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DEVELOPMENT AND TESTING OF AUTONOMOUS FIXED-WING UAV FOR SAFE MEDICAL PAYLOAD DELIVERY

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A PROJECT REPORT
SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF BACHELOR IN AEROSPACE ENGINEERING

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING
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DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a project report entitled **"DEVELOPMENT AND TESTING OF AUTONOMOUS FIXED-WING UAV FOR SAFE MEDICAL PAYLOAD DELIVERY"** submitted by **Aayush Chapagai, Bhimraj Karki, Dakshesh Thapa and Niyat Sapkota** in partial fulfillment of the requirements for the Bachelor's Degree in Aerospace Engineering.

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ABSTRACT

This project endeavors to develop a cost-effective and efficient Unmanned Aerial System (UAS) designed for transporting medical supplies to remote and challenging locations. The UAS, a fixed-wing aircraft, incorporates a parachute system to ensure the secure and safe delivery of medical cargo. The design process involves optimizing aerodynamic characteristics, flight dynamics, payload capacity, and the parachute deployment mechanism to ensure successful deliveries, especially across difficult terrains.The major objective of the project is to ensure a quality built of a fixed wing UAV which can effortlessly deliver the medical goods to the remote location of the Solukhumbu district in time of crisis and need. The Terrain of Nepal itself being quite complex and difficulty for mode of transportation to reach the remote location make use of UAV like Aid-Plane more viable. The prototype underdevelopment later can be used not just for medical sectors but also facilitate other major sectors and regions of Nepal.

Keywords: Unmanned Ariel System, Payload Delivery, Remote Locations, Parachute System, Medical Supplies, Fixed-Wing Aircraft, Fabrication Process, Efficiency.

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LIST OF ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
AOA	Angle of Attack
AR	Aspect Ratio
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CATIA	Computer Aided Three Dimensional Interactive Application
CG	Center of Gravity
CNC	Computer Numerical Control
D	Drag
ESC	Electronic Speed Control
GPS	Global Positioning System
IMU	Inertial Measurement Unit
LASER	Light Amplification by Stimulated Emission of Radiation
LiPo	Lithium-Polymer
LLT	Lifting Line Theory
MAV	Micro Air Vehicle
MATLAB	Matrix Laboratory
NACA	National Advisory Committee for Aeronautics
PM	Power Module
PLA	Polyactic Acid
RC	Radio Control
RGB	Red Green Blue
RPM	Revolutions per Minute
UAS	Unmanned Aerial System

UAV	Unmanned Aerial Vehicle
VLM	Vortex Lattice Method
XFLR	XFoil Low Reynolds

LIST OF SYMBOLS

α	Angle of attack
β	Sideslip angle
C_d	Drag coefficient
$C_{L\beta}$	Coefficient of Lateral Stability
$C_{n\beta}$	Coefficient of Directional Stability
D	Drag
E_d	Energy Density
g	Acceleration due to gravity
HT	Horizontal tail
KV	Kilovolt
L	Lift
L_β	Lateral Stability
L_t	Tail Arm
m	Mass of aircraft
m_b	Battery mass
M	Moment
M_f	Moment due to fuselage
N_β	Directional Stability
N_o	Neutral Point
P	Power
P/W	Power Loading
ρ	Density
R	Range
S	Wing planform area
T	Thrust

V_p	Velocity of parachute
VT	Vertical tail
W	Weight
W_A	Autopilot Weight
W_B	Battery Weight
W_E	Empty Weight
W_{PL}	Payload Weight
W_{TO}	Maximum take-off weight
Wh	Watt hour
x	Range

CHAPTER 1: INTRODUCTION

1.1 Background

Unmanned Aerial Vehicles (UAVs), have been used widely all over the world.UAVs are being used for military applications like surveillance,target designation, combat operations, etc and in civilian and commercial purposes like agriculture, construction, delivery, flim making, search and rescue,crowd monitoring, wildlife monitoring and many more sectors.

UAVs, being dearth of people are very suitable for dull, dangerous and dirty tasks.UAVs can be controlled from a ground station or by the autopilot for the operation.UAVs are from simple to complex in structure and manufacturing, mini to large in sizes and very cheap in multiple of thousands Nepalese rupees to very expensive to billion rupees.The selection of UAV should be done on the basis of the function that the UAV should perform.

Looking at the aerodynamics involved in the UAVs, there are fixed wing and rotary wing UAVs and the hybrid UAV which possesses features of these both UAVs is called VTOL(vertical landing and takeoff) UAV.The selection of the UAV among above is done on looking the function to be carried out.

1.2 Unmanned Aerial System

An Unmanned Aerial System (UAS) is a group of coordinated multidisciplinary elements for an aerial mission by employing various payloads in flying vehicle(s).It is a system comprising of hardware and software components functioning together.[4].

A UAS basically includes five main elements:

1. Air Vehicle
2. Control Station
3. Payload
4. Launch and recovery System
5. Maintenance and support system

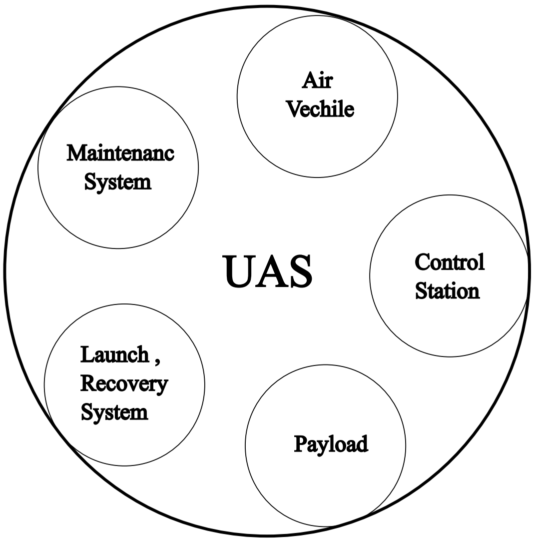


Figure 1.1: UAS

The environment where the UAV operates, also known as the airspace brings a lot of consideration and effects to the UAS.Hence, it can be also taken as the sixth element of the UAS.

1.3 Unmanned Aerial Vehicle(UAV)

Unmanned Aerial Vehicle (UAV) is a remotely piloted or self-piloted aircraft that can carry payloads such as camera, radar, sensor, and communications equipment. All flight operations (including takeoff and landing) are performed without on-board human pilot.UAVs are employed in numerous flight missions; in scientific projects and research studies such as hurricane tracking, volcano monitoring, and remote sensing; and in commercial applications such as tall building and bridge observation, traffic control, tower maintenance, and fire monitoring.[2].

There is no consensus for the definition of autonomy in UAV community. The main systems drivers for autonomy are that it should provide more flexible operation, in that the operator tells the system what is wanted from the mission (not how to do it) with the flexibility of dynamic changes to the mission goals being possible in flight with minimal operation re-planning. Autonomy is classified in 10 levels, from remotely piloted, to fully autonomous swarm. Autonomy includes a level of artificial intelligence. An autopilot is the main element by which the level of autonomy is determined. For instance, stabilization of an unstable UAV is a function for autopilot[8].

1.4 Payload Drop and its Mechanism

UAVs have become so much popular due to this feature and it's advance improvement and growth.Today, UAVs can drop payload either missile or a cargo in the exact allocated place.For this, different flight controllers and control mechanism are being used.Flight controllers are fed with program to detect the location of the way point through different sensors and the flight controller helps to actuate the control mechanism to drop the payload.

1.5 Objective

1.5.1 Main Objective:

The main objective of the project is to develop and test autonomous fixed wing UAV along with the system for medical supplies delivery.

1.5.2 Specific Objectives:

The specific objectives of the project are listed below:

1. To develop and autonomously test flight of the fixed wing UAV
2. To develop and test the autonomous deployment system for medical supplies delivery
3. To improve the modular structure modular structure with easy assmebly features
4. To ensure the safety of the supplies dropped

1.6 Feature

Some of the features of Fixed Wing UAV are mentioned below:

1. **Endurance:** Fixed-wing UAVs typically have a longer flight duration compared to multi rotor drones. This allows them to survey larger areas and remain airborne for longer periods, making them ideal for tasks such as mapping, surveillance, and surveying.
2. **Range:** These UAVs can cover long distances in a single flight, making them perfect for monitoring pipelines, power lines, or conducting extensive aerial surveys.
3. **Speed:** Fixed-wing UAVs can reach higher speeds than many multi-rotor drones. This speed advantage is useful for tasks requiring quick data collection or rapid response times, such as emergency response or military reconnaissance.
4. **Payload Capacity:** Fixed-wing UAVs often have a larger payload capacity than their multi-rotor counterparts. This allows them to carry more advanced sensors, cameras, and other equipment, increasing their versatility in various applications.
5. **Stability:** The aerodynamic design of fixed-wing UAVs offers inherent stability during flight, allowing for smoother and more controlled movements. This stabil-

ity is essential for tasks requiring high-quality aerial data, such as surveying and mapping.

6. **Efficiency:** Fixed-wing UAVs are generally more energy-efficient than multi-rotor drones. Their efficient power usage allows them to cover larger areas with less energy consumption, leading to longer flight times.
7. **Autonomous Flight:** Many fixed-wing UAVs come equipped with advanced navigation and autopilot systems, enabling autonomous flight. This feature is beneficial for tasks like precision agriculture, where pre-programmed flight paths can be used to systematically cover a field.
8. **Weather Resistance:** Fixed-wing UAVs are often more resilient in adverse weather conditions, including wind. This makes them suitable for operations in challenging environments, such as maritime applications or coastal surveillance.
9. **Versatility:** Fixed-wing UAVs are adaptable and can be modified for various applications by changing payload configurations. They can carry different types of sensors, cameras, or even specialized equipment based on the specific needs of the task.

1.7 Feasibility Analysis

1.7.1 Economic Feasibility

The initial cost estimation for our project was set at Rs 128,500/-, a figure that initially appeared quite substantial. However, our project benefited significantly from the fact that several key electronic components, including the transmitter, PX 4 controller, GPS module, telemetry, servo, and ESC, were readily available, generously provided by the department. Additionally, the propulsion system components, and brush-less motors, were already at our disposal. Given the presence of these crucial components, our project incurred minimal expenses, primarily limited to the procurement of structural components. These structural elements, fortunately, were reasonably priced, contributing to a significant reduction in overall project costs. Consequently, our undertaking emerged as economically feasible and aligned with budgetary considerations. The strategic utilization of existing electronic and propulsion components allowed us to leverage resources effectively, focusing financial resources on specific areas that required attention. This approach not only streamlined the project budget but also showcased the cost-effective nature of our strategy. By minimizing expenditures through the utilization of available resources, we demonstrated a judicious use of funds, ensuring that our project remained economically viable and within the allocated budget.

1.7.2 Technical Feasibility

In the scope of our project, which centered on the creation and design of a Fixed Wing Unmanned Aerial Vehicle, we identified a series of specific technological needs. These needs included both software and hardware components crucial for the design, analysis, flight testing, and manufacturing stages. For the design and analysis phases, the use of sophisticated software tools was key. We chose XFLR 5, CATIA V5, and X-PLANE as comprehensive solutions that met the requirements for the design, analysis, and simulation of the UAV. These tools offered a solid platform for the conceptualization, improvement, and assessment of the UAV's structural and aerodynamic features. Furthermore, the addition of a dedicated flight simulator allowed for effective and controlled testing of the designed UAV in a simulated environment. Moving on to the manufacturing process, a CNC LASER Cutting Machine was crucial in the precise cutting of ribs from plywood, ensuring accuracy in the assembly of the UAV's wing structure. At the same time, a CNC Hot Wire Cutting Machine was used to mold Styrofoam into the required airfoil shapes for the central structural component. Despite this machine's limitations, which prevented fully automated cutting of Styrofoam, it was effectively used for manual shaping of airfoil profiles and creating spar holes in the specified wing segments. The incorporation of these advanced tools, ranging from sophisticated design and analysis software to precision CNC machines and 3D printing technology, demonstrated a comprehensive and technologically proficient approach to the project. This suite of tools not only enabled the efficient execution of the UAV design but also highlighted the project's dedication to utilizing state-of-the-art technologies for successful implementation.

1.7.3 Operational Feasibility

The core objective behind the development of our Fixed Wing UAV is to address the critical need for medical payload delivery in the challenging terrain of the hilly regions of Nepal. The geographical complexities of these areas often render traditional modes of transport impractical. The Fixed Wing UAV serves as a promising solution, offering the capability to traverse difficult landscapes efficiently and deliver medical supplies swiftly to remote locations. However, despite the UAV's potential to revolutionize medical logistics, its commercialization is currently impeded by the absence of a regulatory framework in Nepal. The current regulatory vacuum for the operation of UAVs poses a significant obstacle to the deployment of this technology for medical payload delivery. Without established regulations, the UAV cannot be employed for commercial purposes. With a robust regulatory framework in place, the Fixed Wing UAV could emerge as one of the most effective and feasible means for medical payload delivery in Nepal. Its ability to cover long distances efficiently, coupled with the capacity to carry medical supplies, positions it as an ideal solution for reaching remote and inaccessible areas in the hilly regions. The impact of the Fixed Wing UAV extends beyond its immediate application in medical logistics. Once regulatory guidelines are established, this technology could revolutionize the landscape of medical transportation, ensuring timely and reliable delivery of critical supplies to communities that face challenges in accessing conventional means of healthcare.

1.8 Hardware Requirement

On developing and testing autonomous fixed wing UAV and payload deployment system numbers of hardware components are used.These hardware components are listed below.

1.8.1 Pixhawk and its Accessories

Pixhawk alone can't perform the autonomous mission.It requires more sensors and singal transmitting and receiving devices along with the external power supply.

Pixhawk

Pixhawk is an open-source autopilot system designed for inexpensive autonomous aircraft. It can run software like PX4 and ArduPilot. It supports various airframe configurations like Fixed Wing, Rotorcraft, BWB, etc. It includes flight control hardware with accessories such as magnetometer, sensors, gyroscope, accelerometer, and barometer. These sensors, along with the Pixhawk flight controller, provide relevant feedback to the user on specific conditions and maintain stability. The Pixhawk can be programmed to perform various auxiliary functions and tasks like flip, land, loiter, etc.

Figure 1.2: Pixhawk

Accessories that can be incorporated with Pixhawk

The other hardware components that pixhawk need additionally for the function of autonomous flight control are listed as below.

- **GPS Module** A GPS module is a small device that uses signals from satellites to determine accurate location information. The GPS module used is M8N, a high-precision GPS module designed for use with Pixhawk flight controller.

- **Power Module** The Power Module used in our UAV is PM02. It is designed for integration with the Pixhawk PX4 flight controller, serving as an efficient power supply solution.

Figure 1.3: Power Module

- **Electronic Speed Controllers (ESCs)** ESCs play a pivotal role in the world of unmanned aerial vehicles (UAVs), acting as intermediaries between the Pixhawk and the brush-less motors.

Figure 1.4: ESC

- **Radio Control and Receiver** The RC and its receiver establishes a wireless communication link between the pilot’s transmitter and the unmanned vehicle.

Figure 1.5: Radio Control

- **Telemetry** Telemetry involves the wireless transmission of real-time data from the vehicle to a ground station or operator's device.

1.8.2 Styrofoam

Styrofoam is a closed-cell extruded polystyrene foam, often referred to as 'Blue Board.' It is a lightweight yet durable foam used for insulation in walls, roofs, and structures. Styrofoam is used in our UAV for making wings, horizontal stabilizers, vertical stabilizers, and the nose of the fuselage.

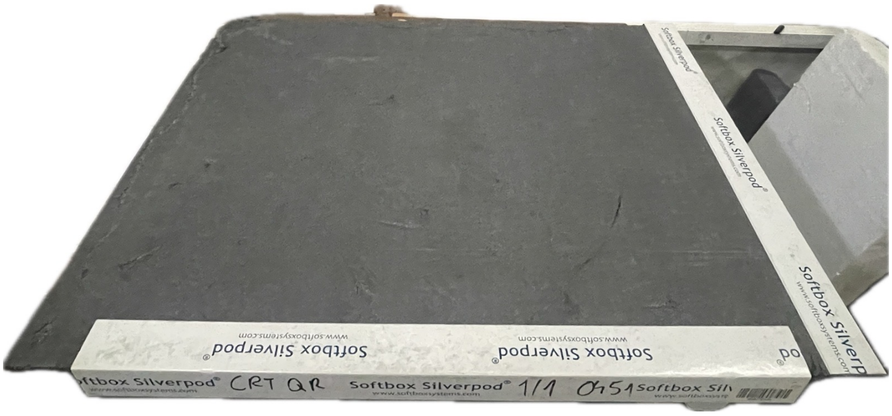


Figure 1.6: Styrofoam

1.8.3 Servo Motor

A servo motor is a rotary actuator allowing for precise control of position, velocity, and acceleration. It consists of a motor coupled with a position feedback sensor and requires a sophisticated controller. Servo motors find applications in UAVs, automated manufacturing, and robotics. The control of ailerons, elevators, rudder, and payload drop mechanism is done with the help of servos and servo is controlled directly by the Pixhawk.

1.8.4 Plywood

Plywood is a material manufactured from thin layers of wood veneer glued together. The layers have their wood grain rotated up to 90 degrees to one another. 5mm, 3mm, 10mm plywood are used in our UAV for structural components such as bulkhead and frames. Plywood is also used to make the motor mount in UAV that is directly linked with the nose of the aircraft and is also used to make the payload storage box.

1.8.5 Tapes and Adhesives

Tapes, narrow strips of material used for holding or fastening, and adhesives, sticky substances for sticking objects together, are essential for assembly and securing components.

1.8.6 Aluminium Rods

Aluminum rods are thin straight bars of aluminum metal formed through an industrial process. Aluminum rods serve various purposes in the project such as booms or spars of the wing.

1.8.7 CNC LASER Cutting Machine

A CNC laser cutter is a piece of equipment that uses a concentrated, strong laser beam to cut, engrave, or mark a material to produce certain shapes. Due to its unique design and application, it is incredibly accurate, especially when cutting delicate motifs and tiny holes.

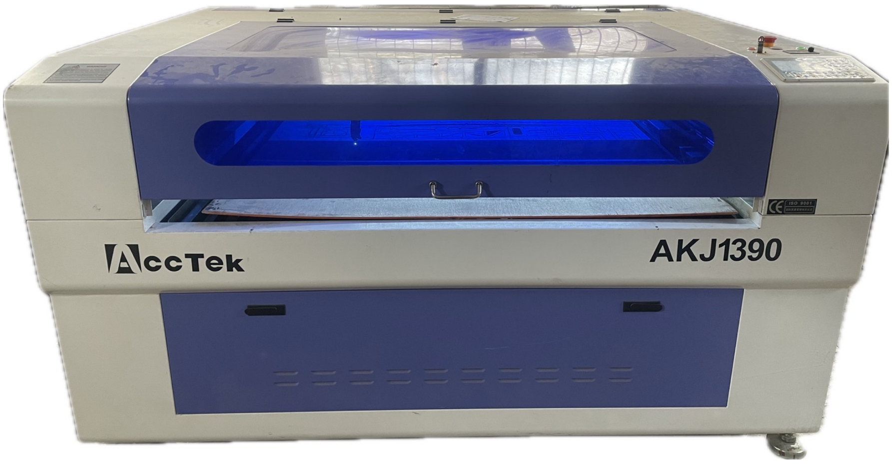


Figure 1.7: CNC LASER Cutting Machine

1.8.8 Hot Wire CNC

Hot wire CNC foam cutters enable virtually any product with the most complex shapes to be produced quickly, precisely, and at a reasonable price. A hot wire, or a particular kind of resistance wire that becomes extremely hot when current flows through it, is the key component of this gadget.

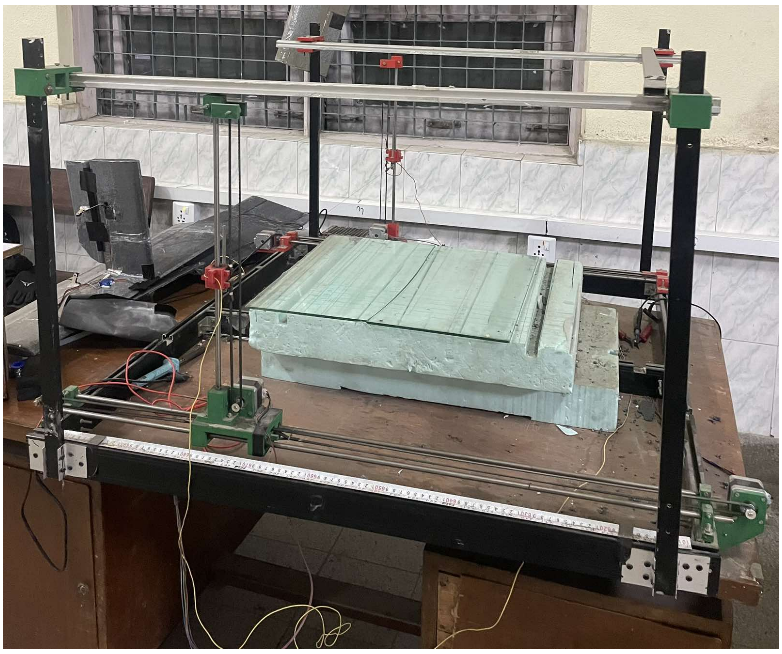


Figure 1.8: Hot Wire CNC

1.8.9 3D Printer

A 3D printer is a device that builds up layers of material, such as plastic, resin, or metal, to produce three-dimensional objects. CAD software is used to create the objects, which are then submitted to a 3D printer to be printed.Poly Lactic Acid (PLA) was the basic material used in 3D printing.

Figure 1.9: 3D Printer

1.8.10 Battery

The batterries used in our prototypes of were UAV 4-cell battery and 6-cell LiPo battery according to our various mission requirements.The most commonly used battery for our prototype is 4S LiPo battery, consisting of four individual cells connected in series. Each cell provides approximately 3.7 empty volts, resulting in a total voltage of around 14.8 volts for the entire battery. These batteries are widely used in radio-controlled applications of UAVs. The choice of capacity depends on flight duration requirements, with higher capacities suitable for longer missions.

1.8.11 Other Equipment and Tools

- Drill Machine
- Hex Saw
- Aluminum tube
- Glue Gun
- Soldering Iron
- Sandpaper
- Wrenches
- Screwdrivers
- Pliers
- Fasteners and Screws
- Power Tools
- Safety Equipment (Gloves, Safety Glasses)
- Batteries and Chargers

1.9 Software Requirement

1.9.1 QGroundControl

QGroundControl is an open-source ground control station (GCS) software that is widely used in the field of (UAVs) and drones. It provides a user-friendly interface for planning, monitoring, and controlling the flight of UAV equipped with PX4 or ArduPilot flight stacks.

Key features of QGroundControl include:

- **Mission Planning:** Users can plan missions by defining way points, specifying the UAV's flight path, and configuring various parameters. The software allows for easy creation of complex missions, including survey patterns, way points, and other mission-specific tasks.
- **Real-time Telemetry:** QGroundControl provides real-time telemetry data, including UAV's position, altitude, speed, battery status, and other essential information. This allows operators to monitor the UAV status during the mission.
- **Flight Monitoring:** The software offers a graphical interface to monitor the UAV flight in real-time. Users can view the UAV position on a map and receive visual feedback on its orientation, sensors, and other critical parameters.
- **Vehicle Setup:** QGroundControl assists users in configuring and calibrating their UAVs. This includes setting up sensors, calibrating the compass and accelerometer, and configuring flight modes.
- **Firmware Updates:** Users can update the firmware of their UAV through QGroundControl, ensuring that the UAV is running the latest and most stable software.

1.9.2 XFLR5

XFLR5 is a specialized tool used for designing and analyzing airfoils, wings, and planes that operate at low Reynolds Numbers. It incorporates a powerful module called XFOIL, which is specifically designed for detailed analysis of individual subsonic airfoils. XFOIL is interactive and excels in determining crucial aerodynamic parameters such as pressure distribution, lift, and drag characteristics. These parameters are essential for understanding the performance of a 2D airfoil based on input coordinates that define its shape, along with specified Reynolds and Mach values.

One of the key features of XFLR5 is its ability to extend the functionality of XFOIL through an inverse foil design. This means that not only can it analyze existing airfoil designs, but it can also assist in the design process by working backward. Inverse foil design allows users to input desired aerodynamic characteristics, and the tool helps generate airfoil shapes that meet those specifications. This capability is valuable for engineers and designers seeking to optimize the performance of their aircraft at low Reynolds Numbers, where traditional aerodynamic principles may differ from those at higher speeds.

1.9.3 Airfoil Maker

The Airfoil Maker is a versatile tool that facilitates the creation of new airfoils and the modification of existing ones. Users can finely tune the characteristics of the airfoil, specifying parameters such as lift, drag, and moment data. These parameters include Cl intercept, Cl slope, Cl curvature near stall, Clmax, Cdmin, Cl at minimum Cd, Cd curvature, laminar drag bucket location, laminar drag bucket curvature, Cm at low and high AOA change points, stall minimum and maximum AOA, as well as values of Cl, Cd, and Cm at specific AOAs. This functionality empowers users to tailor airfoils precisely to their desired aerodynamic properties.

1.9.4 Plane Maker

Plane Maker is a robust software tool designed for the creation of a wide range of aircraft models, providing users with the ability to design virtually any imaginable airplane. Its seamless integration with the X-Plane simulator makes it a powerful tool for predicting the real-world flight dynamics of the aircraft being constructed. The software offers a user-friendly interface where individuals can input a variety of physical characteristics that define the aircraft, including parameters such as weight, wing span, control deflections, engine power, and airfoil sections. By incorporating these details, Plane Maker generates a detailed model of the aircraft's performance. This process is similar to the X-Plane simulator's built-in aircraft, ensuring that users gain valuable insights into how their designed aircraft will behave and handle in different flight scenarios.

1.9.5 X-Plane

X-Plane is hailed as the most complete and sophisticated personal computer flight simulator globally, renowned for providing the accurate flight model available. This simulator serves diverse purposes, from aiding pilots in maintaining proficiency through realistic simulations to assisting engineers in forecasting the flight behavior of new airplanes. Aviation enthusiasts also use X-Plane to explore the complex world of aircraft flight dynamics. The simulator allows for the testing of dynamic stability characteristics in various flight modes, including Phugoid, Short-Period, Dutch roll, and spiral. Additionally, it facilitates the examination of specific aspects such as ascent and descent, roll sensitivity, and pitch sensitivity.

1.9.6 CATIA V5

CATIA V5 is a multi-platform program renowned for its prowess in CAD, CAM, and CAE applications. Widely adopted across various industries, it expedites the analysis, design, and manufacturing processes for new products. System architects, engineers, and industrial designers benefit from CATIA's integration of numerous approaches to product design and development. The software encompasses a various of works on the design and analysis of parts and products, ranging from simple 3D part design to intricate shape designs, surface design, and assembly design. In the context of our project, specific workbenches such as Mechanical Part Design, Generative Shape Design, and Assembly Design were extensively utilized to meticulously design each component of the UAV, including the complete Platform and the assembly of all components[17].

1.9.7 UP Studio

UP Studio emerges as a sophisticated software application dedicated to the realm of 3D printing. Its feature-rich environment encompasses essential functions such as slicing, printing, and monitoring capabilities, providing users with robust tools to manage, develop, and control their 3D printing processes. UP Studio is very useful in engineering, product design, and prototyping. The effective print management of this software, enables users to control printing parameters such as speed, temperature, and cooling speed. Moreover, UP Studio offers tools to enhance print quality, including the automatic generation of support structures and the ability to adjust printing parameters. Notably, the software simplifies the management and control of multiple print jobs simultaneously, streamlining the 3D printing workflow by allowing users to handle multiple printers from a unified interface.

1.9.8 RD Works

RD Works is a software application tailored for laser cutting and engraving tasks. It is a user-friendly interface that empowers users to create, edit, and execute various laser-related tasks with precision. In our project, RD Works played a crucial role in setting up the ribs drawing geometry based on the CATIA V5.dxf file, preparing it meticulously for CNC LASER cutting. This software served as a pivotal component in ensuring precision and accuracy in the manufacturing process.

1.9.9 KiCAD

KiCAD is an open-source electronic design automation suite that plays a crucial role in the development of electronic components. It enables the creation of accurate and detailed schematics, providing a graphical representation of the connections and relationships between various electronic elements. Additionally, KiCAD facilitates the design of printed circuit boards by allowing engineers to translate schematics into physical layouts. Its suite of tools ensures proper component placement, trace routing, and signal integrity, contributing to the overall functionality and reliability of electronic systems.

1.9.10 SOLIDWORKS

SOLIDWORKS stands out as a powerful 3D computer-aided design (CAD) software tailored for mechanical design and engineering. It empowers designers and engineers to create detailed 3D models of mechanical components and assemblies. This capability aids in visualizing how individual parts fit together, ensuring proper form, fit, and function. This software is instrumental in the precision modeling of mechanical components, contributing to the overall efficiency of the design process.

1.9.11 Arduino Integrated Development Environment

The Arduino Integrated Development Environment serves as the primary platform for programming Arduino micro-controllers. Its user-friendly interface simplifies the coding process, making it accessible for both beginners and experienced developers. Arduino IDE supports the creation of firmware that defines the behavior of electronic systems. Programmers can write, compile, and upload code to Arduino boards seamlessly. This functionality ensures the proper integration and functionality of embedded systems, making Arduino IDE an essential tool in the development of electronic components for the project.

1.9.12 Fusion 360

Fusion 360, a cloud-based CAD/CAM tool, provides a unified platform for collaborative and integrated design processes. It offers parametric modeling capabilities, allowing designers to create flexible and easily modifiable 3D models. Additionally, it features computer-aided manufacturing (CAM) functionality, enabling the generation of tool paths for machining and manufacturing processes. Fusion 360's collaborative features make it a valuable tool for teams working on complex projects, promoting efficient communication and coordination throughout the design and manufacturing phases.

CHAPTER 2: LITERATURE REVIEW

2.1 Medifly

Initiated by the students of 075BAS batch the Medifly along with it's specific objectives, they were able to take various test flights. Taking what they build into consideration we planned on continuing their project and make several changes in design, aerodynamics and other factors. The major objective of their UAV was to deliver payload to a remote location at Tilahar from Khusma Municipality.

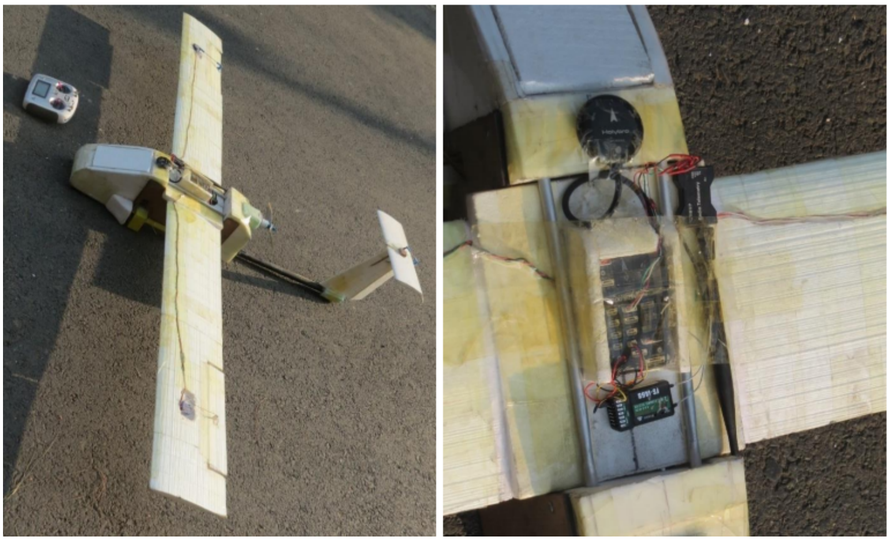


Figure 2.1: Medifly

The team of Medifly included Mandeep Prasad Shah,Pravesh Bhandari and Shankar Malla. They were responsible for the prior successful test flight and deployment of the payload that was carried out in the field of Pulchowk Campus. Taking their work into account, we based it to our project and set a new mission plan on supplying medical supplies to Maha Kulung Primary Hospital located at a remote location in Solukhumbu. The Medifly in design had a single boom configuration supported by a rectangular framed fuselage. T-tail configuration was used in the aircraft along with the a rectangular wing of span 1.8m. Various structural changes from fuselage to the overall tail configurations were carried out in our work to meet the need of the mission requirement.[14]

2.2 Some Medical Delivery Goods

2.2.1 Blood

In emergencies or remote areas where access to medical facilities is limited, the role of fixed-wing medical delivery UAVs becomes crucial. These unmanned flying vehicles are specifically designed to swiftly transport life-saving blood and blood products to locations in need[11]. Picture a situation where someone urgently requires a blood, but traditional transportation methods would take too long or may not be feasible. In such cases, these UAVs act as rapid responder , ensuring that essential blood supplies reach the patient quickly. Their ability to cover distances swiftly and access hard-to-reach places makes them indispensable in critical medical interventions, significantly improving the chances of saving lives.[3]

These UAVs essentially serve as airborne heroes, flying above geographical barriers to deliver medical support where it's needed most. Whether it's a natural disaster, a remote area with limited infrastructure, or any situation demanding urgent medical attention, these unmanned aircraft play a vital role. By facilitating the rapid transport of blood, they contribute to the efficiency and effectiveness of emergency medical responses, making a significant impact on healthcare outcomes in challenging circumstances[1].

2.2.2 Vaccines

The utilization of fixed-wing medical delivery UAVs proves to be crucial in the effective distribution of vaccines, particularly in regions with challenging terrain and lacking proper health infrastructure. These unmanned aerial vehicles play a pivotal role in vaccination programs, where traditional transportation methods may struggle to navigate difficult landscapes. By overcoming geographical obstacles, these UAVs significantly enhance the reach of vaccination programs, ensuring that even remote or inaccessible areas can benefit from timely and essential vaccine deliveries[11].

In the broader context of public health, the contribution of these UAVs becomes essential in limiting the spread of infectious diseases. By quickly transporting vaccines to distant locations, they aid in creating a more widespread and strong defense against the threat of illnesses[1]. In essence, the use of fixed-wing medical delivery UAVs emerges as a vital strategy, not only for enhancing the efficiency of vaccine distribution but also for promoting global health by extending vaccination coverage to areas that would otherwise face logistical challenges.

2.2.3 Medicines and Medical Kits:

Medical delivery UAV, which are like small airplanes, play a crucial role in quickly bringing medicines and first aid to people during emergencies. When there's a problem and someone lives in a place where regular vehicles can't reach, these UAV act very fast in delivering essential items directly to those in urgent need. They efficiently navigate through the sky, reaching inaccessible areas and providing a swift and direct means of assistance, particularly in locations that are hard to reach. During tough times, these UAV serve as necessary lifelines, ensuring the rapid delivery of medical aid. It's not just about delivering medicines; these airborne heroes can also transport crucial medical tools and supplies, offering a comprehensive solution to urgent healthcare needs. Their quick and accurate response establishes them as front line responders, showcasing the significant impact of technology in addressing challenges during emergencies[11].

2.3 Medical Supplies Storage

Medical supplies storage is a critical facet of effective healthcare management, playing a pivotal role in ensuring the availability, accessibility, and safety of essential medical items. The implementation of proper storage practices is indispensable for maintaining the integrity of medical supplies, preventing contamination, and facilitating efficient inventory management.

One fundamental consideration in medical supplies storage is the maintenance of a controlled temperature environment. Preserving the efficacy of various medical supplies, including medications and sensitive equipment, is contingent upon storing them within a specific temperature range. Typically, this falls between 15 to 25 degrees Celsius (59 to 77 degrees Fahrenheit). Such temperature control is essential to prevent degradation and ensure the stability of pharmaceuticals and other temperature-sensitive items, thus safeguarding their effectiveness and reliability.

Equally crucial is the control of humidity levels within the storage facility. Medical supplies, especially those susceptible to moisture-related damage, benefit from being stored in an environment with controlled humidity. Aim for a humidity range of 30% to 60% to mitigate the risk of issues such as mold growth, deterioration of packaging, and the potential for bacterial contamination. This is particularly pertinent for items like wound dressings and diagnostic reagents, where the presence of excess moisture could compromise their efficacy and safety[3].

Efficient medical supplies storage relies on proper organization, labeling, and adherence to cleanliness protocols. Categorizing items based on their nature, usage, and expiration dates facilitates easy identification and retrieval, while regular inspections and audits of the storage facility are imperative for promptly addressing potential issues. Simultaneously, stringent cleanliness measures, including regular cleaning schedules and the maintenance of a dust-free environment, are crucial to preserving the sterility of medical supplies, particularly those designated for surgical procedures or invasive treatments. These combined efforts contribute to the overall quality, accessibility, and safety of essential healthcare resources.

2.4 Payload Delivery Mechanism

For the deployment of the payloads, several operating mechanisms can be employed and are currently in use[13].Each of the specific mechanisms have their own advantages.Major of these mechanisms operate on specific electronics while some use pyrotechnics.The most popularly used mechanisms are mention below on this section[15].

1. Servo operated
2. Electromagnetic
3. Pyrotechnic method
4. Spring loaded
5. Magnetic release

2.4.0.1 Servo operated Rack and Pinion

A simple layout of rack and pinion setup has been selected for the deployment of payload.The rotational motion of the servo is converted to linear motion for the sliding latch configuration.

To calculate the linear displacement of the rack we multiply the pitch to the no of available teeth of the gear.The displacement obtained is the linear translation that can be achieved in a single complete rotation.

$$D = P.Np \tag{2.1}$$

For the servo motor we used the overall rotation is 180° hence the overall displacement is calculated as half of the displacement for the full rotation.

$$D = P.Np/2 \tag{2.2}$$

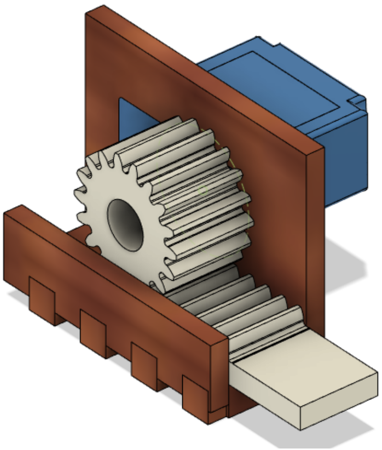


Figure 2.2: Rack and Pinion setup

2.5 Parachute

A parachute is a flexible device who's purpose is to produce drag. Thin canopy material and slender suspension lines allow a big device to be packed in a small volume. The purpose of parachute is to create a large drag area[18].

The stability and open position of a parachute are maintained through a carefully balanced interplay of forces and design features. The parachute comprises a canopy connected to a suspended body by a network of suspension lines. These lines serve as the crucial link between the canopy and the load they support. The weight of the suspended body is transferred through these lines to the canopy, creating both vertical and horizontal force components. While the vertical forces contribute to supporting the load, the horizontal forces have a crucial role in keeping the parachute open. These forces counteract tendencies for the canopy to collapse or close by exerting outward pressure, ensuring that the parachute remains fully deployed and functions effectively during descent[9].

The force applies a vertical force component and a horizontal force component to the base of the canopy. The force(weight) is transferred along the suspension lines as the canopy moves through the atmosphere it captures a huge bubble of air. The internal pressure forces created by this bubble offset the suspension line tension forces and the canopy stays open. Drag and weight act on a body as it falls through the atmosphere. When the parachute deploys, it creates more drag area and thus more drag.

$$F = ma$$

$$a = \frac{\text{force} - \text{drag}}{\text{mass}}$$

where:

a is the acceleration,

force is the total force acting on the object,

drag is the drag force,

mass is the mass of the object.

Whether the body actually decelerates or not depends on the velocity and altitude and thus the drag when the chute is deployed.

If the body has high velocity at parachute deployment, the drag may be greater than the weight.In this case the body will have a negative acceleration and the system will slow down.

If the body has a low velocity at parachute deployment ,the drag may be less then the weight. In this case the body will continue to accelerate and speed up but not with the same magnitude. And the velocity changes so does the drag. Eventually the system will reach an equilibrium point where the drag equals the weight.

$$F_d = \frac{1}{2} \cdot C_d \cdot \rho \cdot A \cdot V^2$$

Where:

F_d is the drag force,

C_d is the drag coefficient,

ρ is the air density,

A is the reference area,

V is the velocity of the object relative to the air.

If the drag starts off lower than the weight, the acceleration will be positive,this means the velocity will increase. Increasing velocity means increasing the drag. Eventually drag will increase to a point where it will equal the weight and acceleration will be zero.

When drag is equal to the weight the composite force (numerator)becomes zero, which makes the overall acceleration zero. An acceleration of zero means the velocity is not changing. When velocity stops changing, the descending system reaches terminal velocity. When the system has reached terminal velocity it will descend at a constant velocity until it will hit the ground. [7]

CHAPTER 3: THEORETICAL BACKGROUND

3.1 Design

Designing an UAV does not only include creating a layout for the aircraft,it takes into account the structural integrity, aerodynamic,control surface, aerodynamic, propulsion system.The design of an aircraft takes into account many systems and subsystems where they must function efficiently and not hinder any process.A design must be constructed in such a way that they can perform many operations with very less modifications and changes required.That is what a good design resembles[10].It must pass the required analysis and structural to aerodynamic tests that are required for meeting the operational needs.In conclusion,design of an UAV includes creating the required layouts,carrying out all calculations and creating a system where all the other subsystems and operations operate as intended.[12]

3.2 Phases of Design

The design process had three main steps. Firstly, initial ideas were generated in the conceptual design phase, considering the performance, appearance, and alignment with requirements. Additionally, decisions were made on whether to proceed to the next phase or address any unresolved issues before advancing. In the preliminary design phase, efforts were focused on identifying and resolving design problems to enhance its suitability for building a prototype capable of flight. This phase aimed to validate the feasibility of the initial idea. Finally, in the detailed design phase, the refined design was transformed into a concrete plan, specifying the external and internal features of the aircraft. This marked the initiation of the construction phase. The primary objective was to achieve optimal weight for the aircraft while ensuring it could lift substantial loads. The decision-making process incorporated with various analysis to determine crucial performance factors early in the process, guiding the design of individual components such as wings, tail, and engine, culminating in the selection of the overall design.

3.2.1 Conceptual Design

We have taken fixed wing UAV into consideration due to it's features and advantages that can efficiently carry out our mission to deliver medical payloads.For our mission plan and objective for the delivery of the payload we require many specific properties that can be found in fix wing UAV.

- High Endurance
- Stability
- Long range of operation
- High Altitude
- High Payload weight

Wing Configuration

The tapered wing in combination with the multi-element airfoil had issues that directly affected flight safety due to difficulty of mounting the second element accurately on its designed axis, leading to unsymmetrical control surface deflections, so an early decision was made to favor a rectangle wing. We decided not to have wing tips although it will have some induced drag reduced as it doesnt play much significant role in reduction of high amount of induced drag[5].

Table 3.1: Wing platform trade-off.

Criteria	Weighting	Rectangular	Tapered	Midway Taper	Elliptical
Lift Coefficient	0.35	0.8	0.85	0.8	0.9
Manufacturing	0.3	0.9	0.7	0.75	0.55
Induced Drag	0.2	0.9	0.85	0.8	0.7
Wing Weight	0.1	0.7	0.8	0.75	0.6
Total	1	0.8025	0.7575	0.775	0.7875

Despite the low difference between the high and medium wing options. We had used mid wing configuration in our first design and in our second design we preferred high wing configuration as the high wing was favorable for increased stability[5].

Table 3.2: Wing mounting position trade-off.

Criteria	Weighting	High Wing	Mid Wing	Low Wing
Stability	0.3	0.9	0.75	0.55
Ground Effect	0.3	0.6	0.75	0.9
Ground Clearance	0.2	0.9	0.75	0.65
Structural Weight	0.1	0.8	0.6	0.9
Downwash on Tail	0.1	0.6	0.8	0.9
Total	1	0.77	0.74	0.745

Tail Configuration

The conventional tail was favored over T-tail and other configurations because of its stability and its ease of both control ability and manufacturing[5].

Table 3.3: Tail configuration trade-off.

Criteria	Weighting	Conventional	T-tail
Weight	0.3	0.9	0.6
Stall	0.1	0.8	0.5
Efficiency	0.3	0.6	0.8
Stability	0.2	0.8	0.7
Control ability	0.1	0.8	0.8
Total	1	0.77	0.69

Fuselage Configuration

The shape of the fuselage was chosen circular to be more effective according to our requirements as it can have more internal space for payload allocation. It also have other considerable parameters on comparison with other shapes[5].

Table 3.4: Fuselage cross-section trade-off.

Criteria	Weighting	Rectangular with conical nose	Zero-drag body shape	Circular
Structure weight	0.3	0.4	0.79	0.65
Manufacturability	0.3	0.7	0.5	0.3
Drag	0.2	0.45	0.85	0.75
Stability	0.1	0.3	0.85	0.8
Usable cargo space	0.1	0.48	0.8	0.85
Total	1	0.498	0.722	0.6

Engine and Propeller configurations

A single puller motor was chosen over pusher for forward C.G, less drag and more efficiency [5].

A 2-blade constant pitch propeller was chosen over 3-blade propeller due to higher efficiency and equal thrust production and satisfy power limitations and decreased weight[5]
.

Table 3.5: Engine configuration trade-off.

Criteria	Weighting	Puller	Pusher
Efficiency	0.4	0.85	0.65
Drag	0.3	0.7	0.85
Safety	0.2	0.75	0.85
Down wash on tail	0.1	0.85	0.55
Total	1	0.785	0.7

Table 3.6: Blades trade-off.

Criteria	Weighting	2 Blades	3 Blades
Efficiency	0.3	0.9	0.7
Power consumption	0.35	0.9	0.8
Thrust	0.25	0.7	0.7
Noise	0.1	0.8	0.6
Total	1	0.722	0.6

Overall configuration selection

In the meticulous conceptual design phase of the aircraft, an XFLR5 model was employed to approximate the aerodynamic characteristics of the chosen configuration. This simulation tool facilitated a detailed analysis of the rectangular wing, high wing configuration, and other design elements, allowing designers to assess lift, drag, and various parameters crucial for aerodynamic performance. The tool played a pivotal role in fine-tuning the overall design, ensuring that the chosen configuration meets the goal of achieving optimal weight, performance, and functionality. The decision was to use the aircraft with rectangular wing and conventional tail supported by a boom (aluminum section that connects aircraft's parts with each other)) with a circular body fuselage attached.Also To minimize empty weight hollow shapes was proposed in structure where trade off structural integrity with weight can be considered.

Additionally, trade off was instrumental in validating and optimizing the propulsion system, which includes a single puller motor and a 2-blade constant pitch propeller. Also XFLR allowed for a comprehensive assessment of factors such as forward center of gravity, drag reduction, and overall efficiency, enabling us to make informed decisions about the propulsion system to be used. Through a thorough analysis of aerodynamic parameters, the chosen configuration was refined to align with the desired performance goals, demonstrating the crucial role of trade offs and XFLR5 in achieving an aircraft design that balances aerodynamic efficiency and functionality.

3.2.2 Preliminary Design

As the name is "preliminary", it defines that the parameter and calculation made are not the final from very beginning. Aircraft's maximum take off, wing surface area and engine power or thrust are determined in this phase of design.These factors determine the size of aircraft, manufacturing cost and the level of calculations.

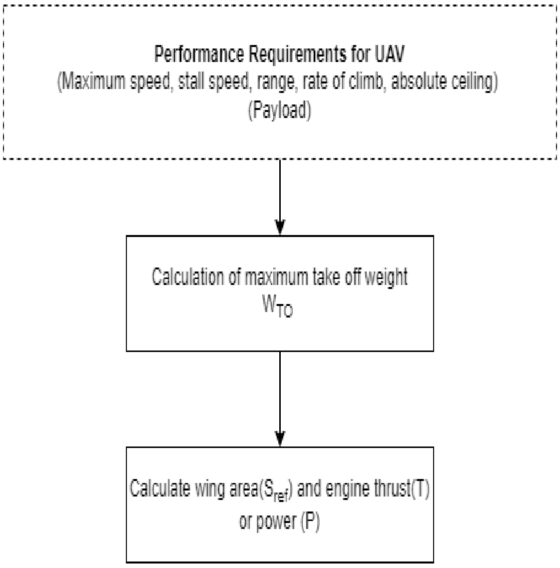


Figure 3.1: Preliminary Design Procedure

Maximum Takeoff Weight Estimation

i) **Weight Build Up**

The maximum weight takeoff of UAV is broken down into following three elements:

a) Payload Weight

b) Autopilot Weight

c) Battrey Weight

d) Empty Weight

$$W_{TO} = W_{PL} + W_B + W_E + W_A \tag{3.3}$$

Rearranging the known and unknown values we obtain:

$$W_{TO} = \frac{W_{PL} + WA}{1 - (\frac{W_B}{W_{TO}}) - (\frac{W_E}{W_{TO}})} \tag{3.4}$$

ii) **Payload Weight**

Payload weight is known or desired value for UAV.Payload include camera,sensors and other intended loads.

iii) **Autopilot Weight**

Autopilot weight includes the weight of the flight controller that controls the autonomous flight and serves sub system and payloads.Autopilot weight includes the weight of flight controller,receiver,transmitter,data link etc.

iv) **Empty Weight**

Empty weight is normally calculated from the historical data.

v) **Battery Weight** Electric propulsion system includes battery, propeller and electric motor. Battery weight is the function of endurance and range, aerodynamics and energy consumption for payload (not in all UAVs)of the aircraft

$$\text{Energy Density} = \frac{\text{battery output power} \times \text{time of energy consumption}}{\text{battery mass}}$$

$$E_d = \frac{P \times t}{m_b} \tag{3.5}$$

Battrey weight can be calculated from the above formula.Here, t denotes the time of flight for cruise only when other segments are considered it becomes,

$$W_B = \sum_{i=1}^{n} \frac{P \times t \times g}{E_d} \tag{3.6}$$

Cruise time is function of range and cruising velocity and it is specified by customer or need.

$$t = \frac{R}{V_c} \tag{3.7}$$

The power required for the cruising flight for propeller is given by :

$$P_{prop} = \frac{\rho v^3 S C_d}{2\eta_p} \tag{3.8}$$

When five percent of the battrey is assumed to be finished in other segments of flight than cruise battrey weight can be calculated as:

$$W_B = 1.05\left(\frac{W \times g \times R}{2\eta_p \times \frac{C_L}{C_D}}\right) \tag{3.9}$$

3.2.3 Detail Design

Wing

The major portion of this section includes creating wing that generates required amount of lift as well as consider other factors of stability,manufacturing,control surfaces,maneuverability and cost.The wing design aspects take into wing reference area, aspect ratio, wing location, stability, lift generation and other many factors

Wing Location

Wing location selection is one of the earlier and important criteria for the design of a

UAV. For the purpose and objective of our mission to deploy payload high wing configuration was selected. High wing configuration have several advantages over other mid-wing and low-wing configurations.

1. Eases the unloading of payload as well as design feasibility dfor the compartment area.
2. Higher dihedral effect which creates higher lateral stability due to fuselage contribution in dihedral.
3. Smoother fuselage shape which creates the aircraft to be more aerodynamic.
4. This configuration creates mor lift than other two configurations.

Airfoil Selection

Airfoil selection is a major part for designing an aircraft.There are two major ways of selecting an airfoil one is airfoil design and another being the airfoil selection. There are several airfoil designs which are designed and published. Three of the major airfoil resources are (a)NASA;(b)NACA;and (c)Eppler.One of the most reliable and stable one are the NACA airfoils.The NACA Airfoils include the four digit , five digits and six digits airfoils. Some properties required for selection of an airfoil for better performance and manufacturing are mentioned in this section.

1. Highest lift coeffcient(Cl$_max$)
2. Proper or ideal design lift coefficient (Cl$_d$)
3. Lowest minimum drag coefficient(C$_d$)
4. Highest lift to drag ratio ((Cl/Cd)$_max$)
5. Lowest pitching moment coefficient (C$_m$)
6. Ease in manufacturing
7. Thick enough for spar placement

8. Cost

Wing Incidence

The wing incidence angle is the angle between the fuselage center line and the wing chord line at the root.The wing incidence can be appropriated from the evaluation of C_l vs α graph. Also known as the wing setting angle the wing can generate appropriate amount of lift during cruise.The typical value of the incidence angle lies between 1-4°

Aspect Ratio

Aspect ratio for the rectangular wing is defined as the ratio of the wing span to the chord of the wing.

$$AR = b/c$$

1. b is span of the wing
2. c is the chord of rectangular wing

Rectangular wing have good lift generating properties, they do have certain disadvantages when compared with the tapered wings. They are simple in design, also cost less for manufacturing. Due to ease for manufacturing they can be build for flight test when needed and also have ease on spar installation.

Tail Design

The general selection for a tail configuration are majorly done from the requirement rather than mathematical calculations. From estimation of various factors the convectional tail configuration was selected. The convectional tail design met the criteria for the mission carried by the UAV and was quite suitable for manufacturing as per the resources available.

1. Stability - The convectional tail design are highly stable and even suitable for adverse weather conditions.
2. Manufacturing - This design is simple and suitable for fabrication.

3. Low speed performance - Convectional tail have good low speed handling characteristics

Horizontal Tail parameters

The horizontal tail design are majorly focuses for the trim requirements and also for the longitudinal stability and controllability of the aircraft. The various parameters for the tail design include Horizontal tail span, tail chord and the aspect ratios.

Vertical Tail Parameters

The vertical tail are required for the directional trim, stability and control. Several other factors that will effect the design criteria are manufacturability, reliability , cost. Similar to the horizontal tails the parameters for the vertical tail includes span, chord length , the rubber chord and the deflection angle.

Airfoil Selection

Tail airfoil selection fundamentals deals on two major features of the tail. The two distinct properties of the tail is they must incorporate large lift curve slope ($C_L\alpha_t$) and also must have similar properties at the positive and negative lift conditions during the cruise flight of the UAV.

Fuselage Design

Fuselage design is a vital part of UAV design. Various considerations including aerodynamics, weight, space, manufacturing, payload and other factors should be accounted. The basic properties for the fuselage include several points.

1. Small and compact as possible.
2. Symmetrical from top-view
3. Sufficient space as required
4. Payload should not effect the cg of the aircraft.
5. Satellite and radar placement on line of sight

Figure 3.2 shows the fuselage configurations used for the UAV including all the subsystems.

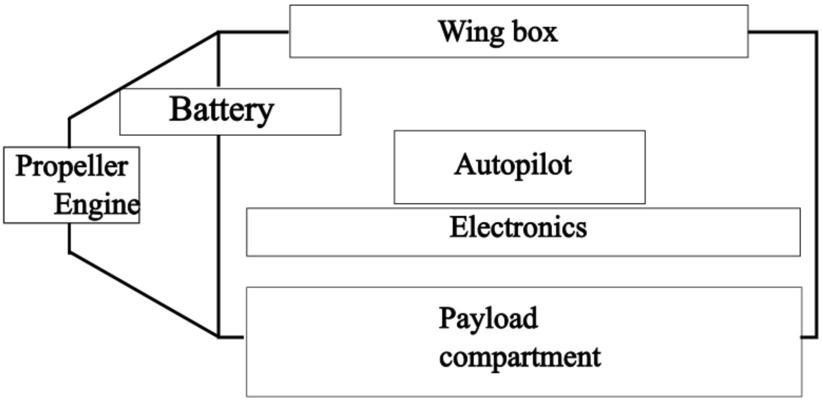


Figure 3.2: Fuselage Configuration

Fuselage Aerodynamics

The fuselage must be as aerodynamic as possible to produce as less amount drag and make it fuel efficient. taking the aerodynamics into considerations as well as compactness, a cylindrical fuselage structure has been selected. The slenderness ratio of the fuselage is simply the ratio of the optimum length to the diameter of the fuselage. The optimum fuselage slenderness ratio determines :

1. lowest zero-lift drag
2. creates lowest wetted area
3. lightest fuselage
4. maximum internal volume
5. generates lowest mass moment of inertia
6. contributes in aircraft stability
7. low cost for fabrication

$$\text{Slenderness Ratio} = L_f/Df$$

The slenderness ratio optimum for the most low-speed UAVs as reccommended between 5 to 10.

3.3 Equilibrium and Stability of UAV

UAV has six degrees of freedom, three in translational motion and three in rotational motion. Equilibrium is the at which the forces in all direction balance each other. During equilibrium, L=W and T=D. When disturbances occur in the aircraft, there are three possible cases.

i) Aircraft returning to its original equilibrium state,
ii) Attain a new equilibrium state or
iii) Never attain any equilibrium state

Disturbances can be any among gust, air turbulence or rapid deflection of control surfaces. If the aircraft returns to its original state after being disturbed, it is called stable. If the aircraft can't attain any equilibrium, it is called unstable and if aircraft attain a new equilibrium state, it is called neutral equilibrium. The matter of either returning to equilibrium or not is the result of the moment being produced. If the aircraft generates counter moment to the moment produced due to gust equilibrium is achieved but if aircraft produce moment in the direction of moment due to gust aircraft is unstable on its own. And if no moment is induced, the aircraft becomes neutrally stable. Sign conventions are given to the moments in different directions. Noseup pitching moment and starboard sideslipping moment are taken positive and nosedown pitching moment and port sideslipping moment are taken negative. Following are assumptions made for the open-loop static stability:

i) Aircraft possess vertical plane of symmetry,
ii) Deflection of control surfaces of each stability axis produce forces or moments in the respective axis only,
iii) Forces and moments follow superposition principle and

iv) Aerodynamic forces and moments vary linearly with aerodynamic/control variables.[16]

Static and Dynamic Stability

It is the tendency of aircraft to return to its original state when disturbances occur. Dynamic stability is the tendency of static stability that undergoes when aircraft tries to return to the original state.

3.3.1 Static Longitudinal Stability

It is the stability of aircraft with respect to the change in AOA in vertical plane. The criterion for static longitudinal stability is expressed in mathematical form as

$$\frac{dM}{d\alpha} < 0$$

when expressed in terms of coefficient,

$$\frac{dC_m}{d\alpha} < 0$$

Aircraft is unstable if,

$$\frac{dM}{d\alpha} > 0$$

and neutrally stable if

$$\frac{dM}{d\alpha} = 0$$

Equilibrium condition in pitch is called trim condition. For pitch trim, no net pitching moment occurs about CG. Stable pitch trim is obtained one on only if

$$C_{mo} > 0 \qquad \& \qquad \frac{dC_m}{d\alpha} < 0 \tag{3.10}$$

Aircraft is flyable and stable at this condition.

If,

$$C_{mo} < 0 \qquad \& \qquad \frac{dC_m}{d\alpha} < 0 \tag{3.11}$$

aircraft is not flyable as it cannot be trimmed though it is statically stable.

If,

$$C_{mo} < 0 \qquad \& \qquad \frac{dC_m}{d\alpha} > 0, \tag{3.12}$$

aircraft is unstable statically, but it is flyable.

From the open-loop static stability,

$$M_{cg} = M_f + M_{ac,w} + L_w X_a + M_{ac,w} - L_t l_t \tag{3.13}$$

Fuselase Contribution

According to Munk's theory, foe the streamline fuselase the pressure distribution over a streamlined body at an angle of attack yields a zero net force accompanied by a pure couple that is of a destabilizing nature.It means
L=0, D=0, $M \neq 0$. The destabilizing pitching moment varies linearly with angle of attack α.

Wing Contribution

Wing contribution on static longitudinal stability depends on the relative distance between aerodynamic center and CG.For low speed aircraft AC being ahead of CG produces destabilizing moment and vice-versa.Mathematically,

$$M_w = M_{ac,w} + L_w X_a \tag{3.14}$$

Tail Contribution

Contribution of horizontal tail in static longitudinal stability is stabilizing in nature and it is expressed mathematically as below:

$$M_t = M_{ac,w} - L_t l_t \tag{3.15}$$

Effect of Power

Power influences the static longitudinal stability from two perspectives in propeller driven aircrafts.

i) Direct effect from propulsion force

ii) Indirect effect caused by propeller slipstream

In direct effect , a high thrust line that induces stabilizing moment is aids in static longitudinal stability where as a low thrust line inducing destabilizing moment makes the aircraft statically unstable.Due to propeller slipstream, wing sections are exposed to high dynamic pressure which eventually produces high local lift and drag forces.The changes are generally small and are ignored[6].

Stick-Fixed Neutral Point

Static longitudinal stability is strongly influenced by the location and movement of CG.It is observed that level of static stability increases as CG moves forward and vice-versa.The location of CG at which $dc_m/d\alpha$=0 is called the stick-fixed neutral point.Elevator is kept fixed during the occurance of disturbance,so it is called stick fixed neutral point.Mathematically, neutral longitudinal stability is expressed as:

$$N_o = \bar{x} - (\frac{dC_m}{dC_L})_f + \frac{\alpha_t}{\alpha_w}(1 - \frac{d\varepsilon}{d\alpha})\bar{V}_1 \eta_t \tag{3.16}$$

Other than at neutral point the above equation is stated as:

$$\frac{dC_m}{dC_L} = \bar{x}_{cg} - N_o \tag{3.17}$$

Aerodynamic center is point where wing-pitching moment doesn't change with angle of attack. From definition of neutral point no moment is induced, so that additional lift due to change in angle of attack act through neutral point.In general neutral point can be considered as aerodynamic center of the complete aircraft.

Static Margin

The level of stick-fixed longitudinal static stability is described by the static margin.Mathematically,it is expressed as:

$$H_n = N_o - X_{cg} = -(\frac{dC_m}{dC_L})_{fix} \tag{3.18}$$

Static margin is always positive for stable aircraft.CG of aircraft can shift upto a point till which the elevator deflection is just capable of trimming the maximum C_L in level flight. CG can travel from neutral point in backward to the CG of fuselase in forward. Mathematically,

$$\delta\bar{x} = N_o - \bar{x}_{cg,f} \tag{3.19}$$

3.3.2 Static Directional Stability

Directional stability is associated with the change in sideslip angle occuring in the horizontal plane.The parameters involving in the directional stability are sideslip velocity(v),yaw angle(ψ) and yaw rate(r) and lateral involves bank angle(ϕ) and roll rate(p).Directional and lateral motion are always linked as sideslip creates both rolling and yawing moments and yawing creates rolling and sideslip motion.Sideslip motion are induced due to the deflection of rudder,horizontal gust and wind turbulence. Due to the destabilizing moment induced to encounter the disturbance aircraft changes its position in space still with the same heading wrt earth.

Sideslip angle and yaw angle both being formed on the horizontal plane are essence to be known in directional stability. Sideslip angle is the angle between the velocity vector and aircraft's plane of symmetry.Mathematically,with denotation of β,it can be expressed as:

$$sin(\beta) = \frac{v}{V} \tag{3.20}$$

Yaw angle is the change in heading of the aircraft wrt earth.It is the angle between airplane's plane of symmetry and a refrence plane fixed in space.

The criterion for directional stability is

$$N_\beta > 0 \qquad or \qquad C_{n\beta} > 0 \tag{3.21}$$

Wing Contribution

Only dihedral and sweep angle affect on directional stability .Directional stability can be ignored in the absence of wing dihedral and sweep.

Fuselage Contribution

Fuselase contributes to the destabilizing static stability and is influenced by the placement of wing wrt fuselase.

Tail Contribution

Horizontal has no noticeable contribution on static directional stability in the absence of tail dihedral and sweep angle.Vertical tail one and only largest contributor to static directional stability.The contribution to directional stability due to rudder is influenced by the following factors:

i) CG
ii) Sweep
iii) Aspect Ratio
iv) Aft Fuselase Geometry (Endplate effect)
v) Fuselase Sidewash

Effect of Power

Power influences the static directional stability from two perspectives in propeller driven aircrafts.

i) Direct effect from propulsion force

ii) Indirect effect caused by propeller slipstream

In direct effect, the contribution can be ignored in other cases with an exception on an engine failure. The side force due to slideslip depends on location of propulsion unit.For puller aircraft it is stabilizing and destabilizing for pusher.

3.3.3 Static Lateral Stability

It is the tendency of aircraft to counter disturbance to attain equilibrium with change in bank.There is no any means to generate restoring moment when aircrafts starts banking.One and only means of counterbalance is sideslip.If the sideslip induces the restoring moment, aircraft is said to be laterally stable, if no moment is produced,aircraft is neutrally stable and induced moment is destabilizing,it is unstable laterally.

The induction of rolling moment as the result of sideslip is called dihedral effect.For a laterally stable aircraft, positive dihedral effect is required and vice-versa.The criteria for the lateral stability is:

$$L_{\beta} > 0 \qquad or \qquad C_{l\beta} > 0 \tag{3.22}$$

Contribution of different individual parts on lateral stability are as below:

Fuselase and Tail Contribution

Fuselase doesn't affect the lateral stability directly and in ignored,however fuselase interference with wing induces an indirect contribution.The contribution of tail in lateral stability is also very small and ignored.

Wing Contribution

Factors influencing on contribution to lateral stability due to wing are :

i) Wing-fuselase interference
ii) Wing dihedral angle
iii) Wing leading edge sweep

A high wing configuration is laterally stable and a low wing configuration contributes for lateral unstability.

3.4 Aerodynamics

Several components on assembly make up ma full a UAV. Each component has task of their own. Wing and tail have the function of producing lift,drag and pitching moments.Lift and drag are influenced by the followings:

i) Aircraft configuration
ii) AOA
iii) Aircraft Geometry
iv) Freestream Velocity
v) Air Density
vi) Reynolds Number
vii) Air Viscosity

Mathematically, Lift and drag are calculated as:

$$L = \frac{1}{2} \cdot \rho \cdot V^2 \cdot S \cdot C_L \tag{3.23}$$

$$D = \frac{1}{2} \cdot \rho \cdot V^2 \cdot S \cdot C_D \tag{3.24}$$

While designing a UAV, one must consider to maximize lift and minimize drag and pitching moment.One must consider the following for aerodynamic design process:

i) Wing planform area
ii) Cross section
iii) Main aerodynamic chord
iv) Aspect Ratio
v) Wing configuration
vi) Span
vii) Air Viscosity

CHAPTER 4: METHODOLOGY

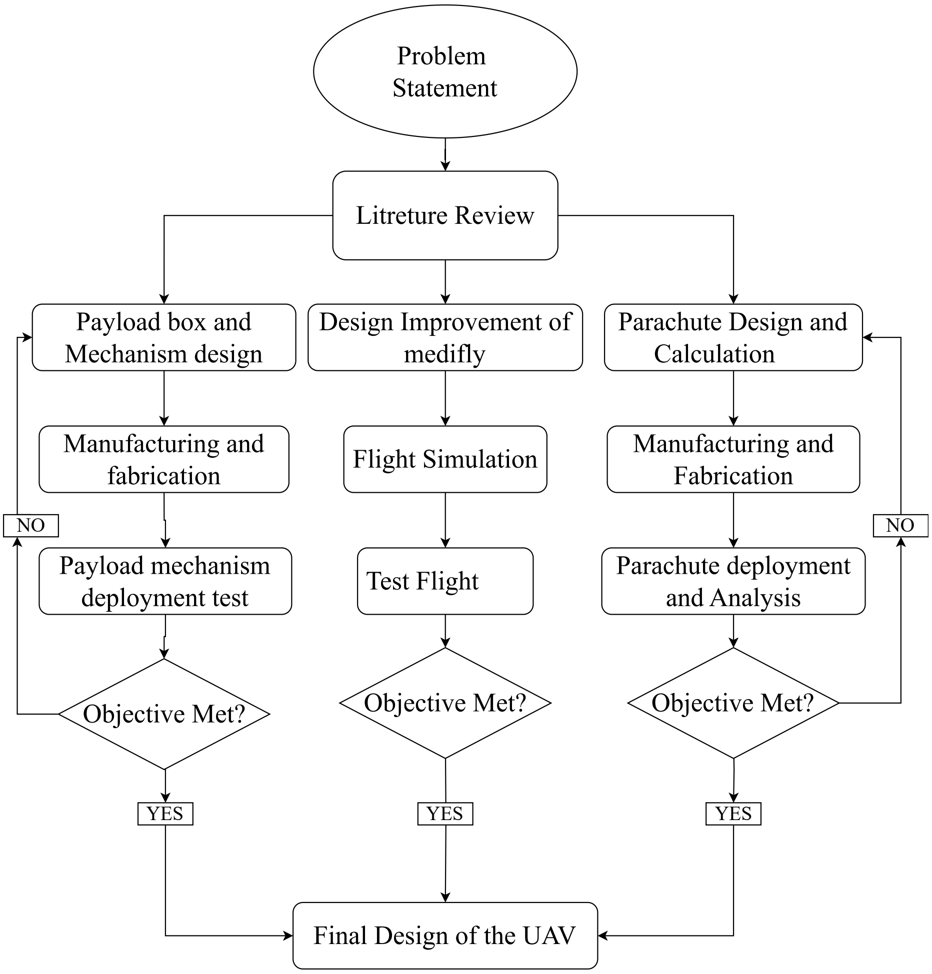


Figure 4.1: Methodology Flowchart

4.1 Mission Analysis

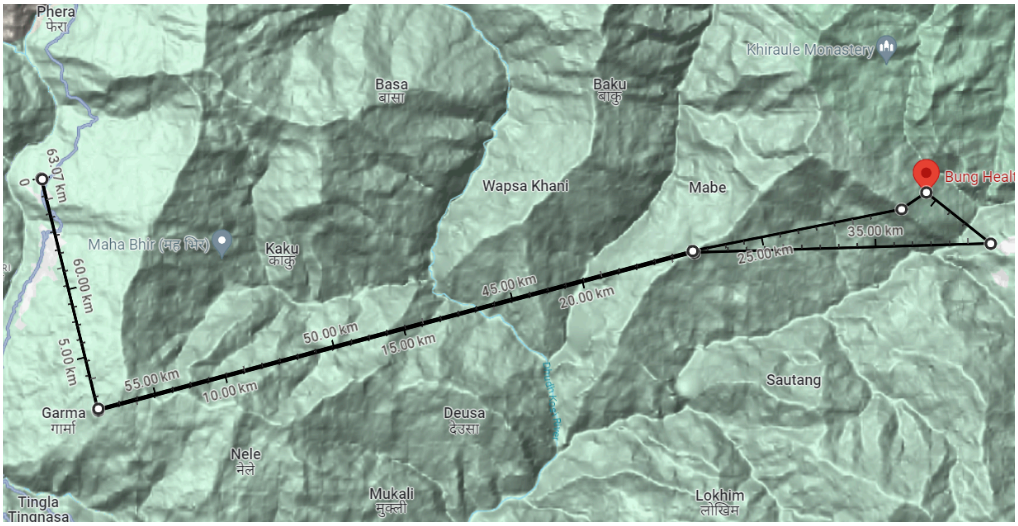


Figure 4.2: Mission Distance

The major objective of the UAV is to carry medical supplies from the District hospital Phaplu (2413 m above mean sea level) to the remote location at Mahakulung Health Center(1850m).The mission includes loading of medical supplies like vials of vaccines and human blood from a blood bank, a pharmacy or a suitable medical reservoir; transporting it to the demand location in the form of a package which is dropped with parachute deployment, and then returning to the location where the UAV took-off.

Taking the general terrain into consideration the overall Mission plan was created where there are certain requirements for the UAV to ascent and descent as well as loiter for payload delivery.The aircraft must meet the required stable conditions to delivery medical supplies without any damages attained by the payload.

The overall mission profile consists of catapult takeoff at the altitude of 2413m, then the UAV would climb to 2850m and cruise for 17km range reaching Sotang.When the UAV reaches Sotang the aircraft should descend to the altitude of 1900m at Bung Health Post, Mahakulung .Upon reaching the destination the UAV would loiter and deliver the medical package through it's payload deployment system.After the unloading of payload the aircraft cruises to Namlung and climb phase to Sotang is initiated reaching the altitude of 2850m. Then cruise back to Garma of range 17km is planned.The UAV

Table 4.1: Mission Steps

Phase	**Description**
Launch and Takeoff	Ttakes off from Phaplu Airport(2413m)
Climb	the altitude of 2800 m to Garma
Cruise	The UAV cruises to Sotang
Descent	descends to altitude of Mahakulung (1850m)
Payload Drop	Drop payload in Bung Health Post
Cruise	upto Gudel
Climb	upto Sotang
Cruise	upto Garma
Descent	upto Phaplu Airport

descends to the landing spot at Phaplu Airport after the cruise back phase ends. The landing is done through the net landing procedure. The overall distance travelled by the UAV in this mission is calculated as 64km including all the phases.

4.2 Maximum take off Weight Estimation

The maximum take-off weight is the sum of payload weight, autopilot weight, battery weight and empty weight. Payload weight is of 1 kg, autopilot weight of 40 gm, battery to MTOW weight ratio of 12 percent and empty weight ratio of 0.76 yields the maximum take off weight of 8.5 kg.

4.3 Preliminary Wing and Engine Sizing

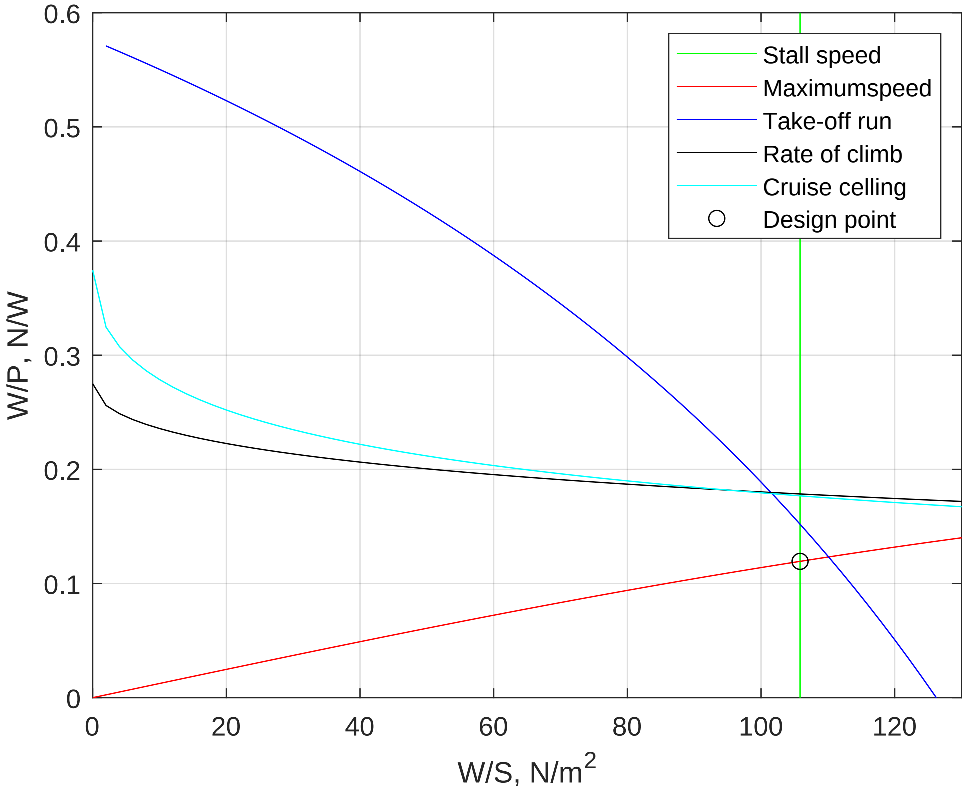


Figure 4.3: Matching Plot

From the matching plot, we have calculated a design point that has wing loading of 105 N/m^2 and power loading of 0.12 W/P. The required wing size for MTOW is 0.80 m^2 and engine size is of 750 Watt.

4.4 Motor and Battery Selection for Mission

The power required for level flight can be estimated using the following equation:

$$P = \frac{1}{2} \times \frac{C_D \times \rho \times S \times V^3}{\eta} \tag{4.25}$$

Where:

- P is the power required (Watts)
- C_D is the coefficient of drag
- ρ is the air density (kg/m^3)
- S is the wing area (m^2)
- V is the airspeed (m/s)
- η is the overall efficiency

So, a motor of 1000 Watt output power can fulfil our mission requirements for cruise speed of 30 m/s.

The mission from Phaplu to Bung Health Post, Mahakulung Rural Municipality is almost 32 kilometers.So, the battery for 64 kilometers is always required.The motor consumes 1000 watt power in maximum, a battery should be chosen accordingly.First, we fix the number of cells i.e. 6 cells that has output voltage of 25 v .So, the maximum current that can be drawn is 40 A.Our cruise velocity is 30 m/s. Then, the time required for mission is 36 minutes.So, a battery of minimum of 30,000 mAh is sufficient.

So, the battery with following specs is chosen.

Table 4.2: Battery Specs

Specifications	**Values**
Capacity	30000 mAh
Nominal Voltage	6S 22.2 v
Maximum Voltage	25.2 v
Minimum Voltage	16.8 v
Chemistry	LiPo
Max Continuous Discharge	80 Amps
Watt Hours	236.8 Wh
Energy Density	252 Wh/Kg
Weight	2570 g

4.5 Weight Estimation

Weight estimation is one of the major critical step for the design of an aircraft as it effects the overall performance,stability,cost and resources needed.Taking the conceptual design and preliminary design into consideration the weight of the aircraft was estimated and calculated with the goal of making it as much as low on weight as possible keeping other aspects secured.

Table 4.3: Mass Calculation

Accessories	**Mass**	**Quantity**	**Total Mass**
Wing and Structure	2000 gm	1	2000 gm
Battery (6S, mAh)	852 gm	1	852 gm
Motor and Propellers	150 gm	1	150 gm
ESC 50A	70 gm	1	70 gm
Servos	13 gm	6	78 gm
Controller	16 gm	1	16 gm
Miscellaneous	100 gm	1	100 gm
payload	700 gm	1	700gm
		TOTAL	**3699 gm**

4.6 Wing Design

A rectangular wing configuration was selected due to the ease of manufacturing .The first iterative design consisted of mid-wing configuration which was later re-designed and a high wing structure was selected. High wing due to it’s several advantages was selected including stable flight and area for the payload compartment. First Iteration

1. Wing span = 1.8 m
2. Chord length = 27cm
3. Vertical location = High-wing

4. Aspect Ratio = 6.67

Second Iteration

1. Wing span = 1.6 m
2. Chord length = 25cm
3. Vertical location = High Wing
4. Aspect Ratio = 6.4

Airfoil Selection

Several airfoils were selected for analysis and choosing the optimum airfoil as needed by the the mission criteria of the aircraft.The requirement as per needed where few of similar airfoils were selected and the required properties for the airfoil were analysed and we came with the conclusion for the selection of NACA 4412. It had several advantages over other as seen in the table with the score of 0.58.

Airfoil	$C_L max$	$\alpha_s tall$	C_{Lo}	$(C_l/C_d)max$	$C_d min$	$C_m(c/4)$	Score
NACA 2412	2.9	15	0.22	50	0.0065	-0.05	0.46
NACA 2415	2.2	15	0.22	45	0.007	-0.047	0.4
NACA 2418	1.6	16	0.22	40	0.0075	-0.045	0.36
NACA 4412	3.8	16	0.44	53	0.0068	-0.095	0.58
NACA 4418	3.7	12	0.32	55	0.0061	-0.067	0.52

Table 4.4: Airfoil scoring

After comparison between the selected airfoils the NACA 4412 was selected as the wing for the UAC. The results were obtained from XFLR 5 where the required criteria and conditional parameters were used for the analysis. NACA 0012 as a symmetric airfoil was selected for both the vertical and horizontal stabilisers.

4.7 Fuselage Design

All the variables taken into consideration along with making the fuselage as compact as possible, a cylindrical frame was designed with the maximum diameter of 16cm. The overall length of the fuselage is 54cm. The overall slenderness ratio of the fuselage as calculated is 3.54.

Figure 4.4: Fuselage structure

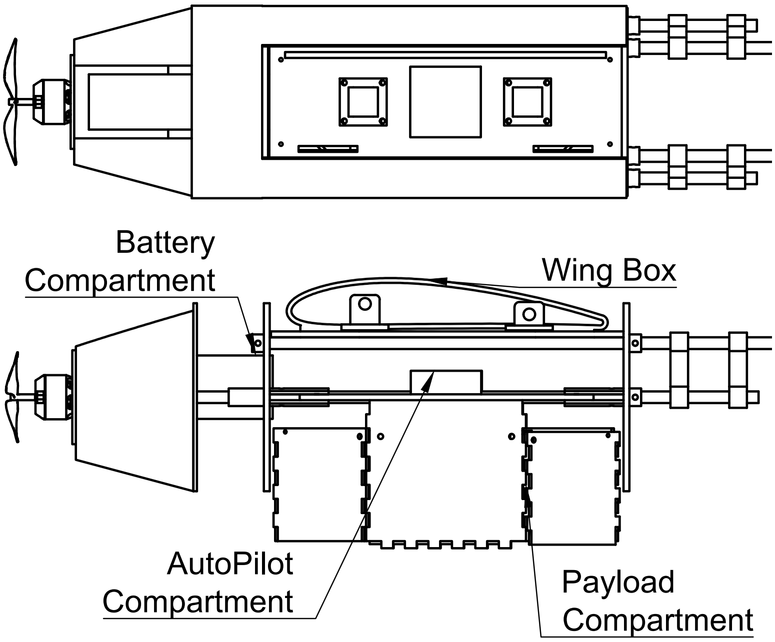


Figure 4.5: Fuselage Layout

4.7.1 Wing Box and Twin Boom Design

Both the wing box and twin boom factors were taken into the design for both the ease of manufacturing and assembly. The Wing box was made as a detachable component for the ease of work in the electronics compartment which can be referred in the fig4.6. The twin boom configuration implemented for the tail stability and to reduce the tail flex during flight. It also assures structural integrity.

Figure 4.6: Wing box and Fuselage

4.7.2 Payload Compartment

The payload compartment compromises of medical payloads,first aid kits ,vials. Required amount of space must be available as well as proper insulation should be provided for the payloads. A diamond shaped hexagonal contour is selected for the payload compartment as it provides more amount of area and volume for the payload than other configurations. As well a overall drag is less in the diamond shaped compartment that rectangular payload box.

Figure 4.7: Payload Box

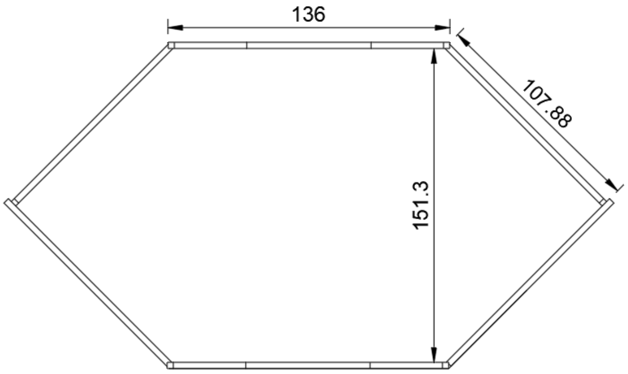


Figure 4.8: Payload dimension

4.7.3 Deployment Mechanism

The deployment mechanism simply consists of a rack and pinnion assembly actuated through the servo motors rotation. The rack of the system holds the overall payload compartment. On the 180° servo rotation the rotational motion is translated to linear actuation which slides over the notch releasing the overall payload compartment.

1. pinnion pitch diameter = 18mm
2. number of teeth = 18
3. rack length = 39.65 mm
4. Linear pitch = 3.14 mm
5. angular pitch = 18°

The wings were fabricated using 4 axis CNC foam cutter where the materials used for the wings were styrofoam. Both the tails sections were manufactured using same material of the wings. For the overall structural design the longerons were used of aluminum and carbon fibres. The spars were used of aluminum tubes and the 5mm plywood were used for the formers and bulkheads of the aircraft.

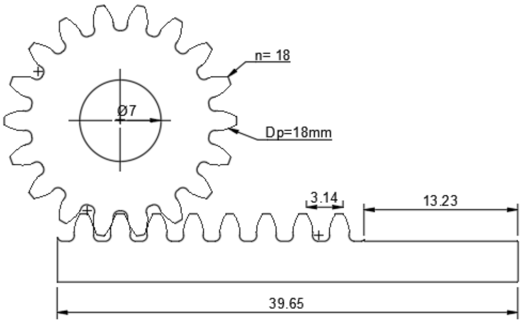


Figure 4.9: Rack and Pinion

For the calculation of overall linear displacement of the rack in the setup, we have :

$$Lineardisplacement = Numberofteethonthepinion \times Pitchoftherack$$

$$L = N \times P$$

This is the overall rotation of 360° which cannot be provided by the servo motor we have used. Hence, the overall displacement of the rack is exactly half of the calculated value. The overall displacement is calculated as 2.86 cm. The overall displacement meets the requirement for the sliding notch mechanism of the payload compartment.

4.8 Tail Design

The convectional tail configurations were selected and both the horizontal and vertical stabilisers were designed as per the parameters selected and analysed. The airfoil for both the horizontal and vertical are NACA0012 due to it's suitability for the mission requirement.

Horizontal Tail Parameters

1. Horizontal tail span(b_h) - 70cm
2. Horizontal tail chord(c_v)- 20cm
3. Tail arm (l_h) - 68cm

4. Elevator chord length - 8cm

Vertical Tail Parameters

1. Vertical tail span(b_v)-28cm
2. Vertical tail chord(c_v)-20cm
3. Tail arm (l_v)- 68cm
4. Rudder chord length- 6cm

4.9 Fabrication and Manufacturing

All the factors and parameters were taken into consideration and fabrication process for the aircraft was initiated. A CAD model of the UAV was designed and the overall estimation and analysis were performed. In the CAD model parameters such as the cg of the aircraft, payload deployment, payload compartment, electronics , actuators were taken into account. Initially , a basics framework and lay out of the fuselage was designed where the overall structure and applications were put in place.

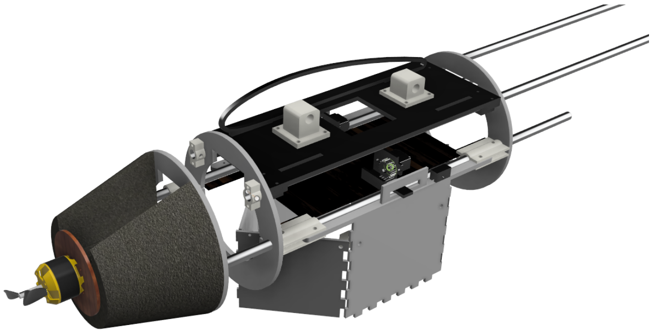


Figure 4.10: Fuselage CAD Design

As seen on figure(4.8) the overall surface area of the base for the payload compartment is 305 cm^2. The overall volume available for the payload compartment is 295 cm^3. The payload configuration contributes lesser drag also provides required volume for other several medical supplies, suitable for the compact design of the fuselage and easier for the overall payload deployment. The overall payload weight has been estimated from 750 grams to 1kg.

4.10 Parachute Design Process

1. W=1kg
2. Shape-circular
3. Cd=0.73
4. Impact velocity(v)=5
5. A=0.8 m^2

Simple Parachute Types

- **Cross:**
    - Easy to manufacture
    - Lower C_d - 0.70
    - More stable (less swinging)
- **Square:**
    - Easiest to build
    - Intermediate C_d - 0.73
    - Less stable
- **Flat Circular:**
    - A little more difficult to build
    - Highest C_d of all shapes - 0.78
    - Least stable

The value of C_d for a flat circular parachute is higher because C_d is dependent on how much frontal area is presented to the airflow. The larger the frontal area, the larger the drag.

4.11 Size Calculation:

The size of the parachute is calculated using the following formula:

$$V_t = \frac{2m}{\sqrt{C_d \cdot \rho \cdot A}}$$

Where,

V_t = Descent velocity of the payload box

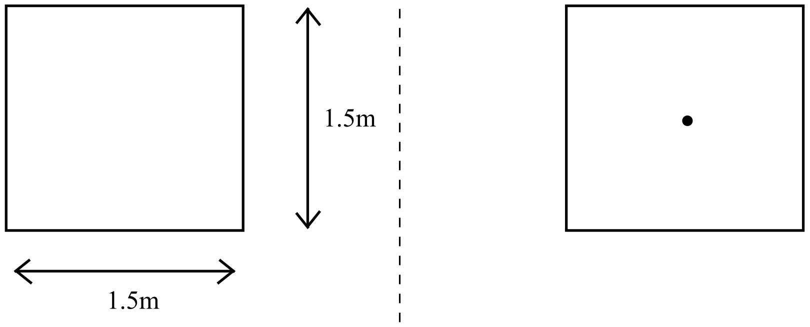
m = mass of the payload

C_d = Drag coefficient of the parachute

ρ = Density of the air (around $1.255\,\mathrm{kg/m^3}$)

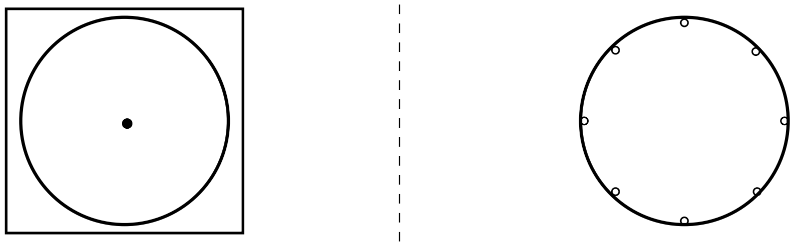
A = Total area of the parachute

4.12 Steps for making Parachute:



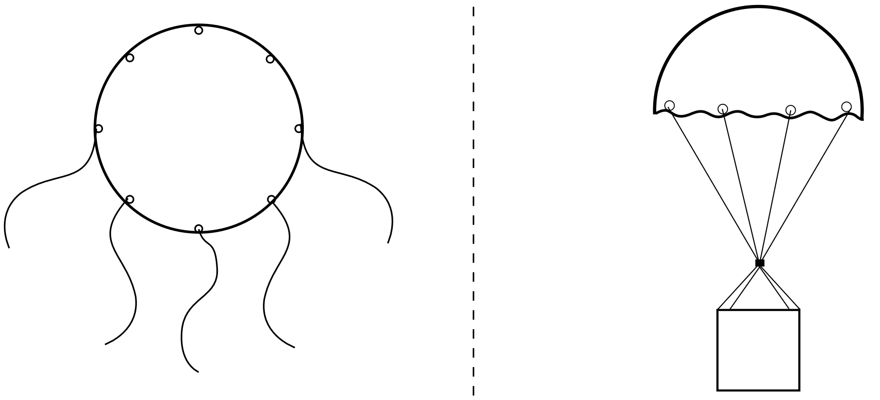
Step 1 : Select a fabric of given dimension

Step 2 : Locate the center point of the fabric



Step 3 : Cut a cirle of radius 50.4 cm

Step 3 : Place 8 holes uniformly for suspension lines



Step 5:Place a suspension line of 40 cm on each hole

Step 5:Fix the suspension lines on fixed length and attach it to payload

Figure 4.11: Parachute fabrication

4.13 Test Flight and Calculation of the Aid-Plane

The flight testing phase for the Aid-Plane UAV is a crucial step in validating its performance and ensuring that it aligns with the specified requirements for accurate payload delivery. This comprehensive testing process involves meticulously assessing key parameters such as velocity, weight, range, and endurance to gauge the UAV's capabilities under real-world conditions.

To initiate the flight tests, the Aid-Plane will undergo a series of controlled maneuvers and operations to measure its velocity, ensuring that it meets the designated speed requirements. The velocity data obtained will be scrutinized and compared with predetermined specifications, enabling a precise evaluation of the UAV's ability to navigate and cover distances within the expected timeframe. Weight is another critical factor influencing the UAV's performance, affecting its stability, maneuverability, and overall efficiency. Through a thorough examination, the weight of the Aid-Plane will be measured and assessed during various flight scenarios. Any deviations from the specified weight parameters will prompt a careful analysis, leading to necessary adjustments or modifications to ensure optimal payload delivery.

Range and endurance are pivotal considerations in the Aid-Plane's functionality, directly impacting its ability to operate over extended distances and sustain flight for the required duration. Flight tests will involve assessing the UAV's range capabilities and endurance under different conditions, comparing the obtained results with theoretical values derived from meticulous calculations. If any disparities arise, adjustments will be made to enhance the UAV's range and endurance, aligning them with the project's objectives. Throughout the flight testing phase, historical data from similar UAVs will serve as a valuable benchmark for performance comparison. This comparative analysis provides insights into industry standards and best practices, helping to validate the Aid-Plane's performance against established norms.

In the event that the obtained data deviates from the required parameters, a systematic approach to modifications will be implemented. This may involve refining the UAV's design, adjusting propulsion systems, or fine-tuning control algorithms to address any identified shortcomings. The goal is to iteratively enhance the UAV's performance until it meets or surpasses the specified requirements for accurate payload delivery. By conducting thorough flight tests, drawing on historical data, and implementing necessary modifications, the Aid-Plane project aims to deliver a UAV that not only meets but exceeds performance expectations, ensuring its effectiveness in diverse real-world applications. This iterative testing and refinement process is essential for achieving a reliable and robust UAV capable of fulfilling its intended mission with precision and efficiency.

4.14 Part Design and Simulation

Following the flight testing phase, modifications identified for the UAV undergo rigorous part design and simulation. Utilizing tools like XFLR and X-PLANE, the modified parts are analyzed for aerodynamic characteristics and tested in simulated mission conditions, accounting for factors such as altitude and wind velocity.

The XFLR software aids in modeling and assessing aerodynamic forces, providing crucial insights into how the modified parts interact with airflow. Once validated, the modified parts are translated into detailed Computer-Aided Design (CAD) models using software like CATIA or Solidworks. These models are then integrated into the UAV design, ensuring compatibility and structural integrity.

The assembly undergoes a validation process, including structural analysis and aerodynamic simulations, to confirm the enhanced performance of the UAV with the modified components. This iterative approach to design and testing ensures that the UAV meets or exceeds the required specifications for accurate payload delivery under diverse mission conditions.

4.15 Payload Box Design And Fabrication

The payload system comprises three main components:

- The payload box provides a space to store and secure the payload.
- The payload box is mounted by brackets glued into the sides of the airframe.
- The drop mechanism is a servo actuated controlled via controllers or any time or zone setting parameters.

The payload box along with the drop mechanism will be first designed in 2D sketch with all the required dimensions and all the required fittings as well as connectors. After the design is completed in sketch we will make a full CAD model of the design and assembly it along with our UAV design to see it fits with the required dimensions. Then various drop testing and control actuation's can be tested for the payload box and drop mechanism.

4.16 Verification and Validation

The Unmanned Aerial System (UAS) undergoes rigorous testing using various tools. XFLR, a software for aerodynamic analysis, validates the design by simulating flight behavior. Xplane, a flight simulation software, assesses the UAS in realistic virtual environments, identifying issues and enhancing flight capabilities.

After virtual testing, practical evaluation with the Pixhawk flight data recorder occurs. Pixhawk, an open-source autopilot, records crucial flight parameters, offering insights into real-world performance for design validation.

Structural integrity is tested through simulations and visual inspections. Simulations stress the UAS model, ensuring it meets requirements, while visual inspections identify wear or weaknesses. This thorough testing ensures the UAS design is aerodynamically efficient and durable in real-world conditions.

4.17 Design Constraints

There are several design constraints that must be taken into consideration when designing a UAV. These constraints may include different parameters like size and weight of the aircraft, its cruise speed, the type of propulsion system used, wing loading, etc. These design constraints must be thoroughly understood to create a UAV that is optimized for specific task.

Few parameters that we assumed based on the selected configuration and mission requirements are:

- Weight: 4kg
- Wing Loading: 60kg/m^2
- Cruise Speed: 20m/s
- Cruise Altitude: 2300m

These variables serve as a starting point for the calculation of other required parameters.

4.18 Wing Parameters

Wing design is indeed a critical and complex task in the overall process of aircraft design. The efficiency and performance of an aircraft are heavily influenced by the design of its wings, as they play a crucial role in providing lift, stability, and control during flight. Designers must carefully optimize various geometric factors to achieve an efficient wing geometry that meets the specific requirements and objectives of the aircraft.

One of the primary considerations in wing design is the aspect ratio, which is the ratio of the wingspan to the mean chord (average width) of the wing. Higher aspect ratios generally result in lower induced drag, improving the overall aerodynamic efficiency of the wing. However, the choice of aspect ratio is a trade-off, as it also affects other aspects of the aircraft's performance, such as maneuverability and structural integrity.

Wing airfoil selection is another fundamental aspect of achieving the desired aerodynamic characteristics. Airfoil profiles dictate the lift and drag characteristics of the wings at different angles of attack. Engineers carefully choose airfoils based on the specific mission profile of the aircraft, considering factors such as takeoff and landing performance, cruising efficiency, and overall stability. The wing's taper ratio, or the ratio of the wingtip chord to the root chord, is another critical parameter. Tapered wings can improve the distribution of lift along the span, enhancing overall efficiency and reducing the risk of structural issues. However, achieving an optimal taper ratio requires careful consideration of various factors, including weight distribution and aerodynamic loading.

4.18.1 Wing Area

Given that the entire structure of our aircraft essentially consists of wings, the wing area emerges as a pivotal variable in our design considerations. It becomes imperative to strike a balance – the wing area must be substantial enough to produce adequate lift throughout all phases of flight, yet it should not surpass specified size and weight limits. This delicate equilibrium ensures optimal performance, adhering to both the necessity for sufficient lift and the constraints imposed by size and weight restrictions.

The wing area can be calculated from wing loading and weight by the following formula:

$$\text{Wing Area} = \frac{\text{Weight}}{\text{Wing Loading}} = \frac{4 \times 9.8}{60} = 0.65\,\text{m}^2$$

4.18.2 Wingspan

The wingspan of an airplane refers to the distance between the tips of its wings. Irrespective of the wing's specific shape or sweep, the wingspan is consistently measured as a straight line from one wingtip to the other. This wingspan is closely tied to both the aspect ratio and the overall wing area of the aircraft.

The aspect ratio can be expressed in terms of wing span as:

$$\text{Aspect Ratio} = \frac{b^2}{\text{Wing Area}},$$

$$b = \sqrt{\text{Aspect Ratio} \times \text{Wing Area}} = 1.7\,\text{m}$$

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4.21 Structural Design

The design we are aiming for with the available resources is for quick and replaceable structures rather than a crash-proof design which may withstand a high amount of impact. Due to the need for a high number of test flights and pre-payload drop checks, we do not have the facilities and materials for the fabrication of high-end models of UAV, which can be used for a high number of flights. We aim on structurally designing our aircraft structure with easily removable and installation of aircraft parts. We have modeled the structure based on attachments using 3D print models as well as the use of bolts and inserts for reducing the time of installation and fabrication.

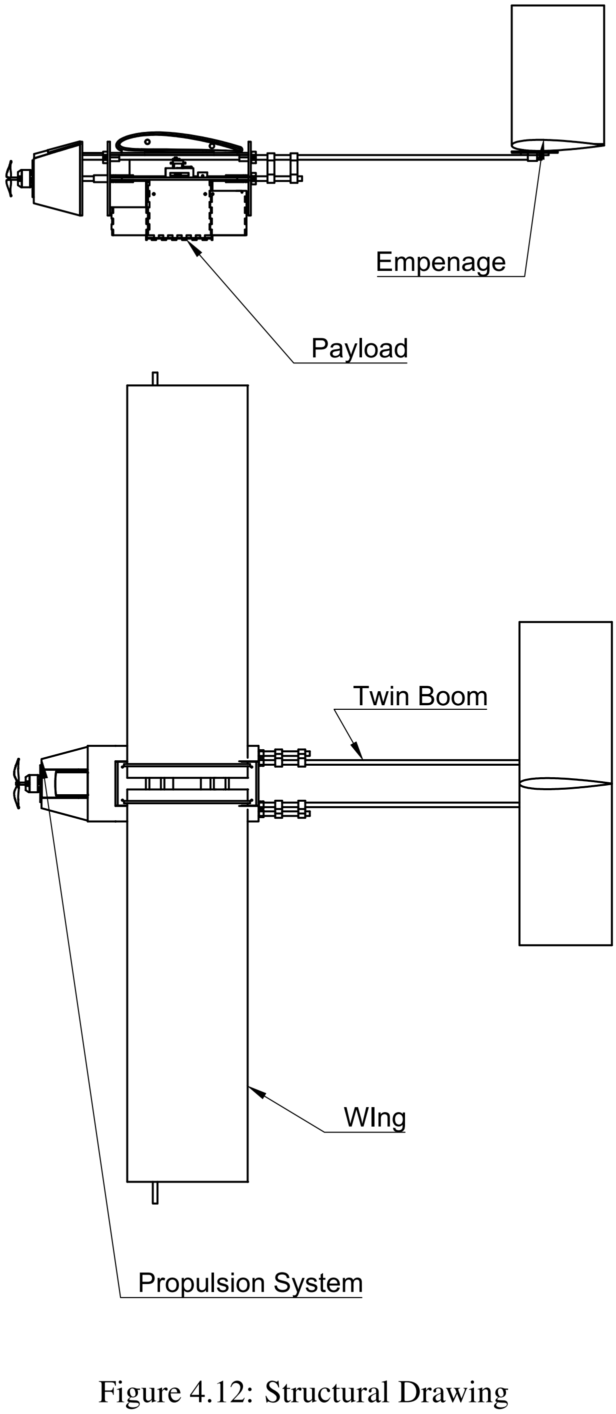

Figure 4.12: Structural Drawing

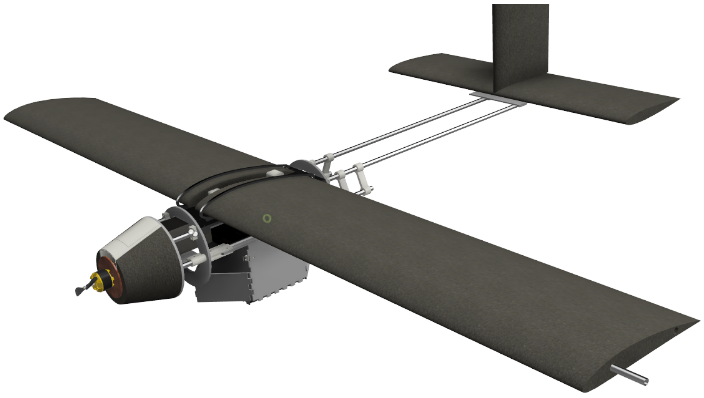

Figure 4.13: CAD Design

4.22 Control Surface Sizing

Control surface sizing stands as a pivotal facet in the intricate realm of aircraft design, necessitating the meticulous determination of dimensions and characteristics for key control surfaces like ailerons, elevators, and rudders. These surfaces, strategically positioned on the wings and tail, play a fundamental role in guiding and managing the aircraft's orientation throughout different flight phases. Ailerons, situated near the wingtips, orchestrate roll control, elevators on the horizontal tail manage pitch adjustments, and the rudder affixed to the vertical tail governs yaw. The significance of control surfaces lies in their ability to respond promptly and effectively to pilot inputs, ensuring maneuverability and stability across the entire operational spectrum of the aircraft.

In the intricate process of sizing control surfaces, engineers grapple with a myriad of considerations, including aerodynamic loads, control effectiveness, and stability requirements. Achieving the delicate balance between providing sufficient authority for maneuvering and minimizing the aerodynamic forces induced by these surfaces is a central challenge. This intricate trade-off demands a comprehensive approach, utilizing computational methods, wind tunnel testing, and sophisticated flight simulations. Through these means, engineers scrutinize and refine the sizing of control surfaces, striving to meet stringent regulatory standards and guarantee a safe and predictable response to pilot commands.

Ultimately, control surface sizing emerges as an integral and interconnected component within the broader aircraft design framework. The challenge lies in harmonizing aerodynamic efficiency, structural considerations, and the imperative for precise and responsive control throughout the entirety of the aircraft's operational envelope. This delicate balance ensures that the aircraft not only complies with regulatory mandates but also delivers optimal performance and safety in diverse operational scenarios.

Table 4.5: Control Surface Parameters

Control Surface	Chord Ratio	Span	Airfoil
Elevator	0.3	0.48 m	NACA 0012
Ailerons	0.3	0.27 m	NACA 4412
Rudders	0.25	0.2 m	NACA 0012

4.23 Motor and Battrey Selection for Mission

The power required for level flight can be estimated using the following equation:

$$P = \frac{1}{2} \times \frac{C_D \times \rho \times S \times V^3}{\eta} \tag{4.26}$$

Where:

- P is the power required (Watts)
- C_D is the coefficient of drag
- ρ is the air density (kg/m^3)
- S is the wing area (m^2)
- V is the airspeed (m/s)
- η is the overall efficiency

So, a motor of 1000 Watt output power can fulfil our mission requirements for cruise speed of 35 m/s.

The mission from Phaplu to Bung Health Post, Mahakulung Rural Municipality is almost 25 kilometers.So, the battrey for 50 kilometers is always required.The motor consumes 1000 watt power in maximum, a battrey should be chosen accordoingly.First, we fix the number of cells i.e. 8 cells that has output voltage of 29.6.So, the maximum current that can be drawn is 33.7 A.Our cruise velocity is 35 m/s. Then, the time required for mission is 22 minutes.So, a battrey of minimum of 12500 mAh is required.

So, the battrey with following specs is chosen.

Table 4.6: Battrey Specs

Specifications	**Values**
Capacity	12000 mAh
Nominal Voltage	8S 29.6 v
Maximum Voltage	33.6 v
Minimum Voltage	24 v
Chemistry	LiPo
Max Continuous Discharge	40 Amps
Watt Hours	236.8 Wh
Energy Density	180 Wh/Kg
Weight	1800 g

CHAPTER 5: RESULT AND DISCUSSION

5.1 Phugoid Mode

The Phugoid Mode, a critical dynamic characteristic in aircraft, manifests as a slow oscillation in altitude and airspeed in response to disturbances like changes in the Angle of Attack. This mode, characterized by a deliberate damping response to minor disturbances, involves a repeating pattern of ascent and descent until disturbances are mitigated. When designing UAVs, careful attention to the lift-to-drag ratio is imperative, as a higher ratio enhances Phugoid Mode stability, while a lower ratio may render the aircraft more susceptible to oscillations. Optimizing this ratio is essential for ensuring the stability of the Phugoid Mode during the design process, as depicted in the provided graph illustrating the fluctuation of pitch angle, angle of attack, and altitude over a 60-second period. Managing the Phugoid Mode is paramount for ensuring safe and efficient flight operations, underscoring the importance of meticulous design considerations for UAVs.

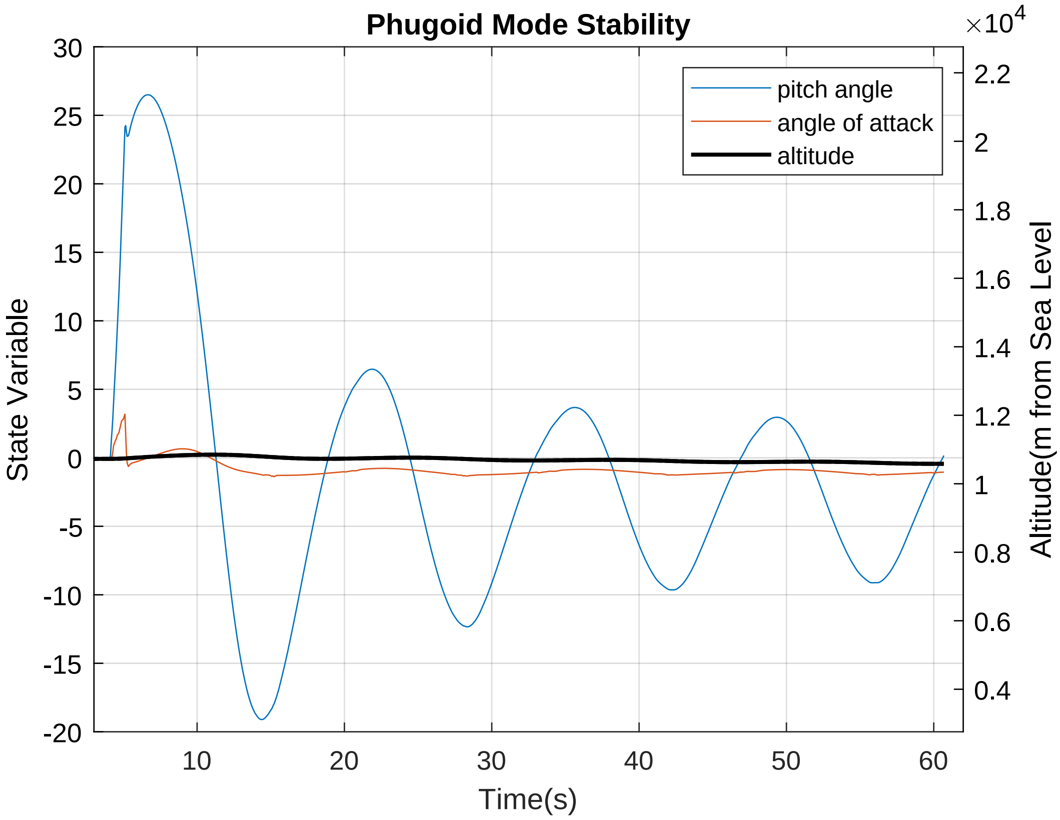

Figure 5.1: Phugoid

5.1.1 Short Period Mode

The "Short Period Mode" in aircraft dynamics involves rapid oscillatory movements along the longitudinal axis, responding to changes in the angle of attack.Analyzing and comprehending the pitch angle variations during the short period mode is instrumental in refining and optimizing control systems, ensuring precise adjustments in stabilizers and elevators for enhanced UAV safety and stability. The above graph of "Short Period Mode Stability" provides a visual depiction of an aircraft's pitch angle over time (0 to 20 seconds). Notable fluctuations between 2 and 6 seconds reveal the initial response to a disturbance, followed by a stabilization period. This graphical representation enhances our understanding of the short period mode's transient nature, guiding the design of stabilizers and elevators to ensure safe and stable flight conditions, ultimately contributing to UAV safety.

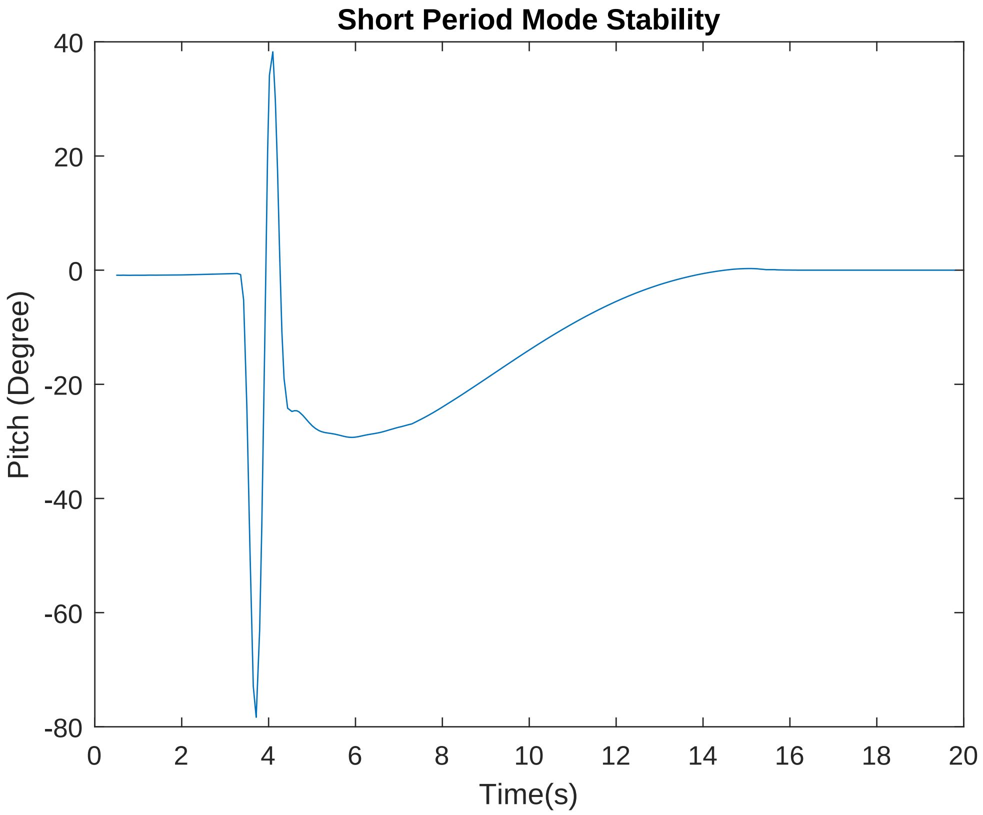

Figure 5.2: Short Period

5.1.2 Dutch Roll

Dutch roll, a specific dynamic response in aircraft, occurs due to conflicting demands on the lateral and directional stability systems. This phenomenon arises when these systems exhibit varying natural frequencies or damping ratios, resulting in a distinctive combination of slow rolling and fast yawing motion. Inconsistencies in stability systems, like a low dihedral angle with a high-authority rudder, coupled with atmospheric conditions such as turbulence, can intensify Dutch roll tendencies. Failure to address Dutch roll can lead to a loss of aircraft control.In the above graph of Dutch Roll Stability x-axis represents time in seconds (ranging from 1 to 7), while the y-axis represents bank angle in degrees (ranging from -20° to 40°). A blue dashed line illustrates the oscillation of an aircraft experiencing a Dutch roll, a type of yawing oscillation typically found in aircraft. The graph shows that the bank angle sharply increases and decreases between the 2nd and 3rd second before stabilizing with minor oscillations. Understanding and managing dutch roll is crucial for maintaining stable flight dynamics

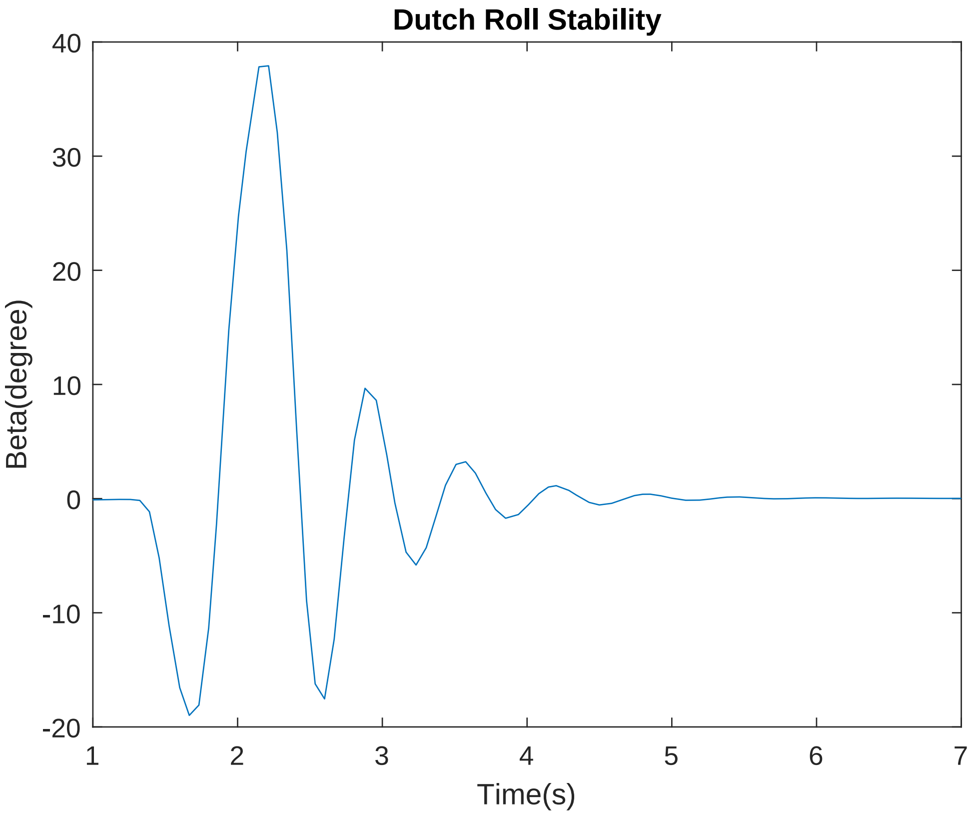

Figure 5.3: Dutch Roll

5.2 Various Flight

The development of an unmanned aerial vehicle (UAV) is a demanding yet enlightening journey, marked by rigorous testing and continuous refinement. Each test flight contributes valuable insights, shaping the path towards a more sophisticated and capable UAV. From initial challenges to structural redesigns, the team's commitment to overcoming obstacles becomes evident, leading to a strategic shift towards adaptability and iterative development.

1. It appears that the first test flight of the vehicle encountered significant challenges, particularly related to the forward shift in the center of gravity and inadequate thrust. These issues highlighted vulnerabilities in the initial design, ultimately resulting in structural damage. In response, there was a need for a thorough

reevaluation of the fabrication materials used, emphasizing the importance of a comprehensive approach for future iterations of the design. This iterative process is crucial for identifying and addressing weaknesses, ensuring the overall improvement and success of the project.

2. As the team delved into the intricacies of the first test flight, it became apparent that a more comprehensive approach was needed for subsequent iterations. The decision to prioritize the replaceability of fabricated parts over a solid, robust structure reflected a strategic shift towards adaptability and iterative development. This approach acknowledges the dynamic nature of UAV design and the importance of quick adjustments and improvements. The second test flight proved to be a critical juncture in the project, highlighting the significance of thorough technical validation. The initial altitude gain, sudden loss, and subsequent crash underscored the importance of precise parameter inputs and the con- sequences of technical oversights.

3. After the Swift correction of the parameter found in second test flight, the errors paved the way for a successful flight, revealing a UAV that not only flew with minimal error but also displayed stability. The third test was done for the straight level flight was successful and following results were obtained.

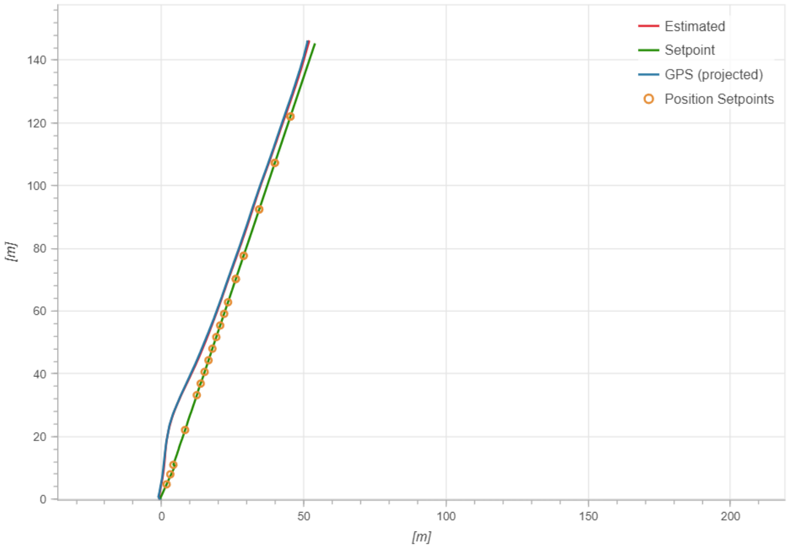

Figure 5.4: Mission given and followed in straight level flight

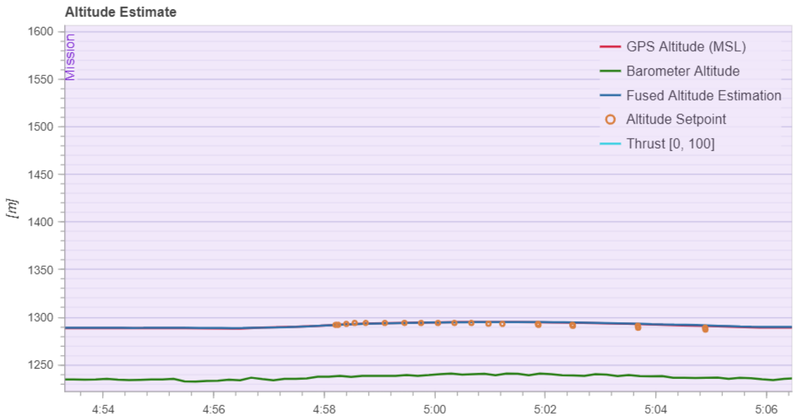

Figure 5.5: Mission given and followed in straight level flight

4. Despite this success, the flight was confined to a linear path, and also the flight time is also less. Also performance metrics prompted the team to scrutinize the design further, leading to the completion of the second structural redesign. While the redesign marked a significant milestone, the decision to conduct another test flight using the initial design demonstrated a commitment to comprehensive testing and a desire to benchmark the performance against the revised structure.

The Fourth test flight, set over the football and cricket ground of IOE Pulchowk Campus, aimed to push the boundaries of autonomy and trajectory. Extending the flight time to approximately 90 seconds, the UAV not only demonstrated its ability to navigate a curved path but also showcased improved endurance and adaptability. The success of this flight validated the iterative approach, proving that the initial design, with its replaceable parts, could be optimized for diverse missions.

Figure 5.6: Curved Mission Path Followed By Aid-Plane

5. The subsequent fifth test flight marked the inaugural flight of the second structural redesign. Even in its maiden voyage, the redesigned UAV exhibited commendable performance. The flight over the specified ground covered a diverse path with minimal error, and the stability demonstrated during the 40-second flight time spoke volumes about the effectiveness of the structural changes. The positive results from the data analysis post this flight further solidified the team's confidence in the project's direction.

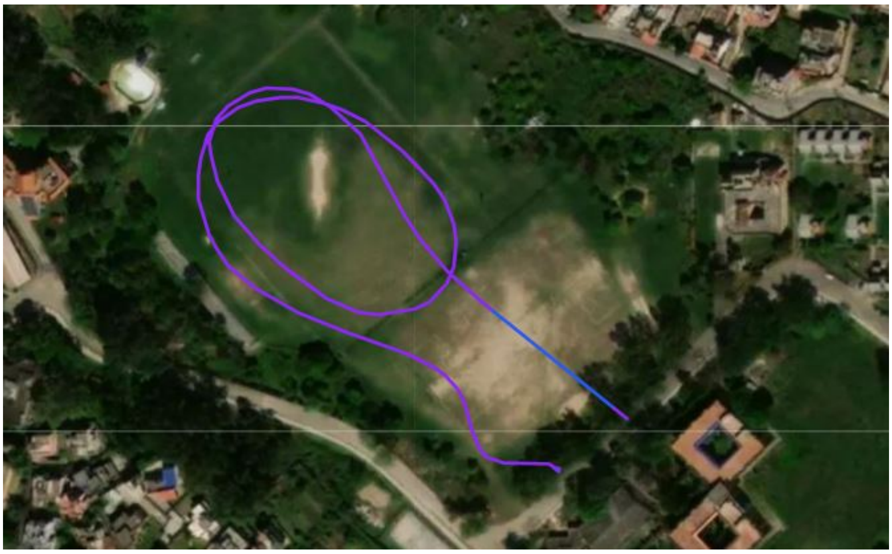

Figure 5.7: Mission Path Followed By UAV In Fifth Test Flight

6. In the pursuit of our objectives, our team set out not only to achieve a successful

UAV flight but also to execute a parachute deployment at a specific location thus our next few flight were related to payload drop and delivery using parachute. The meticulously planned test, conducted at Pulchowk Campus, yielded exceptional results as we successfully dropped the payload with precision, aligning seamlessly with our predetermined goals.

Figure 5.8: Payload Delivery Using Parachute

The iterative process undertaken by the team encapsulates the essence of the scientific method, where each test flight serves as an experiment, contributing to the cumulative knowledge and refinement of the UAV's design. The emphasis on data analysis after each flight is not just a formality but a pivotal step in informed decision-making, shaping the course of subsequent iterations.

As the project advances, it becomes increasingly apparent that success is not just about achieving flight but about achieving flight with specific parameters and meeting predefined objectives. The team's ambition to extend flight times and achieve autonomy in curved paths reflects a commitment to real-world applicability and versatility.The UAV's journey, from a nose-diving first flight to autonomously navigating a curved path, symbolizes a triumph of resilience, adaptability, and continuous improvement. The challenges faced and overcome, the technical errors rectified, and the structural redesigns undertaken are all building blocks contributing to a more sophisticated and capable UAV.

Looking forward, the team is poised to leverage the insights gained from these test flights to inform future designs, potentially incorporating more advanced materials, propulsion systems, and autonomous navigation algorithms. The experience gained from this iterative process not only advances the specific UAV project but also contributes to the broader field of unmanned aerial systems, providing lessons and knowledge that can benefit future endeavors.The UAV's journey through multiple test flights, technical corrections, and structural redesigns epitomizes the spirit of innovation and determination. The team's commitment to learning from setbacks, adapting to challenges, and pushing the boundaries of what the UAV can achieve sets a commendable precedent for the iterative development of cutting-edge technology.

Figure 5.9: Flying Aid-Plane

5.3 Work Completed

5.3.1 Design and Fabrication Process

The initial phase encompassed the comprehensive process of designing, manufacturing, and executing the first test flight. This involved meticulous consideration of potential issues, ensuring a thorough analysis of the UAV's performance. The aim was to address any challenges encountered during the maiden flight and lay the groundwork for subsequent improvements.

5.3.2 Payload Deployment Mechanism

A critical aspect of the UAV's functionality was the payload deployment mechanism. A design incorporating a simple operation utilizing two servos was implemented. The payload box, integral to this mechanism, was intricately crafted to accommodate medical supplies, with a specific focus on factors such as volume and thermal insulation. Figure 5.10 illustrates the design of the payload box.

Figure 5.10: Payload Box

5.3.3 UAV Structure Redesign

In response to the insights gained from the crash landing during the initial flight, a detailed analysis of the encountered problems was conducted. Rather than pursuing an impact-resistant UAV, the team opted for a redesign strategy emphasizing ease of dismantling. This approach enables the disassembly of individual components, facilitating swift replacement in case of flight test failures or structural damage. Figure 5.11 provides a visual representation of the structural redesign.

Figure 5.11: Structural Design

5.3.4 Parachute Fabrication

To enhance the UAV's capabilities, a deploy able parachute was fabricated. Designed with a circular section, the parachute aimed to successfully deliver a payload of approximately 1kg. Through rigorous testing, the parachute deployment was deemed successful, effectively carrying the specified payload weight. The successful integration of this parachute system enhances the versatility of the UAV, opening possibilities for various applications.

5.3.5 Multiple Test Iterations of the First Design

Throughout the development process, multiple test iterations were conducted on the first design. Each test served as a crucial learning opportunity, allowing the team to identify weaknesses and areas for improvement. These iterative tests not only informed subsequent modifications but also contributed to a deeper understanding of the UAV's behavior under different conditions.

5.3.6 Fabrication of the Second Structural Redesign

The culmination of insights gathered from the initial flight and iterative testing prompted the completion of the second structural redesign. This phase involved meticulous attention to the identified issues and an innovative approach to enhance overall structural integrity. The fabrication process adhered to lessons learned from the initial design, focusing on ease of assembly and component replace ability.

5.3.7 Test of the Second Structural Design

The deployment of the UAV equipped with the second structural redesign marked a critical phase in the project. With enhanced structural features, the UAV underwent rigorous testing to evaluate its performance in real-world scenarios. The flight data analysis post this test aimed to validate the effectiveness of the structural redesign, ensuring that the UAV maintained stability and adherence to the designated flight path.

5.4 Limitations

Obstruction in the workflow of the project is majorly caused due to limitations on various factors. Some limitations faced are:

- Undesignated space for a flight test for the UAV.
- Lack of required resources in the market.
- Complexity in Autopilot interface.
- Iterative fabrication after crash landing from flight tests.
- Difficulty in manufacturing due to the limited resources available.

5.5 Problems Faced

- **Technical Challenges:**
    - *Problem:* Difficulty in achieving the desired flight path precision due to unpredictable wind patterns in the hilly region.
- **Autonomous Control System Challenges:**
    - *Problem:*No access to accurate map and location by GPS
- **Unforeseen Technical Hurdles:**
    - *Problem:* Encountered unforeseen technical issues during UAV development, causing delays.
- **Test Zone insufficiency:**
    - *Problem:* The college test field was not vast enough to carry out several flight tests as planned for the UAV.

5.6 Budget Analysis

The cost estimation for the overall project from start to finish is shown in the table below:

Material	Quantity	Rate (Rs)	Cost (Rs)
Pixhawk and its accessories	1	25000	25000
Brushless motor	2	8500	17000
LiPo Battery	1	18000	18000
Battery charger	1	4000	4000
Radio Transmitter and Receiver	1	10000	10000
Styrofoam	NA		4000
Aluminum rods and sheets	NA		3000
Servos	10	500	5000
Materials for insulation	N/A		3000
Travel Cost	NA		5000
Documentation Cost	NA		4000
Tapes and adhesives	NA		4000
Glass fiber and resin	NA		5000
GPS Module	1	10500	10500
Propellers	4	1000	4000
Miscellaneous	NA		1000
Total	-	-	128500

Table 5.1: Cost Estimation

CHAPTER 6: CONCLUSION AND FUTURE ENHANCEMENT

6.1 Conclusion

The journey aimed through the comprehensive phases of UAV design, spanning from conceptualization to realization, has been a testament to the meticulous and systematic approach employed in this project. The initial conceptual phase laid the groundwork for the subsequent stages, as we fine-tuned parameters and constraints, shaped wing characteristics, and constructed a foundational design using the powerful XFLR5 software. This iterative process, with a keen focus on achieving optimal lift coefficients, moment coefficients, and lift-to-drag ratios, proved instrumental in shaping a UAV design that not only met but exceeded expectations.Moving into the preliminary design phase, the integration of SolidWorks and Fusion360 facilitated the development of an internal structure that embodied precision and efficiency. The subsequent testing in X-plane provided invaluable insights, serving as a crucial bridge between the virtual and physical realms. Success in flight tests marked a pivotal point in the project, affirming the validity of our design choices and ushering in the fabrication and assembly of individual components to bring the UAV model to life.

The implementation of XFLR5 software in the design process was a cornerstone, offering a robust platform for testing and refining the UAV's stability and functionality. Results from this software-driven testing revealed not only longitudinal stability but also a well-defined center of gravity range and optimal payload placement, critical for ensuring stable flight. The incorporation of a conventional configuration, including a tail and payload compartment with parachute deployment capabilities, showcased the versatility and safety measures embedded in the UAV design.As we conclude this project, it stands as a testament to the collaborative effort, innovative thinking, and technological prowess that underpin UAV design. The success achieved thus far provides a strong foundation for future endeavors, setting a high standard for the potential applications of XFLR5 in crafting efficient and stable UAVs across various domains. This journey has not only unveiled the intricacies of UAV design but has also opened doors to continuous improvement and exploration of new frontiers in unmanned aerial vehicle technology.

Table 6.1: Flight Test Results and Conclusion

N	Test Flight Date	Result	Conclusion
1	2024/01/16	Failure in Takeoff	Due to the cg placement forward of the static margin, the aircraft nose dived at the Takeoff phase and took major damages to the wing and tail structures.
2	2024/01/26	Flight test taken	A straight flightpath was planned for the UAV which was completed without any issues.
3	2024/01/30	Flight test taken for stability	A circular flight path with a radius of 50m was planned which the aircraft took successfully, yet landing failed as the UAV overshot the landing spot and crashed with minor damages.
4	2024/02/15	Flight test taken for Loiter and Altitude gain	The UAV successfully initiated the loiter phase where it gained an altitude of 10m, but the landing failed and the UAV overshot and crash landed with major damages to the wing and fuselage.
5	2024/02/20	Failure in the flight test for payload delivery	The UAV failed to takeoff as it initiated the Takeoff phase before the motor provided sufficient thrust.
6	2024/02/25	Flight test for Payload delivery	The UAV took a successful flight but failed to deliver the package due to minor damages faced by the payload compartment during the Takeoff phase.
7	2024/03/02	Flight test Failure	The UAV failed to takeoff due to an issue in the Autopilot parameter of maximum takeoff altitude.
8	2024/03/05	Payload delivery test	The UAV took flight and dropped the payload through a parachute from a height of around 20m.

6.2 Future Enhancement

- Study and collection of terrain data of health posts of Nepal can be done to implement path optimization software for delivery.
- Implementation of catapult takeoff and arrested landing to address the high number of crashes during takeoff and landing adds sugar in the project.
- Real time condition monitoring to dropping the payload advances the project.
- Development and application of collision avoidance system revamp the project.

References

Timothy Amukele, Paul M Ness, Aaron AR Tobian, Joan Boyd, and Jeff Street. Drone transportation of blood products. *Transfusion*, 57(3):582–588, 2017.

Reg Austin. *Unmanned aircraft systems: UAVS design, development and deployment*. John Wiley & Sons, 2011.

Victor Cohen, Samantha P Jellinek, Leftherios Teperikidis, Elliot Berkovits, and William M Goldman. Room-temperature storage of medications labeled for refrigeration. *American Journal of Health-System Pharmacy*, 64(16):1711–1715, 2007.

Jaime del Cerro, Christyan Cruz Ulloa, Antonio Barrientos, and Jorge de León Rivas. Unmanned aerial vehicles in agriculture: A survey. *Agronomy*, 11(2):203, 2021.

Mohammed El Adawy, Elhassan H Abdelhalim, Mohannad Mahmoud, Ibrahim H Mohamed, Mostafa M Othman, Gehad S ElGamal, Yahia H ElShabasy, et al. Design and fabrication of a fixed-wing unmanned aerial vehicle (uav). *Ain Shams Engineering Journal*, 14(9):102094, 2023.

Ghozali S Hadi, Rivaldy Varianto, Bambang Riyanto, and Agus Budiyono. Power and autonomous system in uav for payload dropping mission. In *Proceedings of International Conference on Intelligent Unmanned Systems*, volume 10, 2014.

Theo W Knacke. *Parachute recovery systems: design manual*. Para Pub., 1992.

Vasile Prisacariu. Analysis of uavs flight characteristics. *Review of the Air Force Academy*, (3):29–36, 2018.

Raquel Remington, Ramon Cordero, Larry March, and Daniel Villanueva. Multipurpose aerial drone for bridge inspection and fire extinguishing. *Unpublished Thesis). Florida International University. Retrieved April*, 10:2016, 2014.

Giulio Romeo, Giacomo Frulla, and Enrico Cestino. Design of a high-altitude long-endurance solar-powered unmanned air vehicle for multi-payload and operations. *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, 221(2):199–216, 2007.

James C Rosser Jr, Vudatha Vignesh, Brent A Terwilliger, and Brett C Parker. Surgical and medical applications of drones: A comprehensive review. *JSLS: Journal of the Society of Laparoendoscopic Surgeons*, 22(3), 2018.

Mohammad H Sadraey. *Design of Unmanned Aerial Systems*. John Wiley & Sons, 2020.

Darren Sawicz. Hobby servo fundamentals. *Acesso em*, 12:292–302, 2001.

Pravesh Malla Shankar Shah, Mandeep Prasad Bhandari. Design and fabrication of autonomous fixed-wing uas for medical supplies delivery, 2023.

Rohan Pratap Singh and Akash Garg. Autonomous payload drop system using mini unmanned aerial vehicles.

SP Singh, Gary Burgess, and Jay Singh. Performance comparison of thermal insulated packaging boxes, bags and refrigerants for single-parcel shipments. *Packaging Technology and Science: An International Journal*, 21(1):25–35, 2008.

Sham Tickoo. *CATIA V5-6R2018 for designers*. Cadcim Technologies, 2018.

J Wim Wegereef and Henk W Jentink. Modular approach of precision airdrop system spades. In *19th AIAA Aerodynamic Decelerator Systems Technology Conference and Seminar*, page 2547, 2007.

References

Timothy Amukele, Paul M Ness, Aaron AR Tobian, Joan Boyd, and Jeff Street. Drone transportation of blood products. *Transfusion*, 57(3):582–588, 2017.

Reg Austin. *Unmanned aircraft systems: UAVS design, development and deployment*. John Wiley & Sons, 2011.

Victor Cohen, Samantha P Jellinek, Leftherios Teperikidis, Elliot Berkovits, and William M Goldman. Room-temperature storage of medications labeled for refrigeration. *American Journal of Health-System Pharmacy*, 64(16):1711–1715, 2007.

Jaime del Cerro, Christyan Cruz Ulloa, Antonio Barrientos, and Jorge de León Rivas. Unmanned aerial vehicles in agriculture: A survey. *Agronomy*, 11(2):203, 2021.

Mohammed El Adawy, Elhassan H Abdelhalim, Mohannad Mahmoud, Ibrahim H Mohamed, Mostafa M Othman, Gehad S ElGamal, Yahia H ElShabasy, et al. Design and fabrication of a fixed-wing unmanned aerial vehicle (uav). *Ain Shams Engineering Journal*, 14(9):102094, 2023.

Ghozali S Hadi, Rivaldy Varianto, Bambang Riyanto, and Agus Budiyono. Power and autonomous system in uav for payload dropping mission. In *Proceedings of International Conference on Intelligent Unmanned Systems*, volume 10, 2014.

Theo W Knacke. *Parachute recovery systems: design manual*. Para Pub., 1992.

Vasile Prisacariu. Analysis of uavs flight characteristics. *Review of the Air Force Academy*, (3):29–36, 2018.

Raquel Remington, Ramon Cordero, Larry March, and Daniel Villanueva. Multipurpose aerial drone for bridge inspection and fire extinguishing. *Unpublished Thesis). Florida International University. Retrieved April*, 10:2016, 2014.

Giulio Romeo, Giacomo Frulla, and Enrico Cestino. Design of a high-altitude long-endurance solar-powered unmanned air vehicle for multi-payload and operations. *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, 221(2):199–216, 2007.

James C Rosser Jr, Vudatha Vignesh, Brent A Terwilliger, and Brett C Parker. Surgical and medical applications of drones: A comprehensive review. *JSLS: Journal of the Society of Laparoendoscopic Surgeons*, 22(3), 2018.

Mohammad H Sadraey. *Design of Unmanned Aerial Systems*. John Wiley & Sons, 2020.

Darren Sawicz. Hobby servo fundamentals. *Acesso em*, 12:292–302, 2001.

Pravesh Malla Shankar Shah, Mandeep Prasad Bhandari. Design and fabrication of autonomous fixed-wing uas for medical supplies delivery, 2023.

Rohan Pratap Singh and Akash Garg. Autonomous payload drop system using mini unmanned aerial vehicles.

SP Singh, Gary Burgess, and Jay Singh. Performance comparison of thermal insulated packaging boxes, bags and refrigerants for single-parcel shipments. *Packaging Technology and Science: An International Journal*, 21(1):25–35, 2008.

Sham Tickoo. *CATIA V5-6R2018 for designers*. Cadcim Technologies, 2018.

J Wim Wegereef and Henk W Jentink. Modular approach of precision airdrop system spades. In *19th AIAA Aerodynamic Decelerator Systems Technology Conference and Seminar*, page 2547, 2007.

APPENDIX

Listing 6.1: Maximum Take-off Weight Estimation

```
%Payload Weight
Wpl=1;%weight in kg
%Autopilot Weight
Wap=0.04;
%Calculation of Battrey Weight Ratio
Ed=140*3600; % Energy density Wh/kg
R=64000; % Range in meters
mu=0.85; %prop efficiency
CL_CD =13; % aerodynamic efficiency
g=9.81; % Acceleration due to gravity in m/s^2
% Calculate battery weight ratio
Wb_Wto =(1.05 /(mu*CL_CD))*((R*g)/Ed);

%Empty Weight Ratio
We_Wto=0.76;

% Define the equation
syms Wto
eqn = Wto - (Wap + Wpl) / (1 - Wb_Wto -We_Wto) == 0;

% Solve the equation using solve
solution = solve(eqn, Wto);

% Filter the solutions to keep only positive values
```

```
    greater than one
MTOW = double(solution(solution > 1));
```

Listing 6.2: Matching Plot

```
V_s = 12; % stall speed (m/s)
V_c = 30; % cruise speed (m/s)
V_max = 35; % maximum speed (m/s)
V_to = 11.05; % take-off speed, m/s
h_C = 3300; % Normal service altitude (m)
h_ac =3500; % Absolute ceiling altitude, m
Cl_max = 1.2; % Maximum lift coefficient
e = 0.8; % Oswald efficiency factor
AR = 6.4; % Wing aspect ratio
K = 0.062; % Calculated induced drag coefficient
g = 9.81; % Gravitational acceleration, m/s^2
Cd_0 = 0.0245; % Zero lift-drag coefficient
Cd_0_to = 0.0835; % Zero lift-drag coefficient at take-
    off
Cl_to = 0.85; % UAV lift coefficient at take-off
Cd_to = 0.10747; % UAV drag coefficient at take-off
Cd_g = 0.03947; % Coefficient
Cl_r = Clto; % Lift coefficient at take-off rotation
nu = 0.04; % Drag coefficient for runway
S_to =17; % Takeoff length
rhos_l = 1.225; % Air density at sea level
rho_c = 0.86; % Air density at a cruise altitude of 3100
    m above sea level
rho_ac = 0.82; % Air density at absolute ceiling altitude
mup = 0.55; % Prop efficiency coefficient at take-off
mup_ac = 0.8; % Prop efficiency coefficient at cruising
    altitude
LD_max = 10; % Aerodynamic efficiency
```

```
ROC_AC = 0; % ROC at absolute ceiling(m/s)
ROC_SC = 0.5; % ROC at service ceiling (m/s)
ROC_CrC = 1.5; % ROC at cruise ceiling (m/s)
% Stall speed.
WS = 1/2*rhos_l*Vs^2*Clmax;
x1 = WS;
x2 = WS;
y1 = 0;
y2 = 1.5;
plot([x1,x2],[y1,y2],'g')

axis([0 150 -0.5 1.5])
xlabel('W/S,␣N/m^2')
ylabel('W/P,␣N/W')
grid on
hold on
% Maximum speed.
WS_ms = 0:2:150;
WP_vmax = mup_ac./((0.5*rhosl*V_max^3*Cd_0./WS_ms)+(((2*K
    )./(rho_c*(rho_c/rhos_l)*V_max)).*WS_ms));
plot(WS_ms,WP_vmax,'r')

% Take-off run
WP_sto = (((1-exp(0.6*rhos_l*g*Cd_g*Sto)./WS_ms))./(nu-(
    nu+Cd_g/C_lr).*(exp(0.6*rhos_l*g*Cd_g*Sto)./WS_ms))).*(
    mup/V_to);
plot(WS_ms,WP_sto,'b')

% Rate of Climb
WP_roc = 1./(3.6363+(sqrt(1.0969.*WS_ms)*0.1826));
plot(WS_ms,WP_roc,'k')
```

```
% Cruise ceiling
WP_slc = (rhoc/rhosl)./((ROC_CrC/mup_ac)+sqrt((2/(rho_c*
    sqrt(3*Cd0/K)))*WS_ms)*(1.115/(LDmax*mupac)));
plot(WS_ms, WP_slc, 'c')


%Design Point
[xint, yint] = polyxpoly([x1, x2], [y1, y2], WS_ms, WP_vmax);
plot(xint, yint, 'ok')
legend('Stall␣speed', 'Maximumspeed', 'Take-off␣run', 'Rate␣
    of␣climb', 'Cruise␣celling', 'Design␣point');
```