.

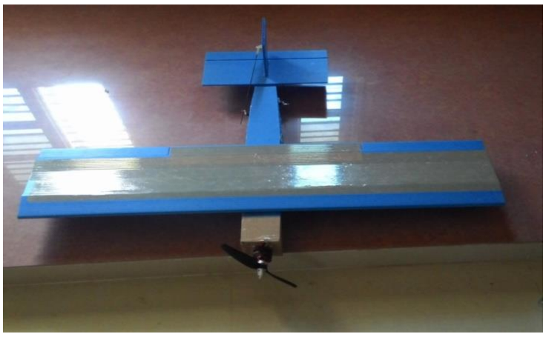

Fig 23. Top view of the unmanned aerial vehicle.

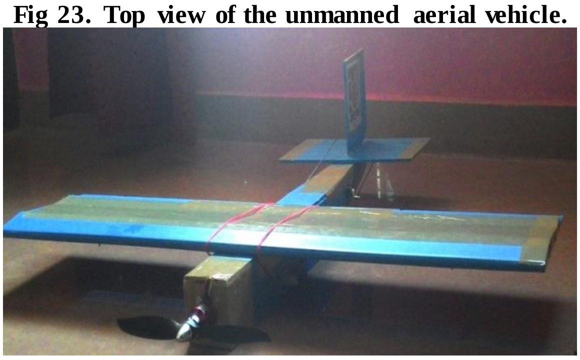

Fig 24. Right isometric view of the aircraft.

Fig 25. Left isometric view of the aircraft.

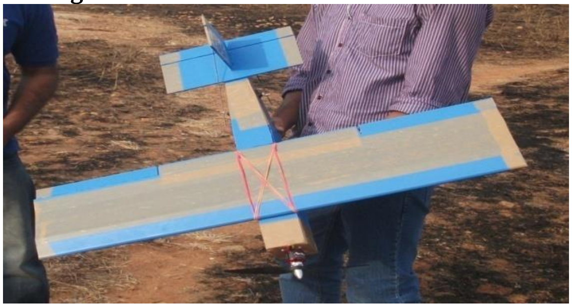

Fig 26. View of the UAV.

Technical Properties Of Our 4ch Uav

Table 2. Technical properties of the aircraft

SL	Parameters	aircraft
1	Material	Coroplast
2	Wing	Flat Wing
3	Plan form area	2403.5 cm^2
4	Weight	1000gms
5	Aspect Ratio	5.5
6	Wing loading	0.45 gm/ cm^2
7	Co-efficient of lift	$C_{L3D=}$0.3235
8	Angle Of Attack	1 Deg
9	Airfoil	NACA2412

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Future Scope

In spite of the budget cuts that loom over the industry, the future of unmanned aerial vehicles (UAV) is still looking bright. Future UAVs may be capable of reaching heights that are over double or triple what the A160 can reach and stay in the air for months at a time. These UAVs would resemble gliders with solar panels to maintain power and sensor arrays. Rather than rely on satellite imagery these UAVs would give war fighters persistent situational awareness.

Tiny UAVs that can be flown through open windows are in the works. These minuscule aircraft will stay airborne in times measured in seconds or minutes while giving valuable information to soldiers on the ground without giving away their position like a thrown ground vehicle might.

In addition to new technical capabilities, the future of UAVs is trending towards automated systems. Rather than having several personnel monitoring a UAV, in the future it is expected that one person can monitor many different UAVs at once. In the field of Defence, Automation frees up soldiers to perform other tasks and ultimately is a cost-saving measure, as fewer personnel are needed for UAV flights.

Since ours is a basic experimental aircraft, future scope of our project related to UAV, lies in the field of CFD Analysis of the complete prototype, Mat lab programming, implementation of the innovative design to big scale, improvement of aircrafts weight, empennage configuration, fabrication methods and also wind tunnel testing. The UAVs aren't just the product of wishful thinking; they are the main source of technology in the near future especially in the field of defence.

Conclusion

- This project work deals with "Design & Analysis of a experimental 4 channel unmanned aerial vehicle". The project has been successfully carried out and also the 2D drawings of the Front view, Top View and Side View are shown. Also the technical properties are shown in table.2.
- Modifications can further be done on model to improve the design and quality.
- Analysis is done on Aircrafts wing using Design Foil software & the airfoil chosen is NACA-2412.
- Comparison is done between Theoretical calculations & values obtained in design foil software& virtual wind tunnel test.
- As per analysis results, the value of lift obtained from the software is nearly equal to that of the calculated value.
- The Aircraft designed was flown successfully.
- The aircraft that we have designed has achieved stable flight, further modifications can be made such as mounting of the cameras for surveillance, improving its scale, design & pay load.

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