Journal of Aeronautics, Astronautics and Aviation, Vol. 55, No. 3S, pp. 479 – 483 (2023)
DOI: https://doi.org/10.6125/JoAAA.202309_55(3S).07

Experimental Investigation on Gas Turbine Engine Performance using Alternative Fuel

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ABSTRACT

The usage of fossil fuels is a significant contributor to carbon emissions in the aviation industry. Therefore, it is essential to identify alternative energy sources to power modern aircraft. This paper examines the application of biofuels as aviation fuel, which has a lower lifecycle emission compared to fossil fuels. The chosen biofuel was Palm methyl ester, which was blended with Jet A1 at various volume ratios to determine the optimal blend ratio. The KingTech K180 micro gas turbine engine was used to evaluate the thrust produced for each fuel type at different engine speeds, and the engine pump pulse width was recorded for the corresponding thrust. The results were manually recorded and compared using Python. The study found that the performance remained satisfactory for a blend ratio as high as B50 (50% biodiesel mixed with Jet A1), with maximum thrust comparable to Jet A1. However, B70 and B100 produced significantly less thrust (around 11% and 15% less, respectively). The pump pulse width, which indicates fuel flow, was particularly good for B20, but increased linearly with additional biofuel content.

Keywords: Biofuel, Alternative Fuel, Gas Turbine Performance, Micro Gas Turbine Engine, Experimental Investigation.

I. INTRODUCTION

The commercial aviation industry's use of fossil fuels is a significant contributor to climate change. Therefore, finding fossil fuel alternatives to make aviation more sustainable is crucial. Biofuels can be used as fuel alternatives that can reduce overall carbon emissions while utilizing existing infrastructure. Investigating the performance of biofuels at various blend ratios is essential to maximizing their capacity without degrading engine performance. Many researchers have conducted various studies on gas turbine engine performance using alternative fuels [1-5]. Recently, Altarazi et al. [6] reported a comprehensive review of performance and emissions using single and dual biodiesel fuels, and Altarazi et al. [7] reviewed the effects of biofuels on engine performance and emission characteristics.

Manuscript received, February 14, 2023, final revision, May 31, 2023

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Abu Talib et al. [8] conducted an analysis of the experimental and simulated performance of an Armfield CM4 turbojet engine using palm oil methyl ester biodiesel (PME) and its blends with conventional Jet A-1 fuel in an Armfield CM4 turbojet engine. PME is available in volumetric blends of 20, 50, 70, and 100 percent with Jet A-1 (B20, B50, B70, and B100). The experiment was conducted using the B20 fuel blend, while fuel blends above 50% mixing ratio were simulated using GasTurb software. According to their findings, the thrust for Jet A-1, B20, and B50 was equivalent, whereas B70 and B100 performed poorly. They also found that fuel blends above 50% PME content showed a decrease in performance.

Altarazi et al. [9] simulated a turbojet engine with an afterburner using Gasturb 13 and GSP 11 software. The engine rpm was set at 150,000 with input parameters, including pressure ratio, mechanical and burner efficiency, and more. Their findings showed that the fuel heating value was the primary contributor to thrust-specific fuel consumption, with lower heating value leading to higher specific fuel consumption. They concluded that biofuel performance parameters are primarily dependent on calorific value and viscosity, and a lower mass flow rate of the fuel leads to better performance.

Altarazi et al. [10] conducted a simulation of a KingTech K180 turbojet engine using Gasturb details 6, analyzing the performance and emission characteristics of single and dual biodiesel blends. The heat of combustion for each fuel type was calculated using Gasturb details 6 and NASA Chemical Equilibrium Application software. CO, CO_2, and NOx emission characteristics and performance of each fuel type were analyzed. The study revealed that B10 had the best thrust-specific fuel consumption while producing lower carbon emissions compared to Jet A1.

Altarazi et al. [11] discussed the performance and exhaust emission of biodiesels in different engines, finding that biodiesel blends can reduce carbon and NOx emissions while improving engine performance. In a separate study, they simulated the KingTech K180 micro gas turbine engine using Gasturb 13 with green diesel produced from waste cooking oil as the biofuel. The results indicated that green diesel had better performance in terms of specific fuel consumption and carbon monoxide emissions compared to conventional diesel, but the EINOx emission was higher. The authors concluded that green diesel could be a viable alternative for aviation fuel.

This project aims to investigate the performance of gas turbine engines using alternative fuels. Different blends of biofuels will be used to analyze the engine performance and compared with fossil fuels. The experiment will measure the engine thrust at various engine speeds (rpm) and analyze the results.

II. SETUP AND METHODOLOGY

In this experiment, the KingTech k180 micro gas turbine engine was utilized (as shown in Figure 1). It is composed of a single-stage centrifuge compressor and a single-stage turbine. The performance of gas turbine engines can be influenced by the fuel type used. The fuel heating value is one of the crucial fuel parameters that can impact performance. As indicated by Altarazi et al. [9], better performance in terms of higher thrust and lower fuel consumption can be achieved with higher fuel heating values.

Additionally, fuel viscosity and density can also impact engine performance. Biofuels, such as palm oil methyl ester biodiesel, have lower calorific values compared to conventional Jet A-1 fuel. Therefore, it is important to investigate the effect of different blend ratios of biofuel and Jet A-1 on engine performance. The experiment aims to determine the optimum blend ratio of palm oil methyl ester biodiesel and Jet A-1 fuel that produces the highest engine thrust while maintaining acceptable levels of fuel consumption and exhaust emissions.

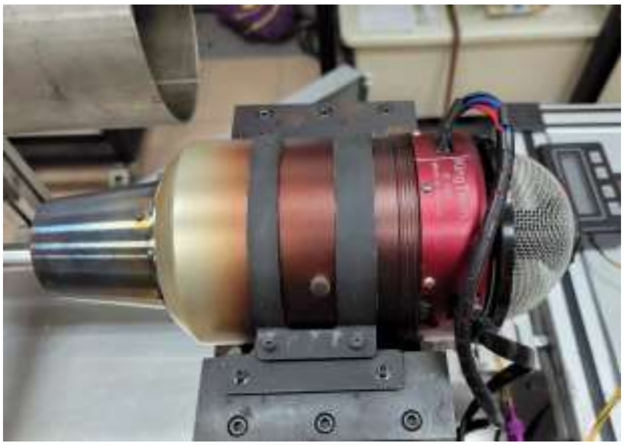

Figure 1 KingTech k180 micro gas turbine engine

In this project, Jet A1 and Palm methyl ester and their blends were used as fuel. Palm methyl ester or Palm based Biodiesel primarily contains hydrocarbon chains of saturated fatty acids. Whereas Jet A1 consists of mostly Kerosene which is mixed with additives to achieve performance requirements and ASTM standards. Along with these fuels, off-the-shelf Kerosene was also evaluated. The Fuel Heating Value of fuel blends are shown in Table 1:

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The experimental setup for the project is shown in Figure 2. The throttle and trim slider are used to input the desired settings, which are then sent to the Xicoy FADEC. The FADEC controls the engine and manages the fuel flow from the pump, which is powered separately. The real-time engine parameters are displayed on the data terminal and are also sent to the PC via USB. The Fadec v5 program on the PC shows the engine parameters. The FADEC or ECU requires a 9-12v dc power supply, which is provided by a

3-cell 9.9 volts LiFe battery in this case. The data terminal requires a dc power supply from two or three 12v lead acid batteries. The ECU is connected to the fuel pump to control the speed of fuel flow. The rate of fuel flow depends on the engine RPM set by the user. However, during the start sequence (Kero start), the FADEC automatically controls the fuel flow to reach the idle engine RPM. The fuel flows from the fuel tank through the fuel line to the engine burner.

Table 1 Fuel heating values for Jet A-1 and PME blends (Abu Talib et al. [8])

Fuel	Jet A1	B20	B50	B70	B100	Kerosene
Fuel Heating Value (MJ/kg)	46.190	44.905	42.824	41.548	39.964	43.1- 46.2

The load cell and the Gas Analyzer operate independently of the engine system. The load cell is directly linked to the PC through USB, which also serves as its power source. The load cell displays real-time engine thrust via the DSC USB app. The thrust and other engine parameters can be recorded in real-time using a screen recorder. Camtasia was used in this case. Assuming that the time delay between the ECU (Engine Control Unit) and the load cell is within the margin of error, the outcomes can be plotted.

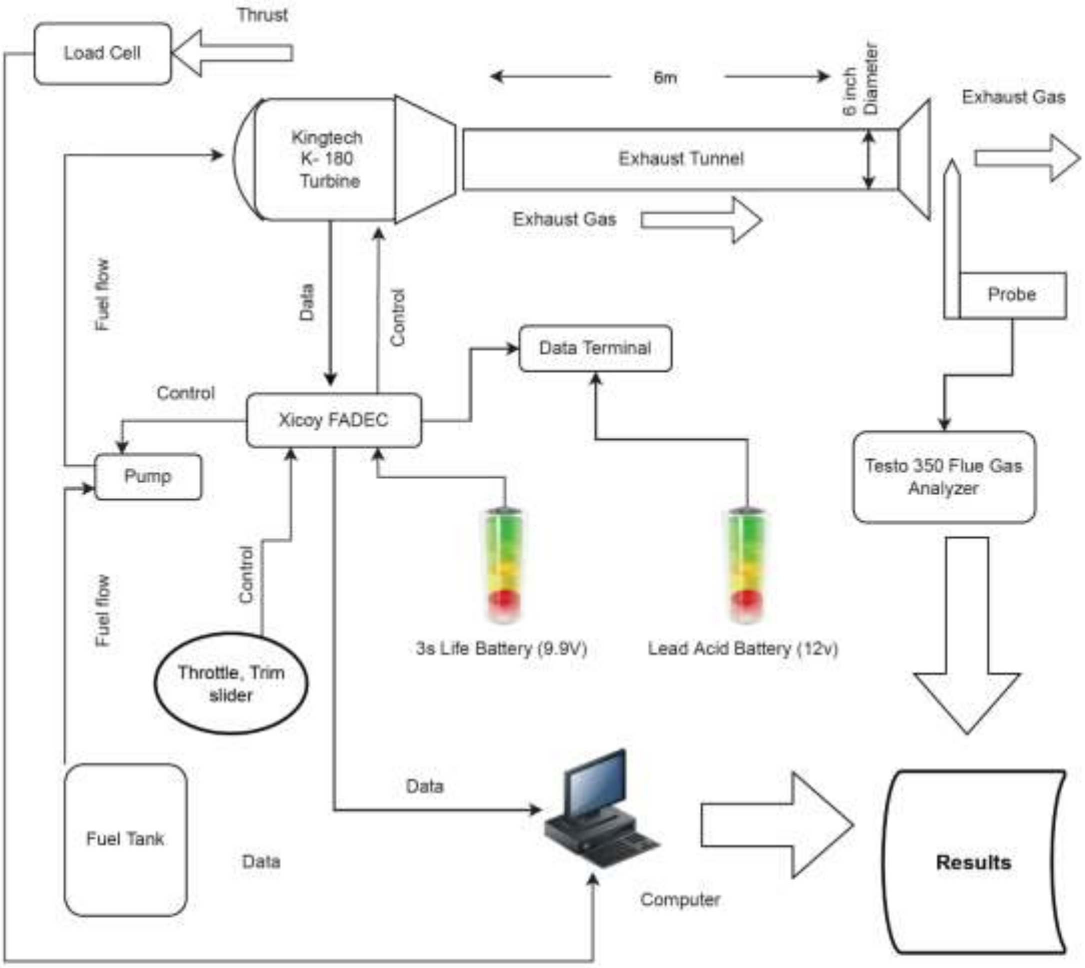

Figure 2 Schematic drawing of experimental Setup

The performance parameters of each fuel type were analyzed using the KingTech k180 micro gas turbine engine, which has a maximum thrust rating of 18 kgf (kilogram-force) as per the manufacturer's specifications. The engine is capable of running on Kerosene, Diesel, and Jet A1 fuels. It is important to note that engine lubricant must be added at a rate of 5% of the fuel volume (3-5% for diesel).

The engine data, such as RPM, Exhaust Gas Temperature, Pump Pulse width, Pump power, battery voltage, and ampere, were collected by the Xicoy FADEC, which was connected to a computer via a data cable. The

FADEC v5 software was used to display the engine data in real-time, and the engine was controlled using a Futaba Transmitter connected to the FADEC. The engine thrust was obtained by connecting a strain gauge to a computer via USB and using the DSC USB software to display the real-time thrust value. The engine was tested at similar ambient conditions for each fuel type, and the results were obtained by manually analyzing the recorded values from the FADEC v5 and DSC USB software. The data was then visualized using Matplotlib on Python. To ensure unbiased emission test results, each test was conducted at a fixed engine RPM of approximately 35-37k, which is the idle RPM, with the throttle stick position set to 11%, and the fuel flow constant at 12%.

III. RESULTS AND DISCUSSIONS

Figure 3 displays the thrust values of the engine for different RPMs, which is a significant performance parameter measured in kgf or kilogram-force. The pump pulse width, which indicates the pump power, was measured in milliseconds. A higher pulse width implies a higher fuel flow rate into the engine.

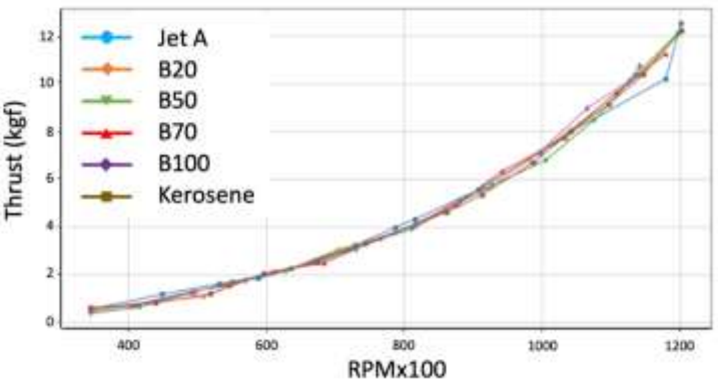

Figure 3 Thrust vs RPM

Figure 3 displays the relationship between the engine thrust and engine RPM for each fuel type. All fuels tested followed a similar trend, with an exponential increase in engine thrust as RPM increased. This trend was also reported by Abu Talib et al. [8] and Abd Lati et al. [12]. The figure indicates that Jet A1 produced the highest amount of thrust, peaking at around 12.5 kgf. Kerosene followed closely behind with around 12.2 kgf of thrust. B20 (20% blend) and B50 performed similarly, while B70 produced a maximum thrust of approximately 11.2 kgf at 118,000 RPM. In contrast, pure Palm diesel or B100 performed the worst compared to the other fuels, producing a maximum thrust of approximately 10.7 kgf. The maximum RPM that B100 could reach was around 114,000, likely due to its low heating value and high viscosity when compared to Jet A1 and other blends.

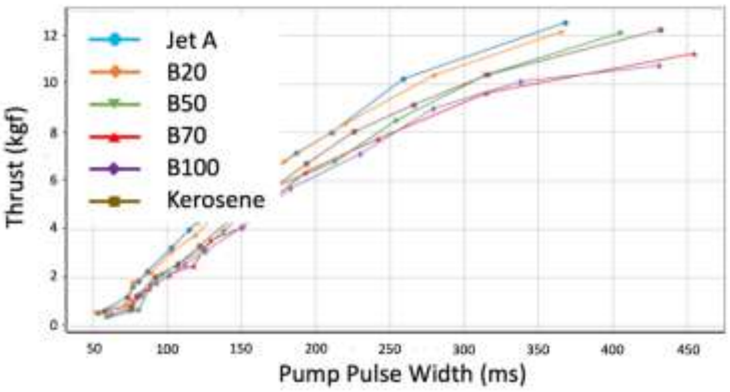

Figure 4 Thrust vs Pump Pulse Width

The exponential relationship between engine RPM and thrust can be inferred. Similar thrust values were demonstrated by Jet A1, Kerosene, B20, and B50 while attaining a maximum RPM of about 120,000, whereas B70 and B100 were unable to achieve that RPM and performed poorly with respect to maximum thrust. These findings align with those of Gires et al. [13], who discovered that the B20 blend produced similar thrust to Jet A and remarked that the TSFC performance was only 0-5% lower for B20 fuel. Pump Pulse width denotes the duration during which fuel flows through the pump for a specific cycle. The greater the pulse width, the greater the quantity of fuel that flows to the engine burner. Thus, for a given thrust, a lower pump pulse width corresponds to higher fuel efficiency.

Conclusive evidence for fuel performance is demonstrated in Figure 4, where Jet A1 produces a higher thrust at a fixed pump pulse width compared to other fuels due to its high heating value. The second-best fuel in terms of performance was B20, followed by B50 and kerosene. B70 and B100 performed poorly, with B70 producing slightly higher thrust. Examining Figure 4 closely, it shows the pump pulse width at which the maximum thrust was achieved for each fuel. Jet A1 produced the highest thrust of around 12.5 kg at a pulse width of approximately 367 milliseconds. B20 achieved its maximum thrust of around 12.1 kg at a pulse width of approximately 365 ms, while B50 produced similar thrust to B20 but at a higher pulse width of approximately 405 ms. Kerosene produced a slightly higher thrust of around 12.2 kg but required a longer pulse width of around 432 ms. B70 produced a maximum thrust of 11.2 kg with the highest pulse width of around 450 ms, while B100 showed a lower thrust of 10.7 kg and a lower pulse width of approximately 430 ms.

IV. CONCLUSIONS

The study's findings indicated that fuels with high heating values generated greater thrust values, with Jet A1 and Kerosene producing the highest thrust values, followed by B50. In contrast, B70 and B100 demonstrated significantly lower thrust values. The relationship between thrust and pump pulse width illustrated the fuel efficiency of each fuel type, revealing that Jet A1 provided the highest thrust value at a lower pump power, followed by B20, B50, Kerosene, B70, and B100. As the viscosity value increases with a rise in the volume ratio of biodiesel, it is suggested that a biofuel blend with Jet A1 could be utilized as a fuel source for modern airliners, lowering the CO_2 lifecycle emissions while maintaining the high performance of Jet A1.

ACKNOWLEDGMENT

The authors would like to thank the Ministry of Higher Education (MoHE) for the funding allocated in this project under the Malaysia Spain Innovation Programme (MySIP) no. 5540547. Special thanks to Mr. Nasir Johari for his technical expertise during the engine performance test.

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