DESIGN AND EVALUATION OF THE EMPENNAGE FOR RECONNAISSANCE UAV

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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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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Dedicated to my parents,
Hasmah Binti Razali and Mohd Ibrahim Bin Pa'wan

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ABSTRACT

This project describes and explains the process to estimate conceptual design and sizing of a new small unmanned aerial vehicle (UAV). The small UAV was designed for use in the civil reconnaissance missions such as aerial photography and agriculture monitoring and can be expand for use in the government sectors. The length of the UAV is 1.2 meter and the wing span is 2meter. Initially, the mini-UAV designed for loiter at an altitude 1000ft (300meter) and the take-off weight of 3.8kg.This report contains a statistical analysis to determine the weight of the UAV. The study of the similar type of UAV will give the guidelines description during the initial weight analysis. Next, the design covers the aircraft sizing analysis which is follow the Federal Aviation Regulations (FAR) sizing requirements as the basis of airworthiness purpose. The sensitivity analysis will help the designer to find the parameters that dependent to take-off weight of the UAV. This UAV will implement the conventional tail configuration based on empennage sizing. This report also contains the analysis of the airfoil and finally the design of the empennage and the UAV will be done by CAD software.

ABSTRAK

Projek ini mengambarkan dan menerangkan proses untuk menganggarkan reka bentuk konseptual dan pensaizan pesawat tanpa pemandu (UAV) yang kecil dan baru. UAV kecil direka bentuk untuk digunakan dalam misi-misi peninjauan awam seperti pengambilan foto udara dan pengawasan pertanian dan boleh jadi diperluaskan untuk kegunaan dalam sektor-sektor kerajaan . Panjang UAV ini ialah 1.2 meter dan mempunyai ukuran sayap 2meter . Permulaannya, mini-UAV direka bentuk untuk terbang pada altitud 1000 kaki (300meter) dan berat berlepas ialah 3.8kg. Laporan ini mengandungi analisis statistik untuk menentukan berat UAV. Kajian tentang UAV yang serupa akan memberi panduan awal semasa analisis untuk menentukan berat UAV.Selepas itu, reka bentuk UAV juga mengandungi analisis pensaizan pesawat mengikut syarat-syarat pensaizan oleh Persekutuan Peraturan-peraturan Penerbangan (FAR) sebagai asas layak terbang. Analisis kepekaan pula akan membantu pereka bagi mencari parameter bergantung kepada berat UAV ketika berlepas. UAV ini akan menggunakan ekor konvensional berpandukan pensaizan ekor pesawat. Laporan ini juga mengandungi analisis “airfoil” dan akhir sekali reka bentuk ekor dan keseluruhan UAV akan dibuat mengunakan perisian CAD.

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LIST OF SYMBOLS

A	Area, Aspect ratio
A_H	Aspect ratio of horizontal stabilizer
a_h	Lift curve slope of horizontal stabilizer
A_V	Aspect ratio of vertical stabilizer
b	Span of main wing
$b_{aileron}$	Span of aileron
$b_{elevator}$	Span of elevator
b_H	Span of horizontal stabilizer
b_{rudder}	Span of rudder
b_V	Span of vertical stabilizer
C	Chord length of main wing
$\bar{C}$	Mean Aerodynamic Chord length of main wing
C_{D0}	Zero angle of attack drag coefficient
$C_{elevator}$	Chord length of elevator
C_H	Chord length of horizontal stabilizer
$\bar{C}_{\mathrm{H}}$	Mean aerodynamic chord length of horizontal stabilizer
C_L	Main wing lift coefficient
C_l	Airfoil section lift coefficient
C_{Lmax}	Maximum main wing lift coefficient
C_{lmax}	Maximum airfoil section lift coefficient
C_m	Airfoil section moment coefficient (quarter chord)

C_{root}	Root chord length
C_{rootH}	Root chord length of horizontal stabilizer
C_{rootV}	Root chord length of vertical stabilizer
C_{rudder}	Chord length of rudder
C_{tip}	Tip chord length
C_{tipH}	Tip chord length of horizontal stabilizer
C_{tipV}	Tip chord length of vertical stabilizer
C_V	Chord length of vertical stabilizer
D	Drag
e	Oswald span efficiency factor
g	Gravitational constant, 9.81ms^{-2}
kts	Knots
L	Lift
nm	Nautical mile
P	Motor power
Re	Reynolds Number
S	Main wing planform area
$S_{aileron}$	Aileron planform area
S_H	Horizontal stabiliser planform area
S_V	Vertical stabiliser planform area
S_{wet}	Wetted surface area
v_{cr}	Nominal cruise velocity
V_H	Volume coefficient of horizontal stabilizer

V_s	Stall velocity
V_V	Volume coefficient of vertical stabilizer
W	Weight
W_e	Empty weight
$W_{payload}$	Payload weight
W_{TO}	Take off weight
x_H	Horizontal stabiliser lever arm
x_V	Vertical stabiliser lever arm

Greek Symbols

α	Angle of attack of main wing
$\alpha_{Hmain-wing-stalled}$	Angle of attack of horizontal stabiliser when main wing is stalled
$\alpha_{installedH}$	Installed angle of horizontal stabiliser, relative to longitudinal axis of aircraft
$\alpha_{installedV}$	Installed angle of vertical stabiliser, relative to longitudinal axis of aircraft
α_{stall}	Stall angle of attack of main wing
λ	Taper Ratio
λ_H	Taper ratio of horizontal stabilizer
λ_V	Taper ratio of vertical stabilizer
η_p	Propeller efficiency
η_s	Horizontal stabiliser efficiency

LIST OF ABBREVIATIONS

AEO	All Engine Operating
AR	Aspect Ratio
ARCAA	Australian Research Centre for Aerospace Automation
BDA	Battle Damage Assessment
CAD	Computer Aided Design
CGR	Climb Gradient
FAR	Federal Aviation Requirements
GPS	Global Positioning System
iSOAR	Intelligent Surveillance for Outback Aerial Rescue
ISRT	Intelligence, Surveillance, Reconnaissance & Target Acquisition
MAC	Mean aerodynamic chord of main wing
MAV	Mirco Air Vehicles
MIO	Maritime Intervention Operations
MOUT	Military Operations in Urban Terrain
MTOW	Maximum take off weight
RC	Radio Control
SFC	Specific Fuel Comsumption
UAV	Unmanned Aerial Vehicle
VBSS	Visit Board Search Seizure

CHAPTER 1

INTRODUCTION

1.1 GENERAL DESCRIPTION

An unmanned aerial vehicle (UAV) is an aircraft that operating without the presence of a pilot and is controlled by remotely and others fly autonomously using pre-programmed flight plans. UAV can be classifying into four different groups which is large, medium, small and micro .The examples of large UAVs are Global Hawk (20m wingspan) and Predator(14.8m wingspan) (Bowman, 2004).The representative for mid-size and small UAVs are Malat Hunter (8.8m wingspan)(Rocky,2004) and Raven (1.28m wingspan) respectively. The micro air vehicle (MAV) is miniature aircraft with a maximum wingspan of 15mm.

Early used of unmanned aerial vehicle (UAV) was to replace the manned aircraft in the military operations. The advantages of using UAV instead of manned aircraft are that the UAV can reduce the exposure risk of the operating pilot in the war zone and capable to perform the large variety of dangerous missions including providing a ground and aerial gunnery a target that may simulates an enemy aircraft and also can attack the enemy territories using the missiles weapon.

Nowadays, the development and interest of small unmanned aerial vehicles (UAV) are slowing finding their way into civil and commercial applications. UAVs are finding use in the following industrial fields such as agriculture industry, crop monitoring, weather research, air traffic control and many more (Wong et al ,1997) and easily handled by human without expertise in aviation industry.

1.2 PROJECT BACKGROUND

The purpose of this project is to design a small Unmanned Aerial Vehicle (UAV) which can be use for the reconnaissance missions. This included the process estimating weight of the UAV, wing area and the power used to generate the mini-UAV. The project focused on the evaluating and designs the chosen empennage configuration including the vertical stabilizers, horizontal stabilizers and also the control surface sizing for the mini-UAV. Finally, the suitable airfoils were analyzed where the best airfoil based on suitable requirements is selected.

1.3 PROBLEM STATEMENT / TECHNICAL TASK

1.3.1 Introduction

A small UAV is selected to use in the civil reconnaissance applications because it is less expansive, more portable than the large UAV and easily to operate by the human. Generally, design requirements for a typical low-altitude small UAV flied at speeds between 20 and 100 km/h (12 to 62 mile/h), cruise altitudes of 3 to 300 m (10 to 1000 ft), light weight, and all-weather capabilities. The vehicles has the wing spans less than approximately 6 m (20 ft) and masses less than 25 kg (55 lb) are usually considered as a small UAV(Mueller, 2003). The technical task needed to determine first before the design process of the UAV took place. Developing a new UAV, desired the designer to decide the technical task for the small UAV such as the cruise speed, cruising altitude, range, endurance , take-off distance and landing distance based on assumption with good justification.

The mini-UAV is build to do the civil surveillance and reconnaissance missions. The type of civil surveillance and reconnaissance missions such as:

a. Scenery snapshot / Aerial Photography
b. Wildlife and ecological monitoring
c. Deforestation Vigilance
d. Agriculture Industry
e. Traffic monitoring
f. Monitoring disaster areas.

1.3.2 Standard Requirements

As the UAV is used for civilian missions, it must conform to international standards and follow the Federal Aviation Regulations, or FARs (Epps et al, 2008). The UAV will follow the FAR 23 specifications that contain airworthiness standards for airplanes in the normal, utility, acrobatic, and commuter categories.

1.3.3 Performance Parameters

Cruise speed -60 km/h

The higher cruise speed ensures the aircraft to reach the mission area quickly, hence it will increase the efficiency of the mission's flight. But if the aircraft is travelling to fast it will weakened the camera performance where the picture will become unclear or blurry. Therefore, a suitable cruise speed needs to determine to satisfy all the missions' requirement. Hence, for this project it is suggested the cruise speed for the aircraft is 60 km/h.

Loiter Speed – 40 km/h

Aircraft loiter speed is lower than cruise speed where the smaller loiter speed able to increase focused point monitoring and resolution during the mission. For the successfully reconnaissance mission, the aircraft should be able to provide the clear image and accurate data information during the flight time. Hence, the suitable loiter speed that will used for the loiter phase of the mission profile is 40 km/h.

Endurance - 1 hour

Endurance is the duration that the aircraft is able to remain in the airborne. This requirement was set up to one hour to increase the practicality of the system and extend the surveillance capabilities. The endurance of the closed linked to the camera performance and the fuel consumption where the small UAV cannot carry a lot of fuel during the flight. Therefore, the duration of the 1 hour is acceptable for the UAV.
The phase of the missions:
-60 minutes for works (search, monitor)
-9 minutes for take –off, landing, climbing and descend.

Range -10 km

The selection of the operating range for small UAV needs to study carefully during the initial process of the design aircraft. The range of the operating UAV was depending to the communication equipments and the fuel weight carries on the aircraft. The small UAV leads to the smaller take-off weight and low fuel weight carries by the aircraft. Hence, the range of 10 km radius is suggested for the small UAV and to make sure the UAV return to the base safely.

Altitude -1000ft

Operational altitude for UAV based on the camera performance and mission requirements. If the UAV goes to high the camera visibility is weakened and if too low the camera becomes narrower. The higher resolution camera can provide a clear image during the reconnaissance missions. Since the UAV is use in civil application, there is no requirement for UAV to be stealth or to avoid detection by the enemy radar like in the military used. Hence, the suggested operational altitude for the small UAV is 1000ft (300m) as recommended by the light aircraft pilots.

Take off distance-10 meter

The short take off distance due to the mini-UAV will launch by hand. The shorter distance make sure that the UAV can be operate at restriction areas where there not enough distance allotted for take-off.

Landing distance –5m

The suggested landing distance for the small UAV is 5m where the longer landing distance will increase the landing time which can reduce the impact from the crash landing. Hence, the damage for the UAV will be minimizing from the crash landing.

The performance parameters can be simplified as below:

Cruise Speed, V_{cr}	: 60 km/h
Loiter Speed, V_{ltr}	: 40 km/h
Endurance, E	: 1 hour
Range, R	: 10 km
Altitude, h	: 1000ft
Take off distance, s_{TO}	: 10m
Landing distance, s_L	: 5m

1.3.4 Mission Profile

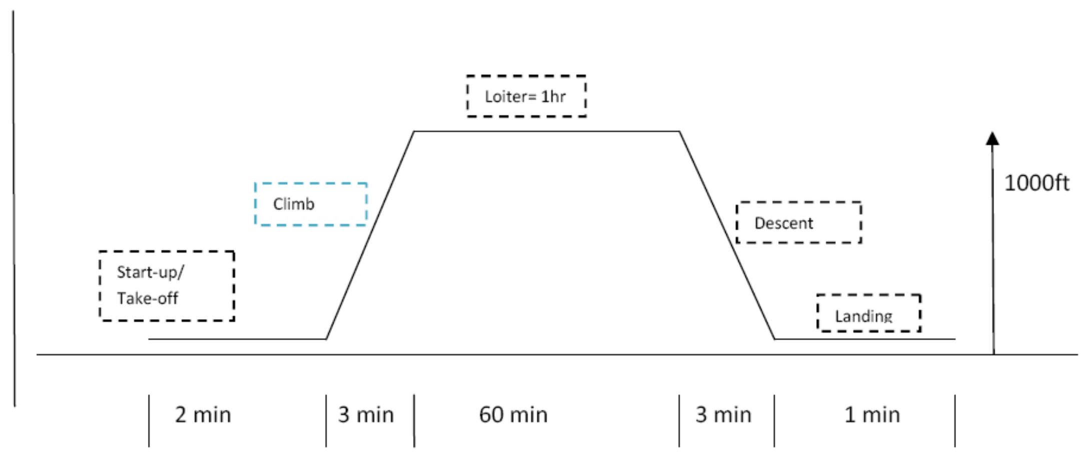

Figure 1.1: Mission profile.

1.3.5 Technical Level

The main mission for the mini-UAV is to perform surveillance and reconnaissance missions. It will use to operate in a number of different locations such as in the terrain, forest and coastal. The operation of the aircraft should be kept simple to ensure that it can be used by people on the rural area and the people without a pilot license (Balnaves et al, 2008). The UAV should be able to operate in a range of weather conditions from high temperatures to raining condition. The UAV must be easy to assemble where it can save a lot of the operation time.

1.3.6 Economical Parameter

The main target for this small UAV is to use for the civil applications where the cost is the main concern whether it can affordable to the civil users. Therefore it is important to keep the aircraft cost lower as possible. The UAV was equipped with the expensive electronic equipment such as camera and Global Positioning System (GPS) but this seen necessary to achieve the successful reconnaissance missions. This aircraft is not limited to use by the civil users only but can be expand to use by the private and government sector such as army, law enforcer and fire fighter. As an example, police agencies can use the UAV to obtain evidence and gather information on each mission before performing their actions. This can minimize the risk for the police officer safety and make sure the criminal can be caught (Darsono et al,2007). The operational cost for small UAV is relatively low compared to manned aircraft where the aircraft are very expensive to buy and operate, require dedicated pilots, and their availability is limited.

1.4 OBJECTIVES

The objectives of the project are:

1. To estimate the conceptual design of the mini-UAV.
2. To evaluate and design the structural of the empennage for the reconnaissance UAV including the vertical stabilizer and horizontal stabilizer.

1.5 SCOPES

This project is focusing on studying and designing an empennage for the mini-UAV. This focus area is done based on the following aspect:

1. Deciding the overall empennage configuration (T-tail, conventional, boom mounted).
2. Determine the size and the location of empennage.
3. Control surface sizing (elevator and rudder).
4. Airfoils selection.
5. Prepared dimensioned drawings (CAD).

CHAPTER 2

LITERATURE REVIEW

This phase of the project focused on the review of the current literature related to Unmanned Aerial Vehicle (UAV) technology. This included the review of the commercial UAVs providing a detailed statistical data that were used to develop design requirements for the proposed mini-UAV.

2.1 PROJECT BENCHMARK

A review of the current operating UAVs from around the world was conducted and provided the external design benchmark for the proposed UAV. The chosen UAVs prototype should had the similar missions requirements and application , similar weight to the expected final design , success in industry and availability of the knowledge (Avalakki et al, 2007). The criteria of the selected UAVs must not exceed 20 kg weight take-off and used for the reconnaissance and surveillance missions.The general statistical data of the UAV can be obtained from the internet and the UAVs handbook .

2.1.1 Raven RQ 11-B

Figure 2.1: The Raven RQ 11-B

Source: AeroVironment, Inc. (2009)

Raven RQ 11-B is a small and lightweight Unmanned Aerial Vehicle (UAV) built for remote reconnaissance and surveillance missions. The Raven is of a conventional configuration where the tail and wing were directly mounted to the fuselage of the aircraft. The aircraft was launch by the hand and the recovery method by deep stall landing. The technical specification for the aircraft was available in Table 2.1 :

Table 2.1 : Technical specification of Raven RQ 11-B

Mission Descriptions	Remote Reconnaissance and Surveillance, Target Acquisiton, Force Protection and Convoy Security, Battle Damage Assessment for Light Infantry, Dismounted Warfighter and Military Operations in Urban Terrain (MOUT).
GCS	Lightweight, Modual Components, Waterproof Softcase, Many Advanced Features Without Laptop, Optional FalconView Moving Map and Mission Planning Laptop Interface, Digital Video Recorder and Frame Capture.
Payloads	Dual Forward and Side-Look EO Camera Nose, Electronic Pan-tilt-zoom with Stabilization, Forward and Side-Look IR Camera Nose (6.5 oz payloads).
Range	10 km

Table 2.1: Continued

Endurance	60–90 minutes (Rechargeable Battery), 80–110 Minutes (Single Use Battery)
Speed	32-81 km/h, 17-44 knots
Operating Altitude	100-500 ft (30-152 m) AGL, 14,000 ft MSL max launch altitude
Wing Span	4.5 ft (1.4 m)
Length	3.0 ft (0.9 m)
Weight	4.2 lbs (1.9 kg)

Source: AeroVironment, Inc. (2009)

2.1.2 Puma AE

Figure 2.2: The Puma AE UAV

Source: AeroVironment, Inc. (2009)

Puma-AE (All-Environment) is small reconnaissance UAV designed for land based and maritime operations, capable landing in salt water or on land. The Puma AE is of a conventional configuration and the system is stealth to prevent being tracked by radar. The aircraft was launch by hand launch and recovery method by landing recovery. The characteristic of the vehicle satisfied with the expected design; hence the Puma AE was selected as the prototype for the project. The technical specification was available in Table 2.2.

Table 2.2: Technical specification of Puma AE UAV

Mission Descriptions	Intelligence, Surveillance, Reconnaissance & Target Acquisition (ISRT), Battle Damage Assessment (BDA), Maritime Intervention Operations (MIO), VBSS (Visit Board Search Seizure), Search and Rescue, Port and Coastal Patrol ,Drug Interdiction .
GCS	Common GCS with Raven and Wasp
Payloads	Gimbaled payload, +/-180 degrees pan, +10 to -90 degrees tilt, stabilized EO, IR camera, and IR Illuminator all in one modular payload.
Range	15 km
Endurance	2 hours
Speed	37-83 km/h, 20 to 45 knots
Operating Altitude (Typ.)	500 ft (152 m) AGL
Wing Span	9.2 ft (2.8 m)
Length	4.6 ft (1.4 m)
Weight	13 lbs (5.9 kg)

Source: AeroVironment, Inc. (2009)

2.2 Power Plant Type

One important aspect need to analyze when designing the aircraft is the selection of the power plant to generates the UAV. The UAV can use either battery or gasoline engine. The engine should have light weight to keep the aircraft weight is low. Engine selection is crucial because it affects the performance, emissions, fuel consumption, and mission range of the aircraft (Epps et al,2008).

The RCV 60-SP –engine was selected for this project because some of the criteria were took into account such as the weight of this engine was low about 4.3 lbs (1.95

kilos) and produce the power output up to 0.67 kW bhp. The specific fuel consumption for climb and loiter is 285.6 g/kWh and 276.1 g/kWh respectively.

Figure 2.3: RCV 60-SP engine

Source: http://www.rcvengines.com/rcv60sp.htm

2.3 Special Systems

In order for the UAV to perform successfully its surveillance and reconnaissance operations, its needs to be equipped with appropriate optical equipment. Before that some aspects need to analyze it like camera mounting. The camera was mounted on the front of the fuselage to prevent from damaged when landing and also to get the better observation.

The FlyCamOne2 Micro Video Camera was selected as the optical device to record the video/photo because it ability to record with a resolution of 640x480 for clear playback, and 1280x1024 pixels for still photos. . The video camera includes audio, still photos, a voice recorder, USB drive, and a Webcam. The camera also has the light weight which only 1 oz (0.02kg) and well suit with proposed UAV.

Figure 2.4: The FlyCamOne2 Micro Video Camera

Source: http://www.hobby-lobby.com/video-camera.htm

2.4 EMPENNAGE

Empennage is the tail section of the aircraft. It typically consists of the horizontal tail structure (the horizontal stabilizer and the elevator) and the vertical tail structure (the vertical stabilizer and the rudder).

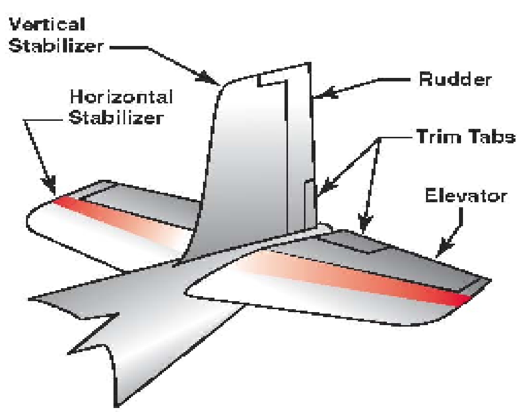

Figure 2.5: The empennage component.

Source: Bliss. (2009)

2.4.1 Empennage Configuration

The horizontal tail structure of the empennage consists of the horizontal stabilizer and the elevator. The control surface on the horizontal stabilizer which is elevator provides controls and balances the pitching of the aircraft. When the elevators deflected upward the velocities on the upper the horizontal stabilizers faster than below it, hence the pressure on the bottom will pushed the force upward and the aircraft begin to ascend. Deflecting the elevators downward will make the aircraft to descend.

The vertical tail structure of the empennage consists of the vertical stabilizer and the rudder. The control surface on the horizontal stabilizer which is rudder provides the directional (yawing) stability. Deflecting the rudder to the right produced a sideward force at the centre of pressure, resulting in a moment about the vertical axis that pushing the tail to the left. The same concept was applied if the rudder is deflected to the left.

Aircraft empennage can be designed in different configurations. They could be studied in three main configurations: conventional, canard, three-surface. The conventional canard configuration typically applied to the most of the aircraft in the world and will used for this project. The tail configuration illustrated in figure 2.7 below.

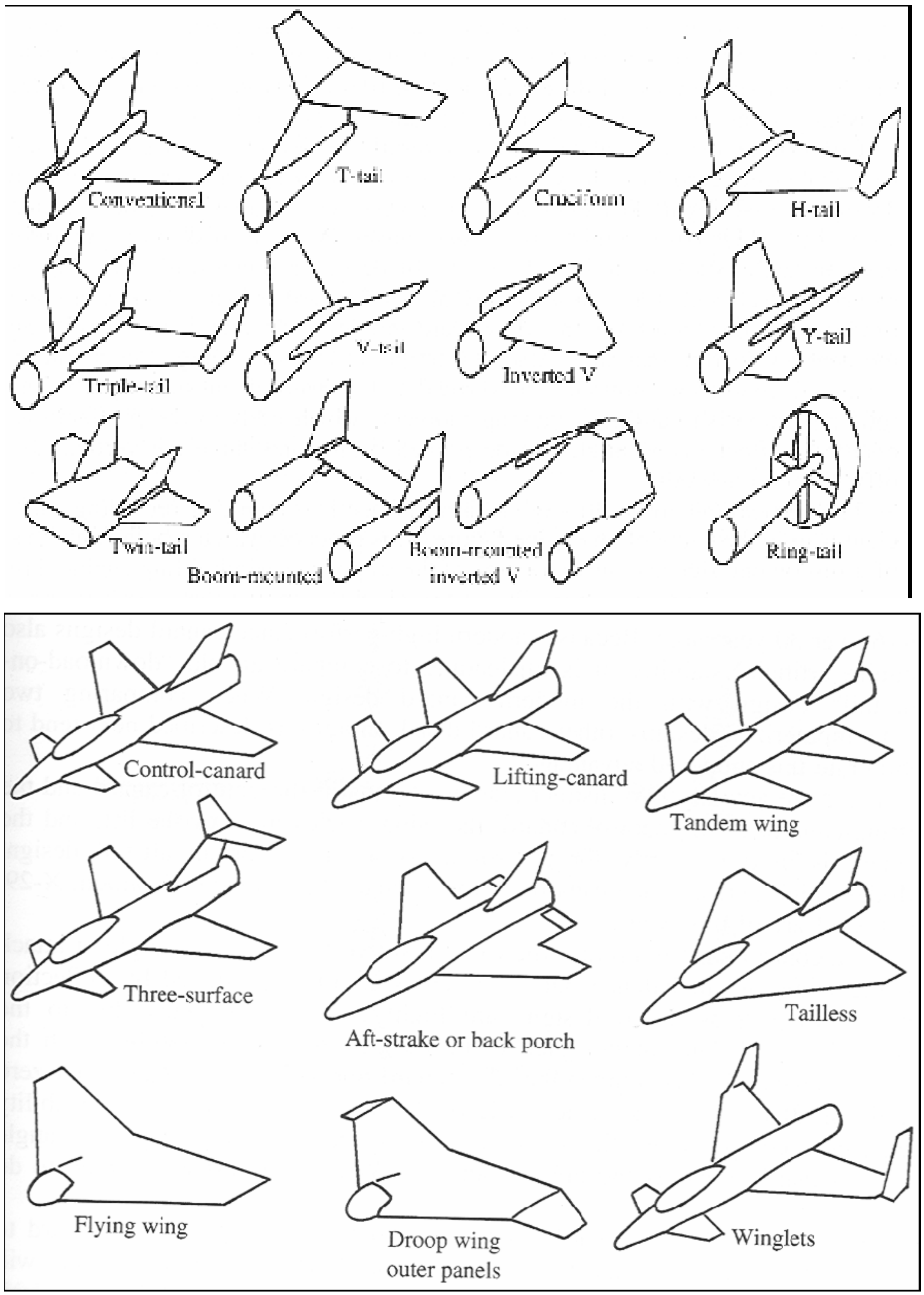

Figure 2.6: Different empennage configuration

Source: Raymer. (2006)

The conventional tail is popular tail arrangement and probably 70 % or more of the aircraft in service used that kind of tail. The conventional tail provides adequate stability, eases to control simple design and needs short development time (Avalakki et al, 2007). The horizontal control surface are fairly large and the vertical and horizontal stabilizers were support to the fuselage (Carr et al,2008).

The T –tail configuration is relatively heavier than conventional tail because the vertical stabilizer need to support the horizontal stabilizers but it will allow the elevator to placed outside the propeller slipstream to avoid large pitching moment during flight. This also reduces buffet on the horizontal tail which can reduce the fatigue on the structure and increase the longer lifetime for empennage (Raymer, 2005).

The twin boom tail configuration will provide the adequate space for the propeller and the stabilizers will experience clean airflow rather than being in the wake of the propeller and main wing (Balnaves,2008).

V-tails combine functions of horizontal and vertical tails. They are sometimes chosen because of their increased ground clearance, reduced number of surface intersections, or novel look, but require mixing of rudder and elevator controls and often exhibit reduced control authority in combined yaw and pitch maneuvers.

Since, the small UAV do not commit the difficult maneuverable, therefore the conventional tail is used in this project as the main empennage configuration.

2.5 AIRFOILS

The airfoil is the surface such as wing or empennage that provide the aerodynamic force which is produce lift for the aircraft. The good airfoil should have the greater component of lift force than the drag force. The good airfoil selection will affects the cruise speed, takeoff and landing distances, stall speed, handling qualities (especially near the stall) and overall aerodynamic efficiency during all phases of flight. The airfoil generates the lift force by changing the angle of attack, α of the wing or horizontal stabilizers. This will cause the air travel the upper airfoil faster by the air beneath the airfoils. Bernoulli equation shows the higher velocities will produce the less pressure so the lower surface will be pushed upward by the higher pressure at the bottom of the airfoil. Angle of attack, α is the angle between a reference line of lifting body typically the chord line of the wing and the free stream velocity vector,. At the stall angle of attack, α the airfoil will produce the maximum lift coefficient where the flow separation occurs and the aircraft begin to stall (Nelson and Pelletier, 2003). Dynamic stall occur where the airfoil pitches through the static stall angle, while the normal force continues to increase beyond its maximum value for unstalled conditions (Akbari and Price, 2003). Figure 2.8 illustrated the definition of angle of attack.

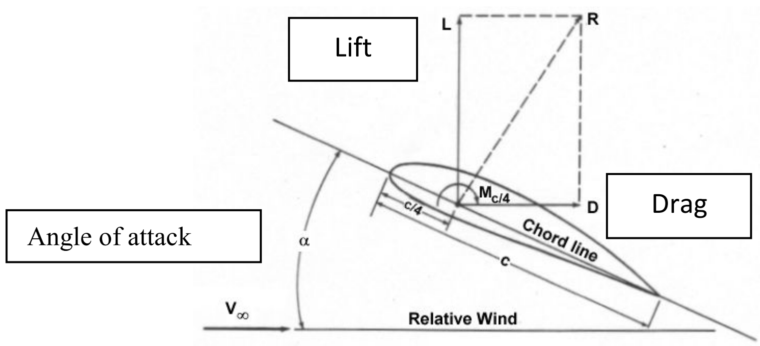

Figure 2.7: Definition of angle of attack on an airfoil

Source : Scott.(2004)

The Reynolds number is the important aspect that affected the aerodynamic of the airfoils (Mueller DeLaurier,2003). The Reynolds number will determine whether the air flow will be laminar or turbulent. The airfoil tend to stall at the higher Reynolds number following by the decrease of the lift coefficient, C_L and the effect of the separation bubble (Alam et al,2009).

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. 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. Figure 2.9 shown the key geometric parameters of an airfoil:

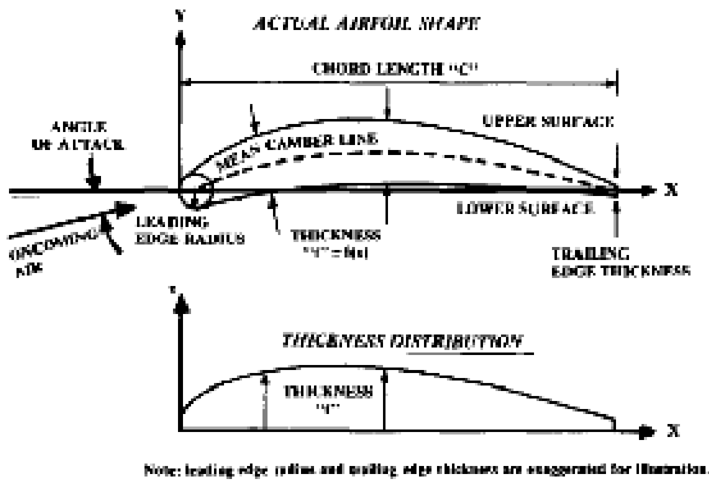

Figure 2.8: Airfoil Geometry

Source : Raymer. (2006)

Widely used airfoils for aircraft wing and empennage was developed by The *National Advisory Committee for Aeronautics* (NACA) called NACA airfoils.The first digit referred the maximum camber as the percentage of chord, the second referred the distance of maximum camber from the airfoil leading edge in tens of percents of the chord. The last two digits defined the maximum thickness of the airfoil as percent of the chord. A variety of airfoils is shown in Figure 2.10.

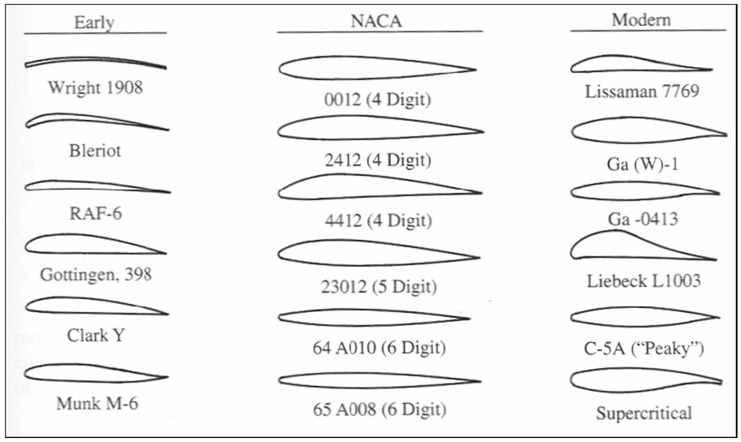

Figure 2.9: Airfoil Families

Source : Raymer.(2006)

2.6 FORCES ON AN AIRCRAFT

2.6.1 Weight

The weight is the force that acting downward of the aircraft. The magnitude of weight is determined from Newton second law:

$$W = mg$$

Where m is the mass of the body and g is the gravitational acceleration (9.807 m/s^2). The weight of the aircraft was dependent to the gravitational acceleration if the mass of the body remain the same. Assuming the aircraft was flying near the earth hence the gravitational acceleration acting on the body remains constant. During the process designs of an UAV, the weight and balance analysis need to be done for ascertain the stability of the vehicle.

2.6.2 Lift

Lift is defined to be the component of this force that is perpendicular to the oncoming flow direction (Kuethe and Chow1998). Lift is typically generated by the aircraft's wings but the empennage also can contribute the lift force. The aircraft will flying if the lift produces by wing or empennage greater than the weight of the aircraft itself. The good selection of the airfoils will affected the magnitude of the lift produce by the aircraft.

2.6.3 Thrust

An aircraft produced thrust force using the engine that pushed the air in the opposite direction of the aircraft. As the engines thrust the airplane in the flight direction, the wing will encountered the coming air that flows over and under the wings which created the lift force.

2.6.4 Drag

The drag on an aircraft is the force acting on the opposite direction to the flight direction. Drag force will obstructs the aircraft motion when flying through the air. Drag force can be minimize by selected the suitable airfoil that has smaller magnitude of the drag coefficient. Lowering the drag force will make the aircraft flying faster and the less power used from the engine.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, we will be discussing on the methods involved during the course of this project and the processes of designing an aircraft. The flowchart shows a sequence of method used in every process to ensure that the project run smoothly and finally to complete the objectives before submitting the report. Below are the steps of the project which briefly being shortlisted into the flow chart schematic diagram

3.2 Flow Chart

3.2.1 Flow Chart of the Study for FYP 1

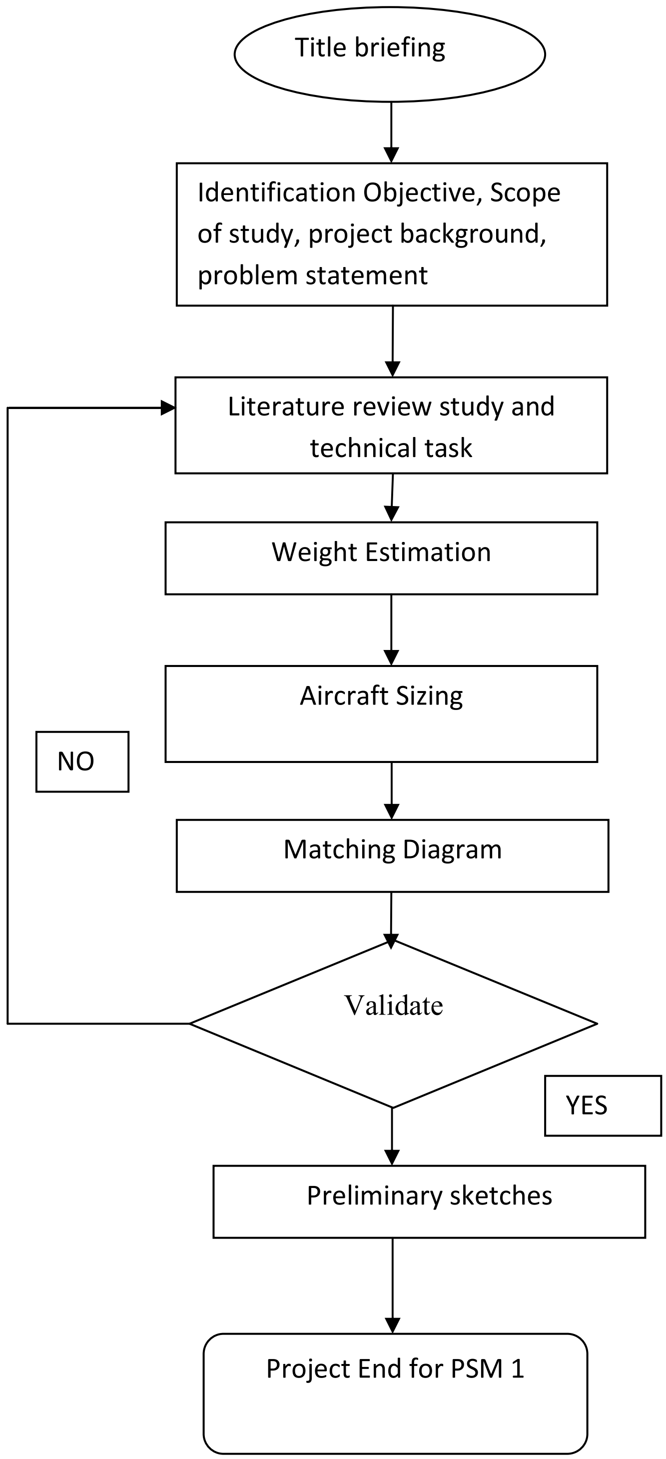

Figure 3.1: Flow Chart of the Study for FYP 1

3.2.2 Flow Chart of the Study for FYP 2

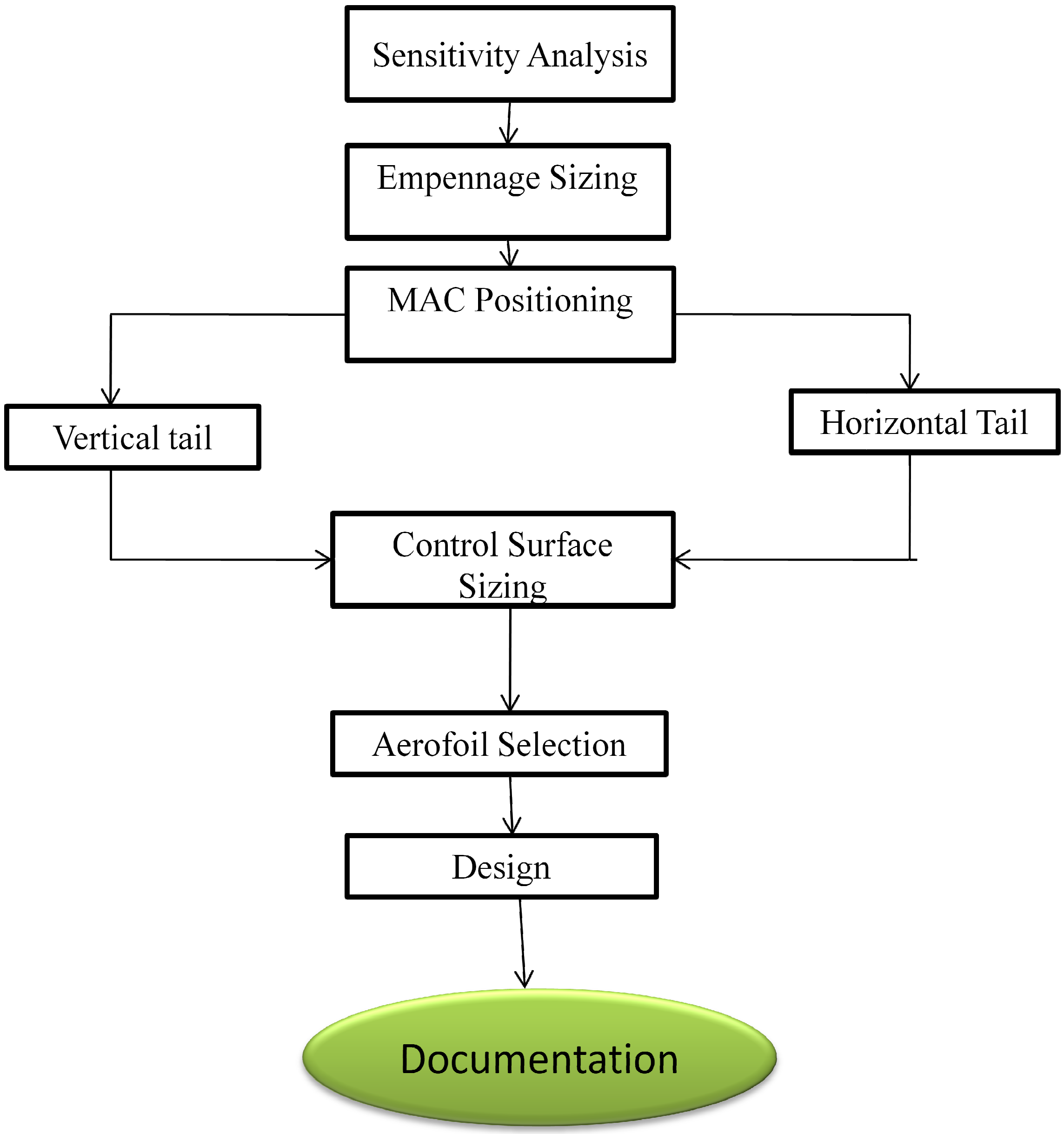

Figure 3.2: Flow Chart of the Study for FYP 2

3.3 Project Briefing

The project was started with the introduction about this project from the supervisor. This includes the identification of the objectives, scopes of study, the project background and also the problem statement.

The technical task was the important step in the design process. This included the process to determine the standard requirement that the UAV must follow to ensure the safety in civil application. The UAV must conform the FAR23 the international standard for airworthiness for airplanes in the normal, utility, acrobatic, and commuter categories. The performance parameters for the proposed aircraft were identified initially before the design process was carried out. This was done based on the assumptions from the studied of the commercial UAVs earlier. The accepted missions profile was set to show the graphic presentation of the flight plan that contained the time for the each phase of the flight leg .The technical task also included the technical level of the aircraft, economical parameters, power plant requirements and finally the special system that we used on the proposed UAV.

3.4 Literature Review

The literature review is the best way to get the information about the UAV design and also important to understand the project clearly. The sources to get the required information were taken from the internet, journals, and books, also from the discussion with supervisor. In the literature review study also contained the definition of the term that might be used in this design process.

During the literature review study, the review on the commercials UAVs was carried out to provide the performance benchmark for the UAV's design. The technical data including weight empty, weight take-off, and wing span was selected from the existence UAVs that have the similar missions requirement and size estimated requirement with the proposed aircraft. This is done to obtain the reasonable performances and wingspan figure of the proposed aircraft based on similar design parameters.

3.5 Weight Estimation

This section was concerned with the estimating the take off weight and empty weight for the UAV. The data from the technical task and statistical analysis was needed to perform the weight estimation analysis. The fuel weight from each phase of flight leg calculated using mass fuel fraction. From the intersection of the graph “We (tent) and We (all) vs Wto “ the value for the take-off weight , empty weight and the fuel weight can be determine.

3.6 Aircraft Sizing

The sizing of the aircraft was based on the FAR23 standards for the civil applications. For this mini-UAV, the criteria of sizing applied were following as below;

1. FAR-23.65 Rate of Climb Requirement
2. FAR-23.65 Climb Gradient
3. FAR-23.77 Climb Gradient
4. Stall Speed Sizing Requirement
5. Cruise Speed Sizing Requirement

3.7 Matching Diagram

Based on all sizing requirements, matching diagram that satisfy all the parameters required for the design were plotted and essential values can be determined from the graph. From matching diagram, the point that satisfies the design requirement is taken and the values of the wing loading and power loading can be obtained. The value for the wing loading and the power loading to generate the UAV can be calculated based on the value from matching diagram.

3.8 Preliminary Drawing

3.8.1 Concept Sketch One

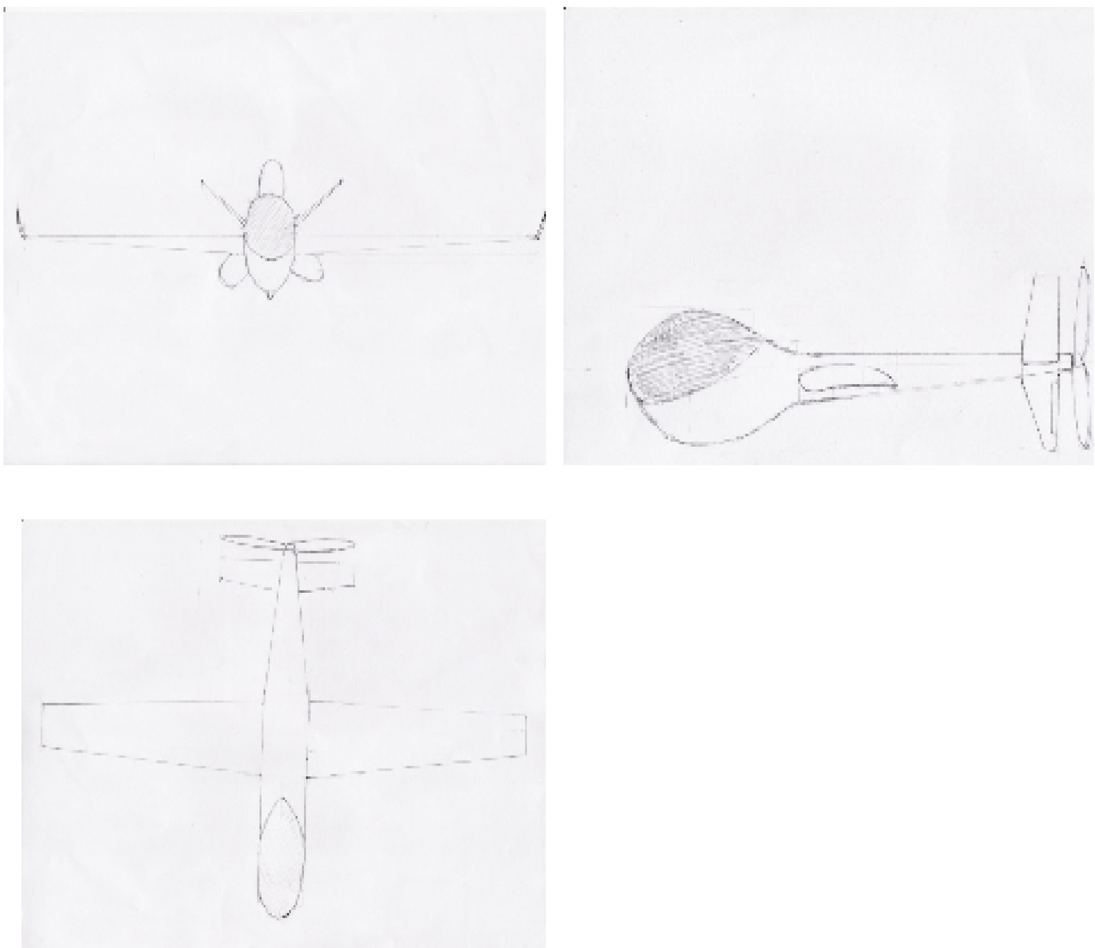

Figure 3.3: Concept sketch one

General Specification:

- Mid wing
- V-tail shape configuration

- Pusher propeller configuration

3.8.2 Concept Sketch Two

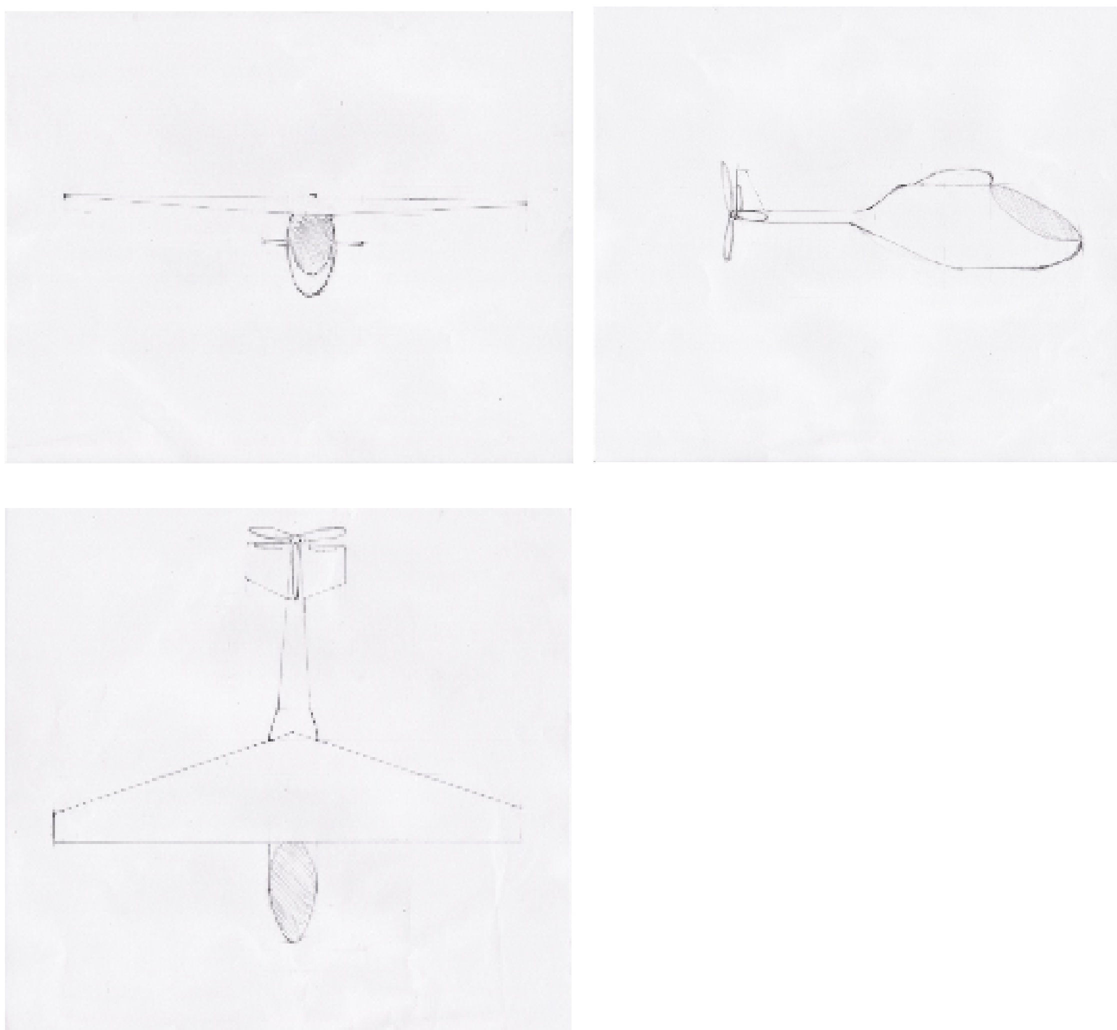

Figure 3.4: Concept sketch two

General Specification:

- High wing
- Conventional tail configuration
- Pusher propeller configuration

3.8.3 Concept Sketch Three

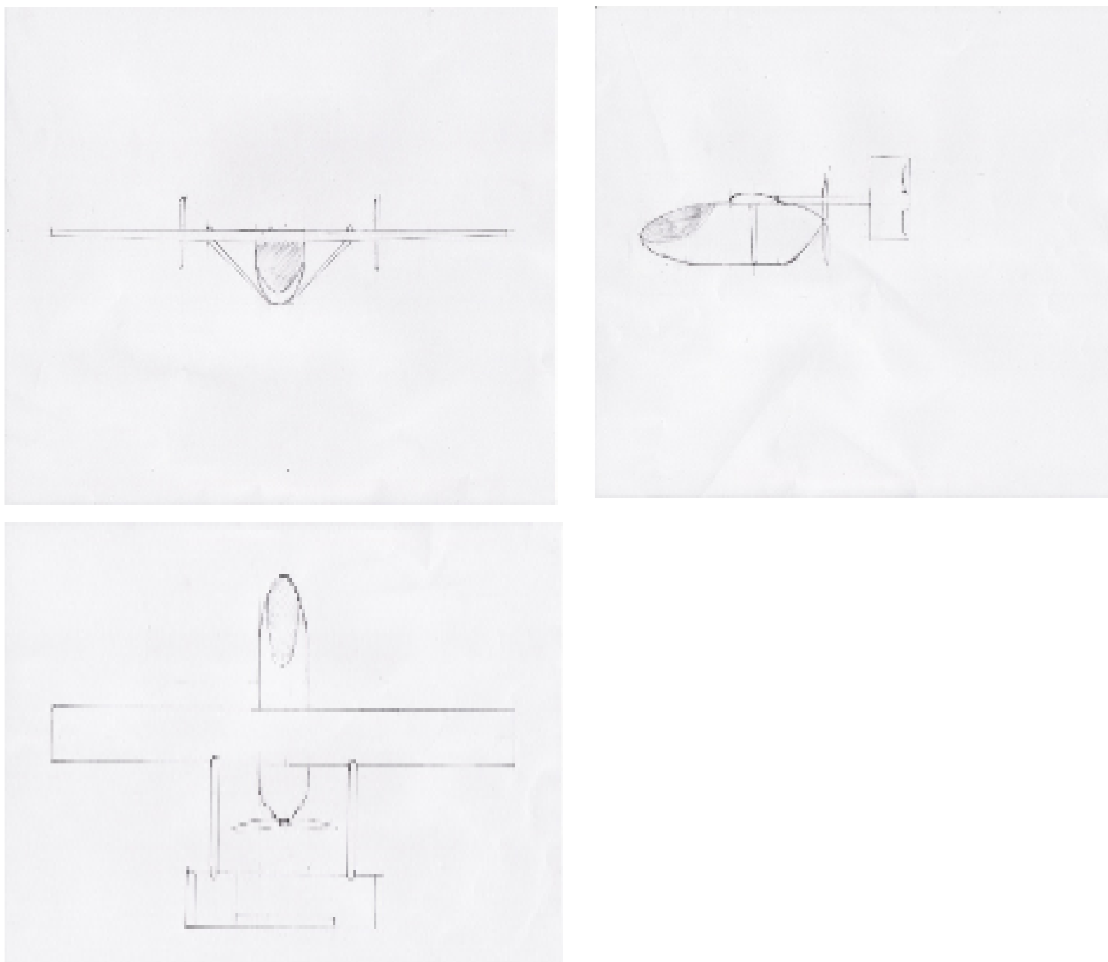

Figure 3.5: Concept sketch Three

General Specification:

- High wing
- Boom mounted configuration
- Pusher propeller configuration

3.9 Sensitivity Analysis

The sensitivity study is required to find the parameters to which the takeoff weight highly dependent. Their outcomes depend on the various parameters in range and endurance equation. The parameters used to calculate the sensitivity based on:

1. Range ,R
2. Endurance, E
3. Lift-to-Drag ratio L/D
4. Specific Fuel Consumption c_p
5. Propeller efficiency n_p
6. Speed Sensitivity V_{Cruise}

3.10 Empennage Sizing and Disposition

From empennage sizing and disposition study the area for empennage can be calculated. The process involved during the empennage sizing listed as below (Roskam,2005):

1. Decide the overall empennage configuration to be used. From the literature review the suitable empennage configuration for this application was the conventional design.
2. Determine of volume coefficients for the tail. The suitable volume coefficients were selected by analyzing the specification of similar UAVs and the data taken from Raymer (2006) for single-engined general aviation aircraft.
3. Determine the disposition of the empennage. The tail moment arm of the empennage can b determine from the approximation which is 45%-50% of fuselage length (Raymer 2006).

4. Calculate the tail area. The tail area for horizontal tail and vertical tail were calculated based of the result we get above and also from main wing properties.

3.11 Mean Aerodynamic Chord (MAC) Positioning

The MAC was calculated for horizontal tail and vertical tail to locate the aerodynamic center for the both tails. The aspect ratio, A used for the both tails must be lower from the aspect ratio, A of the wing because the capabilities stall at higher angle of attack. The taper ratio $\lambda = 0.5$ was chosen to reduce the undesirable flow separation and stall behavior. The tails span can be obtained from the given formula(Roskam2005).

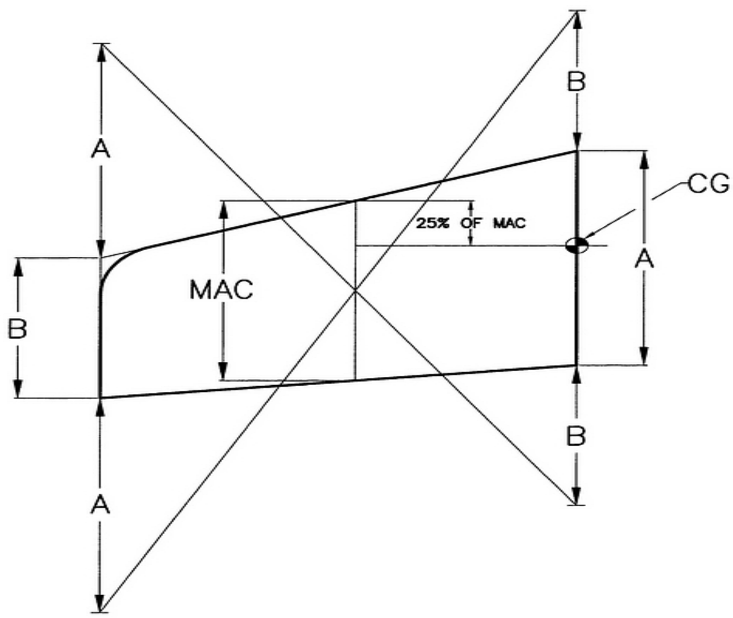

Figure 3.6: The location of the MAC and aerodynamic center

Source: www.rc-airplanes-simplified.com

3.12 Control Surface Sizing

The control surface using for the empennage are the elevator (horizontal stabilizer) and rudders (vertical stabilizers).General guidelines for the elevator design are that the chord length should be between 20% to 30% of the chord length of the horizontal stabilizer. General guidelines for the rudder design are same as elevator .The span of the elevator and rudder was selected to be as large as possible

3.13 Airfoil Selection

The airfoils used for the horizontal tail and vertical tail can have the same profile for ease of manufacture and simplicity. Three different types of NACA airfoils were analyzed and the airfoils which have higher lift coefficient and lower drag coefficient was selected.

3.14 Design

The mini-UAV was designed using SOLIDWORKS software based on the result and the calculation from the above methodology.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter is to investigate and discuss about the result obtained from the manual calculation and the software as to be the main outcome of the project. All the assumption and equation was guided from the reference books (Roskam, 2005 and Raymer, 2006). The main ideas were to determine the weight of the UAV, aircraft sizing to FAR23 requirements, empennage sizing and also the selection of the suitable airfoil for the tail section. From the results, a complete 3D drawing of the aircraft can be illustrated and discuss in this chapter.

4.2 WEIGHT ESTIMATION

4.2.1 Statistical Analysis

The statistical analysis was carried out in order to plot the technical diagram. Data for Weight Take-off (W_{TO}) and Weight Empty (W_E) for existing small Unmanned Aerial Vehicle (UAV) for similar mission's requirement in order to develop a regression line for statistical analysis process are collected. Data of (W_{TO}) and (W_E) for various types of current small UAVs were obtained from the UAV handbook and indicated as in Table 4.1 below;

Table 4.1: Technology Data

UAV	We (lb)	Wto (lb)
Buster	9	12
Golden Eye	13	16
Javelin	8.7	20
Marti	19.8	26.46
Micro Air Vehicle(MAV)	14	15
Silver Fox	26.01	30.86
Aerosonde	33	45
ScanEagle	39.6	46.6
Bayraktar	7.716179	11.02311
Biodrone	13.22773	19.8416
Carolo P330	9.920801	11.02311
Carolo T200	9.920801	13.22773
Gabbiano	8.81849	9.920801
Remoeye 002	2.866009	5.952481
Remoeye 006	9.259414	14.33005

Source: Sephard (2007)

The basic equation used for a statistical analysis (Roskam, 2005) given in Eq.(4.1) , where A and B are constants value for a particular type of aircraft.

$$\log Wto = \mathrm{A} + \mathrm{B}\log We \qquad (4.1)$$

Used the data from the Table 4.1, the graph was plotted to obtain the value of A and B. This is done by producing a graph of $\log We$ versus $\log Wto$.

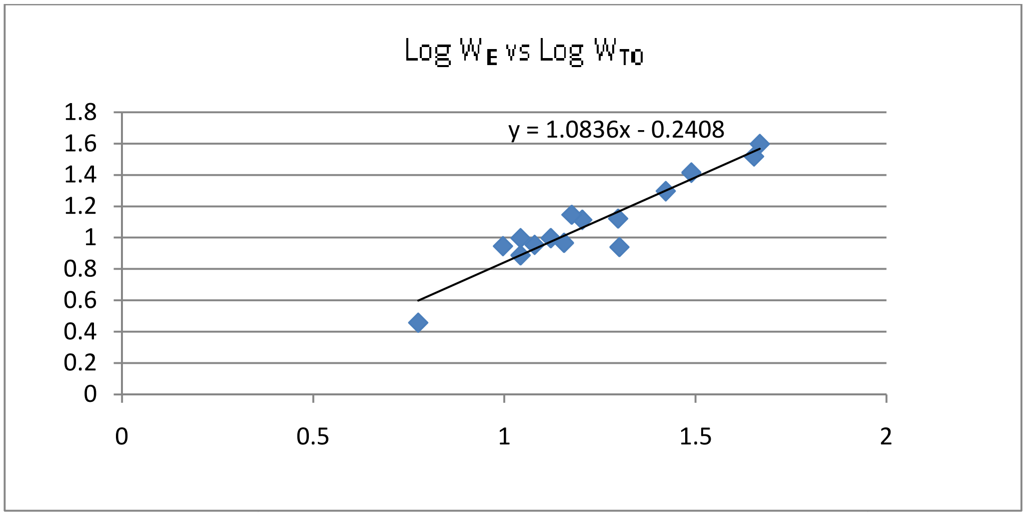

Figure 4.1: Technology Diagram ($\log We$ versus $\log Wto$)

The graph shown in the form $\log We = 1.083 \log Wto - 0.24$. Rearranged this equation to match the Eq. (4.1) and get log W_{TO} = 0.2216 + 0.9284 log W_E . Finally the values of A and B can be obtained that useful in sensitivity analysis.

A = 0.2216

B = 0.9234

4.2.2 Mission Fuel Weight (W_F) calculation

From engine data specification, the specific fuel consumption (sfc) for climb and loiter is 285.6 g/kWh and 276.1 g/kWh respectively**.** The amount of fuel fraction for each leg were calculated to obtain the overall mission fuel fraction (mff) for the mission. Assumption needs to be done regarding the sfc and power used by the engine for each mission leg. The relationship between the amount of fuel used for each stage and the sfc is as follows in Eq. (4.2):

$$\text{Fuel Weight (WF) for each leg (g)} = \text{sfc } \left(\frac{g}{kWh}\right) \text{ x time (hr) x power (kW)} \tag{4.2}$$

$$\frac{W_i}{W_{i+1}} = \frac{(W_{TO})_{i-1} - W_F}{(W_{TO})_{i-1}} \tag{4.3}$$

Table 4.2: Sfc for different type of flight

Leg	t,hr	SFC, g/kWh	P, kW	Fuel weight, g
Start-up	0.033	285.6	4.1	38.64
Climbing	0.05	285.6	4.1	58.548
Loiter	1	276.1	3.73	1029.853
Descend	0.05	276.1	3.73	51.49
Landing	0.0167	276.1	3.73	17.198

For the first iteration it is assumed that W_{TO} is to be 3500g. From here, the value of fuel fraction for each leg of the flight can be calculated using Eq. (4.3) as follows;

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

$$\frac{W_1}{W_{TO}} = \frac{3500\text{-}285.6\,(4.1)(0.033)}{3500}$$

$$= 0.989$$

<u>Leg 2: Climb</u>

$$\frac{W_2}{W_1} = \frac{3461.36\text{-}285.6\,(4.1)(0.05)}{3461.36}$$

$$= 0.983$$

<u>Leg 3: Loiter</u>

$$\frac{W_3}{W_2} = \frac{3402.81\text{-}276.1(3.73)(1.00)}{3402.81}$$

$$= 0.697$$

Leg 4: Descend

$$\frac{W_4}{W_3} = \frac{2372.957\text{-}276.1(3.73)(0.05)}{2372.957}$$

$$= 0.978$$

Leg 5: Landing

$$\frac{W_5}{W_4} = \frac{2321.46\text{-}276.1(3.73)(0.0167)}{2321.46}$$

$$= 0.993$$

The overall mission fuel fraction can be calculated using Eq. (4.4).

$$M_{ff} = \prod_{i=1}^{n} \frac{W_i}{W_{i+1}} \tag{4.4}$$

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

$$= 0.6581$$

From the mission fuel fraction, the mission fuel used during the mission flight was calculated using Eq. (4.5):

$$W_{\text{Fuel Used}} = (1- M_{ff}) W_{TO} \tag{4.5}$$

Typically the aircraft will carry 6% of excess fuel onboard for the safety reason.

$$\begin{aligned} W_{\text{Fuel Used}} &= 1.06\ (1 - 06581)\ W_{TO} \\ &= 0.3625 W_{TO} \end{aligned}$$

Next step is to calculate the value of the tentative value of operating empty weight (W_{OE}) tent (Roskam 2005) which can be calculated using Eq.(4.6) where the aircraft will carry 0.05kg of payload during the flight mission;

$$(W_{OE})\ \text{tent} = (W_{TO})\ \text{Guessed} - W_F - W_{PL} \tag{4.6}$$

$$\begin{aligned} (W_{OE})\ \text{tent} &= (W_{TO})\ \text{Guessed} - 0.3625 W_{TO} - 0.05 \\ &= 0.63748\ W_{TO} - 0.05 \end{aligned}$$

From above result, the value of tentative empty weight (W_E) tent can be calculated using Eq. (4.7). It is assumed that the aircraft will have 0.5% amount of W_{TfO} (trapped oil and fuel) and the UAV will not carry the crew members.

$$(W_E)\ \text{tent} = (W_{OE})\ \text{tent} - W_{tfo} - W_{crew} \tag{4.7}$$

$$\begin{aligned} (W_E)\ \text{tent} &= 0.63748\ W_{TO} - 0.05 - 0.005 W_{TO} - 0 \\ &= 0.6324\ W_{TO} - 0.05 \end{aligned}$$

From the technology diagram (Table 4.1) the graph for W_{TO} versus (W_E) allowable can be obtained.

$$W_{TO} = 1.1666W_{E,allow} + 1.0568$$
$$1.1666W_{E,allow} = W_{TO} - 1.0568$$
$$W_{E,allow} = 0.8572W_{TO} - 0.9059$$

Series of (W_E) allowable and (W_E) tent are then plotted for a given (W_{TO}) Guessed. At the point of interception between these two-plotted lines an in Figure 4.2 will give the most acceptable value of the actual W_{TO}. From there, the amount of fuel and empty weight can be determined.

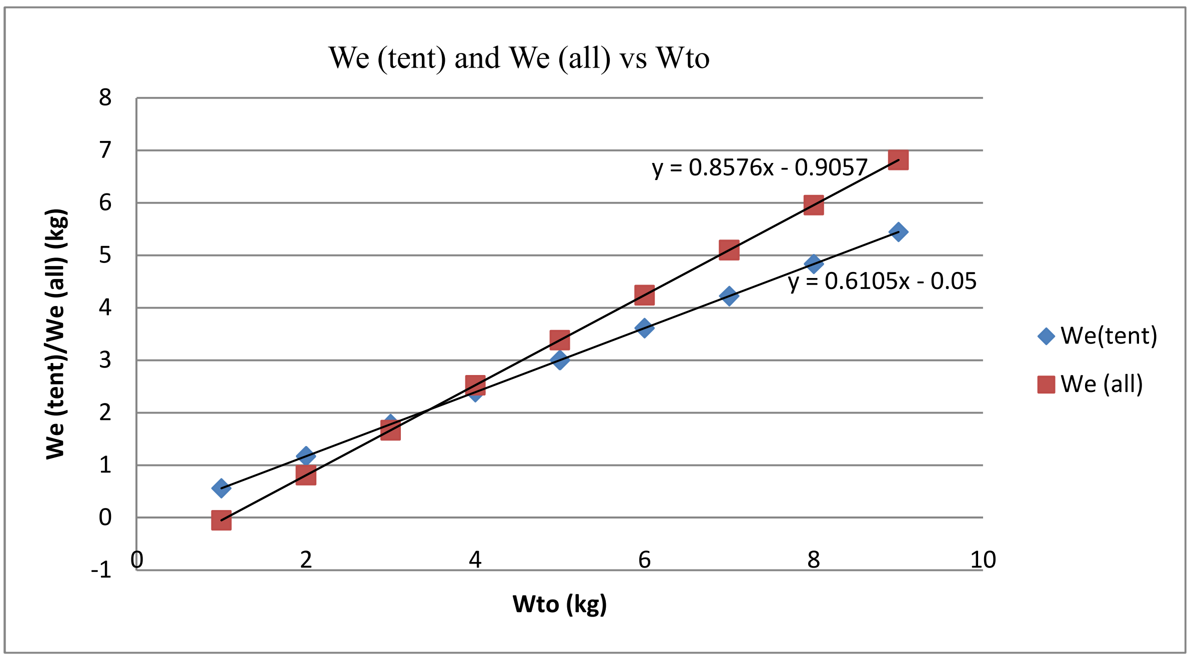

Figure 4.2: (W_{TO}) Guessed versus (W_E) allowable and (W_E) tent

From Figure 4.2, at the interception point the $(W_{TO})_{Actual}$ and other operating weights was yield the following values;

$$\text{Take off weight, } W_{TO} = 3.807 \text{ kg}$$

$$\text{Empty weight, } W_E = 2.36 \text{ kg}$$

$$\text{Fuel Weight, } W_F = 1.38 \text{ kg}$$

4.3 AIRCRAFT SIZING

The mini-UAV that is designed for the reconnaissance missions must follow the Federal Aviation Regulation (FAR) standard. The mini-UAV used the FAR 23 specifications that contain airworthiness standards for airplanes in the normal, utility, acrobatic, and commuter categories. This method used to determine the values of wing loading and thrust loading produce by the aircraft.

4.3.1 Stall Speed Sizing

From the discussion in the Technical Task in chapter 2, the mini-UAV is designed for reconnaissance missions have the speed of 40km/h during loitering to ensure it gives the better performance during the flight time. So the stall speed sizing will follow the Eq. (4.8).

$$Vs = \left(\frac{2\, W/S}{\rho CL}\right)^{1/2} \tag{4.8}$$

Loiter speed ,V_s = 40 km/h @ 21.59 knots

Air Density at 1,000 ft, $\left(\frac{slug}{ft^3}\right)$ =0.00206

Lift coefficient (max), $C_{L\,max}$ = 1.3

$$41.01 = \frac{2\left(\frac{W}{S}\right)}{0.00206(1.3)}$$

W/S = 2.25 lbs/ft^2

4.3.2 Climb Sizing

The UAV operates using a single engine hence climb requirements for One Engine Inoperative (OEI) can be neglected. So, the UAV will follow the FAR 23.65 climb requirements for the All Engine Operating (AEO) only.All the values were selected was taken from the table Airplanes Design book (Roskam, 2005) based on the reasonable assumption and were outlined in Table 4.3:

Table 4.3: Coefficient used in the Aircraft Sizing

Aspect ratio, A	9
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
$C_{L\ max}$	1.3
$C_{L\ max\ TO}$	1.6
$C_{L\ max\ L}$	1.9
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)

4.3.2.1 Airplane Drag polar

Airplane drag polar need to estimate first before proceed sizing an aircraft sizing requirement. The drag polar coefficient for an airplane can be written in Eq. (4.9):

$$\text{Drag Polar,} C_{Do} = f / S_{wet} \tag{4.9}$$

The wetted area need to be calculating first using the Eq.(4.10).The c and d are the constant value of regression line coefficients (Roskam,2005).

$$Log\ S_{wet} = c + d\ log\ W_{TO} \tag{4.10}$$

$$S_{wet} = 35\ ft^2$$

Then calculate equivalent parasite, f using Eq. (4.11) yield the following value

$$Log\ f = a + b\ log\ S_{wet} \tag{4.11}$$

$$f = 0.14\ ft^2$$

Finally the drag coefficient can be calculated using the equation 4.9

$$\text{Drag Polar, } C_{Do} = 0.004$$

4.3.2.2 FAR 23.65 RC (Rate of Climb)

The UAV must have the minimum climb rate at sea level of 300 fpm. Rate of climb for FAR23 written in Eq.(4.11) and Eq.(4.12):

$$RC = \text{Rate of Climb} = 33000 \text{ x } RCP \tag{4.12}$$

Hence, $RCP = \text{Rate of Climb Parameter} = \frac{300}{33000} = 0.0091$

$$RCP = \frac{\eta_P}{W/P} - \frac{(W/S)^{1/2}}{19(C_L^{3/2}/C_D)\sigma^{1/2}} \tag{4.13}$$

The ($C_L^{3/2}/C_D$) can be determine using Eq.(4.14).

$$(C_L^{3/2}/C_D)_{max} = (1.345\,(Ae)^{3/4}) / (C_{Do}^{1/4}) \tag{4.14}$$

$$= (1.345(9 \times 0.81)^{3/4}) / (0.004^{1/4})$$

$$= 23.51$$

Substitute above value into equation 4.12 and yield the following equation.

$$0.0091 = \frac{0.7}{W/P} - \frac{(W/S)^{1/2}}{19(23.51)^{1/2}}$$

$$0.0091 = \frac{0.7}{W/P} - \frac{(W/S)^{1/2}}{111.5}$$

4.3.2.3 FAR 23.65 CGR (Climb Gradient)

The FAR 23.65 climb gradient can be calculated using the Eq. (4.15).

$$CGRP = \frac{18.97\eta_P \sigma^{1/2}}{\left(\frac{W}{P}\right)\left(\frac{W}{S}\right)^{1/2}} \tag{4.15}$$

The best way to find climb gradient by calculated the minimum value of CGRP. These values depend on the lift coefficient and lift to drag ratio. Finding the minimum value of CGRP by using Eq. (4.16) where L/D is lift to drag ratio and C_L is lift coefficient when climbing.

$$CGRP = \text{Climb Gradient Parameter} = CGR + \frac{1/(\frac{L}{D})}{C_L^{1/2}} \tag{4.16}$$

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

$= 1.6 - 0.2 = 1.4$

$$C_D = 0.004 + \frac{{C_{L\ TO}}^2}{\pi A e}$$

$= 0.091$

$$\frac{C_L}{C_D} = \frac{L}{D} = \frac{1.4}{0.091} = 15.44$$

By using Eq. (4.16), the minimum CGPR can be determined.

$$CGRP = 1/12 + \frac{1/15.44}{1.4^2}$$

$= 0.1164$

Finally substitute the values into the Eq. (4.15) and yield the final equation.

$$CGRP = \frac{18.97(0.7)(0.971)^{1/2}}{\left(\frac{W}{P}\right)\left(\frac{W}{S}\right)^{1/2}} = 0.1164$$

$$= (W/P)(W/S)^{1/2} = 112.41$$

4.3.2.4 FAR 23.77 (Balked Landing Climb)

The sizing FAR23.77 standard is very same to the FAR 23.65 climb gradient sizing. Hence, it used the same equation which is Eq.(4.15).The different here only the C_L and C_D values and CGR that equal to 1/30 rad. First, determine the C_L and C_D values , the L/D ratio can be obtained.

$C_{L\ max\ L} = 1.9$

$C_{L\ climb} = 1.9 - 0.2 = 1.7$

$$C_D = 0.004 + \frac{1.7^2}{\pi(9)(0.8)} = 0.1318$$

$$\frac{C_L}{C_D} = \frac{L}{D} = \frac{1.7}{0.1318} = 12.9$$

Use the Eq. (4.16) where the climb gradient is shown below,

CGR =1 /30 = 0.0333

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

$$= \frac{0.0333 + \frac{1}{12.9}}{\sqrt{1.7}} = 0.085$$

Finally, the climb gradient parameter (CGRP) was put into Eq.(4.15) and yield the relation between (W/P) and (W/S)..

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

$$= \frac{18.97(0.7)(1)^{1/2}}{\left(\frac{W}{P}\right)(\frac{W}{S})^{1/2}} = 0.085$$

$(W/P)(W/S)^{1/2} = 156.22$

The final climb sizing values are presented in Table 4.4. Before that, the power loading (W/P) values need to convert to $(W/P)_{TO.}$. Hence , the W/P values will divided by 1.1 and gives the values for $(W/P)_{TO.}$

Table 4.4: Final 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	45.33	41.21	158.97	144.52	220.92	200.84
1	38.74	35.21	112.41	102.19	156.22	142.01
1.5	34.85	31.68	91.78	83.43	127.55	115.95
2	32.13	29.21	79.48	72.25	110.46	100.42
2.5	30.06	27.33	71.09	64.63	98.80	89.82
3	28.41	25.83	64.90	59.00	90.19	81.99
3.5	27.04	24.59	60.08	54.62	83.52	75.91
4	25.89	23.53	56.205	51.09	78.11	71.00
4.5	24.88	22.62	52.99	48.17	73.64	66.94
5	24.01	21.82	50.27	45.701	69.863	63.512

4.3.3 Cruise/Loiter Speed Sizing

Cruise speed sizing is determined using Eq.(4.17) where I_P is called the power index can be determinefrom the chart (Roskam, 2005) equal to 0.27.From the technical task the UAV will be fly at 60km/h , hence the final cruise sizing equation shown below.

$$\frac{W}{S} = (I_P)^3(\sigma)\left(\frac{W}{P}\right) \tag{4.17}$$

$$\frac{W}{S} = 52.38\,\frac{W}{S}$$

4.3.4 Matching Diagram

Table 4.5: Summarizing to FAR 23 requirements

Parameter	Equation
Drag Polar, C_{Do}	0.004
Stall Speed Sizing	W/S = 2.25 lbs/ft^2
FAR 23.65 RC (Rate of Climb)	$0.0091 = \frac{0.7}{W/P} - \frac{(W/S)^{1/2}}{111.5}$
FAR 23.65 CGR (Climb Gradient)	$(W/P)(W/S)^{1/2} = 112.41$
FAR 23.77 (Balked Landing Climb)	$(W/P)(W/S)^{1/2} = 156.22$
Cruise/Loiter Speed Sizing	$\frac{W}{S} = \quad 52.38\,\frac{W}{S}$

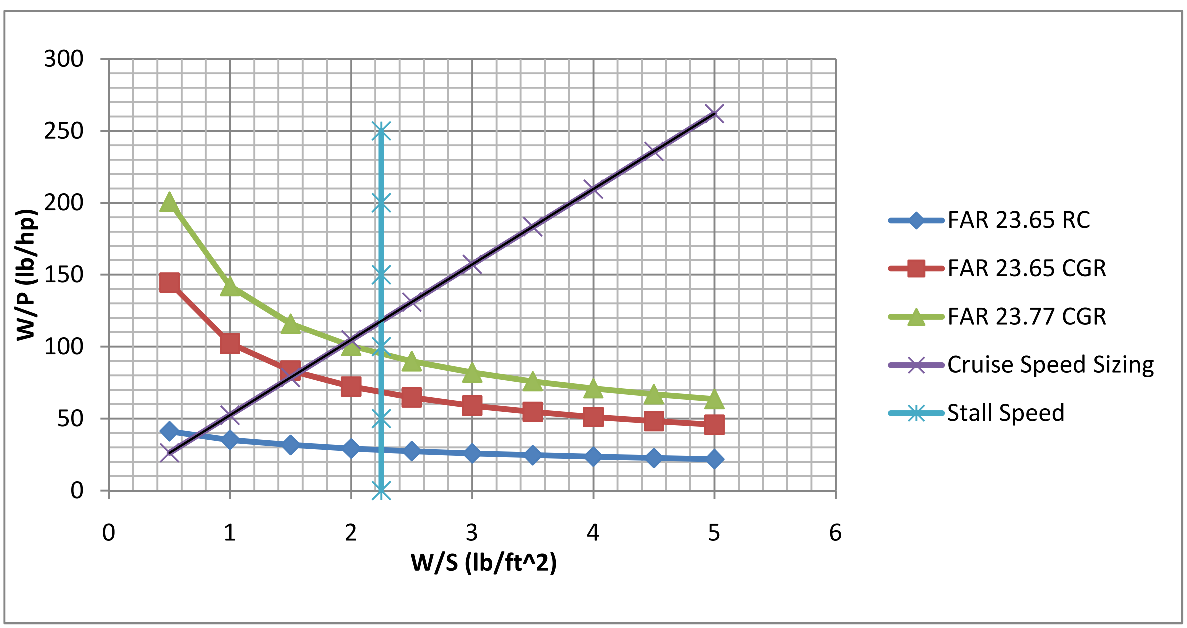

Figure 4.3: Matching Diagram

All the aircraft sizing that calculated can be shown in the Matching Diagram. The best suitable point will be selected and yield the following values.

Wing loading, $W/S = 2.25\ lb/ft^2$

Power loading, $W/P = 30\ lb/hp$

The weight of the aircraft which is 3.807kg (8.39lb) already knows in the weight estimation analysis, hence it will give the following value:

Wing area, $S = 0.347\ m^2\ (3.73\ ft^2)$

Power, $P = 208\ W$

4.4 SENSITIVITY ANALYSIS

The sensitivity analysis was conduct to find out which parameter will affect the take-off weight. The calculation was following the step provided from Roskam, 2005 and Belnaves ,2008. The sensitivity was study due to the requirement of endurance and range case that are following major aircraft parameters:

1. Range ,R
4. Endurance, E
5. Lift-to-Drag ratio L/D
6. Specific Fuel Consumption c_p
7. Propeller efficiency n_p
8. Speed Sensitivity V_{Cruise}

The regression line constants A and B were obtained from technology diagram (see Figure 4.1). The values of the regression line constants A and B were found to be 0.2216 and 0.9234 respectively. The Eq. (4.18) is the calculation for the take-off weight sensitivities for range and endurance case.

$$\frac{\delta\,\mathrm{Wto}}{\delta\,\mathrm{y}} = \mathrm{F}\,\frac{\delta\,\overline{\mathrm{R}}}{\delta\,\mathrm{y}}$$

$$\frac{\delta\,\mathrm{Wto}}{\delta\,\mathrm{y}} = \mathrm{F}\,\frac{\delta\,\overline{\mathrm{E}}}{\delta\,\mathrm{y}} \tag{4.18}$$

The value of $\frac{\delta\,\overline{\mathrm{R}}}{\delta\,\mathrm{y}}$ and $\frac{\delta\,\overline{\mathrm{E}}}{\delta\,\mathrm{y}}$ can be found determine using the Table 4.6 for the single propeller driven aircraft case. Before that, F needs to be determining first using Eq. (4.19).

$$F = -B\,(W_{TO})^2 (C\,W_{TO}(1-B)-D)^{-1}\,(1 + M_{reserve})\,M_{ff} \tag{4.19}$$

Table 4.6: Values for sensitivity equations

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 1, Roskam.(2005)

For F calculation, there are need to determine the value of A, B, C and D. Since, the value of A and B already know, the Eq.(4.20) and Eq.(4.21) used to calculate C and D using the values in Table 4.7.

Table 4.7: Values to calculate C and D

W_{TO}	8.4 lb
We	5.203 lb
$M_{reserve}$	0
M_{ff}	0.658
W_{PL}	0
W_{crew}	0
$M_{funusable}$	0.005

$$C = 1 - (1 + M_{reserve})(1 - M_{ff}) - M_{funusable} \tag{4.20}$$

$$D = W_{PL} + W_{crew} \tag{4.21}$$

Hence, this will yield the following values:

A: 0.2216

B: 0.9234

C: 0.653

D: 0

The following values displaced in Table 4.8 used to calculate sensitivity analysis.

Table 4.8: Required values for sensitivity analysis

Parameter	Cruise	Loiter
C_p	0.8161	0.844
η_p	0.7	0.7
L/D	15	12
V(mph)	37.3	27.96
R (sm)	3	0
E	0	1

From the result that was obtained above, F can be obtained using equation 4.18 and yield the value as 102.04 lb. This value was used in the sensitivity equation shown in Table 4.6 to calculate the parameters mention earlier. Hence, all the parameters values obtained shown in tabulate data in Table 4.9 and were explained in discussion section.

Table 4.9: Sensitivities of the main parameter

Range	Sensitivities	Endurance
0.021	R/E	0.7623
0.0777	C_p	0.9056
-0.0906	η_p	-1.0919
	V	0.019
-0.004	L/D	-0.064

4.5 EMPENNAGE SIZING

The empennage sizing calculation will follow the step that have been provided by the Airplane Design Part 2 book (Roskam,2005).

4.5.1 Deciding the overall configuration

The empennage consist the horizontal tail and vertical tail. The primary function of the horizontal tail is to provide longitudinal stability .The elevator is the control surface on the horizontal tail provides longitudinal control and trim. The primary function of the vertical tail is to provide directional (yawing) stability .The rudder is the control surface on the vertical tail provides the directional control. The size of the horizontal and vertical tail must be sufficient to provide the necessary stability and control of the airplane. The conventional tail was selected because of the advantages that might be able to improve the performance of the mini-UAV. The advantages of conventional tail are:

1. The horizontal control surface fairly large and provides adequate control.
2. Structural support from fuselage attach
3. Lightest weight and lower the drag force.
4. 70% aircraft used this type of tail.
5. Simple design
6. Providing reasonable stability and control

Figure 4.4: Conventional Tail

Source: https://www.rtrhobbies.com

4.5.2 Determination of Volume Coefficients

Since the value volume coefficients provided by Roskam(2005) is used for the larger aircraft, hence statistical data of similar UAVs and the values presented by

Raymer(2006) for tail volume coefficients of UAV can be accepted. The values obtained presented in Table 4.10.

Table 4.10: Aircraft volume coefficient data

Aircraft	$\bar{V}_H$	$\bar{V}_V$	Reference
BAI ‘ Javelin’	0.6364	0.0372	Janes-Information-Group (2002)
INTA ‘Alo’	0.5935	0.0337	Janes-Information-Group (2002)
Aerosonade	0.93	0.0201	Janes-Information-Group (2002)
General Aviation – single engine	0.70	0.04	Raymer (2006)
Average	0.715	0.033	

Source: Avalakki et al.(2008)

The selected volume coefficients for the UAV derived from this method are as follows.

$$\bar{V}_H = 0.8$$
$$\bar{V}_V = 0.04$$

A slightly higher value of tail volume coefficients was selected as the result to improve control authority and stability level that the tail plane is to provide. Higher volumes coefficients will increase surface planform areas which gave greater control authority and stability for the aircraft (Avalakki et al, 2008). However, if the surfaces that were used too large, it would create excessive weight in the tail plane and also increase the drag force that acting on the tail plane. Thus the sizing ensured the values of the coefficients used fell within the accepted boundry.

4.5.3 Tail Moment Arm, X_H And X_V

The lever arms of the horizontal and vertical stabilisers are the distances between the quarter chord points of the mean aerodynamic chords of the surfaces and the quarter chord point of the mean aerodynamic chord of the main wing (Raymer, 2006). The lever arms are measured in percent of the Mean Aerodynamic Chord (MAC) of the main wing. The definition of the lever arms is shown in Figure 19.

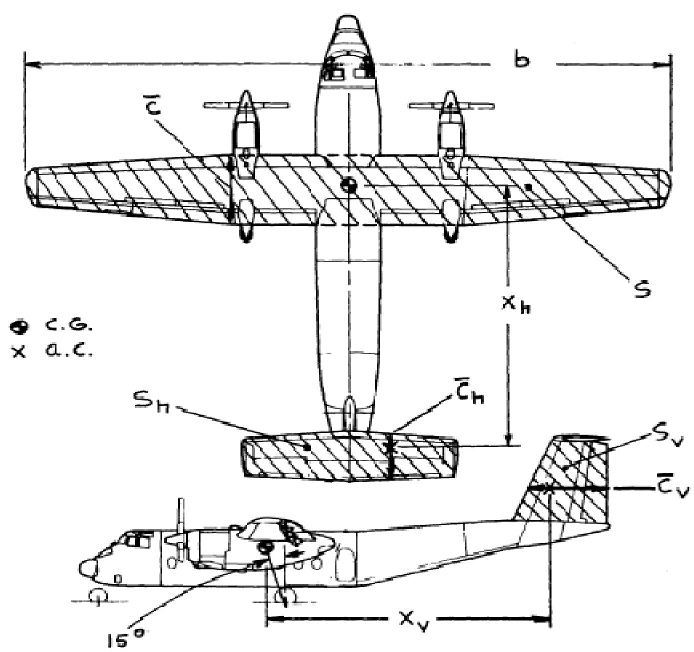

Figure 4.5: Tail Moment Arm

Source: Airplane Design Part 2 ,Roskam.(2005)

Raymer(2006) suggested that for aft-mounted engines such as one mounted for "pusher propeller" operation , the tail arm approximately 45% of the fuselage length .Both distance horizontal and vertical lever arm should be equal to assist the manufacturing process. This aircraft will not be performing complicated maneuvers and so uneven tail arms which used to improve performance during adverse conditions (Raymer, 2006) were seen unnecessary. The length of the UAV was 1.2 m, hence yield following values

$$\boldsymbol{X}_{\mathbf{H}} = 0.54\text{m}$$

$$\boldsymbol{X}_{\mathbf{V}} = 0.54\text{m}$$

4.5.4 Tail Area, S_H and S_V

The UAV tail area will provide the movement for aircraft in pitch and yaw direction. As mention earlier, the UAV tail area should be keeping smaller to reduce the weight of the aircraft but still can produce enough force for the aircraft movement. The tail area is calculated using Eq. (4.22) for horizontal tail area and equation Eq. (4.23) for vertical tail area. The data of the main wing properties shown in Table 4.11 need to determine first before finding the value of tail area. These values were taken from other researcher of the same project that was study on the wing configuration.

Table 4.11: Main wing properties

Parameter	Values
Aspect ratio	5
Span, b_w	2.0m
MAC, $\bar{\boldsymbol{C}}$	0.18m
Area, S_w	0.347m^2

$$S_H = \frac{\bar{V}H \ \bar{C} \ Sw}{XH} \tag{4.22}$$

$$S_V = \frac{\bar{V}v \ bw \ Sw}{Xv} \tag{4.23}$$

Using the above results in conjunction with equation 4.22 and equation 4.23, the planform areas of the horizontal and vertical stabilisers were calculated. These areas were found to be:

$$\mathbf{S_H} = \frac{(0.8)(0.18)(0.347)}{(0.54)} = 0.093\text{m}^2$$

$$\mathbf{S_V} = \frac{(0.4)(2.0)(0.347)}{(0.54)} = 0.051\text{m}^2$$

4.6 MEAN AERODYNAMIC CHORD (MAC) POSITIONING

Mean aerodynamic chord defined as the average part for the whole stabilizers. The calculation of MAC depends on the design of the stabilizers planform such as triangular and trapezoid .For the rectangular planform, the MAC just located at middle of the stabilizers. The aerodynamic center is located 25% of the MAC and fundamental for stability study on moving aircraft.

4.6.1 MAC for Horizontal Tail

The horizontal tail span can be evaluated using the Eq.(4.24).The aspect ratio selected for the aircraft need to be lower than used on the wing .The lower aspect will provide the tail to stall at the higher angle of attack. The tail required to balance of the aircraft if the main wing stall and give the adequate control .Taper ratio is ratio between the root chord and tip chord .It was choose to be 0.5 and separated will occur on the middle but the stabilizer still can provide the control for the aircraft.(Anderson, 1999).

Horizontal tail area, S_H = $0.093m^2$

Aspect ratio, A = 4

Taper ratio, λ_H = 0.5

Horizontal tail span , b_H = $\sqrt{A\ Sh}$ (4.24)

= 0.61m

The root chord and tip chord were calculated using Eq.(4.25) and Eq.(4.26) respectively.

$$C_{root} = \frac{2s}{b(\ 1+\lambda)} \tag{4.25}$$

$$= \frac{2(0.093)}{0.61(\ 1+0.5)}$$

$$= 0.203 \text{ m}$$

$$C_{tip} = \lambda.\ C_{root} \tag{4.26}$$

$$= 0.5\ (0.203)$$

$$= 0.102 \text{ m}$$

Used the value obtained in Eq. (4.25) and Eq.(4.26) to evaluate the MAC position on the horizontal stabilizer that shown in Eq.(4.27). Then, the distance from root to MAC was determined using Eq.(4.28). The distance of the aerodynamic centre was quarter of the MAC and illustrated in Figure 4.6.

$$\bar{C} = C_{root} - \frac{2(\text{Croot}-\text{Ctip})\times(\frac{1}{2}\,\text{Croot}+\text{Ctip})}{3(\text{Croot}+\text{Ctip})} \tag{4.27}$$

$$= 0.203 - \frac{2(0.203-0.102)\times(\frac{1}{2}0.203+0.102)}{3(0.203+0.102)}$$

$$= 0.158 \text{ m}$$

$$\bar{Y} = \frac{b}{6}\left(\frac{1+2\lambda}{1+\lambda}\right) \quad (4.28)$$

$$= \frac{0.61}{6}\left(\frac{1+2(0.5)}{1+0.5}\right)$$

$$= 0.136\text{m}$$

Aerodynamic center = 0.25% MAC

= 0.25(0.158)

= 0.0395 m

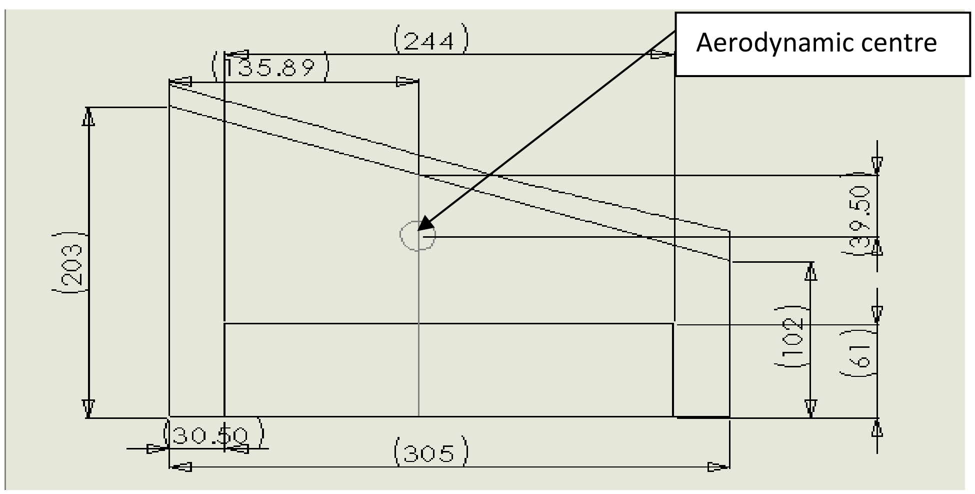

Figure 4.6: Horizontal tail MAC location

4.6.2 MAC for Vertical Tail

The lower aspect ratio was used because the vertical stabilizer only moving in the lateral direction .The taper ratio remains the same with the horizontal stabilizer. The Eq.(4.29) is to determine the vertical tail span.

Vertical Tail Area, S_v = $0.051m^2$

Aspect ratio, A = 1.5

Taper ratio, λ_V = 0.5

$$b_v = \sqrt{A\,Sv} = 0.277m \tag{4.29}$$

The process to estimate the root and tip chord is following Eq. (4.25) and Eq. (4.26).The MAC position and the distance to MAC from root chord similar horizontal positioning. Hence both calculations were using the same equation which is Eq. (4.27) and Eq. (4.28).

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

$$= \frac{2(0.051)}{0.277(1+0.5)}$$

$$= 0.246 \text{ m}$$

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

$$= 0.5\ (0.246)$$

$$= 0.123 \text{ m}$$

$$\bar{C} = C_{root} - \frac{2(\text{Croot}-\text{Ctip})\times(\frac{1}{2}\text{Croot}+\text{Ctip})}{3(\text{Croot}+\text{Ctip})}$$

$$= 0.246 - \frac{2(0.246-0.123)\times(\frac{1}{2}0.246+0.123)}{3(0.246+0.123)}$$

$$= 0.191\text{m}$$

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

$$= \frac{0.277}{6}\left(\frac{1+2(0.5)}{1+0.5}\right)$$

$$= 0.062\text{m}$$

Aerodynamic center = 0.25% MAC

= 0.25(0.191)

= 0.0.048 m

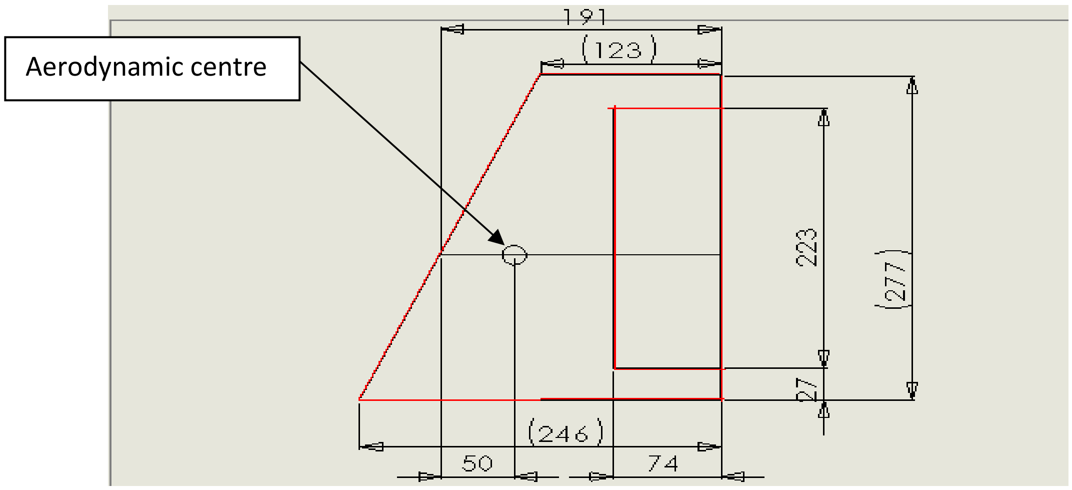

Figure 4.7: Vertical tail MAC location

4.7 CONTROL SURFACE DESIGN AND INTEGRATION

4.7.1 Elevator sizing for Horizontal Stabilizers

The UAV used two elevators that were mounted on the horizontal tail to control the pitch motion of the aircraft. Simons, (2002) is suggested that the chord length of the elevators should be range around 20% and 30% of the chord length of the horizontal stabilizer. The elevators were designed to be rectangular to allow the elevators to have the constant chord length which was chosen $0.30C_H$. The span of the elevators was selected to be as large as possible from the existing horizontal span to increase the control perfomance of the aircraft. Eq. (4.30) used to find chord length of the elevator.

$$0.20CH \leq Celevator \leq 0.30CH \tag{4.30}$$

Hence the chord and span of the elevators yield the following values:

$$C_{elevator} = 0.30C_H = 0.061 \text{ m.}$$

$$b_{elevator} = 0.80 \text{ b} = 0.244 \text{ m}$$

4.7.2 Rudder sizing for Vertical Stabilizer

The conventional tail used a single rudder that was located on vertical stabilizer, is used to control the yaw motion of the aircraft. The sizing for the rudder is the same as elevators and using the recommendations of Simons (2002) and the chord length of the rudder should be between 20% and 30% of the chord length for the vertical stabilizer.The rudder was designed to be rectangular to allow the rudder to have a constant chord length and to simply the manufacturing process. The chord length was chosen 0.30Cv .Same as the elevators, the span of the rudder was selected to be as large as possible.

$$0.20C_V \leq C_{rudder} \leq 0.30C_V$$

Hence the chord and span of the rudder yield the following values:

$$C_{rudder} = 0.30C_v = 0.074 \text{ m.}$$

$$b_{rudder} = 0.80 \text{ b} = 0.223 \text{ m}$$

4.8 AIRFOILS SELECTION

Four different airfoils were analyzed ,hence the best suitable airfoil which has higher lift coefficient and lower drag coefficient , also can stall at higher angle of attack was selected. Only NACA 4 digit airfoil series was considered as these airfoils are in common use on many aircraft tails due to their gradual stall characteristics.

The airfoils that were choosing to be analyzed were NACA 0006, NACA0008, NACA0012 and NACA0018 were analyzed using 'Profili' software. All the selected airfoils are capable to operate of operating in flow with $1.0\times105 < Re < 3.0 \times 105$ (Avalakki et al, 2008). The graph of C_L Vs C_D, C_L Vs Alpha (AOA), C_D Vs Alpha, C_L/C_D Vs Alpha and C_m Vs Alpha that operating at Re=100000 was shown in Figure 4.8, Figure 4.9 and Figure 4.10 .

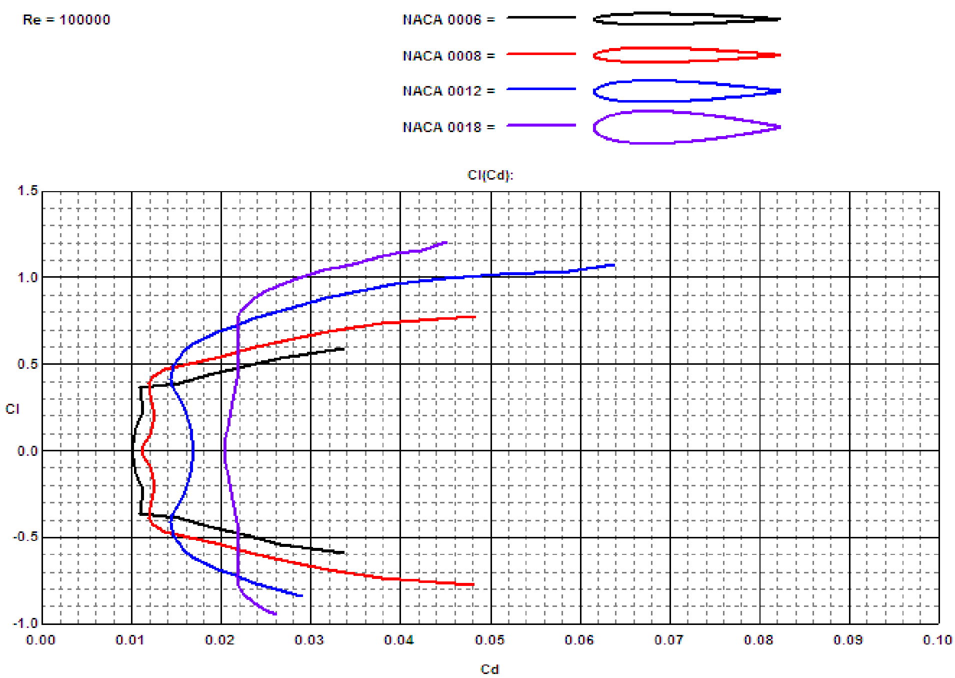

Figure 4.8: Graph C_L versus C_D

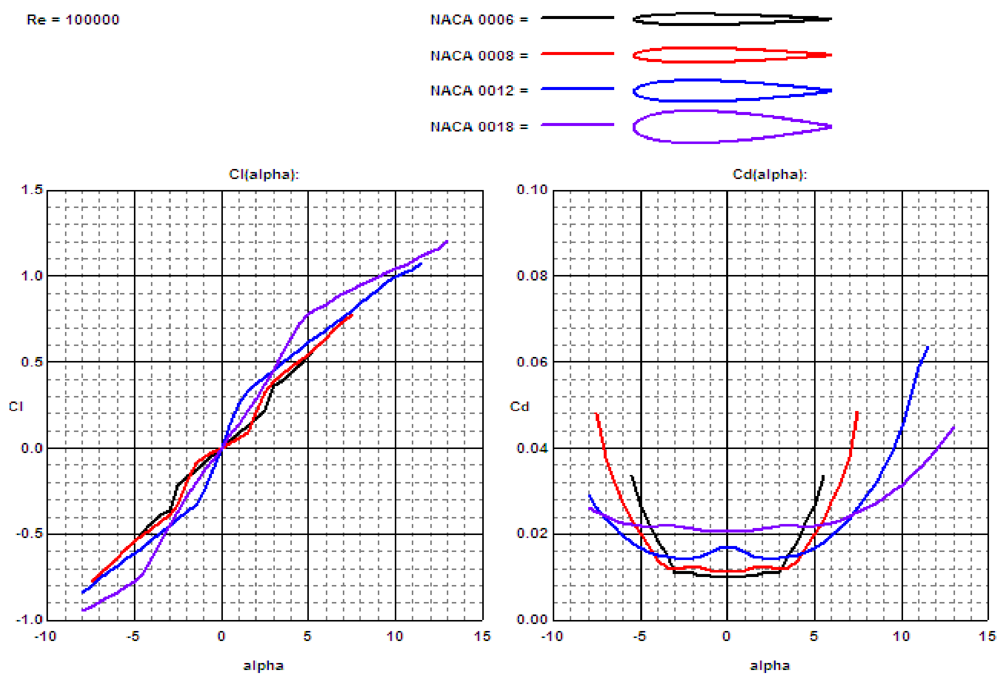

Figure 4.9: Graph C_L Vs Angle of attack and C_D Vs Angle of attack

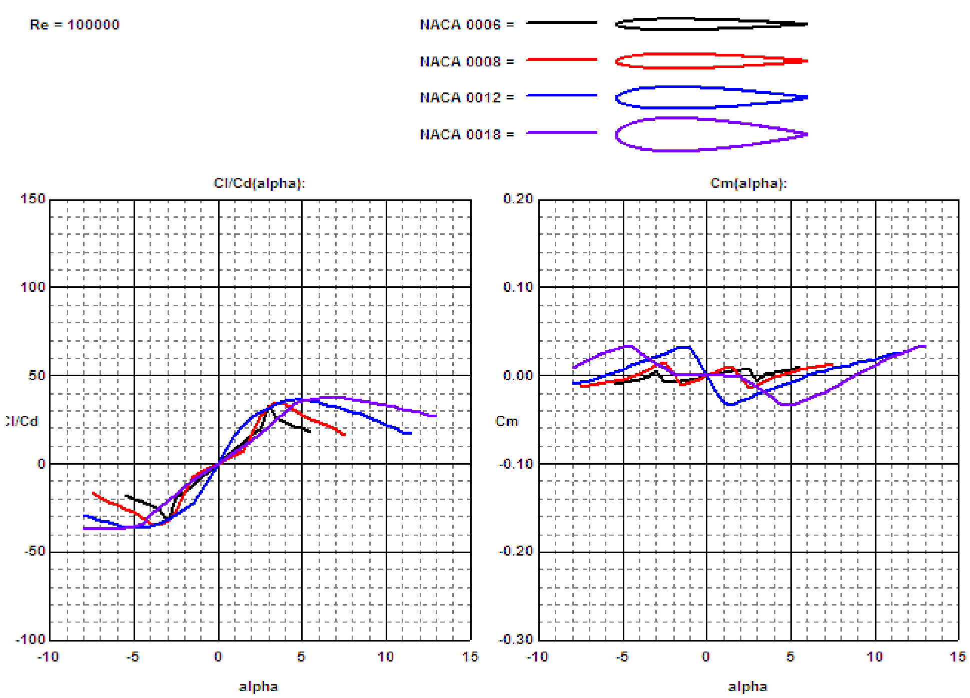

Figure 4.10: Graph C_L/ C_D Vs angle of attack and C_m Vs angle of attack

The results of '*Profili*' testing of four reasonable thickness airfoils are presented in Table 4.12.

Table 4.12: The NACA 4 digit Aerofoil Analysis

Profile	C_{Lmax}	α ($C_{L\ max}$)	C_{Dmax}	Cl/Cd	C_m
NACA 0006	0.5903	5.5	0.0337	17.5163	0.0095
NACA 0008	0.7751	7.5	0.0483	16.0476	0.0134
NACA 0012	1.0767	11.5	0.0637	16.9027	0.0250
NACA 0018	1.2023	13.0	0.0450	26.7178	0.0331

The best airfoils to be selected and use in the tail of the aircraft must satisfied the requirement below (Avalakki et al, 2008);

- Able to provide the maximum lift coefficient
- Produce the lower drag coefficient to increase the flying performance.
- Give the higher lift to drag ratio
- Able to stall at higher angle of attack .This is important to recover the aircraft to the normal position again if the main wing stalls.
- Low and constant Cm to reduce torsional loads and induced drag of trimming.

Hence, the best suited airfoil that fit to tail of the aircraft was NACA 0012. This aerofoil provides the better aerodynamic efficiency and show gradual stall than others option. The selected NACA 0012 shown in Figure 4.11.

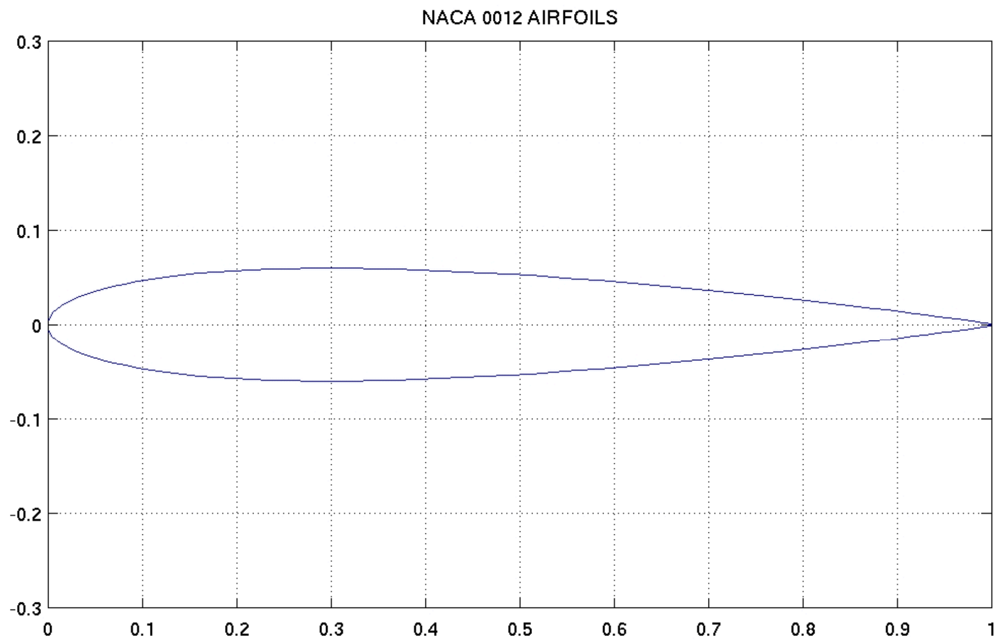

Figure 4.11: Cross Section of NACA 0012 Airfoil as used in both Stabilizers

Source: Selig, (2006)

4.7 DESIGN

The design of the empennage and the whole aircraft illustrated in Figure 4.12 and Figure 4.13. The empennage is drawn using SOLIDWORKS software and the airfoil is designed using DESIGNFOILS software then imported to the SOLIDWORKS.The detailed drawing of the airframe can be found in Appendix F.

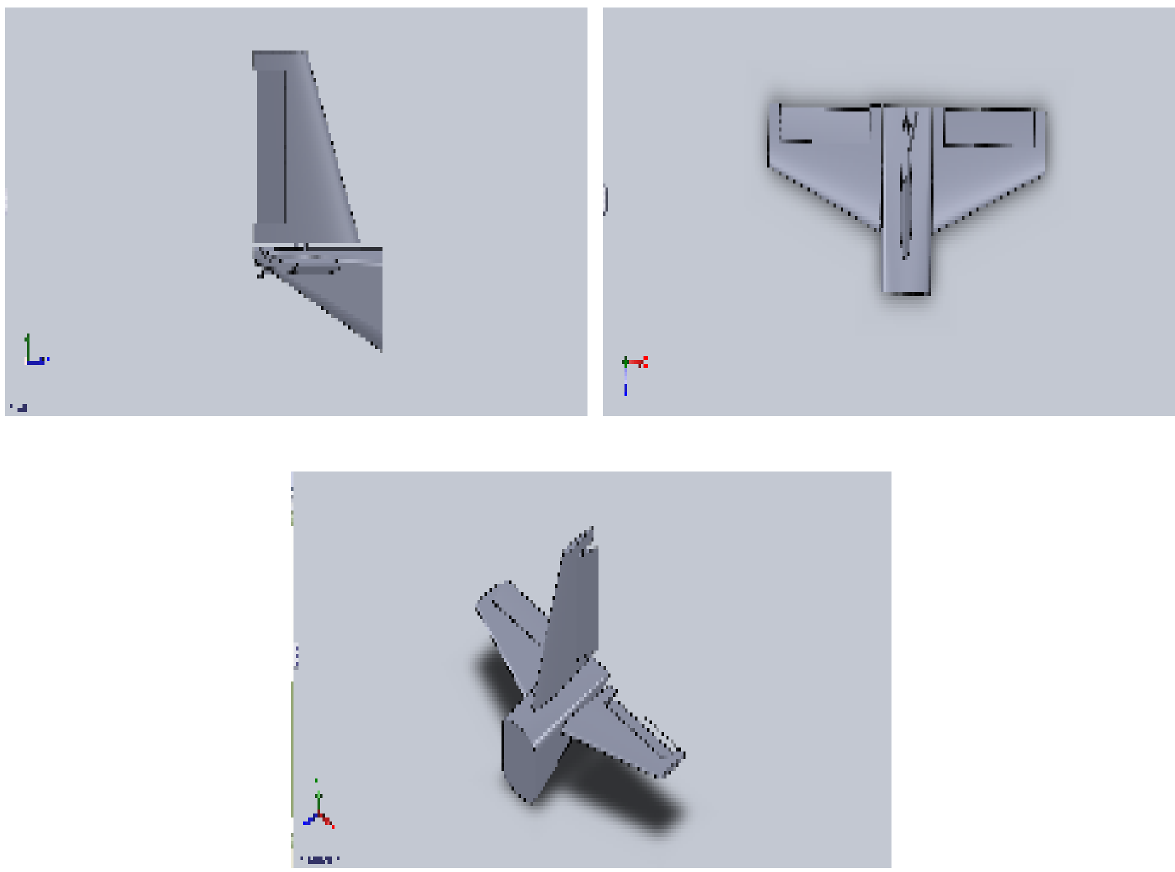

Figure 4.12: Empennage design

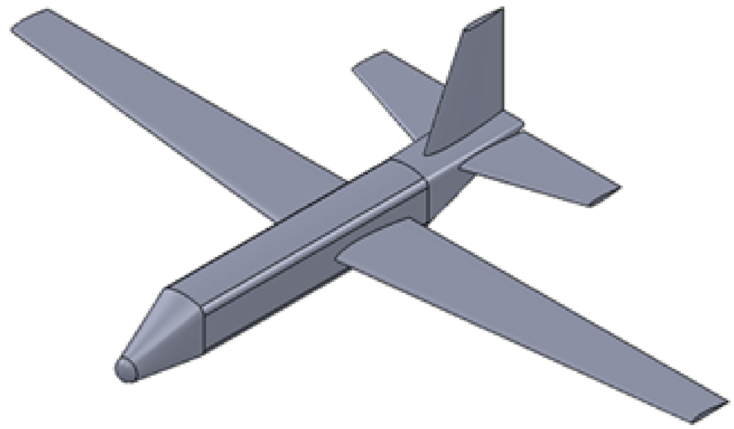

Figure 4.13: Overall configuration design of the UAV

4.8 DISCUSSIONS

The study to design an UAV can be divided into three main parts that are wing, fuselage and empennage. For this project, each researcher are responsible for their part but must work together because each part closed related to others and for example the effect of the wing design will affect all aircraft configuration design. The technical task should be decided before the design process can start.

Design the aircraft distributed into three stages which are conceptual design, preliminary design and detailed design. During the conceptual design process, the designers need to determine the aircraft preliminary sizing including weight (payload weight, empty weight, fuel weight, and take-off weight), thrust or power (thrust loading) and the wing area (wing loading). As the conceptual study was done, the sensitivities analysis must be carried out as a refinement of preliminary sizing.

The preliminary design was conducted after the early conceptual design. During the preliminary design, the designer will proposed a configuration design including initial layout of wing, fuselage and empennage. The configuration design also contained the study of tail sizing, weight and balance, drag polar and landing gear disposition.

During detailed design stage, more and precise wind tunnel tests are done, hence the prototypes can be manufactured and flight tests are done to check whether the aircraft flied properly or not.

This project was following the design stages above but will not cover the detailed design stage due to time and resource constraints. As mention earlier, this project is to design a small UAV that can be use for civil reconnaissance missions. The small UAV is selected because typically this type of UAV is less expensive compared to mid-size and large UAV and it is crucial to attract civilians and government sectors to buy it. Also, the small UAV is much more portable and can be assemble in the shorter time. The small size will enable it handling by one person only and can reduce the operation cost. The small UAV has many advantages including can operate in lower altitude and lower flight speed to provide clearer view during reconnaissance missions. As this UAV is used in civil applications, therefore it is not required for this UAV to be stealth to avoid the enemy radar.

The weight of the UAV needs to determine first by studying the aircraft that has similar requirements with the proposed UAV. Using fuel weight fraction analysis, the weight take-off for, weight empty and weight fuel can be obtained. The weight take-off for UAV, W_{TO} is 3.8 kg including empty weight, fuel weight, engine weight, control system weight and payload weight. The weight empty for the UAV W_E is 2.36 kg .The empty weight is the weight for the aircraft airframe including the engine oil, engine coolant and unusable fuel sometimes called as factory weight to refer the weight of an aircraft when it leaves the factory. The weight fuel, W_F is 1.38kg and it describe as the amount of the fuel carry by the aircraft. The aircraft usually carry excessive amount of fuel onboard for the safety reason.

The aircraft sizing follow the FAR sizing requirement as the basis of airworthiness purpose. The matching diagram was drawn based on the result obtained from the aircraft sizing. From the Matching diagram, the power loading and wing loading as well power and wing area can be obtained. These values were use to in the empennage sizing later. Power loading, W/P for the UAV is 30 lb/hp used to measure the actual performance of the engine .Wing loading, W/S = 2.25 lb/ft^2 is the take-off weight for the aircraft divide by its wing area. The wing loading used to estimate the general maneuvering performance of an aircraft. The higher wing loading cause landing and take-off speeds will be higher and decreases maneuverability From the weight estimation analysis, the take-off weight of the aircraft is 3.807kg (8.39lb), hence it will yield the values for wing area, S and power, P which are 0.347 m^2 (3.73 ft^2) and 208 W respectively. Usually, larger wing area generates more lift force due the wing encounter more air movement than the smaller wing at any given speed. The power plant consideration for this aircraft must capable to give the power up to 208W and lightweight. During loiter phase that is important in reconnaissance missions, the engine power is keeps minimum to reduce the fuel consumption; hence it can increase the flight time and contributes to better performance efficiency.

The sensitivities analysis was done to check the parameter that was dependent with the take-off weight. The sensitivity was calculated for both endurance and range case. The sensitivities in Table 4 .9 can be discuss as follows.

Range Sensitivities. For every mile added to the range of the aircraft, the take-off weight will increase by 0.021 lb. If the specific fuel consumption, C_p increase by 0.5 , the take-off weight will be increase by 0.5 x 0.0777 lb. As the propeller efficiency, η_p and L/D increased the take of weight will decrease shown by the negative sign.

Endurance Sensitivities. The sensitivities for the endurance case much higher than the range case. For every hour added to the loiter time, the aircraft take-off weight will increased by 0.7623 l due to the excess fuel carry by the aircraft. If the specific fuel consumption during loiter could be improved from the assumed value 0.844 to 0.85, the take-off weight will increase by 0.006 x 0.9056. If the L/D ratio increased to 13, the take-off weight will reduce0.064 lb .The take-off weight will increased if the propeller efficiency was decrease. If the cruise speed could be increased without changing any other parameter, the gross weight would actually raise.

Later, the design process goes to sizing of empennage or the tail section of the aircraft. The primary function of the tail plane is to generate lift forces to create the required lateral and longitudinal moments for vehicle control. The tail plane is not required to contribute to the lift force which supports the weight of the aircraft during flight. The conventional tail was selected because it gives the aircraft better control stability and lower in weight. The small UAV do not required executing the difficult maneuver, hence the conventional tail is acceptable to use in this project. The tail area was determined and area for vertical tail and horizontal tail were $0.051m^2$ and $0.093m^2$ respectively. The larger tail areas will give the better control movement for the aircraft but the area must not too large because it will increase the weight of the aircraft itself.

Typically, the aspect ratios for the tail must be less than the wing aspect ratio. The lower aspect ratios will stall at higher angle of attack, hence it will delaying the tail stall and used to recover the aircraft to it stable position back if the main wing stall. Therefore, the aspect ratio used for horizontal tail and vertical tail were 4 and 1.5 respectively. The aspect ratio is the square of the tail span divided by the tail area, b^2 / S.

Taper ratios are selected for both tails is 0.5. It means the tip chord will be half the root chord. MAC is the average for the whole stabilizers .For the rectangular stabilizer, the MAC location is the half of the span. But for stabilizers with some other planform (triangular, trapezoidal, compound,.) the mean aerodynamic center, MAC which is the average for the whole stabilizer need to be calculate. The location of the MAC depends on the shape of the tail planform. The aerodynamic center for the tail is located at the MAC line. The aerodynamic center lies at quarter of the MAC chord from the leading edge of the airfoils. The aerodynamic center is points where the pitching moment for the airfoil remains the same at any angle of attack. The study of the aerodynamic center is crucial in analysis of the stability for the aircraft.

The analysis of the four common airfoils for the empennage was done using “Profili” software .From, the result obtained ,the good airfoil must have lower drag coefficient and higher lift coefficient as to improve the missions performance and fuel used during the flight . It is important for airfoils that use in empennage to have higher the angle of attack than the wing. This will able the aircraft to recover back to its normal position if the main wing stalls first. As the outcome, NACA 0012 will be selected as the airfoil for both vertical and horizontal tail.

From the Table 4.12, although the higher lift coefficient and lower drag coefficient was contribute by NACA0018, but the thickness of the airfoil which is 18% will create a redundant weight to the tail configuration in manufacturing process. Hence, the NACA0012 is the best for this application. This airfoil provides the best aerodynamic efficiency and gradual stall than other options and so has been selected. For the ease of manufacture, a symmetrical airfoil was specified so as the lift forces produced by the tail plane would be approximately equal in both directions.

The design of the empennage will be drawn using Solidworks software. The finished tail part was assembled with the wing and fuselage to create a new UAV design.

The result can be summarizing in Table 4.13 and Table 4.14 below.

Table 4.13: Summary of Aircraft Geometry

Parameter	Value
Aircraft length,	1.2m
Wing Span , b_w	2.0 m
Take-off weight ,W_{TO}	3.807 kg
Empty Weight ,W_E	2.36 kg
Fuel Weight, W_F	1.38 kg
Wing Loading, W/S	2.25 lb/ft^2
Power Loading, W/P	30 lb/hp
Wing Area , S_w	0.347 m^2 (3.73 ft^2)
Power, P	208 W

Table 4.14: Summary of Empennage Geometry

Parameter	Horizontal Tail	Vertical Tail
Tail Area, S_H and S_V	0.093m^2	0.051m^2
Span, b_h and b_v	0.61m	0.277m
Root chord, C_{root}	0.203 m	0.246 m
Tip chord, C_{tip}	0.102 m	0.123 m
MAC, $\bar{C}$	0.158 m	0.191m
Aerodynamic center ,a.c	0.0395 m	0.0.048 m
Moment arm , x_h and x_v	0.54m	0.54m
Volume Coefficient, $\bar{V}_{H}$,$\bar{V}_{V}$	0.8	0.04
Aspect ratio, AR	4	1.5
Taper ratio, λ	0.5	0.5
Airfoil section	NACA0012	NACA0012
Incidence angle	0	0

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The overall study presents the process to design a small UAV used in civil reconnaissance and surveillance missions. The UAV weight can be determined using the mass fuel fraction equation and the statistical data from the commercial UAVs that have similar specification with the proposed UAV. The final weight of the small UAV is 3.8kg and the wing span is 2 meter. The matching diagram enabled the researcher to obtain the values for the wing loading and power loading which is 2.25 lb/ft^2 and 30 lb/hp respectively. The UAV implemented the conventional tail configuration. Conventional tail provides the aircraft the better stability, lower weight and can be found in 70% of the commercials aircraft. The horizontal tail area is 0.093m^2 and vertical tail area is 0.051m^2 were determined from empennage sizing. Data provided by empennage sizing enabled to locate the position of mean aerodynamic chord (MAC) for horizontal tail and vertical tail which is 0.158 m and 0.191m respectively. The aerodynamic center located at the quarter of MAC chord and fundamental in stability analysis. The NACA0012 airfoil was selected to use for the empennage based on better lift coefficient, lower drag coefficient, able to stall at higher angle of attack and capable to provide low and constant moment coefficient. The drawing of the small UAV was illustrated using Solidworks software. Thus this project has achieved the objectives to determine the conceptual design for the UAV and designed the empennage for the UAV based on the results obtained from the calculation. The result obtained can be the guidance during the fabrication process but will not cover in this project.

5.2 RECOMMENDATIONS

From the study of this project, there are a few recommendations that can be implemented to enhance the result for further study:

1. Since the project only considers two dimensional airfoils analysis, hence it will give slightly different values for the lift and drag coefficient. Therefore, the three dimensional analysis need to be done to compared the result and the best suitable airfoils that satisfied both analyses will be selected.
2. The analysis of the UAV's airframe using finite element analysis (FEA) can be determined the impact force due to the crash landing. If the impact for the airframe is too high, it is necessary for the UAV to install a landing gear and other landing recovery. The selection of suitable materials also can reduce the impact force during landing.
3. The fabrication process is used to determine whether the proposed UAV will fly or not. The fabrication process needs the designer to consider the communication system and control system use in the UAV that required a lot of manpower assistance.
4. Future research could allow the small UAV to do the surveillance of larger search areas and can take off and land in more restricted areas.

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APPENDICES

APPENDIX A

Project Gantt Chart For Final Year Project 1

Week / Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Briefing of the project title														
Introduction														
Literature Review Study														
Methodology														
Preliminary result														
Proposal Writing														
Presentation														

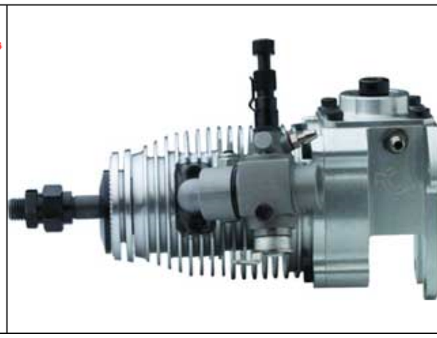
Project Gantt Chart For Final Year Project 2

Week / Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Overview on preliminary result														
Sensitivity Analysis														
Empennage Sizing														
MAC location														
Control surface sizing and Airfoil selection														
Drawing														
Slide Preparation														
Presentation														

APPENDIX B

Engine Specification

RCV60-SP - 0.60 cu in / 10 cc



SP Series Features

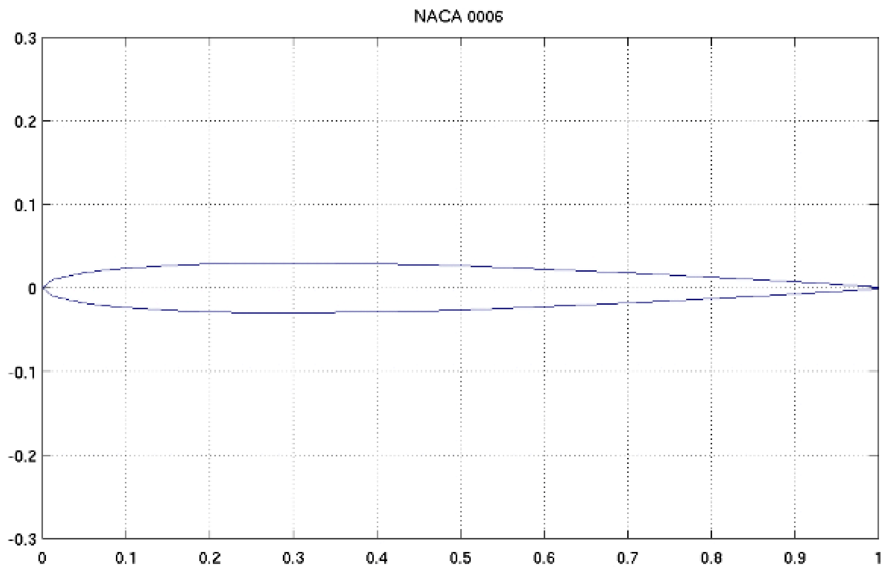
- ✓ Streamline shape, perfect for cowling
- ✓ 2:1 Reduction Gearing
- ✓ Uses Scale Props - 2, 3 & 4-blade
- ✓ Low Maintenance
- ✓ Behind the prop starting facility
- ✓ 2-Year Guarantee

RCV60-SP Specification

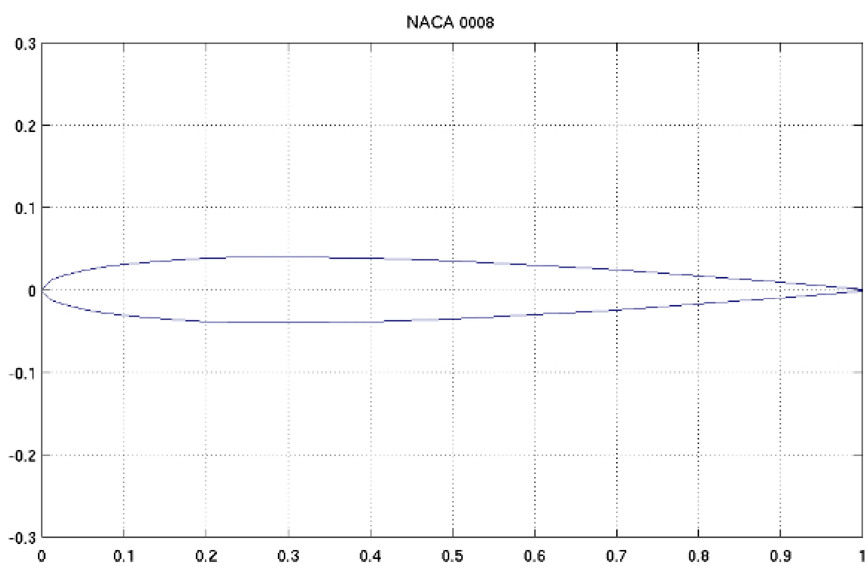
	RCV60-SP	
Specification	*Imperial*	*Metric*
Manufacture	CNC Machined from Solid	
Engine Type	4-stroke - Glow ignition	
Displacement	0.6 cu inch	10 cc
Max Power (approx.)	0.9 bhp	0.67 kw
Weight (exc. silencer)	20.7 oz	570 g
Length	4.11 inch	104.4 mm
Cowling Radius		R36
Propeller shaft diameter	5/16" UNF	
Practical RPM range @ prop	1,400 - 6000 rpm	
Example Prop Sizes 2 Blade	14x14, 15x12, 16x12	
3 Blade	13.4x13.5	
4 Blade	13x13, 14.5x11	
Recommended Fuel	10% Nitro / 15% Oil including max 6% Castor	

APPENDIX C1

Airfoils Shape (Selig, 2006)



Cross Section of Airfoil (NACA0006)



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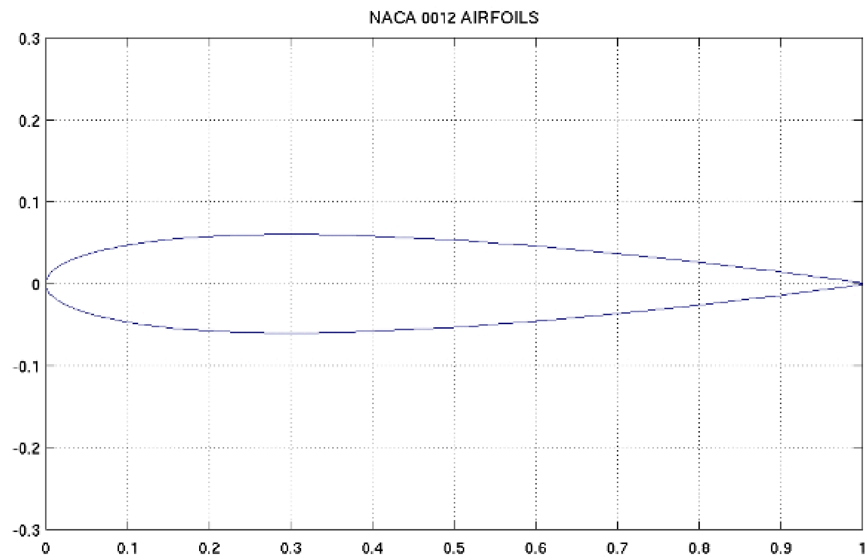
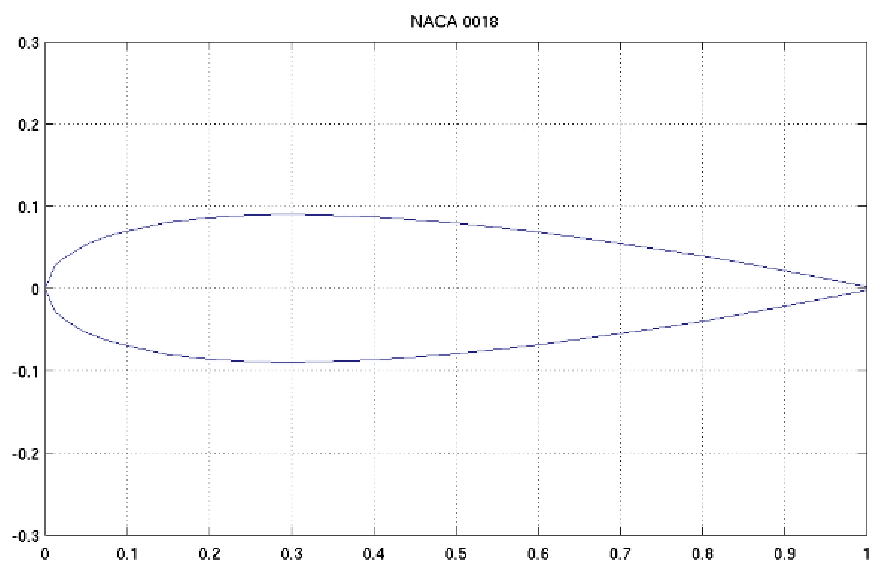


Cross Section of Airfoil (NACA0012)

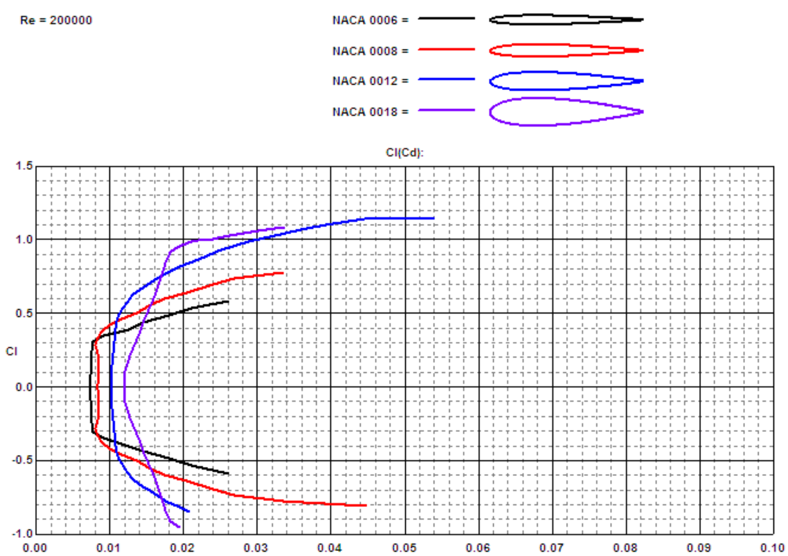


Cross Section of Airfoil (NACA0018)

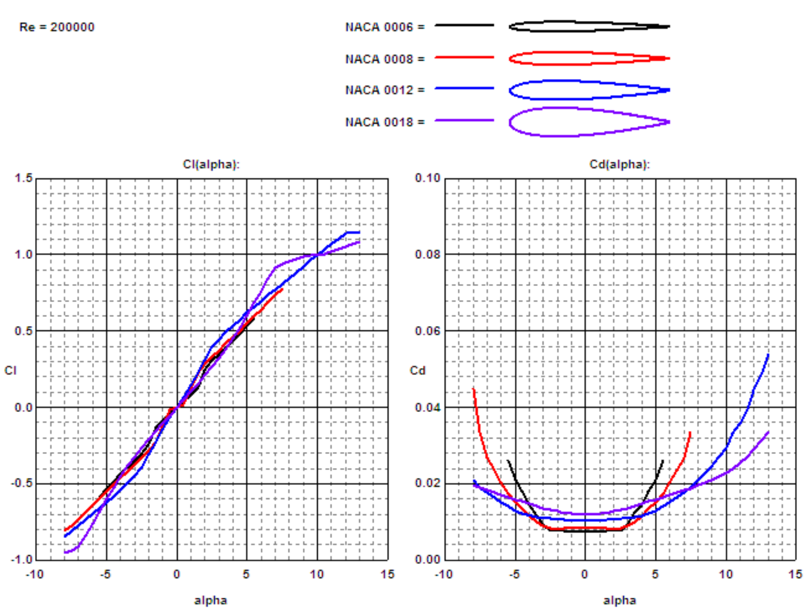
APPENDIX C2

Polar Plot Comparison

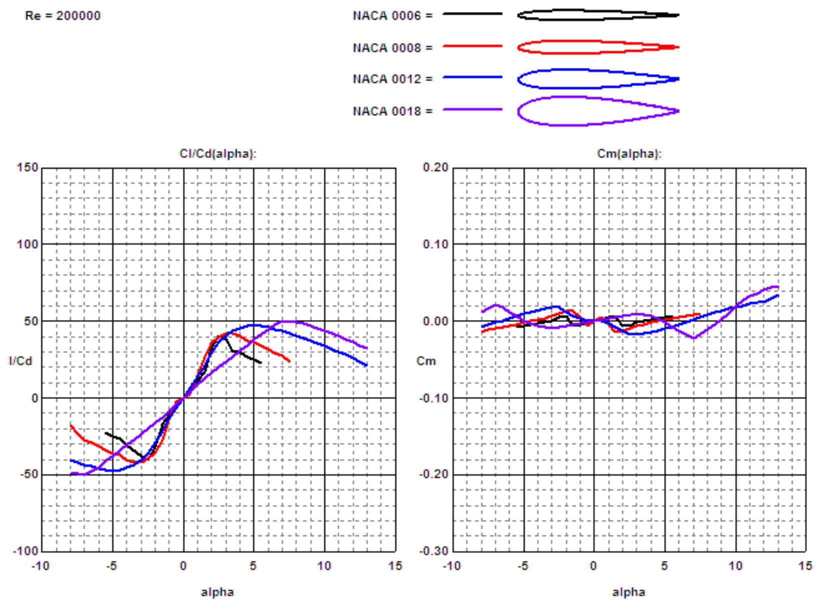
Re = 200000



Graph C_L versus C_D

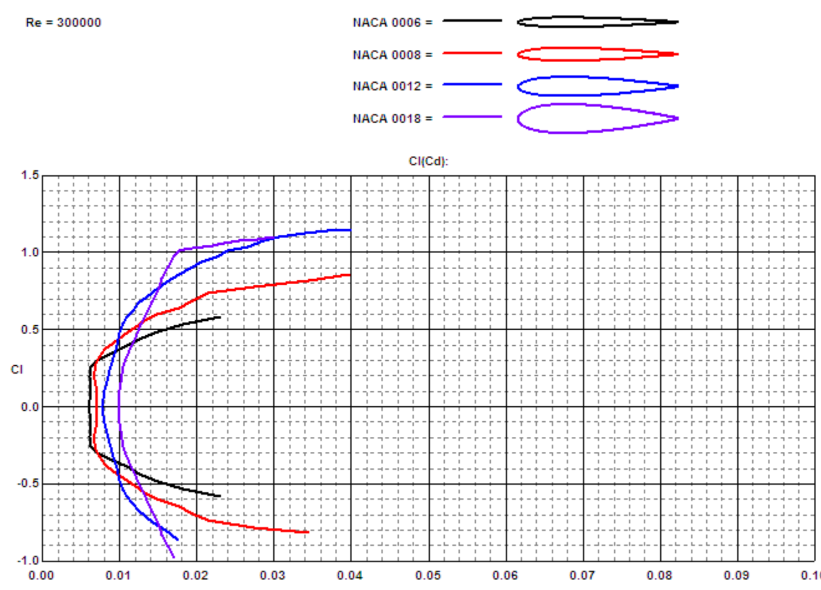


Graph C_L Vs Angle of attack and C_D Vs Angle of attack

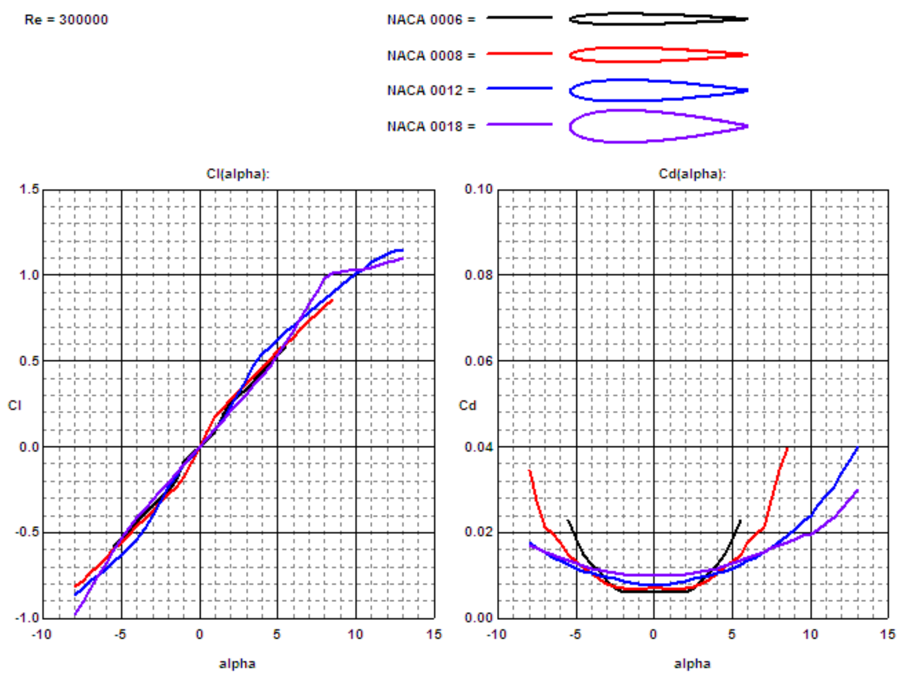


Graph C_L / C_D Vs angle of attack and C_m Vs angle of attack

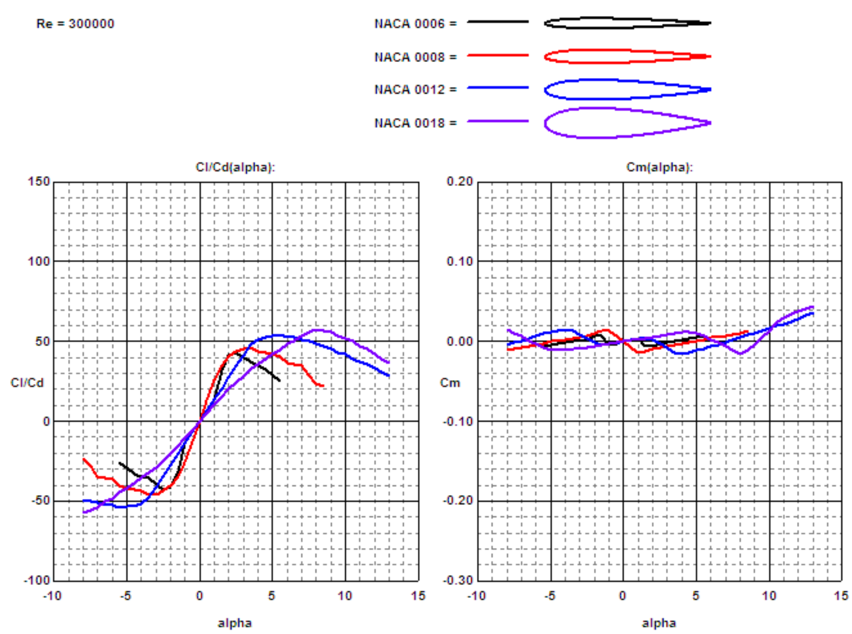
Re = 300000



Graph C_L versus C_D



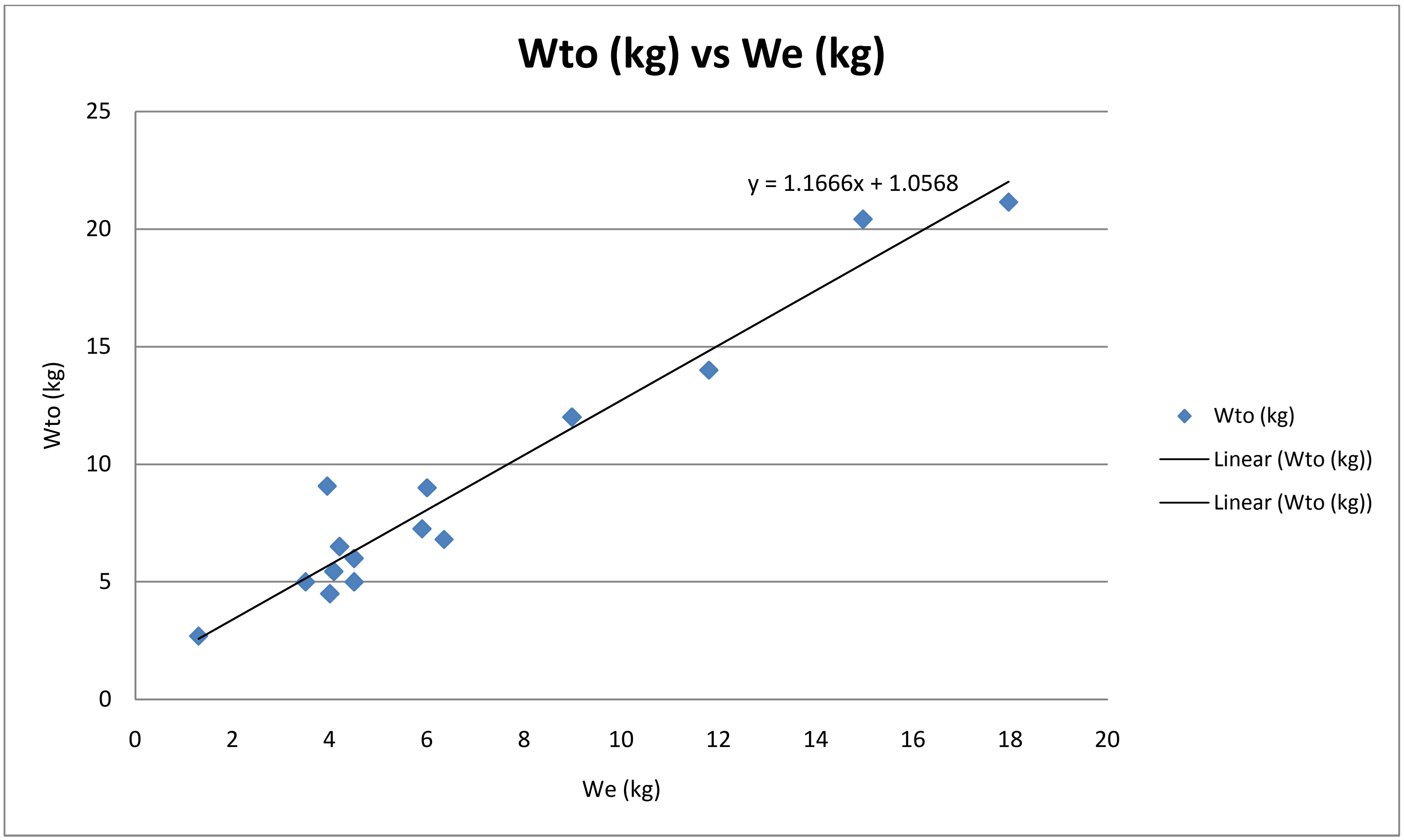
Graph C_L Vs Angle of attack and C_D Vs Angle of attack



Graph C_L/ C_D Vs angle of attack and C_m Vs angle of attack

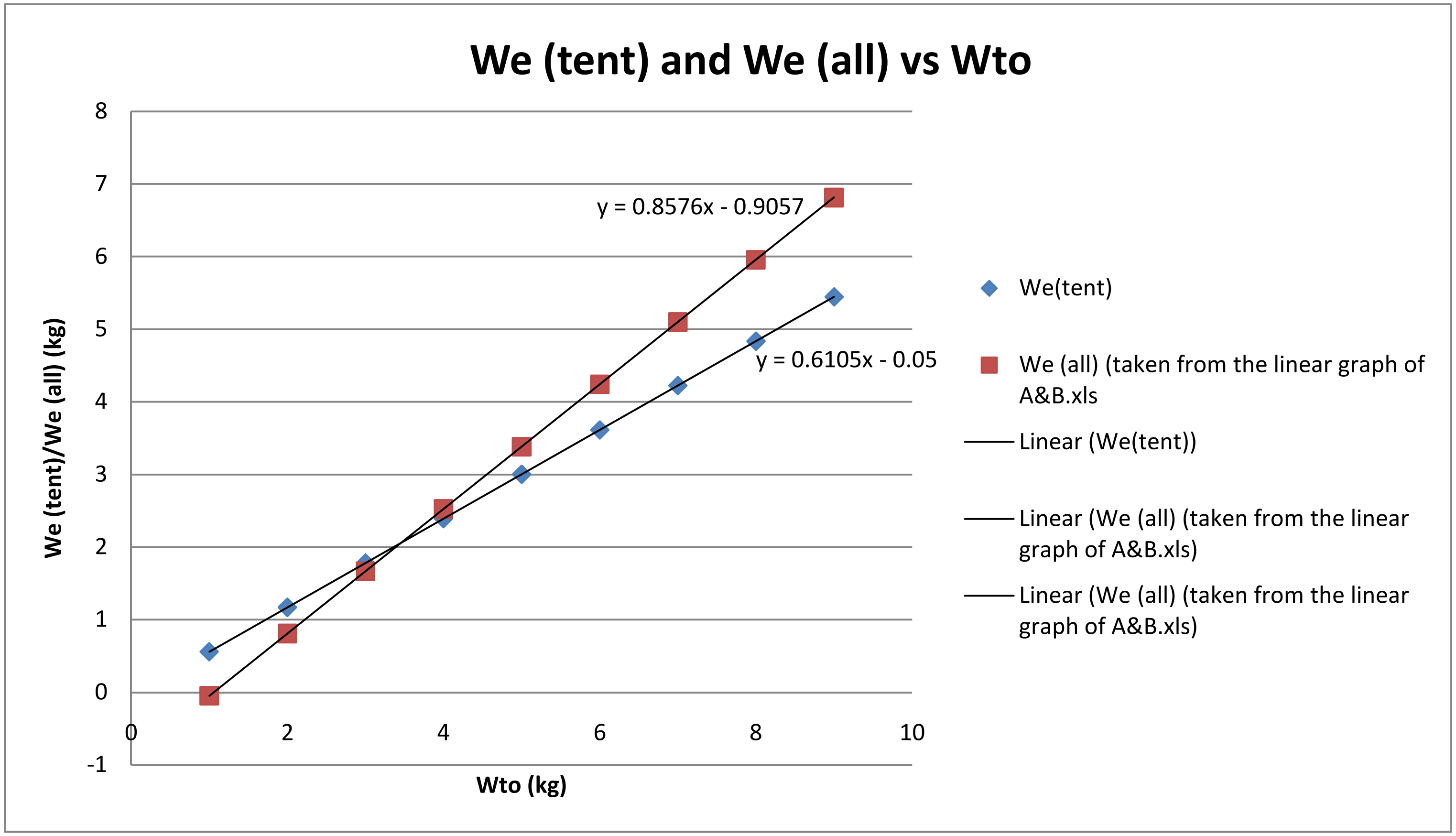
APPENDIX D1

Technology Diagram



APPENDIX D2

(W_E) allowable and (W_E) tent versus (W_{TO}) Guesse.



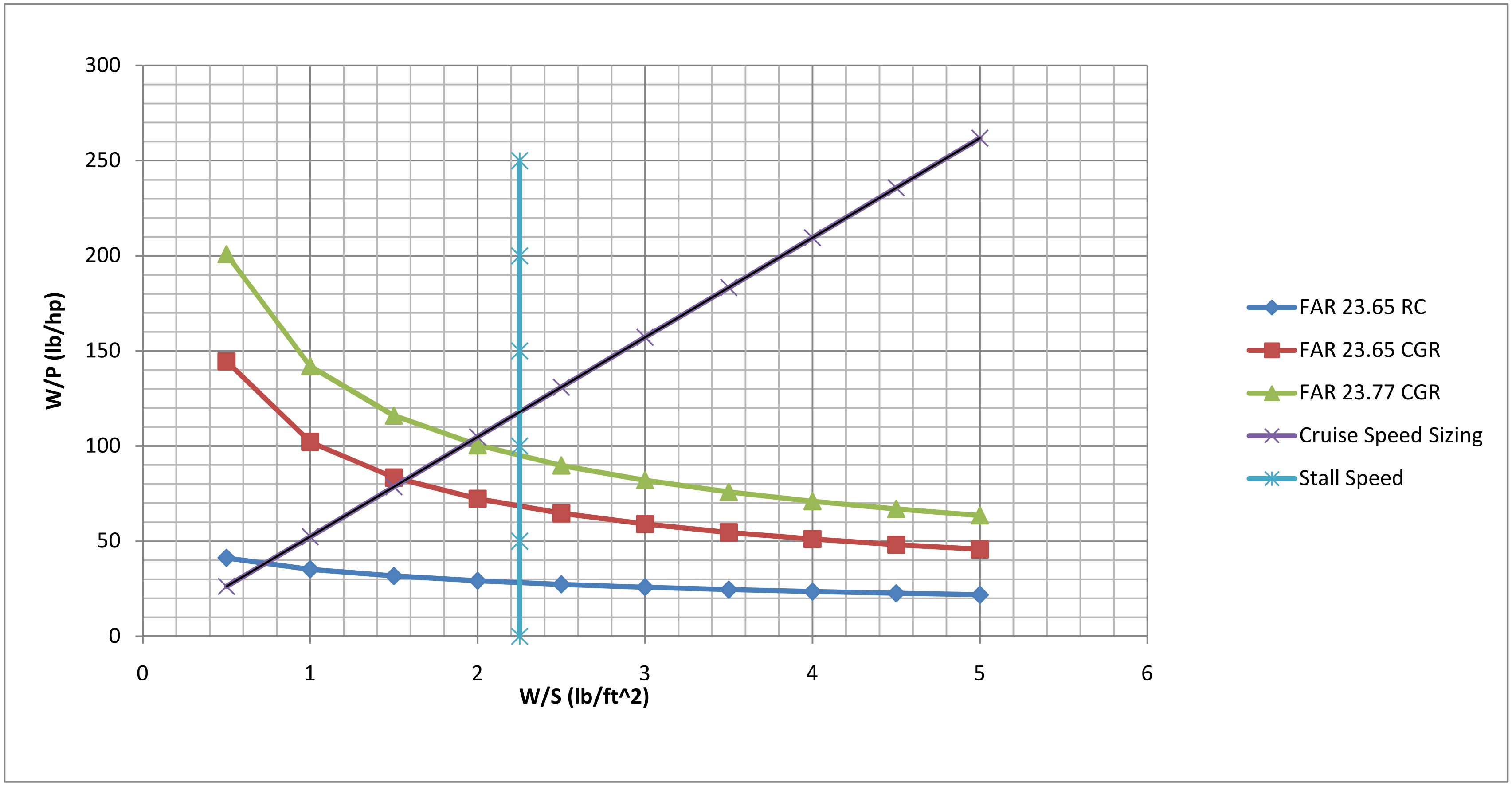
APPENDIX E1

Aircraft Sizing to FAR23 Requirements

	FAR 23.65 RC	**FAR 23.65 RC**	**FAR 23.65 CGR**	**FAR 23.65 CGR**	**FAR 23.77 CGR**	**FAR 23.77 CGR**	**Cruise Speed**
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) ((lb/hp)**	**W/P**
0.5	45.33160598	41.21055089	158.9717465	144.5197696	220.9284427	200.8440388	26.19
1	38.74122056	35.21929142	112.41	102.1909091	156.22	142.0181818	52.38
1.5	34.85316547	31.68469588	91.78238066	83.43852787	127.5530959	115.9573599	78.57
2	32.13436984	29.21306349	79.48587327	72.25988479	110.4642214	100.4220194	104.76
2.5	30.06793122	27.33448293	71.09432636	64.63120578	98.80220321	89.82018474	130.95
3	28.41590893	25.83264448	64.89994376	58.99994887	90.19365905	81.9942355	157.14
3.5	27.04923803	24.59021639	60.08567241	54.62333855	83.50310242	75.91191129	183.33
4	25.89023601	23.53657819	56.205	51.09545455	78.11	71.00909091	209.52
4.5	24.88862822	22.62602566	52.99058218	48.17325653	73.64281424	66.94801294	235.71
5	24.0100804	21.82734582	50.27128027	45.70116388	69.86370789	63.51246172	261.9

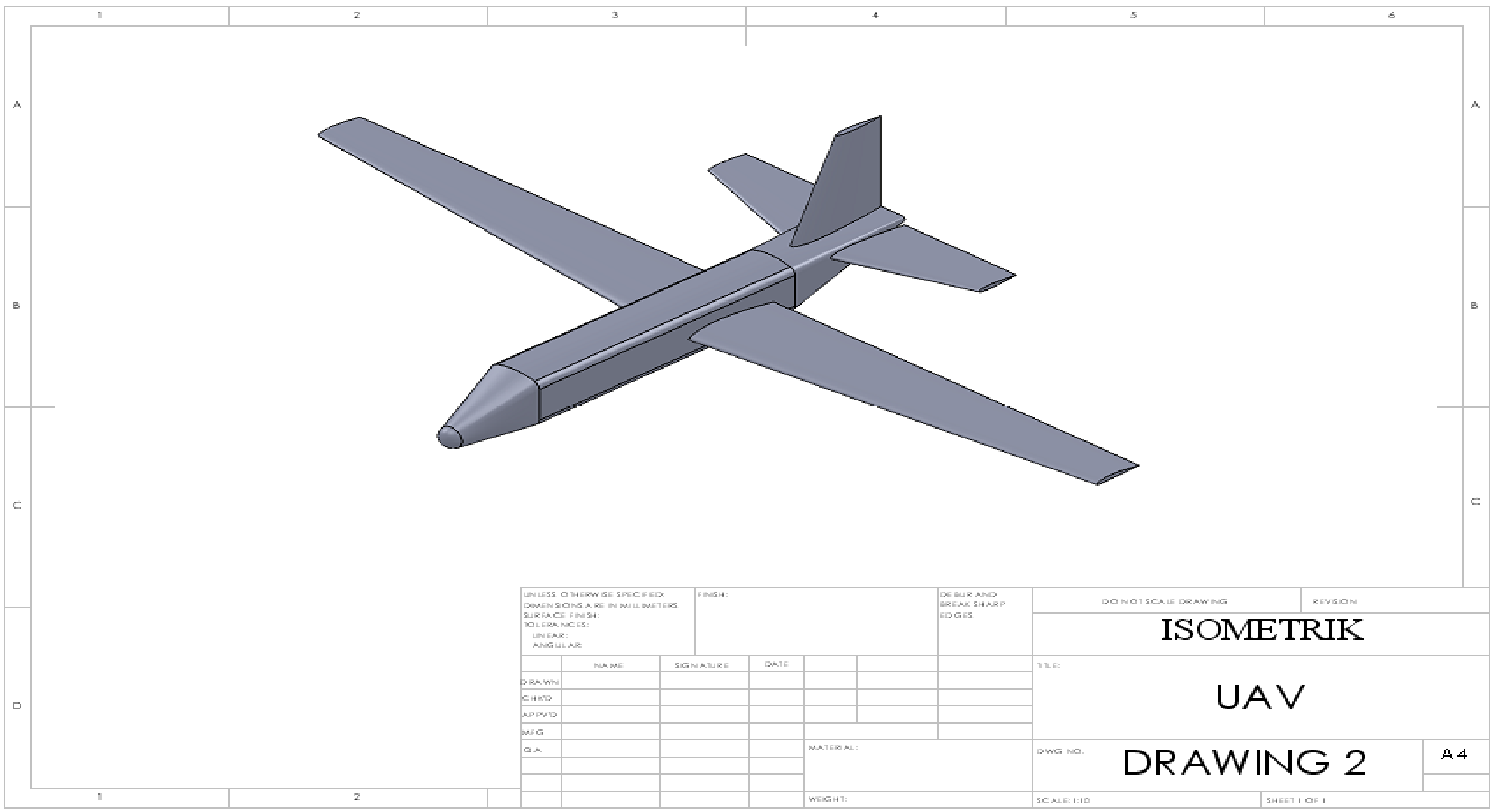
APPENDIX E2

Matching Diagram



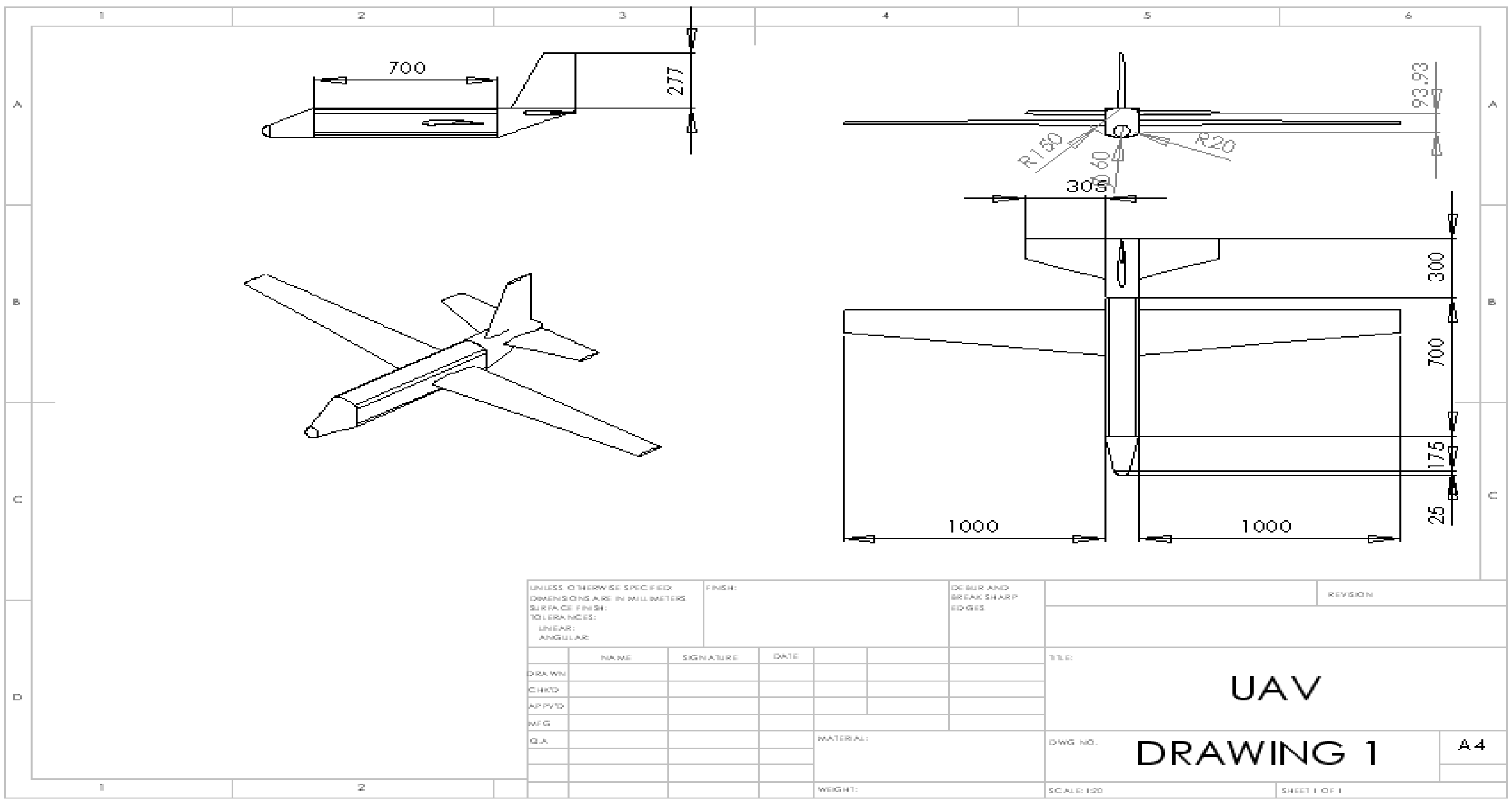
APPENDIX F1

Rendered Image



APPENDIX F2

Three View Drawing



APPENDIX F3

Exploded View