Numerical Investigation of a Fixed Wing Mini UAV

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NUMERICAL INVESTIGSTION OF A FIXED WING MINI UAV

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Abstract

Unmanned Aerial Vehicle (UAV) is an unmanned aircraft which can be controlled from the distance or it can control itself using advanced algorithm. In recent years the field of UAV has been expanded and got attention from various sectors. The development of an UAV has become a popular engineering phenomena and unique application is increasing day by day. Fixed wing UAVs are one of a kind that can fly like an actual fixed wing aircraft and carry different missions. A mini fixed wing UAV resemblances several aerodynamic characteristics like full size airplane. For its fixed wing feature, it can generate lift just like ordinary aircraft based on the famous Lifting Line Theory. The design process of the UAV is similar to the traditional fixed wing aircraft. In this study, a mini UAV is designed based on various design parameters which are selected for flying conditions. The final model is created using CAD software named CATIA V5. Based on the design parameters, the performance of the UAV is calculated. The aerodynamic parameters are evaluated using Ansys 19.2 software. The UAV is capable generating required amount of lift to continue cruise flight. At the maximum speed the UAV can generate more lift, but with the cost of more power which limits the range.

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Chapter 1

Introduction

1.1 BACKGROUND OF THE STUDY

An unmanned Aerial Vehicle is a remotely piloted or a self-piloted aircraft that carry payloads such as camera, sensor, and communication equipment. In recent years, the usage of UAVs has increased rapidly in both military and civilian fields. UAVs can perform various kinds of jobs which were unthinkable or expensive in the past. In a field like agriculture, UAVs are changing the dimension by implementing more preciseness [1]. Healthcare is also a new field, where UAVs are being used in recent times [2]. Due to recent pandemic the demand of UAVs in healthcare sector has been increased, as UAVs can deliver medical equipment faster than traditional delivery system. UAVs can deliver blood, vaccine, medicine and in some cases, important organs. UAV are vital in recent agricultural productions as the crop color and properties can be judged by various sensor. Surveillance has become an important part of various institutional security as UAV can give better view of the sites. Apart from the military institutions, civilian places are also using UAVs for security. The demand of various kinds of UAVs are increasing as they can solve various problems which were difficult in the past.

1.2 BRIEF HISTORY OF UAVS

Humans always wanted to make flying objects. In 1903, Wright Brothers conducted a successful crewed flight. Before that, various attempts were made to make both human-crewed and unmanned vehicles, and earlier attempts were based on balloons. The modern idea of UAVs originated from the writings of Nicola Tesla. In 1897, Tesla displayed a radio-controlled boat, the foundation of unmanned vehicles. During the Second world war, UAVs were used for pilot training and target practicing. After these periods, we saw extensive use of UAVs in military fields. In various conflicts, drones were used both as aggressive and defensive weapons. In recent years the usage of civilian drones has increased. The availability of camera drone in form of quad-copter and other short-range drones increased the popularity and awareness about UAVs. Several startups are trying to solve different real-world problems using different UAVs. UAVs now become part of space exploration. In February 2021, NASA UAV, Ingenuity became the first UAV to fly in the Mars atmosphere [3].

1.3 CLASSIFICATION OF UAV

UAVs can be found in various shapes and forms depending on their role and missions. Based on the feature of wing UAV can be found in two types. They are fixed wing and rotary wing UAV. Rotary wing UAVs use rotor to generate lift and control the direction of paths.

Fixed wing UAVs are a type where the wings generate lift without rotation. It resembles the structure of traditional aircraft design. The wing or fuselage carry the propulsion system. On the other hand, the rotary wing is a structure where wing spins to generate lift. These features can be used in two ways, traditional single rotor with tails or the quadcopter. Recently, the quadcopters have become very popular. Rotary wing UAV can vertically take-off where the fixed-wing UAVs need a place to take off.

UAVs can be classified on the basis on their overall weight, payload, range and mission. Most of them are used for military reason.

Fig. 1. 1: Sitaria Fixed Wing UAV [4]

Figure 1.1 shows a typical fixed wing UAV which is used in civilian platforms. Sitaria UAV was developed to perform various tasks of daily life problems. UAV can come in hybrid format like VTOL, which has characteristics of both fixed and rotary wing UAV. As the fixed wing UAV need a runway to perform to take off and landing the VTOL UAV has a good opportunity and sphere of perform. Besides VTOL came in form of a mixture of both category, which can outperform the rotary wing in case of its performance in many cases. Another category of fixed wing UAV is flying wing, in which the wing control every aspects of the UAV. This configuration can reduce the drag generated from an ordinary UAV, thus focus more on lift generation and less on control surface. Blended wing design is also focusing on these kinds of situations.

Figure 1.2 shows Desert Hawk, an American military mini UAV which was deployed for surveillance. This UAV is a popular example of mini UAV in military application.

Fig. 1. 2: Desert Hawk Mini UAV [5]

Table 1. 1:Types of Fixed wing UAVs [8]

Types	**Typical Range**	**Payload**	**Role**	**Example**
High altitude long endurance(HALE)	More than 5000 km	Around 1000 kg	Military	Global Hawk
Medium Altitude Long Endurance	Around 5000 kms	Around 200 kg	Military	Predator
Medium range Tactical	Around 250 km	Less than 50 kg	Military	IAI Malat
Close Range	Less than 50 Km	Less than 10 Kg	Military,Civilian	Pioneer
Mini UAV	Less than 20 km	Less than 1.5 Kg	Military,Civilian	Desert Hawk
Micro UAV	Very Small	Very Small	Military,Civilian	WASP

1.4 OVERVIEW OF MINI UAV

Mini UAV is defined as an unmanned flying vehicle whose overall weight is no more than 10 Kgs. Previously they were designed as hand-launched and controlled via electric medium. As their size is not suitable for engine system, their propulsion is based on electric motor and battery. Recent development of electric control systems made them easier to control. A practical example of these kinds is Lockheed Martin Desert Hawk III, which is used by US military. It is equipped with advanced battery, modern GPS and other navigation systems and the weight is not more than 4 kg. It was deployed for tactical surveillance in battlefield like Iraq. Mini UAVs have smaller range and endurance than that of HALE and MALE UAVs, but their applications are also different as these are built for smaller ranges. Mini UAVs can be used for various purposes. It can replace rotor UAVs in some sectors like agriculture and delivery systems.

1.5 ADVANTAGES OF FIXED WING OVER ROTARY WING

Fixed wing aircrafts have some advantages over rotary wing aircraft. For these reasons fixed wing UAVs perform better in some cases as they are based on similar principles. Quadcopters are less operationally effective than fixed-wing vehicles. Longer flying periods, greater range, and hence more ground covered per mission result from this. Fixed wing systems have a longer flying time (1–5 hours) than the average quadcopter (15–25 minutes), which makes them more suitable for missions requiring extended data collection as well as long-range ISR, search and rescue support and disaster management. Additionally, fixed wing systems have higher aerodynamic performance and are barely impacted by environmental factors, enabling them to complete missions in strong winds and being suitable for usage in a variety of environments. Fixed-wing platforms have a much bigger payload capacity and can travel further than quadcopters. As a result, the user can transport additional and larger sensors, twin sensor combinations, and essential supplies for tasks like search and rescue missions and humanitarian projects, among others.

The primary factors that can affect flying, such as the cruise velocity which can be maintained and regulated using the fixed-wing UAV. This fact makes it possible to control the shootings accuracy; It is necessary to post process the images in a way that can significantly alter the final quality of the restitution because multi-copters UAV typically cannot coordinate the shooting modality with flight parameters, making it impossible to guarantee images analogous with each other in typology and quality[8]. The fixed wing UAV can fly without propeller propulsion (as a glider) this capability, which is not available for multi-copters drones, ensures a higher level of flight safety and is further utilized during the shooting moment, the engine is turned down and in this manner, any potential physical and electromagnetic noises, which may affect the quality of the taken image are minimized.

1.6 OBJECTIVES OF THE STUDY

- To design and develop a Mini Unmanned Aerial Vehicle.
- To study the aerodynamic feature of the UAV.
- To study the feasibility of the UAV.
- To determine the performance and flight envelope of the UAV.

1.7 SCOPES AND IMPORATANCE OF THE STUDY TO THE SOCIETY

- The UAV can be used in humanitarian effort.
- Mini UAV has agricultural usage potential.
- Mini UAV can be used for surveillance.
- UAV can be used for engineering research purposes.
- UAVs cause less environmental pollution.
- Can be used for building safety inspection.

1.8 METHODOLOGY OF THE RESEARCH

This project is about designing a Mini fixed-wing UAV. In any aerial vehicle, the most important part is the payload. After determining the size and weight of the payload. The next step is to determine the overall weight of the aircraft. Then we have to figure out the suitable lift to weight ratio. From that parameter, we can get an approximate length of the wing. From the desired lift coefficient range, we will choose a suitable airfoil. After that, we will find out a proper range of thrust to weight ratio. From that ratio, we will find a suitable motor to run. Next, the CAD model will be drawn in CATIA V5 software. In Ansys 19.2 the design will be tested. After studying the CAD model, the actual model will be developed. The body of the UAV will be made using foam board. Servo motors will be as control element.

1.9 THESIS OUTLINE

This thesis is organized into four major parts. In Chapter 1 the history, classification and advantages of the fixed wing UAV have been discussed. In Chapter 2, the review of previous studies is presented. The limitation of those previous is also included in chapter 2. In Chapter 3, the research methods, design and analysis process is discussed. The final model of the UAV is also presented in this chapter. In chapter 4, the performance result, flight envelope and the numerical analysis are presented. The outcome of the research is discussed in Chapter 5. The recommendations for further improvement are also added in this chapter.

Chapter 2

Literature Review

2.1 INTRODUCTION

Recent development of UAVS redefined the perspective. Parameters used in UAVS are range, endurance, altitude and weight. Based on the factors. Weibel et al [9] classified UAVs in HALE, MALE, mini and micro. Aerodynamic plays an important role in aircraft. The study is based on various different factors. Ramesh et al[10] identifies various parameters for both military and civilian UAVs. The author analysed the performance of various UAVs and categorized them. They also categorized the performance parameters, like range, endurance, size, maximum take-off weight and operating altitude. The research offers a reasonably thorough grasp of the criteria that constitute a Mini UAV and its implications for both military and non-military applications.

2.1.1 Important Parameters for Design and Classification

UAVs are designed based on various factors. These factors are determined in the design period. These factors change with the mission profile of the UAVs.

2.1.1.1 Operating altitude

The altitude above the sea level upto which an aircraft can fly is the operating altitude. Operating altitude is given in terms of mean sea level reference, while the AGL (above ground level) flying ability is a factor of the payload and the data link.

2.1.1.2 Endurance

Endurance means the time an airborne machine fly. Endurance depends on engine type, fuel etc. Determination of endurance of a Battery operated UAV is different from a fuel. Usually military UAV needs greater endurance than civilian UAVs.

2.1.1.3 Operating Range

Operating range means the radial distance which is measured from the ground control station. Military UAV usually have greater range. On the other hand in civilian application UAVs have smaller range. In agriculture or traffic control application UAV have limited application.

2.1.1.4 Max Take-off Weight

This means the total weight of an aircraft. It consists of payload, battery weight or the fuel, propulsion system and structural weight.

2.1.1.5 Payload

Payloads depends on the mission of a UAV. In civil usage the payload may be a medical equipment, agricultural products or camera. Payload is determined before the design as it effects the total weight of an aircraft.

2.1.1.6 Size

The size of the UAV depends on the payload and total weight. Size means the length of the fuselage, wing and landing gears.

2.2 RELATED PREVIOUS STUDY OF MINI UAV

Many studies have done to categorize the mini-UAVs. Cai et al surveyed on various types of UAVs. They categorized UAVS on the basis of range, endurance, overall weight. Authors also discussed the implementation of various flight control system is fixed wing UAVs. Authors discussed the research background of the UAV construction, like platform design and dynamic construction. Later the control of the UAVs, like navigation, guidance and advanced control system were discussed. Later the future advancement on the field of various UAVs were analysed [11].

Hazim et al. surveyed on different aspects of UAV regarding civil applications. Here author discussed about the UAVS in precision agriculture. Another application they discussed is using UAV in road traffic monitoring. UAVs are cost effective and new technologies will make them better. They emphasizes on various mission category of various kinds of UAVs. In search and rescue missions(SAR) these UAVs can play a vital role by giving information such as location and carry important loads. They also surveyed on the usage of UAVs in agricultural and mail delivery sectors [12].

Panagiotu et. al developed a MALE UAV and analyzed its various aspects. The design was based on the overall weight. On the basis of mission profile, several model were produced. Later the authors did CFD analysis of the models and chose the best one. CFD analysis of the design helped to found the best design possible. In this research, the general methodology of designing of an UAV was also discussed. Later a Medium altitude long endurance surveillance UAV design weas developed Greek border security forces [13].

Panagiotu et. al studied the aerodynamic aspects of the UAV. Author discussed about various methods of aerodynamic analysis and determining the best result. Simulation study shows the major sources of Drag in a UAV. They studied generation of drag in different angle of attacks. Later the author discussed about the flow control and blended wing [14].

Panagiotu et. al later designed a blended wing MALE UAV. Author also analyze the design in Ansys simulation and found several results. Author experimented on different airfoil for wing of the UAV. Later the CFD results were compared with wind tunnel results. The author found better lift to drag ratio in a blended wing configuration. In that research author found better lift to drag ratio in the blended wing formation than the conventional one. Though in higher angle of attack the conventional wing produce more lift than the blended wing system, it is prefer for its less drag generating body [15].

Kontogiannis et. al developed a small size UAV and they optimized it using simulation software Fluent. They followed a designed methodology and drafted a preliminary design. Author approached numerically. They successfully used winglet to optimize the wing design. Later battery, control and propeller. The CFD analysis served the the foundation of the optimization. The optimization was propsed by the increment of wingspan and aspect ratio. These developments later increased the range and endurance of the UAV [16].

Hassanalian et al worked on the methodology of desigining a micro UAV. Their study was based on the traditional aircraft design method, but it was modified for small UAVs. Author studied the method, estimated weight, select a suitable airfoil for the the UAV, designed a launch system for the UAV. As the UAVs fly in low Reynold range, panel method was used to analyse various aspects of the micro UAVs. Author researched on the airfoil selection techniques using Xflr5 software which could decrease the time. Later a model was built on the basis of the research [17].

Soemaryanto et al studied on the wing loading of an UAV. Author used Schrnek Method for the study. These study accounts of average of life per lift per span between platform span and elliptical lift distribution. The method shows the higher value od lift in wing model. Later they simulate the model in Ansys CFX and found the similar results. Here they compared the lift generation in the wing [18].

Triet et al analysed the wing aerodynamic features using computational fluid dynamics. They chose NACA airfoil based wing UAVs and used Ansys software and find lift and drag and other performances. Using the aerodynamic forces found on the surface, they calculated the stress load on the wing of the UAV. The wings were also tested on various velocities. They found that lift increased with the increment of the velocity. But it also has consequences as the drag also increased in the same manner in the wing [19].

Panagiotou et al developed a blended wing design for the UAVs and analysed its various aspects on multiple area. As blended wing decrease drag forces and increases the efficiency, the formation was chosen. The traditional design methodology was used to design the UAV and blended shape was installed. Later just like other previous model, the design was tested using numerical methods. On the basis of the result the model was optimized [20].

Kulshreshtha et al analysed NACA 2412 airfoil and find out its various properties based on CFD modelling. Lift and drag was measured in multiple angle of attack on various velocity ranges. They later cataroizecd the result based on the computational analysis. The whole experiment was about to find the exact aerodynamic coefficient of airfoil in various velocity measure [21].

Grendysa et al developed a wing for long endurance UAV for the agricultural purposes. The author developed a methodology to design a wing for the UAV and analysed it. Later the design was optimized for real life applications. Major emphasis was given to increase the range of the aircraft for general uses [22].

Panagiotou et al developed a MALE UAV which is powered by solar energy as it can provide long endurance. It was a different approach from his previous works as those were based on traditional fuel approach. The method was a modified version of previous method to design an UAV. The UAV is capable of carrying 50 kg loads with a longer endurance, flying at 7000 km. The UAV provides an advantages of the use of renewable energy in these field. However, neither the design process nor the notion itself are complete. Incorporating a more thorough structural weight estimation methodology, for instance, might allow the geometry parameters to be added into the refined weight estimation loop when taking into account the presizing calculations tool. Regarding the ensuing aerial study was restricted to the conceptual design stage for vehicles. However, this idea can act as a foundation for future studies on the basic and detailed designs of a hybrid solar or a solar-only UAV platform [23].

Dundar et al developed a vertically takeoff capable of VTOL mini UAV which can carry 700g as payload. The design methodology was very similar to the other’s work as it is similar kind of UAV. The author chose NACA 5 series airfoil can calculated the performance. Here, author find an significant thing that, the UAV fly in lower Reynold number and he analysed on the basis of that findings. Later required power was calculated on the basis of the capacity of the

Lithium based batteries. As the UAV has extra motor for vertical takeoff, it requires more power than an ordinary fixed wing UAV [24].

Park et al. designed a propeller suitable for high altitude long endurance(HALE) UAV. Most of the studies were done on the UAV sizing and propeller were selected on the basis of historical data. But the author chose to design specific propeller for the UAV design. The design was based on blade element theory, which provides the explanation for the rotation and the lift generation of the propeller. After analyzing the geometry, lift coefficient, drag and pressure conditions, a final geometry of the propeller was adopted. Later the model was tasted on a real UAV and significant result was found [25].

Hieu et al researched on airfoil selection for smaller UAVs. As airfoil testing is both costly and time consuming work, the authors approached for an alternative. The alternative was the software like Xflr5 and Javafoil for selection. As the author mention no airfoil is superior to others, they are only used on the basis of necessity and applications. These software uses the Panel method to determine the coefficients of various airfoils. The author first selected some criteria for UAV an then collected the data for multiple airfoils. Then they graded them on the basis of the those criteria and selected the best one. The author selected from the AG series, S series and Eppler airfoil, which are developed for lower Reynold number applications and small UAVs [26].

Michailidis et. al studied the future of control of UAV. They surveyed on various aspects of the control of the UAV. Author found the limitation of the UAVs due to their design criteria, which limited their potentials. But he saw the future of UAVs as new technologies are constantly being developed. The survey was based on different types of control system used in UAVs [27].

Alam et al designed a airfoil sized fuselage to reduce the drag of an UAV. The Fuselage was based on the NACA 4416 airfoil. They performed the CFD analysis of the fuselage and compared them with the data from the wind tunnel. This airfoil shaped fuselage generated significantly amount of extra lift. But the problem was the fuselage also generated some extra amount of drag due to tip vortices. Author later expressed the possibility of future of using of airfoil shaped fuselage [28].

Goetten et al reviewed the process of using RANS in various software and advocated for the best practices to perform, They discussed from the geometry selection to the wing modelling and calculation of various aspects of the aerodynamic models. They authorized a proper guideline on the basis of various previous works and improved the methods so that proper data can be obtained [29].

2.4 RESEARCH GAP OF THE PREVIOUS STUDIES

Most of the UAVs have been used are made for military purposes. For civilian uses, most of the UAVs are rotor winged. Rotor wing UAVs are short ranged and energy consuming. Multi Rotor wing UAVs consumed more energy compared to single engine fixed wing UAV. Next important factor is aerodynamic design feature, which makes Fixed wing UAVs better than a Rotary wing UAVs. Most of fixed winged UAVs are designed for either military or research purposes. In civilian Usage, this kinds of UAVs are not always feasible. Like HALE UAV is not always suitable for agriculture. The limitation of the many previous studies is about the limited usage of UAVs in civilian usage, Some UAVs are also being used in photography. This element can be used for surveillance and security. But most of the previous studies are only based on the aerodynamic optimization of the UAV.

2.5 PROBLEM STATEMENT OF THE STUDY

The UAV design process is a vast and multidisciplinary task. The way to solve the problem is to make it aerodynamically efficient. The UAV will be categorized as Mini UAV. It will be fixed wing in configuration. The UAV will be light weight, radio controlled for take off and landing. Electronic control system will be used to control the UAV. The design process will be vigorus, the CAD model will be developed using OpenVSP and Catia software. The model was later analysed using computational fluid dynamics methods.

Chapter 3

Research Framework

3.1 INTRODUCTION

Design of an UAV is a thoughtful and time consuming job, as various aspects of engineering work together. The design is based on the mission requirement, sizing and aerodynamic features. The most important part of the design in the wing section, which is responsible for lifting the UAV. To design a wing, an airfoil must be selected, whose shape is responsible for maximum lift. Another important part is electric propulsion. Different criteria should be made to create a cad model, which will be the basis for computational testing, which will determine the performance of the UAV.

3.2 PRELIMINARY DESIGN

The mini-UAV consists of various parts, which are part of design section. The first part of the design is weight estimation. The overall weight is calculated on the basis of payload, structural weight and mission criteria. In Fig 3.1 the flow chart of the design on a mini UAV is shown. The process is discussed in details later in later part of the chapter.

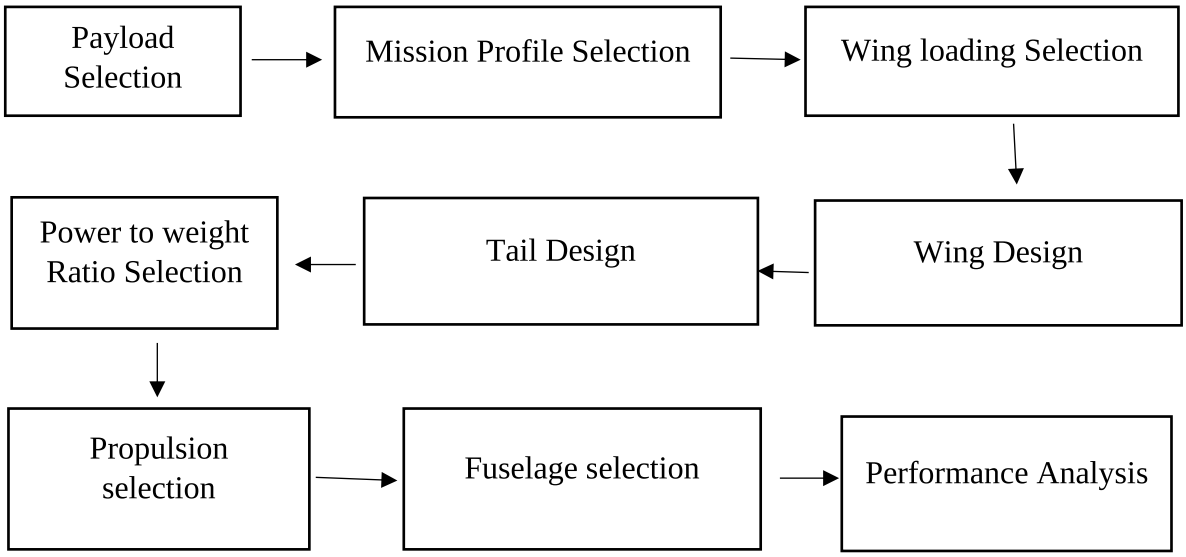

Fig. 3. 1: Design of a Mini UAV

3.2.1 Weight estimation

The weight of traditional aircraft is calculated on the basis of the following equation [7]:

$$W = W_{crew} + W_{payload} + W_{fuel} + W_{empty} \quad (1)$$

Where,

W = Overall weight or the take off weight(kg)

W_c= Weight of pilot and crew(kg)

$W_{payload}$ =Weight of payload(kg)

W_{empty} = Weight of structure and engine(kg)

W_f = Weight if fuel(kg)

The equation is later transformed into this to calculate the take off mass for full sized aircraft. From the fuel section calculated from the mission profile, the total weight of a full sized aircraft is calculated. But the equation can not be properly used as the mini UAV is a battery driven small aircraft, which is not run on battery. Thus a new equation is formed to derive the whole equation.

The equation is not fully applied to a electrically propelled UAV as it has not pilot or fuel. The modified equation for the mini UAV is[14]:

$$W = W_{control} + W_{battery} + W_{payload} + W_{empty} \quad (2)$$

3.2.2 Payload Sizing

Payload is an important part of a UAV. In typical mini UAV, the payload is camera or sensor, which is no more than 20% of the total weight of the UAV. Payload is a object which is carried by an aircraft or a flying object. The size of a payload is an important design criteria, on the basis of which an aircraft is designed.

3.2.3 Battery Weight

Battery is an important part of a mini UAV as it is crucial part of the propulsion system. In typical aircraft the weight of fuel is constantly decreasing, as the fuel is being burnt. But, in battery operated system, the energy is generated through chemical operation, while the weight remains same. Thus the range estimation is UAV is different from a traditional aircraft.

3.2.4 Empty Weight

The propulsion system is traditional aircraft is an IC engine or a gas turbine. In the electric powered UAV, the system is replaced by electric motor. In a mini-UAV brushless DC motor is used. It is a kind of motor where direct current is provided to run the rotor synchronously, thus it is also called synchronous DC motor. These kinds of motors are very essential in running the UAV.

Another part of the empty weight is the weight of the structure. The structure consists of the fuselage, wing, tails and landing gear. These components will be constructed using basal wood and Depron foam board, which are common material in use. It is an extruded polystyrene, which is widely used as insulation in thermal machinery. Its quality also shows its capability to hold a design model. That’s why it is widely used for building various kinds of model, including model aircraft. It is also used to develop fixed wing UAVs. It is also available and easier to cut. That’s why Depron was chosen.

Besides the landing gear, the weight of the wire also plays a vital role in making the weight complete for the UAV. Some extra weight can be added due to the fabrication as the proper techniques may vary.

3.2.5 Control Weight

Control system is the most important part of any vehicle system. In flying object, it is essential for its complexity and reliability. The control system consists of servos, lever arm and radio receiver system and various kinds of wires. The servo are the major contributor in the control system, as they provide the angular motion of the control surfaces.

In the table the total weight of the mini UAV has been calculated on the basis of its equipment.

Table 3. 1: Total Weight of the UAV

Components	Weight
Payload	0.3 kg
Propulsion System	0.75 kg
Control System	0.35 kg
Structure	1.5 kg
Total	2.9 kg

In table 3.1 the total weight is estimated using previous study and specification of various parts of the propulsion and control element [12].

3.3 MISSION PROFILE

Mission is term that describes the trip of an aircraft. It is related to weight determination and performance. For mission profile, the range, take off distance, loiter and landing distance. To design an aircraft it is necessary to determine the mission first, as the weight fraction depends on the profile. The propulsion system and cost also depend on the profile. In a typical aircraft mission profile, several section are mentioned are take off, cruise, loiter, climb and landing.

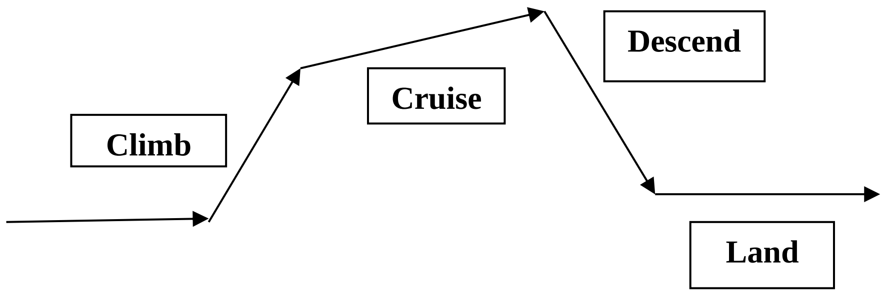

Fig. 3. 2 : Mission Profile

In fig 3.2 the mission profile of the mini-UAV has been shown. It is the outlines the phases of an aircraft mission where various activities and surroundings take place. The duration of each phase of a mission can be recorded, and the frequency of related maintenance tasks can be changed to better match aircraft usage. Record can be saved, but it will be marked as an invalid mission profile record if the total time reported for mission profile meters does not equal the total hours for the flight. An asynchronous task updates the frequencies on linked task cards and master task cards as you save flight records. Frequency intervals and thresholds are reset to the worst-case levels when readings are updated in the Task Card application if the sum of the meter readings does not equal the sum of the flight hours for the aircraft.

Just like an aircraft, the mission of an UAV must be determined as the weight and battery size depend on them. Complex mission is a high-professional job, which will need industrial level experience. To reduce the complexity of the design and manufacture, the simple mission profile has been chosen. The diagram depicted the simple mission of the UAV, which start by taking off and ends by landing on the desired location [7].

3.4 WING DESIGN

Wing is an integral part of an aircraft as it generate sufficient lift to fly an aircraft. All the aerodynamic feature are found in the wing. A portion of wing is also essential for controlling the aircraft. In commercial airlines, wing also carry fuel. In many aircraft, wing carry engine, weapon, payload, landing gear etc. Wing design is the most fundamental part of any aircraft design program.

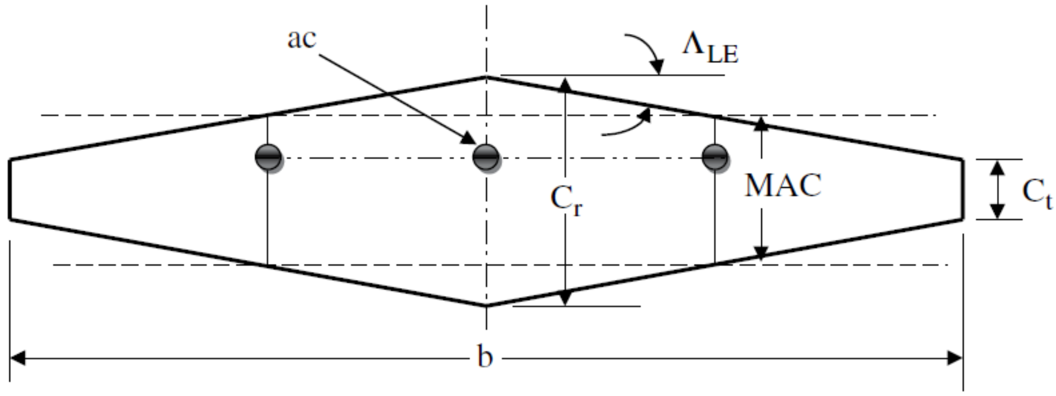

Fig. 3. 3: Wing of an Aircraft [4]

Wing consists of various parts and parameters. In Fig 3.3 those parts are shown. The MAC is the mean aerodynamic chord of the wing. The full span of the wing is presented by b. There are two chords of the wing, the root chord and the tip chord. The swept angle is also presented in the figure.

3.4.1 Wing loading

Wing loading is an important parameter of an aircraft. It is the ratio of total weight of the aircraft and the wing area. Most of the fueled aircraft the wing loading is determined by the stall speed and the maximum lift coefficient. Wing loading can also be determined using historical data. The Wing Loading for the design will be 130 N/M^2.

The wing loading is determined on the basis of historical data. Similar kinds of aircrafts are in similar range of wing loading, To design the UAV the wing loading is measured on the basis on these kinds of analysis. Wing loading data is verified over the years on the basis of various kinds of design.

3.4.2 Wing area

Wing area is an important aspect of any aircraft, as the weight lifting depends on the criteria. The wing area depends on wing loading selection and the total weight of the aircraft. From the calculation of overall weight and the wing loading the wing area can the found. The wing is crucial to determine the wing span.

$$S = \frac{\boldsymbol{W_{to}}}{\boldsymbol{W}/\boldsymbol{S}} \qquad (3)$$

Where, S is the wing area(m^2)

W_{to} is the Total weight (kg)

W/S is the Wing loading (Nm^{-2})

3.4.3 Aspect Ratio

Aspect ratio is defined as the ratio of wing span and mean aerodynamic chord. It is an important part of the wing design as the wing length, stall speed and stall angel depend on it. High aspect ratio provides skinny wing, while reducing drag while low aspect ratio wing does exact opposite. High aspect ratio ensure stall at smaller angle of attack, ensuring high lift ratio. But it also has a consequences, as not all kind of aircraft needs high aspect ratio. In smaller aircraft, the low aspect ratio is also needed for controllability and production. The wing span also contribute in drag generation.

$$\textit{Aspect Ratio} = \frac{\boldsymbol{b^2}}{\boldsymbol{s}} \qquad (4)$$

Where, b is the wing span(m)

S is the wing area(m^2)

For the design criteria and historical data, the aspect ratio of the mini UAV is taken 4.

3.4.4 Wing span

Wing span is the total length of the wing from one side to another. The span depends on the wing loading, take-off weight, aspect ratio and swept angel. The wing span in directly proportional to the root of aspect ratio. Bigger aspect ratio ensures bigger wing span.

$$\text{Wing span } B = \sqrt{\boldsymbol{AR} \times \boldsymbol{S}} \qquad (5)$$

Where,

AR is the aspect ratio

S is the wing area(m)

3.4.5 Wing Sweep

Wing swept angel is very important for high speed aircraft as they fly in high Reynold conditions. Swept angel reduce the effects of shock and reduce drag in high speed flight. Furthermore, it can increase the Mach number capability by decreasing the effects of compressibility. So, the advantages are all for the high speed flight, specially the supersonic flight. The mini-UAV will fly at a lower range of speed, thus high angel is unnecessary.

3.4.6 Taper Ratio and Chord Size

Root is the center cross-section of the wing while the tip is the furthermost cross-section of the wing. Root and tip may have similar cross-sections, but they can also defer in some cases. The size of the root and tips depends on the wing span and taper ratio. On the basis of taper ratio different types of wings has been developed. The popular one are rectangular, elliptical and trapezoidal. Taper is very essential in controlling the lift distribution. In high speed wing, smaller taper ratio is preferred[7].

$$\lambda = \frac{\boldsymbol{C_t}}{\boldsymbol{C_r}} \tag{6}$$

where,

λ is the taper ratio

C_t is the tip chord(m)

C_r is the Root chord(m)

Usually the taper ratio is derived from historical data, based on similar kinds of aircraft for similar situation.

The size of the root and tip is based on the wing size, aspect ratio and taper ratio. They are[7];

$$C_r = 2bAR(1+\lambda) \tag{7}$$

$$C_t = C_r \times \lambda \tag{8}$$

Where, C_r is root chord(m) and C_t is the tip chord(m)

3.4.7 Wing Vertical Location

Wing vertical location is determined on the basis of application, not on the basis of mathematics, as it is simply a design decision. Apperantly, there are three wing location.

- High Wing
- Mid wing
- Low wing

Three positions have their own merits and demerits. For example, in high wing configuration, the engine and propeller have proper ground clearance. Another advantage is the fuselage remain close to ground, which make payload loading-unloading easier. That's why high wing design is very popular for cargo aircraft. The wing box also remain secure in this configuration. For short take of landing aircraft, high wing is also preferred. High wing can also ensure flaps to generate high lift. In Fig. 3. 4 the first picture represent high wing configuration where the fuselage carries the landing gear which increase the weight, which is a major disadvantage.
Mid wing configuration also provide the similar ground clearance like high wing, and provide maneuverability, which is very popular in military aircraft. But mid wing also create structural problems. Structural carrythrough is a significant disadvantage for mid wing. Mid wing aircraft preferred to have better rolling moment than the high wing aircraft. It also contain less interference drag than other kinds of wing. It is preferred in both military and civilian use. Many fighter aircraft have mid wing configuration.

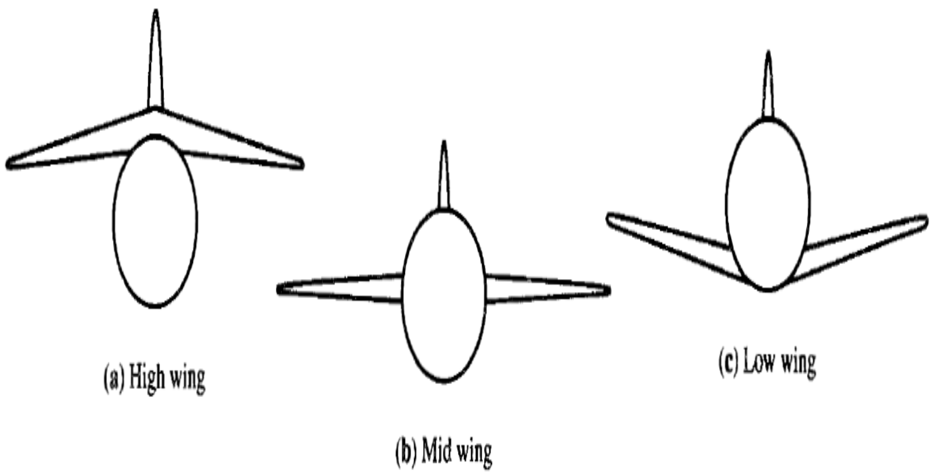

Fig. 3. 4: High Wing, Mid wing And Low Wing[31]

The low wing configuration is very common in commercial aircraft. In Fig. 3.4 the third portion represents a low wing which usually has an upward angle which is essential for stability and control. Major advantages of the low wing is the installation of the landing gear system. In high wing the landing gear tends to be installed in the fuselage, whereas, in low wing, the landing gear can be installed in the wing. But, in the low wing the dihedral angle must be high for ground clearance.

3.5 AIRFOIL SELECTION FOR WING

Airfoil is the two dimensional cross section of a wing. Selection of an airfoil is crucial for any aircraft design, as it is responsible for most of the aerodynamic parameters of an aircraft. Given that the drone being constructed and studied is a relatively slow UAV, low-speed airfoils have received the majority of the attention. Several factors are taken into account when selecting an airfoil. It's also critical to realize that no airfoil is better than another. The airfoil is one of the most crucial elements for UAV performance, which also affects their chance of success. The airfoil is chosen from a database of others operating under similar conditions, and if necessary, it is later optimized to fit the UAV's configuration as best as possible.

3.5.1 Criteria of airfoil selection

There are some criteria which are maintained for the selection of the airfoil of the wing. For the selection a number of airfoil are studied and these parameters are measured. The criteria for selecting the airfoil are:

- The lift coefficient (C_L) must be as high as possible
- The drag coefficient (C_d) must be as low as possible
- The lift to drag ratio should be high
- The lift curve slope should be high
- The stall angle of attack (α_{stall}) should be higher

3.5.2 Analysis with Xflr5 using Panel method

The testing of an airfoil in a wind tunnel is a time-consuming work. A software which can analyze the airfoil can be a good alternative for the analysis. Xflr5 is a software that uses the Panel method to analyze the airfoil.

The panel method is an analysis technique that can be applied to find a rough answer for the forces exerted on a moving object. Since the method is based on inviscid flow analysis, it can only account for the pressure forces that result across the surface. The panel approach basically uses discrete elements on an object's surface and then prescribes a flow element (such a vortex, doublet, source, or sink) on each element that will satisfy specific boundary requirements (like no flow crosses the surface of the object). The interaction of the components must be taken into account and must also meet the requirement that flow far from the object equal the free stream velocity approaching the item. Numerous books and articles have been written that give extremely general descriptions of the method, including the addition of viscous forces to some extent. To test the method's applicability in external flows, we will utilize a simple geometry and a simple distribution of the flow elements in this instance. There are more complex models, but they are all based on the streamlined version shown here.

It is significant to highlight that the calculation model employed by the panel methods in XFLR5 has a limitation in the prediction of boundary layers, flow separations, and rotating flows. In the case of low-speed UAVs, these phenomena and conditions do not apply. Choosing a list of frequently used low-speed airfoils and evaluating their performance under the same test conditions is the first step in the process of choosing the best airfoil.

3.5.3 Available Airfoils

For UAV, various kinds of airfoil were considered. NACA airfoil, which were developed by the National Advisory Committee for Aeronautics (NACA) in 1930s were first considered. The NACA 4 series airfoils, which are very common in research field were first considered. The next kind of airfoil is AG airfoil. These kinds of airfoil was developed by Dr. Mark Drela from MIT, which are very useful for smaller aircraft and glider. The S series airfoil are developed by Prof. Michael Selig from the University of Illinois Urbana-Champaign, are widely used in glider and sailplane. The last kind of airfoil are in consideration are the E series of Eppler airfoil.

The selected airfoils are:

- AG 12
- NACA 2512
- S9000
- E231
- E274

3.5.4 Airfoil performance table

The parameters of the airfoils are calculated in multiple ranges of Reynolds number, angle of attack etc. From various analysis, we get a clear idea of airfoil data.

The data given below are:

Reynolds number 600000

Angle of attack at 5 degree

The below analysis was based on these conditions. The specific Reynold number was chosen because it is in turbulent region and close to the critical number.

Table 3. 2: Airfoil Performance

Airfoil name	Lift Coefficient(C_l)	Drag Coefficient(C_d)	Lift to Drag Ratio(L/D)	Stall
AG 12	0.763	0.010	78.774	10
NACA 2512	0.808	0.009	88.416	9
S9000	0.861	0.009	92.117	9
E231	0.854	0.009	93.924	10
E274	0.809	0.009	90.086	10

From the table, we can see S9000 airfoil shows a better performance. Thus S9000 is preferred for the Mini UAV design.

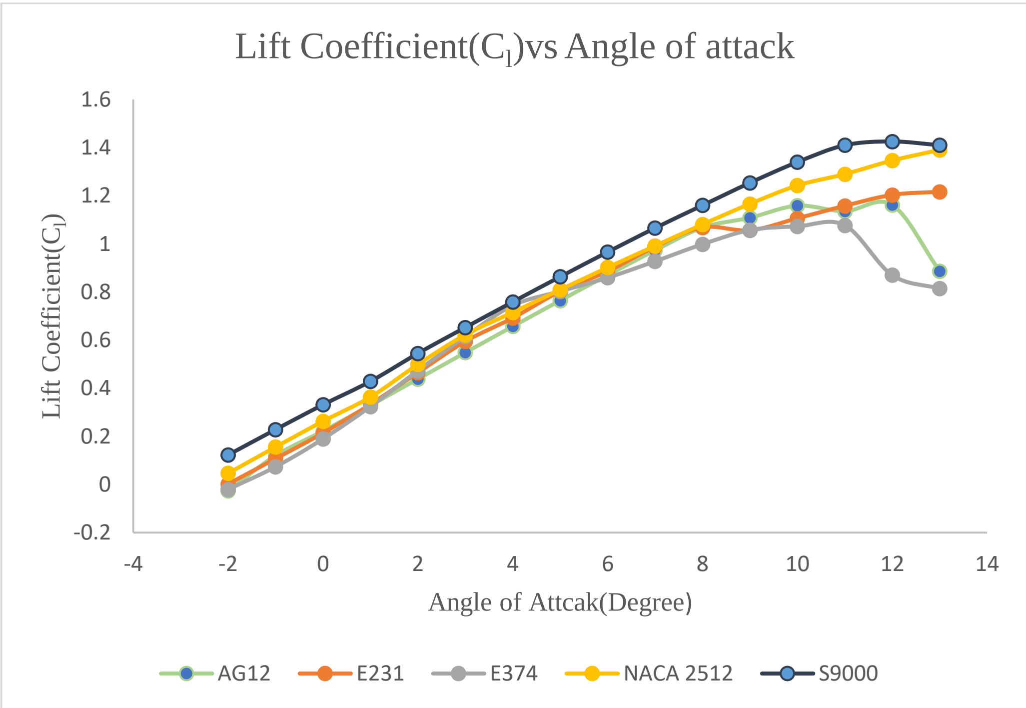

Fig. 3. 5: Lift Coefficient Comparison of different airfoil

The lift coefficients of the selected airfoils are found. From Fig. 3.5 it can be shown that S9000 performed significantly better than the other airfoil. NACA 2512 is the closest in term of lift generation but could not surpass the high lift generation of the S9000 airfoil. The panel method showed the lift generation properly. S9000 also reach the stall speed at 11 degree where other airfoil reached earlier, except the NACA 2512 airfoil.

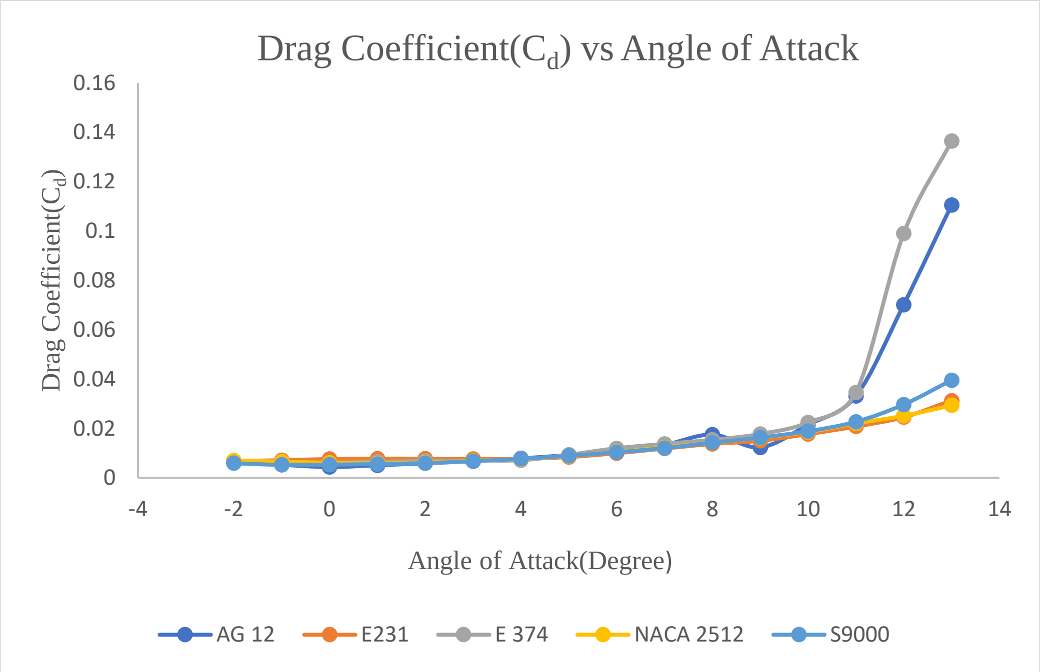

Fig. 3. 6: Drag Coefficient comparison of different airfoil

Figure 3.6 shows the variation of the drag coefficient with the change of angle of attack. It is clearly visible that at lower angle of attack the airfoil are generating similar amount of drag. But at higher angle of attack S9000 is generating less drag compared to others.

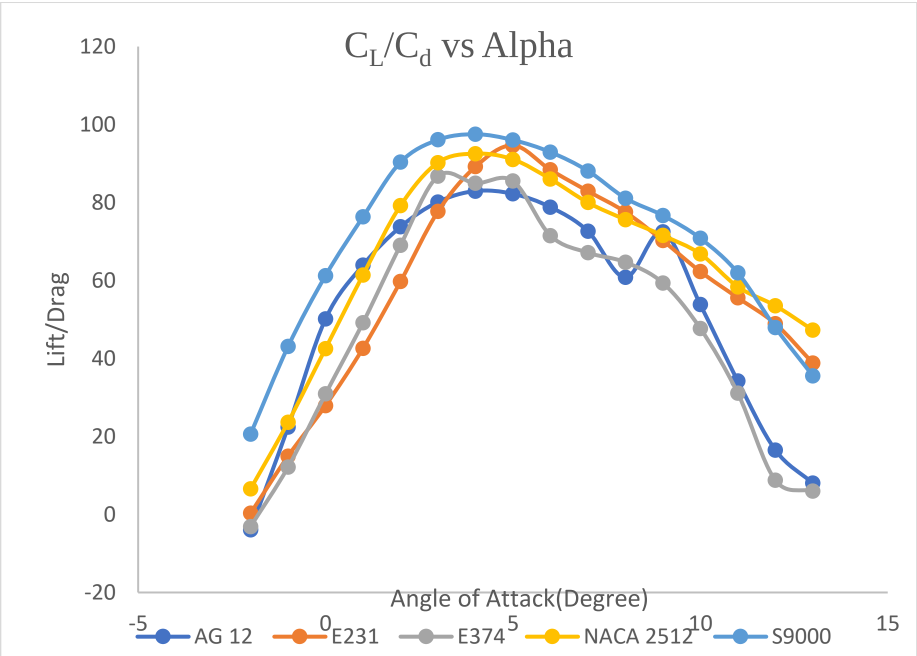

Fig. 3. 7: Comparison of the lift to drag ratio at different angle of attack

Figure 3.7 shows the variation of lift to drag ratio at various angle of attack. S9000 airfoil is clearly producing more lift at certain drag force than other airfoil. E231 is closest airfoil in this section. From above three analysis the S9000 airfoil perform significantly better than other airfoil. These airfoils can fulfill the prior condition of the selection of the airfoil.

3.6 WING SPECIFICATION

The specification of the wing is presented in the table 3.3. The design criteria which are previously discussed in these sections are presented here. The decision was taken on the basis of previously discussed. The wing loading and aspect ratio is taken to get an optimum span of the wing, which will no be too short or too long to create structural damages. The root and tip chord are determined on the basis of wing span and taper ratio. The wing is slightly swept to provide stability to the UAV.

Table 3. 3: Wing specification

Wing Loading	127 N/m^2
Aspect Ratio	4
Taper ratio	0.9
Wing Area	0.229 m^2
Wing span	0.958 m
Root Chord	0.252 m
Tip Chord	0.227 m
Average Chord	0.239 m
Sweep	4 degree
Airfoil	S9000

3.7 HORIZONTAL AND VERTICAL TAIL

Like wing, which is an important part of an aircraft, as it create lift, the tails are important for controlling. Tails carry two important controlling surfaces, which is crucial in both longitudinal and lateral control. Tail can also contribute in lift generation, but it is unnecessary as it makes the whole control system more complex.

The tails, both horizontal and vertical came in different combinations of size and form. The shape depends on the propulsion system, wing location etc.

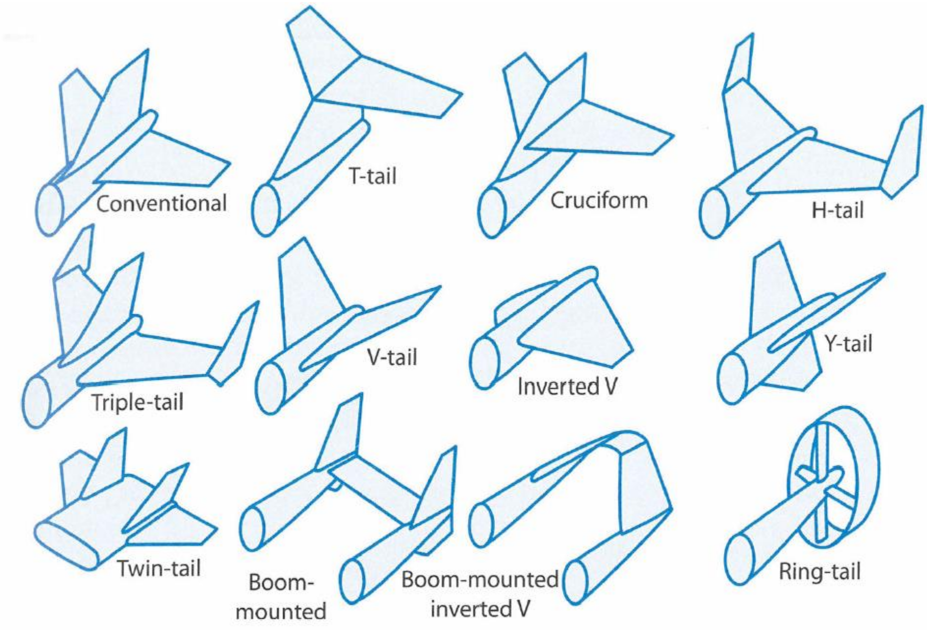

Fig. 3. 8: Tails Variation [7]

Various kinds of tail configuration have been shown in Fig. 3.8. Each of the configuration has its own merits and demerits. The first one is conventional tail which is very common in both the civilian and military aircraft as it is easy to develop and control. The controllability is an important factor while choosing a proper tail arrangement. Other types of widely used tail configurations are the Y tail, V tail, inverted V tail and H tail. H tail is widely used for those UAVs whose engines are placed at the back of the fuselage. This tail configuration helps to generate thrust without causing any hindrance for airflow.

For the design of the UAV, the conventional tail is chosen. A conventional tail consists of a vertical and a horizontal tail. The size of the tails depends on these factors are the size of the wing, the length of the lever arm and the area of the wing. These factors contribute

The tails contain two important control surfaces, the elevator and rudder. Both are essential for controlling the aircraft. The elevator is responsible for controlling the pitch and the rudder is important for yaw control. The tails behave like the wings in some cases, as their shape can also generate lift. The lift generation can cause more moment, which is essential to be controlled, otherwise, these can affect the controllability of the UAV. Conventional tails are easier to mathematically derived, thus can be made with ease.

3.7.1 Tail calculation

For horizontal tail[7],

$$SHT=\frac{\boldsymbol{V_{HT}cS}}{\boldsymbol{L_{HT}}} \quad (9)$$

Where,

S_{HT} = area of the tail(m^2)

V_{ht} = Volume coefficient of horizontal tail

C = MAC of the main wing(m)

S = Area of the wing(m^2)

L_{HT} = Lever arm length(m)

Table 3. 4: Horizontal tail parameters

V_{ht}	0.3
L_{bt}	0.55 m
Aspect Ratio	6
Span	0.424 m
Sweep	2.32 degree

Table 3.4 shows the specification of the horizontal tail of the mini UAV. The volume coefficient which is a dimensionless parameter of the tail selection is always in between 0.3 to 0.6, for this UAV the selection was 0.3 as it is a small size aircraft. The lever arm and aspect ratio is taken.

For Vertical stabilizer[7],

$$S_{VT}=\frac{\boldsymbol{V_{VT}bS}}{\boldsymbol{l_{vt}}} \quad (10)$$

Where,

V_{VT} = Volume coefficient of the Vertical tail

S_{vt} = Area of the vertical stabilizer(m^2)

b= Span of the main wing(m)

S= Area of the main wing(m^2)

L_{vt} = lever arm length(m)

Table 3. 5: Vertical tail parameters

V_{vt}	0.03
L_{vt}	0.49 m
Taper ratio	0.5 m
Span	0.17 m

The specification of the vertical tail is shown in Table 3.5. Here the volume coefficient always remains between 0.002 to 0.005. Here a mid value is chosen to find the vertical tail length well enough to preserve the stability of the UAV. The tail is slightly tapered to sustain the in the wing flow and reduce the drag which may cause speed reduction.

Airfoil plays an important role in the tail section of any aircraft. The role of the airfoil in the tail section is not to create additional lift but to maintain stability. If the tail section generate lift like the wing, it will create additional moment for the aircraft, which will make the whole system uncontrollable. For these problems, only the symmetrical airfoil is chosen for tail section.

3.8 FUSELAGE CONFIGURATION AND DESIGN

Fuselage is the main body of an aircraft as it carries the passengers, payload, pilots and all the necessary equipment. Single engine aircraft usually carry their engine on fuselage. The size of fuselage should be enough to fit in all the elements like control units, engine, payload etc.

On the basis of engine placement, there are two kinds of fuselage configuration. They are Tractor and pusher.

Tractor is a kind of configuration where the engine is placed in front of the fuselage. This configuration is useful to maintain the stability of an aircraft as the heavier engine place the center of gravity forward. On the other hand, the propeller can maintain undistributed free stream. But tractor configuration also generates local skin friction over the fuselage.

Pusher is a configuration where the engine is placed backward. This configuration provides clear air through the fuselage and the wing. Furthermore, the engine can provide pressure inflow, which reduce the size of the fuselage. The disadvantages are about the stability of the aircraft. As the engine is in back of the fuselage, maintaining stability become difficult. The propeller in the back can be damaged while landing in the configuration. Furthermore, In pusher configuration, only certain kinds of tail arrangement, like H tail or inverted v tail can be used.

For the mini UAV, the tractor configuration is selected. The reason behind the selection is the longitudinal stability. Tractor configuration can make the UAV easier to maintain stability. The size of the fuselage depends on several factors. First one is the size of the lever arm which is already taken in the selection of both tails. The width is based on the components like motor, battery, control electronics etc. From various consideration, the length of the fuselage is taken is 0.9 m.

3.9 PROPULSION SYSTEM

Propulsion system is essential for any aerial vehicle, as it generates the required thrust to fly forward. The mini UAV will be run by electric motor. To find the propulsion system of the UAV we need to find the thrust to weight ratio, the battery power and propeller size of the UAV. These are the major parameters to be maintained to find the optimum power to run the UAV.

3.9.1 Thrust to weight ratio

Thrust to weight ratio is a dimensionless parameter which indicates the performance of any aircraft or flying vehicle. In propeller driven aircraft, it is changed to power to weight ratio. Generally, the ratio is determined based on historical data. In most of the propeller driven aircraft, the ratio is less than 1. In high-speed aircraft, like the fighter jet, the ratio in greater than 1. For the mini-UAV the ratio is taken 0.5. The decision of taking the value is based on historical data and

3.9.2 Elements of propulsion system

The propulsion system consists of a BLDC motor, propeller, Li-po battery and Electronic Speed controller(ESC). For propulsion system a 2200 mAh Lithium Polymer battery was chosen. The battery can provide 24.42 kW of power to the system.

The major element of the propulsion system is the brushless DC motor. Brushes are not used in brushless DC motors. In brushed motors, the coils on the rotor get current from the brushes through the commutator. Consequently, how does a brushless motor transfer current to the rotor coils? Because the coils are not situated on the rotor, it doesn't. The coils are fixed in place on the stator rather than rotating with the rotor, which is a permanent magnet. Brushes and a commutator are not required because the coils are stationary. While the magnetic field produced by the stationary magnets remains fixed, rotation is achieved with the brushed motor by adjusting the magnetic fields produced by the rotor's coils. The coils voltage can be altered to change the rotation speed. In a BLDC motor, the permanent magnet spins, which is accomplished by shifting the magnetic fields that are produced by the surrounding stationary coils. For the mini UAV 1400 KV BLDC motor is used.

The component which is responsible for generating thrust is the propeller. For generating required amount of thrust, proper size of the propeller must be selected. Based on previous analysis 2 blade propeller is selected. Larger propeller tends to produce more thrust. From various analysis and availability in the market, 11inch propeller is selected for the UAV.

3.10 CAD MODEL

Based on all the previous design decision a final model was selected. To design the model CAD software was used. In Fig. 3.9 the 3D model of the mini UAV has been shown. The model is generated using surfacing technique which is widely used for generating complex 3D model. Later the model was rendered to present it properly.

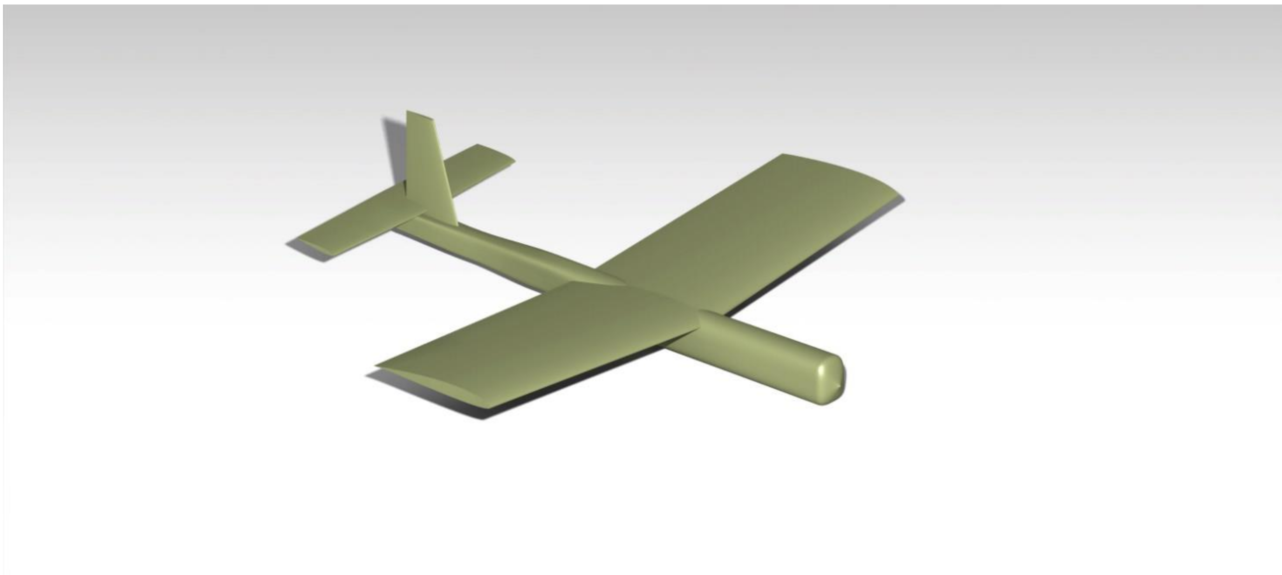

Fig. 3. 9: 3D CAD model of the mini UAV

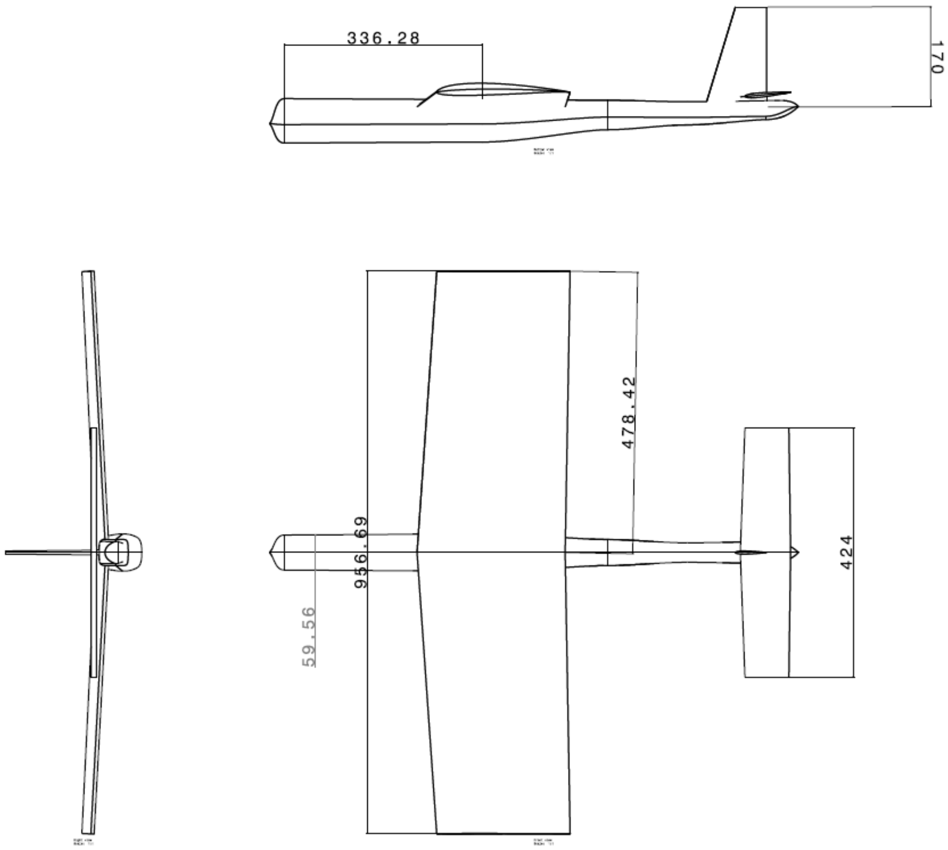

Fig. 3. 10: Detailed design of the Mini UAV(dimension in mm)

The detail parameter of the design has been shown in fig. 3.10. Here the size of various parts of the UAV has been shown. In the figure the top, front and the right side views are presented. In 3D view all the detail parameter can not be shown properly. For this reason, detailed 2D design is created to provide the dimension of various parts of the UAV.

3.11 PERFORMANCE

Performance is an essential aspect of any aircraft design , as it determines whether the design is feasible or not. For an aircraft there are various performance parameters to determine. The major performance parameters are range, endurance, battery performance etc. As traditional methods will not work in these case, as it is a battery operated UAV, alternative methods are applied. Battery operated UAVs have different way to calculate range and endurance.

3.11.1 Range and Endurance

There are several ways that endurance can be included into aircraft design. The mission profile of some aircraft, such as the P-3 Orion or U-2 espionage plane, calls for high endurance characteristics (often referred to as loiter time (on target)). Finding the fuel proportion for an aircraft depends heavily on endurance. Like range, endurance is also influenced by fuel efficiency; as a rule, fuel-efficient aircraft will have better endurance characteristics.

The farthest distance an airplane may travel between takeoff and landing is known as the maximal total range. The aviation fuel energy storage capacity (chemical or electrical), taking into account both weight and volume restrictions, determines the range of powered aircraft. The range of an unpowered aircraft is affected by things like cross-country speed and weather. The range can be calculated by multiplying the maximum duration in the air by the cross-country ground speed. For powered aircraft, the fuel duration limit is determined by the amount of fuel that is available (after accounting for reserve fuel needs) and the rate of consumption. The endurance and range equation based on the battery power[8],

$$\boldsymbol{E_d} = \frac{\boldsymbol{PT}}{\boldsymbol{M_b}} \tag{11}$$

Where,

E_d = Endurance

P = power

T = Thrust

M = mass of the battery

And the range will be

$$R = E_d \times V_{cruise} \tag{12}$$

From this equation the range of the UAV can be measured using the weight of the battery.

3.11.2 Take off and landing

The maximum aircraft mass must be determined for the aircraft type, the height, length, slope, and braking action of the runway, as well as the current weather conditions, such that the aircraft can maintain the required minimum climb rates after takeoff while operating all power units at full capacity. If a power unit failure is discovered during the takeoff run, you have two options: abandon the takeoff and stop within the length of the runway, or continue the takeoff while ensuring that all impediments in your climb-out path are cleared by a predetermined distance. Take of distance is the summation of ground roll and accelerated distance.

Continue the flight with one engine off, returning to the starting airfield, landing at the intended location, or landing at a predetermined alternate airfield after clearing all terrain in the way by predetermined margins.

Land securely at the airfield of departure, the location, or the designated alternate airfield.

For the takeoff, first ascent, approach, and landing, the aircraft must be flown at prescribed configurations, power settings, and speeds that are appropriate to the actual aircraft mass. In terms of configuration, things like how many power units are active, if the landing gear or speed brakes are extended, etc.

3.11.3 Other Performance Parameters

Other performance parameters like maximum air speed, turn radious, maximum airspeed at range and endurance and stall velocity. These performance parameters are important for the analysis of any aircraft including UAVs. Thus an UAV's parameters can be maintained using these criteria.

Stall velocity is the lowest possible velocity for any aircraft to maintain the level flight [8].

$$\textit{Stall Velocity} = \sqrt{\mathbf{2} \times \left(\frac{\boldsymbol{W}}{\boldsymbol{S}}\right) \times \frac{\mathbf{1}}{\boldsymbol{C_{lmax}} \times \boldsymbol{\rho}}} \tag{13}$$

Where,

W/S = wing loading(N/m^2)

C_{lmax} = Maximum lift coefficient

ρ = Density of the air(kg/m^3)

The stall speed can be considered the minimum speed(V_{min}) of the UAV.

Maximum Velocity for the UAV will be [7]:

$$\boldsymbol{V_{max}} = \sqrt{\frac{\mathbf{2}\boldsymbol{W}}{\boldsymbol{\rho S}}\sqrt{\frac{\boldsymbol{k}}{\boldsymbol{C_{D0}}}}} \tag{14}$$

Where,

$\boldsymbol{C_{D0}}$ = Parasite drag coefficient at zero lift

$$\boldsymbol{k} = \frac{\mathbf{1}}{\boldsymbol{\pi e AR}} \tag{15}$$

Where,

e = Oswald Factor

AR = Aspect ratio of the wing

$$R/C = \frac{\boldsymbol{P_A} - \boldsymbol{P_R}}{\boldsymbol{W}} \tag{16}$$

Where,

R/C = Rate of climb

P_A= Power available

P_R = Power required

3.12 FLIGHT ENVELOPE AND V-N DIAGRAM

In terms of maximum speed and load factor for an aerial platform given a specific atmospheric density, the flight envelope in aerodynamics establishes operational boundaries. The area a plane may fly safely is known as the flight envelope. The restrictions should never be exceeded since doing so could cause harm to the aircraft if it flies "outside the envelope." The phrase, "outside the flight envelope," has also been borrowed in other engineering domains to describe a system's behavior when it operates outside of its typical design parameters (even if the system is not even actually flying). The VN diagram, which depicts structural load restrictions as a function of airspeed, is the most significant and often used figure. Typically, this flying envelope is established during the design stage. A speed versus load factor chart, often known as a V-n diagram, can be used to display the performance envelope of an aircraft. It demonstrates the maximum load factor that may be reached safely at various airspeeds.

3.13 STABILITY ANALYSIS

Three translational and three rotational motions, which are essential for the stability of maneuvers, make up the six degrees of freedom that make up the drone movement control system. Control and stability are essential factors of the drone building design process. The pitching motion of the drone is a challenge for longitudinal stability and control. The drone's lateral stability and control deal with its rolling motion, while its directional stability and control deal with its yawing motion. When an aircraft naturally reverts to its initial equilibrium state following a modest perturbing displacement, it is considered to be stable. As a result, the aircraft's response is solely a result of its fundamental design. We typically refer to this as static stability at level flight. As a result, the plane is statically stable when it resumes steady flight after a little disturbance, statically unstable when it keeps moving away from steady flight after a disturbance, and neutrally stable when it maintains steady flight in a new condition after a disturbance. The longitudinal stability is associated with the pitching moment of the aircraft. The pitching moment is generated by the horizontal stabilizer in the UAV. The lateral moment on the other hand depends on the slidslip angle generated from the vertical angle of the UAV. The stability of any UAV is desired for flying as it is easy to control.

3.14 COMPUTATIONAL FLUID DYNAMICS

Using numerical analysis and data structures, the field of computational fluid dynamics studies and resolves issues involving fluid flows. It is extremely important to the design and testing processes. Prior to creating expensive prototypes and performing physical tests, it is used to analyze, optimize, and verify the performance of designs. The use of computational fluid dynamics has various benefits. One is potentially possible to simulate any bodily situation thanks to it. It gives us enormous control over the physical process and enables us to isolate particular occurrences for investigation. Mesh is a key component of CFD. Complex geometries are broken down into basic parts that can be employed as discrete local approximations of the wider domain as part of the engineering simulation process known as meshing. Accuracy, convergence, and simulation speed are all impacted by the mesh. Mesh quality also plays a vital role in CFD analysis. The mesh density should be high enough to capture all the relevant flow features. The boundary layer as well as the type of cells used in meshing play an important role as well. The different types of cells used include quad/hex/prism or wedge cells.

Chapter 4

Results and Discussion

4.1 INTRODUCTION

The design of the mini-UAV was analysed using numerical method to determine its various parameters. Mathematical formula of various kinds of performance were used to determine various performance parameters of the UAV as they are necessary for any flying object. Later, Computational Fluid Dynamics techniques is used to find some aerodynamical parameters if the mini-UAV can fly or not. Besides the stability of the aircraft was calculated for further research.

4.2 UAV PERFORMANCE

The performance result of the UAV is based on the mathematical formula which are discussed in the previous chapter.

Table 4. 1: Performance of the UAV

Lift Force(at Cruise Speed)	29.23 N
Drag Force(at Cruise Speed)	2.57 N
Maximum velocity	25.56 m/s
Cruise Velocity	16 m/s
Stall Velocity	12.90 m/s
Range	15.36 km
Endurance	17 min
Take off Distance	12 m
Landing Distance	4 m
Rate of Climb	3.4 m/s

In Table 4.1 various performance parameters are shown. The velocity data which are taken from the mathematical calculation are later used for computational analysis. The UAVs aerodynamic performance has been measured based on the data taken from these table. The flight envelope which is essential for any aircraft is based on these performances. The drag force of the UAV is the combination of parasite drag and lift induced drag. The lift force here is the highest possible lift force can be generated by the UAV which is higher than the total weight force of the UAV. The thrust, generated by the propulsion system is higher than the total drag force of the UAV.

4.3 FLIGHT ENVELOPE AND V-N DIAGRAM

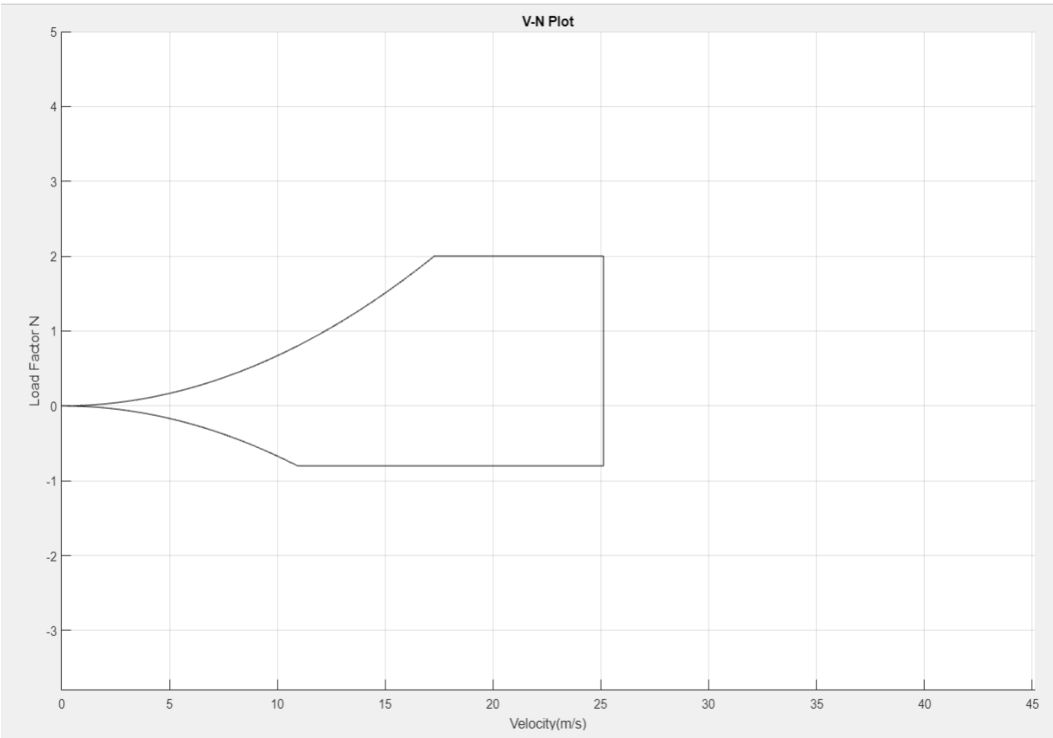

Fig. 4. 1: V-N Diagram of the mini UAV

The V-N diagram of Fig. 4.1 shows us different characteristics of the mini-UAV. The highest positive load factor is 2 at which the speed is 18 m/s. The curve from load factor 0 to 2 is the stall region. If aircraft crosses the curve line while flying, it will stall, which means it reaches the highest lift coefficient, But the V- N diagram also shows us the structural limits of the UAV, The intersection point of the stall curve and the highest load factor defines the maximum airspeed for maneuverability. This speed is called corner speed. Above the line, the region is called structural damage region. If the aircraft speed cross the line, the structure of the aircraft may be damaged. So, the UAV must fly under the horizontal line.

In the negative load zone the airspeed is relatively higher than the positive load area. It denotes the diving speed of the UAV, as while diving the gravity also adds more forces. The negative load factor also shows the structural limit in the negative zone. Just like the positive factor, crossing the negative load limit also causes significant structural damages.

4.4 COMPUTATIONAL FLUID DYNAMICS ANALYSIS

The UAV was tested on the basis of its component's lift generation skill. In any flying object the airfoil generates both lift and drag. On the basis of the lift and drag analysis we can verify the performance of the aircraft.

The airfoil was simulated in a turbulent viscous condition using Spalart-Allmaras model. The Spalart-Allmaras model is a one equation model that resolves the kinematic eddy turbulent viscosity transport equation. This model has shown effective results for boundary layers subjected to unfavorable pressure gradients and is specifically intended for aeronautical applications involving wall-bounded flows.

In airfoil analysis structural meshing was used. For the close surface of the airfoil, the mesh has higher concentration for creating accuracy.

The airfoil was tested on two different condition to judge the flying condition of the aircraft.

In the first condition the airfoil was tested in the cruise speed of the aircraft. The speed was 16 m/s which in the condition generate. The airfoil is analysed for 16 m/s at the 10m from the

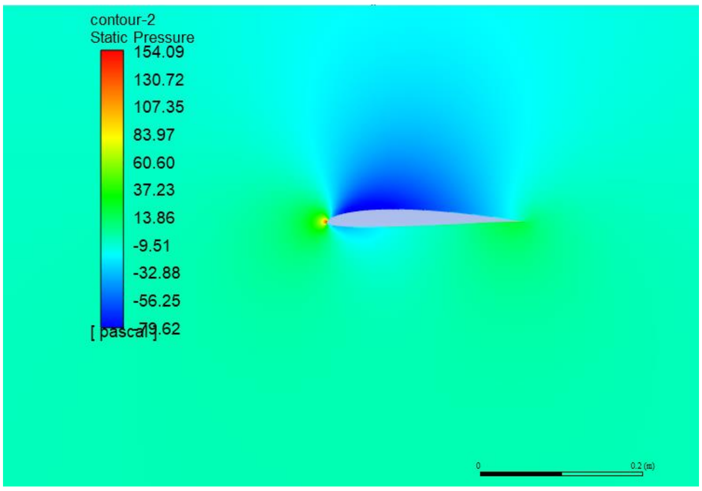

Fig. 4. 2: Static pressure Contour at angle of attack

Figure 4.2 shows the pressure difference on the both sides of the airfoil. The upper case of the airfoil is on the low pressure side and the low pressure is on the high pressure side. This is a significant lift generation condition for an airfoil in viscous condition and the airfoil is in success. This signifies the lift generation a level flight which most of the time remains at 0 degree in compared to the direction of the airflow.

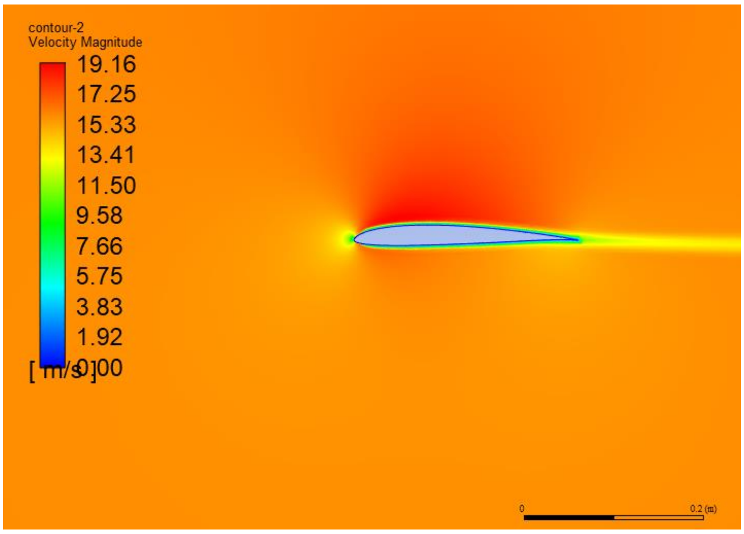

Fig. 4. 3: Velocity contour at 0° angle of attack for 16 ms^{-1}

Figure 4.3 shows the velocity contour we can see the velocity difference on the different sides of the airfoil. Due to the viscosity, the airfoil is also creating wake zone in the flow field. The velocity of air is higher on the upper side of the airfoil. This also indicate the low pressure at the upper side which is related to the Bernoulli's principle. This phenomena also signifies the lift generation at 0 degree angle of attack.

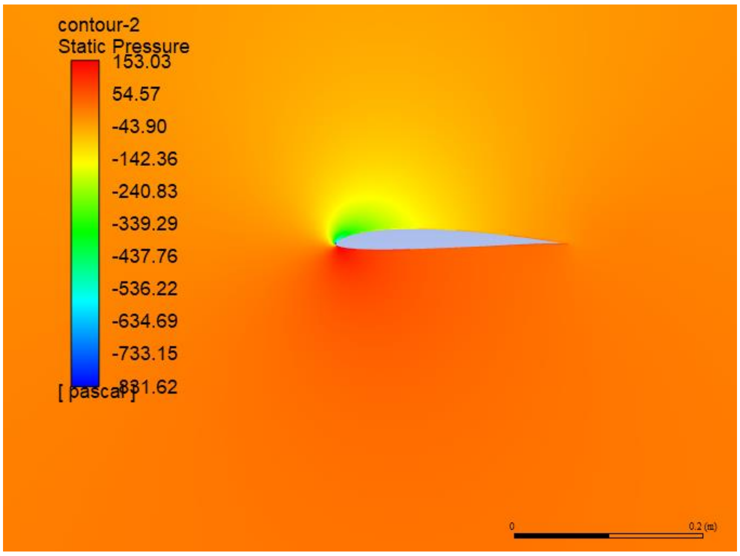

Fig. 4. 4: Static pressure contour at 10° angle of attack for 16 ms^{-1}

Figure 4.4 shows the static pressure contour for 10 degree angle of attack for 16 m/s flight. Similarly to the prior result, the pressure difference on the both side of the airfoil is significant enough to generate lift. At 10 degree angle of attack, the stagnation of pressure forms slightly upward where at 0 degree angle of attack it forms in front of the airfoil.

The behavior of the airflow is shown in term of velocity at Fig. 4.5. The velocity contour clearly shows the affects of viscosity around the airfoil. The boundary layer around the airfoil is clearly visible. Due to the high angle of attack, the wake region form at an angled position.

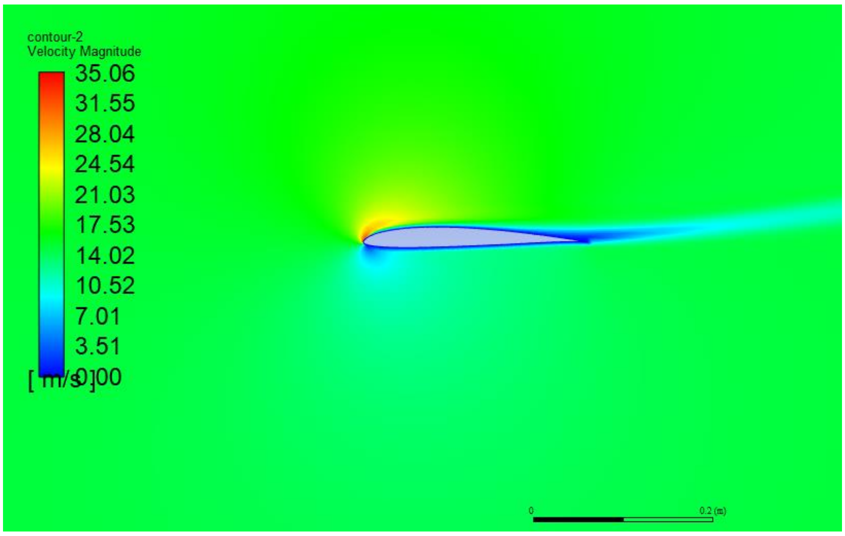

Fig. 4. 5: Velocity contour at 10° angle of attack at 16 ms^{-1}

From the above analysis it is clear that, at cruise speed, the airfoil is capable of generating required amount of lift force to fly. At lower level, the cruise speed remains at laminar region. Though lower speed create less lift, but the analysis shows it is good enough to uplift the weight of the UAV.

The CFD analysis is performed at multiple angle of attack in the same air speed. The data was gathered using the reference point and lift coefficient techniques used in Ansys. From above contour plots the aerodynamic behavior of the airfoil for the wing is verified. At different angle of attack in lower speed, the airfoil can generate sufficient amount of lift force, which is an essential condition for flying. The contour shows the UAV is capable of generating lift at lower angle of attack. For the higher angle of attack, up to the stall angle, the lift will increase.

Table 4. 2: Performance of the airfoil at 16 m/s

Angle of Attack(°)	Lift Coefficient(C_l)	Drag Coefficient(C_d)
-2	0.0901	0.0120
-1	0.1812	0.0072
0	0.2923	0.0079
1	0.3512	0.0086
2	0.5345	0.0098
3	0.6485	0.0102
4	0.7612	0.0158
5	0.8623	0.0182
6	0.9745	0.0190
7	1.0704	0.0202
8	1.1525	0.0252
9	1.2512	0.0282
10	1.3413	0.0360
11	1.3514	0.0450
12	1.3332	0.0680
13	1.2912	0.0852
14	1.2825	0.0121
15	1.1513	0.0072

In table 4.2 the values were derived by changing the angle of attack for the same velocity. The reference area and length were used to derive the value. For each angle of attack, both lift and drag co-efficient are derived. The data from the table is presented in Fig. 4.6 and 4.7.

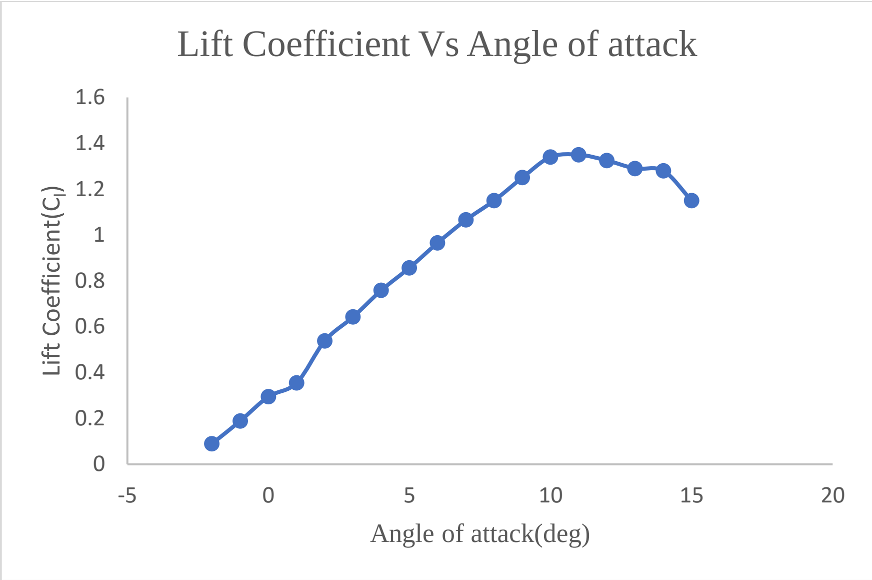

Fig. 4. 6: Variation of Lift coefficient at different angle of attack at 16 ms^{-1}

Figure 4.6 shows the variation of the lift coefficient at different angle of attack. The lift coefficient increase and the slope of the curve upto 11 degree angle of attack is upward. At 12 degree angle of attack the lift coefficient started decreased. This is the stall for the airfoil, the lift will decrease in this region. Figure 4.7 Shows the variation of drag coefficient at different angle of attack. Around 0 angle of attack it slightly decreased but at higher angle of attack it started increasing. The reason is the formation of wake at higher angle of attack and addition of the lift induced drag.

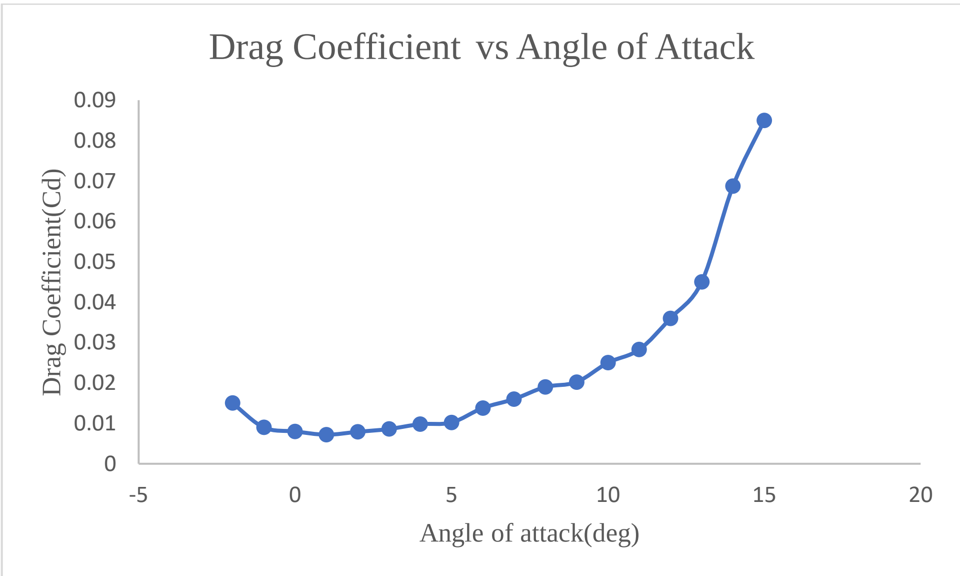

Fig. 4. 7: Variation of Drag coefficient at different angle of attack at 16 ms^{-1}

The second boundary condition the airfoil was 25 ms^{-1} which is the highest permitted speed for the UAV to fly. The data was taken at multiple angle of attack. At 10 m from the ground level in this speed, the Reynold number become around 580000 which is the turbulent zone.

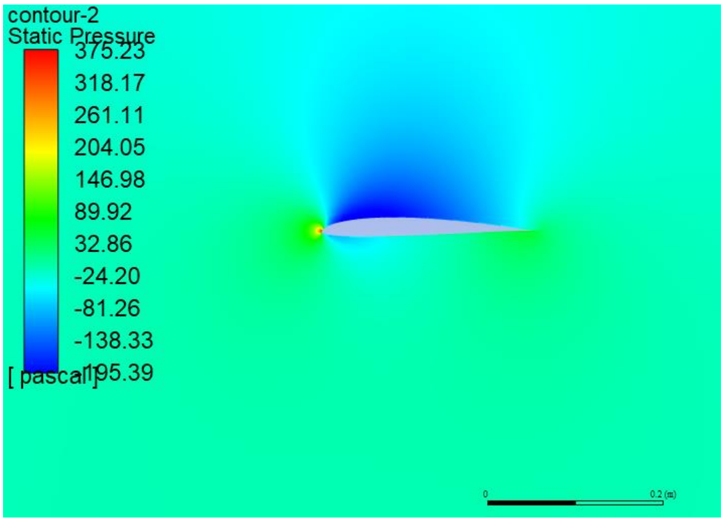

Fig. 4. 8: Static Pressure contour at 0° Angle of attack at 25 ms^{-1}

Figure 4.8 shows the variation of the pressure on the both sides of the airfoil. At higher speed the pressure difference is significantly higher, which indicates higher lift generation. The velocity contour is shown in Fig. 4.9. Due to Bernoulli's principle, the velocity is higher at the upper side of the airfoil. Due to viscosity, wake region is formed at the back of the airfoil.

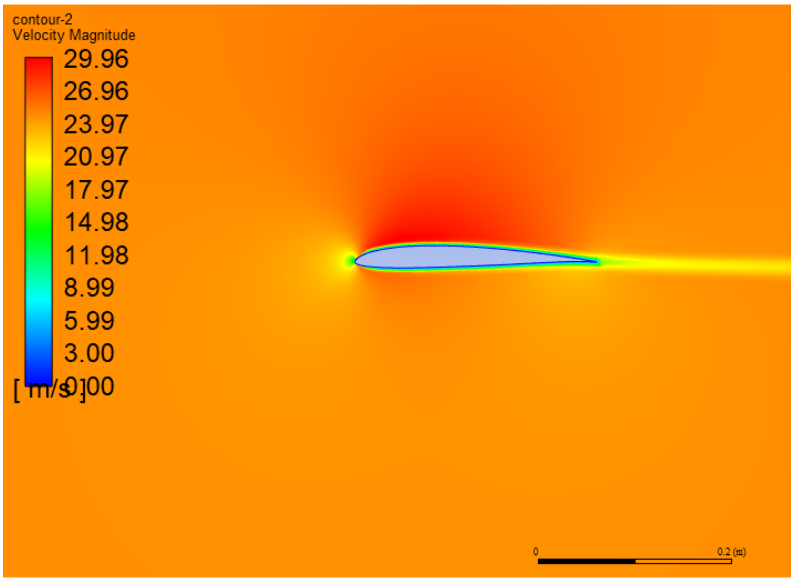

Fig. 4. 9: Velocity Contour at 0° Angle of attack at 25 ms^{-1}

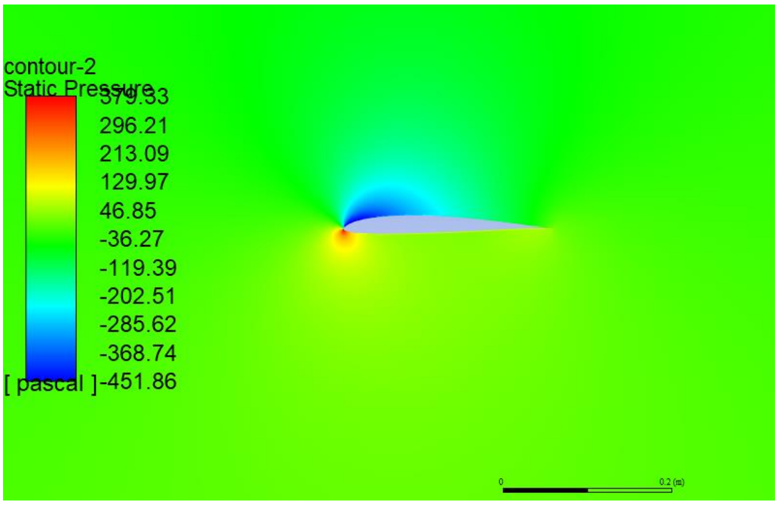

Fig. 4. 10: Static Pressure contour at 4° Angle of Attack at 25 ms^{-1}

Figure 4.10 shows the pressure difference at 4 degree angle of attack. The lower pressure area is lower than previous angle of attack. The pressure gradient is downward for this behavior of the airflow. The lower part of the airfoil has higher radius of the curvature for which the bottom surface generate more pressure.

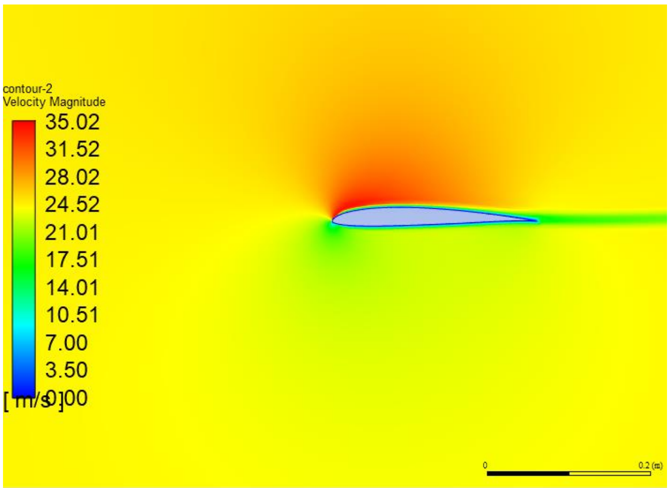

Fig. 4. 11: Velocity Contour at 4° angle of attack at 25 ms^{-1}

Figure 4.11 shows the velocity distribution over the flow field due to the angle of attack. The velocity at the upper surface of the airfoil is higher than the previous angle of attack which also indicate the higher lift generation. But at higher speed the drag coefficient also increases. The boundary layer, wake region and the normal force due to the lift generation contributes in the higher drag,

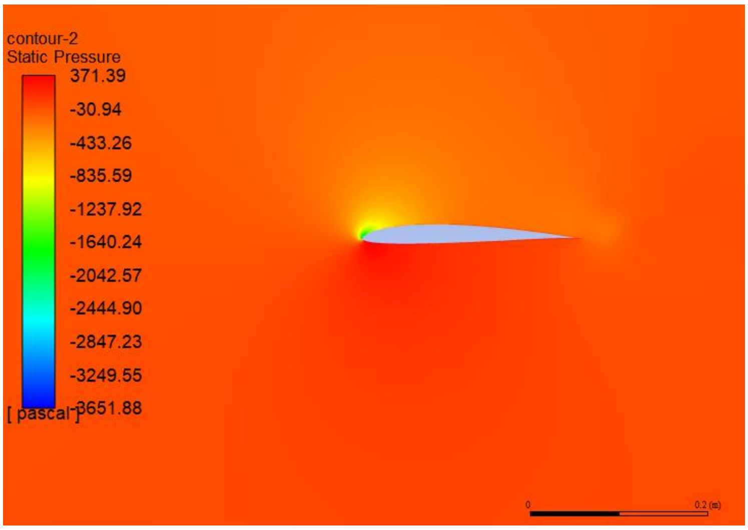

Fig. 4. 12: Static Pressure at 15° angle of attack at 25 m/s

At 15 degree angle of attack, the behavior of the airfoil certainly changes as it is now in stall region. The lift of the airfoil is not increasing at that region. In Fig. 4.12 the pressure difference on the both side of the airfoil is not as big as the previous angle of attack. Thus the lift has been decreased in compared to the lower angle of attack.

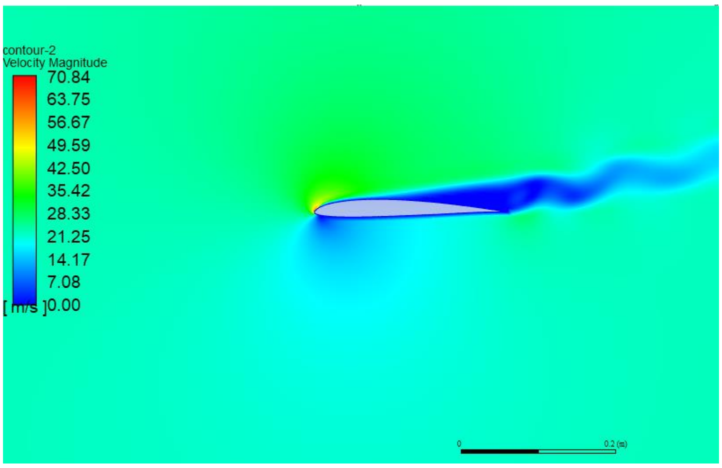

Fig. 4. 13: Velocity contour at 15° angle of attack at 25 m/s

Figure 4.13 shows the affects of stall angle of attack at the velocity field. The wake region formed at the back of the airfoil is chaotic compared to the lower angle of attack. This behavior is contributing in high drag generation, compared to the lower angle of attack. Flying at high angle of attack is only applicable for changing altitude.

In table 4.3 the values were derived by changing the angle of attack for the same velocity. The reference area and length were used to derive the value. For each angle of attack, both lift and drag co-efficient is derived. The data from the table is presented in fig. 4.14 and fig. 4.15. Later the data is compared to the previous condition.

Table 4. 3: Performance of the airfoil at 25 ms^{-1}

Angle of attack(°)	Lift Coefficient(C_l)	Drag Coefficient(C_d)
-2	0.1211	0.0061
-1	0.2242	0.0042
0	0.3021	0.0054
1	0.3938	0.0057
2	0.5343	0.0063
3	0.6424	0.0068
4	0.7383	0.0075
5	0.8518	0.0085
6	0.9494	0.0098
7	1.0412	0.0112
8	1.1059	0.0120
9	1.2393	0.0140
10	1.3372	0.0160
11	1.3911	0.0198
12	1.4288	0.0225
13	1.4012	0.0315
14	1.3523	0.0425
15	1.2933	0.0570
16	1.2142	0.0850

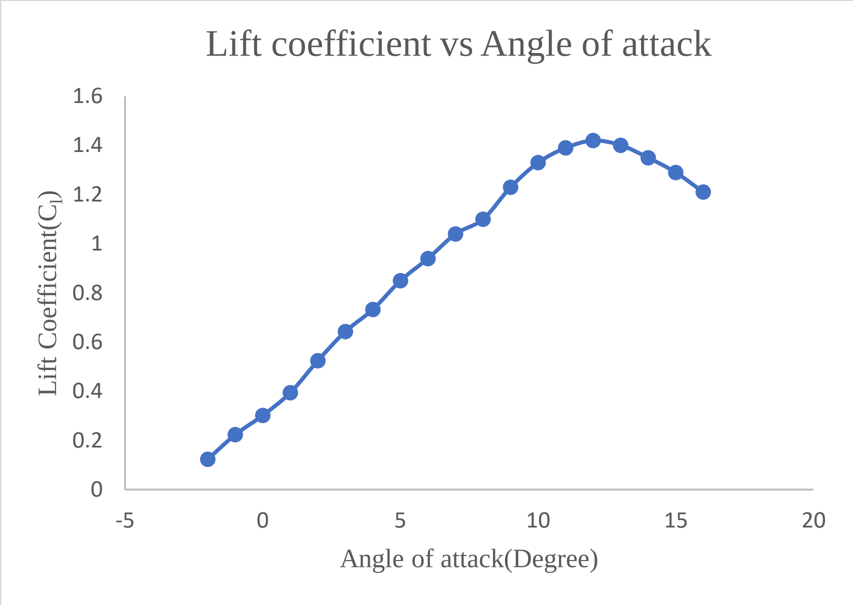

Fig. 4. 14: Variation of lift coefficient at different angle of attack at 25 m/s

Figure 4.14 shows the variation of lift coefficient at different angle of attack. The lift coefficient tends to increase upto 12 degree angle of attack. After that position, the lift starts to decrease, which denotes the stall of the airfoil. The variation of drag coefficient has been shown in Fig. 4.15, where higher drag coefficient can be observed at higher angle of attack. The reason is separation of fluid from surface, normal force due to the lift which work on the airfoil.

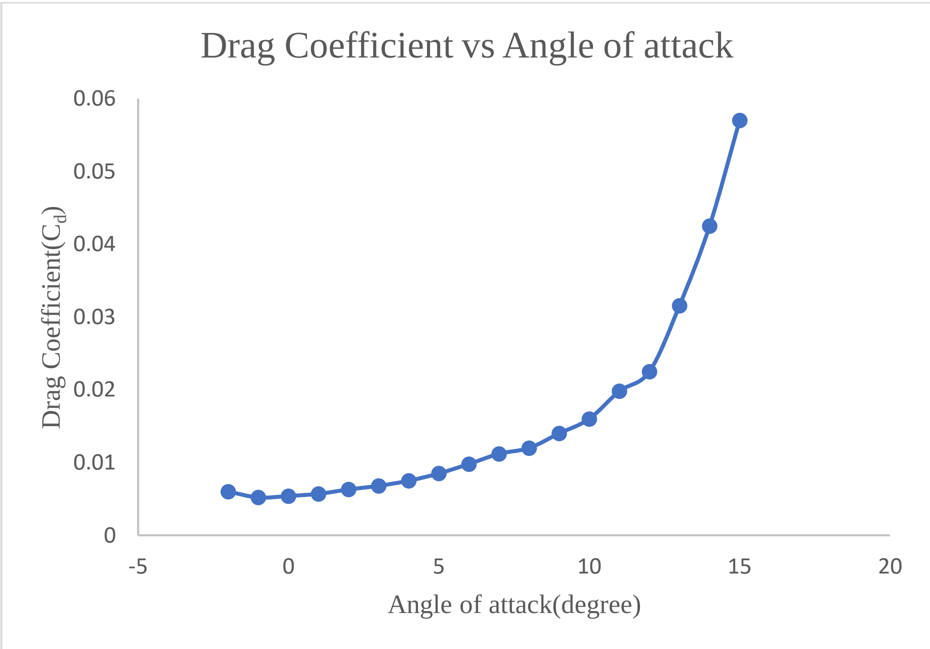

Fig. 4. 15: Variation of lift coefficient at different angle of attack at 25 ms^{-1}

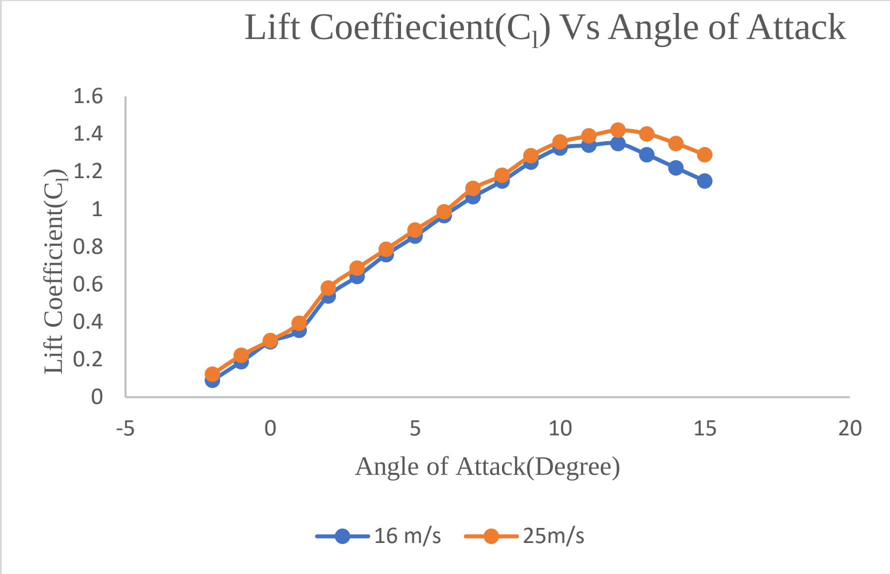

Fig. 4. 16: Comparison of Lift coefficient at two different velocity conditions

Figure 4.16 shows the lift coefficient of the same airfoil at two different angle of attack. At higher speed the airfoil tends to generate more lift than the lower one. At higher angle of attack, the airfoil generates higher lift. In both condition the airfoil reach the stall at the same angle of attack. Figure 4.17 shows the difference of drag coefficient at different angle of attack. At higher speed the drag coefficient is slightly lower than the lower speed. Induced drag decrease at higher velocity, for this reason total drag decreases.

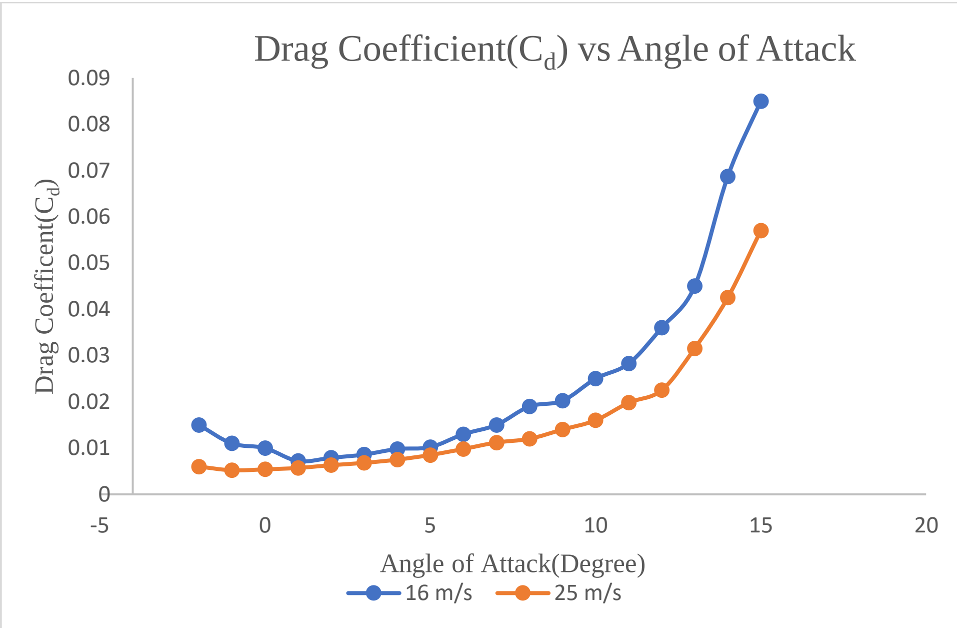

Fig. 4. 17: Comparison of Drag coefficient at two different velocity conditions

For the wing and the full body of the mini UAV 3D techniques were used. In this process, a large body of farfield is created to determine the aerodynamic aspects of the UAV. The aerodynamic aspects of the UAV is determined on the basis of the reference value. The UAV was simulated in two different conditions so far to find out it can generate significant lifts or not. The same turbulent model was followed in this section. Spalart-Allmaras turbulent model was again followed in this section to determine the aerodynamic parameters of the UAV.
For the first condition, the UAV was tested in its cruise speed which is 16 m/s. In these condition the UAV showed its lift generation.

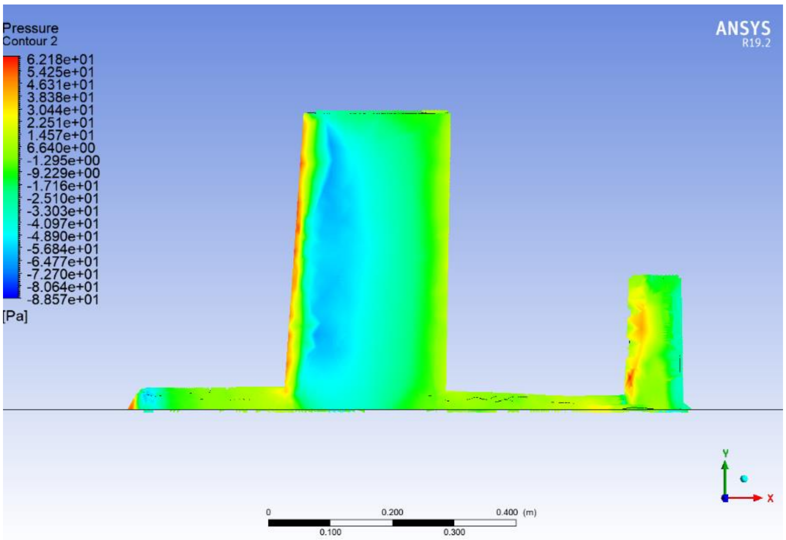

Fig. 4. 18: Pressure Contour of the Upper side at 0° angle of attack at 16 ms^{-1}

Figure 4.18 and 4.19 shows the pressure difference at 0 angle of attack. In Fig. 4.18 the upper side of the UAV has been shown. In Fig. 4.19, the negative pressure is shown on the upper side of the UAV wing. On the contrary the lower portion of the wing experience a positive pressure which generate a pressure difference on the both sides of the wing. On the basis of Bernoulli's principle, these pressure differences is generating lift at these speed at 0 degree angle of attack. These analysis show in the cruise speed in the lower angle of attack the UAV can generate sufficient amount of lift to fly, which is the most essential part of the performance. The phenomena is similar to the previous analysis with different velocity and different angle of attack.

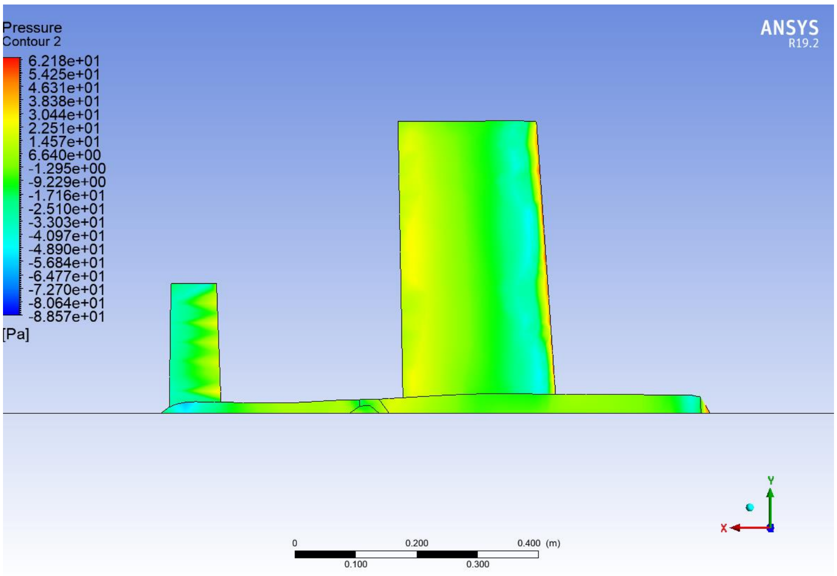

Fig. 4. 19: Pressure contour of the lower side at 0° angle of attack at 16 ms^{-1}

The result of fig. 4.18 and fig. 4.19 can be shown in different way in Fig.4.20. In this figure the pressure difference of the wing is visible, which is the condition for generating lift. In these contour we can clearly see the lift generation in the wing and negative lift generation in the tail as expected. The negative lift generated by the tail is significant for the stability of the UAV. The tail section, which is a symmetrical airfoil is creating negative lift, which is creating moment for the UAV. These moment balance the UAV while flying, which maintain the stability of the UAV. The moment also indicates there are no extra pitch moment for the UAV.

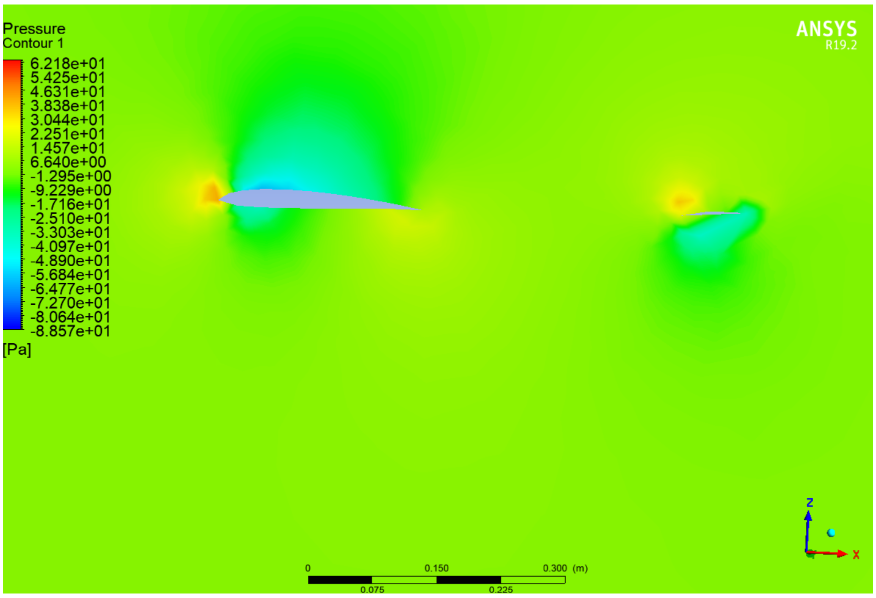

Fig. 4. 20: Pressure Contour at 0° angle of attack at 16 ms^{-1}

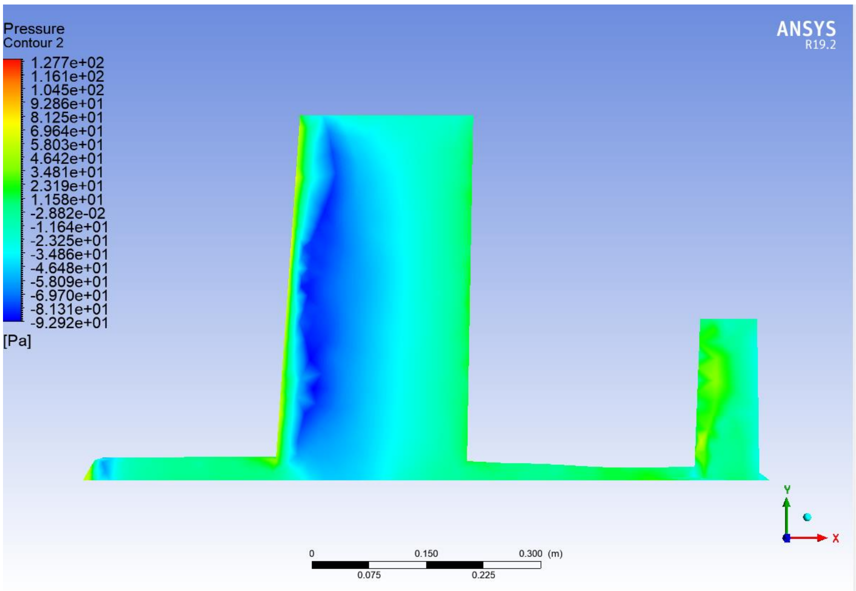

Fig. 4. 21: Pressure Contour of the upper side at 10° angle of attack for 16 ms^{-1}

Figure 4.21 and fig. 4.22 show the pressure differences at 10 angle of attack. Figure 4.21 shows the upper side of the UAV has been shown. In Fig. 4.22, the negative pressure is shown on the upper side of the UAV wing. On the contrary the lower portion of the wing experience a positive pressure which generate a pressure difference on the both sides of the wing. On the basis of Bernoulli's principle, these pressure differences is generating lift at these speed at 16 degree angle of attack. The pressure difference is greater than the previous angle of attack, which indicate greater lift coefficient than the lower angle of attack.

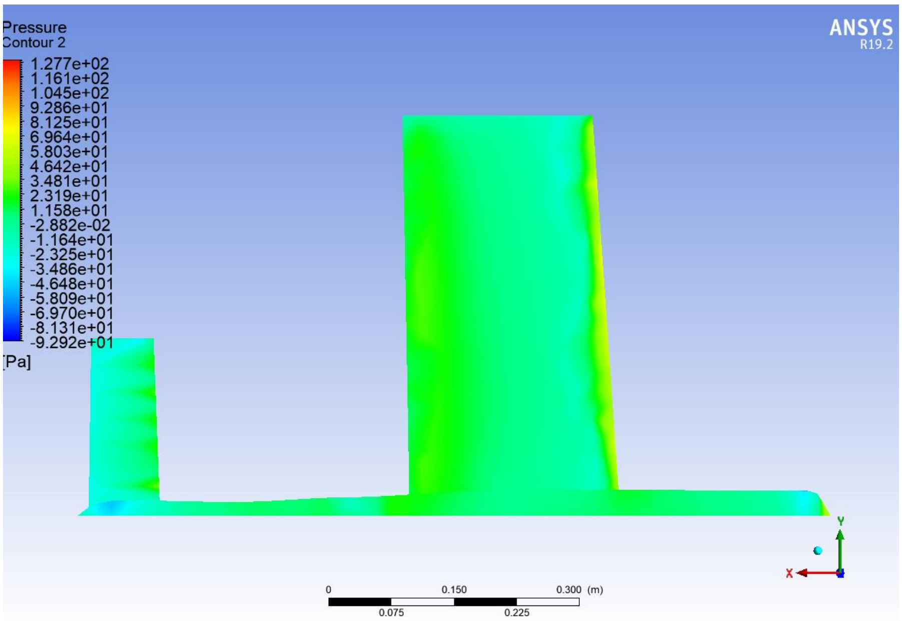

Fig. 4. 22: Pressure Contour of the lower side at 10° angle of attack at 16 ms^{-1}

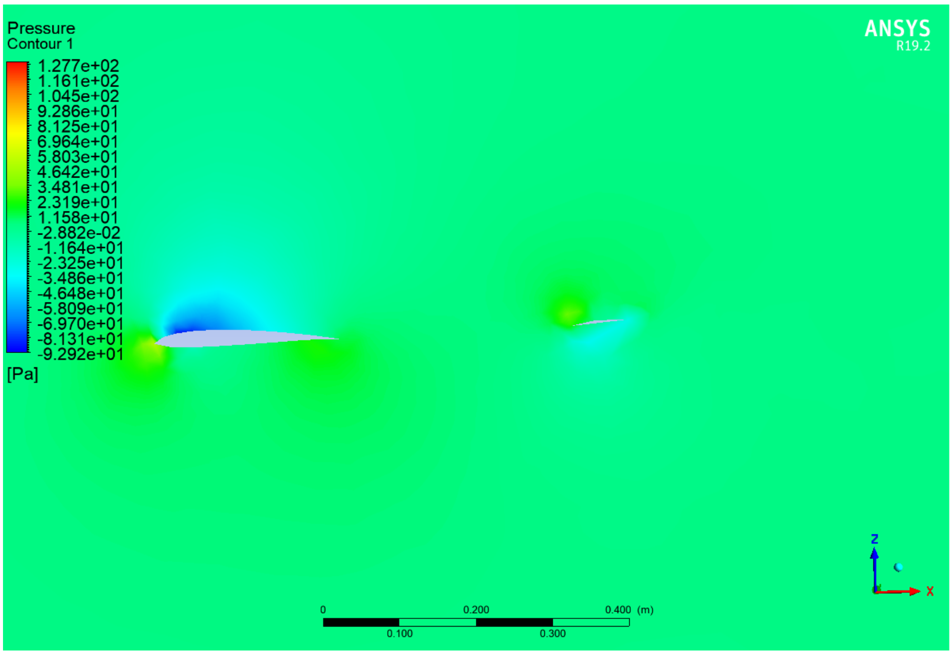

Fig. 4. 23: Pressure Contour at 10° angle of attack

Figure 4.23 shows the pressure contour we can say the in higher angle of attack, the UAV generate more lift as like the performance of the airfoil. In these section the tail airfoil generate negative lift to balance the moment generated due to the lift of the UAV. As expected the UAV generated proper lift to fly. The downward force in the tail section is essential for balancing the forces like weight and lift in the UAV. The downward force in the tail section indicates lower pitch moment which is essential for the stability of the UAV.

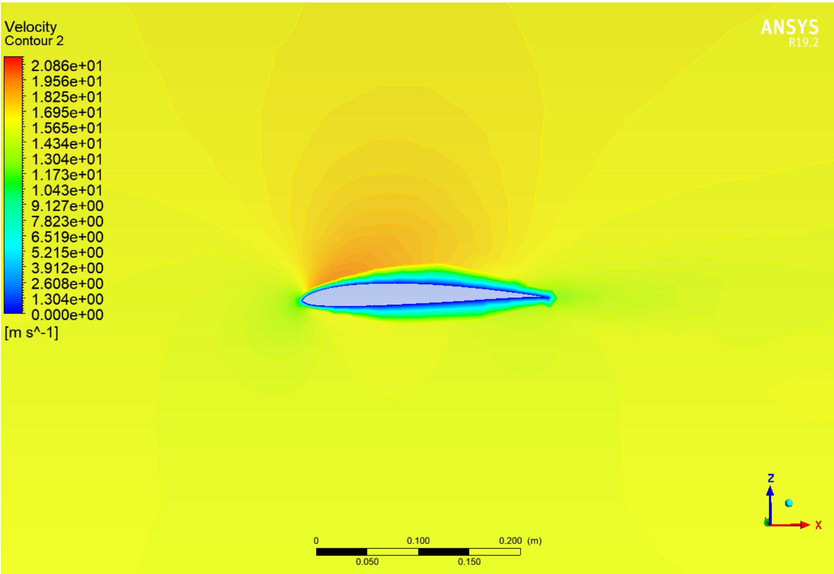

Fig. 4. 24: Contour of Velocity of the wing cross section at 10° angle of attack

Figure 4.24 shows the velocity contour around the wing cross section. The analysis of the 3D wing slightly different than the 2D airfoil analysis. Here we can see the effects of aspect ratio and the swept angle of the wing which is missing in the airfoil. For these reasons, the result is slightly different than the airfoil analysis. In Fig. 4.23 we can see larger boundary layer than the 2D airfoil. The no slip condition on the surface of the wing is also visible in the figure.

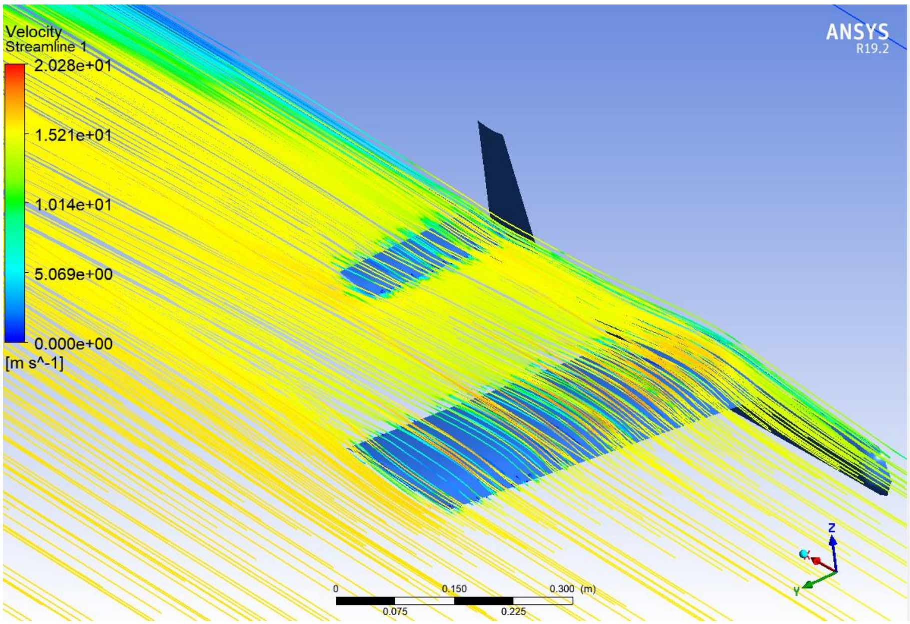

Fig. 4. 25: Velocity Streamline over the UAV at 10° angle of attack

Figure 4.25 shows the velocity streamline around the wing body of the UAV. The velocity streamline shows the airflow, airspeed and any kind of disturbance in the flow field. The smoothness decreased around the wingtip, which indicate the creation of vortex. These is essential for a wing to create vortex. The vortex also generate drag, for which the total drag of the UAV increases.

This analysis clearly shows that the UAV is capable of generating lift at the cruise speed, which further verify the previous study of airfoil. In this 3D analysis, the effects of swept angle and the aspect ratio is visible. The data will be compared with the higher velocity condition.

The UAV is further analysed in its highest permitted velocity from the flight envelope analysis. The velocity is 25 m/s from which the Reynold number transform into around 60000 which is in the turbulent zone, The airfoil was previously simulated in these condition.

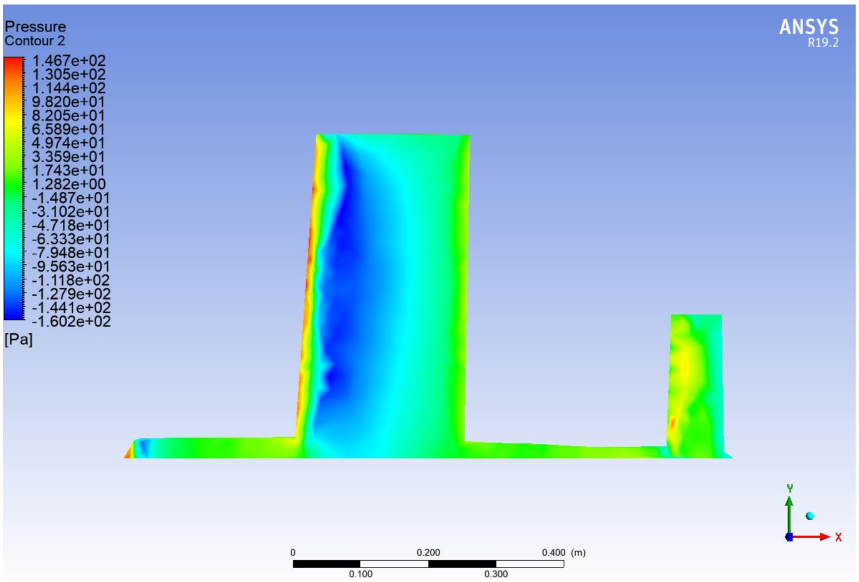

Fig. 4. 26: Pressure Contour of Upper side at 0° angle of attack at 25 ms^{-1}

Figure 4.26 and 4.27 shows the pressure difference at 0 degree angle of attack for velocity condition of 25 m/s. The pressure difference is higher than the lower speed condition which also indicates higher lift generation. On the upper side, the negative pressure form due to Bernoulli’s principle. At the same place on the lower side, positive pressure occur, which generate significant pressure difference. These pressure difference generate lift for the UAV.

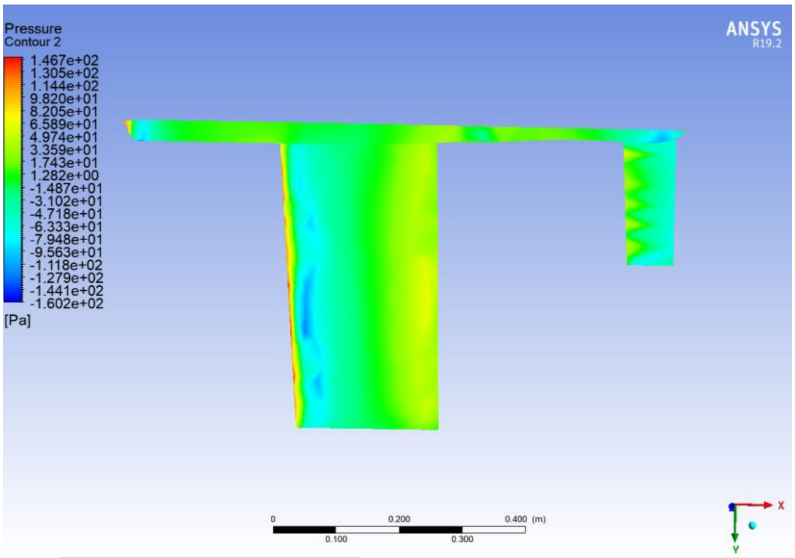

Fig. 4. 27: Pressure Contour of lower side at 0° angle of attack at 25 ms^{-1}

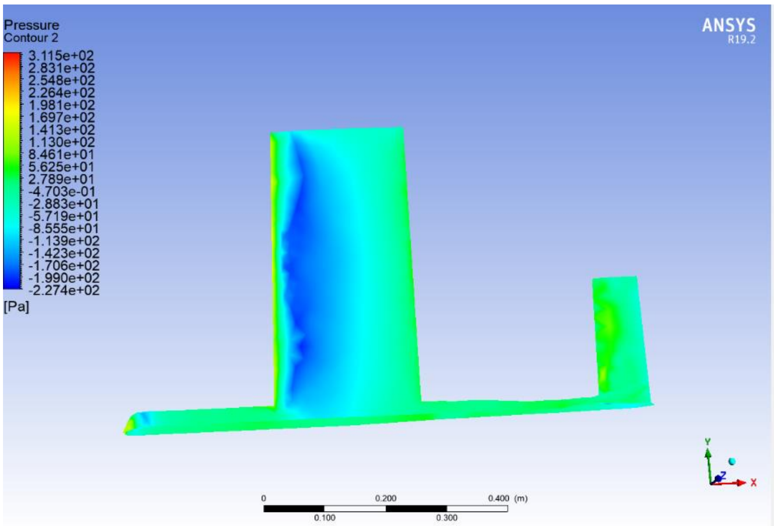

Fig. 4. 28: Pressure Contour of Upper side at 10° angle of attack at 25ms^{-1}

Figure 4.28 and 4.29 show that the pressure difference is significantly higher than the 0 degree angle of attack of 25 m/s. The major cause is emergence of the pressure difference on the both side of the wing, which is significantly higher than the zero angle of attack. Increase in the speed also increased the lift. But that’s also has a limitation due to the flight envelope. In the higher angle of attack the UAV was consistently generating more lift just like the previous calculation.

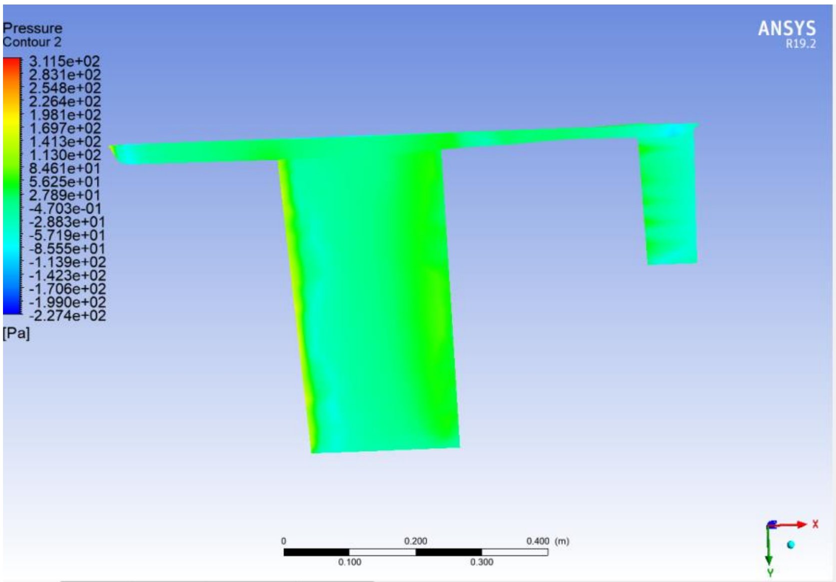

Fig. 4. 29: Pressure Contour of Down side at 10° angle of attack at 25 ms^{-1}

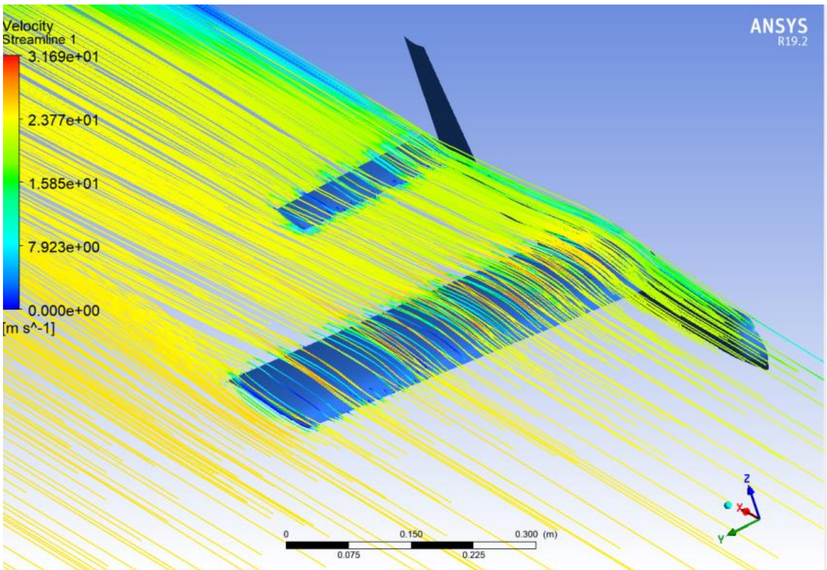

Fig. 4. 30: Velocity streamline at 10 angle of attack at 25 ms^{-1}

In Fig. 4.30 ,the velocity streamline is flowing around the wing smoothly. In the tip of the wing, the velocity streamline is creating a vortex, which is very similar in terms of real life aircraft application. Around the wingtip the velocity streamline is performing little disturbance which indicates the creation of vortex in the fluid flow. The vortex is also responsible for creation of drag at the tip of the wing, which increase the total drag of the UAV. At high angle of attack the drag coefficient increases. This feature further increases the total drag of the UAV.

Compared to the previous condition, the velocity streamline is further chaotic in high velocity condition. At high velocity the UAV is in complete turbulent section, which also indicate further disturbance in the airflow. So, the drag at the tip of the wing will be increase. But the total drag of the UAV will be less than the previous low speed one. For this reason at higher speed the UAV experience less drag than the cruise speed.

This analysis clearly shows that the UAV is capable of generating lift at the highest permitted speed, which further verify the previous study of airfoil. In this 3D analysis, the effects of swept angle and the aspect ratio is visible. The data will be compared with the higher velocity condition. The speed limit is based on the flight envelope which is derived earlier. Though higher lift can be achieved in greater velocity, it may cause permanent structural damage to the UAV.

Table 4. 4: Lift and Drag at Mini UAV

Angle of attack	Lift Coefficient(C_l) at 16 m/s	Drag Coefficient(C_d) at 16 m/s	Lift Coefficient(C_l) at 25 m/s	Drag Coefficient(C_d) at 25 m/s
-2	0.071	0.009	0.075	0.008
-1	0.135	0.010	0.136	0.008
0	0.195	0.011	0.211	0.009
1	0.254	0.013	0.255	0.012
2	0.331	0.016	0.335	0.015
3	0.385	0.020	0.414	0.018
4	0.435	0.024	0.465	0.023
5	0.524	0.029	0.548	0.028
6	0.587	0.036	0.635	0.034
7	0.650	0.042	0.694	0.041
8	0.725	0.050	0.741	0.048
9	0.754	0.058	0.791	0.056
10	0.821	0.066	0.865	0.064
11	0.896	0.075	0.975	0.074
12	0.956	0.085	1.087	0.083
13	1.032	0.096	1.174	0.094
14	1.135	0.107	1.256	0.105
15	1.130	0.120	1.237	0.116

The lift and drag coefficient data are derived from the analysis using the reference value of the UAV. In table 4.3 the values were derived by changing the angle of attack for the same velocity. The reference area and length were used to derive the value. For each angle of attack, both lift and drag co-efficient is derived. The data from the table is presented visually in Fig. 4.31 and 4.32. These data are compared and

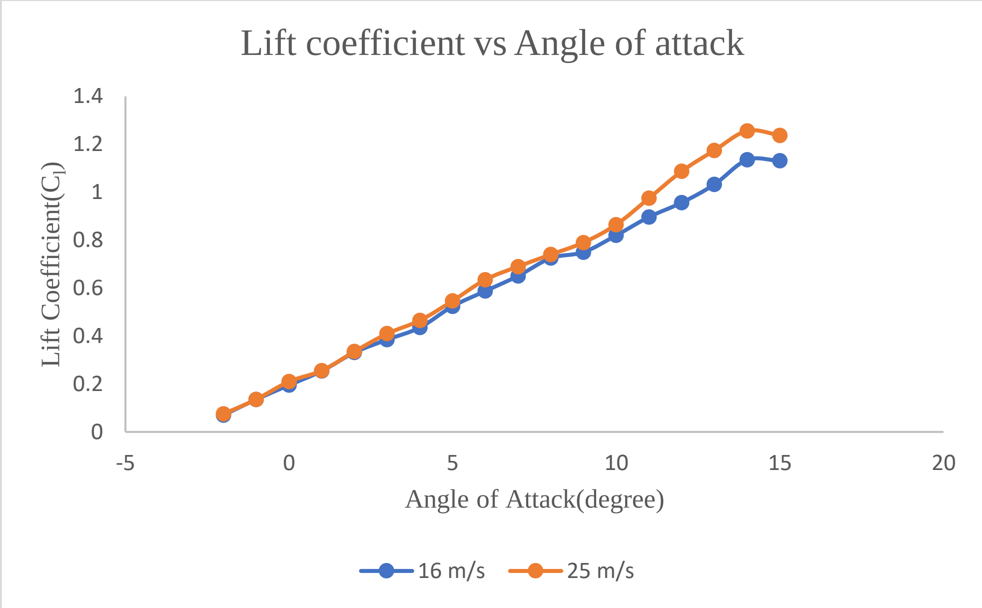

Fig. 4. 31: Comparison of lift coefficient of the wing at two different velocity

From Fig. 4.31 it can be shown that, at higher Reynold number, the wing generates more lift as compared to the cruise speed of the UAV. As compared to the other Reynold number in highest possible speed, the UAV perform better in terms of lift generation. But, as it is the highest possible speed, the limit should not be crossed for lift generation. Some alternate source can be applied to generate more lift in the lower speed section. But, it can be assured that, the wing can generate proper amount of lift for the UAV. The differences between the lift coefficients in the airfoil and the wing is because of the affects of wing sweep angle and the aspect ratio. Due to the lower aspect ratio, we can experience Stall at higher angle of attack.

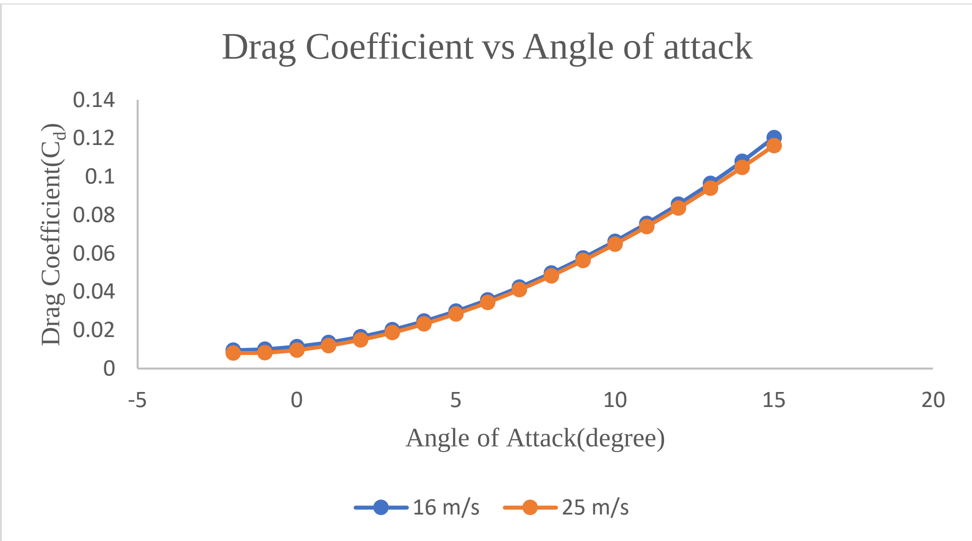

Fig. 4. 32: Comparison of the drag coefficient at two different velocity

In Fig. 4.32 the difference of drag coefficient at two different angle of attack has been shown. In higher angle of attack, the UAV generate less drag than lower one. The drag is significantly higher than the airfoil result. The reason is the two types of drag is working on the fuselage of the UAV. These drags are the induced drag and the profile drag. The profile drag was missing in the airfoil result, as the it was not significant enough to generate. But in the UAV, the profile and 3d shape of the wing is also generating the drag for the UAV. That's the reason, there are more drag than the airfoil simulation. The induced drag is caused by the lift, which is possible at higher angle of attack. In higher angle of attack, the drag coefficient is also decreased at a certain level. For these reasons the UAV is generating drag more than just the airfoil.

4.5 STABILITY ANALYSIS

The slope must be negative in order for longitudinal stability to be stable. The downward tendency of the nose for stability is demonstrated by the negative slope. There is no divergence or distortion at greater angles of attack when a linear equation is applied. The stability is calculate using MATLAB coding and later verified using MATLAB Aircraft Intuitive Design module.

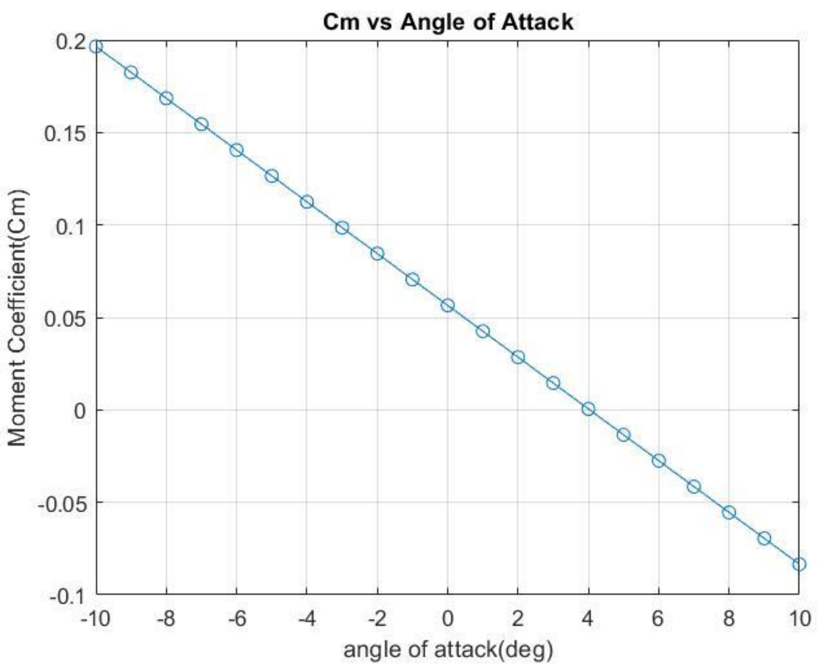

Fig. 4. 33: Variation of Coefficient of moment at different angle of attack

Figure 4.33 represents the longitudinal stability of the UAV. The analysis is performed in MATLAB using mathematic tool. To stable any aircraft, the slope of the graph must be negative. The negative slope also intersect the vertical line of 0 angle of attack at positive realm, which indicate that, the UAV can generate positive moment, which is essential condition for the UAV. At 1 degree angle attack the UAV achieve trim condition. At this condition aircraft can maintain stable altitude without the help of control system. From this analysis, it can be stated that, after changing the pitch moment of the UAV, it can reinstate its previous position, which is the condition for any stable aircraft or UAV.

Another analysis is performed to further validate the stability condition of the UAV. Aircraft Intuitive Design(AID), a module developed for MATLAB to design and test an aircraft. In the module same design parameters are given and the design is analysed.

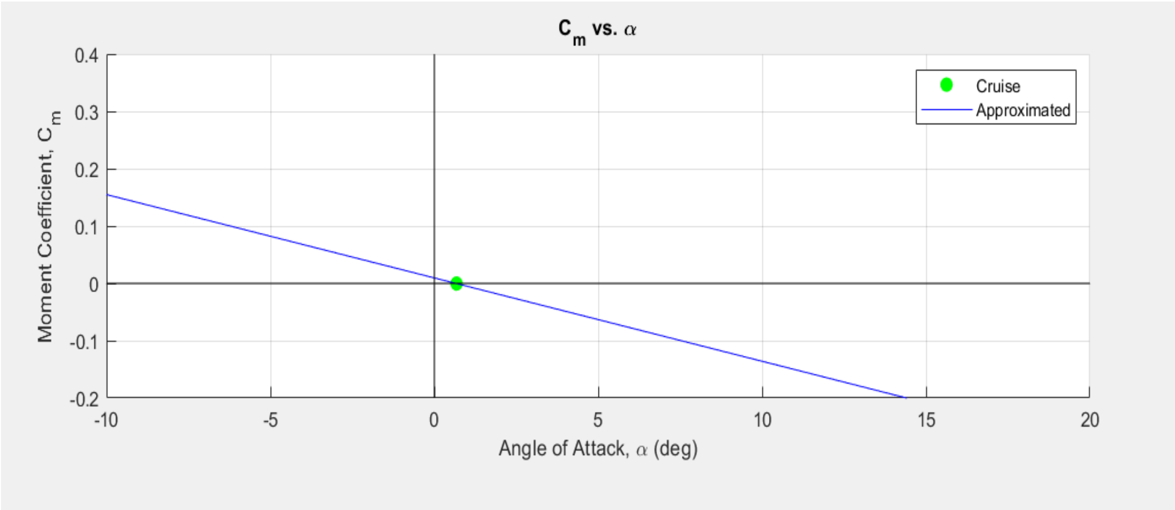

Fig. 4. 34: Variation of Coefficient of moment at different angle of attack using MATLAB AID module

Figure 4.34 shows the similar stability result. Just like previous Fig 4.34 here the trim occurred at 1 degree angle of attack. The slope of the moment coefficient graph is negative which further validate the previous analysis. This graph also shows the cruise condition which is similar to the trim condition of the previous study. In the real application, to maintain the stability the UAV must have slightly nose heavy condition. Some extra weight in front of the UAV can ensure the stability of the UAV.

4.7 DISCUSSIONS

The performance evaluation of the UAV is important as it validate the model. The CFD analysis further substantiate the result. In the analysis two important value is used, the cruise velocity and the maximum velocity. The UAV is capable of generating required amount of lift at the cruise velocity which is essential for the flying condition. Further analysis shows that at maximum speed the UAV is capable of generating more lift than the previous cruise velocity. But the flight envelope also set the speed limit to prevent structural damages.

Chapter 5

Conclusion and Recommendation

5.1 CONCLUSION

The technologies in the field of UAV are advancing very rapidly as the demand is increasing. The design of UAVs is getting diversified day by day as unique problems are arising. Coping with the situation with the help of technology is a challenge. In the study the general methodology is applied for designing the UAV. From the analysis of the performance the cruise and maximum speed are determined. The development of the flight envelope is based on the estimated performance. Based on the flight envelope the aerodynamic performance was measured numerically.

The CFD analysis also verify the performance of the UAV. To fly the UAV, a certain amount of lift force and thrust is needed. From the analysis it is found that the wing section of the UAV is capable of generating required amount of lift to counter the downward force of the weight of the UAV. This analysis also indicates that the mini UAV is capable of carrying the payload at the cruise velocity. Based on the design and performance analysis the UAV can fly at the range of fifteen kilometers, which is very usual for a mini UAV. From the wing analysis the effect of aspect ratio is found, as it affects the stall angle. The 3D analysis also shows the effects of different drag forces on the UAV. The mini UAV is also capable of restoring stability with the change of pitch angle.

5.2 RECOMMENDATION

In the UAV design, there were some shortcomings as it is difficult job to do. The aspect ratio can be changed in later design. Better electric motor can be chosen based on the design parameters. Lift enhancement techniques can be used in future for better performance. To fabricate the UAV advanced techniques like additive manufacturing should be used. These techniques will ensure proper dimensions for the UAV, which will maintain the aerodynamic profile exactly like the original design.

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Appendices

Appendix-A

Cost of the Project:

Item	Cost
N/A	N/A

Appendix-B

Work/Activities Plan of the project/thesis using Gantt chart:

Work/ Activities	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14-26
Study of the research paper	✓	✓												
Finding the research gap			✓	✓										
Fixing the objectives and research methodology				✓	✓									
Writing the project proposal					✓	✓								
Presenting an proposal							✓							
Develop the design/process								✓	✓					
Formulations and evaluations										✓				
Results analysis											✓	✓		
Writing thesis													✓	
Thesis correction and presentation preparation														✓
Final thesis presentation														✓

Appendix-C

Originality Report by Turnitin Plagiarism Software

Thesis_1603008

ORIGINALITY REPORT

17%	10%	9%	11%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Laurel Springs School Student Paper	4%
2	Submitted to Emirates Aviation College, Aerospace & Academic Studies Student Paper	1%
3	lib.buet.ac.bd:8080 Internet Source	1%
4	Submitted to Institute of Technology, Nirma University Student Paper	<1%
5	Wang, Libo, Long Shen, Lei Chen, Zhigang Wu, and Chao Yang. "Design and Analysis of a Wind Tunnel Test Model System for Gust Alleviation of Aeroelastic Aircraft", 53rd AIAA/ASME/ASCE/AHS/ASC Structures Structural Dynamics and Materials Conference< BR> 20th AIAA/ASME/AHS Adaptive Structures Conference< BR> 14th AIAA, 2012. Publication	<1%
	Submitted to University of Glamorgan	

Appendix-D

(This part will be filled/checked by the supervisor)

CO-PO-K-P-A Mapping

PO1	**Engineering knowledge:** Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
PO2	**Problem analysis:** Identify, formulate, research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
PO3	**Design/development of solutions:** Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
PO4	**Conduct investigations of complex problems:** Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
PO5	**Modern tool usage:** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
PO6	**The engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
PO7	**Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
PO8	**Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
PO9	**Individual and team work:** Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
PO10	**Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
PO11	**Project management and finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply these to one’s own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
PO12	**Life-long learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

Title of the Project: Numerical investigation of a Fixed wing Mini UAV

Student ID : 1603008

	CO-PO-K-P-A Mapping																															
	Program Outcomes												**Knowledge Profile**								**Complex Engineering Problem Solving**							**Complex Engineering Activities**				
	PO 1	**PO 2**	**PO 3**	**PO 4**	**PO 5**	**PO 6**	**PO 7**	**PO 8**	**PO 9**	**PO 10**	**PO 11**	**PO 12**	**K1**	**K2**	**K3**	**K4**	**K5**	**K6**	**K7**	**K8**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**A1**	**A2**	**A3**	**A4**	**A5**
Course Title	**Engineering Knowledge**	**Problem Analysis**	**Design/ Development of Solutions**	**Investigation**	**Modern Tool Usage**	**The Engineers & Society**	**Environment and Sustainability**	**Ethics**	**Individual and team work**	**Communication**	**Project Management and Finance**	**Life-long Learning**	**Science**	**Math**	**Engineering fundamentals**	**Engineering specialization**	**Design**	**Technology**	**Society**	**Research**	**Knowledge K3,K6,K8**	**Wide ranging/conflicting**	**No obvious solution**	**Infrequent issues**	**Outside problems**	**Diverse groups**	**Many components**	**Range of resources**	**Level of interaction**	**Innovation**	**Consequences**	**Familiarity**
Project Thesis																																

Needs complex engineering problem solution (p1+another P)

Related to project