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Inspection the Fuel Spray Pattern of The Injector Nozzle in Turboprop Engine by Using Fuel Testing Device

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ABSTRACT

This study deals experimental study to inspect the fuel spray pattern in fuel injector nozzle in turboprop engine type PT6A-60 SERIES produced by Pratt & Whitney Canada by using fuel testing device. due to incomplete combustion which is mainly occurred due to incorrect shape of fuel spray, it results in carbon formation inside the combustion chamber, which negatively effects on the fuel injector and compressor turbine (CT) vane. The cleaning procedure to fuel injector is done by two methods which are handling clean and ultrasonic clean device. The testing is done by using fuel injector testing machine which is use fuel to check spray pattern. This machine was made due to the need for it by the maintenance team, and the actual machine used by the manufacturer was not available. This test was carried out at different conditions which is the first at the start of operation at 20 psi, the second at low speed, 30 psi pressure, and the third at maximum speed at high pressure 60 psi. The case 01 and 02 have been taken at the time of maintenance check of the fuel injector in 15/12/2022, while the case 03 and 04 were taken also randomly from the same engine but in different time at 09/03/2023. From obtained results, most of the cases were acceptable and does not need to re-cleaning after testing, except case 04 was not acceptable and need to clean by ultrasonic device.

Keywords: Fuel Injector Nozzle, Cleaning Methods, Fuel Testing Device, Shape of Spray.

فحص نمط رذاذ الوقود لفوهة الحاقن في محرك توربيني مروحي باستخدام جهاز اختبار الوقود

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ملخـــــص البحـــــث

تتناول هذه الدراسة، دراسة عملية لفحص نمط رش الوقود من فوهة حاقن الوقود في المحرك التوربيني نوع(Pratt &Whitney) من إنتاج شركة (PT6A-60 SERIES) الكندية باستخدام جهاز اختبار الوقود. نتيجة الإحتراق غير التام والذي يحدث بشكل رئيسي بسبب الشكل غير صحيح لرذاذ الوقود وينتج عنه تكوين الكربون داخل غرفة الاحتراق، مما يؤثر سلبا على حاقن الوقود وريشة توربين الضاغط .(CT) تتم عملية التنظيف لحاقن الوقود بطريقتين وهما، التنظيف يدويا والتنظيف بجهاز الموجات فوق الصوتية. يتم بعدها الاختبار باستخدام آلة اختبار حاقن الوقود، التي تستخدم الوقود للتحقق من نمط الرش. تم تصنيع هذه الآلة، نظرا لحاجة فريق الصيانة إليها، ولم تكن الآلة الفعلية التي استخدمتها الشركة المصنعة متوفرة. تم إجراء هذا الاختبار في

ظروف مختلفة حيث كانت الأولى في بداية التشغيل عند ضغط 20 (psi)، والثانية عند السرعة المنخفضة وضغط 30 (psi)، والثالثة عند السرعة القصوى وضغط 60 (psi). تم أخذ الحالتين الأولى والثانية وقت فحص الصيانة لحاقن الوقود بتاريخ 2022/12/15، بينما تم أخذ الحالتين الثالثة وال اربعة أيضا بشكل عشوائي من نفس المحرك ولكن في وقت مختلف بتاريخ 2023/03/09. من النتائج التي تم الحصول عليها، فإن معظم الحالات كانت مقبولة ولا تحتاج إلى إعادة تنظيف بعد الاختبار، باستثناء الحالة ال اربعة لم تكن مقبولة وتحتاج إلى تنظيف بجهاز الموجات فوق الصوتية.

الكلمات الدالة: فوهة حاقن الوقود، طرق التنظيف، جهاز اختبار الوقود، شكل الرذاذ.

1. INTRODUCTION

In turboprop engines, the fuel system is one of most importance and working to examine this system is extremely important to control the amount of fuel consumption in aircraft and the quality of combustion, and to achieve the best performance of the engine in all conditions.This study deals the fuel system in turboprop engine and about the fuel injector in particular, how it works, the effects on it, how to clean it, its cleaning device, and its testing device, then check the fuel spray pattern of injector nozzle, when an acceptable spray pattern is obtained, this ndicates that combustion will be normal. Otherwise, the combustion will not be correct. The fuel injection type of this engine is known as a direct injection, where a fuel sprayed directly into the combustion chamber rather than into the intake manifold. This can lead to incomplete burning of the fuel, resulting in the formation of carbon deposits on the intake valves and other internal engine components which actually effect directly into compressor turbine blades (CT) in PT6A-60 engine. Additionally, the air fuel mixture in combustion chamber weather was poor or rich of fuel will produce incomplete combustion and it should be mixture well based on certain ratio of air and fuel. In fact, it is difficult to maintain complete combustion, especially in direct injection engines, and incomplete combustion cannot be prevented from occurring completely. Regular maintenance, such as using fuel additives and following manufacturer recommended cleaning procedures, can help mitigate carbon buildup in direct injection engines. Turboprop aircraft use energy from a gas turbine to move propellers and generate power. Using the aerodynamic thrust generated by propellers, turboprop engines can do much more than aircraft engines at speeds below 400 knots. Although turboprops generally have a lower level of service compared to jets, they burn less fuel per passenger for the same duration, making them useful for short flights. [1] Modern turboprops also have a level of versatility unmatched by light aircraft. The short takeoff and landing capabilities of turboprop aircraft enable pilots and passengers to reach remote areas around the world. [1]. The Pratt & Whitney Canada PT6 is a turboprop aircraft engine produced by Pratt & Whitney Canada. Its construction started in 1958, its first operation was in February 1960, its first flight was on May 30, 1961, it entered service in 1964 and is regularly updated. It has two main parts: a gas generator with a generator and a free generator with reduced power; Since the air enters from the rear and the exhaust is in the center, it will most likely return to the plane. Many variations of the PT6 have been developed for use not only as turboprop engines but also as turboshaft engines for helicopters, ground vehicles, flying vehicles and ships; as a power group; and for work. As of November 2015, 51,000 units were produced with 400 million flight hours between 1963 and 2016. It is known for its reliability, with a flight rate of 1 flight every 651,126 hours in 2016. The PT6A-60seruios has a power range of 580 to

1,940 hp (430 to 1,450 kW), while the PT6B/C is a model aircraft turboshaft. [2] There are four main sections in PT6 engine which are, compressor section, combustion section, turbine section, and exhaust section, each of them consists parts as shown in figure1. The concentration of this study only about fuel system and spray nozzles which are insulated around the combustion chamber.

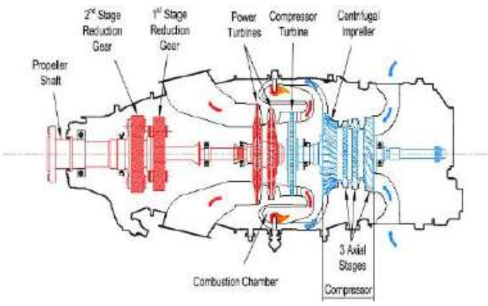


Fig. 1. Cross section Pratt & Whitney PT6 engine [2].

The problem of carbon formation inside the combustion chamber and internal parts of the engine and the occurrence of incomplete combustion is a major challenge for researchers, as the problem has been studied by researchers from all its aspects, by looking into the causes of its occurrence and ways to improve it.Studying the spray characteristics of aircraft engines is one of the most important factors to achieve the best fuel combustion and to obtain the highest engine performance. A series of experiments were conducted on an aircraft gas turbine engine hybrid fuel nozzle to evaluate spray performance and atomization quality. Malvern Spraytec particle sizer within the combustion research laboratory was used to obtain droplet size measurements and distributions. [3[

Experimental Testing were conducted at different cases. The first two test conditions are employed at low- and high- pressure air in flux seen inside a gas turbine engine during different stages of operation. The last two test conditions reflect engine relevant flow rates of air and fuel, respectively. In particular, flow rates that mimic engine- start up conditions and take-off. [3] Overall, the industry hybrid fuel injector exhibits stable performance with optimal atomization quality and symmetry among all experimental conditions. [3]. One of the most important problems caused by incorrect fuel spray form is the formation of soot and carbon as a result of incomplete combustion, which negatively effects on the environment.

An experimental program to investigate hardwire configurations which attempt to minimize carbon formation and soot production without sacrificing performance in small gas turbine combustors has been conducted at the United Technologies Research Center. [4] Fourfuel injectors, embodying either airblast atomization, pressure atomization, or fuel vaporization techniques, were combined with nozzle air swirlers and injector sheaths, and evaluated at test conditions which included and extended beyond standard small gas turbine combustor operation. The testing was conducted in three phases. In the initial phase, eight configurations were screened at both sea-level-takeoff and idle test conditions in an attempt to identify the two most promising (low soot and carbon deposit) designs. The second phase of testing focused on the selected configurations in an attempt to quantify the influence of combustor pressure, inlet

emperature, primary zone operation and combustor loading on scat and carbon formation. The third phase, a cycle test, which included specified time periods at idle, sea-level takeoff and cruise test conditions, was performed to simulate deposit formation during engine operation. The cycle test was performed with both Jet A and ERBS fuel.

Test results indicated that smoke emission levels depended on the combustor fluid mechanics (especially the mixing rates near the injector), the atomization quality of the injector and the fuel hydrogen content. Reduced smoke emissions were attained by employing swirl to enhance the fuel-air mixing rates near the spill return nozzle. [4]

1.1 fuel system

A. General description of fuel system

The function of the fuel system is to provide the engine with fuel suitable for controlling the mixture and flow required for easy starting, acceleration and stability at the end of all engine operations. To do this, one or more fuel pumps are used to deliver fuel to the fuel nozzles, which is injected into the combustion system. Since the flow rate must vary according to the amount of air passing through the engine in order for the selected engine speed or high ratio to remain constant, the controls are automatic unless there is a selection of engine power (performed by manual throttle). Power button. The fuel shutoff valve control level is also used to stop the engine, but sometimes the two manual controls are combined for a single operation. [5]

B. **Operation of fuel system**

According to the concentration of this research about fuel spray nozzle, which is one of the fuel system components, so it is important to overview about components of fuel system and how a fuel arrived from the fuel tank to last component which is fuel nozzle. The maintenance teams care greatly about understanding operation of aircraft systems, including the fuel system, even they can identify the malfunction and track it through the system to which this malfunction belongs. Figure 2, illustrate the fuel system components which are:

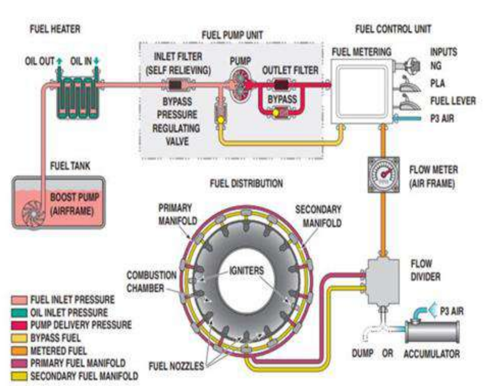


Fig 3. Fuel system diagram.

- Fuel tank
- Fuel heater
- Fuel pump unit
- Fuel control unit
- Fuel control unit (metering(
- Flow divider
- Fuel distribution

Fuel begins to flow from the aircraft's tanks and is sent to the engine through one or more airframe boost pumps. Fuel is sent from the fuel heater to the fuel pump. The fuel pump sends fuel to the Fuel Control Unit (FCU), which determines the amount of fuel the engine needs based on ambient conditions to produce the power the engine needs. [2]

The excess fuel is returned to the inlet of the fuel pump and the fuel flow going to the engine goes through the fuel flow meter to indicate the fuel consumption in the cockpit. Then, the fuel reaches the flow divider where it is directed to the primary and secondary fuel manifolds to supply all the nozzles. The fuel nozzles atomize the fuel in the combustion chamber to sustain the combustion. [2]

C. Fuel nozzle

The last element of the fuel system is the fuel spray nozzle, that have as their essential function the task of atomizing or vaporizing the fuel to ensure fast burning. The challenges that occur in this process, which can be appreciated when taking into account the speed of the air coming from the compressor and the short length of the combustion system where combustion must be finished completely. [5]

The fuel is passed through the discharge orifice which removes the swirl motion as the fuel is atomized to form a cone-shaped spray. This is called 'pressure jet atomization'. The rate of swirl and pressure of the fuel at the fuel spray nozzle are important factors in good atomization. The shape of the spray is an indication of the degree of atomization as shown in figure 3. Later fuel spray nozzles utilize the air spray principle which employs high velocity figure 3, fuel spray shape [5] air instead of high velocity fuel to cause atomization. This method allows atomization at low fuel flow rates (provided sufficient air velocity exists) thus providing an advantage over the pressure jet atomizer by allowing fuel pumps of a lighter construction to be used. [5]

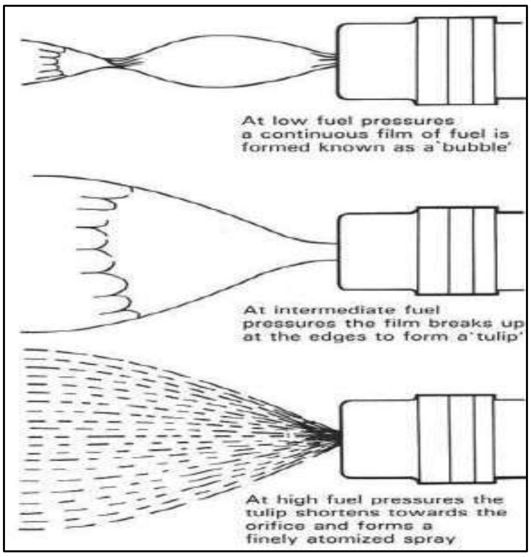


Fig 3: Shape of nozzle's spray [5]

2. METHODOLGY

Poor fuel nozzle flows are a major cause of reduced hot section life in turboprop engine. It may cause overheating of combustion chamber and failure of turbine blade, especially the vane ring. If fuel nozzles are not maintained in good condition, it could also lead to local overheating of burning, improper flame propagation and burning of compressor blades, all these issues occur due to poor of fuel nozzle flow and unacceptable spray pattern. [6]

Why Fuel Nozzle Blockages Happen?

Fuel injection nozzles require attention, especially when they become clogged with carbon deposits on the tips. This may be due to low quality of fuel or, in some cases, faulty operation. For example, to prevent raw fuel from hitting the nozzles before shutting down, it is important to stabilize the engine for two minutes after flight before shutting down to prevent clogging of the fuel nozzles. [7]

A. Fuel injector

The fuel injector consists of the nozzle, nozzle valve, spring and body. The fuel is forced under pressure by the fuel injection pump. The fuel lifts the nozzle valve due to of the pressure, and then the fuel is sprayed out of the nozzle hole. Fuel nozzle characteristics such as spray distribution angle, droplet size, and velocity distribution and evaporation have an impact on combustion chamber performance. Injection quality affects safety parameters, combustion efficiency and pollutant emissions. Good atomization enhances oil evaporation and reduces the need for ignition energy.[8]

Fig 4: Fuel injector without head sheath.

The figure 4, illustrate an external fuel injector shape with its main contents without head sheath.

While in figure 5, illustrate the shape of fuel injector from the outside, with head sheath, which is used to protect the fuel injector head from the heat resulting from the combustion of fuel inside the combustion chamber. It is also use to cool the fuel injector head so that it does not affect the fuel injection pressure at the nozzle and to protect it from collapse.

B. Acceptable and unacceptable conditions of fuel spray pattern:

Definition of terms used to describe specific test conditions for nozzles as in figure 6.

- Acceptable Cases:

Fig. 5: Fuel injector with head sheath.

There are two types of acceptable cases which are:

1. Good uniform spray quality: it is the perfect case of spray pattern.
2. "Streakiness": is defined as variation in spray quantity between different parts of spray cone and appearing as lighter or darker streaks in spray.
Acceptable case is only when total of 20% of fuel spray may show light streaks.
The reason: Caused by carbon deposit at nozzle face.
The repairing: Brush nozzle surface during flow test. [9]

- Unacceptable cases:

There are many cases of spray pattern should not be allowed which are:
1. "Spitting": is a condition which exists when large drops of anatomized fuel occur intermittently and usually on outside of spray cone.
The reason: Caused by carbon deposit at nozzle face.
The repairing: Brush nozzle during flow test.

"Drooling": is a condition which occurs when large drops of anatomized fuel form on nozzle face

2. "Drooling": is a condition which occurs when large drops of anatomized fuel form on nozzle face.

The reason: Caused by carbon deposit at nozzle orifice or by partial obstruction of fuel nozzle distributor.
The repairing: Brush nozzle surface during flow test and ultrasonically clean. [9]
3. "Void": is area of fuel spray showing discontinuity in fuel flow (air gap).
The reason: Caused by obstruction on internal fuel passage.
The repairing: Clean by ultrasonic device. [9]
4. "Skewness": describes a spray condition that is not centered.
The reason: Caused by damage to nozzle orifice.
The repairing: Not repairable at field level. [9]

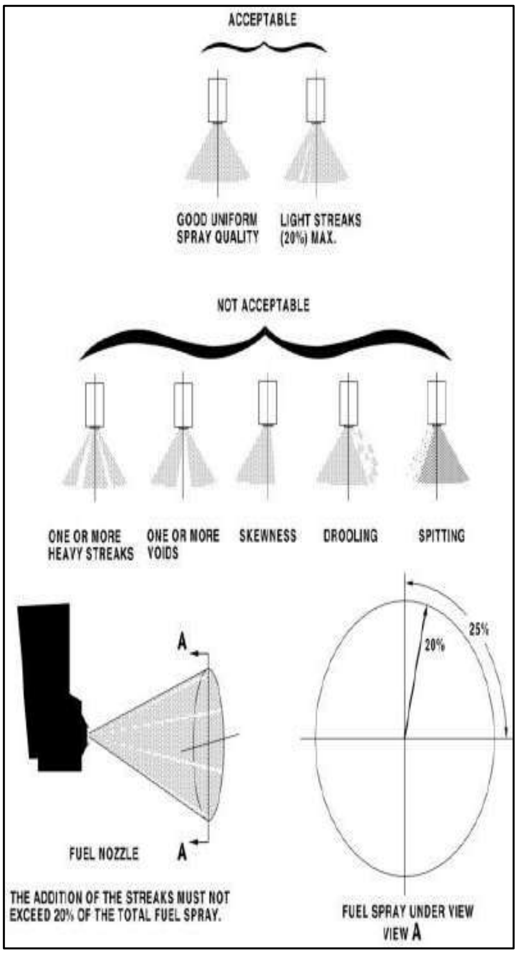


Fig. 6. Acceptable and unacceptable conditions of fuel spray pattern [9].

C. Maintenance procedure to check fuel spray pattern for fuel injector:

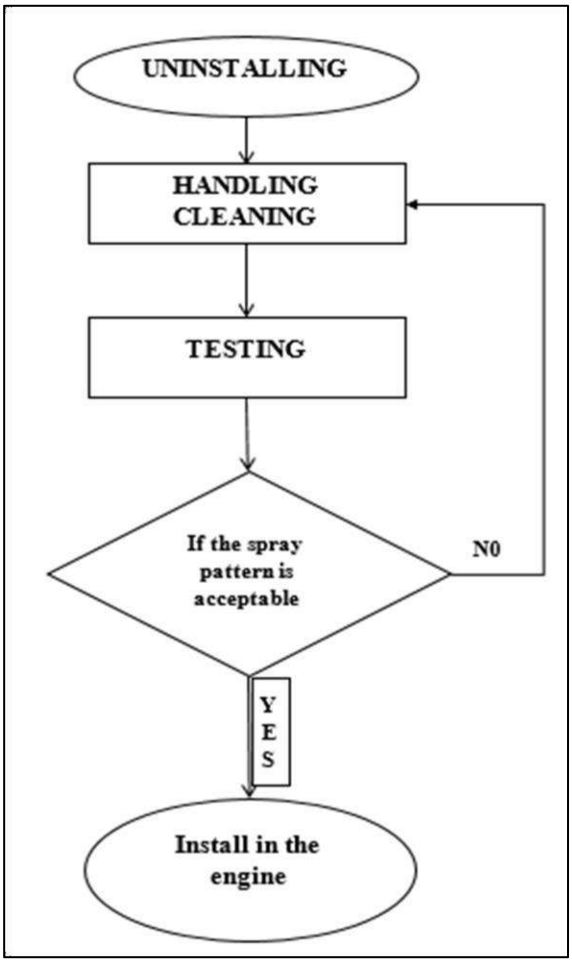


Fig 7: Maintenance procedure to check fuel spray pattern.

Note: after repeating more than one times, prefer to use ultrasonic cleaning or changing fuel nozzle orifice tip.

Figure 7, illustrate the maintenance steps to check the fuel spray pattern for fuel nozzle, in the beginning, uninstalling for fuel injector from the engine as mentioned in maintenance manual for Pratt & Whitney company [8]. The second step is cleaning, which is the most important step in maintenance procedure to evaluate the spray of fuel nozzle correctly.

After uninstalled fuel injector should be cleaning using one or both of the following methods which are:

- Handle cleaning
- Ultrasonic cleaning

1. Handle cleaning:

a. Put it in the liquid cleaning (lacquer thinner).
b. Use soft brush for cleaning then put it in hot water.
c. In addition, when spraying, brush tip with a non- metallic brush to loosen any possible carbon debris.

Fig. 8: Handle cleaning tools.

During the cleaning process, it was observed that carbon particles fell into the cleaning fluid, as in Figure 9. The fuel injector head and fuel injector cover must also be cleaned well and the thickness of the injector cover must be checked so that the thickness of the cover is not less than 0.040 inches. [9]

Due to expose the injector cover to combustion heat inside the combustion chamber and particles of carbon which resulting from combustion cause corrosion of the tip of the injector cap, this is why the thickness of the injector cap must be periodically checked. If it is less than the required thickness, it must be replaced.

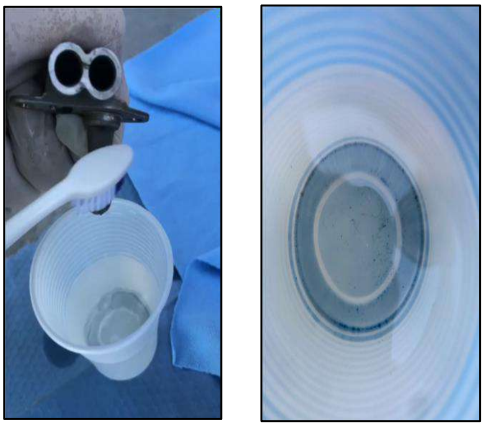


Fig. 9: During cleaning procedure.

2. Ultrasonic cleaning:

If the first method is not effective, the ultrasonically cleaning method is extremely effective to remove carbon formed on the fuel injector cover and injector nozzle.

How Ultrasonics cleaning works?

Ultrasound is sound that is usually transmitted at frequencies higher than humans can hear. Ultrasonic
cleaners use ultrasonic waves (sound waves) to clean materials and surfaces. [10]
When sound waves from the transducer propagate through the solution in the tank, they cause alternating high and low pressures in the solution. [10]
During low pressure, millions of tiny bubbles form and grow. This process is called CAVITATION, which means "cavity formation". [10]
In the high-pressure phase, the bubbles collapse or "burst" and a lot of energy is released. This explodes like a swarm of little brushes. They attack in all directions, attacking all areas, invading all cavities and openings. [10]
There are several types of ultrasonic cleaner devices depended on size and power and selection of device depended on type of part which need to clean.
Figure 10, illustrate one of ultrasonic cleaning device that used to clean fuel injectors, but in this research, the ultrasonic cleaning device is not available.

Fig 10: Ultrasonic cleaning device [11].

D. Fuel injector testing machine (Current Machine):

The injector tester consists of a small tank, a pump, a pressure gauge and a handle. There is a separate bowl that receives the fuel sprayed from the nozzle. The fuel injector to be tested is mounted on the fuel injection equipment. Start by opening the valve that controls the fuel, then press the handle. The downward movement of the lever causes fuel to be sprayed from the injector. [12]

- **Components:**

1. Fuel tank:

The tank in which the test liquid is located contains the pump and the filter, there are many liquids used in the test and it is possible to use aircraft fuel.

2. Fuel pump:

There are two of Electrical pump but they both give the same pressure

- **Main pump:**

The electric pump gives a fixed pressure of 72.5 psi, drawing liquid from the tank connected to a filter.

- **Sub pump:**

It is like the main pump; its pressure is 72.5 psi. The aim of this pump is to give more pressure that we need in high pressure, so that the final pressure is 145 psi.

3. fuel filter:

The purpose of the filter is to filter the liquid from impurities to keep the fuel injectors clean.

4. return valve:

It prevents the liquid from returning to the tank at low pressure coming from the main pump.

5. **shut off valve:**

There are two shut off valve:

i. Main shut off valve: Control the input pressure of the fuel injector.

ii. Return shut off valve: Control the fluid return pressure to the tank.

6. **Pressure gages:**

There are three pressure gauges:

- Main pressure: Measures the fluid pressure entering the fuel injector.
- Sup pressure: Measures the return fluid pressure from the fuel injector.
- Return pressure: Measures the return fluid pressure to the fuel tank.

7. **Reservoir:**

A tank for pumping is non-existent fuel inside to avoid fuel scattering and preserving the environment. Figure (4.5)

8. **Power supply:**

By using battery that given 12Volt and between 35 to 90 Ampere.

Figure 11, illustrate the components of fuel injector testing machine which is made by researchers in this research and the idea of this machine come from actual machine which use air and fuel mixture to evaluate the fuel spray pattern from the injector fuel nozzle.

Due to an actual machine to check fuel spray is not available, so that was a reason to provide current machine by researcher's team.

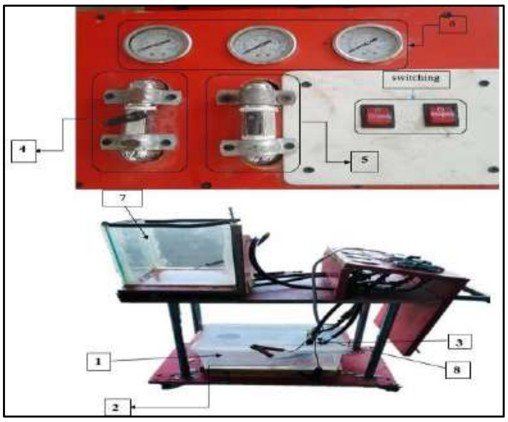


Fig 11: Fuel testing machine (Current Machine)

- **The method of work:**

1. Start by installing the fuel injector with an adapter like figure 12 in the machine.
2. Start operating the main pump so that it gives a pressure of 72.5 psi.
3. Start by slowly opening the main shut-off and closing slowly the return shut-off.
4. Monitor the pressure in the gauges, provided that the main pressure gauge is equal to the sup pressure gauge.
5. Monitor chap of the spray. This is to simulate running at low speed.
6. Start operating the sup pump so that gives a pressure of 145 psi.
7. Start by increasing the pressure in the pressure gauge and fuel injector. by shut-off valves.
8. Monitor shape of the fuel spray to evaluate it whether it is acceptable or not by visual observation. Especially at high speeds.

Fig 12: Fuel injector with adapter

- **Cases of spray pattern which are got it after cleaning and testing:**

After doing test, there are three results perhaps you will find it:

1. Getting the required result for the shape of fuel spray as in figure 6, for acceptable cases.
2. If did not get the required result so try to repeat cleaning.
3. If did not get require shape after repeat cleaning so try to use cleaning by ultrasonic or change the tip of nozzle head of the injector or replace the fuel injector.

- **Repeat Cleaning:**

The P&W maintenance manual states that if the nozzle is not clean, the process must be repeated. It is important to repeat cleansing while continuing the use of fuel nozzle. In fact, the second cleaning often leads to a return to the normal spray. Replacing nozzle tips is very expensive and is only necessary when repeated cleanings fail.

4. RESULT AND ISSCUTION

The results were obtained experimentally by using fuel spray testing machine which was talking about it in methodology.

As Known, the testing step coming after cleaning procedure which has two kinds of cleaning.

In the beginning, the cleaning will be done manually without using the cleaning device, then the test will be conducted for each case. If the obtained result is acceptable, then there is no need to perform the cleaning again, but if the obtained result is unacceptable, the cleaning will be performed again to the extent of obtaining the acceptable result in reality, the ultrasonic cleaning device does not used in this project due to it is not available and need special equipment.

Each case was tested separately, so that the best test is under different operating conditions, which is the first at the start of operation at 1.2 bar (20 psi), the second at low speed and 2 bar (30 psi) pressure, and the third at maximum speed and high pressure 4.1bar (60 psi). these testes were taken based on the pressures which are used for testing in actual testing machine.

This test was carried out as shown in Figure 3 of the fuel injectors at different pressures:

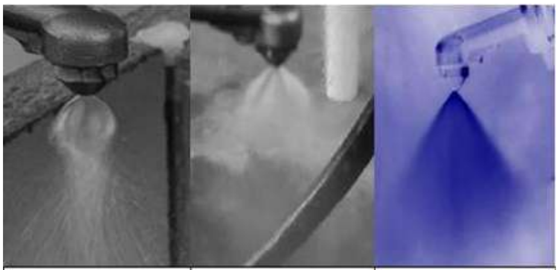
A. At low fuel pressures a continuous film of fuel is formed known as a bubble

B. At intermediate fuel pressures the film breaks up at the edges to form a tulip

C. As high fuel pressures the tulip shortens towards the orifice and forms a finely atomized spray.

The cases of this study were four cases, the case 01 and 02 have been taken at the time of maintenance check of the fuel injector in 15/12/2022, these cases were taken randomly from the PT6-A60 PRATT & WHITNEY turboprop engine, while the cases 03 and 04 were taken also randomly from the same engine but in different time at 09/03/2023 so it's after around three months. The reason for taking the third and fourth cases after three months is due to the first and second cases were taken a short period after their last examination, so we decided to take other cases after a longer period of operation and observe what would happen to the injectors and the form of the spray obtained.

A. Case 01:

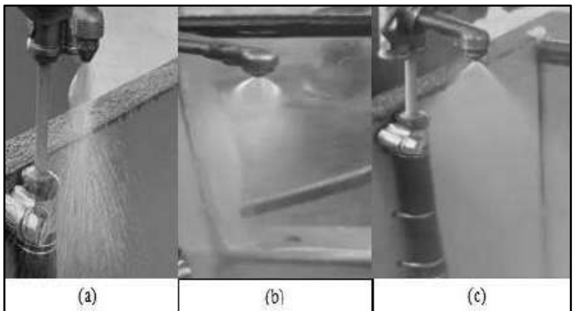


(a) (b) (c)

Fig. 13. Obtaining result of spray pattern in case 01 of at different conditions so that Fig (a) At low pressure1.2 bar (20 psi), (b) At medium pressure 2 bar (30 psi), and (c) At high pressure 4.1bar (60 psi)

Figure 13, illustrated the shape of spray pattern in case 01 at different conditions, based on the spray shape obtained at all pressures in the test, the fuel injector is good and does not need re-cleaning or other maintenance. Comparing the shape of results with an acceptable spray pattern in figure 6 was conforming. So, it is ready to installed in the aircraft engine, based on maintenance instruction.

B. Case 02:

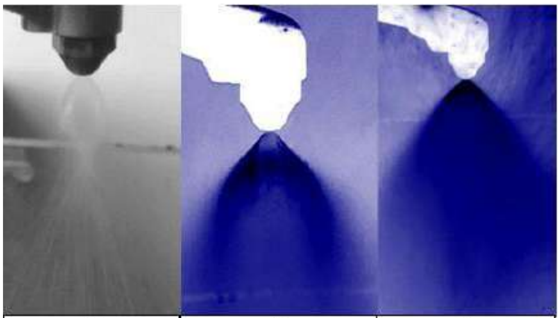


(a) (b) (c)

Fig. 14. Obtaining result of spray pattern in case 02 at different conditions so that Fig(a) At low pressure 1.2 bar (20 psi), (b)At medium pressure 2 bar (30 psi), and (c)At high pressure 4.1 bar (60 psi)

Figure 14, illustrated the shape of spray pattern in case 02 at different conditions. This test was also carried out by taking a random sample from the engine and it was manually cleaned and tested and the following results are obtained from the spray patterns. Based on these results, it is a good fuel injector and can be installed in the aircraft.

C. Case 03:

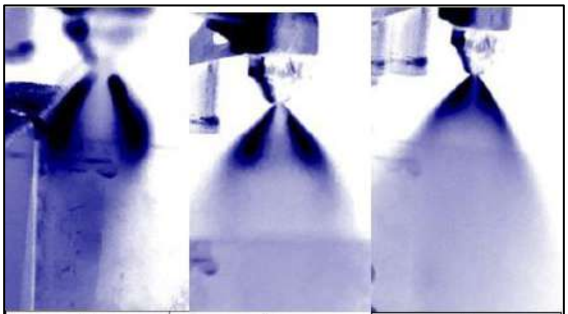


(a) (b) (c)

Fig. 15. Obtaining result of spray pattern in case 03 at different conditions so that Fig(a) At low pressure 1.2bar (20 psi), (b)At medium pressure 2 bar (30 psi), and (c)At high pressure 4.1bar (60 psi)

Figure 15, illustrated the shape of spray pattern in case 03 at different conditions. The third case was taken after three months from case 01 and 02, Found the results that the spray pattern of the injector is good and acceptable, and there is a little bit space in spray in case 03 at medium pressure but it is generally acceptable, while the results at figure 15 (c) and (a) are acceptable and confirmed with acceptable spray pattern in figure 6.

D. Case 04:



(a) (b) (c)

Fig. 16. Obtaining result of spray pattern in case 04 at different conditions so that Fig(a) At low pressure1.2 bar (20 psi), (b)At medium pressure 2 bar (30 psi), and (c)At high pressure 4.1bar (60 psi)

Figure 16, illustrated the shape of spray pattern in case 04 at different conditions. As seen in the results of spray pattern at all conditions are not acceptable comparing with an acceptable case in figure 6. the shape of spray appears a void in the middle and this is not allowed and the causing is obstruction on internal fuel passage and to repair this problem need to clean by ultrasonic device.

5. CONCLUSION

From obtained results, most of the cases were acceptable and does not need to re-cleaning after testing, except case 04 was not acceptable and need to clean by ultrasonic device. The reason that made the case 04 not acceptable was the formation of carbon disposed on the nozzle tip, it was more than the other nozzles tips. The fourth case can become acceptable if it is cleaned well and tested several times or cleaned with an ultrasonic device because it is effective in cleaning the injectors.

The testing was done at different conditions which is the first at the start of operation at1.2 bar (20 psi), the second at low speed, 2 bar (30 psi) pressure, and the third at maximum speed at high pressure 4.1bar (60 psi). based on the pressures which are used for testing in actual testing machine.

The results were evaluated based on comparing the spray pattern obtained from the study cases with the acceptable and unacceptable spray pattern recommended by the manufacturer. In generally, one of the most important effects on fuel injector is formed carbon on the fuel injector orifice and dome sheath and caused corrosion on its surface. in addition, it is effect on shape of spray pattern.

RECOMMENDATION

There are many important steps that must be taken into account in the future, to improve the quality of inspection of the fuel spray pattern, the most important of which is the use of ultrasonic cleaning of the injectors in order to obtain better cleaning, including obtaining the best performance of the fuel injectors. One of the most common problems the

research team faced was taking appropriate photos of the spray pattern, preferably using a high-quality thermal camera that gives more details of the spray shape. If it is possible to provide an actual machine to check the spray pattern, it would be better because it is recommended by the manufacturer. On the other hand, the current machine is suitable for examining study cases because it provides the necessary pressures for examining injectors under different operating conditions. In addition, the pumps used do not consume high voltage and do not consume a large amount of fuel.

The current machine available for testing gave satisfactory results, but it needs some modifications to it to be easy to use, such as using a pressure regulator, using a well-closed and insulated fuel tank, and the testing chamber for spraying fuel should be closed, clean, and made entirely of glass. There should also be an orifice to return the used fuel for testing and return it for fuel tank.
In future studies, we recommend focusing on the effect of the spray pattern shape on the combustion chamber and compressor turbine blades.

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