Design and Fabrication of Cargo Unmanned Aerial Vehicle featured with Vertical Take-Off and Landing

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ABSTRACT:
An aircraft that can hover vertically both for take-off and landing operations. Due to the convenience in mission requirements and advantageous of less or no dependency on airports and airfields, this VTOL technology is much suitable for UAVs. Therefore, the comparative study on VTOL MAVs and UAVs id necessary. This paper mainly focussed on VTOL technologies and their representing aircraft designs. The recent VTOL studies reviewed and provided an insight comparison into the technological issues, applications and future developments the for urban air mobility. From the reviews and comparisons, the constraints and challenges of VTOL aircraft are summarized. As an advanced technology replacement or state of art, with the present research studies in Europe on active flow control for commercial aircrafts on short take-off and landing technologies is also figured out.

The objective is to fabricate a drone for delivery service that is both fast and safe. This idea struck us during the pandemic, it is very hard to control the spread of the virus and thus there is a great need for a new delivery system. Being a tilt-rotor aircraft, it is suitable to be used in tight spaces. Drone delivery is not only safe but also an efficient way to deliver
products to customers residing in the outskirts of a city, thus rapidly increasing the reach of restaurants, in case of food businesses or reducing delivery time in case of the goods delivery.

1. INTRODUCTION

An aircraft that can hover vertically in both take-off and landing operations is termed as Vertical Take-off and landing (VTOL). Fixed wing aircrafts, aircraft with powered rotors like cyclocopters, cyclogyros and tiltrotors even helicopters are included in this category. STOL (short take-off and landing), CTOL (conventional take-off and landing), STOVL (short take-off and vertical landing) are some other modes where these VTOL can also operate. Some aircrafts which cannot handle horizontal landing especially helicopters can only land in vertical mode. VTOL of some other category aircraft which is lighter than air being tested successfully as they can now take-off, hover and landing.

The Passenger Air Vehicles are designed for complete autonomous namely hybrid and electric VTOL's, and the ubiquitous helicopter, In military services, presently there are two forms of VTOL aircraft. One such VTOL which uses tiltrotor. Bell Boeing V-22 Osprey, and other type where vectored jet thrust is used to attain hover for the craft. At present only helicopters are in general use under civilian services. In state of art there are many VTOL technologies are under development both military and passenger services. In general when compared with VTOL, STOVL have superior capabilities but the only disadvantage is the payload increases than pure VTOL.

1.1 Theory behind VTOL:

VTOL which stands for Vertical Take-Off and Landing and, as name implies, the aircraft that capable of vertically hover, take off, and land. The best-known VTOL is the helicopter, on other hand, the fighter F35B jet can also be featured VTOL, that it can take-off and land from a standing start off the back of an aircraft carrier.

VTOL technologies are of two different categories: first one is the rotorcraft and other one is powered-lift craft. Rotorcraft, also known as rotary wing aircraft, where the lift comes with the forces generated by rotor blades and spinning whole round the central mass so called quadcopters, helicopters and gyrocopters.

Powered-lift rotorcraft performs differently when its takeoff and land vertically. Such design has more flexible and conventional type of fixed wings. Bell Boeing V-22 Osprey is the best example of convertiplanes means using fixed wing lift in normal flight, it can take-off and land vertically.

Harrier Jump Het are the known crafts comes under Vectored thrust planes category, also use powered-lift and control the flight by modifying the thrust from the engine or motor.

VTOL technology refers to more flexible for takeoff and land anywhere in vertical direction. Various maneuvers can also be possible where other conventional planes cannot perform which turned to an advantage for combat aircraft series.

VTOL-Vertical Take-Off and Landing characteristics are desired features of this work. There is a great possibility to have autonomous flight capability in the drone, it is possible because of the three-rotor configuration. The drone is controlled by a flight controller, which uses PID algorithms to keep the flight stable. Initially, we are aiming to operate the drone traditionally and gradually make our way up to autonomous navigation.

The rotors used in the drone are convertible, this puts the drone under the category of "Tiltrotor UAVs". This perk enables the plane to eliminate all kinds of dead-weight, which is a major problem in existing tilt-rotor UAVs and makes more room for battery or payload.

1.2 Present Problem in UAVs

There is a significant increase in the number of drones. The problem with the expansion is scarcity of required infrastructure need to operate them. Some elements like runways can be eliminated by implementing VTOL capabilities in the drones that are yet to be manufactured. VTOL drones can answer many existing problems like poor range and low payload capacity. We intend to find a solution to these problem through our drone and point out the advantages of VTOL drones in delivery application over other types of drones.

2. PID–TUNING AND CONTROL TECHNIQUE

PID tuning for this drone is done by trail and error method. the drone is mounted on the plat form and two of the 3 rotational axes are constrained. The values of all three proportionality constants (i.e, Kp, Ki, Kd) are set to zero. the value of Kp is increased in small steps until the drone over shoots the set point and reaches unstable state. After the overshooot is achieved the Kp is halved and fixed. The Kd value is now set to half of the Kp value and then the drone is shaken until it feels responsive enough, even to minute changes. If the drone is not responsive then Kd is increased in steps of 0.5 until a satisfactory state is reached. Even though the drone is now ready to fly it still needs Ki to over come the errors overtime. Ki value is set to 10% of Kp and worked on until a steady state is reached. Ki is limited by a limiting constant so that th corrections can be made in real time. Too high value for Ki will result in delay in response.

A proportional–integral–derivative controller (PID) controller which is frequently used in industrial applications to control systems which requires modulation control on employing control loop mechanism termed as feedback. A PID controller is named after P, I, D because it will correct the errors appeared in calculations such as error value e(t) as the difference between measured process variable (PV) and a desired setpoint (SP) and made correction based on the terms proportional, integral, and derivative

In general terms this PID is applied to a control function and solution will be obtained with accuracy. A real time example is when it is desired to control the speed of a car in its cruise. When a car climbing the hill, and it experiences lowering the speed and lowers the engine power. The desired speed will be measures with appropriate speed and restored by an algorithm of PID controller and problem will be rectified by increasing the desired speed as output.

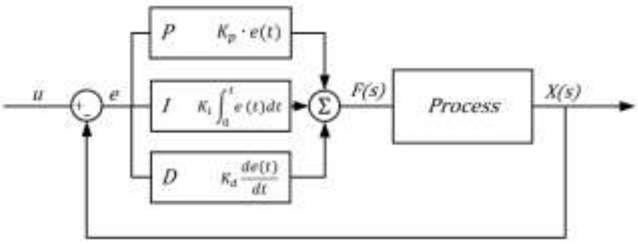

Figure-1: PID Schematic Flow Chart

2.1 Error control by Proportional technique

The proportional control technique is suitable method for proportional control, where the current flowing through the motor will be kept at proportion related to the error raised. If the arm of the model needs to work on different weights, then this method will get failed. For the error which is on upside needs a smaller force and thereby a greater weight, and for a downside error there is a need for greater weight needs a greater force applied. This is how the derivative and its integral will have its significance on error control.

2.2 Error Control by Integral technique

This technique may increase error control with respect to time including the error for which it is rely on. Even if to bring the error null, this applied force is not sufficient to bring the error null since the force increases on passing time. But the process is quite slow to set the error zero because it reacts slowly at the starting thereby the as long as the error is positive the action will increase and also when error approaches to zero.

2.3 Error Control by Derivative technique

Unlike the proportional and integrate, the derivative technique cannot nullify the error. so, a derivative never considers the term error whether it is positive or negative. A derivative term does not consider the error nor it will not set the system to its set point. Instead of nullify this can change the rate of error. This will flatten the error line on to horizontal line in order to reduce the overshoot damping forces are applied to the system.

When the error is decreasing and small, then too much applying impetus will leads to overshoot. If continuously overshoot to work on a large error correction over the required position, the output will oscillate and the setpoint will become either decayed sinusoid. Therefore, the system gets unstable, if the amplitude and increased in oscillations with respect to time. If the oscillations decreased again the system gets stable. And the system is neutrally stable when these oscillations remain at a constant magnitude.

2.4 Tuning Method

Tuning can be done by making a mathematical model of the drone and simulating the whole model until we get the right values for the system.

We are doing it in Trial-and-Error method as creating a mathematical model of the drone is complex and not in the scope of this project. A tool has been designed to arrest degrees of freedom of the drone, this way we can find the correct values for each axis and arrive at the base values of the drone. This method is simple and efficient for tuning a range of multi-copters.

Figure-2: PID Calibrator

2.5 FEASIBILITY STUDY

Problems Identified:

- Dead-weight in both flight modes
- High fuel to range ratio

Goals:

- Elimination of deadweight in both flight modes.
- Finding the optimal Take-off Throttle.

The Unmanned Aerial Systems was broken into three components: Control station, Vehicle, and system. This study establishes significance of UAS applications in transportation and construction disciplines, traffic management, and operations related to DOTs, such as providing a "bird’s eye view", digital photographs/videos of traffic scenes, ability to get real time, which are available in past only with the support of a manned version aircraft, integrating aerial data and programming softwares, and dealing complicated issues, restricted area investigations, is a big problem for DOT to continue the task. The results of this study will grab the focus of researchers on further design, development, and flight testing of UAVs

3. METHODOLOGY FOR STRUCTURAL DESIGN

3D Modelling in Solidworks design tool

This drone is built with a sole purpose of eliminating the dead weight in either of the flight modes. we concentrated on the drone mode at the initial, the goal was to build a stable hovering platform. Various types of drones were analysed and tricopter was chosen to be the core of the plane. Although it is a complex flying machine, it is also the only type of drone that can be morphed into a plane. After the selection of frame type the task was to convert it into the plane. for that, we chose a trainer aircraft and shelled the body. the frame is then merged into the plane and with a few modifications the task was complete. A V-tail was chosen to provide more clearance to the tail motor.

3.1 Structural Design Parameters

To design a VTOL Unmanned Aerial Vehicle, the limiting of certain parameters is very important and designing of UAV to a reasonable initial size. Therefore it is feasible with the other parameters which need to be evaluate for fabrication. The parameters which sized for the design must obey the theoretical concepts and framing of equations to satisfy whether the UAV with VTOL technology can design and fabrication task accomplish and when the model tested for flight it should be stable and safe in all flight modes.

The following are the sequence of steps which defines the design parameters.

1. Gross weight calculations: Total structural weight to be estimated

2. Initial Sizing for Wing Design: Initial sizing to be done to determine the size of the wing span, Aspect ratio, type of airfoils to be included in structure, wing loading, chord

3. Lofting method for Fuselage Design: Lofting process can determine the size, volume and fuselage L/D ratio.

4. Interpolation and sizing for Tail Design: Interpolation will decide the no of airfoils to be incorporated to give external structure of wing, strength in lateral and longitudinal directions. This determines the size and volume of the tail wing. Distance from tail to wing can be calculated with this. These general procedures will be followed initially fix the components for the UAV. After fabrication using the designs a series of flight tests are conducted, the actual dimensions will be adjusted accordingly after evaluating the performance parameters.

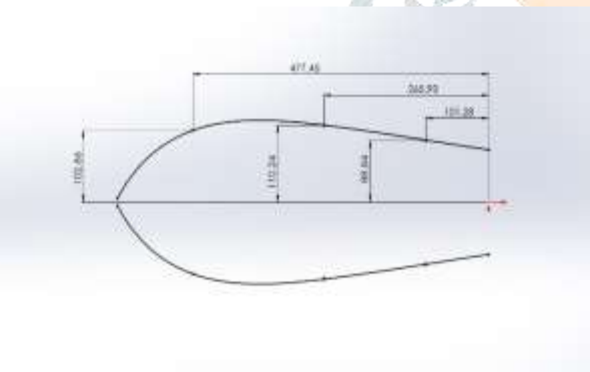

Figure-3: Fuselage design specifications

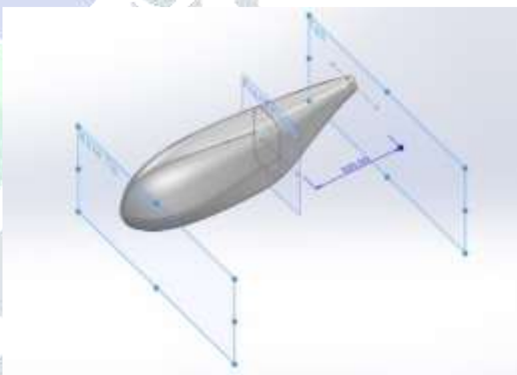

Figure-4: Design of Fuselage with Lofting method

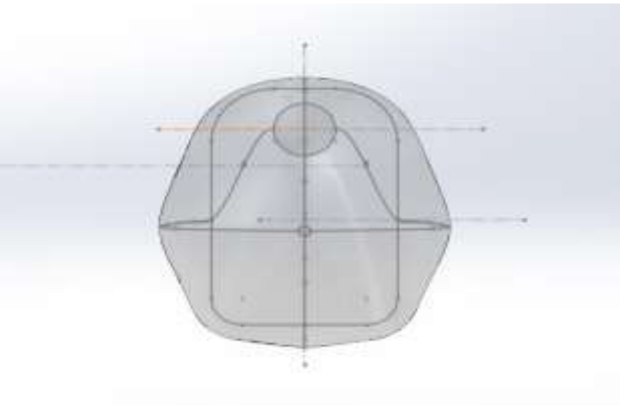

Figure-5: Forebody design in Solidworks

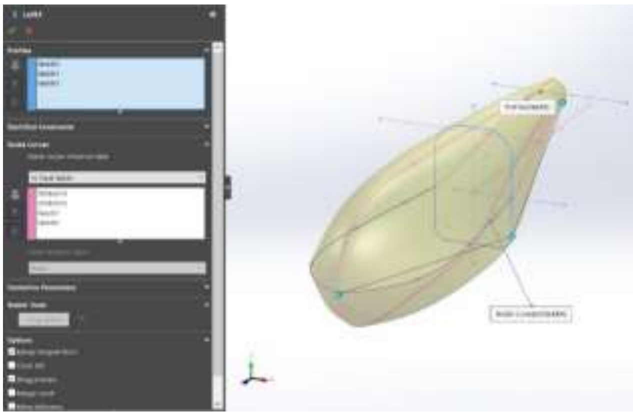

Figure-6: Final Design of fuselage after lofting process

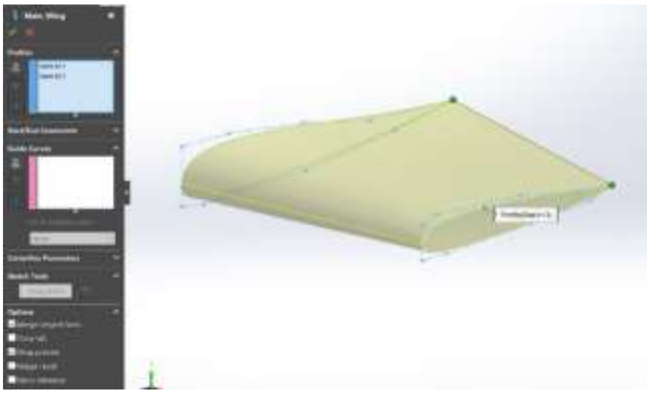

Figure-7: Wing Design in Solidworks with NACA 2412 airfoil coordinates

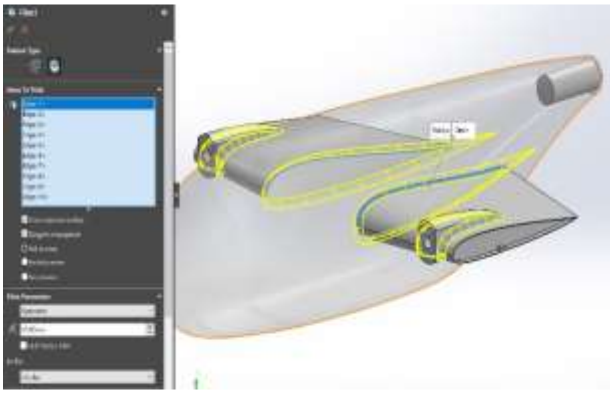

Figure-8: Wing and Fuselage Assembly in Solidworks

3.2 Design of tail rotor section:

The tail rotor handles an important task of keeping the drone stable in case of an error in pitch or yaw axes. There is no counter rotating mass to cancel out the moment created by the tail rotor; therefore, this also falls on the tail rotor. Instead of keeping the motor vertical, it is placed at an angle such that the thrust produced by it splits into vertical and horizontal components. The horizontal component compensates for the moment created by the motor. This eliminates the need for a counter rotating mass, thus stabilizing the drone. This correction is handled by the PID controller, as it is tiresome and requires undivided attention of the pilot.

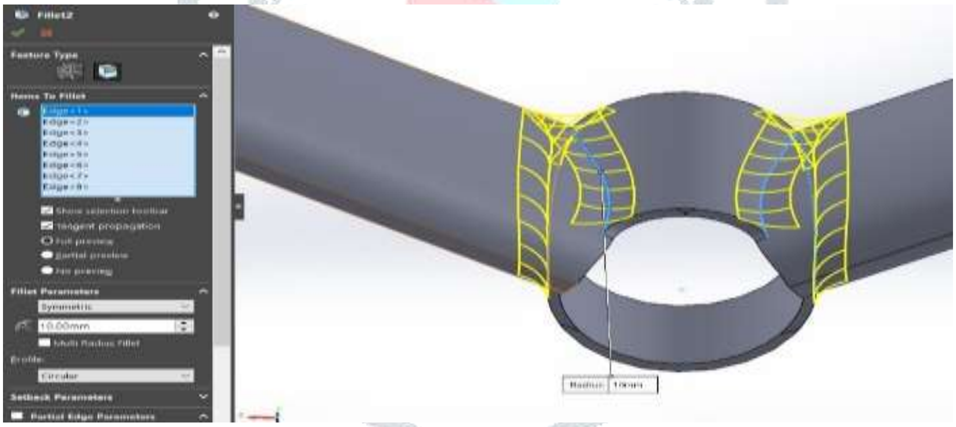

Figure-9: Design of Tail Section including Elevators with NACA 2412 airfoil using Solidworks

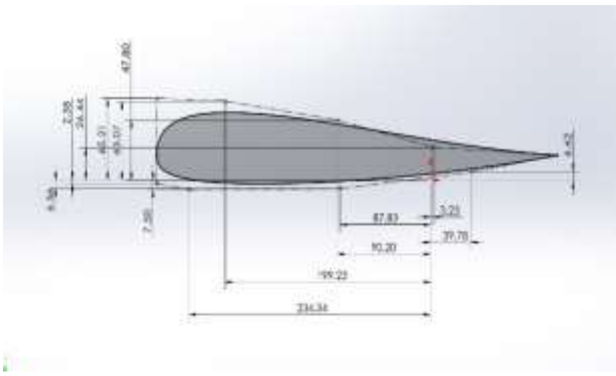

Figure-10: NACA 2412 Airfoil Nomenclature and design specifications

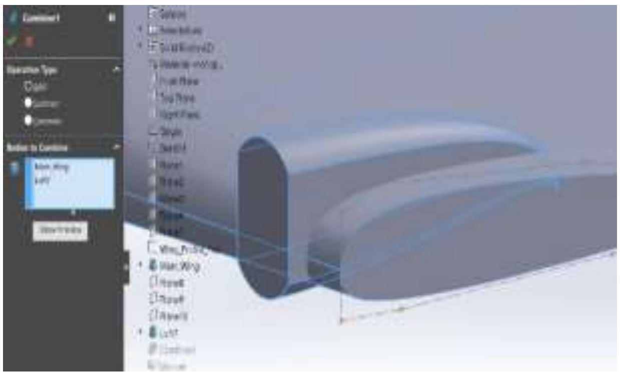

Figure-11: Assembly of wing in Solidworks

3.3 Final Assembly of individual fabricated components

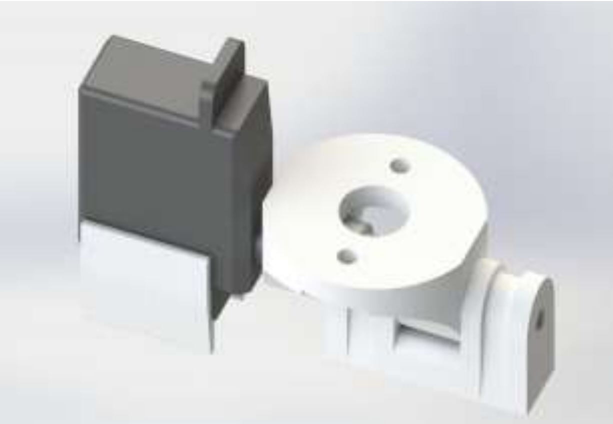

Figure-12: Tilt mechanism to rotate motor designed in Solidworks

Figure-13: Parts used in Tilt Mechanism

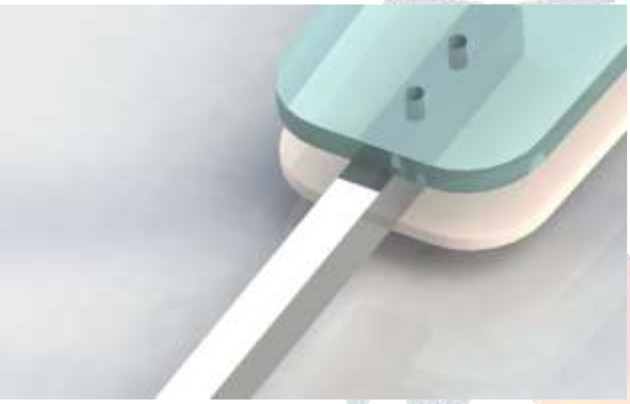

Figure-14: Fuselage longitudinal strengthener's

3.4 Frame Design:

To build the entire UAV based on tricopters as they are the ideal fit to be converted into a plane. Tricopter frames have a lot in common with the shape of fixed wing UAV. There are 2 types of tricopter frames, "T" shaped and "Y" shaped tricopter frames.
The "T" Shaped frame has been chosen due to its resemblance with an aircraft and the simplicity with which a wing can be added to the frame.

The motors are added at the ends of the frame. They are placed in way that makes them the vertices of an equilateral triangle. The combines thrust produced by the 3 motors act on the centroid. The tail rotor is used for "Yaw" and "Forward Pitch" functionality. The tail rotor can tilt to control the heading of the Drone.

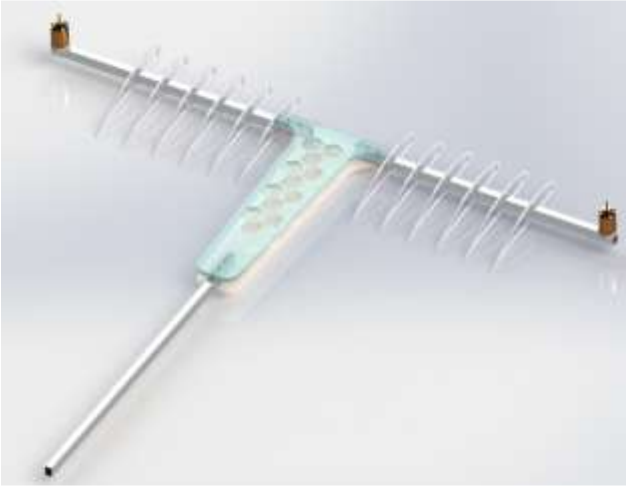

Figure-15: Fabricated frame Assembly

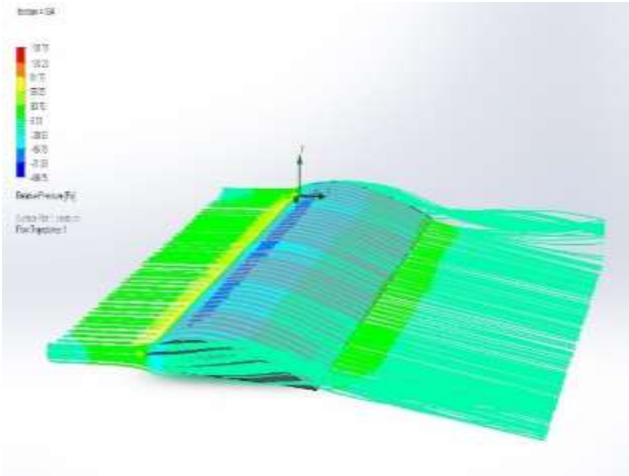

Figure-16: Flow analysis carried out on NACA 2412 airfoil in ANSYS CFD tool

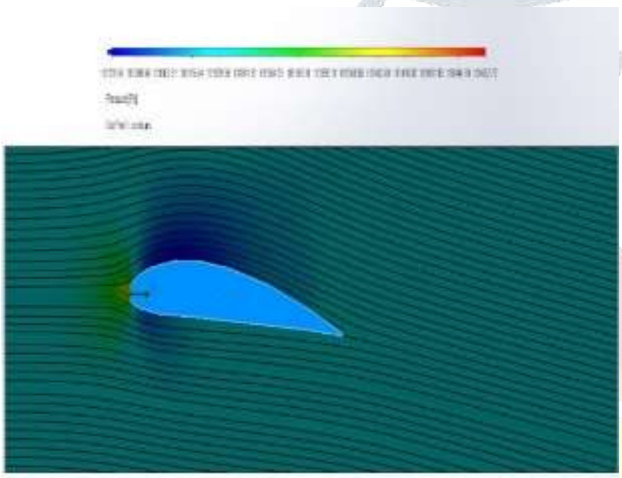

Figure-17: Laminar Flow patterns captured from simulation carried out on NACA 2412 airfoil

Figure-18: Flow simulation for NACA 2412 flow

4. MATERIAL SELECTION AND FABRICATION:

The chosen materials were carbon fibre and PLA plastic but reduce the manufacturing cost further the carbon fibre components are replaced with aluminium components. This is only done to reduce the overall cost and has little to no effect on the drone at this scale.

4.1 FABRICATED MODEL:

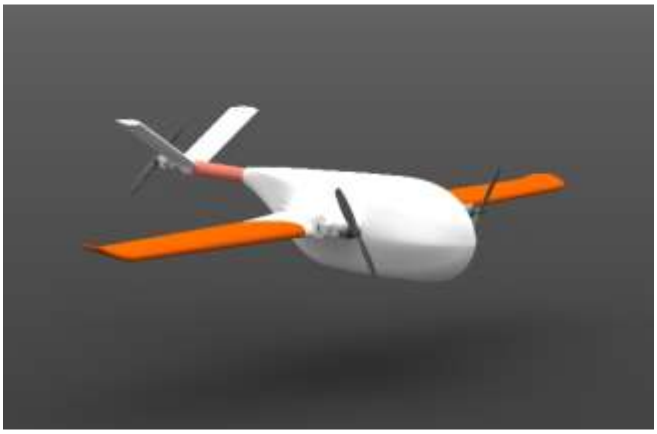

Figure-19: Fabricated and assembled model from isometric view

Figure-20: Fabricated model from side view

5. CONCLUSIONS AND FUTURE SCOPE

Unmanned Aerial Vehicle featured with wing configuration VTOL (vertical take-off and landing) is designed and fabricated with desired dimensions successfully. Performance parameters such as thrust power of the motor are obtained as per the calculate design parameters. Series of flight tests have been conducted on the fabricated model and better endurance limits have been observed.

The present model can be further improved by using carbon fibre composites. The endurance can be improved by using a hybrid power pack containing Lithium-ion cells for flight mode and lithium polymer cells for the drone mode. due to these implementations the all up weight of the drone and manufacturing cost will reduce and gives out a more economical UAV.

6. REFERENCES

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