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INSTITUTE OF ENGINEERING  
PULCHOWK CAMPUS**

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**DESIGN, MANUFACTURING AND FLIGHT TEST OF A FIXED WING UAV  
FOR AERIAL EXPERIMENTS**

**SUBMITTED BY  
SANJIV PAUDEL**

**A THESIS**

**SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND AEROSPACE  
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DEGREE OF MASTER OF SCIENCE IN MECHANICAL SYSTEMS DESIGN AND  
ENGINEERING**

**DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING**

**LALITPUR, NEPAL**

**FEBRUARY 2022**

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled “**DESIGN, MANUFACTURING AND FLIGHT TEST OF A FIXED WING UAV FOR AERIAL EXPERIMENTS**” submitted by Sanjiv Paudel in partial fulfilment of the requirements for the degree of Master of Science in Mechanical Systems Design and Engineering.

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## **ABSTRACT**

This thesis focuses on the manufacturing design and experimental analysis of a twin boom fixed wing aircraft. The thesis includes the three major phases namely manufacturing design of the UAV, assembly, and flight test. The conceptual design of the aircraft is done using XFLR 5 and simulated in X-Plane. The manufacturing design is developed including all the UAV components in design parameters. In this research, fabrication and experimental analysis of the twin boom fixed wing aircraft is carried out. The manufacturing design of the aircraft is done using materials with higher strength to weight to ratio. The wing, fuselage of the aircraft is fabricated using PU foam due to its lighter weight ratio as compared to the volume and strength it possesses, while carbon fibre rod is used as boom for connection between tail and fuselage. The carbon fibre rod is used considering the higher strength to weight ratio. The capability of design and manufacturing of a UAV in the present context with available resource and materials is examined. The selection of materials for the wing, fuselage, frame and landing gears play an important role in defining the final shape of the UAV. It is shown how the manufacturing limitation has forced the designers and manufacturers to implement design improvisations during the manufacturing process in the UAV as in the landing gear support, motor mount and wing to wing connection system. Aesthetically better UAV is possible on after better revision of any preliminary design, but the concept and the manufacturing process along with the materials remain as manufactured in the thesis. The selection of best lightweight materials for the structural integrity is aluminium sections of different dimensions. Use of plastic rubber tyres and carbon fibre tubes for the wing – tail attachments are other components available for structural design of a UAV. 3D printing technology has given a better flexibility for a designer to fabricate a UAV. This has reduced the use of MS plates and Aluminium plates for frame-to-frame connections.

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## **LIST OF ABBREVIATIONS**

UAV Unmanned Aerial Vehicle

PU Polyurethane

VTOL Vertical take off and landing

UAV Unmanned aerial system

NASA National Aeronautics and Space Administration

ERAST Environment Research Aircraft and Sensor Technology

IOE Institute of Engineering

CNC Computer Numeric Control

GUI Graphics User Interface

CAD Computer Aided Design

AMC Annual Maintenance Contract

NDVI Normalized Difference Vegetation Index

RGB Red Green Blue

CATIA Computer-Aided Three-dimensional Interactive Application

PLA Polylactic Acid

# CHAPTER 1: INTRODUCTION

## 1.1 Background

Unmanned aerial vehicles have expanded their application through military applications to medical applications, from normal toy drones to serious rescue missions, from agricultural applications to video and photo shoot entertainment applications, these drones have proved as one of the safest and reliable modes of transport in difficult situations and terrains. From small scale to larger applications, the drones and UAVs are designed to fit the mission objectives. (Paudel, S., Rana, S., Ghimire, S., Subedi, K., Bhattarai, S, 2016)

UAVs are getting a good popularity due to their multiple benefits like handling costs, maintenance costs and ease of operation (Sadraey, M. H., 2013). They can be deployed easily in autonomous modes to complete a mission. Various models of UAV are being developed worldwide based on their applications. NASA deployed a UAV research programme which lasted for 9 years, programmes named ERAST (Environment Research Aircraft and Sensor Technology), which started in 1990 (Valavanis, K. P., & Vachtsevanos, G. J., 2015). Here in this chapter, we are going to do the comprehensive analysis of UAV on Penguin BE model, to be proposed for medical as well as various transport applications.

Figure 1-1 is the Penguin B model under study in this chapter. VTOL (Vertical take-off and landing) model of Penguin B model as shown in Figure 1-2 is also widely used UAV for various applications.



Figure 1-1: Twin Boom VTOL UAV



Figure 1-2: Twin Boom fixed wing UAV

Basically, fixed UAVs are driven through different propulsion systems, they are mostly driven by internal combustion engines and electric motor with desired thrust. This research focuses on the experimental analysis of the UAV with electric motor propulsion system.

Basically, in the context of Nepal, the use of drones has been used to provide emergency relief materials like medical facilities and surveying in difficult geographical terrains because Nepal is a country where there is limited access of roads in hilly regions.

From fire rescue mission to drones as ambulance, drones have proved their usage in every different emergency sectors as one of the fastest and reliable means of support. (Karki, A., Darlami, K., & Bhattra, S., 2021)

## **1.2 Problem Statement**

The multi rotor drones are used in multiple applications and are widely used till date, but the limitations in endurance and payload capacity in compared to the system size and capacity is less as compared to the fixed wing UAVs (T. Oktay, M. Konar, M. Onay, M. Aydin, and M. A. Mohamed, 2016). So, a comparative analysis is done in this chapter to verify the use of the fixed wing twin boom model UAV for different payload capacities.

## **1.3 Objective**

### **1.3.1 Main Objective**

The main objective of the research is to carry out the experimental analysis of the fixed wing UAV model as conceptually designed to carry out a specific mission objective.

### **1.3.2 Specific Objectives**

The specific objective of this research is:

1. To carry out the manufacturing design of the twin boom fixed-wing UAV
2. To fabricate the fixed-wing aircraft model
3. To perform the preliminary flight test of the UAV

## **1.4 Limitations**

The limitations of the study are mentioned below:

1. The preliminary flight test of a fixed wing UAV from an irregular runway is a high-risk test.
2. The fabrication of the fixed wing aircraft on the recent facility at IOE has limits on the fabrication of the aircraft structure to the exactness of the design.

3. There might be some discrepancies in the design model and fabricated model due to the availability of the materials for fabrication like landing gears, propeller size, carbon fibre rod and other similar materials, which might make the aircraft slightly different in aesthetics and control than designed model of the aircraft.

## **CHAPTER 2: LITERATURE REVIEW**

The mostly used UAV for multiple applications are micro-UAV and mini-UAV with a payload capacities less than 35 kg. The low cost in operation and handling for fixed wing aircrafts have enticed many researchers to gain attention towards fixed wing aircrafts for multi-disciplinary applications. (Panagiotou, P., Kaparos, P., Salpingidou, C., & Yakinthos, K., 2015)

The design, manufacturing and flight test of a UAV involves different parameters and software analysis during its experimental verification to its analytical research.

### **2.1 Existing Manufacturing Technologies for UAV**

Prototype UAV models are generally fabricated with either wooden, fibre glass, 3D printed technology or by using Styrofoam. The test and application of the UAV defines the type of material to be used in its overall manufacturing process.

Globally, small UAVs have been extensively manufactured using balsa wood and carbon fibre reinforcement components like rods, tubes and strips (Valavanis, K. P., & Vachtsevanos, G. J., 2015). More recently, injection moulding of aerodynamic sections has been widely used, in addition to other foam-based fabrication techniques. On the costly ends, the composite materials have garnered significant attention due to their durability, robustness and lightweight. The applications of composites extend into the larger UAV systems, replacing aluminium alloys for much of the structural applications. (M. Mirzaei and M. Z. Mohiabadi, 2017)

Larger systems, such as the Remotely Piloted Aerial Systems (RPAS), now extensively use advanced design for manufacturing coupled with composite and CNC manufacturing techniques (including, metal machining, 3D printing, and filament winding) to ensure a seamless process from design to fabrication. This is also the current necessity in Nepal, and this research attempts to integrate and apply such techniques in the design and fabrication of the current UAV, to test and evaluate the technique as much as the flight vehicle.

### **2.2 Types of Manufacturing Techniques in Nepal**

Prevailing manufacturing techniques in Nepal is limited to cutting and grinding of metal structures. Fabrication of oddly shaped structures and shapes using fibre materials, foam and plastics are yet difficult in context of Nepal. Different CNC machines like plasma cutting machine, laser cutting machine and milling machines are in use in Nepal, but all

are used to cut in two axes. Moulding and shaping the objects are still a major issue for design engineers to bring their concept into reality with exactness and precision.

The most prevalent method of aerodynamic shape fabrication in Nepal has been the hot-wire cutting of EPP foam for shape and wooden profiles for ribs and frames. Carbon fibre tubes and rods have been used for reinforcements. This method has worked crudely, in that the vehicles built as such have flown, but the performance of such vehicles cannot be guaranteed. Therefore, an adequate design for manufacturing and fabrication method has been largely lacking in the current UAV development scenario in Nepal.

The development of foam cutter in IOE Pulchowk campus premises recently has provided a very comfortable zone for the UAV manufacturers who are building UAVs with foam in their design.



Figure 2-1: Foam cutter machine at Incubation Centre, Pulchowk



Figure 2-2: Sample wing section with spar fabricated by foam cutter

The simple GUI of foam cutter allows us to cut the foam by providing tolerance and offset parameters during the cut. On efficient feed of input parameters considering the density of the foam, the precise product can be manufactured as per the need. The method also saves time and effort, thus streamlining the fabrication process. It also enhances manufacturing precision, and above all, it fits perfectly with the advanced design for manufacturing as performed in this research. In this method, all components can be designed as they are intended to be manufactured, and most of the fabrication can be done directly out of the CAD model.

Additionally, 3D printing, sheet metal work, and the normal cutting, riveting, and drilling operations will be performed during the manufacturing of the current UAV. It is noted

here that most of the fabrication is thus performed using numerical operations and automated machine operations.

### **2.3 3D Printer Machine**

3D printer is used to fabricate the regular/irregular objects using CAD file. The 3-dimensional axis motion of the nozzle melts the plastic feed material into the platform to create the 3D geometry. In the development of the UAV, multiple fixture elements like motor holding geometry, landing gear components, wing joints, internal combustion engine holding platforms is designed in CAD and fabricated in 3D printer. This reduces the inaccuracy of fabrication of the parts using hand tools and machines.

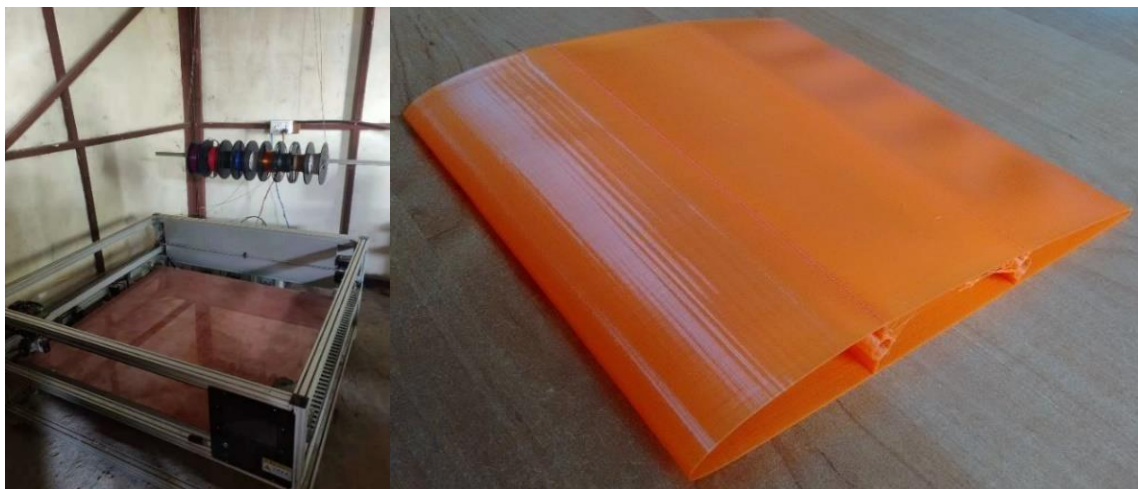


Figure 2-3: 3d Printer machine with different coloured plastic rolls (on the left) and 3D wing section fabricated by 3D printer (on the right)

### **2.4 Application of UAVs in aerial experiments**

Unmanned systems are the best choice to use mostly in risk bearing sectors such as oil and mining sectors et cetera. Some of the mostly used sectors of fixed wing drones and multi rotor drones are listed below:

#### **2.4.1 Oil and gas facilities for security**

Be it monitoring of the vehicles or to check and inspect the construction sites, the 360-degree viewing angle of cameras attached to the drones provide faster and reliable videos to the gas and mining facilities. Some UAVs are attached with sensors like ultrasonic to find the faults in the segments in the oil and gas pipelines. Multiple renowned companies have done AMCs to the drone companies for their services like British Petroleum cooperated with AeroVironment to expand the drones in USA becoming the first company to obtain commercial license to operate as drone company. Other companies

like Chevron Corporation have been using drones to collect field data to improve the safety, ConocoPhillips to monitor its assets. Several other companies like Equinor, Exxon Mobil, Gazprom-A Russian gas giant, Shell have been using drones from different laboratories to conduct research and overview their assets.

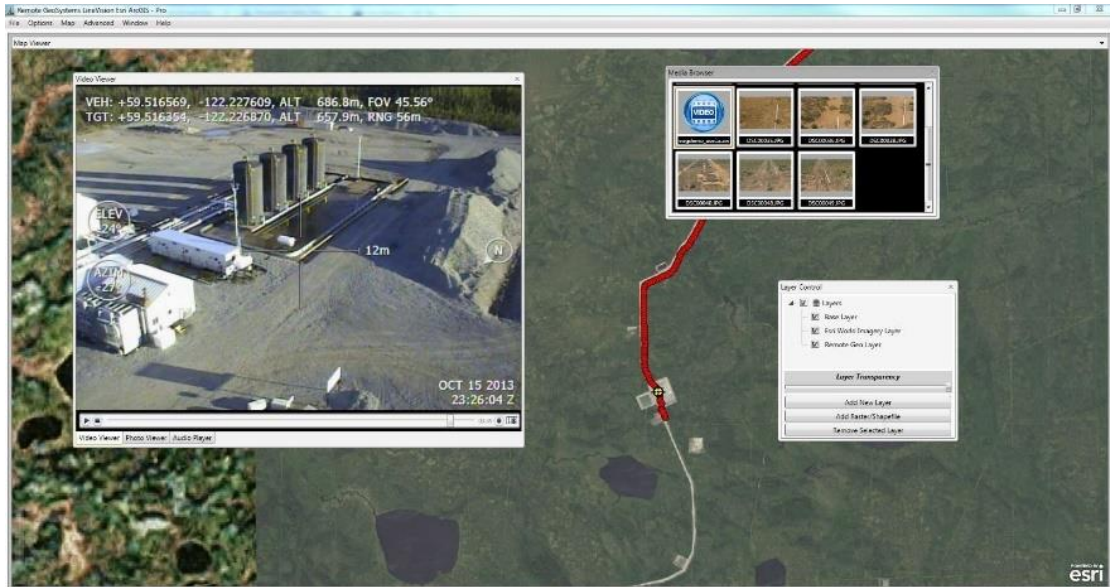


Figure 2-4: Remote Surveillance of Oil Facility using UAV (Source: IATEC)

#### 2.4.2 Traffic control and monitoring

The use of UAVS in ground traffic control is being developed in various laboratories. This is developed to assist the vehicles in ground during high congestion traffic hours to lead them to the best alternative way to reach the destination. Besides, UAVs are planned to be used to provide data about emergency vehicle approaching to them. Such data can be used by surveillance team of the city to monitor the traffic and provide the data to police, hospitals, and other emergency support team to lead them to the less congested zone to travel.

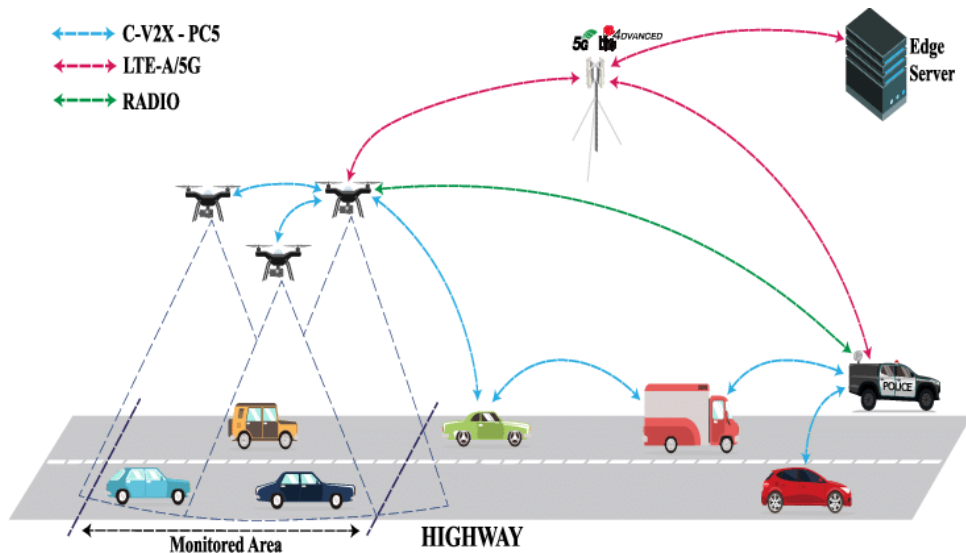


Figure 2-5: Network of Ground Vehicles as mapped by UAV (Source: IOV Asia)

### 2.4.3 Mapping and Surveying

Survey drones generate high resolution and detailed images of any geographical regions with accuracy. Selecting the altitude, speed and area are the major feed parameter required for drones for mapping and surveying. A full 3D geometry is then generated of any type of terrain providing ease in construction at vulnerable zones, inspection of difficult piping sections in oil and hydropower industries.

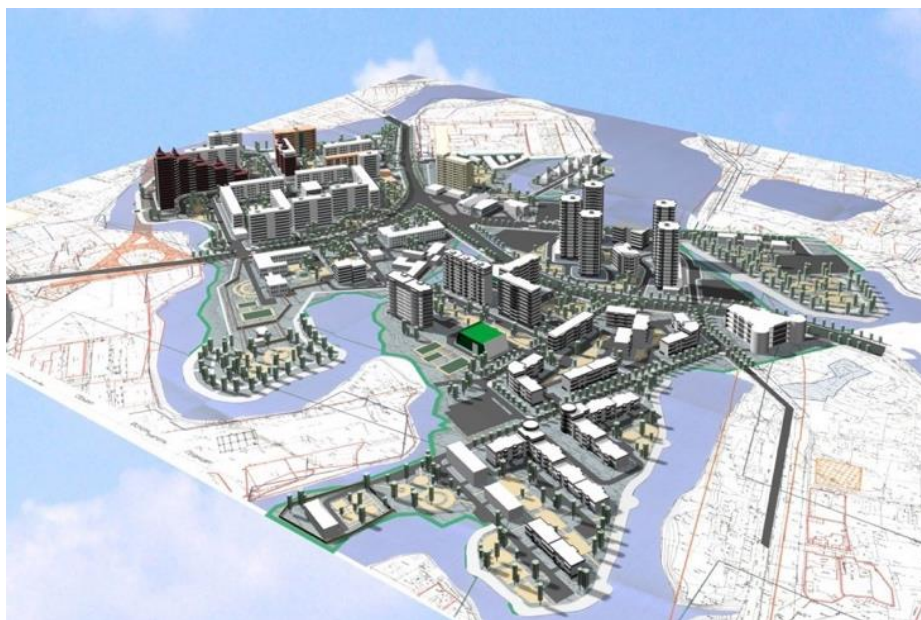


Figure 2-6: Geographical mapping of a city by UAV (Source: Pixtier)

### 2.4.4 Emergency response-medical

Drones are used as firefighting response team, emergency medical supplies transport system in different countries. The benefit of having remote support is providing the fast

response teams in such emergency team an extra safety feature alongside being faster and efficient.



Figure 2-7: Pictorial representation of drones as emergency response team (Source: Gravoc)

#### **2.4.5 Agriculture**

One of the mostly used sectors of UAVs is as a tool for agriculture. Most of the agriculture entrepreneurs use the UAVs as a medium to spray the medicines, fertilizers, herbicide, pesticide, seeds, desiccants in the fields. To obtain the high-resolution videos and monitor the huge fields, UAVs are used. The cost of using a helicopter is highly reduced.

#### **2.4.6 NDVI mapping technology**

The NDVI (Normalized Difference Vegetation Index) helps to divide the field sections from the RGB maps to differentiate the regions with drought and malnourishment with other better field regions for agriculture. This helps to increase the production to the farmers by field selection according to the crop types and predict their yield.



Figure 2-8: RGB maps converted to NDVI Maps for selection of field region (Source: Coptrz.com)

## 2.5 Performance Analysis of Conceptual Design of The Aircraft

The performance analysis of the conceptual design of the aircraft after fixed speed analysis resulted to the following plots of lift, drag and Angle of Attack.

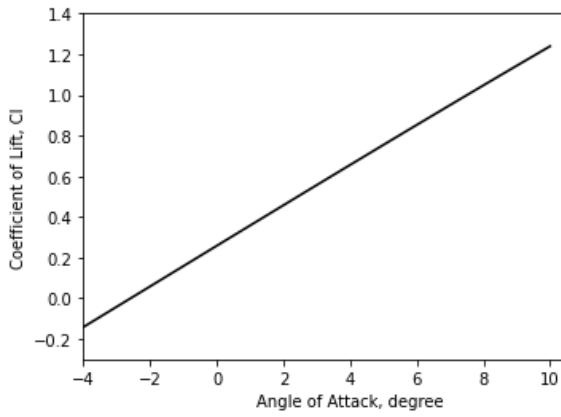


Figure 2-9: Lift Curve

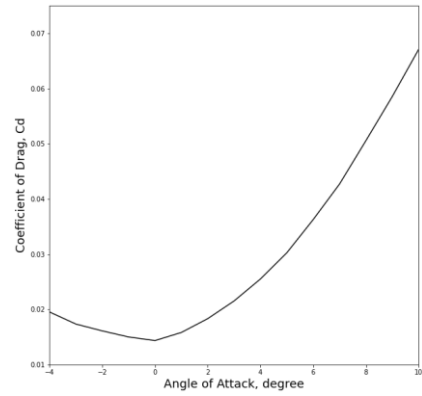


Figure 2-10 Drag Polar

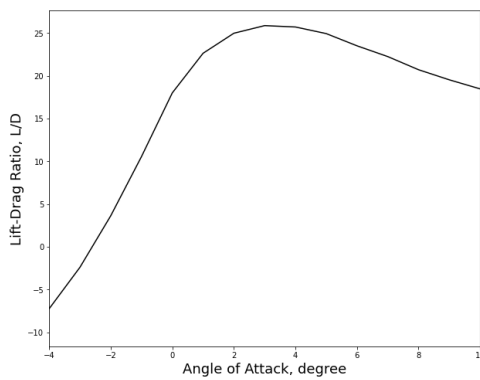


Figure 2-11: L/D Ratio Vs Angle of Attack (AOA)

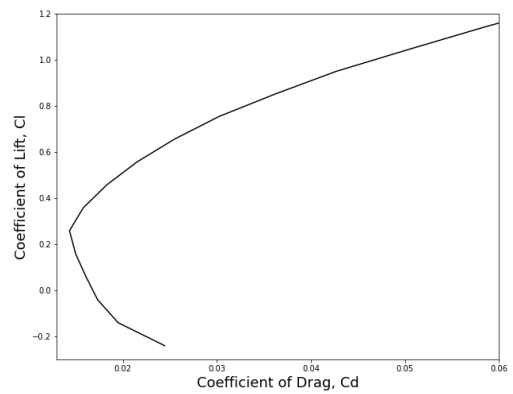


Figure 2-12: Cl Vs Cd

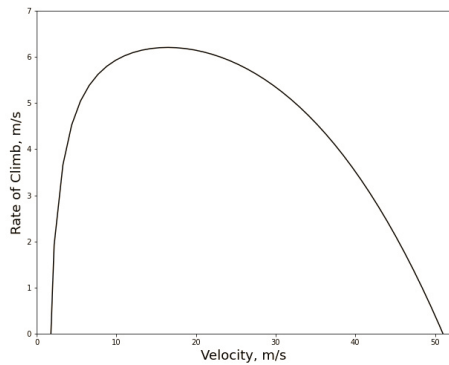


Figure 2-13: Climb Performance

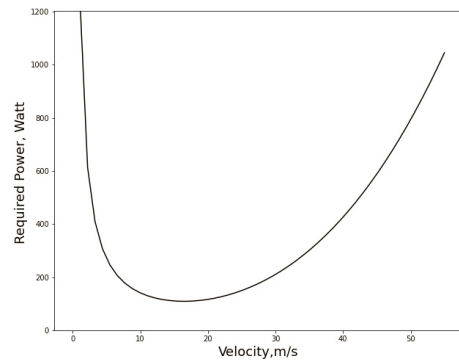


Figure 2-14: Cruise Performance

The above figures show that for the cruise speed of 25 m/s, power of 200 watt is approximately required (Karki, A., Darlami, K., & Bhattarai, S., 2021).

## **2.6 UAV Elements**

### **2.6.1 Propulsion System**

Electric motors are the most preferred propulsion system among the multirotor drones and fixed wing aircrafts. However, for higher payload fixed wing UAV, use of piston engine is also a common practice by most of the drone fabricators since past years. A performance analysis was done with the available piston engine with the following specifications. On doing the performance evaluation, various parameters like engine weight, vibration, fixtures and nut and bolts seem to be used in a very specific strategy which was beyond the scope of the thesis due to time limitation. During the testing, the available propeller broke upon higher throttle, so to avoid the accidents which may occur during the test of the UAV with this engine without extensive study switched our UAV to a 5000 g and 14000 g thrust motor which given specification.

### **2.6.2 Piston Engine Specifications**

A 2 stroke cycle (petrol) piston engine was tested to check its utility as a propulsion system in the current UAV. The piston had the following specifications:

- Model: DLE-55RA
- Displacement: 55.6 cc
- Performance: 5.5Hp, 8500 rpm
- Idle Speed: 1500 rpm
- Recommended propeller: 22\*8, 22\*10, 23\*8, 23\*10
- Sparkplug type: CM6
- Compression ratio: 7.6:1
- Diameter\*Stroke: 1.76 Inch \* 1.37 Inch

However, the model did not meet the expected operational requirements, due to extreme vibration, requirement of heavy support structure, and the complications with fuel supply system. In addition, the thrust to weight ratio of the piston engine was too low to justify its application with the current UAV. Therefore, an electric alternative was explored to be used with the current UAV. The specifications of the brushless motor chosen for the current UAV is the following:

- Model: Emax GT 4030
- Thrust: 5000 g
- Weight: 400 grams



Figure 2-15: Piston Engine Model DLE - 55RA



Figure 2-16: Emax GT 4030 Motor with clamps

### 2.6.3 Propeller for propulsion

Propeller provide the thrust required for any kind of aircraft to gain the thrust. Various types of propellers, in terms of type and made are used in the UAVs to provide thrust. Due to higher RPM and reliability of the material, carbon fibre propellers are widely used in UAVs since past years.



Figure 2-17: Carbon fibre propeller



Figure 2-18: Wooden propeller

#### **2.6.4 Battery**

The battery is the power source of the aircraft. Lithium Polymer batteries are used due to its high energy density and also higher voltage it bears in one cell.

#### **2.6.5 Lifting Surface**

The wing is the lifting surface of the UAV. Spars are used to connect the wing sections together for stiffness.

#### **2.6.6 Payload**

For a UAV with a definitive mission, payload is the load it bears to be delivered to a certain location during its mission. The position of the payload is well defined and analyzed during stability analysis of the aircraft.

#### **2.6.7 Landing Gear**

The landing for fixed wing UAV with light weight are generally made with aluminium or 3D printed material whereas the gears for the UAVs generally ranging above 7 kgs are made with metal or aluminium frame embedded with shock absorbing mechanism.

#### **2.6.8 Fuselage**

The fuselage is the component where all the electrical components, payload, wings and propulsion system (engine/motor) is attached in the aircraft. The fuselage holds the landing gear and is centrally located in the aircraft.

#### **2.6.9 Pixhawk**

Pixhawk is the open hardware design to the hobby and student communities as well as industrial communities.

### 2.6.10 Pitot Probe/Air data sensor

Pitot probes are used to measure the air speed in wind tunnels. In the UAV in this project, pitot probe is used to measure the wind speed before/during the flight. The probe used to measure the flow of liquids is specifically called as flow meter.

### 2.6.11 Landing Gear

Landing gear are components which helps a UAV to take off and land before and after the flight. The landing gears are normally fabricated using rubber at the outer surface and plastic or metal inner rim at the inner frame. Steel is unnecessarily heavier for the UAVs, so plastic and rubber tyres are normally preferred over steel frame tyres.

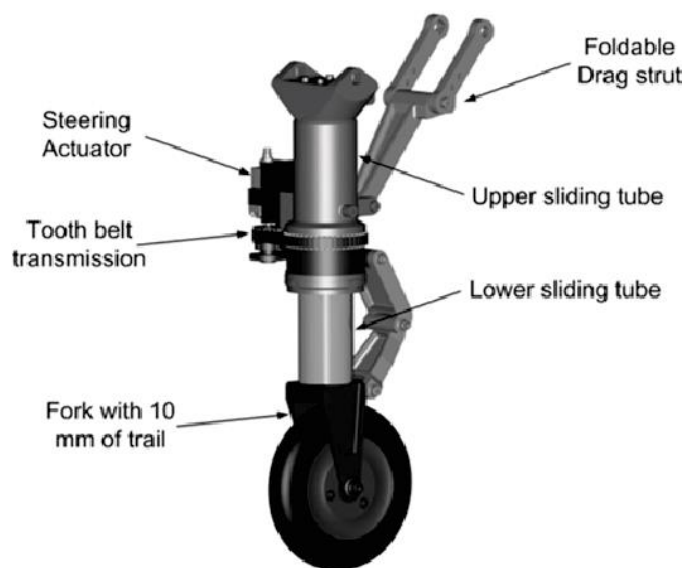


Figure 2-19: Landing Gear Schematic (Source: Sematic.org)

### 2.6.12 ESC

The electronic speed controller (ESC) are control devices which are used to control the motor speed in the UAV. The rating of ESC to be used in a UAV depends on the power rating of motor used.

### 2.6.13 Control surface, aileron, stabilizers

To provide roll, pitch, and yaw motion for any UAV, there are types of control surfaces cut out in the wing sections. This helps the UAV to move in the desired direction and height during the flight.

### 2.6.14 Telemetry Device

To extract the live position of the drone and for Realtime information and communication, telemetry modules are implemented in a UAV.

## CHAPTER 3: METHODOLOGY

### 3.1 Experimental Bench Tests

#### 3.1.1 Selection of propulsion system

The initial choice for the propulsion system for the project was 55.6 cc piston engine for the UAV.



Figure 3-1: Piston Engine mounted on wooden frame

Figure 3-2: Wooden propeller fixed to piston engine

A series of tests and experiments were performed with the piston engine at variable rpm. However, multiple issues faced during the tests has generated significant scepticism to use this engine as propulsion system for our UAV.

#### 1. Mount and vibration

Since the piston engine was a new type of propulsion system under trial at our facility, we were unable to find the best mount method for the engine, due to which we had to face an issue in vibration.

#### 2. Attachment for piston engines

The hit and trial of attachments like engine mount, propeller mount did not seem to work on simple mechanisms as we were unable to damp slight oscillation in the propeller during our test. Since the system to fit the piston engine attachments is yet under tests and

trial, so we are now switching to electric motor propulsion system till our tests are confident on piston engine propulsion system.

**3. The thrust capacity of the piston engine is above 10 kg, which is beyond the need of the project.**

The electric brushless motor with a thrust of 5000 grams is chosen for the first test flight of the experimental UAV. The final weight of the UAV is estimated to be at 6.5 Kgs, so the thrust of 5000 kgs with 16\*8 propeller is considered enough for the take off. Hence, it is used in the UAV as the propulsion system. To gain maximum thrust with the motor, 16\*8-inch carbon fibre propeller is chosen. The maximum propeller length that could be used without interference with the twin boom is 16”.



Figure 3-3: Figure 24 Motor propeller with clamp for the designed UAV



Figure 3-4: Motor propeller reference picture

### **3.2 Manufacturing Technology**

The research is being carried out under a specific methodology as charted below. The target of each method adopted is to enable the design for manufacturing and the preliminary flight tests to evaluate the feasibility and performance of the UAV model and to inform future design modifications.

The intended purpose of the manufacturing exercise is to select key fabrication components, test fabrication methods of the parts of the UAV, and evaluate how robust the final product can be. This exercise is based on the exploration of four aspects of the current state of the manufacturing technologies:

1. The current market and industrial capability for procurement and fabrication of UAV parts
2. The current manufacturing technologies that can be immediately adopted into a UAV research project
3. The cost and timeframe required to rapidly develop prototypes and test them
4. The evaluation of the usability and performance of the manufactured UAV.

Hence, this research is also an exploration of the feasibility of performance-based manufacturing and testing of UAV and associated systems. A simple example of this is approach is: how can a vehicle designed to meet a certain performance can be manufactured to meet the expected performance? This study attempts to answer such questions in a stepwise manner, one components and technique at a time.

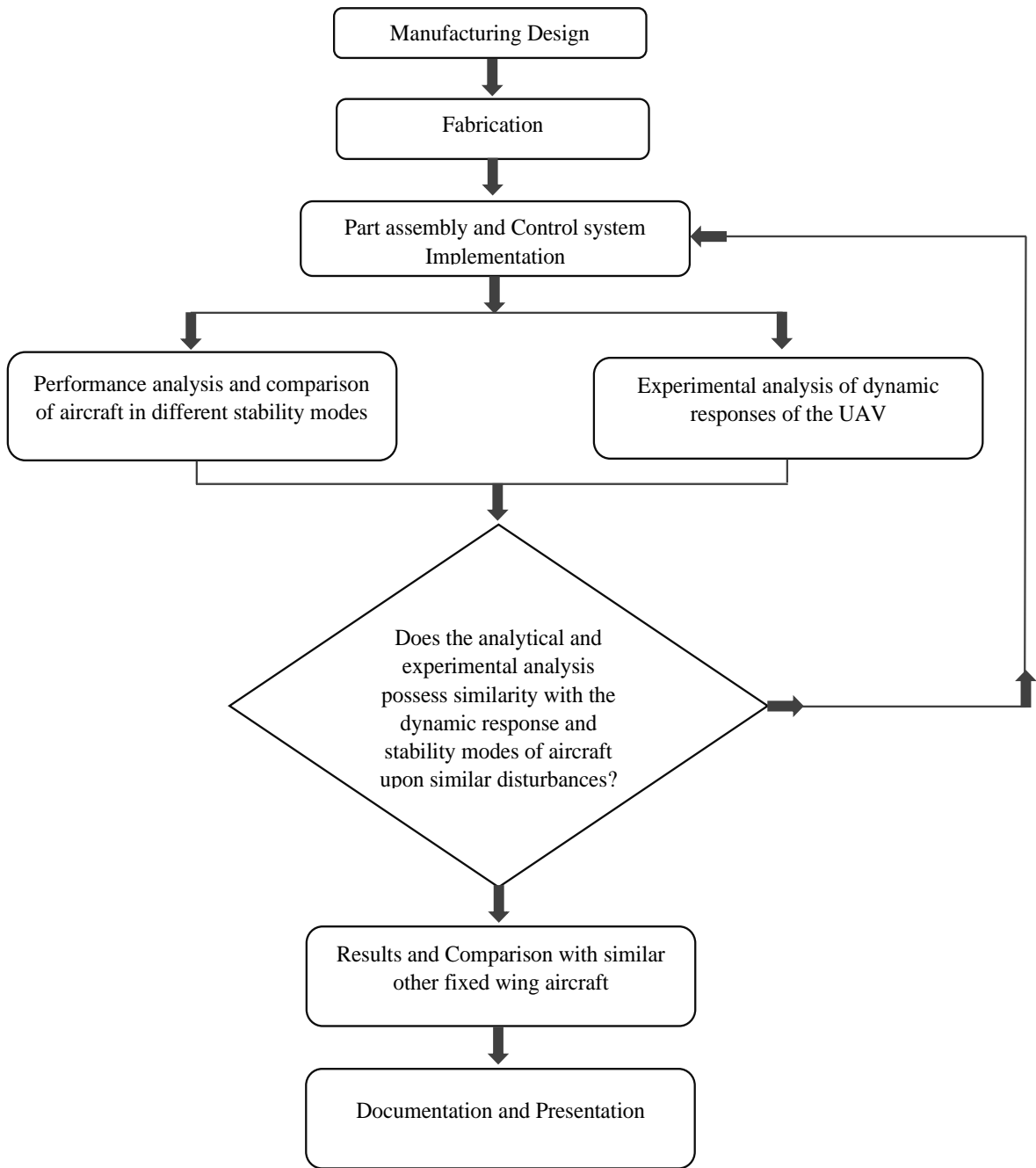


Figure 3-5: Work chart

### 3.3 Design methodology

The conceptual design of the aircraft is completed and the preliminary design for manufacturing is then done using CATIA. After flight tests, the design will be reviewed and then modified as per the feedback received from the flight test. Basically, the design of the finalized twin boom fixed wing UAV takes the sequence as shown.

The design ensures that each part is manufacturable using the techniques available largely within IOE Pulchowk. The components and techniques are detailed in the following chapters.

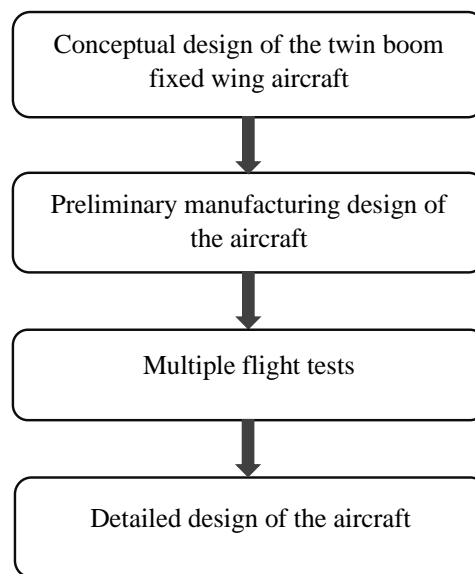


Figure 3-6: Flowchart of design sequence of the UAV

### 3.4 Fabrication flowchart

The UAV is a vast subject to start with during the fabrication of each of the components. A proper flow of work during the fabrication can effectively manufacture the UAV in proper time and proper management of the parts during the assembly. The following schematic is used to manufacture the UAV in the facility at Pulchowk Campus, IOE.



Attachment of Avionics and control surfaces



Shaping for final flight test



Figure 3-7: Fabrication flowchart

### 3.5 Design for manufacturing

The manufacturing design is developed from the conceptual design of the aircraft. From material selection to fabrication procedure and finally to assembly of the UAV, market availability of resources has played a significant role. The design selection of each component in UAV while development of such kind of UAV in Nepal is limited by the market and resource availability. The following describes the design procedure of the UAV in context of Nepal. The UAV manufacturing assembly design is shown in Figure 7-1. It's a V tail twin boom UAV. In this chapter, the design structure of each major component of the UAV is discussed.

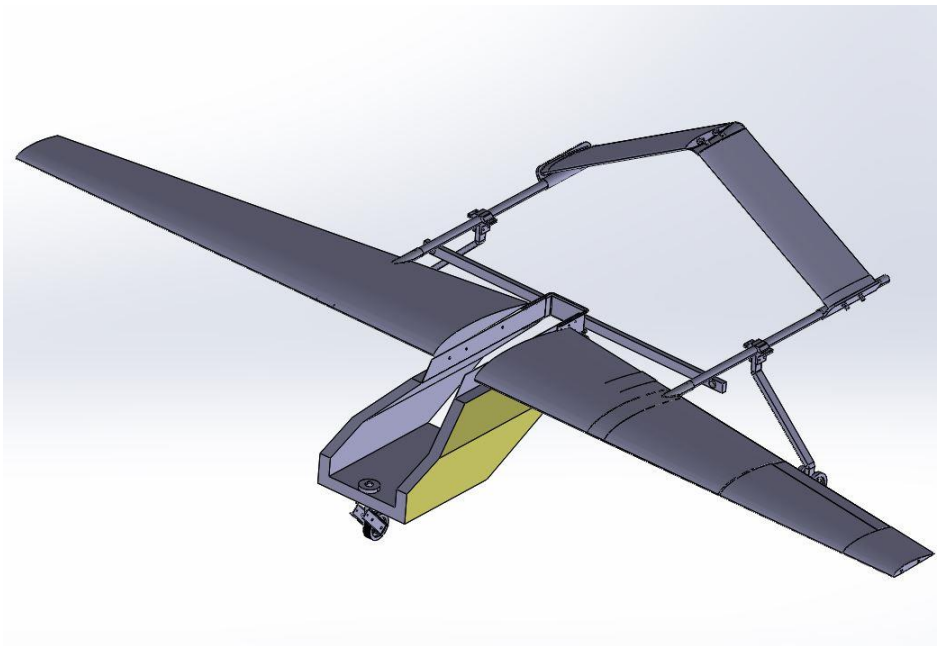


Figure 3-8: Design of UAV

#### 3.5.1 Fuselage

The fuselage is developed into an angular shape in design as viewed from side view. One of the major reasons is to give the fuselage an aerodynamic shape and, another, is to reduce the weight of the fuselage to the optimum level. The upper section is designed to bear the wing load in both the sides which clearly shows holes for twin spars. Each level of twist in the fuselage is designed to be different sections, to be assembled using rivets or fasteners, to avoid whole body failure during possible crash during flight.

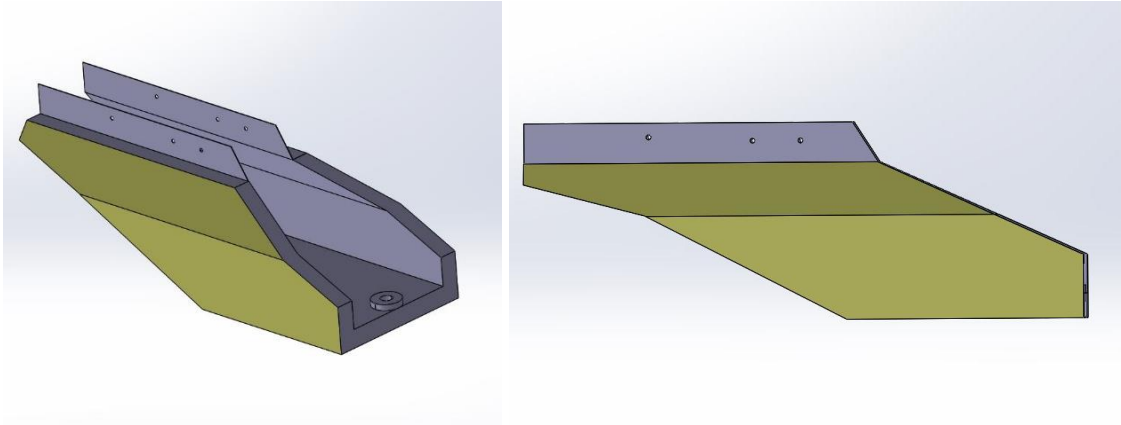


Figure 3-9: Fuselage: Isometric View on the left and Side view on the right

### 3.5.2 Wing

The wing is symmetric, and two spars pass through the wing to provide the stiffness to the structure. The wing is designed to lift the 7-11 kg of the aircraft weight (including payload). The above picture shows right half of the wing, connected to the fuselage.

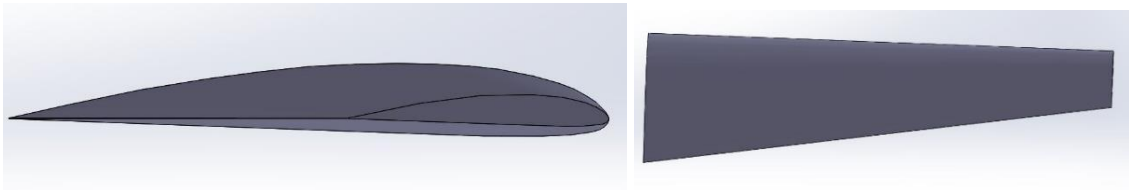


Figure 3-10: Wing section: side view on the left and half wing section on the right

### 3.5.3 Rear Landing gear

The rear landing gear is designed into an angular model to attach itself with the boom or section in the fuselage and align itself in line with the boom from top view. Two plastic wheels attached with 6 mm shaft and spacer in between provides more firmness in the motion. The 3D printed clamp will be used in the connection with the boom.

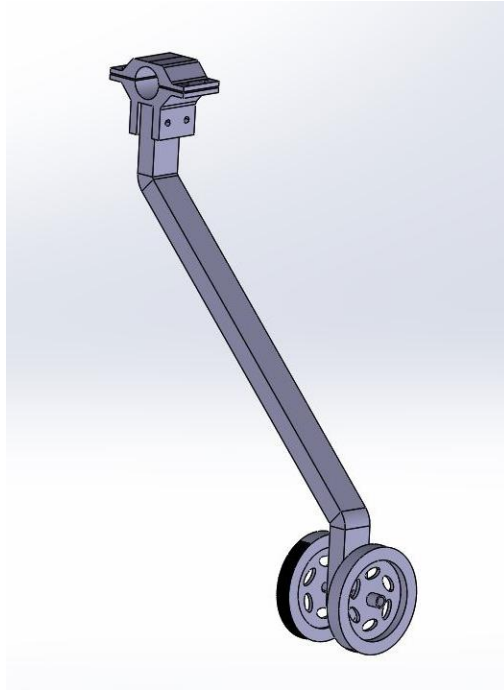


Figure 3-11: Design of Rear Landing Gear

#### 3.5.4 Motor mount

The engine mount is designed in the shape as shown, which shows the holes for rivets for fixing it firmly with the fuselage section on top. The motor – propeller placement being at the front of the mount. To stiffen the mount, 10-12 mm flange is bent in each side of the mount.

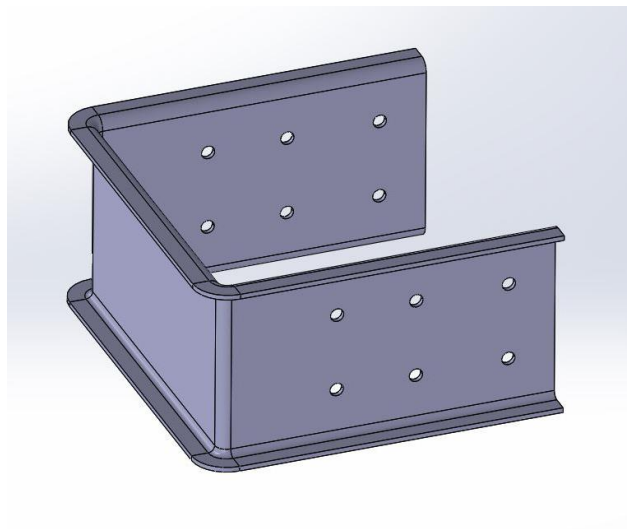


Figure 3-12: Design of Engine Mount

### **3.6 Fabrication and assembly**

The manufacturing design of the aircraft is designed and drafted with manufacturing standards. The position of the components like ribs, spars, connection joints for boom and tail with wings which are located through surface modelling are then created with 3D modelling techniques and then assembled. The processes involved during the manufacturing are described in the following sequence:

#### **3.6.1 Manufacturing design**

The manufacturing design of the UAV is done using CATIA. The ribs are designed with 3mm wooden plank. The carbon fibre spars are due to its higher strength to weight ratio. 3D printed wing sections are used in certain section to connect the boom with the wing and tail of the aircraft.

#### **3.6.2 Fuselage**

The fuselage of the aircraft must bear load, payload and be stiff enough to hold the lifting surfaces. So, the PU foam and panel used as the material for the fuselage structure jointed with steel and aluminium edge caps to hold the panel in curves. The following picture shows the 3D manufacturing design and manufactured fuselage using the PU panel with thickness of 50 mm.

The fuselage fabricated material has steel reinforcement of 0.55 mm to get the stiffness to stay intact in cases of crash during the flight test. The material is chosen due to the high-density property of the foam and pre attached steel which provides further rigidity to the fuselage. The fuselage is seemed to be in angular design to reduce the mass property. It is designed to accommodate sensors, battery, esc, velocity probes, and few other flight data receivers.

The desired curvature of the fuselage as per the design is achieved through foam spray and sanding the excess foam from the curves and edges. The 0.5 mm steel is attached to the 50 mm thick foam inside the body of the fuselage. The smoothness of the fuselage is later achieved by attaching smooth plastic layer over the fuselage to reduce the unnecessary drag in the aircraft.



Figure 3-13: Initial development of fuselage using PU Foam Panel

The fuselage was constructed out of a PU foam block metal sandwich structure. The outer metal panel was removed, while the inner foam layer was carved to form the outer fuselage shape. The initial foam structure is shown in Figure 30, and an initial carved shape is shown in Figure 31 and 32. The shape approximately resembles the intended design created during the preliminary design phase, as shown in Figure 29. Although the exact shape in this case is relatively arbitrary, the internal volume of the fuselage that will be used to carry the payload has been preserved.



Figure 3-14: Fuselage (left side) sealed with PU Foam (on the left) and fuselage with motor propeller frame (on the right)

The fuselage is cut into an angular design from both sides, front end, and tail end to give a proper aerodynamic shape. The top portion of the PU foam is then left with steel reinforcement to attach a spar into the fuselage.

The nylon bush is then added to the fuselage where the connection of the spar is made so that it would provide more strength and work as a spacer to maintain the gapping between the fuselage steel section.



Figure 3-15: Nylon Bush attached in between wing sections for spar connection as well as rigidity

### **3.6.3 Wing section development**

The foam cutter machine is a CNC based wire cutting device with fixed span to cut the foam (body of the aircraft including fuselage, wing, tail configuration) for the experimental study. The X, Y and Z motion of the servo motor facilitates the motion of the heated wire to cut the foam into desired sections. The limitation of the cutting area makes the wing and other parts of the aircraft to be cut into multiple sections and later be joined using adhesives.

The wing section then developed were then connected to the aircraft to check the preliminary examination of the geometry and its alignment with the fuselage body. The sections of the wing were fabricated by using Styrofoam and cut using multiple sections due to limitation of the foam cutter CNC machine at our facility.

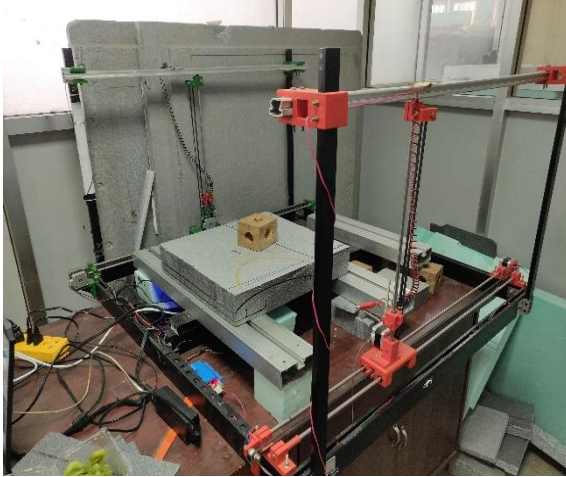


Figure 3-16: Airfoil profile being cut for the designed UAV



Figure 3-17: Airfoil profiles after cutting using foam cutter



Figure 3-18: Wing sections as cut by CNC Foam Cutter



Figure 3-19: Wing section (right) as connected to fuselage



Figure 3-20: Spar holes for spar connection in wing sections



Figure 3-21: Tail connection without stabilizer cutting

The spars and the holes are then connected using the carbon fibre rod at the wing sections at front and then using carbon fibre and aluminium pipe sections at the tail and stabilizers. The 3d printed sections are used at tail parts to connect the wings between each other and

at many joints in between for rigidity. One of the benefits of using the 3D printed technology is that we can shape the joints required in our own ways.



Figure 3-22: Spar connection in wing (twin spar)

The 3D printed section was found to be weaker in surfaces. So, we had to bind it with black locally available binding tape for smoothness and somewhat rigidity too. The 8 mm and 10 mm carbon fibre rod are the major connecting rods between the wing sections. Since the inside diameter of 8 mm rod is 6 mm and the inside diameter of the 10 mm rod is 8 mm, it became a bit easier for us to work using the 6mm ,8mm and 10-mm carbon fibre tubes during connections at the edges between them.

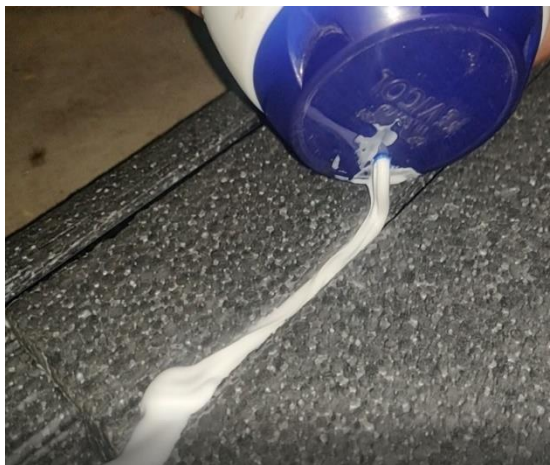


Figure 3-23: Spreading fevicol SH for rigidity in spar



Figure 3-24: Joining wing sections using Fevicol SH

The Fevicol (SH) was used to fill the gap aroused during connection of the spar in the wing and in the gap aroused during the wing-wing connections in the foam. It was then left to dry for 24 hours and then the rigidity was obtained. Furthermore, PU foam was

again sprayed over the spar connections and grinded to obtain the original aerodynamic shape of the wing.



Figure 3-25: Wing section sprayed with PU foam and grinded to obtain the aerodynamic shape of the wing

Figure 3-26: PU foam spread and grinded to wing for rigidity

PU foam was further pasted over the body and then let dry to 28 hours to obtain more rigidity. PU foam was grinded to bring the aerodynamic shape. Fevicol, MR, was again spread over the surface to get the smoothness over the body to reduce drag due to irregularities and porous material of PU.



Figure 3-27: Initial nose landing gear: side view on the left and front view on the right

The preliminary design of the nose landing gear was made using aluminium sections on both sides and torniquet as the spring and shock mechanism. This was done considering the light weight of the material required for the aircraft. This showed some irregularity in the movement due to multiple joints and sections in this model. This was further changed in the next phase in next model increasing the rigidity included later in the following diagrams Fig 46 and Figure 47. The aluminium sections were then used to create a more rigid structure for nose landing gear and then tested.



Figure 3-28: Second design of nose landing gear



Figure 3-29: Nose landing gear into UAV

The preliminary design of the landing gear showed some irregular motion in lateral and vertical direction with lacking rigidity in required positions. Hence, the aluminium section (12.5mm \* 25 mm) was used to fabricate the similar but a bit more rigid nose landing gear. The spring was used to provide the required shock absorbance to the UAV during take-off and landing of the UAV.



Figure 3-30: 3D printed clamps for rear landing gear attachment



Figure 3-31: Side view of rear landing gear attached with 3D printed clamp

One of the major flaws was found in using the 3D printed sections and profiles in the joints as clamp for landing gear. It was found that the 3D printed parts cannot guarantee the use as clamps in places where we need to tighten and fasten often. Late the design was changed which is included in the chapter in later pictures.



Figure 3-32: Tail connection

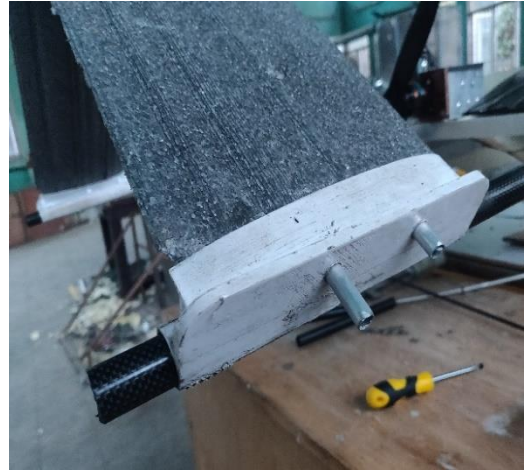


Figure 3-33: Tail spar connection

The tail was then connected with 3D printed parts as connection joints between each other. Carbon fibre was inserted in between the aluminium tubes and then supported at the tip. In further steps, we attached the pins at the ends of carbon fibre tubes not to allow the tail wing to fall during the flight.



Figure 3-34: Modified rear landing gear connection position



Figure 3-35: Rear landing gear top view

Since the 3D printed parts did not provide the rigidity in the rear landing gear section, we had to use the CPVC pipe clamp and connect the rear landing gear at a different position with a rectangular section, having direct connection with the fuselage. This structure provided a support as well as created a rigidity for the wing sections to be rigid enough during flight and crash failures. Black tape was used often wherever necessary to obtain the required diameter of carbon fibre tube to clamp with the CPVC clamp.



Figure 3-36: Straightener for tail connection



Figure 3-37: Tapered tail without straightener



Figure 3-38: 6 mm stud fitted for wing end to end connection

The 6 mm stud is used to connect the whole wing to fuselage to one single body allowing more rigidity during the flight as shown in Figure 3-38. Lock nut is used at the two ends with 6 mm washer. Lock nut is preferred to avoid unnecessary opening of the nut at times during rough terrain during take – off and landing and at turbulence in sky.

### 3.7 3D printed boom wing attachment

Various sections of 3D printed profiles have been created to connect the wing sections together with stiffness. Wing, tail, and boom attachments are fabricated with PLA 3D printed material.



Figure 3-39: Tail attachment 3D Design



Figure 3-40: Wing attachment 3D printed adapter

### 3.8 Spar and Wing Assembly

The 8 mm carbon fibre spar is used to join the sections of the wing to each other. Ribs are then joint in every cross section between two wing sections cut through foam cutter.



Figure 3-41: Selected carbon fibre tube for spar

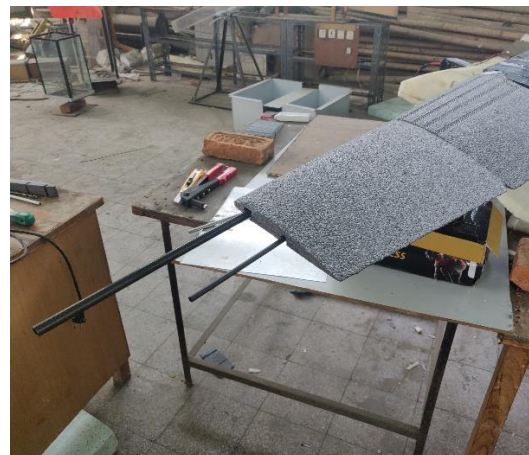


Figure 3-42: Carbon fibre tube used in wing as spar

The final wind body is then generated using multiple assembly tools. The preliminary finalized design was tested in ground with the first phase design of the nose landing gear. The test showed some disturbance in the movement of the nose landing gear giving a instability in the aircraft during motion. This was further changed to the new model of nose landing gear as explained further.



Figure 3-43: Ground testing of UAV



Figure 3-44: Ground testing of UAV with new design of Nose Landing Gear

The new design of the nose landing gear is then developed as final model which gave the aircraft the desired straight rigid motion required during take - off and landing. The holes in the centre shaft can be adjusted to bring rigid or rotary motion to the aircraft as desired during flight tests.



Figure 3-45: Surface smoothening using black tape and Fevicol



Figure 3-46: Finalized UAV without Nose surface

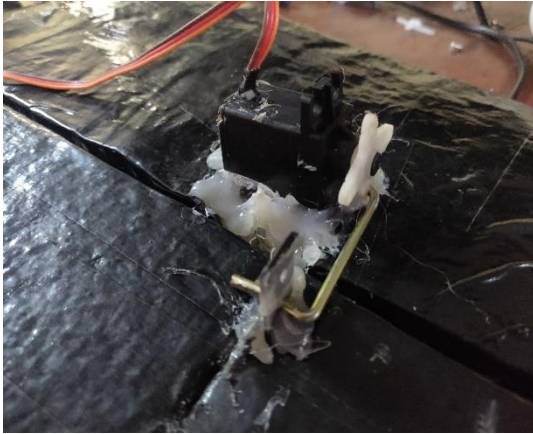


Figure 3-47: Servo Motor mounted on wing with a spoke link



Figure 3-48: Servo motor mounted on tail wing

The servo motors are then mounted on the wing of the aircraft. The mounting is done by cutting a section of the foam wing which was then fixed using glue and duct tape. The servo motors are fixed on tail and wing section on stabilizers and ailerons. The link was made using the bicycle spoke found in local market. The spokes were then bent to form a simple locking mechanism not to allow the spoke linked to fall during flight.

Fevicol (SH) is used extensively in the UAV because of its better sticky nature and quick dry property. The polyurethane foam used in the development of the fuselage does not allow any kind of duct tape or stickers to stick with it so the use of fevicol prior the duct tape seemed to allow the duct tape to stick with the fuselage. Duct tape is attached to reduce the drag developed by the rough and porous body of the fuselage of the UAV.



Figure 3-49: Fevicol sprayed over the fuselage PU foam body to increase stickiness with duct tape



Figure 3-50: After wrapping the fuselage with black duct tape

### 3.9 Aircraft Systems

The UAV will be integrated with the essential avionics and other aircraft systems directly during the fabrication process. The landing gear will be designed and fabricated in house. It uses a elastic suspension system that can be sources from the local market, e.g. for hobby or toy cars. The servo motors to be used for flight dynamic control will be sources from the inventory of the IIEC at Pulchowk campus. The candidate has sourced other parts such as the brushless motor and the propeller from the local market, and 24 V battery has been obtained for an adequate combination of parts.

Although the aircraft will be manually controlled during the current tests using an RC controller, the aircraft design is intended to be used with a Pixhawk flight controller board, hence the board with a GPS system will be flown on board the UAV. The board will be able to collect essential flight test data and enable post-processing the flight performance. The flight test data will be stored on a Micro-SD card during the entire duration of flight.



Figure 3-51: Aileron attached using 3 mm Carbon Fibre Rod



Figure 3-52: Stabilizers attached using 3 mm carbon fibre rod

The flight test data will be analysed in the post-processing phase of this study to inform the future design changes to the UAV. The design revisions will be recommended at the end of this study, and potentially performed depending on the significance of those changes and the potential timeline.

## CHAPTER 4: RESULTS AND DISCUSSION

### 4.1 Ground test and initial flight test

The UAV developed was then ready for field test. The football ground of IOE Pulchowk Campus was used as the take-off runway. Estimated runway length at field was 30 metres. The picture shows the calibration and ground testing of the UAV.



Figure 4-1: UAV ready for initial ground test



Figure 4-2: Rear view of the UAV developed



Figure 4-3: Front view of UAV



Figure 4-4: Positioning for first flight test



Figure 4-5 UAV ready for flight test



Figure 4-6 UAV during first test flight

The first flight test of the UAV was carried out in the IOE Premises. The UAV took a vertical take-off for an instance and landed back to the ground. Multiple calibration of the CG of the aircraft was done and tested for few more flights to understand the mechanisms and deflections, for design revision.

## 4.2 System Deviation

The UAV is manufactured with certain deviations than the conceptual design and manufacturing design. This may be due to two reasons: on one side due to lack of manufacturing capabilities being the first prototype of the design, and secondly, due to manufacturing limitations in context of Nepal. This has created a deviation in the manufactured design and CAD design of the UAV.

The aerodynamic and stability analysis of the manufacturing design of the UAV seems to be necessary as the weight of the wing section, fuselage, battery positioning, and other components shifts the aesthetic and manufactured design to a different form. Thus, the comparative analysis is sure to give us greater degree of variation in the aerodynamic as well as stability analysis. The structural analysis is missing in the current project. During manufacturing, we found different weaker sections in the fuselage, wing, landing gear connections as well as in 3D printed clamps, due to which the design of the components needed on site improvisation. Had the structural analysis been done previously, the weaker and sections of failure could be analysed and kept under high consideration during manufacturing. A short example of design improvisation and it's effect on the overall lift and drag is shown in the following section.

## 4.3 Effects of design improvisation:

The following rectangular bar section was added to the manufacturing design during the process of manufacturing to strengthen the motor and landing gear section. A short analysis is done in fluent to compare the lift and drag it has on the final design.



Figure 4-7 Rectangular bar addition behind the wing



Figure 4-8 Rectangular bar positioned just below the motor mount

The rectangular bar is attached as shown in the figure above.

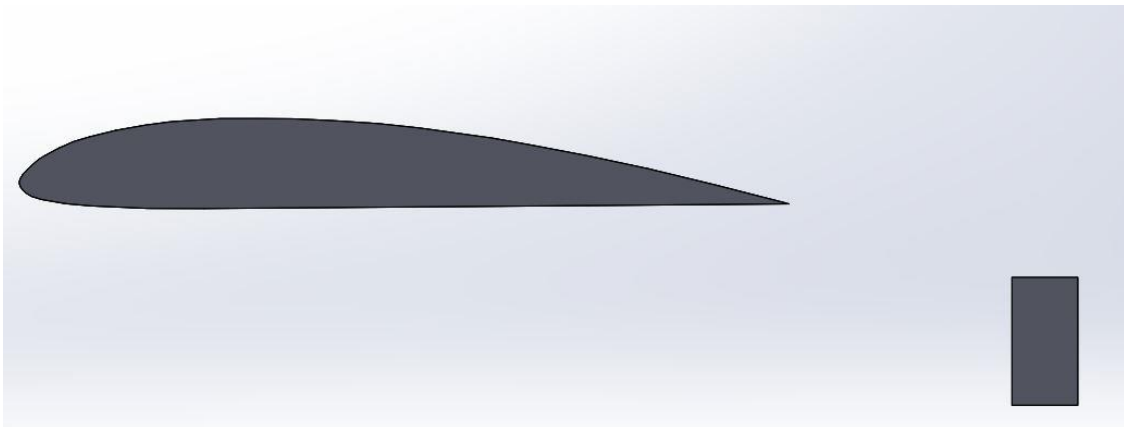


Figure 4-9 CAD design of rectangular bar addition as improvised during manufacturing of the UAV

The rectangular bar CAD design is then done by reverse engineering. The CAD design is shown above, for which the mesh is created in ICEM CFD. The pressure and velocity distribution of the wing with and without the rectangular bar addition is elaborated in the following contours.

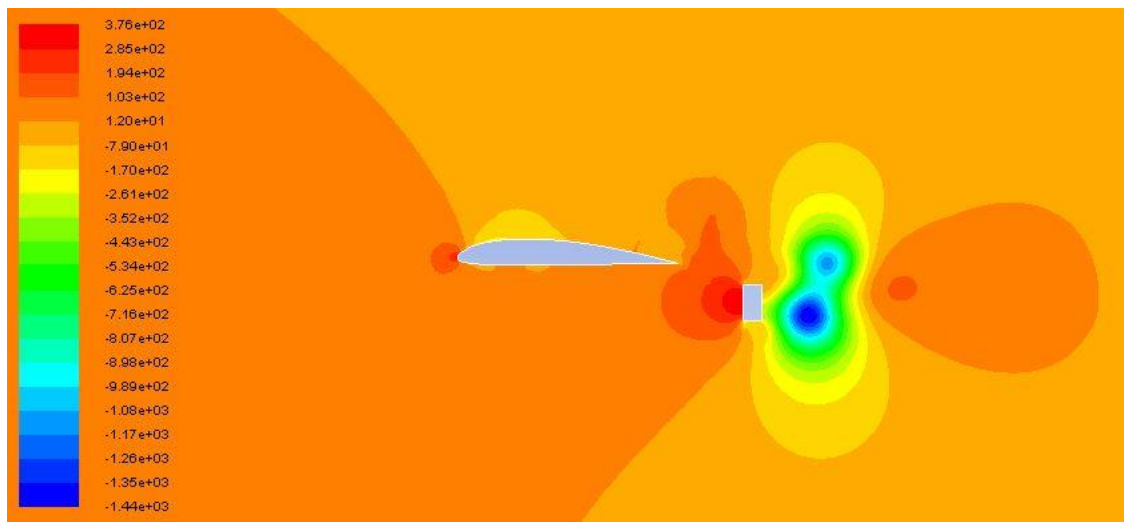


Figure 4-10 Pressure distribution after rect. bar addition

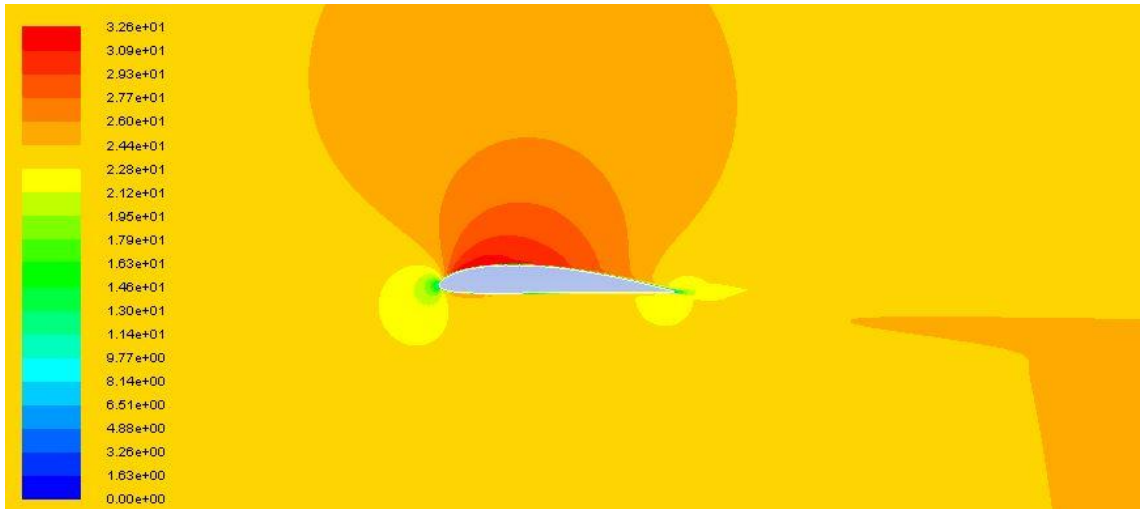


Figure 4-11 Pressure distribution of airfoil

The pressure distribution contours with and without the addition of the rectangular bar is shown in above illustrations.

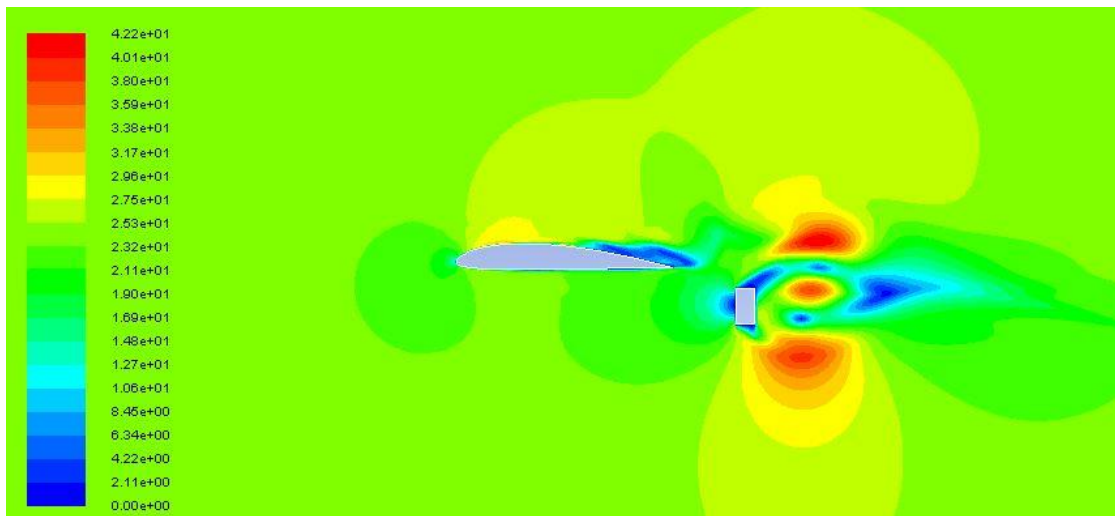


Figure 4-12 Velocity distribution after rectangular bar addition

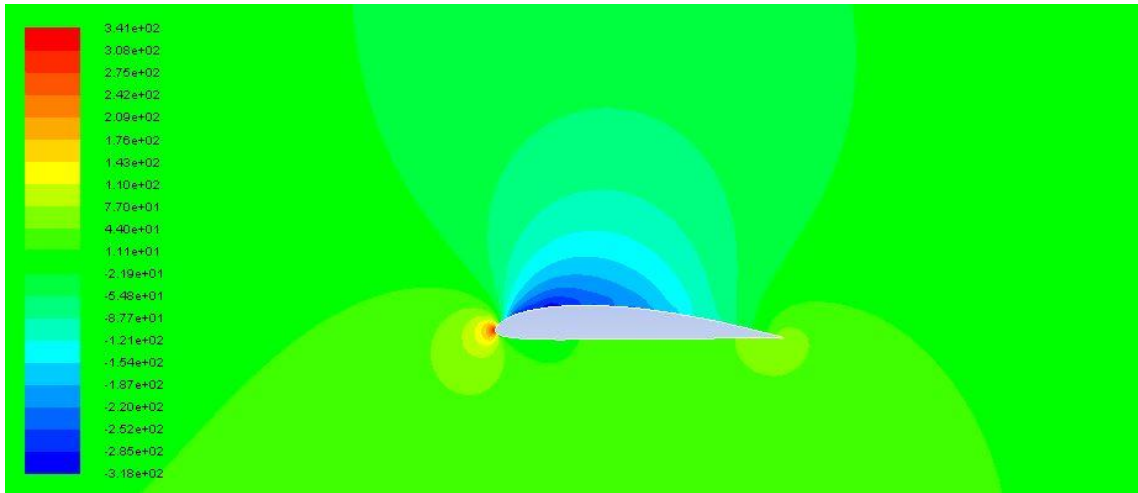


Figure 4-13 Velocity distribution of airfoil

The velocity distribution with and without the rectangular bar addition is shown in the above illustrations. This shows the increment in drag. The value of  $C_d$  increased from 0.4905 to 0.4938 (data retrieved from fluent coefficient calculation tool). This is one of the examples of the improvisation that was done during the manufacturing process which was reverse engineered to quantify the change in design with respect to the aerodynamic property and their changes in the aircraft. It is thus recommended to structurally analyse the aircraft prior to finalizing the aircraft towards manufacturing process.



Figure 4-14 Crash landing during the initial flight of the UAV

The first flight was thus done after necessary improvisations and after the addition of structural rigidity in the required portions of the UAV. The initial flight crashed, for which

the deflection in the wing as shown in figure below was considered to be the probable reason.



Figure 4-15 Edited photo to show deflection and actual wing section



Figure 4-16 Addition of support to reduce the deflection

To eradicate those issues, the support was added through landing gear to wing tip 6 mm stud using washer at both ends to tie them up. This reduced the deflection. We positioned the CG to rear end. The second flight was also done during which the flight took off but crashed again. Following reasons were approximated resulting in the crash.

1. Take off in excessive head wind
2. Positioning of CG



Figure 4-17 UAV during take off



Figure 4-18 UAV snap just before crash landing

To analyze the stability of the aircraft for possible reason due to change in CG, a stability analysis was done by shifting the CG to rear side by 150 mm. The following plots show the change in basic aerodynamic parameters due to the change in CG

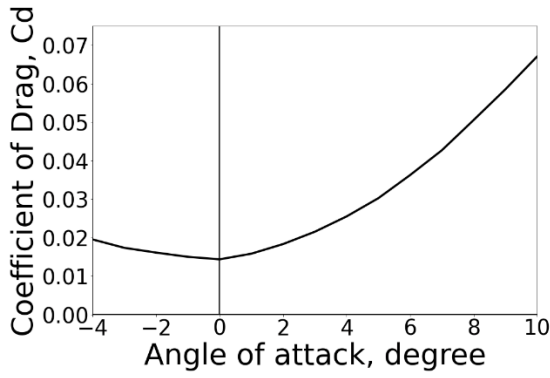


Figure 4-19 Cd Vs AOA Plot before change in CG

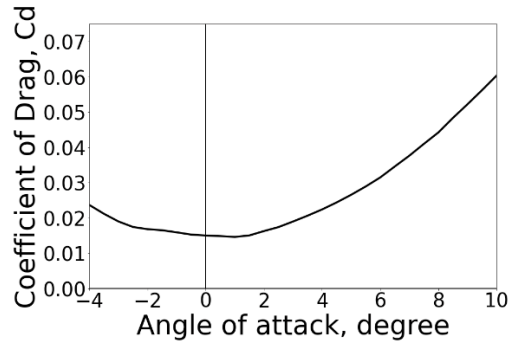


Figure 4-20 Cd Vs AOA plot after shift in CG

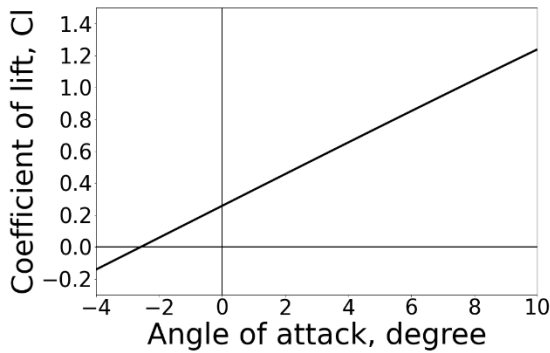


Figure 4-21 Cl Vs AOA plot before change in CG

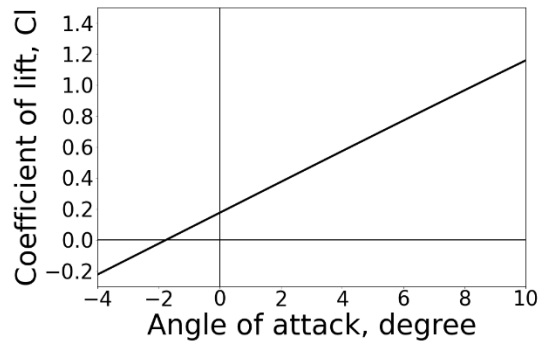


Figure 4-22 Cl Vs AOA plot after change in CG

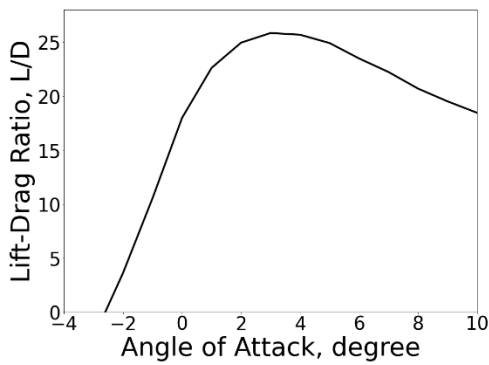


Figure 4-23 L/D ration Vs AOA plot before change in CG

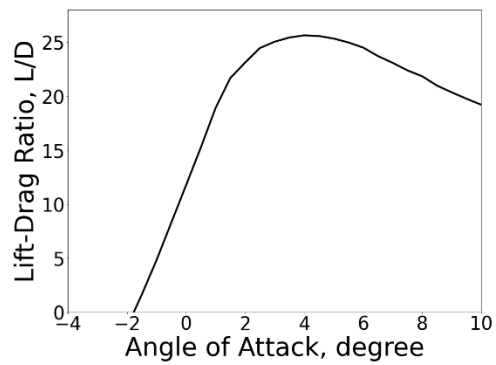


Figure 4-24 L/D ratio Vs AOA plot after change in CG

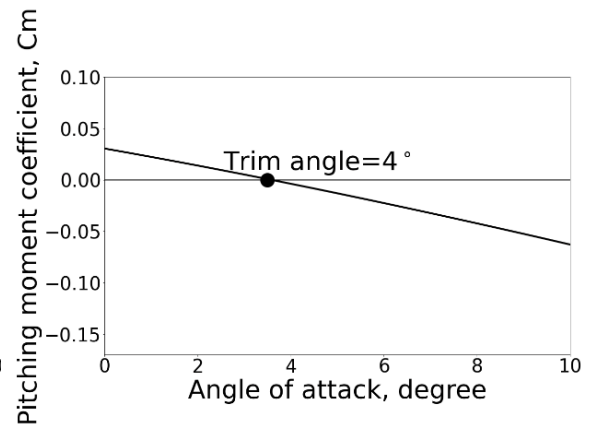
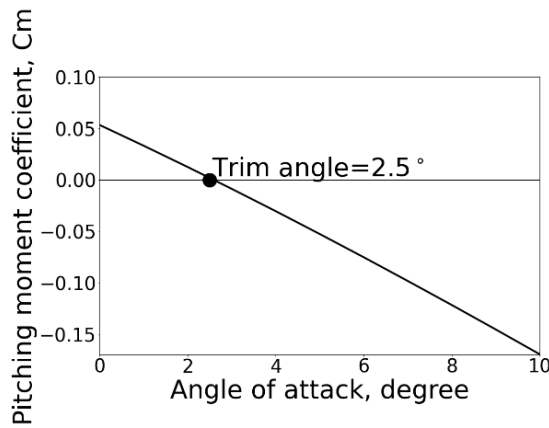


Figure 4-25 Trim angle before change in CG

Figure 4-26 Trim angle after change in CG

Almost all other plots show similarity before and after the change in CG location in the aircraft. The trim angle however is changed from 2.5 degrees to 4 degrees. This is not a significant change to prove the change in CG resulted in the crash. Thus, further analysis is found necessary which could be done only after multiple flight tests.

## **CHAPTER 5: CONCLUSION AND RECOMMENDATION**

### **5.1 Conclusion**

The purpose of this thesis is to examine the capability of design and manufacturing of a UAV in the context of Nepal with available resource and materials. This thesis presents the manufacturing process of any UAV in Nepal. The selection of materials for the wing, fuselage, frame and landing gears are major parts which play an important role in defining the final shape of the UAV. This thesis also shows how the manufacturing limitation has forced the designers and manufacturers to implement design improvisations during the manufacturing process in the UAV as in the landing gear support, motor mount and wing to wing connection system. Aesthetically better UAV is possible on after better revision of any preliminary design, but the concept and the manufacturing process along with the materials remain as manufactured in the thesis. The use of light weight material for the wing is always the foam as in context of Nepal. The selection of best lightweight materials for the structural integrity is aluminium sections of different dimensions. Use of plastic rubber tyres and carbon fibre tubes for the wing – tail attachments are other components available for structural design of a UAV. 3D printing technology has given a better flexibility for a designer to fabricate a UAV. This has reduced the use of MS plates and Aluminium plates for frame-to-frame connections.

### **5.2 Recommendation**

The recommendation of this study is listed as below:

1. The wing-to-wing connection is recommended to be fabricated using one single wing structure or a rigid spar throughout the wing section, end to end.
2. The use of PU Foam for the fuselage body restricted the use of any kind of duct tapes due to its nonresponsive property to the stickiness of the tape and sticker made it difficult for us to make a smooth and aerodynamic shape. Addition of fevicol to add the stickiness increased the weight by 300-400 grams.
3. The structure to connect the fuselage and landing gear should be made with a single chassis type structure as in 4-wheel ground vehicle to transform the ground reactive forces to the body effectively during crash and land to avoid any structural damage during test flights.
4. The tyres for nose and rear landing gear need to be strong enough to hold the bumps and breaks over the runway during take-off. A better suspension at the nose landing gear is must to avoid the breakage during take-off and landing.

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## CHAPTER 7: APPENDIX: MANUFACTURING PHOTOS



Figure 7-1 Support addition



Figure 7-2 Ground run



Figure 7-3 Take - off sequence



Figure 7-4 Preliminary crash flight



Figure 7-5 Fuselage front view during assembly



Figure 7-6 During take - off

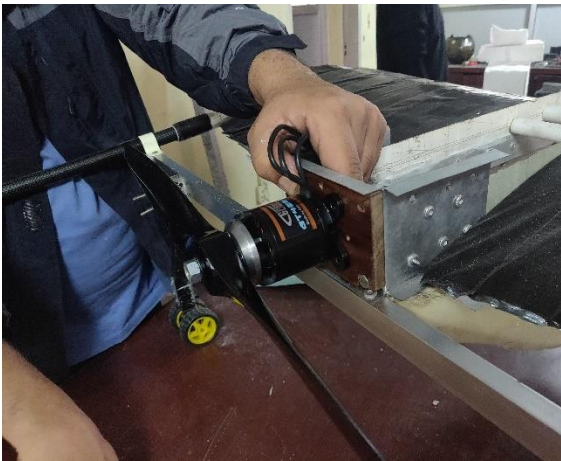


Figure 7-7 Motor assembly trial



Figure 7-8 Boom attachment for cross examination



Figure 7-9 Tyre selection for rear landing gear



Figure 7-10 Failure of motor clamp due to high torsion during opening closing



Figure 7-11 Final Design of rear landing gear (side view)



Figure 7-12 Final Design of rear landing gear (Front view)



Figure 7-13 Final Design of rear landing gear with spring attachment for suspension



Figure 7-14 Rear landing gear (Isometric view)



Figure 7-15 Preliminary ground testing and positioning



Figure 7-16 Movement during ground testing



Figure 7-17 Landing gear backward position during ground testing



Figure 7-18 Picture during ground test



Figure 7-19 Motor and motor clamp



Figure 7-20 Newly fabricated motor and propeller clamp as original broke due to torsion

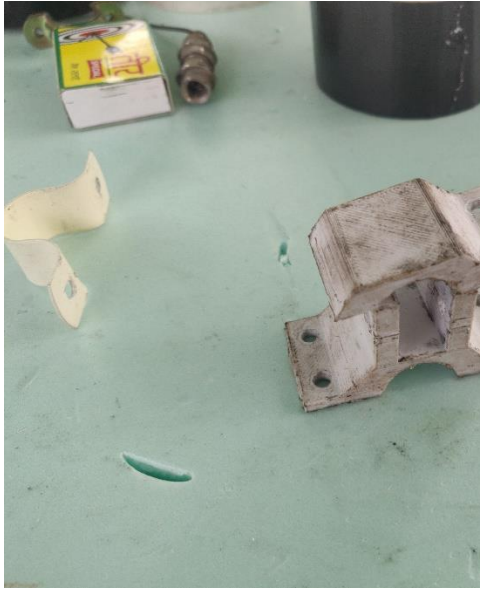


Figure 7-21 Broken 3D printed clamp from rear landing gear



Figure 7-22 Steel ribs fabricated to visualize the wing offset from real design during manufacturing

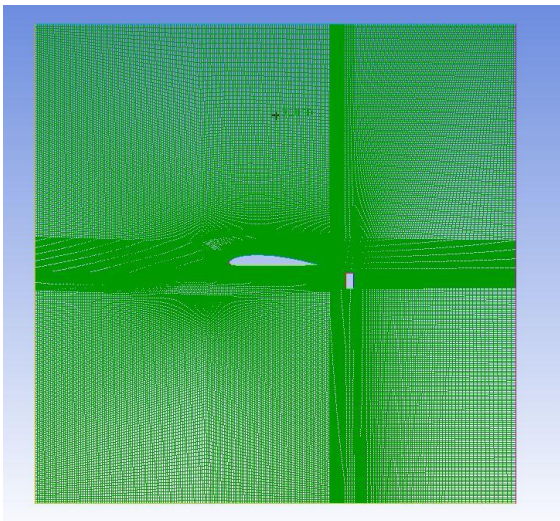


Figure 7-23 Hexa meshing of Wing and Bar



Figure 7-24 View of UAV wing from bottom



Figure 7-25 Wrinkled sections of wing as the foam did not support the stickiness of the duct tape



Figure 7-26 PU Foam sprayed wing section to obtain rigidity in spars



Figure 7-27 Links made out of bicycle spoke for servo linkage



Figure 7-28 Ground testing of UAV before servo motor wiring



Figure 7-29 Ground testing of UAV (Side View)



Figure 7-30 Effect of Fevicol (Heat X) to medium density foam



Figure 7-31 Stud fixation to wing