DESIGN, DETAIL ANALYSIS AND PERFORMANCE TESTING OF UAV PROPULSION SYSTEM

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JUDUL: DESIGN, DETAIL ANALYSIS AND PERFORMANCE TESTING OF UAV PROPULSION SYSTEM

SESI PENGAJIAN: 2011/2012

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DESIGN, DETAIL ANALYSIS AND PERFORMANCE TESTING OF UNMANNED AERIAL VEHICLE (UAV) PROPULSION SYSTEM

CHE MUHAMMAD RIDHWAN BIN CHE HASHIM

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

Faculty of Mechanical Engineering
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JUNE 2012

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "*Design, Detail Analysis and Performance Testing of Unmanned Aerial Vehicle (UAV) Propulsion System*." is written by *Che Muhammad Ridhwan bin Che Hashim*. I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

MOHD FADZIL BIN ABDUL RAHIM ________________

Examiner Signature

SUPERVISOR'S DECLARATION

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

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STUDENT'S DECLARATION

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

Signature : ________________________________

Name : CHE MUHAMMAD RIDHWAN BIN CHE HASHIM

Id Number : MH08049

Date : 25th JUNE 2012

DEDICATION

I specially dedicate to my beloved parents
(Che Hashim bin Awang & Fatimatul Kifliah binti Abdullah), my siblings,
My supervisor and those who have guided
And motivated me for this project

ACKNOWLEDGEMENT

In the name of Allah S.W.T the most gracious and merciful, first and foremost, after a year of struggle and hard work, with His will, this thesis is completed. Thanks to Allah for giving me the strength to complete this project and the strength to keep on living. I would like to convey heartiest appreciation to my supervisor, Mr. Ahmad Basirul Subha bin Alias for his consistency, advising and giving ideas throughout this thesis. I appreciate his consistent support from the first day I start doing the thesis.

To my parent, Che Hashim bin Awang and Fatimatul Kifliah binti Abdullah, thank you for all the support and sacrifice that both of you gave me. Your sacrifice is too great to be measured and it will be never forgotten. Also to my young brothers Che Muhammad Firdaus bin Che Hashim, my young sisters Fatimatuz Zahraa binti Che Hashim, Fatimatul Qurratuaini binti Che Hashim, Fatimatul Hazwani binti Che Hashim and to my youngest sister Fatimah Al-Syahirah binti Che Hashim.

Last but not least, to all people that did not involve directly nor directly in succeeded the thesis, especially to all my beloved friend, that is cannot find appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to attain my goals. Hopefully, they will continue to support me and thanks for making this possible to happen.

ABSTRACT

This project report is being conduct because the use of an Unmanned Aerial Vehicle (UAV) is getting popular among people either to have fun or study but the choices of powerplant are not fully deployed (in term of operational and performance sizing) and thus limiting the selection. The objective of this project is to propose a design, detail analysis and performance testing of an Unmanned Aerial Vehicle (UAV) propulsion system. In this study, the test bed model was designed to test the nitro engine Radio Control (RC) which is model of 46-LA OS Engine Series of aircraft performance which are four performance parameters that was studied such as thrust, available power and shaft brake power, propulsive efficiency and brake specific fuel consumption thus the performance parameters value can be calculated by measure the unknown value of parameters regarding to the equation involves within the range 2000 to 16000 RPM of engine speed by setting the test bed design with suitable apparatus. From this experiment, the result shows that the fabricated test bed can be use to study the engine performance and performance parameters are directly proportional to the engine speed which is mean the faster the speed of engine effected the increasing of performance parameters. As a conclusion, even without testing the engine to the real body of aircraft, all the engine performance parameter can be calculated from this experiment, and it will reduce the time and cost.

ABSTRAK

Laporan projek ini telah dijalankan kerana penggunaan Kenderaan Udara Kawalan Jauh (KUKJ) semakin popular di kalangan rakyat sama ada untuk berseronok atau kajian tetapi pilihan janakuasa tidak dilaksanakan sepenuhnya (dari segi operasi dan prestasi saiz) dan oleh itu membataskan pemilihan. Objektif projek ini adalah untuk mencadangkan reka bentuk, analisis terperinci dan ujian prestasi Kenderaan Udara Kawalan Jauh (KUKJ) sistem dorongan. Dalam kajian ini, model ujian katil diadakan bertujuan untuk menguji enjin nitro Kawalan Radio (KR) iaitu model 46-LA Engine Siri OS prestasi pesawat yang mana empat parameter prestasi yang telah dikaji seperti Teras, kuasa yang ada dan kuasa brek aci, kecekapan pendorongan dan penggunaan bahan api brek yang tertentu maka nilai prestasi parameter boleh dikira dengan ukuran nilai yang tidak diketahui parameter mengenai persamaan terlibat dalam lingkungan 2000 hingga 16000 RPM kelajuan enjin dengan menetapkan reka bentuk ujian katil dengan radas yang sesuai. Dari eksperimen ini, hasilnya menunjukkan bahawa katil ujian yang direka boleh digunakan untuk mengkaji kebolehan engin dan parameter prestasi adalah berkadar terus dengan kelajuan enjin yang mana bermakna semakin laju kelajuan enjin yang dilaksanakan semakin meningkat parameter prestasi. Kesimpulannya, walaupun tanpa menguji enjin kepada badan pesawat sebenar, semua parameter prestasi enjin boleh dikira dari eksperimen ini, dan ia akan mengurangkan masa dan kos.

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LIST OF ABBREVIATION

UAV	Unmanned Aerial Vehicle
RC	Radio Controlled
RPM	Revolution Per Minute
ASTM	American Society for Testing and Materials
BSFC	Brake Specific Fuel Consumption

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

The use of Unmanned Aerial Vehicle (UAV) for civil purposes is getting wider from day to day. The main advantages of UAV include the elimination of the need of air crews onboard, and its versatility in performing various operations such as to help researcher to reach inaccessible places that may contain research value, and use for reconnaissance purpose in military operation. However for a specific UAV mission, the powerplant choices are not fully deployed and thus limiting the selection. In this study, testing of a type and size of nitro engine that are normally used for radio control (RC) aircraft will be conducted as a preparation for it to power an UAV. Model aircraft are often dismissed as `toys' and their potential for teaching many aspects of engineering is often ignored. This is rather unfortunate because the technology in modern radio controlled model aircraft is leading edge and has considerable potential for productive and interesting projects in a number of areas (Raine et. al., 2002).

The mission used for the test is traffic monitoring and the test bed will be developed to conduct the testing. Test bed will be design to able to incorporated with fittings for different sizes of engine, propellers, and equipped with throttle control. Engines performances will be measured respective to the engine's type and propeller sizes.

The importance of this study is to obtain the engine performance parameters such as force, available power, shaft brake power, propulsive efficiency and brake specific fuel consumption from the testing and to suggest suitable powerplant.

The method that has been chosen for this project is by doing experiment to predict the engine performance parameters. This is because by using this method the measurement of engine performance parameters will be more accurate.

1.2 PROBLEM STATEMENT

For a specific UAV mission, the powerplant choices are not fully deployed (in term of operational and performance sizing) and thus limiting the selection. In this study, testing of a type and size of nitro engines that are normally used for RC airplanes will be conducted as a preparation for it to power UAV.

1.3 PROJECT OBJECTIVES

The objectives of this project are listed as follows:

1. To design a comprehensive test bed for detail testing.
2. To analyze the designed test bed for data collection reliability and execute calibration programmed to the test bed.
3. To perform detail testing for nitro engine at various RPM setting and evaluate corresponding performance parameter associated to the setting.

1.4 PROJECT SCOPE

Basically, this analysis based on:

1. Design test bed according to appropriate apparatus to find the unknown of parameters and detail analysis of UAV propulsion system by using mathematical equation.
2. Performance testing of UAV propulsion system can be executed by calibration for Force (*N*), Available Power ($\dot{W}$A), Shaft Brake Power ($\dot{W}$B), Propulsive Efficiency (%) and Specific Fuel Consumption (μg/(W.s)).
3. The instruments such as tachometer to measure the engine speed were used to evaluate corresponding performance parameters at various RPM setting.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, the discussion is more on about UAV propulsion systems. The detail on type of engines, thrust, combustion, and propeller design will be used. From that we can determined the engine performance parameters from output for each engine type such as thrust, available power, shaft brake power, propulsive efficiency, and brake specific fuel consumption. The history of unmanned aviation can be traced back at least as far as World War I (Newcome, 2004). Recent technological advances including the miniaturization of components and other developments in the fields of electronics, navigation and telemetry, are creating new possibilities for UAVs. As sensors and other payloads become smaller and lighter, tasks which once required a manned aircraft can now be performed with a small unmanned aircraft (Office of Secretary of Defense, 2002). There many usage of UAV which is as state by (Herwitz et. all, 2004; Herwitz et. all, 2005), potential civil and commercial applications include, communication relay linkages, surveillance, traffic monitoring, search-and-rescue, emergency first responses, forest fire fighting, transport of goods, and remote sensing for precision agriculture.

2.2 SMALL / UAV PROPULSION SYSTEMS

There are different views about the precise definition of UAVs (Newcome, 2004). For the purpose of this study, the definition provided by ASTM International was adopted. UAVs are here defined as an airplane, airship, powered lift, or rotorcraft that operates with the pilot in command off-board, for purposes other than sport or recreation (ASTM, 2005). The UAVs are designed to be recovered and reused (ASTM, 2005).

Radio controlled flight, usually referred to as RC, was largely developed by people with interests in both flying and amateur radio, like two early pioneers named Clinton DeSoto and Ross Hull, who flew gliders in the first public exhibition of RC flight (Raine et. all, 2002). He also mention about 1933 the first gasoline powered engines were developed for model airplanes. Although this made the model more realistic it also created the problem of preventing model with its expensive engine simply flying off over the horizon. It was Clinton DeSoto who first envisaged radio as the solution to this problem. Two other names must be mentioned in conjunction with the origins of RC whose is the twin brothers Bill and Walter Good. Walter had an enormous passion for model airplanes while Bill understood radio transmission, and together in 1937 they built the first RC model plane. That first plane was given the name “Guff,” had an 8-foot wingspan, and weighed 8.5 lbs (Raine et. all, 2002).

In the area of propulsion, the main challenges facing UAV designers are related to the type of engine to employ. The main area of concern for small piston engines (under 50 hp) is reliability and maturity. The trend today is moving towards engines which have obtained certification and are of a high level of maturity. Improvements in UAV propulsion systems are very much dependent on improvements in engines developed for manned aircraft in general aviation, and turbofan / turboprop engines for larger aircraft. The improvements in piston engines are improved power/thrust to weight ratio, lower SFC and noise reduction.

There are several types of engine are used to drive propellers. These engines can be categorized into two major groupings which are internal combustion engines and gas turbine engines (Ward, 1966). Internal combustion engines also known as piston aerodynamic engines. The types of internal combustion piston engines are rotary engines, reciprocating engines, and supercharged reciprocating engines (Ward, 1966). But for this study, the focus only on reciprocating engines.

The engine types commonly used to propel UAVs are four-cycle and two-cycle reciprocating internal combustion engines, rotary engines, and increasingly, electric motors. In some cases, gas turbines are used in UAVs (Fahlstrom & Gleason, 1998).

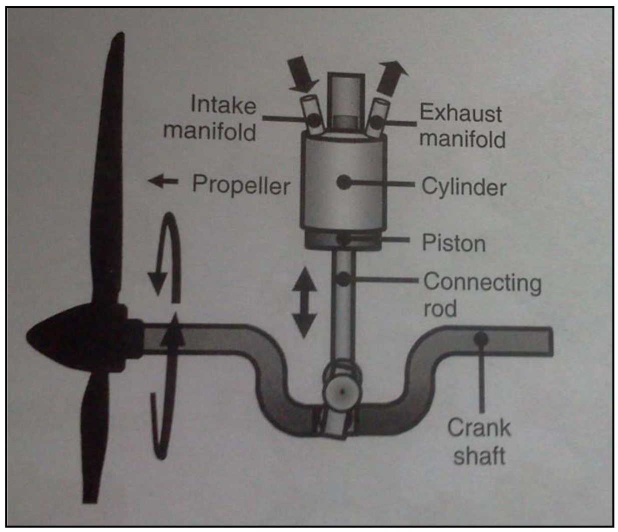


Figure 2.1: Reciprocating engine

Source: Ward, 1966

There are two main propulsion systems used by RC models today which is the internal combustion system (nitro engines) and the electric motors. Combustion engines energy source has so far a higher energy/weight ratio than the batteries used to power the electrics. However, the combustion engines are usually noisier and more prone to oil spillage than the electric motors. There are two types of glow engines which is four-stroke and two-stroke. Two-stroke engines are the most used, mainly because they are simple made, light, easy to operate, easy to maintain, and are usually inexpensive. Two-stroke engines operate at a high RPM and therefore can be quite noisy without a good silencer. As state by (Bird, 2005), when talk about the size of a model airplane, it will usually refer to the size of engine needed to power it (measured in cubic inches). Typically models will be described as a size 20 (which needs a 0.20 to 0.36 engine), 40 (0.40 to 0.53) or 60 (0.60 to 0.75). These sizes refer to the capacity in cubic inches, such as, 0.36 cu in, of the most popular 2-stroke glow engines in use and will be adjusted if you change to a different type of engine.

The nitro engine was used in this project was the Max-46LA OS engine. As state by (Hobbico, 2000), the engine have been developed to meet the requirements of beginners and sport flyers which is modern design and having a separate needle-valve unit mounted at rear, where manual adjustment is safely remote from the rotating propeller, they offer the advantages of reliability and easy handling, at lower cost.

Figure 2.2: Nitro engine

Source: Hobbico, 2000

Nevertheless, the four-stroke engines also enjoy some popularity, mainly because they produce a lower, more scale-like sound and consume less fuel. They have lower power/ weight ratio and lower RPM, but provide more torque (use larger propellers) than theirs two-stroke counter-parts. However, since the four-stroke engines require high precision engineering and more parts to manufacture, they are usually more expensive. They also need more maintenance and adjustment than the two-stroke, yet they are not too difficult to operate and maintain.

Figure 2.3: Cutaway of a typical 2 stroke glow engine

Source: Tressler, 2008

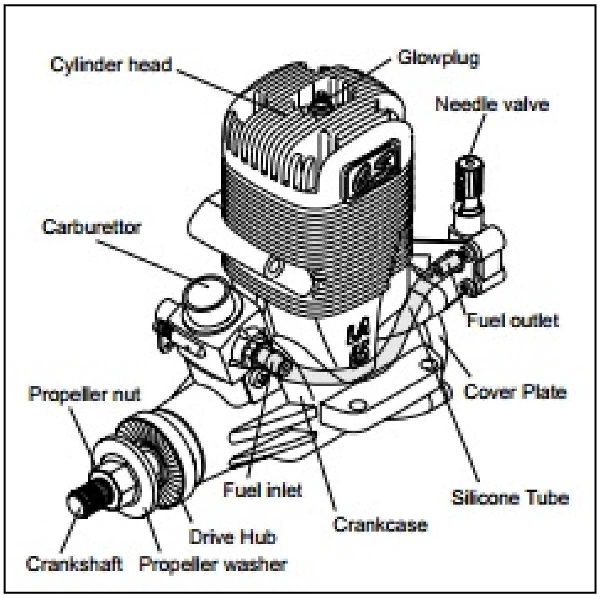


Figure 2.4: Glow engine description

Source: Hobbico, 2000

The glow motor's Carburetor consists basically of:

1. Rotating barrel- to controls the amount of fuel/air mixture going to the combustion chamber.
2. Throttle arm connected to the barrel- which enables the engine's speed to be controlled by a servo.
3. Propeller nut- to tight the propeller to the drive hub.
4. Silicon tube- to join fuel from fuel outlet to the fuel inlet to flow the fuel to the carburetor.
5. Needle Valve- to adjust the amount of fuel entering the carburetor during medium and high-speed operation.
6. Crankcase- which is the main body of the engine and houses the internal parts.
7. Head- mounted on the top of crankcase. It has fins to provide engine cooling.
8. Muffler- to damps the exhaust noise as it exits the combustion chamber.

9. Carburetor- to control the amount of fuel and air that enters the engine.
10. The Crankshaft- transforms the movements of the piston into rotational motion.

2.3 EFFECT OF PERFORMANCE PARAMETERS ON TEST BED DESIGN

The parameters of this study are to measure the engine performance such as available power, shaft brake power, brake specific fuel consumption, propulsive efficiency, and thrust. There is only one type of engine that will be used in this study which is 2-stroke engine. The throttle control of the engine will be used to simulate the engine operating range from idle speed condition until achievable the maximum speed.

2.3.1 Performance Parameters Identification

There are four performance parameters that will be study as follows:

1. Thrust.
2. Available and Shaft Brake Power.
3. Propulsive Efficiency.
4. Brake Specific Fuel Consumption.

Table 2.1 shows the summarized of the equations that are used in this study and the unknown parameters to be finding from the test bed.

Table 2.1: The summary of performance parameters

No.	Performance Parameters	Equation	Parameter to be measured
1	Thrust	$F = kx$	x
2	Available Power	$\dot{W}_A = F_N V_o = \dot{m}V_o (V_e\text{-}V_o)$	V_e , V_o
	Shaft Brake Power	$\dot{W}_B = \dot{m} ((V_e^2/2) - (V_o^2/2))$	V_e , V_o
3	Propulsive Efficiency	$\eta_p = F_{N\,prop} V_o / \dot{W}_B = \dot{W}_A/\dot{W}_B$	V_o
4	Brake Specific Fuel Consumption	$BSFC = \dot{m}_{fuel} / \dot{W}_B$	$\dot{m}_{fuel}$

Where, x is displacement of spring; V_e , V_o is exit velocity and entry velocity; and $\dot{m}_{fuel}$ is mass flow rate of fuel.

2.3.2 Thrust of the engine

The forces acting on the airfoil-shaped cross section of a propeller blade are complicated to determine analytically. At first glance, a seemingly simple method of calculating the thrust produced by a propeller blade would be to sum the forces for a small differential radial element (dr) along the length of the blade. It is possible to determine the differential lift (dL) and drag (dD) from the lift and drag coefficients (C_L and C_D) derived from the local airfoil shape and then integrate this equation (Ward, 1966).

However, an ideal approximation of thrust can be derived from the momentum equation by considering a control volume enclosing the airflow accelerated by the propeller (Figure 2.9). This analysis assume that the air flow steadily from a region in front of the propeller (P_o, V_o, ρ_o) to the exit region behind it (P_e, V_e, ρ_e). This method is generally known as the momentum theory (Ward, 1966).

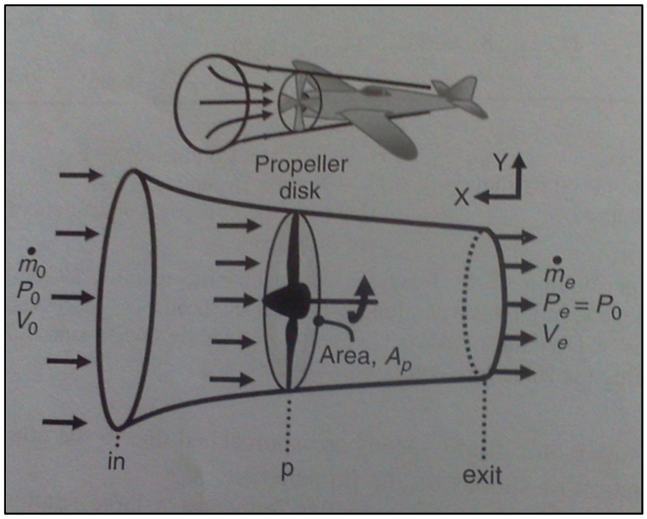


Figure 2.5: Control volumes surrounding a propeller

Source: Ward, 1966

It is assumed that flow outside of the propeller stream tube does not experiences any change in total pressure. Therefore the pressure terms everywhere are balanced, so the only force on the control volume is due to changes in longitudinal (x-direction) momentum fluxes across its boundaries. Propeller was known by modelers, as “props”, the sole purpose of this import and often overlooked piece of equipment is to pull (and sometimes push) the airplane through the air (Tressler, 2008). The suitable type and size of propeller is important to draw maximum power output from the nitro engine. As the ideal propeller diameter, pitch and blade area vary according to the size, weight and type of model, final propeller selection will require in flight experimentation. The suggested propeller sizes are given in the table (Hobbico, 2000).

Table 2.2: The suggested propeller sizes

LA Series	Running-in	Trainer & Sport
40 LA	11×5	10×6-7, 10.5×6, 11×5-6
46LA	11×6	11×6-7
65LA	12×6	12×7-8, 13×6-8

There are several types of propellers in use on model airplanes. They include two, three, and four blade types. By far, the most popular propeller for a trainer plane is a two blade type made of wood or plastic (Tressler, 2008). Most used are plastic propellers. Propellers are sized using two numbers; diameter and blade pitch. A very common prop size for a 40 to 46 trainer engine is a 10-7. The first number is the diameter of the propeller in inches. The second is the blade pitch expressed as a number representing the theoretical distance the airplane travels forward for each revolution of the propeller.

In the example propeller, the 10-7 indicates a 10 inch propeller that moves the airplane forward 7 inches per revolution. Model engine propellers range in overall diameter from 5 inches up through and including. As state by (Tressler, 2008), the choice of plastic or wood is depends. The main advantage of plastic over wood primarily is the increased durability of plastic. Chances are good to break a wood prop more easily during initial flight training.

Most important thing while handling the propeller is never touch, or allow any object to come into contact with the rotating propeller and do not crouch over the engine when it is running (Hobbico, 2000). The rotating propeller will produce thrust as shown in Figure 2.5. The ideal thrust equation for piston aerodynamics engines as shown in Eq. (2.1).

$$F_N = \dot{m}_e V_e - \dot{m}_o V_o = \dot{m}(V_e - V_o) \qquad (2.1)$$

Where,

$\dot{m}_e$: mass flow rate at exit;

$\dot{m}_o$: mass flow rate at inlet;

V_o : air velocity at inlet;

V_e : air velocity at exit;

But for this study, assume that the force is equal to spring constant time to the distance the spring is elongated from its equilibrium position in meters. The force can be measure by the simple equation known as Hooke's Law as Eq. (2.2).

$$F = kx \tag{2.2}$$

Where,

k : spring constant;

x : elongation of spring;

Hence, in order to measure the thrust exert by propeller while the engine start, the spring was placed on between the rear slider and spring's stand to measure the force by measure the elongation of the spring while force from the propeller pulls the slider toward. The value of force can be calculated because the spring constant can be measured.

2.3.3 Available Power and Shaft Brake Power

A propeller generates thrust by inducing a low pressure region in front of itself – and a high pressure region behind itself ($P > P_o$). (A detail kinematic model that describes all the aerodynamics forces involved is very complex and beyond the scope of this study.) The air pressure downstream of the propeller eventually returns to free stream conditions, but just behind the propeller the air velocity is greater than the free stream velocity (V_o). This is because the propeller has done work on the airflow (Ward, 1966).

In actual piston aero engines the shaft brake power cannot be perfectly transmitted to the propeller as available power, because of losses associated with the compressibility of air. The available power is the rate that useful work is done. The equation of available power can be simplified as shown in Eq. (2.3).

$$\dot{W}_A = F_N V_o = \dot{m} V_o (V_e - V_o) \quad (2.3)$$

Where,

F_N : force;

$\dot{m}$: mass flow rate;

V_o : air velocity at inlet;

V_e : air velocity at exit;

The shaft brake power is simply equal to the power expended by the propeller and imparted to the fluid. This is simply the rate of change in the kinetic energy of the flow passing through it. The equation of shaft brake power can be simplified as shown in Eq. (2.4).

$$\dot{W}_B = \dot{m} \frac{V_e^2}{2} - \frac{V_o^2}{2} \quad (2.4)$$

Where,

$\dot{m}$: mass flow rate;

V_o : air velocity at inlet;

V_e : air velocity at exit;

Base on the Table 2.1 above, the unknown that needed to solve the equation is the speed of the air in front and rear the propeller. Hence, the anemometer is used to get the value of Vo and Ve in front and rear the propeller at specific engine speed so that the available and shaft brake power data can be obtain.

2.3.4 Propulsive Efficiency

Aircraft propellers generally consist of two to six propeller blades as discuss in previous section. The number of blades needed depends upon the power of the engine. More powerful engines require a greater number of blades to efficiently convert this power into thrust. Unlike marine propellers, all aircraft propeller blades are arranged radials perpendicular to the axis of rotation and consist of a set of airfoil-shaped cross section. The term station is used to define radial positions (r) along a propeller from root (or hub) to tip. At any station the blade cross section has an airfoil shaped, but this shape may vary in outline at different stations. A wing is fixed (with respect to the airplane) and only experiences the relative free-stream flow of the air. A propeller is not fixed because it rotates. Therefore a propeller experiences an oncoming flow of air that is the vector sum of the airplane's velocity (also called the free-stream velocity, V_o) and the propeller rotational velocity (Ward, 1966).

As state by (Ward, 1966), Figure 2.6 illustrates the airfoil cross section of a propeller. Early propellers generally used airfoil cross sections that were similar to those used in wings. But as new higher speed aircraft were developed these airfoils proved to be inefficient. This is because the local velocity acting on specific propeller section is higher than the speed of the aircraft. This can cause flow separation or the formation of shock waves in the propeller airstream. This phenomenon known as a compressibility burble causes thrust losses and additional drag.

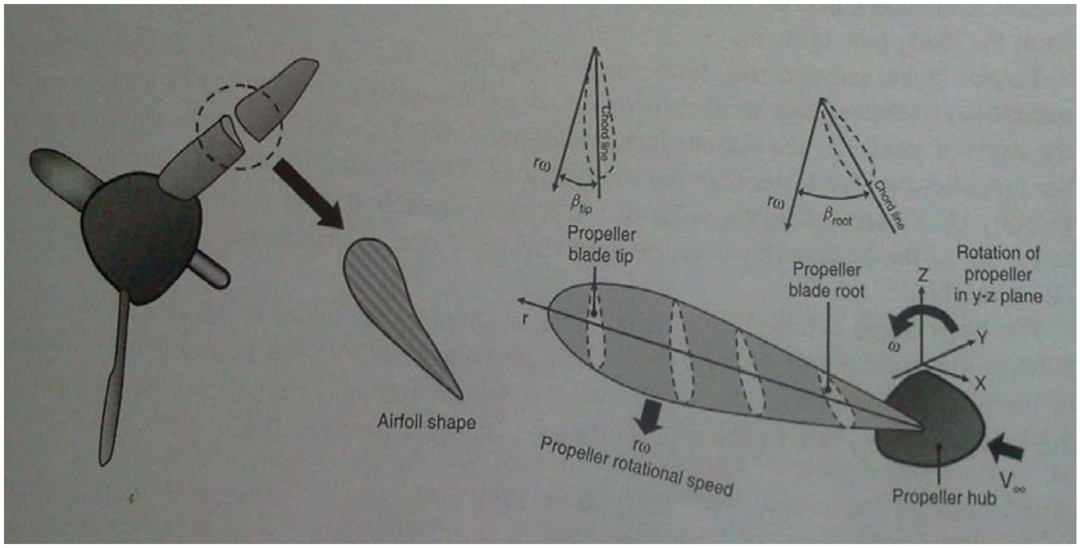


Figure 2.6: Cross-Section of a propeller

Source: Ward, 1966

It is useful to define a propeller efficiency (η_{prop}) that relates the fraction of shaft brake power delivered to the propeller and converted into propeller thrust power (available power) as shown in Eq. (2.5).

$$\eta_{prop} = \frac{F_{N,prop}\, V_o}{\dot{W}_B} = \frac{\dot{W}_A}{\dot{W}_B} \qquad (2.5)$$

Where,

F_N : force exert by propeller;

V_o : velocity of air at inlet;

$\dot{W}_A$: available power;

$\dot{W}_B$: shaft brake power;

The available and shaft brake power can be calculated as describe in previous section. Then it means the value of propulsive efficiency also can be calculated because every value needed is available and can be found by solving the mathematical equation. There is no different between the propeller efficiency (η_{prop}) and propulsive efficiency

(η_p) because as state by (Ward, 1966), the propeller efficiency (η_{prop}) is generally equal to the propulsive efficiency (η_p) for aero piston engines.

2.3.5 Brake Specific Fuel Consumption

Brake specific fuel consumption (BSFC) is a measure of the efficiency of an internal combustion engine. The term "specific fuel consumption" refers to the amount of fuel used normalized to the amount of power generated, which gives you an efficiency at certain operating point of the engine. All glow engines require a special fuel, called glow fuel. It consists of methanol as base, with some amount of nitro methane to increase the energy and pre-mixed oil into the fuel, which lubricates and protects the engine parts. Most glow engines will come with a manufacturer’s recommendation for fuel/oil mix with a type and percentage of oil specified. This is probably applicable to running in the engine and should comply with the manufacturer’s recommendation.

Two-stroke engines operate by igniting the fuel in its combustion chamber once every turn of its crankshaft. The fuel is mixed with air at the carburetor and forced into the cylinder during the down movement of the piston (1st stroke). While the piston moves up, the mixture is compressed and when the piston reaches the top, the glow plug ignites the compressed gases, forcing the piston down (2nd stroke). On the way down exhaust gases escape through the exhaust port while the fuel mixture enters the cylinder again.

In a four-stroke engine the fuel/air mixture enters the combustion chamber during the down movement of the piston through a valve operated by the camshaft (1st stroke). When the piston moves up, the valve closes and the mixture is compressed (2nd stroke). When the piston reaches the top, the glow plug ignites forcing the piston down (3rd stroke). On the next up movement of the piston, a second valve opens and allows the exhaust gases to escape (4th stroke). The piston moves down and the fuel mixture enters the combustion chamber again, repeating the 1st stroke.

The fuel tank size and location will affects the engine operation. A typical fuel tank placement is shown on the picture below:

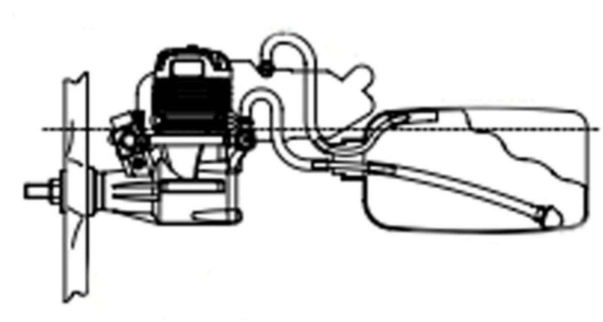


Figure 2.7: Fuel tank placements
Source: Hobbico, 2000

As state by (Hobbico, 2000), when the engine is in the upright position, the fuel tank's centerline should be at the same level as the needle valve or no lower than 1cm, (3/8in) to insure proper fuel flow. A too large fuel tank may cause the motor to run "lean" during a steep climb and "rich" during a steep dive. Normal tank size for engines between 3.5cc (0.21) and 6.5cc (0.40) is 150 - 250cc.

Model engine fuel is poisonous. Never allow it come into contact with the eyes or mouth. Always store it in a clearly marked container and out of the reach of children. Model engine fuel is also highly flammable. Keep it away from open flame, excessive heat, sources of sparks, or anything else which might ignite it (Hobbico, 2000).

The type of specific fuel consumption that is commonly used as a figure of merit in piston aero engines is called the brake specific fuel consumption (BSFC). It is defined as the rate of fuel consumption divided by the rate of shaft brake power production (Ward, 1966). The equation for brake specific fuel consumption can be state as shown in Eq. (2.6).

$$\text{BSFC} = \frac{\dot{m}\text{fuel}}{\dot{W}B} = \eta_p \frac{\dot{m}\text{fuel}}{\dot{W}A} \tag{2.6}$$

Where,

$\dot{m}_{fuel}$: mass flow rate of fuel;

η_p : propulsive efficiency;

$\dot{W}_A$: available power;

$\dot{W}_B$: shaft brake power;

Base on the Table 2.1 above, the unknown that needed to get the value of BSFC is the mass flow rate of fuel. The mass flow rate of fuel can be measure by the mass of fuel divided to the time taken while run the nitro engine. Then the mass flow rate of fuel that just calculated is used again to calculate the value of BSFC. From the definition of BSFC it is clear that lower values represent more fuel efficient engines.

2.4 SUMMARY

In this chapter, the discussion is more on introductions about UAV propulsion systems for two-stroke and four-stroke engine (glow engine). The detail on type of engines, thrust, combustion, and propeller design will be used. From that we can determined the engine performance parameters from output of engine type such as thrust, available power, shaft brake power, propulsive efficiency, and brake specific fuel consumption by solving mathematical equations. The unknown can be obtained by data given by the apparatus used such as spring, anemometer, and tachometer that are installing within the test bed design.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This section will briefly describes the way of fabricate the test bed from the equipments and parts with the material selection for making test bed to determine the best and accurate result for this study. The test bed modeling by using Solidworks software also will be show later in this section. In this section also briefly describes the way how the study being conduct, which is by doing experiment to obtain data from test bed.

The variables and performance parameters also will be explained other than problem setup. So, all the value data from the experiment will be obtain for nitro engine type and finally are able to suggest the suitable powerplant.

3.2 METHODOLOGY PROCESS FLOW CHART

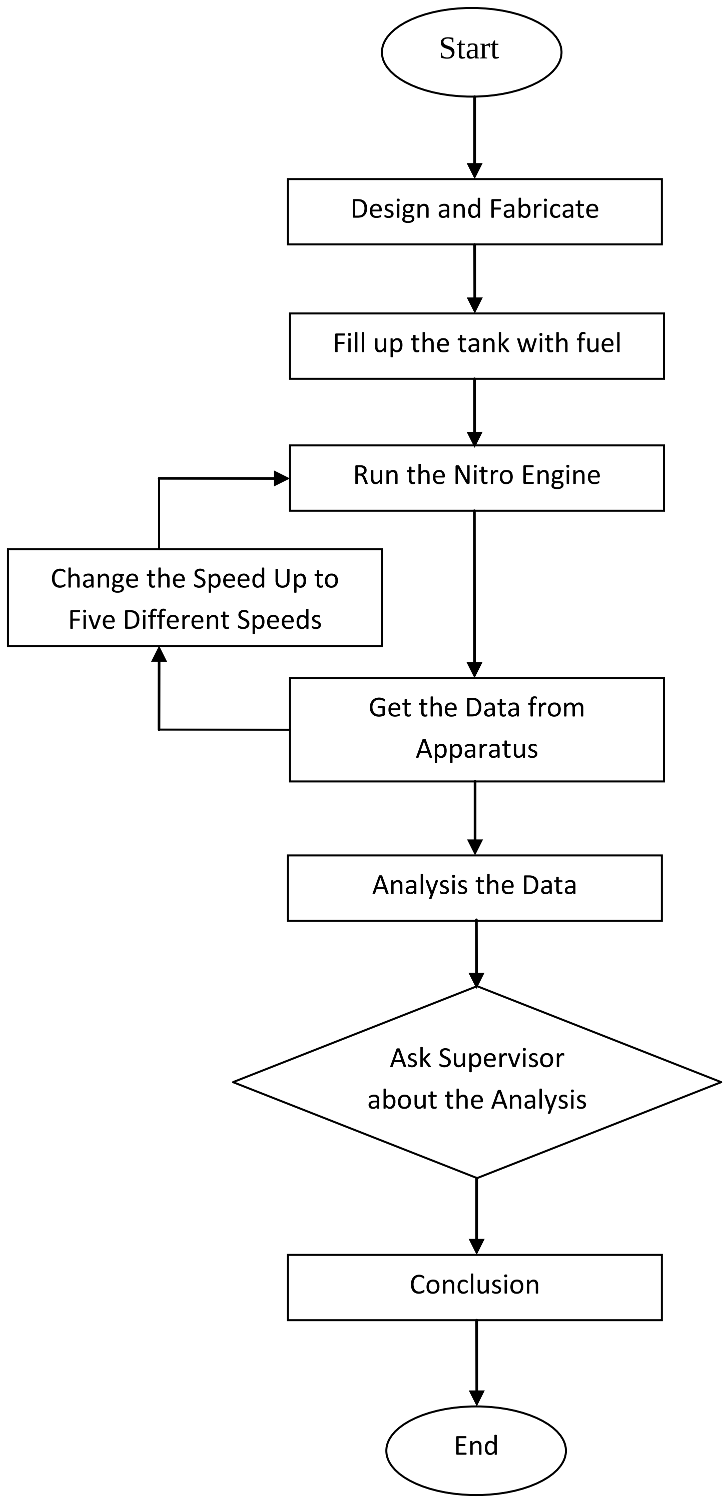
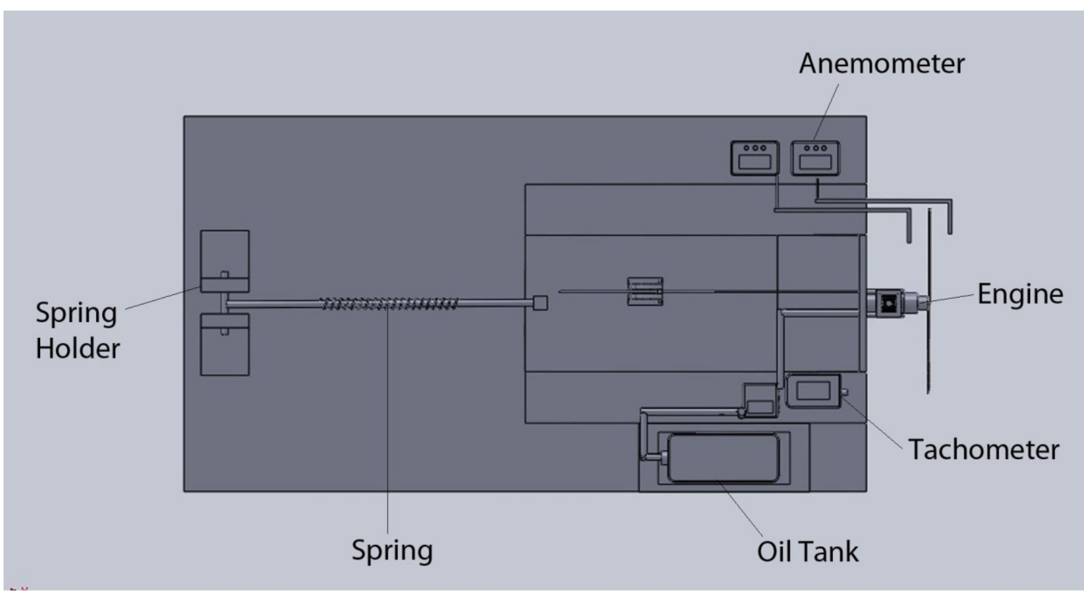


Figure 3.1: The methodology process flow chart

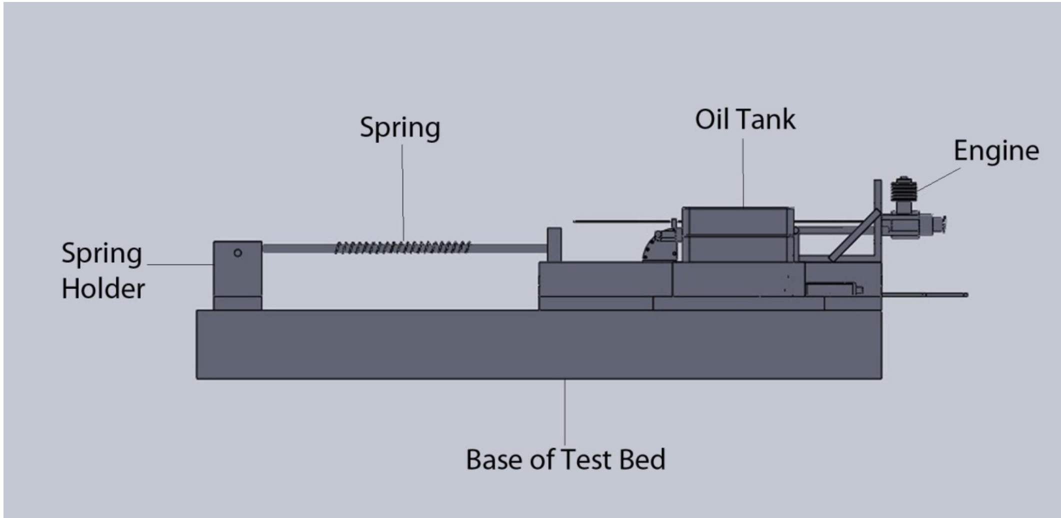
3.3 TEST BED MODELING USING SOLIDWORKS

This section will describe the details of the test bed modeling by using Solidworks software. Solidworks is a 3D mechanical CAD (computer-aided design) program. Building a model in Solidworks usually starts with a 2D sketch (although 3D sketches are available for power users). The sketch consists of geometry such as points, lines, arcs, conics (except the hyperbola), and splines. Dimensions are added to the sketch to define the size and location of the geometry. Relations are used to define attributes such as tangency, parallelism, perpendicularity, and concentricity. The parametric nature of Solidworks means that the dimensions and relations drive the geometry, not the other way around. The dimensions in the sketch can be controlled independently, or by relationships to other parameters inside or outside of the sketch.

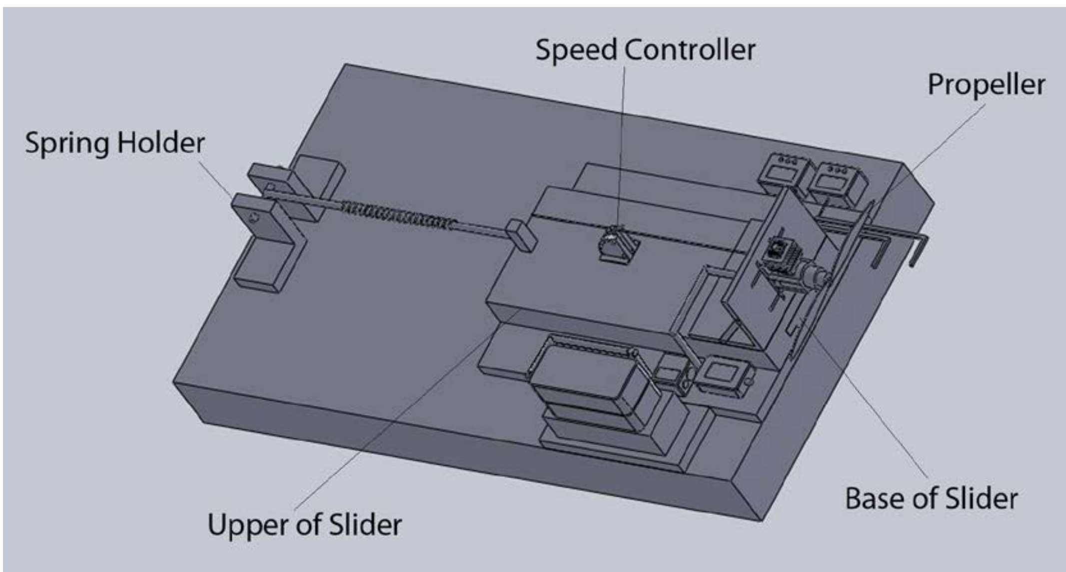
The parts of the test bed are made one by one before assembly it according to actual size. The assembly design as shown in Figure 3.2.



(a) Top view



(b) Side view



(c) 3D view

Figure 3.2: The test bed design by using Solidworks
(a) Top View (b) Side View (c) 3D View

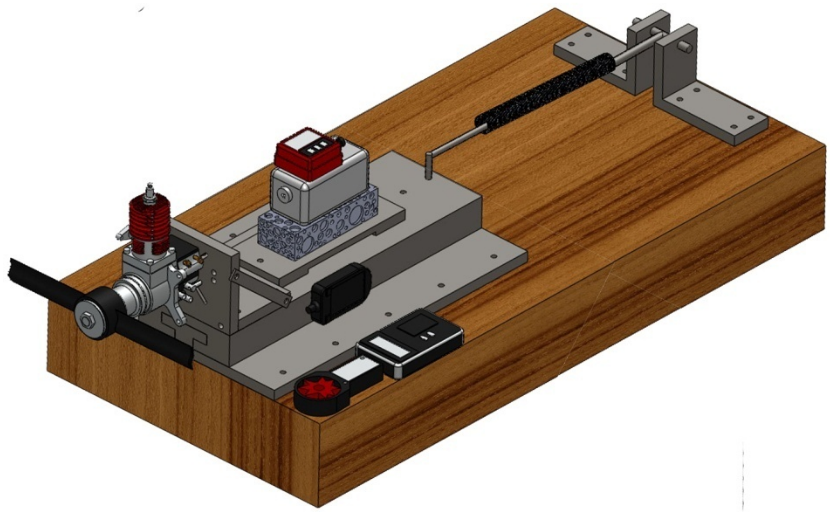


Figure 3.3: The final test bed design by using Solidworks

Figure 3.3 above is the final design of test bed by using Solidworks software. It shows the placement of the apparatus such as anemometer, tachometer, oil tank, the nitro engine, the slider and spring.

3.4 MATERIAL SELECTION FOR TEST BED

It is important to choose the suitable materials to build the test bed because it will affect the result of the project either the measurement become inaccurate or not applicable.

3.4.1 Base of Wood Plate

The wood plate is used for base of the test bed because it has the ability to absorb the vibration of the running engine. Vibration is a mechanical phenomenon whereby oscillations occur about an equilibrium point. The oscillations may be periodic such as the motion of a pendulum or random such as the movement of a tire on a gravel road. The lower rate of vibration will defend the oil in oil tank to be unstable and may give effect to the running engine. More than that, the wood plate weight is heavy and able to avoid the test bed moving from it spot.

3.4.2 Engine Mount

The engine mount will be made from the wood and spring holder will be made from aluminum. So that it will stand from corrosion and last longer.

Figure 3.4: The nitro engines mount

3.4.3 Slider

The object that will be chose as to slide the engine from the base of wood plate is slider from waste of table drawer. It is chosen because it has suitable size and shape to combine another two wood plates that act as slider. It is also to reduce the friction forces that exist from the two wood slides.

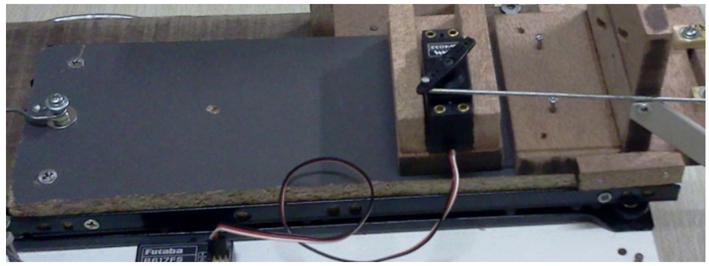


Figure 3.5: The slider part

3.4.4 Nitro Engine

The nitro engine used for this project is O.S Engine 46LA Series. The specification of the nitro engine as shown below:

Table 3.1: The O.S Engine 46LA Series specification

Parameters	**Specification**
Displacement (cu in)	0.467
Bore (in)	0.906
Stroke (in)	0.724
RPM	2000-16000
Output (HP @ rpm)	1.18 @ 16000
Weight (oz)	9.6

Figure 3.6: The O.S. 46LA series nitro engine

This nitro engine has more cooling fin area to extend the life of the engine and overall tighter needle valve fit utilizes on “O” ring to help maintain the performance levels that needed. The propeller that used is wood type 12×6.

3.4.5 Tachometer

The tachometer is used to measure the needed revolution per minute for experiment setup.

Figure 3.7: The tachometer

3.4.6 Anemometer

The anemometer is used to measure the speed of air in front and rear of the rotating propeller.

Figure 3.8: The anemometer

3.4.7 Spring

The spring is used to calculate the force exert by the nitro engine.

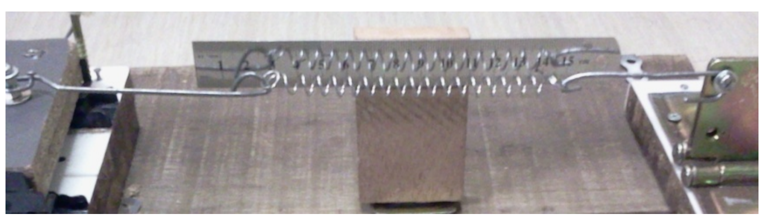


Figure 3.9: The spring

3.4.8 Oil Tank and Fuel

The oil tank and fuel contain nitro methane is used to power the nitro engine.

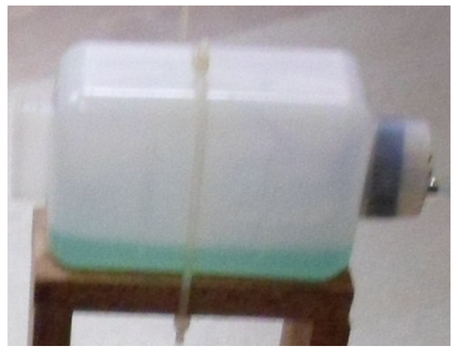


Figure 3.10: The oil tank

Figure 3.11: The fuel of nitro engine

3.4.9 Servo Set and Radio Controller

The servo set with the radio Futaba brand is used to control the speed of nitro engine from long distance.

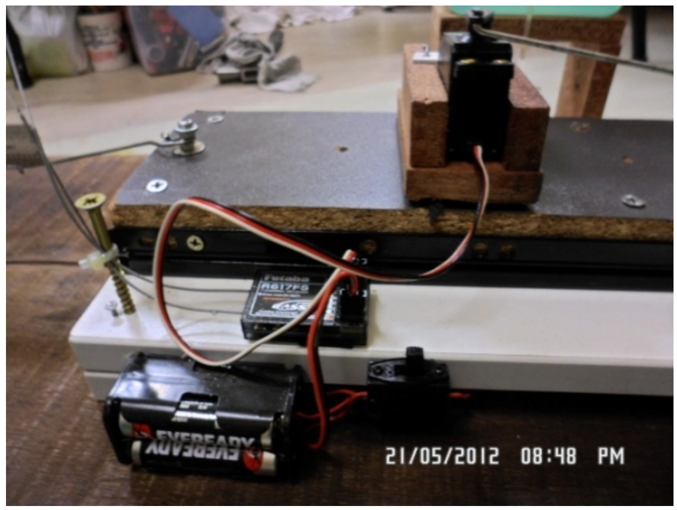


Figure 3.12: The servo set

Figure 3.13: The Futaba radio controller

3.4.10 Steel Ruler

The steel ruler is used to measure the elongation of spring.

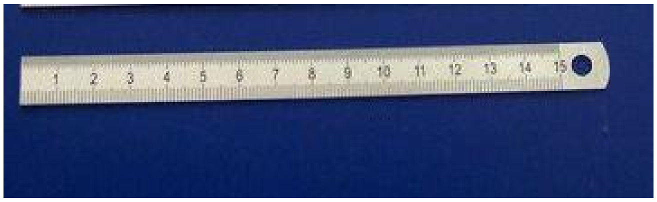


Figure 3.14: The steel ruler

3.4.11 Stop Watch

The stop watch is used to measure time taken when run the nitro engine.

Figure 3.15: The stop watch

3.5 STEPS TO FABRICATE THE TEST BED

Firstly, after complete collect and select the material needed, start by combine the two wood plates into one as a base because there is no exact size of wood plate needed at shop. After combine the wood plate by using metal rope and some screws, put the base of slider on the wood and screw it tightly. Combine the upper slider with the base of slider by using slider from waste table drawer and now the upper part of slider can be slide on that slider track. The rubber mount was placed under the wood base to absorb the vibration from the nitro engine. The holder also was placed beside the wood base so that it is more portable and easy to carry the test bed.

Secondly, just put some metal’s plate on the other end of wood plate. The metal’s plate function as to hold the spring from the slider part so that when the slider are moving the spring will give the reading on elongation.

Thirdly, for the engine mount part. The design is created suppose to able to mount every sizes and type of nitro engine whether at horizontal or vertical condition. The engine mount was created by using the wood plate, according to exact size and shape in modeling in Solidworks. Drilling machine as Figure 3.16 was used to create the hole at wood plate. Then the engine mount was placed on the end of slider part. After that, tighten the nitro engine with propeller on the engine mount.

Figure 3.16: Drilling machine

Fourthly, make the stand for the oil tank beside the slider and the oil tank placement level must be same or higher than carburetor of the nitro engine. It is because to give more pressure in oil tank that makes fuel movement into the engine fluent. The sponge also can be put under oil tank to give less vibration to the oil tank. It is to avoid bubble occur that can ruin the nitro engine performance.

Lastly, servo set which is servo part, receiver, on/off switch and battery holder was added to control the speed of the nitro engine by using radio so that the engine speed can be change in long distance.

Figure 3.17: The actual test bed design

3.6 EXPERIMENT SETUP

After the engine test bed had been developed for testing process. The nitro engine which is 2-stroke engine can be tested to analysis the performance of engine. For the engine testing, the throttle is set to five different speeds to obtain different RPM as shown in Table 3.2.

Table 3.2: The case setup

CASE	ENGINE SPEED (RPM)
1	2010.23
2	4032.33
3	8023.35
4	12011.21
5	16054.32

The engine speed will be the control parameter and the performance parameters will became the variable parameter. The apparatus to measure the value of unknown will be installed to the test bed such as the anemometer to measure the speed rear and front of the propeller, the tachometer to measure the revolution per minute of the propeller, and the spring to measure the thrust of the engine. Hence, the unknown of each mathematical equation will be known by this apparatus and lastly all of the performance parameters can be obtain by solving the mathematical equations.

The five different speeds setup will give different values for performance parameters. All the data obtained from the test bed will be recorded and analyses in next chapter to get know the relationship between the performance parameters and the engine speed.

3.7 SUMMARY

This chapter present on how the project is being conducted. By developing the test bed, any types of engine could be tested due to the flexibility of the engine mount design. For this project, the case setups are used to experiment the engine by setting up five difference speed of the engine. The value of the performance parameters can be obtained by using the unknown that know by apparatus and calculate it by using the mathematical equations as state in Chapter 2. Hence, the suitable powerplant can be suggested according to the types of RC aircraft.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter presents and describes results acquired through experiment made with the test bed model. The results are compared to data which appear in some articles in order to prove the accuracy.

The test bed model is experimented between 2000 to 16000 RPM of nitro engine speed range and the value of performance parameters accord to the speed range.

4.2 RESULT OF THRUST

The term thrust, is used to specify that the force exert by the engine to slide the slider as told in previous chapter. The force is measured by using the Hooke’s Law which is the force (F) is defined as the rate of elongation of spring (x) times the spring constant (k). Table 4.1 show the force data obtained by the test bed according to five different engine speeds.

Table 4.1: Tabulated data for Force

Engine Speed (RPM)	**Elongation of spring, x (m)**	**Force (N)**
2010.23	0.000	0.000
4032.33	0.011	3.793
8023.35	0.014	4.828
12011.21	0.017	5.862
16054.32	0.020	6.897

Example calculation of force:

By using the Hooke's Law equation as state in Chapter 2 as Eq. (2.2).
The spring constant, k = 344.83 N/m

At maximum engine speed = 16054.32 RPM
The elongation of spring, x = 0.02 m

Hence, $F = kx$

$= (344.83\ N/m)\ (0.02\ m)$

$= 6.897\ N$

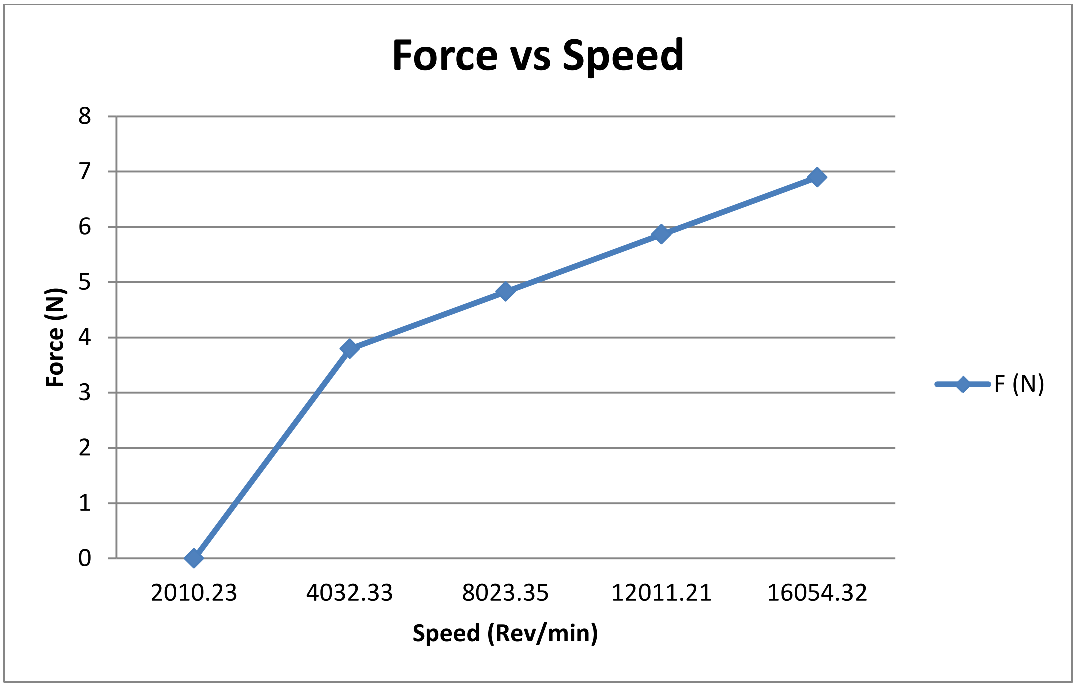


Figure 4.1: Graph of Force versus Speed

4.2.1 Discussion Result of Thrust

From the experiment the force was determine at five different speeds, which is 2010.23 RPM, 4032.33 RPM, 8023.35 RPM, 12011.21 RPM, and 16054.32 RPM by using the slider part that was placed on the base of wood and the spring attach to it. The spring constant had been set so that the value of the force can be calculated through the elongation of the spring. The tachometer was set up in front of the propeller, this tachometer will give the value of the speed so that the speed can be set constant while conduct this experiment. According to the graph on Figure 4.1, at minimum speed which is 2010.23 RPM the value of force is zero. It is because the speed of propeller is unable to force the slider toward and the spring did not elongated. Assume that the friction force is neglect. By using the equation of Hooke's Law as state above, the value of the force will be zero. The value of force at maximum speed which is 16054.32 RPM is 6.897 N. The graph had shown that the value of force increase by increasing of the value of speed.

4.3 RESULT OF AVAILABLE POWER AND SHAFT BRAKE POWER

The available and shaft brake power can be calculated from the test bed. The available power ($\dot{W}_A$) is define as the rate that useful work is done meanwhile the shaft brake power ($\dot{W}_B$) is define as the power expanded by the propeller and imparted to the fluid. Table 4.2 show the available power and shaft brake power data obtained by the test bed according to five different engine speeds.

Table 4.2: Tabulated data for Available Power and Shaft Brake Power

Engine Speed (RPM)	**Velocity inlet, Vo (m/s)**	**Velocity exit, Ve (m/s)**	**Available Power, $\dot{W}_A$ (Nm/s)**	**Shaft Brake Power, $\dot{W}_B$ (Nm/s)**
2010.23	3.625	8.783	0.000	0.000
4032.33	4.517	9.835	11.09	21.36
8023.35	4.967	10.900	23.98	38.31
12011.21	6.467	11.967	37.92	54.04
16054.32	7.533	12.933	51.96	70.56

Example of calculation of available power:

The available power is the rate that useful work is done, as state in Chapter 2 as Eq. (2.3).

At maximum engine speed = 16054.32 RPM,

The velocity of air inlet through the propeller, V_o = 7.533 m/s

Hence, $\dot{W}_A = F_N V_o$

$= (6.897 \text{ N}) (7.533 \text{ m/s})$

$= 51.96 \text{ Nm/s}$

Example of calculation of shaft brake power:

The shaft brake power is simply the rate of change in the kinetic energy of the flow passing through it, as state in Chapter 2 as Eq. (2.4).

$\dot{m}$ = 1.277 N.ms^{-2}

At maximum engine speed = 16054.32 RPM

The velocity of air inlet, V_o = 7.533 m/s

The velocity of air exit, V_e = 12.933 m/s

Hence, $\dot{W}_B = \dot{m}\,((V_e^2/2)-(V_o^2/2))$

$= 1.277\,((12.933^2/2)-(7.533^2/2))$

$= 70.56$ Nm/s

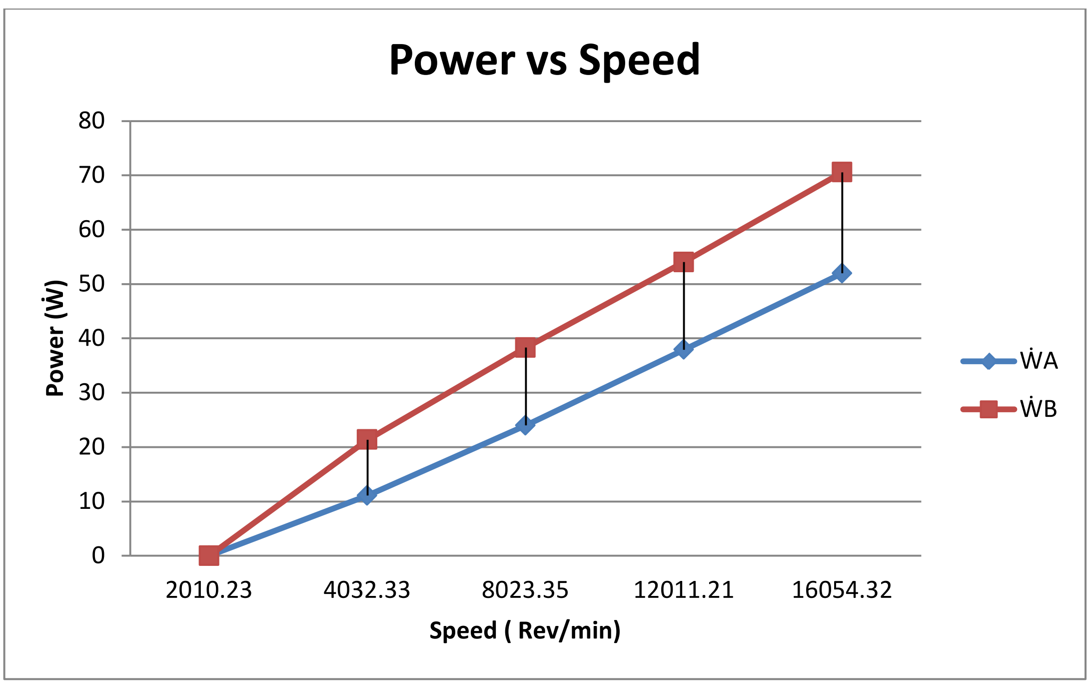


Figure 4.2: Graph of Available and Shaft Brake Power versus Speed

4.3.1 Discussion Result of Available Power and Shaft Brake Power

From the experiment the available power and shaft brake power was determine at five different speeds, which is 2010.23 RPM, 4032.33 RPM, 8023.35 RPM, 12011.21 RPM, and 16054.32 RPM by using the anemometer to measure the speeds of the air inlet and exit from propeller. The anemometer was set up in front and rear of the propeller, this anemometer will give the value of the air speed so that the both powers can be calculated by using the exact equation as show above. According to the graph on Figure 4.2, at minimum speed which is 2010.23 RPM the values of both powers are zero. It is because the force as discuss above is zero and assume that friction force is neglect. The value of available power at 4032.33 RPM is 11.09 Nm/s meanwhile the value of brake shaft power at the same speed is 21.36 Nm/s. The value of available power at maximum speed which is 16054.32 RPM is 51.96 Nm/s meanwhile the value of brake shaft power at the same speed is 70.56 Nm/s. The graph had shown that the values of both powers are increase by the increasing of the value of speed.

4.4 RESULT OF PROPULSIVE EFFICIENCY

The propulsive efficiency (η_p) is defined as the fraction of shaft brake power delivered to the propeller and convert into propeller thrust power (available power). The propeller efficiency (η_{prop}) is generally equal to the propulsive efficiency (η_p) for aero piston engines. Table 4.3 show the propulsive efficiency data obtained by the test bed according to five different engine speeds.

Table 4.3: Tabulated data for Propulsive Efficiency

Engine Speed (RPM)	**Available Power, $\dot{W}_A$ (Nm/s)**	**Shaft Brake Power, $\dot{W}_B$ (Nm/s)**	**Propulsive Efficiency, η_p (%)**
2010.23	0.000	0.000	0.000
4032.33	11.09	21.36	51.92
8023.35	23.98	38.31	62.59
12011.21	37.92	54.04	70.17
16054.32	51.96	70.56	73.64

Example of calculation of propulsive efficiency:

The propulsive efficiency relates the fraction of shaft brake power delivered to the propeller and converted into propeller thrust power (available power), as state in Chapter 2 as Eq. (2.5).

At maximum engine speed = 16054.32 RPM

The available power = 51.96 Nm/s

The shaft brake power = 70.56 Nm/s

Hence, $\eta_p = \dot{W}_A / \dot{W}_B$

$= 51.96 \text{ Nm/s} / 70.56 \text{ Nm/s}$

$= 0.736 \approx 73.64\%$

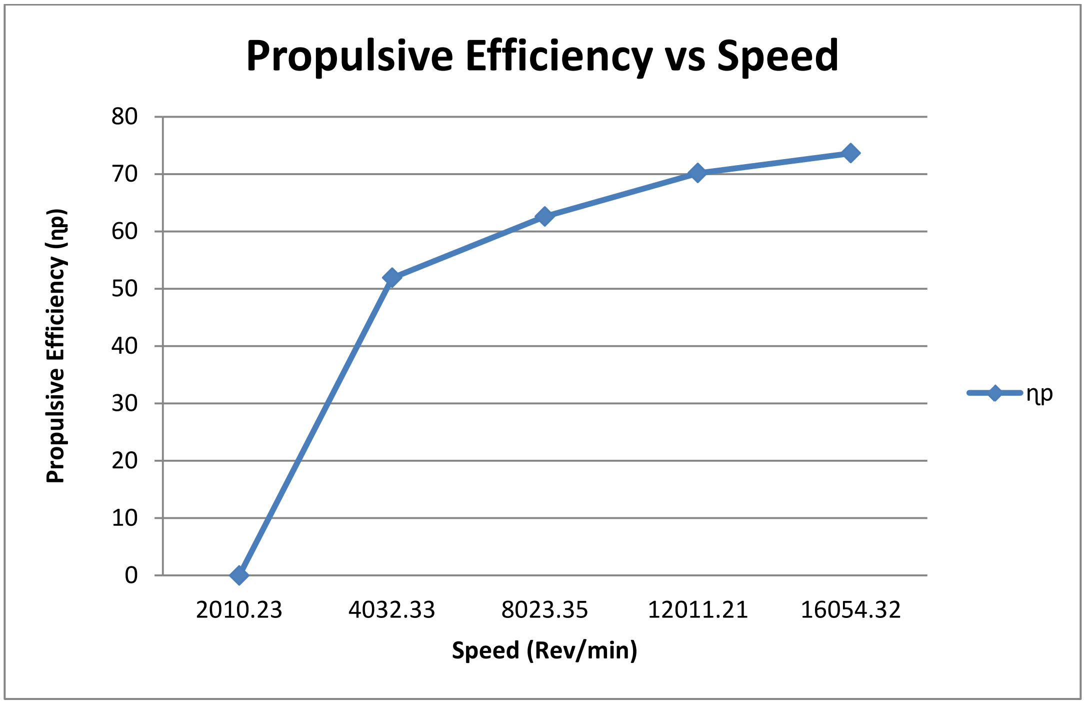


Figure 4.3: Graph of Propulsive Efficiency versus Speed

4.4.1 Discussion Result of Propulsive Efficiency

From the experiment the propulsive efficiency was determine at five different speeds, which is 2010.23 RPM, 4032.33 RPM, 8023.35 RPM, 12011.21 RPM, and 16054.32 RPM by using the anemometer to measure the speeds of the air inlet and exit from propeller. The value of the propulsive efficiency can be calculated by divided the value of available power to the shaft brake power. According to the graph on Figure 4.3, at minimum speed which is 2010.23 RPM the value of propulsive efficiency is zero. It is because the both powers described previously cannot be calculated due to the spring that is not elongate at minimum speed as discussed above and friction force was assumed to be neglect. The value of propulsive efficiency at 4032.33 RPM is 51.92% meanwhile the value of propulsive efficiency at maximum speed which is 16054.32 RPM is 73.64%. The graph had shown that the value of propulsive efficiency increase by the increasing of the value of speed.

4.5 RESULT OF BRAKE SPECIFIC FUEL CONSUMPTION

The brake specific fuel consumption (BSFC) is defined as the rate of fuel consumption or mass flow rate of fuel ($\dot{m}_{fuel}$) divided by the rate of shaft brake power ($\dot{W}_B$) production. From the definition of BSFC it is clear that lower values represent more fuel efficient engines. Table 4.4 show the BSFC data obtained by the test bed according to five different engine speeds.

Table 4.4: Tabulated data for Brake Specific Fuel Consumption

Engine Speed (RPM)	Mass of fuel m, (kg)	Mass flow rate of fuel, $\dot{m}_{fuel}$ (kg/sec)	Brake Specific Fuel Consumption, BSFC (µg/(W.s))
2010.23	0.006	2.000×10^{-5}	/
4032.33	0.013	4.333×10^{-5}	2.029
8023.35	0.024	8.000×10^{-5}	2.088
12011.21	0.034	1.133×10^{-4}	2.097
16054.32	0.046	1.533×10^{-4}	2.172

Example of calculation of specific fuel consumption:

The equation of specific fuel consumption is simply the mass flow rate of fuel ($\dot{m}_{fuel}$) divided by the rate of shaft brake power ($\dot{W}_B$) production, as state in Chapter 2 as Eq. (2.6).

At maximum engine speed = 16054.32 RPM

The mass of fuel used = 0.046 kg

The engine runs for 5 minute = 300 sec

$\dot{m}_{fuel}$ = mass / time

$\dot{m}_{fuel}$ = 0.046 kg / 300 sec

= 1.533×10^{-4} kg/sec

Hence, BSFC = $\dot{m}_{fuel}$ / $\dot{W}_B$

= 1.533×10^{-4} / 70.56

= 2.172 µg/ (W.s)

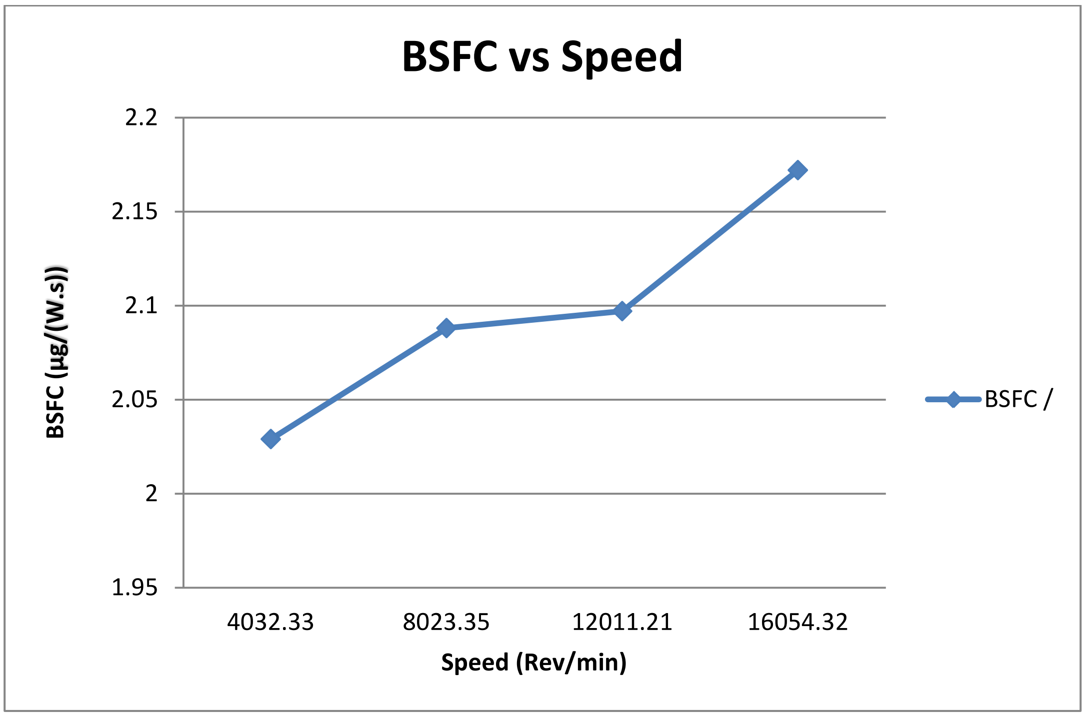


Figure 4.4: Graph of Speed versus Brake Specific Fuel Consumption

4.5.1 Discussion Result of Brake Specific Fuel Consumption

From the experiment the BSFC was determine at five different speeds, which is 2010.23 RPM, 4032.33 RPM, 8023.35 RPM, 12011.21 RPM, and 16054.32 RPM by using the oil tank with label of level to measure the fuel usage while the nitro engine operating at different speeds. The five minutes are given to the nitro engine to run at different speeds while times are taken by using watch. The value of the BSFC can be calculated by calculate the mass flow rate of fuel ($\dot{m}_{fuel}$) first before divided it by the shaft brake power ($\dot{W}_B$) as shown above. According to the graph on Figure 4.4, at minimum speed which is 2010.23 RPM the value of BSFC is cannot be calculated. It is because the shaft brake power cannot be determined. The value of BSFC at 4032.33 RPM is 2.029 μg/(W.s) meanwhile the value of propulsive efficiency at maximum speed which is 16054.32 RPM is 2.172 μg/(W.s). The graph had shown that the value of BSFC increasing by the increasing of the value of speed. BSFC is directly proportional to engine volume, such as engine volume goes down so does BSFC. This is due to the heat losses from the end gas to the cylinder walls. Higher engine speeds produce a high because of rising friction losses in the engine. Higher friction losses reduce brake torque, which increases BSFC.

4.6 SUMMARY

From this experiment, the result shows that the performance parameters are increase along the increasing of speed. The obtained data from performance parameters are proportional to the speed. The data from the nitro engine can be obtained and analysis by design and fabricate the test bed without using the actual body of remote control aircraft. The test bed is able to use to perform detail testing at various RPM setting and nitro engines. All the performance parameters needed can be calculated from this test bed by using the apparatus such as tachometer and anemometer that had been setup along the process of designing and this will reduce the time and cost to test the nitro engine by using the actual body of aircraft.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

A test bed model had been produced base on the project title which is to design, analysis and performance testing of UAV propulsion system. The detail design of test bed model had been modeled by using the Solidworks software to produce the actual body of test bed model.

The performance parameters such as force, available power, shaft brake power, propulsive efficiency and brake specific fuel consumption can be calculate by using the test bed. As mention before, the apparatus such as anemometer and tachometer that had been setup are used to find unknown that exist in any equation involve in this project. In simple words, the apparatus are used to get the value of performance parameters through simple calculation.

The variable that is setup in this project is the speed of the nitro engine. The five different speeds had been setup to study and analysis the connection between the variable and the performance parameters. All of the objectives which is to design a comprehensive test bed for detail testing, to analyze the designed test bed for data collection reliability to the test bed, and to perform detail testing for nitro engine at various RPM setting and evaluate corresponding performance parameter associated to the setting were achieved.

5.2 RECOMMENDATIONS

1. The further study can be made by using various types of nitro engine and size. So that the test bed is able to be prove that it can be test by various types of nitro engine and size. The different types and size of propeller also can be test. The data that will obtain also can be comparing to this data on this study.

2. The weight of test bed is slightly heavy and difficult to carry even though it already had the holder to hold it. However, this problem can be solving which is by adding the tires and adjustable holder to the base of test bed. By then the test bed is portable and more convenient to use.

3. For engine mount part, the wood plate had been used to hold the engine by support of two plastic plates and it not durable and weak against power output of nitro engine. Then it better to use steel plate to make it more durable and strong enough to overcome the power output from the nitro engine.

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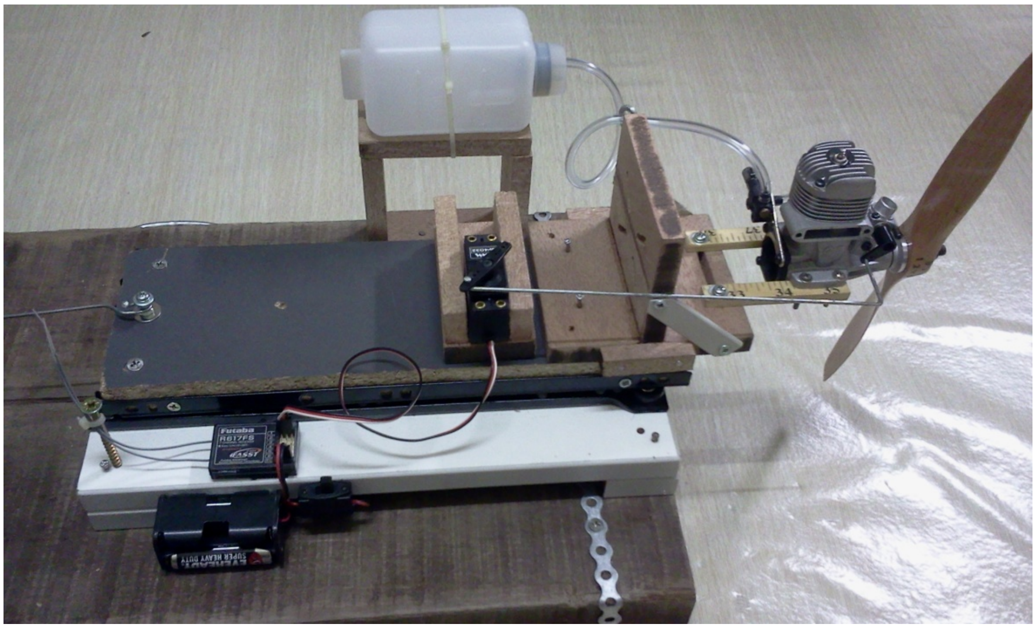
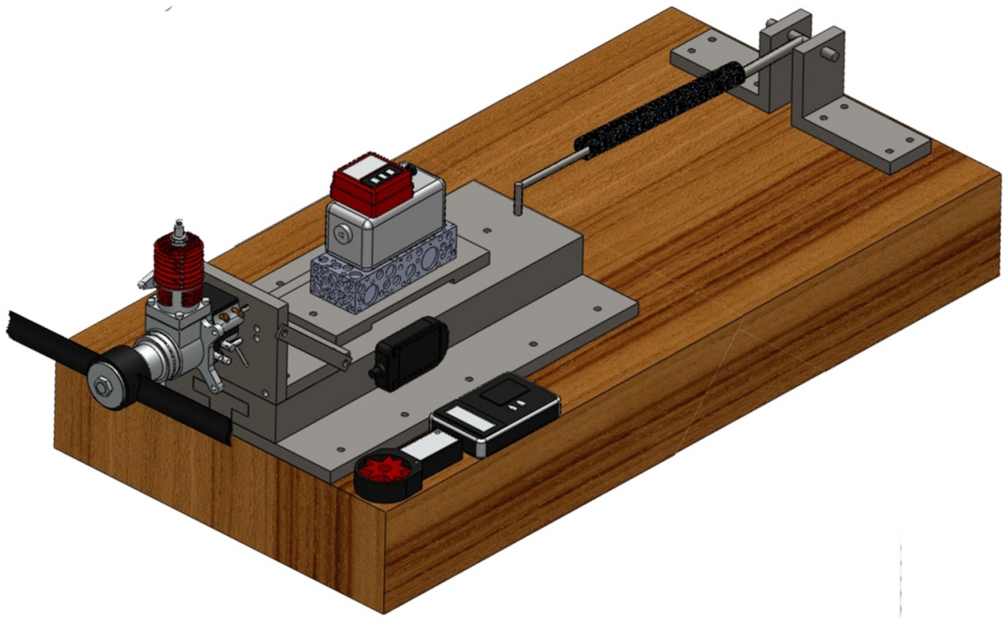
APPENDIX A1

Adjustable engine mount design made from wood plate.



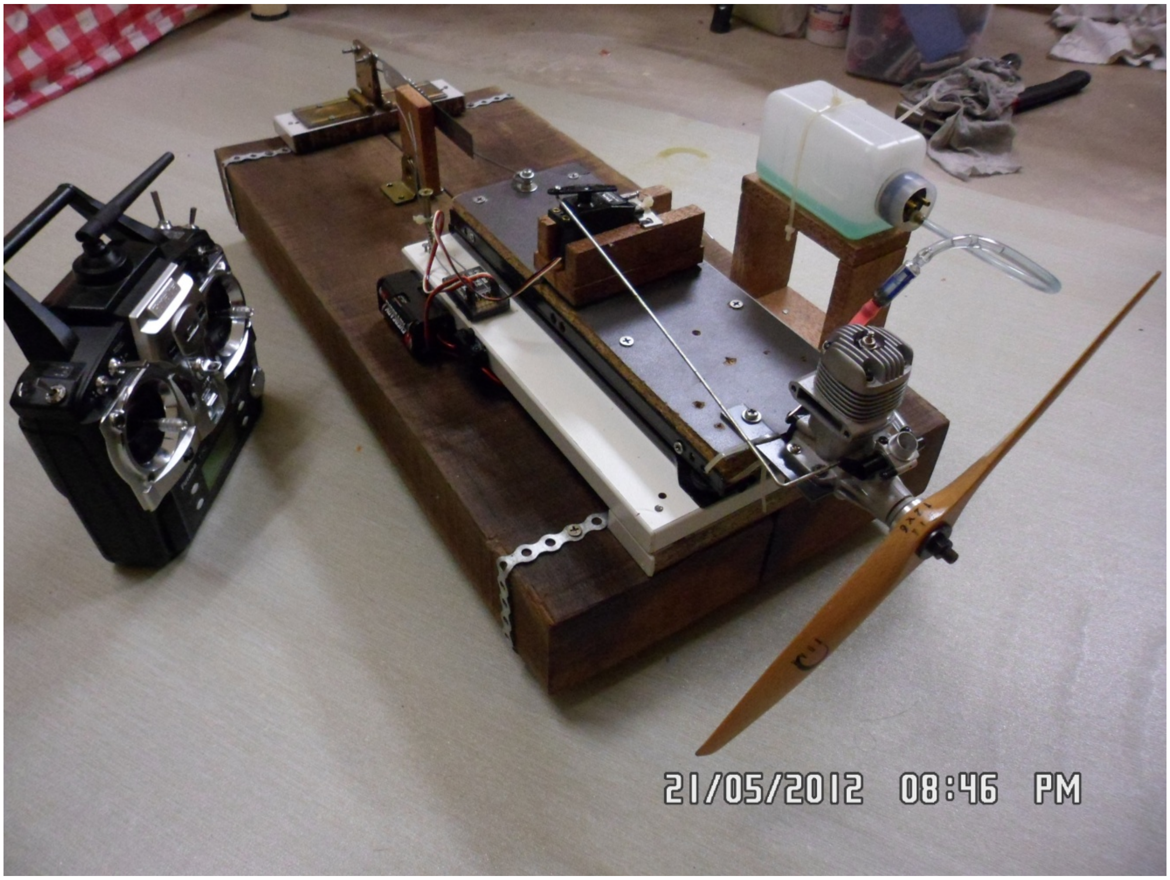
APPENDIX A2

Test bed design by using Solidwork 2008 software.



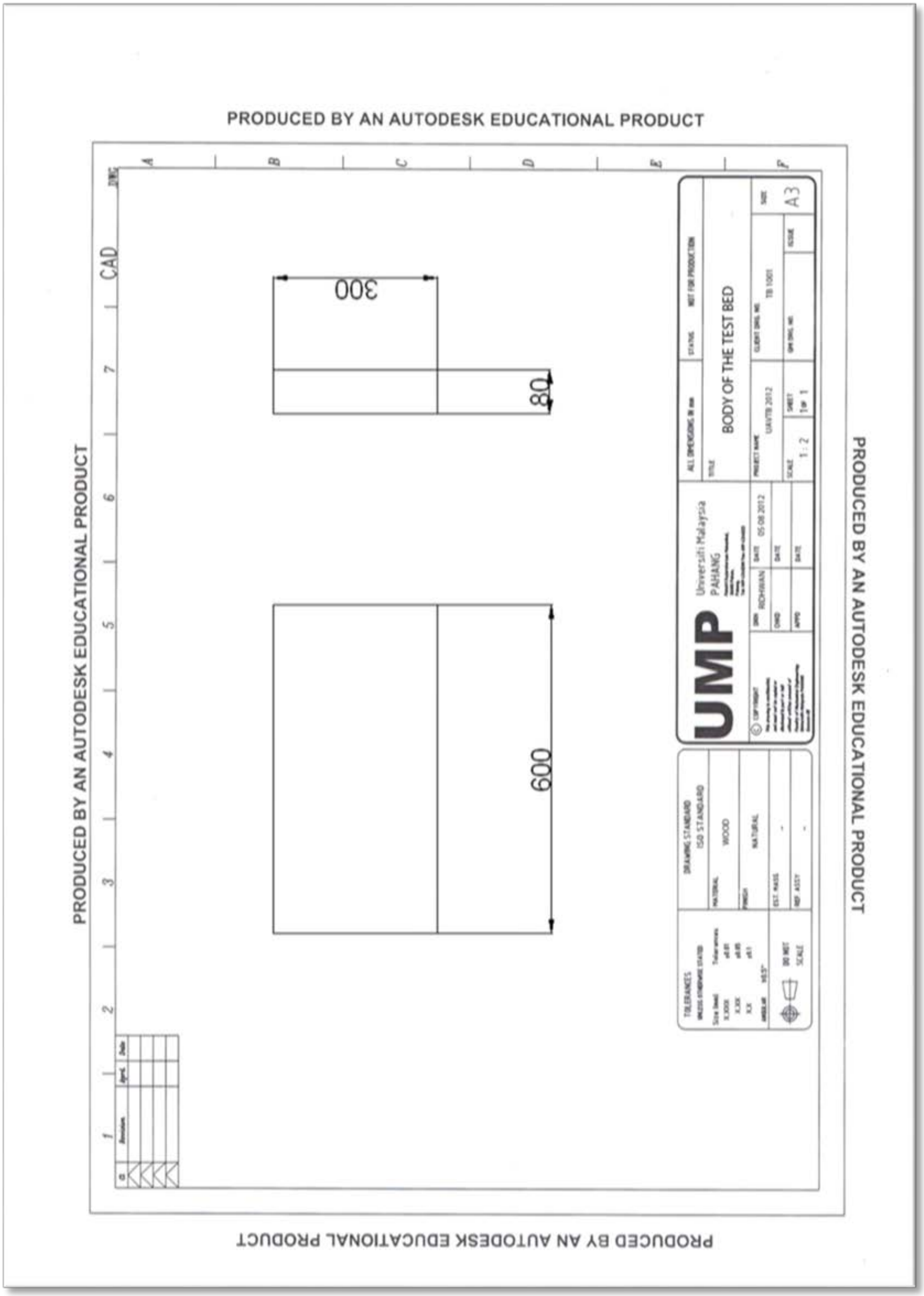
APPENDIX A3

Actual test bed design was produced.



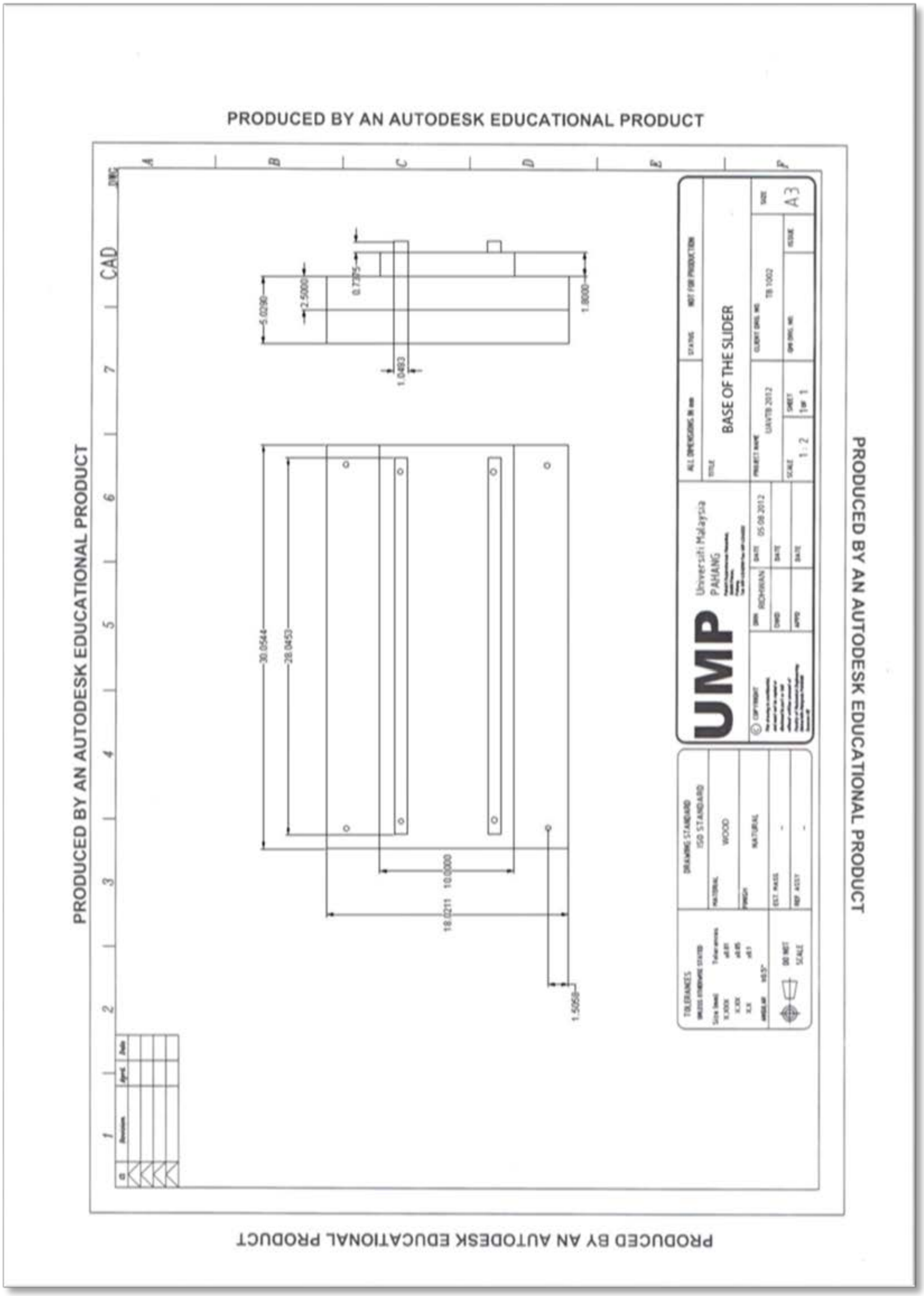
APPENDIX B1

Base of test bed part drawing by using AutoCAD 2012.



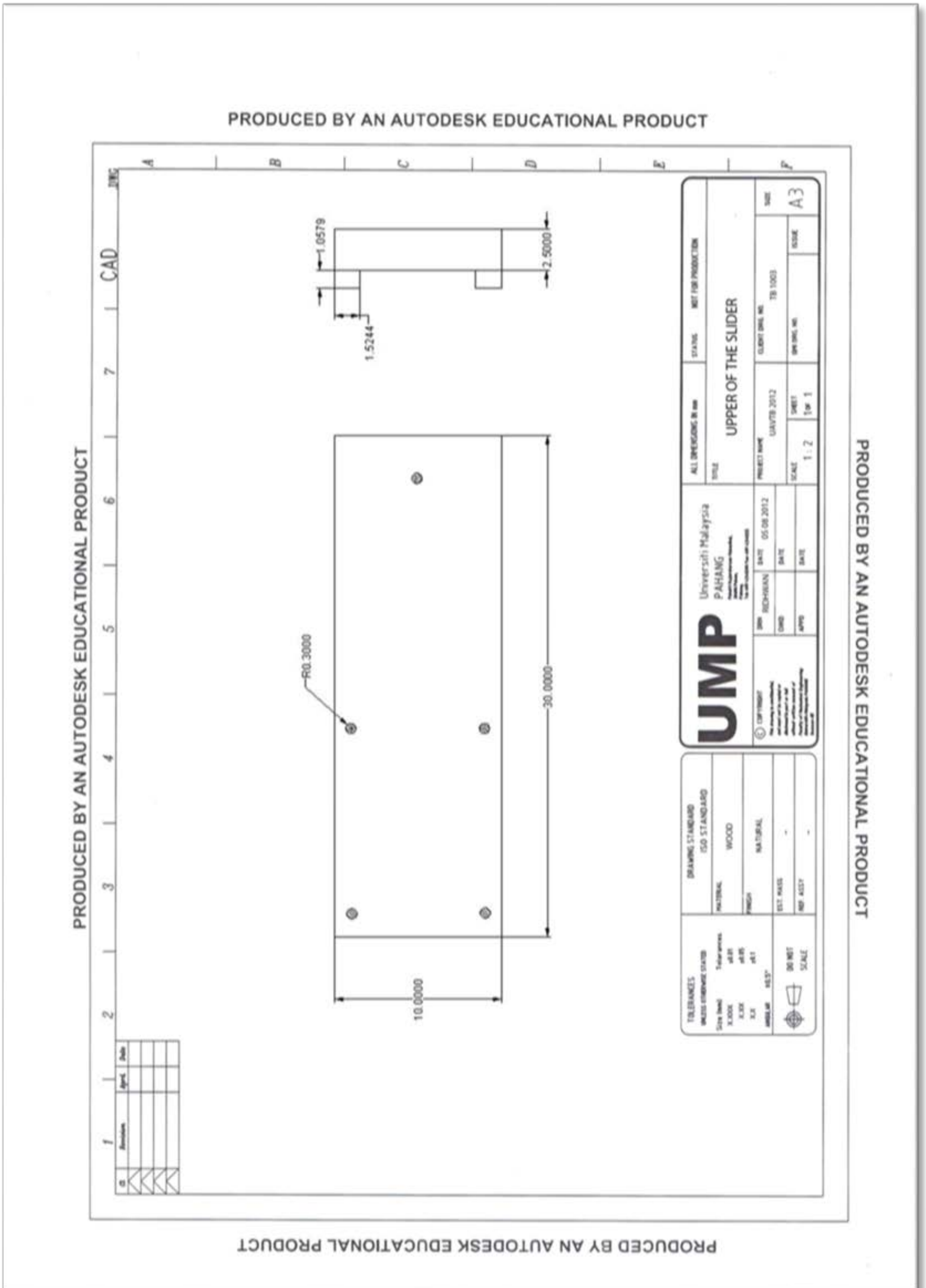
APPENDIX B2

Base of slider part drawing by using AutoCAD 2012.



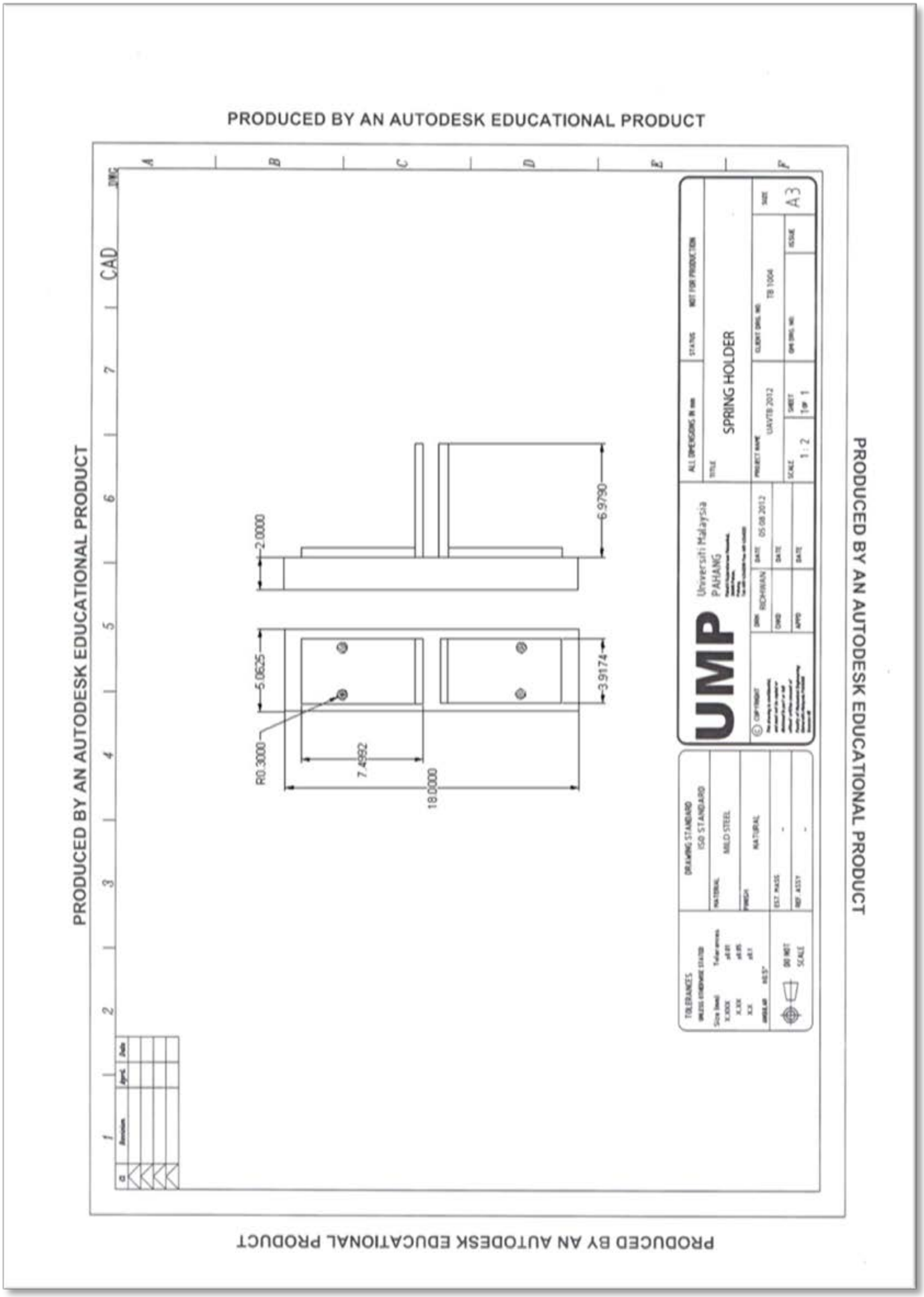
APPENDIX B3

Upper of slider part drawing by using AutoCAD 2012.



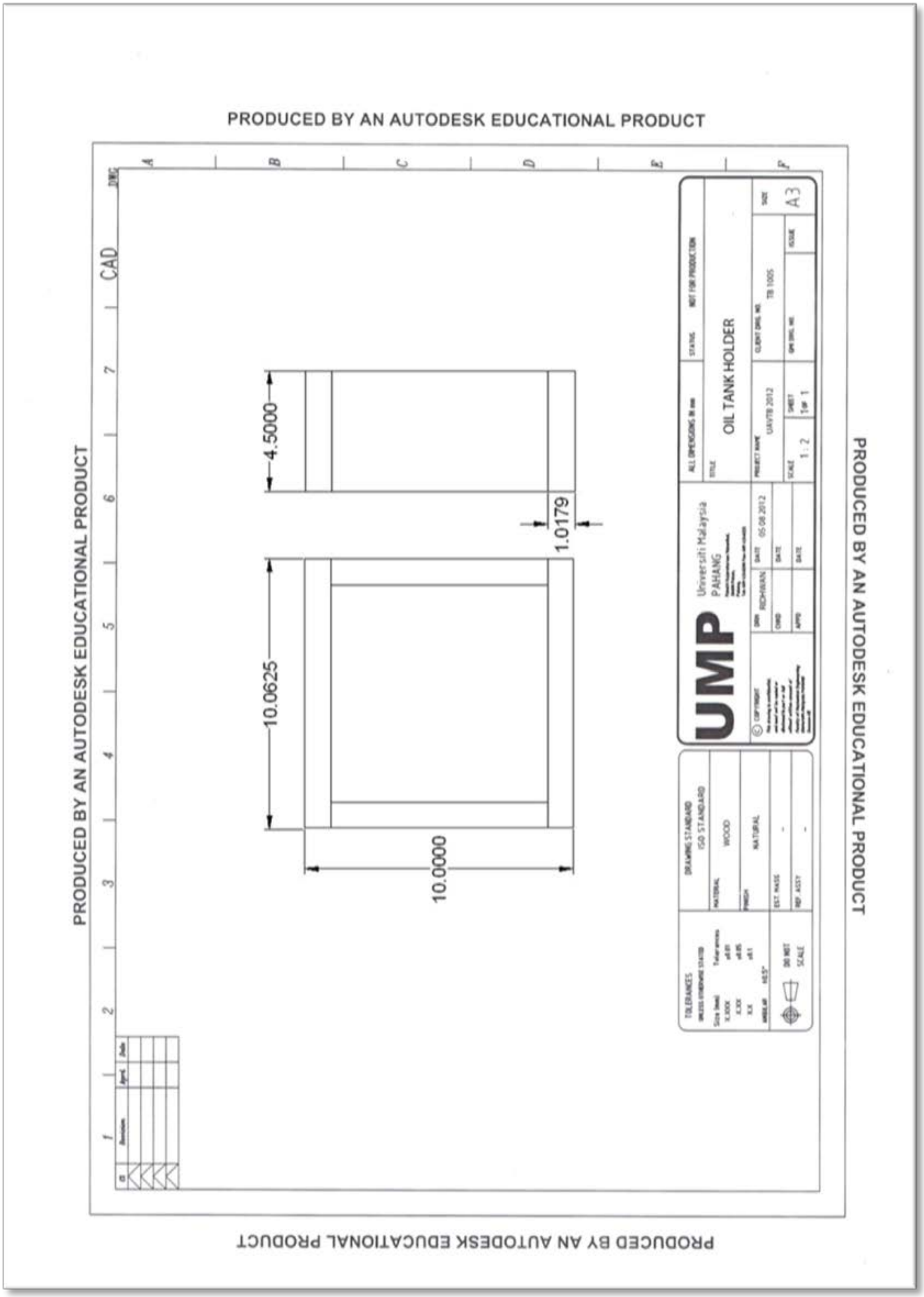
APPENDIX B4

Spring holder part drawing by using AutoCAD 2012.



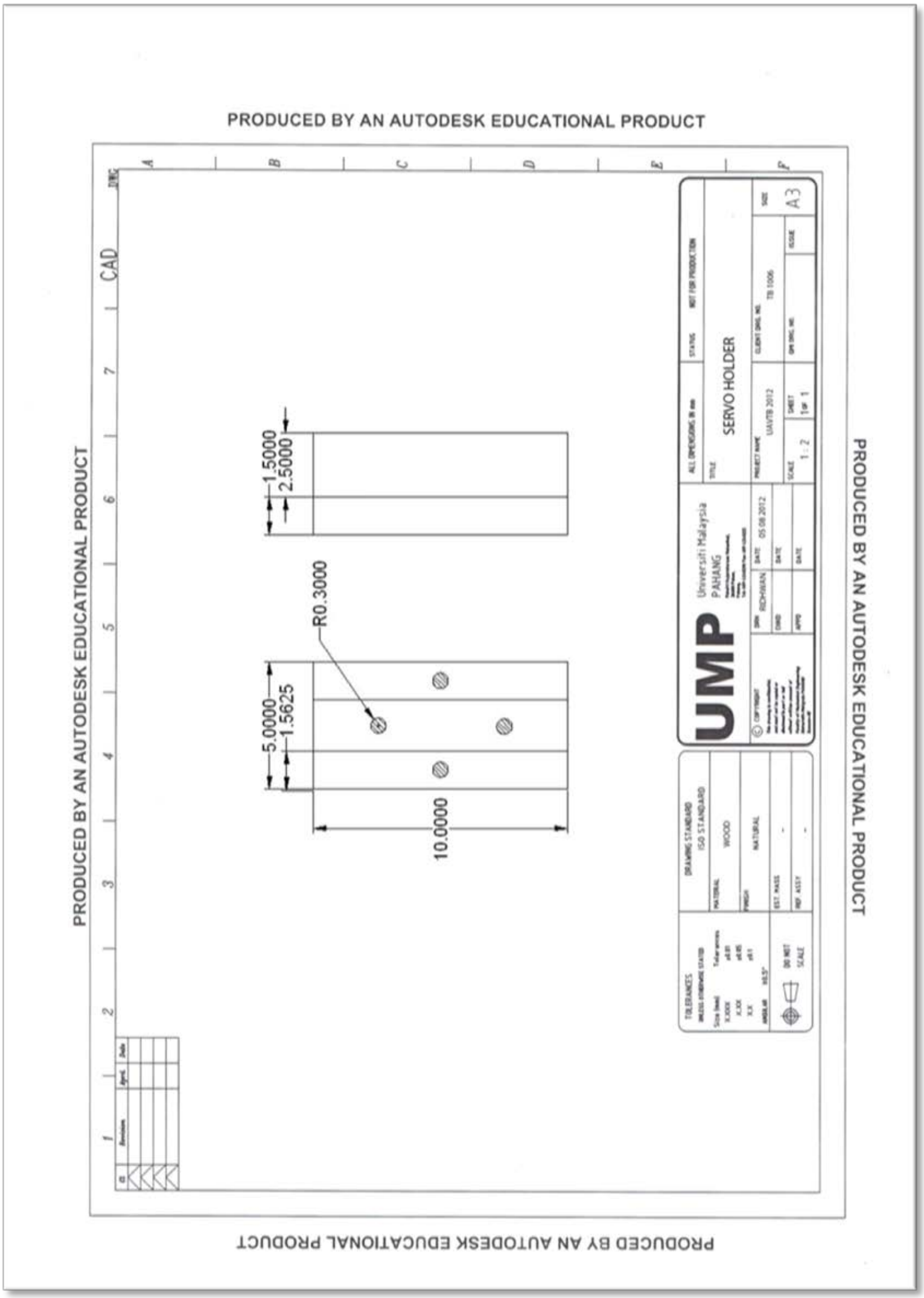
APPENDIX B5

Oil tank holder part drawing by using AutoCAD 2012.



APPENDIX B6

Servo holder part drawing by using AutoCAD 2012.



APPENDIX B7

Engine mount part drawing by using AutoCAD 2012.