International Journal of Engineering and Advanced Technology Studies,14 (1),12-20,2026

Print ISSN: 2053-5783(Print)

Online ISSN: 2053-5791(online)

Website: https://www.eajournals.org/

Publication of the European Centre for Research Training and Development -UK

Assessment and Analysis of Fuel Efficiency and Emission Control in Turbojet Engines

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doi: https://doi.org/10.37745/ijeats.13/vol14n11220 Published March 21, 2026

Citation: Muhammad A., Rano U.A., Falalu M., Tenimu S.R., Marafa J.A., and Bello B.A. (2026) Assessment and Analysis of Fuel Efficiency and Emission Control in Turbojet Engines, *International Journal of Engineering and Advanced Technology Studies*,14 (1),12-20

Abstract: *Emission control and fuel efficiency are important performances in modern aviation as the cost of aviation fuel is rising and the environmental issues are on the increase. Although the turbojet engines have a long and significant history in the evolution of the aircraft propulsion system, it is characterized as one of the engines that consume a lot of fuel and emit a lot of emissions compared to modern turbofan engines. The paper is a thorough evaluation of fuel efficiency and emission control system in turbojet engines through the evaluation of thermodynamic performance, the combustion, and the formation of pollutants. Specific attention is given to the compressor pressure ratio, combustion temperature, and the process of fuel atomization that affects the efficiency of engines and the level of emission. Key components of emissions such as carbon dioxide, nitrogen oxides, carbon monoxide and unburned hydrocarbons produced during combustion are evaluated by the study. The analysis of comparative performance shows that the enhancement of combustion stability is important and optimized fuel injection can lead to a better use of fuel and a less harmful impact on the environment. There are also advanced technologies of emission control, like lean combustion and staged fuel injection. The results are used to come up with more sustainable propulsion technology in future aviation systems.*

Keywords: Turbojet engines, fuel efficiency, emission control, combustion stability, pollutant formation.

INTRODUCTION

Aviation industry is a critical part of the global economic growth as it allows the transportation of passengers and cargo over a long distance and in an efficient manner [1]. But the growth of fast air transport has greatly augmented the fuel consumption, and the emission of pollutants in the environment. The engines of the aircrafts are some of the greatest sources of pollution in the atmosphere in the transport industry because of the fact that the aircraft engines use fossil-based aviation fuels [2][3][4]. One of the earliest gas turbine propulsion technology aviation utilizations was the Turbojet engines and was commonly used in early jet-powered aircraft. Turbofan engines However, in spite of much of current civil aviation being based on the use of turbofan engines, turbojet engines are still relevant in the military, supersonic, and experimental propulsion studies. The fuel efficiency of turbojet engines is one of the biggest issues that come to mind that the engines are not as efficient in fuel consumption as more advanced propulsion engines [5][6]. Besides the fuel consumption problem, the turbojet engines are also linked to a high level of emission, especially nitrogen oxide and carbon-based pollutants. These emissions are among the environmental issues like global warming and worsening of air quality. This means that fuel efficiency and emission control in turbojet engines are under consideration nowadays, and these aspects of the work have become a significant topic in aerospace engineering studies [7].

The conversion of chemical energy of fuel into the way of producing a thrust is what defines fuel efficiency in turbojet engines [8]. The thermodynamic performance of an engine is regulated by the Brayton cycle that comprises of air compression, combustion, turbine expansion, and exhaust cycles. The functioning of all components of this cycle affects the functioning of the entire propulsion system directly [9][10][11][12][13]. As an example, compressor efficiency can be improved, raising pressure ratios, improving thermal efficiency and lowering fuel consumption. On the same note, efficient turbine operation allows the extraction of more energy with the combustion gases. Nevertheless, raising engine operating temperatures to enhance engine efficiency can also raise the quantity of nitrogen oxides that is formed during combustion. This makes the correlation between fuel consumption and generation of emissions complicated and demands engineering optimization. Scientists have consequently emphasized in coming up with design techniques that will enhance energy conversion and at the same time reduce the impact on the environment [14][15].

The issue of environmental concerns about aircraft emissions has been on the rise over the past decades because it has led to climate change and atmospheric pollution. Aircraft engine exhaust has numerous types of pollutants such as carbon dioxide, nitrogen oxides, carbon monoxide, sulfur oxides and unburned hydrocarbons [16]. Fuel consumption is directly linked to carbon dioxide emissions which are also a cause of greenhouse effect. High dimensions lead to the formation of nitrogen oxides and pose to the formation of photochemical smog and ozone in the upper atmosphere. Incomplete combustion products are carbon monoxide and unburned hydrocarbons that might have adverse impacts on the quality of air. These are environmental issues that have led to regulatory bodies like the international civil aviation organization developing strict standards of emissions that aircraft engines are supposed to operate. These standards must be observed, and to achieve that, more advanced combustion technologies that can decrease the formation of pollutants must be developed. As a result, the control of emissions has turned into the crucial design in the contemporary propulsion systems [16].

One of the most important parts that affect fuel consumption and emitted emissions in the turbojet engines is the combustion chamber [17]. To ensure maximum chemical reactions in the chamber, fuel and air should be efficiently mixed to guarantee efficient combustion. Unless fuel and air are properly mixed, the incomplete combustion may arise, which increases the emissions of carbon monoxide and unburnt hydrocarbons. On the other hand, too high combustion temperatures can enhance the generation of nitrogen oxides by thermal reaction process. A perfect compromise between efficiency in combustion and emission reduction thus constitutes a huge engineering problem. New developments on the fuel injector have contributed greatly in the atomization of the fuel droplets, which increases their mixing with the compressed air. There comes a more stable combustion process and an improved fuel consumption as a result of such enhancements. Consequently, the current designs of the combustion systems seek to ensure that the systems are very efficient with minimal formation of the pollutants [18][19].

Another major issue that affects the performance of a turbojet engine is thermodynamic cycle optimization. The efficiency of the Brayton cycle is determined by the compressor pressure ratio; the inlet temperature of the turbine [20]. By increasing pressure ratio, thermal efficiency is usually enhanced as more energy can be recovered out of the combustion gases. However, stresses in engine components are also increased with increases in turbine inlet temperatures. The engineers thus use high-level materials and cooling technology so that the engines can run safely at high temperatures [21]. Computational modeling and testing are used to exhaustively study the thermodynamic relationship to establish the optimum conditions of operation. By these means, scientists can assess the effect of change in design to understand the influence on fuel consumption and in the formation of emissions. These types of analyses are important in enhancing the performance of the modern gas turbine engines [22].

Advanced materials have also contributed immensely to the improvement of the efficiency and durability of the turbojet engine in addition to the improvement in the combustion system. Alloys and ceramic matrix composites with high temperature allow engine parts to work under severe thermal conditions [23]. Such materials allow the turbines to operate under a high temperature without the degradation of the structure. There are also better cooling technologies that can be used to relieve excessive thermal stressing of turbine blades. Such innovations result in the overall thermal efficiency of the engine because it becomes possible to run at higher temperatures. Moreover, the steady operating conditions facilitate the steady combustion reactions, thereby minimizing the formation of pollutants. In turn, the development of materials science has also helped a great deal in the area of fuel efficiency and emission control [24][25].

Although such technological developments are evident, there are still a number of issues in attaining optimum performance and greener turbojet engines [26]. The increased fuel prices and the availability of very strict environmental laws have escalated the necessity of better propulsion technologies. Alternative aviation fuels, new ways of combustion and hybrid propulsion systems are some of the new avenues that researchers are exploring in order to handle these predicaments. Renewable bioaviation fuels can greatly decimate carbon emissions in the fuel lifecycle [27]. On the same note, further advances in the design of the combustion chambers can be used to reduce the generation of the pollutants during the oxidation of the fuel. Further interdisciplinary studies of thermodynamics, materials science and aerodynamics are necessary in order to achieve next-generation propulsion technologies. Hence, in-depth evaluation and monitoring of fuel efficiency and emissions containment are critical in the development of the performance of turbojet engines and environmental friendliness [28][29].

Table 1: Key Components of Emission of Turbojet Engines.

Emission Component	Source within Engine	Environmental Impact
Carbon dioxide	Total hydrocarbon fuel burning.	Greenhouse effect and climate change.
Nitrogen oxides	Combinations of high temperature combustion.	Development of photochemical smog.
Carbon monoxide	Incomplete combustion	Toxic air pollutant
Unburned hydrocarbons	Poor fuel atomization or incomplete oxidation	Atmospheric pollution
Sulfur oxides	Aviation fuel Sulfur compounds in aviation fuel	Acid rain formation

Fuel Efficiency Analysis

The specific fuel consumption is often used as a parameter to assess fuel efficiency in turbojet engines, whereby the fuel consumption required to generate a unit of thrust is used to measure the efficiency. The low specific fuel consumption is a good indication of good engine operation and utilization of fuel efficiently. Specific fuel consumption is a variable that is sensitive to a number of thermodynamic and mechanical variables in the engine. Such parameters are compressor pressure ratio, combustion efficiency, turbine inlet temperature and exhaust velocity. The compressor design can be improved to amplify incoming air pressure so that more combustion can be made possible. Likewise, the better the fuel injection systems, the better the atomization, and thus, the more chemical reactions occur in the combustion chamber. Such advances make fuel waste less, and the propulsion generated per unit of fuel more. Therefore, these parameters should be optimized to realize more engine efficiency [14].

Table 2: Typical Performance parameters of a Turbojet engine.

Engine Thrust (kilonewtons)	Fuel Flow Rate (kilograms per second)	Specific Fuel Consumption (kilograms per kilonewton hour)	Combustion Efficiency (percentage)
20	0.85	0.153	96
40	1.70	0.153	97
60	2.55	0.153	98
80	3.40	0.153	98.5

Emission Control Techniques

A number of the technologies have been invented to minimize pollutant emissions of the turbojet engines. Lean combustion is one of the approaches and it works by running the engine at a higher air to fuel ratio than the stoichiometric ratio. Lean combustion lowers the maximum temperature of the flame, therefore curbing the formation of nitrogen oxide. A different method that many have utilized is staged combustion where the fuel is injected in the combustion chamber in stages. The method assists in the regulation of temperature distribution in the chamber and a decrease in the formation of pollutants. The design of the fuel injector is also advanced to enhance atomization, so that there is increased homogeneity in the fuel and air mixing. Enhanced mixing leads to a high level of combustion efficiency and reduction of carbon monoxide and unburned hydrocarbon formation. Moreover, the emission of carbon in the lifecycle can be greatly decreased by using sustainable aviation fuel that is made of renewable sources. All these strategies make less polluted and efficient aircraft propulsion systems [13].

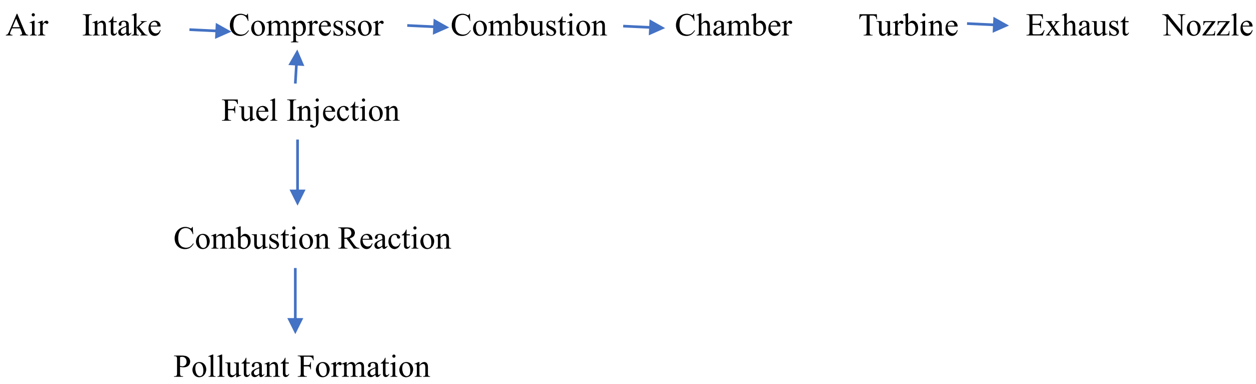

Figure 1. Diagrammatic Model of Fuel flow and formation of emissions in a Turbojet Engine.

Figure Description

The diagram shows the basic working cycle of a turbojet engine. The intake of air is then compressed into the compressor stage and then to the combustion chamber. Compressed air is injected with fuel which is ignited to form high temperature combustion gases. These gases are operating on the mechanic through the turbine to create the mechanical labor that powers the compressor. This energy gets rid of the remaining energy via the exhaust nozzle to generate thrust. Emission products formed in the process of combustion are carbon dioxide, nitrogen oxides, and carbon monoxide.

CONCLUSION

The evaluation of fuel efficiency and emission control in turbojet engines indicates that thermodynamic performance, as well as combustion processes are important aspects in defining engine efficiency and environmental impacts. The efficiency of the modern propulsion systems has been greatly increased due to improvements in compressor design, technology in combustion chambers and improvement in the materials of turbines. Nevertheless, turbojet engines have not passed the obstacles of high fuel consumption and pollutants emission. Lean combustion, staged fuel injection and enhanced fuel atomization are all emission control technologies that have been proven to be effective in controlling the formation of pollutants. Moreover, sustainable aviation fuels provide a good prospect of the reduction of greenhouse gas emission in the aviation industry. Nevertheless, the optimal balance between fuel efficiency and the reduction of the emissions is a complicated engineering problem even with these improvements. Further studies are thus needed to come up with improved propulsion mechanisms that can handle the demands of the future environment and performance.

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