DESIGN AND FABRICATION OF SMALL SCALE TRAINER AIRCRAFT

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DESIGN AND FABRICATION OF SMALL SCALE TRAINER AIRCRAFT

ARUNAN S/O SIWARAJU

Report submitted in partial fulfillment of the
requirements for the award of the degree of
Bachelor of Mechanical Engineering

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DECEMBER, 2010

SUPERVISOR DECLARATION

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I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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I specially dedicate to my parents and
those who have guided and
movitated me for this project.

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ABSTRACT

This is a study on the designing of small scale trainer aircraft by using balsa wood and plywood. The objective of this paper is to design and fabricate small scale trainer aircraft that will avoid crash landing by using an aerial drop modules technology such as parachute, anti-crash servo and night mode kits for night flying. Based on the design, we can measure it weight and it is to be 2.83 kg and wing span of 1.5 m. The existing small scale trainer aircraft available in market is subject to crash landing due to pilot at ground unable to control the aircraft. Besides that, flying the radio controlled at evening is common and preferred by most of the instructor. For more challenging and fun fly, night mode will give more added challenge and experience. Hence, to avoid crash landing, parachute will be used and night mode kits will be installed. In terms of design, I preferred to choose glow engine powered trainer aircraft compared to aircraft powered by motor due to high power. This aircraft is designed based on Federal Aviation Regulations (FAR). Little early assumption with project scope to be followed will help to design complete structure of the trainer aircraft over the two semesters. This report consists of full details on designing the aircraft to get the parameters that involved in the entire project.

ABSTRAK

Projek ini adalah mengenai proses yang terlibat dalam menganggarkan reka bentuk konseptual dan pensaizan pesawat kecil yang baru. Pesawat ini digunakan bagi tujuan pembelajaran bagi para penerbang sebelum didedahkan dengan pesawat sebenar yang lebih besar dan kompleks. Pesawat kecil ini dikemudikan dengan alat kawal jauh. Pesawat ini menggunakan payung terjun sebagai alat untuk mengelakkan pesawat daripada jatuh menjunam dan turut dilengkapi dengan lampu untuk diterbangkan pada waktu malam. Berdasarkan reka bentuknya, kita dapat menganggarkan berat pesawat adalah 2.83 kg dan panjang sayap berukuran 1.5 m. Kebanyakkan model yang terdapat di pasaran boleh jatuh terbabas ketika pendaratan kerana juruterbang tidak dapat mengawal pesawat dengan baik. Bagi mengelakkan situasi ini, pesawat kawalan jauh ini dilengkapi dengan payung terjun. Bagi tujuan menambahkan dayatujahan yang tinggi, pesawat ini dilengkapi dengan enjin menggunakan bahan api nitromethane. Pesawat ini direka bentuk berdasarkan syarat-syarat pensaizan yang ditetapkan oleh Persekutan Peraturan Penerbangan (FAR). Berdasarkan beberapa andaian awal, pesawat ini di reka bentuk dalam masa 2 semester. Laporan ini menyediakan nilai-nilai penting yang telah dianalisis bagi merekabentuk sesebuah pesawat terbang.

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LIST OF SYMBOLS

R	Range
E	Endurance
S_{TO}	Takeoff Distance
S_L	Landing Distance
h	Altitude
V_{ltr}	Loiter Speed
V_{cr}	Cruise Speed
m	Meter
kg	Kilogram
km/h	Kilometer per hour
%	Percentage
ft	feet
C_L	Lift Coefficient
lbs	Pound
W_e	Empty Weight
W_{to}	Takeoff Weight
L/D	Lift to Drag Ratio
c_p	Specific Fuel Consumption

η_p	Propeller efficiency
V_{cruise}	Speed sensitivity
λ	Taper Ratio
AR	Aspect Ratio
b_H	Span of horizontal stabilizer
C_O	Chord length
C_{mean}	Mean aerodynamic centre of the wing
Y_{mean}	Aerodynamic centre of the wing
C_{DO}	Zero angle of attack drag coefficient
C_L	Lift coefficient
$C_{L,max}$	Maximum lift coefficient
C_m	Airfoil section moment coefficient
b	Wing span
C_{root}	Root chord length
C_{tip}	Tip chord length
e	Oswald span efficiency factor

kts	Knots
P	Power
S	Main wing planform area
S_H	Horizontal stabilizer planform area
S_V	Vertical stabilizer planform area
v_{cr}	Cruise velocity
V_{HT}	Volume coefficient of horizontal stabilizer
V_{VT}	Volume coefficeint of vertical stabilizer
V_s	Stall velocity
W	Weight
$W_{payload}$	Payload weight
W_{fuel}	Fuel weight
λ_H	Taper ratio of horizontal stabilizer
α	Angle of attack
λ_v	Taper ratio of vertical stabilizer
η_P	Propeller efficiency

η_S	Horizontal stabilizer efficiency
$C_{elevator}$	Chord length of elevator
b_{rudder}	Span of rudder
D	Neutral point
A	Area
x_o	Neutral point
x_l	Centre of gravity

LIST OF ABBREVIATIONS

RC	Radio Controlled
RTF	Ready to Fly
GHz	Gigahertz
LED	Light Emitting Diode
NASA	National Aeronautics and Space Administration
CP	Centre of Pressure
RPM	Revolution per Minutes
STOL	Short takeoff and landing
MAC	Mean Aerodynamic Centre
FAR	Federal Aviation Regulations
AC	Aerodynamic Centre
SFC	Specific Fuel Consumption
CGR	Climb Gradient
MAC	Mean Aerodynamic Centre
AEO	All Engine Operating
CG	Centre of gravity

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CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Over a century, trainer aircraft is widely used in training to develop piloting, navigational or war fighting skills in flight crew. New pilots are normally trained in a light aircraft, with two or more seats for students and instructors. Trainer aircraft is commonly used for training in flying as well in military bases. The study combines both theoretical and practical knowledge which at the end of the project, a small scale radio controlled aircraft will be manufactured (Cho, 2004).

A radio control small scale aircraft is an aircraft that is controlled remotely with a hand held controller consisting of transmitter and receiver. The receiver controls the corresponding servos that move the control surfaces based on the position of the joysticks on the transmitter which in turn affect the orientation of the aircraft.

From the studies on design of an aircraft, the theoretical aspect drawn from the topics of aircraft aerodynamic, aircraft structures, aircraft stability and control with the propulsion can be applied to produce a new concept of aircraft design. From the beginning, complete design followed by analysis and fabrication will be done. This will be accomplished over two semesters. The study deals with the steps involved in the conceptual design and preliminary design in the first phase. In the second phase, detail design, analysis and fabrication will be given an importance.

In this project, two parameters were given importance that is critical performance parameters and requirements parameters. Critical parameters consist of determination of weight of the aircraft, maximum lift coefficient, and lift to drag ratio, thrust to weight ratio and sizing of the aircraft. Requirement parameters consist of range, endurance, takeoff distance, landing distance, altitude, cruise speed and loiter speed.

1.2 PROBLEM STATEMENT

For trainer aircraft available nowadays is subject to crash landing. This is due to the human factors as the new pilot does not possess good skills in handling and controlling the aircraft. Military statistic shows that there is an accident involving in each training session conducted by the new pilot and the trainer aircraft subject to crash landing. Hence, the cost of training increases. In small scale radio controlled trainer aircraft, instructor from the ground unable to control the small scale trainer aircraft and is subjected to crash landing. Implementations of new technologies are essential in order to overcome these limitations.

1.3 PROJECT OBJECTIVE

The objective of the project is to design and fabricate a small scale trainer aircraft with capability of avoiding crash landing by introducing an aerial drop modules technology.

1.4 PROJECT SCOPES

To complete the model of small scale trainer aircraft, it requires precise studies and project scope to be followed. Unique scopes of work determined to achieve the goals of the project are:

- By using the knowledge of conceptual design, preliminary design and detail design to design a small scale trainer aircraft.
- Fabrication of small scale trainer aircraft based on the design specification.
- Improve the safety of flight by using an aerial drop modules technology.
- To improve the quality of night flying by having a night mode kits.

- Flight test of the manufactured model.

1.5 PROJECT ASSUMPTIONS

For this project, the requirement parameters are subjected to early assumptions for designing a small scale trainer aircraft.

Range, R : 50 meter radius
Endurance, E : 20 minutes
Take off Distance, S_{TO} : <30 m
Landing Distance, S_L : 10 m
Altitude, h : 1000 ft
Cruise Speed, V_{cr} : >40 km/h
Loiter speed, V_{ltr} : <25 km/h

1.6 TECHNICAL TASK

1.6.1 Introduction

Radio controlled aircrafts are built to meet the requirement parameters. Basically radio controlled aircraft are designed to make learning as easy as possible and have the basic characteristics. Radio controlled aircraft need to be stable, able to fly straight on level and has high lift. There are two types of radio controlled aircraft that is electric RC using motor and gas RC using gasoline fuel. Before a designer starts to design an aircraft, requirement parameters or performance parameters need to be decided. For this project, the weight of the aircraft is light in average of 3 kg and compatible to weather conditions. For this project, the range is 50 meter radius, endurance of 20 minutes, take off distance less than 25 m, landing distance of 20 m, altitude of 150 m, cruise speed in between 50 km/h to 60 km/h and loiter speed of 40 km/h. Once the designer had set the technical task, the small scale trainer aircraft is build based on the assumption that has been justified. There are few types of radio controlled aircraft such as trainer aircraft, sport aircraft, aerobatic aircraft, war birds, vintage aircraft and float aircraft. In this project, the type of the small scale aircraft will be a trainer aircraft.

1.6.2 Standard Requirements

In designing the small scale trainer aircraft, understanding of basic knowledge in science of aeronautical engineering is important to design a small scale trainer aircraft that meets the requirements parameter. Basically, the major concern of this project is to design and to fabricate a small scale trainer aircraft. Technically, stages of the design include conceptual design, preliminary design and detail design to be followed.

As to target the productivity, capability, cost, power, speed and distance of the small scale trainer aircraft need to be studied. In terms of design, user's safety and also stability especially for the wing and weight distribution of the aircraft need to be justified. To achieve this, certain standard requirements stages need to be followed. Hence, to calculate certain parameters, detail analyses through the computer simulation or manual iterations need to be carried out.

1.6.3 Performance Parameters

Performance parameter is set by the designer. The designer has determined the performance of RC aircraft. The design of a small scale trainer aircraft should meet the specified parameters:

1.6.3.1 Range – 50 meter radius

For a small scale trainer aircraft, the selection of range depends on type of a radio controller transmitter we are using. Basically, 2.4GHz frequency radio controlled will be used. The range needs to be covered in sense of fuel consumption of an engine and also the safety of the aircraft. If the aircraft is out of the range then the aircraft will subjected to crash landing. Range of 2.4GHz is 3000feet. Therefore, range of football size field is targeted.

1.6.3.2 Endurance – 20 minutes

Endurance is the amount of time that an aircraft can stay in the air. Most of the small scale aircraft required time of flight between 15 minutes up to 30 minutes depends on types of engine that been used. Endurance depends on fuel consumption. For this project, 20 minutes has been chosen. Refer to figure 1.8 for the time fraction details.

1.6.3.3 Take off Distance – 25 meter

Take off distance is how much does the aircraft cover along the runway before it lifts into the air. Basically for the current small scale aircraft, take off distance is in range of the 10m < Sto < 50m. The aim of this project is to achieve take off distance less than 25m. Take off distance depends on the airfoil shape, weight of the aircraft and the size of the gasoline engine used.

1.6.3.4 Landing Distance - 10 meter

Landing distance is the distance that an aircraft rolls on the ground from touchdown to the point where the velocity goes to zero. The appropriate landing is important to avoid crash landing. For this project, the aim is to achieve landing distance less than 10 meters. This can be achieved by using a parachute to reduce the impact of the landing.

1.6.3.5 Altitude – 1000 ft

For an adequate distance for the parachute to work in optimize condition, altitude of range in 1000ft < h < 3000ft is used. For this project, the best altitude will be as minimal as possible but high enough for the parachute to work. In this case, altitude of 1000 ft is appropriate since the aircraft is visible to controller on the ground.

1.6.4 Technical Level of Trainer Aircraft

Based on the literature review and technical views, gasoline fuel aircraft is the best to be designed due to the efficiency and versatility. It is also important to make sure that the aircraft is easier to be control by pilot on the ground. The concept of this design is modeled after the Alpha 40 RTF and EZ Trainer nitro plane, which available in the market. The trainer aircraft is designed with straight wing with zero angle of attack and no dihedral angle to allow the increasing speed of the trainer aircraft. The target is to build a sporty small scale trainer aircraft that could perform an aerobatic.

In this project, the trainer aircraft is assumed to fly for 20 minutes and land to the ground without crashing by using the parachute. It could fly to maximum level of 1000 feet in 3 minutes, loiter approximately 3 minutes and land within the distance of 10 meter in 30 seconds. The trainer aircraft happens to crash landing because the pilot unable to land safely. Hence, parachute is introduced to help the instructor from the ground to land within the 10 meter with prepared runway surface to avoid any damaged to the landing gear.

1.6.4.1 Economical Parameters

Added systems such as an aerial drop module and night mode LED will increase the cost of the productivity. For the trainer aircraft with higher flight performance, the cost factors can be ignored. But for this project, there is a continuous research to minimize the cost and to make the aircraft works in optimum performance. Typically, if the aircraft has low running costs, it will reduced the maintenance costs and favorable for everyone to use it. The aircraft was designed so that it can perform an aerobatic and avoid crash landing. It should satisfy the mission profile as shown in Figure 1.8 below. Basically, the trainer aircraft was built with high wing and Clark Y airfoil shape. It is a recommended aircraft for beginner. Trainer aircrafts has low stall speed which is to level it back on a straight line and generate enough lift to fly. This trainer aircraft named MC Trainer could perform as referred model such as EZ Trainer nitro biplane and Alpha 40 RTF.

1.6.4.2 Power Plant Requirements

The selection of an aircraft power plants is crucial because importance to the design of the aircraft according to the technical task and required parameters. Engine selection is important because it will effects the performance, emissions, fuel consumption and mission range of the trainer aircraft. The selection is also based on the cost and maintenance of the engine.

Engine selection was chosen varies from 40 horsepower to 46 horsepower. It is suitable for a small scale trainer aircraft. Types of an engine will be either gasoline engines or glow engines. Selection of an engine will help to achieve the mission profile.

1.6.4.3 Special Systems

To avoid crash landing and for night mode fly, special systems is required. For MC Trainer, it will be equipped with an aerial drop module system that is parachute and night mode LED. The aircraft is visible to pilot on ground for night fly. Parachute helps to reduce the impact on ground while landing hence it will avoid the aircraft from crashing. The specification of night mode LED and the types of parachute will be discussed in literature review.

1.6.4.4 Reliability and Maintainability

Small scale trainer aircraft is reliable when it has high probability to perform as EZ Trainer nitro biplane and Alpha 40 RTF. The design should have the ability to avoid parts failure. It is important to perform its mission without failure. Reliability of the aircraft must be 100% for the operation to achieve its mission. The design should meet the FAR 23 requirement. The aircraft is optimized to avoid any design failure that affects the safety of the instructor and the aircraft.

The aircraft also need to have high maintainability. The parts are easy to maintain and the parts is available when required for a change. Maintainability is measured in terms of how long the trainer aircraft takes to be service the system or

Mean Time to repair in hours. For MC Trainer, the maintainability is very low due to the less consumption of time for maintenances.

1.6.4.5 Unification Level

The projects begin with the conceptual design. At early phase of the design, it need to meet the seven intellectual pivot points consists of requirements, weight of the aircraft, critical performance parameters configuration layout, better weight estimation, performance analysis and optimization. The selection of the wing was straight wing or tapered wing. Besides that, the selection of an airfoil is very important. The selection will be either Clark Y or NASA. Most of the trainer aircraft available in market used Clark Y flat bottom airfoil shape. The combination of all the configuration and characteristic above is used to design a small scale trainer aircraft based on the technical task, standard requirements and requirements parameter.

1.7 MISSION PROFILE

From the technical task requirements, a Mission Profile of the project design is drawn as Figure 1.8 as below:

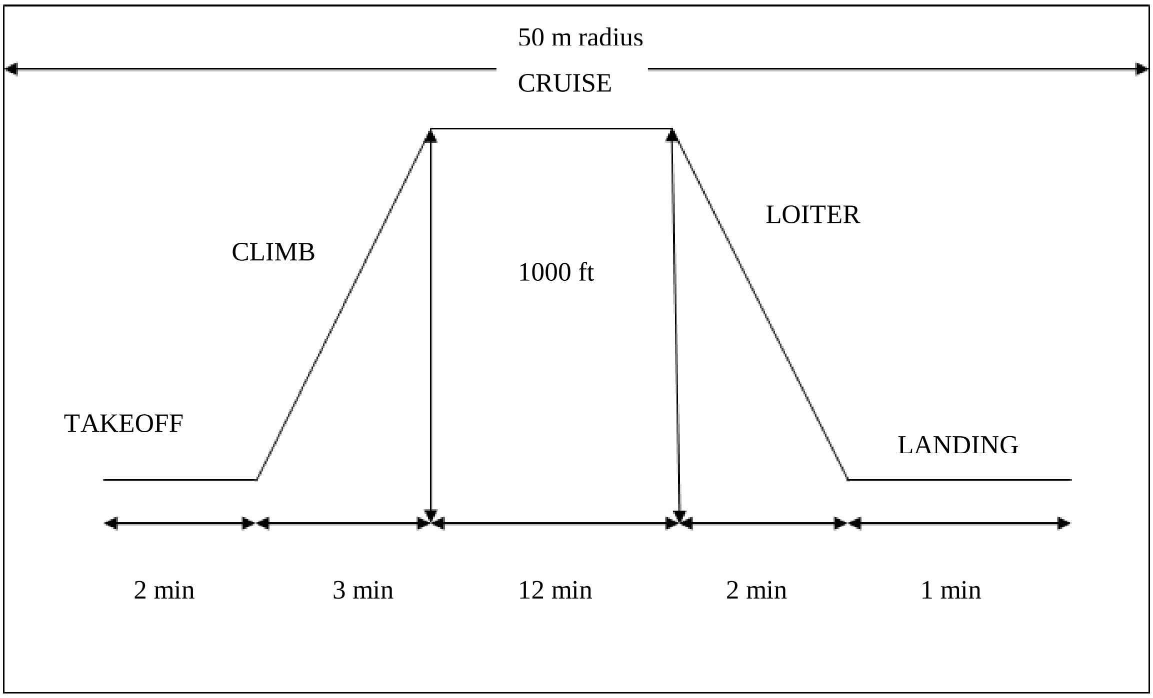


Figure 1.8: Finalized Mission Profile for the project

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Radio controlled aircraft is a small scaled aircraft that can fly and can be controlled by using a remote control. Radio control is used with a hand-held transmitter and a receiver which is placed inside the fuselage of the aircraft. The receiver controls the corresponding servo mechanisms that moves the control surface based on the position of the joysticks on the transmitter, which in turn maneuvers the plane (Cho, 2004).

From the design's study based on my research, I am going to demonstrate how the theoretical aspects, drawn from the topics on an aircraft aerodynamics, an aircraft structure, the stability and control and propulsion system that can be applied to produce a new conceptual aircraft design, which is my own original design, named MC-1987 aircraft will be developed into a complete design step by step starting with the production of the wing, body and also an empennage. This will be accomplished within two semesters. This study deals with the steps involved in the making of a conceptual design of an aircraft. These consist of main wing design, an engine selection, remote control selection, structure design and material selection for the project. These elements are the most important parameters to produce an aircraft with good performance. In addition, I would like to thank my supervisor, Mr. Ahmad Basirul Subha Bin Alias for guiding me to design and fabricate the small scale trainer aircraft. I am very grateful for the guidance and the information he has provided to me to accomplish this final year project.

2.2 HISTORY OF AN AIRCRAFT MODELING

2.2.1 Model of an Aircraft

Revolution in modeling an aircraft begin in 1871 when a Frenchman known as Alphonso Penaud demonstrated his rubber powered airplane *"Planophore"* and flew as high as 131 feet. Wright brothers inspired by the helicopter toy model by Alphonso Penaud developed the powered aircraft. Wright brothers has developed Kitty Hawk in 1903 and formed model club in New York, 1907. The material selection for the basic design of body's aircraft was bamboo, basswood, tissue paper, pine and spruce. The 1920's to 1930's was called the *"Golden Age of Air Racing"*. At this period, full scale model was developed for the purpose of air racing where big prizes of money offered for the winner. The Granville brother of Massachusetts build a two seater biplane called the *"Gee Bee Model A*" (Bird, 2005).

Clinton DeSoto and Ross Bull had flew the first ever glider in radio-controlled flight exhibition. In 1933, the first gasoline powered model aircraft developed. Clinton DeSoto developed the simplest radio for single channel. In 1937, the twin brothers Bill and Walter Good developed first radio-controlled 2 channel model plane named *"Guff"*. The model is displayed at Smithsonian National Air and Space Museum in Washington.

2.2.2 Radio Control

The idea in radio control was developed by Nikola Testa. In 1898, Nikola Testa demonstrated a small boat which able to respond to the audience commands but eventually controlled by Nikola Testa where he interpreted the verbal requests and sending appropriate frequencies to tuned circuits inside the boat. Immediately, he was granted with US patent for his invention in November 8, 1898. The idea in radio control was developed by the Spanish engineer known as Leonardo Torres in 1903 (Carpenter, 2007). In 1904, Jack Kitchen launched "*Bat",* a Windermere steam launch controlled by using a radio control. In 1909, Gabet a French inventor invented *"Torpille Radio-Automatique"*. Development of radio control in an aircraft started by Archibald Low as a head of the RFC Experimental Works successfully used a radio control on an aircraft in 1917. In the 1930s, British developed the radio controlled *"Queen Bee"* and *"Queen Wasp"* an aircraft of higher performance trainer aircraft (Cho, 2004).

2.2.3 Industrial Control

Today the radio control is used in industry for such devices as overhead cranes and switchyard locomotives. Radio-controlled teleoperators are used for such purposes as inspections, and special vehicles for disarming of bombs. Some remotely-controlled devices are loosely called robots, but are more properly categorized as teleoperators since they do not operate autonomously, but only under control of a human operator.

2.2.4 Military applications in the Second World Wars

Radio control was further developed during a Second World War by Germans and used in number of missile projects. Their main target will be for a radio-controlled missile, glide bombs against ships. However at the end of the war the Luftwaffe having problems to attacks allied bombers, therefore they developed a number of radio-controlled anti-aircraft missiles. In 1944, the German Kriegsmarine operated FL-Boote; radio controlled motor boats filled with explosives to attack enemy shipping. Leading into the race are both British and US where they also started to develop radio controlled systems to avoid the huge anti-aircraft batteries set up by the Germans targets. US effort, *"Project Aphrodite"* proved to be far dangerous for its target in sense of radio-controlled systems. Radio control systems of this era were generally electromechanical in nature, using small metal "fingers" or "reeds" with different resonant frequencies each of which would operate one of a number of different relays when a particular frequency was received. The relays would in turn then activate various actuators acting on the control surfaces of the missile. The controller's radio transmitter would transmit the different frequencies in response to the movements of a control stick; these were typically on/off signals.

These systems were widely used until the 1960s, when the increasing use of solid state systems greatly simplified radio control. The electromechanical systems using reed relays were replaced by similar electronic ones, and the continued miniaturization of electronics allowed more signals, referred to as control systems to be packed into the same package. While early control systems might have two or three channels using amplitude modulation, modern systems include 20 or more using frequency modulation.

2.2.5 Modern applications and aerospace industries

Remote control military applications are typically not radio control in the direct sense, directly operating flight control surfaces and propulsion power settings, but instead take the form of instructions sent to a completely autonomous, computerized automatic pilot. Instead of a *"turn left"* signal that is applied until the aircraft is flying in the right direction, the system sends a single instruction that says *"flies to this point"*. Some of the most outstanding examples of remote radio control of a vehicle are the Mars Exploration Rovers such as Sojourner.

2.3 BASIC FORCES ACTING ON AN AIRCRAFT IN A STEADY FLIGHT

Generally, there are four forces acting on the aircraft that is lift, drag, thrust and weight. While in a steady-state flight, the attitude, direction and speed of the aircraft will remain constant until one or more of the basic forces changes in magnitude. In non accelerated flight the opposing forces are in equilibrium. Lift and thrust are considered as positive forces, while weight and drag are considered as negative forces, and the sum of the opposing forces is equal to zero. In other words, lift equals to weight and thrust equals to drag. When pressure is applied to the aircraft controls, one or more of the basic forces changes in magnitude and becomes greater than the opposing force, causing the aircraft to accelerate or move in the direction of the applied force. The forces acting on the aircraft is shown in figure 1.1 (Bird, 2005).

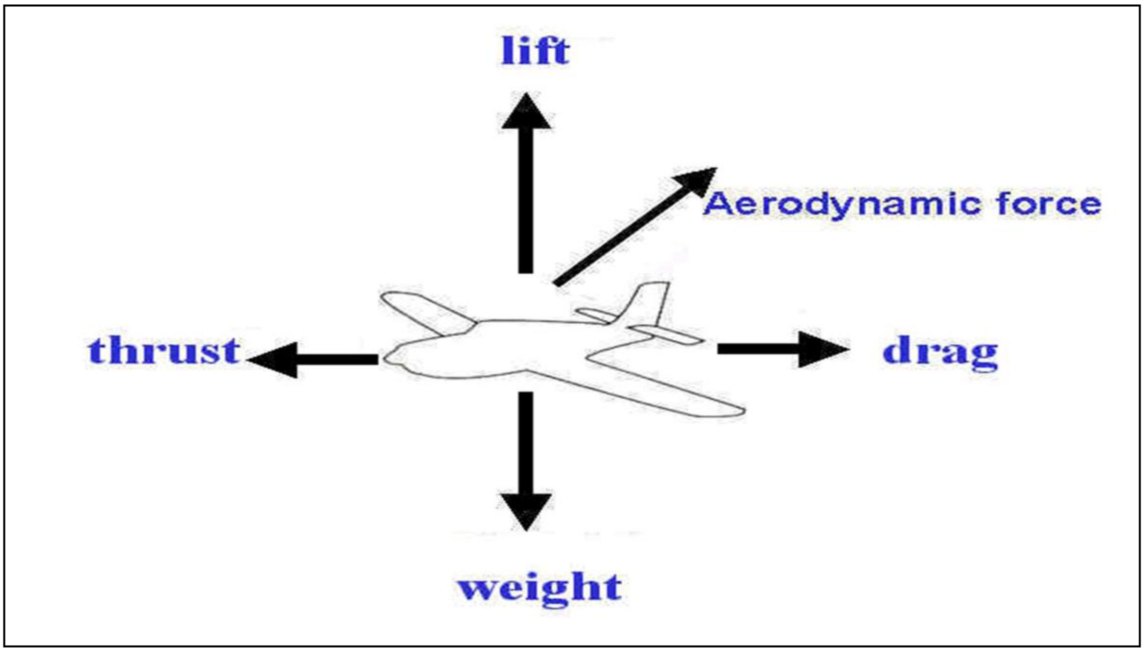


Figure 2.1: Basic forces acting on an aircraft in a steady flight

Source: http://www.rcaeronautics4dodos.com

2.3.1 Lift

This is the upward force that causes the aircraft to fly. Lift is created by the airfoil shape based on Bernoulli's Principle and Newton Third Law. The accelerating airflow over the top surface exerted less pressure than the airflow across the bottom. For every action there is an equal and opposite reaction. Hence, an additional upward force is generated as the lower surface of the wing deflects the air downward. Thus, both the development of low pressure above the wing and reaction to the force and direction of air as it is deflected from the wing's lower surface contribute to the total lift generated. The amount of lift generated depends on speed of the wing through the air, angle of attack, platform of the wing, wing area and the density of the air.

2.3.2 Thrust

This is the force that causes the aircraft to move forward. The propeller on the front of the aircraft spins and causes air to move over the wings. Thrust is changed by increasing or decreasing the speed of the throttle in the engine. The propeller is acting as an airfoil and produces the thrust that pushes the aircraft through the air. It receives its power directly from the engine and is designed to displace a large mass of air to the rear. It is the displacement of rear that developed the forward thrust that carries the aircraft through the air. This thrust must be strong enough to counteract the forces of drag and to give the aircraft the desired forward motion. The direction of this thrust force is referred to as the thrust line.

2.3.3 Drag

Drag is the rearward acting force which resists the forward movement of the aircraft through the air. Drag acts parallel to and in the same direction as the relative wind. Each part of the aircraft is exposed to the air while the aircraft is in motion producing some resistance and contributed to the total drag. Total drag consists of induced drag and parasite drag. Induced drag is the undesirable lift and increased in direct proportion to increase in angle of attack. The greater the angle of attack, the greater the amount of lift developed and the greater the induced drag. Parasite drag is the resistance of the air produced by any part of the aircraft that does not produce lift. Parasite drag can be divided into skin friction and interference drag. Skin friction drag is caused by air passing over the aircraft’s surfaces. Interference drag is caused by interference of the airflow between adjacent parts of the aircraft.

2.3.4 Weight

Gravity is the downward force which tends to draw all bodies vertically toward the centre of the earth. The aircraft’s center of gravity is the point on the aircraft where all the weight is considered to be concentrated. The center of gravity is located along the longitudinal centre line of the aircraft and near the centre of lift of the wing. The location of the centre of gravity depends upon the location and weight of the load placed in the aircraft. This is controlled through weight and balance calculation prior to flight. The exact location of the centre of gravity is important during flight, because it will effect on aircraft stability and flight performance.

2.4 MODEL AIRCRAFT ANATOMY

Anatomy of an aircraft consists of five major parts of fuselage, wings, stabilizers, flight control surfaces and landing gear. The motion of the aircraft is controlled by manipulating the control surfaces. Control surfaces are sections of the wing and tail that move, resulting in a change of airflow and forces. Every control surface operates on the same principle. According to Newton's third law, for every action, there is an equal and opposite reaction. If the airflow from any part of the aircraft is tilted downwards, the resulting opposite force will push that part upwards. By adjusting the amount of each force the glow fuel model aircraft is subjected to flight can be controlled. A typical small scale aircraft has all of the following features (Bird 2005).

2.4.1 Ailerons

These two control surfaces are movable sections of the main wing. By moving one of them aileron upwards and the other one downwards, the amount of lift produced by each side of the wing can be changed. Ailerons control the roll of the aircraft about its longitudinal axis. When used in conjunction with elevators, ailerons caused the aircraft to turn and are also used in all aerobatic maneuvers that require the aircraft to roll. Ailerons come in pairs and are found on the trailing edge of the wing. Figure 2.2 shows effect of aileron on roll motion:

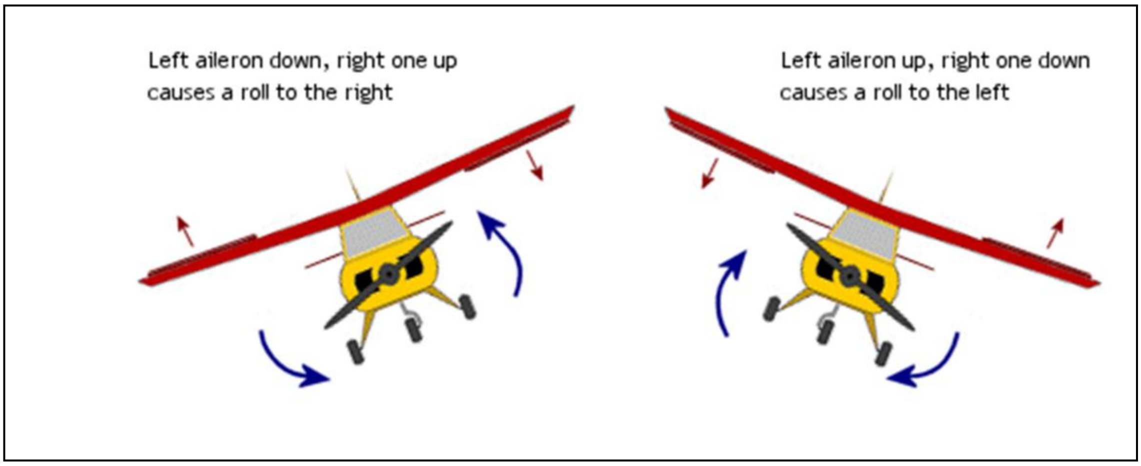


Figure 2.2: Effect of an aileron on a roll motion

Source: http://www.rc-airplane-world.com/rc-airplane-controls.html

2.4.2 Elevator

The elevator is a movable section of the horizontal stabilizer. The elevator is the hinged sections of the aircraft. An elevator controls the pitch motion of the aircraft. Elevator controls lateral motion of an aircraft. When elevators are in the up position, the nose of the airplane is forced to point upwards and the aircraft climbs. With the elevator down, the nose is forced downwards and the aircraft begins to dive. When the elevator is moved upwards, the airflow from the tail pushes the tail down, and the nose up. The opposite happens when the elevator is moved down. Figure 2.3 shows the effect of elevator on pitch motion:

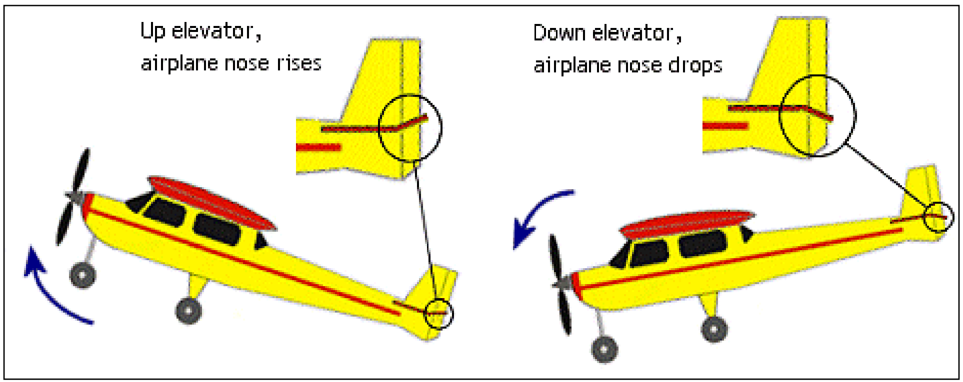


Figure 2.3: Effect of an elevator on a pitch motion

Source: http://www.rc-airplane-world.com/rc-airplane-controls.html

2.4.3 Rudder

The rudder is a movable section of the vertical stabilizer. By moving the rudder left or right, the horizontal direction of the nose can be changed. The rudder is the hinged section or vertical stabilizer of the aircraft. It is used for directional control by changing the yaw of the aircraft and works in the correct sense by moving the rudder to the left causes the aircraft to turn left and vice versa. Yaw is different to roll because when an aircraft yaws to the left or right because of rudder it remains more or less level. Rudder controls directional motion of an aircraft. Figure 2.4 shows effect of rudder on yaw motion.

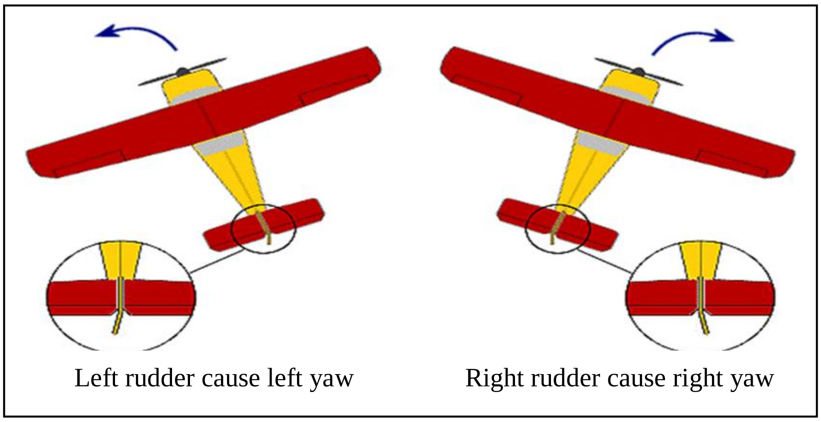


Figure 2.4: Effect of the rudder on a yaw motion

Source: http://www.rc-airplane-world.com/rc-airplane-controls.html

2.4.4 Throttle

Throttle controls the speed of the engine. In a nitro or glow plug, the throttle works the same as any internal combustion engine throttle by changing the amount of fuel and air that enters the combustion chamber of the engine. In the air, throttle not only controls the speed of the aircraft but also the rate of climb and descent. It is because different amounts of lift are generated at different airspeeds. Figure 2.5 shows axis of rotation of roll, yaw and pitch motion:

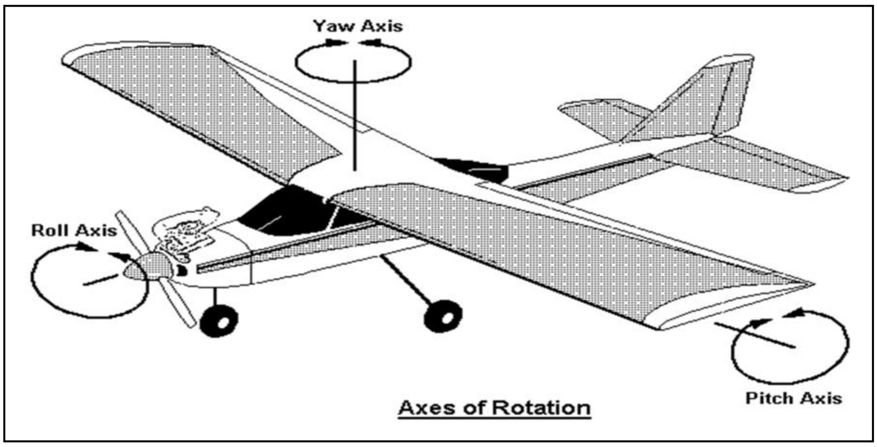


Figure 2.5: Axis of rotation of an aircraft

Sources: http://www.geistware.com/rcmodeling/articles/beginner_1/

2.4.5 Gasoline fuel engine

Gasoline fuel engine used to supply power for the aircraft. There are various types of gasoline engine depends on the size of the aircraft (Carpenter, 2007). For radio-controlled aircraft there are two primary choices of internal combustion engines. Glow that burns nitro methane fuel or gasoline fuel that is a mixture of gas and oil. Besides two stroke engine, there is also four stroke engine used for small scale trainer aircraft.

2.4.6 Fuselage

Fuselage is the main structure of the aircraft. Fuselage plays vital role in determination of centre of gravity and neutral point of the aircraft for the stability of the aircraft. Fuselage is normally long and very narrow body. Fuselage consists of nose, wing, tail and horizontal stabilizer. Nose is part of the fuselage. The nose is the front of the aircraft forward of the wings. This part of the aircraft is susceptible to damage in diving crashes. Main fuselage is the body of the aircraft. Wing is attached to the fuselage. Wings may be straight, curved, flat, rounded, elliptical or triangular. Tail is at the back end of the fuselage and the tail comes in many forms including conventional or T-tail, V-tail or flat tail. Figure 2.6 shows components of fuselage in the aircraft:

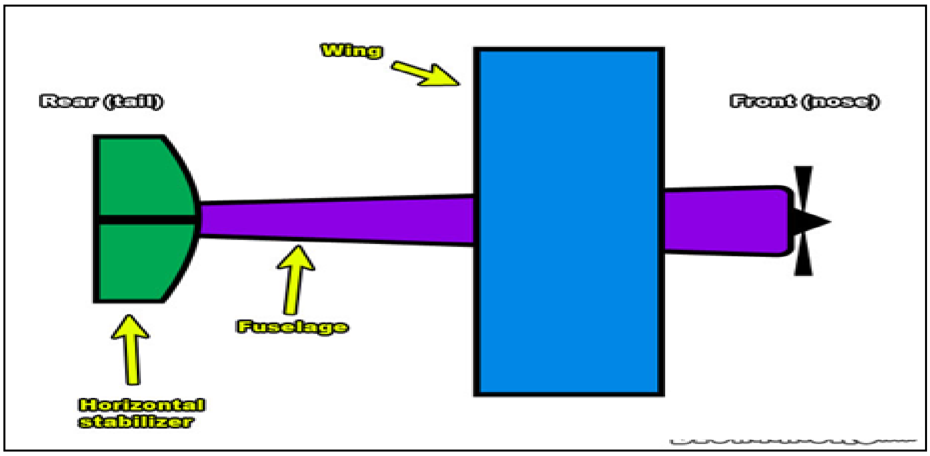


Figure 2.6: Components of the fuselage in the aircraft

Source: http://www.beginningrc.com/components/airplane-rc-fuselage-wings.php

2.4.7 Landing Gear

The structure and wheels support the aircraft on the ground as it takes off and lands. The two primary types of landing gear are the tail-dragger, with two wheels under the wing and a skid under the tail also known as tricycle, with two wheels under the wings and one under the nose.

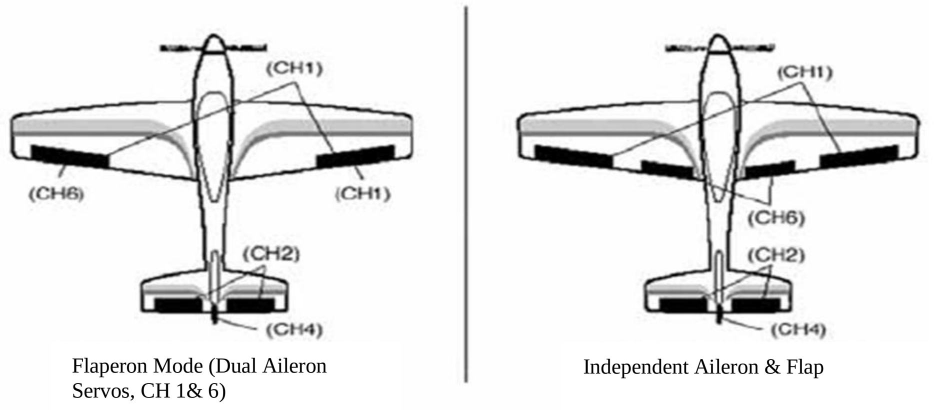
2.4.8 Pushrods

A pushrod is used to transfer motion from one device to another. In a radio control aircraft, a pushrod is used to transfer motion from a servo to a control surface, throttle, retractable landing gear, rudder and elevator. Almost all pushrods are reliable if properly constructed. The failure of any part will most likely cause the aircraft to crash. It should be obvious that the pushrod system must be carefully assembled and free from any defects. There few types of pushrods that is short pushrods, long pushrods, very long pushrods and tube-in-tube pushrods. The pushrods are under compression at the one end and tension in another end. At the compression, there is tendency for pushrods to fail if not properly installed.

2.5 RADIO CONTROL LED TRAINER AIRCRAFT

2.5.1 Radio Control

Radio control aircraft can be divided into two parts based on types of radio channels used and materials. Both this criteria will affect performance of flight. For radio channels, there is transmitter varies from 2 channels to 6 channels (Carpenter, 2007). Types of channels are important to control the throttle, elevator, aileron and rudder and to maintain the stability of the aircraft from crash landing. Radio control used for this project is 6 channels Futaba radio control. Each part is designed to carry out its own purposes. Transmitter has dual rate facility. Upon flight, we are able to control exponential movement because ability to control the throw maximum and throw angle of the control surfaces. There are two types of transmitter available, servo reversing features and channel mixing of flaperons and elevons. Figure 2.7 shows types of transmitter control in aircraft (Blake, 2010).



Flaperon Mode (Dual Aileron Servos, CH 1& 6)

Independent Aileron & Flap

Figure 2.7: Types of the transmitter

Source: Instruction Manual for Futaba 6EZAP 6-Channel

2.5.2 Mechanism of Radio Control

All the control surfaces of the aircraft can be manipulated from the ground to determine the functions and movement of the RC model. The engine issues the speed at which the model aircraft operates. The RC pilot manipulates a series of sticks and switches on the face of the transmitter box, generating signals that correspond to tiny servos within the fuselage of the RC model and attached by servo rods to the control surfaces.

2.5.2.1 Transmitter

Transmitter works by sending data to the receiver which generates radio frequency carrier. The receiver is tunes to transmitter's carrier frequency. The receiver detects data from the modulated carrier, decodes it, and then instructs the appropriate servo to move according to the user input. There are four types of transmitter modes. For mode 1, left stick operates elevator and rudder; right stick operates throttle and ailerons. For mode 2, left stick operates throttle and rudder; right stick operates elevator and ailerons. For mode 3, left stick operates elevator and ailerons; right stick operates throttle and rudder. For mode 4, left stick operates throttle and ailerons; right stick operates elevator and rudder. The schematic motion is shown in Figure2.8.

Figure 2.8: Radio controller mechanism mode 1

Figure 2.8(b): Radio controller mechanism mode 2

Figure 2.8(c): Radio controller mechanism mode 3

Figure 2.8(d): Radio controller mechanism mode 4

Source: http://www.rc-airplane-world.com/rc-transmitter-modes.html

2.5.2.2 Receiver

There is a variety of receivers available for difference types of flying performance such as long distance flying, safe programming and miniature planes. Selection of receiver also varies based on weight of the aircraft.

2.5.2.3 Servo

A servo is a small motor wired to the receiver. The receiver decodes the signals from the transmitter and instructs the servo to move at certain distance. This movement is transmitted to the aircraft's control surfaces usually by the pushrods connecting them to the servo. This component converts the incoming radio signal and moved the pushrods connected to the flying control surfaces such as the rudder, elevator, and ailerons of the aircraft. Servos work very well in the range of 4V to7V. The signal is supposed to be at TTL levels. Usually, servos are run near 5V, for both power and signal high (Refer Appendix B1). Figure 2.9 shows the basic idea of servo functions:

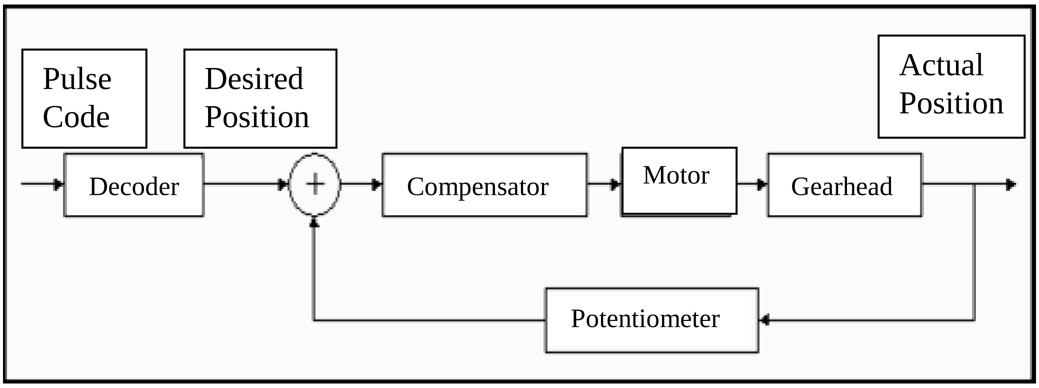


Figure 2.9: Basic idea of a servo functions

Source: http://www-cdr.stanford.edu/dynamic/servo/

2.5.2.4 Radio Frequency

Radio frequency has few frequency bands called as Pulse Position Modulation system, Pulse Code Modulation, Intelligent Pulse Decoding and Digital Signature Recognition. Pulse Position Modulation system has a data frame with synchronizing pulse followed by a series of shorter pulses equal to the number of channels. The transmitter encoder circuit reads each of the potentiometer's values, along with switch position, sequentially. Pulse Position Modulation is used in most of the radio controlled aircraft because we can use different brands of transmitter and receiver together. The transmitter is able to operate the servo quickly in the range of the transmitter. Figure 2.10 shows the principle of a pulse position modulation.

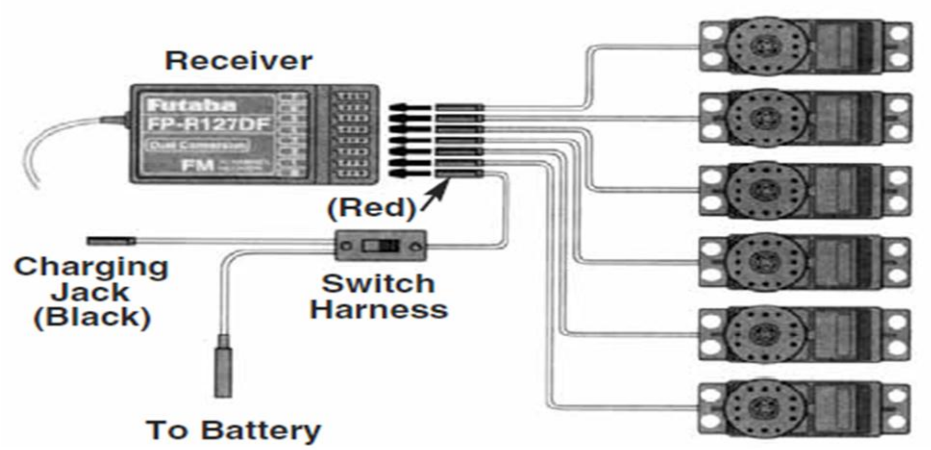


Figure 2.10: Principle of a pulse position modulation in a radio controller
Source: Instruction Manual for Futaba 6EZAP 6-Channel

2.6 AIRCRAFT CONFIGURATION

Aircraft configuration is the highest level of organization within an aircraft container. Each aircraft has its own configuration that has been designed by the designer. It also refers to the internal arrangement or layout of such as types of engine, type of propeller, wing selection and airfoil selection. Aircraft configuration is important to meet the standard of FAR 23 and requirements parameter (Roskam, 2005). Refer to appendix D1 for the specification details of RC trainer aircraft.

2.6.1 Glow Engine

Most radio control aircraft used a 2 or 4 stroke glow engine. Glow plug does not have coil, magneto or points. The glow plug is heated by a battery-operated glow starter. When fuel enters the combustion chamber, it's ignited by the heated glow plug and with that the engine started and gains the momentum to continue running. The engine's carburetor supplies the fuel and air needed for combustion. A rotating throttle arm controls the amount of fuel and air that enters the combustion chamber. The high speed needle valve controls the proportions of fuel to obtain higher speed. Two-stroke engines are the most used mainly because they are simple made, light, easy to operate, easy to maintain and are usually inexpensive. Two-stroke engines operate at a high RPM and therefore can be quite noisy without a good silencer. Combustion engine energy source has higher to energy weight ratio then the battery used for electric motor. Hence, for this project, 2 stroke glow engine had been choose. Figure 2.11 is a model of stroke glow engine (Bird, 2005).

Figure 2.11: Model of a 2 stroke glow engine

Source: http://adamone.rchomepage.com/guide4.htm

2.6.1.1 Fuel System

A glow fuel engine consumes twice the amount of fuel compared to a gasoline engine of the same size. Gas engine carburetor has a built in pump that draws gas from the tank. The pump operates off the pressure pulses from the engine crankcase. Gasoline resistant stopper in the tank will allow glow fuel to dissolve in gasoline. The tank on a gas engine is not pressurized. When the engine is in the upright position, the fuel tank is centre line should be at the same level as the needle valve or no lower than 1cm, to insure proper fuel flow. A too large fuel tank may cause the motor to run unsmooth during a steep climb and stall during a steep dive. Normal tank size for engines is in between 3.5cc to 150 - 250cc (Blake, 2010). Figure 2.12 shows fuel tank placement inside the aircraft:

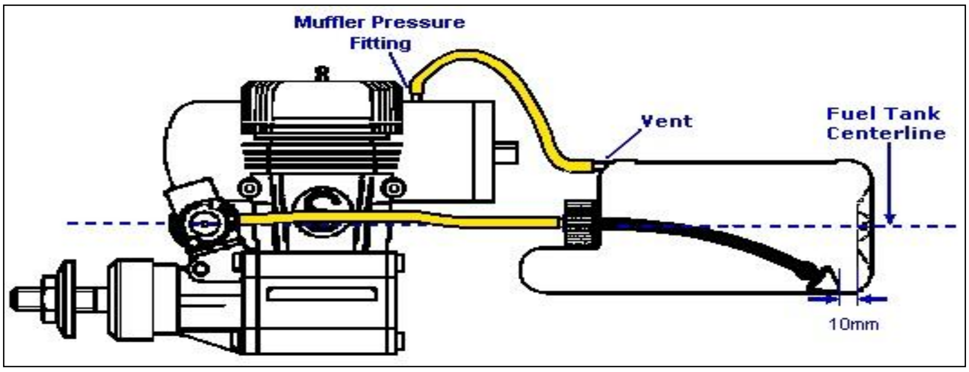


Figure2.12: Placement of a fuel tank in an aircraft

Source: http://adamone.rchomepage.com/guide4.htm

2.6.1.2 Ignition and Radio Interference

. There should be at least a 3.5 meter separation between radio components and ignition parts. No metal parts used to make engine control linkages. Nylon clevises are used to insulate the engine from the throttle or choke pushrods. Assure before starts the engines there is no metal to metal contacts that can rattle. Metal pushrods in a metal holes, metal clevises, will cause radio noise and interference. Spark plug cap must be in good condition so as not to allow any sparks to jump out to the ground (Carpenter, 2007).

2.6.2 Propeller

The rotating device located on the nose of the aircraft. It is designed to convert its rotation into thrust. Propellers, along with Bernoulli’s principle, propel the aircraft through the air by creating a difference in the air pressure between the surfaces of the blades. The thrust of a propeller depends in large part on the volume of air it accelerates to what extent this volume is accelerated and the density of the air. These factors depend on the diameter of the propeller, RPM and torque of the engine which is responsible for turning the propeller. The aerodynamic design of the propeller also influences its performance

Propellers for radio controlled aircraft are vertically mounted rotating wings. Propeller is used to convert the engine power into thrust. Thrust is generated in exactly the same way as lift by the wing and the propeller has a profiled airfoil section. The propeller sizing is shown in Figure 2.13:

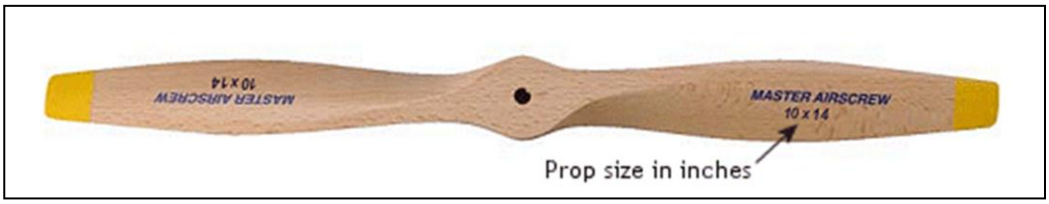


Figure 2.13: Propeller Configuration

Source: http://www.rc-airplane-world.com/propeller-size.html

The first number refers to the diameter of the imaginary disc ('arc') created by the spinning propeller and the length of prop from tip to tip. The second number refers to the pitch. The pitch measurement of a prop indicates how far that propeller will move through the air per every single revolution of the engine. The higher the pitch, the faster the aircraft will be. Effect of propeller diameter to pitch speed is shown in Figure 2.14:

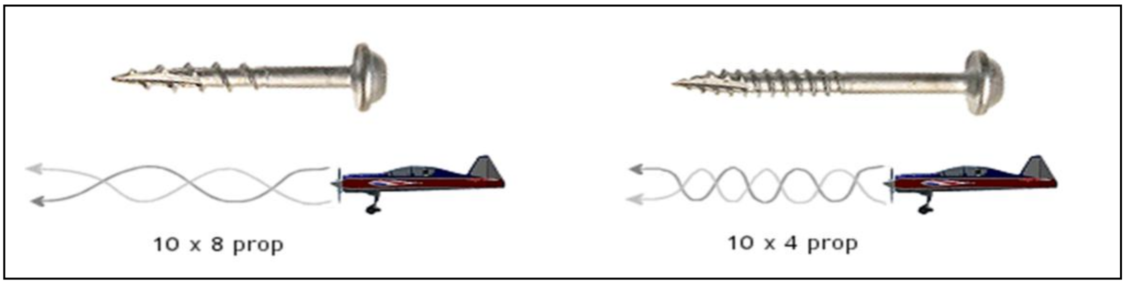


Figure 2.14: Effect of a propeller diameter to the pitch speed

Source: http://www.rc-airplane-world.com/propeller-size.html

2.6.3 Wing Configuration

The position of the wing also will influence the aircraft performance and there are 3 types of position that can be made, which are high wing, middle wing and low wing. High wing is widely used for trainer aircraft compared to low wing and middle wing that are used for commercial and passenger carrier aircraft (Anderson, 1999).

2.6.3.1 High Wing

High wing is more stable and have gravity feed system compared to others type of wings. High wing is placed on level or on top of the fuselage where the high wing acts as wing upper surface. High wing aircraft is the wing upper surface or above the top of the fuselage. High wing aircraft are generally more stable and have gravity feed system. These aircraft generally have good visibility while landing. STOL aircraft particularly have this configuration for increased ground clearance. Figure 2.15 shown different types of wing placement (Stevenson, 2009).

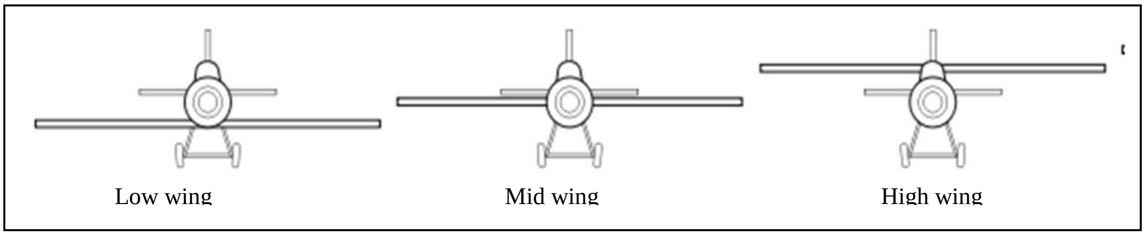


Figure 2.15: Different types of wing placement on the aircraft

Source: http://quest.nasa.gov/aero/planetary/atmospheric/aerodynamiclift.html

2.6.4 Types of wing

Aircraft designers have designed several wing types that have different aerodynamic properties. These have different shapes and attach to the aircraft body at different angles at different angles at different points along the fuselage. Not all of these planes have a practical use. Some of it has been used for research purposes. There are four types of wing that is tapered wing, straight wing, swept wing and delta wing. Figure 2.16 shown wing design configuration of an aircraft:

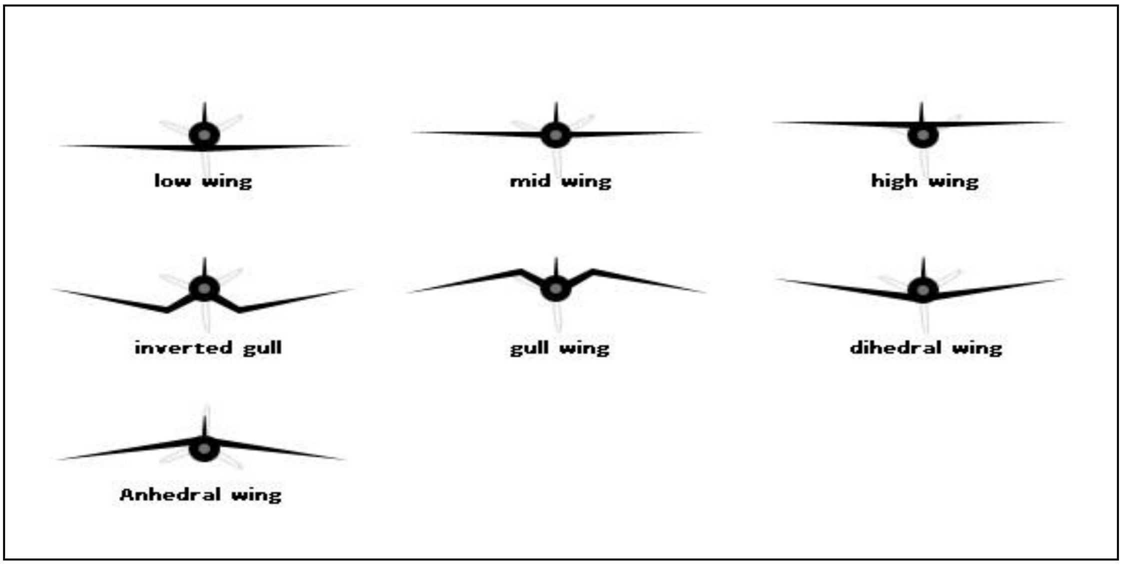


Figure 2.16: Types of wing design

Source: http://quest.nasa.gov/aero/planetary/atmospheric/aerodynamiclift.html

2.6.4.1 Straight Wing

The conventional straight wing extends out from the fuselage at approximately right angles. One wing is suspended above the fuselage by bracing supports and the other wing is crossed under the fuselage. Designers positioned the wings at different heights depending on the design crossed above the fuselage and the other wing attached at the lower part of the fuselage. Straight wing is chosen because it is easy to construct and do not have any dihedral angle. It will fly very fast and satisfies the sport trainer requirements such as capable to do aerobatic. Straight wing also has lower stall speed that helps to land easily (Loftin, 2004).

2.6.5 Tail configuration

Tail is one of the control areas in the aircraft and it provides stability for the aircraft. The tail includes horizontal tail and vertical tail. The horizontal tail is used to give longitudinal stability and longitudinal control (elevator) while the vertical tail is used to provide directional control (yaw), the rudder in the vertical used as the control surface of the aircraft (Benson, 2006).

2.6.5.1 Conventional Tail

A conventional tail is often chosen to move the horizontal tail away from engine exhaust and to reduce aerodynamic interference. The vertical tail is quite effective, being end-plated on one side by the fuselage and on the other by the horizontal tail. By mounting the horizontal tail at the end of a swept vertical, the tail length of the horizontal can be increased. This is especially important for short-coupled designs such as business jets. The disadvantages of this arrangement include higher vertical fin loads, potential flutter difficulties and problems associated with deep-stall (Bird, 2005).

We can mount the horizontal tail part-way up the vertical surface to obtain a cruciform tail. In this arrangement the vertical tail does not benefit from the end plating effects obtained either with T-tails however the structural issues with conventional tail is mostly avoided and the configuration may be necessary to avoid certain undesirable interference effects, particularly near stall.

2.7 AIRFOIL SHAPE

An airfoil is the shape of a wing or blade. The different of velocity between the upper and lower surfaces of airfoil will create a fore. Due to the design of the airfoil, different airfoil shape will have different types of lift and characteristic. When the pressure of the lower surface is bigger that the upper surface, it will generate lift force (Hubert et al., 1992). Figure 2.17 shows types of airfoil shape:

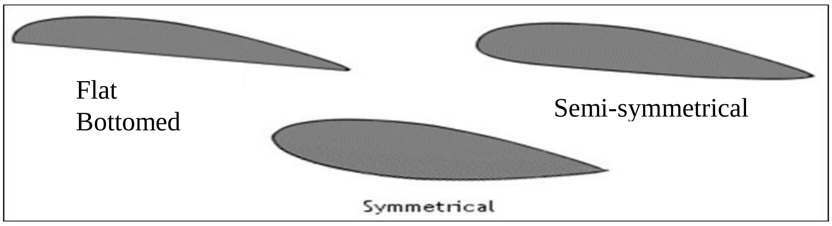


Figure 2.17: Types of an airfoil shape

Source: http://www.free-online-private-pilot-ground-school.com/aerodynamics.html

An airfoil shaped body moved through a fluid produces a force perpendicular to the motion called lift. With increased angle of attack, lift increases in a roughly linear relation, called the slope of the lift curve. At about eighteen degrees this airfoil stalls and lift falls off quickly beyond that. Drag is least at a slight negative angle for this particular airfoil and increases rapidly with higher angles (Simons, 2002). The Reynolds number is the important aspect that effected the aerodynamic of the airfoils. The Reynolds will determine the airflow is laminar or turbulent. The airfoil is tending to stall at higher Reynolds number followed by decreases of the lift coefficient, C_L and the effect of the separation bubble (Sathaye, 2004). The percentage of laminar flow on airfoil shape is shown in figure 2.21: The effect of angle of attack on centre of pressure is further elaborate in Figure 2.18:

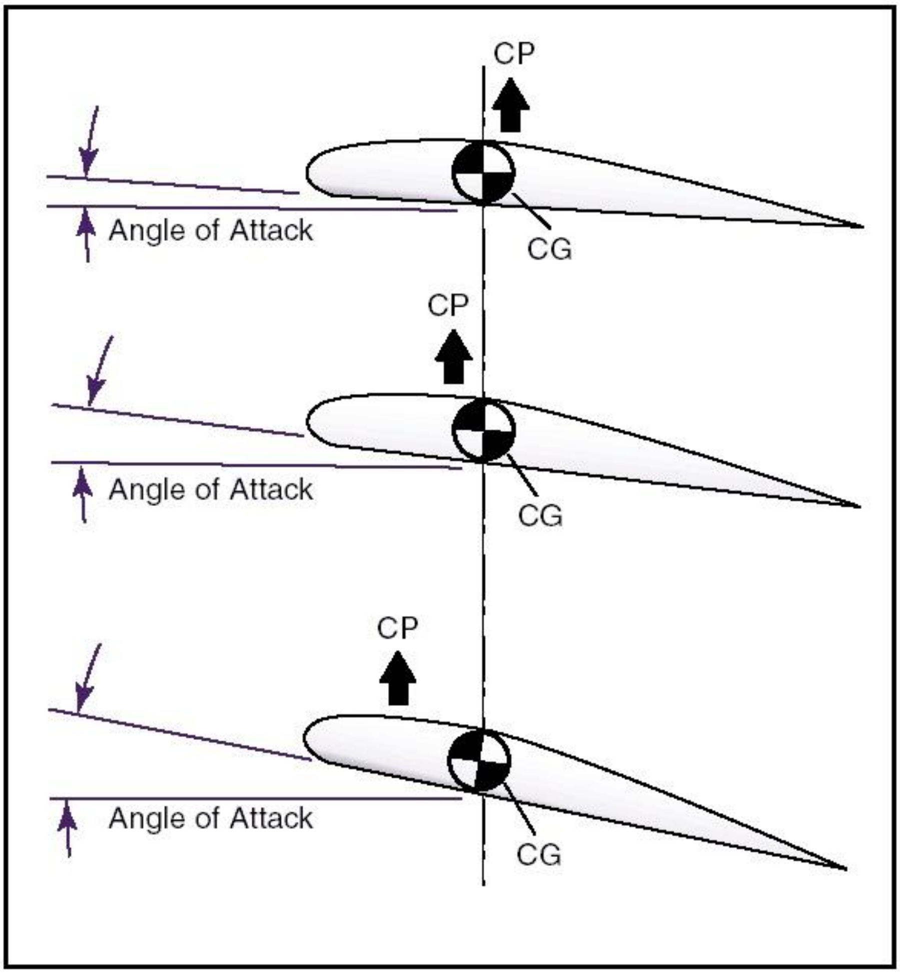


Figure 2.18: Effect of an angle of attack to the centre of pressure movement
Source: http://www.free-online-private-pilot-ground-school.com/aerodynamics.html

Airfoil design is a major fact of the aerodynamics. Various airfoils serve different flight regimes. Asymmetric airfoils can generate lift at zero angle of attack, while a symmetric airfoil may better suit frequent inverted flight as in an acrobatic aircraft (Anderson, 1999). Supersonic airfoils are much more angular in shape and can have a very sharp leading edge. A supercritical airfoil, with its low camber, reduces transonic drag divergence. Moveable high-lift devices, flaps and sometimes slats are fitted to airfoils on almost every aircraft as shown in Figure 2.19:

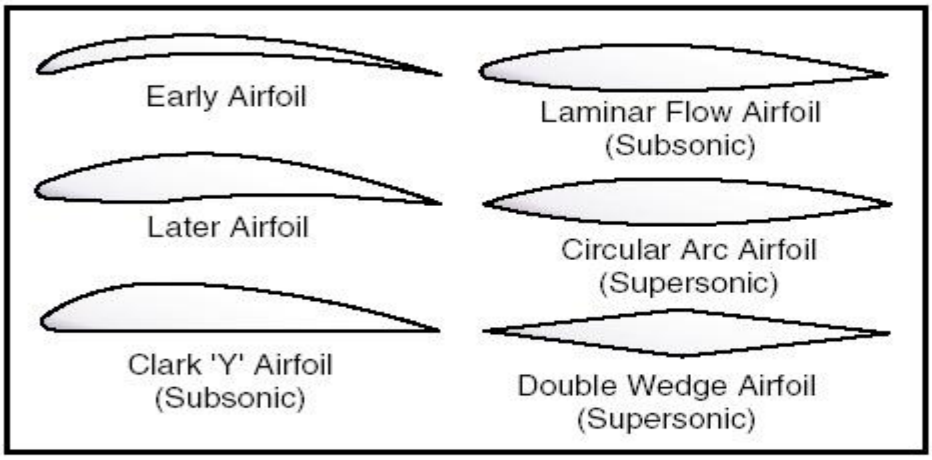
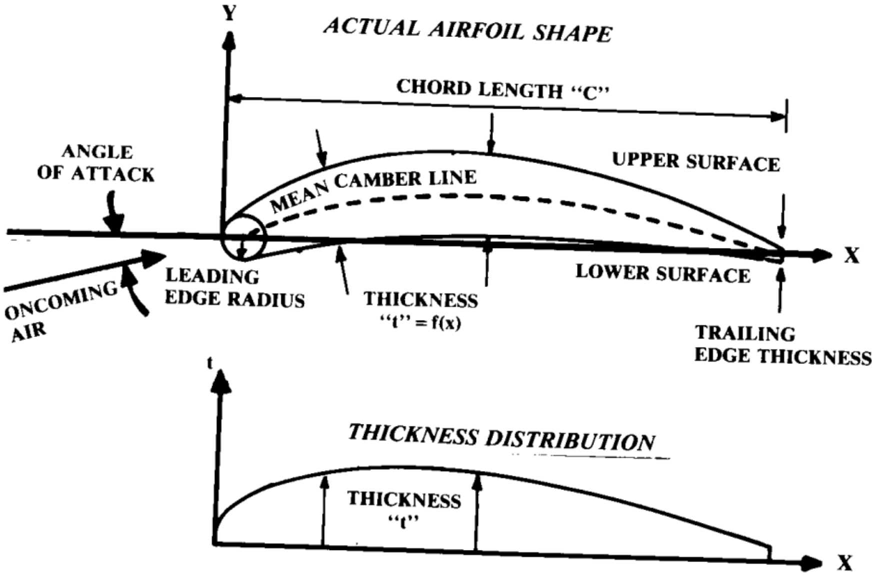


Figure 2.19: Airfoil shape geometry

Source: http://www.free-online-private-pilot-ground-school.com/aerodynamics.html

Airfoils are designed for specific functions using inverse design programs such as PROFIL and XFOIL. In this project, the type of airfoil shape will be Clark Y. Leading-edge radius located at the front of the airfoil which is tangent to the upper and lower surfaces. The chord of the airfoils is the straight line from the leading edge to the trailing edge. The camber of an airfoil can be defined by a camber line which is the curve that is halfway between the upper and lower surfaces of the airfoil (Abe, 2003). The thickness distribution of the airfoil is the distance from the upper surface to the lower surface measure perpendicular to the mean camber line, and is a function of the distance from the leading edge. The airfoil thickness ratio (t/c) refers to the maximum thickness of the airfoil divided by its chord (Mason, 2006). Figure 2.20 shows the parameters of the airfoil shape and the thickness distribution:



Note: leading edge radius and trailing edge thickness are exaggerated for illustration.

Fig. 4.1 Airfoil geometry.

Figure 2.20: Parameters and thickness distribution of Clark Y airfoil

Source: Raymer, 2006

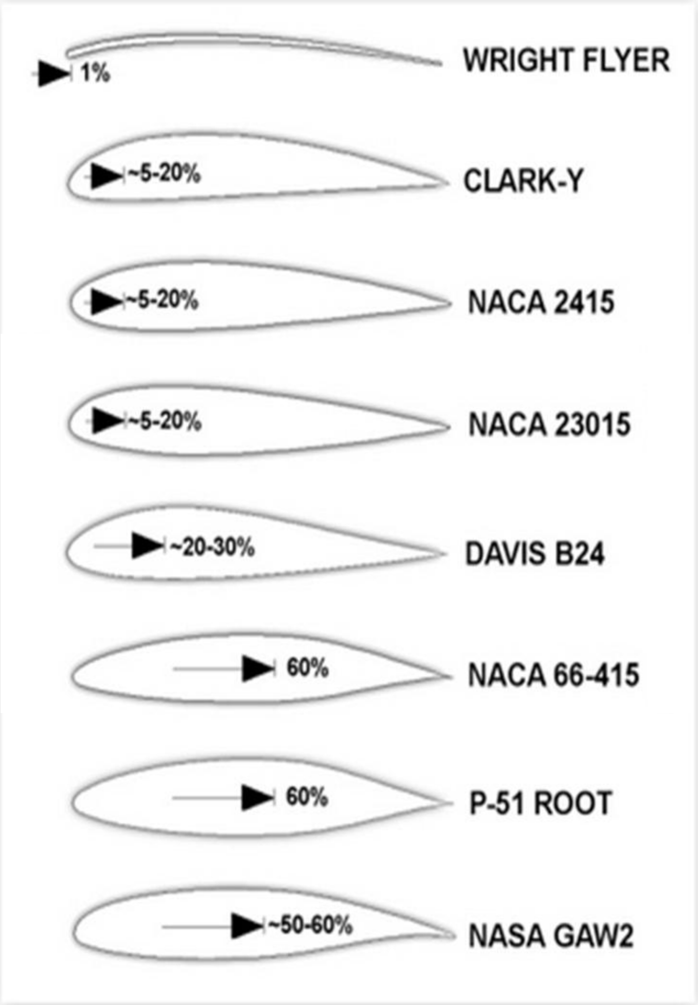


Figure 2.21: Percentage of Laminar Flow on an Airfoil Shape

Source: http://www.dreesecode.com/primer/airfoil5.html

2.8 AERIAL DROP MODULES

Add excitement to radio controlled aircraft by adding an aerial drop module. Is used parachute released by the servo to reduce the speed of the aircraft when land. It is easy to design. Basically, for the weight of the aircraft within 3 kg to 5 kg, the size of the parachute will be 3 m diameter so that it can withstand the weight of the aircraft and do not crash when land. Besides that, using night mode LED will help in night flying. It will add excitement to the fly. Type of the parachute chosen was ballistic parachute that give more stability and easy to designed and constructed. The sketch of the parachute is shown in Figure 2.22 below:

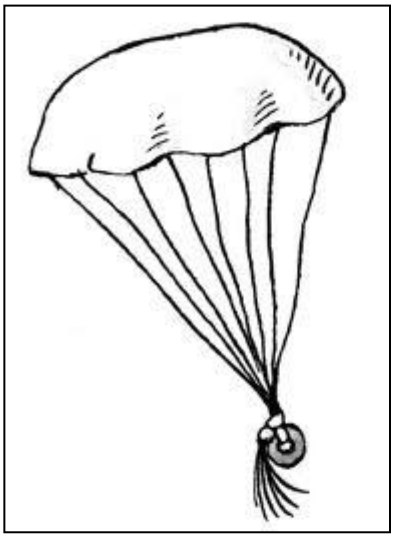


Figure 2.22: Sketch of a recovery ballistic parachute

CHAPTER 3

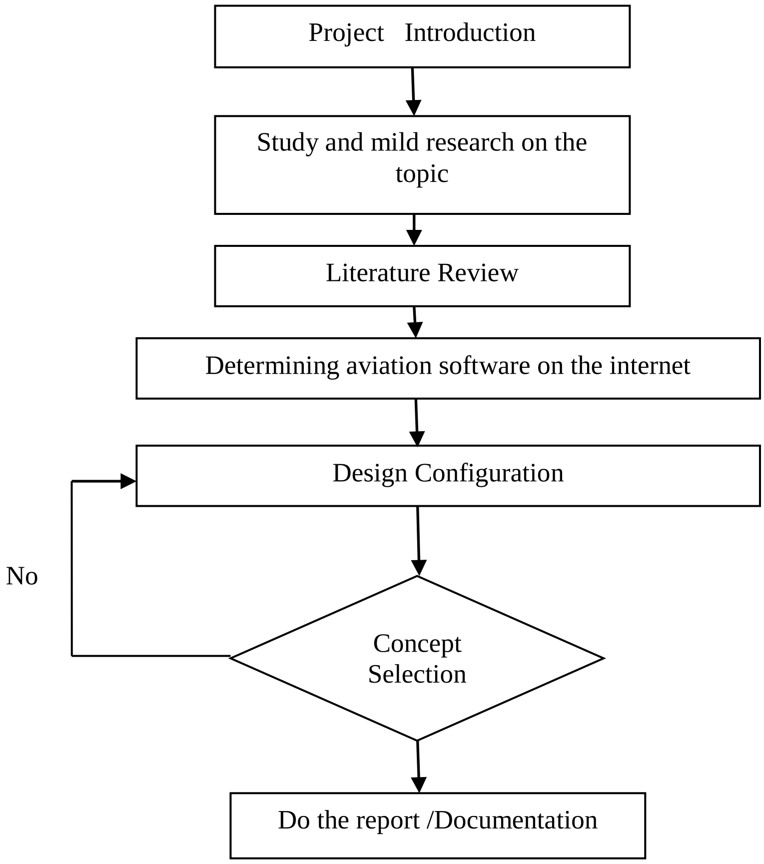
RESEARCH METHODOLOGY

3.1 INTRODUCTION

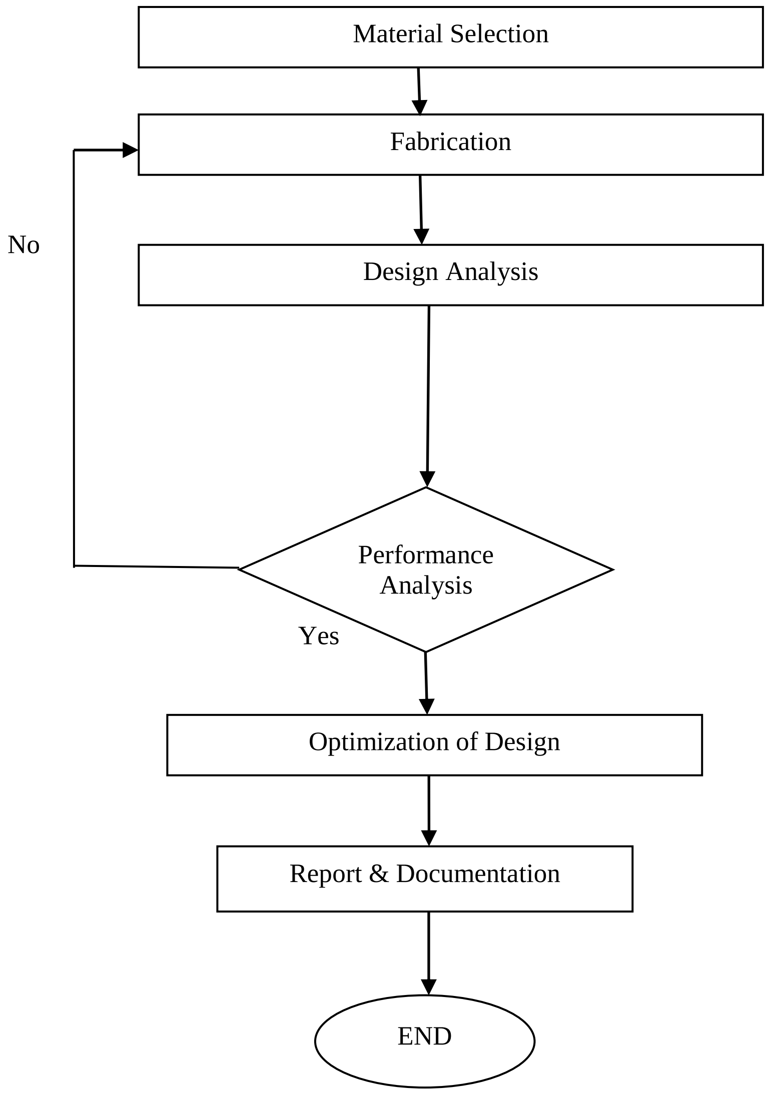
This chapter will present the research methodology that had been used for the design and fabrication of small scale trainer aircraft. The main idea of this chapter is to describe all the findings about the steps that were used. Based on the findings in chapter 2, this chapter will emphasize all the process that had been carried out from the beginnings of this chapter until the end of the project. This chapter will cover all the flow chart and Gantt chart (Gantt chart: please refer Appendix A1 and A2).

3.2 FLOW CHART

3.2.1 Flow chart for Final Year Project Semester 1



3.2.2 Flow Chart for Final Year Project Semester 2



3.2.2.1 Project Introduction

The project started with the title confirmation by the faculty. Upon discussion with the supervisor of the project, the main contents were determined. Project objectives, project background and problem statement have been identified. Since, the title given is totally new and not been thought before, hence overview of the topic was done by referring to available models in market. A survey has been conducted to determine the problem on design configuration of current small scale trainer aircraft available in market nowadays.

3.2.2.2 Literature Review

Literature review helps to gather information about the trainer aircraft and to understand the objectives of the project. The sources for the information are from books, journals, internet and from the supervisor. It helps to understand the project better and future discussion with the supervisor lead to designing process. During the literature review, a model is chosen as a reference model which has the similar design configuration and requirements parameter. Based on the reference model, a proposed aircraft has been modeled. The main reference for this project was book titled aircraft performance and design by John D. Anderson and Airplane Design by Dr. Jan Roskam.

3.2.2.3 Design Configuration

Designing involved three main categories of conceptual design, preliminary design and detail design (Anderson, 1999). All aircraft must meet certain climb rate or climb gradient requirements. FAR 23 have been chosen as the international standard for a proposed aircraft. FAR 23 is a reference to civil airplanes and its weight is below than 12000 lbs. FAR 25 is used as international standard for aircraft above 12000 lbs. Trainer aircrafts is one of the civil airplanes. Consider FAR 23.65 AND FAR 23.77 all engine operating and neglect FAR 23.67 one engine operating because in this project there is only single engine operating (Roskam, 2005). Before performing the designing task, requirements parameter has to be identified. Requirements parameter determined type of the aircraft and also important for performance analysis. Mission profile was presented graphically for better view. The technical data has been calculated include empty weight, weight takeoff and wing span selection of the small scale trainer aircraft.

3.2.2.4 Concept Selection

In early phase, the design is sketched based on the design configuration. Before performing conceptual design, design of an aircraft was sketched so that it meets the requirements parameter. Based on the discussion with supervisor and theoretical justification, the sketch has been remodeled by using designing software AUTOCAD. The sketch is shown in Figure 3.1:

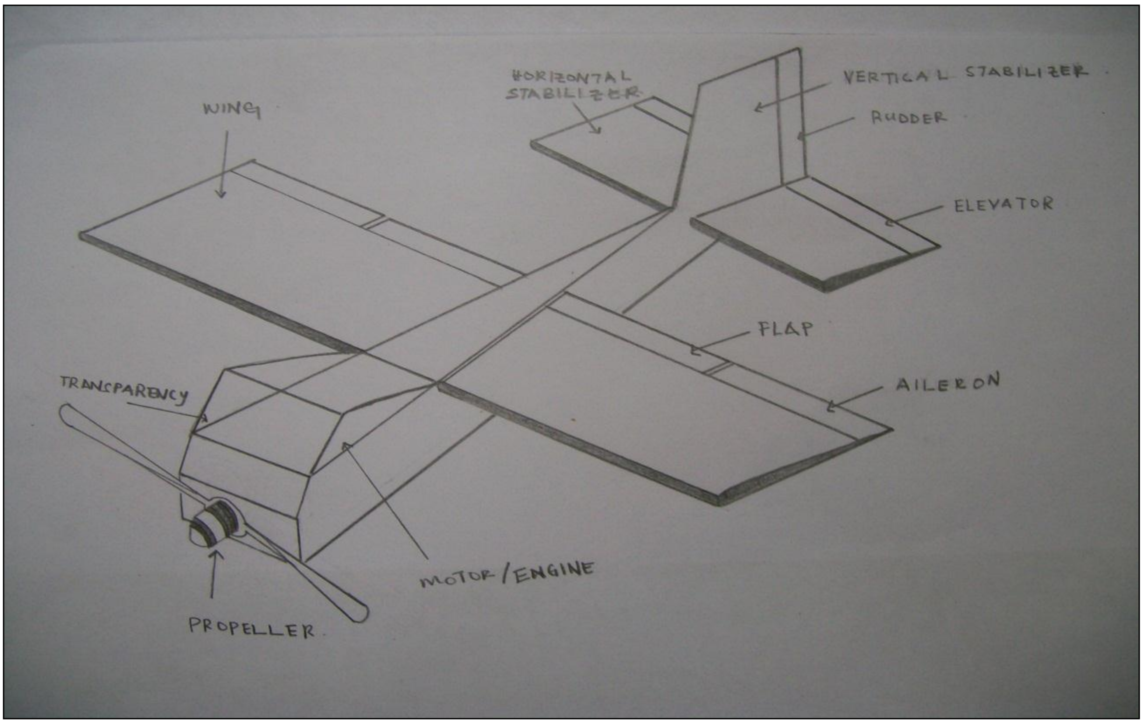


Figure 3.1: Sketch of a small scale trainer aircraft

General specification:

- High Wing
- Conventional tail configuration
- Tractor propeller configuration

- Powered by motor or engine

3.2.2.5 Design Analysis

Design analysis involved weight estimation, aircraft sizing and matching diagram. Weight analysis is estimation on the takeoff weight and empty weight for a small scale trainer aircraft. The data acquired from the technical task and statistical analysis required to performed the weight analysis. Fuel fraction is calculated for different flight leg by obtained the data for fuel weight. By using the graph of W_e (tent) and W_e (all) vs. W_{to}, values for takeoff weight, fuel weight and empty weight was obtained.

Aircraft sizing was based on FAR 23 standards for the trainer applications. For the small scale trainer aircraft, the criteria of sizing were following as below (Roskam, 2005);

- FAR-23.65 Rate of Climb Requirement
- FAR-23.65 Climb Gradient
- FAR-23.77 Climb Gradient
- Stall Speed Sizing Requirement
- Cruise Speed Sizing Requirement
- Takeoff Sizing
- Time to Climb Sizing
- Landing Sizing

Matching diagram was plotted to obtain important parameters such as wing loading and power loading. Wing loading is important to determine the wing span and wing area of the main wing.

3.2.2.6 Performance Analysis

Performance analysis important to justified the outcome of requirement parameters. If the performance analysis do not exist the values of the requirement parameter, the design of an aircraft described as perfect. Performance analysis includes the following parameters as below (Roskam, 2005);

- Power required and power available
- Rate of climb
- Range
- Stalling speed
- Landing distance
- Takeoff distance

Besides that sensitivity studies is required to obtain the values of the parameters dependent to the takeoff weight. The parameters involved were as below;

- Range, R
- Endurance, E
- Lift to Drag Ratio L/D
- Specific Fuel Consumption c_p
- Propeller efficiency η_p
- Speed sensitivity V_{cruise}

3.2.2.7 Report Documentation

Once all the process of designing completed, all the important details were gathered and checked with the help of the supervisor. Once finalize the report, the details was presented as documented written report. By having the report, it will help the other reader to seek for the information on designing a small scale trainer aircraft. The report consists of introduction to the project, literature review, findings, methodology, result and discussion and recommendation to improve the quality of design in future research.

3.3 DESIGN CONFIGURATION

The term design configuration characterizes the information that defines the performance, functional and physical attributes of an aircraft. As described earlier, all designs are based on FAR 23 and related to information on requirements parameter. A typical example of a configuration problem is to design mean aerodynamic chord (MAC) positioning, control surface sizing and airfoil selection.

3.3.1 Requirements Parameter

Range	: 50 meter radius
Endurance	: 20 minutes
Take off Distance	: <30 m
Landing Distance	: 10 m
Cruise Speed, Vcr	: >40 km/h
Loiter speed, Vltr	: <25 km/h

3.3.2 Mean Aerodynamic Chord (MAC) Positioning

The design of wing will be a straight wing. Mean Aerodynamic Chord is important to determine centre of gravity and neutral point to give stability to the aircraft when fly (Carpenter, 2007). For straight wing, the aspect ratio of wing is higher than aspect ratio of the tail configuration due to capable to stall at higher angle of attack The taper ratio, λ =1 because it will give minimum flow separation and stall behavior (Raymer, 1949). Aspect ratio was chosen to be 6 (Refer to Appendix D1). Figure below shows the location of MAC in straight wing;

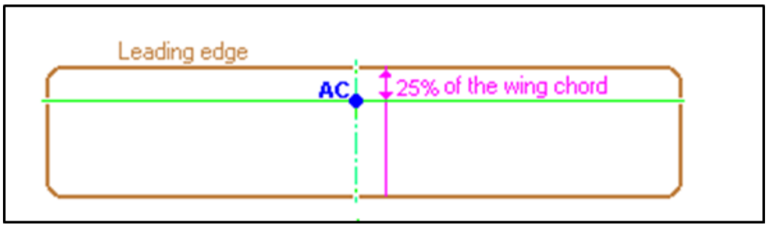


Figure 3.2: Location of MAC in a straight wing

Source: http://adamone.rchomepage.com/index5.htm

3.3.3 Control Surface Sizing

The control surface refers to elevator and rudder. A general guideline for the elevator design is that the chord length should be in between 20% to 30% of the chord length of the horizontal stabilizer (Benson, 2006). A guideline for rudder is as same as the elevator. The span of the elevator and rudder is chosen as large as possible to give longitudinal stability to aircraft in motion. Parameter that considered in designing the tail structure was aspect ratio, taper ratio, sweep, dihedral and thickness. The geometry dimensions necessary for a layout of the reference tail or wing can be obtained. Figure 3.2 shows the MAC and centre of gravity positioning on the control surface:

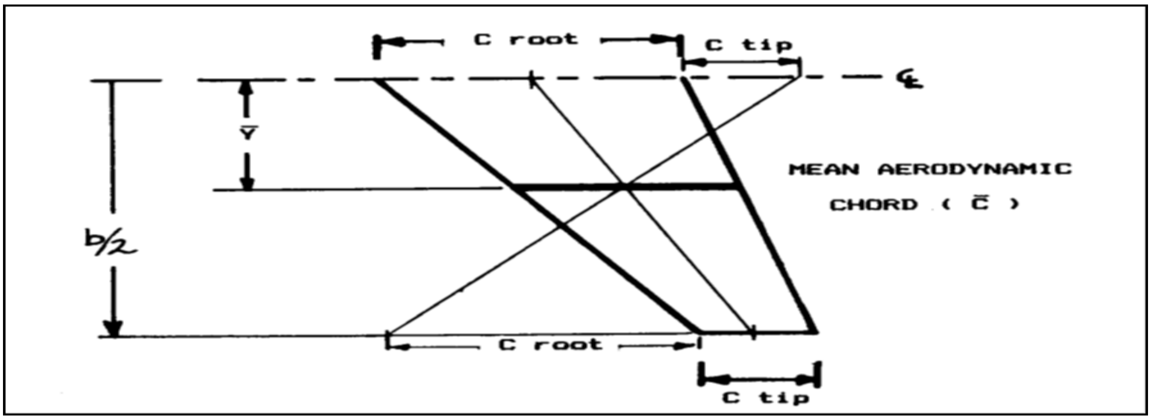


Figure 3.3: MAC positioning on a tail structure of an aircraft

Source: Raymer, 2006

3.3.4 Airfoil Selection

The airfoil shape chosen was Clark Y airfoil shape. Clark Y used in most of the trainer aircraft. It is built with the bottom half of the wing being basically flat. It gives reasonable overall performance in respect of its lift-to-drag ratio and stall characteristics. Clark Y airfoil trailing edge produced a more positive pitching moment for improved longitudinal stability. Figure 3.3 shows relation of percentage of mean aerodynamic centre and pressure distribution.

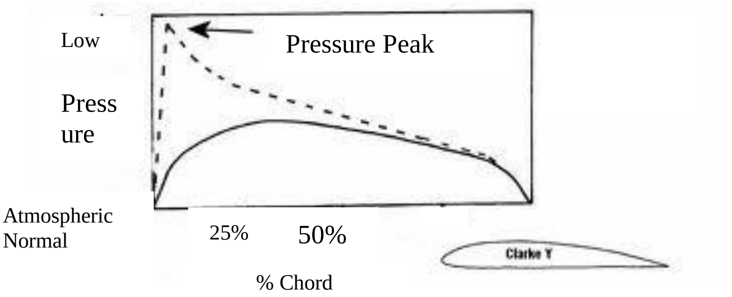


Figure 3.4: Pressure distribution for the Clark Y airfoil
Source: http://www.recreationalflying.net/tutorials/groundschool/umodule9.html

3.3.5 Design

The trainer aircraft was design with AutoCAD software base on the result and the calculation from the methodology. AutoCAD is chosen compared to SOLIDWORKS because the design is easily constructed in 3D AutoCAD and the dimension is accurate.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter is important to investigate and to discuss about the results and calculation involved in this project. All the equation and assumed value was extracted from the reference books mainly from Roskam, 2005 and Raymer, 2006. The main concepts are to get all the parameter value for designing and fabrication of a small scale trainer aircraft. It is include determination of weight of the aircraft, an aircraft sizing accordingly to FAR 23 requirements, wing configuration, tail configuration and an airfoil selection.

4.2 TAKEOFF WEIGHT (W_{TO}) AND EMPTY WEIGHT (W_E) CALCULATION

4.2.1 Statistical Analysis

Data for W_{TO} and W_E is obtained for current trainer aircraft available in the market. Statistical analysis was used to find the value for A and B by developing a regression line (Roskam, 2005). Statistical analysis obtains by developing the technical data consists of takeoff weight and empty weight of different type of radio controlled trainer aircraft available (Carpenter, 2007). Tabulation of W_{TO} and W_E for various type of RC trainer aircraft is shown in Table 3.1:

Table 4.1: Takeoff Weight (W_{TO}) and Empty Weight (W_E) for current RC Trainer Aircraft

RC Trainer Aircraft	W_E **(g)**	W_{TO} **(g)**
Dreamer	1300	1900
Courage 11 Trainer	1650	2300
Lucky Star	1800	2450
Super Trainer	2140	2300
AT-40/Explorer-H	1900	2150
AMR Trainer	4850	5442
Alpha Trainer	2050	2400
P-51 Mustang	4250	4536
Piper Cub	3100	3402
Calmato Trainer	1950	2500

Use equation in Eq. (4.1), to get the constants value for A and B.

$$\log W_{TO} = A + B\log W_E \tag{4.1}$$

Used the data from Table 4.1, the graph log W_E versus log W_{TO} was plotted. Plotted data to find the values of A and B are attached in the Appendix C2. From the graph, the equation of log $W_E = 0.7898\log W_{TO} - 0.24$ obtained. Rearrange the equation to match the Eq. (4.1). Hence, the value of A and B are;

A = 1.226 and B = 0.3039

4.2.2 Mission Fuel Weight (W_F) calculation

For the calculation of W_F, Evolution 0.46 NX glow engine from Alpha Trainer is chosen and will be used as a reference. By referring to Appendix A4, the specific fuel consumption (sfc) for climb and loiter is 127.42 g/kWh and 122.35g/kWh respectively. The total amount of fuel fraction for each leg was calculated to obtain the overall mission fuel fraction (mff) for the mission. The relationship between the amount of fuel used for each stage and the sfc is shown in Eq. (4.2):

$$\text{Fuel Weight } (W_F) \text{ for each leg } (g) = \text{sfc } (gkWh^{-1}) \text{ x time } (hr) \text{ x power } (kW) \quad (4.2)$$

Table 4.2 shows the values of sfc for different leg during the flight:

Table 4.2: Sfc for different type of flight

Leg	t, hr	Sfc,gkWh^{-1}	P, kW*	Fuel Weight, g
Start-up	0.0333	127.42	1.63	6.916
Climbing	0.0500	127.42	2.44	15.55
Loiter	0.5000	122.35	9.77	400.00
Cruise	0.0333	122.35	1.63	6.64
Landing	0.01667	122.35	0.051	0.104

Note: * is calculated based on formula $P = 2\pi Tt$

Where;

P = Power

T = Torque

t = time in hour

For the iteration, it is assumed that W_{TO} is to be 3000 g. From the assumption, the value of fuel fraction for each leg of the flight was calculated as follows;

<u>Leg 1: Start-up and Warm-up</u>

$$\begin{aligned} W_1 &= (Sfc)\,(Power)\,(Time) \\ &= (127.42)\,(1.63)\,(0.0333) \\ &= 6.9162 \end{aligned}$$

$$\begin{aligned} \frac{W_1}{W_{TO}} &= \frac{(3000 - 6.9162)}{3000} \\ &= 0.9976 \end{aligned}$$

Leg 2: Climbing

$$\frac{W_2}{W_1} = \frac{2993.08-127.42(2.44)\,(0.05)}{2993.08}$$

$$= 0.9948$$

Leg 3: Loiter

$$\frac{W_3}{W_2} = \frac{2977.53-122.35(9.77)\,(0.5)}{2977.53}$$

$$= 0.7993$$

Leg 4: Cruise

$$\frac{W_4}{W_3} = \frac{2738.46-122.35(1.63)\,(0.0333)}{2738.46}$$

$$= 0.9975$$

Leg 5: Landing

$$\frac{W_5}{W_4} = \frac{2731.82-122.35(0.051)\,(0.01667)}{2731.82}$$

$$= 0.9999$$

The overall mission fuel fraction can be calculated by using Eq. (4.3):

$$M_{ff} = \prod\nolimits^{n}_{i=1} w_i \qquad (4.3)$$

$$M_{ff} = \left(\frac{W_1}{W_0}\right)\left(\frac{W_2}{W_1}\right)\left(\frac{W_3}{W_2}\right)\left(\frac{W_4}{W_3}\right)\left(\frac{W_5}{W_4}\right)$$

$$= (0.9976)\,(0.9948)\,(0.7993)\,(0.9975)\,(0.9999)$$

$$= 0.7912$$

From calculated mission fuel fraction, the weight of the fuel used during the mission flight was calculated by using Eq. (4.4);

$$W_{Fuel\ Used} = (1-M_{ff})\ W_{TO} \tag{4.4}$$

The aircraft need to carry an extra 6% of fuel onboard due to the safety purposes during flight time.

$$W_{Fuel\ Used} = 1.06\ (1-0.7912)\ W_{TO}$$
$$= 0.2214\ W_{TO}$$

Then, the value of the tentative value of operating empty engine $(W_{OE})_{tent}$ was calculated from the Eq. (4.5). The aircraft will carry a 5% payload weight equal to 0.05 kg during the flight mission.

$$(W_{OE})_{tent} = (W_{TO})_{guessed} - W_F - W_{PL} \tag{4.5}$$
$$= 0.7786\ W_{TO} - 0.05$$

By referring to the result above, the tentative empty weight $(W_E)_{tent}$ (Roskam, 2005) was calculated by using Eq. (4.6). It was assumed that the aircraft will have a 1% amount of W_{TfO} and there is no crew members since it is a radio controlled trainer aircraft.

$$(W_E)_{tent} = 0.7786 W_{TO} - W_{tfo} - W_{crew} \tag{4.6}$$
$$(W_E)_{tent} = 0.7786 W_{TO} - 0.05 - 0.01 W_{TO} - 0$$
$$= 0.7686 W_{TO} - 0.05$$

From the technology diagram (Table 4.1), the graph W_{TO} versus $(W_E)_{allow}$ was plotted. Refer to Appendix C1. Linear regression line for $(W_E)_{allow}$ was obtained as in Eq. (4.7):

$$W_{TO} = 0.9851\ W_{E,allow} + 0.4313$$
$$W_{E,allow} = 1.01513\ W_{TO} - 0.4378 \tag{4.8}$$

Iteration is done by using the value of $(W_{TO})_{guessed}$. Series of $W_{E,allow}$ and $(W_E)_{tent}$ are then plotted for a given $(W_{TO})_{guessed.}$ Point of the interception between the two plotted lines as in figure 3.1 will give the value for $W_{TO,actual}$. Hence, the amount of fuel weight, empty weight and takeoff weight can be determined.

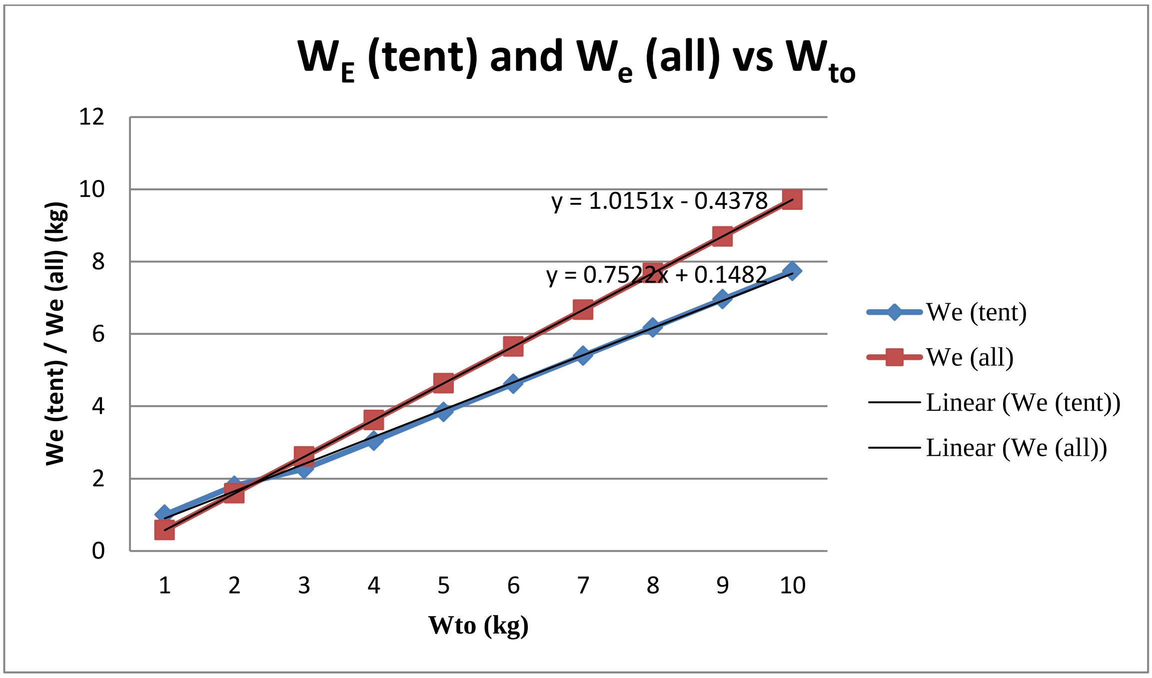


Figure 4.1: $W_{TO,guessed}$ versus $W_{E,allowable}$ and $W_{E,tent}$

From Figure 3.1, at the point interception the value of operating weight was determined as follows;

Takeoff weight, W_{TO} = 2.83 kg

Empty weight, W_E = 2.05 kg

Fuel weight, W_F = 0.57 kg

4.3 AIRCRAFT SIZING

4.3.1 Takeoff Sizing

From the technical task, the takeoff distance was set at 30 m. This will help the operation of a radio controlled trainer aircraft at any fields with short runaway length. The data for takeoff requirement are as follows:

Takeoff Distance, S_{TO} (ft) = 98.4251

Maximum Lift Coefficient, $(C_{L,max})_{TO}$ = 1.3 (Homebuilt airplanes $(C_{L,max})_{TO}$ = 1.2-1.8)

Air Density at MSL, $\left(\frac{Slug}{ft^3}\right)$ = 0.002377

Air Density Ratio at MSL, $\sigma = 1.0000$

By using Eq. (4.9), the value of $(C_L)_{TO}$ was calculated as;

$$(C_L)_{TO} = \frac{(C_{L,max})_{TO}}{1.21} \qquad (4.9)$$

$$= \frac{1.3}{1.21}$$

$$= 1.07438$$

By using Eq. (4.10), the value of S_{TOG} was calculated as follows;

$$S_{TOG} = \frac{S_{TO}}{1.66} \qquad (4.10)$$

$$= \frac{98}{1.66}$$

$$= 59.2922 \text{ m}$$

By using Eq. (4.11), takeoff performance for FAR 23 requirement (TOP_{23}) was calculated;

$$S_{TOG} = 4.9TOP_{23} + 0.009TOP^2_{23} \qquad (4.11)$$

By solving this equation will give the value of TOP_{23} equal to $11.8428 \frac{lbs^2.}{ft^2hp}$

This value is then substituted into the equation relating the wing loading and power loading.

$$\left(\frac{W}{S}\right)_{TO} = (\text{TOP } 23)\ (\sigma)\ (C_L)_{TO} \left(\frac{P}{W}\right)_{TO}$$

$$= (11.8428)\ (1.0)\ (1.3) \left(\frac{P}{W}\right)_{TO} \qquad (4.12)$$

$$= 15.3956 \left(\frac{P}{W}\right)_{TO}$$

This relationship is then tabulated as in Table 5 to indicate changes of power loading to wing loading. Refer to Appendix C4 for graphically sizing shown.

Table 4.3: Takeoff Size Data Tabulation

Wing Loading, $\left(\frac{W}{S}\right)\left(\frac{lbs}{ft^2}\right)$	**Power Loading,** $\left(\frac{P}{W}\right)\left(\frac{lbs}{ft^2}\right)$
5	0.3248
10	0.6495
15	0.9743
20	1.2991
25	1.6238
30	1.9486
35	2.2734
40	2.5981
45	2.9229

4.3.2 Landing Sizing

For the landing sizing, the requirement landing distance was set at 1000 ft. Its requirements data are as follows (Roskam, 2005);

Landing Distance, S_L (m) = 32.8084
Maximum Lift Coefficient, C_{Lmax} = 1.6 (Homebuilt airplanes $(C_{L,max})_{TO}$ = 1.2-2.0)
Air density at MSL, $\left(\frac{lbs}{ft^3}\right)$ = 0.002049
Air Density Ratio at MSL, σ = 1.0000

By using Eq. (4.13), the value of stall speed during landing was calculated.

$$S_L = 0.5136 V_{SL}^2 \tag{4.13}$$

These formulas give the value of VSL equal to 7.9925 kts. The value for wing loading was calculated by using Eq. (4.14);

$$(VSL)^2 = \frac{2\left(\frac{W}{S}\right)_L}{\rho \; C_{Lmax}} \qquad (4.14)$$

$$= \frac{(7.9925\text{x}1.689)^2 \; (0.002049) \; (1.6)}{2}$$

$$\left(\frac{W}{S}\right)_L = 0.2987$$

By considered the corrected factor for takeoff condition shown as follows;

$$\left(\frac{W_L}{W_{TO}}\right) = 1.2308$$

Hence, the value of wing loading takeoff equal to;

$$\left(\frac{W}{S}\right)_L = 0.2427 \left(\frac{lbs}{ft^2}\right)$$

4.3.3 Stall Speed Sizing

From the discussion in the technical task, the radio controlled aircraft was designed to satisfy the loiter speed of 40 km/h. The value will give maximum flying performance during a flight time. Stall speed sizing follows the Eq. (4.15);

$$V_S = \left(\frac{2\ W/S}{\rho CL}\right)^{1/2} \qquad (4.15)$$

Loiter Speed, V_S = 40 km/h @ 21.5983 kts

Maximum Lift Coefficient, C_{Lmax} = 1.2(Homebuilt airplanes ($C_{L,max}$) = 1.2-2.0)

Air density at MSL, $\left(\frac{lbs}{ft^3}\right)$ = 0.00206

$$40 = \left(\frac{2\,\frac{w}{s}}{0.00206(1.2)}\right)^{1/2}$$

$$\left(\frac{W}{S}\right) = 1.98\left(\frac{lbs}{ft^2}\right)$$

4.3.4 Climb Sizing

The trainer aircraft was designed to operate with a single engine. Hence, the design needs to satisfy FAR 23.65 and FAR 23.77 for ALL Engine Operating (AEO) (Roskam, 2005). All the selected parameters was taken from the table in Airplane Design book with considerable assumed values and tabulated in Table 4.4:

Table 4.4: Important Coefficients Value for Climb Sizing

Aspect Ratio, A	**6**
Oswald coefficient, e	0.8
Propulsion Efficiency, η_P	0.7
Density Ratio, σ	1
Fixed Gear, I_p	0.27
Rate of Climb, RC	300fpm
C_{Lmax}	1.2
$(C_{L,max})_L$	1.3
$(C_{L,max})_{TO}$	1.6
Skin Coefficient, C_f	0.044
a	-2.3979
b	1.0
c	1.0892 (single engine propeller driven)
d	0.5147 (single engine propeller driven)

Source: Airplane Design Part 1, Roskam. (2005)

4.3.4.1 Drag Polar

Estimation of drag polar was done in the first place to ease the sizing process (Hull, 2007). Drag polar estimation formula is given as in Eq. (4.16) below;

$$\textit{Drag Polar},\ C_{DO} = \frac{f}{S_{wet}} \tag{4.16}$$

The wetted area was calculated by using Eq. (4.17). The value of c and d represents the constant regression line coefficients.

$$Log\ S_{wet} = c + d\ log\ W_{TO} \tag{4.17}$$

$$= 8.6836\ \text{ft}^2$$

By using Eq. (4.18), the value of equivalent parasite was calculated.

$$Log\ f = a + b\ log\ S_{wet} \tag{4.18}$$

$$= 0.03473\ \text{ft}^2$$

Drag Polar Coefficient was calculated as in Eq. (4.16):

$$\text{Drag Polar, } \mathrm{C_{DO}} = 0.004$$

4.3.4.2 FAR 23.65 RCP (Rate of Climb)

The radio controlled trainer aircraft has minimum climb rate of 300 fpm at sea level. Rate of climb for FAR 23 was given in Eq. (4.19) and Eq. (4.20):

$$RC = 3300 \text{ x } RCP \tag{4.19}$$

$$RCP = \frac{RC}{33000} \tag{4.20}$$

$$= 0.00909$$

$$RCP = \frac{\eta_p}{W/P}$$

$$= \frac{\left(W/S^{1/2}\right)}{19(C_L^{3/2}/C_D)\,\sigma^{1/2}} \qquad (4.21)$$

By using Eq. (4.22), the value of ($C_L^{3/2}/C_D$) was determined;

$$(C_L^{3/2}/C_D)_{max} = \frac{1.345(A_e)^{3/4}}{C_{DO}^{1/4}} \qquad (4.22)$$

$$= \frac{(1.345)\,(6x0.81)^{3/4}}{(0.004)^{1/4}}$$

$$= 17.5059$$

The value at above was used in Eq. (4.21) and give the following equations and stated as in Eq. (4.23):

$$0.00909 = \frac{0.7}{W/P} - \frac{(\frac{W}{S})^{1/2}}{79.4961}$$

$$0.00909 = \frac{0.7}{W/P} - \frac{(\frac{W}{S})^{1/2}}{79.4961} \qquad (4.23)$$

4.3.4.3 FAR 23.65 CGR (Climb Gradient)

Value of climb gradient was calculated by finding the minimum value of CGRP. CGRP value depends on the lift coefficient and lift to drag ratio. $C_{l,max}$ for Clark Y airfoil shape is 1.3. The FAR 23.65 climb gradient was calculated by using Eq. (4.24).

$$\mathrm{CGRP} = \frac{18.97\eta p\sigma^{1/2}}{\left(\frac{W}{P}\right)\left(\frac{W}{S}\right)^{1/2}} \qquad (4.24)$$

Minimum value of CGRP was calculated based on Eq. (4.25);

$$CGRP = CGR + \frac{1/\frac{L}{D}}{C_L^{1/2}} \tag{4.25}$$

$$\begin{aligned} C_{L,climb} &= C_{L,TO} - \Delta C_{L,margin} \\ &= 1.6 - 0.2 \\ &= 1.4 \end{aligned}$$

$$\begin{aligned} C_D &= 0.004 + \frac{{C_{L,TO}}^2}{\pi A_e} \\ &= 0.174 \end{aligned}$$

$$\begin{aligned} \frac{C_L}{C_D} &= \frac{L}{D} \\ &= \frac{1.4}{0.174} \\ &= 8.04597 \end{aligned}$$

Substituted the value of 8.04597 into Eq. (4.24) to find the minimum value of CGRP.

$$\begin{aligned} CGRP &= 0.08333 + \frac{1/8.04597}{1.4^{1/2}} \\ &= 0.1884 \end{aligned}$$

$$0.1884 = \frac{18.97(0.7)(0.971)^{1/2}}{\left(\frac{W}{P}\right)\left(\frac{W}{S}\right)^{1/2}}$$

$$\left(\frac{W}{P}\right)\left(\frac{W}{S}\right)^{1/2} = 69.4535$$

4.3.4.4 FAR 23.77 CGR (Climb Gradient)

Climb gradient sizing for FAR 23.77 is same as climb gradient sizing for FAR 23.65. Only the values of C_L and C_D and CGR change. The methods are the same used in FAR 23.65 CGR sizing.

`

$$\mathrm{CGRP} = \frac{18.97\eta p\sigma^{1/2}}{\left(\frac{W}{P}\right)\left(\frac{W}{S}\right)^{1/2}}$$

Minimum value of CGRP was calculated based on Eq. (4.25);

$$\mathrm{CGRP} = \mathrm{CGR} + \frac{1/\frac{L}{D}}{C_L^{1/2}}$$

$$C_{L,climb} = C_{L,TO} - \Delta\, C_{L,margin}$$

$$= 1.3 - 0.2$$

$$= 1.1$$

$$C_{D\,=}\ 0.004 + \frac{C_{L,}^{\ 2}}{\pi A_e}$$

$$= 0.07695$$

$$\frac{C_L}{C_D} = \frac{L}{D}$$

$$= \frac{1.1}{0.07695}$$

$$= 14.2957$$

Substituted the value of 14.2957 into Eq. (4.24) to find the minimum value of CGRP.

$$\mathrm{CGRP} = 0.03333 + \frac{1/14.2957}{1.1^{1/2}}$$

$$= 0.1000$$

$$0.1000 = \frac{18.97(0.7)(1)^{1/2}}{\left(\frac{W}{P}\right)\left(\frac{W}{S}\right)^{1/2}}$$

$$\left(\frac{W}{P}\right)\left(\frac{W}{S}\right)^{1/2} = 132.79$$

4.3.5 Cruise Speed Sizing

Cruise speed is determined by using the Eq. (4.26) where the value of I_P was taken from chart (Roskam, 2005). From the specification requirements for this aircraft, the cruise speed will be 55 km/h. Cruise speed is determined to find the value of wing loading and power loading in matching diagram.

$$\frac{W}{S} = (I_P)^3\ (\sigma)\ \left(\frac{W}{P}\right) \tag{4.26}$$

$$= 0.01968 \left(\frac{W}{P}\right)$$

4.3.6 Matching Diagram

Based on the all sizing requirements, matching diagram that satisfies all the parameters required for the design of small scale trainer aircraft was plotted and important parameters such as wing loading and power loading was determined from the graph. Table 4.5 shows finalize climb sizing values and Table 4.6 shows summarize to FAR 23.

Table 4.5: Climb Sizing Values

	FAR 23.65 RC	**FAR 23.65 RC***	**FAR 23.65 CGR**	**FAR 23.65 CGR***	**FAR 23.77 CGR**	**FAR 23.77 CGR***
W/S (lb/ft^2)	**W/P (lb/hp)**	**W/P_{TO} (lb/hp)**	**W/P (lb/hp)**	**W/P_{TO} (lb/hp)**	**W/P (lb/hp)**	**W/P_{TO} (lb/hp)**
0.5	38.92	35.38	98.22	89.29	187.79	170.72
1.0	32.30	29.36	69.45	63.14	132.79	120.72
1.5	28.58	25.98	56.71	51.55	108.42	98.56

2.0	26.04	23.67	49.11	44.65	93.90	85.36
2.5	24.15	21.95	43.93	39.94	83.98	76.35
3.0	22.67	20.61	40.10	36.45	76.67	69.70
3.5	21.46	19.51	37.12	33.75	70.98	64.53
4.0	20.44	18.58	34.73	31.57	66.40	60.36
4.5	19.57	17.79	32.74	29.76	62.60	56.91
5.0	18.81	17.10	31.06	28.24	59.39	54.00

- Wing loading changed to wing loading takeoff by dividing with 1.1

Table 4.6: Summarizing to FAR 23 requirements

Parameter	**Equation**
Drag Polar, C_{DO}	0.004
FAR 23.65 RCP (Rate of Climb)	$0.00909 = \frac{0.7}{W/P} - \frac{(\frac{W}{S})^{1/2}}{79.4961}$
FAR 23.65 CGR (Climb Gradient)	$\left(\frac{W}{P}\right)\left(\frac{W}{S}\right)^{1/2} = 69.4535$
FAR 23.77 CGR (Climb Gradient)	$\left(\frac{W}{P}\right)\left(\frac{W}{S}\right)^{1/2} = 132.79$
Stall Speed Sizing	W/S = 1.98 lbs/ft^2
Cruise Speed Sizing	$\left(\frac{W}{S}\right) = 0.01968\left(\frac{W}{P}\right)$

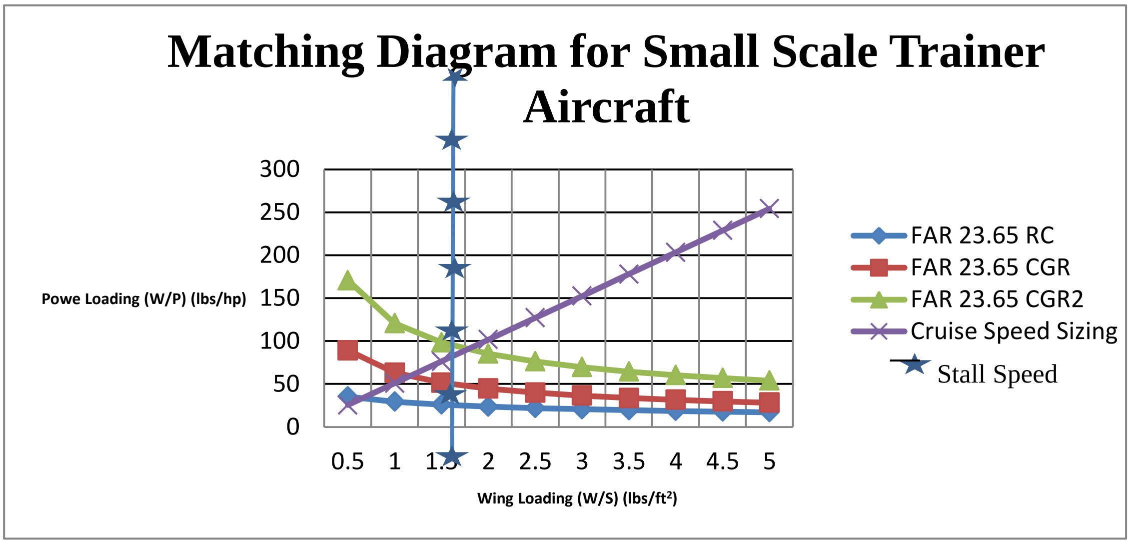


Figure 4.2: Matching Diagram for a Small Scale Trainer Aircraft

Aircraft sizing calculation shown in the Matching Diagram and yield the values for wing loading and power loading. From the matching diagram in Figure 4.2;

Wing Loading, W/S = 1.98 lbs/ft^2

Power Loading, W/P = 20 lb/hp

Since the weight of the aircraft is 2.83 kg as calculated in the weight estimation analysis, the value of wing area and power required was calculated and yield the following values;

Wing area, S = 2.88 ft^2 (0.2676 m^2)

Power = 0.3633 KW

4.4 SENSITIVITY ANALYSIS

Sensitivity analysis is important to find the parameter that effecting the takeoff weight value. The calculated values was taken from the step provided (Roskam, 005). The sensitivity analysis is used to find the value of the requirement of endurance and range case involving parameters as follows;

- Range, R
- Endurance, E
- Lift to Drag Ratio, L/D
- Specific Fuel Consumption, C_P
- Propeller efficiency, η_p
- Speed sensitivity, V_{cruise}

The regression line constant A and B was obtained from the technology diagram as in Appendix C2. The value of A is 1.226 and the value of B is 0.3039. Eq. (4.27) was used to find the value of takeoff weight sensitivities for range and endurance cases.

$$\frac{\delta W_{TO}}{\delta y} = F\ \frac{\delta R}{\delta y}$$

$$\frac{\delta W_{TO}}{\delta y} = F\ \frac{\delta E}{\delta y} \tag{4.27}$$

The values of $\frac{\delta R}{\delta y}$ and $\frac{\delta E}{\delta y}$ was determined by using the equation from the Table 4.7 for the single propeller driven aircraft. F value was calculated by using Eq. (4.28).

$$F = -B\,(W_{TO})^{2}\,(CW_{TO}\,(1-B)-D)^{-1}\,(1+M_{reserve})\,M_{ff} \tag{4.28}$$

By using Eq. (4.29) and Eq. (4.30), the value of C and D was calculated as the values of A and B already known from the technology diagram. Table 4.8 was used to find the values of C and D.

Table 4.7: Parameters to find the values of C and D

W_{TO}	5.7 lb
W_E	4.5 lb
$M_{reserve}$	0
M_{ff}	0.7912
W_{PL}	0
W_{crew}	0
$M_{funusable}$	0.005

$$C = 1 - (1+ M_{reserve})\,(1-M_{ff}) - M_{funusable} \tag{4.29}$$

$$D = W_{PL} + W_{crew} \tag{4.30}$$

Hence, the values of C and D will yield as followings;

$$C = 0.7892$$

$$D = 0$$

Table 4.8 shows required parameters to calculate the values for sensitivity analysis.

Table 4.8: Parameters required for sensitivity analysis

Parameter	Cruise	Loiter
C_P	0.8161	0.844
η_p	0.7	0.7
L/D	15	13
V (mph)	34.18	24.85
R (sm)	3	0
E	0	1

By using Eq. (4.28), the value of F is equal to 2.5 lb. The value of calculated F was used in equation given in Table 4.9 and values for range sensitivity and endurance sensitivity was obtained and tabulated as in Table 4.10.

Table 4.9: Sensitivity equations involved to find the sensitivities values

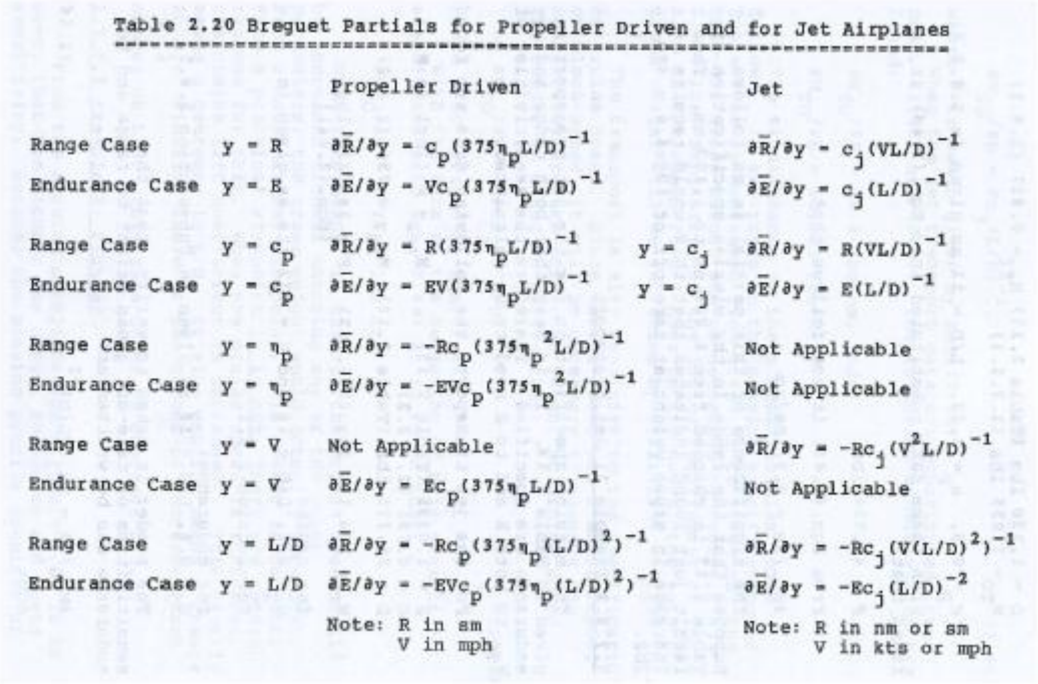


Table 2.20 Breguet Partials for Propeller Driven and for Jet Airplanes

		Propeller Driven		Jet
Range Case	$y = R$	$\partial\bar{R}/\partial y = c_p(375\eta_p L/D)^{-1}$		$\partial\bar{R}/\partial y = c_j(VL/D)^{-1}$
Endurance Case	$y = E$	$\partial\bar{E}/\partial y = Vc_p(375\eta_p L/D)^{-1}$		$\partial\bar{E}/\partial y = c_j(L/D)^{-1}$
Range Case	$y = c_p$	$\partial\bar{R}/\partial y = R(375\eta_p L/D)^{-1}$	$y = c_j$	$\partial\bar{R}/\partial y = R(VL/D)^{-1}$
Endurance Case	$y = c_p$	$\partial\bar{E}/\partial y = EV(375\eta_p L/D)^{-1}$	$y = c_j$	$\partial\bar{E}/\partial y = E(L/D)^{-1}$
Range Case	$y = \eta_p$	$\partial\bar{R}/\partial y = -Rc_p(375\eta_p^2 L/D)^{-1}$		Not Applicable
Endurance Case	$y = \eta_p$	$\partial\bar{E}/\partial y = -EVc_p(375\eta_p^2 L/D)^{-1}$		Not Applicable
Range Case	$y = V$	Not Applicable		$\partial\bar{R}/\partial y = -Rc_j(V^2 L/D)^{-1}$
Endurance Case	$y = V$	$\partial\bar{E}/\partial y = Ec_p(375\eta_p L/D)^{-1}$		Not Applicable
Range Case	$y = L/D$	$\partial\bar{R}/\partial y = -Rc_p(375\eta_p (L/D)^2)^{-1}$		$\partial\bar{R}/\partial y = -Rc_j(V(L/D)^2)^{-1}$
Endurance Case	$y = L/D$	$\partial\bar{E}/\partial y = -EVc_p(375\eta_p (L/D)^2)^{-1}$		$\partial\bar{E}/\partial y = -Ec_j(L/D)^{-2}$
		Note: R in sm V in mph		Note: R in nm or sm V in kts or mph

Source: Airplane Design Part I, Roskam (2005)

Table 4.10: Sensitivities of the range and endurance values

Range	Sensitivities	Endurance
0.02926	R/E	0.04024
0.07619	C_P	0.7282
-0.08883	η_p	-0.8780
-	V	-0.02473
-0.004145	L/D	-0.04728

4.5 EMPENNAGE SIZING

Empennage sizing refers to the tail of the aircraft. Tail of the aircraft consists of horizontal stabilizer and vertical stabilizer (Raymer, 2006). Elevator was used as a control surface in horizontal stabilizer with longitudinal stability. Rudder was used as a control surface with yawing stability in vertical stabilizer. Sizing of horizontal and vertical stabilizer important to give the stability and ease the controlling of the aircraft from crash landing. The size of the stabilizer determined the stability of the control surface. The type of tail chosen was to be a conventional tail.

4.5.1 Conventional Tail Design

Conventional tail is used in most of the aircraft. Conventional tail is easily constructed. It is also have a simpler design which had lightest weight and lower drag force. Conventional tail was attached to the fuselage and supported by the fuselage structure.

4.5.1.1 Volume Coefficients

Sizing of the horizontal stabilizer initiated with finding the values of volume coefficients. A volume coefficient chosen was to be as follows as stated in an aircraft performance and design (Anderson, 1999).

$$V_{HT} = 0.7$$
$$V_{VT} = 0.04$$

A larger value of volume coefficients was chosen so that it will have a higher stability. Higher volume coefficients will increase the surface panform area. The values chosen is within the boundary given of $0.04 \leq V \leq 0.8$. Too larger values of volume coefficients will increase drag force at the tail and put off excessive weight and will effect the stability of an aircraft. The value chosen was in between the range and is used in most of the aircraft.

4.5.1.2 Tail Area, S_H and S_V

`Tail area is important because it provided with the movement for an aircraft in pitch and yaw direction. Tail area designed as small as possible but large enough to provide stability to the aircraft. Tail area was calculated by using Eq. (4.31) for horizontal tail and Eq. (4.32) for vertical tail. Few parameters such as aspect ratio, wing span, MAC and area of the wing was calculated and tabulated as in Table 4.11;

Table 4.11: Properties of the main wing

Parameter	Value
Aspect Ratio, AR	6
Wing span, b_w	1.5 m
MAC, C_{mean}	0.24 m
Area, S_w	0.2676 m^2

$$S_{HT} = \frac{V_{HT}\, C_{mean}\, S_w}{X_H} \tag{4.31}$$

$$S_{HT} = \frac{(0.7)\,(0.24)\,(0.2676)}{0.45}$$

$$= 0.09990 \text{ m}^2$$

$$S_{HT} = \frac{V_{HT}\, b_w\, S_w}{X_V} \tag{4.32}$$

$$= \frac{(0.04)\,(1.5)\,(0.2676)}{0.45}$$

$$= 0.03568 \text{ m}^2$$

4.5.1.3 MAC for Horizontal Tail

Aspect ratio chosen is lower than the main wing. The lower aspect ratio will have higher stall at higher angle of attack. Horizontal tail provides control for the aircraft if the wing of the aircraft having higher stall. Table 4.12 shows parameters involved for horizontal sizing.

Table 4.12: Main parameters for the horizontal stabilizer sizing

Horizontal tail area, S_H	0.0990 m^2
Aspect Ratio, AR	4

Taper ratio, λ_H (for straight wing)	1
Horizontal tail span, b_H	0.63 m

The root chord and tip chord was calculated by using Eq. (4.31) and Eq. (4.32).

$$C_{root} = \frac{2s}{b(1+\lambda)}$$

$$= 1.571 \text{ m}$$

$$C_{tip} = \lambda.\ C_{root}$$

$$= 1.571 \text{ m}$$

The values that were obtained in Eq. (4.31) and Eq. (4.32) were used to evaluate the MAC position on the horizontal stabilizer shown in Eq. (4.33). The distance from root to MAC was determined by using Eq. (4.34).

$$C_{MAC} = C_{root} - \frac{2\left(C_{root} - C_{tip}\right)\times(\frac{1}{2}C_{root}+C_{tip})}{3(C_{root}+C_{tip})} \tag{4.33}$$

$$= 1.321 \text{ m}$$

$$Y_{MAC} = \frac{b}{6}\left(\frac{1+2\lambda}{1+\lambda}\right) \tag{4.34}$$

$$= (0.105)\ (1.5)$$

$$= 0.1575 \text{ m}$$

4.5.1.4 MAC Positioning for Vertical Tail

Aspect ratio chosen is lower than the main wing. Vertical stabilizer only move in lateral direction. Table 4.13 shows parameters involved for vertical sizing.

Table 4.13: Main parameters for the vertical stabilizer sizing

Vertical tail area, S_H	0.03568 m^2
Aspect Ratio, AR	4
Taper ratio, λ_H (for straight wing)	1
Vertical tail span, b_H	0.3778 m

The calculation involved is as same as the calculation involved for the horizontal stabilizer. The root chord and tip chord was calculated by using Eq. (4.31) and Eq. (4.32).

$$C_{root} = \frac{2s}{b(1+\lambda)}$$

$$= 0.0944 \text{ m}$$

$$C_{tip} = \lambda.\ C_{root}$$

$$= 0.0944 \text{ m}$$

The values that were obtained in Eq. (4.31) and Eq. (4.32) were used to evaluate the MAC position on the vertical stabilizer shown in Eq. (4.33). The distance from root to MAC was determined by using Eq. (4.34).

$$C_{MAC} = C_{root} - \frac{2\left(C_{root} - C_{tip}\right)\times(\frac{1}{2}C_{root}+C_{tip})}{3(C_{root}+C_{tip})}$$

$$= 0.0694 \text{ m}$$

$$Y_{MAC} = \frac{b}{6}\left(\frac{1+2\lambda}{1+\lambda}\right)$$

$$= (0.005947)\ (1.5)$$

$$= 0.00892 \text{ m}$$

4.5.1.5 Elevator sizing for Horizontal Stabilizer

The elevator should be in range of 20% to 30% of the horizontal chord length. By using the Eq. (4.35), the values of chord length and span of the elevator was found.

$$0.20CH \leq C_{elevator} \leq 0.30CH \qquad (4.35)$$

$$C_{elevator} = 0.30CH$$
$$= 0.054 \text{ m}$$

$$b_{elevator} = 0.7b$$
$$= 0.441 \text{ m}$$

4.5.1.6 Rudder sizing for Vertical Stabilizer

The rudder should be in range of 20% to 30% of the vertical chord length. By using the Eq. (4.36), the values of chord length and span of the elevator was found.

$$0.20CV \leq C_{elevator} \leq 0.30CV \qquad (4.36)$$

$$C_{rudder} = 0.30CV$$
$$= 0.072 \text{ m}$$

$$B_{rudder} = 0.7b$$
$$= 0.2645 \text{ m}$$

4.6 CENTRE OF GRAVITY

Centre of gravity is the place where the sum of the moment is equal to zero where the weight is balance (Lee, 2004). Centre of gravity help to stabilize the aircraft from crash landing.

Table 4.14: Weight Fraction to determine Centre of gravity of an aircraft

Item	**W_t(N)**	**X(m)**	**Y(m)**	**W.X(N.m)**	**W.Y(N.m)**
Fuselage Structure	0.600	0.570	0.045	0.342	0.027
Equipment	2.060	0.470	0.045	0.968	0.0927
Landing Gear	4.081	0.430	0.000	1.755	4.081
Fuel in Fuselage	0.652	0.235	0.0225	0.153	0.0147
Payload	5.033	0.035	0.045	0.176	0.226
Special Equipment	-	-	-	-	-
Horizontal Tail	0.200	0.980	0.030	0.196	0.006
Vertical Tail	0.100	0.925	0.035	0.0925	0.0035
Wing Group (unswept configurations)	7.799	0.190	0.045	1.482	0.351
Wing Group (swept configurations)	7.799	0.230	0.045	1.793	0.351

$$\Sigma\, W.X = 5.1645 \text{N.m}$$

$$\Sigma W.Y = 4.8019 \text{N.m}$$

The parameters of the wing are,

Weight, W = 25.6041 N

Wing Area, A = 0.2676 m^2

Wing Span, x = 1.5 m

Wing root chord, C_r = 0.180 m

Tip Chord, C_t = 0.180 m

Mean Aerodynamic centre, MAC= 0.045 m

The quarter chord of the MAC was calculated by using Eq. (4.37);

$$\begin{aligned} \textit{Quarter chord of MAC} &= \frac{1}{4}(0.045) \\ &= 0.01125 \text{ m} \end{aligned} \tag{4.37}$$

Leading edge of wing root chord, $x_{le} = x_{le} + 0.01125$

Location of the wing centre of gravity from the leading edge of wing root chord was calculated by using Eq. (4.38);

$$MAC + (0.4-0.25) \times MAC \tag{4.38}$$

$$= 0.045+0.15(0.045)$$

$$= 0.05175 \text{ m}$$

The location of centre of gravity calculated based on Eq. (4.39);

$$W.X + Wx\,(x_{le}+0.05175) = W.Y + W\,(x_{le}+0.01125) \tag{4.39}$$

$$5.1645+25.6041(1.5)\,(x_{le}+0.05175) = 4.8019+25.6041(x_{le}+0.01125)$$

$$x_{le} = 0.109 \text{ m}$$

$$\textit{Centre of gravity, CG} = 0.109 + 0.01125$$

$$= 0.1203 \text{ m}$$

4.6.1 Static Margin

Static margin is a percentage of mean aerodynamic centre (Anderson, 1999). When the static margin is zero the aircraft is neutrally stable. For designing purposes, the static margin will be in range of 5% to15% percentage ahead of neutral point. Eq. (4.40) used to find the percentage of the static margin.

$$\textit{Static margin} = \frac{x_n - x_0}{c_0} \tag{4.40}$$

$$= \frac{0.1484 - 0.1203}{0.045}$$

$$= 4.21$$

$$\cong 5\%$$

4.6.2 Neutral Point

Neutral point is referring to an aerodynamic centre of an aircraft. As the angle of attack increases, neutral point will change the position of the net lift increments. Neutral point is affected by the main wing, stabilizer, surfaces and fuselage (Raymer, 2009). The bigger the stabilizer area relative to the wing area and longer the tail moment arm relative to the wing chord, the further the neutral point will be and keep centre of gravity ahead of neutral point for stability (Gerard, 2007).

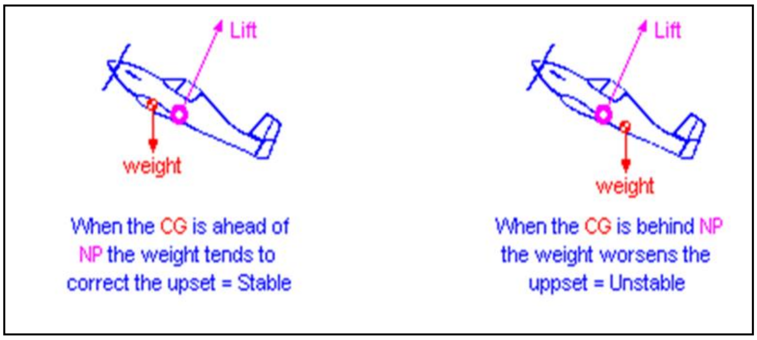


Figure 4.3: Effect of a neutral point on the stability of an aircraft

Source:

file:///C:/Users/arunmc/Desktop/cad/psm%20finding/Stability%20Concepts.html

Eq. (4.41) shows calculation to determine the neutral point of the designed aircraft and Eq. (4.42) shows tail volume ratio for the aircraft.

$$D = \frac{L \text{ x } Stabilizer\ Area}{Main\ Wing\ Area + Stabilizer\ Area} \qquad (4.41)$$

$$= \frac{0.5495\text{x } 0.0990}{0.2676 \text{ x } 0.0990}$$

$$= 0.1484 \text{ m}$$

Tail Volume Ratio, Vbar = $^{4}\sqrt{}$*AR.0.25 (Stabilizer net area/Wing gross area) (L/Wing*$_{MAC}$*)*

$$= 0.821 \qquad (4.42)$$

4.6.3 CG Envelope Calculations

The Centre of Gravity Envelope was calculated by omitting few major weights of the aircraft. Those weights were W_{fuel}, $W_{payload}$ and $W_{empty.}$ Table 4.15 shows parameters involved in calculating the CG Envelope (Raymer, 2006).

Table 4.15: Parameters to calculate the CG Envelope

Configuration	**W_{EMPTY}**	**W_{FUEL}**	**$W_{PAYLOAD}$**	**$\bar{x}$, unswept configuration**	**$\bar{y}$, swept configuration**	**W**
1	20.1105	0	0	0.3258	0.3074	20.1105
2	20.1105	0	5.033	0.2442	0.2409	25.1435
3	20.1105	5.5917	5.033	0.2516	0.2339	30.7354
4	20.1105	5.5917	0	0.3220	0.2954	25.7022

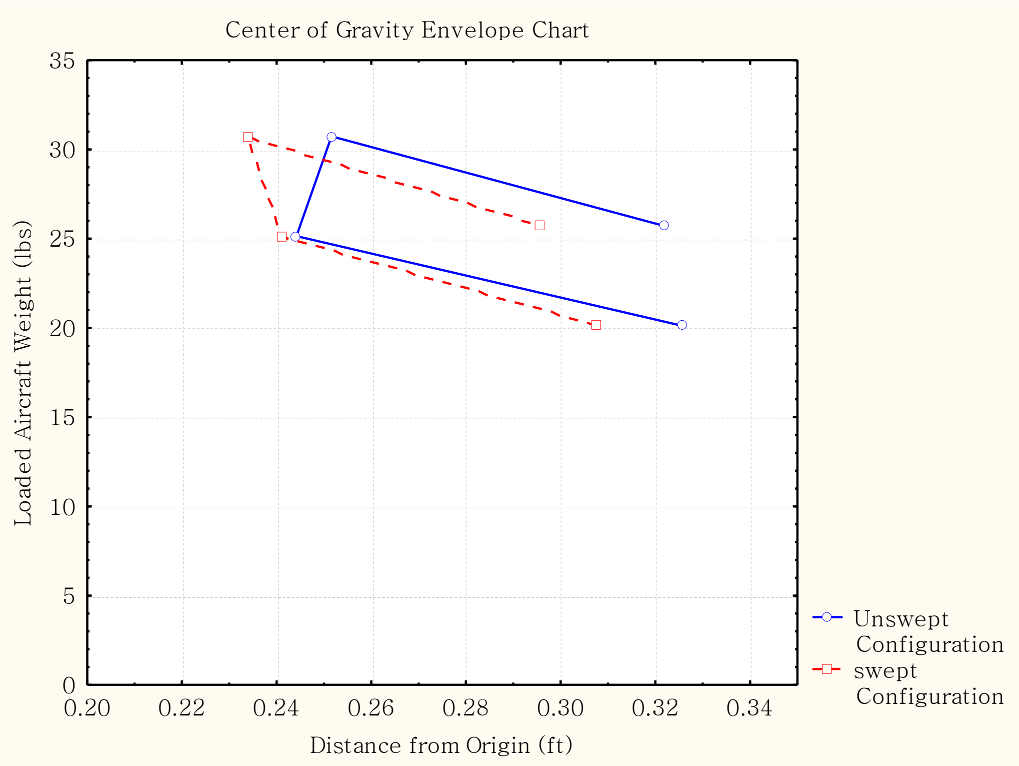


Figure 4.4: CG Envelope

4.7 DESIGN CONFIGURATION

The design of an aircraft is shown in the Figure 4.4 and Figure 4.5. The aircraft was designed by using AutoCAD software. The design was completed within an empennage design and an airfoil shape design. The detail designs are shown in Appendix E.

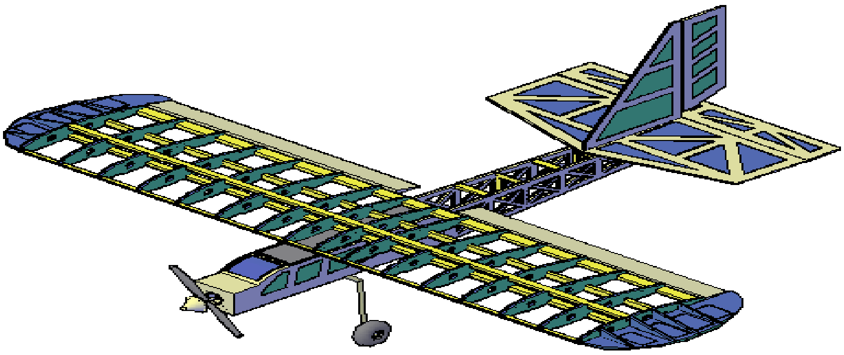


Figure 4.5: Aircraft shaded view

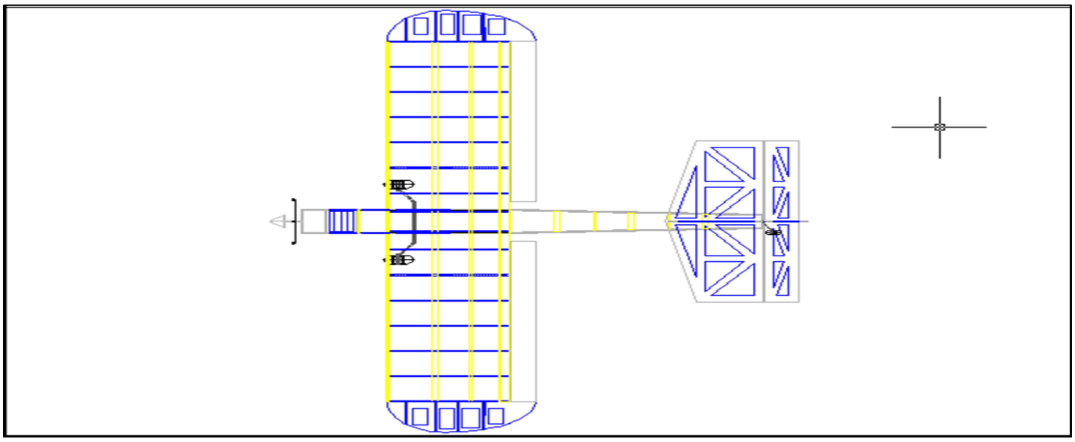


Figure 4.6: Aircraft top view

4.9 DISCUSSIONS

The studies of the trainer aircraft can be divided into few major parts that are wing configuration, fuselage configuration and empennage configuration. For this project, all assumption and theoretical values calculated based on the reference model of Alpha 60 trainer aircraft and aircraft designing books. The technical task needs to be done before designing the aircraft. Literature review of the topic is important to find the relationship between each configuration of the aircraft such as determining the centre of the gravity of the aircraft, MAC position of the wing and horizontal stabilizer with the vertical stabilizer.

Design of the aircraft can be divided into three phases which are conceptual design, preliminary design and detail design. Conceptual design includes seven intellectual pivot points that are requirements, weight estimation, critical performance parameters, configuration layout, better weight estimation, performance analysis and optimization. In the preliminary stage, sensitivities analysis is important to determine the sensitivities of the aircraft during cruise and endurance. During the preliminary design, a model of the small scale trainer aircraft is proposed by considering the entire configuration such as wing configuration, empennage sizing and fuselage configuration. The configuration design also includes the studies of the tail sizing, weight and balance analysis, drag polar determination and CG Envelope.

Detail design is drawn by using AutoCAD and for more precise sizing, the aircraft is to be analysis in wind tunnel so the prototypes can be manufactured in mass production. The objective of this project is to design a small scale trainer aircraft. The trainer aircraft need to be cost effective and could perform according to the specification requirements. The trainer aircraft is implemented with a recovery parachute to avoid crash landing and LED for night vision flight.

By doing weight estimation, the takeoff weight, empty weight and fuel weight of the aircraft are calculated. W_{TO} is equal to 2.60 kg, W_E are equal to 2.05 kg and W_F is equal to 0.57 kg. The takeoff weight compromise of empty weight, engine weight control system weight and payload weight. Empty weight refers to the weight of the body and also the unusable fuel. Fuel weight refers to the amount of the fuel carries by the aircraft. Additional fuel need to be onboard for safety reason.

The aircraft sizing follow the FAR sizing for all FAR 23.65 and FAR 23.77 for all operating engine. FAR 23.67 can be neglected because it is used for one engine operating. FAR is a basis of the airworthiness purpose. By doing the FAR sizing, matching diagram is drawn to find the values of the wing loading and power loading. Wing loading is equal to 1.98 lb/ft^2 and power loading is equal to 20 lb/hp. By using the wing loading, wing area and wing span can be obtained by taking the aspect ratio equal to 6. The higher wing loading will lead to higher takeoff speeds. Power provided is 0.3430 kW and wing area is 2.88 ft^2. By using the 0.46 hp mini glow engine, power rated can be achieved. Larger wing area will generates more lift and cause the aircraft to fly. Due to the different in the air pressure on the surface of the wing, the aircraft can lift smoothly. To increase the flight time, engine power is reduce by reducing the pull on the throttle for longer flight time and reduce the fuel consumption.

The sensitivities analysis was done to check the parameter that was dependent to takeoff weight. The sensitivity for was calculated for both range and endurance cases. For range sensitivities, for every mile added the takeoff weight will increase by 0.02926 lb. Increases in specific fuel consumption, C_p will increases the takeoff weight by 0.00229 lb. As the propeller efficiency, η_p and lift to drag ratio, L/D increased the takeoff weight will decrease and it is proven by the negative sign. For endurance, for every hour added, the takeoff weight will increase by 0.04024 lb due to added fuel. Increases in specific fuel consumption, C_p will increases the takeoff weight by 0.02929 lb. By reducing the propeller efficiency, η_p and increasing the cruise speed the net weight will increases.

The type of the design configuration for tail is conventional tail. Conventional generate more lift and stable. It is easy to construct and control the lateral and longitudinal moments. Empennage consist both horizontal stabilizer and vertical stabilizer. The area of both stabilizers needs to be accurate and large enough to support the aircraft. Larger tail area will give better control movement for the aircraft. The horizontal stabilizer area is 0.0990 m^2 and the area of the vertical stabilizer is 0.03568 m^2.

The aspect ratio chosen is 6 used in most of the trainer aircraft. The aspect ratio of tail is less than aspect ratio of the main wing. The lower aspect ratio will have higher angle of attack. Lower aspect ratio will help to recover the aircraft to its position by reducing the stall at the tail. In this case aspect ratio of the horizontal tail is equal to 4 and for vertical tail is 1.5. For a straight wing configuration, the taper ratio is equal to 1 hence the tip chord and root chord is equal. The mean aerodynamic centre, MAC of wing is calculated and lies at one quarter from the leading edge of the airfoils. The aerodynamic centre is the place where the pitching moment for the aircraft will remains the same at any angle of attack. The airfoil chosen is Clark Y and flat bottom. The airfoil shape is design by using the XFOILS software. To improve the flight performance, the airfoils should have low drag coefficients and high lift coefficients.

Finally, the aircraft is designed by using the AutoCAD and fabricated to get the entire results as discussed earlier. Fabrication need to be done precisely to avoid any major tolerance that could effect the performance of the aircraft. Small tolerance within 0.02cm is accepted where it does not effect too much on the aircraft performance during flight. Balsa wood and plywood are used for body structure. Weight balancing is important so that the aircraft will be nose heavy to avoid crash landing. Table 4.16 and Table 4.17 show the summarizing of the designed trainer aircraft.

Table 4.16: Finalized Aircraft Sizing Values

Parameter	Value
Aircraft length	1 m
Wing span, b_w	1.5 m
Takeoff weight, W_{TO}	2.83 kg
Empty weight, W_E	2.05 kg
Fuel Weight, W_F	0.57 kg
Wing loading, (W/S)	1.98 lb/ft^2
Power Loading, (W/P)	20 lb/hp
Wing area, S_w	0.2676 m^2
Power, P	0.3034 kW

Table 4.17: Finalized Empennage Sizing Values

Parameter	Horizontal Tail	Vertical Tail
Tail area, S_H and S_V	0.0990 m^2	0.03568 m^2
Span, b_H and b_V	0.6300 m	0.3778 m
Root chord, C_{root}	1.571 m	0.0944 m
Tip chord, C_{tip}	1.571 m	0.0944 m
MAC, $\bar{C}$	0.1575 m	0.00892 m

Aerodynamic centre, a.c	1.321 m	0.0694 m
Volume coefficients, V_H and V_V	0.7	0.04
Aspect ratio, AR	4	1.5
Taper ratio, λ	1.0	1.0
Airfoil selection	Clark Y	Clark Y
Incidence angle	0	0

Table 4.18: Summaries of Performance Analysis

	Requirements Parameter	**Performance Analysis**
Range	50 meter radius	50 meter radius
Endurance	20 minutes	20 minutes
Takeoff Distance	< 30 m	21.4548 m
Landing Distance	10 m	9.1653 m
Altitude	1000 ft	1000 ft
Loiter Speed	> 25 km /h	25 km /h
Cruise Speed	< 40 km/h	40 km/h

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

The overall studies of the project was about designing and fabricating a small scale trainer aircraft. Initially, surveys has been conducted to find suitable model as a reference model. Alpha 60 was chosen as a reference model to fabricate the trainer aircraft. Weight estimation was determined by using mass fuel fraction and statistical analysis. Data obtained from the statistical analysis was used to find the takeoff weight, empty weight and fuel weight. The weight of the aircraft is 2.83 kg and the wing span is 2 meter. From the matching diagram, values of wing loading is equal to 1.98 lbs/ft^2 and power loading is equal to 20 lbs/hp. High wing with straight configuration gave the aircraft more speed in the air. The type of the tail is conventional tail. Conventional tail give is more stable nand has lower weight ratio. The area of the horizontal stabilizer is 0.0990 m^2 and the area of the vertical stabilizer is 0.03568 m^2.

Mean Aerodynamic Centre (MAC) positioning was determined for the wing and the stabilizers. For main wing, MAC equal to 0.045 m and the centre of gravity is equal to 0.1203 m. Centre of gravity is between 5 % of static margin. Hence, neutral point is to be behind the centre of gravity. Aircraft is to be nose heavy. Clark Y airfoil was used because it give more stability and widely used in most of the trainer aircraft. The calculation used in the entired project enable for fabrication process. Parachute is used to avoid crash landing and the size of the aircraft is 1.5 meter diameter. Night mode vision will help the pilot for night flying which the aircraft is implemented with LED.

5.2 RECOMMENDATIONS

Followings reccomendations can be implemented for future research and development on designing and fabricating of small scale trainer aircraft.

- CNC machine or rapid prototyping can be used instead of jigsaw to shaping the body of the aircraft. Laser cutting is more precise and smooth compared to the jigsaw.
- High wing should be used with dihedral angle so that the aircraft can float in air and do not stall. By increasing the dihedral angle, the aircraft is more stable and easy to be controlled by the pilot's instructor.
- Retractable landing gear should be used in the aircraft for more smooth run in runaway track.It will avoid more takeoff distance and the aircraft needs short takeoff distance to fly in the air.
- Future research should allow the aircraft to takeoff and land in more restricted area and could perform well in terms of performance analysis.

5.3 COST COMMERCIALIZATION

The overall cost of the whole project is based on the hardware development. As discussed in previous chapter, the hardware development consist fabrication of the trainer aircraft. Therefore the whole project cost is depends on the cost of electronic devices, mechanical parts and also the raw materials. Table 5.1 shows the overall cost for the hardware development of this project.

Table 5.1: Table of project costing

Devices	**Specification**	**Quantity**	**Cost (RM)**
Body	Alpha type	1	280.00
Servo	Futaba	4	100.00
Propeller	11 x 9 (inch)	1	12.00
Glow Engine	Thunder Tiger 0.46hp	1	250.00
Radio control	Futaba 6 channel	1	500.00
Parachute	Recover ballistic	1	35.00
Night mode LED	Turnigy Power System	1	75.00
		TOTAL	1252.00

The total cost for the radio controlled trainer aircraft is RM 1252.00. This is not too high for aircraft configuration system and it is only for fabrication, so it can be reduced its price if it goes into market with mass production. Needless to say, the product has high potential to be commercialized.

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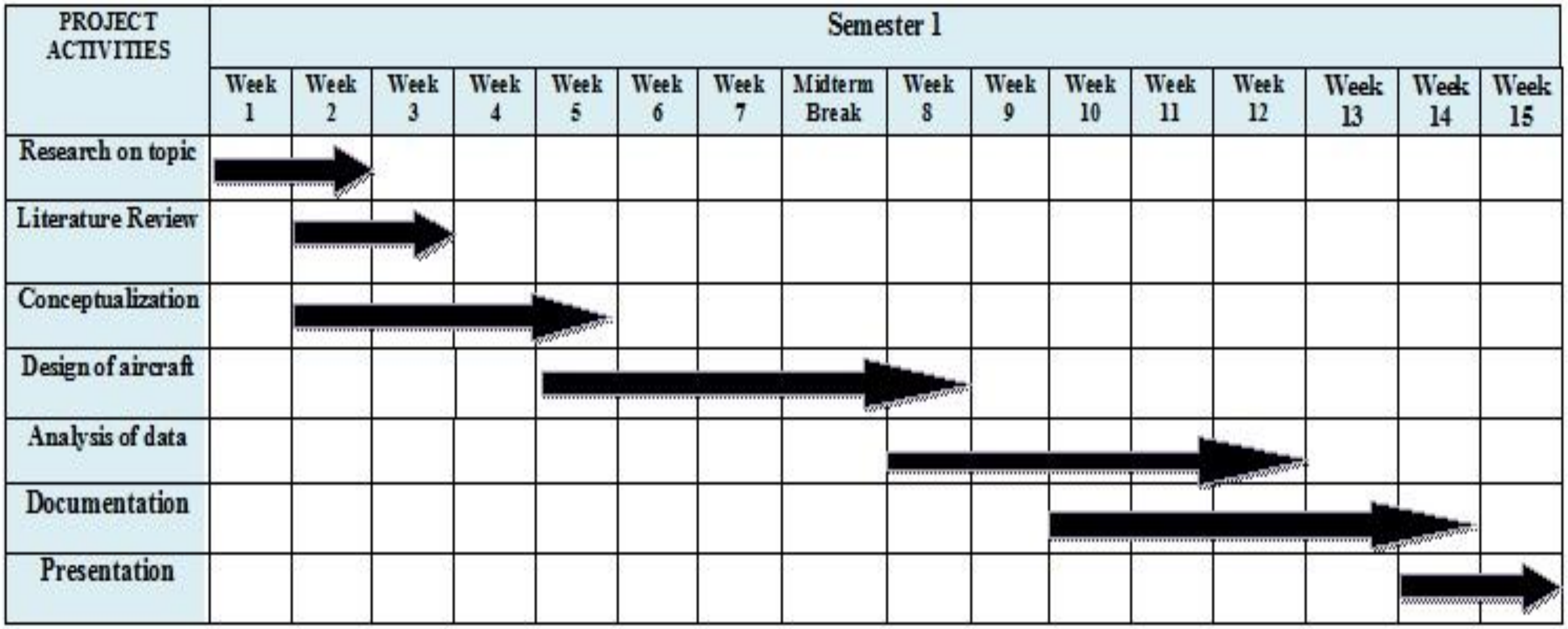
APPENDIX A1

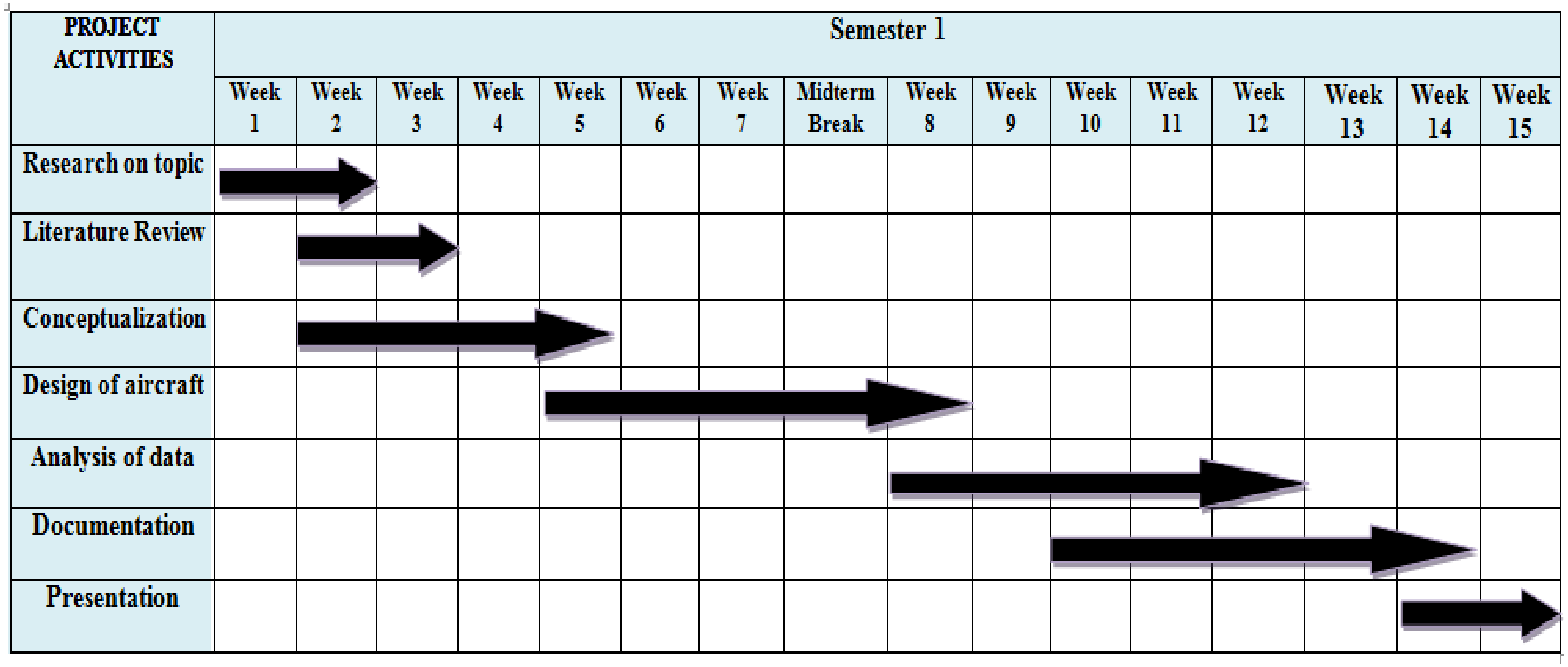
Gantt Chart for Final Year Project 1



PROJECT ACTIVITIES	Semester 1															
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Midterm Break	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
Research on topic	→	→														
Literature Review		→	→													
Conceptualization		→	→	→	→											
Design of aircraft					→	→	→	→	→							
Analysis of data									→	→	→	→	→			
Documentation											→	→	→	→	→	
Presentation															→	→

APPENDIX A2

Gantt Chart for Final Year Project 2



PROJECT ACTIVITIES	Semester 1															
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Midterm Break	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
Research on topic	→	→														
Literature Review		→	→													
Conceptualization		→	→	→	→											
Design of aircraft					→	→	→	→	→							
Analysis of data									→	→	→	→	→			
Documentation											→	→	→	→	→	
Presentation															→	→

APPENDIX A3

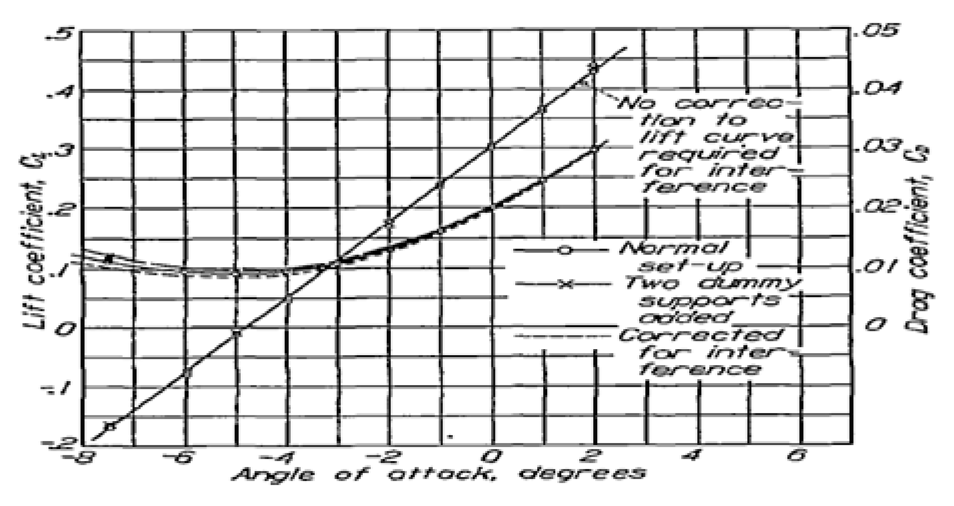
Technical Data of an Evolution 0.46 NX Glow Engine

Specification Parameters Data

• Type: 2-stroke glow	• Displacement: .47 cu in (7.65cc)
• Bore: .86 in	• Stroke: .80 in
• Cylinders: single	• Total Weight: 16.96 oz
• Engine (Only) Weight: 13.76 oz	• Muffler Weight: 3.20 oz
• Crankshaft Threads: 1/4 x 28	• Benchmark Prop: 11x6 @ 12,500 rpm
• RPM Range: 2000 to 12,500	• Fuel: 10% - 30% Nitro
• Mounting Dimensions: 44mm x 17.5mm	• Muffler Type: Cast
• Cylinder Type: ABC	• Carb Type: Barrel, with two needles
• Crank Type: Ball Bearing	

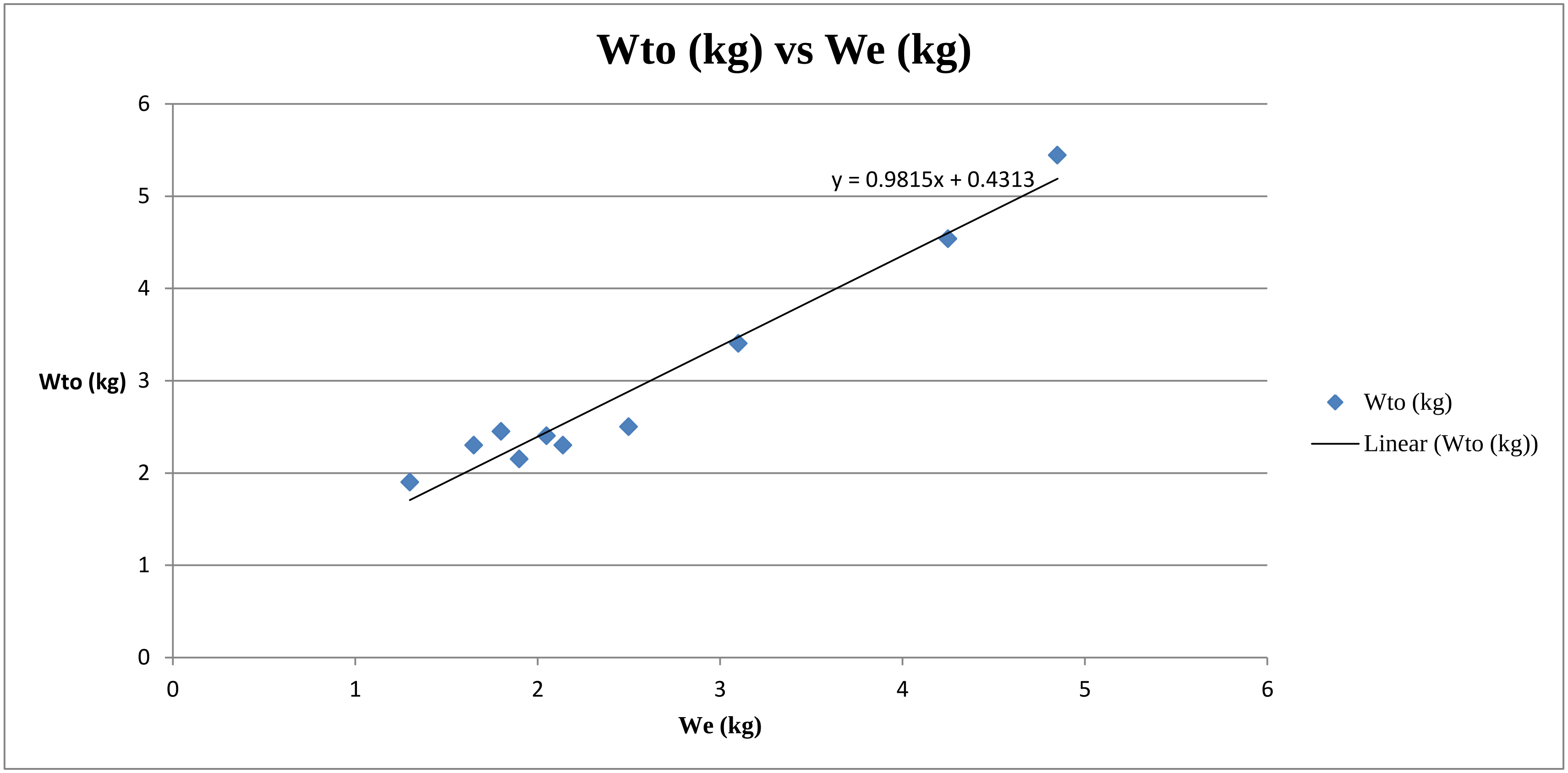
APPENDIX B1

Effect of an Angle of Attack on a Lift Coefficient, C_L



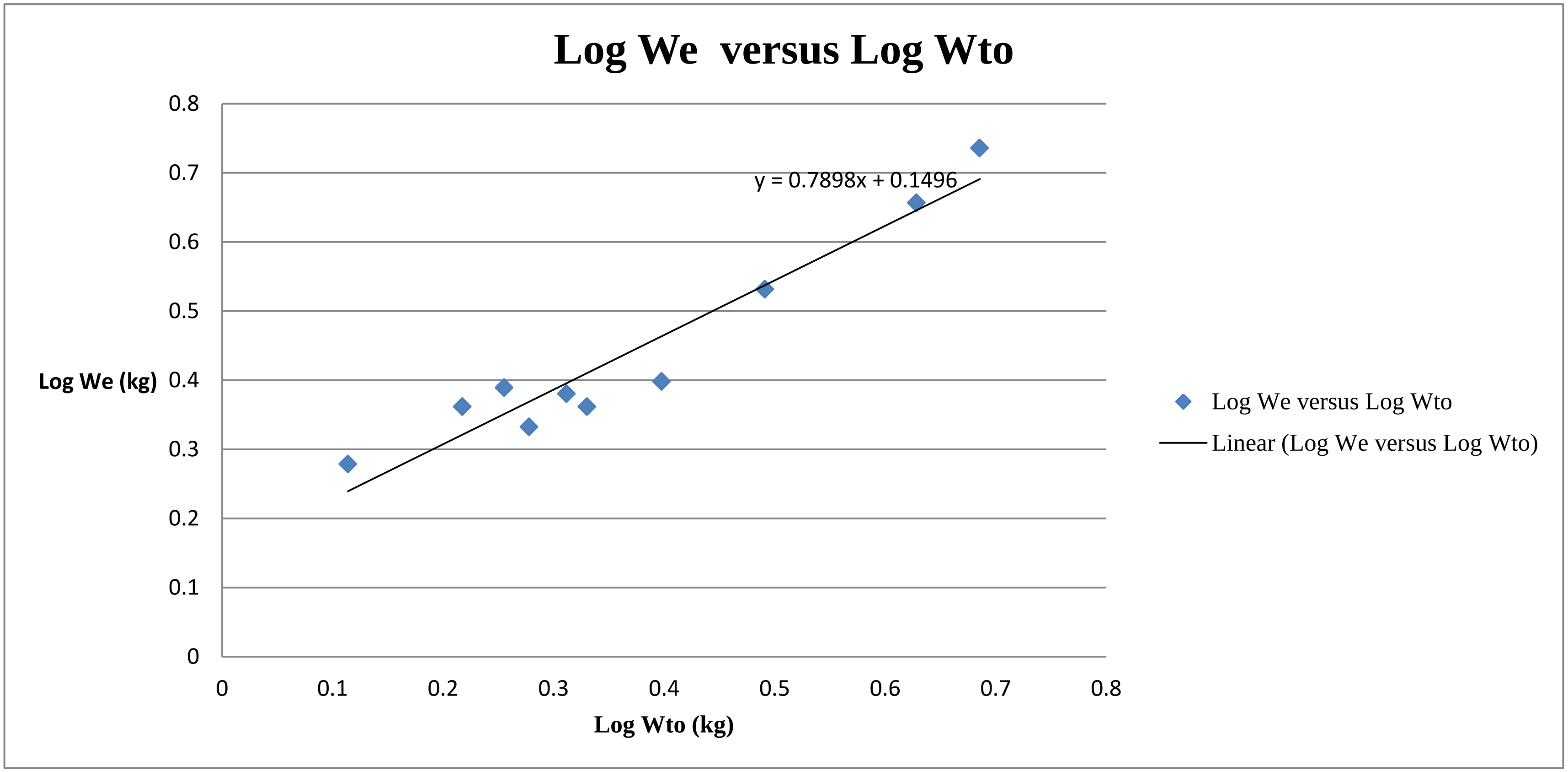
APPENDIX C1

Takeoff Weight (W_{TO}) versus Empty Weight (W_E)



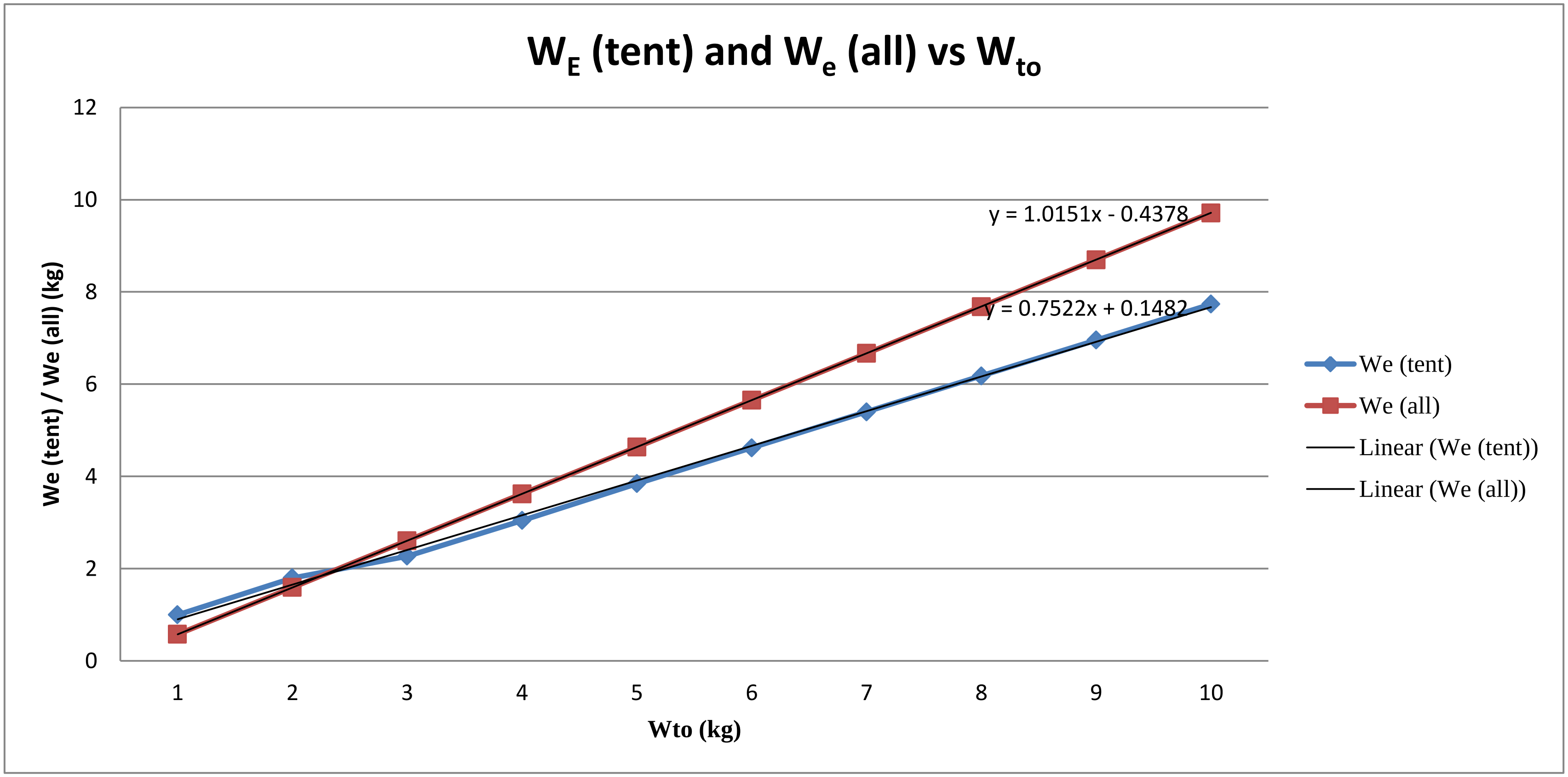
APPENDIX C2

Technology Diagram



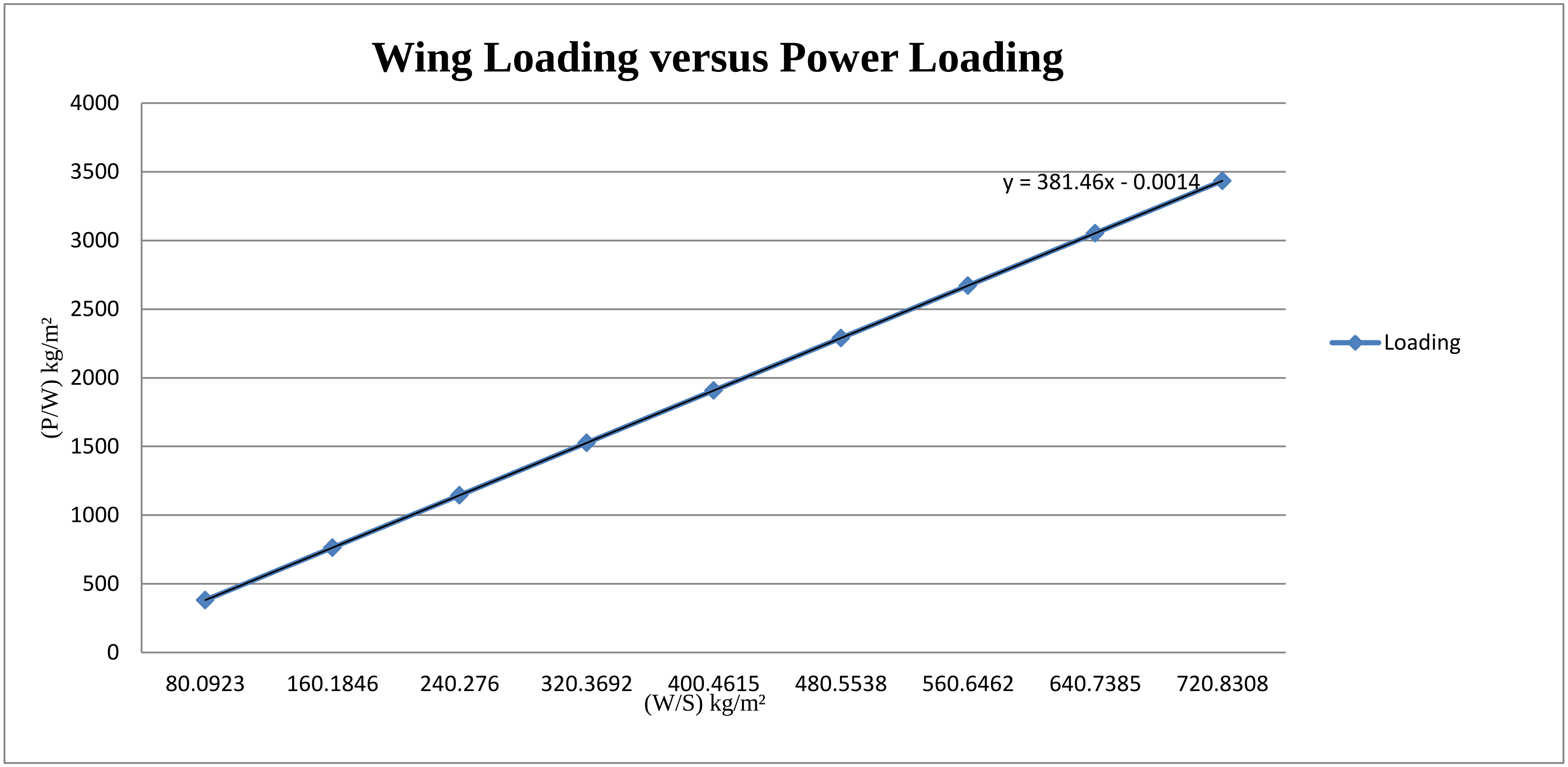
APPENDIX C3

W_E (tent) and W_E (all) vs W_{TO}



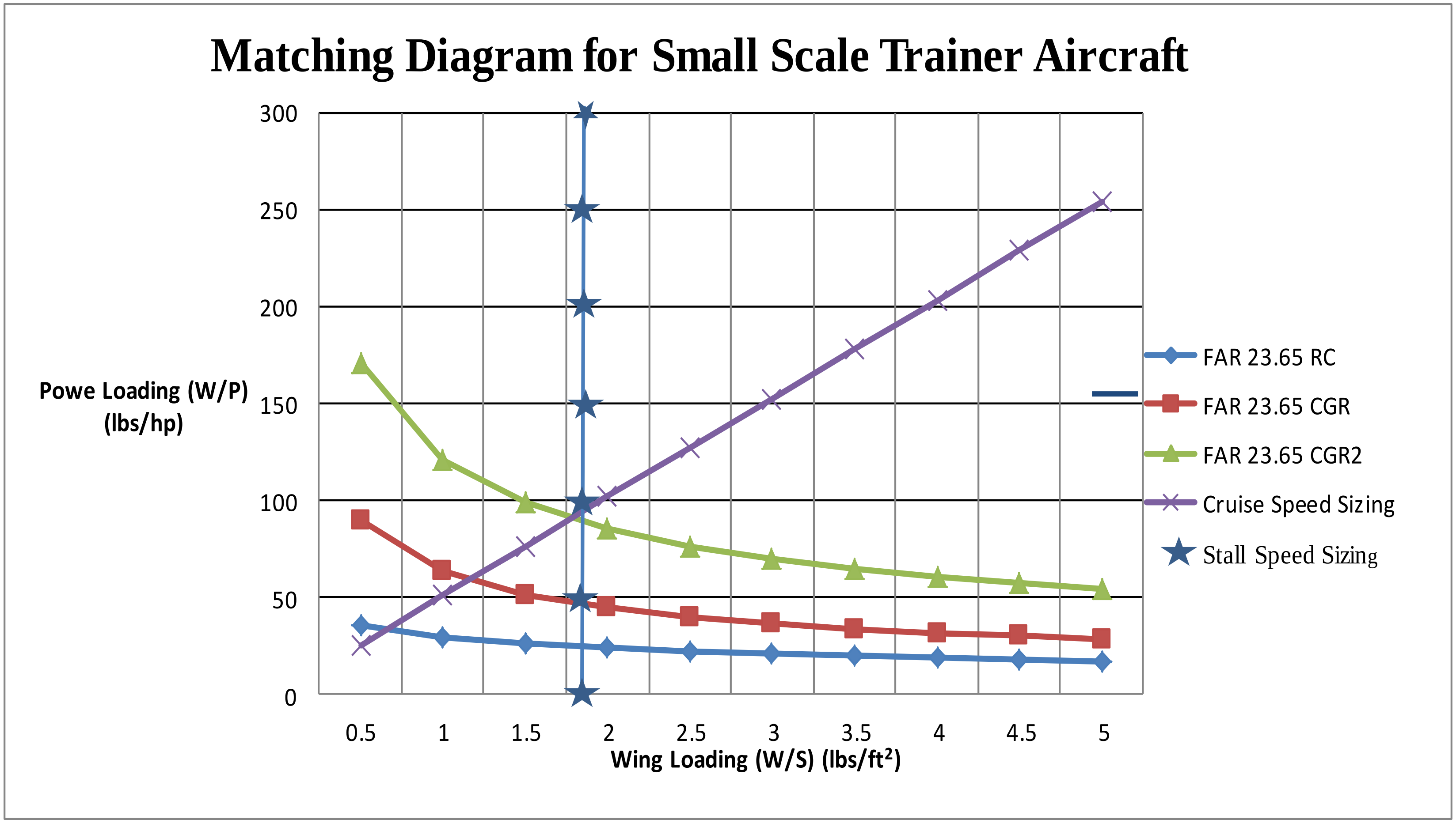
APPENDIX C4

Takeoff Sizing



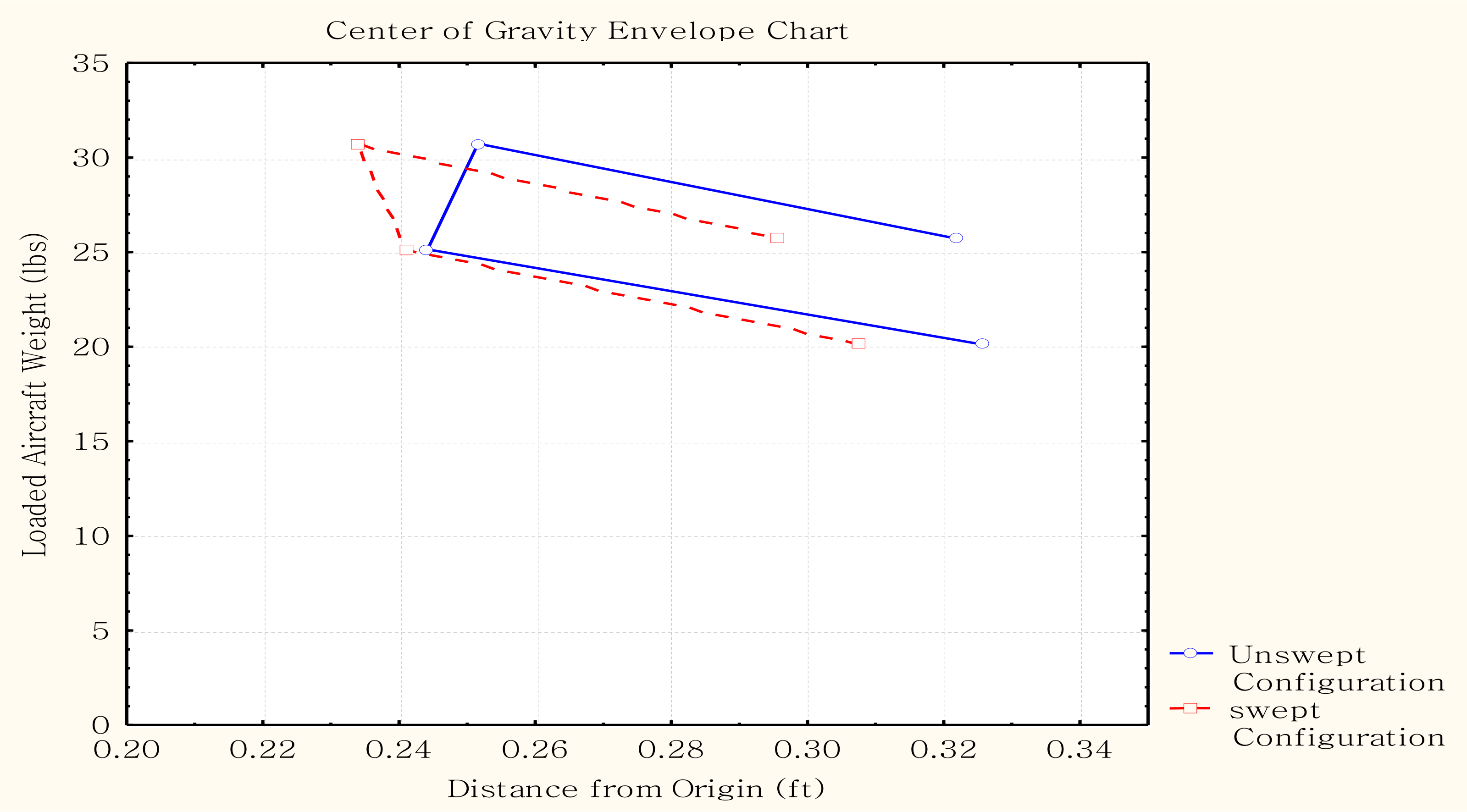
APPENDIX C5

Matching Diagram



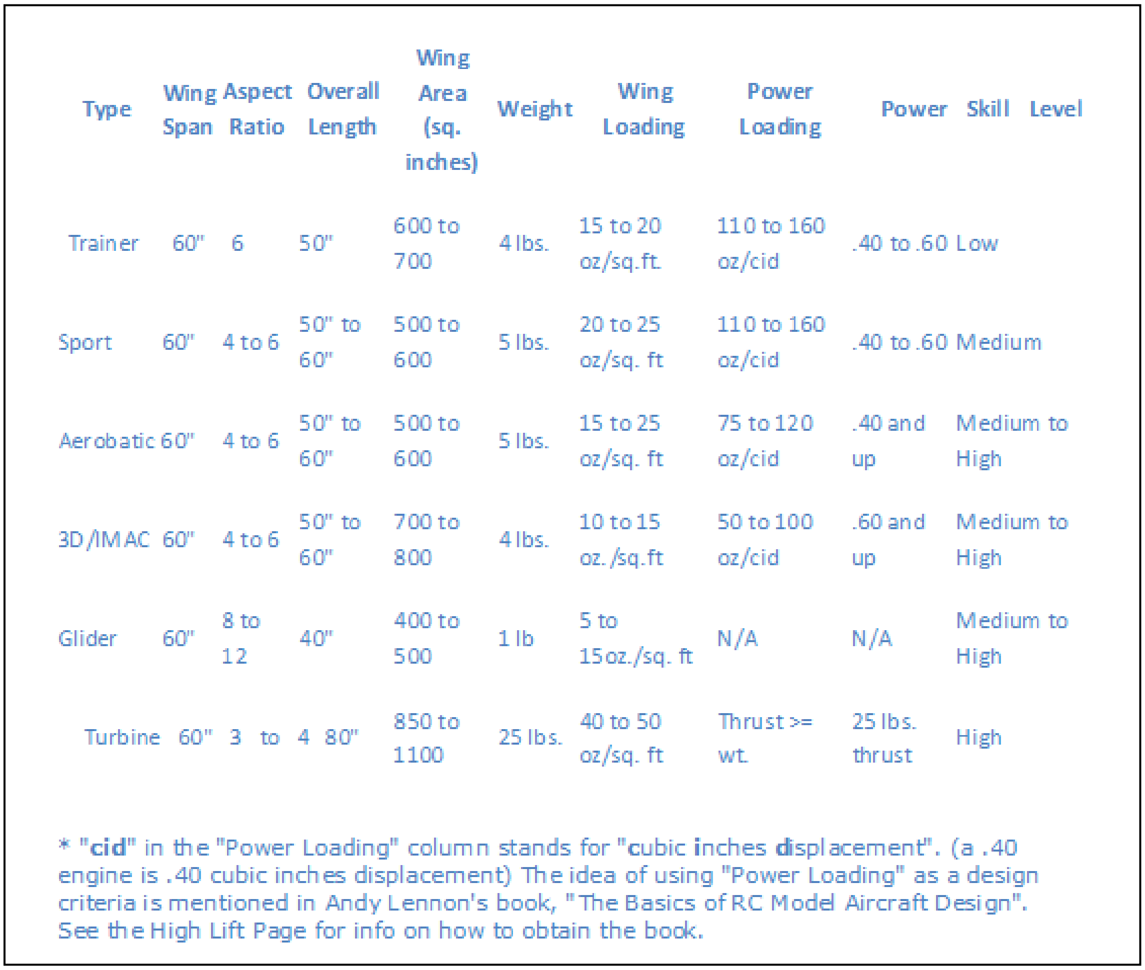
APPENDIX C6

CG Envelope



APPENDIX D1

Specification Detail of RC Trainer Aircraft

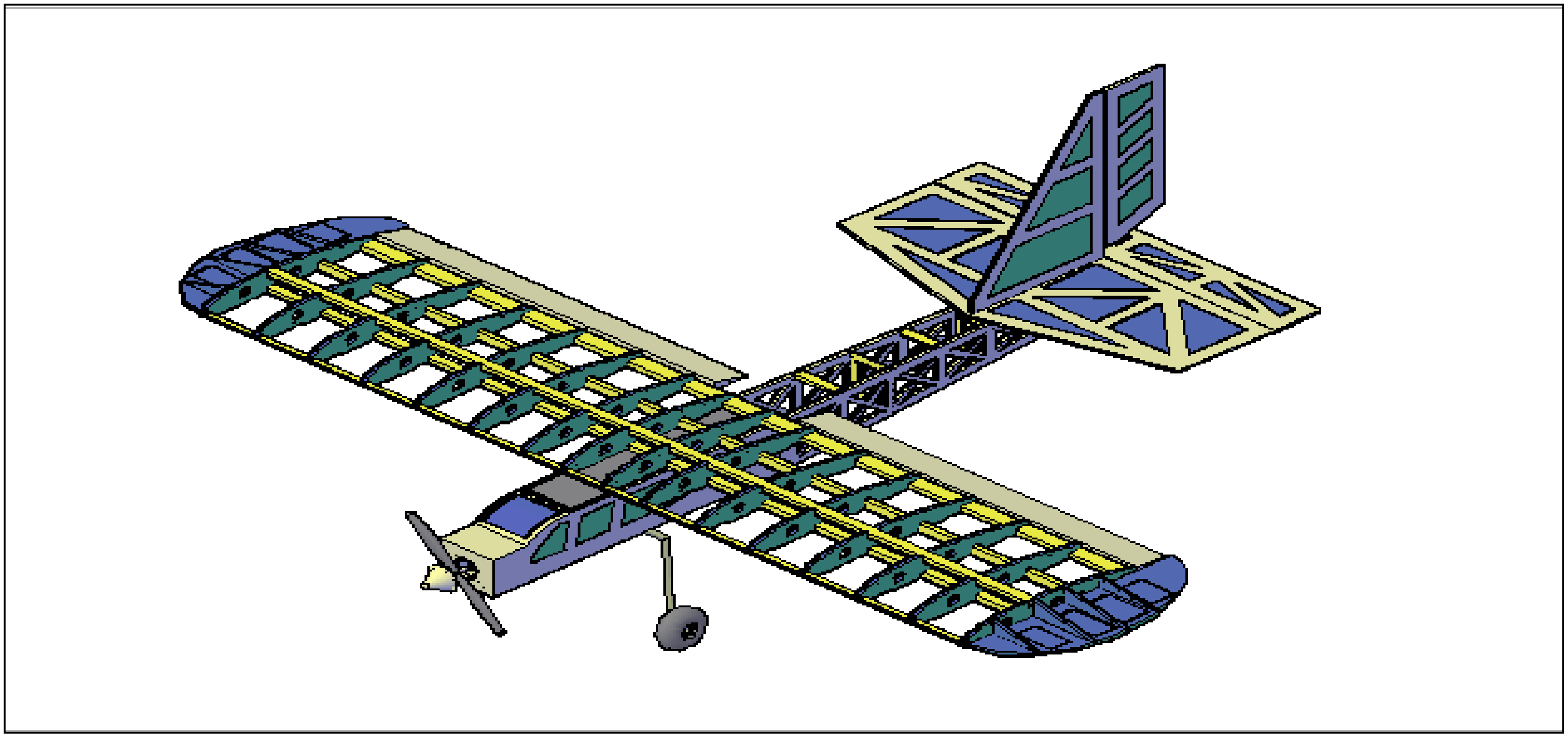


Type	Wing Span	Aspect Ratio	Overall Length	Wing Area (sq. inches)	Weight	Wing Loading	Power Loading	Power	Skill Level
Trainer	60"	6	50"	600 to 700	4 lbs.	15 to 20 oz/sq.ft.	110 to 160 oz/cid	.40 to .60	Low
Sport	60"	4 to 6	50" to 60"	500 to 600	5 lbs.	20 to 25 oz/sq. ft	110 to 160 oz/cid	.40 to .60	Medium
Aerobatic	60"	4 to 6	50" to 60"	500 to 600	5 lbs.	15 to 25 oz/sq. ft	75 to 120 oz/cid	.40 and up	Medium to High
3D/IMAC	60"	4 to 6	50" to 60"	700 to 800	4 lbs.	10 to 15 oz./sq.ft	50 to 100 oz/cid	.60 and up	Medium to High
Glider	60"	8 to 12	40"	400 to 500	1 lb	5 to 15oz./sq. ft	N/A	N/A	Medium to High
Turbine	60"	3 to 4	80"	850 to 1100	25 lbs.	40 to 50 oz/sq. ft	Thrust >= wt.	25 lbs. thrust	High

* "**cid**" in the "Power Loading" column stands for "**c**ubic **i**nches **d**isplacement". (a .40 engine is .40 cubic inches displacement) The idea of using "Power Loading" as a design criteria is mentioned in Andy Lennon's book, "The Basics of RC Model Aircraft Design". See the High Lift Page for info on how to obtain the book.

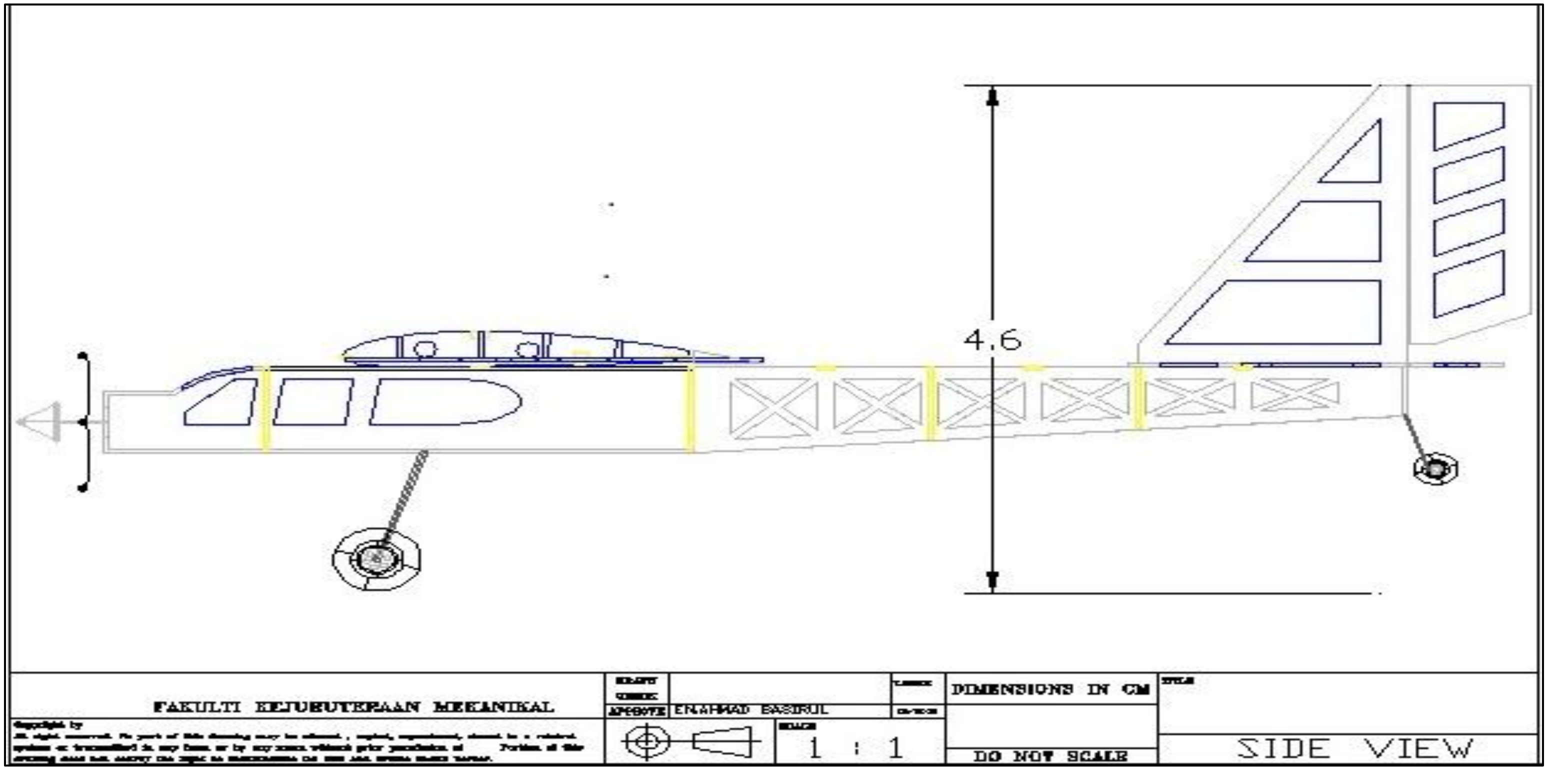
APPENDIX E1

Aircraft Shaded View



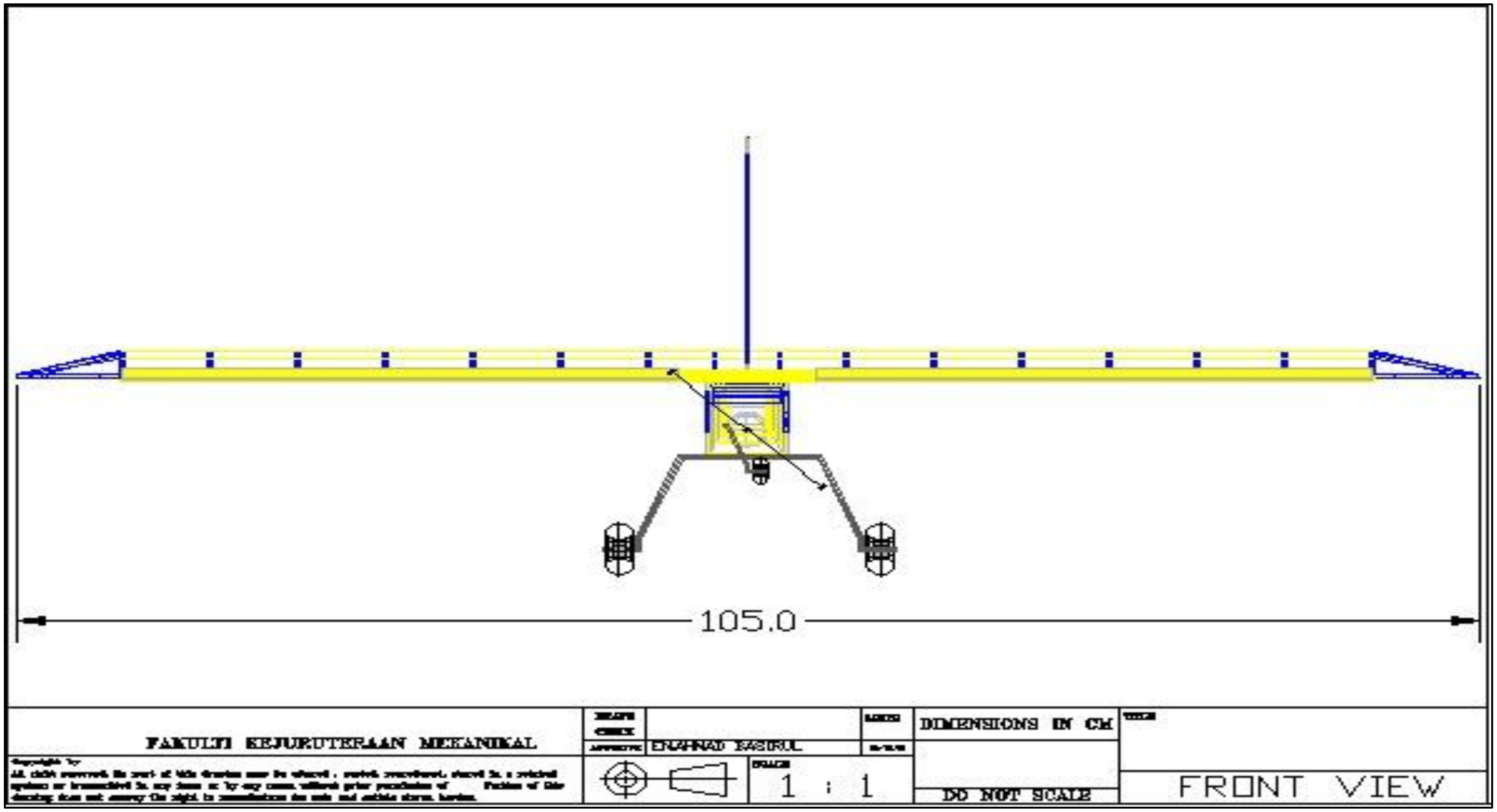
APPENDIX E2

Aircraft Side View



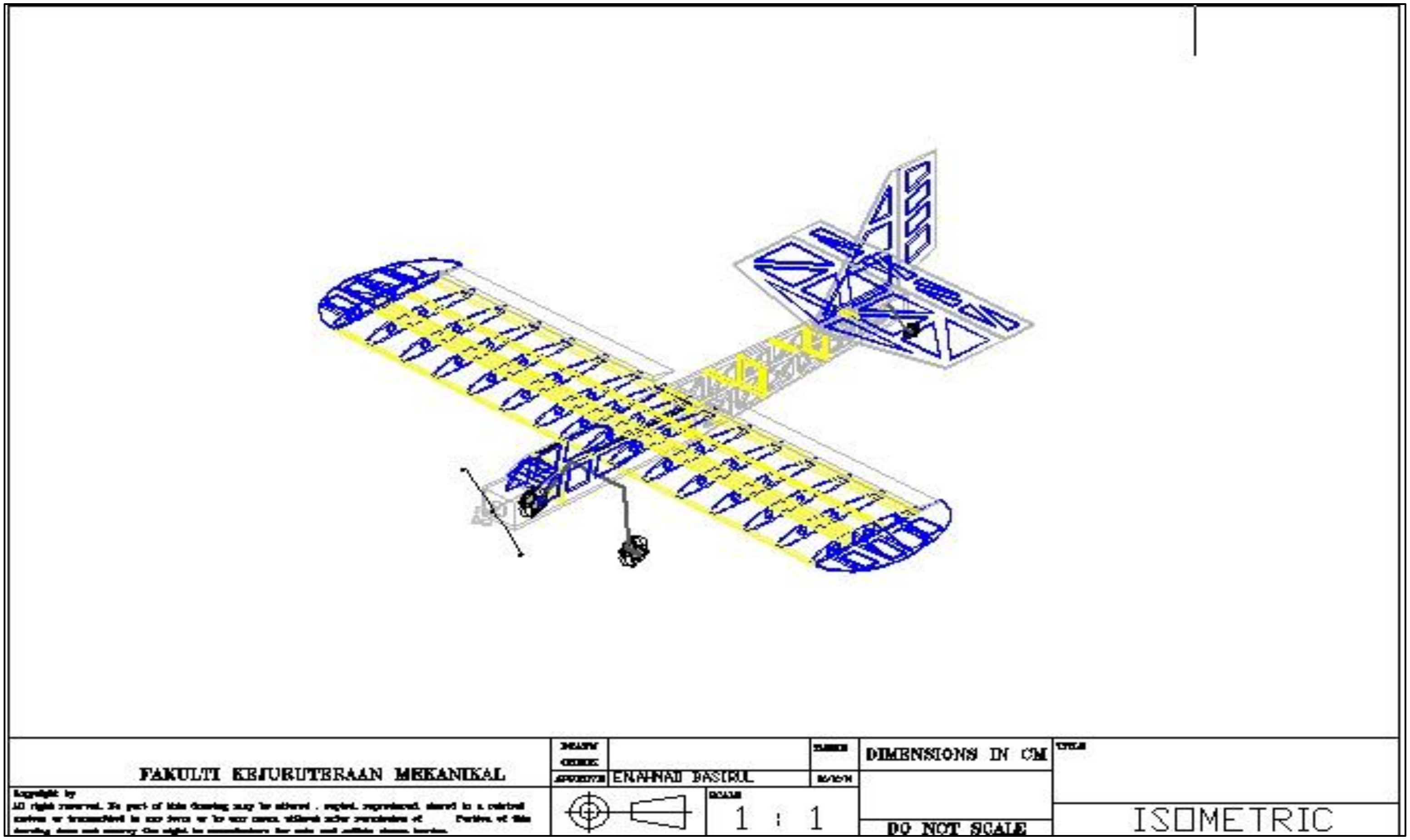
APPENDIX E3

Aircraft Front View



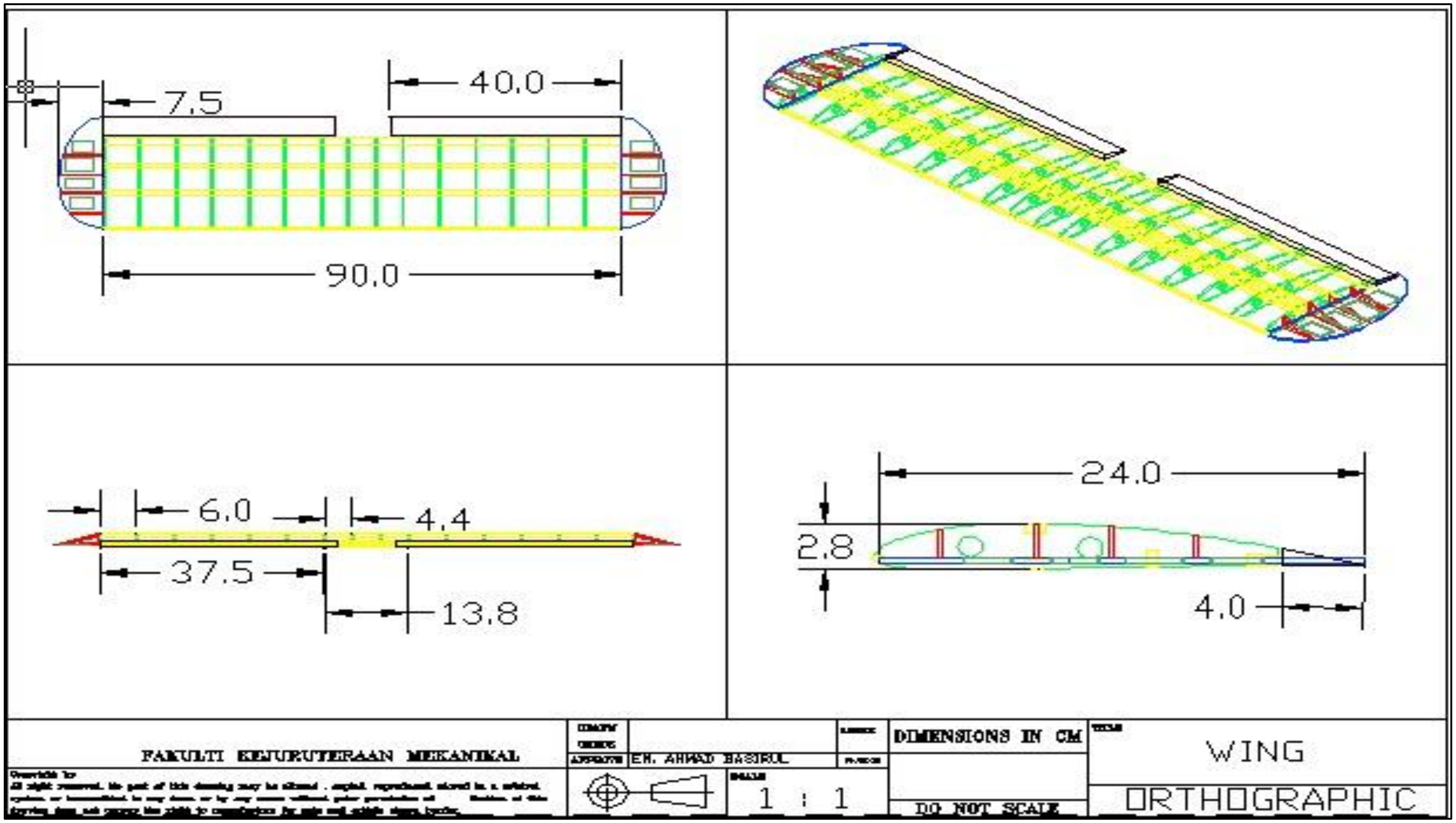
APPENDIX E4

Aircraft Full View



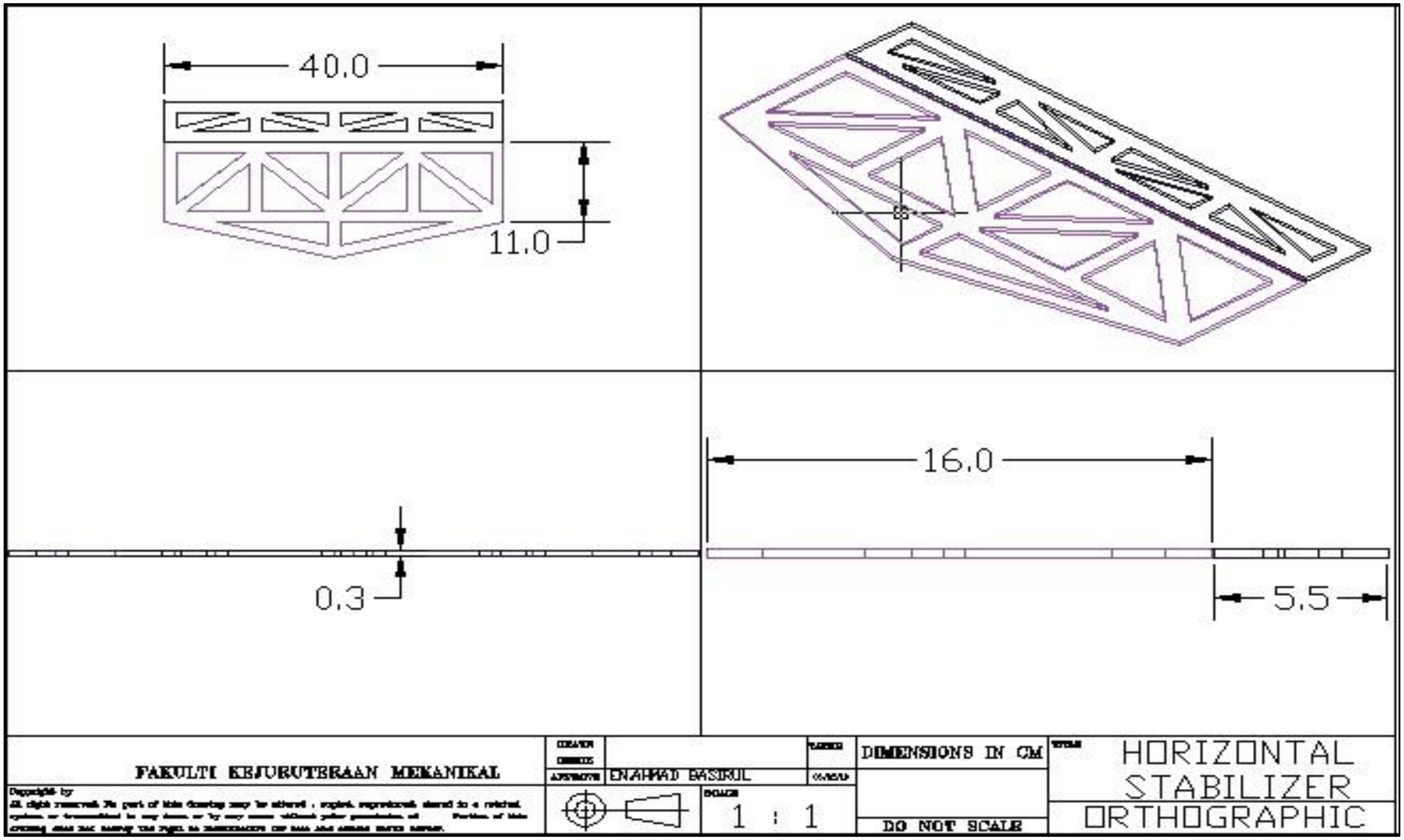
APPENDIX E5

Wing Design



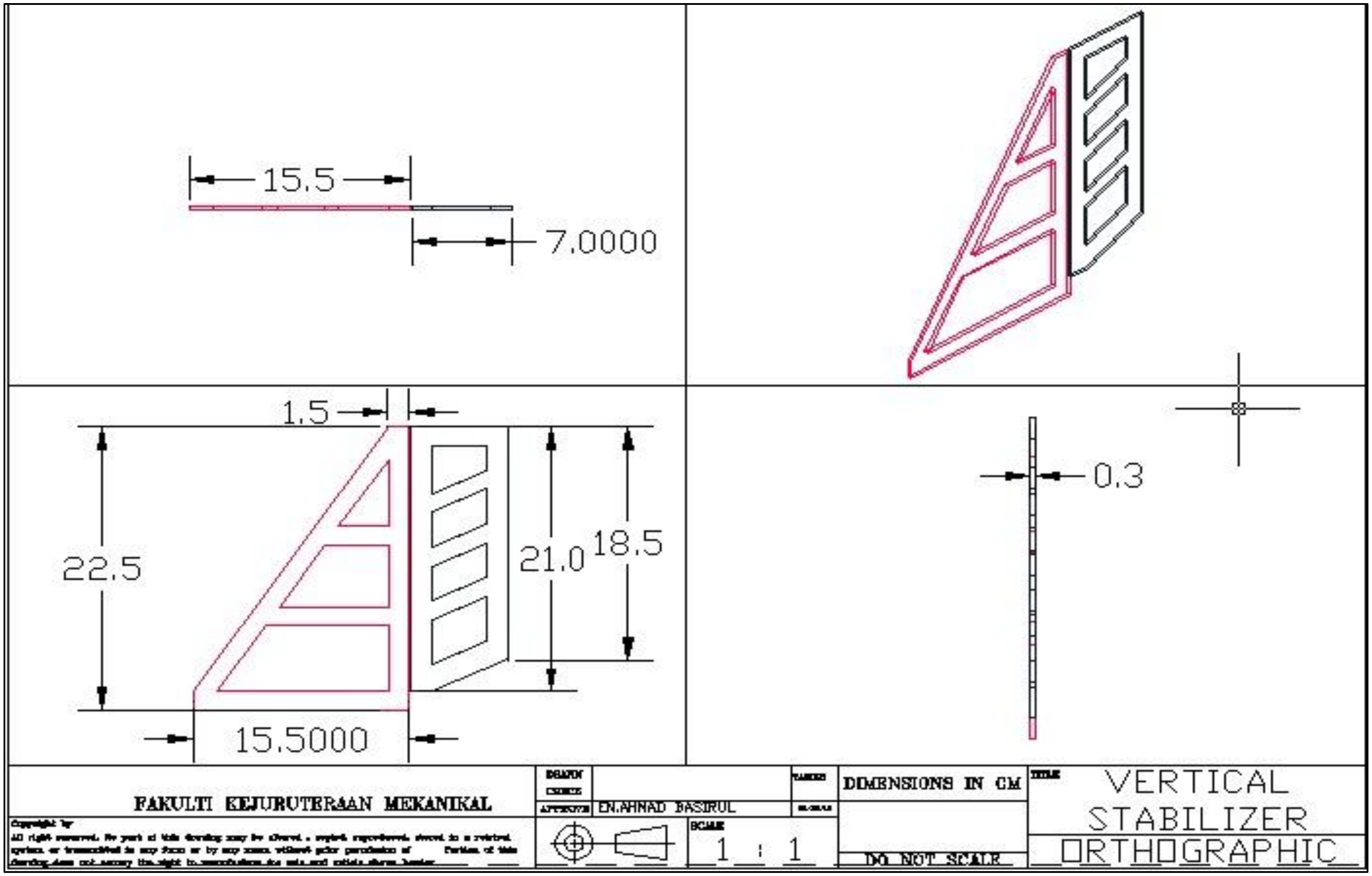
APPENDIX E6

H-Tail Design



APPENDIX E7

V-Tail Design



APPENDIX E8

Fuselage Design