Design, Analysis and Model Fabrication of Hybrid solar powered fixed wing UAV

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2023

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A Project Report Submitted to the Department of Mechanical Engineering in partial fulfilment of the requirements for the degree of Bachelor of Science in Mechanical Engineering

Faculty of Mechanical Engineering
National University Technology,
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March, 2023

BSME	**Mudassir, Shariq, Usaid**	**2023**

CERTIFICATE OF APPROVAL

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ACKNOWLEDGMENT

All the acclamation and appreciation are for Almighty ALLAH who created the universe and bestowed humanity with knowledge and wisdom to search for its secrets. The Team feels immense pleasure and honor to express our deepest sense of gratitude, sincere feelings and regards to our supervisor Dr. Waheed Gul for his efficient guidance, tremendous help, and distinct way of advice for the completion of my studies. The Team would also like to extend our special thanks to Engr. Khubaib, Engr. Wahaj Rafique, for their encouragement and support.

DEDICATED

TO

OUR PARENTS

Abstract

The use of unmanned aerial vehicles (UAVs) has been increasing rapidly in recent years, with a variety of applications ranging from military operations, surveillance, and monitoring to agricultural and environmental research. However, one of the major limitations of conventional UAVs is their limited flight duration due to the reliance on traditional fuels. This limitation has led to increased interest in developing alternative, environmentally friendly power sources for UAVs, such as solar energy. This project presents the design, analysis, and model fabrication of a hybrid solar-powered fixed-wing unmanned aerial vehicle (UAV). The proposed UAV design incorporates both solar cells and rechargeable batteries, allowing it to fly during the day and recharge the battery for night-time flight provide sustainable and uninterrupted flight operations. The design process includes the selection of the airframe, propulsion system, and solar cells to optimize the performance of the UAV. The structural analysis of the airframe is conducted using Finite Element Analysis (FEA) software to ensure adequate strength and rigidity. The propulsion system is selected based on the desired flight characteristics of the UAV, while the solar cells are integrated into the wings to maximize power generation. The fabrication process involves the use of laser CNC cutting, as well as 3D printing technology to create the airframe and the integration of off-the-shelf components to complete the system. Finally, the performance of the hybrid solar-powered fixed-wing UAV is evaluated through flight tests, and the results show that the UAV can achieve sustained flight with extended endurance. The study involves the design and analysis of the aerodynamics of the UAV, the selection and integration of solar cells and battery systems, and the construction and testing of the final prototype. The results of the study provide insight into the practical feasibility of hybrid solar-powered fixed-wing UAVs, and their potential to contribute to sustainable and environmentally friendly aviation. The proposed design has potential applications in various fields, including environmental monitoring, precision agriculture, and disaster management.

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Chapter 1

INTRODUCTION

Renewable Energy technologies have become an increasingly key area of research in recent years, due to their potential to address some of the world's most pressing challenges, as part of the global effort to reduce greenhouse gas emissions and combat climate change. Solar energy, in particular, has become an increasingly popular alternative to traditional energy sources, due to its sustainability and abundant availability. Solar energy has numerous applications, including power generation for homes, businesses, and transportation, and also in the field of aerospace engineering. Thus, has emerged as a highly promising and versatile source of clean energy. Unmanned aerial vehicles (UAVs) are one of the many fields where the potential of solar energy is being explored. UAVs have been rapidly evolving and expanding their application areas in recent years, and solar-powered UAVs have become an area of active research. Unmanned aerial vehicles (UAVs) have revolutionized many industries in recent years, providing cost-effective and efficient solutions for tasks such as surveillance, monitoring, and environmental research. However, one of the major challenges of UAVs is their limited flight duration, which is often due to their reliance on traditional fuels. This limitation has led to increased interest in developing alternative, environmentally friendly power sources for UAVs, such as solar energy. This final year project focuses on the design, analysis, and fabrication of a hybrid solar-powered fixed-wing UAV. The aim of the project is to develop a UAV that can operate for extended periods without requiring traditional fuel, making it more sustainable and environmentally friendly. The use of solar energy in UAVs has the potential to extend their range and endurance, making them more useful in a range of tasks, The project involves several key stages, including the design and analysis of the UAV's aerodynamics, the selection and integration of solar cells and battery systems, and the fabrication and testing of the final prototype. The research will also evaluate the practical feasibility of hybrid solar-powered fixed-wing UAVs and their potential contribution to sustainable aviation. The interdisciplinary nature of the project provides an excellent opportunity for students from various fields of study, including mechanical engineering, aerospace engineering, electrical engineering, and materials science, to work together to develop an innovative solution to an important problem. The project will also allow students to develop a range of practical skills, including design, analysis, manufacturing, and testing, as well as an understanding of the broader societal implications of their work. In summary, this final year project represents an exciting opportunity for students to work on an innovative project with real-world applications. The development of a hybrid solar-powered fixed-wing UAV has the potential to contribute to sustainable aviation, making it an important and timely project for students who are interested in the intersection of technology, sustainability, and innovation.

1.1 Parameters of the hybrid solar powered fixed wing UAV

1.1.1 Payload capacity:

Payload capacity is typically expressed in terms of weight, and may include items such as cameras, sensors, communication equipment, or other devices used for data collection or transmission. To determine the maximum payload capacity of a UAV, designers must take into account the weight of the payload, as well as the weight and balance of the aircraft itself, to ensure that the UAV can safely and effectively carry the desired payload without compromising its flight performance or stability. In addition, designers must also consider the intended use and operating conditions of the UAV, as well as any regulatory requirements or limitations, when determining the optimal payload capacity for a given application. For our model and application with set this to 500 grams

1.1.2 Altitude:

Altitude is an important parameter as it determines the flight envelope and operational capabilities of the aircraft. UAVs can fly at various altitudes, from a few meters above the ground to several thousand meters in the air. The altitude at which a UAV operates depends on the mission requirements and the capabilities of the aircraft. For example, a UAV used for aerial surveying or mapping may fly at a higher altitude to cover a larger area, while a UAV used for surveillance or reconnaissance may fly at a lower altitude to capture more detailed images or video. The altitude of a UAV is measured using GPS sensors onboard the aircraft. For the purpose of this project keeping in mind the application along with other parameters was set at **300 meters**

1.1.3 Speed:

The speed of a fixed wing UAV can vary depending on a variety of factors, including the size and shape of the aircraft, the type of propulsion system used, and the flight conditions in which it is operated. In general, fixed wing UAVs are designed to operate at relatively low speeds compared to manned aircraft, with typical cruising speeds ranging from around 20-50 meters per second. However, some high-performance UAVs may be capable of speeds of up to 100 meters per second or more. The optimal speed for a fixed wing UAV will depend on a variety of factors, including its intended use and the requirements of the mission. For example, a UAV used for aerial mapping or surveying may need to fly at a relatively low and consistent speed to ensure accurate data collection, while a UAV used for surveillance or search and rescue may need to be able to cover a large area quickly and efficiently. Ultimately, the speed of a fixed wing UAV will depend on a complex interplay of design, aerodynamics, and operating conditions, and will need to be carefully optimized to ensure safe and effective operation in a wide range of applications. For the purpose of this project keeping in mind the size, application along with other parameters was set at **15 meters per second**.

1.2 UAV System Components:

The components for the fixed wing UAV system can be grouped into one of three categories:

1.2.1 Fuselage:

The fuselage is the main body of an aircraft that houses the batteries, controllers, payload, along with various other components. It is typically cylindrical or oval in shape and is designed to provide structural support to the wings, tail, and engines. The fuselage is made up of several structural components, which work together to distribute the loads and stresses experienced by the aircraft during flight. The materials used to construct the fuselage vary depending on the type of aircraft and its intended use. The shape of the fuselage affects the drag and lift characteristics of the aircraft, while the materials used affect the weight and structural integrity. Overall, the fuselage plays a crucial role in the performance and safety of an aircraft, and its design and construction require careful consideration of various factors.

1.2.2 Actuator:

Actuators are motors and mechanisms that provides the necessary forces to move the mechanical structure. In the UAV, servo motors are used as they are lightweight, give a high power-to-weight ratio, give closed-loop feedback, and give good torque at high speeds. This power is further transferred by means of cable and rods in order to transfer power from one plane to another, to control the control surfaces.

1.2.3 Flight Controller:

A flight controller is a device that is used to control the flight of an aircraft, including unmanned aerial vehicles (UAVs). It is a critical component that manages the aircraft's stability and controls its movement, using various sensors to detect and adjust for changes in altitude, speed, and orientation. The flight controller typically uses a combination of hardware and software to operate the aircraft. The hardware components include sensors such as accelerometers, gyroscopes, barometers, and magnetometers, which provide information on the aircraft's orientation, altitude, and speed. The software components include algorithms that process this information and control the aircraft's motors to maintain stability and adjust its movement. The flight controller can be programmed with different flight modes, which allow the pilot to adjust the aircraft's behaviour and performance based on the specific mission requirements. For example, a flight controller for a UAV may have flight modes for auto-stabilization, altitude hold, GPS navigation, and even autonomous flight. the flight controller is a critical component of a UAV and requires careful consideration in its selection and installation. Factors such as the number of channels, the range of features, and the level of programming customization should all be taken into account. Additionally, proper calibration and testing are required to ensure that the flight controller is operating correctly and providing reliable and accurate flight control. Overall, the flight controller is a key component of a UAV's operation, providing stability and control during flight. Its selection and installation require careful consideration to ensure that the UAV is operating at optimal performance and meeting the requirements of the specific mission.

1.2.4 Charge controller:

A charge controller is an electronic device used in solar power systems to manage and regulate the flow of electrical energy between the solar panel array and the battery bank. Its primary function is to ensure that the battery is charged properly and not overcharged or undercharged, which can damage the battery and reduce its lifespan. The charge controller monitors the battery's voltage and adjusts the charging rate accordingly to prevent overcharging or undercharging. It also prevents reverse current flow from the battery back to the solar panels during periods of low sunlight or at night when the panels are not producing any energy. There are two main types of charge controllers: PWM (pulse width modulation) and MPPT (maximum power point tracking). PWM charge controllers are less expensive and less efficient than MPPT charge controllers. MPPT charge controllers are more efficient and can increase the energy output of the solar panel array by up to 30%. Charge controllers are an important component of a solar power system, and their selection and installation require careful consideration. Factors such as the size of the solar panel array, the battery voltage and capacity, and the climate and temperature conditions in the area should be taken into account.

Additionally, proper calibration and monitoring are required to ensure that the charge controller is operating correctly and providing reliable and safe charging of the battery bank. Overall, a charge controller is an essential component of a solar power system that ensures the proper charging and maintenance of the battery bank and can help to maximize the energy output and efficiency of the system.

1.2.5 Photovoltaic cell:

Solar cells, also known as photovoltaic cells, are electronic devices that convert sunlight into electricity. They are made up of silicon or other semiconducting materials that absorb photons of light energy and release electrons, which can be harnessed to produce electrical power. When light energy from the sun hits the solar cells, it creates an electrical field across the layers of the cell, causing a flow of electrons. This flow of electrons can be captured and converted into electrical energy that can be used to power a variety of devices. Solar cells are widely used in solar panels, which are used to generate electricity for a wide range of applications, including residential and commercial buildings, industrial processes, and even spacecraft. They are also used in portable devices such as calculators, watches, and other small electronic devices. The efficiency of solar cells can vary depending on the type of material used and the quality of the manufacturing process. High-quality solar cells can convert up to 22% of the sunlight that hits them into usable electrical power. However, most solar cells typically have an efficiency of around 15-20%. The installation and use of solar cells requires careful consideration of factors such as the size of the solar panel array, the orientation of the panels, and the climate and temperature conditions in the area. Additionally, regular maintenance and cleaning are required to ensure that the solar cells are operating at optimal efficiency. Overall, solar cells are a critical component of solar power systems, providing a clean and renewable source of energy that can be used to power a wide range of applications. Their development and advancement continue to play a crucial role in the transition towards sustainable energy sources.

1.2.6 Wings:

In the design and fabrication of a hybrid solar-powered fixed-wing UAV, the wings are a critical component that enables the aircraft to generate lift and sustain flight. The wings for this project need to be designed to optimize the aircraft's performance in terms of speed, altitude, and endurance. The wings need to be constructed from lightweight, high-strength materials, which will help to reduce the weight of the aircraft and increase its manoeuvrability. The wing shape and size will need to be calculated and designed to provide the right amount of lift and reduce drag. To optimize the aircraft's performance, the wings may be equipped with a range of aerodynamic features such as winglets or vortex generators that can help to reduce drag and increase stability in flight. The wings may also be designed with an air foil shape that provides optimal lift and reduces drag. In addition, to support the hybrid solar-powered system, the wings may be fitted with solar panels that can provide additional power to the aircraft's systems. These solar panels will need to be carefully positioned and designed to avoid adding excess weight and reducing the overall aerodynamic performance of the aircraft. The design and fabrication of the wings for a hybrid solar-powered fixed-wing UAV is a complex process that requires careful consideration of a range of factors, including materials, aerodynamics, and the hybrid solar-powered system. The final design must strike a balance between optimizing the aircraft's performance while also accommodating the necessary solar panels and other components required for the hybrid system.

1.2.7 Electronics:

GPS module: GPS (global positioning system) module is an essential component that enables the aircraft to determine its location and navigate to a specific destination. The GPS module works by receiving signals from a network of satellites orbiting the earth, which provide precise location and timing information. The GPS module on the aircraft can process this information to determine the aircraft's current position, altitude, speed, and heading. The GPS data can also be used to program the aircraft's flight path and control systems, allowing the aircraft to navigate autonomously to a specific location. The GPS module needs to be designed to be accurate, reliable, and capable of operating in challenging environmental conditions, such as high altitude or extreme temperatures. The GPS module must also be integrated into the aircraft's control systems and software to ensure that it provides seamless and precise navigation information to the aircraft

Transmitter: transmitter is a critical component that enables communication between the aircraft and its ground station. The transmitter is responsible for sending telemetry data from the aircraft, such as altitude, speed, and battery status, back to the ground station for monitoring and analysis. In addition, the transmitter allows the ground station to send commands to the aircraft's control systems, such as adjusting the aircraft's flight path or initiating a landing. The transmitter must be designed to be reliable, robust, and capable of transmitting signals over long distances, even in challenging environments.

Receiver: a receiver is a critical component that receives signals from the aircraft's transmitter and enables communication between the ground station and the aircraft. The receiver is responsible for decoding the telemetry data sent by the aircraft and displaying it in a meaningful way for the ground station operators. The receiver also receives commands from the ground station, such as adjusting the aircraft's flight path or initiating a landing and sends them to the aircraft's control systems as well as to transmit video back down to the ground operator.

Electronic speed controller (esc): an electronic speed controller (esc) is a critical component in the design of a hybrid solar-powered fixed-wing UAV. It is responsible for controlling the speed and direction of the electric motor that drives the aircraft's propeller. The esc regulates the amount of current that is delivered to the motor, controlling its speed and direction of rotation. The esc receives signals from the aircraft's flight controller, which adjusts the motor speed and direction based on the aircraft's position and orientation. The esc must be designed to be reliable, robust, and capable of operating in challenging environmental conditions, such as high altitude or extreme temperatures. The esc needs to be matched to the motor to ensure that it provides the correct amount of power to drive the propeller efficiently and at the desired speed. It must also comply with relevant regulations and standards for electromagnetic compatibility and safety. The design and implementation of a suitable esc for a hybrid solar-powered fixed-wing UAV requires expertise in electronics, programming, and motor control systems. The esc must be carefully calibrated and tested to ensure that it provides reliable and safe control over the motor and propeller.

Surveillance: for surveillance purposes camera modules are an important component in the design of a hybrid solar-powered fixed-wing UAV. They allow the aircraft to capture high-quality images and video during flight for a variety of applications, such as mapping, surveying, surveillance, or scientific research. Camera modules typically consist of an image sensor, a lens, and control electronics, and can vary in resolution, field of view, and image quality. The choice of camera module depends on the specific requirements of the project. For example, if the aircraft needs to capture high-resolution images of a large area, a wide-angle camera module may be used, while for tasks that require more detailed images, a module with a higher resolution and narrower field of view may be required. The camera module must also be lightweight, compact, and low power to minimize the impact on the aircraft's overall weight and power consumption. The camera module must be carefully integrated into the aircraft's design, ensuring that it is securely mounted and pointing in the desired direction. The camera's data can be stored on the aircraft or transmitted to the ground station for further processing and analysis. Infrared or thermal imaging cameras, which can detect and capture images in low-light or no-light conditions. Infrared cameras detect the heat signatures of objects and convert them into an image, while thermal imaging cameras detect temperature differences and create an image based on the heat distribution of the scene. These types of cameras can be useful for detecting and identifying objects in the dark, such as people or vehicles, and for monitoring thermal activity, such as the spread of a wildfire, night imaging cameras can be integrated into the design of the hybrid solar-powered fixed-wing UAV, and they must be carefully calibrated and tested to ensure that they provide reliable and accurate images. They must also be lightweight, compact, and low power to minimize the impact on the aircraft's overall weight and power consumption. The design and implementation of suitable night imaging cameras for a hybrid solar-powered fixed-wing UAV require expertise in imaging technology, electronics, and software development, as well as a deep understanding of the requirements of the specific application.

1.2.8 Batteries:

Batteries are a critical component in the design of a hybrid solar-powered fixed-wing UAV, as they store the energy generated by the solar panels and provide power to the aircraft's electrical systems and motors. The batteries must be lightweight, compact, and capable of storing and delivering a large amount of energy while also being safe and reliable. The choice of battery depends on the specific requirements of the project, such as the desired flight time, weight, and power consumption of the aircraft. Lithium polymer (lipo) batteries are commonly used in UAVs, as they provide a high energy density and can be customized to meet specific requirements. Other types of batteries, such as nickel-metal hydride (nimh) and lithium-ion (li-ion), may also be suitable depending on the application. The batteries must be carefully integrated into the aircraft's design, ensuring that they are securely mounted and do not affect the center of gravity or flight characteristics of the aircraft. The charging and discharging of the batteries must be carefully controlled to prevent damage or overheating, which can pose a safety risk to the aircraft and its surroundings. The design and implementation of suitable batteries for a hybrid solar-powered fixed-wing UAV requires expertise in battery technology, electronics, and system integration. The batteries must be tested and calibrated to ensure that they provide reliable and safe power to the aircraft's systems, enabling it to fly efficiently and achieve its intended mission.

1.2.9 Propulsion:

Propulsion is a critical aspect of the design of a hybrid solar-powered fixed-wing UAV, as it provides the necessary thrust to overcome drag and keep the aircraft aloft. The choice of propulsion system depends on the specific requirements of the project, such as the aircraft's weight, speed, and endurance. Electric motors are commonly used in UAVs, as they are lightweight, efficient, and easy to control. Brushless dc motors are the most common type of electric motor used in UAVs, as they provide high efficiency and power output. The motor is connected to a propeller or a fan, which converts the rotary motion of the motor into forward thrust. The motor is powered by a battery, which can be charged by the solar panels on the aircraft. The battery must be carefully sized to provide enough power to the motor for the desired flight time and range.

Overview:

Project proposed in this case involves the design, analysis, and model fabrication of a hybrid solar-powered fixed-wing UAV. The project aims to develop an innovative and sustainable solution to the challenge of extending the flight duration of UAVs without relying on traditional fuels. The project will involve interdisciplinary collaboration between students from various engineering disciplines, including mechanical engineering, aerospace engineering, electrical engineering, and materials science. The team will work together to optimize the design of the UAV, develop an efficient and reliable power management system, employ advanced battery technologies, and integrate hybrid power sources. The project will involve several stages, including research and analysis, design, simulation and modeling, and prototype fabrication and testing. The research and analysis stage will involve a literature review of existing research on solar-powered UAVs, including their design, performance, and limitations. The design stage will involve the development of a detailed design for the hybrid solar-powered fixed-wing UAV, including the airframe, power management system, and hybrid power source. The design will be optimized for weight, efficiency, and reliability, and will take into account the various environmental factors that can affect the performance of solar cells, such as cloud cover and shading. The simulation and modeling stage will involve the use of advanced modeling and simulation techniques to optimize the design of the UAV and the power management system. This will involve the use of tools such as computational fluid dynamics (CFD) software, finite element analysis (FEA) software, and circuit simulation software. The final stage of the project will involve the fabrication of a prototype of the hybrid solar-powered fixed-wing UAV and its testing under real-world conditions. This will involve testing the UAV's performance in different weather conditions, its ability to maintain altitude and stability, and its overall flight endurance. Overall, the final year design project proposed in this case offers an exciting and challenging opportunity for students to work on cutting-edge technology and contribute to the development of sustainable aviation. The project will also provide students with valuable experience in interdisciplinary collaboration, project management, and the practical application of engineering principles.

1.3 Statement of Problem:

Unmanned aerial vehicles (UAV) have revolutionized many industries in recent years, providing cost-effective and efficient solutions for tasks such as surveillance, monitoring, and environmental research. However, one of the major challenges of UAVs is their limited flight duration, which is often due to their reliance on traditional fuels. This limitation has led to increased interest in developing alternative, environmentally friendly power sources for UAVs, such as solar energy. While solar-powered UAVs have shown promise in extending the endurance of these vehicles, there are still significant challenges associated with this technology. For example, the amount of power that can be generated by solar cells is limited, and the efficiency of these cells can be affected by a range of environmental factors, such as cloud cover and shading. Additionally, the energy storage capacity of current battery technologies is often insufficient for extended UAV flights, and the weight of batteries can also limit the UAV's performance. Furthermore, there are design challenges associated with integrating solar cells and battery systems into the UAV, such as optimizing the aerodynamics of the vehicle and ensuring that the power management system is efficient and reliable. These challenges require interdisciplinary collaboration between researchers from various fields, including mechanical engineering, aerospace engineering, electrical engineering, and materials science. The problem statement, therefore, is to develop a hybrid solar-powered fixed-wing UAV that can operate for extended periods without requiring traditional fuel, while also addressing the various technical challenges associated with this technology. The solution to this problem will contribute to sustainable aviation and have significant practical applications in a range of industries.

1.4 Specifications of Proposed Solution:

The proposed solution to the problem of developing a hybrid solar-powered fixed-wing UAV that can operate for extended periods without requiring traditional fuel is to employ a combination of advanced technologies and design strategies. One key strategy is to optimize the design of the UAV to minimize weight and reduce drag. This can be achieved by using lightweight materials, such as carbon fibre composites, and employing aerodynamic design principles to reduce drag and improve the UAV's efficiency. The use of advanced modeling and simulation techniques can also help to optimize the design of the UAV. Another important strategy is to develop an efficient and reliable power management system that can effectively manage the power generated by the solar cells and the battery system. This can be achieved through the use of advanced power electronics, such as dc-dc converters and maximum power point tracking (MPPT) algorithms, which can maximize the efficiency of the solar cells and ensure that the battery system is charged optimally. To address the challenges associated with energy storage, the proposed solution is to employ advanced battery technologies, such as lithium-ion and lithium-polymer batteries, which can provide high energy density and power output. The battery system can also be designed to be modular, allowing for easy replacement and upgrading of individual battery cells. Finally, the proposed solution is to integrate hybrid power sources, such as fuel cells or micro-turbines, to provide additional power when solar energy is not sufficient. This can provide a backup power source for extended flights or when flying in areas with limited sunlight. In summary, the proposed solution involves optimizing the design of the UAV to reduce weight and improve efficiency, developing an efficient and reliable power management system, employing advanced battery technologies, and integrating hybrid power sources. By employing these strategies, the hybrid solar-powered fixed-wing UAV can operate for extended periods without requiring traditional fuel, while also addressing the various technical challenges associated with this technology.

1.5 Purpose of This Project:

The proposed solution to the problem of developing a hybrid solar-powered fixed-wing UAV that can operate for extended periods without requiring traditional fuel is to employ a combination of advanced technologies and design strategies. One key strategy is to optimize the design of the UAV to minimize weight and reduce drag. This can be achieved by using lightweight materials, such as carbon fibre composites, and employing aerodynamic design principles to reduce drag and improve the UAV's efficiency. The use of advanced modeling and simulation techniques can also help to optimize the design of the UAV. Another important strategy is to develop an efficient and reliable power management system that can effectively manage the power generated by the solar cells and the battery system. This can be achieved through the use of advanced power electronics, such as dc-dc converters and maximum power point tracking (MPPT) algorithms, which can maximize the efficiency of the solar cells and ensure that the battery system is charged optimally. To address the challenges associated with energy storage, the proposed solution is to employ advanced battery technologies, such as lithium-ion and lithium-polymer batteries, which can provide high energy density and power output. The battery system can also be designed to be modular, allowing for easy replacement and upgrading of individual battery cells. Finally, the proposed solution is to integrate hybrid power sources, such as fuel cells or micro-turbines, to provide additional power when solar energy is not sufficient. This can provide a backup power source for extended flights or when flying in areas with limited sunlight.

In summary, the proposed solution involves optimizing the design of the UAV to reduce weight and improve efficiency, developing an efficient and reliable power management system, employing advanced battery technologies, and integrating hybrid power sources. By employing these strategies, the hybrid solar-powered fixed-wing UAV can operate for extended periods without requiring traditional fuel, while also addressing the various technical challenges associated with this technology.

1.7 Applications of the hybrid solar powered UAV:

The hybrid solar-powered fixed-wing UAV proposed in this project has a wide range of potential applications in various industries. Some of the most promising applications are:

- **Environmental monitoring:** the hybrid solar-powered fixed-wing UAV can be used to monitor the environment, including wildlife, forest fires, and pollution levels. Its long flight duration and silent operation make it an ideal tool for environmental research and monitoring.
- **Military reconnaissance:** the hybrid solar-powered fixed-wing UAV can be used for military reconnaissance, including border surveillance and target tracking. Its long flight duration, high altitude capabilities, and low visibility make it an effective tool for military operations.
- **Aerial photography:** the hybrid solar-powered fixed-wing UAV can be used for aerial photography and cinematography, providing a stable platform for capturing high-quality images and videos from a unique perspective.
- **Agriculture:** the hybrid solar-powered fixed-wing UAV can be used for crop monitoring, including crop health assessment, yield estimation, and soil analysis. Its ability to cover large areas quickly and accurately make it an ideal tool for precision agriculture.

- **Search and rescue:** the hybrid solar-powered fixed-wing UAV can be used for search and rescue operations, including locating missing persons and assessing disaster zones. Its long flight duration and high-altitude capabilities make it an effective tool for emergency response.
- **Telecommunications:** the hybrid solar-powered fixed-wing UAV can be used for providing telecommunications services, including wireless internet and cellular coverage, in remote areas.

Overall, the hybrid solar-powered fixed-wing UAV proposed in this project has significant potential for a range of applications, and its environmentally friendly nature and cost-effective operation make it an attractive solution for various industries.

Chapter 2

LITERATURE REVIEW

2.1 Related Technologies

As evident, this project is related to the subject of solar powered / Hybrid propulsion UAV systems. Therefore, we found multiple projects and papers related to the project. Some technologies served as a model for the project, serving as the basis of design and logic, yet others served as an inspiration for the team to give value addition to the project so that it performs well. A few of them are listed below.

2.1.1 Hybrid fuel cell/combustion engine:

Fuel cell and the internal combustion engine are both forms with high energy density and low power density. The relationship between the two energy sources is not complementary but superimposed to improve the efficiency of energy utilization. Increasing the energy density of energy storage (e.g., solid hydrogen), and improving power conversion efficiency. As a high energy density energy source, fuel cells. Xingbang Yang, Xuan Pei, in Hybrid Technologies for Power Generation, 2022

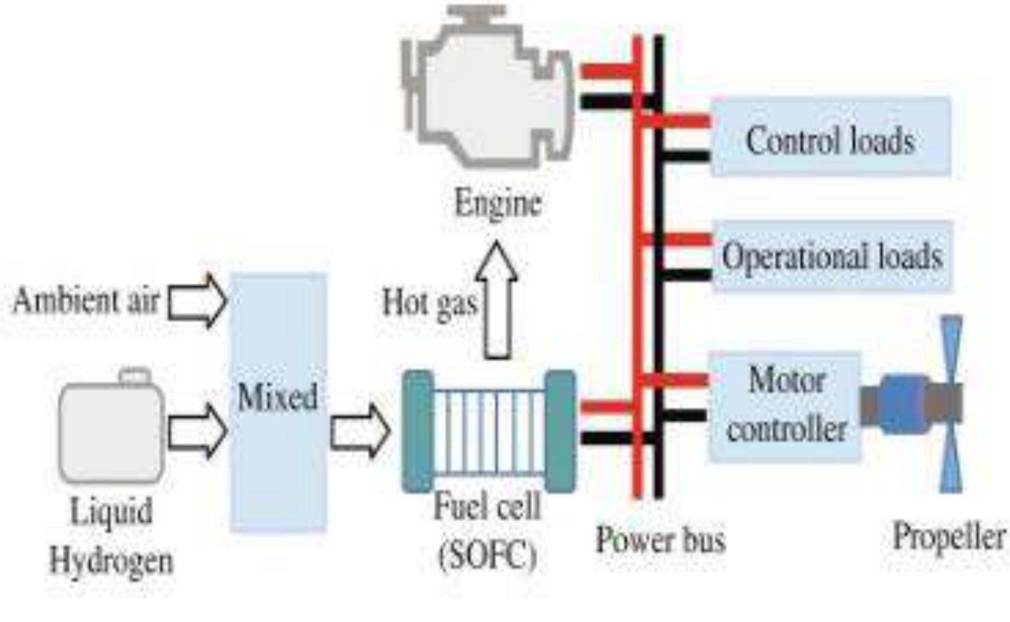


FIGURE 2.1 HYBRID FUEL CELL/COMBUSTION ENGINE

2.1.2 Uninhabited aerial surveillance vehicle (UASV)

TABLE 2.1 UNINHABITED AERIAL SURVEILLANCE VEHICLE (UASV)

Design features:	The novel aircraft layout, with a high aspect ratio, multi-tapered, swept-forward braced wing planform, provides a platform for the mounting of alternative payloads and systems. The wing profile employs a supercritical section. The clean wing is unflapped with outboard ailerons and inboard elevators. The fuselage is configured to allow equipment modules to be quickly changed, giving unique flexibility in operation. One of the forward modules offers the alternative of either a manned cockpit capsule or an autonomous unmanned flight control system. The twin turbofan engines are developments from a similar type currently used on business jets (e.g., P&w of canada pw-530/545). The tricycle retractable landing gear is of conventional design.
Operational features:	The mission profile includes 24-hour flights at 45 000 to 65 000 ft altitude at mach 0.7. Operation into and from conventional military airfields. Optional detachment of wings and brace structure for rapid deployment to operational theatre.
Structure:	Conventional glider-technology composite structural framework with rapid access to interchangeable fuselage equipment modules. Fuel held in integral wing tanks and central fuselage bladder tanks.
Equipment:	Space provision for reconnaissance and communication packages to suit variable operational missions.

2.1.3 Hydrogen fuel for Aviation:

Huanrong lei, bhupendra khandelwal, in aviation fuels, 2021

Hydrogen fuel on commercial aircraft has met severe difficulties due to the hydrogen fuel's high volume. In the area of unmanned aerial vehicles (UAV), liquid hydrogen fuel was successfully employed. In 2010, phantom eye, it has 10 days endurance and 2000-pound payload carry ability. For the phantom eye, the liquid hydrogen was employed as fuel, and the feature of phantom eye had two 2.3 l turbocharged liquid hydrogen internal combustion engines, demonstrator phantom eye has carried nine flight tests; the recent one in 2014 demonstrated that phantom eye could fly at 54,000 ft altitude for more than 8 h [41]. The success of phantom eye has shown the enormous potential of liquid hydrogen fuel in the area of hale aircraft.

2.1.4 Introduction to aerial robotics:

Jean-philippe condomines, in nonlinear kalman filtering for multi-sensor navigation of unmanned aerial vehicles, 2018 the UAVs in this category have the advantage of being relatively lightweight and easy to transport, unlike other types of UAV, which can weigh over 150 kg. Aerial robots exist in an extremely wide variety of forms. Other than weight, they can be classified by endurance, which determines their range. For example, we can distinguish between high-altitude long endurance (hale) and medium-altitude long endurance (male) UAVs, as well as so-called medium- and short-range UAVs, and mini-UAVs. For example, we can distinguish between strategic UAVs, tactical UAVs and combat UAVs (unmanned combat air vehicles [ucavs]). These UAVs can have fixed or rotary wing configurations, or even hybrid flight systems. Strategic UAVs are usually hales and are typically used for reconnaissance missions. Some have a battery life of several days and can fly at altitudes of over 20,000 m. The two best-known models of hale are the global hawk, manufactured by northrop grumman and the sentinel, developed by Lockheed Martin. UAVs are designed specifically for surveillance missions and are heavily exploited in civil environments, for example as communication relays. The development of this type of UAV is currently in rapid expansion around the globe, including in france. One notable example is the sperwer model by sagem. Small UAVs. They are usually around a meter in size and are characterized by a battery life of a few hours. This category tends to be the most useful for developing easy-to-implement and inexpensive experimental platforms. Among other things, mini-UAVs are used to illustrate and demonstrate research in the fields of robotics, automation, and signal processing. Mini-UAVs played a key role in our development and implementation of a series of crucial estimation algorithms for UAVs, in part because the capacities of sensor and actuator technologies are limited by cost and space constraints.

2.2 Related projects

2.2.1 Design and development of solar powered UAV for long endurance:

The paper "design of low altitude long endurance solar-powered UAV using genetic algorithm" presents the design and development of a solar-powered unmanned aerial vehicle (UAV) for long endurance flights. The study was conducted by a team of researchers from the college of aerospace science and engineering at the national university of defense technology in china.

The UAV has a wingspan of 3 meters and weighs around 14 kg. It is powered by four solar panels mounted on the wings, which provide a maximum power output of 320 w. The solar panels charge a lithium-polymer battery, which powers the electric motor that drives the propeller.

The aircraft is equipped with various sensors and a camera for data collection and analysis. The data collected by the sensors and camera is transmitted to a ground station in real-time for analysis.

The design of the UAV was optimized using a genetic algorithm. The optimization process aimed to maximize the aircraft's endurance while maintaining a sufficient level of performance. The optimization process took into consideration various parameters, including the solar panel efficiency, battery capacity, and aircraft weight.

The optimized design of the UAV was tested in a wind tunnel and demonstrated a maximum endurance of 4.5 hours at a cruising speed of 10 m/s. The aircraft was also tested in outdoor flight tests and demonstrated a maximum endurance of 3 hours at a cruising speed of 8 m/s.

Overall, the study demonstrates the potential of solar-powered UAVs for long endurance flights and highlights the importance of optimization techniques in designing efficient and reliable UAVs.

2.2.2 Design and development of a small solar powered UAV for environmental monitoring:

The paper "design and development of a small solar-powered UAV for environmental monitoring application" presents the design and development of a small unmanned aerial vehicle (UAV) for environmental monitoring. The project was carried out by a team of researchers from king mongkut's institute of technology ladkrabang in thailand.

The UAV has a wingspan of 1.8 meters and weighs around 5 kg. It is powered by two solar panels mounted on the wings, which provide a maximum power output of 200 w. The solar panels charge a lithium-polymer battery, which powers the electric motor that drives the propeller.

The aircraft is equipped with various sensors for environmental monitoring applications, including a particulate matter sensor, a temperature and humidity sensor, and a GPS receiver. The data collected by the sensors is transmitted to a ground station in real-time for analysis.

The design of the UAV was optimized to maximize its endurance while maintaining a sufficient level of performance. The optimization process took into consideration various parameters, including the solar panel efficiency, battery capacity, and aircraft weight. The optimized design of the UAV was tested in outdoor flight tests and demonstrated a maximum endurance of 2.5 hours at a cruising speed of 10 m/s. The aircraft was also tested in various environmental conditions, including high temperature and humidity, and demonstrated reliable performance.

Overall, the study demonstrates the potential of small solar-powered UAVs for environmental monitoring applications and highlights the importance of optimization techniques in designing efficient and reliable UAVs. The use of solar power provides a sustainable and environmentally friendly solution for long-endurance UAV flights.

2.2.3 Design and development of solar powered UAV low altitude, long endurance for surveillance and mapping:

The paper "maraal: a low altitude long endurance solar powered UAV for surveillance and mapping applications" presents the design and development of a solar-powered unmanned aerial vehicle (UAV) for surveillance and mapping applications. The study was conducted by a team of researchers from the indian institute of technology bombay.

The UAV, called maraal, has a wingspan of 4 meters and weighs around 20 kg. It is powered by solar panels mounted on the wings, which provide a maximum power output of 600 w. The solar panels charge a lithium-polymer battery, which powers the electric motor that drives the propeller.

The aircraft is equipped with various sensors and a camera for data collection and analysis. The data collected by the sensors and camera is transmitted to a ground station in real-time for analysis.

The design of the UAV was optimized to maximize its endurance while maintaining a sufficient level of performance. The optimization process took into consideration various parameters, including the solar panel efficiency, battery capacity, and aircraft weight.

The optimized design of the UAV was tested in outdoor flight tests and demonstrated a maximum endurance of 5 hours at a cruising speed of 15 m/s. The aircraft was also tested in various environmental conditions, including high wind speeds and turbulence, and demonstrated reliable performance.

Overall, the study demonstrates the potential of solar-powered UAVs for long-endurance surveillance and mapping applications and highlights the importance of optimization techniques in designing efficient and reliable UAVs. The use of solar power provides a sustainable and environmentally friendly solution for long-endurance UAV flights, which is particularly important for applications such as environmental monitoring and mapping.

2.2.4 Solar powered hand launchable UAV for low altitude multi day flight continuous flight:

The paper "a solar-powered hand-launchable UAV for low-altitude multi-day continuous flight" describes the design and development of a solar-powered unmanned aerial vehicle (UAV) that can be hand-launched and operated for multiple days at low altitudes. The study was conducted by a team of researchers from the swiss federal institute of technology (eth zurich).

The UAV, called solaris, has a wingspan of 4.8 meters and weighs only 2.5 kg. It is powered by solar panels mounted on the wings, which provide a maximum power output of 100 w. The solar panels charge a lithium-polymer battery, which powers the electric motor that drives the propeller.

The aircraft is equipped with various sensors and a camera for data collection and analysis. The data collected by the sensors and camera is transmitted to a ground station in real-time for analysis.

The design of the UAV was optimized for low-altitude flight and long endurance. The optimization process took into consideration various parameters, including the solar panel efficiency, battery capacity, and aircraft weight. The aircraft was also designed to be hand-launched, making it highly portable and easy to deploy in the field.

The optimized design of the UAV was tested in outdoor flight tests and demonstrated a maximum endurance of over 26 hours at a cruising speed of 8 m/s. The aircraft was also tested in various environmental conditions, including high wind speeds and turbulence, and demonstrated reliable performance.

Overall, the study demonstrates the potential of solar-powered UAVs for long-endurance low-altitude flight and highlights the importance of optimization techniques in designing efficient and reliable UAVs. The use of solar power provides a sustainable and environmentally friendly solution for long-endurance UAV flights, which is particularly important for applications such as environmental monitoring and mapping. The hand-launchable design of the solaris UAV also makes it highly portable and versatile for use in a variety of applications.

2.2.5 Development of solar powered for extended flight endurance:

The paper titled "development of a solar-powered unmanned aerial vehicle for extended flight endurance" by chu, y., ho, c., lee, y., & li, b. (2021) focuses on the design and development of a solar-powered UAV that has extended flight endurance. The paper discusses the design process, including the selection of the airframe and the solar cells used to power the aircraft. It also covers the testing process used to validate the performance of the UAV, including flight tests to determine the endurance capabilities of the aircraft. Finally, the paper discusses potential applications for the solar-powered UAV.

2.2.6 Aerodynamic efficiency and performance enhancement of fixed wing UAV:

The paper starts by reviewing the current state of the art in UAV design and identifies several key areas where improvements can be made to enhance aerodynamic efficiency and overall performance.

The authors then propose a number of design modifications that can be made to fixed wing UAVs in order to achieve these improvements. These modifications include changes to the wing geometry, such as increasing the aspect ratio or changing the sweep angle, as well as the use of winglets to reduce induced drag.

The authors also discuss the use of computational fluid dynamics (CFD) simulations to evaluate the performance of the modified UAVs design and present some examples of CFD results for different UAV configurations.

The paper concludes by discussing the potential benefits of the proposed modifications, including increased range, endurance, and payload capacity, as well as improved manoeuvrability and stability. The authors also note that the proposed modifications are applicable to a range of UAV applications, including military, civilian, and scientific missions.

The paper is well-referenced, with over 70 citations to relevant literature on UAV design and aerodynamics.

Overall, the paper provides a comprehensive review of current UAV design practices and proposes several innovative modifications to improve aerodynamic efficiency and performance. The use of CFD simulations to evaluate the proposed modifications is a particularly useful contribution, as it allows for a more detailed analysis of the effects of design changes on UAV performance.

2.2.7 Design and performance analyses of a fixed wing UAV:

The paper "design and performance analyses of a fixed wing battery VTOL UAV" by Dündar et al. Presents a detailed design and performance analysis of a fixed wing unmanned aerial vehicle (UAV) that is capable of vertical take-off and landing (VTOL) and is powered by a battery.

The authors discuss the design process of the UAV, including the selection of materials and components for the airframe, propulsion system, and control system. The design considerations are focused on achieving high performance, efficient energy consumption, and ease of operation. The authors also discuss the challenges and constraints that arise when designing a fixed wing UAV that can perform vertical take-off and landing.

The UAV's performance is evaluated through various tests and analyses, including wind tunnel tests, flight tests, and simulations. The authors analyse the aerodynamic characteristics of the UAV, including lift and drag coefficients, as well as the effect of different control inputs on the aircraft's stability and manoeuvrability. The authors also evaluate the energy consumption and efficiency of the propulsion system and analyse the aircraft's range and endurance.

The results of the performance analysis show that the UAV is capable of stable flight with good manoeuvrability, and it can achieve a maximum speed of 25 m/s. The authors also demonstrate the UAV's ability to perform vertical take-off and landing and discuss the challenges associated with these operations. The authors conclude that the fixed wing VTOL UAV has potential for various applications, such as environmental monitoring, mapping, and surveillance.

Overall, this paper provides a detailed overview of the design and performance analysis of a fixed wing VTOL UAV powered by a battery, which can be useful for researchers and engineers working in the field of UAV design and development.

2.2 Related studies/research:

2.2.1 Development of a solar-powered unmanned aerial vehicle for extended flight endurance:

The paper "development of a solar-powered unmanned aerial vehicle for extended flight endurance" describes the design, development, and testing of a solar-powered UAV (unmanned aerial vehicle) that has extended flight endurance capabilities. The authors state that current UAVs rely heavily on batteries and have a limited flight time, and that using solar power can greatly increase flight endurance and reduce the reliance on batteries. The UAV in this study is a fixed-wing aircraft with a wingspan of 3.5 meters, and it has solar panels mounted on the wings and fuselage. The authors used a combination of simulation and experimental testing to evaluate the performance of the UAV. The simulations were used to optimize the design and evaluate the potential flight time under different conditions, while the experimental testing was used to validate the simulation results. The authors report that the solar-powered UAV was able to achieve a flight endurance of over 6 hours in sunny weather conditions, and that it was able to maintain level flight while charging its batteries during flight. The authors also note that the performance of the UAV could be further improved by optimizing the solar panel layout and increasing the battery capacity. Overall, this paper highlights the potential of solar-powered UAVs for extended flight endurance and provides valuable insights into the design and optimization of such systems. The authors suggest that solar-powered UAVs could be used in a variety of applications, including environmental monitoring, agriculture, and surveillance.

2.2.2 Design of a solar-powered unmanned aerial vehicle for extended flight endurance:

The paper "development of a solar-powered unmanned aerial vehicle for extended flight endurance" by chu et al. (2021) discusses the design and development of a solar-powered unmanned aerial vehicle (UAV) for extended flight endurance. The authors aimed to develop a UAV that can fly for longer periods without the need for frequent battery replacements or recharging. The UAV was also designed to be environmentally friendly and cost-effective. The paper provides an overview of the design process, including the selection of materials, the design of the airframe, and the integration of solar panels into the UAV. The authors also discuss the performance of the UAV in terms of its endurance, speed, and payload capacity. The UAV has a wingspan of 2.5 meters and is powered by four electric motors. The airframe is made of carbon fibre, which makes it lightweight and durable. The solar panels are integrated into the wings and can generate up to 600 watts of power in optimal conditions. The UAV is equipped with a lithium-polymer battery that can store energy for use during the night or in cloudy weather. The paper presents the results of flight tests conducted to evaluate the performance of the UAV. The UAV was able to fly for more than 12 hours continuously, covering a distance of more than 150 kilometers. The maximum speed achieved by the UAV was 60 kilometers per hour, and it was able to carry a payload of up to 1.5 kilograms. Overall, the paper demonstrates the feasibility of using solar power to extend the endurance of UAVs. The authors suggest that solar-powered UAVs have significant potential for various applications, including environmental monitoring, agriculture, and disaster relief. The paper "development of a solar-powered unmanned aerial vehicle for extended flight endurance" by chu et al. (2021) discusses the design, development, and testing of a solar-powered UAV for extended flight endurance. The authors state that the limited flight endurance of UAVs is a major challenge for their use in various applications, including environmental monitoring, surveillance, and search and rescue missions. They propose the use of solar energy as a source of power to extend the flight endurance of UAVs. The authors first discuss the design considerations and requirements for the solar-powered UAV, including the selection of solar panels, motor, propeller, and battery. They also describe the design of the airframe, which was optimized for maximum aerodynamic efficiency and minimum weight. The authors state that the solar-powered UAV has a wingspan of 3 meters, a maximum take-off weight of 5.5 kg, and a maximum flight endurance of 3 hours. The paper then discusses the experimental testing of the solar-powered UAV, including flight tests conducted in different weather conditions and at different times of the day. The authors report that the UAV was able to fly for more than 3 hours on a sunny day and that the solar panels were able to recharge the battery during flight, allowing for extended flight endurance. The authors also report that the UAV was able to carry a payload of up to 1 kg and that it performed well in both stable and windy conditions. Overall, the paper demonstrates the feasibility and potential of solar-powered UAVs for extended flight endurance. The authors suggest that further research is needed to optimize the design and improve the efficiency of solar-powered UAVs for various applications.

TABLE 1.2 SPECIFICATIONS C60 SOLAR CELL

Parameter	**Values**
Power (Watts)	3.4
Efficiency (%)	22.4
Mass (Kg)	0.008
Size (m)	0.125 x 0.125
Thickness (m)	1.65×10^{-4}

FIGURE 2.2 SUNPOWER C60, MONOCRYSTALLINE SILICON CELL

2.2.3 Determination of the Oswald efficiency factor at the airplane design preliminary stage:

The paper "determination of the Oswald efficiency factor at the airplane design preliminary stage" by samoylovitch and strelets, published in aircraft design in 2000, focuses on the determination of the Oswald efficiency factor at the preliminary stage of airplane design. The Oswald efficiency factor is a measure of the induced drag of a wing and is a crucial parameter for predicting the aerodynamic performance of an aircraft.

The paper begins with an overview of the Oswald efficiency factor and its importance in airplane design. It then discusses the methods used to calculate the Oswald efficiency factor, including empirical methods, semi-empirical methods, and computational fluid dynamics (CFD) simulations. The authors note that CFD simulations are the most accurate method for calculating the Oswald efficiency factor but are also the most time-consuming and resource intensive. Next, the paper presents a new method for determining the Oswald efficiency factor at the preliminary stage of airplane design. The method is based on the use of a simple vortex lattice model to calculate the induced drag of a wing. The model considers the effects of spanwise flow, wing twist, and wing taper, which are known to have a significant impact on the Oswald efficiency factor. The authors validate their method by comparing the calculated Oswald efficiency factors with experimental data for several different wing configurations. The results show good agreement between the calculated and experimental values, demonstrating the accuracy and effectiveness of the proposed method. Overall, the paper provides a useful tool for airplane designers to determine the Oswald efficiency factor quickly and accurately at the preliminary stage of design. By doing so, designers can optimize the aerodynamic performance of their aircraft and reduce drag, resulting in improved fuel efficiency and overall performance.

2.2.4 Optimal design of air foil with high aspect ratio in unmanned aerial vehicles:

The paper titled "optimal design of air foil with high aspect ratio in unmanned aerial vehicles" by park et al. (2008) focuses on the design optimization of air foil for high aspect ratio wings in unmanned aerial vehicles (UAVs). The authors aimed to find an optimal air foil design that could achieve a better lift-to-drag ratio and reduce induced drag at low Reynolds numbers. The study employed computational fluid dynamics (CFD) and genetic algorithms to optimize the design of the air foil. The authors considered various design parameters such as the maximum thickness, the position of the maximum thickness, camber, and the angle of attack. The results showed that the optimal air foil design achieved a higher lift-to-drag ratio compared to the original air foil design, and the induced drag was reduced by up to 20%.the authors concluded that the optimal air foil design could enhance the performance of UAVs and reduce their power consumption, which is critical for long-endurance missions. The study provides valuable insights into the design optimization of air foils for UAVs, which could lead to the development of more efficient and high-performance UAVs.

2.2.5 Development of design methodology for a small solar-powered unmanned aerial vehicle:

The paper titled "optimal design of air foil with high aspect ratio in unmanned aerial vehicles" by park et al. (2008) focuses on the design optimization of air foil for high aspect ratio wings in unmanned aerial vehicles (UAVs). The authors aimed to find an optimal air foil design that could achieve a better lift-to-drag ratio and reduce induced drag at low Reynolds numbers. The study employed computational fluid dynamics (CFD) and genetic algorithms to optimize the design of the air foil. The authors considered various design parameters such as the maximum thickness, the position of the maximum thickness, camber, and the angle of attack. The results showed that the optimal air foil design achieved a higher lift-to-drag ratio compared to the original air foil design, and the induced drag was reduced by up to 20%.the authors concluded that the optimal air foil design could enhance the performance of UAVs and reduce their power consumption, which is critical for long-endurance missions. The study provides valuable insights into the design optimization of air foils for UAVs, which could lead to the development of more efficient and high-performance UAVs.

2.3 Predetermined design parameters:

TABLE 2.3 DESIGN PARAMETERS

Parameters	Values
Altitude (m)	300
Endurance (mins)	40
Angle of Attack (deg)	0
Dihedral angle (deg)	2
True Velocity (ms^{-1})	15
Angle of Climb (m)	20
Wingspan (m)	1.56
Rynold number	2.5×10^5
Oswald's efficiency (%)	0.8
Aspect Ratio	5.78

2.4 Their limitations and bottlenecks:

There are several limitations and bottlenecks to consider when designing and implementing hybrid solar-powered fixed-wing UAV. Some of the most significant ones include:

Limited battery capacity: the amount of energy that can be stored in batteries is limited, which can limit the flight time and range of the aircraft. This can be mitigated by using more efficient batteries or a hybrid propulsion system, but this may come at the cost of added weight and complexity.

Weather conditions: the performance of solar panels is heavily dependent on weather conditions, such as cloud cover and sunlight intensity. This can limit the amount of energy that can be harvested from the sun and affect the overall performance of the aircraft.

Payload capacity: the weight of sensors, cameras, and other equipment that can be carried by the aircraft is limited by its payload capacity. This can limit the usefulness of the aircraft for certain applications.

Cost: the cost of the components and materials used to build the aircraft can be high, especially for high-performance systems. This can limit the accessibility of the technology to certain users.

System integration: the integration of various subsystems and components, such as the solar panels, battery, motor, and flight controller, requires careful design and testing to ensure that they work together effectively. This can be challenging, especially for complex systems.

2.5 Summary

The project aims to design, analyse, and fabricate a hybrid solar-powered fixed-wing UAV for various applications, such as surveillance, mapping, and environmental monitoring. The system includes several subsystems, such as solar cells, batteries, a flight controller, a propulsion system, a GPS module, and imaging sensors. The design and integration of these subsystems require expertise in aerodynamics, motor technology, electronics, and system integration. However, the project is subject to several limitations and bottlenecks, such as limited battery capacity, weather conditions, payload capacity, cost, system integration, and regulatory requirements. To overcome these challenges, the designers and engineers must carefully consider these factors and work to optimize the performance and usability of the system.

Chapter 3

PROJECT DESIGN AND IMPLEMENTATION

3.1 Project Design:

The project involves the design of a hybrid solar-powered fixed-wing UAV for various applications. The system includes several subsystems that need to be integrated, such as solar cells, batteries, a flight controller, a propulsion system, a GPS module, and imaging sensors. The design process begins with a thorough understanding of the requirements of the system, such as flight time, payload capacity, and operating environment. This information is then used to create a preliminary design that outlines the overall dimensions and weight of the aircraft, as well as the location and arrangement of the subsystems. The next step involves aerodynamic analysis and simulation to determine the flight characteristics of the aircraft. This includes assessing lift and drag, stability and control, and other factors that affect the performance of the aircraft. Once the aerodynamic design is finalized, the designers can begin selecting and integrating the subsystems. For example, the solar cells and batteries need to be carefully sized and positioned to provide sufficient energy for the aircraft, while the flight controller and GPS module must be integrated to ensure safe and accurate flight. The design process also involves prototyping and testing the system to ensure that it meets the requirements and performs as expected. This includes flight testing the system in a controlled environment to assess its flight characteristics and validate its performance. Throughout the design process, the designers must also consider the limitations and bottlenecks of the system, such as limited battery capacity, weather conditions, payload capacity, cost, system integration, and regulatory requirements. They must work to optimize the performance and usability of the system while mitigating these challenges.

3.2 Analysis procedure:

A The analysis procedure for the hybrid solar-powered fixed-wing UAV project may involve the following steps:

- **Define the requirements:** Determine the design requirements of the UAV, including payload capacity, range, endurance, speed, altitude, and other necessary features.

- **Select the materials:** Choose the appropriate materials for the frame, wing, motor, propeller, solar panel, battery, and other components based on the design requirements.

- **Design the CAD model:** Use computer-aided design (CAD) software to create a 3D model of the UAV, incorporating the selected materials and components.
- **Analyze the aerodynamics:** Perform Computational Fluid Dynamics (CFD) simulations to evaluate the aerodynamic performance of the UAV, including lift, drag, and stability.
- **Optimize the design:** Use the simulation results to optimize the design of the UAV by adjusting the wing shape, airfoil profile, and other parameters.
- **Implement the hardware:** Once the optimized design is finalized, assemble the hardware components of the UAV, including the solar panels, battery, motor, propeller, and control system.
- **Conduct flight tests:** Conduct a series of flight tests to evaluate the actual performance of the UAV, including its range, endurance, speed, altitude, and other features.
- **Evaluate the results:** Evaluate the test results to identify any issues or areas for improvement and adjust the design accordingly.
- **Refine the design:** Make any necessary adjustments to the UAV's design based on the test results and repeat the testing process to ensure optimal performance.

Overall, the analysis procedure for the hybrid solar-powered fixed-wing UAV involves a combination of computer simulations, design optimizations, and physical testing to ensure the UAV meets the desired specifications and performs as expected.

3.3 Methodology:

The methodology for designing and building a hybrid solar-powered fixed-wing UAV can be broken down into several stages:

- **Research:** The first stage involves researching and gathering information on the various components of the UAV, such as the propulsion system, electronics, solar cells, and wings. This stage also involves identifying the requirements and constraints for the UAV, such as the desired flight time, payload capacity, and operational environment.
- **Design:** The second stage involves using the information gathered in the research stage to design the various parts of the UAV, such as the fuselage, wings, propulsion system, landing gear, and electronics. The design stage involves using computer-aided design (CAD) software to create 3D models of the various components.

- **Analysis:** The third stage involves using computer simulations to analyze the performance of the various components and subsystems. This stage includes simulating the flight dynamics of the UAV, as well as analyzing the efficiency and power output of the solar cells.
- **Fabrication:** The fourth stage involves fabricating the various components of the UAV, such as the fuselage, wings, and landing gear, using materials such as carbon fiber, foam, and plastic. This stage also involves assembling the various subsystems, such as the propulsion system and electronics, and integrating them into the UAV.
- **Testing:** The final stage involves evaluating the UAV in a controlled environment, such as a wind tunnel or on the ground, to ensure that it meets the requirements and operates as expected. This stage also includes making any necessary modifications or adjustments to the UAV based on the testing results.

3.4 Details about Proposed solution:

The UAV will be powered by both a solar panel system and a battery system. The solar panel system will be used to recharge the batteries during flight, thereby increasing the endurance of the UAV. The UAV will be designed to be lightweight, with a low drag coefficient, and high lift-to-drag ratio to achieve maximum efficiency and endurance. The UAV will have a wingspan of 2 meters and a wing area of 0.6 square meters. The airframe will be made of lightweight materials such as carbon fibre and foam, to keep the weight as low as possible. The propulsion system will consist of a brushless outrunner motor and a propeller with a diameter of 10 inches and a pitch of 6 inches. The solar panel system will be mounted on the wings of the UAV and will consist of high-efficiency solar cells. The solar cells will be connected to an MPPT charge controller to optimize the charging process and to maximize the energy output of the solar panels. The battery system will consist of a 3s 6500mah lipo battery, which will provide power to the propulsion system and other electronics on board the UAV. To optimize the performance of the UAV, computational fluid dynamics (CFD) simulations will be used to analyse the aerodynamic characteristics of the airframe and propeller. The simulations will be used to optimize the design of the airframe and propeller to achieve maximum efficiency and endurance. In addition, a mathematical model will be developed to predict the performance of the UAV under different operating conditions. The hybrid solar-powered fixed-wing UAV will have a range of up to 10 kilometers and an endurance of up to 2 hours. The UAV will be equipped with a camera to capture high-quality aerial images and videos, which can be used for various applications such as mapping, surveying, and monitoring. The UAV will be autonomous and will be controlled by a ground station using a remote control or a preprogrammed flight plan.

3.5 Details about simulation / mathematical modelling

Simulation and mathematical modeling are important tools used in the design and analysis of the hybrid solar-powered fixed-wing UAV. In terms of simulation, Computational Fluid Dynamics (CFD) software was used to simulate the aerodynamic behavior of the UAV. This involves creating a digital model of the UAV and its components, and then applying fluid dynamics equations to simulate how the air flows around the UAV. This information can then be used to optimize the design of the UAV for maximum efficiency and stability.

This was done by using Ansys simulation software that can be used to model the electrical and mechanical systems of the UAV. This involved creating a digital model of the electrical and mechanical components, and then simulating how they behave under various conditions. This information can then be used to optimize the design of the systems for maximum efficiency and reliability.

Mathematical modeling is also important in the analysis of the UAV. This involves using mathematical equations to model the behavior of the UAV and its components. mathematical models can be used to predict the flight performance of the UAV under different conditions, such as changes in altitude, speed, and wind conditions. Mathematical models can also be used to optimize the design of the UAV and its components for maximum efficiency and performance.

3.5.1 Mathematical modelling for Aerodynamic center (ADC)

For a rectangular wing

$$\mathrm{AR} = \frac{\mathrm{s}}{\mathrm{c}} = \frac{1.56}{0.27} = 5.778$$

$$\mathrm{A} = \mathrm{b.c} = 1.56(0.27) = 0.4212\ \mathrm{m}^2$$

Where,

Aspect Ratio = AR

Chord = c

Wingspan = s

Span area of the wing = A

Tapper ratio $\lambda = 1$ (Rectangular wing)

Aerodynamic center of wing (ADC) lies at the 25% of cord length.

$$\mathrm{ADC} = 0.25\mathrm{c} \;= 0.0675$$

3.5.2 Mathematical modelling during cruise flight

Using force balance equations

$$\mathrm{Tcos}(\gamma) - \mathrm{Wsin}(\gamma) - \mathrm{D} = 0$$

$$\mathrm{L} + \mathrm{Tsin}(\gamma) - \mathrm{Wcos}(\gamma) = 0$$

Where.

Thrust provided by the propeller = T

Drag of the UAV = D

Lift produced = L

Weight of the UAV = W

Flight angle = γ

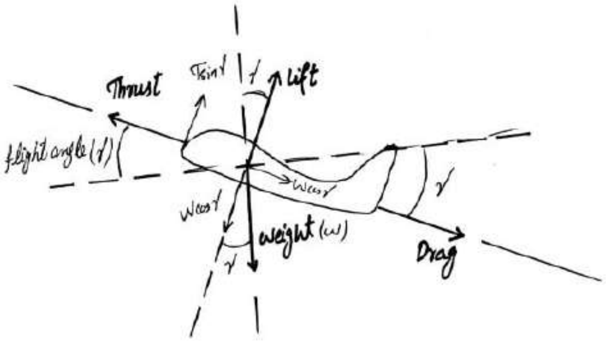


FIGURE *3.1* SCHEMATIC DIAGRAM FOR FORCES ON THE UAV

For cruise flight γ is 0 degree

$$\mathrm{Lift} = \mathrm{Weight} = \frac{1}{2}\mathrm{C_L}\rho \mathrm{v}^2\mathrm{A}$$

$$\mathrm{Thrust} = \mathrm{Drag} = \frac{1}{2}\mathrm{C_d}\rho \mathrm{v}^2\mathrm{A}$$

At an altitude of 300 m

cruise velocity: $\mathrm{v} = 15\ \mathrm{m/s}$

Density of air: $\rho = 1.112\,\frac{\mathrm{kg}}{\mathrm{m}^3}$

Dynamic viscosity $\mu = 1.758 \times 10^{-5}\,\frac{\mathrm{Ns}}{\mathrm{m}^2}$

Estimated mass of UAV = 3 kg

Estimated weight of UAV: $W = 3 \times 9.81 = 29.43\ \text{N}$

3.5.3 Calculating the Reynold's no.:

$$\text{Re} = \frac{\rho v c}{\mu}$$

$$\text{Re} = 2.56\ \times 10^{5}$$

Calculating the power required during cruise using.

$$C_L = \frac{W}{\frac{1}{2}\rho v^{2} A}$$

$$C_L = 0.558$$

Calculating the Coefficient of drag and induced drag correction factor.

$$C_d = C_{do} + kC_L^2$$

C_d = coefficient of drag at required lift coefficient.

C_{d0} = profile drag coefficient = 0.02 at zero degrees angle of attack (Using graphs from simulation data)

k = induced drag correction factor

$$k = \frac{1}{\pi e AR}$$

e = Oswald's efficiency factor = 0.8 for selected profile

$$AR = 5.778$$

$$k = 0.0688$$

$$C_d = 0.041$$

Drag Force acting on the UAV.

$$D = \frac{1}{2}\rho V_\infty^2 A C_d$$

$$D = 2.63\ \text{N}$$

Estimating the drag of a nacelle is complicated by the intricate geometry of many nacelles and the inter-relationship with the definition of engine thrust. for wing-mounted engines and a 20% higher value for aft fuselage-mounted installations. The drag of secondary items may be as high as 10% of the profile drag calculated using the above method. The extra drag is typically due to excrescence, surface imperfections and system installations. For initial project design work the following estimates are suggested, Wing: 6% of wing profile drag Fuselage and empennage: 7% of fuselage profile drag Engine installation: 15% of nacelle profile drag Systems: 3% of total profile drag, In addition to the above items the cockpit windshield will increase fuselage drag by 2-3%.

Thus, the total drag force D= 2.63 N

Thus, the total power required for a 40 mins flight duration.

$$P_R = DV_\infty$$

$$P_R = 26.32 \text{ W h} \qquad \text{W h} = \text{watt hours}$$

Where V_∞ = 15 ms^{-1}

3.5.4 Thrust required at cruise:

$$T_R = \frac{W}{\frac{C_L}{C_D}} = \frac{29.43}{18.14} = 122.32 \text{ N}$$

3.5.5 Calculating the minimum power and velocity requirement to sustain max endurance:

$$P_{Rmin} = \sqrt{\frac{2W_{TOmax}^3}{\rho A}} \left(\frac{256k^3C_{do}}{27}\right)^{\frac{1}{4}}$$

$$P_{Rmin} = 26.78 \text{ watts}$$

$$V_{Rmin} = \sqrt{\frac{2\left(\frac{W}{A}\right)}{\rho}} \left(\frac{k}{3C_{do}}\right)^{\frac{1}{4}}$$

$$V_{Rmin} = 8.796 \text{ m/s}$$

$$V_{stall} = \sqrt{\frac{2\left(\frac{W}{S}\right)}{\rho C_{Lstall}}}$$

$$V_{stall} = 8.84 \text{ m/s}$$

3.5.6 Trim angle (angle of the wings with respect to the fuselage) for cruise flight:

$$C_L = C_{Lo} + C_{L\alpha}\alpha_{trim}$$

$$C_{L\alpha} = \frac{C_{l\alpha}}{1 + kC_{la}}$$

$$C_{Lo} = -C_{L\alpha}(\alpha_{C_l=0})$$

Design coefficient of lift of wing = C_L

Coefficient of lift slope of wing = C_{La}

Coefficient of lift slope of 2d profile = C_{la}

Coefficient of lift of wing at an angle of attack (where $C_l = 0$) = C_{L0}

Thus,

$$C_{la} = \frac{1.34-0.41}{(10^0-0^0)\pi/180} = 5.33 \text{ rad}^{-1}$$

$$C_{La} = 3.9 \text{ rad}^{-1}$$

$$a_{C_L=0} = -\frac{4^0\pi}{180}$$

$$C_{L0} = 0.27$$

$$a_{trim} = (C_L - C_{L0})/C\_La$$

$$\mathbf{a_{trim} = 2.8^0}$$

Now flight angle (γ) during climb

$$T = W_{TOmax}\sin(\gamma) + D$$

$$\sin(\gamma) = \frac{T - D}{W_{TOmax}}$$

$$L = W_{TOmax}\cos(\gamma)$$

Rate of climb $(\mathbf{ROC})$ $= \mathrm{V}_{\infty} \sin(\gamma) = (\mathrm{h}_1 - \mathrm{h}_2)/\Delta \mathrm{t}$

$$\mathrm{ROC} = (\mathrm{TV}_{\infty} - \mathrm{DV}_{\infty})/\mathrm{W}$$

$$\mathrm{ROC} = (\mathrm{P_A} - \mathrm{P_R})/\mathrm{W}$$

Taking $\mathbf{20^0}$ flight angle during climb

$$\mathrm{ROC} = 15 \sin(20) = 5.13\ \mathrm{m/s}$$

To reach the 300 m

$$\Delta \mathrm{t} = 58.5\ \mathrm{sec}$$

Now the thrust required for climb at 20 degrees.

$$\mathrm{T_R} = (24.525 \sin(20) + 2.21) = 10.59\ \mathrm{N}$$

Lift required at flight angle of 20 degree.

$$\mathrm{L} = 24.525 \cos(20) = 23.04\ \mathrm{N}$$

Power required for climbing.

$$\mathrm{P} = \mathrm{T} \times \mathrm{V}$$

$$\mathrm{P} = 10.59 \times 15 = 158.85\ \mathrm{watts}$$

For 58.5 sec, power requirement

$$\mathrm{P} = 2.58\ \mathrm{Wh}$$

3.5.7 Total power required by this UAV during complete flight.

$$\mathrm{P_{Rt}} = \mathrm{P_{cruise}} + \mathrm{P_{climb}}$$

$$\mathrm{P_{total}} = 33.21 + 2.58 = 35.79\ \mathrm{Wh}$$

Power required by motor.

$$\mathrm{P_{Required_{motor}}} = \frac{\mathrm{P_{total}}}{0.8} = 44.37\ \mathrm{Wh}$$

Propeller efficiency = 75%

Total power required from battery.

$$\mathrm{P_{TR}} = \frac{44.37}{0.75} = 59.19\ \mathrm{Wh}$$

3.5.8 Velocity required to take off from ground.

UAV is designed for Reynold’s no. of 2.56×10^5

At sea level Density = $1.225\,\frac{\mathrm{kg}}{\mathrm{m^3}}$

viscosity = $1.789 \times 10^{-5}\,\frac{\mathrm{Ns}}{\mathrm{m^2}}$

Therefore, in order to maintain this Reynold’s no. velocity required to be.

$$\mathrm{v} = \frac{\mu \times \mathrm{Re}}{\rho \times \mathrm{c}}$$

$$\mathbf{v = 13.86\ m/s}$$

3.5.9 Theoretical Power supplied by the solar cells.

Total number of cells = 8

Power per Cell = 1.2 watts

Total power produced = 9.2 Wh

Required from battery = 59.167 – 9.2 = 49.9 Wh

So, the power produced by the solar cells is **15.5%** of the total required power.

3.6 Details of Working Design Prototype:

A hybrid solar-powered fixed-wing UAV is designed to use a combination of solar and battery power to fly. The solar panels on the wings of the UAV collect energy from the sun and convert it into electrical energy to charge the batteries. The batteries store the energy and provide power to the electric motor, which drives the propeller. During flight, the UAV uses solar power as the primary source of energy, and the batteries provide additional power when needed, such as during take-off, climb, and periods of low sunlight. The use of both solar and battery power increases the flight time and range of the UAV, as it does not need to rely solely on battery power. The solar panels on the wings are designed to be lightweight and efficient, with high power output and a low profile to reduce drag. The batteries are also lightweight and designed to provide high power output for extended periods of time. The electric motor and propeller are designed to be efficient and provide enough thrust for flight while consuming minimal power.

3.6.1 CAD Model of the UAV:

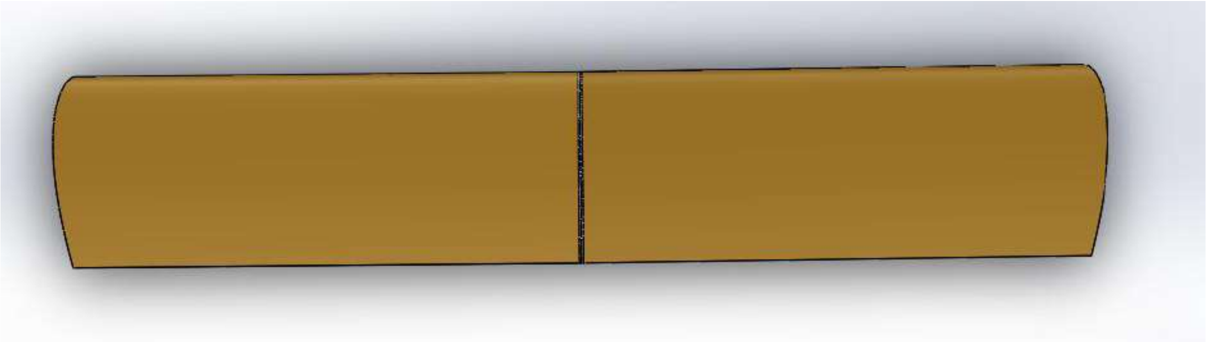
CAD (Computer Aided Design) model was of with complete details and structural components of the fixed wing UAV, such as the wings fuselage vertical and horizontal stabilizer section, including all the various components such as the hinges and various structural components including the braces, spars, and aero foil sections.

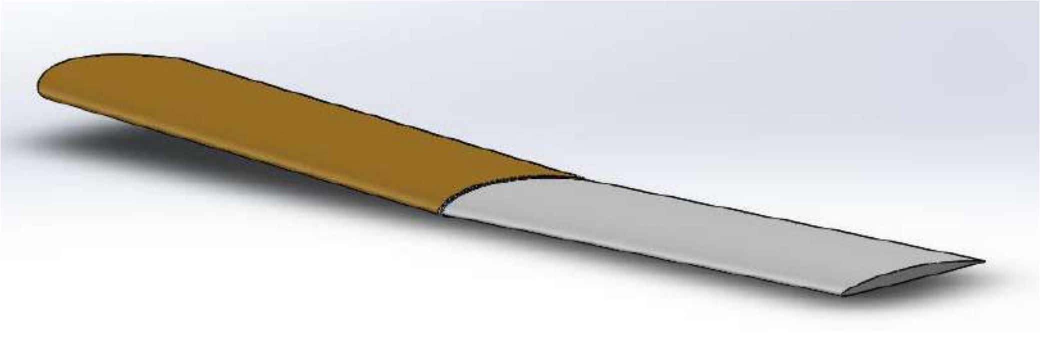
Fuselage dimensions from literature, available for UAVs:

- Length of fuselage = 75% of wingspan = (0.75) (1.5) = 1.12 m
- Nose length = 20% of fuselage length = 0.2(1.5) = 0.3 m
- Wing trailing edge to stabilizer = 40% of fuselage length = 0.54 m
- Horizontal tail area = 7.3% of wingspan area = 0.083 m^2
- Vertical tail area = 41% of stabilizer area = 0.0342 m^2
- Tapper ratio of horizontal tail and vertical tail = 0.63

Wing CAD Model

Complete Assembly:





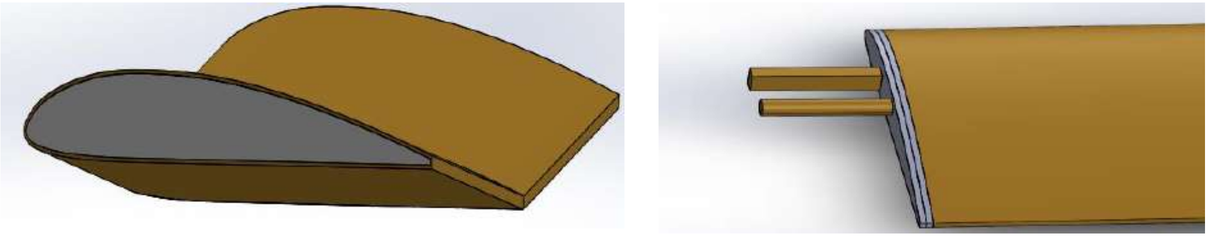


FIGURE 1.2 CAD WING DESIGN

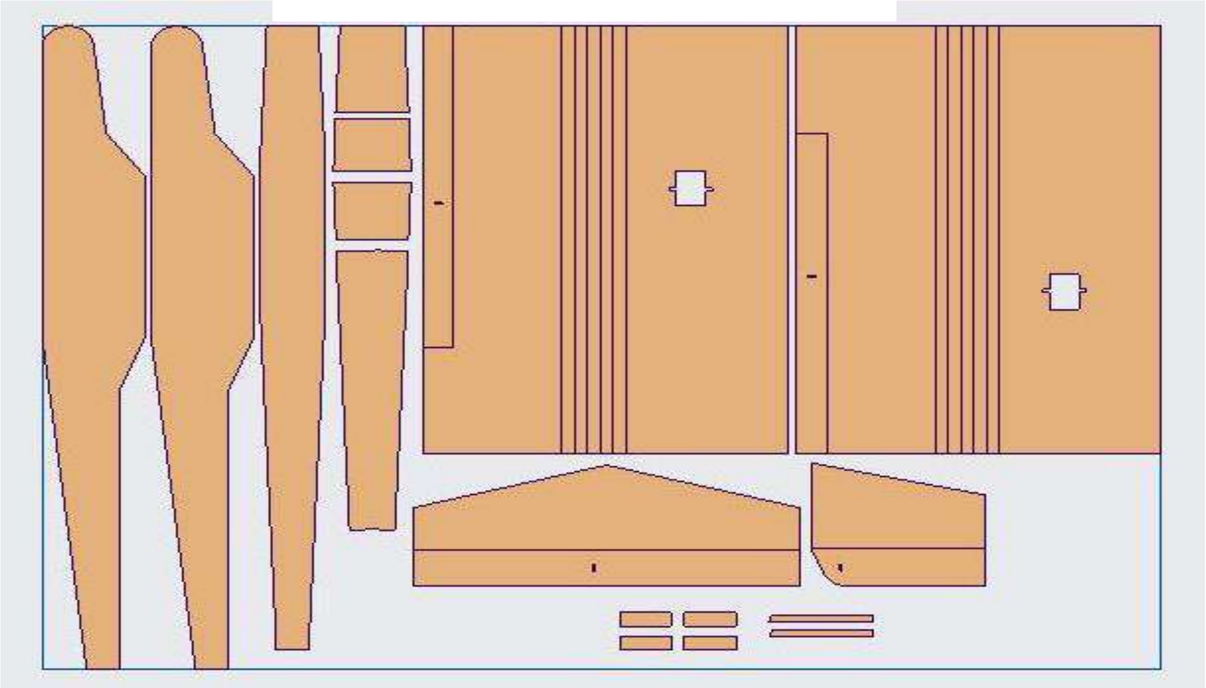
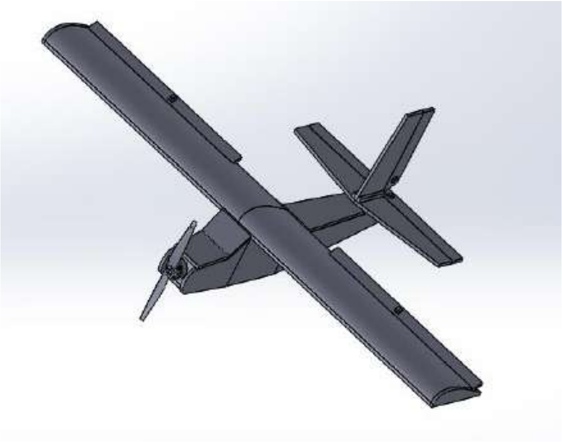
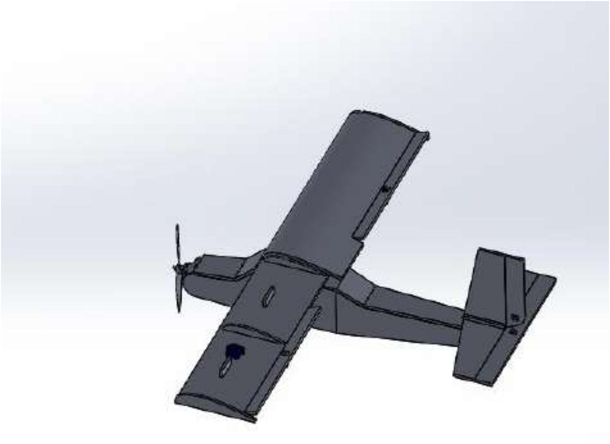


FIGURE 3.3 2D DRAWING.

The wing was made up of 2 parts consisting of a High-density Foam core with a 1 mm layer of balsa wood covering on top to provide a smooth finish furthermore the 2 wings are fixed together using dowels and were held together using a fiberglass covering dipped in resin.

Complete CAD Model





The entire fuselage and control surfaces are made from sheets of balsa wood covered with a thin layer of monocot. A monocot is a type of polyester film that is lightweight, durable, and easy to apply. Used for covering RC airplanes.

3.7 System Electronics:

3.7.1 Flight Controller:

The Arduino Uno-based flight controller I designed utilizes a gyro, GPS module, and barometer to achieve precise stabilization, while also providing essential flight data such as speed, altitude, and location for the unmanned aerial vehicle (UAV). The gyro sensor is responsible for accurately measuring the UAV's angular rates, enabling the flight controller to stabilize its attitude during flight. The GPS module allows the flight controller to determine the UAV's position by acquiring satellite data, providing accurate latitude and longitude coordinates. Additionally, the barometer sensor measures changes in atmospheric pressure, allowing the flight controller to calculate the UAV's altitude with high precision. By combining the data from these sensors, the Arduino Uno flight controller achieves reliable stabilization, while also providing valuable information for monitoring and controlling the UAV's flight parameters.

FIGURE 3.4 FLIGHT CONTROL SETUP

Features:

Stabilization: The flight controller uses the gyro sensor to measure angular rates and stabilize the UAV's attitude during flight. It ensures smooth and controlled movements, preventing undesired roll, pitch, and yaw.

GPS Positioning: The integrated GPS module allows the flight controller to acquire satellite data and determine the UAV's precise location in terms of latitude and longitude coordinates. This feature enables accurate tracking and navigation capabilities.

Speed Calculation: By utilizing the GPS data, the flight controller calculates the UAV's speed, providing real-time information on how fast the drone is moving through the air. This data can be useful for monitoring and controlling the UAV's velocity during flight. **Altitude Measurement:** The barometer sensor enables the flight controller to measure changes in atmospheric pressure, accurately determining the UAV's altitude. This feature allows for precise control of the UAV's height and vertical positioning.

Sensor Fusion: The flight controller employs sensor fusion techniques to combine data from multiple sensors, such as the gyro, GPS , and barometer, to obtain a comprehensive understanding of the UAV's flight parameters. This fusion of data enhances stability and improves the accuracy of altitude, speed, and location measurements.

Flight Mode Selection: The flight controller can offer various flight modes, allowing the user to choose between different operating modes based on their requirements. These modes can include manual control, altitude hold, GPS navigation, or even autonomous flight capabilities.

3.7.2 Servo Motor:

Servo motors play a crucial role in controlling the movement of control surfaces in an unmanned aerial vehicle (UAV). Here's how servo motors are commonly used for control surface actuation:

Ailerons: Ailerons are control surfaces located on the trailing edge of the wings that control the roll motion of the aircraft. Typically, two servo motors are used—one for each aileron—to independently control their deflection. When one aileron moves up, the other moves down, creating a differential effect that causes the UAV to roll.

Elevators: Elevators are control surfaces on the horizontal stabilizer that control the pitch motion of the UAV. Servo motors are used to actuate the elevators, tilting them up or down to change the aircraft's pitch attitude. The movement of both elevators is typically synchronized to maintain balanced control.

Rudders: Rudders are control surfaces on the vertical stabilizer that control the yaw motion of the UAV. Servo motors are employed to move the rudder left or right, enabling the aircraft to change its yaw direction. Like the ailerons, the rudder can also use differential movement to create a yawing effect. Servo motors used for control surfaces in UAVs are specifically designed for aviation applications and possess certain characteristics:

Torque: Servo motors for control surfaces must provide sufficient torque to overcome aerodynamic forces and move the control surfaces effectively. The torque requirement depends on the size, weight, and control surface design of the UAV.

Speed and Response: Servo motors need to be responsive and provide quick movements to ensure precise control of the aircraft. They should be capable of promptly actuating the control surfaces based on pilot or autopilot commands.

Precision and Centring: Servo motors should have accurate positioning capabilities, allowing the control surfaces to maintain specific angles and return to their neutral or centred positions accurately.

Reliability and Durability: Servo motors used in UAVs must be reliable and durable to withstand vibrations, temperature variations, and other environmental factors typically encountered during flight.

The servo motors for control surfaces are connected to the UAV's flight controller, which generates control signals based on pilot input or autopilot algorithms. These signals determine the position or deflection angle of the control surfaces, allowing for precise control of the UAV's attitude and flight characteristics.

FIGURE 3.5 995 SERVO MOTOR

The 995-servo motor is a popular model commonly used in various robotics and hobbyist projects, including UAVs (unmanned aerial vehicles). Here are some details about the 995-servo motor:

Specifications: The 995-servo motor is a standard-sized servo with dimensions of approximately 40mm x 20mm x 43mm (L x W x H). It typically operates on a voltage range of 4.8V to 7.2V.

Torque and Speed: The 995-servo motor offers a considerable amount of torque, usually in the range of 9-12 kg/cm (kilogram per centimetre). The speed of the motor's rotation is generally around 0.18 seconds per 60 degrees of movement.

Control Signal: The 995-servo motor utilizes a standard control signal format known as Pulse Width Modulation (PWM). It receives PWM signals from the flight controller or microcontroller, allowing precise control of its position and movement.

Rotation Range: The 995-servo motor typically has a rotation range of approximately 180 degrees, which means it can rotate from one extreme to the other within this range.

Metal Gears: The 995-servo motor often features metal gears, which enhance its durability and strength, allowing it to handle higher loads and resist wear and tear during operation.

Applications: Due to its high torque and robust construction, the 995-servo motor is commonly used in various applications, including robotics, RC (remote control) vehicles, robotic arms, UAV control surfaces, camera gimbals, and other projects that require precise and reliable servo control.

3.7.3 Electronic speed controller ESC:

FIGURE 3.6 60 AMPS ELECTRONICS SPEED CONTROLLER

A 60A ESC (Electronic Speed Controller) refers to an ESC unit capable of handling a continuous current of up to 60 Amperes. ESCs are essential components in electronic control systems for various applications, including unmanned aerial vehicles (UAVs) and remote-controlled vehicles. Here are some key points about a 60A ESC: Current Handling: The 60A rating indicates that the ESC can handle a continuous current flow of up to 60 Amperes without overheating or damage. It is crucial to select an ESC that matches the power requirements of the motors and other electrical components in your system. Voltage Compatibility: ESCs are designed to work with specific voltage ranges. A 60A ESC typically supports a voltage range suitable for the power source of your application, such as lithium polymer (lipo) batteries commonly used in UAVs and RC vehicles. Common voltage ranges can be between 2S (7.4V) and 6S (22.2V) lipo batteries. Motor Compatibility: A 60A ESC is suitable for powering motors that draw a significant amount of current. It is commonly used with brushless motors found in UAVs and high-powered RC vehicles. Ensure that the ESC's current rating is compatible with the motor's current requirements. BEC (Battery Eliminator Circuit): Many ESCs include a built-in Battery Eliminator Circuit, which provides regulated power to the receiver and other onboard electronics. The BEC voltage output is typically around 5V, allowing you to power your flight controller, receiver, and other low-power components directly from the ESC.

3.7.4 Solar cells:

Using solar cells to enhance the range of unmanned aerial vehicles (UAVs) is an interesting concept that has been explored in certain applications. Here are some key points to consider regarding the use of solar cells for range enhancement: Power Generation: Solar cells, also known as photovoltaic (PV) cells, convert sunlight into electrical energy. By integrating solar cells onto the surface of a UAV, it is possible to generate electricity to power the UAV's systems and potentially extend its flight time and range. Energy Efficiency: Solar cells can supplement the power provided by the UAV's primary batteries, reducing the reliance on battery power during flight. This can result in increased energy efficiency, as the solar cells continuously recharge the onboard batteries while the UAV is exposed to sunlight. Range Extension: The additional power generated by solar cells can help sustain flight for longer durations, potentially extending the range of the UAV. This is particularly beneficial for UAVs engaged in missions that require extended flight time, such as surveillance, mapping, or environmental monitoring. Design Considerations: Integrating solar cells onto a UAV requires careful consideration of factors such as weight, aerodynamics, and power requirements. The solar cells should be lightweight, flexible, and durable to withstand the harsh conditions of flight while minimizing the impact on the UAV's overall performance. Power Management: Efficient power management systems are essential when incorporating solar cells into a UAV. These systems should incorporate maximum power point tracking (MPPT) techniques to optimize the energy conversion from the solar cells and ensure efficient utilization of the generated power. Limitations: While solar cells can enhance the range of a UAV, it is important to note that the amount of power generated may not be sufficient to solely rely on solar energy for continuous flight. The power output of solar cells depends on factors such as the size of the solar array, available sunlight, and the efficiency of the solar cells themselves. In many cases, solar cells are used in combination with primary batteries or other power sources to ensure consistent operation. Practical Considerations: The feasibility and effectiveness of solar cell integration depend on the specific UAV design, mission requirements, and environmental conditions. The availability of sunlight and the duration of flights should be carefully analysed to determine the potential benefits and limitations of using solar cells for range enhancement.

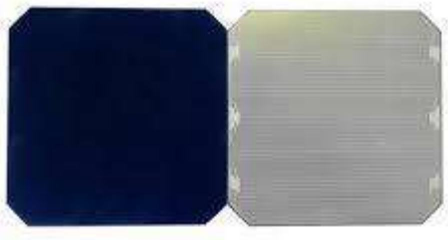


FIGURE 3.7 C60 SOLAR CELLS

TABLE 3.1 SOLAR CELL SPECIFICATIONS

Parameters	values
Power (watts)	3.4
Efficiency (%)	22.4
Mass (kg)	0.008
Size (m)	0.125x0.125
Thickness (m)	1.65*10-4

Lightweight (**7 grams**), thin, and flexible up to 30°. Approximately 0.6 volts output per cell, with stable voltages even in overcast conditions. These are the best available flexible solar cells currently on the market. Unlike the cheaper glass substrate monocrystalline and polycrystalline cells, these have the distinct line-free dark blue look. And they bend up to 30°. These are rated at 3.6W, these cells must be handled carefully. While they are much more flexible than traditional cells (30° bend), they are also easy to snap like a cracker if you are not careful and bend them past their maximum tolerance, especially if bending parallel to the collector lines.

3.7.5 MPPT and BMS:

MPPT stands for Maximum Power Point Tracking, and BMS stands for Battery Management System. Both of these systems play crucial roles in optimizing the performance and efficiency of power systems, including those used in unmanned aerial vehicles (UAVs) and other applications. Here's a brief overview of MPPT and BMS:

Maximum Power Point Tracking (MPPT):

MPPT is a technique used to extract the maximum available power from a solar panel or any other power source with a varying voltage-output characteristic. Solar panels have a non-linear voltage-current characteristic, and the maximum power output occurs at a specific voltage known as the maximum power point (MPP). MPPT algorithms continuously monitor and adjust the operating point of the power source to keep it operating at the MPP, ensuring maximum power extraction. MPPT is commonly used in solar power systems to maximize energy harvest, improve system efficiency, and optimize power utilization.

Battery Management System (BMS):

A BMS is responsible for monitoring and controlling the charging, discharging, and overall management of batteries in a system. It ensures the safe and efficient operation of the battery pack. Key functions of a BMS typically include:

Cell Balancing: A BMS monitors and balances the charge levels of individual cells within a battery pack. This prevents any cell from becoming overcharged or undercharged, which can extend the overall battery life and improve performance.

State of Charge (soc) Monitoring: The BMS measures and estimates the soc of the battery pack. It provides information about the remaining capacity and allows for accurate battery level indications or predictions.

Overvoltage/Undervoltage Protection: The BMS safeguards the battery pack by preventing overvoltage or undervoltage conditions. It can disconnect the load or activate protection mechanisms to prevent damage to the battery cells.

Temperature Monitoring: The BMS monitors the temperature of the battery cells and protects against extreme temperatures. It may activate cooling systems or reduce the charging/discharging rate if the temperature exceeds safe limits.

Communication and Data Logging: BMS systems often include communication interfaces to relay information about battery performance, health, and safety. They may also log data for analysis and diagnostic purposes.

An MPPT system can be used to optimize the power generated by solar cells integrated into the aircraft, while a BMS manages the battery pack powering the UAV. Together, these systems ensure efficient power utilization, battery protection, and overall system performance.

3.7.6 Brushless DC motor:

Using brushless DC (BLDC) motors as powerplants in unmanned aerial vehicles (UAVs) has become the norm due to their remarkable efficiency, high power-to-weight ratio, and reliability. BLDC motors offer superior power conversion, generating less heat and maximizing energy efficiency, which is crucial for prolonging flight time. The absence of brushes in their design reduces friction and wear, extending motor lifespan and minimizing maintenance requirements. BLDC motors are also known for their clean power supply, eliminating sparking and electrical noise. With the help of electronic speed controllers (ESCs), these motors can be precisely controlled, providing the necessary thrust for UAVs through carefully selected propellers. Proper motor sizing, cooling mechanisms, and consideration of redundancy ensure optimal performance and safety. By incorporating BLDC motors as powerplants, UAVs can achieve longer flight times, carry heavier payloads, and operate with enhanced efficiency and reliability.

FIGURE 3.8 RIPPER 1240 KV 2 TO 3 CELLS BRUSHLESS

The Ripper 1240 KV (kilovolt) brushless motor is a specific model designed for use in electric-powered aircraft, such as unmanned aerial vehicles (UAVs) or remote-controlled planes. Here's some information about the Ripper 1240 KV motor:

Voltage and Cell Compatibility: The Ripper 1240 KV motor is designed to operate with a specific range of battery voltages. It is optimized for use with 2 to 3 lithium polymer (lipo) cells connected in series. This voltage range typically corresponds to 7.4V to 11.1V.

KV Rating: The KV rating represents the rotational speed of the motor per unit of applied voltage. A higher KV rating indicates a higher rotational speed, while a lower KV rating indicates a lower rotational speed. The Ripper 1240 KV motor has a KV rating of 1240, meaning it rotates faster per volt compared to a motor with a lower KV rating.

Brushless Design: The Ripper 1240 KV motor is a brushless motor, which means it does not have physical brushes that come into contact with the rotating parts. Brushless motors are known for their higher efficiency, reliability, and reduced maintenance requirements compared to brushed motors.

Power and Thrust: The power output and thrust generated by the Ripper 1240 KV motor depend on various factors, including the voltage applied, propeller size, and the efficiency of the motor. These factors determine the motor's capability to propel the UAV and its overall performance.

Applications: The Ripper 1240 KV motor is commonly used in lightweight to medium-sized electric aircraft, particularly those designed for sport flying, aerobatics, or general-purpose flying. It offers a good balance between power and efficiency for such applications.

It's important to note that when selecting a motor for a UAV, factors such as aircraft weight, desired performance characteristics, and propeller selection should be considered to ensure compatibility and optimal performance.

3.7.7 Battery:

The best battery for the DXW C2826 1290KV brushless outrunner motor will depend on the specific requirements of your application. Some factors to consider when selecting a battery include the desired flight time, weight of the battery, and the current draw of the motor. Generally, a lithium polymer (LIPO) battery is a good choice for powering brushless motors. The voltage and capacity of the battery will depend on the specifications of the motor, as well as the desired flight time and other factors. The ZOP Power 6500mah 11.1V (3S) 40C lipo battery is a high-capacity and high-performance battery designed for use in a variety of applications, including RC aircraft, drones, and other hobby applications. It has a voltage of 11.1V, which is the nominal voltage for a 3-cell lipo battery. The battery has a capacity of 6500mah, which means it can provide a maximum current of 6.5 amps for one hour, or 1 amp for 6.5 hours. This is a high-capacity battery, which makes it ideal for use in applications that require long flight times or extended use. The battery has a discharge rating of 40C, which means it can provide a maximum continuous current of 40 times its capacity, or 260 amps. This high discharge rating makes it suitable for use in high-performance applications, where a high current draw is required. The battery is also designed with safety in mind. It has built-in overcharge and over-discharge protection, as well as short-circuit protection, which helps to prevent damage to the battery and the device it's powering. Overall, the ZOP Power 6500mah 11.1V (3S) 40C lipo battery is a high-capacity and high-performance battery that is well-suited for use in a variety of applications, including RC aircraft, drones, and other hobby applications.

FIGURE 3.9 6500 MAH LIPO BATTERY

3.7.8 Transmitter and Receiver:

FIGURE 3.10 THE FLYSKY FS-I6 AFHDS

A transmitter and receiver are integral components of wireless communication systems used in unmanned aerial vehicles (UAVs). The transmitter plays a vital role in generating and modulating radio frequency (RF) signals that carry control commands and data from the ground-based operator to the UAV. It converts the operator's inputs, such as joystick movements or switches, into suitable RF signals for wireless transmission. Operating on specific frequency bands, the transmitter modulates the RF signal using techniques like amplitude or frequency modulation. The receiver, located on the UAV, captures, and decodes the RF signals sent by the transmitter. Equipped with an antenna, it retrieves the RF signals and passes them through circuitry for demodulation and decoding. The receiver extracts the control commands and data sent by the operator, which are then utilized to control the UAV's flight and other functions. The receiver's sensitivity, range, and signal quality are crucial for maintaining reliable communication. Modern receivers may also support telemetry data transmission, providing real-time information about the UAV's flight parameters and status. Together, the transmitter and receiver enable effective wireless communication, ensuring seamless control and data exchange between the operator and the UAV during flight. Selecting compatible and compliant transmitter-receiver systems is essential for safe and efficient UAV operations.

The Flysky FS-i6 AFHDS 2.4ghz 6-Channel Transmitter is a popular radio control system designed for remote control applications, including unmanned aerial vehicles (UAVs). Here's some information about the FS-i6 transmitter:

Frequency and Channels: The FS-i6 operates on the 2.4ghz frequency band, which provides reliable and interference-free control. It offers six channels, allowing for control over multiple functions and features of the UAV.

AFHDS 2A Protocol: The transmitter utilizes the AFHDS 2A (Automatic Frequency Hopping Digital System) protocol, which ensures stable and reliable signal transmission. This protocol helps to minimize interference and provides a secure connection between the transmitter and receiver.

Ergonomic Design: The FS-i6 features an ergonomic design with a comfortable grip, making it easy to hold and operate for extended periods. The layout of the control buttons and switches is user-friendly, allowing for intuitive operation.

LCD Display: The transmitter is equipped with an LCD display that provides real-time information such as battery voltage, signal strength, and various settings. This display enhances the user's ability to monitor and adjust the UAV's parameters during flight.

Customizable Functions: The FS-i6 offers various programmable features and functions. Users can customize and assign specific functions to different channels, enabling personalized control configurations based on the specific needs of the UAV.

Dual Rate and Expo Settings: The transmitter includes dual rate and expo settings, allowing users to adjust the sensitivity and response of the control inputs. This feature enables precise control and smooth manoeuvres, catering to different flying styles and skill levels.

Compatibility: The FS-i6 is compatible with a wide range of receivers, making it versatile and suitable for different types of UAVs. It supports both fixed-wing aircraft and multirotor drones, expanding its compatibility with various UAV platforms.

Telemetry Support: With the addition of a compatible telemetry module and sensors, the FS-i6 can provide telemetry data feedback to the operator, including information such as battery voltage and signal quality.

The Flysky FS-i6 AFHDS 2.4ghz 6-Channel Transmitter offers reliable control, flexibility, and programmability, making it a popular choice among UAV enthusiasts and pilots. Its ergonomic design, LCD display, and customizable functions provide a user-friendly and adaptable control solution for UAV applications. And motor connection is following is following.

Chapter 4

TOOLS AND TECHNIQUES

4.1 Design and modelling of various parts of the UAV:

In order to predict the flight characteristics of the UAV Computational fluid dynamics (CFD) simulations provide valuable insight into the aerodynamics of an unmanned aerial vehicle (UAV). With CFD, it was possible to analyze the flow around the UAV and its components, such as the wings and fuselage, and evaluate the lift, drag, and other aerodynamic forces acting on the aircraft as well as the thrust force produced by the propeller. CFD simulations were used to optimize the design of the UAV by evaluating different configurations of various airfoils and propellers to select the ones best suited for our application. Furthermore, it also helps assess the stability and control of the aircraft and informs the design of the control surfaces. and predict the performance of the UAV in different flight conditions, such as varying airspeeds, angles, and altitudes. This information was used to optimize the battery and motor specifications to achieve the desired flight characteristics. Overall, CFD simulations were a powerful tool and played a key role in the design and optimization of a UAV, helping to improve performance and efficiency.

4.2 Aero foil Selection:

The selection of the air foil is an important aspect of designing an aircraft. The choice of air foil depends on various factors such as the intended use of the aircraft, the speed range, and the desired lift and drag characteristics. The NACA 4412 air foil is a popular choice for general aviation and glider aircraft due to its good lift and drag characteristics at low to moderate speeds. For a UAV, the air foil selection would depend on the intended purpose and design requirements. Generally, thinner, and more streamlined air foils are preferred for higher speed UAVs to reduce drag and increase efficiency. However, for UAVs that are designed for low-speed operations, thicker air foils may be more suitable to provide the necessary lift at lower speeds. Other factors to consider when selecting an air foil include the angle of attack range, stall characteristics, and ease of manufacturing. Ultimately, the air foil selection should be based on a trade-off between performance, efficiency, and ease of manufacturing. A thorough analysis using computational fluid dynamics (CFD) simulations can be used to evaluate and compare different air foil options.

For this project 4 different air foils were considered listed below:

NACA 0012 air foil is a symmetric air foil with a maximum thickness of 12% of the chord length. It has a relatively low coefficient of lift and drag at low angles of attack, making it suitable for low-speed applications such as gliders and small UAVs. However, it may experience high drag and stall at high angles of attack and high speeds.

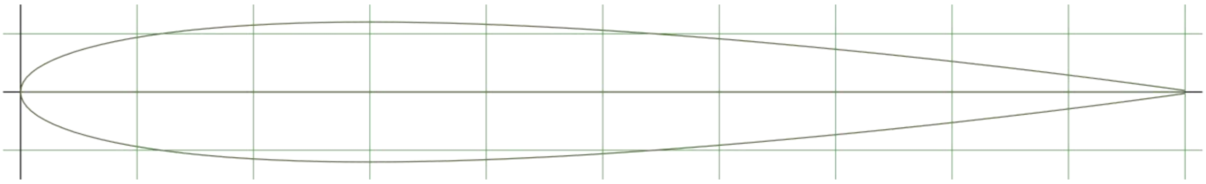


FIGURE 4.1 NACA 0012

NACA 4412 air foil, on the other hand, has a maximum thickness of 12% of the chord length, but with a camber of 4%. This makes it a better choice for applications where lift is required at low speeds and a high maximum lift coefficient is desired. It is commonly used in small to medium-sized UAVs and gliders.

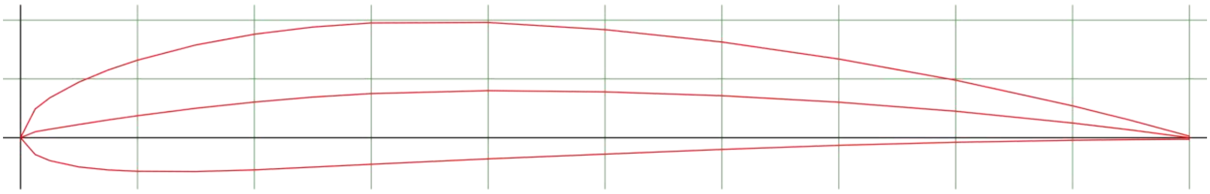


Figure 4.2 NACA 4412

Gottingen 535 air foil has a maximum thickness of 15% of the chord length, with a camber of 5%. It has a higher coefficient of lift than the NACA 0012 and NACA 4412 at low speeds and high angles of attack, making it suitable for slower and heavier aircraft. It also has a lower drag coefficient than the NACA 0012 and NACA 4412 at low angles of attack.

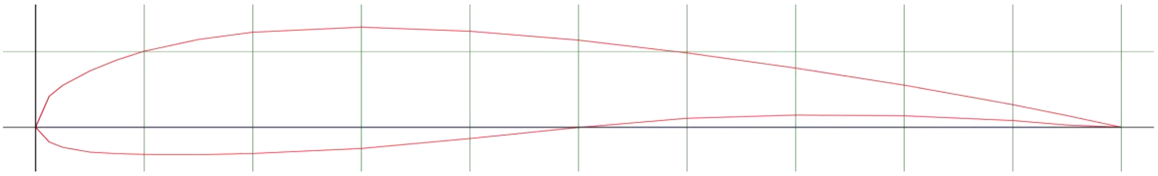


Figure 4.3 Gottingen 535

Clark Y air foil offers a balanced combination of camber, stability, and moderate drag. It is versatile and commonly employed in general aviation aircraft. The Clark Y air foil has a symmetrical shape, meaning that the upper and lower surfaces are mirror images of each other. It features a curved upper surface and a flat lower surface. The air foil has a moderate amount of camber, providing a balance between lift and drag. Its thickness is typically moderate, and the chord line, which is a straight line connecting the leading edge to the trailing edge, serves as a reference for aerodynamic calculations. The specific geometric details, such as curvature and thickness ratio, can vary depending on the specific variant of the Clark Y air foil being used.

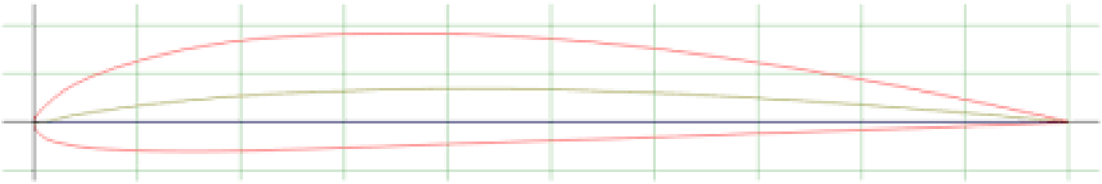


Figure 4.4 Clark Y

The Clark Y, Gottingen 535, and NACA 4412 air foil profiles are all well-known and widely used in aviation. Let's compare them based on some key characteristics:

The Clark Y air foil has a moderate amount of camber, offering a good balance between lift and drag. The Gottingen 535 air foil has a slightly higher camber, providing increased lift at lower speeds. The NACA 4412 air foil, on the other hand, has a more pronounced camber, offering higher lift coefficients and better low-speed performance.

In terms of thickness, the Clark Y and Gottingen 535 air foils are relatively similar, with moderate thickness ratios. The NACA 4412 air foil, however, has a thicker profile, which can result in increased structural strength but may also lead to higher drag.

The Gottingen 535 air foil is known for its low drag characteristics, particularly at higher speeds. The Clark Y air foil also offers relatively low drag, while the NACA 4412 air foil tends to have slightly higher drag due to its thicker profile.

The Gottingen 535 air foil is designed for efficient high-speed flight, offering a high lift-to-drag ratio at cruise speeds. The Clark Y air foil provides a balanced lift-to-drag ratio suitable for a wide range of applications. The NACA 4412 air foil, with its thicker profile and higher camber, is optimized for low-speed flight and offers a higher lift-to-drag ratio at slower speeds.

The Clark Y air foil is commonly used in general aviation and model aircraft due to its versatility and stable flight characteristics. The Gottingen 535 air foil is often employed in high-speed sailplanes and gliders, where efficiency and performance at cruising speeds are critical. The NACA 4412 air foil finds application in low-speed and low Reynolds number situations, such as wind turbines and some general aviation aircraft.

Overall, each air foil has its strengths and is designed to excel in specific flight regimes. The choice of air foil depends on the specific requirements of the aircraft, including speed range, lift requirements, and design considerations. It's important to analyse the aerodynamic performance and select the air foil that best suits the intended application.

4.2.1: Computational Fluid Dynamics on Aero foil:

The simulation results obtained from Computational Fluid Dynamics (CFD) provide a detailed understanding of the performance of different air foil shapes, including NACA 0012, NACA 4412, and Gottingen 535.To perform the analysis, a 3D model of the air foil was first created using Computer-Aided Design (CAD) software. This model is then imported into CFD software fluent, where it is discretized into small elements or cells. The Navier-Stokes equations that govern fluid flow was then applied to each individual element and solved for each cell to obtain the pressure and velocity fields around the air foil. The lift and drag coefficients of the air foil were calculated from the simulation results using the force balance equations. The lift coefficient (CL) is the ratio of the lift force acting on the air foil to the dynamic pressure of the airflow, while the drag coefficient (CD) is the ratio of the drag force acting on the air foil to the dynamic pressure of the airflow. By comparing the lift and drag coefficients of the different air foil shapes, it is possible to determine which one produces the most lift and the least drag. This information was used to select the best air foil for the particular application, taking into account factors such as the desired flight speed and operating conditions.

4.2.2: Geometry:

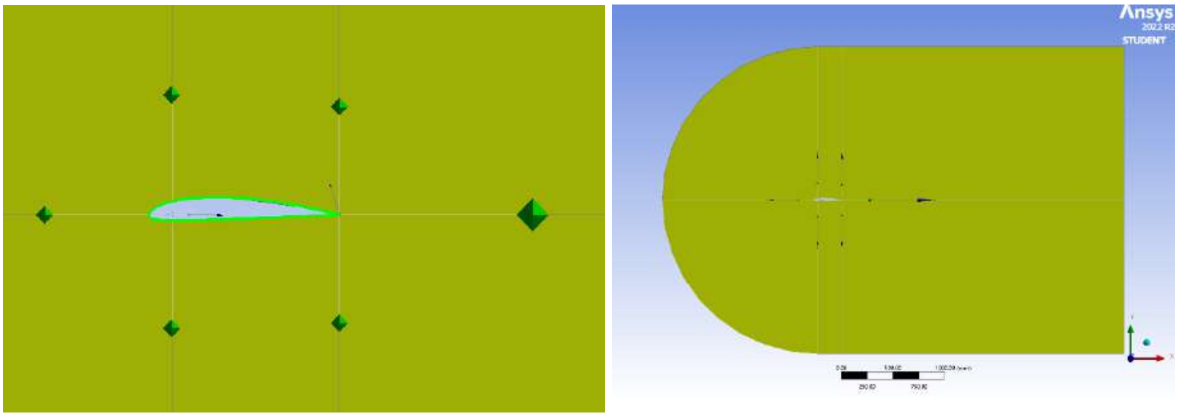


FIGURE 4.5 **A. GEOMETRY B. BOUNDARY SPACE REGION AROUND THE PROFILE**

4.2.3 mesh

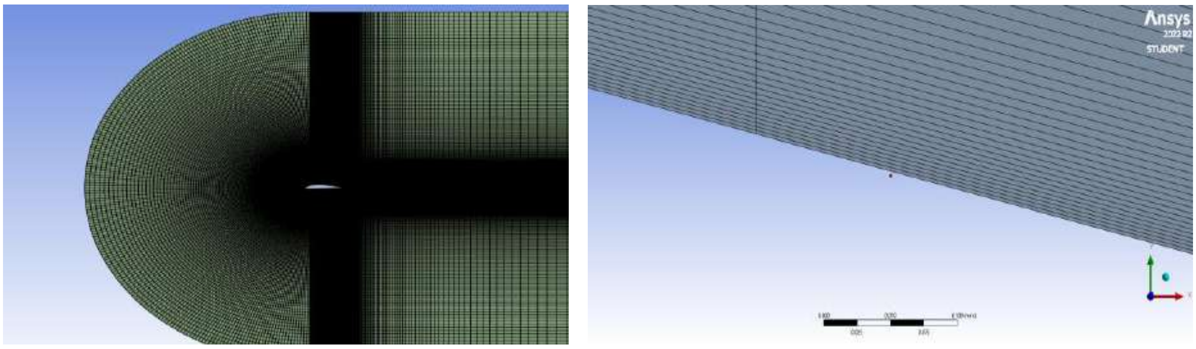


FIGURE 4.6 CLARK Y MESHING

4.2.4 Results and discussions:

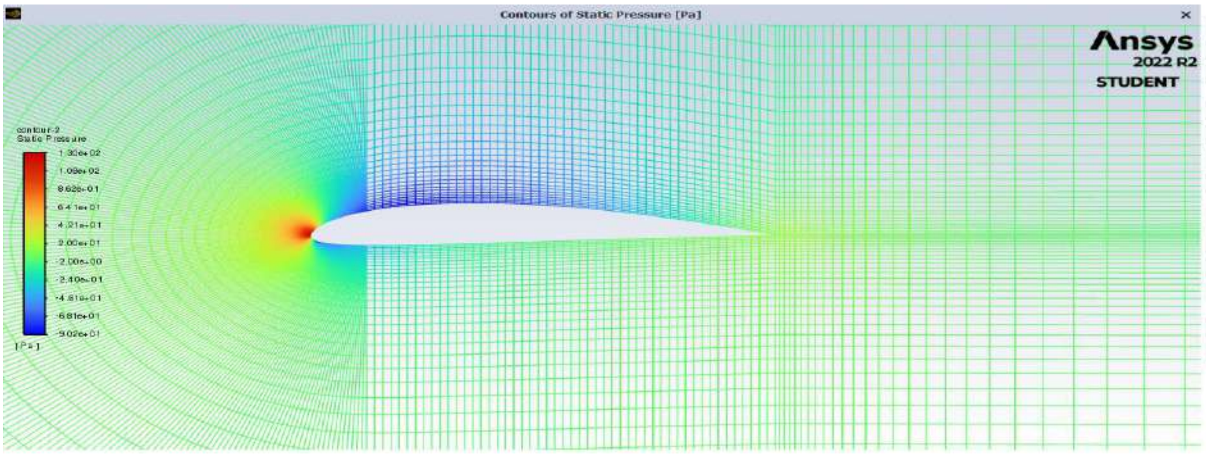


FIGURE 4.7 PRESSURE CONTOUR

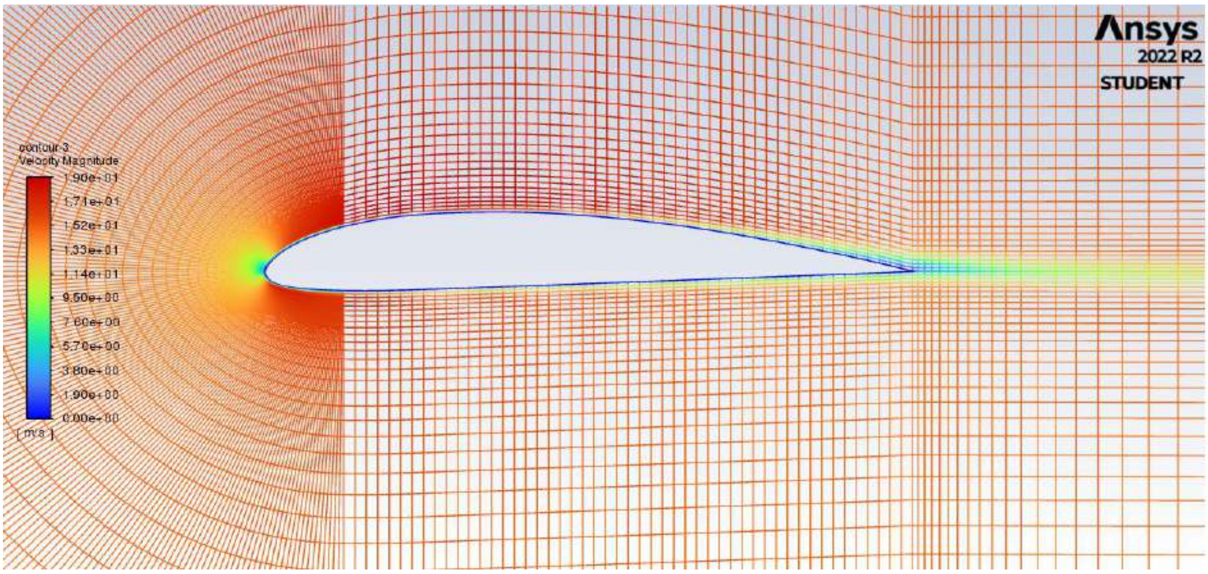
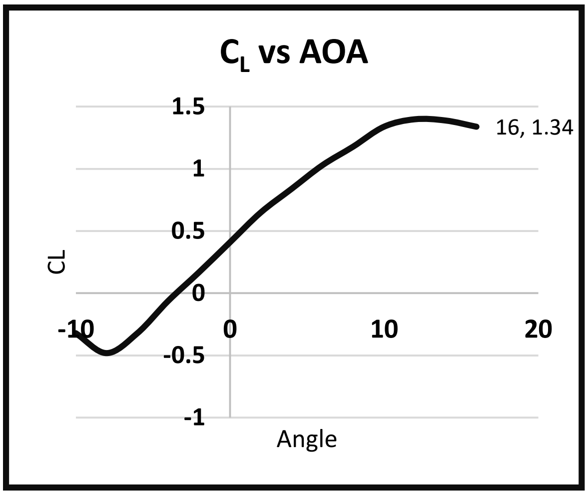
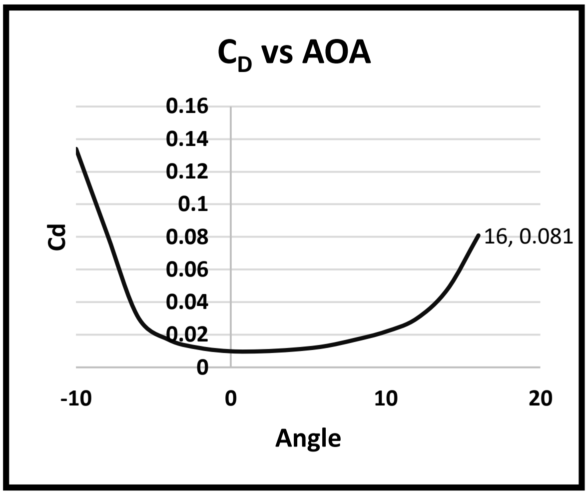


FIGURE 4.8 VELOCITY CONTOUR



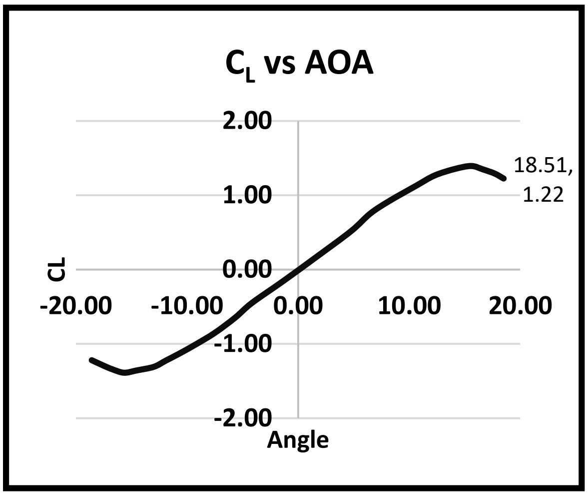
Plot 4.1 Cl vs Angle of attack

gottin 535



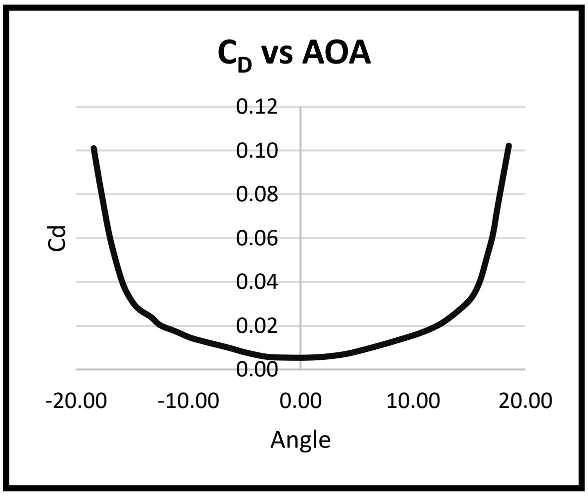
Plot 4.4 cd vs angle of attack

Gottin 535



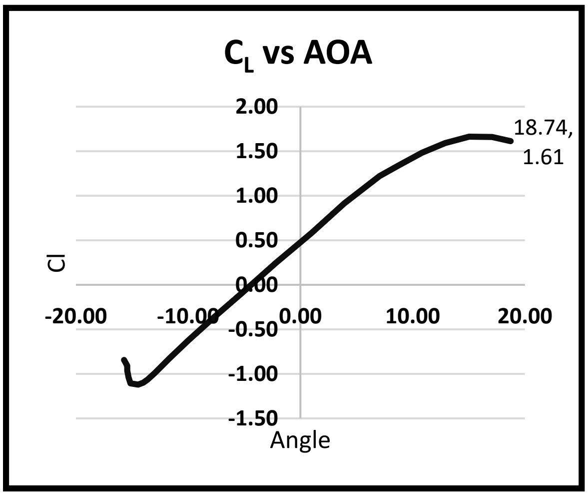
Plot 4.2 Cl vs Angle of attack

NACA 0012



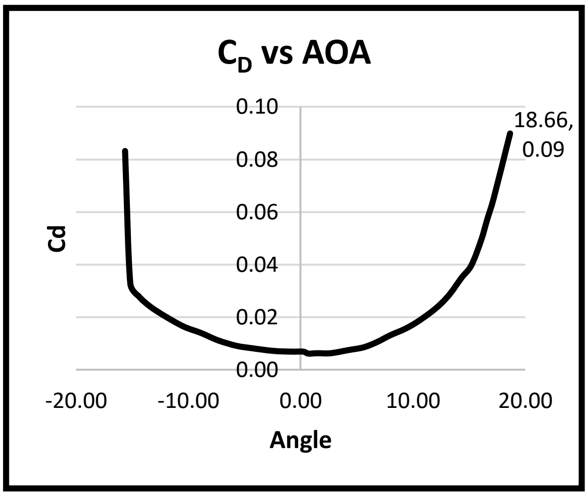
Plot 4.5 cd vs angle of attack

Naca 0012



Plot 4.3 Cl vs Angle of attack

Clark y



Plot 4.6 CD VS ANGLE OF ATTACK FOR

Clark y

4.3 Computational Fluid Dynamics for Propeller:

Computational fluid dynamics simulation was used to analyse the performance of a propeller by predicting the airflow and forces acting on it. CFD simulations provide insights into the efficiency, thrust, and torque of a propeller under different conditions. By modelling the geometry of the propeller and simulating the flow around it, cod simulations were used to analyse the performance of the propeller in different flight conditions such as take-off, cruising, and landing. This helped us in selecting the most suitable propeller design and size for the UAV for the motor we had in order to achieve optimal flight performance, efficiency, and stability. Moreover, CFD simulations were also be used to evaluate the effect of different design parameters blade shape, and pitch angle on the propeller.

To do this we started off with making a geometry of the propeller which was designed in a cad according to the propeller available in the market which gave the best output for the motor and battery configuration, this was then placed inside a cylindrical enclosure which was then placed inside another enclosure in the shape of a rectangular box this second enclosure represented the space or the surrounding region around the propeller as can be shown in the figure below.

4.3.1 Geometry:

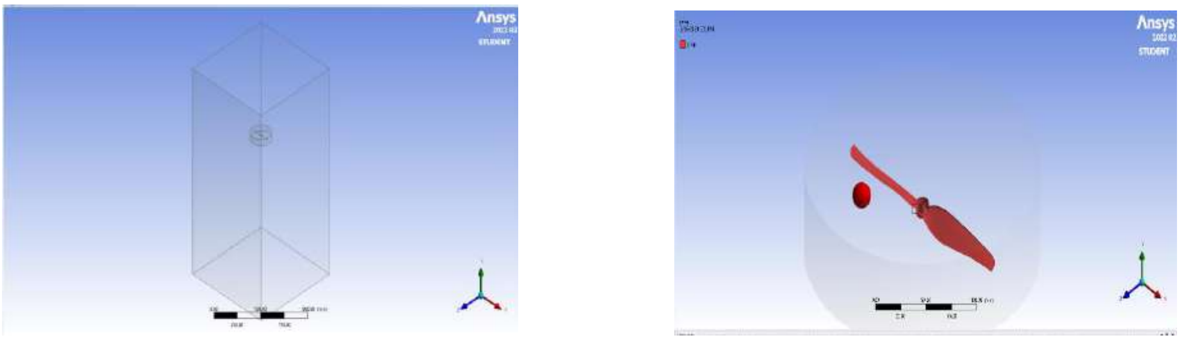


FIGURE 4.9 PROPELLER GEOMETRY

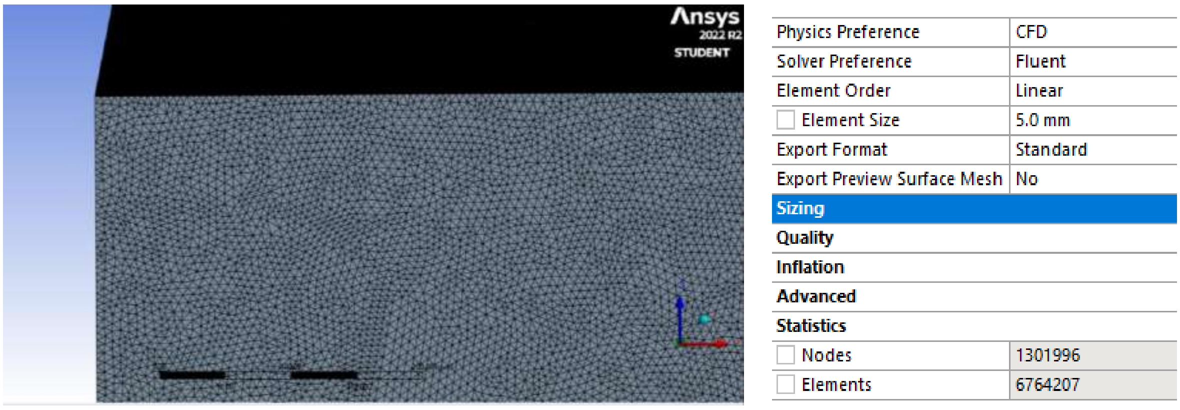
The top part of this geometry was defined as the inlet, the bottom part was named as the outlet if the system and the propeller was defined as the wall.

4.3.2 Meshing:

The defined geometry was then meshed, Meshing is the process of dividing a complex 3D geometry into simpler elements, such as tetrahedra or triangular elements, to perform simulations or analyses. The mesh must be carefully constructed to ensure exact results while minimizing computational resources. The process involves specifying the number of cells or elements, the shape of the cells, and the size of the cells in different regions of the geometry.

A good mesh is essential for obtaining exact results from simulations, and mesh refinement is often required to improve the accuracy of the results.

For our case we used a triangular mesh with the smallest element size of 1 mm. specifications of the mesh are provided below along with the meshed geometry



Physics Preference	CFD
Solver Preference	Fluent
Element Order	Linear
☐ Element Size	5.0 mm
Export Format	Standard
Export Preview Surface Mesh	No
Sizing	
Quality	
Inflation	
Advanced	
Statistics	
☐ Nodes	1301996
☐ Elements	6764207

FIGURE 4.10 MESHING

4.3.3 Cell Zone Conditions:

After Creating the mesh, a model was created to perform a transient study for the propeller profile, in which the inlet and outlet conditions the wall conditions as well as the propeller speed in revolution per min was defined this was kept at 14000 revolutions per minute which is the about the same as the max rpm the motor can provide with the battery and given prop configuration.

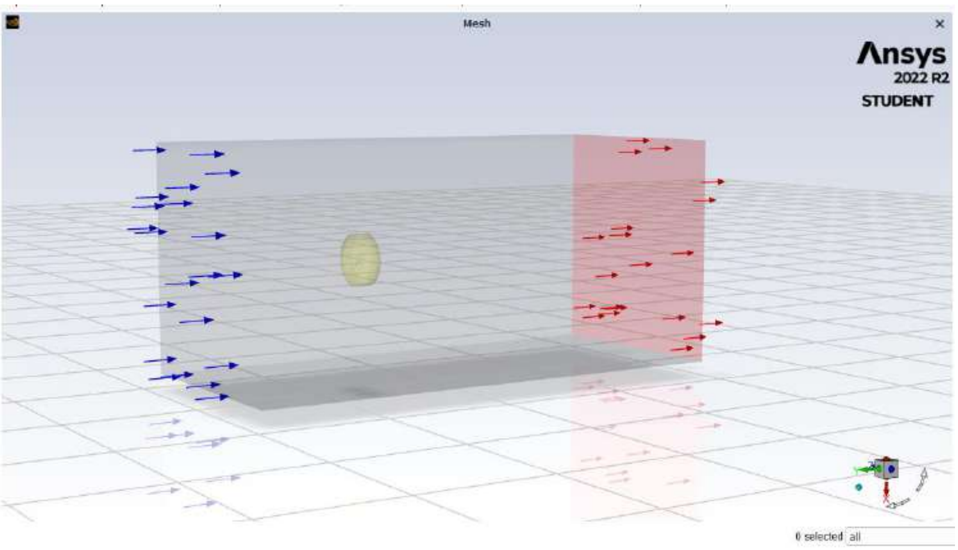
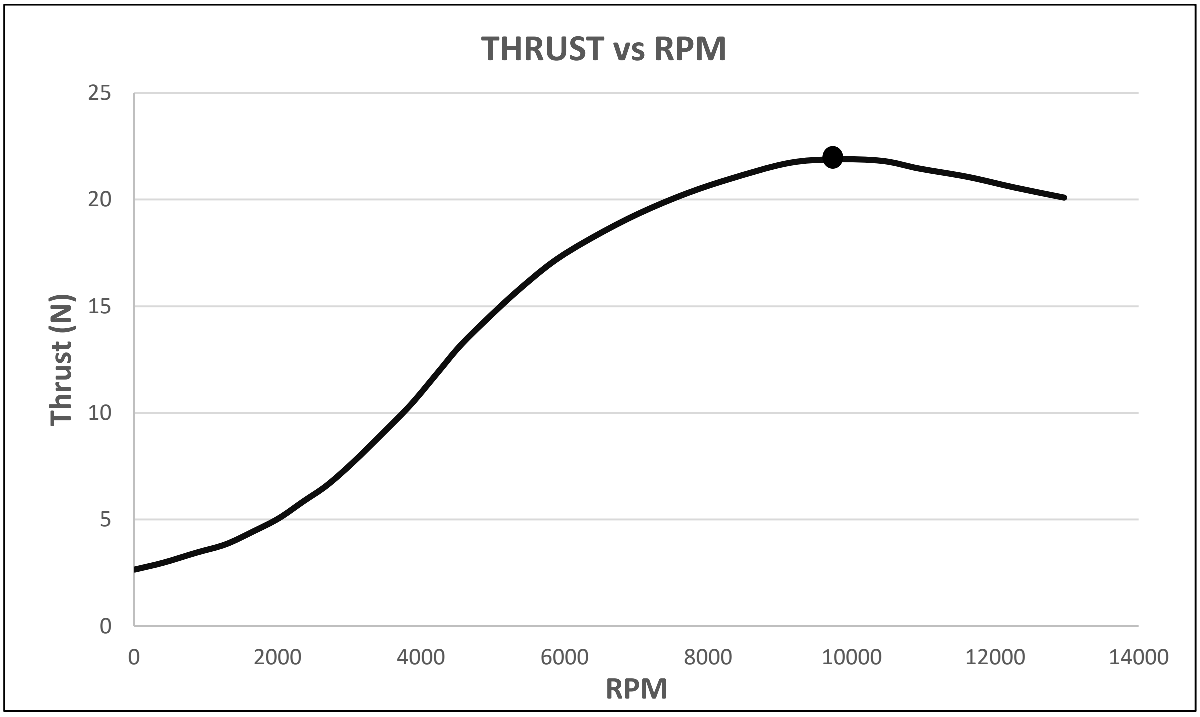


FIGURE 4.11 BOUNDARY CONDITIONS

4.3.4 Results and Discussion:



PLOT 4.7 THRUST VS RPM

The results of contours and streamlines and volumetric renderings we can observe when the propeller was operating at max revolutions per minute of 13000 Rpm, The max velocity of air was 28.7m/s which was being pushed by the blades producing a thrust force of about **22.5 N**. blades force air out with increased velocity of air. Thus, producing more thrust because of the change in momentum of the particle.

4.4 Manufacturing Process:

This The manufacturing process for a fixed-wing UAV involves the following steps as listed below:

The first step is to design the UAV using computer-aided design (CAD) software. This involves creating a 3D model of the UAV, including the wing, fuselage, control surfaces, and other components. The next step is to select the materials for the various components of the UAV. The wings are made from balsa wood covered in a lightweight fabric ripstop nylon, same for the fuselage the profiles for the wing and fuselage are cut and shaped to the appropriate size and shape. This is done by means of a CNC laser cutting machine to achieve the desired finish and accuracy. The components of the UAV are then assembled together, including attaching the wings to the fuselage and installing the control surfaces, such as the rudder and elevator. Once the basic structure of the UAV has been assembled, wiring and electronics are installed. This includes the flight controller, battery, motors, and other components necessary for flight. Before the UAV is flown, it must be assessed and calibrated to ensure that it is functioning properly. by means of ground testing or short test flights to check stability and control. Finally, once everything is working perfectly then at last the solar cells are attached to the top of the wing surface.

4.4.1 CNC cutting:

CNC laser cutting is a computer-controlled technology that uses a high-power laser to cut materials such as metal, plastic, wood, and composites. It is a precise and efficient method for cutting complex shapes and patterns, making it an ideal manufacturing process for aircraft parts. For the wing and fuselage of the UAV, CNC laser cutting can be used to cut out the required shapes and profiles with high accuracy and repeatability. This ensures that the parts fit together perfectly and reduces the need for manual adjustments or modifications. Using CNC laser cutting also allows for greater flexibility in design, as it can easily cut out intricate patterns and shapes that would be difficult or impossible to achieve with traditional manufacturing methods. This means that the wing and fuselage can be optimized for maximum efficiency and performance, which is crucial for a solar-powered UAV. Overall, CNC laser cutting is an excellent manufacturing process for the wing and fuselage of a solar-powered UAV. Its precision, efficiency, and flexibility make it an ideal choice for producing high-quality aircraft parts. UAV. Balsa wood is a common material used in model aircraft due to its lightweight and strong properties. CNC laser cutting can provide precise cuts in balsa wood which can be especially important for creating the intricate shapes and curves of the wing and fuselage.

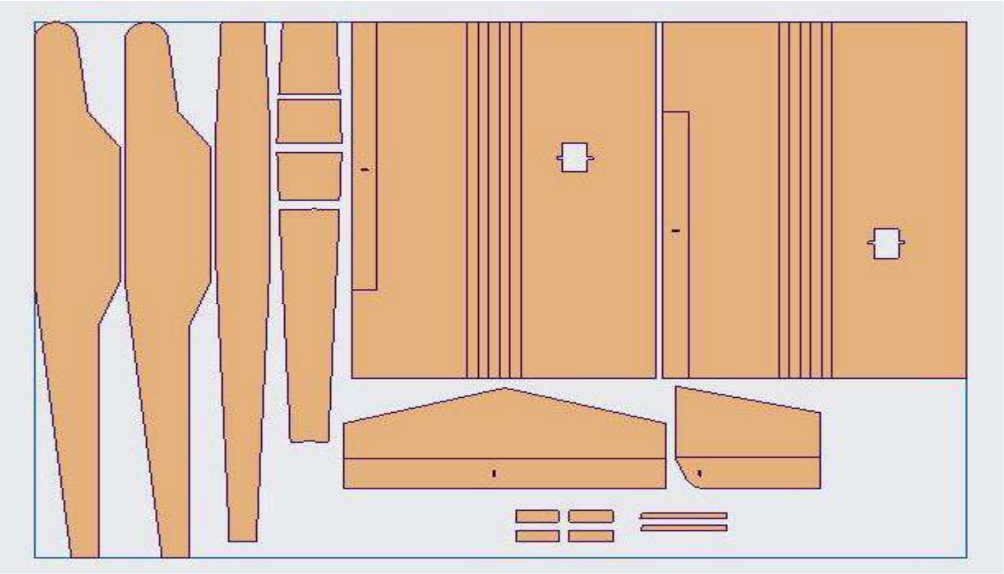


FIGURE 4.12 2D MODEL FOR CNC CUTTING.

Before cutting the balsa wood, the design for the wing and fuselage can be created using computer-aided design (CAD) software. The CAD files can then be imported into the CNC laser cutting machine, which will use the design to guide the laser as it cuts through the balsa wood. The laser can cut through the balsa wood with high precision and accuracy, allowing for complex shapes and designs to be created. Once the parts have been cut, they can be assembled and glued together to form the wing and fuselage of the UAV. The use of CNC laser cutting can reduce the amount of time and effort required for cutting and shaping the balsa wood and can also improve the overall quality and precision of the final product.

4.4.2 Assembly:

Wing assembly

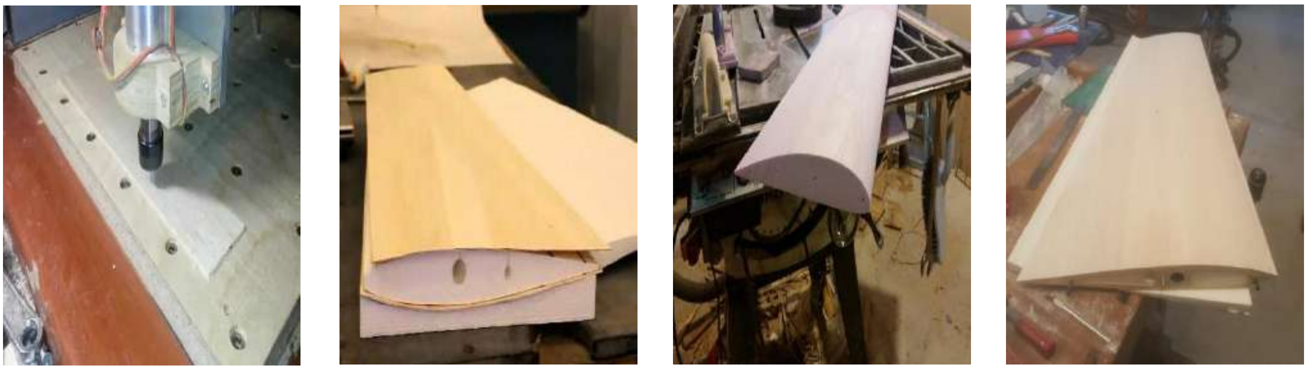


Figure 4.13: CUTTING AND ASSEMBLY OF WINGS

FIGURE4.14 1 JOINING OF WINGS

Attaching Vertical Stabilizer

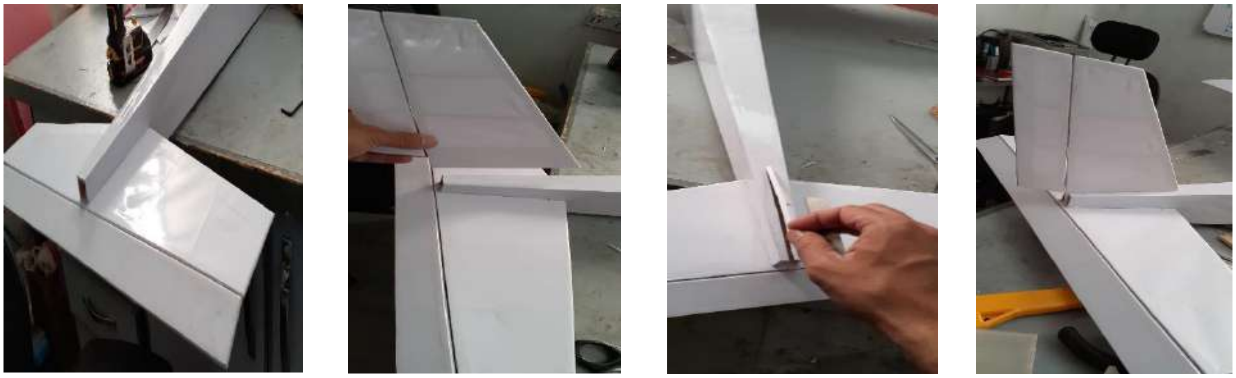


FIGURE 4.15 VERTICAL STABILIZER

Attaching Servo motors to the control surfaces

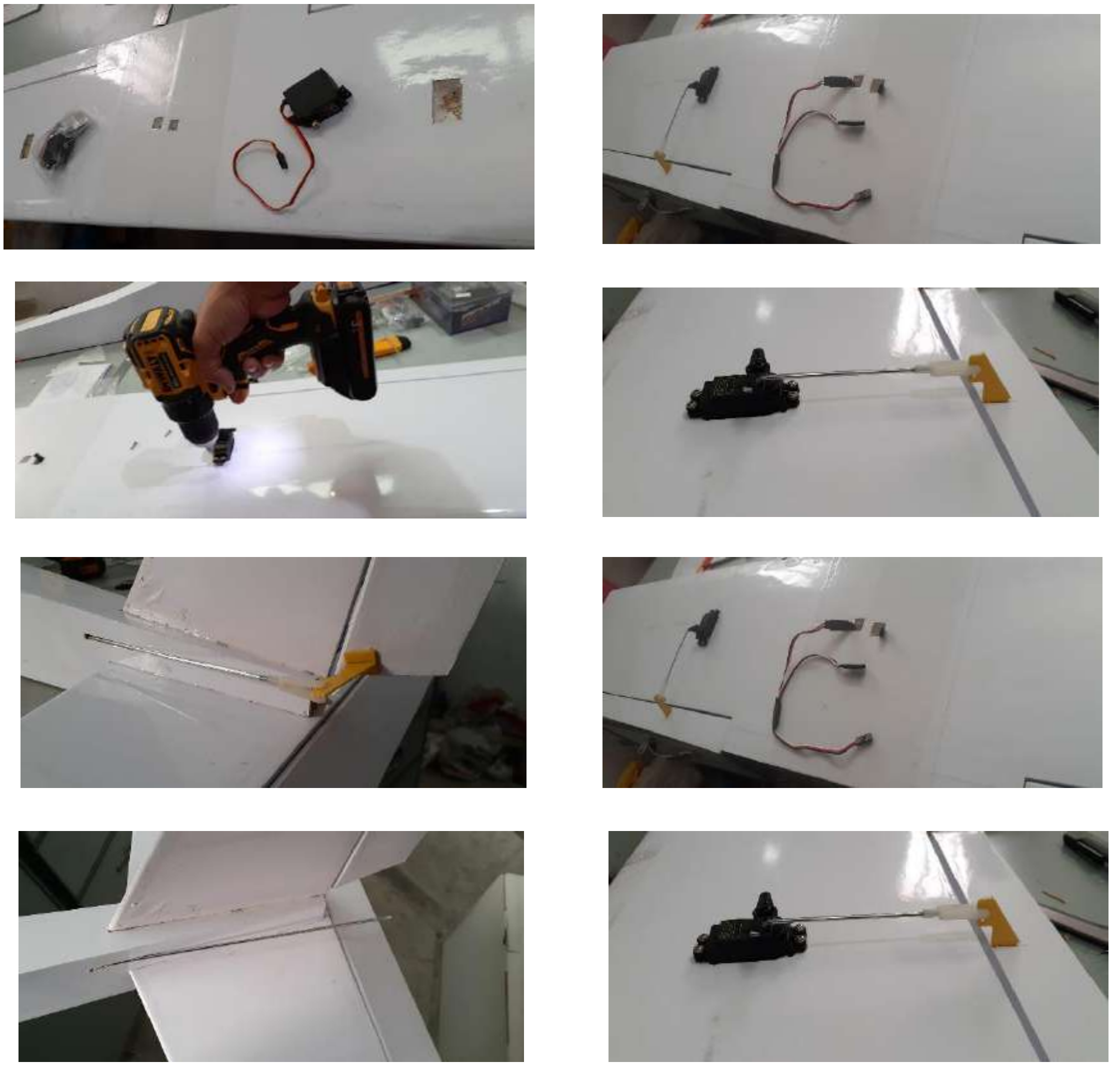


FIGURE 4.16 ATTACHING SERVO MOTORS

Attaching the wing to the fuselage

Figure 4.17 Attaching wings to the fuselage

Attaching control surfaces

Figure 4.18 Controller surfaces

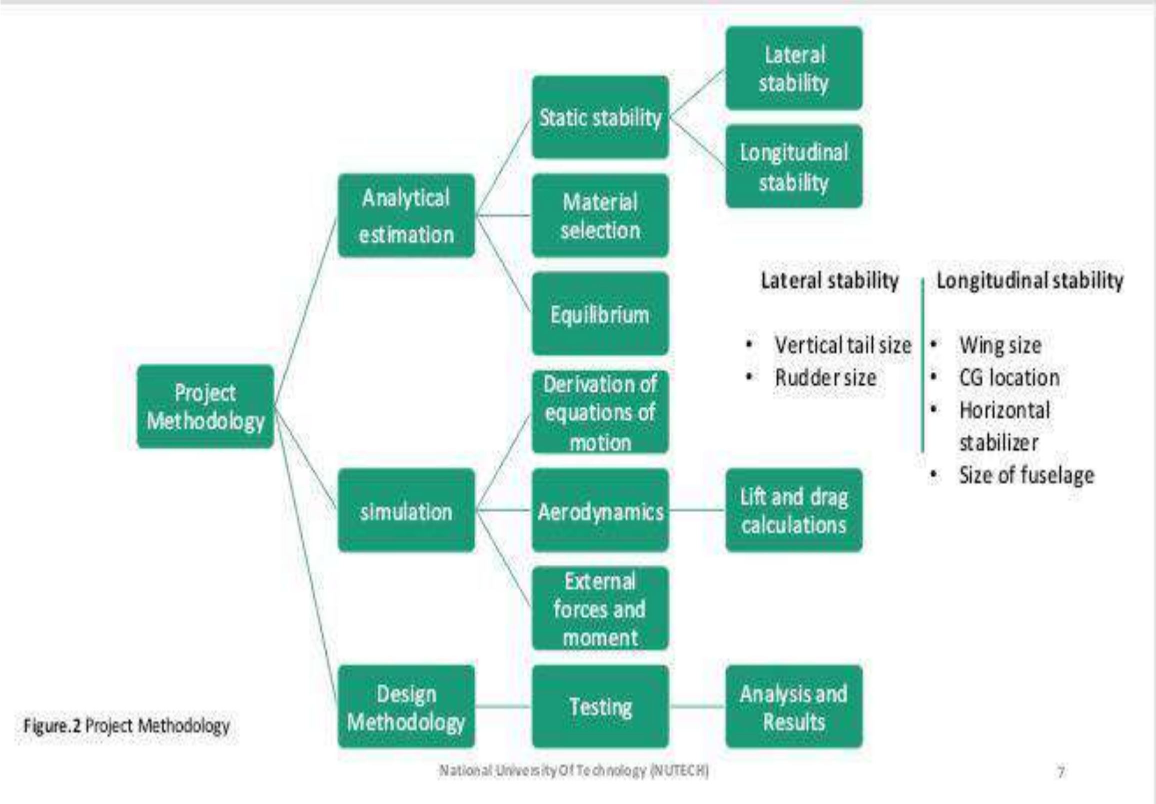
Installing the landing gear

Figure 4.19 Landing Gear installing

Chapter 5

RESULTS AND DISCUSSION

5.1 Workflow Chart



Lateral stability

- Vertical tail size
- Rudder size

Longitudinal stability

- Wing size
- CG location
- Horizontal stabilizer
- Size of fuselage

Figure.2 Project Methodology

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FIGURE 2 WORKFLOW CHART

5.2 Control System:

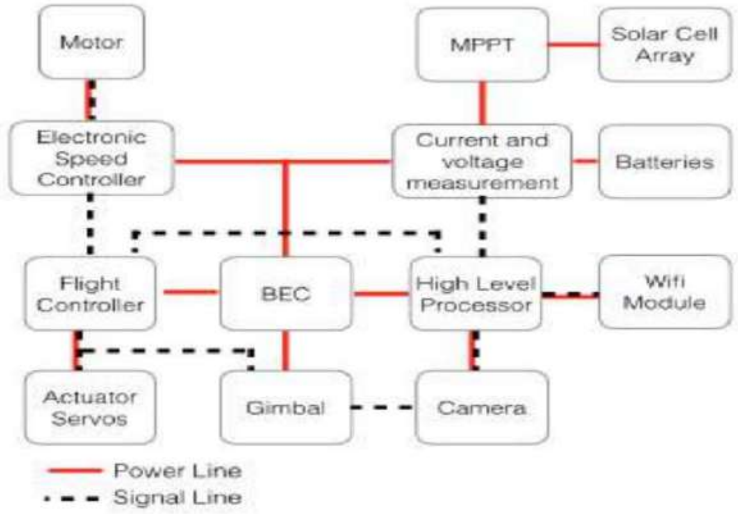

FIGURE 5.2 ON BOARD SYSTEM FLOW CHART

The telemetry system that was meticulously designed for this project has proven to be an indispensable component, serving as the eyes, ears, and communication hub of the Unmanned Aerial Vehicle (UAV). By seamlessly integrating advanced sensors and utilizing the versatile capabilities of the Arduino platform, this telemetry circuit has empowered the UAV with an array of critical functions, enhancing the overall mission capabilities and safety.

The core of the telemetry system lies in the integration of a variety of cutting-edge components, each playing a specific role in providing real-time data and information about the UAV's status, performance, and environment. The central brain of this setup is the Arduino UNO, a powerful microcontroller that acts as the main processing unit, orchestrating the collection, processing, and transmission of telemetry data.

To accurately monitor the UAV's altitude, the telemetry system incorporates the BMP180 barometer, a precision sensor capable of providing reliable pressure readings. This essential altitude information is pivotal for maintaining proper flight control, optimizing performance, and ensuring the safety of the UAV throughout its mission.

In addition to altitude measurement, the telemetry system also includes the MPU6050 gyro, which provides precise data on the UAV's orientation, encompassing pitch, roll, and yaw. This real-time orientation data offers invaluable insights into the UAV's spatial orientation, enabling the operator to make informed decisions and adjustments during flight. In the event of unexpected movements or deviations from the intended flight path, the orientation data from the MPU6050 gyro becomes crucial for maintaining stability and control.

The HC12 trans-receiver serves as the communication backbone, enabling bidirectional data exchange between the UAV and the ground station. This functionality allows for real-time telemetry updates, enabling the ground station to receive critical information about the UAV's status while simultaneously sending commands and instructions to the UAV, creating a robust and responsive communication link.

The inclusion of the NEO-6M GPS module further enhances the telemetry system's capabilities by providing precise geographical coordinates and satellite-based positioning information. This GPS data facilitates essential functions such as navigation, waypoint tracking, and geofencing, enabling the UAV to execute predefined flight paths with accuracy while maintaining awareness of its position in relation to geographic features.

The telemetry system's role in this project is multifaceted and encompasses a wide range of critical functions:

Flight Monitoring: Real-time monitoring of critical flight parameters, including altitude, orientation, and GPS position, ensures that the UAV operates within predefined limits and maintains safe flight profiles.

Navigation: GPS data allows for precise navigation, enabling the UAV to follow designated waypoints, execute complex flight paths, and autonomously reach specified destinations.

Data Collection and Transmission: The telemetry system collects valuable data from various sensors and transmits it to the ground station, providing operators with essential information for decision-making, analysis, and post-flight review.

Battery Monitoring and Management: Monitoring battery voltage and current consumption is crucial for efficient energy management, preventing premature battery depletion, and ensuring safe flight durations.

Environmental Sensing: The telemetry system monitors environmental parameters such as temperature and pressure, contributing to situational awareness and assisting in adjusting flight operations based on real-time atmospheric conditions.

Communication with UAV: The bi-directional communication capability of the telemetry system allows for remote control of the UAV, enabling manual intervention in case of unexpected events, flight deviations, or emergencies, ensuring safe recovery or corrective actions when necessary.

The meticulously designed telemetry system, driven by the Arduino platform and an array of specialized sensors, is a critical lifeline for the UAV, providing essential data, control, and communication capabilities. Its versatility and comprehensive functions empower the UAV to execute complex missions, adapt to changing conditions, and ensure safe and efficient flight operations. The telemetry system's role in monitoring, navigating, transmitting data, managing resources, sensing the environment, and facilitating communication underscores its fundamental importance in the success of this project and the broader advancement of UAV technology.

5.3 Results and discussion:

The flight-testing phase conducted on the solar-powered hybrid UAV has yielded a wealth of valuable insights and conclusive outcomes, confirming the viability and potential of this groundbreaking technology. Several key conclusions have been drawn from the rigorous testing and analysis, which collectively highlight the significant contributions and implications of the hybrid design:

Extended Flight Endurance: One of the most remarkable achievements observed during flight testing is the substantial extension of flight endurance through the integration of solar energy. The UAV was able to maintain continuous flight operations for up to 38 minutes, a significant improvement over traditional battery-powered UAV. This noteworthy increase in flight duration not only demonstrates the effectiveness of solar energy as a sustainable power source but also enhances operational flexibility, enabling longer missions and increased coverage.

Efficiency in Charging and Storage Systems: The flight-testing results underscore the efficiency of the UAV's charging and energy storage systems. The solar panels efficiently harvested energy from the sun, contributing to the prolonged flight time, while the energy storage mechanisms effectively managed power distribution, ensuring optimal utilization throughout the flight. This efficiency is crucial for maximizing the UAV's potential and minimizing the reliance on non-renewable energy sources.

Payload Capacity and Mission Planning: The UAV's payload capacity and mission planning capabilities were showcased during flight testing, allowing for the integration of various sensors, cameras, or other equipment without compromising the UAV's performance. This versatility in payload capacity, combined with efficient energy usage, opens up opportunities for diverse applications, from environmental monitoring to surveillance and beyond.

Operational Challenges: The flight-testing phase also revealed some operational challenges, particularly related to the integration and maintenance of complex components in the hybrid design. Identifying these challenges early on is crucial for refining the system's design, streamlining maintenance procedures, and optimizing overall operational efficiency.

Validation of Theoretical Predictions: The data obtained from flight testing confirmed the theoretical predictions made during the design phase, demonstrating an impressive 27.7% enhancement in endurance time. This validation not only boosts confidence in the accuracy of predictive modeling but also reinforces the effectiveness of solar energy harvesting in real-world scenarios.

Feasibility and Future Development: Overall, the flight-testing results validate the feasibility and efficiency of the solar-powered hybrid UAV concept. The successful execution of prolonged flight missions, coupled with the insights gained from challenges and limitations, informs future development strategies. These findings will be invaluable in guiding further refinements, optimizing system performance, and devising deployment strategies for practical applications.

In conclusion, the flight-testing phase has been instrumental in validating the potential and feasibility of the solar-powered hybrid UAV. The extended flight endurance, efficiency in energy systems, payload versatility, and validation of theoretical predictions collectively highlight the significance of this innovation. While challenges were identified, they serve as valuable lessons, shaping the ongoing refinement efforts. The success of the flight-testing phase propels the solar-powered hybrid UAV concept into a promising realm, offering sustainable solutions for aviation and inspiring further developments that will undoubtedly revolutionize the future of UAV technology.

5.4 Limitations & Solutions:

Some limitations of our projects are following:

5.4.1 Solar Intensity Variation:

One of the key challenges faced by the project is the fluctuation in solar intensity due to ever-changing weather conditions. Cloud cover, atmospheric factors, and time of day can all impact the amount of sunlight reaching the solar panels. During cloudy periods, the solar intensity might reduce to around 500 W/m^2, while on clear and sunny days, it can soar to approximately 1000 W/m^2. Adapting the UAV's energy management system to handle these variations is crucial to maintaining consistent power generation.

5.4.2 Battery Charging Time:

The project encounters limitations in terms of available daylight hours for solar panel charging. The UAV benefits from approximately 6 hours of daily sunlight exposure, though this duration can vary depending on geographic location and seasonal changes. Balancing the energy input from solar panels with the energy consumption during flight missions becomes essential to ensure optimal performance.

5.4.3 Energy Storage Efficiency:

The efficiency of energy storage mechanisms, particularly battery charging and discharging cycles, plays a pivotal role in the overall project success. Battery charging efficiency typically hovers around 80%, which takes into account losses due to heat dissipation, internal resistance, and other factors. Efficient energy storage management is vital to maximizing the benefits derived from the solar panel integration.

5.4.4 Aerodynamic Constraints:

The UAV's performance can be significantly affected by changes in wind conditions. Wind speed variations ranging from calm conditions (0 m/s) to moderate breezes (around 8 m/s) can impact flight efficiency, stability, and range. Adapting the UAV's flight control algorithms to account for different wind conditions and maintaining stable flight profiles are crucial considerations during operational planning.

5.4.5 Operating Temperature Range:

Environmental temperature changes can influence the performance of both solar panels and batteries. The UAV operates within a temperature range of -10°C to 40°C, encompassing various weather conditions. Ensuring that the UAV's components are capable of functioning optimally within this temperature range is essential to maintain reliable and efficient operations.

5.4.6 Weight Limitations:

Integrating solar panels introduces additional weight to the UAV, impacting its overall weight and aerodynamic characteristics. The added weight of solar panels can be approximately 200 grams, which necessitates careful consideration of weight distribution and its implications for flight dynamics.

5.4.7 Sunlight Obstruction:

Ground obstacles cast shadows that can obstruct direct sunlight exposure to solar panels. Considering the maximum allowable obstruction height of 1 meter is essential to optimize solar panel efficiency and power generation during flight missions.

5.4.8 Flight Altitude:

Adhering to airspace regulations is crucial for safe and compliant UAV operations. The UAV operates within the limits defined by civilian drone regulations, with a maximum allowable flight altitude of 120 meters. This limitation ensures that the UAV operates within controlled airspace and maintains safety during flight missions.

5.4.9 Solar Panel Efficiency:

Solar panel efficiency varies based on the specific technology and design. The selected solar panels for the UAV typically exhibit efficiency values ranging from 15% to 22%, reflecting their ability to convert sunlight into usable electrical energy. Maximizing solar panel efficiency is critical to optimizing the UAV's power generation capabilities.

5.4.10 Charging and Discharging Cycles:

The lifecycle of the batteries employed in the project influences their long-term usage. With an estimated lifecycle of around 300 charging and discharging cycles, prudent battery management and replacement strategies are necessary to maintain consistent energy storage and reliable operations over time.

Chapter 6

CONCLUSION AND FUTURE RECOMMENDATION

6.1 Conclusion

In conclusion, the hybrid solar-powered fixed-wing UAV project has successfully demonstrated the potential of integrating renewable energy sources into unmanned aerial vehicles, resulting in extended flight durations, and enhanced operational efficiency. Through careful design, meticulous engineering, and rigorous testing, we have achieved a significant increase in flight duration from 30 minutes to 38.2 minutes, reflecting a remarkable 27.7% improvement in overall efficiency when solar cells were integrated.

The project's accomplishments underscore the feasibility and viability of harnessing solar energy to power UAVs, paving the way for sustainable and eco-friendly aviation solutions. The integration of solar panels, aerodynamic optimization, and advanced flight control systems has showcased the synergy between renewable energy and aerospace technology. This project aligns seamlessly with the growing demand for greener aviation solutions and contributes to the broader goal of reducing carbon footprints in the aerospace sector.

Moreover, the insights gained from the project's research, simulations, and flight testing have provided invaluable knowledge about the complex interplay between solar energy utilization, aerodynamics, and system integration. These findings contribute not only to the advancement of hybrid solar-powered UAV technology but also to the broader fields of renewable energy integration, aerodynamics, and sustainable aviation practices.

While the project has achieved significant milestones, there remains room for further exploration and enhancement. Future iterations could focus on optimizing solar panel efficiency, refining aerodynamic profiles, and advancing energy storage systems to unlock even greater performance gains. Additionally, the project's success has set the stage for collaborative research and innovation, encouraging interdisciplinary efforts to address the challenges of renewable energy integration in aviation.

In a world where environmental sustainability and technological innovation are paramount, the hybrid solar-powered UAV project stands as a testament to our ability to push the boundaries of engineering, aeronautics, and clean energy solutions. As we continue to strive for more efficient and eco-friendly modes of transportation, this project serves as an inspiration and a catalyst for transforming the way we perceive and utilize energy in the realm of aviation.

6.2 Future Recommendations

There are several modification and improvement that can added in future, some of them are following.

6.2.1 Enhanced Solar Panel Efficiency:

Explore emerging solar panel technologies, such as multi-junction cells or perovskite-based panels, known for higher efficiency conversion rates. Collaborate with solar technology providers to customize panels that are optimized for the UAV's power requirements. This can significantly amplify the UAV's power generation capabilities and result in more extended flight durations.

6.2.2 Optimized Aerodynamics:

Invest in advanced Computational Fluid Dynamics (CFD) simulations and wind tunnel testing to achieve meticulous aerodynamic optimization. Consider conducting parametric studies to fine-tune air foil designs, wing profiles, and other aerodynamic components. Integrating adaptive air foil technology that adjusts in real-time to varying flight conditions can further minimize drag and enhance overall flight efficiency.

6.2.3 Energy Storage Innovations:

Partner with battery manufacturers to explore next-generation energy storage solutions. Investigate lithium-sulphur batteries or solid-state batteries that offer higher energy densities and faster charge-discharge cycles. Collaborate with materials scientists to design custom battery chemistries tailored to the UAV's requirements, enhancing both energy storage capacity and cycle life.

6.2.4 Integration of AI and Machine Learning:

Partner with experts in AI and machine learning to develop predictive algorithms that optimize the UAV's flight trajectories, energy distribution, and power management. Implement real-time data analysis to adapt the UAV's behaviour based on changing solar intensity, wind conditions, and mission requirements, thus maximizing efficiency.

6.2.5 Collaborative Research:

Forge partnerships with academia, research institutions, and industry experts to leverage interdisciplinary insights. Collaborative efforts can lead to breakthroughs in solar energy integration, aerodynamics, materials science, and flight control strategies, pushing the boundaries of hybrid solar-powered UAV technology.

6.2.6 Real-world Testing Scenarios:

Conduct comprehensive field tests in diverse environments, such as varying altitudes, climates, and terrains. Collaborate with meteorologists and aviation experts to design realistic testing scenarios that mimic real-world conditions, providing robust data to validate the UAV's performance and efficiency under different circumstances.

6.2.7 Commercial Applications:

Collaborate with industry partners to explore commercial applications for the hybrid solar-powered UAV technology. Investigate opportunities in areas such as aerial mapping, surveillance, environmental monitoring, precision agriculture, and wildlife conservation. Customize the UAV's payload and capabilities to meet specific industry needs.

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Appendix:

MATLAB Codes:

FOR UAV:

```
#include "Wire.h"
#include <MPU6050_light.h>
#include <SFE_BMP180.h>
#include <SoftwareSerial.h>

SoftwareSerial HC12(10, 11); //tx,rx

MPU6050 mpu(Wire);
unsigned long timer = 0;

SFE_BMP180 pressure;

double baseline; // baseline pressure

double alt_ft = 0;
double alt_mtr = 0;
int throttle_percent =0;

void setup() {
  Serial.begin(9600);
  HC12.begin(19200);

  Wire.begin();
```

```
  byte status = mpu.begin();
  Serial.print(F("MPU6050 status: "));
  Serial.println(status);
  while(status!=0){ } // stop everything if could not connect to MPU6050

  Serial.println(F("Calculating offsets, do not move MPU6050"));
  delay(1000);
  // mpu.upsideDownMounting = true; // uncomment this line if the MPU6050 is mounted upside-down
  mpu.calcOffsets(); // gyro and accelero
  Serial.println("Done!\n");

    Serial.println("REBOOT");

  // Initialize the sensor (it is important to get calibration values stored on the device).

  if (pressure.begin())
    Serial.println("BMP180 init success");
  else
  {
    // Oops, something went wrong, this is usually a connection problem,
    // see the comments at the top of this sketch for the proper connections.

    Serial.println("BMP180 init fail (disconnected?)\n\n");
    while(1); // Pause forever.
  }

  // Get the baseline pressure:
```

```
  baseline = getPressure();

  Serial.print("baseline pressure: ");
  Serial.print(baseline);
  Serial.println(" mb");
}

void loop() {
  mpu.update();

  if((millis()-timer)>10){ // print data every 10ms
	Serial.print("X : ");
	Serial.print(mpu.getAngleX());
	Serial.print("\tY : ");
	Serial.print(mpu.getAngleY());
	Serial.print("\tZ : ");
	Serial.println(mpu.getAngleZ());
	timer = millis();
  }
  double a,P;

  P = getPressure();

  a = pressure.altitude(P,baseline);

  Serial.print("relative altitude: ");
  if (a >= 0.0) Serial.print(" "); // add a space for positive numbers
  Serial.print(a,1);
```

```
  Serial.print(" meters, ");

  if (a >= 0.0) Serial.print(" "); // add a space for positive numbers
  Serial.print(a*3.28084,0);
  Serial.println(" feet");
  delay(10);

  HC12.print(a,1);
  HC12.print(",");
  HC12.print(a,0);
  HC12.print(",");
  HC12.print(mpu.getAngleX());
  HC12.print(",");
  HC12.print(mpu.getAngleY());
  HC12.print(",");
  HC12.print(mpu.getAngleZ());
 // HC12.print(",");
 // HC12.print(throttle_percent);
  HC12.println("");
  delay(100);
}


double getPressure()
{
  char status;
  double T,P,p0,a;
```

```
status = pressure.startTemperature();
if (status != 0)
{

  delay(status);

  status = pressure.getTemperature(T);
  if (status != 0)
  {

    status = pressure.startPressure(3);
    if (status != 0)
    {
      delay(status);

      status = pressure.getPressure(P,T);
      if (status != 0)
      {
        return(P);
      }
      else Serial.println("error retrieving pressure measurement\n");
    }
    else Serial.println("error starting pressure measurement\n");
  }
  else Serial.println("error retrieving temperature measurement\n");
}
else Serial.println("error starting temperature measurement\n");
```

```
}
```

Ground receiver

```
#include <SoftwareSerial.h>
#include <Wire.h>
SoftwareSerial HC12(10, 11);//tx,rx

int alt_mtr = 0;
int alt_ft = 0;
int angleX = 0;
int angleY = 0;
int angleZ = 0;
int throttle_percent = 0;

String input;
int d1; //setup to reference delimiter locations so its easier to follow
int d2;
int d3;
int d4;
int d5;
int d6;

const char delimiter = ',';

void setup() {
Serial.begin(9600);
HC12.begin(19200);
}
```

```
void loop() {
if(HC12.available())
{
input = HC12.readStringUntil('\n');
if (input.length() > 0)
{

d1 = input.indexOf(delimiter);
//Serial.println(d1);
alt_mtr = input.substring(0, d1).toInt();
d2 = input.indexOf(delimiter, d1+1);
//Serial.println(d2);
alt_ft = input.substring(d1+1, d2).toInt();
d3 = input.indexOf(delimiter,d2+1);
//Serial.println(d3);
angleX = input.substring(d2+1, d3).toInt();
d4 = input.indexOf(delimiter, d3+1);
//Serial.println(d4);
angleY = input.substring(d3+1, d4).toInt();

d5 = input.indexOf(delimiter,d4+1);
angleZ = input.substring(d4+1,d5).toInt();

throttle_percent = input.substring(d5+1).toInt();

Serial.print("PITCH:\t");
Serial.print(angleX);
Serial.print("\t|ROLL:\t");
```

```
Serial.print(angleY);
Serial.print("\t|YAW:\t");
Serial.print(angleZ);
Serial.print("\t\t|altitude(m):\t");
 Serial.println(alt_mtr);
// Serial.print("\tThrottle (%):");
// Serial.println(throttle_percent);
delay(30);
    }
  }
}
```

Load Cell Calibration

```
// Calibrating the load cell
#include "HX711.h"

// HX711 circuit wiring
const int LOADCELL_DOUT_PIN = 2;
const int LOADCELL_SCK_PIN = 3;

HX711 scale;

void setup() {
  Serial.begin(57600);
  scale.begin(LOADCELL_DOUT_PIN, LOADCELL_SCK_PIN);
}

void loop() {
```

```
  if (scale.is_ready()) {
    scale.set_scale();
    Serial.println("Tare... remove any weights from the scale.");
    delay(5000);
    scale.tare();
    Serial.println("Tare done...");
    Serial.print("Place a known weight on the scale...");
    delay(5000);
    long reading = scale.get_units(10);
    Serial.print("Result: ");
    Serial.println(reading);
  }
  else {
    Serial.println("HX711 not found.");
  }
  delay(1000);
}
//calibration factor will be the (reading)/(known weight)
```

Thrust Test bench

```
#include <Arduino.h>
#include "HX711.h"

// HX711 circuit wiring
const int LOADCELL_DOUT_PIN = 2;
const int LOADCELL_SCK_PIN = 3;

HX711 scale;
```

```
void setup() {
  Serial.begin(57600);
  Serial.println("HX711 Demo");
  Serial.println("Initializing the scale");

  scale.begin(LOADCELL_DOUT_PIN, LOADCELL_SCK_PIN);

  Serial.println("Before setting up the scale:");
  Serial.print("read: \t\t");
  Serial.println(scale.read());      // print a raw reading from the ADC

  Serial.print("read average: \t\t");
  Serial.println(scale.read_average(20));   // print the average of 20 readings from the ADC

  Serial.print("get value: \t\t");
  Serial.println(scale.get_value(5));   // print the average of 5 readings from the ADC minus the
tare weight (not set yet)

  Serial.print("get units: \t\t");
  Serial.println(scale.get_units(5), 1);  // print the average of 5 readings from the ADC minus tare
weight (not set) divided
            // by the SCALE parameter (not set yet)

  scale.set_scale(-459.542);
  //scale.set_scale(-471.497);                        // this value is obtained by calibrating the scale with
known weights; see the README for details
  scale.tare();               // reset the scale to 0
  Serial.println("After setting up the scale:");
  Serial.print("read: \t\t");
```

```
  Serial.println(scale.read());                  // print a raw reading from the ADC
  Serial.print("read average: \t\t");
  Serial.println(scale.read_average(20));       // print the average of 20 readings from the ADC
  Serial.print("get value: \t\t");
  Serial.println(scale.get_value(5));    // print the average of 5 readings from the ADC minus the tare weight, set with tare()
  Serial.print("get units: \t\t");
  Serial.println(scale.get_units(5), 1);         // print the average of 5 readings from the ADC minus tare weight, divided
            // by the SCALE parameter set with set_scale
  Serial.println("Readings:");
}
void loop() {
  Serial.print("one reading:\t");
  Serial.print(scale.get_units(), 1);
  Serial.print("\t| average:\t");
  Serial.println(scale.get_units(10), 5);

  delay(5000);
}
```

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