Sudan University of Science & Technology

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College of Engineering

School of Mechanical Engineering

Design and Simulation of Numerical Model for Fixed Wing Aircraft Hybridized with Tri-copter

تصميم ومحاكاة نموذج حسابي لطائرة هجين بين الطائرة ثابتة الجناح و الطائرة ثلاثية المحرك

A Thesis Submitted in Partial Fulfillment of the Degree of M.Sc. in Mechanical Engineering (POWER)

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الآيـــة

قال تعالي :-

(اولم يروا الي الطير فوقهم صافات ويقبضن ما يمسكهن الا الرحمن انه بكل شئ بصير)

سورة الملك (الاية – 19)

صدق الله العظيم

Dedication

To my father who gives me direction to the sky.

To my mother who gives me lovely life.

To my brother, sisters and friends who give me support.

Acknowledgement

First of all I would like to thank my scientific supervisor, Dr. Obai Younis Taha at the Mechanical Engineering Department of Khartoum University for his guidance and encouragement throughout the duration of this Thesis. I would also like to thank my colleagues from MSc of Mechanical Engineering, namely Sadiq Abu-Alqasim, Muhammad Abdul-Azeez and Amani Abdul-Alwahid. I would like to extend my gratitude to my best friends, namely Elsheikh Yousif and Osman Abdulrahman for their support. Finally I would also like to thank my family.

Abstract

The traditional Fixed Wing aircraft requires a long runway. It is incapable of a vertical take-off and landing (VTOL) scenario. Also its maneuvering capability around objects is limited. This makes it inaccessible for certain applications. On the other hand the Rotary Wing Aircraft (Quadcopter or Helicopter) will have the VTOL ability. But the disadvantage is its slow operational speed. Also the consumption of energy is greater than a Fixed Wing aircraft. To solve these issues, the proposed aircraft is fixed Wing Aircraft Hybridized with Tri-copter. It has higher efficiency and can attain higher speeds than a Tri-copter or Helicopter. This Thesis discusses how to Design and analysis of VTOL aircraft. The wing of the Aircraft has been successfully analyzed using Ansys-15 software to answer some aerodynamic questions associated with the wing. The lift and drag coefficients are calculated over a range of angles of attack (0°-20°). The results lend into the choice of best angles of attack (5°) and the range at which the aircraft must fly (5°-15°).

المُستخلص

الطائرة ثابتة الجناح تتطلب مدرج طويل نسبيا للاقلاع والهبوط . الامر الذي يجعلها غير قادرة علي الاقلاع والهبوط الراسي . اضافة الي ان حركتها حول الاجسام محدود . الامر الذي يجعلها غير فعالة في تطبيقات معينة . علي الجانب الاخر ، نجد ان الطائرة ذات الجناح الدوار تتمتع بخاصية الاقلاع والهبوط الراسي . لكن من مساوئها انها تطير بسرعة منخفضة نسبيا . بالاضافة الي ان استهلاكها للطاقة اكبر نسبيا . الطائرة المقترحة هي طائرة هجين بين الطائرة ثابتة الجناح والطائرة ثلاثية المحركات. حيث تكون ذات كفاءة عالية وسرعة اكبر من الطائرة المروحية. هذا البحث يوضح كيفية تصميم وتحليل هذه الطائرة. تم تحليل جناح الطائرة بنجاح باستخدام برنامج انسس–15 لمعرفة المعلومات المتعلقة بخواص انسياب الهواء حول الجناح . حيث تم حساب قيمة معامل الرفع ومعامل الاعاقة لقيم مختلفة من زوايا الهجوم (0°- 20°). ومن خلال النتائج تم تحديد افضل زاوية هجوم (5°) و مدي زوايا الهجوم المسموح به لطيران امن (5° ـــ15°).

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List of Symbols

Symbol	Details
A	The aspect ratio
b_w	Wing span
C_D	Drag coefficient
C_l	Lift coefficient
$C_{h.t}$	Horizontal Tail volume coefficient
$C_{v.t}$	Vertical Tail volume coefficient
$C_{r.w}$	Wing Root chord
$C_{r.h}$	Horizontal Tail Root chord
$C_{r.v}$	Vertical Tail Root chord
$C_{t.w}$	Wing tip chord
$C_{t.h}$	Horizontal Tail tip chord
$C_{t.v}$	Vertical Tail tip chord
$\bar{C}_w$	Wing mean chord
$\bar{C}_{h.t}$	Horizontal Tail mean chord
$\bar{C}_{v.t}$	Vertical Tail mean chord
L	Lift force
Lh.t	Horizontal tail moment arm
Lv.t	Vertical tail moment arm
P	Centre of pressure
S_w	Wing area
$S_{h.t}$	Horizontal area
$S_{v.t}$	Vertical area
V	Aircraft speed
W/S	Wing loading
W	Weight
W_T	Total weight
W_B	Battery weight
W_P	Propulsion
W_E	Electronics
W_S	Structure
Λ	Taper ratio
$\boldsymbol{\rho}$	Air density

List of Abbreviations

Abbreviations	Details
AOA	Angle of attack
CCPM	Collective cyclic pitch mixing
CFD	Computational fluid dynamic
C.G	Centre of gravity
EPP	Expanded polypropylene
RC	Radio-Controlled
Re	Reynolds number
UAV	Unmanned aerial vehicle
STOL	Vertical and/or Short Take-Off and Landing
VTOL	Vertical Take-Off and Landing

Chapter One

Introduction

1.1 Introduction

Airports occupy large area to receive big number of aircrafts. If a lot of aircrafts come at the same moment. It is impossible for all aircrafts to land. The simple method to solve this problem is to increase the airport area. But this solution needs a lot of money and is limited. The best solution is to design aircraft with small takeoff and landing distance.

Traditionally in Fixed Wing Aircrafts, lot of research has been done to incorporate vertical take-off and landing (VTOL) feature and to increase the maneuverability of the fixed wing aircraft. The alternative was the Rotary Wing Aircraft which is more maneuverable and has the VTOL Feature. The Rotary Wing Aircrafts include the helicopter, tricopter, quad-copter etc. The problem associated with Rotary Wing Aircrafts is that their efficiency and speed are on the lower side. Other problems like the retreating blade stall are also present. These disadvantages have to be removed or nullified. Hence the solution to the above mentioned problems is a hybrid Aircraft. It will have the advantages of both the Fixed Wing and the Rotary Wing Aircrafts and to a large extent should be successful in removing their disadvantages. The concept used was the Tilt Rotor mechanism. The proposed aircraft is fixed Wing Aircraft Hybridized with Tri-copter. It has higher efficiency and can attain higher speeds than a Tri-copter or Helicopter.

In this thesis, a conceptual design process and analysis for a numerical model for aircraft has been shown. The wing of the aircraft has been successfully analyzed using Ansys 15.0 software to determine the aerodynamic characteristics.

1.2 Research problems

Airports occupy large area to receive big number of aircrafts. If a lot of aircrafts come at the same moment, it is impossible for all aircraft to land at same moment. The simple method to solve this problem is to increase airport area. But this solution needs a lot of money and is limited. The best solution is to design aircraft with small takeoff and landing distance.

1.3 Research Objectives

The main objectives of this study cover the followings:

- Design a numerical model for fixed Wing Aircraft Hybridized with Tri-copter.
- Simulate the wing of the aircraft.
- Total weight not exceeds 5 kg.
- Wing span less than 2 meters.

1.4 Research scope

The scope of study covers the followings:

- Small aircraft model.
- Conceptual Design will be used to calculate the aircraft dimension.
- Dimension will be drawn in CATIA V5R20 software.
- Ansys 15.0 software was used to calculate the aerodynamic characteristics for wing.

1.5 Research Methodology

Initially, the Thesis idea was to design and analyze UAV. Several concepts were studied to get optimum design. The idea which was carries out is to design a fixed wing aircraft with vertical take-off/landing (VTOL) capability. After design was made, the calculations are export to CATIA V5R20 software to represent the general geometry for aircraft. Then wing geometry was export to Ansys 15.0 software to calculate aerodynamic characteristics for it.

Chapter Two

Review of Theory & Previous Work

2.1 Introduction

Aircraft have a number of different components to help them fly. The wing is responsible for generating lift. The main central body of the aircraft is called the fuselage. This houses the cockpit, where the pilot sits. It may also contain a cabin for passengers, or a cargo bay for carrying other items. At the rear of the fuselage are the horizontal and vertical tails (or stabilizers). These help the aircraft to fly smoothly and stay heading in one direction. One or more engines provide thrust. These engines may turn a propeller. Engines are usually located at the front of the fuselage, or below the wings if there are a number of them, but they can also be located at the rear of the fuselage, above the wing or in the wing. Aircrafts also have landing gear to allow them to move on the ground, and a number of controls (Aileron, Rudder and Elevator) as shown in Fig (2.1).

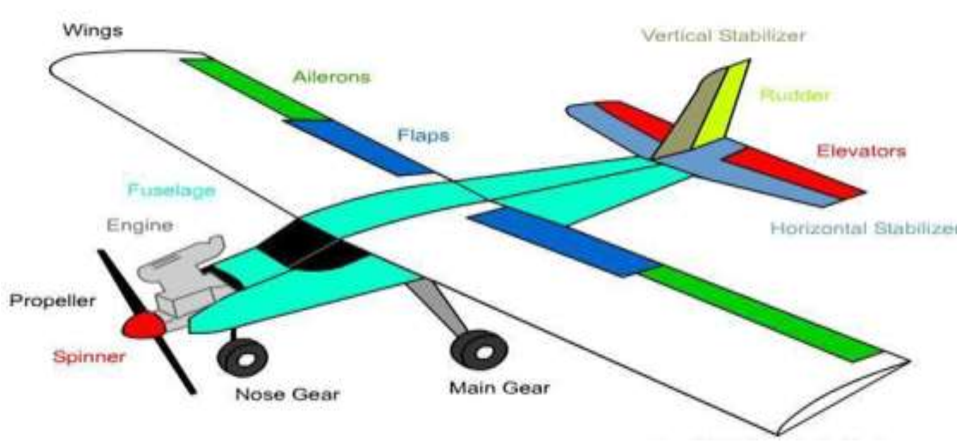

Fig. (2.1): Aircraft main components

2.2 Vertical takeoff and landing aircraft (VTOL)

Since the beginning of powered flight, the idea of very low landing speeds or even vertical takeoff and landing was a highly sought after target. Only until the twentieth century, most manned flights that were capable of achieving this objective were balloons and airships as shown in Fig. (2.2) .This was followed by the gyrocopter and the helicopter. Over time, and as technology advances, considerable research has been carried out in both the vertical and short-takeoff aircraft.

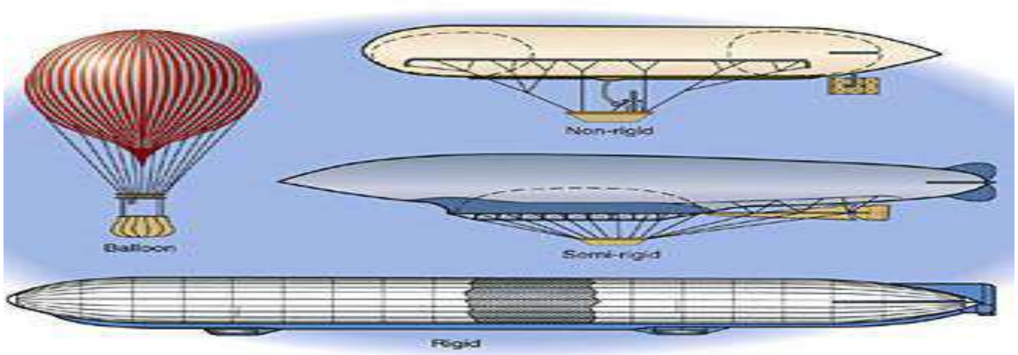

Fig. (2.2): Hot air Balloons and airships [3]

There have been two generally accepted categories; VTOL for Vertical Take Off and Landing and STOL for Short Take-off and Landing. Focusing on some of the more successful or more promising examples, there are three approaches:

- Tilting the whole aircraft.
- Tilting the whole aircraft.
- Tilting the rotors.

The main difference between a fixed wing aircraft and rotary wing aircraft is the main source of lift. Fixed wing aircrafts attains lift mainly from its fixed aerofoil surfaces, as shown in Fig. (2.3), while rotary aircraft attains its lift from rotating aerofoil surfaces namely the rotor blades Fig. (2.4).

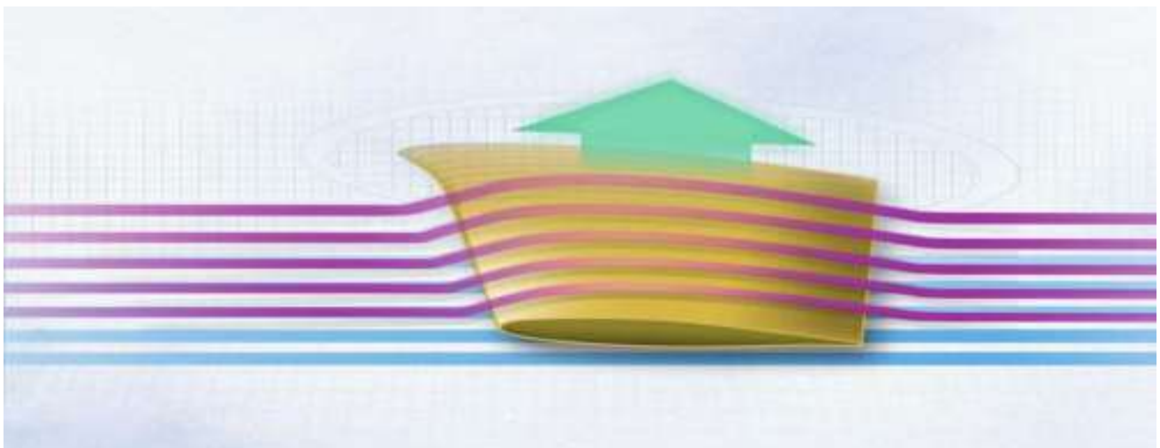

Fig. (2.3): Lift form by Aerofoil Surfaces [1]

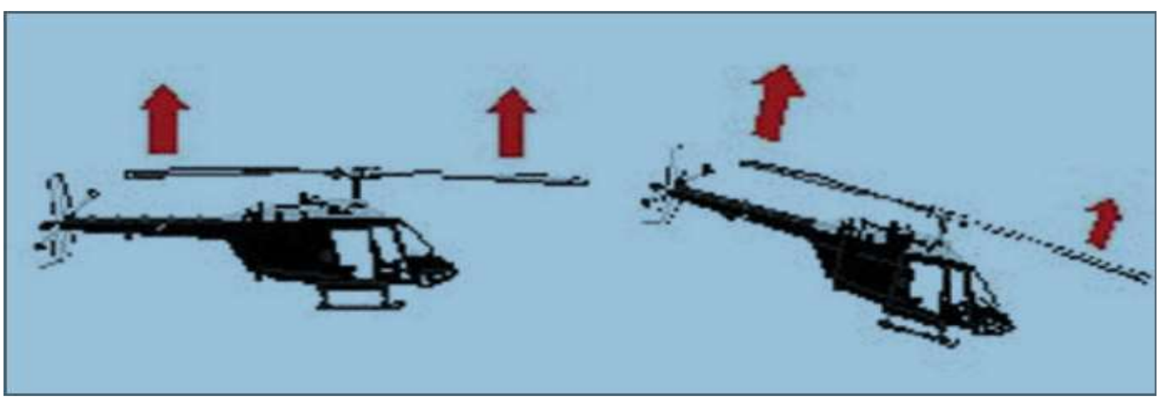

Fig. (2.4): Lift from Rotor Blades [2]

Majority of the rotary wing type are the helicopters but auto-gyros/gyrocopter and tilt rotor aircraft are important members of this category. In creating VTOL that transitions between helicopter mode and aircraft mode, these two concepts of generating lift must be taken into consideration. While in Hover mode, the lift is purely from the rotor blades and the wings is producing zero lift. The transition must be gradual to ensure that there is sufficient time for the wing to generate the lift in the air.

2.3 Definitions

The following definitions should be remembered.

- **Airfoil:** A vertical cut through the wing parallel to flight's direction (plan view) will show the cross-section of the wing as shown in Fig. (2.5).

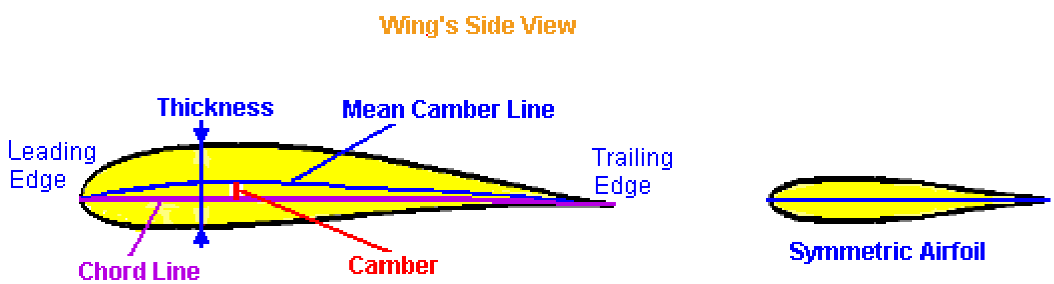

Fig. (2.5): Airfoil geometry

- **Chord Line:** The longest straight line that can be drawn from the Airfoil's leading edge to trailing.
- **Mean Camber Line:** The Chord Line cuts the airfoil into an upper surface and a lower surface.
- **Camber:** The maximum distance between these two lines is called the Camber, which is a measure of the curvature of the airfoil (high camber means high curvature).
- **Aspect Ratio:** is a measure of how long and slender a wing is from tip to tip. The Aspect Ratio of a wing is defined to be the square of the span divided by the wing area and is given the symbol A.

$$A = \frac{(b_w)^2}{S_w} \qquad (2.1)$$

- **Wing Taper:** Wing taper describes the way that some wings get narrower towards the tip. Taper helps to reduce drag, allowing planes to fly faster and use less fuel. The best taper to reduce this drag is an elliptical wing, like the one on the Supermarine Spitfire, a famous British fighter plane from World War 2. Elliptical wings are hard to make, so wings normally have straight edges that form trapezoids. Some low speed aircraft have rectangular wings, as these are the easiest to make. The taper is measured by the taper ratio. This is the width of the wing at the tip divided by the width of the wing where it intersects the fuselage, called the root.

$$\lambda = \frac{c_t}{c_r} \qquad (2.2)$$

- **Incompressible flow:** Flow below sonic speed is assumed to be incompressible.
- **Laminar flow:** Fluid flow in which the streamlines maintain a uniform parallel separation with no turbulence.
- **Streamline:** An imaginary line marking the path of a particle of fluid from one point to another especially in laminar flow.
- **Turbulence flow:** Random motion of fluid with unpredictable fluctuations and vortices.
- **Airspeed:** The speed of the aircraft through the air.
- **Angle of incidence:** The angle the chord line makes with the longitudinal datum line of the aircraft.
- **Centre of pressure:** All pressure difference between the top and bottom surfaces of aerofoil can be added together to produce the total air reaction which can be considered to act at a point called the centre of pressure (P).
- **Mean aerodynamic chord:** close to mean chord. Chord of imaginary wing of constant aerofoil section producing the same force (lift and drag).

- **Angle of attack:** This is the angle between the chord line of the aerofoil and the free-stream flow.

2.4 RC VTOL aircrafts

There have been a number of attempts by individuals to build RC VTOL aircraft but only a handful has succeeded in building a model capable of performing a successful transition to conventional flight. There are many discussions on forum where individuals have expressed an intense interest in the development of a commercially available transition capable RC aircraft. Literature for this section is restricted due to the fact that the people who have attempted to build an RC VTOL aircraft are enthusiasts who do not generally publish their designs in detail. Vertigo is a giant-scale RC VTOL model built by Tom Hunt, with a wing span of 1.7 m and length of 1.5 m. and powered with O.S.46 VRDF engine in a homemade 'prop fan' nacelle as shown in Fig. (2.6). A test-flight of the VTOL made history in 1994 as the first remote-controlled vertical takeoff and landing aircraft using the vane-control principle to go from hover to forward flight and back.

Fig. (2.6): Vertigo [4]

TILT 607 is based on the great VTOL aircraft V 22 Osprey and the Bell BA 609 of the Americans, consists of 2 YELLOW-BL brushless motors with 3-bladed rotors and 1 rear rotor for yaw as shown in Fig. (2.7). the model is developed mainly from EPP and carbon reinforcement. The flight characteristics are a mixture between model airplane and helicopter. It flies nearly like a normal airplane with the rotors forward tilted and achieves high airspeed. In the hovering flight, the level of difficulty of floating is the same as a model helicopter.

Fig. (2.7): Tilt 607 [5]

Verti 4 is the simplest and most successful electric VTOL design. It looks like a fairly conventional trainer-style airplane with four motors on each side of the wing (two in the front, two after of the wing) as shown in Fig. (2.8). The motors can pivot 90º from facing up to facing forward similar to V-22 Osprey style, allowing a transition from hovering to translational flight and vice versa. It is using the quad-rotor contraptions, two rotors turn clockwise and two counter-clockwise on a diagonal. The stabilization and control is not done with some sort of custom electronics, but with a combination of conventional gyros with channel mixing.

Fig. (2.8): Verti 4 [6]

Chapter Three

Conceptual Design

3.1 Introduction

Aircraft conceptual design is a skill best gained through experience. In designing an aircraft, there are various factors that must be taken into considerations. The aircraft weight and propulsion system must be light. The structure must then be strong to withstand impact and rigid to prevent flexing of the wings or vibrations. The conceptual design consists of:

1. Fixed wing aircraft design.
2. Tri-copter aircraft design.

3.2 Fixed wing aircraft design

Design fixed wing aircraft mean calculate main performance parameters which include:

1. Design takeoff gross weight.
2. Cruise speed
3. Mission profile.
4. Wing loading.
5. Wing geometry
6. Tails geometry.
7. Fuselage geometry.
8. Thrust to weight ratio.

3.2.1 Design takeoff gross weight

Design takeoff gross weight is total weight of the aircraft as it begins its mission which it was designed. For electric RC aircraft, design takeoff gross weights can be broken into battery weight, propulsion weight, electronics and structure weight.

$$\mathbf{W_T = W_B + W_P + W_E + W_S} \qquad \textbf{(4.1)}$$

3.2.2 Cruise speed

To have an idea of what speeds the aircraft would be flying at an initial estimate of the weights was made. Assuming:

Straight level unaccelerated flight, where $L = W$

$$L = \frac{1}{2}\rho V^2 S C_L \quad \text{Or} \quad V = \sqrt{\frac{2\,W}{\rho\, S\, C_L}} \qquad (4.2)$$

3.2.3 Mission profile

Typical mission profile for various types of aircraft is shown in Fig (3.1). The simple cruise mission is used for many transport and general aviation designs, including homebuilts.

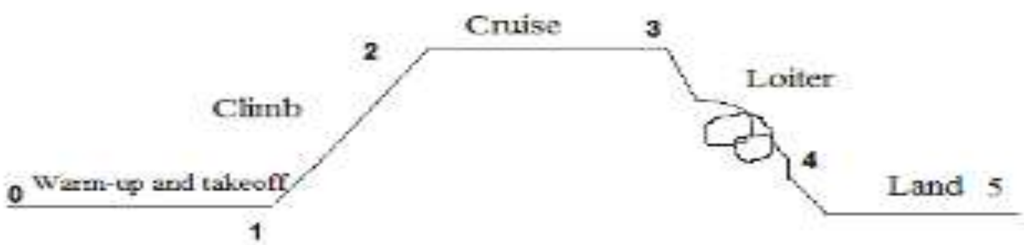

Fig. (3.1): Mission profile [7]

3.2.4 Wing loading

The wing loading is the weight of the aircraft divided by the area of the reference wing. Wing loading affects stall speed, takeoff and landing distance. It is calculated using historical data, equations or similar aircraft.

Table (3-1) wing loading [7]

Historical trends	Typical takeoff W/S (N/m^2)
Sailplane	287.4
Homebuilt	526.89
General aviation – single engine	814.29
General aviation – twin engine	1245.38
Twin turboprop	1915.97
Jet trainer	2394.97

3.2.5 Wing geometry

The wing is airfoil attached to each other and is the main lifting surfaces that support the airplane in flight. There are numerous wing designs, sizes, and shapes. Each fulfills a certain need with respect to the expected performance for the particular airplane. The actual wing sizing can be determined simply as the takeoff gross weight divided by the takeoff wing loading. Reference wing area can be obtained as:

$$S_w = \frac{W}{\left(\frac{W}{S}\right)} \qquad \textbf{(4.3)}$$

The wing design parameters are determined as equations below:

- **Wing span**

Wing span can be calculated as:

$$b_w = \sqrt{A * s_w} \qquad \textbf{(3.4)}$$

Aspect ratio can be taken from the table below:

Table (3-2) Aspect ratio [7]

Propeller aircraft	Equivalent aspect ratio
Homebuilt	6
General aviation – single engine	7.6
General aviation – twin engine	7.8
Agricultural aircraft	7.5
Twin turboprop	9.2
Flying boat	8

- **Wing chord**

Wing chord can be calculated as:

$$C_{r.w} = \frac{2S_w}{b_w(1+\lambda)} \qquad \textbf{(3.5)}$$

Taper ratio $\lambda = \frac{C_{t.w}}{C_{r.w}}$ **(3.6)**

❖ **Mean chord**

$$\bar{C}_w = \frac{\left(\frac{2}{3}\right)C_{r.w}(1+\lambda+\lambda^2)}{(1+\lambda)} \quad \textbf{(3.7)}$$

3.2.6 Fuselage design

The fuselage includes the cabin and/or cockpit, which contains Seats for the occupants and the controls for the airplane. In addition, the fuselage may also provide room for cargo and attachment points for the other major airplane components. Some basic rules of thumb may be followed when designing fuselage and general geometry for small aircraft as shown in Fig (3.2) and Fig (3.3).

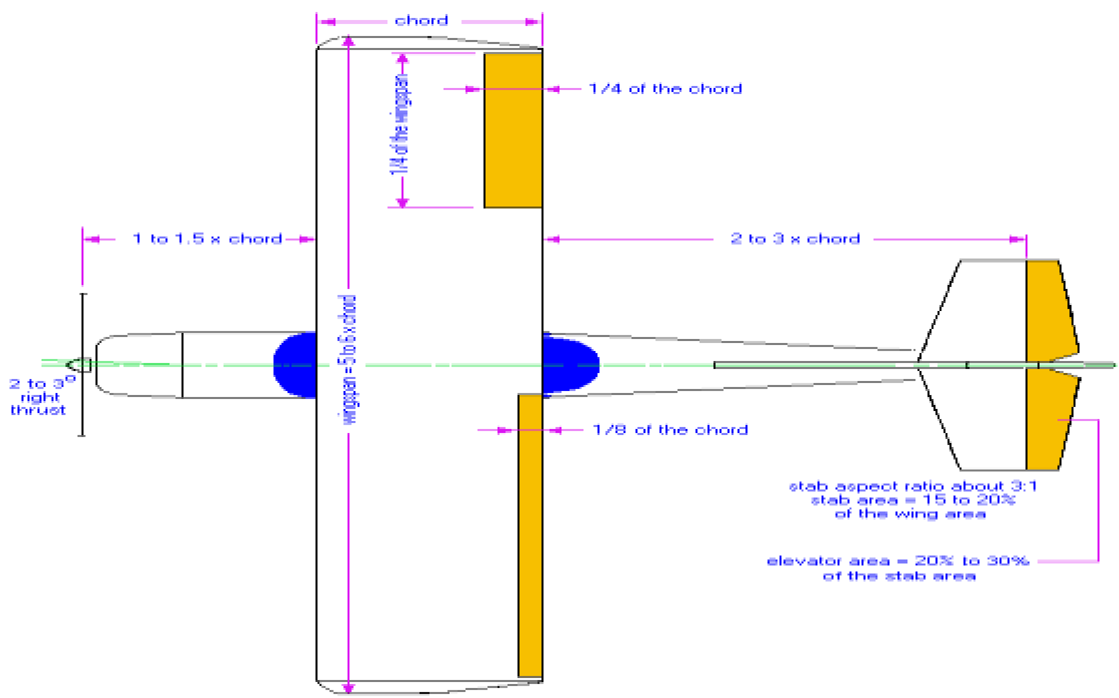

Fig. (3.2): Top view for general geometry for aircraft

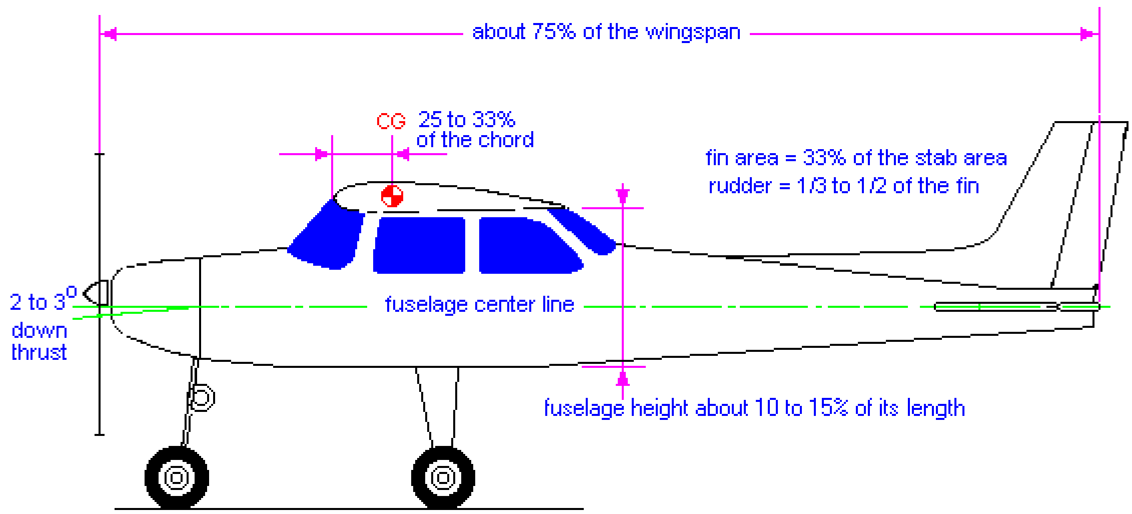

Fig. (3.3): Front view for general geometry for aircraft

3.2.7 Tail geometry

The correct name for the tail section of an airplane is empennage. The (Empennage) includes the entire tail group, consisting of fixed surfaces such as the vertical and the horizontal stabilizer. The movable surfaces stabilizers include the rudder and elevator. For the initial layout, a historical approach is used the estimation tail sizing. The effectiveness of a tail in generating a moment about the center of gravity is proportional to the force (i.e., lift) produced by the tail and the tail moment arm. The primary purpose of a tail is counter moments produced by the wing. Thus, it would be expected that the tail size would be in some way related to wing size. The tail volume coefficient method to estimated tail sizing .Fig 3.4 explains initial tail sizing parameters:

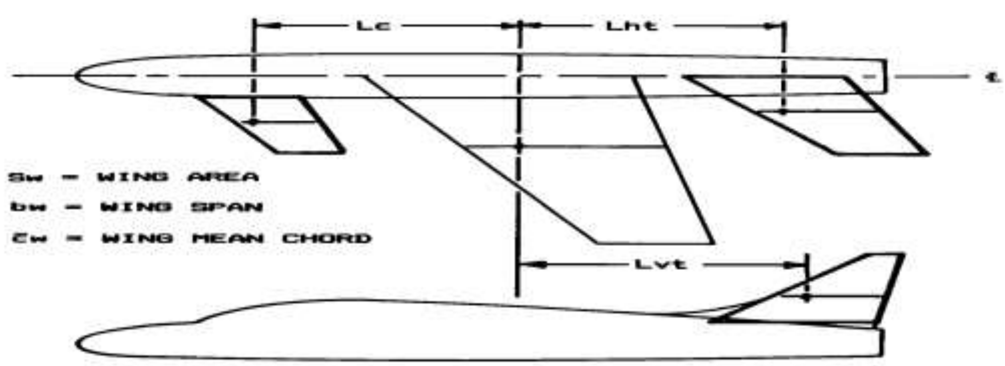

Fig. (3.4): initial tail sizing parameters [7]

Values for volume coefficients of the tail can be taken from statistical data in the table (3-3) below:

Table (3-3) provides typical values for volume coefficients for different aircrafts. [7]

Aircraft type	Typical values	
	Horizontal $C_{h.t}$	Vertical $C_{v.t}$
Homebuilt	0.50	0.04
General aviation	0.70	0.07
Agricultural aircraft	0.50	0.08
Twin turboprop	0.90	0.06
Flying boat	0.70	0.06

To calculated tail size, the moment arm must be estimated. This can be approximated at this stage of design by a percent of the fuselage length. For an aircraft with the engines on the wings, the tail arm is about (50% - 55%) of fuselage length.

❖ **Vertical tail area**

Vertical tail area is estimated as:

$$S_{v.t} = \frac{C_{v.t} * b_w * s_w}{L_{v.t}} \quad (3.8)$$

❖ **Vertical tail span**

Vertical tail span is estimated as:

$$b_{v.t} = \sqrt{A * S_{v.t}} \quad (3.9)$$

- **Vertical tail chord**

  Vertical tail chord is estimated as:

$$C_{r.v} = C_{t.v} = \overline{C}_{v.t} = \frac{2\, S_{v.t}}{b_{v.t}\,(1+\lambda)} \qquad \textbf{(3.10)}$$

- **Horizontal tail area**

  Horizontal tail area is estimated as:

$$S_{h.t} = \frac{C_{h.t} * \overline{C}_{W} * S_{w}}{L_{h.t}} \qquad \textbf{(3.11)}$$

- **Horizontal tail chord**

  Horizontal tail chord is estimated as:

$$C_{r.h} = C_{t.h} = \overline{C}_{h.t} = \frac{2\, S_{h.t}}{b_{h.t}\,(1+\lambda)} \qquad \textbf{(3.12)}$$

- **Horizontal tail Span**

  Horizontal tail span is estimated as:

$$b_{h.t} = \sqrt{A * S_{h.t}} \qquad \textbf{(3.13)}$$

3.2.8 Control surfaces sizing

Final sizing of these surfaces is based upon dynamic analysis of control effectiveness including structural bending and control system effects.

- **Aileron**

Aileron is lateral control surface use to generate roll and it's located at trailing edge of the wing. Aileron span can be taken as percentage of wing span approximately (50%-90%) and chord is (20%) of the wing chord.

❖ Rudder

Rudder is directional control surface use generates yaw it's located at trailing edge of the vertical tail. Rudder span can be taken as percentage of the vertical tail span approximately (90%) of vertical tail span and rudder chord is about (25%-50%) of vertical tail chord.

❖ Elevator

Elevator is longitudinal control surface use generates pitch it's located at trailing edge of the horizontal tail. Elevator span can be taken as percentage of the horizontal tail span approximately (90%) of horizontal tail span and elevator chord is about (25%-50%) of horizontal tail chord. [7]

3.3 Tri-copter design

One of the most integral parts of tricopter is its frame. The frame supports the motors and other electronics and prevents vibrations. Even the geometry of the frame can affect the flight characteristics and performance of the tricopter. To ensure the tricopter is well balanced and able to vector equally 360 degrees, the geometry of the motors must equate to an equilateral triangle with the center of gravity in the middle of the triangle. The two main frame designs are a Y and T configurations as shown in Fig. (3.5). [9]

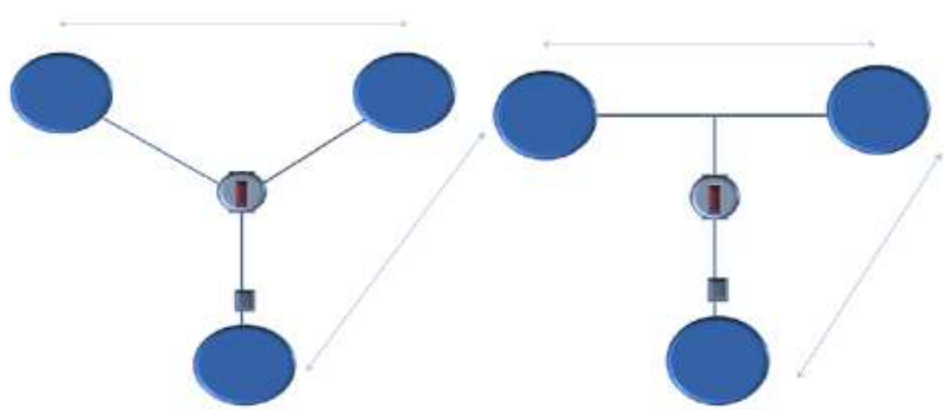

Fig. (3.5): Y and T configurations for The Tri-coptor

3.3.1 Tri-copter Flight Principle

There are three motions for tri-copter. The flight principle of the tri-rotor Fly forward: When flying forward, motors (1) and (2) must decelerate, while motor (3) on the tail axis must accelerate. As a result, the fuselage of the tricopter is inclined forwards, so it flies towards the same direction. On the contrary, when flying backwards, motors (1) and (2) must accelerate, while motor (3) must decelerate.

Fly to the right direction: When the tri-rotor flying robot flies to the right direction, motor (1) on the left side must accelerate, while motor (2) on the right side must decelerate, so as to allow the fuselage to incline to the right side and make the tricopter fly to the right direction.

Clockwise yaw: When the tri-rotor flying robot yaws in the clockwise direction, it needs to use the RC servomotor and linkage to drive the propeller of the motor (3) inclined in the left side. When the motor (3) rolls, it will generate the clockwise yaw torque, so as to make the tri-rotor flying robot yaw in the clockwise direction as shown in Fig. (3.6).

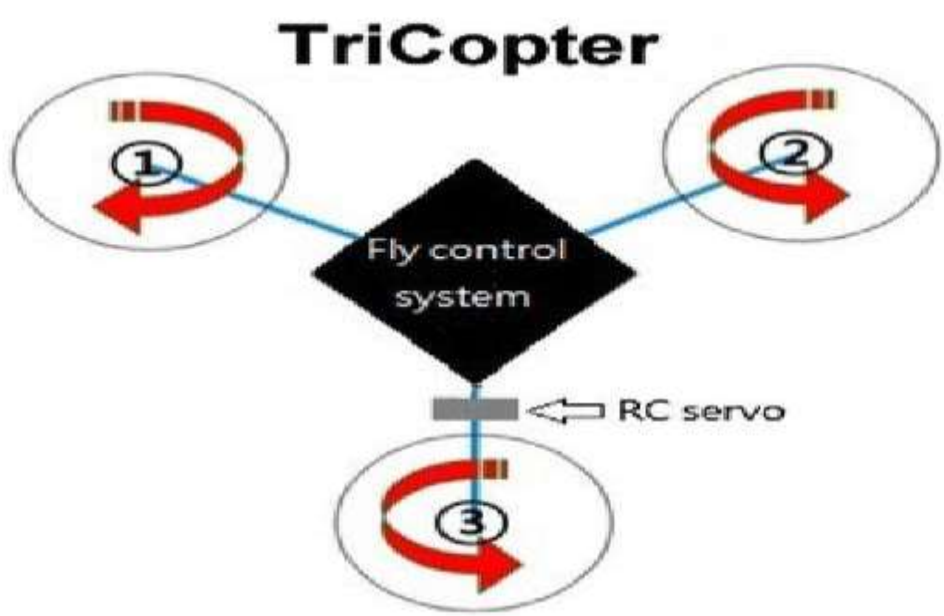

Fig. (3.6): The Flight Principle of the Tri-Rotor

3.3.2 Tri-coper design

Most tri-copter Designs are based on a Y shape, each arm separated by an angle of (120°) as shown in Fig. (3.7). There are various reasons for the specification of (120°) angle between the three arms. Firstly, a tri-copter is controlled in the exact same way as a (120°) CCPM swash plate on a normal helicopter. Second, at (120°) with (3) equidistant arms, the intersection point of the arms will be the exact location of the C.G.

It would be simple to make a Y style tri-copter as there are many guides out in the internet on how to build one. However, for this project a Y shaped tri-copter would not be feasible. The reason for this is simple, when the motors tilt for conventional aircraft performance, in a Y shaped tri-copter, tilting the motor or arms will result in the front two motors pointing (45°) to each other. This is undesirable as it will affect the thrust angle of the aircraft as well as the stability. To solve this problems the Tri-copter T shape was used.

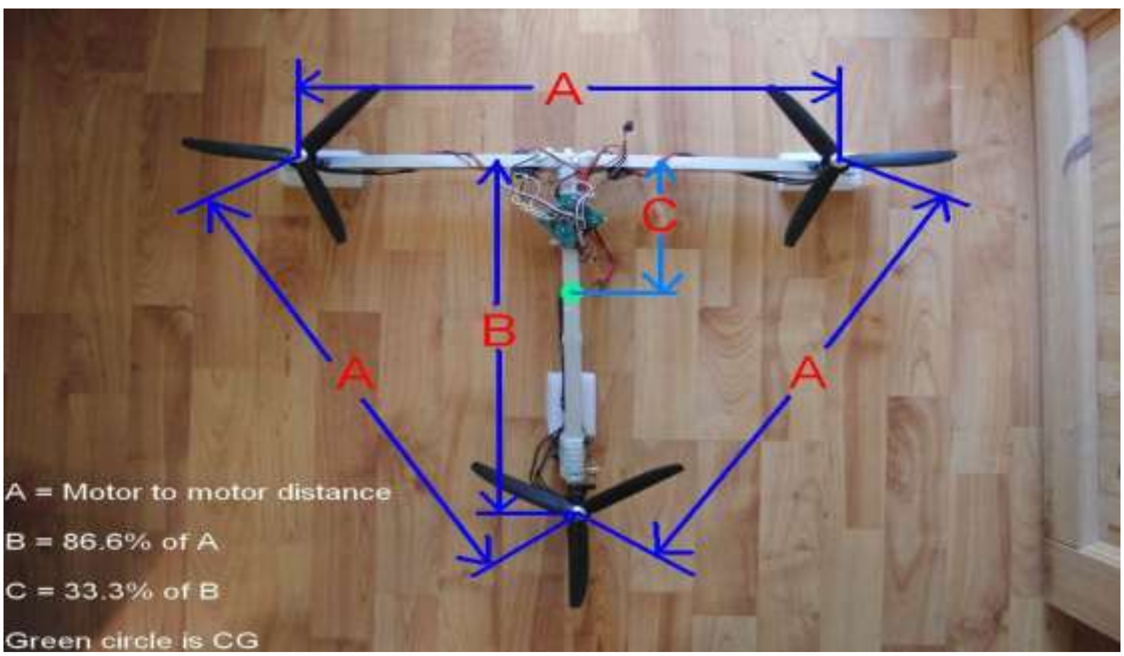

Fig. (3.7): Multi-rotor Design Rules

3.4 Tilt rotor mechanism

To let motor easy to move, gear systems were choosing with one solid rod across the whole wing. Ball bearings were added to the outer and inner parts of the wing. The ball bearing will help to ensure a smooth rotation, reduce load on the servo and also to prevent the rod to move back. A small gear installed in the middle of the tilt mechanism rod. Then a larger spur gear installed, with (3) times the number of teeth of the previous spur gear. This will act in the speed reduction gearing system, the output torque and the travel movement increases by three times but speed decreases at the same time. The speed is not as critical as for the tilt mechanism; in fact, the slower speed will help the stability in hovering. The spur gear is secured to the servo horns as showed in Fig. (3.8).

Fig. (3.8): Spur Gear attached to servo

The mechanism is shown in detail from a cross section view of our Solid Works drawing, Fig 3.9 Cross section view of tilt mechanism.

Fig. (3.9): Cross section view of tilt mechanism

3.5 Thrust to weight ratio

In vertical mode, the Lift (thrust) generated from the blades must be equal to the total weight of aircraft. In normal airplane mode, for a typical aircraft, the thrust from the motors should be about 1/3 weight.

3.6 Centre of gravity

The center of gravity envelope refers to a visual representation of the limitations for the center of gravity depending on different total vehicle weights [8]. In this project, there are two centre of gravity and it’s necessary to make it one point. The recommended distance for centre of gravity is (0.25-0.33) of wing chord from leading edge.

Chapter Four

Simulation and Analysis of Wing

4.1 Introduction

The ANSYS program is used to study aerodynamic characteristics of wing. ANSYS Workbench 15.0 has powerful tools which allow rapid solving of challenging engineering tasks. The ANSYS tools are based on a well-known Finite volume method to model the behavior of the air flow over the wing under different angles of attacks. The simulation was run to calculate the lift and drag coefficients caused by air flowing around wing surface. [10]

4.2 General Description

For an aircraft, there are two main important parameters are the Lift Force and the Drag Force. For any aircraft or flying object:

1. The Lift Force should be more than the Weight of the aircraft.
2. The Drag Force should be less than the thrust on the aircraft.

This project deals with viscous flow over the wing. The variation of C_L & C_d with various angles of attack of the aircraft is studied using CFD methods. Wings without the propellers are modeled for ease of CFD analysis. The model in ANSYS is established describing step-by-step each element in the scheme as shown in Fig. (4.1)

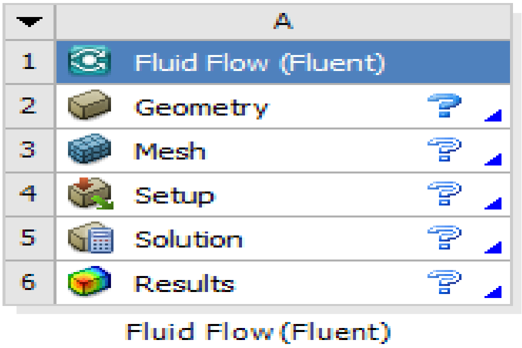

Fig. (4.1): Fluid flow Analysis

4.3 Geometry

The Geometry of the wing is done in CATIA V5R20. The various sketch commands used are spline, point, plane and multi-section solid. The solid model is exported from CATIA V5R20 into ANSYS Workbench as shown in Fig. (4.2).

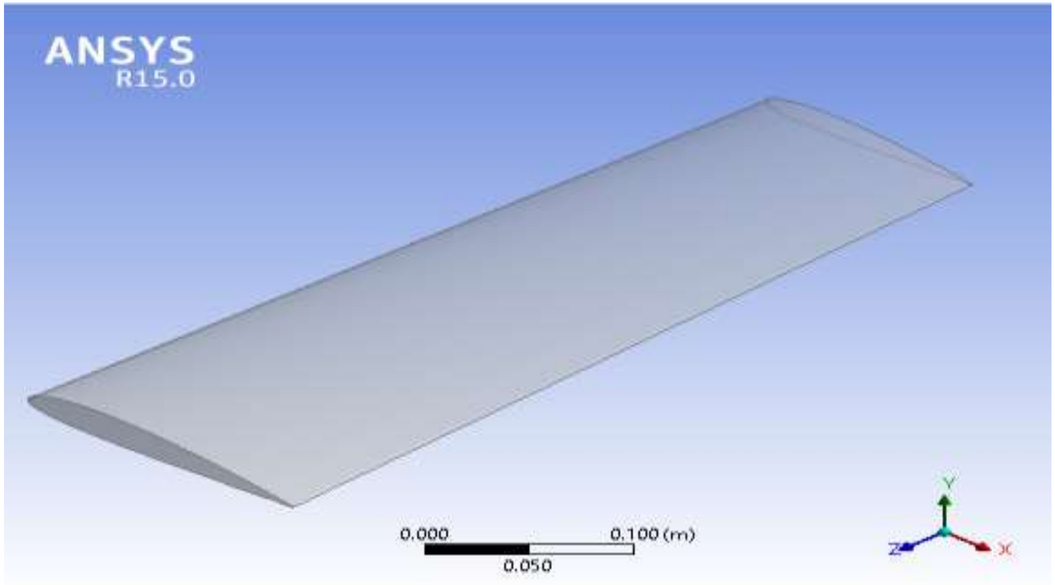

Fig. (4.2): The wing in Design Modeler

4.4 Mesh

The mesh was applied to the wing model. As a result the model is comprised of 1044750 elements on the basis of 185756 nodes' coordinates as showing in Fig. (4.3).

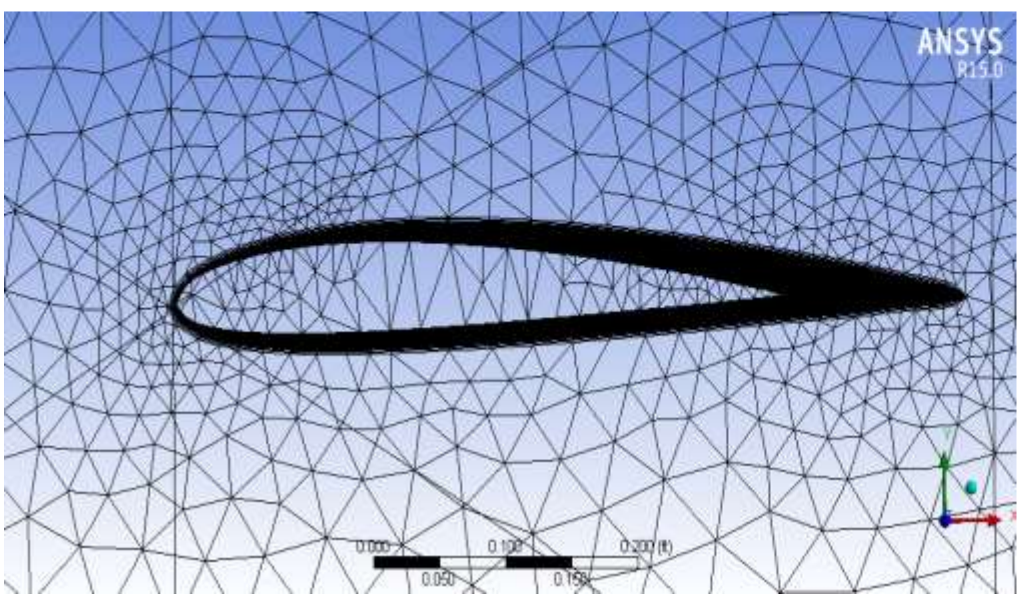

Fig. (4.3): Mesh

4.5 Setting up

Simulation for this model is done in ANSYS Fluent 15. Once the model is exported to Fluent it is opened in Fluent and the required scaling is done and then the mesh is checked for any error and if no errors are found then the appropriate model for the simulation is assigned. The simulation is a pressure-based and steady state simulation as shown in Fig. (4.4)

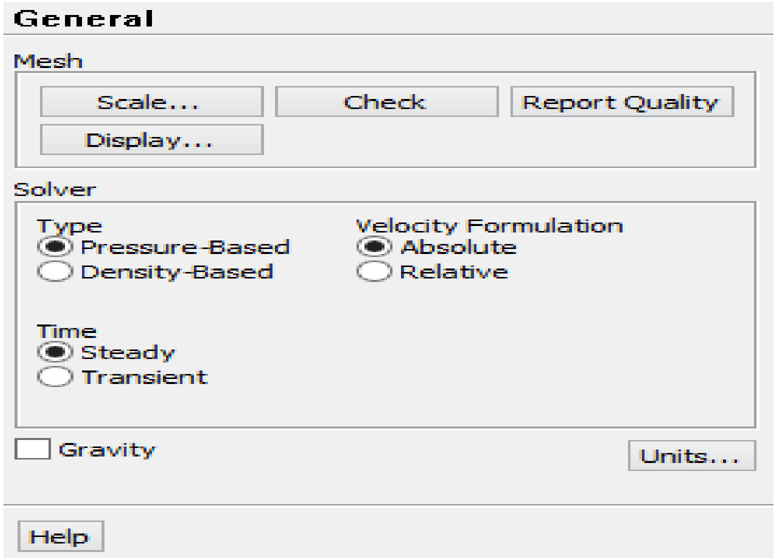

Fig. (4.4): Setting up

4.6 Modelling

The simulation model used is laminar model as shown in Fig. (4.5).

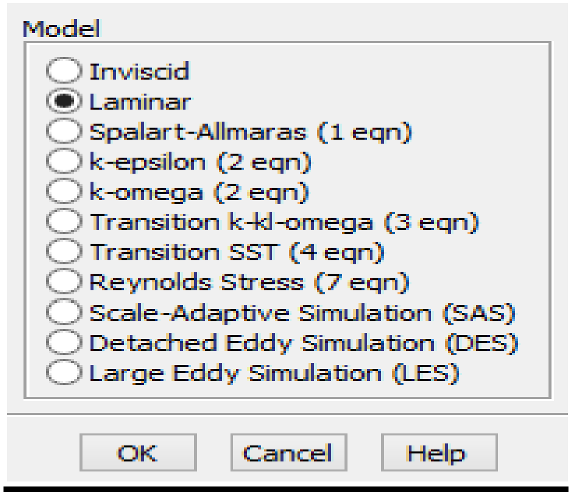

Fig. (4.5): Model

4.7 Material Properties

Once the model for the simulation is set then set the material properties for the flow field as Air. The material properties are set by default for the density of air as shown in Fig. (4.6).

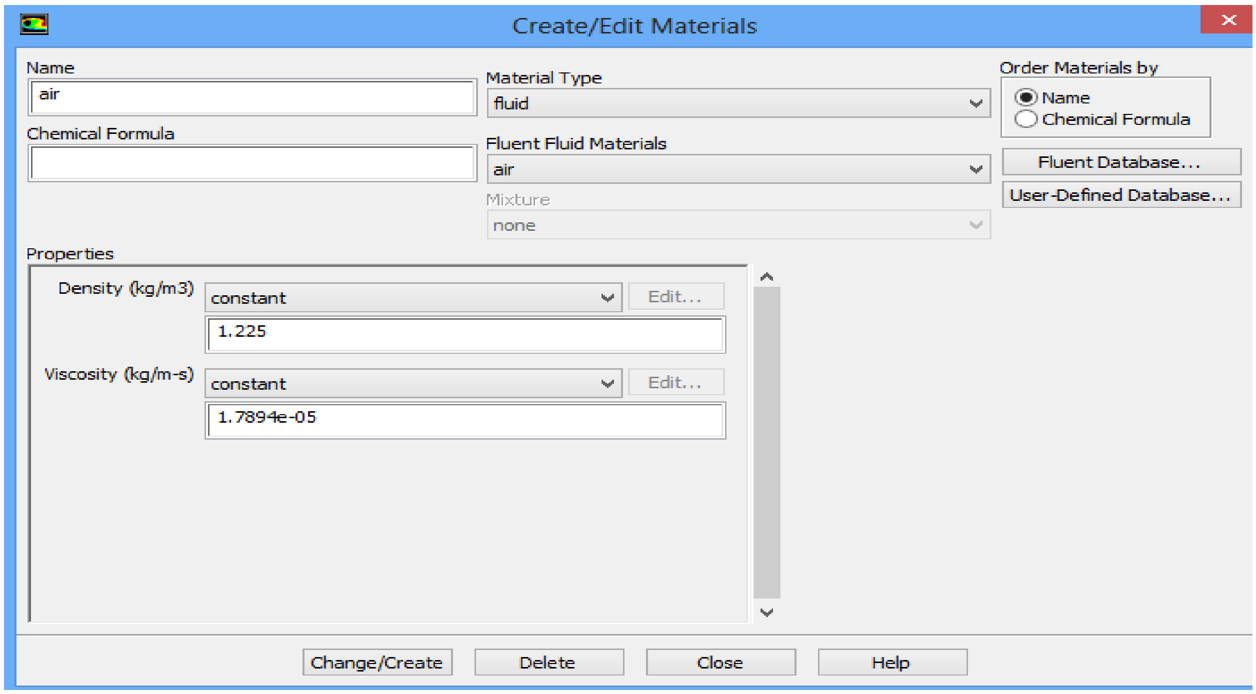

Fig.(4.6): Material Properties

4.8 Boundary Conditions

After the material properties, the boundary conditions were set .The boundary conditions are set as follows: inlet velocity and pressure outlet as shown in Fig. (4.7) and Fig. (4.8).

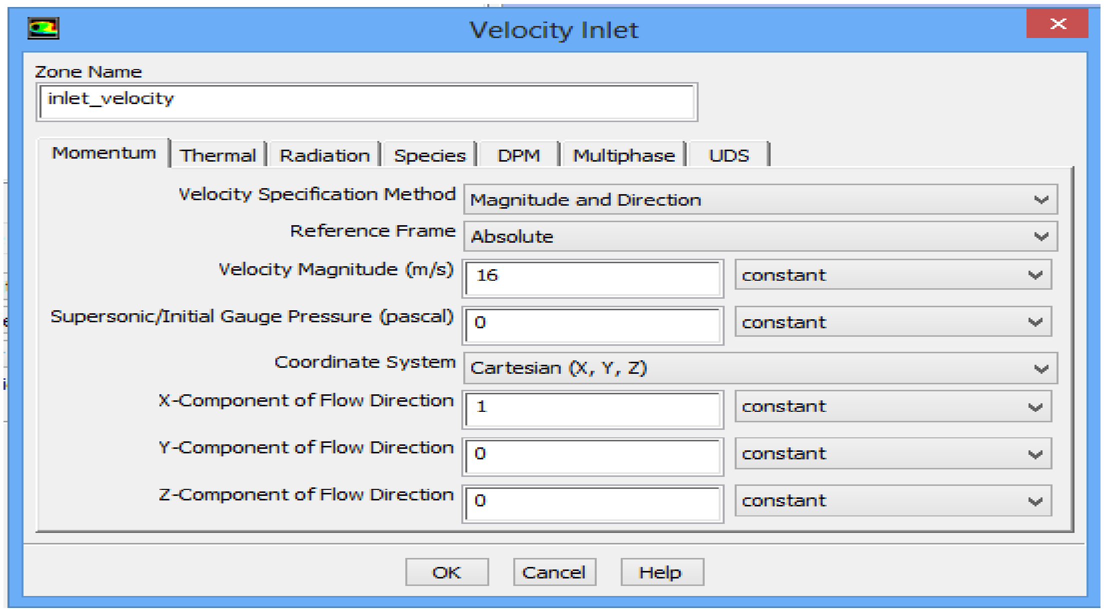

Fig. (4.7): Velocity inlet

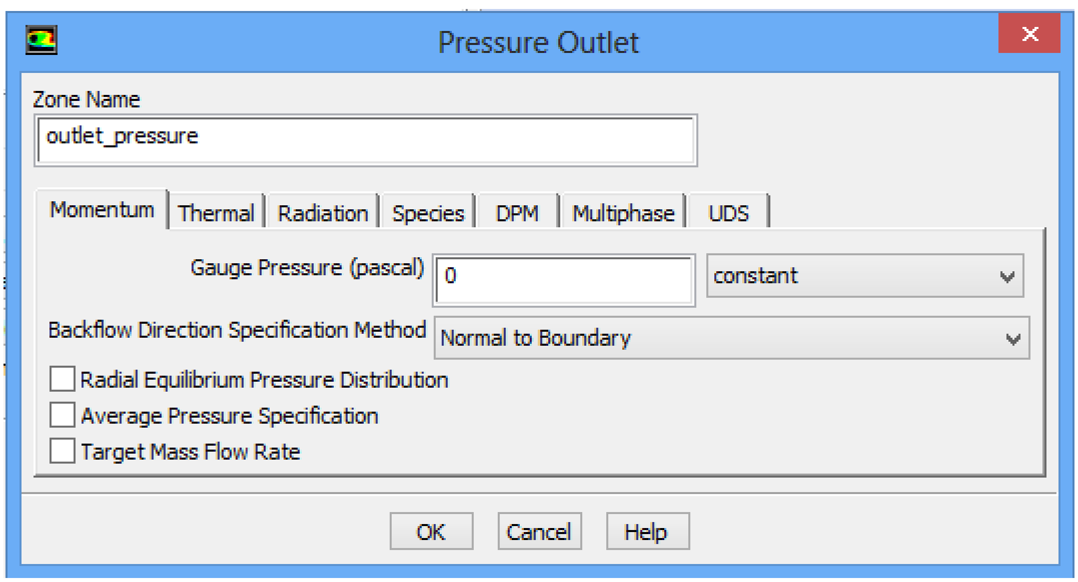

Fig. (4.8): pressure outlet

The same method is applied for Inlet and Outlet. Near Side is set as Symmetry. Wing Surface and Wing tip is set as Wall.

4.9 Solution Stages

After assigning the material properties to the model, the solution stage of the simulation begins. In this solution stage, the solution methods, solution controls, monitors, solution initialization and running of the solution are done.

4.10 Solution Methods & Solution Controls

In solution methods the scheme is set to simple type and the pressure and momentum is set to second order upwind option. The high order term Relaxation options were selected to get fast convergence as possible as shown in Fig. (4.9).

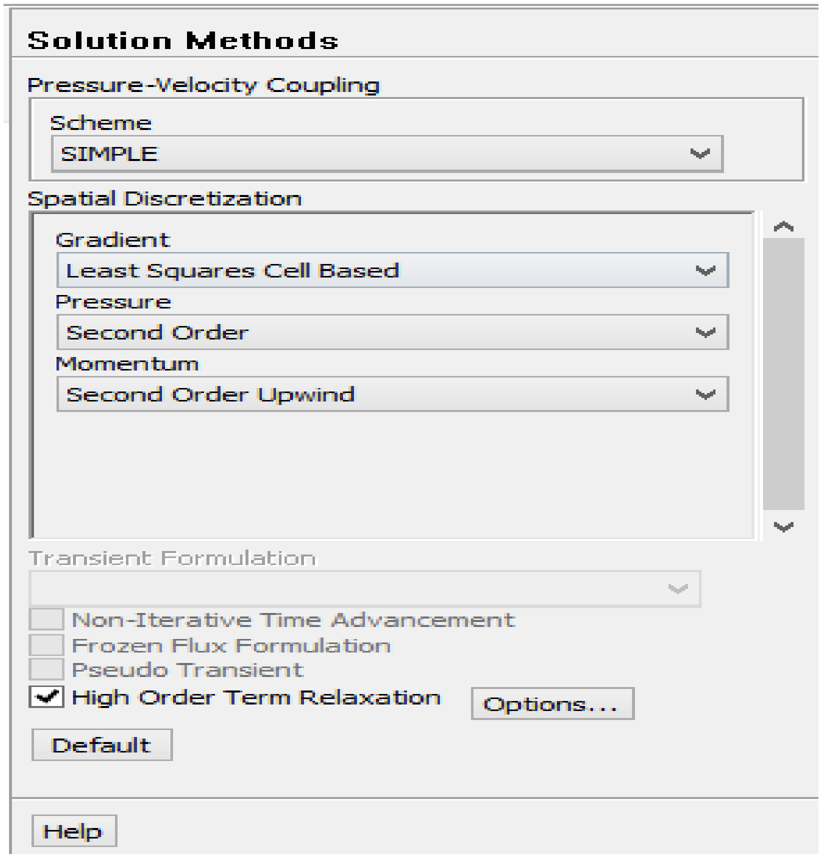

Fig. (4.9): Solution Methods

4.11 Monitors

In the monitors' panel create three monitor plots for Residuals, lift coefficient and drag coefficient. Then for each monitor set the required settings as shown in Fig (4.10). For the lift & drag monitor click on create and then select print to console, plot and write options. Also select surrounding wall zone.

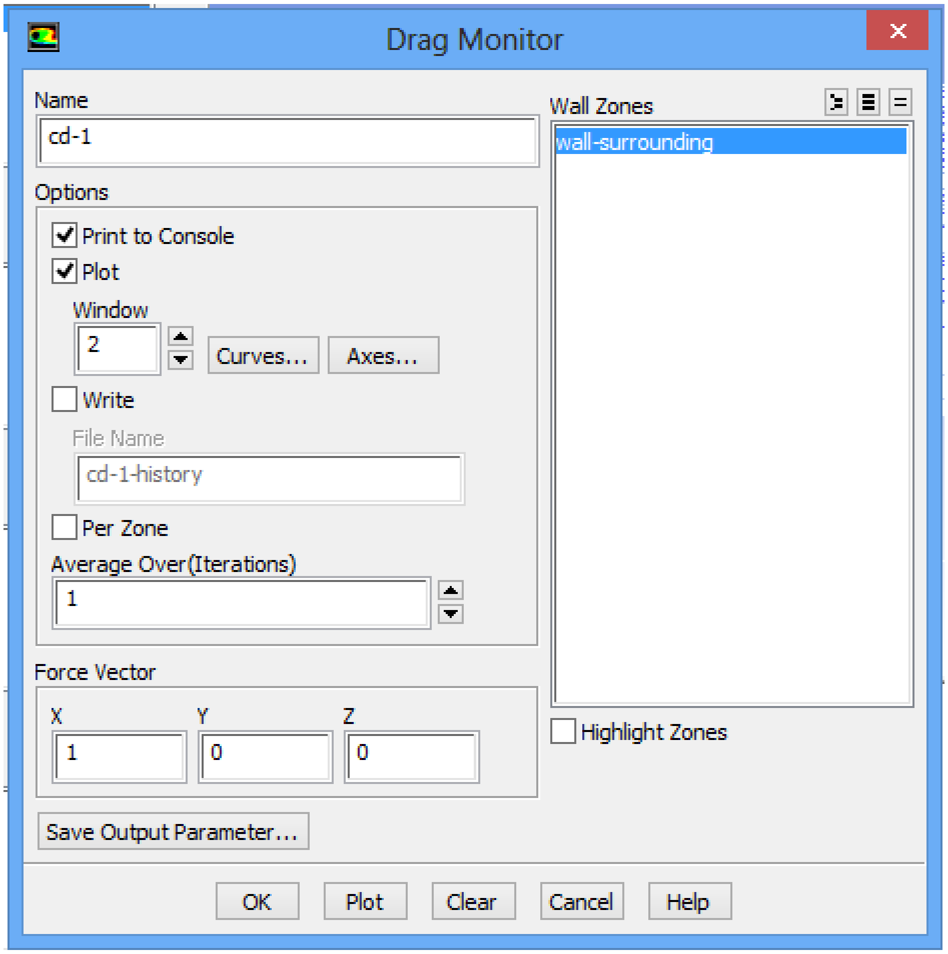

Fig. (4.10): Drag Coefficient

4.12 Solution Initialization

In solution initialization as shown in Fig. (4.11), there are two initialization methods which are Hybrid Initialization and Standard Initialization. Standard Initialization is selected and the inlet is used to compute from it.

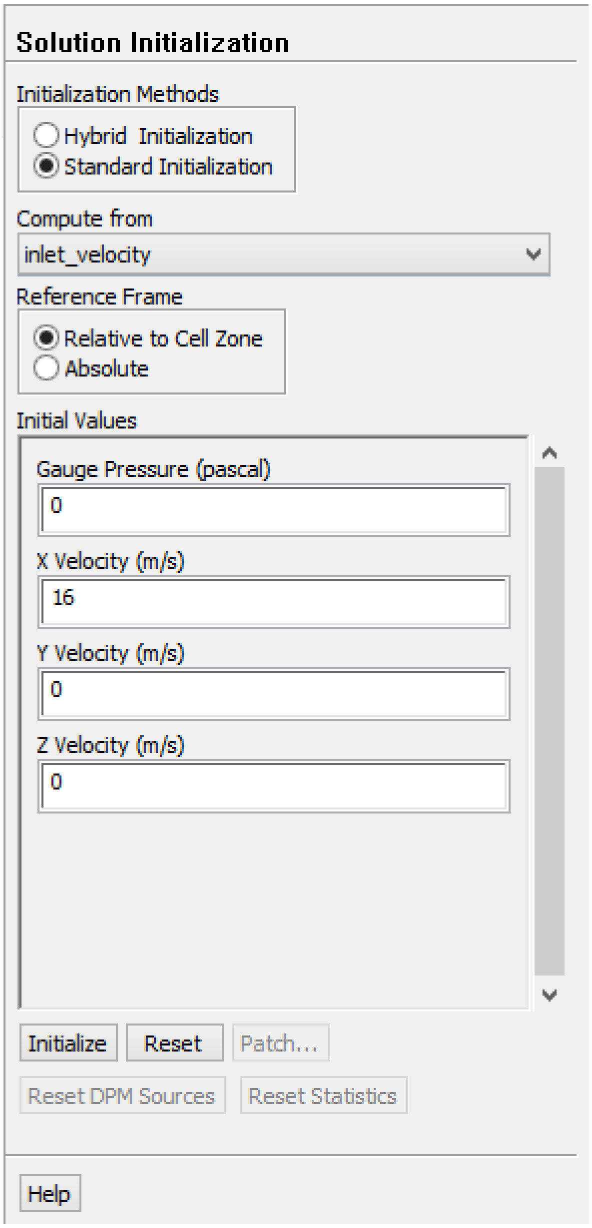

Fig. (4.11): Solution Initialization

4.13 Run Calculation

In run calculation monitor set the number of iterations to (350) and give the value for the auto save option as (1) and then click on calculate.

Chapter Five

Results & Discussions

5.1 Introduction

The conceptual design is used to calculate the geometry of the aircraft. The fluid flow analysis over the wing is conducted at different angle of attacks ranging from (0°–20°) and C_L, C_D. It is observed that solution converges at different iterations for different angle of attack of the model.

5.2 Design results

❖ General specification

General specification is given are basic performance parameters as showing in Table (5-1).

Table (5-1): general specifications

Geometry	Value
Total weight (kg)	**2.00**
Cruise Speed (m/s)	**16.0**
Thrust / weight ratio	**1.30**
Centre of gravity *from wing leading edge (m)*	***0.06***

❖ Wing parameters

By using equations in chapter 3, wing geometry is obtained as showing in Table (5-2).

Table (5-2): wing geometry

Geometry	Description
Airfoil type	**NACA 2412**
area (m^2)	**0.16**
span (m)	**1.00**
Chord root (m)	**0.18**
Chord tip (m)	**0.14**
Taper ratio	**0.78**
MAC wing (m)	**0.16**
Aspect ratio	**6.25**

❖ Horizontal tail parameters

By using equations in chapter 3, the horizontal geometry tail is obtained as showing in Table (5-3).

Table (5-3): Horizontal tail geometry

Geometry	Value
Airfoil type	NACA 0012
area (m^2)	0.032
span (m)	0.320
Chord (m)	0.100
Aspect ratio	3.200

❖ Vertical tail parameters

By using equations in chapter 3, the vertical tail is obtained as Showing in Table (5-4).

Table (5-4): Vertical tail geometry

Geometry	Value
Airfoil type	NACA 0012
area (m^2)	0.017
span (m)	0.180
Chord root (m)	0.130
Chord tip (m)	0.081
Taper ratio	0.450
Aspect ratio	1.910

❖ Aileron parameters

By using equations in chapter 3, the Aileron geometry is obtained as showing in Table (5-5).

Table (5-5): Aileron geometry

Geometry	Value
span (m)	0.500
Chord (m)	0.045

❖ Elevator parameters

By using equations in chapter 3, the Elevator geometry is obtained as showing in Table (5-6).

Table (5-6): Elevator geometry

Geometry	Value
span (m)	0.288
Chord (m)	0.035

❖ Rudder parameters

By using equations in chapter 3, the Rudder geometry is obtained as showing in Table (5-7).

Table (5-7): Rudder geometry

Geometry	Value
span (m)	0.162
Chord (m)	0.045

❖ Fuselage parameters

By using Fig. 2.3 and Fig. 3.3, the fuselage size is obtained, as showing in Table (5-8).

Table (5-8): Fuselage geometry

Geometry	Value
Total length (m)	0.750
Nose length (m)	0.270
Wing length (m)	0.180
Boom length (m)	0.360
Height (m)	0.100
Width (m)	0.080

❖ Tri-copter design

By using Fig (3.5) in chapter 3, the fuselage size is obtained as showing in Table (5-9).

Table (5-9): Tri-copter geometry

Geometry	Value
Distance between front motor (m)	0.210
Rear motor distance from leading edge (m)	0.060

5.3 Simulation results

The simulation was run in specified condition as given in

Table (5-10): Full-scale flight conditions

Characteristic	Value
Mach	0.0432
Angle of attack	0°-5°-10°-15°-20°
Air properties	Standard
Re	$1.97 * 10^5$

The following figures show the Residual plot, C_L &C_D of Converged solution at (0°).

❖ Lift coefficient vs iteration

Fig. (5.1) illustrate the relation between the lift coefficient and the iteration. The value of lift coefficient is begin with 0.014 and decrease with the increase in iteration with small divergence until 200 iteration. After it the value of lift coefficient remains same.

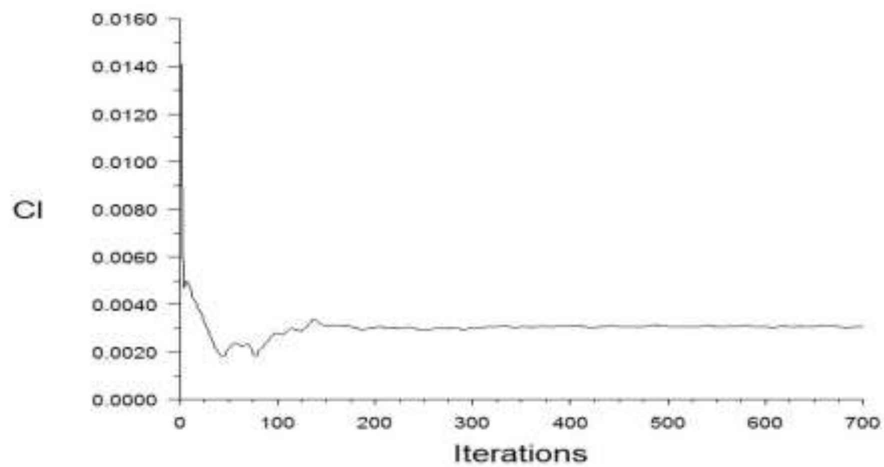

Fig. (5.1): Convergence history of lift coefficient at (0°)

❖ Drag coefficient vs iteration

Fig. (5.2) illustrate the relation between the drag coefficient and the iteration. The value of drag coefficient is begin with 0.07 and decrease with the increase in iteration with small divergence until 200 iteration. After it the value of drag coefficient remains same.

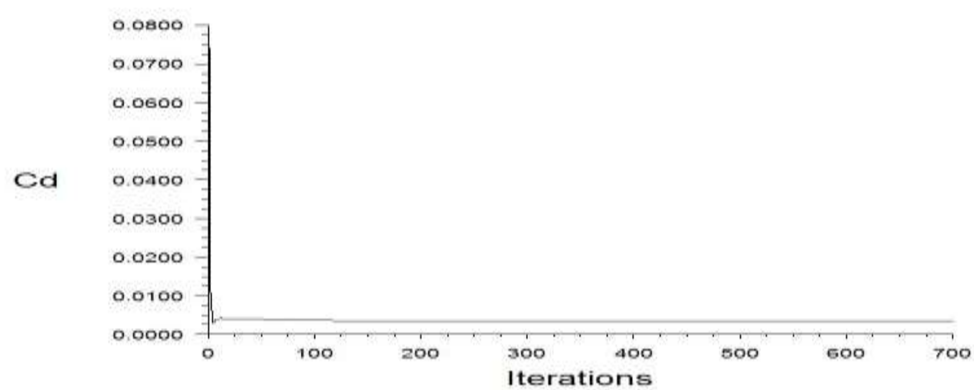

Fig. (5.2): Convergence history of drag coefficient at (0°)

❖ Residual vs iteration

Fig. (5.3) illustrate the relation between the residual and the iteration. The value of residuals is begin with high value and decrease with the increase in iteration with small divergence until 200 iteration. After it the value of lift coefficient remains same.

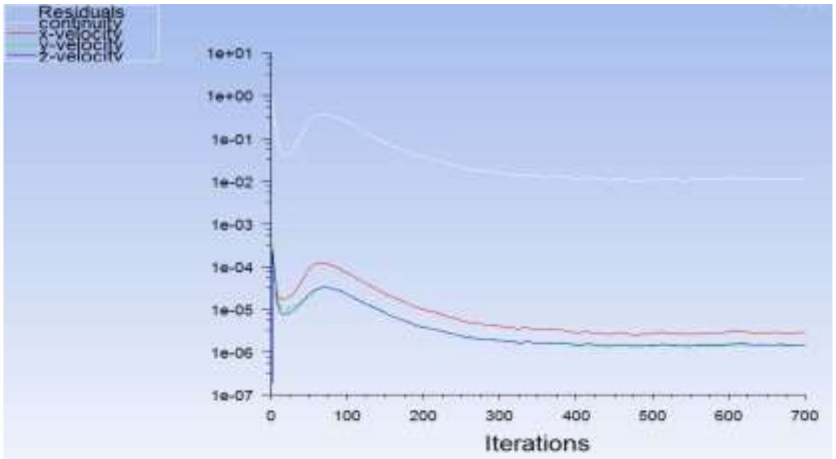

Fig. (5.3): Residuals convergence at (0°)

❖ Pressure contour

Fig. (5.4) illustrate the pressure contour. There are three colors in this figure .Yellow color represent atmospheric pressure region. Red color represent high pressure region. Blue color represent the pressure is low.

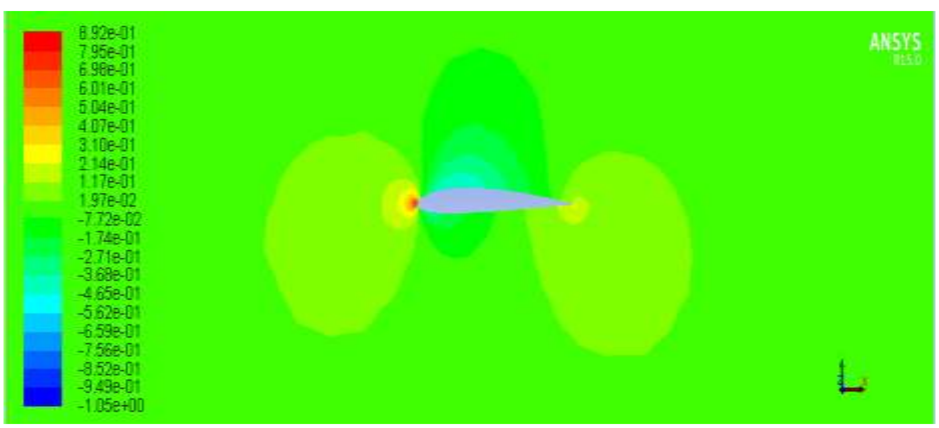

Fig. (5.4): pressure contour at (0°)

❖ Velocity contour

Fig. (5.4) illustrate the velocity contour .There are three colors in figure. In Yellow color, the velocity is equal to free stream velocity. Red color represent the velocity is big than free stream velocity. Blue color represent the velocity is too low.

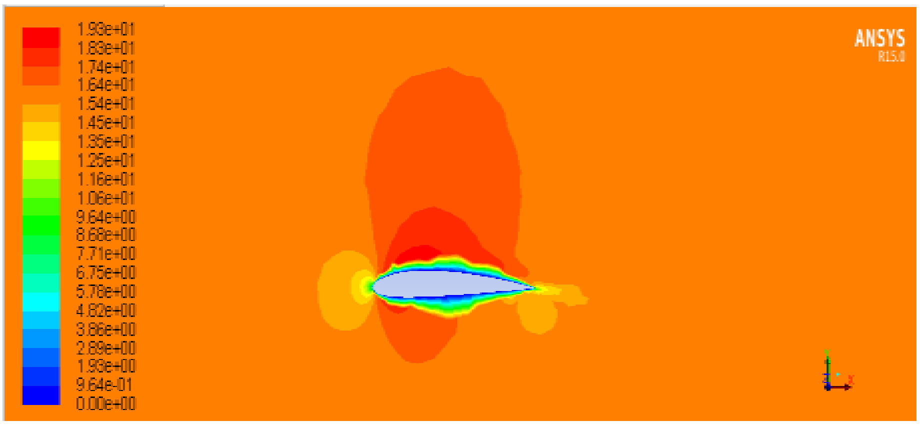

Fig. (5.5): velocity contour at (0°)

To know the effect of angle of attack on lift coefficient and the drag coefficient, the simulation was done at different angles of attack and the results is plotted using Matlab software as in figure below:-

❖ Lift coefficient vs angles of attack

Fig. (5.6) illustrates the relation between the lift coefficient and the angle of attack. The value of lift coefficient is begins with 0.003 at **(0°)** and increase with the increase in the angle of attack until 15. After this angle the value of lift coefficient deceases.

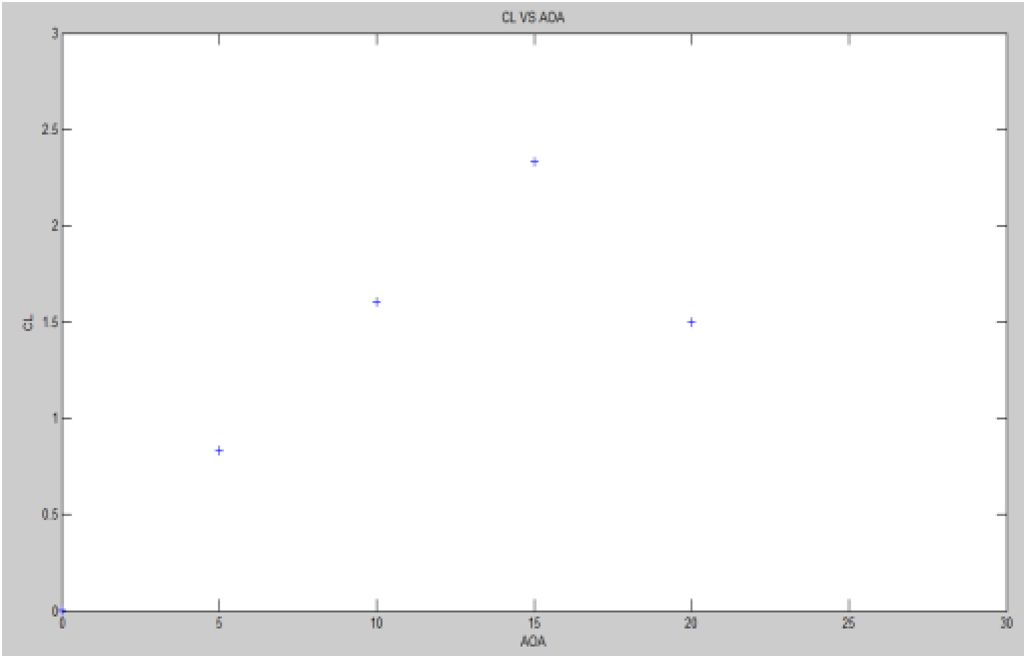

Fig. (5.6): lift coefficient vs angles of attack

❖ Drag coefficient vs angles of attack

Fig. (5.7) illustrate the relation between the drag coefficient and the iteration. The value of drag coefficient is begins with 0.003 at **(0°)** and increase with the increase in the angle of attack until 20.

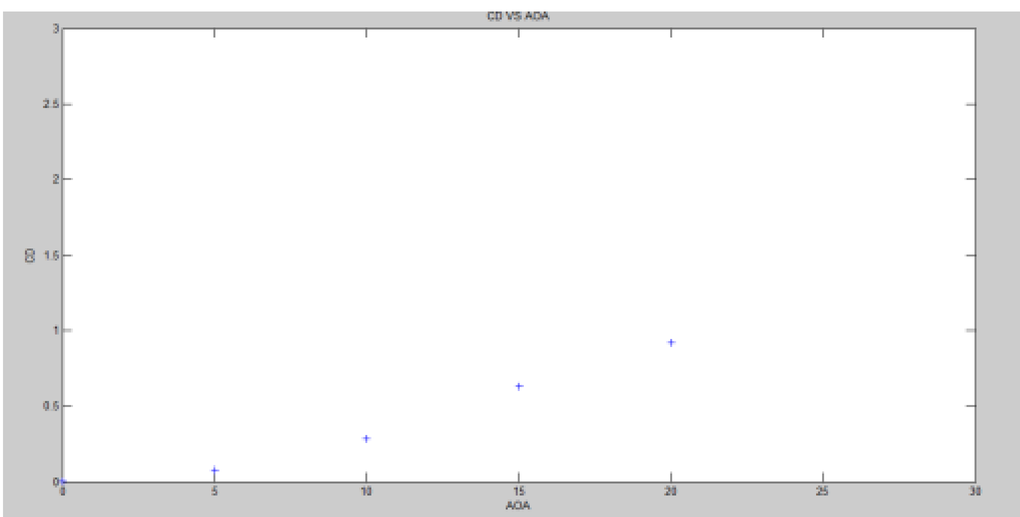

Fig. (5.7): Drag coefficient vs angles of attack

Chapter Six

Conclusion & Future Scope

6.1 Conclusion

This Thesis discusses how to Design and analysis of VTOL aircraft. After Fixed wing tri-copter aircraft was designed, the general geometry was drawn using CATIA V5R20 software as showing in Fig. 6.1

Fig. (6.1): aircraft final geometry

The wing of the aircraft was analyzed using Ansys program to ensure it fly safe. The lift and drag coefficients are calculated over a range of angles of attack (5°-20°). The results lend into the choice of best angles of attack (5°)) and the range at which the aircraft must fly (5°-15°).

6.2 Future scope

1. Analyze the whole aircraft in Ansys program to study the aerodynamic characteristics.
2. Analyze aircraft structure in Nastran program.
3. Studying stability of this aircraft.
4. Study the effect of the gust loads on UAV performance.
5. Test the aircraft in wind tunnel.
6. Design the electric components for the aircraft.
7. Fabricate the aircraft.

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