FABRICATION OF A TEST BED FOR PERFORMANCE TESTING OF UNMANNED AERIAL VEHICLE (UAV) PROPULSION SYSTEM

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ABSTRACT

This project report has been conducted because of the Unmanned Aerial Vehicle (UAV) power plant development performance testing (static test) facilities is not fully deployed. The main purpose of this project is to fabricate a test bed for the UAV propulsion system. To test the capability of measuring aircraft performance namely thrust, available power, brake shaft power, propulsive efficiency, brake specific fuel consumption and thrust coefficient. In this study, the test bed model was designed to test the nitro engine Radio Control (RC) which is a model of Thunder Tiger PRO .36. The unknown value of parameters can be determined by reading the sensors. Some sketches software had been used such as Autocad and Solidwork to draft out the shape of the test bed. The fabrication process for this project must through a lot of process that must be followed step by step. This is to ensure that the design had been fabricated by following the design specification. From this experiment, the result shows that the fabricated test bed can be used to study the engine performance and performance parameters are directly proportional to the engine speed which mean the speed of the engine affects the increasing of the parameters. Some methods of improvement for the combination of test bed are also provided for further improvement of the test bed. As the conclusion, all the engine performance parameter can be calculated from the test bed.

ABSTRACT

Laporan projek ini telah dijalankan kerana di dalam Pesawat Udara Tanpa Pemandu (PUTP), pembangunan fasiliti untuk ujian prestasi (ujian statik) jana kuasa tidak dilaksanakan sepenuhnya. Tujuan utama projek ini adalah untuk memfabrikasi ujian katil untuk PUTP ujian sistem dorongan perlu untuk mengukur prestasi kapal terbang seperti teras, kuasa yang ada dan kuasa brek aci, kecekapan pendorongan,penggunaan bahan api brek dan kecekapan teras. Dalam kajian, model ujian katil yang direka untuk menguji enjin nitro Kawalan Jauh (KJ) iaitu model Thunder Tiger PRO .36. Prestasi nilai parameter boleh dikira dengan mengukur nilai yang tidak diketahui boleh didapati melalui bacaan sensor. Dengan menggunakan Auto-Cad dan solidwork, draf atau gambaran asal mengenai reka bentuk ujian katil dapat diihat dengan jelas. Proses mencipta melalui beberapa langkah yang perlu dituruti secara tersusun, ini adalah untuk memastikan hasil pembuatan akan mengikut spesifikasi rekacipta. 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. Idea penambahbaikan untuk alat uji katil juga disediakan untuk pembaharuan masa akan datang. Kesimpulannya, semua parameter prestasi enjin boleh dikira dari ujian katil ini.

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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
LVDT	Linear Variable Differential Transformer

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

The term UAV is an abbreviation of Unmanned Aerial vehicle, meaning aerial vehicles which operate without a human pilot. At first, UAVs are commonly used in both the military and police forces in situations where the risk of sending a human piloted aircraft is unacceptable, or the situation makes using a manned aircraft impractical. Now days, more advanced UAVs used radio technology for guidance, allowing them to fly missions and return. They were constantly controlled by a human pilot, and were not capable of flying themselves. This made them much like todays RC model airplanes which many people fly as a hobby. Modern UAVs are controlled with both autopilots, and human controllers in ground stations. This allows them to fly long, uneventfully flights under their own control, and fly under the command of a human pilot during complicated phases of the mission. Sometime, for specifics Unmanned Aerial Vehicle (UAV) mission, power plant performance is not fully deployed.

The mission used for the test is traffic monitoring and the test bed will be developed to conduct the testing. Test bed can be designed that will work with different types of engines, props and other equipment in the system. Engine performance will be evaluated according to engine type and size of the props used.

The purpose of study is to find the engine performance parameters such as force, available power, shaft brake power, propulsive efficiency, brake specific fuel consumption and thrust coefficient from the testing and to suggest suitable power plant.

1.2 PROBLEM STATEMENT

In Unmanned Aerial Vehicle (UAV) power plant development performance testing (static test) facilities is not fully deployed. Therefore, less information of the power plant performance can be measured which causes the limitation of the power plant selection. A test bed is required to measure operational characteristic performance of UAV propulsion.

1.3 PROJECT OBJECTIVES

The objectives of this project are listed as follows:

i. To fabricate a test bed for UAV propulsion system testing capable of measuring the following performance parameters:-

   a. Thrust
   b. Available Power
   c. Shaft Brake Power
   d. Propulsive Efficiency
   e. Brake Specific Fuel Consumption.
   f. Thrust coefficient.

ii. To design a set of data instrumentation system for data collection during experiment.

1.4 PROJECT SCOPE

The scope for this project are listed as follows:

i. Design the test bed by using design software namely Solidwork and Autocad.
ii. Materials selection for every part.
iii. Fabricate a test bed using the suitable materials based on the requirements of the project.
iv. Installations of the sensors system at the test bed such as anemometer and tachometer.
v. Evaluate and test to run the fabricated test bed for reliable operation.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, the discussion is more on about the engine test bed. The detail on existing engine test bed, materials used by others and design of the test bed. Some discussion about UAV propulsion system is conducted on this chapter. 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, brake specific fuel consumption and thrust coefficient. The idea for pilotless drones began almost as soon as planes were invented. During World War II, the US built several drones. UAV’s were used to spy on the enemy during the Vietnam War. As the US became involved in wars in the Middle East in the 1990s and 2000s, it added several advanced types of UAVs to its fleet of aircraft. The technological objective of UAVs is to serve across the full range of missions cited previously. UAVs present several basic advantages compared to manned systems that include better maneuverability, lower cost, smaller radar signatures, longer endurance and minor risk to crew (Rogelio Lozano, 2007). 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 TEST BED

An engine test bed is a facility used to develop, characterize and test engines. The facility, often offered as a product to automotive original equipment manufacturer, allows engine operation in different operating regimes and offers measurement of several physical variables associated with the engine operation.

A sophisticated engine test bed houses several sensors (or transducers), data acquisition features and actuators to control the engine state. The sensors would measure several physical variables. Information gathered through the sensors is often processed and logged through data acquisition systems.

The main application of an engine test bed is for research and development of engines, typically at an original equipment manufacturer laboratory. Automobile original equipment manufacturers are usually interested in developing engines that meet the following objectives:

i. To provide high fuel efficiency
ii. To improve drivability and durability
iii. To be in compliance to relevant emission legislation

2.3 EXISTING ENGINE TEST BED.

2.3.1 VMAR Engine Test Bed.

This stand has the flexibility to work with engines that range from .09 to 1.80 cubic inches two and four stroke engines. It offers infinite adjustments to the mounting rails, fuel tank position, and throttle control. The price of this test bed is $17.95. Some of the features on this test bed were the clamp-style engine mounting rails which make it easy to quickly change from one engine to another. The mounting rails are constructed from aluminum and are attached with high quality socket head cap screws.

VMAR Engine test bed can adjust the height of the fuel tank to match the centerline of the carburetor. This helps break in the engine without worrying about rich or lean conditions with regard to the tanks position. Basically, materials that use in this product are wood, plastic and steel.

Another nice feature is the remote throttle arm. It has a pushrod that can easily be connected to the throttle arm. When set the proper RPM's of the engine, tighten the wing nut to maintain that setting. To use the mount, simply attach the engine to the stand and adjust the clamp bolts to the correct holes. Then, connect the fuel lines and throttle arm.

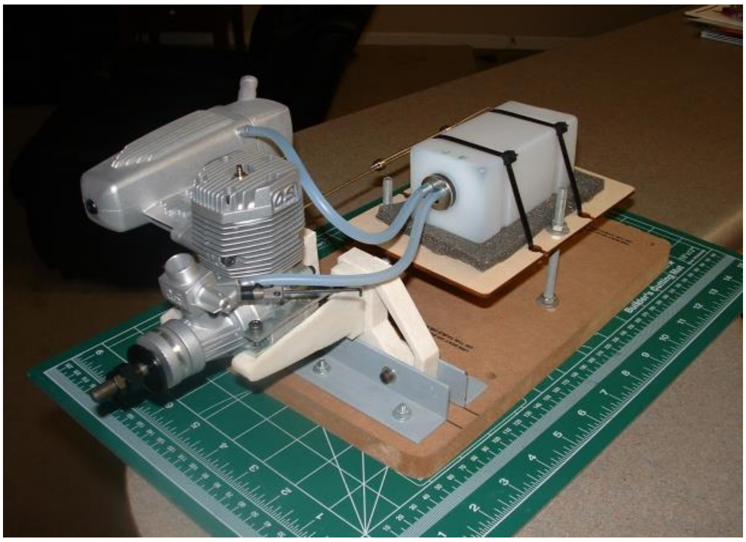

Figure 2.1: VMAR Engine Test Bed.

Source: http://rcgroup.com, (2003)

2.3.2 PSPMGS Engine Test Bed.

The PSPMFG Engine Test Bed is the most versatile and safe stand on the market. PSPMFG Engine Test Stands will accept a very wide range of engines, from the small .10 size to 2.0 cubic inches. Often overlooked is the importance of the relationship between the height of the needle valve and the centreline of the fuel tank, which is needed to obtain optimum setting for the engine. With this variable height fuel tank support this has now been made quick and easy. Also included is a whopping 14oz. (420cc) Slec Maxi Fuel Tank so that the user not constantly having to fill up. To make things safer, this product has also fitted the

Fuel Tank support with a throttle control cable so as to keep fingers away from the prop. The price of this test bed is $56.99. Same with the VMAR Engine Test Bed, the materials used in this product are wooden, steel and plastic.

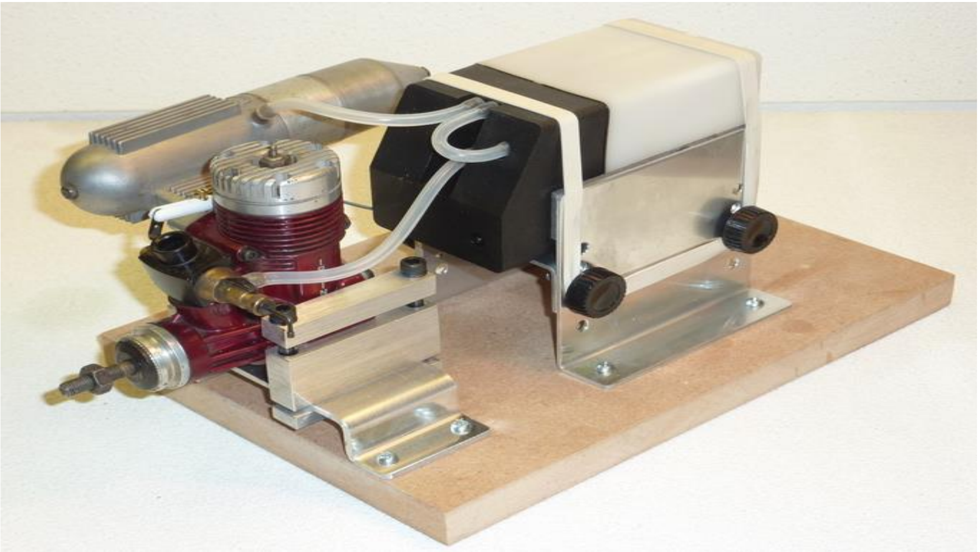

Figure 2.2: PSPMGS Engine Test Bed.
Source: http://rcgroup.com, (2003)

2.4 REQUIREMENT FOR TEST BED DESIGN

In this study, parameters that can be measure is the engine performance such as thrust, available power, shaft brake power, brake specific fuel consumption, propulsive efficiency and thrust coefficient. 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.

2.4.1 Thrust of The Engine

Thrust is the driving force that propels an aircraft, helicopter, missile or rocket forward. An UAV propulsion system is simply a device that converts power into thrust to propel an aerospace vehicle. It is known that the performance of an aircraft engine is heavily dependent on the thrust it produces. Thrust is generated from the change in the momentum of the working fluid as a direct result of motion across the surface of the propeller. Torque results from the rotation of the propeller blades as a consequence of the engine power output. Any change in engine power output brings about a corresponding change in torque, which in turn affects the thrust and hence, the overall aircraft performance through the wind speed. 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).

From Newton's second law of motion, we can define a force F to be the change in momentum of an object with a change in time. Momentum is the object's mass m times the velocity V. According to the basic momentum theory, the propeller is reduced to a rotating disk that imparts axial momentum to the air passing through it. For the purpose of this discussion the air is incompressible. For reference, consider section 0 (far upstream), 1 (just upstream the disk), 2 (just downstream the disk) and 3 (far downstream), as shown in Figure 2.9 (Mike Tooley, 2000).

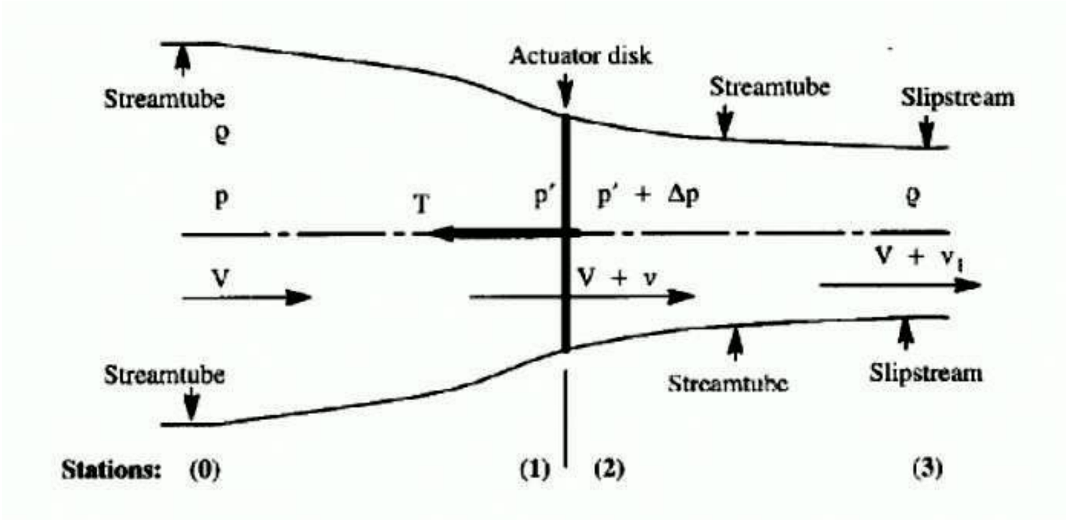

Figure 2.3: Control volumes surrounding a propeller

Source: Mike Tooley, (2000)

The theory assumes that there is no flux along the limiting streamlines and that the velocity is continuous through the propeller. The free stream velocity is equal to the speed $V_0 = V_e$. 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.

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 32 to 40 trainer engine is a 10-5. 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.

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).

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

Where,

$\dot{m}_e$ is the air mass flow at exit(kg/s).

$\dot{m}_o$ is the air mass flow at inlet (kg/s).

V_o is the air velocity at inlet (m/s).

V_e is the air velocity at exit (m/s).

By using the measured thrust, the next calculation will reflect more accurately the actual situation the engine. For this study, assuming that the force is the same as the spring force constant as the applied if the displacement of the spring is combined. It is marked by k. Consider force F stretches the spring so that it change the equilibrium position x. Force can be measure by a simple equation known as Hooke's law as Eq. (2.2).

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

Where,

k is spring constant (N/m)

x is elongation of spring during testing (m).

Hence, in term to measure the thrust exerted by propeller while the engine start, the spring was placed between the spring holders at the base with rear sliders. The value of spring constant, k already knew and the value of elongation of spring can be obtained from the linear variable differential transformer (LVDT) reading.

2.4.2 Available Power and Shaft Brake Power

Aircraft propulsion consists of two distinct parts. There is the engine that converts a source of energy, such as fuel, to work. Then there is the part of the system that converts the work of the engine into work on the surrounding environment to produce propulsion. The most obvious example is a propeller. A piston engine and propeller combination is an example of a complete aircraft propulsion system. Looking at the propulsion system from the standpoint of power, it is convenient to introduce a few terms. That power is required for flight: for supporting the weight of the airplane, for climbing, for turning or accelerating. This is the required power for flight. The power that is actually produced by the engine and delivered to the propeller will call the engine power (Anderson, 2001).

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).

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

Where,

F_N is the force exerted by propeller (N).

$\dot{m}$ is the mass flow rate air (kg/s).

The term brake shaft power is used to specify that the power is measured at the output shaft, this is usable power delivered by the engine to the load. The equation of shaft brake power can be simplified as shown in Eq. (2.4).

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

To solve mathematical equations, then need to find the speed of the air before and after the propeller. Hence, the anemometer is used to get the speed of air 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.

2.4.3 Propulsive Efficiency

Aircraft propeller change rotary motion from piston engines, turboprop or electric motor to provide propulsive force. They may be fixed pitch or variable. At first, the propeller made of solid or laminated woods. After that, the fan blades are made using metal. Based on the performance of the engine that was created on the rise, the use of composite materials of high technology in the design of the fan is good innovation. The fan is usually attached to the piston engine's crankshaft, either directly or through the reduction.

The propulsion efficiency is defined as the ratio of the thrust –power (power generated by the thrust force F at a speed V) and the rate of the production of propellant kinetic energy.

As state by (Ward, 1966), Figure 2.4 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.

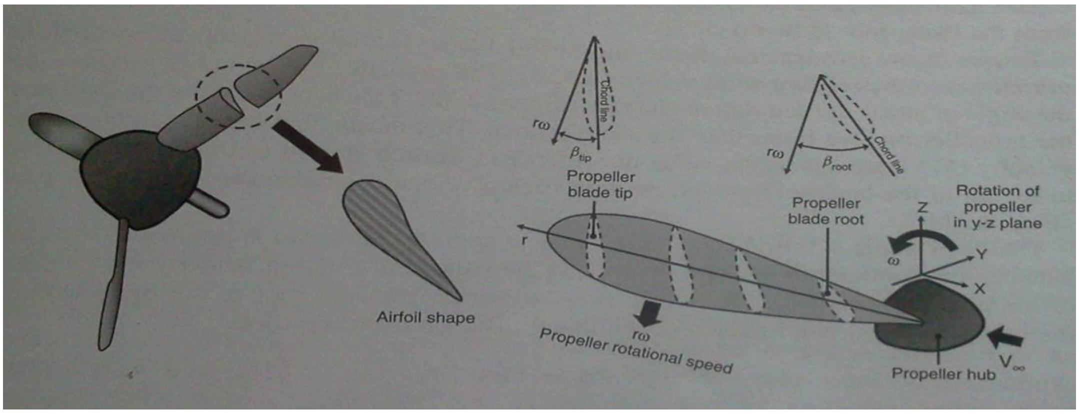

Figure 2.4: Cross-Section of a propeller

Source: Ward, (1966)

It is defined as the ratio of the power transmitted to the flight vehicle and the rate of kinetic energy generation. In this study, 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,

$\dot{W}_A$ is the available power (W)

$\dot{W}_B$ is the shaft brake power (W)

η_{prop} is the propulsive efficiency (rps).

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. Typical values for propulsive efficiency range from 0.8 to 0.9 although lower and higher efficiencies are possible. How the efficiency of a propeller is determined by its design characteristics (diameter, blade geometry, number of blades, blades angle and r.p.m).

2.4.4 Brake Specific Fuel Consumption

Specific fuel consumption is the ratio that compares the fuel used by the engine to the amount of power the engine produces. Specific fuel consumption allows manufacturers to see which engine use the least fuel while still producing high amount of power. It allows engines of all different sizes to be compared to see which is the most fuel efficient.

If the specific fuel consumption is determined on the basis of indicated power, it is called the indicated specific fuel consumption (ISFC), while of it determined on the basis of brake power, it is called the brake specific consumption (BSFC).It is inversely proportional to the thermal efficiency of the 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.

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

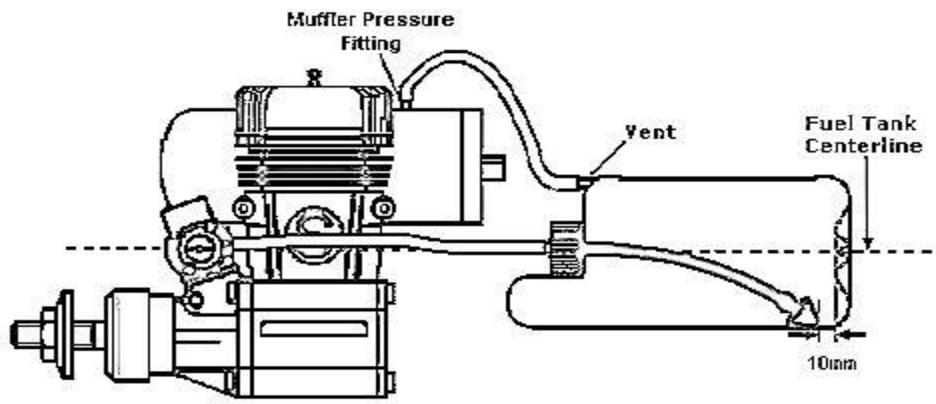

Figure 2.5: Fuel tank placements

Source: Adam, (2003)

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.

A lower number equals a higher efficiency because the engine is creating a high level of power while using a low amount of fuel. Diesel engines typically perform better than gasoline engines in term of BSFC.

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).

$$BSFC = \frac{\dot{m}_{fuel}}{\dot{W}_B} = \eta_p \frac{\dot{m}_{fuel}}{\dot{m}_A} \quad (2.6)$$

Where,

$\dot{m}_{fuel}$ is the mass flow rate of fuel.

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.

2.4.5 Thrust Coefficient

By consider two additional performance parameters, in addition to propeller propulsive efficiency, that are often charted with respect to advance ratio for a propeller with a given number of blades. Given that force in the propeller context is the product of dynamic pressure and area, one can produce the following correlation for thrust coefficient, C_f:

$$C_f = \frac{F_N}{\rho \eta_{prop}{}^2 d^4} \quad (2.7)$$

Where,

C_f is thrust coefficient.

ρ is the density of air (kg/m^3)

d is the diameter of a circular disk formed by rotating propellers (m).

The unknown that needed to get the value of thrust coefficient are density of air and diameter of a circular disk. The density can be measure by reading the anemometer. The measuring tape is used for determine the diameter of a circular disk.

2.4.6 Performance Parameters Identification

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: Summary of the performance parameters

No.	Performance Parameters	Equation	Parameter to be measured
1	Thrust	$F = kX$	X
2	Available Power	$\dot{W}_A = F_N V_o = \dot{m} V_o (V_e - V_o)$	V_e , V_o
	Shaft Brake Power	$\dot{W}_B = \dot{m} \frac{V_e^2}{2} - \frac{V_o^2}{2}$	V_e , V_o
3	Propulsive Efficiency	$\eta_{prop} = \frac{F_{N, prop} V_o}{\dot{W}_B} = \frac{\dot{W}_A}{\dot{W}_B}$	V_o
4	Brake Specific Fuel Consumption	$BSFC = \frac{\dot{m}_{fuel}}{\dot{W}_B} = \eta_p \frac{\dot{m}_{fuel}}{\dot{m}_A}$	$\dot{m}_{fuel}$
5	Thrust Coefficient	$C_f = \frac{F_N}{\rho \eta_{prop}^2 d^4}$	n_{prop}, d

2.5 SUMMARY

In this chapter, the discussion is more on the others model of test bed have done. The detail on requirement parameters for the test bed will be used. The engine performance parameters such as thrust, available power, shaft brake power, propulsive efficiency, brake specific fuel consumption and thrust coefficient can determined from mathematical equations. The unknown can be obtained by data given by the apparatus used such as spring, linear variable differential transformer (LVDT), anemometer, and tachometer that are installing within the test bed design.