PERFORMANCE CHARACTERISTICS MONITORING OF TURBOPROP ENGINE FOR THE DEVELOPMENT OF PRELIMINARY REQUIREMENT OF AN ENGINE TESTING FACILITY

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ABSTRACT

Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia (UTHM) has acquired a Pratt and Whitney PT6A-20 turboprop engine to be used in its aeronautical engineering technology programme. However, to fully utilize the engine, a solid familiarity with its current performance and a proper testing arrangement are important. The main concern on the engine is the age of the engine and lack of information on its previous performance. Therefore, in this study, the actual performance of this turboprop engine was evaluated experimentally. The performance evaluation is also important for the development of preliminary requirements for the engine test cell. A better performance investigation and testing can be conducted in an engine test cell. Altogether, a total of three engine tests were performed by varying engine speed from 55 percent rpm to 75 percent rpm. Performance data obtained include the engine's torque, propeller speed, fuel flow rate, and inter-turbine temperature. They were captured by using data acquisition software from AeroTrain Corp. An averaging was done to the data in order to study engine shaft horsepower, specific fuel consumption, and thermal efficiency. From the result of manual calculation, the engine can produce power up to 34.8 kW while running at 75 percent rpm. The specific fuel consumption is 7.07 kg/kW-hr while the thermal efficiency is at 1.19 percent. On the other hand, the data acquisition system shows that the engine managed to deliver 89.5 kW of power, 3.15 kg/kW-hr of specific fuel consumption and thermal efficiency of 19.5 percent. It was found that the results of manual calculation were significantly lower than the one obtained using the software with 88 percent different in shaft horsepower and 77 percent different in specific fuel consumption. Although the current engine performance is acceptable and satisfactory to be used for aircraft propulsion education, a safer and more reliable testing arrangement is still needed. Considering

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that a proper test facility will be essential to obtain a highly accurate result on the engine performance, an engine test cell was proposed to be built. The test cell was proposed to be an indoor test cell and it was planned to accommodate engine testing on small turboprop engine with power range between 200 to 450 kW.

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CHAPTER 1

INTRODUCTION

1.1 Research background

In today's world economy, as the fuel prices soared it crippled the airline industry whereby the need to have a more reliable, cost effective engine with less fuel consumption has become essential for the industry to sustain as well as to maintain their profit. As such, the industry is now eyeing for turboprop engines as these engine offer an efficient alternative to other turbine engines such as turbojets and turbofans that consume more fuel compared to the turboprops.

Turboprop engines are a particular type of aircraft powerplant that uses a gas turbine to drive a propeller. The propeller is coupled to the turbine through a reduction gear that converts the high revolution per minute, low torque output to low revolution per minute and high torque. In a turboprop engine, almost all of output powers are being used to drive the propeller while only some is used to drive a compressor. However, in comparison to other turbine engines, the turboprop engine's exhaust gases contain little energy and only play a minor role in the propulsion of the aircraft. Moreover, when the Mach number increases, more fuel is needed by the engine. For this type of engine however, it has been proven to be the most efficient engine for aircraft operating at low speed, of about 480 – 720 km/hour, and in a short field takeoff. It also performs well at an altitude below 10,000 m. In general, turboprop engines are used on small subsonic aircraft and the most common application of turboprop engines are in civilian aviation mainly that of small commuter aircraft.

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For instance, in Malaysia the Malaysia Airlines (MAS) through its subsidiaries, Firefly and MASWings, are now equipped with turboprop powered aircrafts to cater for their respective short haul routes. For example, MASWings is operating with 10 ATR 72-500 aircrafts to accommodate air travel demands in Sabah and Sarawak. As for the Firefly, they are planning to double the current fleet from 7 to 14 ATR 72-500 aircrafts by 2012 (Emmanuel, 2010). All these aircrafts are equipped with two powerful Pratt and Whitney PW-127F turboprop engines which each engine delivering power up to 2,051 kW.

As for the ATR, it is said to be five times quieter than Fokker 50; the previous fleet used by MASWings. It is also 60 percent more fuel efficient than the 70 seater jets and more environmentally friendly as it emits 50 percent less carbon dioxide compared with jets ("ATR to play major role in domestic air services," 2010). The decision of these two airlines to opt for ATR aircraft looks likely to decrease their cost on maintenance and operation while not compromising their customer comfort. From this, it also shows that there is a demand for turboprop engine powered aircraft in serving regional areas where speed is not a major concern.

Another example of the application of turboprop engines is that they are being used to power light trainer aircrafts. Its usage can imitate the handling characteristics of jet aircraft and at the same time still offering sufficient performance to access a pilot's technical ability during flight. Examples of such trainers include single-turboprop engine like Pilatus PC-9, Embraer EMB 312 Tucano, and Beechcraft T-6 Texan II.

From the market projections, a promising future for turboprop engine is expected as more short and medium range aircraft will require turboprop as their engine (Banach & Reynolds, 1984). Besides, more maintenance experts will be needed to look after this engine. Therefore, in order to cater the demand for more aircraft maintenance engineers as well as pilots, Universiti Tun Hussein Onn Malaysia (UTHM) is now offering engineering programmes in aeronautical. These programmes comprise of two main programmes consisting of professional flight training and aircraft maintenance training. To support the flight training programme, UTHM has been planning to acquire a few trainer aircrafts. As for the maintenance programme, a hands-on working experience with a real aircraft engine has been planned for the students given that it is important for them to gain more

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confidence as well as better perceptive on the maintenance procedures to attend specific engine problems. In addition, UTHM has purchased a runnable, full-sized turboprop engine to be used not only for teaching and learning purposes, but also to encourage research interests and activities that relate to aircraft powerplants.

Fully utilization of this engine will require a test facility to be built to handle various testings on the engine. The test facility will complement the aircraft engine that has been acquired. Moreover, many of the higher learning institutions in the United States, United Kingdom and Europe already have the capability to provide jet engine experimental facility for their aeronautical engineering education. This type of facility is considered important for academic purposes and it is understandable that it may require high cost. There are a lot of the reported studies were conducted on a small scale engine test bed and microjet engine as both technology are considered robust and affordable (Juste, Montanes & Velazquaz, 2009). It shows the effort of universities abroad in delivering hands on approach to their students, with a type of complex aerospace engineering system that otherwise, the would only encounter in books.

Furthermore, in an article by Joshi (2003), he emphasized the strong competition between aerospace industry in the United States, Europe and Japan and argued for the need to evolve the aerospace engineering education in preparing professionals for this industry. By acquiring the turboprop engine, it also shows that UTHM is determined in producing well trained professionals who are able to generate significant contribution when they join aerospace industry.

1.2 Problem statement

A turboprop engine is essential for aeronautical laboratory in aeronautical engineering education to further enrich students' knowledge in aircraft propulsion. In order to serve this demand, a safe, stable and reliable engine operation is considered important. Therefore, a good knowledge on the engine performance is a vital. Beside that, the primary concern with utilizing the Pratt and Whitney PT6A-20 is the age of the engine. As for the time being, the exact real performance of this old, refurbished engine owned by UTHM is still unknown. This is mainly due to the

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lack of information that explains the current performance of this engine when it was received by UTHM. There is a possibility that the engine performance might have degraded as it has been in service for a long time but the engine comes with no documentation that provides details on its performance. Hence, there is a pressing need for conducting performance evaluation as it is essential to assess the current condition of this engine and to have a solid familiarity with the engine before further improvement or any other research activities can be done.

Besides, a test facility that is suitable and safer for educational purpose as well as able to provide reliable engine testing is presently not available in UTHM. Although this type of facility is available in Malaysia, it is located far from UTHM and the access is limited. As a preliminary step, this research is also essential in proposing a suitable facility for a real-life operation of the propulsion system of an aircraft especially those powered by turboprop engines. In future, experimental studies concentrating on aircraft engine performance within a proper test facility can be conducted to support and validate analytical assumptions and approximations made by computational methods. As a result, the design of the current UTHM turboprop engine can be improved and optimized.

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1.3 Objective of the study

The objective of this study is to determine the following:

(i) to investigate and assess the current performance of a turboprop engine

(ii) to build the preliminary requirement for the development of a laboratory scale engine testing facility

1.4 Scope of the study

An understanding of the current performance of this turboprop engine will lead to a deeper understanding on the impact of its performance on the procedures that need to be considered in order to develop an engine testing facility in UTHM. Therefore, the scopes of this study have been outlined as follow:

(i) Identify and compare different types of aircraft engine that usually used to power aircrafts.
(ii) Perform engine testing on UTHM's Pratt and Whitney PT6A-20 turboprop engine to investigate its performance.
(iii) Monitor engine testing and data acquired to find abnormalities.
(iv) Analyze data to ensure it can perform up to the manufacturer's specifications.
(v) Observe an engine testing and test cells at AIROD Sdn. Bhd.
(vi) Evaluate critically the various types of engine test cell available for aircraft engine testing.
(vii) Propose suitable test cell for current turboprop engine and its variance as well as the testing requirements to perform engine performance testing and evaluation.

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1.5 Thesis outline

This thesis is divided into five chapters. The first chapter provides an introduction and the motivation for selecting turboprop in this study. The second chapter presents the background material necessary to elaborate on the comparison of turboprop engine with other types of aircraft engines. It also explains the various types of test facilities that are available in order to perform engine testing. Therefore, this chapter is important so as to benchmark current aircraft engine performance research available in the literature today. The third chapter delineates the method used to achieve the research objective together with the theory behind the experimental setup and the implementation of the method. Next, in the fourth chapter, it describes the obtained results relating to the main objective of this research together with the recommendations for the engine testing facility. Finally, the conclusions as well as future works are given in the fifth chapter.

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CHAPTER 2

LITERATURE REVIEW

2.1 Aircraft engine overview

Over time, different types of aircraft engines have evolved and they are categorized into two main types namely piston and gas turbine engines. The piston engines which also known as reciprocating engines, have been used since the earlier stage of aviation industry and were the only aircraft engines used until the first introduction of gas turbine engine in 1939. Although they are still in use today, the engine is limited only to private single and twin engine aircraft. As for the turbine engine, it is now powering almost all commercial and military aircraft. This type of engine can be subcategorized to turbojet, turbofan and turboprop engine. Further details on the working principle, configuration as well as the comparison between all these engines will be explained in the following section.

2.1.1 Turbine engine and piston engine working principle

Although the construction of the turbine engine is different from the conventional piston engine, both are using the same basic principle of operation. Both engines develop power or thrust by burning a fuel-air mixture and convert the energy of expanding gases to propulsive force. They are called heat engines due to their utilization of heat energy to produce power for propulsion.

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In the piston engine, the heat is used to expand a combination of gases thus creating a pressure against a piston in a cylinder. This piston causes the crankshaft which connects to the propeller of the aircraft to rotate in order to produce power.

On the other hand, the turbine engine uses the heat to expand the gases, causing a great increase in the gases velocity. The high velocity of gases is then directed through a turbine which rotates and extracts some of the gas's energy to produce shaft power to drive a compressor. The remaining hot gases disperse from the engine through the nozzle with a high velocity to generate thrust to move the aircraft forward.

The piston engine is similar to a turboprop engine; a turbine engine which is also powered by a propeller. In both propeller-powered aircraft, much of the thrust is created by the propeller that creates the forward thrust for the aircraft.

2.1.2 Comparison between turbine engine and piston engine

In comparison, a piston engine is limited by the altitude and speed to which it can climb as it can only fly at much lower Mach number of below 0.3. At a higher altitude, the density changes where it becomes thinner as it is not as rich in oxygen as the dense air found at a lower altitude or sea level. Since the amount of air that enters the cylinder decreases, the piston engine efficiency to burn fuel is decreases as well. For the turbine engine, the situation is different as there is a large amount of air available for combustion. In general, by comparison the air to fuel ratio for the piston engine is smaller than the turbine engine, hence it cannot efficiently burn the fuel at high altitudes.

In a piston engine, the thrust required for the aircraft to move forward is provided by its high speed rotating propellers. Since the thrust developed by the piston engine is limited, the engine is not suitable to be used in aircraft that requires high speed and thrust. Hence, aircraft powered by piston engines are ideally suited for short-range flights, like flying a few passengers or light cargo load when compared to turbine powered aircraft which is well suited for long-range flights.

In contrast to the piston engine, the turbine engine has the ability to develop greater thrust per unit weight which directly leads to better payload and range.

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Therefore the size is smaller than a piston engine with the same capacity. An increment in output power will increase the weight and frontal area of the piston engine far more rapidly than it does for the turbine engine (Walsh & Fletcher, 2004). In addition to that, it also has a greater thrust per unit cross-sectional area than its piston engine counterpart (Hill & Peterson, 2010).

In terms of fuel efficiency, a study done by Peeters et al. (2005) shows that the energy efficiency of the last piston-powered aircraft which was developed in early fifties appeared to have had the same energy efficiency per available seat-kilometre as average modern turbine aircraft. This interesting finding also states that the last piston-powered aircrafts were at least twice as fuel-efficient as the first jet-powered aircraft which was developed in the early sixties. Meanwhile, in terms of runway requirement, a piston engine powered aircraft requires a shorter runway than a turbine-powered engine. However, in terms of reliability between these two, turbine engines offer greater reliability since they lack reciprocating parts. A summary of all the comparisons between the piston engine and the turbine engine is presented in Table 2.1.

Table 2.1: Comparison between turbine and piston engine

Characteristics	Turbine Engine	Piston Engine
Altitude	High	Low
Speed	High	Low
Fuel consumption	More fuel	Less fuel
Reliability	More reliable	Less reliable
Range	Long	Short
Runway requirement	Long	Short

2.2 Types of turbine engines

The differences between each type of turbine engines lies in the type and arrangement of their core components. Sometimes a fan or a propeller may be added and this will change the overall performance of the engine and therefore, are put to different uses. The most common turbine engines used by aircraft are turbojet, turbofan, and turboprop. Table 2.2 presents the advantage and

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disadvantage of these engines, together with examples of actual aircraft and engines utilized.

Table 2.2: Advantage and disadvantage of each type of turbine engine (Walsh & Fletcher, 2004)

Engine Type	Advantage	Disadvantage	Example
Turbojet	• Simple design • Low specific weight per unit thrust • Small frontal area leads to less drag • Efficient at supersonic speed and high altitude	• High thrust-specific fuel consumption • High noise level	• General Electric GE J79 for F-4 Phantom II • Rolls-Royce/Snecma Olympus 593 for Concorde
Turbofan	• High thrust even at low speed • Low thrust-specific fuel consumption • Lower noise level • Less flow separation at high speed • Less trouble with shock developing • Efficient at subsonic speed	• Complex design with more component section in an engine • Big frontal area	• Pratt & Whitney JT9D for Boeing 737 • General Electric GE90 for Boeing 777 • Rolls Royce Trent 900 for Airbus A380
Turboprop	• High fuel efficiency • High take off thrust • Shorter runway for takeoff and landing • Highest propulsive efficiency at low speeds	• High noise level and vibration • More complicated design and heavier • Tend to have flow separation and shock at high speeds • More moving parts	• Pratt & Whitney 125B for Fokker 50 • Pratt & Whitney PT6A-45R for Cessna Caravan

2.2.1 Turbojet engine

The turbojet, consisting of an inlet, engine core components and a nozzle, has the most basic configuration of turbine engines (Figure 2.1). This engine was the first real successful turbine engine and it was first developed in the early 1930s and started to power aircraft in the 1940s (El-Sayed, 2008). Because of superior thrust/weight ratios, the turbojet engines were used to replace the traditional piston engines, which led to longer ranges, higher payloads and lower maintenance costs.

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However, in an area where greatest fuel economy, higher reliability, low noise level, a long endurance and service life are in concerned, the early turbojets were not suitable (Mattingly, 1996).

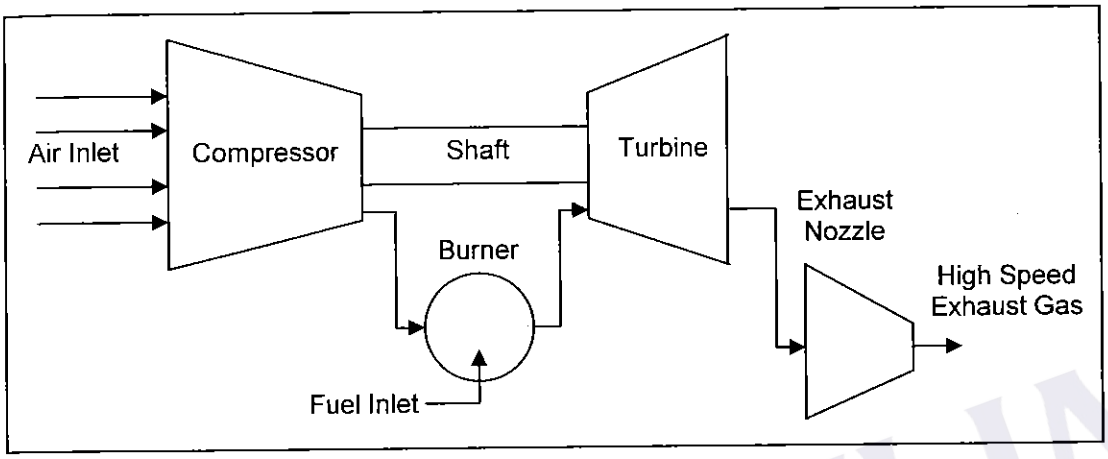

Figure 2.1: Turbojet engine (Hill & Peterson, 2010)

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2.2.2 Turbofan engine

A turbofan engine may be considered a compromise between a turbojet and a turboprop engine. Its component arrangement includes a large set of fan blades in front of the inlet that works like a propeller to draw an additional air for the engine (Figure 2.2). Considering its advantage at flying at subsonic speed, this engine is usually installed in commercial aircraft as shown in Figure 2.3. This engine has two streams of flowing air; the primary stream flows through the core of the engine like a turbojet, while the secondary stream passes through the fan and flows around the core of the engine. The turbofan engine accelerates a smaller volume of air than the turboprop but a larger volume than the turbojet for a higher propulsive efficiency as illustrated in Figure 2.4. In comparison with turbojet engines, the turbofan engines have a much better performance as well as lower thrust specific fuel consumption which makes them more fuel efficient and economical especially at low power level, low speed, and low altitude. However, the frontal area of the turbofan engine is larger than the turbojet, which leads to greater drag and weight (El-Sayed, 2008).

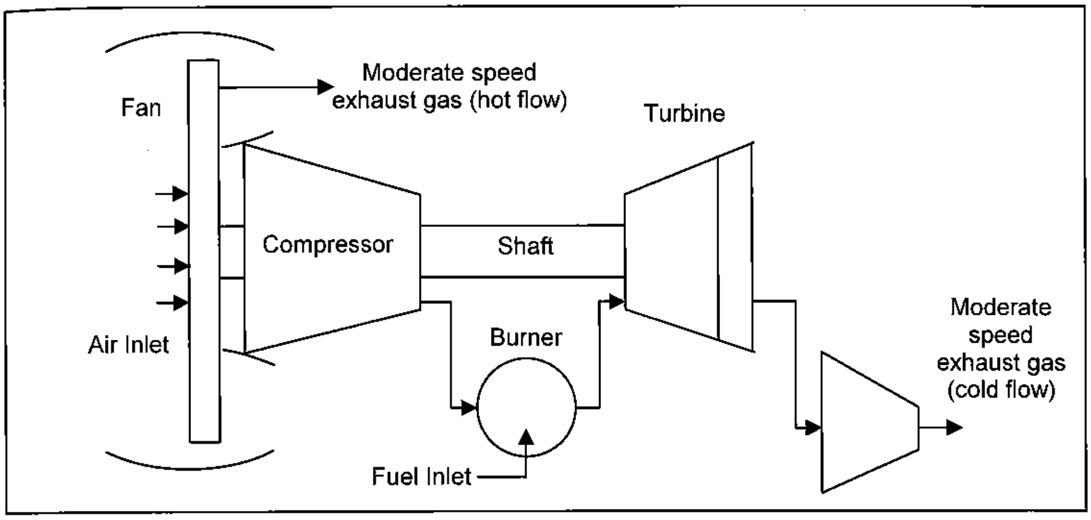

Figure 2.2: Turbofan engine (Hill & Peterson, 2010)

Figure 2.3: One of four Rolls Royce Trent 900 turbofan engines fitted to Airbus A380 (http://www.aviationearth.com/aircraftdata/a380.html)

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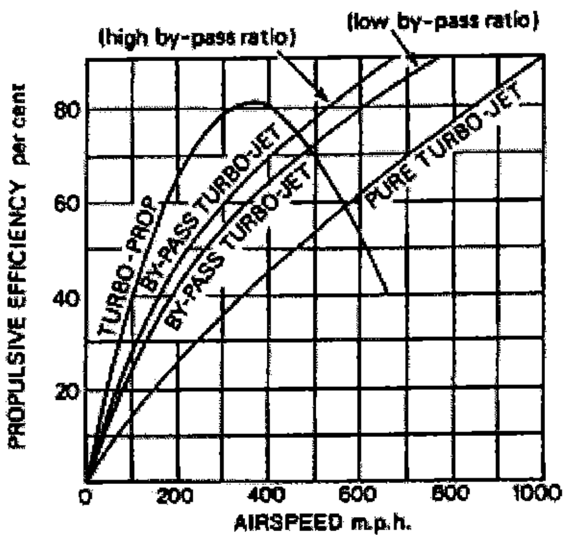

Figure 2.4: Propulsive efficiency comparison for various turbine engine configurations (Walsh & Fletcher, 2004)

2.2.3 Turboprop engine

A turboprop engine is a turbojet with a reduction gearbox mounted in the front end to drive a propeller. The development of this engine is derived from the turbojet and the successful application of propeller in piston engine aircraft (Figure 2.5).

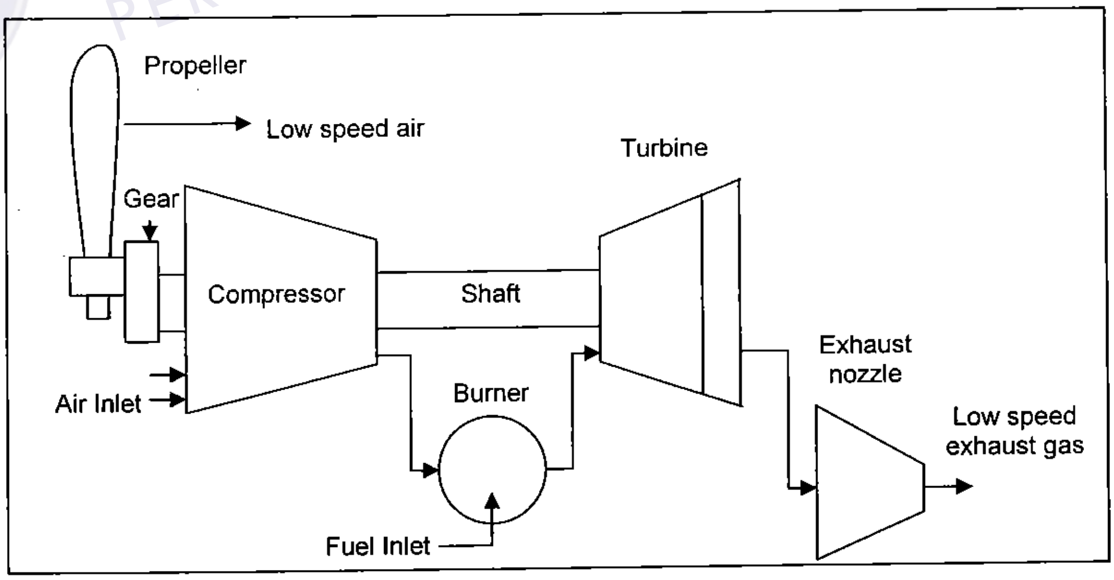

Figure 2.5: Turboprop engine (Hill & Peterson, 2010)

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As illustrated above, the core section is similar to that of turbojet engine but unlike the turbojet that uses the power from core to generate thrust, most of the generated powers in turboprop are used to turn the propeller. As much as 75 to 85 percent of total power output can be extracted by the turbine section to drive both compressor and propeller (Kroes & Wild, 1995). As a result, the engine's exhaust gases contributes little thrust as most of the energy is directed toward driving these two components. This explains why the main source of thrust for turboprop comes from the propeller. Apart from that, the reduction gearbox is used to control the propeller's speed. In order to avoid any possible shock waves and flow separation at the propeller tip, the high speed rotational energy from the turbine needs to be converted to a low speed high torque power. The propeller itself is driven either by the gas generator turbine or by another turbine called free power turbine. Since the exhaust velocity and thrust generated are low, turboprops are not efficient at high speed as depicted in Figure 2.6. Meanwhile, the example of an aircraft flying with turboprop can be seen in Figure 2.7.

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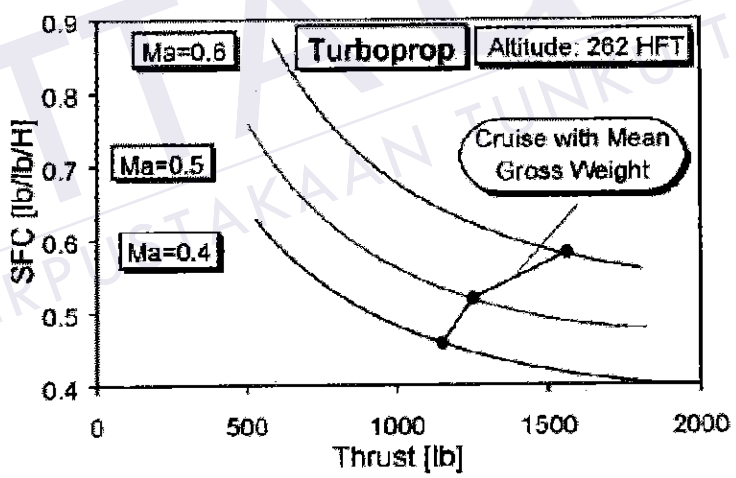

Figure 2.6: SFC and thrust required at different cruise Mach number for turboprop (Xie & Haberland, 1999)

Figure 2.7: Beech King Air 200 powered by two Pratt and Whitney turboprop engine (http://www.aircraft-charter-world.com/propjet/be200.htm)

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2.3 The evolution of turboprop engine

Both the turboprop and piston engines are the two commonly known types of engines used to power propeller-driven aircraft. For several decades, the piston engines coupled with propellers have provided the necessary power for early aircrafts. The aviation was once dominated by the piston propeller aircraft through the 1950's until rapid advancement in aircraft engine technology introduced the turbojet (Banach & Reynolds, 1984). The emergence of turbojet and turboprop engines in the 1940's were encouraged by the difficulties encountered in developing advance technology for piston engines (Constant, 1980). As aircraft safety is greatly improved and these engines allow much faster speed when compared to piston-powered engines, the air transportation business has also dramatically changed.

As the gas turbine technology continues to develop, it let to the introduction of the turbofan engine to replace turbojet engine. However, a serious energy crisis in the 1970's gave a huge impact to the airlines industry as more than half of the airlines' operating costs went to their fuel expenditures (Bowles & Dawson, 1998).

Realizing that the existing turbine engine consumes more fuel and a significant improvement in engine fuel consumption is essential, a new type of engine has been proposed by the United States National Aeronautics and Space Administration (NASA) as shown in Figure 2.8.

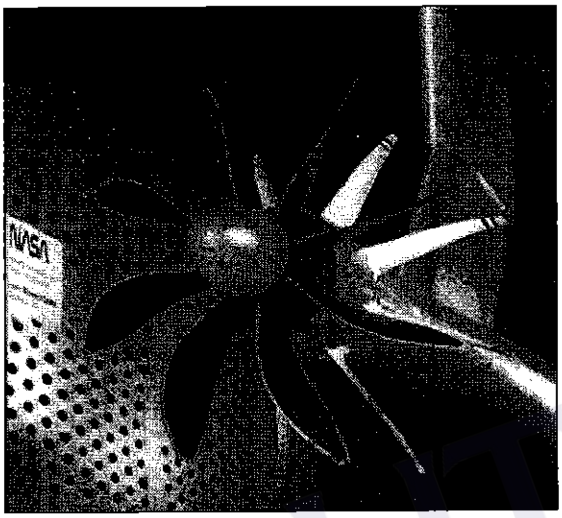

Figure 2.8: NASA advanced turboprop project (Bowles & Dawson, 1998)

The proposed engine by NASA which is referred to as 'propfan', has the performance of turboprop engine with an addition of advanced propellers. The advanced propeller feature thin, swept, and twisted propeller blades, with complex structural properties (Maser et al., 1990). Propfan concept is a trademark of Hamilton-Standard which works on this project together with NASA. It has a bypass ratio of more than 30, and it incorporates some of the characteristics and advantages of a turboprop engine while allowing higher flight speeds (Crane, 2005). In terms of productivity and passenger comfort, it is almost as similar to a turbofan engine and it has a potential to reduce fuel consumption of up to 20 percents when compared to advanced turbofan (Banach & Reynolds, 1984). Many patents have been filed for this new engine design (Cornell & Rohrbach, 1979; Geidel & Rohra, 1989; Grieb & Geidel, 1990; Robey & Bennett, 1984). A similar concept known as unducted fan (UDF) or open rotor concept has been introduced by General Electric as can be seen in Figure 2.9 and Figure 2.10. Nevertheless, this technology has never reached production stage as the fuel prices went down in the late 1980's, thus vanished the pressing need for the advanced turboprop which was believed to be a new, risky technology (Bowles & Dawson, 1998).

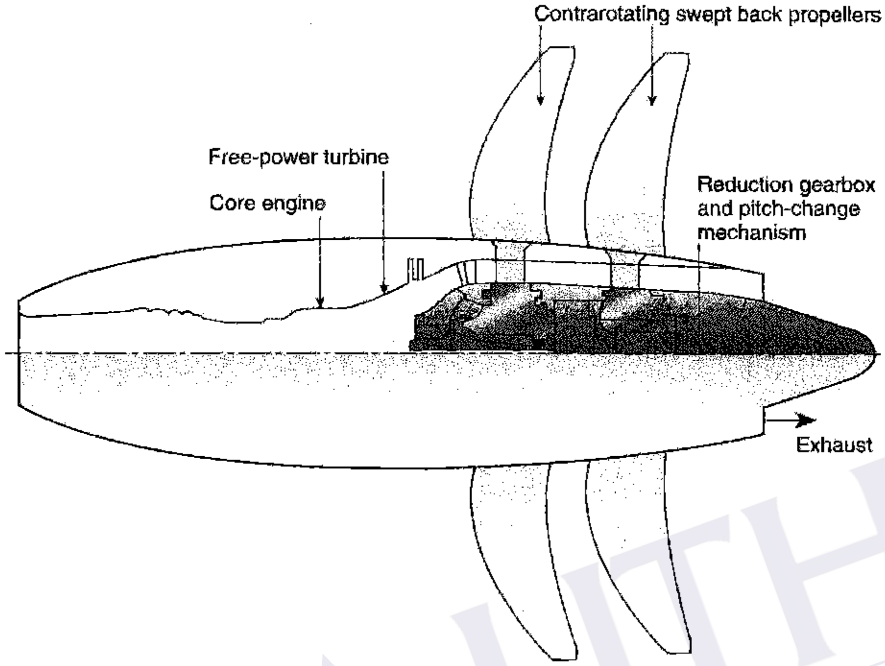

Figure 2.9: The unducted fan concept with contrarotating blades (Crane, 2005)

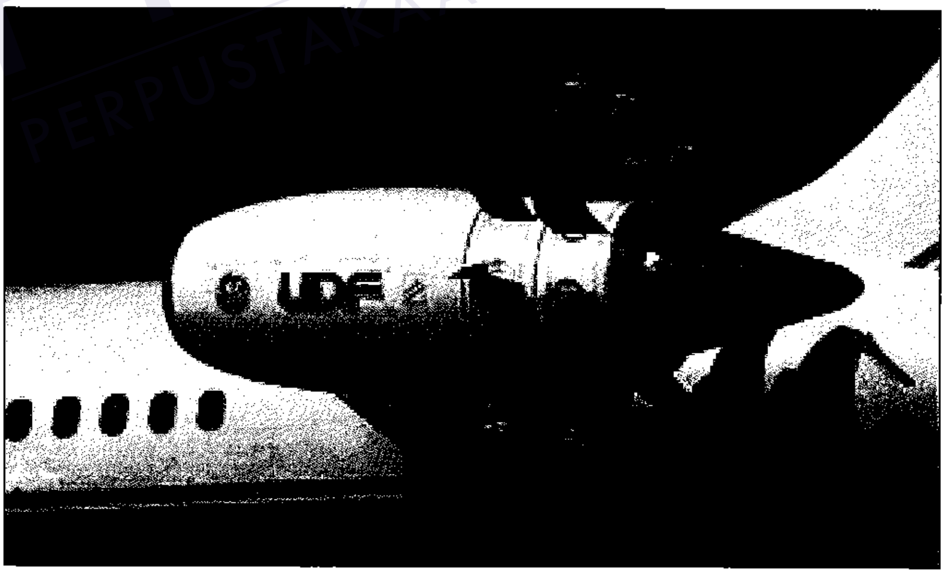

Figure 2.10: The GE-36 unducted fan affixed to its Boeing 727 test aircraft (http://wehavethelocaliser.blogspot.com/)

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In the 2000s, the instability in the fuel price around the world has once again given a great impact on aviation industry. As such, the industry is now eyeing back for turboprop engine as an alternative for their short and medium range commercial transport aircraft. Smirti and Hansen (2009) have examined the potential of current turboprops to reduce fuel consumption by comparing the operating and passenger costs of turboprops with regional jets and narrow body jets. Operating costs include fuel, crew, maintenance, and airports' costs. Meanwhile, passenger costs include among others flying time costs and passenger willingness not to fly on turboprop. In general, the turboprops show that they can offer a lower cost per passenger over a wider range of distances especially when the price of fuel is high (Figure 2.11 and Figure 2.12). However, they are competing with regional jets and narrow body aircrafts, particularly when the passenger costs are taken into consideration.

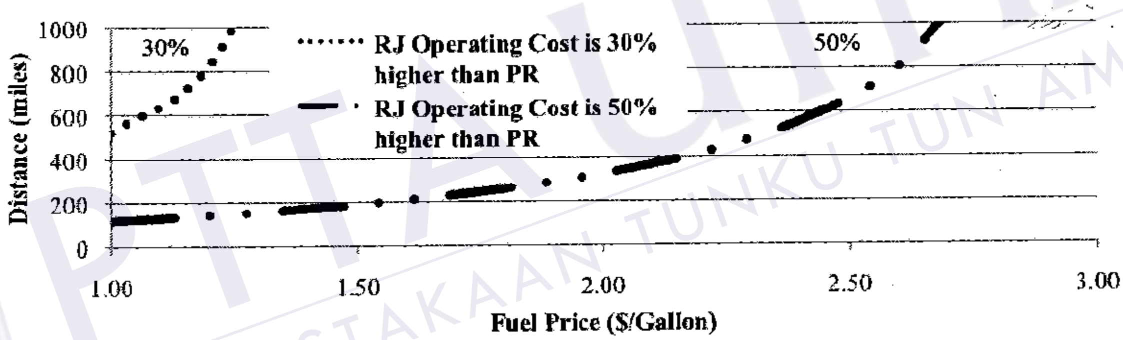

Figure 2.11: Percent difference operating cost per passenger for regional jet and turboprop comparison (Smirti & Hansen, 2009)

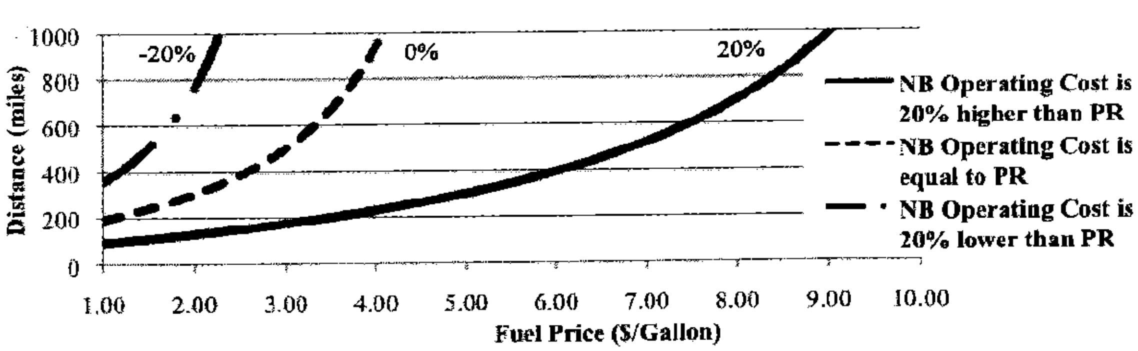

Figure 2.12: Percent difference operating cost per passenger for narrow body and turboprop comparison (Smirti & Hansen, 2009)

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2.4 The importance of engine performance testing

An aircraft engine development comprises of components' tests followed by engine testing where it is intended to give an engine a thorough test for mechanical soundness and to ensure the operating parameters are giving the correct indicators (*Pratt & Whitney Canada PT6A-6 and PT6A-20 Series Engines Maintenance Manual*, 2007). The information such as performance, operability and reliability is necessary, but nonetheless expensive and time consuming process. Designing an engine together with its development stage can take between 3 to 7 years from its beginning to service entry. This is due to the many hours of engine testing are required during the development stage so that the final design conforms closely to the original modification (Walsh & Fletcher, 2004).

Although the reasons behind an engine performance testing are mainly to ensure that the engine meets design parameters predicted by the manufacturer, it is also important to engage in research and development programmes involving modified or new engine concepts. For example, engine testing is critical during the manufacturing process especially in cases where the engine model is in some way different from previous models and its applications. Soares (2008) mentioned that a small component or instrument system change could modify what was a successful engine system without that change. This illustrates the importance of conducting performance testing on an aircraft engine.

Besides that, prior to customer delivery, it is a common practice for the engine to pass production acceptance tests as the final check (Walsh & Fletcher, 2004). Furthermore, following a major refurbishment or overhaul, the engine is also tested to ensure that its performance is within the required standards (Laskaridis, Pilidis & Pachidis, 2004). Testing of engine after minor maintenance, repair or overhaul is important since the performance limits might be altered and different from those of new engines (John, 2007). Besides that, a sophisticated testing is also used as laboratory exercises to illustrate engine principles to engineering students (Keating, 2007) as well as for experimental research tests.

Kraft and Huber (2009) emphasized that engine test cell has been the predominant tool for the development of aeronautical system since the Wright Brothers. Although the foreseen future of the aerospace industry will be more advanced than today, engine test facility will remain as the primary sources of

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information on performance, operability and durability for the development and sustainment of aeronautical system especially the engine itself. Although there are plans in replacing the test facility with modeling and simulation approach in the future, test facility will still be required to validate these models.

Overall, performance is the end product of an engine as the decision in getting an engine for a specific application is usually based on its performance. The most wanted performance parameters may comprise of high thrust or shaft power, low fuel consumption, longer life, light weight, low emissions and smaller engine diameter. These performance parameters must be achieved under all steady and transient conditions in order to ensure stable and safe operation throughout the operational envelope. Frequently, high thrust for jet engine or shaft power for shaft engine together with low fuel consumption are the most desired engine parameters when comparing engines with the same size in the market. All these will require an engine testing facility.

2.5 Types of engine test cell

The engine test cell is designed to evaluate the performance and operation of an engine under controlled conditions. Generally, these facilities are mainly divided into two types: sea level test facility and altitude test facility. Among them, the most common facility is the sea level test facility and it can be further divided into outdoor and indoor test cells. The sea level test facilities are more common than the altitude test facilities due to the operational costs (John, 2007).

2.5.1 Outdoor test facility

This facility consists of an open air stand that mounts the engine and the necessary instrumentations. A typical layout of outdoor test bed is illustrated in Figure 2.13 and Figure 2.14.

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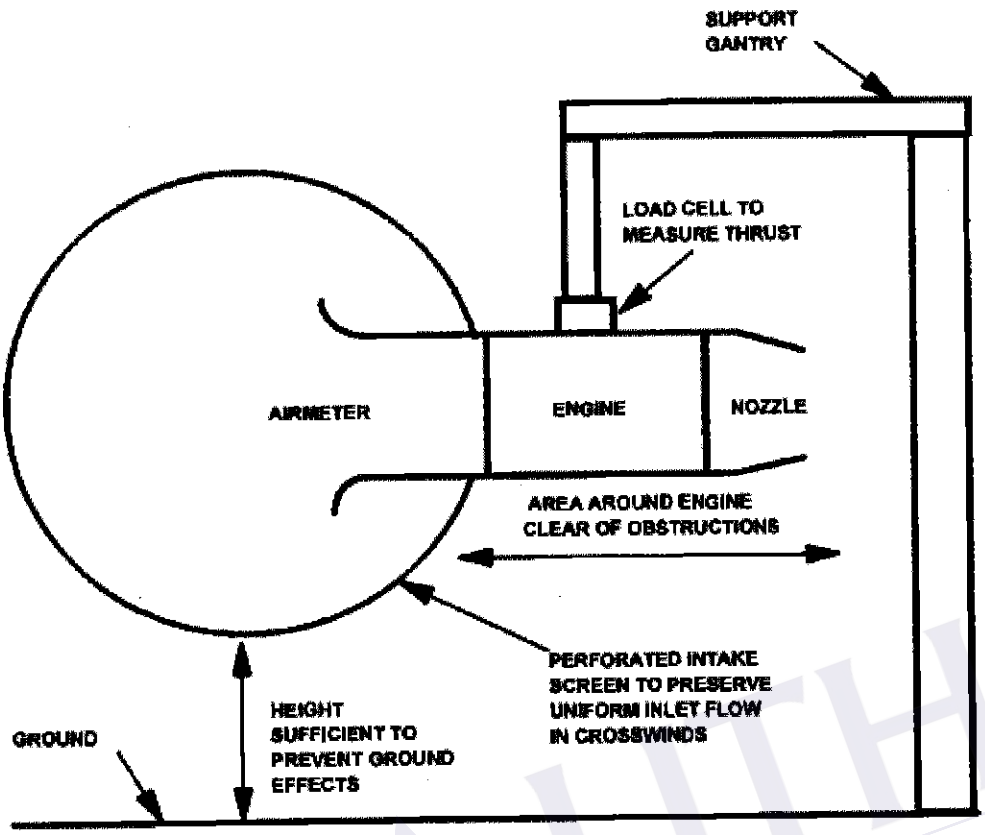

Figure 2.13: Outdoor sea level test facility (Walsh & Fletcher, 2004)

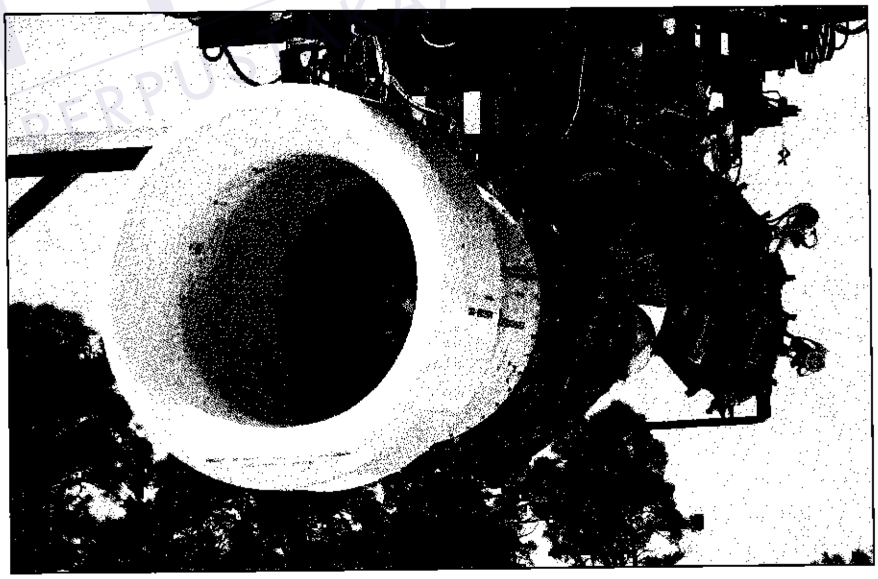

Figure 2.14: An example of an outdoor test cell facility to test a turbofan engine (http://www.mtu.de/en/press/mediapool/index.html)

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In order to setup this facility, the location is considered important as usually it is far from the general public access area so as to avoid noise pollution to the people. In this type of facility the wind effects around the engine are kept to a minimum and the area around the engine should be free of obstructions to prevent disturbances on the mass flow entering the engine. A large mesh screen can also be fitted around the engine inlet to mitigate the effect of cross wind on engine behavior.

According to Freuler (1991), the best possible ideal condition in terms of thrust measurement is represented by an outdoor test environment. To explain this, the installation of this type of facility is capable of providing an ideal environment where the air enters the engine without the forms of recirculation and drag components since the testing is done on an outdoor stand under zero cross wind conditions. There will be zero static pressure gradients along the engine. This means that the thrust measured is the gross thrust produced by the engine as if it were in an infinite atmosphere and it is considered to be the true thrust of the engine (Walsh & Fletcher, 2004).

Although it seems like the proper approach for the sea level engine testing is to use outdoor test facility, it is strongly dependent on the weather and wind condition. The impact of adverse weather conditions is obvious as the performance of the engine and its thrust measurement accuracy depends heavily on the weather conditions. To obtain suitable weather may take a long wait and it ties up with the cost (Laskaridis et al., 2004).

Therefore, given the above factors, this approach is not practical when reliable and repeatable test environment are part of the requirements. Besides the weather, the noise pollution is also among the main factor that can affect the use of this facility as it demands the location to be in more remote area to minimize environmental impacts (Freuler, 1991; Laskaridis et al., 2004). Due to the issues related to the outdoor test cells, indoor test cells are becoming the centre of interest.

2.5.2 Indoor/enclosed test facility

Most engine testers and manufacturers are more incline towards indoor test facilities to measure engine performance because of the complexity associated with outdoor

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test facilities. Usually, these test facilities comprise of three main regions namely, air inlet system, test chamber and the exhaust system. The engine is fixed on a trolley (Figure 2.15) or a cradle (Figure 2.16) in the test chamber and air is provided through the air inlet.

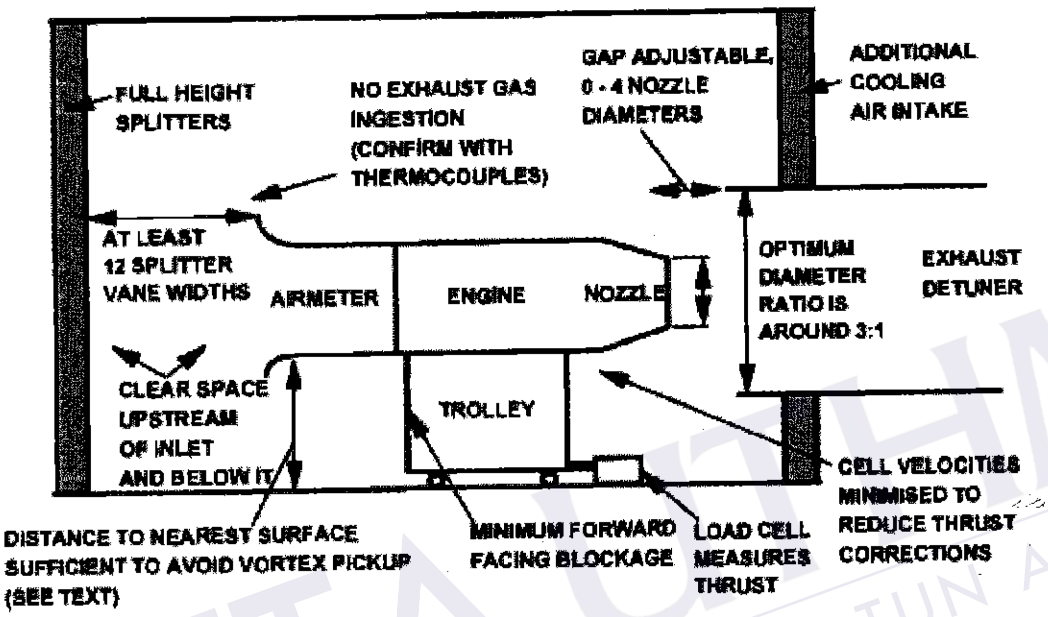

Figure 2.15: Indoor test facility (Walsh & Fletcher, 2004)

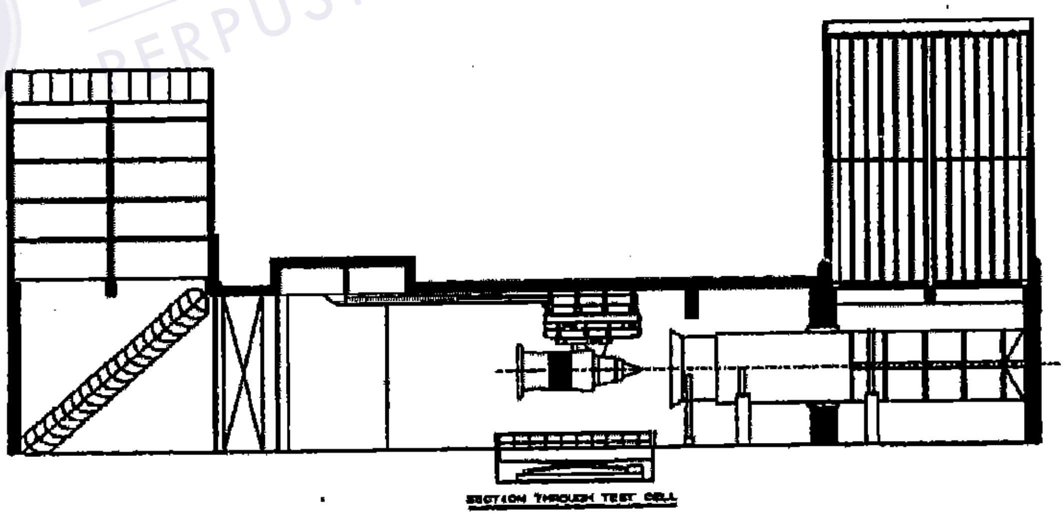

Figure 2.16: Example of design concept of an indoor test facility (Freuler, 1991)

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In contrast to the outdoor test facilities, indoor test facilities have more advantages such as in the provision of all-weather availability, repeatable and less impacts to the environment owing to its controlled conditions. The noise pollution is reduced by employing acoustically treated intake section and exhaust section (Macleod, 1988).

The air inlet system provides a smooth, uniform, low-turbulence flow to the engine with a minimal pressure loss of the incoming air flow. The inlets could be either horizontal or vertical with turning vanes. For example, AIROD Sdn. Bhd., a Malaysian aerospace company engaged in providing aircraft maintenance, repair and overhaul (MRO) services located in Subang, Selangor, employs the vertical air inlet system for their turbojet and turbofan engine test cell while horizontal air inlet system was designed for turboprop and turboshaft engine test cell. The vertical inlet system is common for turbojet and turbofan since this system is less affected by the air direction and dust ingestion can also be avoided. Turning cascade is used in the vertical inlet to guarantee straight and smooth air into the engine.

The test engine is located in an enclosed area called the test chamber. As for the thrust measures in an indoor test cell, it can be up to 10 percent less than the thrust measured in an outdoor test cell. According to Walsh and Fletcher (2004), this is due to "unrepresentative static pressure forces acting on the engine and cradle, caused by the velocity of air within the cell passing around the engine". Within the test chamber, the air passing through the engine is called the primary air and around the engine is called secondary air. The ejector effect of the jet stream from the engine nozzle induces the secondary flow which then raises the unrepresentative static pressure forces thus affecting the thrust measurement (Walsh & Fletcher, 2004). Therefore, correction factors need to be calculated in order to obtain the true thrust of the engine. However, it is also important to emphasize that many experiments and calibrations need to be done to calculate the correction factors and in doing so may lead to a higher cost.

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REFERENCES

Airbus A-380. *Aviation Earth.* Retrieved 1 May, 2011, from http://www.aviationearth.com/aircraftdata/a380.html

ATR to play major role in domestic air services (2010, April 19). *New Sabah Times.* Retrieved 18 June, 2010, from http://www.newsabahtimes.com.my/nstweb/fullstory/37883

Banach, H. J., & Reynolds, C. N. (1984). Turboprop Engine Propulsion for the 1990's. *Journal of Aircraft, 21(4),* 238-243.

Beech King Air 200. Retrieved 1 May, 2011, from http://www.aircraft-charter-world.com/propjet/be200.htm

Benini, E. & Giacometti, S. (2007). Design, Manufacturing and Operation of a Small Turbojet Engine for Research Purposes. *Journal of Applied Energy, 84(11),* 1102-1116.

Bowles, M. D., & Dawson, V. P. (1998). The Advanced Turboprop Project: Radical Innovation in a Conservative Environment. In P. E. Mack (Ed.), *From Engineering Science to Big Science: The NACA and NASA Collier Trophy Research Project Winners* (pp. 321-344). Washington, D.C.: National Aeronautics and Space Administration, NASA Office of Policy and Plans, NASA History Office

British Standard Institution (2009). Gas Turbine – Acceptance Tests. London: BS ISO 2314.

Çengel, Y. A., Cimbala, J. M., & Kanoglu, M. (2010). *Fluid mechanics: Fundamentals and applications.* Boston: McGraw-Hill Higher Education.

Constant, E. W. (1980). *The Origin of the Turbojet Revolution.* Baltimore: The John Hopkins University Press.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Cornell, R., & Rohrbach, C. (1979). *Multi-bladed, high speed prop-fan*. U. S. Patent. 4171183

Crane, D. (2005). *Aviation Maintenance Technician Series: Powerplant*. 2nd ed. Newcastle, Washington: ASA. 687-689.

Davis, M. & Montgomery, P. (2005). A Flight Simulation Vision for Aeropropulsion Altitude Ground Test Facilities. *Journal of Engineering for Gas Turbines and Power, 127(1),* 8-16.

El-Sayed, A. F. (2008). *Aircraft Propulsion and Gas Turbine Engines*. New York: CRC Press. 15-24.

Emmanuel, M. (2010, August 25). Firefly to double ATR fleet to fuel expansion. *New Straits Times*.

Faiz, A., Weaver, C. S., & Walsh, M. P. (1996). *Air pollution from motor vehicles: standards and technologies for controlling emissions*: World Bank Publications.

Ferguson, C. R., & Kirkpatrick, A. T. (2001). *Internal Combustion Engine*. Singapore: Wiley.

Freuler, R. J. (1991). *An Investigation of Jet Engine Test Cell Aerodynamics by Means of Scale Model Test Studies with Comparisons to Full Scale Test Results.* The Ohio State University: Ph.D Thesis.

Geidel, H., & Rohra, A. (1989). *Propfan turbine engine*. U. S. Patents. 4887424

Grieb, H., & Geidel, H. (1990). *Propfan turbo-engine*. U. S. Patents. 4947642

Hill, P., & Peterson, C. (2010). *Mechanics and thermodynamics of propulsion* . 2nd ed. Reading, MA: Addison-Wesley. 141-146, 177-183.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Jackson, A., Laskaridis, P., & Pilidis, P. (2004). A Test Bed for Small Aero Gas Turbines for Education and for University: Industry Collaboration. *Proc. Of GT2004 ASME Turbo Expo 2004: Power for Land, Sea and Air.* Vienna, Austria.

John, E. (2007). *Gas Turbine Performance at Outdoor Test Bed.* Cranfield University: Master's Thesis.

Joshi, D.S. (1997). Viewpoint: Aerospace Education for 2000 and Beyond. *International Journal of Engineering Education, 13(2),* 138-142.

Jusle, G.L., Montanes, J.L., & Velazquez, A. (2009). Micro-Jet Test Facility for Aerospace Propulsion Engineering Education. *International Journal of Engineering Education, 25(1),* 11-16.

Keating, E. L. (2007). *Applied Combustion.* 2nd ed. CRC Press. 337-369.

Kong, C., Ki, J., & Chung, S. (2003). Performance Simulation of a Turboprop Engine for Basic Trainer. *KSME International Journal, 16(6),* 839-850.

Kraft, E.M. & Huber, A.F. (2009). A Vision for the Future of Aeronautical Ground Testing. *International Test and Evaluation Association Journal, 30(2),* 237-250.

Kroes, M. J., & Wild, T. W. (1995). *Aircraft Powerplant.* 7th ed. Singapore: McGraw-Hill, Inc.

Laskaridis, P., Pilidis, P., & Pachidis, V. (2004). Small Scale Engine Test Bed Design and Optimization. *Paper presented at the Design Optimization International Conference*. Athens, Greece.

Léonard, O., Thomas, J., & Borguet, S. (2009). Ten Years of Experience With a Small Jet Engine as a Support for Education. *Journal of Engineering for Gas Turbines and Power, 131*, 012303.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH