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Experimental Validation of Sustainable Aviation Fuel (SAF) Blending and Testing Methodologies for Small Turbofan Engine

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Abstract: *Much research has been undertaken on the sustainable aviation fuels as the alternative to jet A-1 fuels due to magnitude demands of having carbon-free alternative fuel in the aviation industry. This study gives information on the combustion dynamics and emission performance of synthetic fuel blends of a small PTD 500 turbofan engine using a kinetically shaped reactivity model that is dependent on chemical kinetics and thermodynamics. Several blends of fuels containing different volumes of SAF content were created and tested on their conformance with ASTM D7566 and ASTM D4054 requirements. The experimental test of the engine measured thrust, fuel consumption and emissions over a range of operating conditions, reactivity model included activation energy and combustion kinetics to measure the dependence of fuel mass flow on exhaust gas forming Combustion behaviours was correlated to thrust output and CO and CO_2 emissions by use of α 1 reactivity coefficient. In terms of the Take-off operation, the thrust contribution of engines ranged between 80%-90% but in idle operation, recorded 10%-15.As evident in the results, addition of SAF has insignificant impact on engine thrust gain, with significant impacts on combustion paths and routes related to the incomplete combustion formation. This was proved empirically as there was no difference in the consistency of the fuel blends and these differences in combustion chemistry were related to the change in the composition and calorific value of the hydrocarbons. The present research has established the compatibility of SAF with the existing engine systems and also the need to have a detailed kinetic model to optimize the use of fuel and reduce its environmental effects. The reactivity model is expected to be extended in future to include long-term engine operating conditions under typical SAF applications, which can be used to support the propulsion aviation sector transition to green propulsion.*

Keywords: *Aviation, Combustion, Engine, Fuel, Hydrocarbon, Turbofan*

1. INTRODUCTION

The manufacturing process for gas turbine jet fuels which uses kerosene since the 1900s depends primarily on hydrorefining and Merox technologies in crude refinement [1]. Hydrorefining employs catalytic hydrogenation to eliminate sulfur compounds when saturating double bonds thus creating stable fuel with enhanced execution. The refinery needs this process to satisfy stringent quality standards and regulatory requirements that focus on sulfur content [2]. Merox technology performs sulfur compound oxidation using a catalytic reaction method. The procedure makes jet fuels sustainable and resistant to environmental contamination and machinery deterioration. Hydrorefining and Merox processes ensure reliable functioning and efficient performance of jet fuels which together maintain aviation industry growth while meeting environmental standards [3].

The production methods between hydrorefining and Merox result in materials that have comparable hydrocarbon fractions and physicochemical properties in jet fuels. Each fuel composition contains 25% paraffin and 35% isoparafin with 20% cycloparaffins together with 20% aramatics [4]. The reliability of traditional jet fuels in flight has been proven since they meet all established performance standards [5]. The aviation industry now seeks alternative fuels due to rising greenhouse gas emissions worry while many of these alternatives derive from biomass sources [6]. Biofuels obtained from biomass qualify as renewable energy sources since burning these fuels lets biomass, carbon dioxide (CO_2) emissions balance with the growth- related carbon dioxide emissions from biomass. The self-contained carbon management of biofuels makes these fuels attractive to reduce aviation sectors emissions.

The application of sustainable aviation fuels (SAF) leads to important progress in reducing aviation sector global warming effects [7]. Biofuel manufacturers create specific versions for gas turbine engine usage which effectively replace Jet A-1 and similar jet fuels [8]. The typical composition of standard jet A-1 fuel consists of hundreds of hydrocarbons along with aromatics and naphthalene, but SAF contains mainly twelves hydrocarbons comprising of paraffins and isoparaffins [9]. The composition differential shows how producers aim to create environmentally friendly SAF which remains suitable for existing aircraft systems and facilities.

Integrating SAF into air operations enables the industry to reduce its greenhouse gas emissions, while helping worldwide climate change combat initiatives [10]. The production of SAF creates potentials avenues for sustainable aviation that need no major adjustments to present aircraft fleets or infrastructure systems [1].

Safety takes top priority in aviation operations and manufacturers of aircraft and engines need to approve any change to fuel composition [12]. The ASTM D4054 standard serves as the foundation for establishing certifications to approve alternative jet fuels with sustainable aviation fuels (SAFs) among them. Each aircraft platform together with its engine receives a four-stage qualification process through the ASTM D4054 certification system. The assessment framework determines how alternative fuel should meet all essential standards of safety, together with performance and compatibility for civil aviation deployment. Engine makers together with aircraft designers perform extensive evaluations specifically for fuel stability behavoir, alongside combustion behavior with lubricating properties and materials suitability within the engines and fuel systems [13]. The evaluation test for alternative fuel implications on engine performance and emissions production and aircraft safety performance take place in detail. The aviation industry follows ASTM D4054 certification standards to establish a safety-centred and reliable method for introducing alternative fuels such as SAF and to achieve sustainability targets [14]. Modern aircraft manufacturers now approve aviation blends that contain Sustainable Aviation Fuel (SAF) at levels of up to 50% [15]. The blended fuels achieve their objective of lowering greenhouse gas emissions through safe operations that uphold verification requirements. The move to 100% Sustainable Aviation Fuel requires resolution of feedstock availability problems as the main hurdle. Three types of sustainable feedstocks exist for the production of Sustainable Aviation Fuel (SAF) which include dedicated energy crops together with agricultural waste and waste oils [16]. The shortage of available feedstocks alongside other industry needs creates major problems for SAF production scale-up. Building out the necessary production and distribution infrastructure for SAF represents an important requirement that needs advancement for widespread adoption across the market. To make aviation 100% SAF dependent the industry must fund research development projects while policymakers and all stakeholders work together to solve existing barriers. The growing commitment to transform SAF into a practical jet fuel substitute is demonstrated by current initiatives focused on raising feedstock supply and developing production methods and expanding distribution systems.

The evaluation process for alternative jet fuels encounters several testing difficulties that prove difficult to determine their precise effects on engines and exhaust emission patterns [17]. Engine performance evaluation based on traditional testing approaches uses restricted sensor data that fails to measure detailed fuel composition effects on operational mechanics. The comprehension of biofuels' effects demands specific knowledge about their combustion reaction mechanisms and their velocity dynamics [18]. Various methods for jet engine combustion modeling through kinetics exist but most models fail to link engine operational effects to combustion kinetic mechanisms [19]. Multiple research groups have introduced predictive models that explain individual reactions which occur within fuel combustion chains. Complexity together with computational consumption of these advanced models results in high implementation costs and interpretation complexity [20]. Engine performance predictions using statistical approaches represent another proposed method to build correlations between combustion kinetics. These methods provide some useful information yet they do not have substantial physical meanings which constrains their applicability to diverse fuels. Future progress in explaining the combinatorial relationship between engine operation and its kinetic processes needs both academic cross-disciplinary work and novel methodological research development. Researchers should work together using chemical kinetics combined with fluid dynamics and engine thermodynamic knowledge to generate complete mathematical models which improve understanding of alternative jet fuel performance characteristics and emission outputs.

The introduction of reactive coefficient (α_i) represents an important step forward to analyze combustion processes in gas turbine engines better. Addition of chemical reaction kinetic concepts and thermodynamic parameters creates a complete framework that identifies combustion behaviours. The general application of α_i reactivity models permit their use for both thermodynamic procedures involving boundary energy transfers and chemical reaction speed measurements. A combined analysis method proves essential when studying engines since these systems produce complicated thermal-chemical interactions [21]. The α_i reactivity model serves to analyse fuel blends with synthetic components by delivering thorough knowledge about alternative fuel combustion dynamics. The model connects engine operational parameters to chemical reaction kinetics to provide extended knowledge of motor fuel properties and their resulting effects on efficiency and exhaust generation and engine operational quality. The α_i reactivity model serves as a valuable instrument for engineers and researchers who aim to create optimal gas turbine combustion systems and build more efficient fuel usage and produce cleaner air quality. The application of α_i reactivity model enables scientists to link thermodynamics to chemical kinetics which enhances their progress in combustion science and technology development.

The analysis of turbofan engine performance with different SAF concentration blends demands practical application of the reactivity model because it helps aviation engineers understand the impact of alternative fuel technologies. The objectives in this research project involve empirical investigation of reaction chain activation energies during complete and partial combustion together with the assessment of the reactivity coefficients of Jet A-1 fuel and SAF mixture combinations. Research-based parameter measurement helps scientists understand how modifications in fuel composition affect reaction speed and turbine functionality. Engine performance optimization along with emission reduction and flight security rely heavily on this essential information concerning the use of alternative fuels in aircraft systems. The study evaluates SAF blends as it demonstrates the necessity to incorporate sustainable aviation fuels into the industry while preserving turbine performance standards. The study of SAF influence on combustion mechanics and turbine systems serves as a critical foundation for advancing alternative aviation fuels and lowering aircraft sector environmental effects. This review adds essential knowledge to combustion science and engineering which enables the deployment of SAF in commercial aviation while helping worldwide climate change reduction efforts.

The prediction of small-sized turbofan engine performance with associated emission levels through synthetic fuel combustion relies on experimental data to develop mathematical relationships [22]. The engine testing phase starts by measuring thrust alongside fuel usage together with temperature and pressure data accompanied by exhaust gas composition. The collected experimental data becomes subject to analysis for researchers to detect patterns between engine parameters and synthetic fuel combustion characteristics. Model building starts from identified relationships which researchers convert into mathematical formulas using regression analysis as an example statistical technique. The available data determines the complexity of the combustion models which can range from basic mathematical equations to advanced algorithms [23]. They use models that identify the fundamental characteristics of fuel combustion inside the engine while keeping computational processes straightforward. The evaluation process for empirical models depends on experimental data collected from new sources outside the model development stage [24]. The model parameters become subject to adjustment in order to achieve better predictive accuracy levels and enhance performance. Empirical models which examine synthetic fuel combustion within small turbofan engines generate critical information about fuel composition effects on both machinery efficiency and exhaust emissions [25]. These computational methods guide engineers in creating better aircraft engines and developing improved fuels as well as running operational procedures for efficiency optimization and emission reduction and safety assurance across real-world aviation operations [26].

2. METHODOLOGY

2.1 Combustion Modelling

Fuel combustion in gas turbine engines is a highly complex chemical process occurring during several chemical reactions, the specifics of which are extremely sensitive to operating conditions. Different physics and chemistry-based methods are employed to model such intricate phenomena. A couple of these modelling approaches include Chemical Kinetic Models. These models are Combustion models that take into account the rates of different chemical reactions in the combustion chamber. The Chemical kinetics model is represented by the Equation 1. This solves a set of coupled differential equations to follow the changes of conservation of chemical species with time. They provide detailed reaction pathway insight and can predict combustion characteristic under different conditions.

$$v = K[X\}^p[X\}^q \quad (1)$$

The reaction rate constant K is represented in the Arrhenius equation as an exponential function of the temperature at which the reaction occurs. This foundational equation for chemical kinetics is based on the concept of activation energy (E_a), described in Equation 2.

$$K = A\,exp(-E_a/RT) \quad (2)$$

where: A is the Arrhenius pre-exponential factor, E_a is the reaction's activation energy, R is the universal gas constant, and T is the absolute temperature. Equation 3 is applied to expressed in the linear form:

$$\ln K = -E_a/RT + \ln A \quad (3)$$

The SAE Aerospace Recommended Practice ARP 1533 model is widely recognized by being a model for analysing combustion processes in internal combustion engines. The model can be used to explain gaseous emissions from aircraft engines [27]. The typical model in this case is based on measurements from emissions (c.g. carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), and hydrocarbons (C_xH_y) is shown in equation (4) .

$$C_aH_bO_cN_dS_e + X[(O_2)] + S(N_2) + h(H_2O) + u(CH_4) -> c_1(CO_2) + c_2(N_2) + c_3(O_2) + c_4(H_2O) + c_5(CO) + c_6(C_xH_y) + c_7(NO_2) + 8_2(NO) + c_9(SO_2) \quad (4)$$

Although the SAE procedure provides a useful tool to evaluate the emissions of aircraft engines, it is based mostly on some properties of fuels and not on the complete combustion processes. Nevertheless, combustion is made of many sub processes, such as fuel atomization among others. This atomization process is characterized by the Weber number (W_e) of which defines the conditions for atomization of the droplets by the balance between aerodynamic forces and surface tension. The Weber number is described by the Equation 5:

$$W_e = \frac{\rho V^2 L}{\sigma} \quad (5)$$

This occurs where ρ (rho) is the fluid (fuel) density, V is the velocity of the fluid, L is a characteristic length (e.g. droplet diameter), and (sigma) σ is the fluid's surface tension. When W_e passes a certain value, assessing aerodynamic forces over one surface tension, there is atomization of the fuel stream into droplets [28]. Therefore, the atomization process has a significant influence on aircraft engines combustion efficiency and emissions characteristics. Then corrective factors are introduced for unsteady flows in Equation 6.

$$L = 6\sigma E_p - A_1\eta_V \quad (6)$$

E_p is the fuel pulsation energy; A_1 is an area constant volume (average); η is the dynamic viscosity; and v is the fuelling velocity. Thus, factors such as fuel atomization, and combustion reaction kinetics are considered to take a more complete look at combustion processes as they relate to engine performances and emissions. Overflow of such details into the modelling and analysis frameworks can help in making more accurate predictions leading to informed decision making for aircraft engine design and operation. The different modelling approaches have different strengths and shortcomings and the method chosen will be dependent on the particular objectives of the analysis, available resources, and required accuracy [29]. By combining multiple modelling approaches, fuel combustion in gas turbine engine can be understood comprehensively and engine design, performance and emissions can be optimized. Blending commercial Jet A-1 fuel with synthetic components as authorized by ASTM D7566 is a critically important element because it supports a uniquely matching alternative with commercial Jet A-1 fuel standards. The specific proportions or compositions of these blends are outlined in Table 1 and the synthetic components of Jet A-1 fuel are specified.

Table 1: Volumetric composition of tested fuel blends

Blend	**Jet A1**	**SAF**
A20	75%	255%
A30	73%	27%
A0	100%	0%
A	10%	90%

Once these blends are prepared, laboratory testing is conducted to assess their compliance with ASTM D7566 specifications, as outlined in Table 2.

Table 2: Fuel testing result

Property	**A20**	**A30**	**A0**	**A**
Density at 0ºC (kg/m^3)	786	787	800	760
Viscosity at -15ºC (mm^2/s)	3.60	3.65	3.38	4.80
Net Heat Combustion (MJ/k	43.3	43.4	43.1	44.2
Aromatics (v/v%)	12.8	11.0	16.6	0
Naphthalene (v/v%)	0.47	0.42	0.60	0.38
Flash point (ºC)	49.0	48.7	49.6	47.7
Freezing point (ºC)	-66.6	-66.7	-63.7	-67.8
Smoke point (mm	24	27	21	0

These specifications cover different aspects of fuel quality such as chemical composition, performance characteristics, and environmental impact. Researching results and the suitability of blended fuels for future uses in aviation applications can be verified by subjecting the blended fuels to rigorous testing against ASTM D7566 requirements. This helps to ensure that commercial use of alternative fuels is compatible with the needs for safety, performance and the environment. The systematic way to blend and test alternatives fuels is really playing an important role to support the common accepted alternative s fuels without compromising the integrity and reliable on the operation of aviation.

2.2 Engine Testing

The application of the reactivity model to study fuel combustion in the PTD 500 engine is a major step in the understanding of combustion dynamics in small, high bypass ratio geared turbofan engines. The PTD 500 engine shown in figure (3), was specifically designed for education and general aviation through advanced materials and cutting-edge technology to improve performance and longevity. Like all current gas turban engines, PTD 500 has a very high bypass ratio of 6.5 and thruster output of 55 kN, prioritizing low emissions and fuel consumption, and is capable of reliable performance. The electric-centric design also includes an electrically powered oil and fuel pumps as well as an electric starter generator. This design also optimizes efficiency and serves to fulfil trends of electrification in aviation propulsion systems. In particular, the data acquisition system of the test cell is necessary to measure and analyse different engine performance parameters during testing. The thrust, fuel consumption, temperature and pressure are all included, giving the researchers insight into how engine behaves in a variety of conditions. Using the capabilities of the reactivity model and advanced instrumentation in the test cell, processes describing fuel combustion in a small turbofan engine can be more accurately ascertained. It is really useful knowledge in optimizing engine performance, reducing emissions and advancing further development of sustainable aviation fuels to create a greener future of aviation.

Ansys Chemkin-Pro is powerful and robust tool that can be used for modelling the fuelling physicochemical properties and simulation of reactions. It would be very useful to be able to integrate a fuel data library in order to have accurate predictions, since combustion is so complex and theoretically demanding. How such software can rely upon a ton of experimental data to establish realistic relationships for such simulations is impressive. Since the data is complex, it is reasonable to rely on statistical methods to estimate the relationship parameters. Calibration of the parameters of the model is probably carried out with techniques such as regression analysis or optimization algorithms, in order to closely take into account real world behaviour in the model. The approach described here highlights the need for a thorough data analysis and validation during the development of reliable simulation tools. Their development is usually oriented to specific types or classes of fuels for which engineering data are available. It is indeed possible that permitting the introduction of some new components that have not been studied as much or incorporated into the model can result in significant differences between the model predictions and empirical data. This in essence calls for improved refinement and validation of model as data appears and the scope of application is scaled up. In addition, it makes it clear that the limitations and uncertainties of the model must be taken into account when interpreting simulation results in such settings

Figure 3: PTD 500 turbofan engine

Table 3: Specifications of the PTD 500 Engine

Specification	**Value**
Maximum Thrust	55kN
By-pass ratio	6.5
Weight	40g
Life Span	7200 hr

Extensive research is underway to create more sophisticated models that can accurately capture the kinetics of fuel combustion reactions across various reactor configurations. Starting with simple fuels such as hydrogen, methane, and individual hydrocarbons is common, given their well-understood chemical structures and behaviours. The work done by [30] likely highlights progress in this area, noting that while some models effectively represent combustion kinetics, they often do not fully account for engine operating conditions. The challenge lies in bridging the gap between detailed combustion kinetics and the broader context of engine operation, where factors like pressure, temperature, and fuel-air ratios are critical. Integrating these models with engine operating parameters is essential for accurately predicting combustion behaviour in real-world scenarios. This indicates that while current models may perform well in certain areas, there is still significant potential for improvement regarding their relevance to practical engineering applications. If we denote the independent variable as the fuel mass flow rate, and the reactivity coefficient as α_i, we can express the reactivity model as follows in Equation (7).

$$\alpha_i = f(\dot{m}_f) \tag{7}$$

α_i represents the reactivity coefficient for a specific reaction or species i, while m˙_f indicates the mass flow rate of the fuel, which is the selected independent variable. The function $f(\dot{m}_f)$ describes how the reactivity coefficient relates to the fuel mass flow rate. In this setup, all other variables in the model depend on the fuel mass flow rate. This fundamental criterion allows the reactivity model to be effectively utilized by adjusting the fuel mass flow rate and considering its impact on reactivity [30]. This framework lays the groundwork for analyzing and predicting combustion behavior based on the chosen independent variable and its effect on reactivity. The reactivity model can generally be expressed in Equation 8:

$$L = \alpha i K D + L_0 \tag{8}$$

where L represents the generalized work done by the system (engine) and is directly proportional to the thrust F, L_0 is a constant specific to the system and the type of fuel used, k denotes the reaction rate constant governing the combustion process, while D represents the change in the system's internal energy due to chemical reactions occurring at a rate corresponding to the unit value of k.

Describing a simplified model for a gas-turbine engine, where thrust (F) is assumed to have a linear dependence on fuel flow. This linear relationship can be expressed in Equation (9).

$$F = k\dot{m}_f \tag{9}$$

Where:

F represents the produced thrust, $\dot{m}_f$ denotes the fuel mass flow rate, K is a proportionality constant representing the specific thrust coefficient.

If the burning of fuels blended in different concentrations is described by the αi reactivity model, then the series of chemical processes occurring in the system can be written as shown in equation (10).

$$C_xH_y + \left(x + \frac{y}{4}\right) O_2 -> x(CO_2) + \frac{y}{2} H_2O \tag{10}$$

Since CO_2 formation is the predominant reaction, Equation (8) can be rewritten as shown in equation (11).

$$\alpha iCO_2 = (L - L_0)/kCO_2D \tag{11}$$

Where αiCO_2 is the CO_2 combustion-related reactivity coefficient is shown in equation (12).

$$L - L_0 = a\dot{m}_f \tag{12}$$

The reactivity of CO_2 is shown in equation (13).

$$\alpha iCO_2 = a\dot{m}_f/kCO_2D \tag{13}$$

Equation (14) can be used to express the rate of fuel combustion into CO_2 and H_2O as

$$\frac{d[CO_2]}{dt} = kCO_2\dot{m}_f{}^p[O_2]^q \tag{14}$$

By integrating within the range <0, t>, equation (14) can be transformed, resulting relationship to form equation (15).

$$[CO_2] = kCO_2\dot{m}_f{}^p[O_2]^{qt} \tag{15}$$

where O_2 is the concentration of oxygen in the air passing through the engine, t is the reaction time, $\dot{m}_f$ is the reaction substrates concentration represented as fuel flow, and p and q are the effective reaction orders.

Assuming complete combustion in the tested engine, all fuel is converted to CO_2, allowing for the calculation of the reactivity coefficient αiCO_2 for specific fuel blends.

Equations (13) and (15) yielded the following result to equation (16) and (17), when k from the Arrhenius equation (2) was substituted

$$\alpha iCO_{2ch}ACO_2exp(-E_aCO_{2ch}/RT) = a\dot{m}_f/DCO_2 \tag{16}$$

$$[CO_2] = ACO_2exp(-E_aCO_{2ch}/RT)\dot{m}_f{}^p[O_2]^{qt} \tag{17}$$

The following functions in equation (18) and (19), were used to model the dilution of combustion products by air passing through the engine.

$$[CO_2]_{meas} = [CO_2]_{ch}/AF \tag{18}$$

$$ln[CO_2]_{meas} = ln[CO_2]_{ch} \tag{19}$$

where $[CO_2]_{meas}$ is the measured CO2 concentration in the exhaust gases, E_aCO_{2ch} is the activation energy from the combustion reaction kinetics, excluding the effect of CO_2 dilution with air, and AF is the air-fuel ratio.

Four measurable quantities can be found in equation (15). One of these is an independent variable, fuel flow $\dot{m}_f$, and the other three are dependent variables: thrust F, $[CO_2]$ and $[O_2]$. It is possible to empirically ascertain the following dependencies for engine operating points for a given fuel blend.

3. RESULTS AND DISCUSSION

The activation energy and reactivity coefficients are determined based on key engine operating parameters, including thrust, fuel flow rate, mass airflow, combustor outlet temperature, and emissions of CO and CO_2. These parameters provide valuable insights into the combustion characteristics of the fuel blends being tested. The PTD 500 engines were run for eight consecutive operations, at different fuel flow, as shown in table (4)

Table 4: Performance report with fuel flow

S/N	% Thrust	Thrust (kN)	Fuel Flow(L/h)	Operation
1	80	48	10	Take-off
2	100	50	10	Take-off
3	20	30	6	Cruise
4	25	35	7	Cruise
5	60	42	7	Landing
6	75	45	8	Landing
7	10	5	5	Idle
8	15	15	6	Idle

Figure (4) illustrates the linear relationship between mass flow ($\dot{m}_f$) and % thrust (F), as represented by Equation (9). Table (4) presents the regression analysis results, which quantify the relationship between these variables. The slope and intercept derived from the regression analysis reveal differences in the % thrust versus mass flow function between A0 fuel (Jet A-1) and its blends with component A. These differences may stem from variations in the calorific value and hydrocarbon structure of the fuels tested, even when component A is present in low concentrations. The calorific value indicates the fuel's energy content, while variations in hydrocarbon structure can affect combustion kinetics and overall engine performance. By analysing these relationship researchers can gain insights into how changes in fuel composition influence engine operation. This understanding is crucial for optimizing fuel blends to meet performance and emissions goals while ensuring they are compatible with current engine designs and operational needs.

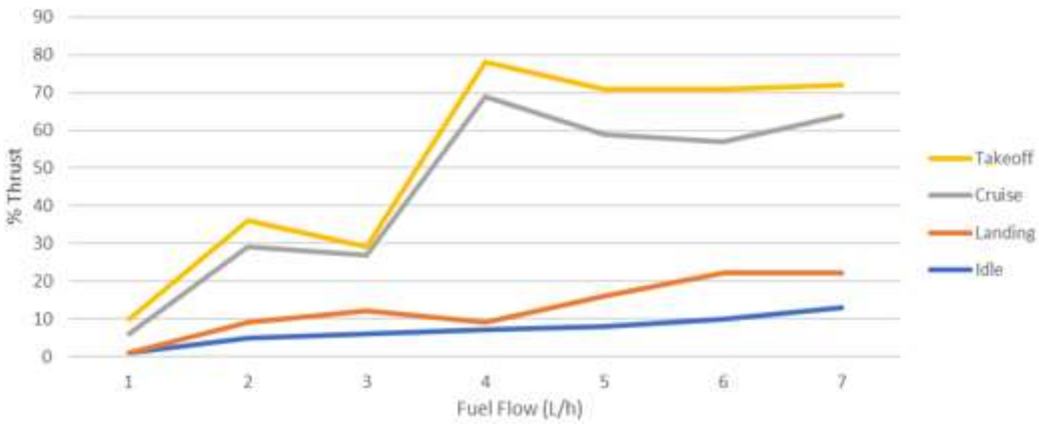

Figure 4: Variation of thrust against fuel flow

The analysis indicates that the addition of the synthetic component in Jet A-1 fuel does not significantly affect the performance of the PTD 500 engine. This conclusion is based on the consistent relationship noted between thrust and fuel flow across all fuel variants tested. Despite variations in fuel composition introduced by the synthetic component, the engine's performance in terms of thrust output relative to fuel consumption shows no significant deviation. Consequently, based on these parameters, the synthetic component does not appear to impact the operational characteristics of the engine. However, SAF significantly influences combustion chemistry and emissions, such as CO_2 and CO. Two criteria were employed to evaluate SAF's impact on combustion chemistry and engine operation: Activation energy (E_a), which pertains to the entirety of combustion reactions and Coefficient of reactivity (α_i), which correlates with thrust (F), fuel flow rate (mf), and a consistent rate established across the entire chain of combustion reactions.

4. CONCLUSION

The study aims to simulate how varying concentrations of synthetic fuel affect combustion within a turbofan engine to generate power at different operating mode. To achieve this, the α_i reactivity model, previously validated in tribochemical research, was employed. The methodology involves employing linear regression to establish reactivity coefficients α_i CO_2 and α_iCO, which characterize the dynamics and kinetics of complete (leading to CO_2) and incomplete (resulting in CO) combustion reactions. This model facilitates a quantitative link between parameters like thrust and fuel flow rates and the kinetics governing exhaust gas formation. To evaluate the impact of synthetic components on combustion in the PTD 500 engine, two key parameters were considered: the activation energy for the whole sequence of reactions leading to CO_2 production, it dependent on the reactivity coefficients α_iCO2 and α_iCO; and the impact on the combustion process yielding CO. The study revealed that concentrations of SAF do not alter the combustion process leading to CO_2. However, its influence on the combustion pathway producing CO is notable. The evaluation of fuel combustion presented here is comparative in nature. Specifically, the reactivity coefficients calculated for SAF-blended fuels are compared with those for traditional Jet A-1 fuel. Future research will aim to establish connections between these reactivity coefficients and a broader range of operational parameters, particularly those that impact engine durability and reliability.

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