Design and Fabrication of a Fixed Wing UAV

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ABSTRACT - An Unmanned Aerial Vehicle (UAV) is an aircraft flown either by an on-board computer or a remote-control from the ground. With recent advancements in the research field, UAVs have gained much prominence, especially in military applications. A fixed wing UAV has high endurance and can be used for long missions. The report describes a UAV using a Clark Y airfoil which gives great stability and produces adequate lift in medium speed. The wing and fuselage are made up of depron sheet and balsa wood respectively, as they give great strength with light weight. The designed UAV is a 3 channel UAV with 3 control surfaces. The emphasized feature of the UAV is the dual characteristic of it being able to fly manually and by an onboard autopilot. The waypoints are fed into the on-board autopilot, which tracks the position, direction, altitude and speed of the UAV with the help of telemetry radio and GPS modules installed in the UAV.

INTRODUCTION

'UAV' is an abbreviation for Unmanned Aerial Vehicle, which is an aircraft with no pilot on board. UAVs can be remote controlled aircraft (controlled by an operator from the ground station) or fly autonomously based on pre-programmed flight plans or other automation systems. UAVs are currently used for a number of missions, including reconnaissance and military attack. A UAV therefore, is defined as an aircraft capable of being controlled at a sustained level of flight and powered by a certain defined powerplant. The acronym UAV is also interchangeably used as UAVS (Unmanned Aircraft Vehicle System). Most UAV systems, both large and small, are operator based, relying on relatively high duty cycle remote control by operators. In his book 'Introduction to Unmanned Aircraft Systems', Charles Jarnot wrote, "As seen in the modern use of unmanned aircraft, historically unmanned aircraft often followed a consistent operational pattern, described today as the three D's, which stand for dangerous, dirty and dull. Dangerous being that someone is either trying to bring down the aircraft or where the life of the pilot may be at undue risk operationally. Dirty is where the environment may be contaminated by chemical, biological or radiological hazards precluding human exposure. Finally, dull is where the task requires long hours in the air making manned flight fatiguing, stressful and therefore not desirable." Having said that, these remotely controlled UAVs require skilled pilots and with such precision that, they must be able to deal with severe airspace demands, mission requirements, and situational changes as the circumstance would demand. From about a decade or two, an increase in research and developments are improving UAVs for multitude of applications and reliability. UAV is still in developmental stages. In the article, 'Design, Manufacturing, and Flight Testing of an Experimental Flying Wing UAV' by Pei-Hsiang Chung and team, it mentions, '...with improvements in avionics devices such as the battery and electric motors, electric-powered UAVs have attracted increasing research attention.' In the last century so much is done in the field of unmanned aircrafts that even a mere 'go-through' web search will reveal hundreds of them. So, with these enhanced processes, to calculate the aerodynamic and structural factors, now it is easy to make robust and reliable airframes in the most efficient manner at low cost and yet suitable for commercial operations.

METHODOLOGY

1. The method of designing and fabricating a UAV generally begins with the purpose as to why the UAV is needed in the first place. The purpose that the UAV would serve forms the basis of UAV design. Based on the kind of action it is going to perform, the UAV type is decided, which thereby leads, to its being designated to any one of the following categories:

1. Micro UAVs: Payload 0 Kgs < 3 Kgs
2. Small UAVs: Payload 3 Kgs < 30Kgs
3. Medium UAVs: Payload 30 Kgs < 50 Kgs
4. Large UAVs: Payload > 50 Kgs

2. But further simplification has been done by various research centers such that the classification is based also on the wingspan as depicted in the Figure 1.1 Hence, the choice of the UAV type is done based on both the classification types.

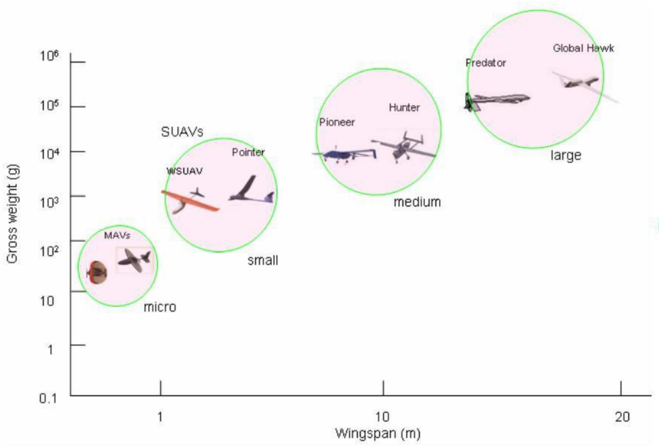


Figure 1.1

3. Finishing all the basic requirements of choices out of the multitudes of possibilities, next is to do with the design of the UAV parts that were chosen. But the design can be initiated only when there are values assigned to each dimension that is to be designed. This creates a need of the formula to be extracted so that the dimensions could be known. To begin with, we determine the Aspect Ratio (AR) as per the attributes we need for our aircraft. In aircrafts, the AR of a wing is the ratio of its span to its mean chord which is also equivalent to the square of the wingspan divided by the wing area. As defined by the Science Learning Hub, 'a high aspect ratio indicates long, narrow wings. A low aspect ratio indicates short, wide wings. Generally, high aspect ratio wings give slightly more lift and enable sustained, endurance flight, while low aspect ratio wings are best for swift maneuverability.' The Figure 1.2 provided by the University of Waikato, would help visualize as to how the wing designed as per the chosen aspect ratio would look like in the end.

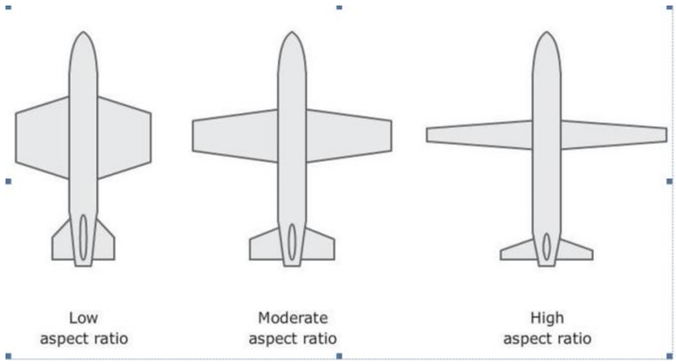


Figure 1.2

4. There are many online design portals which has made the designing aspect easier such that we can use the ratio method to determine the dimension of the entire aircraft, once any one of the dimensions is ascertained as in Figure 1.3. The further step is to assume the loading factors which again is a process determined, iterative calculation. From the charts shown above, once we get to know the payload as such, then wing loading could be calculated. Wing loading is the total weight of an aircraft divided by the area of its wing. Basic idea of wing loading is apparently necessary as the stalling speed of an aircraft in a level flight is determined by its wing loading factor too.

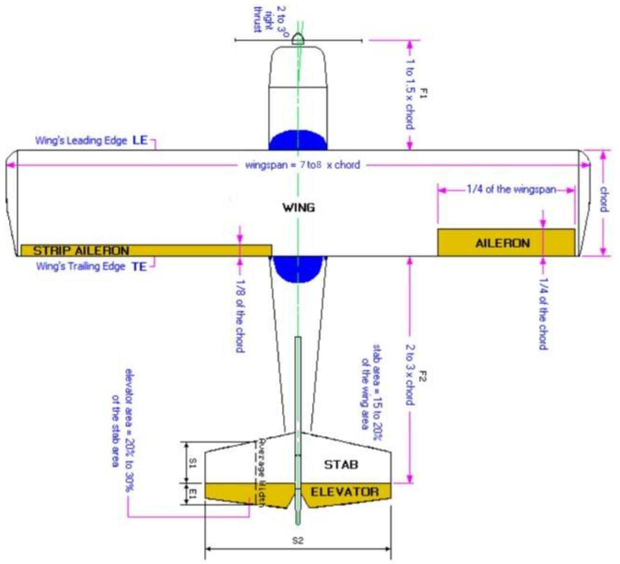


Figure 1.3

5. Thus, knowing all the parameters required to build an aircraft, we finish the design and further the process of fabrication. Fabrication of the UAV takes into consideration, the heavy load and stresses such as torsion, to maintain a higher strength to weight ratio. Hence, the choice of materials such as balsa wood and depron sheet is preferred which has high strength to weight ratio. Added to these benefits is that both depron sheets and balsa wood are easily workable and economical to work with. The fabrication part is then divided into three different parts namely wing fabrication, fuselage fabrication and the fabrication of stabilizers.

Wing fabrication is an important part wherein the considerations to be made are very crucial. Some of the major factors to be kept in mind while making the wings are:

1. Chord length
2. Airfoil dimensions
3. Aspect ratio
4. Wing planform

For determining the airfoil dimensions, the online websites like airfoiltools.com play a major role as they provide coordinates for the plot of a given airfoil type. A simple example of such a plot is shown in the Figure 1.4

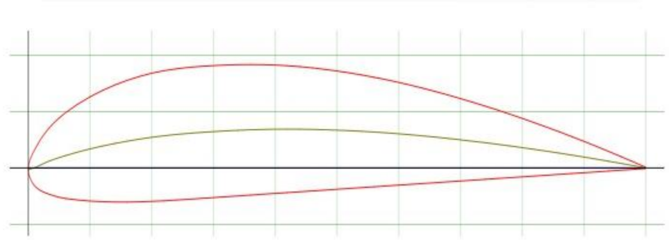


Figure 1.4

6. The next major part is the fuselage fabrication. Fuselage is the main body of the UAV and therefore it needs to hold all the components of avionics along with the batteries, motor, flight control systems etc. Since it should hold all the avionics and the payload if any in the UAV, it should be strong but of light weight so that it may hold them firm. Some of the major factors to be considered while fabricating the fuselage are:

1. Aerodynamic structure
2. Slots to fit wings and stabilizers
3. Center of gravity
4. Spacious interiors for placing the avionics batteries.

LITERATURE SURVEY

DESIGN AND DEVELOPMENT OF A SEMI-AUTONOMOUS FIXED-WING AIRCRAFT WITH REAL-TIME VIDEO FEED, by Cody Torno and team provides sound reasons for the development of a fixed wing UAV as compared to its counterparts like rotary wing UAV, flapping wing UAV etc. They write, 'A fixed-wing UAS platform has a large advantage over similar manned aircraft, e.g., their ability to offer long flight durations and superior flight altitudes with less acoustic propulsion systems, avoiding visual and radar detection.' The deficiency in the above journal was that the outsourced equipment used were not cost effective and the system was built for the US defense which made the system even more complex.

DEVELOPMENT OF UNMANNED AERIAL VEHICLE (UAV) FOR WILDLIFE SURVEILLANCE: This thesis presents the design, fabrication and flight testing of an autopilot capable small UAV with a wingspan lesser than 2 meters for wildlife surveillance. The highly autonomous flight control system has two high resolution cameras and an onboard video recording device, which collects high quality imagery with specified GPS points and altitudes. The featuring fact about this thesis is in its innovative robust construction coupled with light weight and inexpensive hardware. This is also in accordance to what generally engineers desire; reducing the cost with optimum performance.

DESIGN OF LOW-COST FIXED WING UAV: This research paper gives an idea about how to design a low cost of fixed-wing unmanned aerial vehicle using low-cost material that allows it to fly autonomously. Six parameters of UAV's structure are considered for optimization namely, basic airframe configuration, wing configuration, straight wing, tail configuration, fuselage material, and propeller location. The paper vividly explains why certain values are chosen for a given parameter when compared to others and what benefits does it have on the designed UAV.

UAV DESIGN

1. The conceptual design is the initial stage of the design process. In spite of the fact that there are numerous UAVs, each having its own characteristic feature, we can find common features underlying most of them. For example, weight-based calculation of the wing and fuselage specifications or wingspan-based calculation of the UAV and further iterative calculation for the desired payload. Any design team would be required to work with a limited amount of funds and time. The design team must ensure that cost and time over-runs, are minimized to the extent possible. At this point, it is a 'kind of mandate' for the different aspects of the design to be taken up by dedicated teams. Maybe for an aircraft, this might consist of an aerodynamics' team, a structure's team, a control system's team, costing team, and so on, or it might consist of a team considering the fuselage, another considering wing design, others looking at the tail plane, propulsion systems, and so on.

UAVs requirement would cover the following aspects:

1. Flight - This includes performance characteristics like take-off, climb, cruise, descent, and landing. Also, the requirements of stability and controllability are included.
2. Structural – UAV load, payloads including the camera for surveillance, materials used to build the UAV and its reliability.
3. Powerplant or the engine used for propulsion, auxiliary powering unit if required.
4. Others – Safety system if any.

2. Wing planform refers to the shape of the wing as viewed from directly above. It deals with airflow in three dimensions and is very important to understanding wing performance and airplane flight characteristics. The planform chosen was rectangular one because the aircrafts with these wings are easy to fly and easy to land. Rectangular wings are called wing-root stallers. It means the stall begins at the wing root, reaching the control surfaces (ailerons and flaps) last, and making the wing extremely controllable. Rectangular wings are simpler and easier to build because they only need one rib pattern as depicted below.

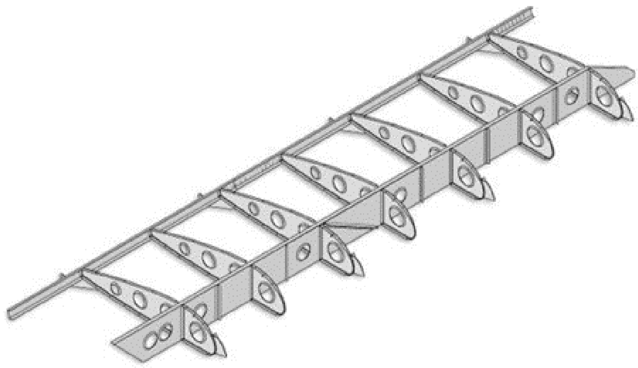


Figure 3.1

As explained earlier in the Methodology section, from Figure 1.1, we get the weight estimation for our UAV. We consider a nominal weight for our aircraft such that it is easy to relate to its components. The weight assumed is 3 Kgs. Wing loading as we know is the total weight of an aircraft divided by the wing area. This factor is very important to be known as it determines the lift-drag characteristics and stall speed as well to certain extent. Also, from the Figure 1.1 we get to know the wingspan for a 3 Kgs aircraft, which comes in between 0.8 to 8 meters. Out of the values that we have, we chose to select 1-meter wingspan. Again, the report by Kyuho Lee gives us a great insight where, their chosen wingspan is 2 meters. We need a high Aspect Ratio as we want the UAV to glide and not swiftly go through the air as gliding would help take steady images during visual survey. From the Figure 3.2 below, we find that AR as high as 8 gives good coefficient of lift characteristics along with gliding features of the UAV enhanced.

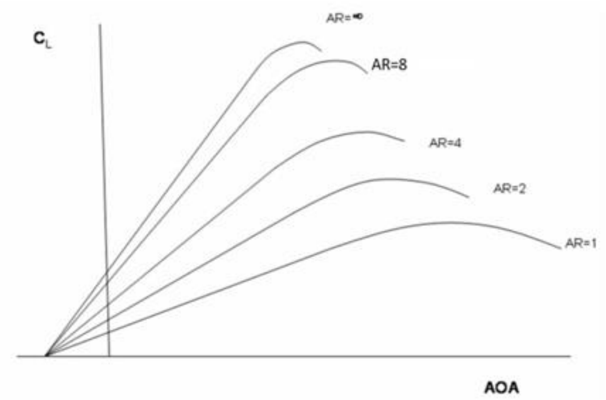


Figure 3.2

Wing loading initiates the decision on what type of airfoil would best suit the UAV that is being worked on.

$$AR = \frac{s}{c}$$

$$c = \frac{1}{8} = 0.125m$$

$$Wing\ Area, S = length * breadth = s * c$$
$$= 0.125m^2$$

$$\frac{W}{S} = \frac{3}{0.125} = 24\ Kg/m^2$$

FoilSim is a simulator provided by NASA to all those who are interested in conducting experiments and knowing about aerodynamics. The recent version is that of April 2019, which is for the undergraduate students. If the input section of simulator is handled well then, the output comes in various forms depending on whatever we need like graphs, real-time simulations, tabulated values etc. The chosen airfoil was Clark Y type, mainly for the ease of construction as well as it suited the requirements. Airfoil is generally tested to know the lift and drag characteristics and thereby the stalling speed in a certain range of angle of attack. With the following characteristics mentioned in Table 3.1, the airfoil was simulated.

Table 3.1

Angle of Attack	4^0
Camber in % chord	3.4%
Thickness in % chord	11.7%
Basic shape	Flat bottom
Speed Avg	65 Kmph
Altitude	1000 m above MSL
Aspect Ratio	8.33

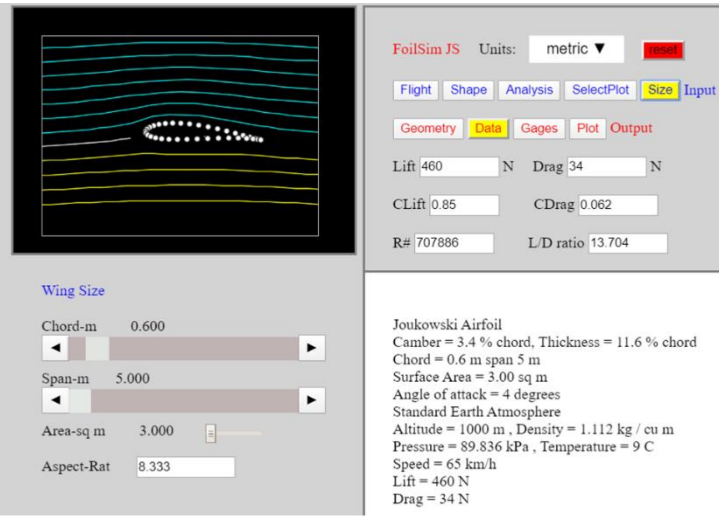


Figure 3.3

Calculating all the parameters and knowing their values, designing process is undertaken. The design is done in CATIA. Initially, the wing is designed and thereafter the fuselage, wherein slots are provided for placing wing, vertical stabilizers and landing gears. The following figures show the design.

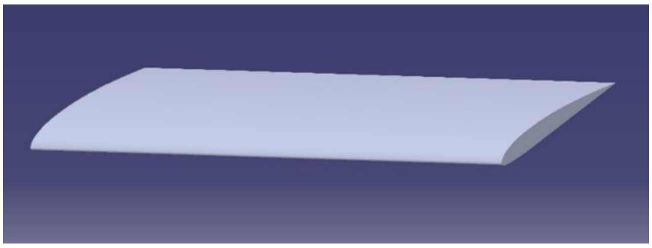


Figure 3.4

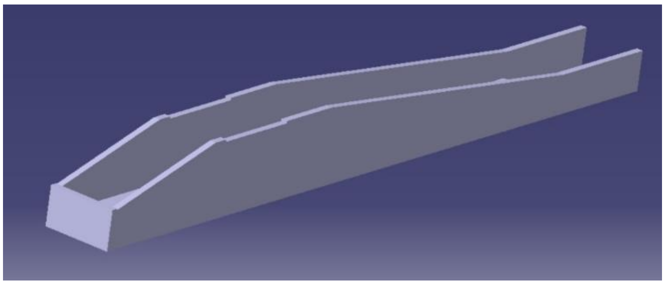


Figure 3.5

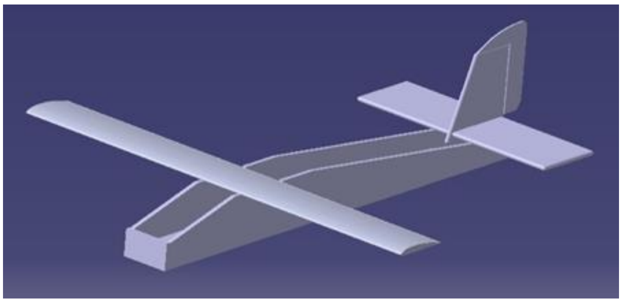


Figure 3.5

FABRICATION OF UAV

Wing Fabrication -Wings are the most important part of an aerial vehicle as it generates the lift and has to support the entire structure once the UAV is in the air. To make the wing light in weight we have to make it hollow. Hence initially, the airfoil is made using balsa thin sheets of wood which are thereafter cut so as to make them light too. A large sheet of depron of size 1.26 m * 0.515 m (l*b) is cut out. The positions for the reinforcements which will keep the wing stable during flight (wind interaction) to be attached are marked five inches apart from each other. Flipping the sheet upside down we taped the entire surface which will be exposed, with insulation tapes. These tapes are water proof as well as resistant to certain extent of dew or mist exposure and therefore will keep the wing resistant to weather and improves its strength. On the inside part of the wing two lines are drawn at 0.24 m, 0.31 m parallel to the length of the sheets. These are the points at which the sheet will be bent to form the wings' outer panel. Small triangular pieces (0.23 m * 0.065 m * 0.20 m) are cut out from depron and placed inside the wing structure using gum and hot glue to keep the wings steady. The wing is closed shut using hot glue at the edges. This covers the airfoil structures that was made fit in one single rod-shaped wood structure.

Figure 4.1

Fuselage Fabrication - Fuselage is the main body of the UAV and thus needs to hold all the components of avionics along with the batteries, motor, flight control systems etc. The fuselage is made out of Balsa wood. The base of the fuselage is a rectangle of length 0.925m and breadth 0.088 m. A small deep slot of is made at 0.1875m away from the fuselage nose for fixing the wing. The side panels are then fixed on the base using hot glue and an industrial use glue 'Flex Quick'. This glue acts on the joint in seconds and makes a very strong bond. The corners of the fuselage are then sanded off using sand paper to make a small fillet to the sharp edges. Further the compartments are made which will improve the rigidity of the structure as well as helps in keeping the internal parts from sliding off. This no sliding will also result in negligible shifting of the Center of Gravity (CG) of the plane during flight, which in-turn results in proper control and this smaller chance of stall failure.

Stabilizer Fabrication - Stabilizers are the component which will gain pitch for the UAV. For the stabilizers, 2mm thick depron sheets are fused together using industrial adhesive forming a sandwich panel. This panel is let to cure for 24 hours and are placed under weight for proper adhesion. After 24 hours, these panels are cut down to specified lengths and sanded down using the sand paper to an aerodynamic shape according to specified calculated angles. These stabilizers are then taped the same way as that of the wings to keep it away from moisture and other corrosives.

Assembly – Finally after the mounting the brushless DC motor onto the fuselage nose and fixing the propeller, the compartments are sealed with the necessary equipment. The fuselage is ready. Next the wing is fixed in the slot given as explained earlier. The wings are supported through the reinforcements. The stabilizers are thereafter fixed; both vertical and horizontal. They have control surfaces fixed up to the servo motors that help control them to required degrees of movement so as to allow both pitch and yaw. Also, the Ardupilot is installed, giving it separate LiPo connection, connecting it to the GPS module so that a waypoint could be later designated to the software such that it follows the given data file path. Finally, the model was ready (Figure 4.2) after checking all the joints and ensuring that every part of the UAV is secured.

Figure 4.2

RESULTS OBTAINED

1. Stall Speed

$$Vstall = \sqrt{\frac{2.W}{\rho.\text{Clmax}.S}}$$

Where, W/S = 24 Kg/m^2

ρ = 1.225 Kg/m^3

Clmax = 0.85

$$Vstall = \sqrt{\frac{2*24}{1.225*0.85}}$$

$$Vstall = 6.79\ m/s$$

$$Vstall = 24.44\ Kmph$$

2. Graphs for Cl vs Cd and Cl vs AOA for the following conditions.

Airfoil – Graph Color	Re No.	Max Cl/Cd
Clark Y – Green	100,000	54.1 at α = 6º
Clark Y – Purple	500,000	78.8 at α = 4.5º
Clark Y - Orange	1,000,000	108.5 at α = 6º

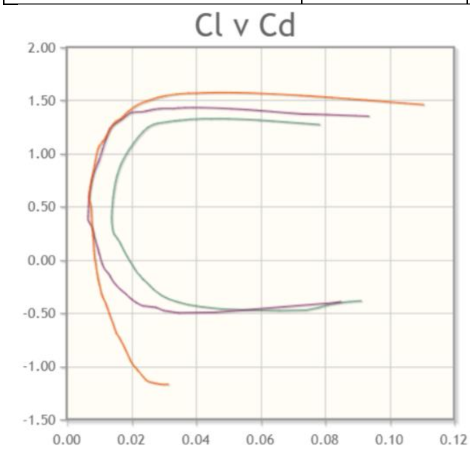


Figure 5.1

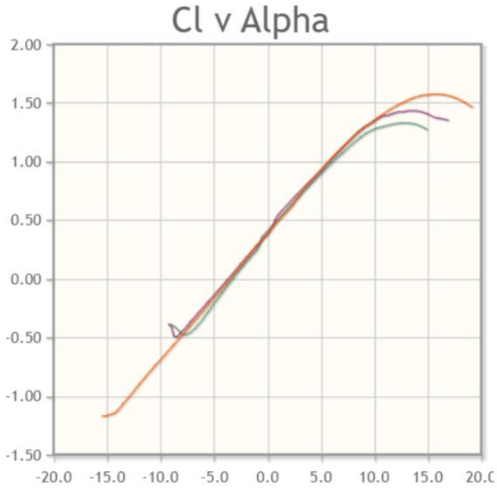


Figure 5.2

3. Lift and Drag

$$L = \frac{1}{2} * Clmax * \rho * V^2 * S$$

Where, V = 65 Kmph or 18.06 m/s,

$$L = \frac{1}{2} * 0.85 * 1.225 * 18.06^2 * 0.125$$

$$L = 19.5\ N$$

But, from FoilSim we find that for an airfoil of similar characteristics, L/D = 13.704. Hence,

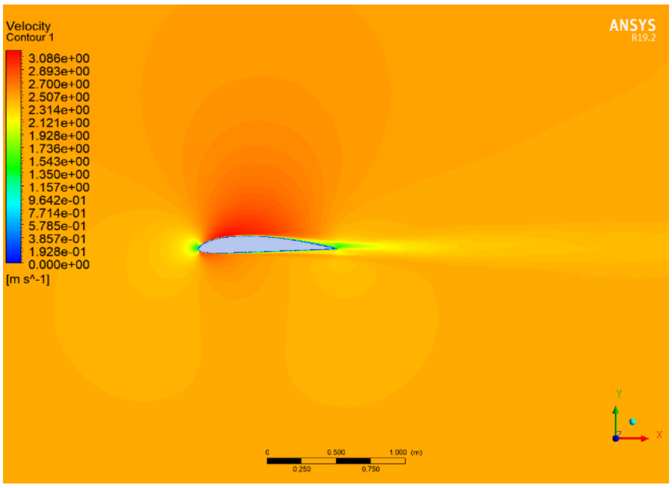
$$D = L/13.704$$

$$D = 1.423N$$

4. CFD analysis of the designed airfoil

Angle of Attack	Wind Velocity	Lift	Drag	Clmax	Cdmax
0	3	1.64031	0.117759	0.297561905	0.026702721
4	3	1.12178	0.134534	0.203497506	0.030506576
-4	3	0.0134165	0.164855	0.002433832	0.037382086
6	3	1.50228	0.162325	0.272522449	0.03680839
-6	3	-0.588106	0.163027	-0.106685896	0.036967574
0	6	5.07296	0.272772	0.230066213	0.015463265
4	6	3.07775	0.638318	0.139580499	0.036185828
-4	6	-1.29511	0.711857	-0.058735147	0.040354705
6	6	6.63367	0.823339	0.300846712	0.046674546
-6	6	-3.32052	0.856289	-0.150590476	0.04854246

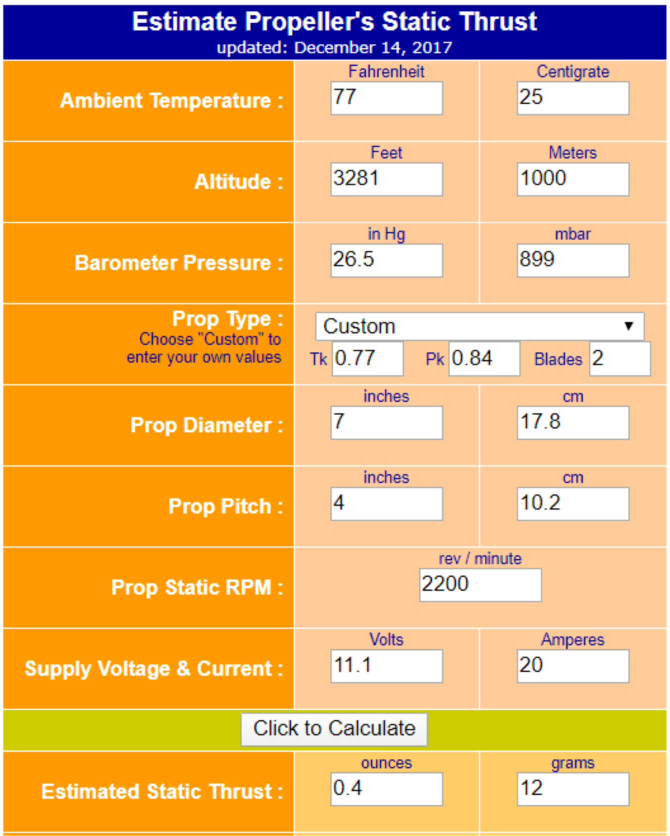
The orange-red part above the wing in the Figure 5.14 shows the higher velocity of air in that particular region which also means that the pressure existing there would be much lower. Just below the airfoil is a thin layer of yellowish-green region which is relatively lower air velocity which in turn would mean existence of a higher pressure along that belt. Thus, this difference in pressure allows the lift to take place from a



region of higher pressure to a region of lower pressure.

Figure 5.3

5. Static Thrust Calculator



Estimate Propeller's Static Thrust (updated: December 14, 2017)		
Ambient Temperature :	Fahrenheit 77	Centigrate 25
Altitude :	Feet 3281	Meters 1000
Barometer Pressure :	in Hg 26.5	mbar 899
Prop Type : Choose "Custom" to enter your own values	Custom; Tk 0.77	Pk 0.84; Blades 2
Prop Diameter :	inches 7	cm 17.8
Prop Pitch :	inches 4	cm 10.2
Prop Static RPM :	rev / minute 2200	
Supply Voltage & Current :	Volts 11.1	Amperes 20
Click to Calculate		
Estimated Static Thrust :	ounces 0.4	grams 12

Figure 5.4

The above Figure 5.4 shows the calculation by an online calculator for the parameters of the designed UAV. The estimated static thrust is 12 grams.

6. Flight Time Calculation

$$\frac{Avg\ Amp\ drawn}{Battery\ discharge} * \frac{time}{60} = Amp.hr$$

$$\frac{20}{0.8} * \frac{x}{60} = 3$$

$$time = x = 7.28\ mins$$

7. Flight Test – Once the assembly is done, there is a checking done through a 6 channel 2.4GHz RC transmitter whether the control surfaces are properly managed so that the motors respond as per the transmitted signal. This phase gives an idea how the controlling would be during the actual flight. The takeoff is done on a runway quite broad and nearly 6 meters in length. The cruise is done on a certain flight level which is around 35-40 feet above the ground. Finally, the UAV is landed in the same runway where it had taken-off. Later above a given area, waypoints were fixed and the information fed in the Ardupilot module after which the autonomous flight was flown.

CONCLUSION AND FUTURE SCOPE

Going as per the objectives, the conclusions drawn are as follows:

1. A fixed wing UAV was selected theoretically as per the data obtained from literature survey.

2. The design of the fixed wing UAV was made taking into considerations all the factors, both aerodynamic and electronic.

3. The Computational Fluid Dynamic Analysis of the designed airfoil was performed to check the lift and drag characteristics. Also, the simulation of the same was done using FoilSim JS platform provided by NASA.

4. The design was made to give the UAV, glider like characteristics, so that it could glide and level-fly above a certain area. This could later help in visual survey of the area.

5. UAV parts were fabricated as per the design and then assembled to complete the model. Later, all the electronic equipment was added and ensured a pre-flight check.

6. Finally, the flight test was performed, both manual and on autopilot mode using Ardupilot.

Considering the future scope, the project work until now encapsulates everything except for the camera; both visual and thermal sensor camera, which could be put forth in the future so that the survey is done. This project could also be made use of, in sectors like city traffic analysis and control, wildlife survey, aerial area survey and geographical survey of forest for the floral density. This could also be enhanced by making use of semi- fixed wing which is foldable so that a runway isn't necessary for take-off or landing.

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