DESIGN THE VTOL AIRCRAFT FOR LAND SURVEYING PURPOSES

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LIST OF ABBREVIATIONS

3D	Three Dimensional
CAD	Computer Aided Design
GIS	Geospatial Information System
GPS	Global Positioning System
L/D	Lift to Drag ratio
LIDAR	Light Detection and Ranging
Li-Po	Lithium polymer
LLT	Lifting Line Theory
RC	Radio Controlled
STOL	Short Take-Off Landing
UAV	Unmanned Aerial Vehicle
UIUC	University Illinois Urbana Champaign
USAF DATCOM	United State Air Force Data Compendium
VLM	Vortex Lattice Method
VTOL	Vertical Take-Off Landing

LIST OF SYMBOLS

Symbol	Description
e	Span efficiency factor
ρ	Density
η_{prop}	Propeller efficiency
η_{sys}	Power system efficiency
λ_{ht}	Horizontal tail taper ratio
λ_{vt}	Vertical tail taper ratio
AR_{ht}	Horizontal tail aspect ratio
AR_{vt}	Vertical tail aspect ratio
AR_{w}	Wing aspect ratio
b_{ht}	Horizontal tail span
b_{vt}	Vertical tail span
b_{w}	Wing span
$c_{r_{ht}}$	Horizontal tail root chord
$c_{r_{vt}}$	Vertical tail root chord
c_{w}	Wing chord
$\bar{c}_{w}$	Mean wing chord
C_{d}	Drag coefficient
C_{d_0}	Parasite drag coefficient
$C_{d,i}$	Induced drag coefficient

C_L	Lift coefficient
E	Endurance
$E_{\max}$	Maximum endurance
$I_{el_{sub}}$	Current of subsystem
$L_{fuselage}$	Fuselage length
L_{vt}	Vertical tail arm length
L_{ht}	Horizontal tail arm length
P_a	Power available
P_0	Power output
P_R	Power required
$P_{R,0}$	Power required to overcome parasite drag
$P_{R,i}$	Power required to overcome induced drag
R	Range
$R_{\max}$	Maximum range
S_{vt}	Vertical tail area
S_{ht}	Horizontal tail area
S_w	Wing area
T_a	Thrust available
$T_{R,0}$	Thrust required to overcome parasite drag
$T_{R,i}$	Thrust required to overcome induced drag
U_{el}	Voltage of power supply
V_{vt}	Vertical tail volume coefficient
V_{ht}	Horizontal tail volume coefficient
V_∞	Free stream velocity
W_0	Total gross weight

W_{crew}	Crew weight
W_{empty}	Empty weight of the aircraft
W_{fuel}	Fuel weight
W_{MTOW}	Maximum take-off weight
$W_{payload}$	Payload weight
ΔC_{el}	Electrical capacity of power supply

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CHAPTER 1

1 INTRODUCTION

Unmanned Aerial Vehicle (UAV) ~~or people easily called it as drone~~ has been widely known of its benefits in changing the 21st century airspace scenery. Its application in the early age of their appearance was widely been used for military purposes especially for deploying mission, reconnaissance and attacking role. At the early age of the UAV's introduction, the configurations and augmentation system of the UAV is complicated and few exposures are given to the civilians about its applications. One of the advantages of UAV is its capability of survey required data in less time compared to manned vehicles (Magnotta, 2015). Thus, it gives potential to bring benefits in both productivity and handling cost.

Into this awareness, recent innovations of UAV has given the possibility to the civilians to use the UAV for either personal purposes or commercial purposes. One of the biggest changes in UAV is the size has been scale down which will give access to the operations in a more confine space. Therefore, some people take this opportunity to implement the benefits of UAV ~~or popularly been called as drone,~~ into our daily life such as land surveying, aerial photography, delivery, wildlife research~~,~~ and news ~~and etc~~. Further innovations in these small scale UAV will improve the user experiences and productivity efficiency. This project will be focused on the design and modification of an aircraft ~~that will be converted as an UAV~~ for land surveying purposes.

1.1 Background Research

1.1.1 Applications of UAV in land surveying

~~Surveillance is one of the main objectives in most of UAV creation.~~ Previously, before UAV was invented, manned vehicles is implemented to carry out the operation of monitoring the condition of the land activity such as the roadway network, vehicle movements, land development and etc (Zaryab et. al, 2016). Nevertheless, implementation of manned vehicle in this operation affect the environmental issues especially the noise produce from the fuel-powered helicopter and aeroplane. Besides, cost are way more expensive if compare to latest implementation of UAV in this activity.

Therefore, UAV have been suggested in most of the land surveying operators because of its cost effectiveness and safety to the pilot's life. Besides, UAV especially the small scale UAV have greater maneuverability and control in a low flight and confined space. Nevertheless, permission of access in a prohibited flying areas is still a main consideration in every land surveying operations in order to respect one's privacy of their properties.

1.2 Problem Statement

Nowadays, the Geospatial Information System (GIS) operators used small UAV to conduct the air-based land surveying operations. It is because the capability of UAV to follow the GPS-guided flight path. Besides, small scale UAV is now capable to be equipped with advanced equipment such as Light Detection and Ranging (LIDAR) sensor, thermal imaging camera, high resolution camera and etc. Consequently, improved flight quality of UAV is obligatory as these equipment carried by UAV are very expensive and fragile.

Some of GIS operators focus on the data collection in a rural areas for future infrastructure development, scheduled site inspection, illegal forest logging activity and etc. For example, illegal logging activity is a serious environmental issue that must to overcome and prevent by the all party. Ability of UAV in offering live streaming view will help the related forestry authorities to terminate the activity of these illegal loggers. Therefore, the ability of UAV to fly in rural areas especially in forest is very important in order for the operators' mission deployment in such area.

The type of UAV been used is varied which mostly depends on the period of mission deployment. For example, land surveying that involves data collection of the topography status of a certain areas might require more than average of one hour flight time. Longer flight time means better endurance of an UAV must have which obviously fixed-wing type of UAV has greater benefits in term of endurance. Therefore, fixed-wing type of UAV is preferable in most GIS since it has better endurance, range and payload access.

Fixed-wing type especially Short Take-Off Landing (STOL) require ~~some~~ a specified take-off and landing airspace ~~to make it launch properly~~. The main problems face by the operators are the difficulty to ~~launch and land these aircraft~~ safely deploy the aircraft ~~during mission deployment especially~~ in a confined space such as forest, crowded city, oil platform and etc. ~~This difficulty will increase the possibility of flight crash.~~ Besides, the ability of the VTOL aircraft to take-off and land in an ~~flight crash also occurred due to~~ unexpected conditions such as gust, poor ground system conditions~~,~~ and technical faulty are crucial~~and etc~~. Therefore, it is very important to prepare ~~make~~ the aircraft ~~launch and land safely for~~ with a stable mechanism of vertical take-off and landing for better flight quality during operation ~~and aircraft's life cycle~~.

1.3 Research Objectives

There are three objectives to be achieved in this project.

1. ~~Firstly,~~ to design an aircraft equipped with Vertical Take-Off Landing (VTOL) mechanism by using parametric study and basic aircraft design process~~. Next, to~~
2. To select most suitable material and structure ~~that will be used for the aircraft~~for fabrication~~. Lastly,~~
3. ~~to~~ To fabricate the designed aircraft and conduct the flight test of the aircraft.

1.4 Research Scopes

~~The scope for this research is listed below:~~

~~1. The aircraft design process of the VTOL aircraft by following the design step mostly from the reference book, Aircraft Design: A Conceptual Approach by Raymer (2006).~~

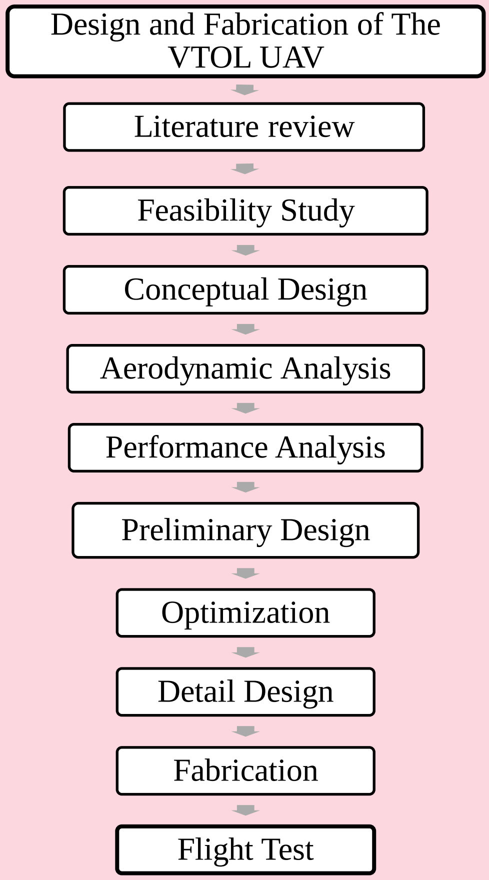
~~2. The materials selection for the main aircraft structure.~~

~~3. Fabrication procedures of the aircraft.~~

~~4. The avionic system of the aircraft~~[u1]~~.~~

1.5 Schedule Planning

Time management during the research and design process is very important in order to achieve specific goals. Therefore, the flow chart and Gantt chart for the design process has been constructed in order to complete it on time given. The flow chart is used to clearly define the ~~targets need to be complete throughout the project~~progress of the project and completion date. ~~Besides that, t~~The Gantt chart of the project is also used as a guidance to complete the task according to a certain period. The Gantt chart of this project presented in Appendix A.



[u2]

Figure 1.1: Flow chart of the project

~~Presented in the flow chart above, t~~The project contains 10 steps to accomplish the specified research objectives specified~~ earlier~~; these steps followed the fundamental of aircraft design process. First step is to conduct the literature review about this project. Literature review is to study the dissertation published by any university to prove our understanding in the methodology, theories and decisions made in this project. The feasibility study is the analysis of the project practicality based on existing project. For example, the feasibility study of this project is to study the fixed-wing type of UAVs that is suitable to carry land surveying mission.

The conceptual design is basically to determine the goals and requirement for the aircraft before the design process takes place. After that, the main part of aircraft design process which are the aerodynamic analysis, performance analysis; and stability analysis will takes place. These analysis will give the preliminary assumption of the designed aircraft's limitation, attitude and performance. Next, the preliminary design is basically to illustrate the designed aircraft according to parameters that have been specified in previous steps.

Optimization is a step where redesign takes place until the best design is achieved to meet all the aircraft's requirements. After that, the detail design will takes place where all the parts in the aircraft is design with such detail; the blueprint and the fabrication procedures are prepared. Fabrication process is takes place once the detail design has been confirmed by following the procedures prepared. Finally, the fabricated aircraft will be tested to validate its flying qualities for further improvisation. By referring to the Appendix A, semester 1 will be focused on literature review until performance analysis while the rest will be continued in semester 2.

CHAPTER 2

2 LITERATURE REVIEW

2.1 RC Aircraft

Radio-controlled (RC) aircraft is a small scaled flying machine that operated by an operator from the ground by using transmitter to send signal to the receiver installed in the flying machine (Boddington, 1978). By using the transmitter, the operator can ~~control the movement of~~steer the aircraft through signal transmission to all the electronic parts in the aircraft. Joystick in the transmitter is used to control the position of the control surfaces of the aircraft which for typical aircraft are throttle, elevator, aileron and rudder.

There are many types of RC aircraft used for different purposes. First is the scale aircraft modelling which people (mostly RC hobbyist) have done this from every era of aviation to replicate most of the real aircraft features by scale it down. Other than that is the sailplanes or glider where it is a plane that typically do not have any type of propulsion. Next is RC jets which use very expensive micro turbine or ducted fan as its main propulsion. Lastly, helicopters is one of the RC aircraft types usually have camera for taking photos and ~~record~~ recordings ~~video for individual or commercial~~ purposes (Boddington, 1978).

Figure 2.1: Scale aircraft RC model[u3]


[u4]

Figure 2.2: Sailplane or glider

Figure 2.3: RC Helicopter

The propulsion of RC aircraft could be categorised into two type which are electric-powered and internal combustion. In general, electric-powered RC aircraft use pack lithium polymer (Li-Po) battery as their main power source while gas powered

RC aircraft use gasoline as their main power source. Table below shows the comparison between electric-powered aircraft and gas-powered aircraft.

Table 2.1: Comparison between gas-powered and electric-powered RC aircraft (Pete, 2017).

Criteria	Gas-powered	Electric-powered
Price to buy	Expensive	Cheaper for beginner setup
Availability	From specialist hobby shops	From hobby shops
Ongoing cost	Cost higher because of the fuel price used	Cost less since Li-Po battery could be recharge.
Environmental issues	Noisy and messy	Quiet and clean
Maintenance	Moderate and quiet complex	Very little and more straight forward
Flight times	Depends on the size of fuel tank	Depends on the battery capacity

2.2 VTOL Aircraft

VTOL aircraft stands for Vertical Take-Off Landing aircraft where the aircraft has different type of take-off and landing compare to short take-off landing. The aircraft unnecessarily use the runway to take-off while capable to enter inaccessible areas (Zafirov, 2013). This could justify the solution of choosing the VTOL aircraft to operate in inaccessible areas especially places surrounded with confined trees' canopy.

The main consideration in the VTOL aircraft development is the vertical thrust vector of the VTOL propulsion system which must be pass through precisely at the maximum centre of gravity of the aircraft in order to achieve good take-off and landing quality (Zafirov, 2013). In addition, the aircraft should have greater than 1 of the thrust-to-weight ratio value in order to achieve successful vertical take-off and landing (Zafirov, 2013).

2.3 Aircraft Design

~~The design process of the VTOL aircraft follows the aircraft design process (Abdelrahman, et. al, 2009). The aircraft design process can be referred to many references (Rabbey et. al, 2013). One of the conservative reference is chosen which is the Aircraft Design: A Conceptual Approach by Raymer (2006).~~ [u5]

Aircraft design is a different discipline separated from other analytical discipline in aeronautical engineering which are aerodynamics, structures, controls and propulsion. Besides, aircraft design is an actual layout that require analytical process in order to determine what should be designed and how the design should be optimized to meet the requirements. In general, small company used the same individuals who do the layout design while large company use specialist to perform aircraft analysis (Raymer, 2006).

The design of an aircraft begins with the requirements of the target user. Design is an iterative effort that consist of four elements ~~as shown in figure below~~(Figure 2.4). The requirement of an aircraft can be done by prior design trade studies. Then, requirements can be fulfilled by developing the concepts. After that, design analysis will frequently points toward new concepts and technologies which will initiate a whole new design effort (Raymer, 2006).

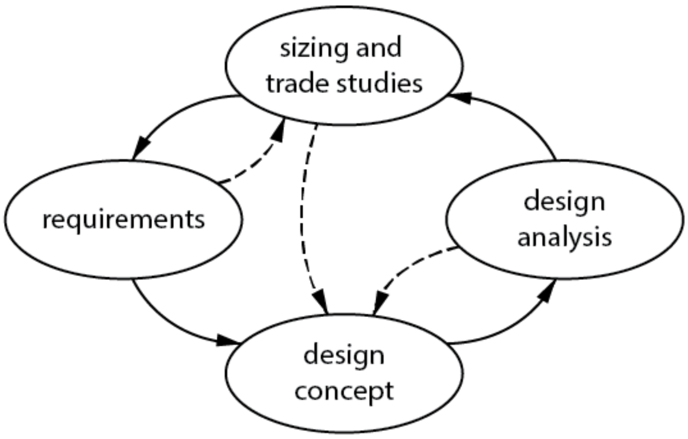


Figure 2.4: The design wheel (Raymer, 2006).

2.3.1 Conceptual Design

The conceptual design is where the designer ~~put~~ accumulate the idea of building an aircraft according to the criteria and specified goals of the aircraft that need to be achieved. The objective of this stage is to conceptualize the idea and to understand the basic configurations of the aircraft. During this stage, the general airframe and sizing is sketched and preliminary analysis is ~~done on the designed aircraft~~carried out. In order to achieve the specification of the designed aircraft, iteration process is needed. Figure ~~below~~ 2.5 shows the aircraft conceptual design process.

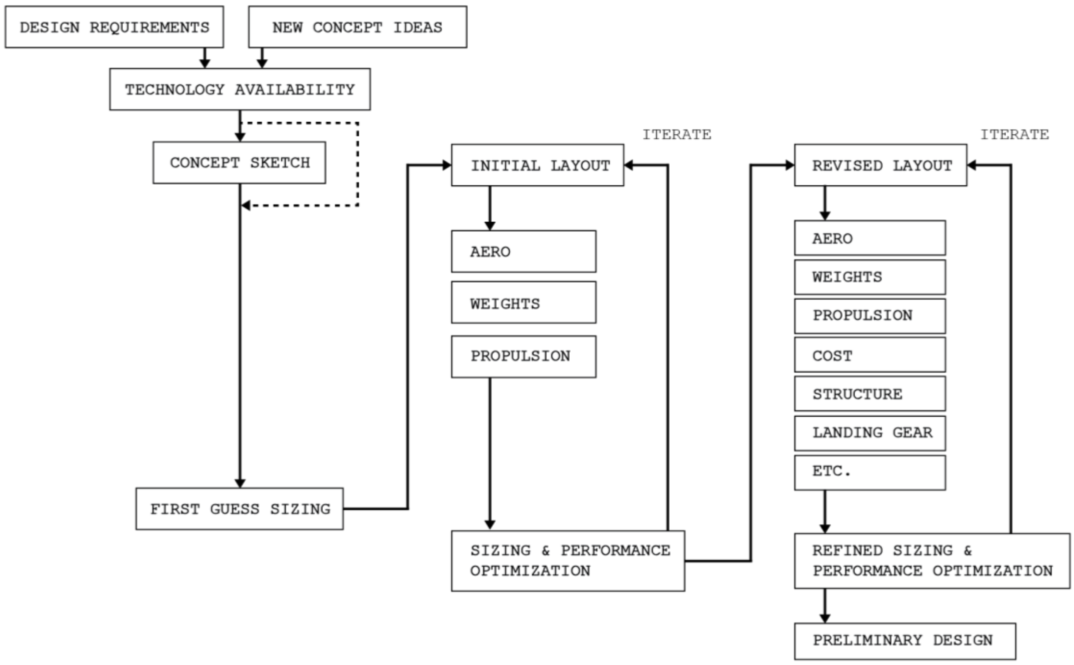


Figure 2.5: Aircraft conceptual design process (Raymer, 2006)

2.3.1.1 Aerodynamic Analysis

The aerodynamic analysis of an aircraft is very important to determine its flying qualities. Generally, lift, drag and moment of the aircraft are the important aerodynamic parameters of an aircraft. To determine these parameters, experimental approach and analytical approach are available methods that can be used. Analytical method is used to estimate the aerodynamic coefficient of the designed aircraft due to time constrain.

Analytical approach method is done by using the XFLR5 software developed by André Deperrois. The XFLR5 software is used to estimate the aerodynamic characteristic of the aircraft (Meschia, 2008). The software is a fast subsonic airplane prototyping software where it includes the lifting theory (LLT), vortex lattice method (VLM) and 3D panel method for aerodynamic characteristic estimation.

The XFLR5 software has some limitation where it only consider inviscid flow for the VLM used. Therefore, XFLR5 results need to be considered as a preliminary and experimental work since it is not fully supported by the mathematical model. Besides, the software must be introduce with both the set of polars derived from viscous analysis of the adopted airfoil and the geometrical model of the lifting surfaces. Nevertheless, the viscous analysis of the selected airfoil could be obtain by using the airfoil database by University of Illinois (Meschia, 2008).

United States Air Force Data Compendium known as USAF DATCOM is a semi-empirical method used to estimate the aerodynamic characteristics. Similarly, Harris (2007) employed the DATCOM method in his thesis, Aerodynamic Study of Flow over UAV. Nonetheless, the DATCOM is more suitable in determining aerodynamic characteristics for aircraft with speed above Mach number of 0.3. In the dissertation of Master of Science by Trips (2010)[u6], the details of setting up XFLR5 is shown and presented. Therefore, the aerodynamic analysis of the aircraft using the XFLR5 can be approximated and estimated.

2.3.1.2 Performance Analysis

Preliminary performance analysis must be conducted in aircraft design process in order to define its general performance and as well to check the efficiency of the whole propulsion system. The performance analysis are examined through some of the important parameters which are the power available, power required, thrust available, thrust required, rate of climb, endurance and range. These parameter can obtained from the analysis by referring to Aircraft Performance and Design by John D. Anderson, Jr (1999).

2.3.2 Preliminary Design

Preliminary design is where the aircraft design will be redesign and reanalysed without takes much changing in its original sizing and basic configurations specified earlier (Raymer, 2006). Further precise analysis especially the structural and performance analysis is one of the important part in preliminary design. Extra testing and prototyping are required in order to define the materials, amount of materials, structure arrangement and propulsion system that will be used in the aircraft design (Zi Yang, 2015).

In most cases, computer aided design (CAD) is used to do the process of reshape and reconfigure the general design perfectly and fast. In the meantime, the fabrication procedure together with cost estimation of the whole design can be established during the preliminary design process (Zi Yang, 2015).

The preliminary design of the VTOL aircraft follows the step guided by Raymer (2006) since the aircraft design is identical to typical fixed wing aircraft design. The aircraft used several different material, thus the aircraft design must be simplified in order to reduce the time constrain. CAD software such as Solidworks, AutoCAD Inventor and etc. can be used to do the full scale modelling. Furthermore, these software provide features to find the actual centre of gravity position and moment of inertia by giving the material properties value into each parts that have been designed.

2.3.2.1 Accessories Selection

The accessories for a small scale aircraft are referred to its propulsion system, servo for control surfaces and the power source which in this project electric power is the main power source (Zi Yang, 2015). The accessories selection is vital since it involves the mission required by the VTOL aircraft. Furthermore, it will cause excessive resource usage and affect the aircraft flying performance if the selection is not conducted properly.

The VTOL aircraft for this project is comparable with the radio-controlled (RC) model aircraft and mini UAV model, hence the accessories selection can be done by referring to Boddington (1978) in RC plane model and journals by Rabbey, et al., (2013). Analysis such as the parametric study, aerodynamic and performance analysis are vital in order to help the designer to list the detail specification of the accessories selection required for the aircraft mission.

2.3.2.2 Material Selection

Materials selection is very important in order to sustain the aircraft shape and to ease manufacturing process. Most of the materials that been used in RC aircraft are balsa wood, foam, fibre and etc. The foam stiffness is comparable to balsa wood while have a cheaper price (Carlos 2017). Nevertheless, the foams do not have strength strong as balsa wood and low in density. Generally, designer must take the feasibility of fabrication, mechanical properties and cost of the materials as consideration (Boddington, 1978) in order to decide which material will be used in each compartments.

2.3.3 Detail Design

Raymer (2006) stated that detail design process is where the production design or fabrication process are required to be define before fabrication process takes place. This is done in order to ensure the product which is the aircraft will be produce accordingly to the specified design. Furthermore, it is to increase working efficiency during the period of fabrication process takes place.

The detail design of VTOL aircraft is done using Solidworks software. The process focus on drawing the 3D model of each compartments and accessories of the aircraft including the major and minor parts. The major part in this process contain five parts;

1. to draw the ribs of the wing,
2. attachment of the ribs to the spar,
3. attachment of the wing to the body,
4. drawing the fuselage structure and the VTOL motor position.

The minor parts in this process is to draw the components of the aircraft. The procedures of the fabrication process of the RC aircraft can be done by referring to Boddington (1978) in Building & Flying Radio Controlled Model Aircraft.

2.4 Fabrication Method

Every completed and inspected aircraft design required fabrication process to transform the idea poured in the design stage into a real aircraft by following the planned procedure. The difficulty of the fabrication stage is depend on the aircraft design itself. Therefore, it is very important to double check the design in order to avoid difficulties in fabrication stage.

The VTOL aircraft concept is comparable to the RC aircraft model specifically the fixed-wing type of RC aircraft. ~~Hence, the fabrication method can be done by referring to Boddington (1978) in Building & Flying Radio Controlled Model Aircraft.~~ It is a good practice to choose simple fabrication process for easier aircraft maintenance and repair.

CHAPTER 3

3 METHODOLOGY

3.1 Flow Chart

Generally, the project flow and the methodology will be discussed accordingly to the flow chart ~~as shown in~~(Figure 3.1). The first semester of the project focused more on study and analysis which will cover from literature review until static stability analysis. The rest of the scope will be cover in the second semester which will focused more on fabrication, further analysis and flight test.

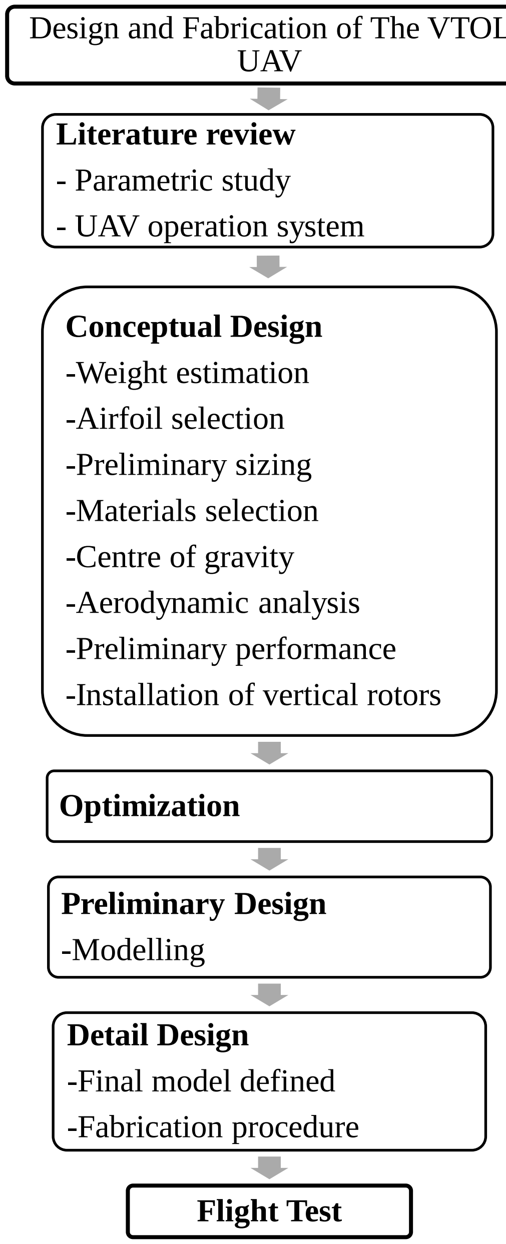


Figure 3.1: Categorised flow chart

3.2 Conceptual Design

The ~~whole conceptual idea and design of the UAV are conducted according to the reference book, Aircraft Design: A Conceptual Approach by Raymer (2006). The fundamental steps and procedure of the aircraft design process are listed in the mentioned earlier book. Basically, it~~ conceptual design consists of feasibility study, preliminary weight estimation, preliminary sizing, aerodynamic analysis, performance and stability analysis which will be conducted in this project.

3.2.1 Feasibility Study

Feasibility study is vital in the preliminary conceptual design. This study is a guidance for the aircraft designer to assume the initial specification based on existed aircraft (name of the aircraft) under the same category. Hence, the first assumption is not totally accurate. Feasibility study can be carried out by performing the parametric study. Table below shows the design specification for a VTOL UAV.

Table 3.1 : Design specification and criteria

Wing configuration	Fixed wing
Tail configuration	Conventional
Weight	Less than 3kg
Range	5 km
Endurance	70 min
Propulsion	Electric motor

From the parametric study, some parameters are analysed graphically for initial assumption. The data obtained is presented in Appendix B1. The considerations that were taken in the graphs are listed as below.

i. Wingspan versus Maximum Take-off Weight (Appendix B2)

ii. Fuselage Length versus Maximum Take-off Weight (Appendix B3)
iii. Endurance versus Maximum Take-off Weight (Appendix B4)
iv. Empty Weight versus Maximum Take-off Weight(Appendix B5)
v. Payload versus Maximum Take-off Weight (Appendix B6)
vi. Endurance versus Wing Span (Appendix B8)
vii. Cruising speed versus Maximum Take-off Weight (Appendix B9)[u7]

3.2.2 Weight Estimation

In Raymer (2006), the preliminary weight estimation can be obtained by using the equation below;

$$W_0 = W_{crew} + W_{payload} + W_{fuel} + W_{empty} \qquad (1)$$

Since the propulsion system for the VTOL UAV is electric motor, hence, we could modified the equation (1) by removing all the unnecessary term such as weight of the crew and fuel. Then, the equation (1) becomes

$$W_0 = W_{payload} + W_{empty} \qquad (2)$$

Before that, we can determine the relationship between gross weight, W_0 and payload weight $W_{payload}$ if we could obtain the value of $\frac{W_{empty}}{W_0}$. Hence, we could modified equation (2) into equation (3) shown below;

$$W_0 = \frac{W_{payload}}{1 - \frac{W_{empty}}{W_0}} \qquad (3)$$

The value of $\frac{W_{empty}}{W_0}$ can be obtained from plotting Graph of Empty Weight versus Total Gross Weight which the graph is shown in Appendix B5. This lead to equation below

$$W_0 = \frac{W_{payload} + 1.673}{0.9767} \quad (4)$$

Other than that, we could determine the maximum take-off weight by examining the wing span of the existing UAV. This could be observe from the relationship in plotted graph between maximum take-off weight and the wing span. This lead to equation below;

$$b_w = 97.515W_0 + 1390.8 \quad (5)$$

3.2.3 Preliminary Sizing

The preliminary sizing of an aircraft can be done through scaling and estimation of each parts required according to Raymer (2006). Generally, all of the geometry for wing, fuselage, tail and control surfaces is estimated.

3.2.3.1 Wing Sizing

Two parameters that are important for the wing sizing of an aircraft which are the wing chord and the wing span. These two parameters can be used to find the aspect ratio of the aircraft. There are no specific aspect ratio requirement for a typical but the lower and high aspect ratio are for high speed and low speed aircraft respectively. It is recommended to determine the wing chord and wing span of the aircraft by refer to the parametric study of the existing aircraft. The relationship of these two parameters can be shown through these two equations below:

$$AR_w = \frac{wing\ span}{wing\ chord} = \frac{b_w}{c_w} \text{ or } \frac{(wing\ span)^2}{wing\ area} = \frac{{b_w}^2}{S_w} \tag{6}$$

$$S_w = b_w \bar{c}_w \tag{7}$$

3.2.3.2 Fuselage sizing

The fuselage length estimation for the aircraft can either follow the parametric study or Raymer (2006). It is preferable to use the parametric study to do the estimation since this aircraft dimension is adapted from existed aircraft. From the graph of fuselage sizing versus the maximum take-off weight, the equation below shows the relationship between these two parameters.

$$L_{fuselage} = mW_{MTOW} + c \tag{8}$$

Referring to Raymer (2006), the fuselage length of the aircraft can be approximated using the equation below.

$$L_{fuselage} = 0.71(W_{MTOW})^{0.48} \tag{9}$$

3.2.3.3 Tail sizing

There are many variations of tail configurations that can be implemented on the aircraft design. Some of the examples are shown in the Figure below.

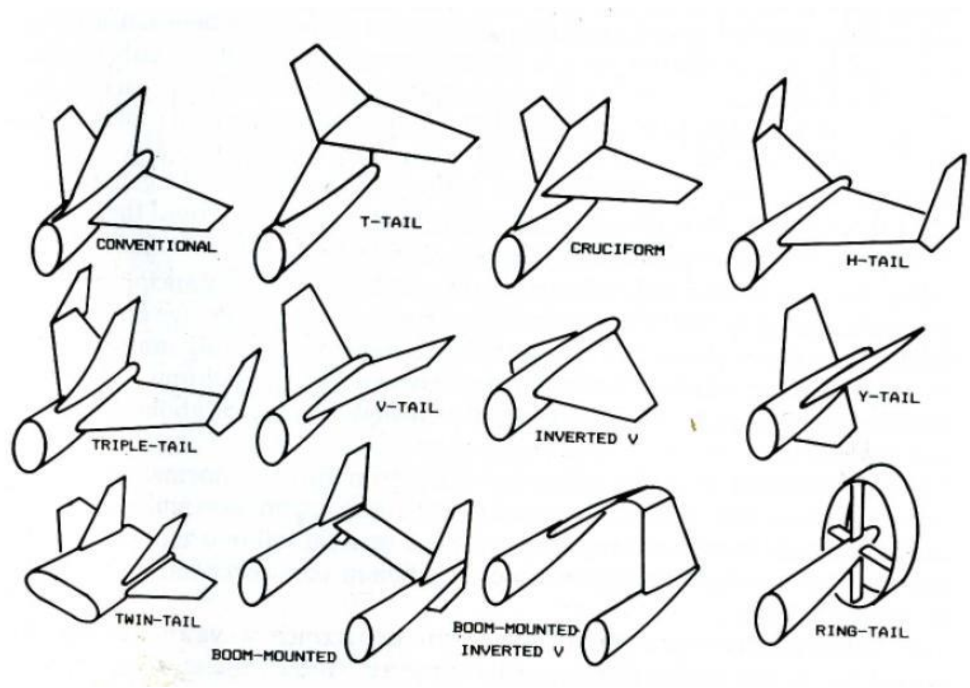


Figure 3.2 : Basic tail configuration of an aircraft (Raymer, 2006)

Generally the tail sizing can be estimated using tail volume coefficient (Raymer, 2006) and equation (10) shows the vertical tail volume coefficient and equation (11) shows the horizontal tail volume coefficient.

$$V_{vt} = \frac{L_{vt} S_{vt}}{b_w S_w} \tag{10}$$

$$V_{ht} = \frac{L_{ht} S_{ht}}{b_w S_w} \qquad (11)$$

Otherwise, the tail volume coefficient can be approximated according to Table 3.2 below

Table 3.2: Tail volume ~~coeffcient~~coefficient

Type of aircraft	Horizontal V_{ht}	Vertical V_{vt}
Homebuilt	0.5	0.04
General Aviation – single engine	0.7	0.04

By using the relationship of the tail volume coefficient, the tail area can be computed. According to Corke (2003), the root chord and tip chord for both horizontal and vertical tail can be estimated according to the tail aspect ratio and taper ratio. Besides that, by using the Table 3.3 the aft tail aspect ratio and taper ratio can be estimated according to Raymer (2006).

Table 3.3~~-~~: Tail arm length

	Aft horizontal tail		**Aft vertical tail**	
	Aspect ratio, AR_{ht}	Taper ratio, λ_{ht}	Aspect ratio, AR_{vt}	Taper ratio, λ_{vt}
Combat	3-4	0.2-0.4	0.6-1.4	0.2-0.4
Sailplane	6-10	0.3-0.5	1.5-2.0	0.4-0.6
Other	3-5	0.3-0.6	1.3-2.0	0.3-0.6
T-tail	-	-	0.7-1.2	0.6-1.0

The tail root chord, tail tip chord, tail aspect ratio and tail taper ratio can be computed using equations as follow

For horizontal tail,

$$AR_{ht} = \frac{{b_{ht}}^2}{S_{ht}} \tag{12}$$

$$c_{r_{ht}} = \lambda_{ht} c_{t_{ht}} \tag{13}$$

$$c_{r_{ht}} = \frac{2S_{ht}}{b_{ht}(1+\lambda_{ht})} \tag{14}$$

For vertical tail,

$$AR_{vt} = \frac{{b_{vt}}^2}{S_{vt}} \tag{15}$$

$$c_{r_{vt}} = \lambda_{vt} c_{t_{vt}} \tag{16}$$

$$c_{r_{ht}} = \frac{2S_{vt}}{b_{vt}(1+\lambda_{vt})} \tag{17}$$

3.2.3.4 Control surfaces

Basically, there are three types of control surfaces used by a typical aircraft which are the aileron, elevator and rudder. These control will control the longitudinal, lateral and directional stability of the aircraft and also will define the maneuverability of the aircraft.

According to Raymer (2006), the aileron is used to control the rolling performance of an aircraft and usually the aileron span will extend about 50% to 90% of the wing span and aileron chord extend from 15% to 25% of the wing chord. Figure below shows the aileron sizing guideline.

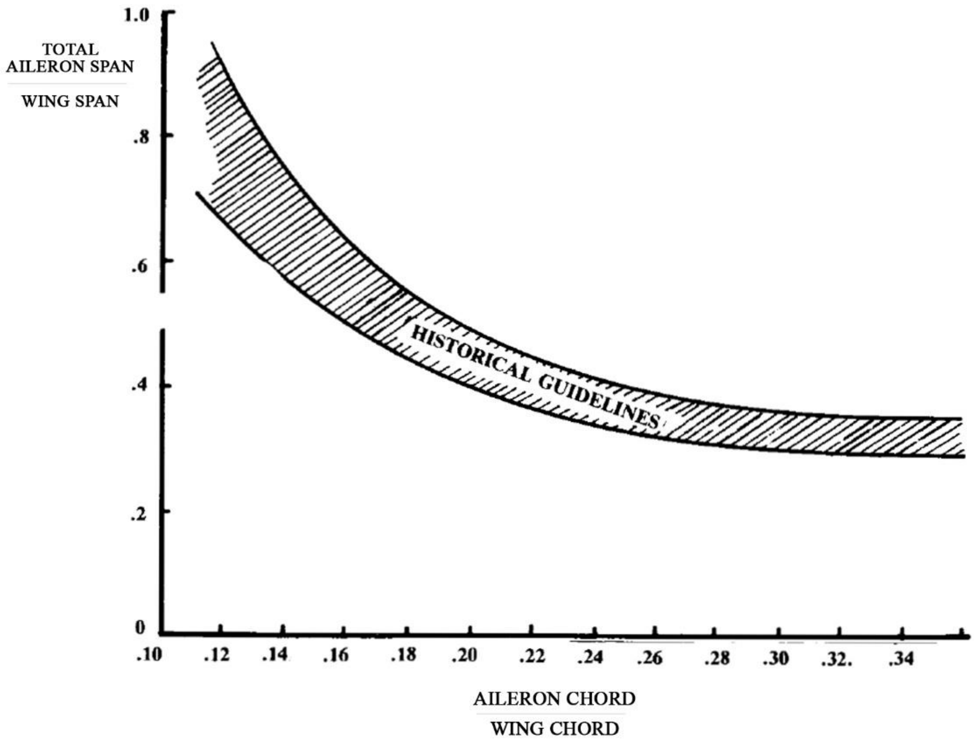


Figure 3.3-: Aileron guideline (Raymer, 2006)

In the other hand, elevator and rudder will control the pitching and yawing performance of an aircraft respectively. The elevator and rudder span extend from the tail root up to 90% of the tail span while both of these control surfaces chord cover 25% to 50% of the tail chord (Raymer, 2006).

3.2.4 Airfoil Selection

In order for an aircraft to glide during unpowered flight especially during emergency cases, it is vital to select suitable airfoil nomenclature in order for the wing to produce enough lift. University of Illinois Urbana–Champaign (UIUC) has big collection of airfoil coordinate database that could be used in the aerodynamic analysis. One of the main consideration in the airfoil selection of this project is the limitation of the fabrication process since it will mostly hand made.

Perfect shape of airfoil may not be achieve without advanced equipment. The characteristic of the selected airfoil could be approximated by conducting the aerodynamic analysis using XFLR5 software for further comparisons.

3.2.5 Materials Selection

The aircraft design should have a stable, stiff and strong body which it is necessary to select material with highest strength to weight ratio (Akshay et. al, 2014). For RC aircraft, the materials selection for every parts is limited due to the weight of material. Two common materials that are used to manufacture small RC aircraft are foam and balsa wood according to Boddington (1978). Balsa, the lightest and most fragile of woods, is classed as hardwood. It has better flexibility and strength compare to foam.

Most of its application in RC aircraft is on the aircraft frame and wing for stable, strong and stiff structure yet accessibility for the maintenance. Nevertheless, foam could replace the balsa wood if the design used monocoque concept. In addition, the aircraft usually will have slight difference in total weight since foam is lighter than balsa wood. In this project, balsa is wood preferable in order to achieve the goal where the aircraft will have accessibility in maintenance for longer lifespan.

Balsa woods grades can be classified into three type; light, medium, high. The grades represents the density of balsa woods itself (Boddington, 1978). Besides, its application are varied based on its grade or density. Table below represents the applications of balsa grades.

~~**Table 3.4:** Application of balsa woods based on its grades (Boddingtoon, 1978).~~

~~Grade~~	~~Application(s)~~
~~Light~~	~~Sheet fill-in on built up fuselages.~~ ~~Semi solid or hollow log fuselages.~~ ~~Sheet covering (fuselage and wings).~~ ~~Wing leading edge sheeting.~~ ~~Cowling blocks.~~
~~Light-medium~~	~~Sheet fill-in on larger models.~~ ~~Large section leading and trailing edges.~~ ~~All-sheet tail surfaces.~~ ~~Solid sheet wings.~~ ~~Sheet-box construction (e.g. fuselages).~~
~~Medium~~	~~Spacers on box fuselages.~~ ~~Trailing edges.~~ ~~Longerons of generous section.~~
~~Medium-hard~~	~~Wing spars of generous section~~ ~~Auxiliary wing spars.~~ ~~Longerons.~~ ~~Small section trailing edges.~~
~~Hard~~	~~Main wing spars.~~ ~~Longerons of small section.~~ ~~Auxiliary spars of very small section.~~
~~Extra-hard~~	~~Inset leading edges on side sheet wings.~~ ~~Wing mainspars of small section.~~

3.2.6 Accessories Selection

In general, accessories are referring to the propulsion system, control surfaces actuators and power source (Zi Yang, 2015). Nowadays, electrical motor is used as main propulsion system and electrical servo is used as the control surfaces actuators (Rabbey et al., 2013). It is recommended to survey on available accessories in the market by examining their datasheet provide by their manufacturers to be used for parametric study and preliminary performance analysis.

3.2.7 Preliminary Centre of Gravity and Moment of Inertia Estimation

Approximation of the centre of gravity can be conducted by using the Solidworks software by giving specific density of the materials that will be used during the modelling process. Modelling included all the accessories such as the propulsion system and control surfaces actuators. The VTOL position is vital in the cg management in order to reduce chances of instability during take-off.

3.2.8 Aerodynamic Analysis

For preliminary aerodynamic analysis, XFLR5 software are used since it is suitable for an aircraft that operates at low Reynold number. XFLR5 could provide the aerodynamic characteristics of the designed wing and tail with less computing time.

Besides, we could also find the reference velocity at particular angle of attack while consider the aircraft will cruise under steady flight using equation (18).

$$V_{\infty} = \sqrt{\frac{W_0}{\frac{1}{2}\rho S_w C_L}} \quad (18)$$

3.2.8.1 XFLR5

The steps and procedures of the XFLR5 software can be found in its official website (Deperrois, 2012). The airfoil shape which is saved in .dat file is imported into the software. Based on selected range of Reynolds numbers, airfoil's aerodynamic characteristics can be approximated. Then, finite wing is inserted to find its aerodynamic characteristics by selecting Fixed Speed configurations. The procedures are repeated for tail aerodynamic analysis. Basic setup is referred to Deperrois (2002) as listed in table below.

Table 3.4 : Reference setup for XFLR5 software

Minimum Reynolds Number	133,00
Maximum Reynolds Number	813,00
Increment Reynolds Number	10,000
Mach	0
NCrit	9
Minimum Alpha	-10^{o}
Maximum Alpha	20^{o}
Increment Alpha	0.5^{o}
Polar Type	Type 1 (Fixed Speed)
Reference Velocity	10 m/s
Density	1.225 kg/m^{3}
Kinematic Viscosity	1.7894 x 10^{-5} kg/ms

In this analysis, the 3D panel method and vortex lattice method (VLM) is taken into consideration as the viscosity effect is included for both of these methods according to Zi Yang (2015).

3.2.9 Preliminary Performance Analysis

The preliminary performance analysis of an aircraft can be conducted by referring to Aircraft Performance and Design by Anderson (1999). The book guide the user to define the performance of a designed aircraft. In general, the preliminary performance analysis will cover the drag polar, power, thrust and the range as well as endurance of the designed aircraft.

3.2.9.1 Drag Polar

Most of the aircraft designers will likely to use the drag polar of an aircraft to determine the performance characteristic and flying qualities of an aircraft. The drag polar describe the relationship between the total lift coefficient and total drag coefficient of an aircraft. The drag polar can be used to calculate the lift to drag ratio and zero lift drag coefficient.

The lift to drag ratio or L/D ratio is the amount of lift created aerodynamically from the wing of the aircraft divided by the aerodynamic drag. Since the lift calculated is set by the aircraft's weight, a higher L/D ratio is preferable. This is because higher L/D ratio will deliver lift with lower drag which will result in better fuel economy in aircraft performance. Zero lift drag coefficient, C_{d_o} is a coefficient of drag produced when there is no lift produced on the wing. C_{d_o} is part of total drag coefficient which represented in equation below. Therefore, drag coefficient, C_d produced by the aircraft during flying at different speed can be calculated when C_{d_o} is available.

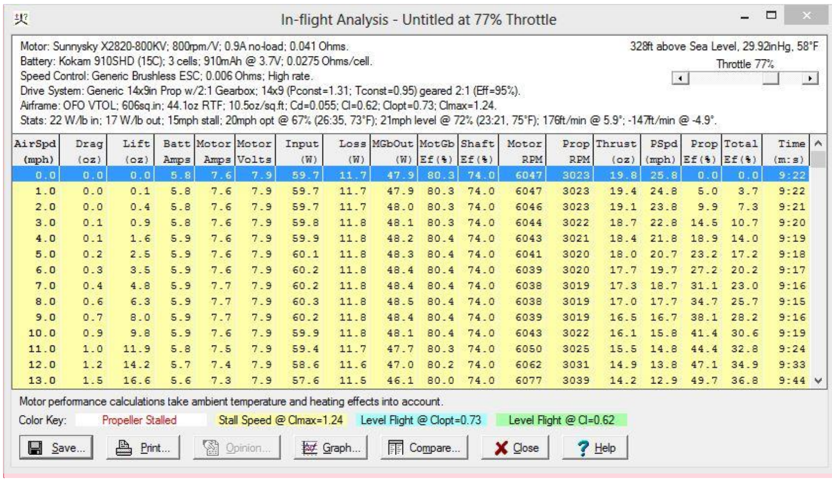
$$C_d = C_{d_0} + \frac{C_l^2}{\pi e AR} \tag{19}$$

3.2.9.2 Power Available and Required

Power available is referred to the power produced by the propulsion system with its specific efficiency of the aircraft. The aircraft is comparable to the latest mini UAV which powered by electrical motor (Rabbey et. al, 2013). Basically, the power available will not be the same with the power output of the motor as each motor will have its own different efficiency which mostly affected by the propeller that been used. The equation below shows the relationship between the power available and power output of the motor.

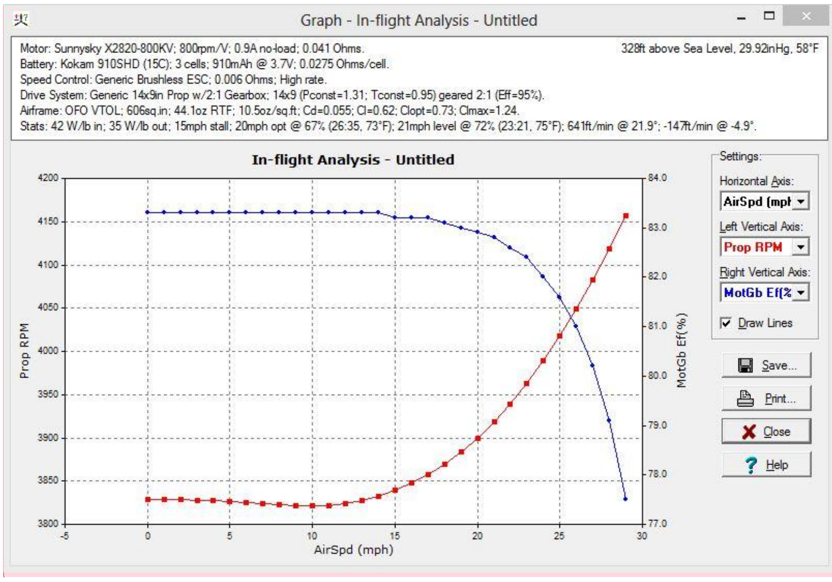
$$P_a = \eta_{prop} P_0 \tag{20}$$

The performance of the electric motor could be done by using the MotoCalc software. By using the software, we could approximate the motor performance based on the percentage of throttle power applied, aircraft flying velocity, electric motor controller used and the battery source. Figure 3.4 and 3.5 shows the graphical user interface for MotoCalc software.



[u8]

Figure 3.4 : XFLR5 interface for motor performance



[u9]

Figure 3.5 : XFLR5 interface for motor performance graph analysis

The propeller characteristic does play an important role in determining the actual power available, P_a (Yew, 2009). Therefore, it is important to study the propeller characteristic in order to approximate the propeller efficiency, η_{prop}. By referring to UIUC Propeller Database (2017), the propeller efficiency, η_{prop} could be obtained.

Power required is referring to the power required for an aircraft to fly at certain airspeed with its total drag force. In general, cruising is the common state taken as the consideration in the analysis. The total power required will divided into two parts which are the power to overcome parasite drag and power to overcome induced drag. The equations are shown below.

Total drag,

$$C_D = C_{D,0} + C_{D,i} \tag{21}$$

Power required to overcome parasite drag,

$$P_{R,0} = \left(\frac{1}{2}\rho V_\infty{}^2 S_w C_{D,0}\right)V_\infty \tag{22}$$

Power required to overcome induced drag,

$$P_{R,i} = \left(\frac{1}{2}\rho V_\infty{}^2 S_w C_{D,i}\right)V_\infty \tag{23}$$

Total power required,

$$P_R = P_{R,0} + P_{R,i} \tag{24}$$

The induced drag coefficient is in a function of lift coefficient (Anderson, 1999) which the relation shown as below,

$$C_{D,i} = \frac{C_L{}^2}{\pi e AR_w} \tag{25}$$

3.2.9.3 Thrust Available and Required

Thrust available is the ability for propulsion system to produce forward thrust. Thrust is a function of power and the aircraft speed, thus thrust available can be obtained using the power available value using equation below

$$T_a = \frac{P_a}{V_\infty} \tag{26}$$

Similarly, the total thrust required is a combination of force to overcome parasite drag and induced drag. The equations are given by

Thrust required to overcome parasite drag,

$$T_{R,0} = \frac{1}{2}\rho V_\infty{}^2 S_w C_{D,0} = \frac{P_{R,0}}{V_\infty} \tag{27}$$

Thrust required to overcome induced drag,

$$T_{R,i} = \frac{1}{2}\rho V_\infty{}^2 S_w C_{D,i} = \frac{P_{R,i}}{V_\infty} \tag{28}$$

Total thrust required,

$$T_R = T_{R,0} + T_{R,i} = \frac{P_R}{V_\infty} \tag{29}$$

3.2.9.4 Range

Range is the distance travel by the aircraft with such amount of power supplied. The range for electrical propulsion system can be obtain by using the Breguet equation (Anderson, 2009) which derived as shown in equations below

$$R = 3.6\eta_{sys}\left(\frac{C_L}{C_D}\right)\frac{U_{el}\left(\Delta C_{el}\right)}{W_0} \tag{30}$$

Maximum range is given by

$$R = 3.6\eta_{sys}\left(\frac{C_L}{C_D}\right)_{\max}\frac{U_{el}\left(\Delta C_{el}\right)}{W_0} \tag{31}$$

Where R and R_{max} unit is in km

The electric power supplied not only supplied the whole propulsion system but also supplied to another subsystem such as the control system. Therefore, the range equation can be derive as shown in equations below.

$$R = 3.6 \frac{(\Delta C_{el})}{\left(\frac{C_L}{C_D}\right)\frac{W_0}{\eta_{sys} U_{el}} + \frac{I_{el_{sub}}}{V_\infty}} \tag{32}$$

While maximum range could be written as

$$R = 3.6 \frac{(\Delta C_{el})}{\left(\frac{C_L}{C_D}\right)_{\max}\frac{W_0}{\eta_{sys} U_{el}} + \frac{I_{el_{sub}}}{V_\infty}} \tag{33}$$

Where R and R_{max} unit is in kilometre

3.2.9.5 Endurance

Endurance of an aircraft is the performance of an aircraft to stay in its flight with given power supplied. By using the same approach, the derivation for endurance, E could be written as

$$E = 60\sqrt{\left(\frac{C_L{}^3}{C_D{}^2}\right)}\sqrt{\frac{S_w \rho}{2W_0{}^3}}\eta_{sys} U_{el} (\Delta C_{el}) \tag{34}$$

While maximum endurance is given by

$$E_{\max} = 60\sqrt{\left(\frac{{C_L}^3}{{C_D}^2}\right)_{\max}}\sqrt{\frac{S_w\rho}{2{W_0}^3}}\eta_{sys}U_{el}\left(\Delta C_{el}\right) \tag{35}$$

Where E and E_{max} unit is in minutes

Previously, using the same consideration in determine range equation, the endurance equation could be written as

$$E = 60\frac{\eta_{sys}U_{el}\left(\Delta C_{el}\right)}{\left\{1\Big/\sqrt{\left(\frac{{C_L}^3}{{C_D}^2}\right)}\sqrt{\frac{2{W_0}^3}{S_w\rho}}\right\}+\eta_{sys}U_{el}I_{el_{sub}}} \tag{36}$$

While maximum endurance is given by

$$E_{\max} = 60\frac{\eta_{sys}U_{el}\left(\Delta C_{el}\right)}{\left\{1\Big/\sqrt{\left(\frac{{C_L}^3}{{C_D}^2}\right)_{\max}}\sqrt{\frac{2{W_0}^3}{S_w\rho}}\right\}+\eta_{sys}U_{el}I_{el_{sub}}} \tag{37}$$

Where E and E_{max} unit is in minutes

3.3 Optimization

The aircraft design is required to be optimised in order to achieve the best configuration with the desired performance specification after all the preliminary analysis done (Zi Yang, 2015). The optimization required modifications to the aircraft design in particular it frequently requires a revised or new design layout (Raymer, 2006). For greater optimization, the drawing is revised after number of iterations until the design meets the goals of the aircraft.

3.4 Preliminary Design, Detail Design and Fabrication

Preliminary design will begin when the major changes are concluded (Raymer, 2006). For example, the tail configurations of an aircraft has been decided by choosing the conventional tail. Besides some minor revisions on the design will occur in order to meet the goals. Nevertheless, these minor changes are stopped after decision is made to freeze the configurations of the aircraft.

Modelling of the aircraft can be conducted by using Solidworks software by including all of the accessories required. Fabrication procedure is established when the modelling process is completed where the methods and steps to fabricate the aircraft will be listed. The procedures to fabricate the aircraft is listed in Appendix C. The items and materials required is listed in Appendix D.

3.5 Validation Works and Flight Test

Finally, the aircraft flying qualities especially the VTOL mechanisms will be conducted by using the radio telemetry. Manual mode will be used during the flight test and no stabilization mode is used since there is no augmentation system will be used. Aim of the flight test is to make the VTOL RC aircraft take off successfully.

CHAPTER 4

4 RESULTS AND DISCUSSIONS

CHAPTER 5

5 CONCLUSION

6 REFERENCES

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APPENDIX A

Gantt Chart

Weeks of semester 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Topic confirmation																
Discussion with supervisor about the research scope	■	■														
Meeting arrangement	■	■														
Literature review																
Definition study			■	■												
Parametric study			■	■												
On board system study			■	■												
Fabrication method study			■	■												
Conceptual design																
Weight estimation					■											
Initial sizing						■	■	■	■							
Modelling						■	■	■	■							
Centre of gravity estimation						■	■	■	■							
Aerodynamic analysis																
Lift, Drag, Moment										■						
Performance analysis																
Power required											■					
Power and thrust required											■					
Range and endurance											■					
Stability analysis																
Static stability												■	■			
1st draft preparation														■	■	
VIVA 1																■

APPENDIX A[u10]

Gantt Chart

Weeks of semester 2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15[u11]
Scope confirmation															
Discussions about the panels feedback from VIVA1	■														
Meeting arrangement	■														
Optimization															
Preliminary Design		■	■												
Preliminary Analysis															
Aerodynamic Analysis				■	■	■									
Performance Analysis				■	■	■									
Static Stability Analysis				■	■	■									
Dynamic Stability Analysis															
Longitudinal Derivatives							■	■	■						
Lateral Derivatives							■	■	■						
Preliminary & Detail Design															
Complete modelling					■	■									
Fabrication										■	■				
Flight Test												■			
Final draft preparation								■	■	■	■	■	■	■	
VIVA 2															■

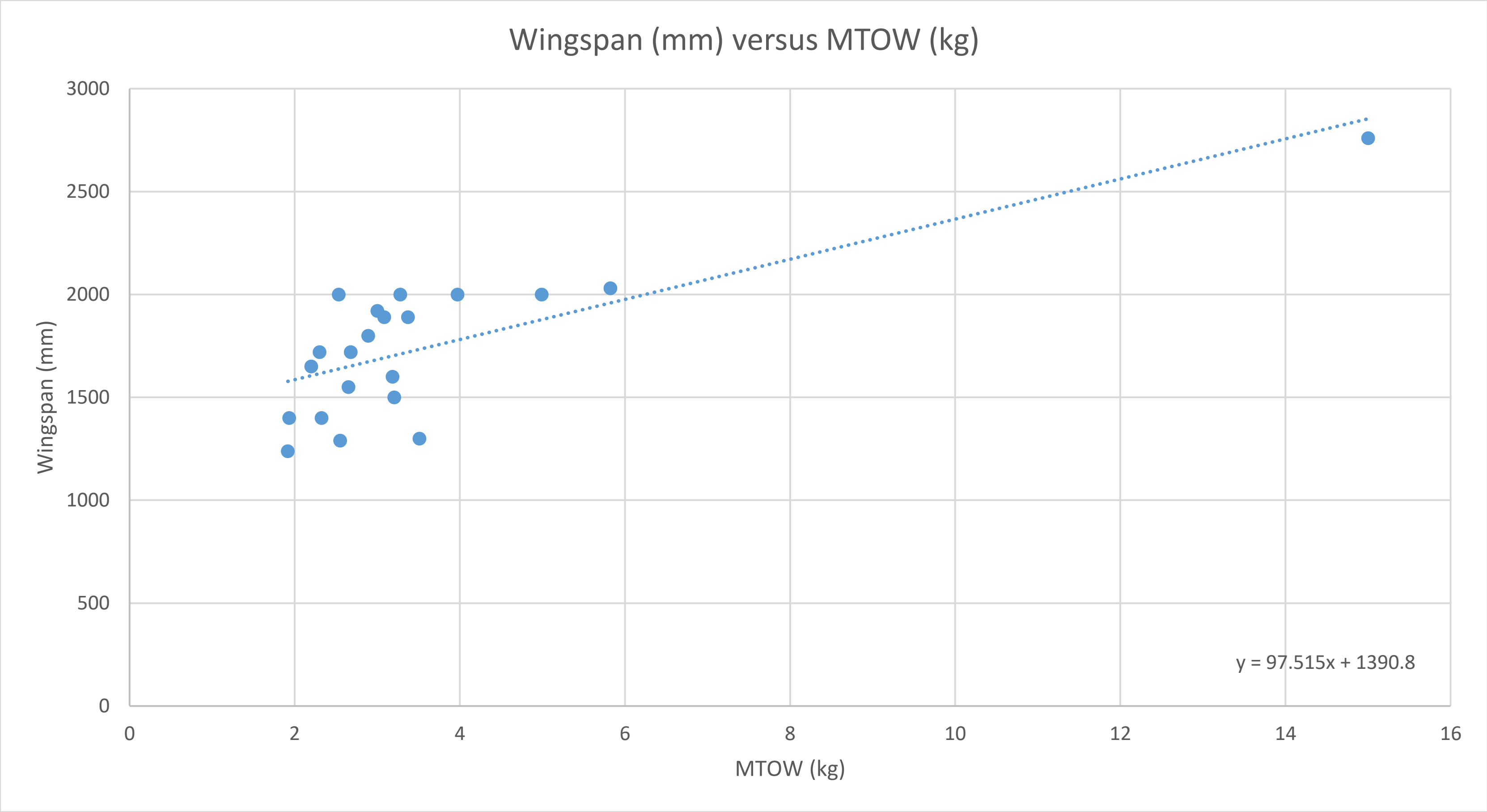
APPENDIX B1

Parametric study

	Model	MTOW, kg	Empty weight, kg	Payload, kg	Fuselage length, mm	Wing span, mm	Cruising speed, m/s	Endurance, mins
1	Skywalker 1680	2.3	1.115	1.185	1180	1720	25	70
2	Zeta Sky Observer FPV	4.991	1.45	3.541	1511	2000		65
3	Skywalker Revolution FPV	2.68	1.115	1.565	1200	1720	25	65
4	Skywalker Naja FPV	3	1.5	1.5	948	1920	27	60
5	AXN Floater-Jet EPO	2.549	1.05	1.499	830	1290	23	30
6	X-Large EPP	2.889	1.2	1.689	1150	1800		30
7	HobbyKing Bixler v1.1	1.935	0.65	1.285	925	1400		30
8	HobbyKing Bixler 2 EPO	3.207	0.76	2.447	963	1500		30
9	HobbyKing Bix3 Trainer	2.652	0.89	1.762	948	1550		30
10	HobbyKing Sky Eye	2.532	1.35	1.182	1050	2000		40
11	Durafly Tundra	3.51	1.15	2.36	1190	1300		30
12	HobbyKing Mini SkyHunter	1.917	0.83	1.087	750	1238	13	25
13	HobbyKing Breeze Glider	2.325	0.63	1.695	1020	1400		30
14	AAI RQ-7 Shadow	3.971	2	1.971	1630	2000	46	35
15	Firstar 2000 V2	3.278	1.05	2.228	1044	2000		30
16	Firstar 1600	3.184	0.95	2.234	1050	1600		28
17	E-Do Model Sky Eye	3.083	1.95	1.133	900	1890		30
18	Skywalker WALL E2000	5.825	2.15	3.675	1120	2030	16	35
19	E-Do Model Sky Eye Twin	3.373	2.1	1.273	900	1890		30
20	Cumulus One	2.2	1.6	0.6	950	1650	40	150
21	ALTI Transition	15	14	1	1500	2760	50	360

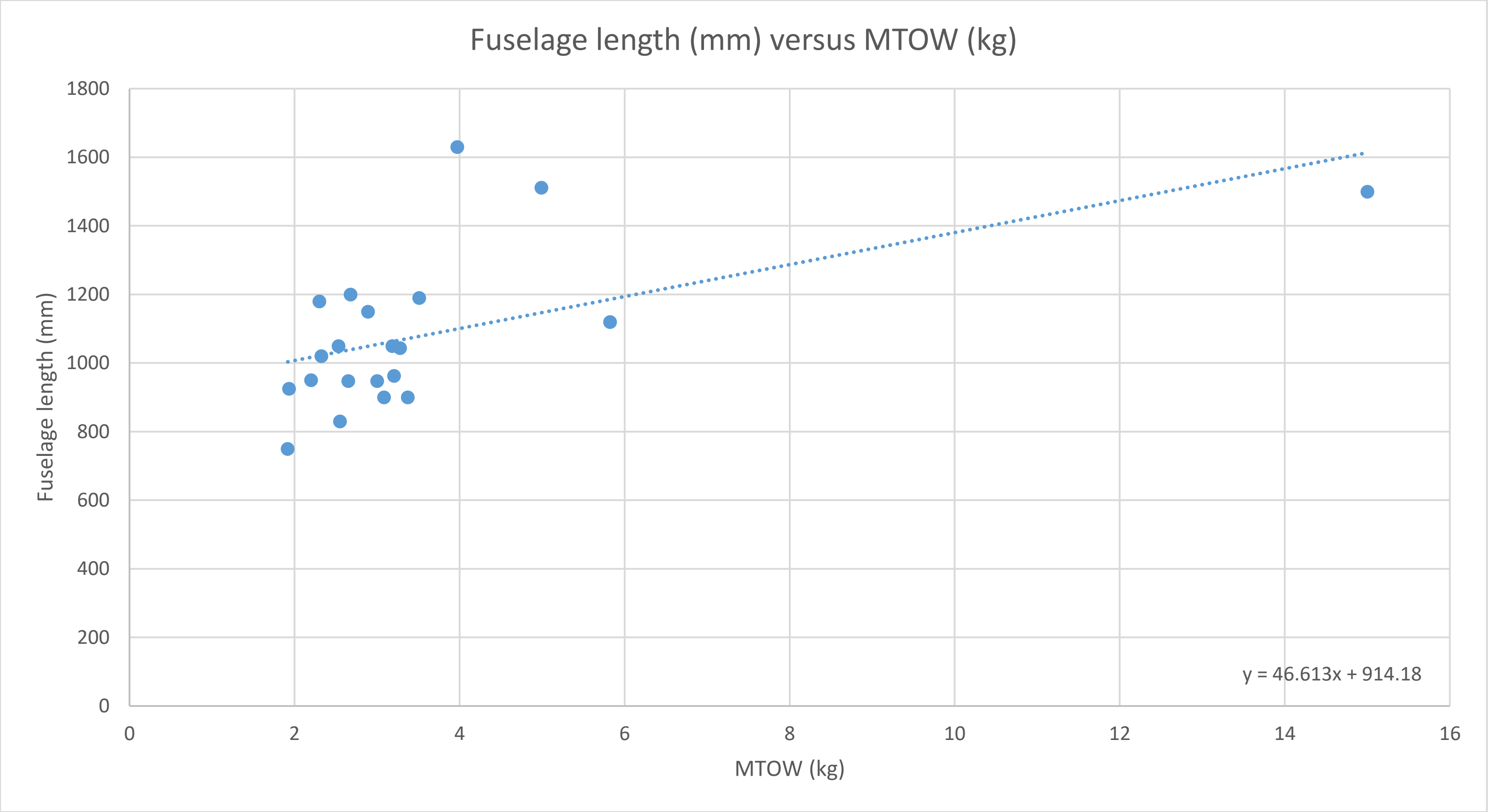
APPENDIX B2

Graph of Wingspan versus Maximum Take-Off Weight



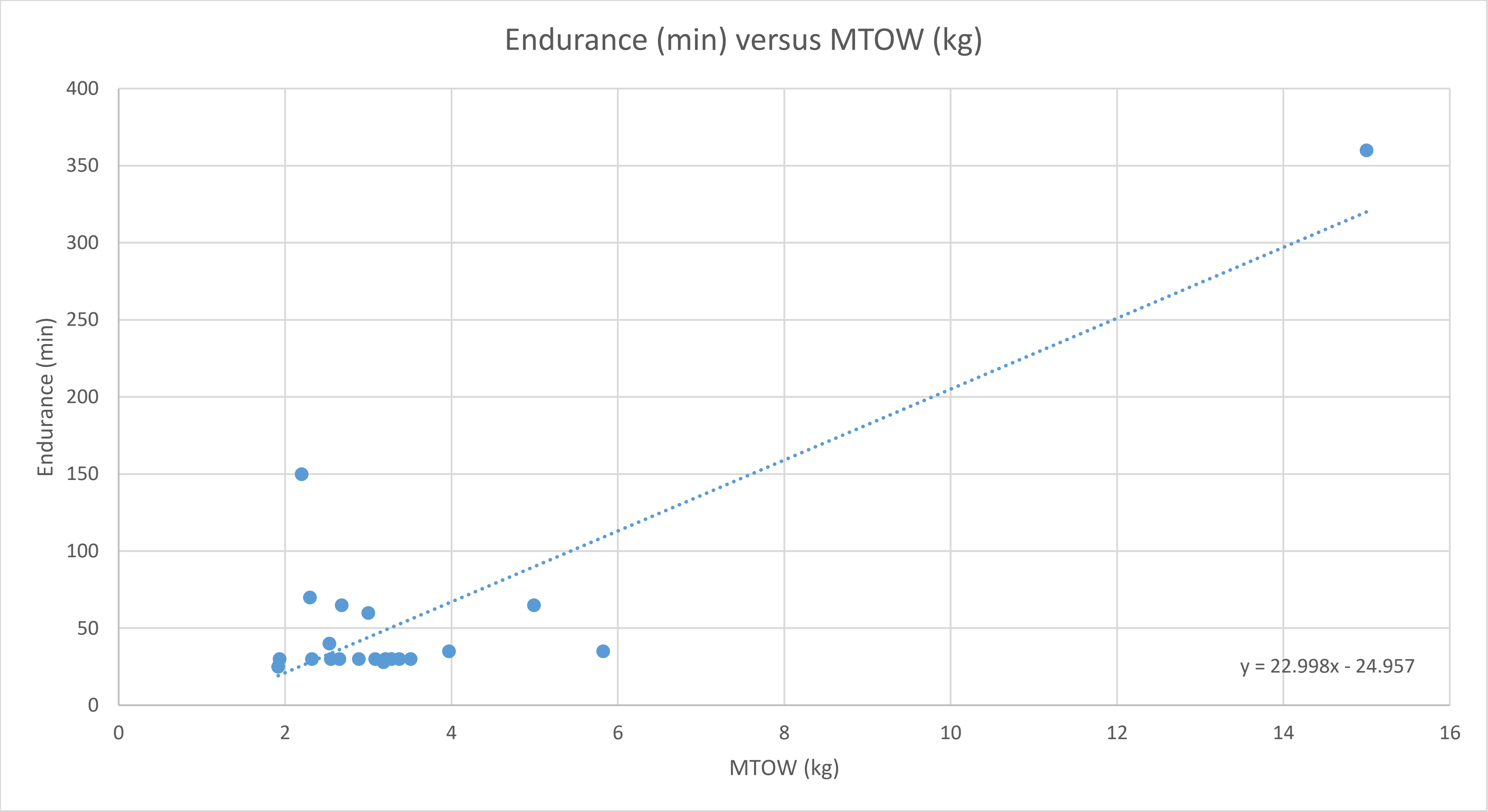
APPENDIX B3

Graph of Fuselage Length versus Maximum Take-Off Weight



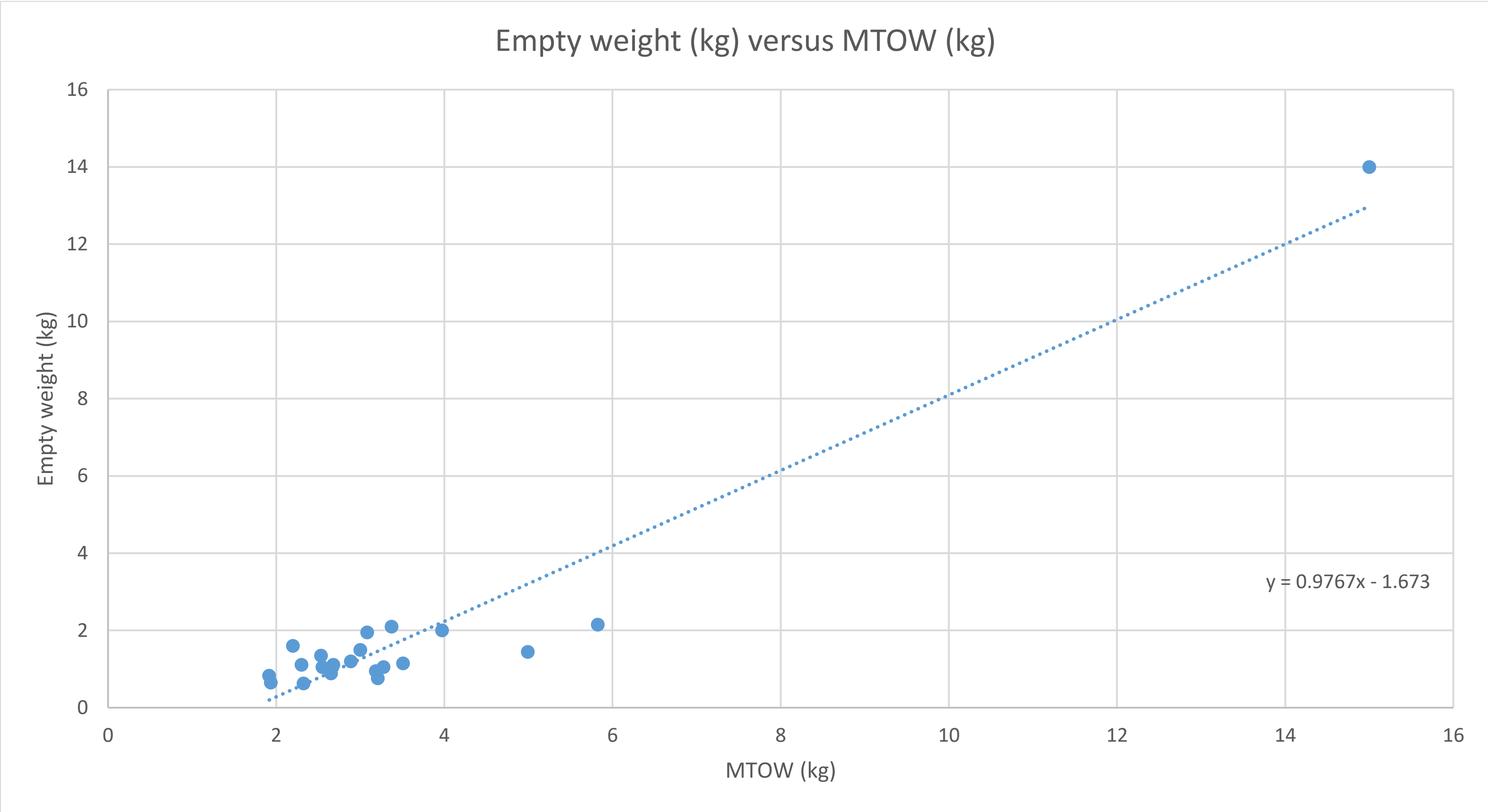
APPENDIX B4

Graph of Endurance versus Maximum Take-Off Weight



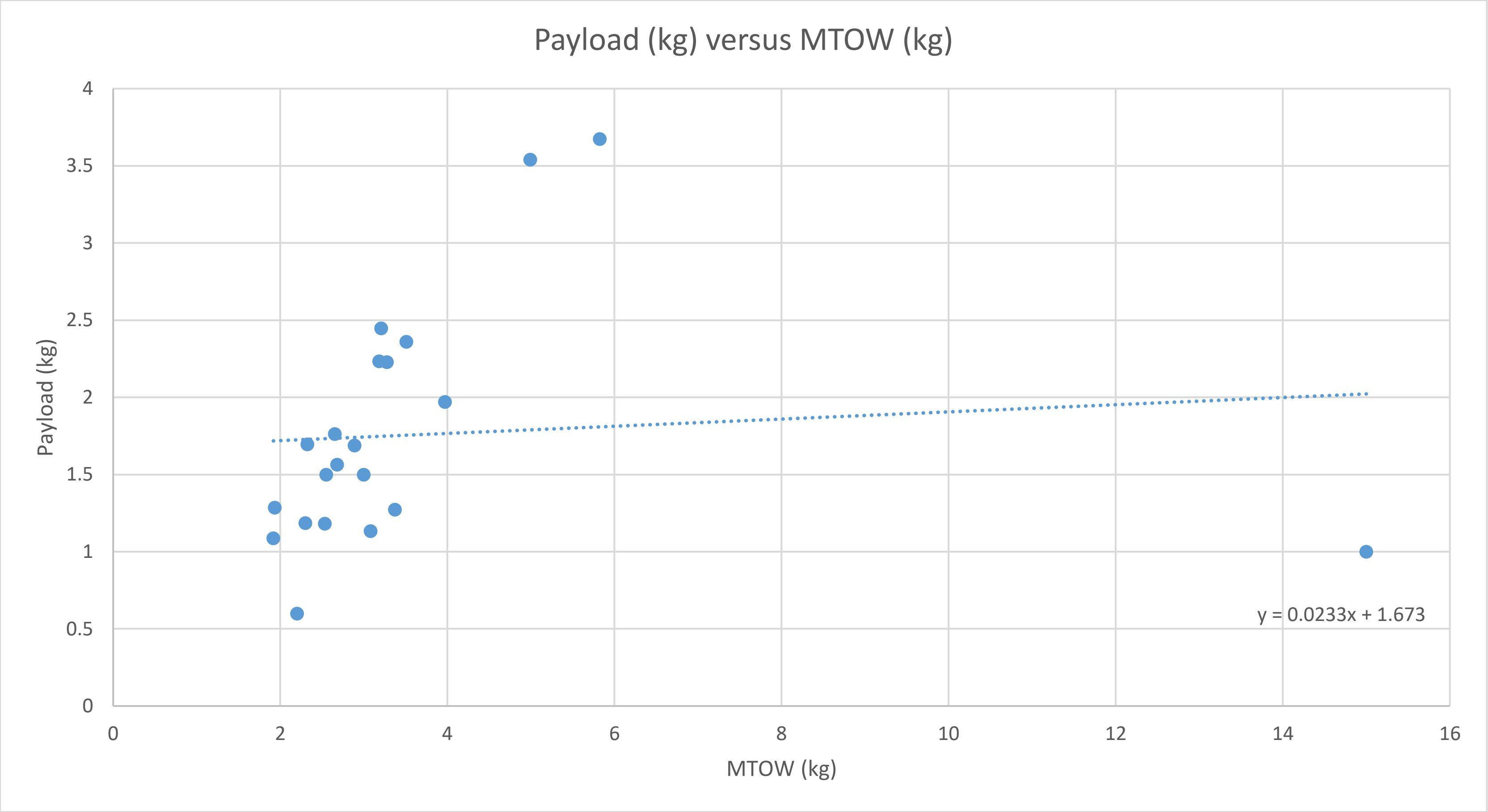
APPENDIX B5

Graph of Empty Weight versus Maximum Take-Off Weight



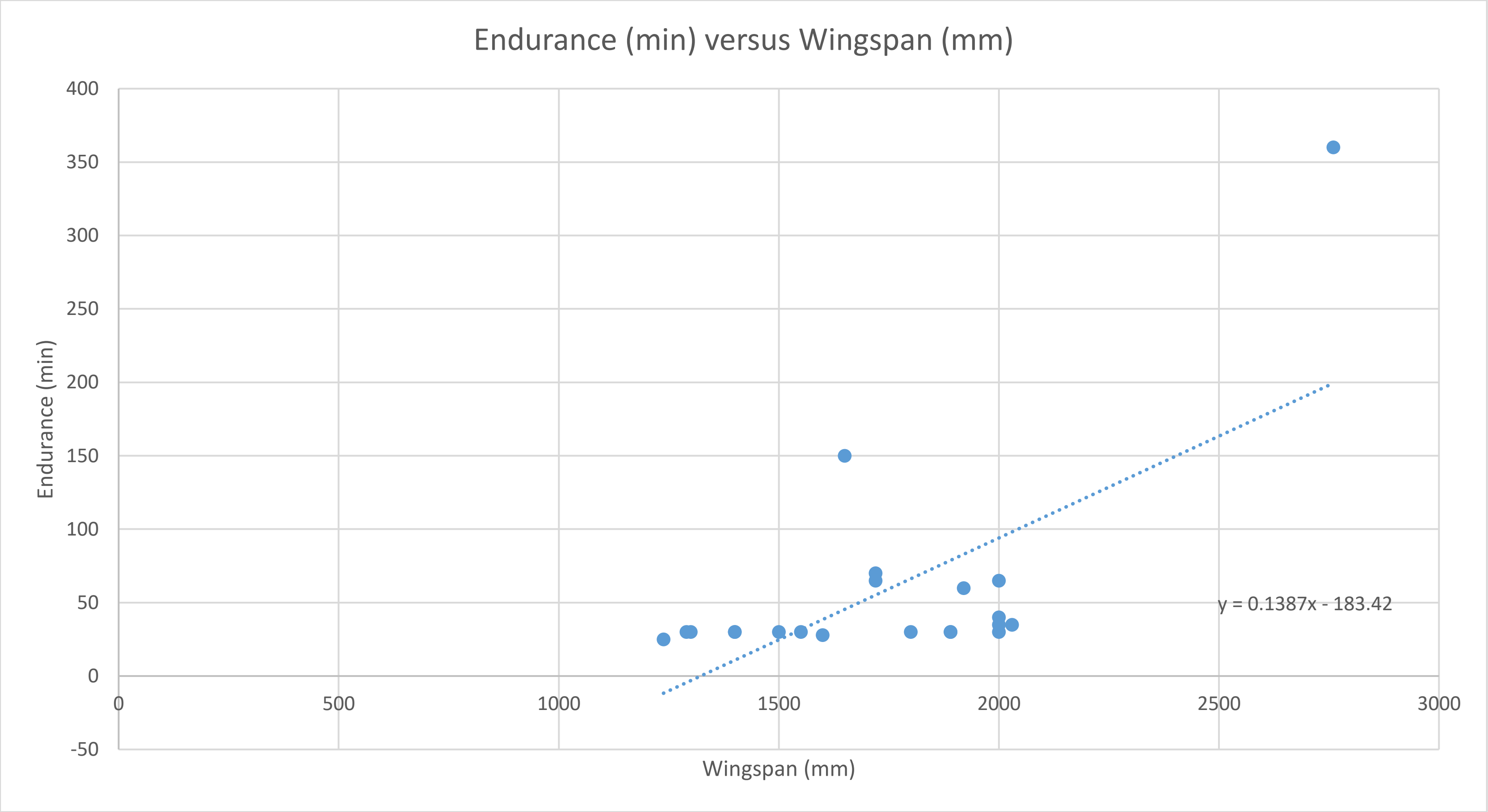
APPENDIX B6

Graph of Payload versus Maximum Take-off Weight



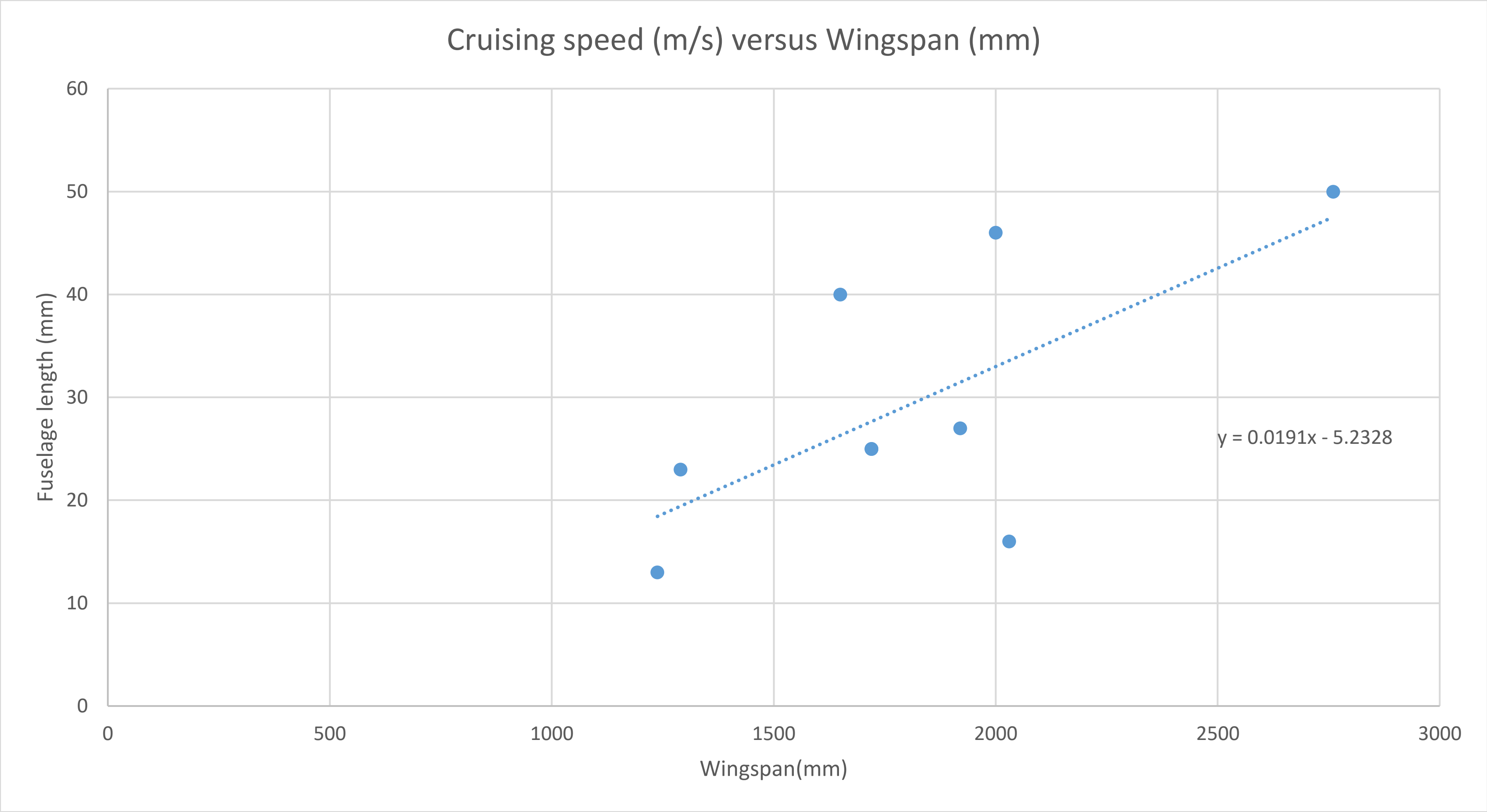
APPENDIX B7

Graph of Endurance versus Wingspan



APPENDIX B8

Graph of Cruising Speed versus Wingspan



APPENDIX C

Fabrication procedures

APPENDIX D

List of items, materials and accessories[u12]

No.	Item	Quantity (Unit)
1.	Radio receiver	1
2.	Radio transmitter	1
3.	Electric motor controller[u13]	2
4.	EMax GT2820 850kv electric motor	2
5.	13 × 11 inches propeller	2
6.	Electric servo	4
7.	Connection wire	TBC
8.	Wire connector	2
9.	1300mAh LiPo Battery	1
10.	5000mAh LiPo Battery	1
11.	RC servo anchor	4

No.	Material	Quantity (Unit)
1.	Balsa wood	TBC
2.	Foam	TBC
3.	Hot glue	5
4.	Fibre tape	1
5.	Epoxy glue	1
6.	0.5” Aluminium square tube (2m)	1

No.	Accessories	Quantity (Unit)
1.	Wire cutter	1
2.	Solder station	1
3.	Hot glue gun	1
4.	Cutter	1
5.		