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# Paramater Estimation of Flying Wing Micro-Aerial Vehicle

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***ABSTRACT***
*An airfoil selection procedure, wind tunnel testing, and the implementation of a 6-DOF model on a flying wing micro aerial vehicle (FWMAV) have been proposed in this research. The selection procedure for airfoils has been developed by considering parameters related to aerodynamic efficiency and flight stability. Airfoil aerodynamic parameters have been calculated using a potential flow solver for five candidate airfoils. Eppler-387 proved to be the most efficient reflexed airfoil and was therefore selected for fabrication and further flight testing of the vehicle. Elevon control surfaces have been designed and evaluated for longitudinal and lateral control.*

*The vehicle was fabricated using EPP (Expanded Polypropylene) styrofoam of density 50 Kg/m3, where a laser cutting machine was used to cut an Eppler 387 airfoil out of foam and the other cuttings were carried out manually. Static aerodynamic coefficients were evaluated using wind tunnel tests conducted at cruise velocity of 11.84 m/s for varying angles of attack. Elevon control derivatives have also been calculated. Since FWMAV was not designed with a vertical stabilizer and rudder control surface, directional stability was therefore augmented through winglets and high wing leading edge sweep. In addition, parameter estimation is performed.*

*Parameter identification is the most illustrated example of identifying the system used to define the characteristics of a dynamic system. Aerodynamic modelling of aerial vehicles is introduced by Bryan, which defines the relationship between forces and moment equations. Aircraft system identification is a tool with wide application to engineering systems like aerial flying vehicles.*

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## I. INTRODUCTION

Over the past three decades, there has been an increase in interest in tiny creatures that fly gradually. Research and development organization (commonly known as RAND) conducted a workshop for Advanced Research Projects Agency (ARPA) on “Future Technology Driven Revolutions in Military Operations” in 1992 which resulted in the birth of Micro Aerial Vehicles. Two of the early micro aerial vehicles were “MITE” with its various variants and “Black Widow”.

Since then, many successful micro aerial vehicles have been developed and flight tested. Initially designed micro aerial vehicles were fixed wing in flying wing configurations having low aspect ratio wing for lifting characteristics. These were battery powered (lithium ion or nickel cadmium) and propeller driven with endurance up to 30 min. In early stages of MAV development, extensive studies were conducted in the low Reynolds number aerodynamics regime in which research focused on laminar boundary layer separation, transition to turbulent boundary layer and reattachment to form laminar separation bubbles. Low speed wind tunnel experimentation was also conducted to validate theoretical results along with wake measurements for authentic drag predictions. In the same era, researchers conducted research in slow moving low aspect ratio wings. This posed a special problem of three-dimensional flows, where wing tip vortices captured most of the wing area and degraded lift with enhanced drag. Therefore, degradation of lift was not only caused by laminar separation bubbles bursting at high angles of attack, but also from a large value of induced drag. Therefore, lower value of lift to drag ratio made small aspect ratio wings difficult to fly at slow speeds. In the recent past with the advancements of experimental facilities, an extensive experimental research work was conducted on low aspect ratio wings at slow speeds. They concluded that low aspect ratio wings at low Reynolds number posed many problems relating to aerodynamic efficiency. Nonlinearity of lift curve, inefficiency of wing planform shapes, and aerodynamic characteristics dependency on aspect ratios were prominent problems. In addition to low-aspect wings' inefficient aerodynamics, it was challenging to accurately estimate flight dynamics throughout the design process. The design of MAVs is a challenging procedure that requires a thorough understanding of rate and acceleration derivatives as well as aerodynamic coefficients. These vehicles have low moments of inertia, which makes them sensitive to oscillations brought on by operator inputs or atmospheric gusts, leading to flying instabilities. It is necessary to acquire and analyze their aerodynamic derivatives in order to construct and analyze a flight dynamic model of MAV.

These aerodynamic derivatives can often be estimated in three different methods. Experiments in wind tunnels, computational techniques (such as a potential solver or a Computational Fluid Dynamics solution), and empirical relationships. These vehicles' geometry, performance, and stability data are not available in open literature since they are so small in comparison to flying devices operated by humans. Furthermore, because of a lack of statistical information on small vehicles, it is impossible to employ Daniel Raymer's traditional design approach to create micro aerial vehicles. Here, we discuss the design of a FWMAV with a flying wing configuration and implied airfoil selection method. FWMAV is tested in a wind tunnel, and aerodynamic coefficients are calculated.

### 1.1 Parameter Estimation

Parameter estimation for a flying wing micro aerial vehicle (MAV) involves determining the unknown parameters that govern the MAV's behavior and performance based on observed data. These parameters can include aerodynamic coefficients, stability derivatives, control effectiveness, and other relevant factors.

Parameter estimation for a flying-wing MAV can be a complex task due to the interaction between various aerodynamic and control parameters. It may require a combination of experimental data, computational simulations, and iterative optimization to achieve accurate parameter estimates. Additionally, it's essential to consider the limitations and assumptions of the model and validate the estimated parameters through further testing and validation procedures.

### 1.2Motivation of the project

The motivation behind developing a flying wing micro aerial vehicle lies in its numerous advantages. The flying wing design offers enhanced aerodynamic efficiency, stability, and maneuverability compared to traditional aircraft configurations. Its compact size and weight enable it to navigate tight spaces and operate in confined environments. Additionally, the absence of a conventional tail reduces complexity and increases payload capacity. By harnessing these benefits, the flying wing micro aerial vehicle promises to revolutionize surveillance, exploration, and disaster response applications, offering a versatile and efficient solution for various aerial missions.

### 1.3 Objectives

The objective is to achieve optimal performance by parameter estimation in terms of stability. The goal is to create a compact and lightweight vehicle that can navigate tight spaces, operate in confined environments, and fulfil tasks such as surveillance, exploration, and disaster response with precision and reliability.

### 1.4 Methodology

#### 1.4.1 Collection of data

A detailed study was carried out to understand the airfoil coordinates. These coordinates were used to examine the nature of graphs.

#### 1.4.2 Design and analysis of airfoil

A study was carried out to understand the characteristics of various airfoils. Among these, five of the airfoils were taken into consideration. XFLR was used to design and analyze the selected airfoils.

#### 1.4.3 Analyzing aerodynamic and stability factors

Various iterations were carried out to analyze the aerodynamic and stability factors of the selected airfoils. Failure of this had to go through the previous procedure.

#### 1.4.4 Selection of optimum airfoil

Comparing the results of five airfoils, reflex airfoil was chosen for FWMAV. Eppler 387 resulted to be the optimum airfoil. The model was designed with E387 airfoil.

#### 1.4.5 Fabrication

Designed model of E387 airfoil was fabricated using EPP styrofoam which was found to be resistant to abrasion.

#### 1.4.6 Testing

A wind tunnel test was performed using six force balance components.

1.4.7 Results
Mathematical and analytical methods were used to generate longitudinal stability derivatives.

# II. LITERATURE REVIEW

### 2.1 Airfoil Selection Procedure, Wind Tunnel Experimentation and Implementation of 6DOF Modelling on a Flying Wing Micro Aerial Vehicle (2020) - *Taimur Ali Shams, Syed Irtiza Ali Shah, Ali Javed, Syed Hossein Raza Hamdani.*

This literature source has information related to the selection procedure for the airfoil for a flying wing micro aerial vehicle. stability. Airfoil aerodynamic parameters have been calculated using a potential flow solver for ten candidate airfoils. The Eppler-387 proved to be the most efficient reflexed airfoil and was therefore selected for fabrication and further flight testing of the vehicle. Elevon control surfaces have been designed and evaluated for longitudinal and lateral control. The vehicle was fabricated using a hot wire machine with EPP styrofoam with a density of 50 kg/m3. Static aerodynamic coefficients were evaluated using wind tunnel tests conducted at a cruise velocity of 20 m/s for varying angles of attack.
Rate derivatives and elevon control derivatives have also been calculated.

### 2.2 Design, Build and Fly a Flying Wing (2016) - *By Ahmed A. Hamada, Abdelrahman A. Sultan, Mohamed M. Abdelrahman*

This research represents one of the graduation projects for the final year of undergraduate students in the Aerospace Engineering Department for the academic year 2015-2016. The objective of the present paper is to design, build and test a flying wing. The purpose of this work is to describe the methodology and decision making involved in the process of designing a flying wing. First, the design is based on the design theories and followed by performance, stability analysis, and motion simulation. The wind-tunnel tests are performed to compare theoretical results based on design with the experimental measured results.
Finally, a real flight test is performed to achieve the objective of the project.

### 2.3 System Identification for a Small, Rudderless, Fixed-Wing Unmanned Aircraft (2019)- *Raghu Venkataraman and Peter Seiler University of Minnesota, Minneapolis, Minnesota*

This paper presents a system identification procedure for a class of small, rudderless, fixed-wing unmanned aircraft. The procedure is demonstrated on an aircraft that is equipped with only two aerodynamic control surfaces (called elevons) and one electric motor. A physics-based, first-principles approach is used to obtain the initial model parameters. The initial model is used to design flight tests wherein the longitudinal and the lateral-directional dynamics are separately excited. The aircraft is rudderless and this introduces a key challenge in the model identification. Specifically, the lateral-directional model has more free parameters than can be identified using the elevon excitations alone. This paper resorts to two novel steps to navigate this roadblock. First, this paper uses black-box methods to identify sensitive modes whose damping ratios and natural frequencies change significantly compared with their initial values. Second, gray-box methods are used to update the stability and control derivatives related to these sensitive modes, while retaining the remaining derivatives at their respective initial values. Additional flight tests are conducted to validate the updated model parameters.

# III. AERIAL VEHICLES

Our approach to world exploration and interaction has changed as a result of flying aircraft. They're designed for particular purposes and available in a variety of sizes and forms. Millions of people travel the world on commercial aircraft, and helicopters offer crucial emergency services. In recent years, unmanned aerial vehicles (UAVs) have gained popularity for uses including aerial photography and scientific study. They have increased human achievement in areas such as transportation, defense, agriculture, and surveillance.

The world of aerial vehicles has transformed our skies and enhanced our knowledge beyond anything we could have previously imagined. Fields including mapping, environmental monitoring, and disaster management have been revolutionised by the deployment of cutting-edge aerial surveillance and remote sensing technologies. We've probed the gigantic universe with the aid of satellites and space shuttles, solving some of its many mysteries.

Aerial vehicles offer a tremendous potential for advancement, but they also present new difficulties in terms of safety, environmental effect, and legal constraints. A sustainable and prosperous future depends on ensuring the responsible usage and integration of these vehicles into our society. Finding a balance between expansion and operational safety is key.

In the coming years, aerial exploration and innovation will reach even greater heights, creating new possibilities for quicker and more sustainable transportation. Aerial vehicles have the potential to revolutionise how we communicate, travel, and conduct business. By overcoming the constraints of the past, we can look towards a future filled with limitless possibilities.

Amazing advancements in aerial technology are being made every day, demonstrating the machines' boundless potential and inspiring us to believe in the potential of human achievement. The sky is now an infinite realm of possibility that is demanding to be explored.

### 3.1 Micro-Aerial Vehicles:

The interesting class of aerial vehicles known as micro aerial vehicles (MAVs) are gaining a lot of attention recently. MAVs, as their name implies, are small, unmanned aircraft that can navigate through tight places and difficult terrain to complete duties. They are perfect for situations where conventional larger aircraft or ground-based vehicles have constraints because of their small size, agility, and maneuverability.

MAVs frequently draw inspiration from nature, mimicking the flight skills of insects, birds, and other small animals. With wingspans ranging from a few centimeters to a few feet, they are typically small and light. Electric motors or other propulsion systems can be used to propel them. With their sophisticated sensing, control, and communication systems, these tiny flying vehicles are capable of a wide range of missions. They serve purposes in industries like security, mapping, search and rescue, environmental monitoring, agriculture, entertainment, and even photography.

The capability of MAVs to access locations that are inaccessible to people or larger aircraft is one of its key advantages. Because of their small size, they may fit through small openings like those in cities, deep forests, or disaster-stricken areas, offering helpful information and support where more conventional approaches fail.

MAVs can be operated automatically or remotely by human operators. Being autonomous is essential because it enables these vehicles to operate in challenging situations, avoid hazards, and adjust to shifting environmental circumstances without continual human supervision.

However, there are drawbacks to MAVs, such as their restricted payload capacity, shorter flying duration due to their smaller batteries, and the requirement for reliable stability and control systems in turbulence. Continuous research and development in fields including lightweight materials, power sources, and enhanced sensing and control algorithms are necessary to meet these challenges.

Despite these difficulties, MAVs have a lot of potential. They have the potential to completely transform industries by making things that were previously prohibitive or unattainable possible. MAVs are changing the way we interact with our environment, helping with anything from disaster response to precision agriculture to assessing infrastructure like bridges and buildings.

MAVs are anticipated to become even more capable, effective, and available as technology develops. These tiny aerial vehicles have the ability to change many parts of our lives, have a substantial impact on numerous businesses, and open up new avenues for exploration and problem-solving with continued study and invention.

## IV. FLYING WING MICRO AERIAL VEHICLE

A distinctive and innovative approach to unmanned aerial vehicles is demonstrated by the Flying Wing Micro Aerial Vehicle (FWMAV). The flying wing MAV, in contrast to conventional aircraft, which have separate wings and fuselages, merges both functions into a single integrated structure, giving it a distinctive and streamlined appearance.

Early aviation pioneers first proposed the idea of flying wings, but more recent developments in materials, control technology, and miniaturisation have made it possible to create microscale flying wing MAVs. These compact unmanned aircraft fly with extraordinary maneuverability and have many advantages over traditional designs.

Flying wing MAVs are incredibly efficient and maneuverable because they don't have a standard fuselage, which also decreases weight and drag. Their efficient wing design, improved lift-to-drag ratios, and enhanced stability are made possible by their aerodynamic shape. Flying wing MAVs can operate more easily in a variety of situations, for longer flight durations, and over greater distances because of their characteristics.

Flying wing MAVs exhibit remarkable flight qualities and can be operated remotely or independently. They can perform precise maneuvers, fly slowly, and keep their flying stable even in difficult circumstances because of their agility. They can properly navigate and adjust to changing environments due to advanced onboard equipment including inertial measurement units and GPS receivers.

Flying wing MAVs provide a lot of benefits, but they also pose special design and engineering difficulties. Without a distinct tail structure, stability and control are only possible with complex control systems and careful weight distribution. Due to the smaller size and less space for power sources, the payload capacity and endurance may also be restricted.

Despite these difficulties, the flying wing MAV is an intriguing advancement in the field of aerial vehicles. Ongoing research and development projects are aimed at further improving their autonomy, cargo capacity, and aerodynamic characteristics. These developments have the potential to open up possibilities and extend the capabilities of micro-scale aerial vehicles.

The flying wing micro aerial vehicle, which combines the functions of wings and fuselage into a single integrated structure, stands out as a unique and effective design. It offers intriguing new opportunities in areas like surveillance, exploration, and data collection due to its small size, improved flight qualities, and versatility.

### 4.1 Applications:

Flying wing micro aerial vehicles (MAVs) have a wide range of applications due to their unique design and capabilities. Here are some notable applications of flying wing MAVs:

1. Surveillance and Reconnaissance: Flying wing MAVs can be equipped with cameras and sensors to perform aerial surveillance and reconnaissance missions. Their small size and maneuverability allow them to navigate urban environments, monitor remote areas, and gather valuable visual and data intelligence.
2. Mapping and Surveying: Flying wing MAVs are valuable tools for mapping and surveying landscapes, infrastructure, and archaeological sites. They can capture highresolution aerial imagery, create 3D models, and collect data for topographic surveys, urban planning, and environmental monitoring.
3. Agriculture and Crop Monitoring: Flying wing MAVs are used in precision agriculture to monitor crop health, identify pest infestations, and assess irrigation needs. They can capture multispectral imagery, enabling farmers to make informed decisions about crop management and optimize yields.
4. Search and Rescue: Flying wing MAVs can assist in search and rescue operations, especially in challenging terrains or disaster-stricken areas. Equipped with cameras and thermal imaging sensors, they can aid in locating missing persons, assessing damage, and providing situational awareness to rescue teams.
5. Environmental Monitoring: Flying wing MAVs are employed in environmental monitoring tasks, such as assessing air quality, tracking wildlife populations, and monitoring habitats. They can access remote or hazardous locations, providing valuable data for conservation efforts and environmental research.
6. Infrastructure Inspection: Flying wing MAVs can perform visual inspections of infrastructure such as bridges, power lines, and buildings. Their agility and ability to access confined spaces make them ideal for identifying structural damage, corrosion, or other maintenance needs.
7. Film and Photography: Flying wing MAVs are utilized in the film and photography industry to capture unique aerial shots and footage. They can provide dynamic perspectives for cinematography, documentaries, and aerial photography.
8. Surveillance and Security: Flying wing MAVs are used for surveillance and security purpose, providing aerial monitoring of public spaces, borders, critical infrastructure, and crowd management. They can transmit live video feeds and gather valuable intelligence for law enforcement and security agencies.
9. Environmental Monitoring: Flying wing MAVs are employed in environmental studies and monitoring programs. They can collect data on air quality, pollution, wildlife populations, and habitat assessment. Their maneuverability allows them to access remote areas and capture valuable information for conservation efforts.
10. Search and Rescue: Flying wing MAVs aid in search and rescue missions, particularly in hard-to-reach or dangerous areas. Equipped with cameras and thermal imaging sensors, they can assist in locating missing persons, assessing disaster-affected regions, and providing real-time situational awareness to rescue teams.
11. Precision Agriculture: Flying wing MAVs are used in precision agriculture to optimize farming practices. They can monitor crop health, detect disease or pest infestations, assess irrigation needs, and help farmers make data-driven decisions to maximize crop yield and reduce resource usage.

These are just a few examples of the many applications of flying wing micro aerial vehicles. As technology advances and new innovations emerge, the potential for their use in different industries continues to expand, unlocking exciting possibilities for aerial exploration and data acquisition.

## V. DESIGN OF FLYING WING MICRO AERIAL VEHICLE

Any vehicle's design process begins with defining its function and is followed by an RFP. In this study, a flying wing micro aircraft (FWMAV) is created for the reconnaissance, surveillance, and target acquisition (RSTA) tasks. Performance of a flying machine can be outlined as a measure of its capacity to complete a particular task. Performance of FWMAV depends on stable flying for optimum duration to enable straightforward execution of RSTA missions.

The goal is to create an FWMAV with a 30 minutes of endurance, a 0.192kg gross takeoff weight, and the capacity to transmit video to a base station from a height of 100 meters. Typically, FWMAV is hand-launched and belly-landed. Mission profile is a stable condition.

Designing a flying wing micro aerial vehicle (MAV) involves considering various factors such as aerodynamics, stability, control, propulsion, and payload capacity. Here's a step-by-step guide to designing a flying wing MAV:

1. Define the mission requirements: Determine the purpose of the MAV, such as aerial surveillance, environmental monitoring, or package delivery. This will influence the design parameters such as range, endurance, speed, and payload capacity.
2. Determine the size and weight: Flying wing MAVs are typically small and lightweight. The size and weight will affect the overall design, material selection, and power requirements.
3. Wing configuration: A flying wing design features a single, integrated wing without a distinct fuselage. The wing typically spans the entire length of the MAV, providing lift and stability. Consider factors such as aspect ratio (wing span to average chord ratio), sweep angle, and wing taper ratio.
4. Aerodynamics: Optimize the MAV's aerodynamic performance by considering factors like airfoil selection, wing profile, and winglets for improved efficiency and stability. Computer-aided design (CAD) software or wind tunnel testing can help refine the wing shape.
5. Stability and control: Flying wings can be inherently less stable than traditional aircraft. Implement stability-enhancing features such as wing dihedral (upward angle) to improve lateral stability and longitudinal stability through careful distribution of weight and control surfaces.
6. Control surfaces: Determine the control surfaces needed for maneuverability. Flying wings usually have ailerons on the wingtips for roll control and elevons (combined elevators and ailerons) on the trailing edge for pitch and roll control. Additional control surfaces like spoilers or flaps may be incorporated as needed.
7. Propulsion: Select an appropriate propulsion system based on the size and weight of the MAV. Electric motors and propellers are commonly used for small-scale MAVs due to their efficiency, lightweight, and low noise. Consider factors such as thrust-to-weight ratio, power requirements, and battery capacity for optimal performance.
8. Power source: Choose a suitable power source, such as batteries or fuel cells, based on the MAV's endurance requirements and weight limitations. Ensure the power source provides sufficient energy for both propulsion and onboard systems.
9. Payload integration: Determine the payload capacity and consider its placement within the MAV. Ensure the center of gravity remains within acceptable limits for stability and control. Install appropriate sensors, cameras, or other payload equipment, ensuring they are well-integrated into the MAV's structure.
10. Structural design and materials: Use lightweight and durable materials such as carbon fiber composites or foam cores covered in lightweight materials like Mylar or fiberglass to construct the flying wing. Structural design should prioritize strength, rigidity, and weight reduction.
11. System integration and electronics: Design the MAV to accommodate necessary electronics, including flight control systems, communication equipment, and data processing units. Integrate sensors, gyroscopes, accelerometers, and GPS modules for accurate positioning and control.
12. Testing and refinement: Once the design is complete, conduct thorough testing, including flight tests, to evaluate performance, stability, and control. Iterate and refine the design as necessary to optimize the MAV's functionality.

## 5.1 Airfoil selection

The available wind tunnel test section cross sectional area was 2 feet × 2 feet; therefore, a restriction was imposed on the span of FWMAV to avoid solid blockage and wake blockage errors during wind tunnel experimentation. Hence, vehicle size was rescaled to a span of 400mm of the total span of the wing (separately). In addition to model size, structural similarity and strength of support mechanism were ensured at maximum test conditions including maximum angle of attack at suitable free stream velocity. Accuracy of a tested model is of prime importance if an accurate prediction of aerodynamic and longitudinal stability parameters are desired. The model was fabricated using EPP foam with density 50Kg/$m^3$ using a manual cutting and the laser cutting for the airfoil. EPP (Expanded Polypropylene) has been intensively used in the RC hobby model planes industry and well known as its lightweight physical property, excellent resistance to impact and abrasion. Since the tested model was flying wing configuration, particular importance was therefore given to airfoil shape selection for which a new procedure is proposed in this report. For trim flight, pitching moment coefficient at zero angle of attack, Cm0, must be positive, whereas, for longitudinal stability, aerodynamic center must be aft of CG. For these two requirements, positively cambered airfoil cannot be used for flying wing configuration because this has negative Cm0. Symmetric airfoil produces zero pitching moment and negatively cambered airfoil produces a positive pitching moment. Negatively cambered airfoil does not fulfill lift requirement; therefore, a negatively cambered airfoil having positive Cm0 cannot be used in a flying wing configuration airplane. The solution is use of positive cambered airfoil with negative camber at trailing edge to neutralize pitching moment at zero angle of attack. This type of an airfoil is called Reflexed airfoil and is considered to be best suited for flying wing configurations. Reflexed airfoils fulfill both the requirements of lift and pitching moment. Selection of best reflexed airfoil for flying wing micro aerial vehicle is discussed in detail in the next subsection. In order to reduce induced drag and to augment lateral stability, carefully designed winglets were installed on the wing tips.

### 5.2Proposed Airfoil Analysis

Selection of reflexed airfoil is a cumbersome process; therefore, a strategy was developed which compared ten reflexed airfoils for selection of an optimum airfoil for flying wing micro aerial vehicles. Reflexed airfoils were selected as candidate airfoils since these nullify the requirement of a horizontal stabilizer for flying wing configuration. These airfoils were computationally analyzed using XFLRv5 software which is a potential flow solver.

### 5.3 Criteria for Selection of airfoil

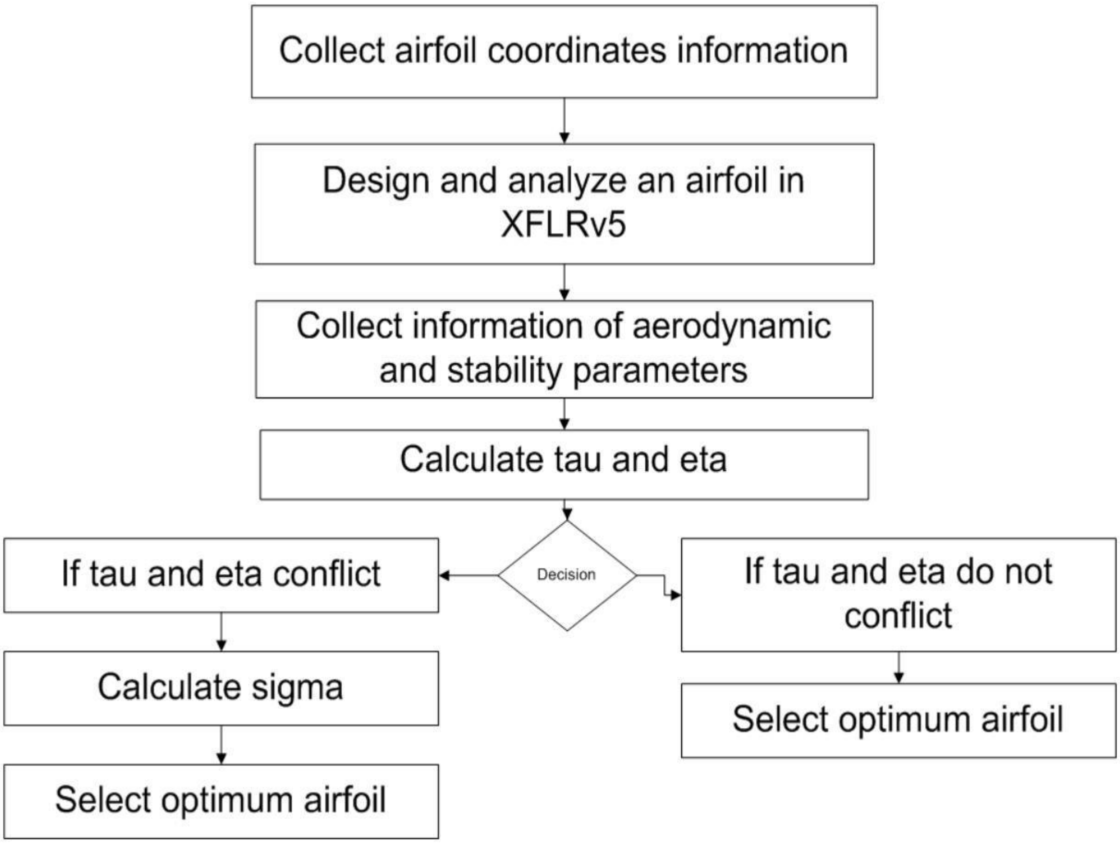

Figure. 5.3.1 flow chart of the proposed reflexed airfoil selection procedure for FWMAV

The strategy for selecting a suitable airfoil considered aerodynamics and stability considerations. Since various parameters define the aerodynamic efficiency of an airfoil in varying flight regimes, all concerned parameters were computed, and the proposed parameters τ (airfoil efficiency parameter) and η (airfoil performance parameter) were defined and calculated.

The selection criterion for Eppler-387 was made on the highest value of τ and η. However, in the case when one airfoil cannot be selected by securing maximum value, an average of τ and η denoted by Σ is to be calculated. For instance, if τ is highest for one airfoil and η is highest for another airfoil, then the highest value of Σ will decide about the selection of a reflexed airfoil.

τ, η, and Σ values for five reflexed airfoils.

**Table.1** The table shows Eppler-387 has best overall performance in terms of τ, η, and Σ

| AIRFOIL | τ | η | Σ |
|---|---|---|---|
| E184 | 10.44 | 44.92 | 27.68 |
| E186 | 10.13 | 45.96 | 28.045 |

| | | | |
|---|---|---|---|
| E387 | 14.242 | 61.08 | 37.75 |
| FX69H083 | 12.11 | 53.19 | 32.65 |
| M5 | 9.82 | 47.07 | 28.445 |

From the above table we can infer that the value of aerodynamic efficiency (η) is greater for E387.
Hence it is considered to be the most suitable airfoil for FWMAV.

### 5.4 Detail design features of FWMAV under considerations

A leading edge sweep of 30° and a trailing edge sweep of 23° were included in the wing design due to lateral stability. The values of leading edge sweep are considered to be optimum. Roll stability could be enhanced in various ways, including wing position on the fuselage, sweep angle, and positioning of the vertical stabilizer. Since FWMAV was not designed with a vertical stabilizer due to complex control problems, lateral stability was augmented by wing leading edge sweep. In a swept back wing, the windward wing has an effective decrease in sweep angle; therefore, it generates more lift as compared to the trailing wing. This decrease in sweep from the windward wing tries to counter-rotate the wing and, hence, enhance lateral stability through differential lift. Apart from lateral stability, wing leading edge sweep augments lift through leading edge vortices. Despite the fact that FWMAV is a slow-moving flying wing, a high wing sweep was designed knowing that wing sweeps are used for high-speed aircraft to increase the critical Mach number. Swept wings also augment directional stability by enforcing more air flow over the leading wing during side slip. Geometric features of designed micro aerial vehicle are shown in table 2

**Table 2.** Geometric features of a flying wing micro aerial vehicle.

| NOMENCLATURE | SPECIFICATION |
|---|---|
| Airfoil | Eppler-387(Reflexed) |
| Planform | Rectangular Swept |
| Leading Edge Sweep | 30° |
| Trailing edge | 23° |
| Propeller | 6 x 4.5mm |
| Span | 600mm |
| Taper ratio | 0.90 |

### 5.4.1 Rectangular swept platform

A rectangular swept planform is a wing design with straight lines on the leading and trailing edges and a rectangular shape when viewed from above. The term "swept" refers to the leading edge of a wing that is inclined rearward (swept back) relative to the direction of flight.

The rectangular sweeping planform can be an appropriate choice for a flying wing micro aerial vehicle (MAV). Flying wings are aircraft designs that combine the wing and body into a single aerodynamic structure and do not have a distinct fuselage. They frequently have a swept-back wing planform to improve stability and reduce drag. The swept wing planform's rectangular shape simplifies design and production, making it ideal for miniature aerial vehicles where lightweight and economical manufacture are critical factors. When compared to more complex wing forms, the straight leading and trailing edges simplify the building process and can give higher structural integrity.

It is essential to note, however, that the specific wing design for a micro aerial vehicle is determined by a variety of parameters, including desirable flight characteristics, payload needs, and aerodynamic considerations. To optimize the performance of the flying wing MAV, engineers and designers would consider aspects such as wing loading, aspect ratio, airfoil selection, and control surfaces.

### 5.4.2 Leading edge sweep

The leading edge sweep is the angle at which the leading edge of the wing is inclined backward relative to the direction of flight. For a flying wing micro aerial vehicle (MAV), the leading edge sweep can significantly impact its flight characteristics and performance. Leading edge sweep is frequently used in flying wing designs to improve stability, reduce drag, and enhance maneuverability.

Here are a few considerations regarding leading edge sweep for a flying wing MAV:

Stability: Leading edge sweep helps to increase the inherent stability of the flying wing. The sweep shifts the center of lift forward, promoting a more stable flight behavior. It reduces the likelihood of the aircraft entering unstable and potentially dangerous flight conditions.

Drag reduction: The sweep of the leading edge can help to reduce the overall drag of the MAV. By angling the leading edge backward, the airflow over the wing encounters less resistance, resulting in lower drag. This can enhance the efficiency and endurance of the
MAV.

Maneuverability: The amount of leading edge sweep can influence the maneuverability of the flying wing. A moderate sweep angle allows for improved roll response and lateral control authority, making the aircraft more agile. However, excessive sweep angles can negatively affect stability and control, so a balance must be struck based on the specific requirements of the MAV.

It's important to note that the optimal leading edge sweep angle depends on several factors such as the MAV's intended mission, desired flight characteristics, and the specific aerodynamic properties of the wing. Engineers and designers use computational fluid dynamics (CFD) simulations, wind tunnel testing, and empirical data to determine the most suitable leading edge sweep for a particular flying wing MAV design.

Therefore, from the above considerations a leading edge sweep of 30 degrees is considered to be optimum.

### 5.4.3 Trailing edge

The trailing edge of a flying wing micro aerial vehicle (MAV) is the wing's rear edge. The trailing edge design can have an effect on the aircraft's aerodynamics, stability, and control.

Here are some considerations regarding the trailing edge for a flying wing MAV: Control Surfaces: The trailing edge is often where control surfaces, such as elevons or flaperons, are located. These control surfaces provide pitch and roll control by deflecting up or down symmetrically or differentially. They can be hinged along the trailing edge to provide control authority and maneuverability for the MAV.

Wing Tip Design: The trailing edge of the wing can influence the wingtip shape. Wingtips are important for reducing the formation of vortices, known as wingtip vortices, which can cause drag and affect the efficiency of the aircraft. Wingtip designs like winglets or endplates can be incorporated into the trailing edge to minimize the formation of these vortices.

Airfoil Shape: The trailing edge is where the airfoil profile of the wing reaches its maximum thickness and gradually tapers to a sharp or rounded trailing edge. The shape of the trailing edge, whether it's sharp or rounded, affects the flow separation and drag characteristics of the wing.

Wing Twist: In some flying wing MAV designs, the trailing edge may incorporate wing twist. Wing twist refers to a variation in the angle of incidence along the span of the wing, with the trailing edge being higher or lower than the leading edge. Wing twist helps to optimize the distribution of lift and control effectiveness across the wing span, enhancing stability and control.

The trailing edge design of a flying wing MAV is determined by elements such as desired flight characteristics, control needs, aerodynamic considerations, and manufacturing restrictions.

Therefore, a trailing edge of 23 degrees was considered to be optimum.

### 5.4.4 Propeller

Several aspects must be considered when selecting a propeller for a flying wing micro aerial vehicle (MAV) to ensure efficient and effective propulsion. Here are some important factors to consider when choosing a propeller for a flying wing MAV:

Size and Diameter: The propeller's size and diameter should be compatible with the MAV's size and weight. It is crucial to select a propeller that provides sufficient thrust to overcome the MAV's drag and achieve the desired performance.

Pitch: The pitch of the propeller refers to the distance the propeller would move forward in one revolution if it were moving through a solid medium. Choosing an appropriate pitch is important to match the MAV's desired speed and flight characteristics. Higher pitch propellers are suitable for achieving higher speeds, while lower pitch propellers provide better low-speed performance and maneuverability.

Blade Count: The number of blades on the propeller affects its efficiency and noise level. Two-bladed propellers are common for flying wing MAVs due to their simplicity and efficiency. However, three-bladed or four-bladed propellers can offer improved stability, reduced vibration, and quieter operation at the expense of slightly reduced efficiency.

Material and Construction: Propellers can be made from various materials, such as plastic, carbon fiber, or wood. The choice of material affects the propeller's durability, weight, and performance. Lighter materials are often preferred for MAVs to maximize flight time and efficiency.

Motor Compatibility: The propeller needs to be compatible with the motor used in the MAV. Considerations include motor power, RPM range, and the mounting mechanism. It is crucial to select a propeller that matches the motor's specifications to ensure efficient power transfer and optimal performance.

To find the best propeller for a flying wing MAV, it is best to run tests and simulations to evaluate thrust, efficiency, and overall performance under various conditions. Propellers should be chosen depending on the MAV's unique requirements, mission profile, and performance goals.

### 5.4.5 Span of Wing

A flying wing micro aerial vehicle's (MAV's) span is the distance between the wingtips or the complete wingspan. Aerodynamics, stability, maneuverability, cargo capacity, and operational requirements are all aspects to consider when determining the appropriate span for a flying wing MAV. Consider the following factors when determining the span of a flying wing MAV:

Aerodynamics: The wingspan plays a significant role in determining the MAV's aerodynamic performance. A larger wingspan generally leads to increased lift generation and improved lift-to-drag ratio. However, it also increases the overall drag of the aircraft. The span needs to be balanced to achieve optimal aerodynamic efficiency for the desired flight characteristics.

Stability: The span affects the inherent stability of the flying wing MAV. A longer wingspan typically enhances the MAV's stability, especially in roll and yaw. It provides more leverage against roll and yaw moments, resulting in improved stability and control. However, an excessively long wingspan can also lead to decreased maneuverability and agility.

Maneuverability: The span influences the maneuverability and agility of the flying wing MAV. A shorter wingspan generally allows for quicker roll rates and increased maneuverability, making it more suitable for agile flight and tight turns. However, reducing the wingspan too much can compromise stability and lift generation.

Payload Capacity: The wingspan can impact the MAV's payload capacity. A larger wingspan can provide more surface area to accommodate payload equipment and sensors. However, it's important to consider weight distribution and structural integrity when determining the optimal span to ensure the MAV can carry the desired payload efficiently.

Operational Considerations: The span should also consider operational constraints such as the intended environment, space limitations, and mission requirements. For instance, if the MAV is designed for indoor operations or confined spaces, a smaller wingspan might be more suitable.

It is vital to note that there is no one-size-fits-all solution for the appropriate span of a flying wing MAV. To achieve the required balance of aerodynamics, stability, maneuverability, payload capacity, and operating needs particular to the MAV's intended use, the span should be chosen by thorough analysis, simulations, and testing.

### 5.4.6 Taper ratio

The taper ratio is the proportion of the wing's tip chord to root chord. In the context of a flying wing, the taper ratio explains how the chord (width) of the wing changes from the root (inner) to the tip (outer). The taper ratio changes the aerodynamic characteristics of the wing and can affect the performance of the flying wing. Here are some things to think about when choosing a taper ratio for a flying wing:

Aerodynamics: The taper ratio affects the wing's lift distribution along the span. A higher taper ratio, where the wing narrows towards the tip, can reduce induced drag and improve the lift-to-drag ratio. It helps to minimize the formation of wingtip vortices and reduces drag, resulting in better overall aerodynamic efficiency. However, excessive taper ratios can lead to spanwise flow and tip stall, which can negatively affect stability and control.

Structural Considerations: The taper ratio can influence the structural integrity and weight distribution of the flying wing. A lower taper ratio with a more uniform chord distribution provides a stronger and stiffer structure, which can enhance the overall rigidity and strength of the wing. It can also facilitate easier construction and manufacturing.

Stability and Control: The taper ratio can impact the stability and control characteristics of the flying wing. A moderate taper ratio can contribute to improved roll stability and control response. However, extreme taper ratios can affect the wing's lateral stability and require careful design considerations to ensure proper handling and control.

Weight and Payload Considerations: The taper ratio can impact the weight and payload capacity of the flying wing. A lower taper ratio can result in a higher wing area, which allows for increased lift generation and potentially greater payload capacity. However, it's important to balance the weight and structural requirements with aerodynamic considerations to achieve the desired performance.

It is crucial to remember that the appropriate taper ratio for a flying wing is determined by a number of criteria, including desired flight characteristics, intended purpose, aerodynamic requirements, and structural considerations. Computational fluid dynamics (CFD) models, wind tunnel testing, and empirical data analysis can all help determine the best taper ratio for a particular flying wing design.

Therefore, a taper ratio of 0.90 was considered to be optimum.

Estimation of stability and performance parameters by analytical means is a difficult task that often results in inaccurate formulations. This results in values that are not dependable for analysis purposes. In order to estimate parameters more accurately, wind tunnel tests are to be carried out. More dependable results will be obtained for full scale models, where tests are conducted at the Reynolds number of actual flight conditions. In that case, both dynamic similarity parameters, Reynolds number and Mach number, are matched with actual flight conditions. Therefore, if flow features and dynamics are matched, then wind tunnel results are reliable for flight dynamic analysis. In addition to similarity problems, errors are likely to arise from the calibration of equipment and instrumentation used for measurements.

### 5.5Weight Estimation of the Model

| **WEIGHT DISTRIBUTION** | |
|---|---|
| wings | 40 gm |
| 2 servos | 6gm + 6gm |
| Battery | 80 gm |
| propeller | 8gm |
| motor | 40gm |
| ESC | 12gm |
| **TOTAL** | **192gm** |

**Table 3**. weight estimation

### 5.6 Computer Aided Design

The flying wing is drawn using SolidWorks to improve the quality of the design, create the database for manufacturing and produce a very accurate design and provide a visualization of the final product (Dassault Systems).

Electronic components are implemented in a way that results in a stable center of gravity position for the flying wing, which is checked by the XFLR5 program (Drela and Youngren,

2000). The CAD model of the flying wing. This CAD model is used to predict the position of the center of gravity. The C.G. position lies at about 130 mm behind the nose of the fuselage.

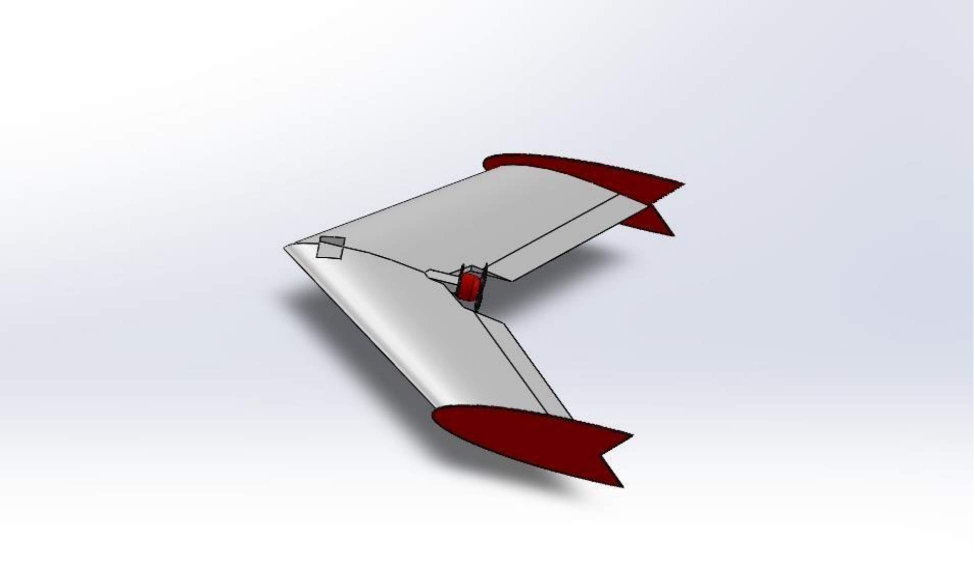

Figure 5.5.1 model in SolidWorks

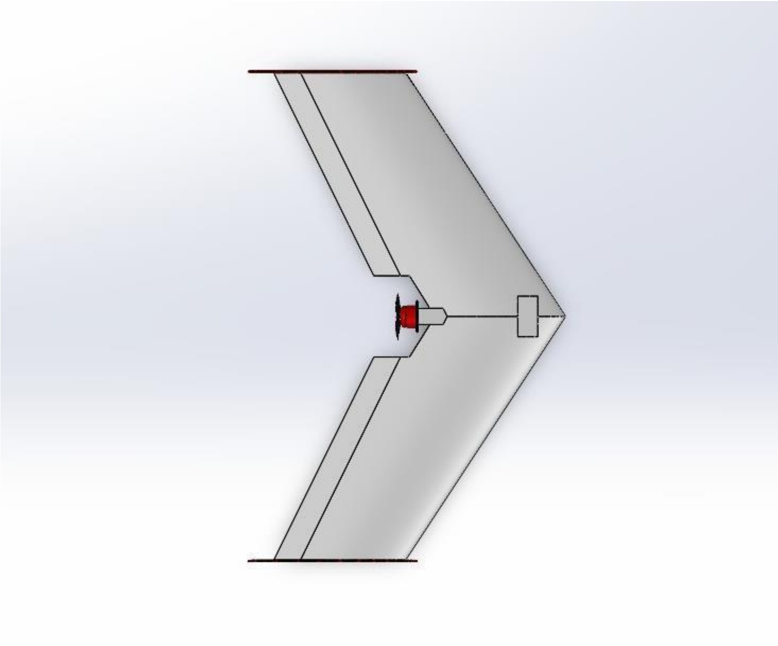

Figure 5.5.2 top view of the model

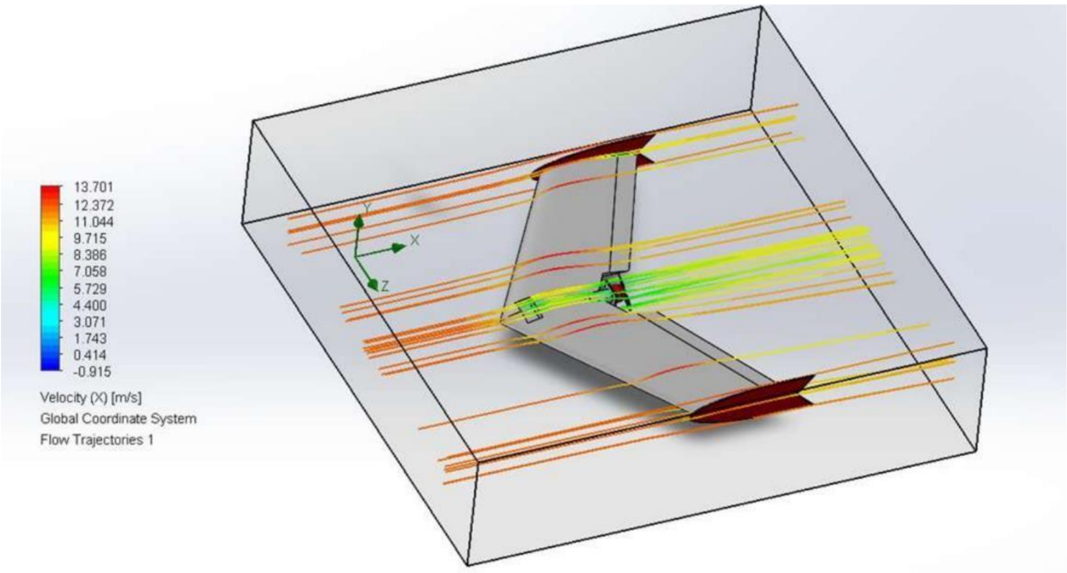

Figure 5.5.3. flow trajectories with a 12m/s velocity

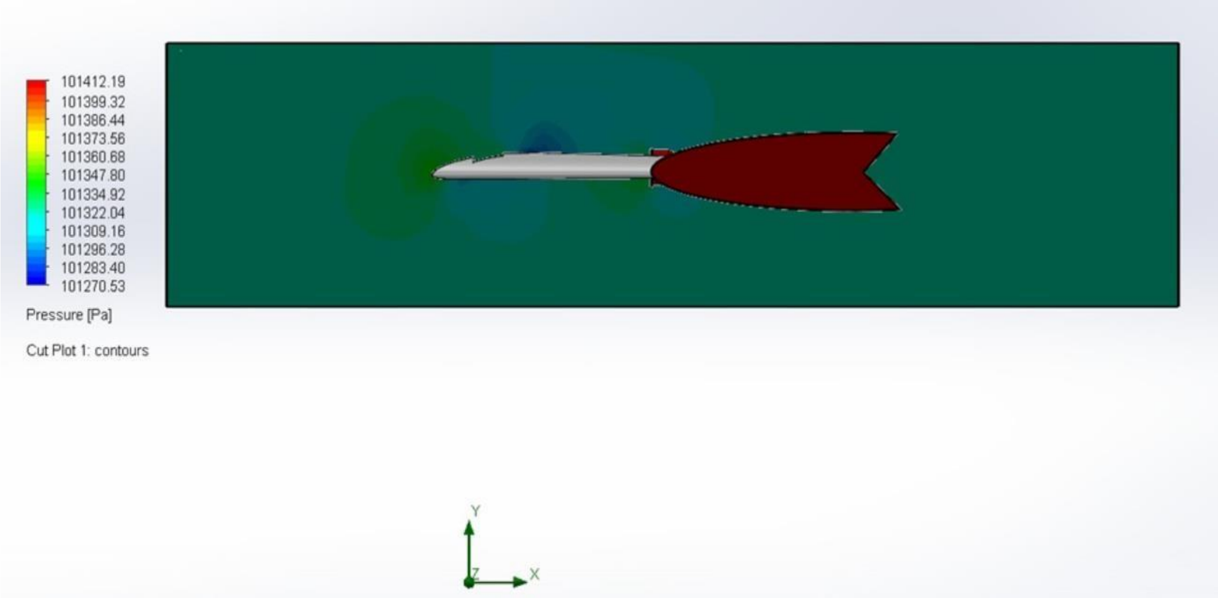

Figure 5.5.4 pressure over whole model

## VI. FABRICATION

### 6.1 Material used

EPP (Expanded Polypropylene) is a type of foam material that is commonly referred to as "styrofoam" However, it is important to note that EPP is not the same as the expanded polystyrene (EPS) foam typically associated with the term "styrofoam."

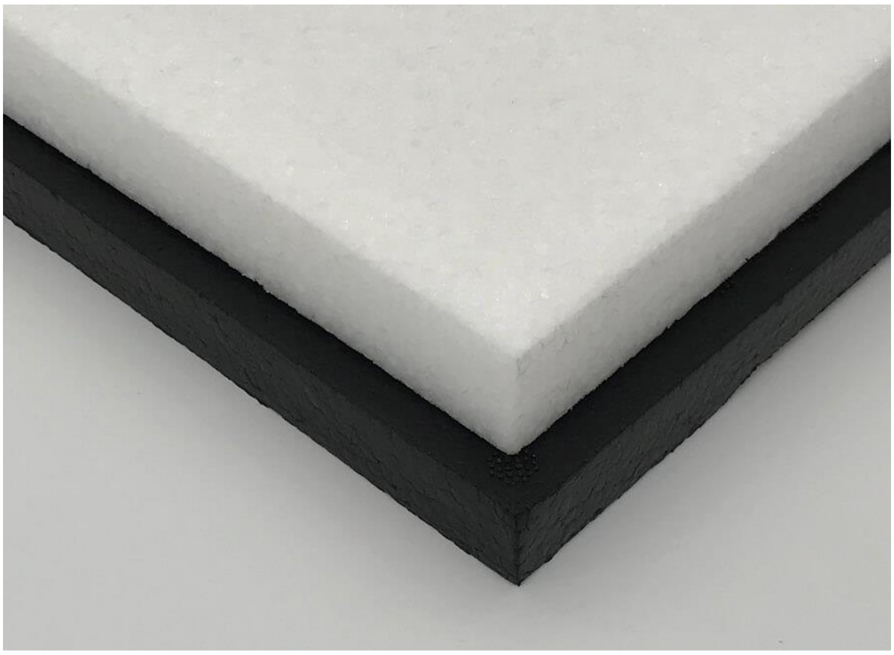

Figure.6.1.1 EPP (Expanded Polypropylene) foam board

EPP foam is a lightweight, closed-cell foam made from polypropylene plastic beads that are expanded using heat and pressure. The resulting material has a cellular structure with interconnected air pockets, giving it excellent insulation and cushioning properties.

EPP foam exhibits several advantageous characteristics. It is highly durable and resistant to impact, making it ideal for applications that require shock absorption or protection against damage. EPP foam can withstand repeated compressions without losing its structural integrity, making it suitable for use in protective packaging, automotive components, sports equipment, and even aerospace applications.

One of the notable features of EPP foam is its ability to recover its shape after being deformed. This property, known as shape memory, allows EPP foam to absorb impact energy and return to its original form, making it well-suited for crash testing dummies, helmet liners, and other safety-related products.

A laser is used in the process of laser cutting to vaporize materials, producing a cut edge. Although it was originally only utilized in industrial manufacturing settings, today it is being employed in small firms, architecture, and by amateurs. The process of laser cutting involves most frequently using optics to focus the output of a high-power laser. The laser beam is guided to the material using laser optics. Using a motion control system, a commercial laser for material cutting follows a CNC or G-code of the design that needs to be cut onto the material. The material is exposed to the concentrated laser beam, which causes it to either melt, burn, vaporize, or be blown away by a jet of gas, leaving an edge with a high-quality finish.

## 6.2 Stages of FWMAV model throughout fabrication:

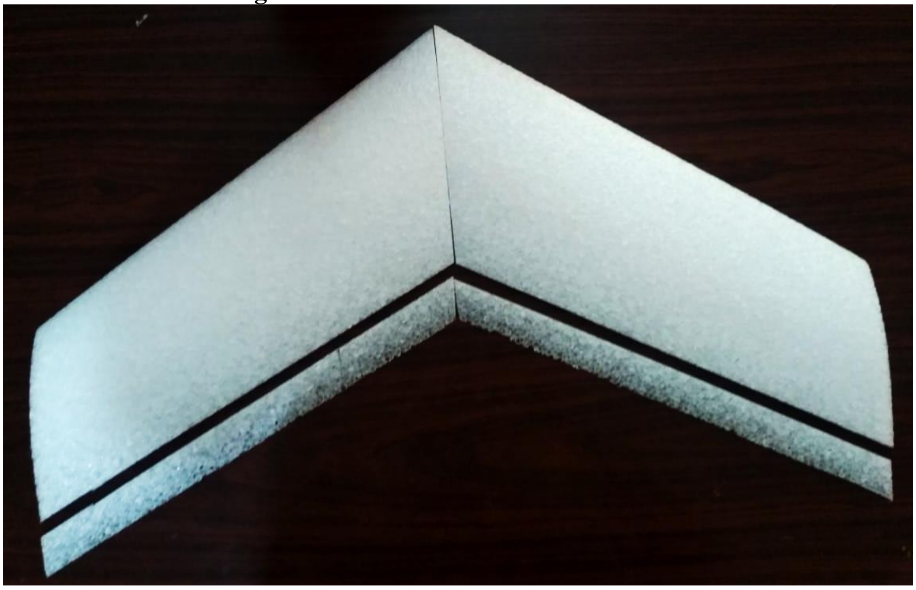

figure 6.2.1. Stage 1

Laser cut EPP foam according to the selected airfoil and manually cut Elevons.

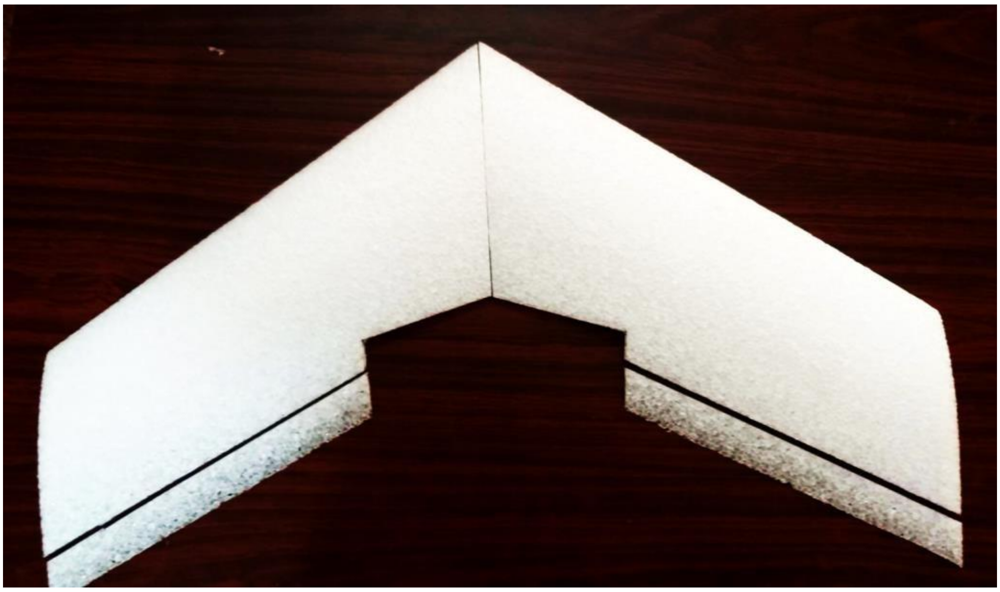

figure 6.2.2. Stage 2

Trimming of the foam for attaching the motor and propeller.

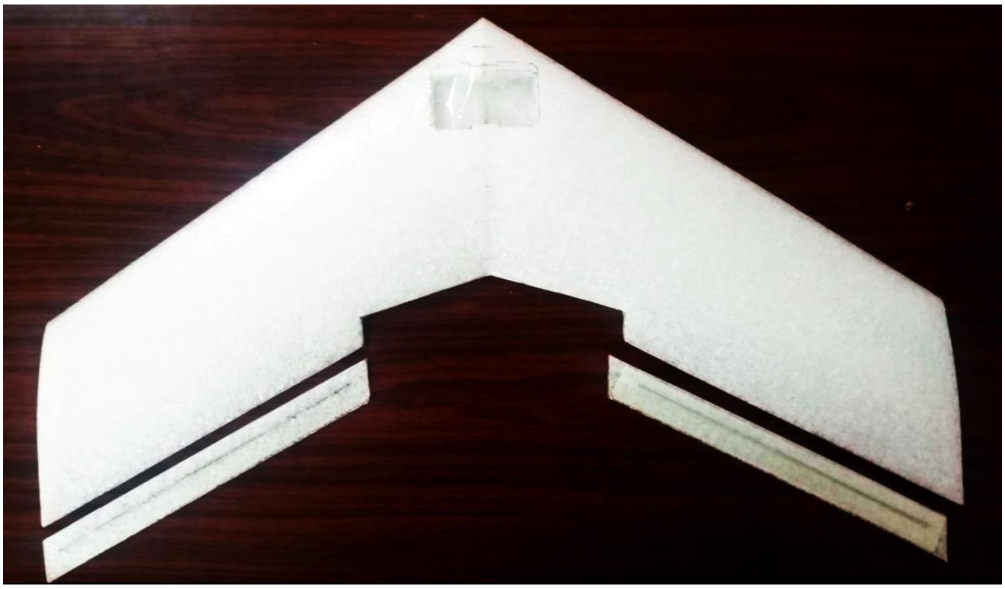

figure 6.2.3 Stage 3

Creating a slot to accommodate the battery at the nose tip and providing support to the elevons by inserting thin carbon fiber rods and attachment of wings with the help of adhesive

figure 6.2.4 Stage 4

Connecting elevons using duct tape followed by the lamination of the model with a light thin film by using hot iron method.

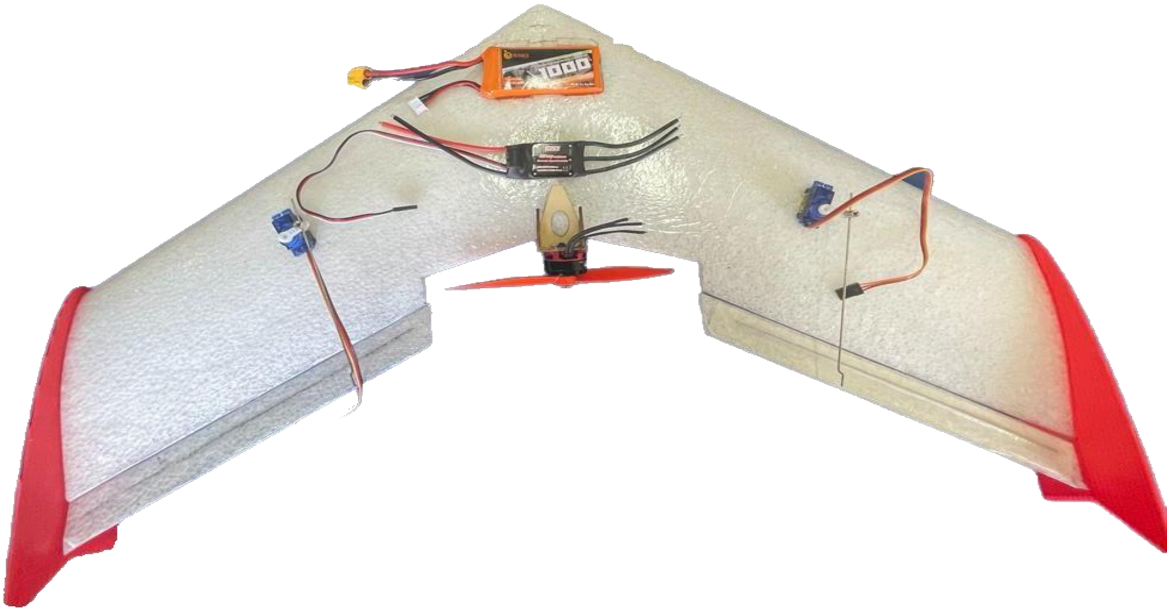

figure 6.2.5 Stage 5
Final assembly with the winglets, electrical systems, and propulsion system mounted on the model.

## VII. WIND TUNNEL TEST

Wind tunnel testing is a crucial step in the development and evaluation of a flying wing micro aerial vehicle (MAV). It allows for controlled and repeatable testing of the MAV's aerodynamic performance. Here's an overview of the wind tunnel testing process for a flying wing MAV:

Define the objectives: Determine the specific goals and objectives of the wind tunnel testing. This could include evaluating lift and drag coefficients, stability characteristics, control effectiveness, or studying flow patterns around the MAV.

Select a wind tunnel: Choose an appropriate wind tunnel facility based on the size and capabilities of your MAV. Wind tunnels range from small-scale low-speed tunnels to larger facilities capable of higher speeds. Consider factors such as the tunnel's maximum airspeed, dimensions, instrumentation capabilities, and availability.

Model preparation: Build a scaled-down model of your flying wing MAV for testing in the wind tunnel. The model should accurately represent the geometry and features of the actual MAV. Use lightweight materials such as foam, carbon fiber, or 3D-printed components to construct the model. Ensure the model's weight and balance match the actual MAV.

Instrumentation: Install appropriate sensors and measurement devices on the model to capture relevant data during testing. This may include pressure sensors, strain gauges, accelerometers, or miniature data loggers. Ensure the instrumentation is properly calibrated and connected for accurate measurements.

Test setup: Mount the MAV model securely in the wind tunnel, ensuring proper alignment and balance. Make any necessary adjustments to the control surfaces, such as elevons or ailerons, to replicate the desired configuration. Connect the instrumentation to the data acquisition system and perform a pre-test check to verify functionality.

Test execution: Start the wind tunnel and gradually increase the airspeed to the desired test conditions. Monitor the data acquisition system to record aerodynamic forces, pressures, and other relevant parameters. Conduct various test cases, such as varying angles of attack, control surface deflections, or simulated flight maneuvers.

Data analysis: Analyze the collected data to evaluate the aerodynamic performance of the flying wing MAV. Calculate lift and drag coefficients, stability derivatives, and control effectiveness. Compare the results to design predictions or established performance criteria. Identify any areas for improvement or design modifications.

Iteration and refinement: Based on the wind tunnel test results, refine the design and make necessary adjustments to optimize the MAV's aerodynamic performance. This could involve modifying the wing shape, control surfaces, or weight distribution. Iterate the wind tunnel testing process as needed to validate design changes

### 7.1 Wind Tunnel Testing Set up

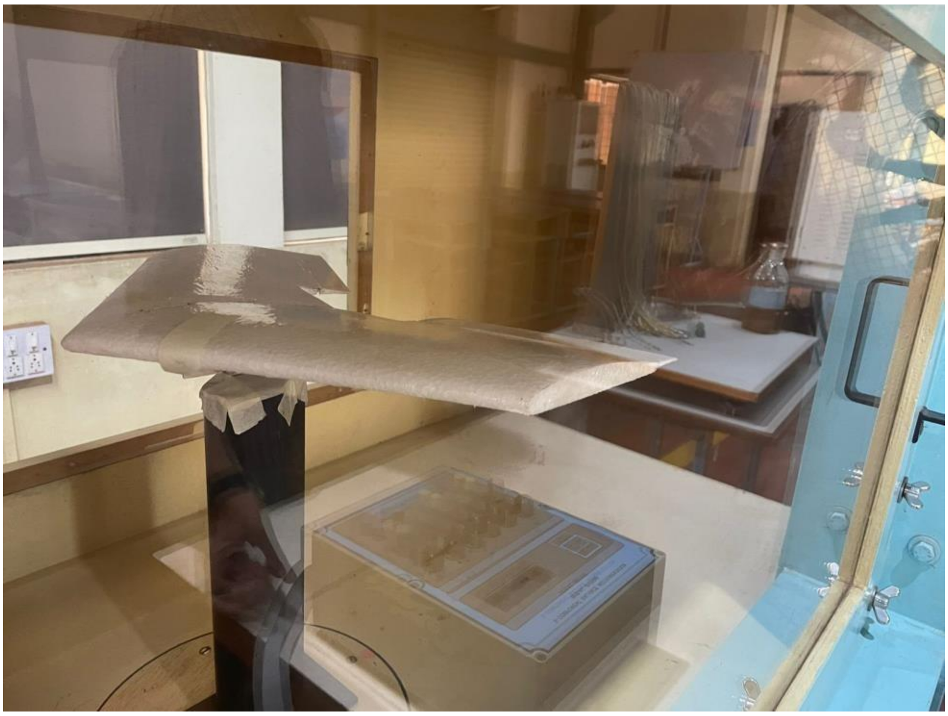

figure 7.1.1. model placed in wind tunnel

In this research, wind tunnel tests were conducted in a 2 feet by 2 feet cross sectional wind tunnel held at the College of Aeronautical Engineering, KLS Gogte Institute of Technology, Belagavi. This wind tunnel is of closed circuit, closed test section, horizontal type, and is capable of producing various speeds (RPM) at atmospheric pressure. The test section is 6.36 feet long and has a rectangular cross-sectional shape. A wind tunnel consists of a motor drive, flow conditioning, a contraction nozzle, and a control console. The drive system of the wind tunnel consists of a 150 HP electric motor designed for an ambient temperature of 30°C. The motor drives the fan in the CCW direction, which is equipped with a variable pitch propeller to permit continuous pitch change. The fan speed is up to 1500 RPM, and the propellers are made of special wood to withstand aerodynamic loads during high-speed rotation. Flow conditioning primarily consists of a diffuser, stilling chamber, and contraction region. Turbulence attenuation is achieved by a honeycomb grid while the screen is in the stilling chamber. A subsonic fixed contour converging nozzle accelerates the flow from the stilling chamber to the rectangular test section. Since converging nozzles are fixed, the desired test section speed is achieved by varying propeller pitch through the electric controller. The control console allows remote control of test section velocity and the model’s pitch attitude. Inside the test section, the pitch attitude of the aircraft model can be altered within ±10◦ . Force and moment readings are reflected on a force-balance component screen, and the lift, drag, side forces, pitch, roll, and yaw moments can be obtained.

### 7.2 Six force balance component

In wind tunnel testing, a six-component force balance, also known as a six-component balance or six-component transducer, is a vital component used to measure the forces and moments acting on an object under aerodynamic testing. It provides detailed information about the forces and moments in six degrees of freedom: three linear forces (X, Y, and Z) and three moments (roll, pitch, and yaw).

The six-force balance typically consists of the following components:

- Axial Force (X): This component measures the force acting along the wind tunnel's axial direction, which is usually the direction of the airflow. It represents the drag or thrust force experienced by the object. While the force axial to the principal direction quantifies the influence parallel to the longitudinal axis, the side force constituent gauges the energy acting perpendicular to that axial course, commonly denoted as the transversal vigor. It indicates the object's resistance or lift in the lateral direction.
- Normal Force (Z): The normal force component measures the force acting perpendicular to the test section floor, usually directed upwards. It represents the lift or downward force experienced by the object.

- Rolling Moment: The rolling moment component measures the rotational force around the longitudinal axis of the object, causing it to rotate in roll.
- Pitching Moment: The pitching moment component measures the rotational force around the lateral axis of the object, causing it to rotate in pitch.
- Yawing Moment: The yawing moment component measures the rotational force around the vertical axis of the object, causing it to rotate in yaw.
- The data obtained from the six-component force balance provides critical insights into an object's aerodynamic behavior, allowing researchers and engineers to understand and optimize its performance, stability, and control characteristics.
- Overall, the six-force balance is a fundamental tool in wind tunnel testing, enabling the precise measurement and analysis of forces and moments exerted on objects under controlled aerodynamic conditions.

### 7.3 Test results:

**Fan Speed: 250 RPM**

| AOA | Inclined manometer reading Δh (mm) | Lift force (kg) | Drag force (kg) | Side force (kg) | Pitch (N) | Roll (N) | Yaw (N) |
|---|---|---|---|---|---|---|---|
| -5° | 10 | 0.68 | 0.297 | 1.55 | 7.177 | 4.00 | 0.757 |
| -3° | 10 | 0.766 | 0.293 | 1.63 | 6.72 | 3.33 | 0.756 |
| -1° | 10 | 0.853 | 0.29 | 1.71 | 6.348 | 5.99 | 0.755 |
| 2° | 10 | 0.94 | 0.286 | 1.79 | 5.933 | 6.98 | 0.755 |
| 5° | 10 | 1.027 | 0.283 | 1.87 | 5.519 | 7.98 | 0.754 |
| 8° | 10 | 1.513 | 0.266 | 2.10 | 5.4 | 7.821 | 0.739 |
| 10° | 10 | 2.00 | 0.25 | 2.32 | 5.3 | 7.66 | 0.725 |

**Table 4**. wind tunnel testing readings

### 7.4 Graphs obtained

for calculated velocity at 250 RPM

$V= 3.72\sqrt{\Delta h}$

$V= 3.72\sqrt{10}$

$V= 11.76$m/s

7.4.1 Graph showing pitching moment v/s alpha

**Table 5** Cm v/s α values

| $C_m$ | Alpha (α) |
|---|---|
| 7.01 | -5 |
| 6.578 | -3 |
| 6.206 | -1 |
| 5.8 | 2 |
| 5.39 | 5 |
| 5.27 | 8 |
| 5.18 | 10 |

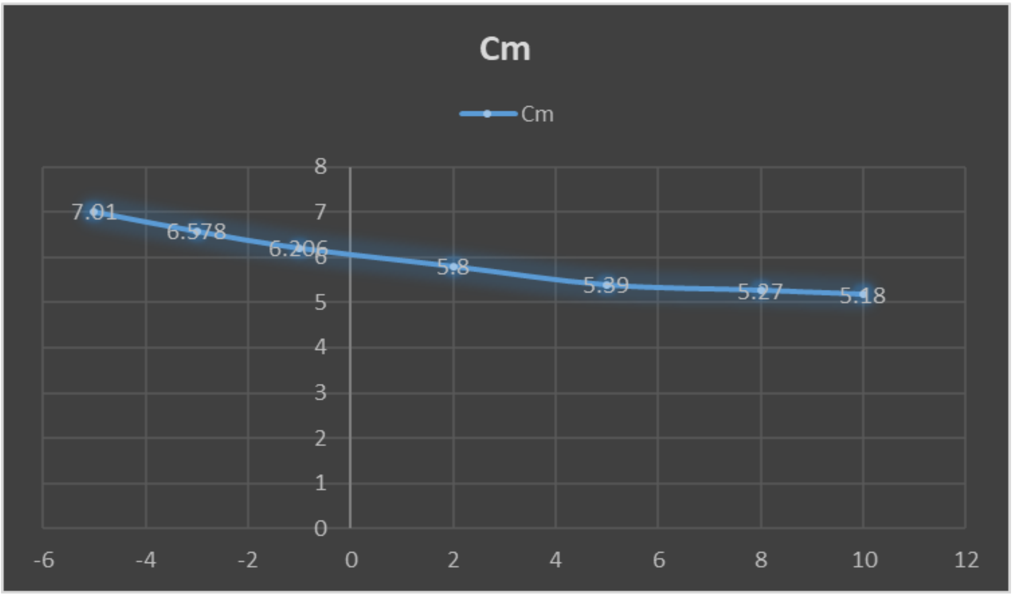

figure 7.4.1 graph Cm v/s α

$C_{m_o}$ = 6

$C_{m_\alpha}$= - 0.136

7.4.2. Graph showing Roll, yaw V/s alpha

**Table 6.** Cl', Cn V/s α

| $C_l'$ | $C_n$ | **Alpha (α)** |
|---|---|---|
| 1.7 | 0.322 | -5 |
| 1.42 | 0.321 | -3 |
| 2.55 | 0.321 | -1 |
| 2.97 | 0.32 | 2 |
| 3.39 | 0.32 | 5 |
| 3.32 | 0.314 | 8 |
| 3.25 | 0.308 | 10 |

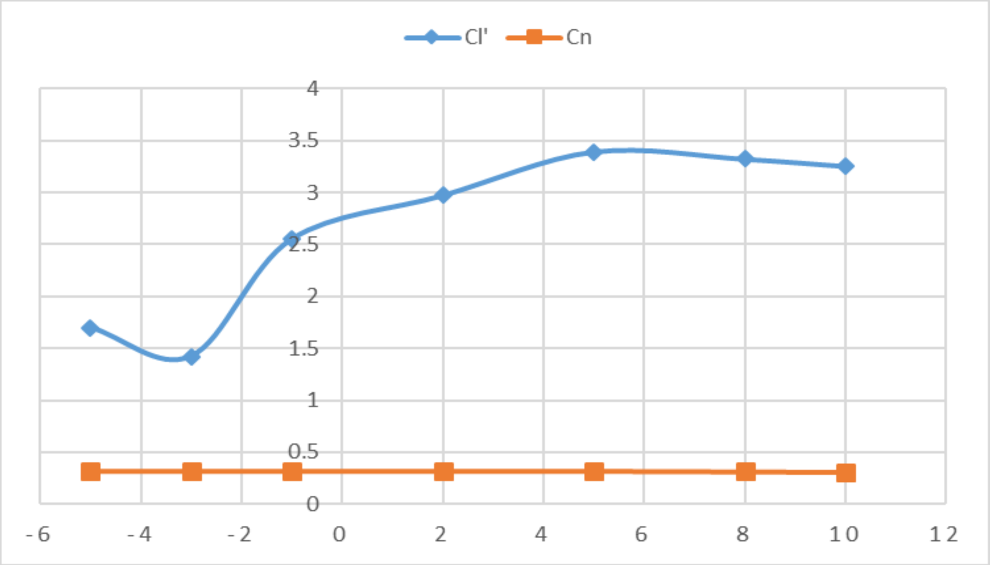

figure 7.4.2 graph Cl', Cn V/s α

$$C_{n_o} = 0.31$$
$$C_{n_\alpha} = -0.002$$

$$C'_{l_o} = 2.6$$
$$C'_{l_\alpha} = 0.14$$

**For calculated velocity at 250 RPM**
V= 3.72√Δh
V= 3.72√10
V= 11.76 m/s
To obtain momentum from,

pitching moment,
$$C_m = \frac{M}{q \cdot S \cdot \bar{c}}$$

Rolling moment,
$$C'_l = \frac{roll}{q \cdot S \cdot b}$$

Yawing moment,
$$C_n = \frac{N}{q \cdot S \cdot b}$$

considering,

$$q_\infty = \frac{1}{2} \cdot \varrho \cdot v^2$$

we know,
Root chord= 182mm
Taper ratio = 0.906
Therefore,

$$MAC = RC \cdot \frac{2}{3} \cdot \frac{1+t+t^2}{1+t}$$

Mean aerodynamic chord, MAC = 0.174
Also,

$$Area, S = \frac{b}{2} * (Cr + Ct)$$

$S = 0.0694\ m^2$

7.4.3 Static Longitudinal Control

$$\begin{aligned}\mathbf{C}_{m\delta_e} &= -\eta\frac{S_t}{S}a_e\left[\frac{\ell_t}{\bar{c}} + \frac{x_{\text{ac}} - x_{\text{cg}}}{\bar{c}}\right]\\ &= -\mathbf{C}_{L\delta_e}\left[\frac{\ell_t}{\bar{c}} + \frac{x_{\text{ac}} - x_{\text{cg}}}{\bar{c}}\right]\end{aligned}$$

where, $S_t$ is elevator (tail) area

$S$ is the wing area

$a_e$ is the elevator effectiveness

$\mathbf{C}_{L\delta_e}$ i.e lift coefficient due to elevator deflection

$\eta = 61.08$

$S_t = 0.0096\ \text{m}^2$

$S = 0.0694\ \text{m}^2$

For $C_{m\alpha}$,

$$C_{m_\alpha} = C_{L_\alpha w} \cdot \left(\frac{X_{ac} - X_{cg}}{\bar{c}}\right) + C_{m\alpha_f us} - \eta \cdot V_h \cdot C_{l_\alpha} t \cdot \left(1 - \frac{d\varepsilon}{d\alpha}\right)$$

Due to rudderless configuration we get,

$$C_{m_\alpha} = C_{L_\alpha w} \cdot \left(\frac{X_{ac}-X_{cg}}{\bar{c}}\right)$$

$C_{m_\alpha}$= -0.0512

The elevator is the aerodynamic control for pitch angle of the vehicle, and its effect is described in terms of the elevator effectiveness

$$a_e = \frac{\partial \mathbf{C}_{Lt}}{\partial \delta_e}$$

where , $C_{lt}$ is the Lift coefficient of the horizontal tail

$\delta_e$ is elevator deflection

∴ Coefficient of lift v/s elevator deflection ( $C_{lt}$ v/s $\delta_e$ )

$$\frac{\partial C_{lt}}{\partial \delta_e} = \frac{\partial C_l}{\partial \alpha} \cdot \frac{\partial \alpha}{\partial \delta_e}$$

$$\therefore \quad \frac{\partial C_{lt}}{\partial \delta_e} = \frac{\partial C_l}{\partial \alpha} \cdot \tau \qquad \because \quad \frac{\partial \alpha}{\partial \delta_e} = \tau$$

value of flap effective parameter to be obtained after plotting the graph of

$$\tau \quad V/S \quad \frac{\text{control surface area}}{\text{lifting surface area}}$$

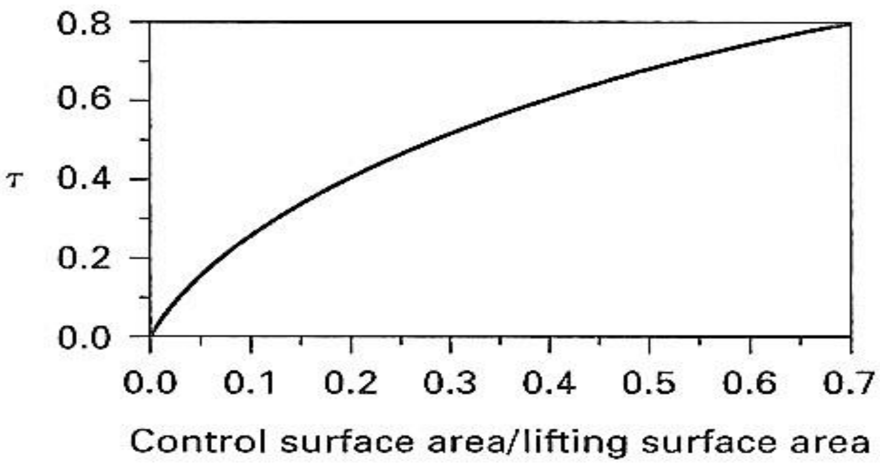

figure 7.4.3 Flap effectiveness parameter graph

$$\frac{\text{control surface area}}{\text{lifting surface area}} = \frac{S_e}{S} = \frac{0.0096}{0.694} = 0.138m^2$$

$\frac{S_e}{S}$ = 0.138 $m^2$

∴ value of $\tau$ obtained from above graph is

$\tau$ = 0.41

$$\frac{\partial C_{lt}}{\partial \delta_e} = 0.0412$$

∴ $a_e$ = 0.0412 (elevator effectiveness)

To obtain $\mathbf{C}_{L\delta_e}$ i.e Lift coefficient due to elevator deflection,

$$Cl_\delta e = \eta \cdot \frac{S_t}{S} \cdot a_e$$

$$C_{l\delta_e} = 0.34$$

∴To obtain the Pitch moment due to elevator deflection

$$C_{m\delta e} = -Cl_{\delta e}\left(\frac{l_t}{\bar{c}} + \frac{X_{ac} - X_{cg}}{\bar{c}}\right)$$

$$C_{m_\delta e} = 0.0158$$

The pitch moment due to elevator deflection is 0.0158

## VIII. CONCLUSION AND FUTURE WORK

It is significant to take into account that parameter estimation is a constantly evolving field of study, and there is much more to discover and develop. More complex measurement methods and data analysis procedures will be made accessible as technology develops, allowing for even more precise parameter estimation for flying wing MAVs.

Overall, the development of these adaptable aerial vehicles has been greatly aided by the advancements made in parameter estimation for flying wing MAVs. We can unleash the full potential of flying wing MAVs and enable them to carry out complicated tasks with increased efficiency, stability, and maneuverability by continuously enhancing parameter estimation algorithms.

We were unable to test for lateral stability parameters, since the wind tunnel test we used to assess longitudinal stability was limited to six force balance component, which only allowed for a variable angle of attack.

This study adopts a wind tunnel test to evaluate the longitudinal stability derivatives while accounting for the flying wing micro aerial vehicle. This method was employed to model and estimate the reflex airfoil aerial vehicle's parameters. If the collected data are biasfree, this approach offers a reliable assessment of the parameters.

**Table 7.** Results obtained

| Sl. No. | Derivatives | Determined values | |
|---|---|---|---|
| | | Wind tunnel (per degree) | Analytical Method |
| 1. | Elevator effectiveness, ($C_{m_{\delta e}}$) | - | 0.0158 |
| 2. | Longitudinal stability, ( $C_{m_\alpha}$) | -0.136 | -0.051 |
| 3. | Yaw moment, ( $C_{n_o}$)<br>( $C_{n_\alpha}$ ) | 0.31<br>-0.002 | -<br>- |
| 4. | Roll moment, ( $C'_{l_\alpha}$)<br>( $C'_{l_o}$ ) | 2.6<br>0.14 | -<br>- |

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