Emission and Efficiency of Alternate Fuel Powered Microturbine and Turbofan

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Original Article

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Abstract

In order to lessen aviation's carbon footprint, alternative fuels comprising biocomponents made by different technologies are being introduced, but there is little information available on how these fuels affect engine performance and emissions. The goal of this research is to compare the gas emissions and performance full-size DGEN380 turbofan and the GTM-140 microturbine, both of which are propelled by mixtures either hydroprocessed esters and fatty acids (HEFA) or alcohol-to-jet (ATJ). An engine emittance model will be created using the collected data to forecast gas emissions. In the lab, the hysicochemical parameters of blends of petroleum based synthetic components were added to the fuel in a range of densities. The Semtech DS gaseous analysis tool and the EEPS spectroscopy were used to measure the emission levels from both engines at specific operating points. The effects of the tested blends on motor operating parameters are negligible, and using them carries no risk of noticeably worsening aircraft performance or raising fuel consumption. The operating conditions of ground personnel shouldn't worsen despite a significant rise in CO emission and a modest increase in some other gas emissions (HC and NOx) caused by increasing the substance of biocomponents. This implies that using tested blends to fuel gas turbine engines is not contraindicated.

Keywords: **Synthesized Kerosene, Fuel Blend, Combustion, Biocomponent, Alternative Fuel, Emissions, HEFA, ATJ, Sustainable Aviation Fuel, Microturbine, Drop-in Fuel Turbofan**

1. Introduction

lternative fuels with biocomponents produced using a variety of technologies are being introduced in aviation in order to lower CO2 emissions and utilise non-edible raw resources from renewable sources [1-3]. However, compared to using mineral fuels, using biofuels to power aircraft has far less experience. The density of toxic compounds in the air is demonstrably increased by an only one take-off or landing operation, according to air-quality measurements [4]. Gas-turbine engines are frequently used, which worsens the air quality around and within airports. Ground staff and nearby communities are concerned about the harmful effects of emitted particles and gases on their health. Although all large engines' emissions are regulated during an aircraft's certification, the high volume of air operations leads to a buildup of pollutants. As a result, it is crucial to monitor and maintain air quality [5], particularly around airports. The use of a new measurement methodology that has been suggested in publications over the past few years has resulted in the adoption of new regulations for the credential of aero engines by the ICAO (International Civil Aviation Organization) after many years [6]. Measurement of particulate and gaseous emissions under actual conditions is the focus of recent research [7] in order to better understand their toxicity and health effects [8–10].

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Small quantities of new kinds of alternative energy sources are synthesised, not enough to run big engines. This is why, Regardless of the fact that they have a structure that differs greatly from a commercial engine, microturbines are frequently used it to try out new blends [11–14].

The advancement of models for toxic compound emissions from aerospace [3] are becoming more and more common focuses of scientific research. Defining their thermophysical properties is necessary in order to describe different fuels and blends. A clear analytical explanation of burning and aggregated points of heating for fuel mixtures are frequently utilized in none whatsoever models of engines established in GSP [15] or GasTurb [16, 17]. Thermodynamic formulas are employed to define combustion and heat transfer in the modelling of combustors [18, 19]. Complicated mathematical Specifications are used to design new combustors with lower emissions [20, 21]. To predict emissions, a database of engine emissions [22], machine learning [23], and models using mathematicl or artificial nural nework [24] are also used.

In this work, a few outcomes that can only be acquired with a microturbine are generalized using both a microturbine and a complete engine. The microturbine GTM-140 as well as the DGEN380 focused turbofan are two separate jet engines used in the study, and their effectiveness and gas emissions are being compared. An emissivity model will be created using the collected data to forecast exhaust gas compound emissions.

2. Methods

Mineral fuel and synthetic blends were created in a variety of concentrations,, and their physicochemical properties were assessed in a lab setting. The Semtech DS gaseous analysis tool and the EEPS spectroscopy were used to measure the emissions out from GTM-140 microturbine at specific operating points. The DGEN380 engine's emissions were measured similarly in a test cell. The measurements were averaged, represented visually, and contrasted. The scope of the results analysis included physicochemical fuel blend parameters, motor operational characteristics, and emissions (Figure 1).

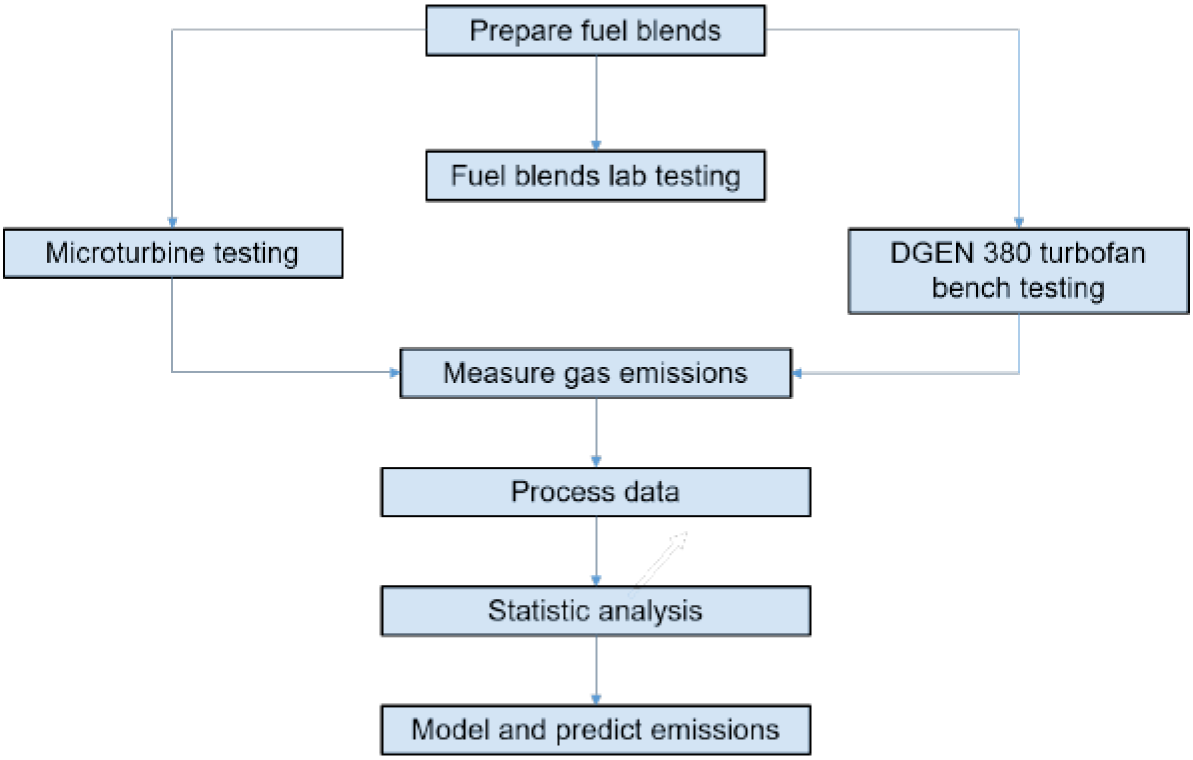

Figure – 1: Testing Model

2.1. Fuel laboratory Testing

Physical and chemical characteristics of the blended fuels were evaluated in the fuel lab, including 15 °C intensity, -20 °C viscosity and -40 °C caloric content, the amount of fragrants and naphthalene, crystallization heat, and diffusion. The chosen characteristics are also described in the ASTM D1655-18a and ASTM D7566-18 records and are crucial for the ignition chamber and engine functioning.

2.2.GTM-140 Microturbine

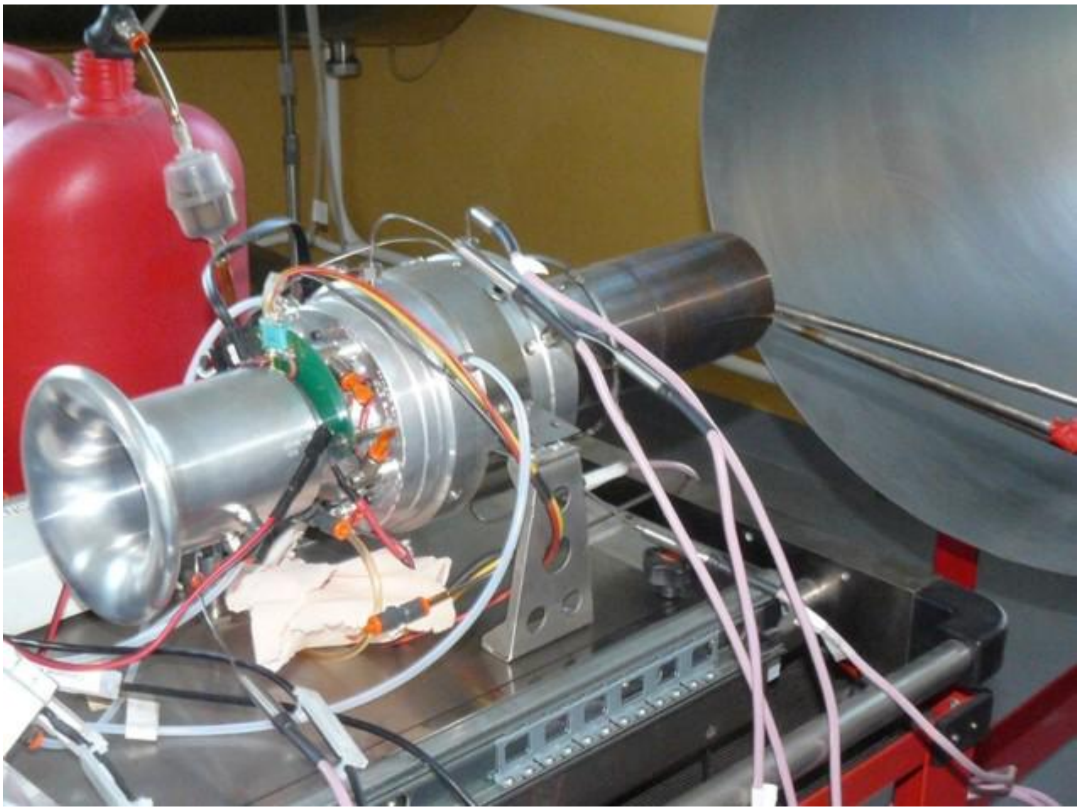

Figure – 2: Microturbine GTM-140

The experiment platform is outfitted with a transportable gas analyzer, which was employed in earlier studies on emission [26–28]. Using a probe, exhaust air are collected from the motor nozzle and delivered to the instrument via a heat exhausting hose.

The analyzing tool has 2 different NDIR (nondispersive infrared) sensor systems for infrared measurements, as well as electrochemical devices to quantify O2, CO, NO, NO2, SO2, and other gases (CO2 and CxHy). Measurements of the exhaust gas constituents have a 5% uncertainty and a clarification of 0.1 ppm. Through a thermocouple incorporated into the probe, the analysis tool also allows measurement of the exhaust gas temperature. The data gathering mechanism created in LabVIEW presents and stores functioning specifications and emissions [29].

Additionally, the Poznan University of Technology's Semtech DS gaseous analyzer (Figure 4) and Engine Exhaust Particle Sizer (EEPS 3090, Figure 5) were utilized in addition to the corresponding exhauster sampler systems (Figure 6).

Through a probe kept at a temperature of 191 °C, exhausted gases were given to the Semtech DS analyzing tool. The exhausted gas was then sent to the flame ionizing detector (FID), in which HC density was evluated.

Following the sample's cooling at an air temp of 4 degree celcius, measurements of the concentrations of NOx, CO, and CO2 were made using an NDIR analyzer, NDUV analyzer, and respective instruments. The raw-emission results in percents are presented in the following sections.

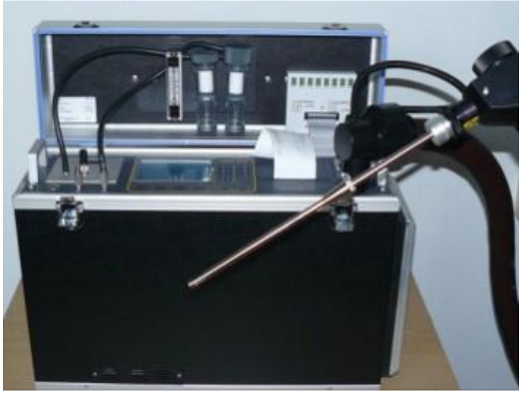

Figure – 3: Emissions Analyser GA-60

Figure – 4: Gaseous Emission Analyzer

Figure – 5: Particle Sizer (Engine Exhaust)

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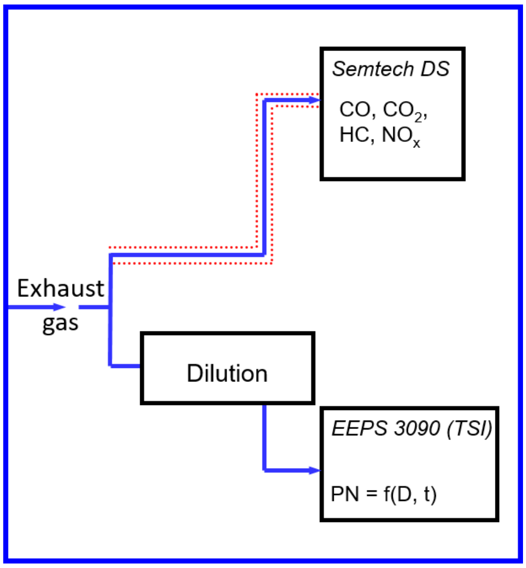

Figure – 6: Exhausting Gas Sampler

2.3.DGEN380 Turbofan

A highly bypassing turbofan proportion focussed turbofan, the DGEN380 generates 255 daN of force (Figure - 7). Its design resembles that of contemporary commercial engines, and it is well instrumented and uses little fuel. The WESTT test cell's information gathering system (Figure 8) allows for the collection and analysis of a number of engine performance variables, including force, fuel economy, temperature, and pressure. Although it has not yet received certification, the turbofan was created for ultralight aircraft and is not included in the ICAO emission levels databank. In this study, CO, CO2, HC, and NOx emissions were determined using the Semtech DS analyzer. These are most likely the first gaseous emissions data for this engine to be published.

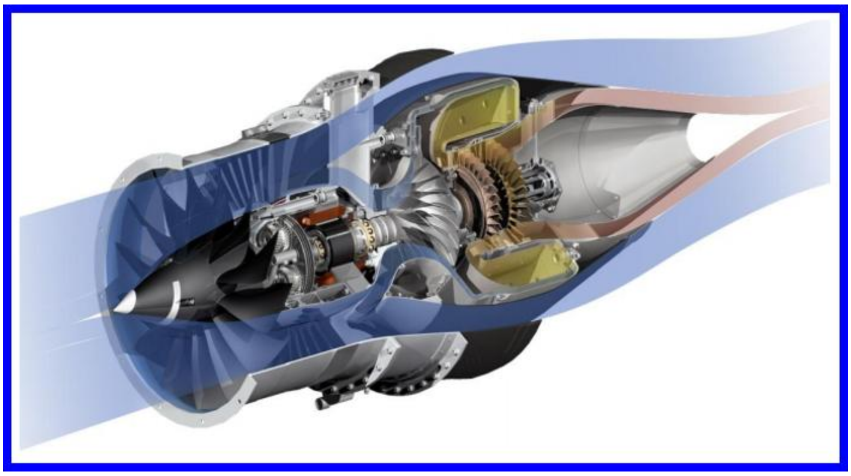

Figure – 7: Turbofan (DGEN380 Geared)

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Figure – 8: Test Cell Module

A limited amount of fuel was used to keep the blend ratio constant throughout test results of the DGEN380 turbofan with biocomponents. This indicates that, unlike during the checking of the Jet A-1 fuel, the container was not continuously filled with the fuel. The flow resistance might have increased as the tank got closer to being empty, but neither the fuel pressure nor the fuel pump's RPM changed. Even though the PLA was set to 100%, it started to turn discovered that the fuel injection was marginally lower (by 2%), which prevented the nominal thrust from being achieved (Section 3.4).

2.4.Testing of Engine

Engine's emission is tested in accordance with ICAO protocol [30] at specific operating points that are associated with the takeoff and landing cycle (LTO), as engine emissions are significantly dependent on an engine's operating mode (Figure 9). Taxi/ground idle, approach, cruise, climb and takeoff operating modes are represented by the engine test procedures. The tests were conducted using both types of engines, and they involved a sequence of operation conditions where the speed was gradually increased (Figure 10). Again for microturbine and the turbojet, performance indicators and emission levels were evaluated and averaged over periods of 30 and 60 seconds, respectively. To better represent LTO operating modes, the variables are presented versus thrust.

Testing with ATJ blends took place in stable ambient conditions over the course of one day, whereas testing with HEFA blends took place in the same conditions over the course of one year. Starting and stopping were finished the primary test using the same fuel because the fuel was not shifted during each test run. Starting or stopping the microturbine using alternative fuels didn't cause any issues. When the turbofan was helped fuel with an ATJ blend, rebooting it following a shutdown was not successful. However, air in the oil was to blame for the low oil pressure, not the fuel.

An exactly equal mission profile with a list of operating points was repeated to compare the various blends. It was challenging, particularly for intermediate speeds, to assure that the rotation speed were identical in subsequent tests. Speed and thrust could not be adjusted; the engine's operations varieties were chosen using FADEC and PLA. The test runs differ slightly but significantly in speed, which is particularly significant when examining adjustments in engine performance.

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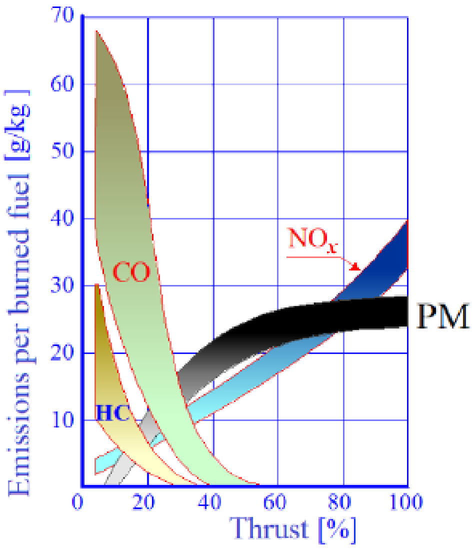

Figure – 9: Power Vs Emission

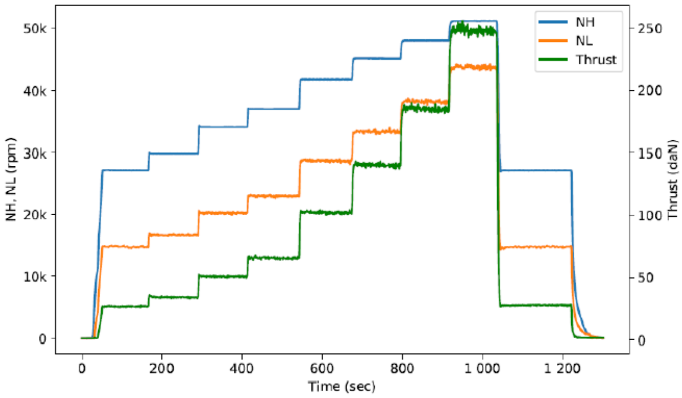

Figure – 10: Test Profile

The motors were not checked for solid excess reserves as well as hot oxidation [31] just after testing because only certificated fuels were employed in the above project and the runtime was brief. This can be accomplished using a match the following or by dismantling the engine issues [33]. However, the microturbine has indeed been done concurrently on a variety of alternative fuels and routinely thoroughly checked when substituting the rotor bearings, later tests using Jet A-1 fuel on the DGEN380 turbofan were successful. No notable deposits or damage were found in the section.

3. Results

3.1. Testing of Fuel Lab

According to laboratory examinations, mineral fuel complies with ASTM D1655 requirements, whereas HEFA and ATJ biocomponents and there own mixture meet ASTM D7566 requirements. The chosen physicochemical characteristics of all the examined fuels are shown in Table 2. According to the findings, Jet A-1 is more dense than neat biocomponents and with there blends. The mass flow of fuel is impacted by this. Additionally, biocomponents have a marginally higher calorific value than other materials, which could lead to higher produced heat and EGT values. It is common knowledge that higher combustion temperatures result in higher NOx emissions. Additionally, neat bio-components are devoid of aromatics, which among the main constituents of kerosene typically have had the least attractive combustion characteristics.

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Fuel	Density at 15 °C kg/m^3	Viscosity at −20 °C mm^2/s	Calorific Value MJ/kg	Aromatics (v/v) %	Naphtha-Lenes (v/v) %	Flash Point °C	Freezing Point °C	Smoke Point mm
ASTM	775–840	Max 8.0	Min 42.8	Max 25	Max 3.0	Min 38	Max −40	Min 18
Jet A-1	798	3.40	43.2	16.7	0.58	49.5	−63.5	20
5% ATJ	796	3.45	43.3	15.7	0.55	49.0	−65.5	23
20% ATJ	790	3.57	43.4	13.0	0.46	49.0	−66.5	25
30% ATJ	786	3.66	43.4	11.3	0.40	49.0	−66.8	28
50% ATJ	776	3.65	43.6	8.8	0.27	44.5	−60.0	30
ATJ	759	4.78	44.0	0.0		47.5	−67.5	
Jet A-1	796	3.25			0.55	49	−62.6	23
5% HEFA	794	3.29			0.52	48	−62.8	27
20% HEFA	787	3.40			0.44	46	−59.6	28
30% HEFA	783	3.47			0.39	46	−56.0	
HEFA	752	4.09	44.2			45	−39.9	

Table – 1: Testing Results (Fuel Lab)

3.2. Microturbine—ATJ

Operating parameters like power (Figure - 11) and SFC (Figure - 12) are study during engine tests, with barely perceptible variations amongst runs. The graphs (Figures 13–16) show the NOx, HC, CO2 and CO emission levels of engines running on mixtures of Jet A-1, Jet A-1 and ATJ component blended to 50%, and neat ATJ component. The triple deviation from either the mean is displayed in error bars along with the values' 30-second averages.

The findings demonstrate that addition of a ATJ component increased CO emission when aligned to the aviation fuel Jet A-1 at all operation conditions (Figure - 13). The uptick in CO emissions is proportional to the amount of ATJ in the mixture. When aligned to the neat Jet A-1 fuel, ATJ component results in a slight reduction in CO2 emissions (Figure 14).

The adding of the ATJ component did not significantly alter HC emissions (Figure 15), so this change is not conclusive. The incusions of the ATJ instrument in comparison to Jet A-1 resulted in an increase in HC emissions at the first two rotational speeds. The inclusion of the ATJ component led to a reduction in Hydrocarbon emission for the Jet A-1 fuel at three successive operating points.

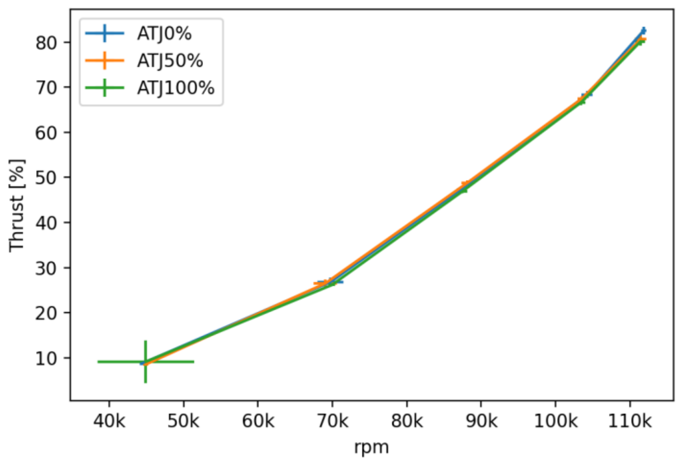

Figure – 11: Power - GTM 140/ATJ

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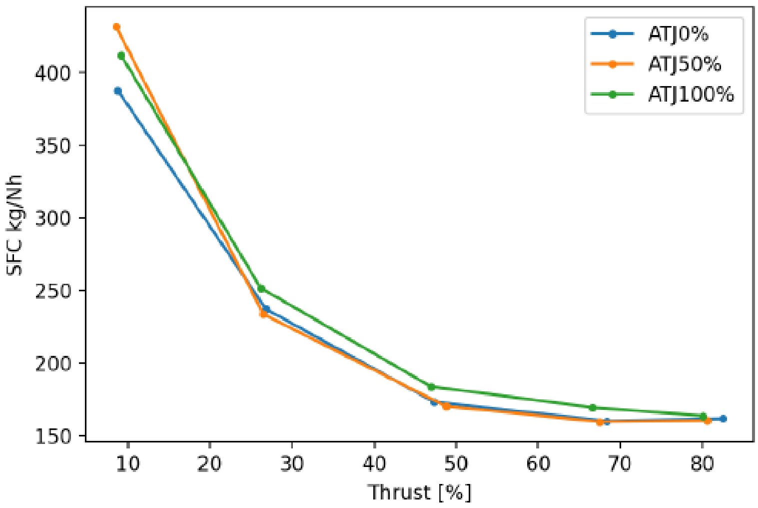

Figure – 12: SFC - GTM 140/APJ

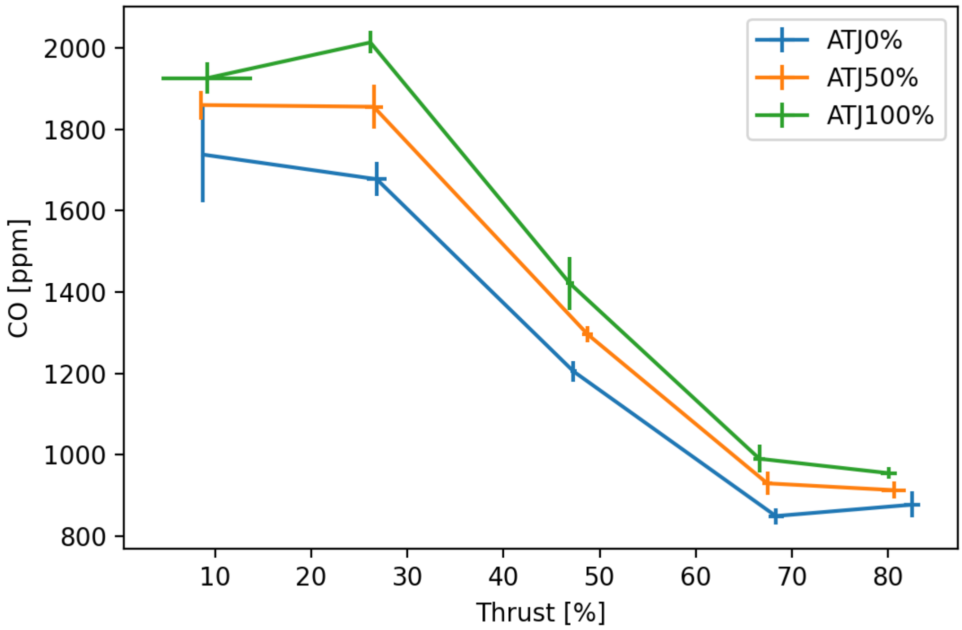

Figure – 13: CO Emission - GTM 140/APJ

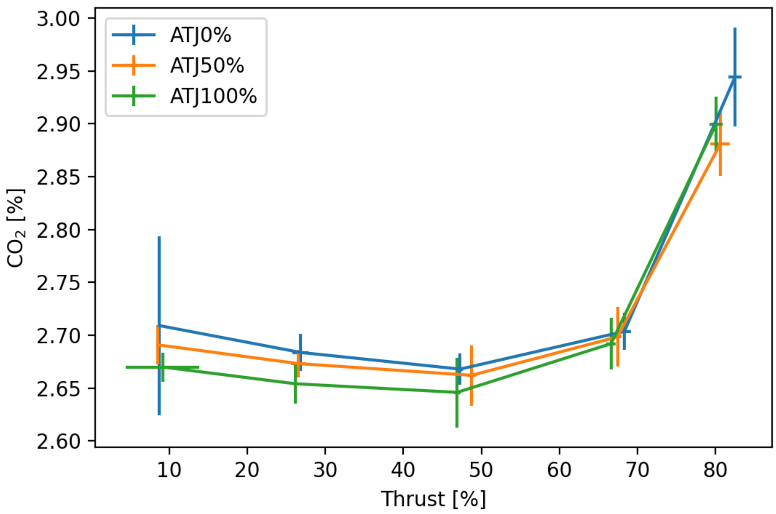

Figure – 14: CO_2 Emission - GTM 140/APJ

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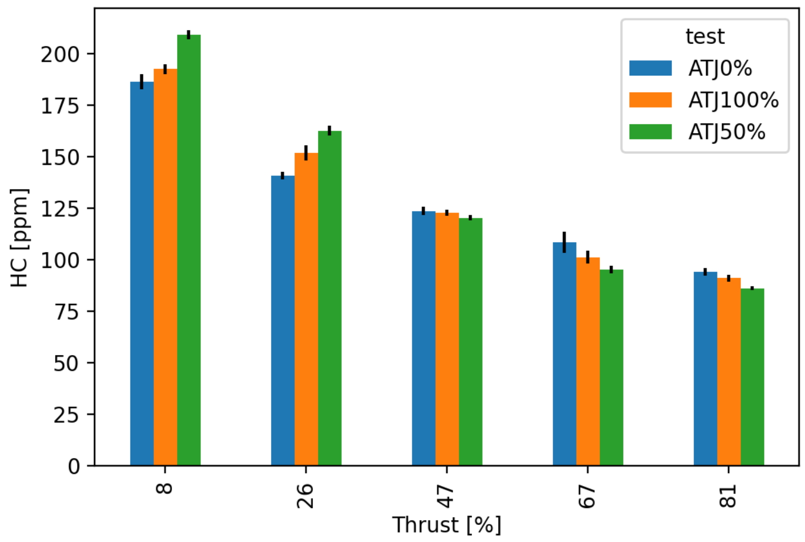

Figure – 15: HC Emission - GTM 140/APJ

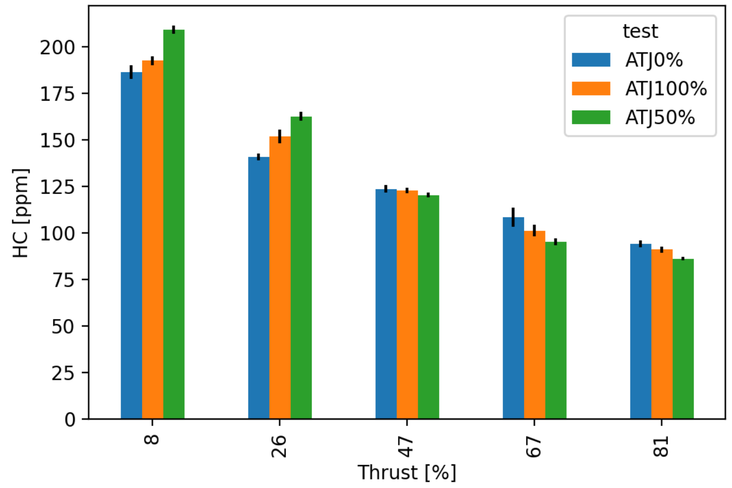

Figure – 16: NOx Emission - GTM 140/APJ

3.3. Microturbine—HEFA

Likewise, the expeimental functionings using HEFA blends had little to no impact on engine power (Figures 17 and 18). Figure 19 shows that, at all examined operating points, the HEFA component causes a rise in CO emissions while having no discernible effect on CO2 emissions (Figure 20). Similar results were obtained for this parameter's changes in NO emissions, showing that the HEFA component typically raises NO emission levels (Figure 21). The hydrocarbon emissions showed a reversal of the trend (HC, Figure 22). When HEFA was added, HC emissions were reduced in comparison to using pure Jet A-1 fuel.

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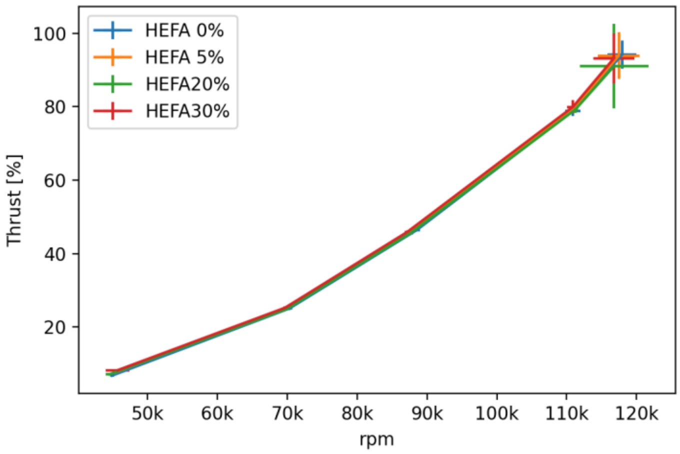

Figure – 17: Power - GTM 140/HEFA

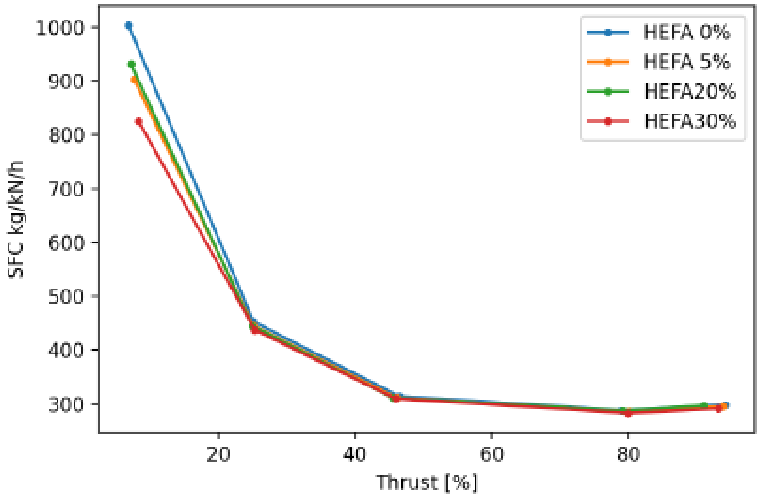

Figure – 18: SFC - GTM 140/HEFA

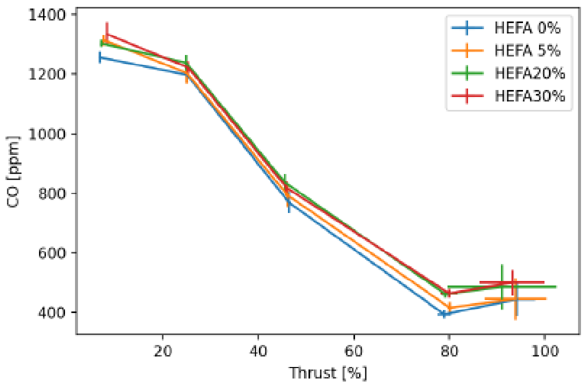

Figure – 19: CO Emission - GTM 140/HEFA

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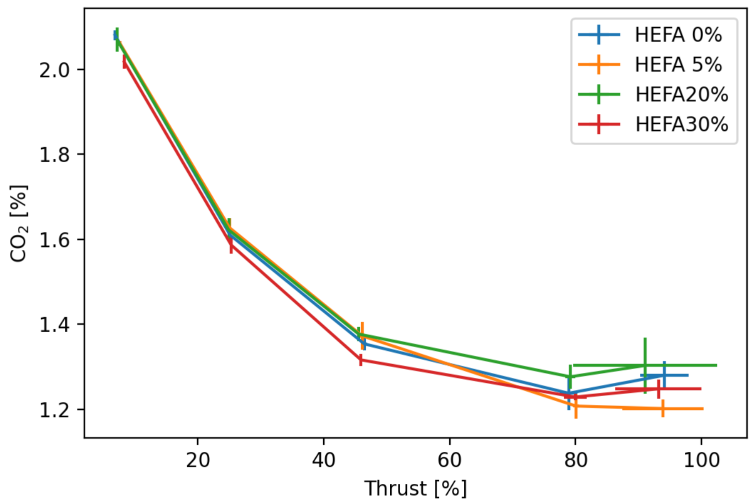

Figure – 20: CO_2 Emission - GTM 140/HEFA

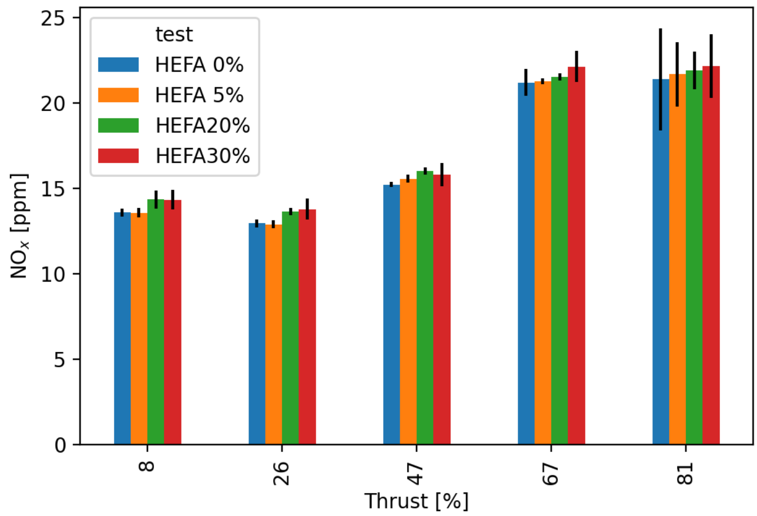

Figure – 21: Nox - GTM 140/HEFA

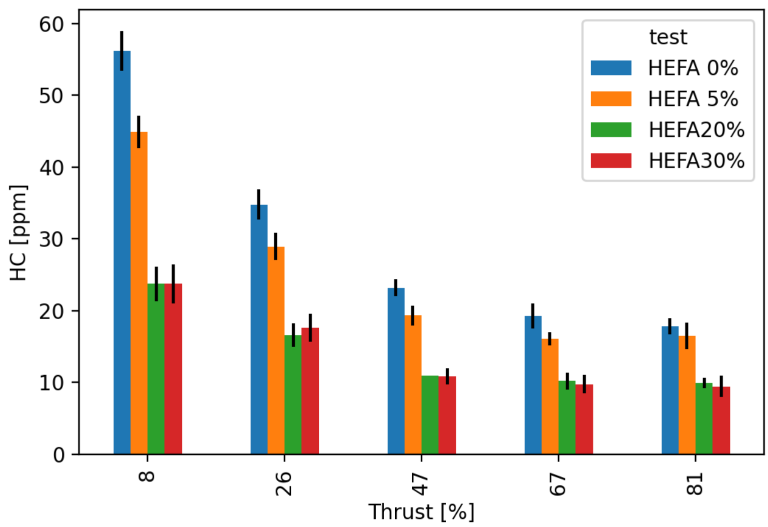

Figure – 22: HC Emission - GTM 140/HEFA

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3.4. Turbofan

Based on the DGEN380 turbofan's performance data, it can be said that there are typically less than 1% differences in relative push (Figures - 23 and 24) and fuel usage (Figures - 25 and 26) amongst tests. The largest ones, though they don't go above 5%, are for the takeoff range.

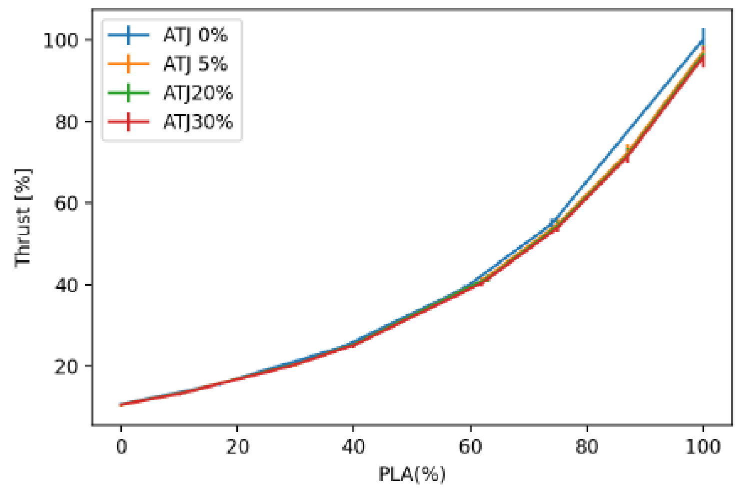

Figure – 23: Power Vs PLA - DGEN380/ATJ

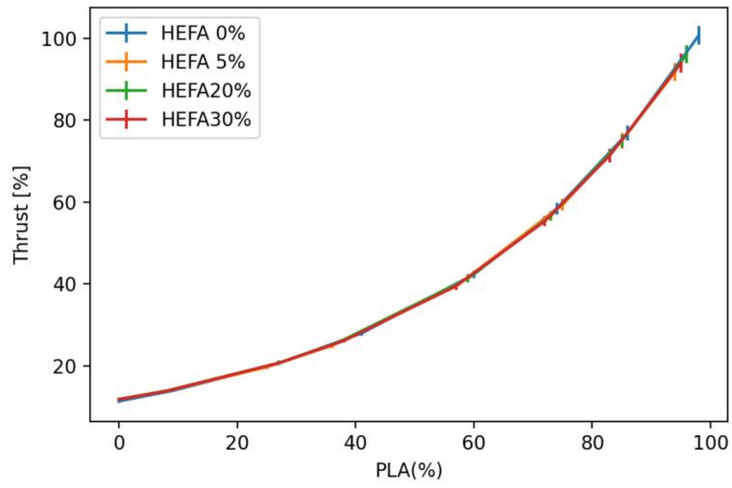

Figure – 24: Power Vs PLA - DGEN380/HEFA

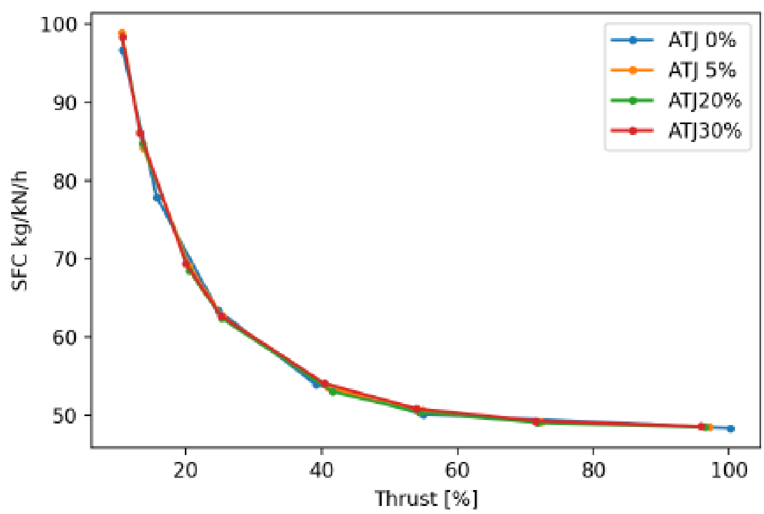

Figure – 25: SFC - DGEN380/ATJ

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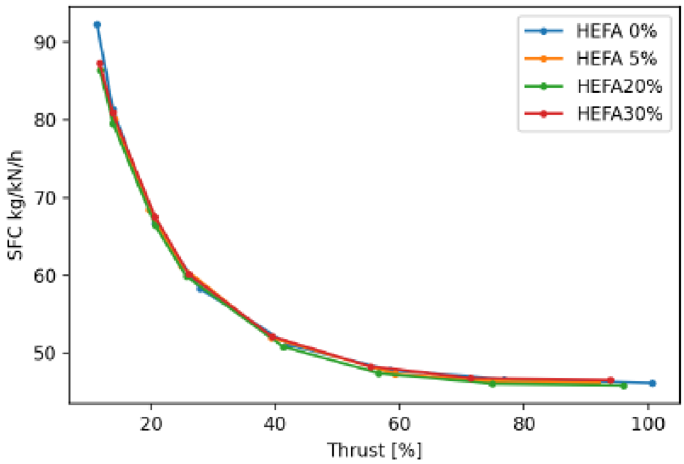

Figure – 26: SFC - DGEN380/HEFA

Analysis of the operation variabes reveals not an obvious pattern in their alteration as a result of the utlization of mixtures containing biocomponents. The model of the engine and its controller are required in order to link the variations to some fuel characteristics. For instance, while using ATJ, a subtle rise in temperature of exhaust gas (EGT) was seen as the biocomponent ratio increased (Figure 27), but HEFA did not show a similar trend (Figure 28). Notably, PLA is directly proportionate to rotational speed rather than thrust despite its name (Figures - 23 and 24).

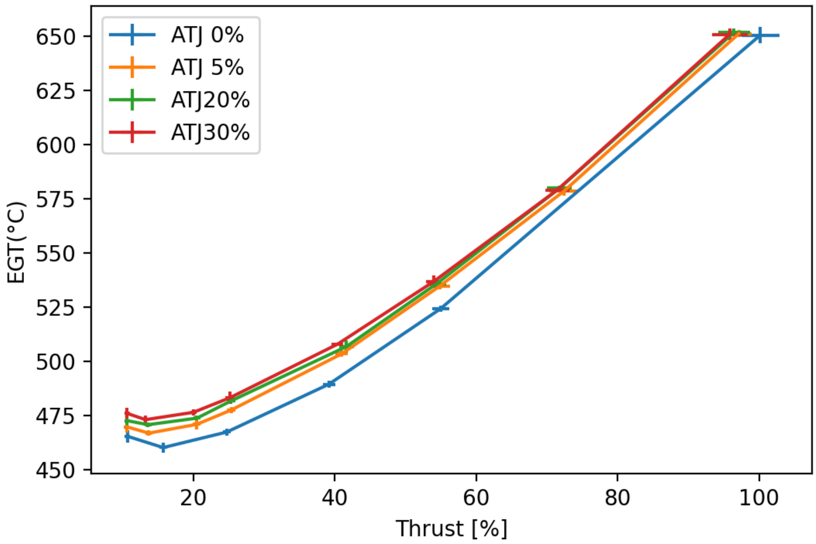

Figure – 27: EGT - DGEN380/ATJ

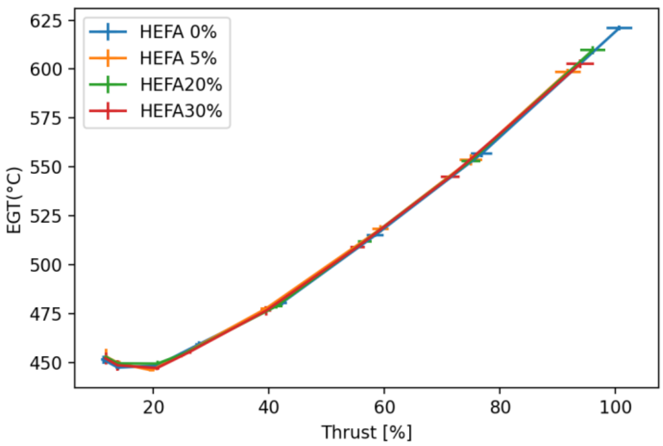

Figure – 28: EGT - DGEN380/HEFA

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In all of such a DGEN380 turbofan's examined operating points, trying to add the ATJ element to the nutrient fuel increased CO emissions significantly (Figure 29) and CO2 emissions marginally (Figure 30). Trying to run a DGEN380 motor that mixes to the ATJ instrument makes this process more obvious because CO formation is connected to inadequate the fuel combustion. For the HEFA instrumentt, its inclusion led to a definite increment in Hc emissions (Figure - 31) and a marginal exponential growth (Figure 32) in all the examined operating points.

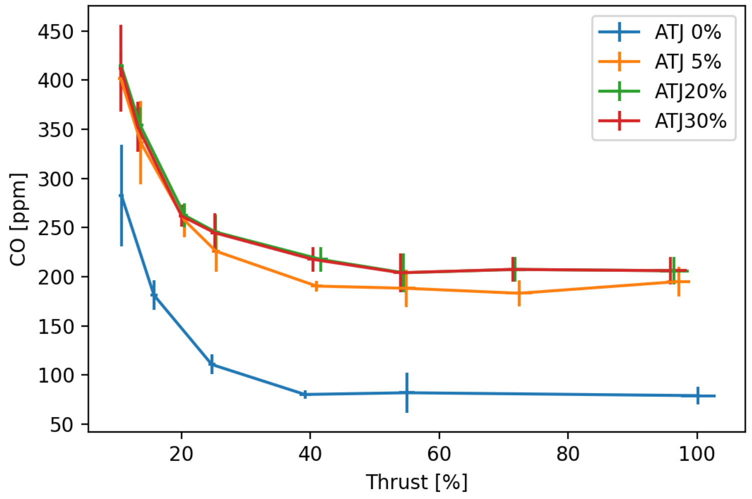

Figure – 29: CO - DGEN380/ATJ

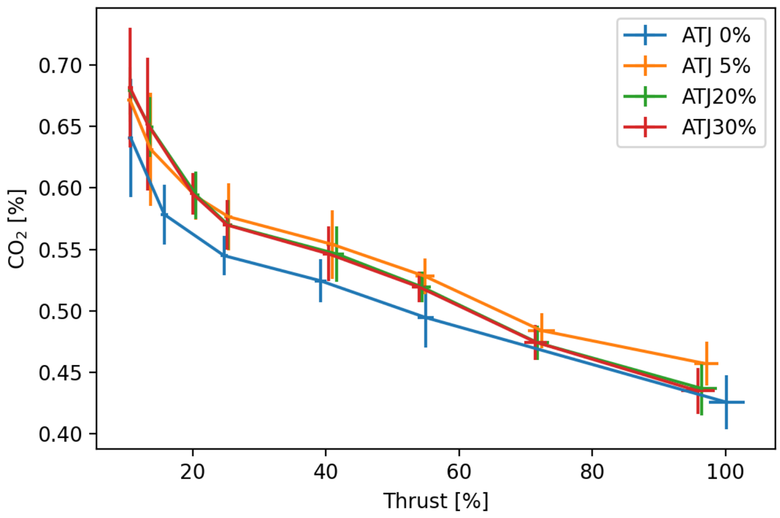

Figure – 30: CO_2 - DGEN380/ATJ

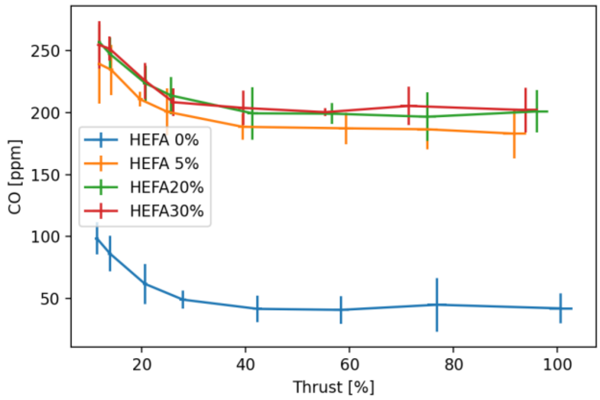

Figure – 31: CO - DGEN380/HEFA

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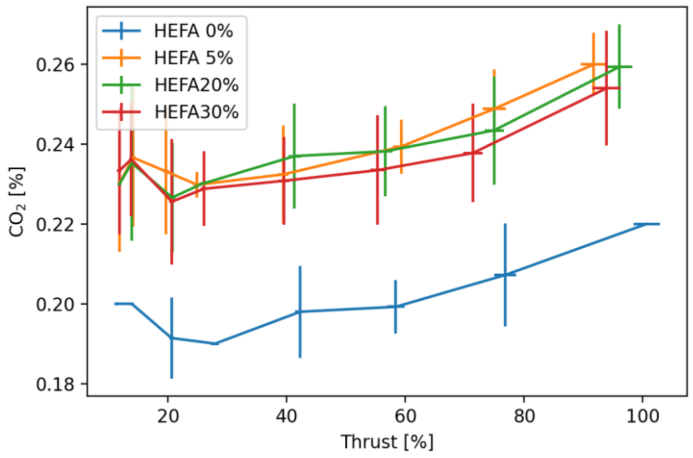

Figure – 32: CO_2 DGEN380/HEFA

It's interesting to note that the absolute emmisions values for ATJ are nearly twice as high as those for HEFA. The solution was diluted of the exhaust stream accounts for the relatively low Emissions of CO2 for both biofuels. It is in accordance with the measurement probe's distance from of the motor, which was determined in light of the outlet nozzle's diameter. The outcomes would be more ambiguous if the probe were positioned close to the engine. It is particularly difficult to take a sample when the gas stream is directed directly just at probe because the measurements are thrown off by the turbulence created by the high dynamic pressure around the probe.

Both biocomponents of the DGEN380 engine showed a significant rise in CO emissions, which has not been fully explained. By referring emission levels to the levvel of CO2, which in itself was equal towards the understandable technique of adjusting emissions to 15% oxygen, different fuel dilution for Featuring an inset visual and HEFA exams is addressed [34]. The observed CO increase is not merely a result of a misspecification, as shown by the obtained regards of CO to CO2 (Figures 33 and 34), which exhibits good behaviour.

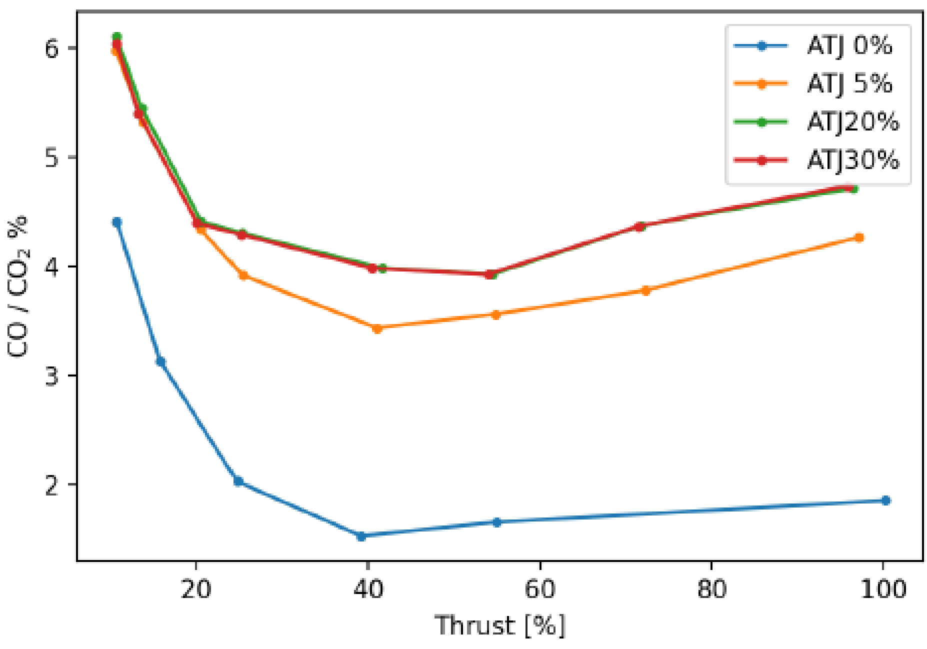

Figure – 33: CO Vs CO_2 - DGEN380/ATJ

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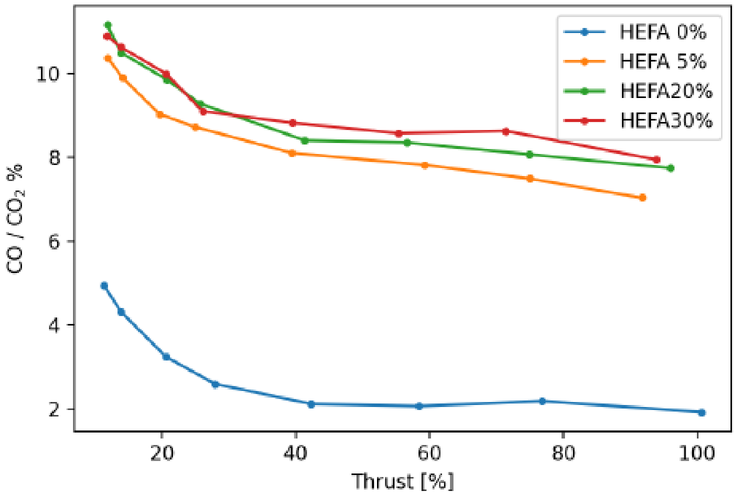

Figure – 34: CO Vs CO_2 - DGEN380/HEFA:

4. Conclusion

The assessment of engine efficiency variables for both engines revealed that because the blended samples' differences by using natural fuel were so negligible that they had little effect on engine operating parameters and did not pose a significant threat to a plane's effectiveness or fuel efficiency. The trial turbofan DGEN380 emissions results have not been released somewhere else. The pollution for the ATJ bio-instrument and internal ratios of HEFA first were observed in relation to the previous tests of the microturbine conducted in ITWL. Also utilised was the Semtech analyzing tool with a more convincing motion. The assessment of engine efficiency variables for both engines revealed that the tested mixtures' differences from raw fuel were so negligible that they had little effect on engine operating parameters and did not pose a significant threat to plane's effectivenes or fuel efficiency. The pollution for the ATJ bio-instrument and transitional ratio of HEFA were studied in comprision to earlier experiments of the successful operations conducted in ITWL. An engine emittance model will be created using the collected data to forecast gas emissions. A basic structure's optimal operating parameters and emissions can be linked to the fuel's thermophysical parameters using statistical techniques and the explanatory combustion model.

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