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COMPARISON OF LEADED AND UNLEADED AVIATION GASOLINE BASED ON ENGINE PERFORMANCE

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ABSTRACT

The aim of this study is to compare the performance of spark ignition engine using leaded and unleaded aviation gasoline. The leaded and unleaded aviation gasoline used for this study contains the same Motor Octane Number (MON) of 91. The lead content in the existing aviation gasoline is a harmful substance to human health. The concerns regarding this matter resulting the development of more unleaded fuel as a replacement for the leaded fuel. Three parameters to be considered while carried out the study are Brake Horse Power (BHP), Exhaust Gas Temperature (EGT) and the Brake Specific Fuel Consumption (BSFC). The performance test is conducted using auto engine dynamometer to measure the listed parameter produced by test engine, Lycoming O320. Based on the results, the test engine using leaded avgas able to produce power 4.66% higher than unleaded avgas at the rated engine speed, 2700 RPM. But, the data for EGT shows that the unleaded avgas is 1.39% better than leaded avgas. For fuel consumption, the unleaded avgas required 27.46% more fuel than leaded avgas at the same engine speed, 2700 RPM. Overall, the leaded aviation gasoline provides better engine performance than unleaded gasoline.

KEYWORDS

leaded avgas, engine performance.

1. INTRODUCTION

Based Aviation industry is one of the significant contributors to lead emission. However, aviation emissions cannot be ignored as the aviation industry continued to grow. As each year passed by, rapid development of this sector raised serious concern regarding the quality of the very air we breathe. Based on a study this latter environmental issue is of particular interest to the scientific community and policymakers, especially in relation to the breach of limit and target values for many air pollutants, mainly nitrogen oxides and particulate matter, near the busiest airports and the resulting consequences for public health [1]. According to research, aviation engine is powered by liquid petroleum fuel such as liquid jet fuel and aviation gasoline, which requires higher energy contents per unit volume than gases and is easier to handle and distribute than solids [2]. Among the existing option for aviation fuel, petroleum-based fuel is currently the most reliable since it has high energy density and reliable at high altitude. Particularly, aviation planes are a concern due to the fact that they run on high-octane fuel aviation gasoline known as avgas, which contains lead. Study showed avgas is used by piston-driven engines while the larger aircraft use turbine engines run off of a nonleaded, kerosene-based fuel [3].

In 2014, United States Environmental Protection Agency (EPA) publish a statistic on the estimated the emission of lead contributed by aviation sector. From the statistic, aviation gasoline contributes roughly 418 212 kg annually lead emission is released to the atmosphere [4]. In order to deal with this issue, using alternative fuel, especially unleaded fuel could turn out to be a game changing for aviation sector. Up to this date, the leaded avgas remains the main choice for aviation industries due to the operational safety issue. The most common leaded avgas available is avgas grade 100LL, which contains 1.56 g Pb per liter of fuel.

Various studied shows that children have a greater susceptibility to the toxic effects of lead than adults. According to research, the exposure to lead can result in reduced IQ and behavioral difficulties, poor academic achievement and damage to renal and cardiovascular [5,6]. A study conducted by Zahran et. al.6 to determine the effect of leaded avgas on children health. Across a series of tests, they found out that the child blood lead levels increase dose-responsively in proximity to airports and decline of blood lead levels among the children sampled post 9/11 incident. The study concludes that the damages are estimated at least USD 10 per gallon of leaded aviation gasoline is used. A study also indicates the children living within 500 m of an airport at which planes use leaded avgas have higher blood lead levels than the children living far from the airport [7].

Generally, most of the existing aviation aircraft spark ignitions have been certified on leaded fuels that meet the ASTM D910 standard specification. Although, there is a new aviation gasoline has been developed to meet the standard avgas specification. The use of unleaded aviation gasoline can cause the performance of the engine differ than using certified leaded gasoline. The performance of the engine can be determine based on the Brake Horse Power (BHP), Exhaust Gas Temperature (EGT) and Brake Specific Fuel Consumption (BSFC). The addition of TEL in aviation gasoline is as a knock suppressant and to boast the octane rating of the fuel. The compound TEL is the primary fuel additive enabling the high-octane quality fuel required by high performance high compression ratio aviation engines. As domestic environmental measures have continued to reduce the use of lead in manufactured products, aviation gasoline today remains the only domestically produced gasoline containing TEL. In 2016, US Federal Aviation Administration have shortlisted 2 potential fuels in search for unleaded to replace the leaded aviation gasoline grade 100LL [8].

From engine performance perspective, the different grade of fuel will have different impact on the engine performance. The aviation gasoline grade is classified according to Motor Octane Number (MON) of the fuel. Octane is the measure of the gasoline ability to resist knocking or pinging during combustion. The higher-octane rating increased the gasoline resistance to knocking. BHP produce by the engine is an important parameter for engine performance is because the more horsepower an engine produces, the better its acceleration, which is a strong factor in its overall performance. EGT is another parameter that is importance to measure the spark ignition engine performance. The EGT can provide insight on the cylinder's air-fuel ratio (AFR), which is an important characteristic when it comes to performance. The temperature of exhaust gas varies according to the AFR. The BSFC shows the engine's fuel consumption per hour. The lower the fuel consumption, the higher the thermal efficiency of the engine.

This study is conducted to compare the performance of an aircraft engine, Lycoming 0320 series using leaded avgas and unleaded avgas. The scopes involved in this study is set-up the proper equipment and test engine for comparison of leaded and unleaded avgas, conducting engine performance test using leaded avgas and unleaded avgas and to determine the compatibility of both on test engine.

2. EXPERIMENTAL

2.1 Fuel Selection

The materials used in this study were including aviation gasoline grade 91 leaded and aviation gasoline grade 91 unleaded. Aviation gasoline 91 leaded and aviation gasoline grade 91 unleaded is chosen since both of the fuel have the same Motor Octane Number, MON. The fuels involved for the testing, which is 91 L and 91 UL is compatible with test engine, Lycoming O320-D3G. The MON of the fuel is determined by the standardized ASTM D 2700-17a test [9]. Both of the aviation fuel selected were met the requirement for aviation gasoline specification as stated in ASTM D910-17a for leaded avgas and ASTM D7547-17a for unleaded avgas. The specification of the selected fuel is shown in Table 1.

Table 1: The selected fuel

	Leaded Avgas	Unleaded Avgas
Grade	91L	91UL
MON	91.9 (ASTM D910-17a)	91.8 (ASTM D7547-17a)

2.2 Equipment Selection

The performance tests were conducted auto engine dynamometer, DYNO-mite on a SI engine, Lycoming O320 D3G. The engine specifications of the test vehicle are as shown in Table 2. The engine is selected due to compatibility of the test engine and selected fuel. All fuel tests were performed without any modifications on the test engine. The dynamometer installed to the test engine were measuring the Brake Horse Power (BHP), Exhaust Gas Temperature (EGT) and Brake Specific Fuel Consumption (BSFC) at given engine speed, RPM.

Table 2: Specification of test engine, Lycoming O320 12

Parameter	Value
Engine name	Lycoming O320 D3G
Number of cylinders	4
Rated Horsepower, HP	150
Rated Speed, RPM	2700
Compression ratio	8.5:1
Propeller drive ratio	1:1

2.3 Preparation of test engine and dynamometer

The test engine, Lycoming O320-D3G was installed in in a separate room from control panel and was monitored through a glass window. Then, the engine was coupled to auto-engine dynamometers. The engine parameter data were recorded at a rate of one scan of all channels every 1 second.

Sensors used to measure the important parameters were installed to the test engine and were calibrated prior to any engine testing. After the engine was installed and the instrumentation calibrated, a series of maintenance runs were performed to verify the engine systems integrity and instrumentation accuracy.

The data recorded by the sensor can be monitor through DYNOmite data-acquisition computer, which automatically records true Hp, torque, RPM, elapsed time, etc. at up to 1,000 readings per second (that is per channel, not just a total). The built-in software, DYNO-MAX™ able to monitor real-time trace graph display, adjustable voice/color limit warnings, pushbutton controls, plus user configurable analog and digital gauge ranges.

2.4 Engine Performance Test

As mention before, the test engine use in this study is Lycoming O320 D3G. The engine was setup at the GASTEG laboratory. The equipment used for performance test is a dynamometer (DYNO-mite). The setup for the test engine and selected equipment is shown in Figure 2.1

The engine was first operated on avgas grade 100LL for 5 min to stabilize the operating condition and to remove all the residue fuel inside the engine. Once the engine has warmed up, set the throttle to obtain the required engine speed. Then, gradually increase the throttle to 100%. The engine was left to stabilize at these running conditions. The engine was turned off and the remaining fuel was drained from the fuel tank.

After 15 minutes, the fuel is then change to the unleaded avgas. The engine was once again turned on. The engine was left running at low speed (2000RPM<) for a few minutes. After the engine stabilize, the data for all engine parameter will be acquired at the same time. The engine test will be operated between 2000 RPM and 2700 RPM with a step up of 100 RPM at 100% load condition. The test engine was again operated under avgas 100LL gasoline to drain all of the remaining Unleaded Avgas in the fuel line. The same procedure was repeated for leaded avgas. The data for each fuel is taken 3 times.

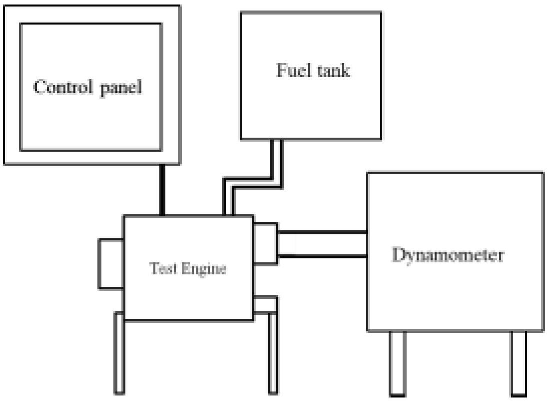

Figure 1: Schematic diagram for performance test.

3. RESULTS AND DISCUSSION

3.1 Engine Performance

The test conducted was to determine the Brake Horse Power, Exhaust Gas Temperature and the Brake Specific Fuel Consumption produce by the engine at different speed. During the operational of the light aircraft, the engine speed is varying according to the flight operational phase. The main focus for engine performance here is during the operational of the light aircraft. One of the common light aircraft that use Lycoming O320 series is Cessna 172.

Table 3: Flight setting for Cessna 172

	Take-off	Climb	Cruise
Engine Speed (RPM)	2700	2600	2450

3.1.1 Brake Horse Power

Figure 2: BHP produce by test engine at different RPM using leaded and unleaded Avgas.

Figure 3.1 shows the engine performance in terms of Brake Horse Power produces at different engine speed, RPM. From the Figure 2, BHP of the engine increased with the increase of engine speed up to 2700 RPM. The BHP produce by the engine increase drastically when the engine speed increase from 2600 RPM to 2700 RPM, which is 7.5% for leaded avgas and 10.8% for unleaded avgas. According to previous researchers, the engine produces its maximum power at the engine speed where the power increase provided by the frequency of cycles is balanced by the decrease in torque [10-14]. For this test engine, Lycoming O320, the rated RPM is 2700 RPM. If the engine speed was increased further, we can observe the BHP produce by the test engine will declined since the engine speed cannot further compensate the decrease in torque.

According to the results, the leaded avgas produces more power compare to the unleaded avgas at the same engine speed. At engine speed 2200 RPM, the Leaded Avgas produce 5.04% more power compare to the unleaded avgas. As the engine speed continue to rise, the leaded avgas continued to produce more power compare to unleaded avgas.

At take-off speed, which is 2700RPM, the test engine using leaded avgas produce 4.66% more power than the test engine using unleaded avgas. At climb speed, the Unleaded Avgas underperformed Leaded Avgas by 7.26%. During the cruising speed, The Leaded Avgas produce slightly more power than Unleaded Avgas by 6.05%.

3.1.2 Exhaust Gas Temperature

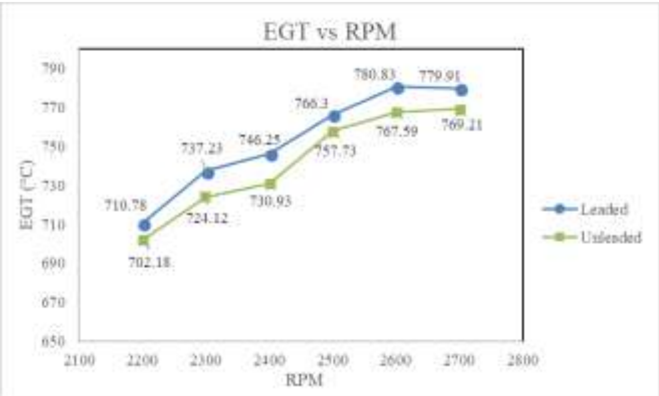

Figure 3: Exhaust Gas Temperature of the test engine using Leaded and Unleaded Avgas

From the Figure 3, we can see similar pattern for both avgas. As the engine speed is increase from 2200 RPM to 2700 RPM, the Exhaust Gas Temperature was also increase from 710.78°C and 702.18°C to 779.91°C and 769.21°C. The highest EGT for leaded avgas is at engine speed 2600 RPM, meanwhile the highest EGT for unleaded avgas is at engine speed of 2700RPM. Overall, the engine test using leaded avgas produce slightly higher temperature than unleaded avgas. The biggest different of temperature is at engine speed of 2400 RPM, where the temperature of flue gas of leaded avgas is 2.1% higher than flue gas of unleaded avgas.

At take-off speed, the EGT of test engine using leaded avgas was 1.39% higher compare to the EGT of test engine using unleaded avgas. During 2600 RPM, which is the climb speed, the EGT of test engine using leaded avgas is 1.72% hotter than the EGT of test engine when using unleaded avgas.

The slightly different in EGT shows the combustion temperature for both fuel is almost identical. According to a scholar, the higher MON fuel will start in-cylinder combustion earlier that assist the utilization more heat of combustion [15]. Since both of the leaded and unleaded avgas has the same Octane Number, the temperature profile for both tests should be almost identical. Apart from that, the EGT can provide insight on the cylinder's air-fuel ratio (AFR), whether it is lean mixture or rich mixture. The rich mixture is the condition where there is too much fuel in the cylinder, will causing the temperature inside the cylinder to become lower than lean-mixture.

3.1.3 Brake Specific Fuel Consumption

Figure 4: Brake Specific Fuel Consumption of test engine using Leaded and Unleaded Avgas.

Figure 4 shows the results of engine performance test in terms of fuel consumption. The graph above shows a different curve for leaded and unleaded avgas. For leaded Avgas, the BSFC is decreasing as the engine speed, RPM is increasing. Meanwhile, the results for unleaded avgas shows that as the engine speed increases, the BSFC also increase. The highest fuel consumption for leaded avgas is 281.12 g/kWhr when the engine speed is at 2200RPM and the lowest fuel consumption for leaded avgas is at engine speed 2600 RPM, which is 268.45 g/kWhr. For unleaded avgas, the highest fuel consumption is 344.23 g/kWhr at 2700 RPM and the lowest is 309.22 g/kWhr at engine speed of 2200 RPM.

At take-off speed, the fuel consumption using unleaded avgas is exceeding fuel consumption of leaded avgas by 27.46%. At climb speed, the BSFC of leaded avgas is 20.56% lower than unleaded avgas. For cruising speed, the BSFC of unleaded avgas is 20.27% higher than BSFC of leaded avgas.

According to a scholar, The BSFC is a measure of overall efficiency of and spark ignition engine and inversely proportional to the thermal efficiency [16]. When the test engine indicates lower BSFC, the engine consumed less fuel and its thermal efficiency will become higher.

4. CONCLUSION

In conclusion, the leaded avgas outperformed the unleaded avgas in term of engine performance. The leaded avgas produce power 4.66% higher than unleaded avgas at the rated engine speed, which is 2700 RPM. In term of combustion, the unleaded avgas slightly better than leaded avgas. The EGT of unleaded avgas is 1.39% less than leaded avgas. The lower EGT using unleaded avgas indicates that the unleaded avgas could optimize the combustion of the fuel in the cylinder. Next, leaded avgas outperformed unleaded avgas in terms of fuel consumption. The different of fuel consumption between leaded and unleaded avgas is as high as 27.46% at engine speed of 2700 RPM.

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