Preliminary Design of Unmanned Aerial Vehicle (UAV) for

Petroleum Pipe Monitoring System

by

Intan Naquiah binti Sharuddin

Dissertation submitted in partial fulfillment of
The requirement for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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Mechanical Engineering Programme
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Approved by,

(Dr. Setyamartana Parman)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
MAY 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

INTAN NAQUIAH BINTI SHARUDDIN

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ABSTRACT

Unmanned Aerial Vehicle or UAV has been designed by numerous inventors due to its importance in multiple industries. One major usage of UAV nowadays is for surveillance.This report basically discusses the progress done on the chosen topic, which is ***Preliminary Design of Unmanned Aerial Vehicle (UAV) for Petroleum Pipe Monitoring sYSTEM***. The basic idea of this project is the design work. An Unmanned Aerial Vehicle (UAV; also known as a remotely piloted vehicle or RPV, or Unmanned Aircraft System (UAS)) is an aircraft that flies without a human crew on board the aircraft. The purpose of this project is to learn all the aspects of designing the preliminary design of UAV specifically for the use in monitoring the petroleum pipe system, onshore and offshore. So, the methodology for this project is more on designing the UAV by determining and investigating its specification that fulfill the need for that particular purpose. The scope of work for semester one final year project is to research more about UAV preliminary design that suitable for monitoring petroleum pipe system; both offshore and offshore. Other than that is investigating the suitable criteria and specifications as the factor that need to be considered for designing and drawing the final configuration. The second part of the project will covers the analysis of both aerodynamics and performance for the designed UAV. It also involved the final drawing of the UAV using AutoCAD 2008 according to its specifications. The objective of studies had been achieved upon the completion of the project.

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INTRODUCTION

1.1 Background of Study

Energy is the most important source for the human to assist their daily life. Maintenance for energy source transportation issues are being greatly discussed all over the world. Pipeline transportation, advanced technologies and intelligent monitoring system are mainly being the focus of discussion to find appropriate measures to solve those issues. Furthermore, the rapid increase of overall energy demand also further complicates energy related problem especially for increasing the efficiency of petroleum transportation as it is a primary source of energy in the world. This phenomenon is a result of the increase in maintenance for pipeline monitoring system.

Energy can be further categorized into two subcategories which are conventional energy and renewable energy. Conventional energy implies to the energy sources that are non-renewable, fossil-fuelled and cannot be recycled; it is related to emission such as petroleum based fuel, coal, and natural gases. Whereas the renewable energy defined as the recyclable energy sources. For example biomass energy, solar energy and wind energy.

As been mentioned, the non-renewable energy cannot be produced, generated and sustained after once used. Therefore, these natural resources are only exist in fixed amount and had been consumed as a primary energy sources from decades until today. Fossil fuels are formed by the anaerobic decomposition of remains of organisms including phytoplankton and zooplankton that settled to the sea (or lake) bottom in large quantities under anoxic conditions, millions of years ago.

Fossil fuels are oil, coal and natural gas. In 2006 primary sources of energy consisted of petroleum 36.8%, coal 26.6%, and natural gas 22.9%, amounting to an 86%

share for fossil fuels in primary energy production in the world. Eventually natural resources will become too costly to harvest and humanity will need to find other sources of energy. At present, the main energy source used by humans are non-renewable fossil fuels, as a result of continual use since the first internal combustion engine in the 17th century, the fuel is still in high demand with conventional infrastructure fitted with the combustion engine. Fossil fuels are non-renewable resources because they take millions of years to form, and reserves are being depleted much faster than new ones are being formed.

The pipelines fill diverse roles. That diversity of supply pattern and consumer need precludes the industry from being monolithic. Pipelines are serving different regions with different consuming patterns. Even within a region, there are additional scheduling and operational challenges presented by contrasts among the output mix of different refineries, the consumption patterns of large consumers on a system, and even seasonal consumption patterns in a region. Pipelines compete with each other and with other modes of transportation in filling these needs. Oil is generally propelled through pipelines by centrifugal pumps. The pumps are sited at the originating station of the line and at 20 to 100 mile intervals along the length of the pipeline, depending on pipeline design, topography and capacity requirements. Most pumps are driven by electric motors, although diesel engines or gas turbines may also be used. Pipeline employees using computers remotely control the pumps and other aspects of pipeline operations. Pipeline control rooms utilize Supervisory Control And Data Acquisition (SCADA) systems that return real-time information about the rate of flow, the pressure, the speed and other characteristics. Both computers and trained operators evaluate the information continuously. Most pipelines are operated and monitored 365 days a year, 24 hours per day. In addition, instruments return real-time information about certain specifications of the product being shipped – the specific gravity, the flash point and the density, for example – information that are important to product quality maintenance.

Generally, oil pipelines provide transportation, temporary storage and logistics services; they do not own the product they transport. In addition to moving the large volumes from producing regions to consuming regions, pipelines fill a critical role in moving smaller quantities of oil from market hubs to more distant consuming areas. Pipeline operations over the years have accommodated a greater number of unique products, carrying products that meet regional and seasonal environmental quality mandates. They are the only practical mode of transportation for most overland movements, and the cheapest. It is not surprising, therefore, that pipelines are by far the most important mode of transportation for oil in thethe world.

Pipelines are the irreplaceable core of the world petroleum transportation system and hence the key to meeting petroleum demand. Without oil pipelines, petroleum products would not reach the millions of consumers in all fifty states. Oil pipelines transport roughly two-thirds of the petroleum shipped in the United States. They deliver over 14 billion barrels (more than 600 billion gallons) of petroleum per year. Because many volumes are shipped more than once (as crude oil and then again as refined product, for instance), these annual pipeline shipments are equal to more than twice the actual U.S. consumption of oil.

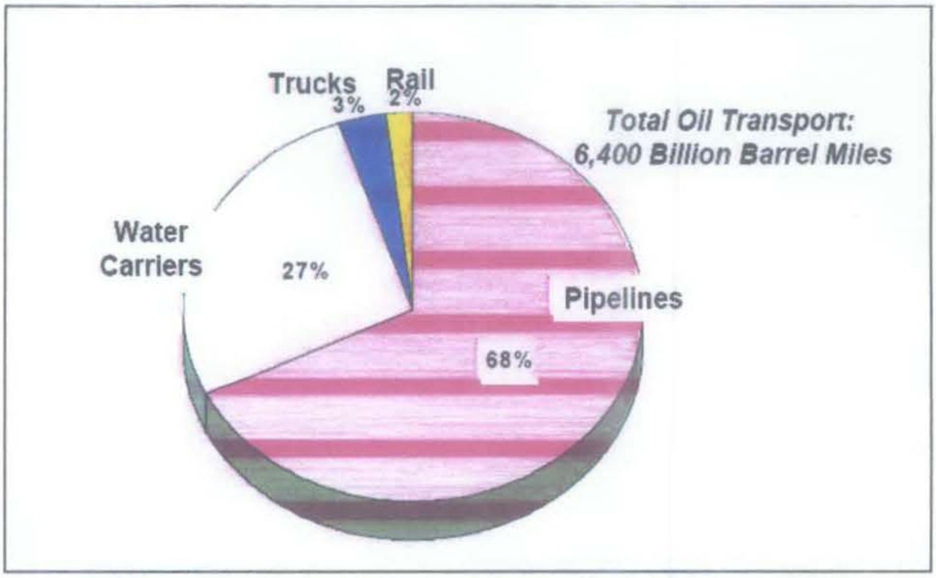

Figure 1.1: Types of oil transportation in United States, 2000

Source: Estimated from Association of Oil Pipe Lines, *Shifts in Petroleum Transportation*, 2000

The area of interest in this project is to focused on the non-renewable energy specifically petroleum main transportation system which is pipeline monitoring system using UAV. Most of the pipelines monitoring system nowadays are using human force manually to inspect the external structure of the pipeline. The technicians will follow the routine of maintenance schedule for checking the outer part of the pipeline. Any defects will then be reported to the superior and issued to the engineer for further action. However, the more sophisticated method is used to inspect the internal layer of the pipeline using pigging system.

Modern intelligent pigs are highly sophisticated instruments that vary in technology and complexity by the intended use and by manufacturer. An intelligent pig, or smart pig, includes electronics and sensors that collect various forms of data during the trip through the pipeline.Pipelines are mainly checked for integrity, aspects such as stress corrosion cracking, general corrosion and human destruction. However, accidents could easily lead to explosion and environmental damage, putting both people and nature at risk.

Therefore, as part of the university commitment to inculcate energy conserving environment, this issue should not be taken for granted only for the sake of certain party. This issue should be further discussed to design an appropriate pipeline monitoring using unmanned aerial vehicle to inspect the external pipeline structure and is continuing by specified the suitable specification for the UAV system.

1.2 Problem Statement

As one of the Universiti Teknologi PETRONAS (UTP) student, it is vital to contribute towards the industry that PETRONAS ventured in. By designing the monitoring device for petroleum pipe, it can lower the consumption of workers workloads using advanced engineering solution.

Hence, a comprehensive study on the UAV specifications needed for petroleum pipe monitoring should be conducted to determine the best design of the UAV. Many criteria and analysis has to be constructed to obtain the finalized design. In the case of monitoring the pipelines, the tools required for that particular has to be studied thoroughly.

1.3 Objective

The objective of this project is to study and understand the design of UAV for petroleum pipe monitoring. Besides, through the project, the investigation on the best specifications of UAV for monitoring thepetroleum pipeline system had been conducted. Other than that, it is aimed to design preliminary configuration of UAV and analyze the performance of the UAV.

1.4 Scope of Study

The work scope for the first semester of Final Year Project will cover the research on the detail about Preliminary Design of Aircraft. The criteria of the UAV that is needed for petroleum pipe monitoring had been conducted and further explained in the methodology. Thorough studies and investigation regarding the aspects involved and preliminary sizing of the UAV had been done for the Semester One of the project.

Other than that is to investigate the suitable criteria and specifications as the factor that need to be considered for designing and drawing the final configuration. The market study of the UAV had been successfully achieved in this stage.

For the scope of work for the second semester of this final year project is to conduct the analysis and detail configurations of UAV. These part objectives are to perform the final touch for the UAV specifications. It will involve the weight and balance part, aerodynamic analysis, performance analysis and stability and control analysis.

If the analysis does not satisfy the requirement of the aircraft, the preliminary sizing of the UAV had to be adjusted. Therefore, every aspect in criteria selection might effects the flow from the beginning. At the end of the project, the final drawing configuration will be constructed according to its optimum specifications.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Petroleum Transportation and Regulation

According to United States Code, Amendment of Title 49 (2009) Section 7, Transportation-Related Oil Flow Lines, this section amends sections 60101 and 60102 to authorize PHMSA to collect information on onshore transportation-related oil flow lines regardless of whether they are currently regulated to determine whether there is any need for future regulation. A number of spills have occurred on (unregulated) onshore transportation-related oil flow lines and PHMSA needs to better understand the extent and condition of these lines. The operation of oil flow pipeline systems can impact the safety and reliability of downstream lines. Production-related oil flow lines would remain non-jurisdictional.

According to Trench (2001), oil is generally propelled through pipelines by centrifugal pumps. The pumps are sited at the originating station of the line and at 20 to 100 mile intervals along the length of the pipeline, depending on pipeline design, topography and capacity requirements. Most pumps are driven by electric motors, although diesel engines or gas turbines may also be used. Pipeline employees using computers remotely control the pumps and other aspects of pipeline operations. Pipeline control rooms utilize Supervisory Control And Data Acquisition (SCADA) systems that return real-time information about the rate of flow, the pressure, the speed and other characteristics. Both computers and trained operators evaluate the information continuously. Most pipelines are operated and monitored 365 days a year, 24 hours per day. In addition. Instruments return real-time information about certain specifications of the product being shipped – the specific gravity, the flash point and the density, for example – information that are important to product quality maintenance.

2.2 Introduction to Existing UAV System Design

2.2.1 Materials for UAV

Istas and Nizam from Universiti Teknologi Malaysia, 2004 reported that composite materials provide capabilities for part integration. Several metallic components can be replaced by a single composite component. Composite structures provide in-service monitoring or online process monitoring with help of embedded sensors. This feature is used to monitor fatigue damage in aircraft structures or can be utilized to monitor the resin flow in resin transfer moulding process. Composite materials also have a high specific stiffness. Composites offer the stiffness of steel at one fifth the weight and equal the stiffness of aluminium at one half of the weight.

According to Team Lemming (2003) from University of Adelaide, aluminium is an abundant low cost material, with characteristics that make it perfect for our UAV construction. It is a versatile material with super corrosion resistance, good formability, flexibility, and strength. Composites are often overlooked when cost is an important consideration. However, with such advanced characteristics, including great fatigue resistance, good damping characteristics, and very light weight they came out on top for best performance. In some cases this performance resulted in an actualcost saving.

2.2.2 Power Supplies for Small UAV

Randall (2005) stated that the propulsion system consists completely of low-cost commercial-off-the-shelf products. Lithium-polymer batteries provide a high energy-density power source for the brushless electric motor and all electronics. With any aircraft of this type, the power budget is of great importance.

Team Lemming (2003) reported that there are two traditional methods for providing electrical power to a UAV. The first method is to simply carry enough batteries onboard to power all the UAV electronics. The second method is a combination of a base battery pack and a generator integrated with the UAV engine, provided the UAV does not use electric propulsion. Lithium-Ion batteries are currently used in many military communication devices, and Zinc-Air batteries have been developed to replace these battery packs.

2.2.3 Aerodynamics Analysis and Calculation

The Reynolds number Re is a dimensionless number that gives a measure of the ratio of inertial forces to viscous forces and consequently quantifies the relative importance of these two types of forces for given flow conditions.

The Mach Number is a dimensionless value useful for analyzing fluid flow dynamics problems where compressibility is a significant factor.

Cruise is the level portion of aircraft travel where flight is most fuel efficient. It occurs between ascent and descent phases and is usually the majority of a journey. Technically, cruising consists of heading (direction of flight) changes only at a constant airspeed and altitude. It ends as the aircraft approaches the destination where the descent phase of flight commences in preparation for landing.

Airfoil sections are of two basic types, symmetrical and nonsymmetrical. Symmetrical airfoils have identical upper and lower surfaces. They are suited to rotary-wing applications because they have almost no center of pressure travel. Travel remains relatively constant under varying angles of attack, affording the best lift-drag ratios for the full range of velocities from rotor blade root to tip.

Advantages of the nonsymmetrical airfoil are increased lift-drag ratios and more desirable stall characteristics. Nonsymmetrical airfoils were not used in earlier helicopters because the center of pressure location moved too much when angle of attack was changed. When center of pressure moves, a twisting force is exerted on the rotor blades. Rotor system components had to be designed that would withstand the twisting forces. Recent design processes and new materials used to manufacture rotor systems have partially overcome the problems associated with use of nonsymmetrical airfoils.

Lift is the force that directly opposes the weight of an airplane and holds the airplane in the air. Lift is generated by every part of the airplane, but most of the lift on a normal airliner is generated by the wings. Lift is a mechanical aerodynamic force produced by the motion of the airplane through the air.

The angle of attack is the angle at which relative wind meets an airfoil. It is the angle that is formed by the chord of the airfoil and the direction of the relative wind or between the chord line and the flight path. The angle of attack changes during a flight as the pilot changes the direction of the aircraft. It is one of the factors that determine the aircraft's rate of speed through the air. The maximal total range is the distance an aircraft can fly between takeoff and landing, as limited by fuel capacity in powered aircraft, or cross-country speed and environmental conditions in unpowered aircraft.

2.2.4 Previous Study on Small Fixed-Wing UAV

According to Randall (2005), the breakdown of the overall mass among the four major subsystems (airframe, propulsion, GNC, and payload) is shown in Fig. 4. From this figure, it is seen that the majority of the mass budget is allocated to the propulsion system. This is expected considering that the subsystem includes the battery required to power all electrical systems onboard the aircraft. It is interesting to note that the payload capacity is only 11% of the total mass. Although it is not uncommon to see this low level of payload capacity in mini/micro air vehicles,1, 2 it is more severe in the case of BATCAM due to the extra mass required by the GNC subsystem required to obtain full autonomy. The final item to note is that the airframe, comprising 28% of the total mass, is rather heavy compared to other aircraft in this class. A large design emphasis on ruggedness accounts for the extra weight in the airframe: BATCAM is designed to survive4 severe impacts with buildings, trees, and the ground.

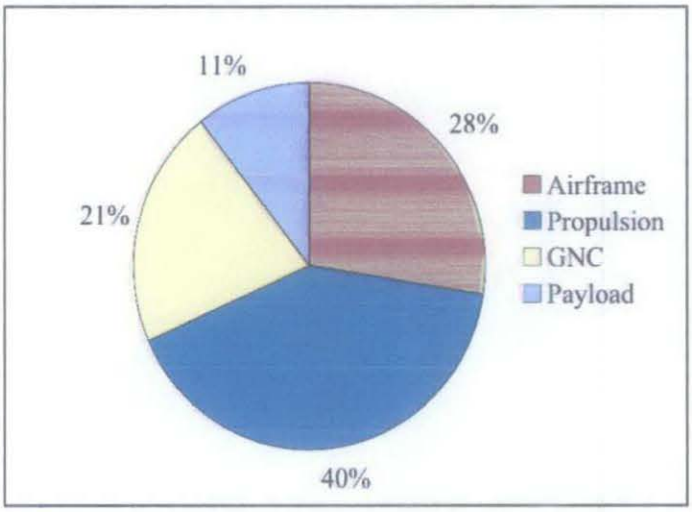

Figure 2.1: Subsystem mass breakdown for the BATCAM mini-UAV

The airframe is constructed primarily of carbon fibre, resulting in a lightweight yet extremely rugged structure. The properties of carbon fibre are advantageous to the fabrication of small UAVs in that the composite material forms complex shapes at relatively low cost, and yet can exhibit incredible strength and stiffness. The wing is fabricated with a carbon fibre skeleton, containing a main spar running the length of the span with thin battens attached, and non breathable rip-stop nylon skin.

This construction technology, developed in part at the University of Florida, 3 results in a flexible wing design providing two features key to the success of this small UAV. First, the elastic properties of the wing battens, constructed of unidirectional carbon fibre strips, allow passive adaptive washout, improving stability and gust response. Much like the feathers of a bird, the battens near the wing root are stiffened with an increased number of layers of carbon fibre, while the tip battens remain thin to promote flexibility.

The second feature is the ability to fold the wings. The main spar of the wing uses a bidirectional carbon fibre mesh with the fibres oriented ±45 deg relative to the span. The fabrication technique, combined with the geometry of the airfoil camber, results in a structure that is stiff in the upward direction and flexible in the downward direction, allowing the wings to be rolled underneath the fuselage. This wing design, along with a non-rigid V-tail design, allows the BATCAM to be stored, fully assembled and ready to fly, inside a tube less than six inches in diameter.

2.2.5 Previous Studies on Low Cost UAV

The method of the low-cost, expendable UAV's deployment was initially considered due to the strong dependence of the UAV's design on the deployment method. Eight deployment options were considered. These options were divided into two groups: aerial deployment and surface deployment. To minimize the cost of the UAV and improve mission and location versatility, the traditional take-off method was not considered. The landing gear required for traditional take-off greatly increases the cost, weight, and complexity of the UAV design. In addition, a runway is needed in a controlled location, greatly reducing the reconnaissance capabilities of the aircraft. The aerial deployment options involve the use of an airplane or helicopter to transport the UAV to the specified drop zone. The surface deployment options involve a launch from a ship or submarine. It was decided for the purposes of versatility and marketability that the UAV would be designed for compatibility with three aerial deployment options. Within the aerial deployment category, five options were analyzed. The aerial deployment options considered were the simple drop, parachute assisted drop, boom launch, hard point launch, and tow line. An initial bias was given to the aerial deployment options due to the immensely greater positioning versatility they exhibit when compared against the surface deployment options. The following is a summary of the aerial deployment options. (Team Lemming, 2003).

2.2.6 Computer Aided Design Software of Engineering Drawing

Alioto (2009) reported study on the analysis on the main variable in sketches was the engine position, and various engine positions were tried in a preliminary CAD model to work out a final concept considering longitudinal stability, thrust line, practicality and overall plane length. This analysis can be characterized into three phases with differing pulsejet positions, attempting tosolve the inherent challenges of pulsejet engine airframe design. The first phase utilized an engine mounted external to the airframe, directly above the fuselage. The second phase used a twin boom layout, enabling the engine to be mounted in line with the airframe. The engine was mounted inside a fuselage cavity in the final phase of development. The initial designs focused on a usable airframe, with pulsejet mounting considered a less important aspect of design. As such, the pulsejet was initially mounted above the fuselage, enabling sufficient air flow for cooling but with additional drag and an uncertain mounting method. Eventually, when these designs were analyzed the drag provided by the airframe was exceptionally high due to the pulsejet mounting location.

CHAPTER 3

METHODOLOGY

3.1 Project Planning

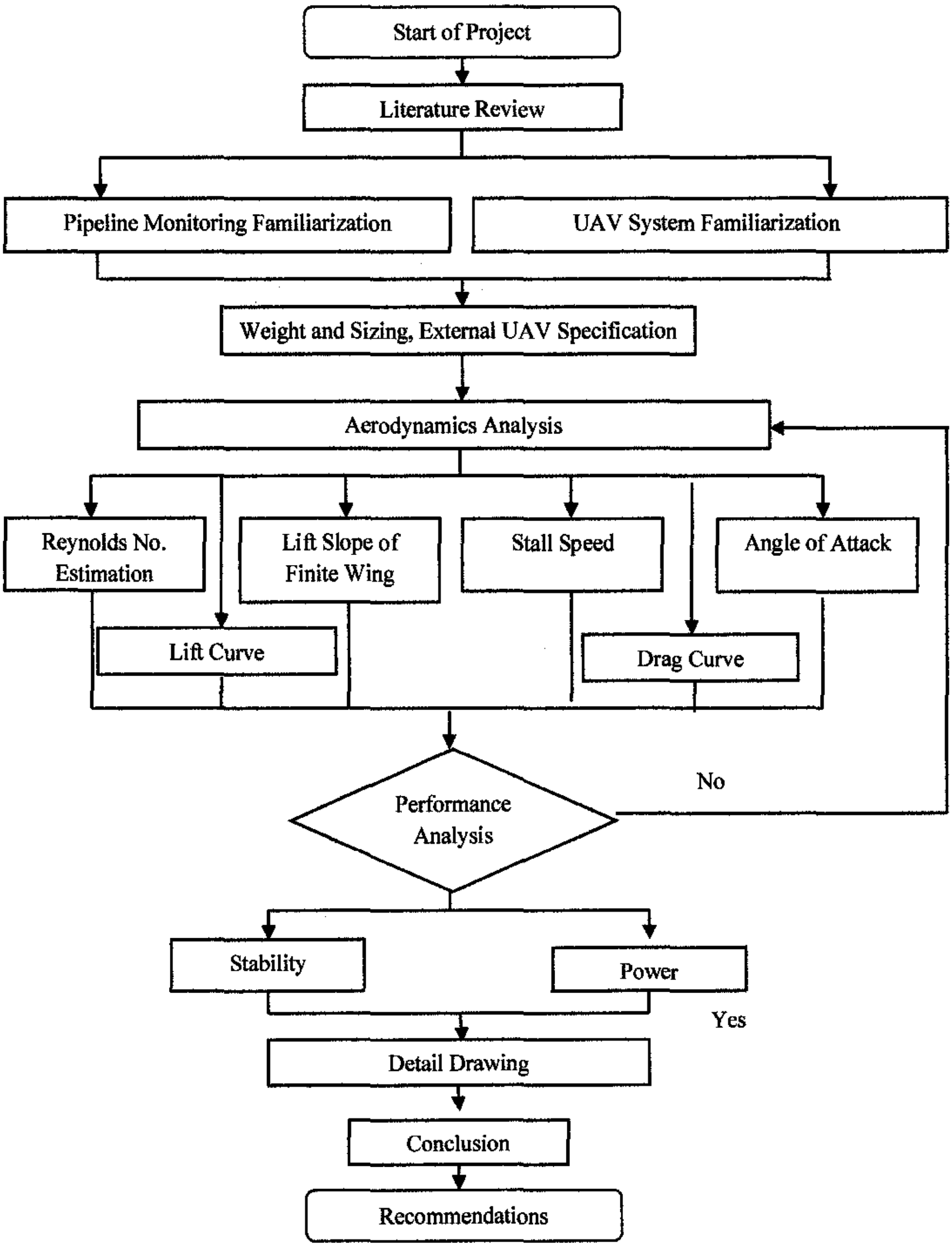

Figure 3.1: Project Flow of Final Year Project

The methodology is started by familiarizing the petroleum pipeline monitoring concept and unmanned aerial vehicle (UAV) for surveillance used presently. The understanding of the maintenance and the method of operations of the pipeline external is required in order to perform this research. The investigating of the UAV characteristics needed is performed in term of its design and operation.

The data collection and monitoring of trend operations is made in the range of required parameters by plotting the graph (e.g Lift and Drag Curve vs Angle of Attack) in order to perform the strategies to analyse the UAV requirements. The implementation of various aerodynamics calculation and theories was performed and the theoretical measurements were obtained on the analysis of the UAV and its external specifications. The calculation of UAV body weight and sizing is determined by manipulating the data of average of existed UAV and compare it according to the petroleum pipeline surroundings to design the detail drawing of the preliminary design.

The finalized detailed drawing and result analysis that will obtain from the implementation of these strategies was determined. The comparison of the result between the various studies, research and analysis was performed in order to determine the most effective monitoring UAV to be used for petroleum pipe monitoring system in the industry.

The method for conducting research is via internet as there are a lot of engineering websites that contains information regarding this topic. Online journals are also a good source of reference. Lastly, there are also a lot of information on studies regarding UAV systems and methods to design the analysis flow of the UAV in books and journals. Duration of this study will take around 8-10 months.

3.2 Specific Project Activities and Milestones

The following diagram shows the Gantt chart for this project. This chart is an on-going changing process; therefore some data may differ from actual process.

3.2.1 Gantt Chart for FYP I

No	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Selection of Project Topic																
2	First meeting with my supervisor																
3	Preliminary Research work																
4	Preliminary report preparation																
5	Submission of Preliminary Report																
6	Seminar 1																
7	Progress Report preparation																
8	Submission of Progress report																
9	Research the suitable UAV specification																
10	Submission of Interim Report Final Draft																
11	Oral presentation preparation																
12	Oral Presentation																

3.2.2 Gantt Chart for FYP II

No	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Project Work Continues																
	1.1 Design and Analysis of UAV																
2	Submission of Progress Report																
3	Project Work Continues																
4	Pre-EDX																
5	Submission of Draft Report																
6	Submission of Dissertation (soft bound)																
7	Submission of Technical Paper																
8	Oral Presentation																
9	Submission of Project Dissertation (Hard Bound)																

Mid-semester break

3.3 External Petroleum Pipeline Inspection Tools

The working inspection schedule of the technician in charge of monitoring was needed to conduct the studies on the subject for this project which includes a camera, a control personnel and access to petroleum pipeline system in plant visited.

3.3.1 Petroleum Pipeline (External) Maintenance

According to Annas (2011), the maintenance engineer in PETRONAS Kerteh, the inspection of the external layer of the petroleum pipeline was done weekly by the technician in charge. They do the routine once a week to ensure that there is no defect at the pipeline external structure. Further report will be issued to the engineer if they had detected any defects on the structure. Therefore, the inspections occupy more technicians and increase the workloads of the teams that involved in the maintenance job. This manual way of carrying inspection of the petroleum pipeline can be extended to a more sophisticated method by using UAV. UAV is used to monitor the pipeline outer structure using a video camera for surveillance and controlled by a controller. In this project, the pipeline monitoring concept which nowadays by using a manual human workforce had been investigated. This pipeline is located onshore and off shore (Annas,2011).

3.4 External UAV Measurement

The criteria such as weight and balance, preliminary sizing need to be considered first before proceeding for the next stage which are analyzing the data and detail drawing of the UAV. The analyzing part is the very significant part in designing because the output for the project is relies on the analysis conducted. The concept of the efficiency of UAV and performance analysis concept need to be mastered before conducting the studies.

3.4.1 UAV Sizing Studies

Comparison studies had been conducted throughout the process. In order to obtain the average range of weight and size for balancing the UAV, the examples of civil UAV available in the internet had been researched. Based on the comparative studies of several types of UAV, the criteria such as weight, height, length, wingspan, cruising speed, endurance nad propulsion had been gathered. In the process of designing the UAV, the operating environment, aerodynamics and airfoils, wings, performance (propulsion), stability and control, structures and sizing are the mandatory aspects need to be considered for the conceptual UAV design.

Type	Weight (kg)	Length (m)	Wingspan (m)	Speed (m/s)	Range (km)	Endurance (min)	Propulsion
Akbaba	14.78	2.379		15			
Pulsejet	8	1.6	1.6	83			
CUAV	72			1.1	1416		One Cylinder
AeroVironment Raven	1.9	0.9	1.37	22.6		110	Battery
BAE System Mantis			22			1440	
Insitu Integrator	59	2.1	4.8	31		1440	
Qinetiq Zephyr	45	5	18.2	25.7		4957	
Mini Saudi Hawk	0.37	0.4	0.5	20	2		COX QZ 48kW

Table 3.1: Example of Civil UAV

By using assumption on the mass of the UAV structure, camera, batteries and flight control system, the total weight of the UAV can be obtained. Besides, extension from the weight calculated, the further measurement on the length from the total weight acted on the UAV can also be calculated.

3.4.2 Material Selection

The essential properties of UAV material for petroleum pipelines monitoring are it has to be lightweight material, low thermal expansion and low radar and microwave absorption. It also has to provide stealth capabilities of the UAV.

The most commonly used fibers are carbon and graphite. In this case, the use of composites versus metal can reduce the overall weight of the aircraft by 15-45%. Therefore, the comparison between several types of materials had been conducted. The material selection for the UAV was derived from an analysis of various materials. The two groups of materials that had been selected to focus on were Aluminum and Composites. Both materials are extremely popular in Aircraft industry due to their suitable qualities.Aluminum is an abundant low cost material, with characteristics that make it perfect for our UAV construction. It is a versatile material with super corrosion resistance, good formability, flexibility, and strength.. Composites are often overlooked when cost is an important consideration. However, with such advanced characteristics, including great fatigue resistance, good damping characteristics, and very light weight they came out on top for best performance. In some cases this performance resulted in an actual cost saving.

3.5 Aerodynamics Analysis

Analysis has been carried out for the estimation of the aerodynamic characteristic for this UAV design project. The aerodynamic principles for UAV are quietly different to the principles that applied on normal aircraft. This is mainly due to the small size of the UAV, which makes the UAV to operate in low Reynolds numbers regime, or in low sub sonic number, so that this UAV can be categorized in the low subsonic aircraft due to the value of Reynolds number as calculated below.

3.5.1 Reynolds Number Estimation

Comparative studies method had been used to differentiate the typical average of Reynolds Numbers for five types of aircraft namely commercial aircraft, light aircraft, pylon racing model aircraft, hang gliders and multi-task remote controlled sailplane. From the data, the range for the designed UAV should fall between the minimum Reynolds Number and the maximum.

Assumption that the velocity of air at sea level is constant had been made. The following equation for Reynolds Number estimation had been used

$$\text{Reynolds Number} = \frac{\rho V c}{\mu}$$

where the density of the fluid (air), $\rho = 1.225$ kg/m^3 (at sea level), V is the velocity of the aircraft, c is the wing chord length,and μ is the viscosity of the fluid (air), = 1.789 x 10^{-5} kg/m/s (at sea level).By using the velocity of the aircraft and divided it by speed of sound, a, the Mach number for the UAV can be obtained. If the value of the Mach number is equal to or lower than 0.75, then it shows that the UAV was a low subsonic aircraft.

3.5.2 Lift and Drag, Stall Speed Calculation

Lift is the force that directly opposes the weight of an airplane and holds the airplane in the air. Lift is generated by every part of the airplane, but most of the lift on a normal airliner is generated by the wings. Lift is a mechanical aerodynamic force produced by the motion of the airplane through the air. The angle of attack is the angle at which relative wind meets an airfoil. It is the angle that is formed by the chord of the airfoil and the direction of the relative wind or between the chord line and the flight path.

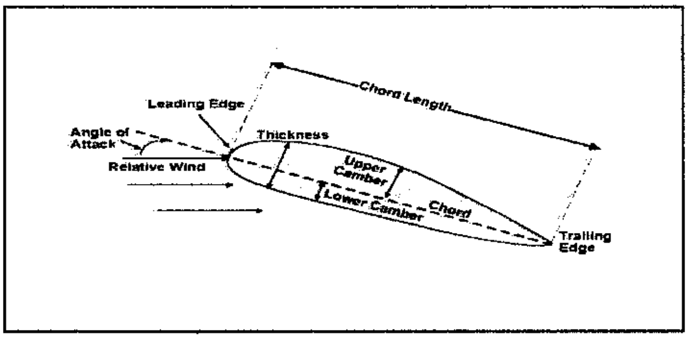

Figure 3.2: Angle of Attack on Wing

For this UAV, some calculation has done in varies angle of attack in order to create its own lift and drag curve. By determining the lift slope for the wing, thus the angle of attack for the UAV can be obtained. It is essential to set the Oswald efficiency factor before estimating the drag coefficient. The angle of attack is related to the amount of lift. Lift will increase as the angle of attack is increased up to the point where the aircraft stalls, the critical angle of attack.

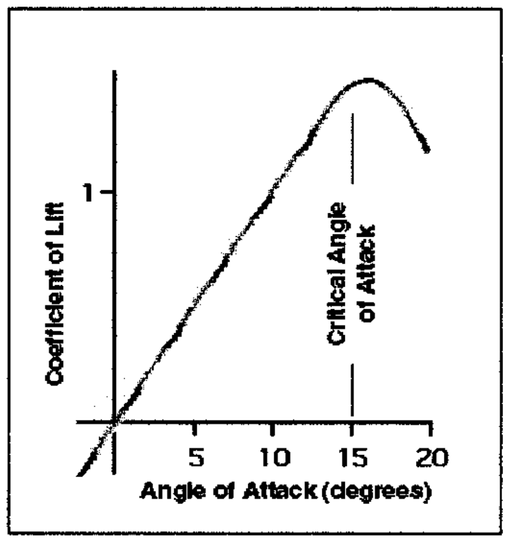

Figure 3.3: Relationship between coefficient of lift and Angle of Attack

Here, c_d is the parasit drag, or zero lift drag. The value can be determined by using equation,

$$C_d = [C_{fe}\frac{S_{wet}}{S_{ref}}.+ C_{d\,LG} + C_{d\,misc}] + 25\% \text{ (for leak, protuberances, cooling effect)}$$

where C_{fe}, is skin friction coefficient and can be determined by using historical data from Raymer . For light aircraft-single engine (homebuilt), the value is given as 0.055, S_{wet} is wetted area for aircraft, S_{ref} is reference area for aircraft, $C_{d\,LG}$ is drag component for landing gear and $C_{d\,misc}$ is coefficient for aileron deflection, exhaust pipe, air intake, and other parts.

The method to obtain the stall speed of the aircraft, the assumption of UAV is flying at the altitude 100m from sea level. Therefore, the density at 30m,

$\rho = 1.217\, kg/m^3$

The lift to drag ratio vs angle of attack graph, the coefficient drag and lift vs angle of attack was plotted respectively.

3.6 Performance Analysis

Steady flight condition had been taken into consideration to calculate the performance of the UAV. Thus, there are no acceleration involved in the operation. Consequently, the drag in this case is equal to the amount of thrust and the lift is equal to the weight of the UAV. By using a constant variable from weight estimation and sizing of the UAV, the take off distance and coefficient of lift for normal flight of UAV can be calculated. As a result, the performance analysis on thrust had been obtained. Based on the value of coefficient of lift and drag, lift to drag ratios and thrust required from the result, the graph of each parameters had been plotted against velocity ranging from 8 to 30 m/s respectively.

For propeller-driven aircraft, engine performance is specified in terms of power. A graph can be developed with drag expressed as power required, P_R. The required power, P_A can be determined using the radius of the propeller and the pitch of the propeller. With the constant values of the power acquired, P_A, thrust acquired, T_A can be calculated with variables velocities. Hence, the performance analysis on power can be obtained. The graph of power vs velocity of the aircraft had been plotted to show the intersection between the power available and power required as one point where the velocity is maximum.

In order to find the best cruising speed, the value of $C_{L\,min\,drag}$ must be calculated. Cruise is the level portion of aircraft travel where flight is most fuel efficient. It occurs between ascent and descent phases and is usually the majority of a journey. It ends as the aircraft approaches the destination where the descent phase of flight commences in preparation for landing. The relationship between coefficients of lift (minimum drag) was used to obtain the best cruising speed.

The climb performance of the designed UAV is an essential part of the overall performance analysis. Rate of climb is the rate of change in altitude. By using power available and power required difference divided by weight of the UAV, thus the rate of climb can be determined.

Endurance, E means the ability of aircraft staying in the air for the longest possible time. The flight endurances for this UAV are depending on the load of power that supply from the engine. The flight range was calculated to determine total distance traversed by the UAV. The equation as follow had been used:

$$\text{Range} = \text{Cruising Speed x Endurance}$$

The power supplies selection method had been done by comparing two types of batteries which are Lithium-Polymer cells and Lithium-Sulphur cells. These two cells are the most reliable power source for miniature UAV.

Types of Batteries	**Li-Po**	**Li-S**
Voltage, volts	3.7	2.5
Specific energy density, kJ/kg	505	1260
Weight, kg	0.442	0.15
Maximum Power, Watts	1221	2600

Table 3.2: Comparison between Batteries

From the table above, it is concluded that the Lithium-Polymer is used for a short duration flight operation. Therefore, to sustain an hour cruising, it is unsuitable to use this type of battery.

3.7 Detailed Drawing of Aircraft

The last stage which will take part in FYP II as been planned is the final drawing configuration. The final drawing configuration will include the size, weight, material selection and performance analysis as well. In this project, the final preliminary design of UAV for the use in monitoring petroleum pipe system is to be obtained.

After familiarized with the software also the flow of the designing, the conducting stage will take over. In this project, there are two main job works to be done in this stage that are constructed a drawing an. The factors such as weight and balance, propulsion, cruising speed, stability and performance need to be analyzed. While the drawing work is constructing the design of UAV by using software either AutoCAD to get clear picture of each body part of the aircraft.

AutoCAD 2008 was used to design the UAV for this project as it is the most reliable engineering drawing software to be used in designing. By implementing past experiences in CAD drawing, the finalized design of the UAV had been obtained. The laboratory is available at Pocket C of Universiti Teknologi Petronas (UTP). The detail drawing design had taken a month to be completed.

The initial steps of the design work were by creating the wing. By following the specifications accordingly for each dimension, thus the wing had drawn. Next was the thrust body of the aircraft followed by the propeller design based on its pitch and radius.

CHAPTER 4

RESULT AND DISCUSSION

4.1 AERODYNAMICS ANALYSIS

4.1.1 Introduction

Analysis has been carried out for the estimation of the aerodynamic characteristic for this UAV design project. The aerodynamic principles for UAV are quietly different to the principles that applied on normal aircraft. This is mainly due to the small size of the UAV, which makes the UAV to operate in low Reynolds numbers regime, or in low sub sonic number, so that this UAV can be categorized in the low subsonic aircraft due to the value of Reynolds number as calculated below.

4.1.2 Reynolds Numbers Estimation

Based on Table 4.1, this UAV were categorized in the multi-task remote controlled sailplanes.

Aircraft Type	Reynolds Number
Commercial aircraft	**10,000,000 upwards**
Light aircraft	**1,000,000 upwards**
Pylon racing model aircraft at max speed	**1,000,000 (roots)** **500,000 (tips)**
Hang gliders, man-powered aircraft, ultra light	**600,000 (roots)** **200,000 (tips)**
Multi-task Remote Controlled sailplanes	**400,000 (roots)** **100,000 (tips)**

Table 4.1: Typical average of Reynolds Numbers

(Source: Model Airplane Aerodynamic book)

The analytical was done to prove the Reynolds number value. Therefore, from this historical data, the suitable Reynolds number should be for the designed UAV is in 100,000 to 400,000 ranges.

The velocity of air over the airfoil for the UAV's wing planform is assumed constant at 12m/s. (At sea lea level)

$$\begin{aligned}\text{Reynolds Number } &= \frac{\rho V c}{\mu} \\ &= \frac{(1.225)(12)(0.27)}{1.789\times10^{-5}} \\ &= 221{,}855 \approx 200{,}000\end{aligned}$$

Where,

Density of the fluid (air), ρ = 1.225 kg/m^3 (at sea level)

Velocity of the aircraft, V = 12m/s

Wing chord length, c = 0.27m

Viscosity of the fluid (air), μ = 1.789 x 10^{-5} kg/m/s (at sea level)

Calculate the Mach number, $M = \dfrac{V}{a}$

Which, speed of sound, $a = \sqrt{\lambda \cdot R \cdot T} = \sqrt{(1.4)(287)(288.16)} = 340.27$

At sea level, absolute temperature, $T = 288.16$ K

Thus,

$$\text{Mach number, } M = \frac{V}{a} = \frac{12}{340.27} = 0.0352$$

Since the value of Mach number ≤ 0.75, the airflow speed over the airfoil is subsonic flow.

$$0.0352 \leq 0.75$$

From this value of Mach number, it is shows that the UAV was a low subsonic aircraft.

4.1.3 Lift and Drag Curve

Lift and drag coefficient play a strong role in the preliminary design and aerodynamic analysis of any aircraft. For this UAV, some calculation has done in varies angle of attack in order to create its own lift and drag curve.

4.1.4 Lift Slope of Finite Wing

First, it is important to calculate the lift slope for the wing. But the value of a is already known, $a = 0.077$/degree.

Determine coefficient of lift by using equation

Coefficient of lift, $C_L = a(\alpha - \alpha_{L=0})$

From Fig. 4.1, the zero-lift angle of attack of the airfoil, which is the same for the finite wing, is

$$\alpha_{L=0} = -4.32^{0}$$

Since the value of Oswald efficiency factor is usually taken as e = 0.80, so, the drag coefficient can be expressed as below;

The drag coefficient is given by equation,

$$C_D = c_d + \frac{C_L^{\,2}}{\pi eAR}$$

$$C_D = c_d + \frac{C_L^{\,2}}{\pi(0.80)(6.37)}$$

$$C_D = c_d + 0.0625C_L^{\,2}$$

Here, c_d is the parasit drag, or zero lift drag. The value can be determined by using equation,

$$C_d = [C_{fe}\frac{S_{wet}}{S_{ref}}. + C_{d\,LG} + C_{d\,misc}] + 25\% \text{ (for leak, protuberances, cooling effect)}$$

Where

- C_{fe} is skin friction coefficient and can be determined by using historical data from Raymer . For light aircraft-single engine (homebuilt), the value is given as 0.055.
- S_{wet} is wetted area for aircraft, 1.532 m^2
- S_{ref} is reference area for aircraft, 0.620 m^2
- $C_{d\,LG}$ is drag component for landing gear
- $C_{d\,misc}$ is coefficient for aileron deflection, exhaust pipe, air intake, and other parts

$C_{d\,LG}$ can be calculated as

$$C_{d\,LG} = C_{fe}\frac{D/q}{S_{ref}}$$

Where D/q is coefficient for landing gear frontal area. (Base on historical data)

$$C_{d\,LG} = 0.0055(\frac{0.15+1.4}{0.620})$$

$$= 0.0138$$

$C_{d\,misc}$ can be calculated as

$$C_{dmisc} = 0.0002bhp,$$

$$= 0.0002(1.75)$$

$$= 0.00035$$

So, the value of C_d can be calculated as

$$C_d = [0.0055\left(\frac{1.532}{0.620}\right) + 0.0138 + 0.00035] + 25\%[0.0055\left(\frac{1.532}{0.620}\right) + 0.0138$$

$$+ \quad 0.00035]$$

$$= 0.0347$$

The total drag equation can be written as

$$C_D = 0.0347 + 0.0625C_L^2$$

The lift coefficient sensed by the airfoil atis then,

$$C_L = a(\alpha - \alpha_{l=0})$$

Hence, the lift to drag ratio,

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

By selecting variable angle of attack, α and apply it to all above equation, the following Table 4.2 are the data that have been calculated. The data are collected from the complete calculation for coefficient of lift, C_L, coefficient of drag, C_D and lift to drag ratio, L/D at variable angle of attack (α).

Angle of Attack α (degree)	Coefficient of Lift, C_L	Coefficient of Drag, C_D	Lift to Drag, C_L/C_D
-8	-0.2833	0.11495889	-2.464359216
-6	-0.1294	0.05144436	-2.515338902
-4	0.0246	0.03530516	0.696782
-3	0.1016	0.04502256	2.256646446
-2	0.1786	0.06659796	2.681763826
-1	0.2556	0.10003136	2.55519869
0	0.3326	0.14532276	2.288698618
1	0.4096	0.20247216	2.022994174
2	0.4866	0.27147956	1.792400135
3	0.5636	0.35234496	1.599568786
4	0.6406	0.44506836	1.439329455
5	0.7176	0.54964976	1.305558652
6	0.7946	0.66608916	1.19293339
7	0.8716	0.79438656	1.097198825
8	0.9486	0.93454196	1.015042706
9	1.0256	1.08655536	0.943900364
10	1.1026	1.25042676	0.881778954
11	1.1796	1.42615616	0.827118399
12	1.2566	1.61374356	0.778686299
13	1.3333	1.81238889	0.735658891
14	1.4106	2.02449236	0.696767263
15	1.476	2.213276	0.666884745
16	1.5646	2.48267316	0.630207804
17	1.6416	2.72955056	0.601417693

Table 4.2: Aerodynamic analysis

From all this data, the lift curve, drag curve and lift-to drag ratio against angle of attack can be plotted.

4.1.5 Stall speed, V_{stall}

From the value of $C_{L_{max}} = 1.479$, the stall speed of the designed UAV can be determine by using equation below. Assume that the UAV fly at altitude 100m from sea level.

Density at 30m, $\rho = 1.217\, kg/m^3$

$$Stall\ speed, V_{stall} = \sqrt{\frac{2W}{\rho_\infty S C_{L_{max}}}}$$
$$= \sqrt{\frac{(2)(3.0)(9.81)}{(1.217)(0.467)(1.479)}}$$
$$= 8.36 m/s$$

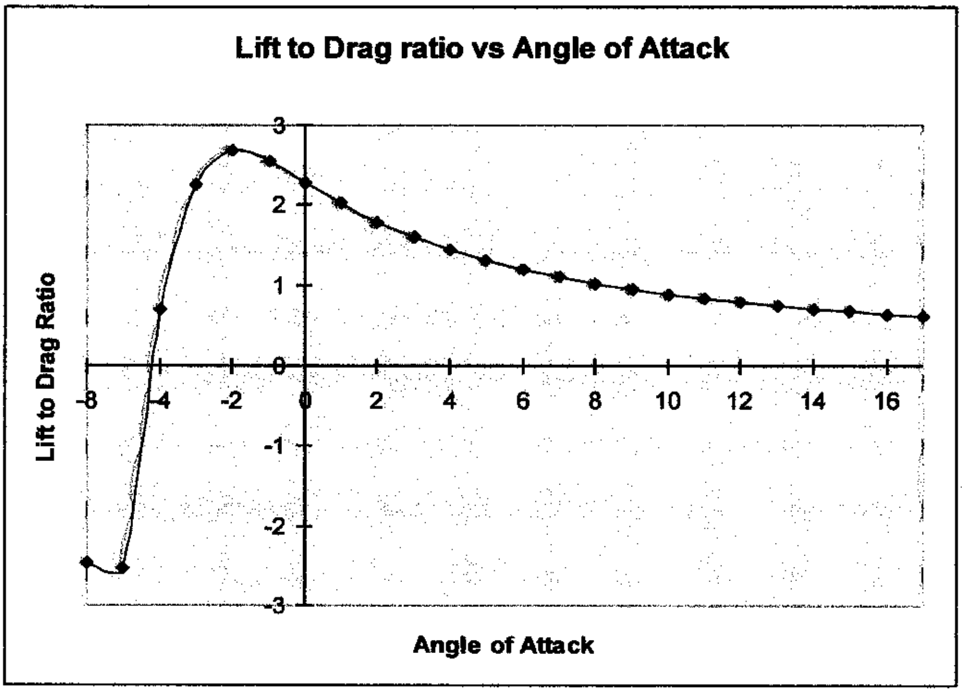

Figure 4.1: Graph Lift to Drag Ratio against Angle of Attack

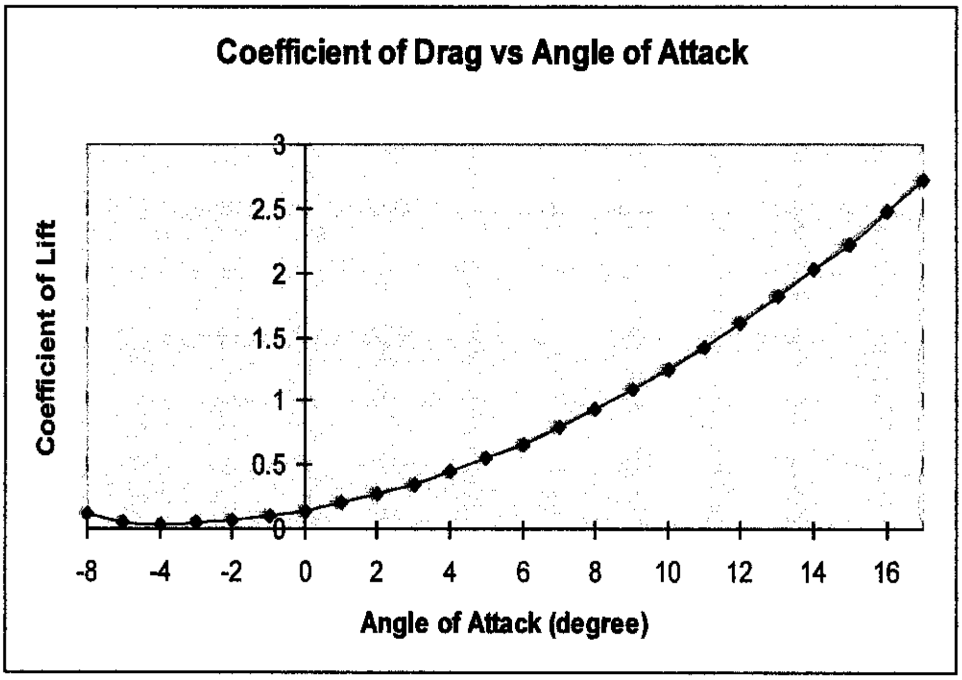

Figure 4.2: Graph Coefficient of Drag against Angle of Attack

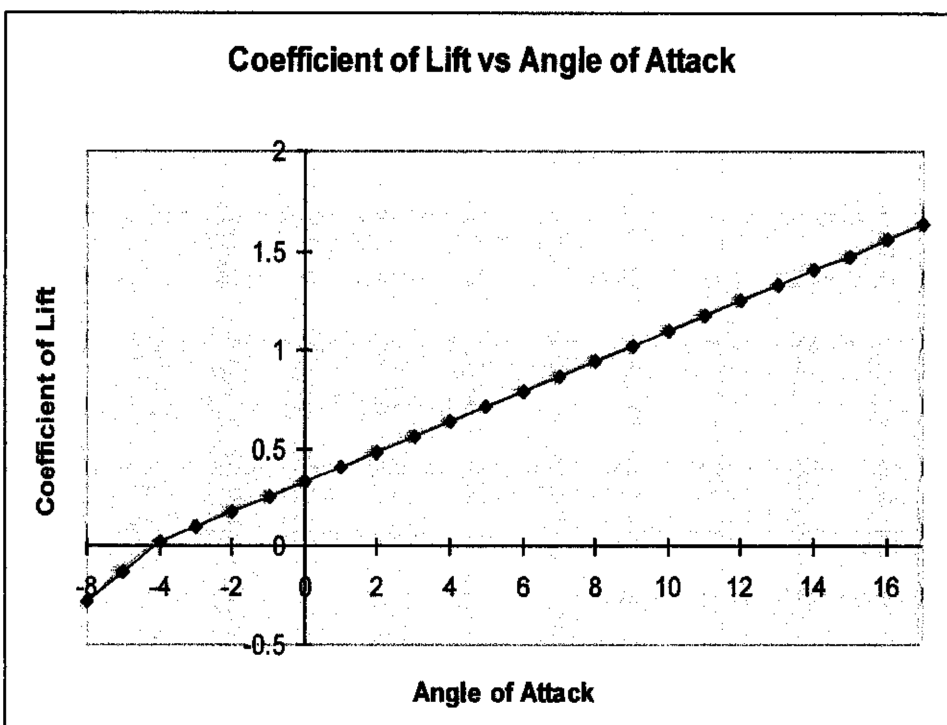

Figure 4.3: Graph Coefficient of Lift against Angle of Attack

4.2 PERFORMANCE ANALYSIS

4.2.1 UAV Performance Analysis (Steady Flight)

Consider the UAV is flying at straight and level flight condition and with no acceleration. For steady flight,

$$Thrust, T = Drag, D$$
$$Lift, L = Weight, W$$

4.2.2 Sample Calculation Based on Altitude, h = 30m

Constant variable that collected from weight estimation and sizing are:

i. Aspect Ratio, $AR = 6.47$
ii. UAV total weight, $W = 29.43$N
iii. Span efficiency factor, $e = 0.8$
iv. Density at altitude 30m, $\rho = 1.217\, kg/m^3$

For ground run analysis, $V_{take\ off}$ can be expressed as 1.2 V_{stall}, and this will give the value of $V_{take\ off}$ as

$$V_{take\ off} = 1.2\ V_{stall}$$
$$= 1.2\ (8.36)$$
$$= 10.32\ m/s$$

From this value, $C_{L\ Take\ off}$ can be calculated.

$$C_{L\ Take\ off} = \frac{2W/S}{\rho V^2_{Takeoff}}$$
$$= 0.966$$

For takeoff distance, the rapid approach can be used to calculate the value,

$$S_g = \frac{W/S}{\rho g C_{LT}(T/W)}$$

$$= \frac{(3x9.81)/(0.467)}{(1.225)(9.81)(0.966)(2.89/3x9.81)}$$

$$= 55.3 \text{ m}$$

Coefficient of lift for normal flight of UAV can be determine by using equation,

$$C_L = \frac{W}{\frac{1}{2}\rho V^2 S}$$

Where, V is the velocity of the designed UAV.

While the drag coefficient equation is given by,

$$C_D = C_{Do} + C_{Di}$$
$$C_D = C_{Do} + \frac{C_L^{\ 2}}{\pi e AR}$$

Where $C_{Do}$is the parasite drag at zero lift. From the previous data, at zero lift $c_l =$ 0, the value of parasite drag, C_{Do}= 0.0347.

Hence,

$$C_D = C_{Do} + \frac{C_L^{\ 2}}{\pi e AR}$$
$$C_D = 0.0347 + \frac{C_L^{\ 2}}{\pi(0.80)(6.47)}$$
$$C_D = 0.0347 + 0.0625 C_L^{\ 2}$$

The lift to drag ratio,

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

The thrust required, T_R for steady flight,

$$T_R = \frac{W}{C_L/C_D}$$

$$T_R = \frac{29.43N}{C_L/C_D}$$

Using variable range of velocities and apply it to all above equation, the following Table 4.3 shows the data that have been calculated.

Velocity, V (m/s)	Coefficient of Lift, C_L	Coefficient of Drag, C_D	Lift to Drag ratio, C_L/C_D	Thrust required, TR (N)
8	1.618	0.1983	8.158	3.60
9	1.278	0.1368	9.341	3.15
10	1.035	0.1017	10.179	2.89
11	0.855	0.0804	10.634	2.76
12	0.719	0.0670	10.729	2.74
13	0.612	0.0581	10.534	2.79
14	0.528	0.0521	10.132	2.90
15	0.460	0.0479	9.600	3.06
16	0.404	0.0449	9.000	3.26
17	0.358	0.0427	8.387	3.50
18	0.319	0.0410	7.779	3.78
19	0.286	0.0398	7.199	4.08
20	0.258	0.0388	6.657	4.42
21	0.234	0.0381	6.155	4.78
22	0.213	0.0375	5.696	5.16
23	0.195	0.0370	5.277	5.57
24	0.179	0.0367	4.896	6.01
25	0.165	0.0364	4.550	6.46
26	0.153	0.0361	4.235	6.94
27	0.142	0.0359	3.950	7.45
28	0.132	0.0357	3.690	7.97
29	0.123	0.0356	3.454	8.51
30	0.115	0.0355	3.238	9.08

Table 4.3:Performance analysis on thrust

With all this values, the C_L, C_D, C_l/C_D and $T_R$can be plotted in graph against variable velocities at altitude 30 m.

4.2.3 Graph $C_D$against Velocity analysis

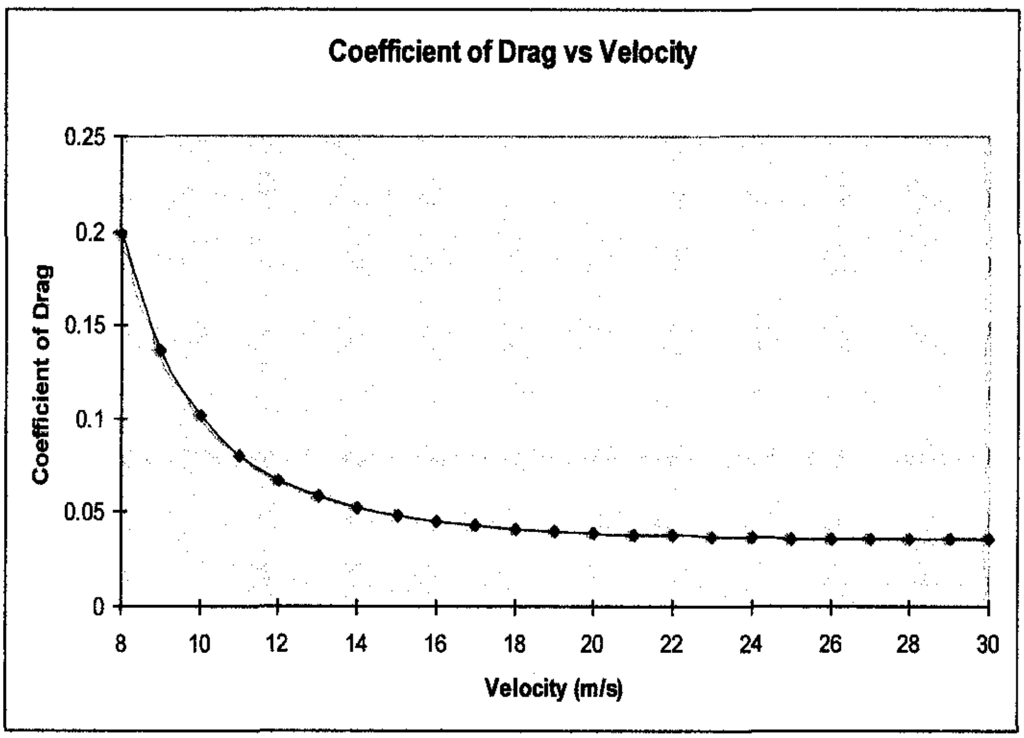

Figure 4.4: Graph Coefficient of Drag vs Velocity

From the graph C_D against velocity, the minimum coefficient of drag can be obtained which is C_{Dmin}= 0.035

4.2.4 Graph C_L/C_D against Velocity analysis

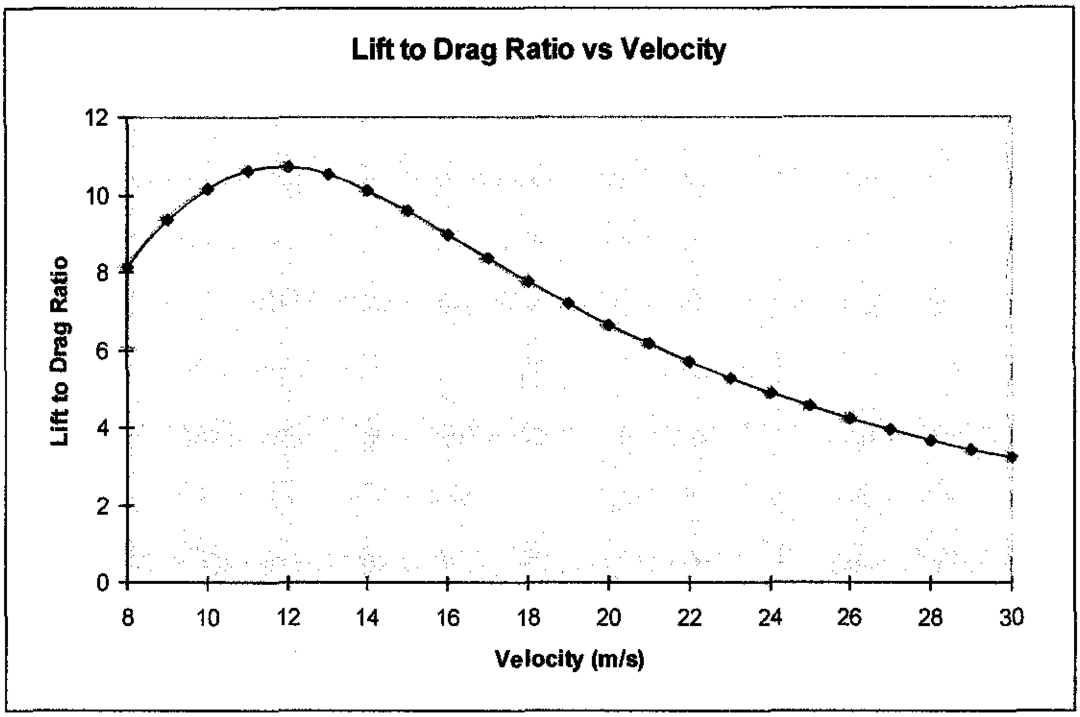

Figure 4.5: Graph Lift to Drag Ratio vs Velocity

Based on the C_L/C_D against velocity graph, as shown above, the $(L/D)_{max}$ can be calculated.

Since

$$Thrust\ required, T_R = \frac{W}{C_L/C_D} = \frac{W}{L/D}$$

$$T_R \ \alpha \ \frac{1}{L/D}$$

L/D_{max} is occurred when T_R is minimum.

Referring to Graph, T_R is minimum when $V = 12$ m/s.

$$L/D_{max} = \frac{W}{(T_R)_{min}} = \frac{29.43}{2.743} = 10.73$$

The value of $L/D_{\max}$ also can be calculated by equation,

$$L/D_{\max} = \frac{1}{2\sqrt{\beta C_{Do}}} = \frac{1}{2\sqrt{(0.0625)(0.0347)}} = 10.73$$

4.2.5 Graph T_R against Velocity analysis

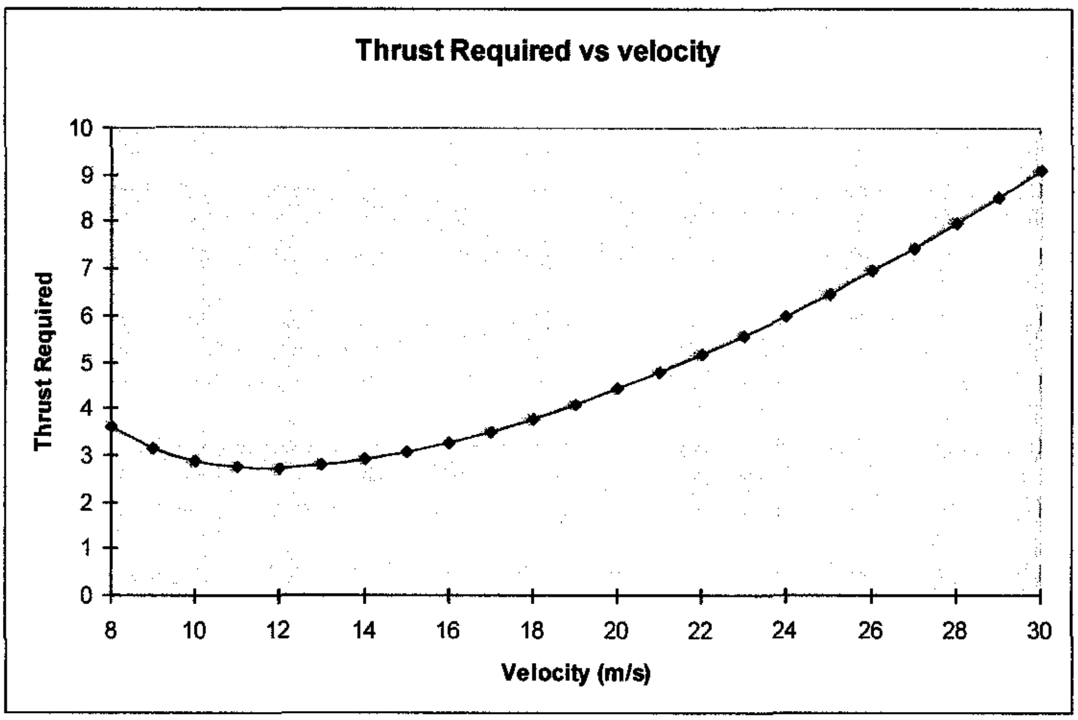

Figure 4.6: Graph Thrust required vs Velocity

From the graph $T_R$against velocity, 12m/s is the velocity at which the designed UAV can maintain the level flight at that altitude, where the thrust required is a minimum, T_{Rmin}= 2.74 N.

4.2.6 Power Required, P_R, Power Available, P_A and Thrust Available, T_A

For propeller-driven aircraft, engine performance is specified in terms of power. A graph can be developed with drag expressed as power required, P_R using the relationship.

$$P_R = T_R \cdot V_\infty$$

While the power acquired, P_A that proposed by the lithium-sulphur batteries can be determined by using equation,

$$P_A = \mathrm{k} \times \mathrm{RPM}^3 \times radius(prop)^4 \times pitch(prop)$$

This power acquired, P_A is the motor output power that have used in this designed UAV. The factor k is depends on the units used to expressed power, pitch, and diameter also on characteristics of the propeller such as the airfoil it used, its overall shape and thickness. For power in Watts, propeller diameter and pitch in inches, k is about 5.3×10^{-15} for an average remote controlled propeller.

From the propeller data,

Propeller radius = 5.5 inch

Propeller pitch = 7 inch

Hence,

$$P_A = \mathrm{k} \times \mathrm{RPM}^3 \times radius(prop)^4 \times pitch(prop)$$
$$P_A = (5.3 \times 10^{-15}) \cdot (18000)^3 \cdot (5.5)^4 \cdot (6)$$
$$P_A = 197.98W$$

The thrust acquired, T_A can be determine by using equation,

$$P_A = T_A V_\infty$$
$$T_A = \frac{P_A}{V_\infty}$$

With the constant values of the power acquired, P_A, thrust acquired, T_A can be calculated with variables velocities.

The lithium-sulphur batteries can sustain long duration flight duration as each cell supplies 2.1 volts of voltage. The batteries can be connected in series and it is a light-weighted cells compared to other innovative cells. The batteries supplied up to 40-55 kWh power to the UAV designed.

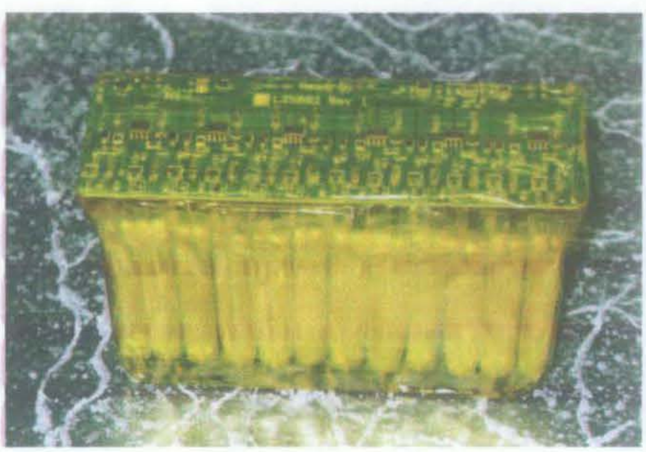

Figure 4.7: Lithium-Sulphur batteries in series connection
Source : http://www.barnardmicrosystems.com/L4E_batteries

By selecting variable range of velocities and apply it to all above equation, the following Table 4.4 are the data that have been calculated for the P_R, $P_A$and T_A.

Velocity, V (m/s)	Thrust Required	Power Required, PR (W)	Power Available, PA (W)	Thrust Available, TA (N)
8	3.60	28.85	197.98	24.74
9	3.15	28.35	197.98	21.99
10	2.89	28.9	197.98	19.79
11	2.76	30.43	197.98	17.99
12	2.74	32.90	197.98	16.498
13	2.79	36.30	197.98	15.22
14	2.90	40.65	197.98	14.14
15	3.06	45.97	197.98	13.19
16	3.26	52.28	197.98	12.37
17	3.50	59.63	197.98	11.64
18	3.78	68.07	197.98	10.99
19	4.08	77.65	197.98	10.42
20	4.42	88.40	197.98	9.89
21	4.78	100.30	197.98	9.42
22	5.16	113.65	197.98	8.99
23	5.57	128.24	197.98	8.60
24	6.01	144.24	197.98	8.24
25	6.46	161.67	197.98	7.91
26	6.94	180.62	197.98	7.61
27	7.45	201.15	197.98	7.33
28	7.97	223.27	197.98	7.07
29	8.51	247.05	197.98	6.82
30	9.08	272.58	197.98	6.59

Table 4.4: Performance analysis on power

With all this values, the P_R and P_A can be plotted in graph against variable velocities at altitude sea level. The graphs are shown as below.

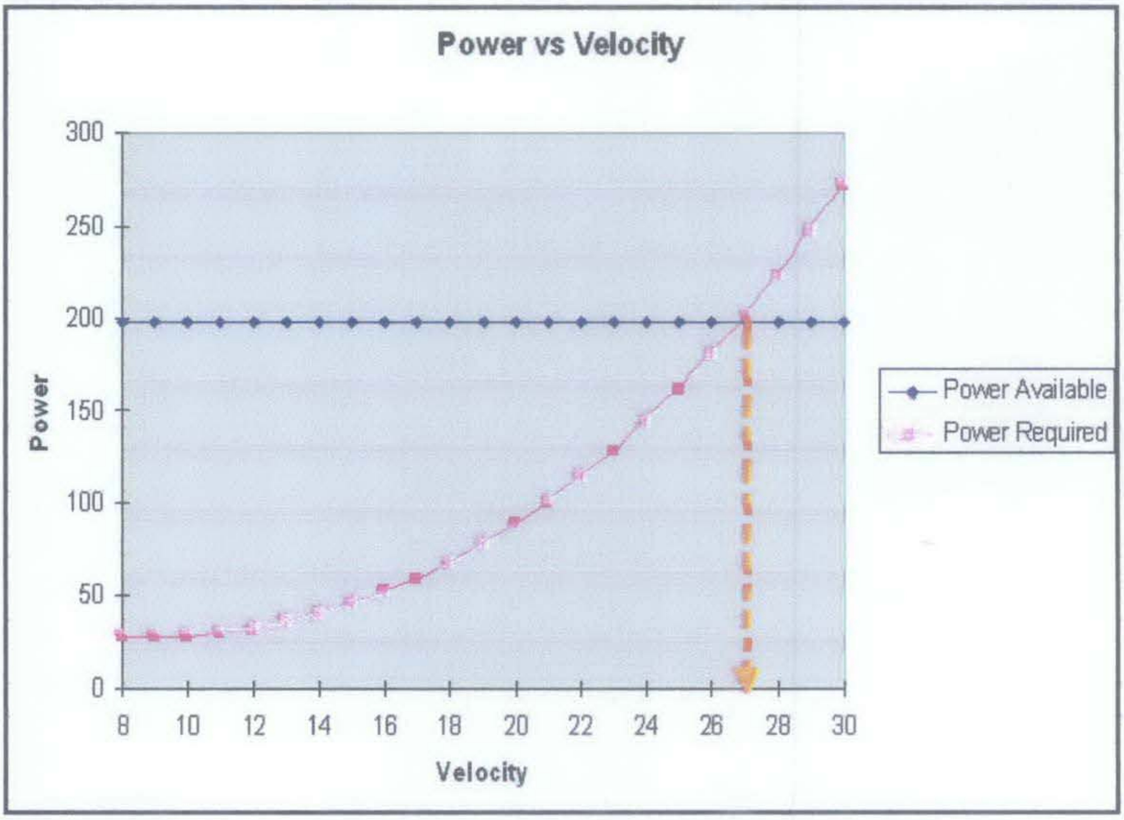

Figure 4.8: Graph Power vs Velocity

4.2.7 Graph P_R and P_A against Velocity Analysis

From the graph P_R and P_A against Velocity, the maximum velocity of design UAV can be estimated from the intersection between P_A = 200W and power required curve gives the V_{max} = 27 m/s as shown in green highlighted in Table 4.4.

4.2.8 Cruising Speed

In order to find the best cruising speed, the value of $C_{L\ min\ drag}$ must be calculated, and the coefficient of lift at minimum drag can be determined by using equation:

$$
\begin{aligned}
C_{L(\min drag)} &= \sqrt{\pi \cdot AR \cdot e \cdot C_{Do}} \\
&= \sqrt{\pi \cdot (6.47)(0.80)(0.0347)} \\
&= 0.751
\end{aligned}
$$

By using this value of $C_{L(\min drag)}$, the best cruising speed can obtain from equation below:

$$
\begin{aligned}
Cruise\ Speed, V &= \sqrt{\frac{2W}{\rho S C_{L(\min drag)}}} \\
&= \sqrt{\frac{2(29.43)}{(1.217)(0.467)(0.751)}} \\
&= 11.74 m/s
\end{aligned}
$$

4.2.9 Rate of climb, *R/C*

The climb performance of the designed UAV is an essential part of the overall performance analysis. As the designed UAV is flying in steady, accelerated climbing flight, the rate of climb can be determined by equation as follows:

$$R/C = \frac{Excess\ Power}{W}$$

$$R/C = \frac{TV_{\infty} - DV_{\infty}}{W}$$

$$R/C = \frac{\bar{P}_A - \bar{P}_R}{W}$$

While the maximum rate of climb, $(R/C)_{max}$:

$$(R/C)_{\max} = \frac{Maximum\ Excess\ Power}{W}$$

$$(R/C)_{\max} = \frac{(P_A - P_R)_{\max}}{W}$$

$$(R/C)_{\max} = \frac{(P_A - P_{R,\min})}{W}$$

From power required versus velocity graph, maximum excess power can be found at P_{Rmin} = 28.35W at the velocity, V = 9m/s.

Hence,

$$R/C_{\max} = \frac{(P_A - P_{R,\min})}{W}$$

$$R/C_{\max} = \frac{197.98W - 28.35W}{29.43N}$$

$$R/C_{\max} = 5.76m/s$$

Velocity, *V* (m/s)	Thrust Required (Newton)	Power Required, *PR* (W)	Power Available, *PA* (W)	Rate of Climb (m/s)
8	3.60	28.856	197.98	5.74
9	3.15	28.35	197.98	5.76
10	2.89	28.9	197.98	5.74
11	2.76	30.43	197.98	5.69
12	2.74	32.90	197.98	5.61
13	2.79	36.30	197.98	5.49
14	2.90	40.65	197.98	5.34
15	3.06	45.97	197.98	5.16
16	3.26	52.28	197.98	4.95
17	3.50	59.63	197.98	4.70
18	3.78	68.07	197.98	4.41
19	4.08	77.65	197.98	4.08
20	4.42	88.40	197.98	3.72
21	4.78	100.38	197.98	3.31
22	5.16	113.65	197.98	2.86
23	5.57	128.24	197.98	2.36
24	6.01	144.24	197.98	1.82
25	6.46	161.67	197.98	1.23
26	6.94	180.62	197.98	0.58
27	7.45	201.15	197.98	-0.10
28	7.97	223.27	197.98	-0.85
29	8.51	247.05	197.98	-1.66
30	9.08	272.58	197.98	-2.53

Table 4.5: Performance analysis (R/C)

4.2.10 Graph *R/C* against Velocity Analysis

From data above, the graph of rate of climb (*R/C*) against velocity is plotted at altitude 100m which shown below. From this graph, the maximum rate of climb, $(R/C)_{max}$ = 5.76m/s occur at velocity, V = 9m/s as shown in green highlighted in Table 4.5.

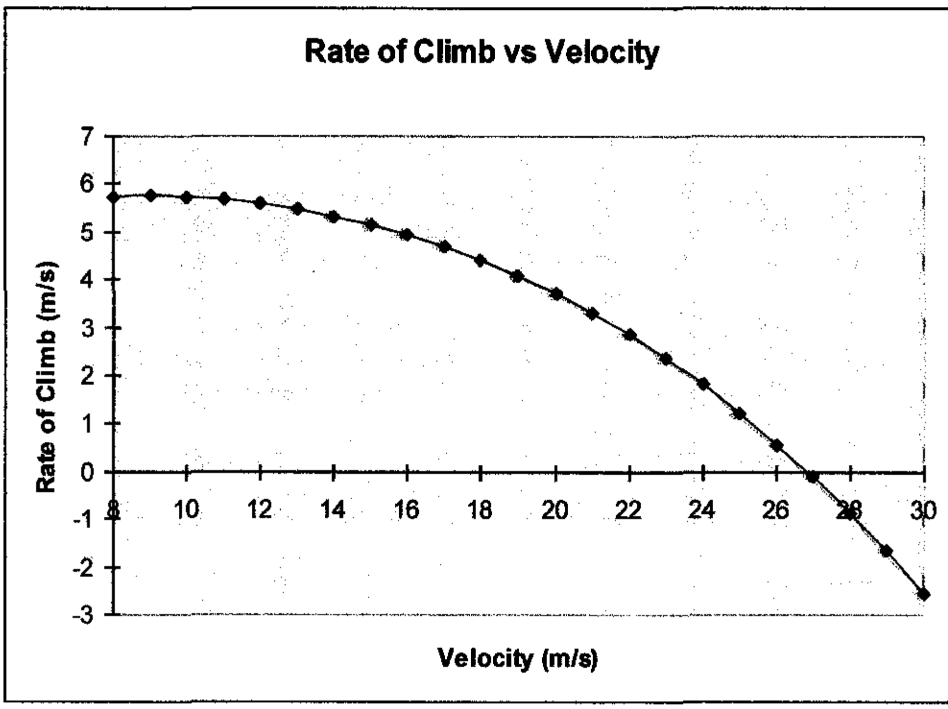

Figure 4.9: Graph Rate of Climb vs Velocity

4.2.11 Flight Endurance and Range

Endurance, *E* means the ability of aircraft staying in the air for the longest possible time. The flight endurances for this UAV are depending on the load of power that supply from the engine.

$$P\ (kWh) = (1/2\ \rho V^2\ S\ C_D)\ V\ t$$

$$45\ kWh = (1/2\ (1.217)(11.74^2)\ (0.62)\ (0.035))\ (11.74)\ (t)$$

$$t = 1.333\ hour$$

$$= 80\ min$$

The flight range was calculated to determine total distance traversed by the UAV. It is importance to ensure that the UAV will cover whole area of the field to make sure all desired area is properly sprayed. From the equation,

$$UAV\ Velocity, V = \frac{Range, R}{Time, t}$$

Then,

$$Range, R = Velocity, V \times Time, t$$

As the UAV fly in maximum speed at 27.0m/s, within an hour, the total range of UAV can fly is

$$MUAV\ Range, R = 27m/s \times 4800s$$
$$MUAV\ Range, R = 129600m$$

Below is the flight performances data that have been calculated at altitude, $h = 30$m.

Flight Performances	Calculated data
Minimum drag coefficient, C_{Dmin}	**0.035**
Minimum power, P_{min}	**28.35W**
Power available, P_A	**197.98 W**
Maximum speed, V_{max}	**27m/s**
Cruising speed, V_{cruise}	**11.74m/s**
Maximum rate of climb, $(R/C)_{max}$	**5.76m/s**
Flight endurance, E	**80 minutes**
Maximum Flight range, R	**129600m**
Take off distance	**55.3 m**

Table 4.6: Flight performances data

4.3 EXTERNAL DESIGN

This section will be discussed about the findings of extended research in selecting the parameters and criteria needed for designing the UAV. There are a lot of factors that affected the design final configuration and its performance. Each criteria listed need to be considered in order to get those objectives since they relate to each other.

4.3.1 Estimated Weight

UAV Parts	Mass (kg)
Video Camera	**0.3**
Batteries	**0.5**
Structures	**2.0**
Flight Control System	**0.2**
	Total Mass = 3

Table 4.7: Mass of UAV

The assumption had been made for the weight of the UAV. From Table 4.7, the total mass (m_T) of the UAV is 3kg. The total weight would be:

$$\mathbf{3kg \times 9.81 = 29.43\ N}$$

Therefore, total weight (WT) of the UAV is equal to 29.43N. Other than that, we assumed that the lift of the wing (LW) and Lift of the horizontal tail (LHT) are reacted upwards. Thus, the weight of total weight of the aircraft which at the center of the aircraft structure (center of gravity) is reacted opposite to the direction of lifts for the UAV.

4.3.2 Length

The total weight acted on the UAV will be equal to total of both wing lift and horizontal tail lift. Another assumption had been made which the wing lift is 75 percent of the total weight and the remaining 25 percent is from the horizontal tail lift. The length from the center of the aircraft wing to the horizontal tail (X_{HT}) is 35.3 cm. From the center of the body structure to the middle of the aircraft wing is represented as X_W, while from the center of the UAV to the horizontal tail is represent as X_{HT}.

$$\mathbf{X_W + X_{HT} = 35.3\ cm}$$

At cruise condition, the acceleration of the aircraft will be zero. At 0m/s2, based on the free body diagram shown, the force equilibrium equation thus can be derived as;

$-W_T (X_W) + L_{HT} (X_W + X_{HT}) = 0\ cm/s^2$

$-29.43 (X_W) + 0.25 (35.3\ cm) = 0\ cm/s^2$

$-29.43 X_W + 8.825\ cm = 0\ cm/s^2$

$\mathbf{X_W = 0.3\ cm}$

Therefore, we obtain the length from center of the structure to the middle of the wing is 0.3 cm.

4.3.3 Lift and Area

Based on the data obtained from the research, the criteria of the UAV had been selected which are, weight, height, length, wingspan, speed, ceiling, range, endurance, and propulsion.

In the process of designing the UAV, the operating environment, aerodynamics and airfoils, wings, performance (propulsion), stability and control, structures and sizing are the mandatory aspects need to be considered for the conceptual UAV design.

For the monitoring purpose, we need the low cruising speed so that the UAV can observe the condition of the pipeline smoothly. The cruising speed that had been calculated is 11.74m/s for monitoring the pipeline. The lift coefficient (C_L) = 0.751. Using equation below, it can be derived to calculate the area of the wing and horizontal tail. Therefore, assumption of the density above sea level is 1.217 kg/m^3; the wing area will be;

$L_W = (\frac{1}{2}\rho V^2)(S_W)(C_L)$

$(0.75)(W_{Total}) = (\frac{1}{2}\rho V^2)(S_W)(C_L)$

$(0.75)(29.43) = (\frac{1}{2}(1.217)(11.74^2))(S_W)(0.751)$

$\mathbf{S_W = 0.35\ m^2}$

The wingspan is 1.0 m. Thus, the length for outer wing, *y* and inner wing, *x* yield;

$0.5(\frac{1}{2}(x + y)) = \frac{1}{2}(SW)$

$0.5(\frac{1}{2}(x + y)) = \frac{1}{2}(0.35)$

$0.5(\frac{1}{2}(x + y)) = 0.175$ m

$\mathbf{x + y = 0.7m}$

Take x = 0.46 m

$\mathbf{y = 0.23m}$

For the horizontal tail, the same equation is used, yields;

$L_{HT} = (\frac{1}{2}\rho V^2)(S_{HT})(C_L)$

$(0.25)(W_{Total}) = (\frac{1}{2}\rho V^2)(S_{HT})(C_L)$

- Low weight / low material density: composite densities range from 0.045 lb/in3 to 0.065 lb/in3 as compared to 0.10 lb/in3 for aluminum
- Ability to tailor the fiber/resin mix to meet stiffness and strength requirements
- Elimination of part interfaces via composite molding
- Low cost, high volume manufacturing methods
- Tapered Sections and Compound Contours Easily Accomplished
- High resistance to corrosion
- Resistance to fatigue
- High Damping Characteristics
- Low coefficient of thermal expansion

The weight of the additional aluminum frame was not of any concern as the team was still well under the initial estimate of the weight provided in the preliminary design.

4.3.5 Video Camera Selection

Figure 4.10: Advanced World's Smallest Camera (HD Edition)
Source : http://www.chinavasion.com/spy-cameras/advanced-worlds-smallest-camera/

The video camera is suitable for petroleum pipe monitoring usage as it can Records audio & video to micro SD card up to 32 GB. With the dimension of 32 (L) x 32 (W) x 28 (D) mm, the weight of the video cameras is light.

It means that it can be plugged in to any micro SD card ports. Despite from the small size, it also saves high definition of 1280 x 720 30FPS video. The primary function of this device is miniature DVR. The material of this video camera is ABS Plastic. It has a CMOS Sensor with 2.0 Mega pixels and auto white balance. The features that also suitable for pipeline monitoring is that it stamped on the date and time of the inspection taken.

The video resolution for the camera is 1280 x 720 and JPEG is used as the image format. The image resolution for this device us 8 Mega pixels and has a built-in microphone for audio which is recommended to be taken in a range of 1-3 meters. The recommended range for video is up to 8 meters. It use a 250mAh built in rechargeable lithium polymer battery (recharge directly from USB port) and takes 2-3 hours for full charge. The battery life is approximately an hour for an hour operation; it is estimated to use about 1GB of memory.

4.3.6 Final Drawing of the UAV

The final drawing was done using AutoCAD 2008 software. The dimensions used in these drawings are in the scale of 1:2 in cm for actual design.

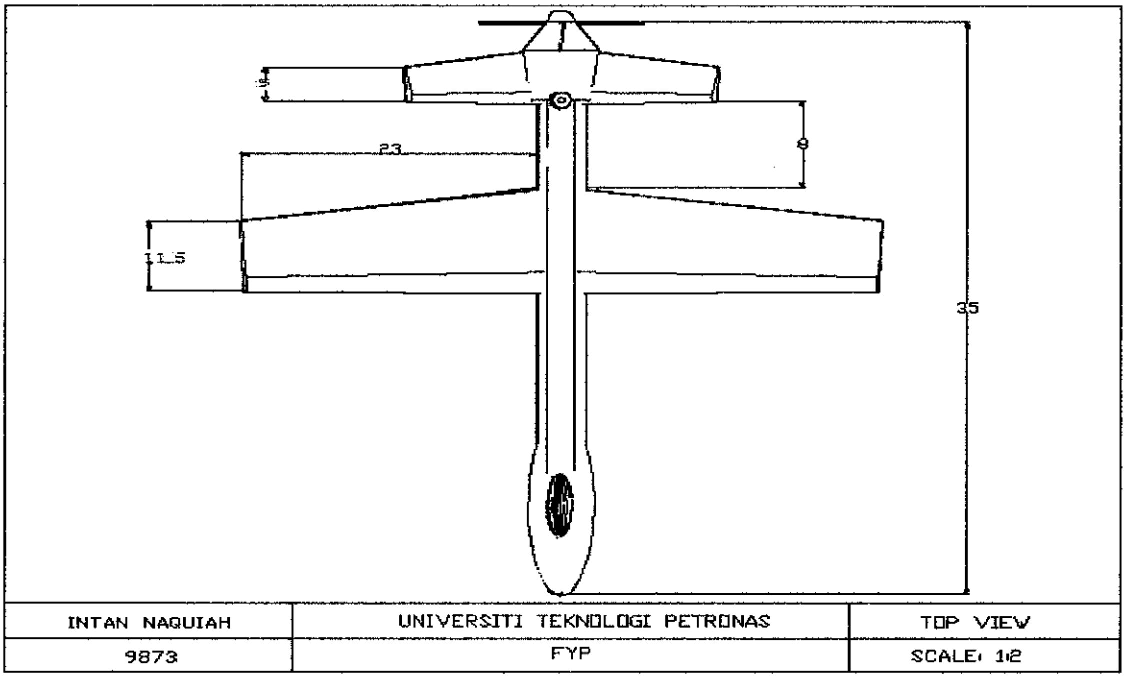

Figure 4.11: Top View of Designed UAV

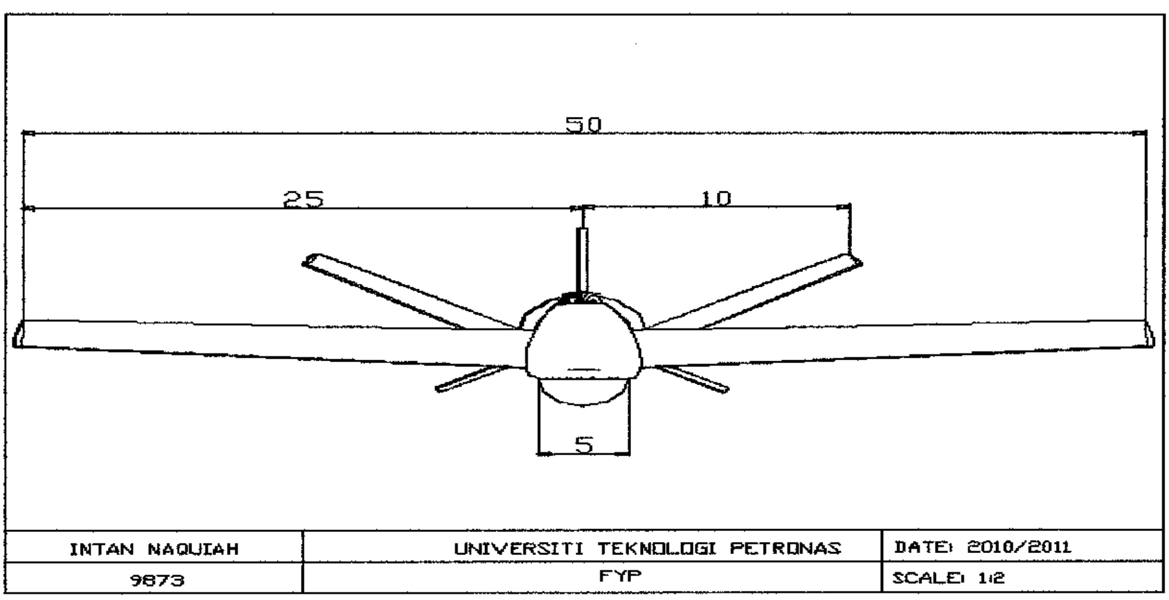

Figure 4.12: Front View of designed UAV

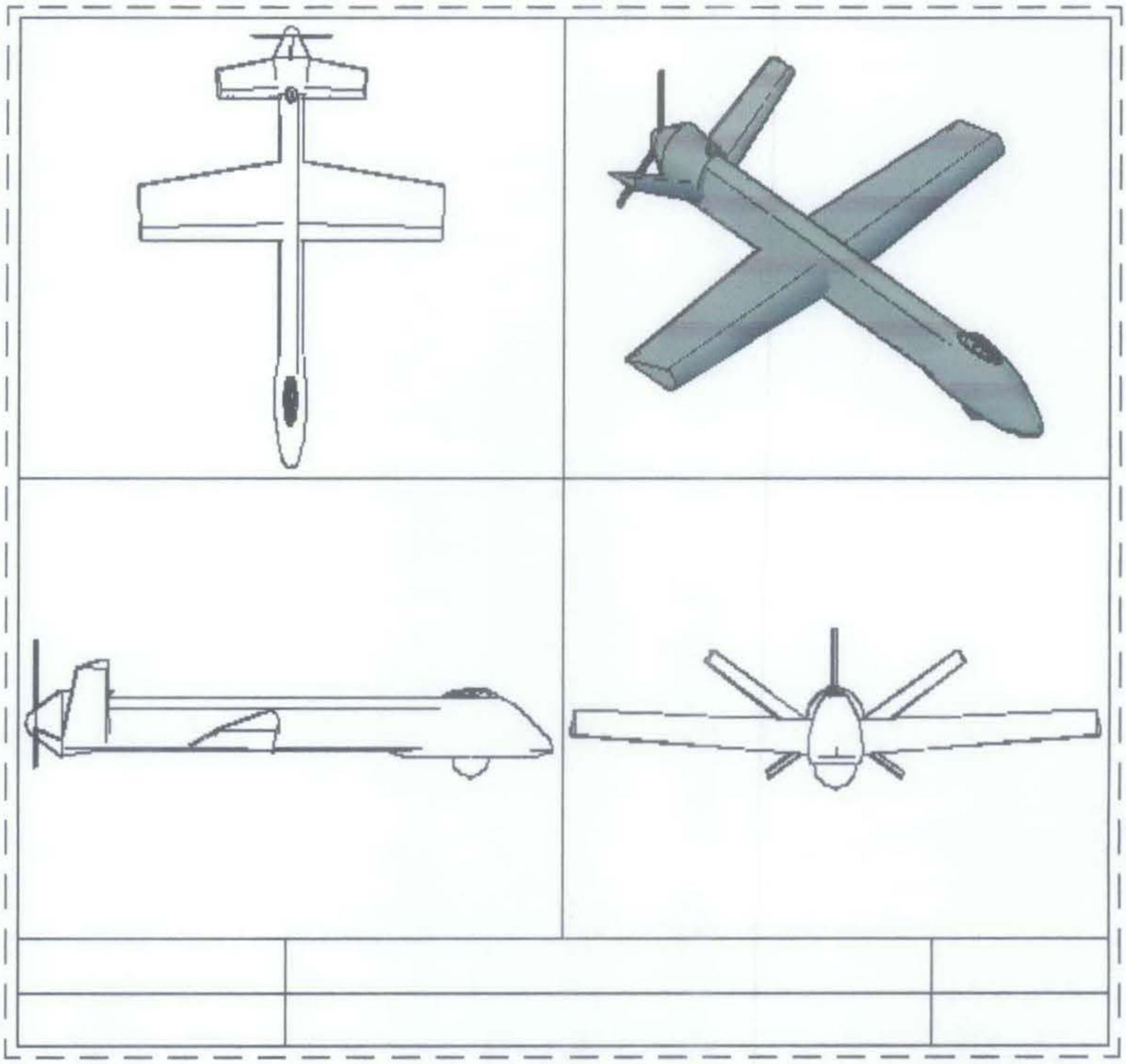

Figure 4.13: Orthographic Drawing of designed UAV

CHAPTER 5

CONCLUSION

5.1 Conclusion

From the research that has been made until now, the existing UAV design can be improved according to the demand for monitoring petroleum pipe system. Not only mechanical aspects such as that need to be consider, this studies also covers the market studies of UAV for an update reference. Other than that, the first stage design (preliminary design) of UTP's unmanned aerial vehicle for petroleum pipe monitoring also is a good reference for this project in helping to guide other student to continue the prototype production on the next stage.

The data collection and monitoring of trend operations is made in the range of required parameters by plotting the graph (e.g Lift and Drag Curve vs Angle of Attack) in order to perform the strategies to analyse the UAV requirements. The implementation of various aerodynamics calculation and theories was performed and the theoretical measurements were obtained on the analysis of the UAV and its external specifications. The calculation of UAV body weight and sizing is determined by manipulating the data of average of existed UAV and compare it according to the petroleum pipeline surroundings to design the detail drawing of the preliminary design.

The objective of this project is to study and understand the design of UAV for petroleum pipe monitoring. To investigate the best specifications of UAV for monitoring the offshore and onshore pipe system. Other than that, it is aimed to design preliminary configuration of UAV and analyze the performance of the UAV. The objectives had been achieved upon the completion of the project.

The finalized detailed drawing and result analysis that will obtain from the implementation of these strategies was determined. The comparison of the result between the various studies, research and analysis was performed in order to determine the most effective monitoring UAV to be used for petroleum pipe monitoring system in the industry.

5.2 Recommendations

By taking this project as a reference, a second part of fabrication can be continued to contribute to the oil and gas industry. UTP as a university fully-subsidized by PETRONAS should take further action on encouraging students and develop their enthusiast to contribute to the industry involved by the university sponsor. Therefore, these studies should be continued by the second stage by other students in near future.

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