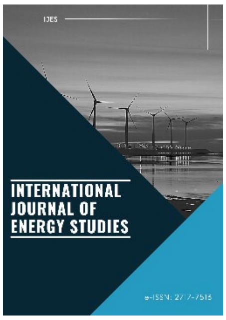
INTERNATIONAL JOURNAL OF ENERGY STUDIES

e-ISSN: 2717-7513 (ONLINE); homepage: https://dergipark.org.tr/en/pub/ijes



Research Article

Int J Energy Studies 2026; 11(2): 953-971

DOI: 10.58559/ijes.1838852

Received : 09 Dec 2025
Revised : 04 Mar 2026
Accepted : 07 Apr 2026

Investigation of effects of component and fuel parameters on performance of jet engine and main units

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Highlights

- The effects of compressor and turbine isentropic efficiencies, combustor pressure ratio, and fuel parameters on thrust, SFC, and thermal efficiency are examined.
- The exergy efficiency of the whole engine is measured to be between 11.87% and 14.9% with the change in fuel lower heating value.
- The influence of combustor pressure ratio is limited to below 1% for the combustor efficiency.

You can cite this article as: Kırmızı M, Aygün H. Investigation of effects of component and fuel parameters on performance of jet engine and main units. Int J Energy Studies 2026; 11(2): 953-971

ABSTRACT

The studies addressing the fuel efficiency of jet engines are of critical significance in terms of mitigating the environmental impact of aviation. In this context, examining aviation engines at the component level reveals the fuel consumption of engine behavior more clearly. In the present study, the influences of design variables (combustor pressure ratio, isentropic efficiencies of compressor and turbine) and fuel lower heating value on performance and exergetic parameters (exergy destruction, exergy efficiency, and exergetic improvement potential) of a micro turbojet engine producing approximately 240 N thrust are investigated on a component basis and for the entire engine. As the isentropic efficiency of compressor raises from 0.9 to 0.98, the exergy destruction of compressor diminishes from 10.297 kW to 0.87 kW, whereas with the influence of isentropic efficiency of turbine, the exergy destruction of turbine drops from 5.915 kW to 0.474 kW. The exergy efficiencies belonging to turbomachinery vary in the ranges of 86.82%-98.63% for compressor and 93.95%-99.48% for turbine, respectively. The exergy efficiency of the overall engine changes between 12.8% and 16.75% due to the effect of isentropic efficiency of turbine. Finally, the influence of combustor pressure ratio is limited to below 1% for the combustor efficiency, whereas the exergy efficiency of the whole engine is measured to be between 11.87% and 14.9% with the change in fuel lower heating value. This study demonstrates that thermodynamic indicators are very beneficial for observing the degree of influence of each variable, and the energy and exergetic metrics of the micro jet engine are highly sensitive to changes in internal design parameters.

Keywords: Isentropic efficiency, Exergy efficiency, Turbojet engine, Improvement potential

1. INTRODUCTION

Approximately 70% of aircraft emissions consist of CO_2, less than 30% water vapor, and less than 1% other gases. Aircraft contribute to climate change and the degradation of local air quality through various emissions, depending on their flight altitude (such as the threshold value of 3000 feet). The aviation industry and scientists have campaigned to develop decarbonization strategies to diminish adverse impacts on climate change and local air quality. Several attempts have been made for this context. For instance, with the Paris Agreement, a commitment was made to limit global warming to 1.5–2 °C [1]. Alleviating emissions released into the atmosphere by the aviation industry has been considered critical in terms of mitigating climate change. The researchers have developed different approaches to reduce this impact, revealing new opportunities and research topics [2]. Increasing concerns about environmental sustainability have led researchers to delve into particularly the greenhouse gas emissions of commercial aviation and ways to alleviate them. Improving fuel efficiency has become an important policy objective for airline companies. However, the increase in air travel demand has outpaced improvements in energy efficiency, which increases the carbon footprint of aviation [3]. When considering the open literature on micro jet engine, Naeim et al. [4] modeled the gas turbine cycle by utilizing the enthalpy-entropy method, and the effects of ambient temperature, relative humidity, and ambient pressure were examined in a program developed in C# language. When the model was compared with the actual data of the El Atf power plant, the difference in GT output power was found to be between 0.01-1.12%. As ambient temperature increased in the range of 14-40 °C, PGT decreased by 18.38-19.01%, thermal efficiency decreased by 2.31-2.44%, and SFC increased by 7.12-7.59%.

Furthermore, Egware and Obanur [5] dealt with the performance of the SGT5-2000E gas turbine power plant under off-design conditions through energy analysis. The analyses were conducted within an ambient temperature range of 21-35 °C and a pressure ratio range of 10.73-10.96, with net power outputs of 148.92-160.70 MW. 60.16% of the total fuel energy was lost as waste heat, and additionally, for each 1°C increase in temperature, a 1.16% decrease in power output, 1.58% decrease in thermal efficiency, 1.58% increase in SFC and HR, and 0.64% decrease in WR were observed. Moreover, Turan [6] parametrically investigated the energy and exergy indicators of a small turbojet engine for unmanned aerial vehicles in terms of compressor pressure ratio ($2 < CPR < 7$) and turbine inlet temperature ($1200 < TIT < 1500$ K) parameters. The results illustrated that under conditions where thrust ranged from 894–907 N, an increase in turbine inlet temperature decreased the exergy efficiency of the engine (from 88.12% to 87.91%), whereas an increase in compressor pressure ratio elevated exergy efficiency (ranging from 82.87% to 86.83%). Balli et al. [7] evaluated the J69 turbojet engine with jet fuel and 100% biofuel and the authors selected methyl-oleate as the model fuel due to its similarity to commercial biodiesel. The use of biofuel resulted in increasing the exergy efficiency from 17.058% to 17.103% and raised the environmental impact factor from 5.261 to 5.299. However, the sustainability index decreased by 1.463% in the combustion chamber, 1.201% in the gas turbine, and 0.735% in the total engine. Yucer [8] experimentally investigated a small-scale jet engine under four load conditions, incorporating idle, partial load-1, partial load-2, and full load, and evaluated energy-exergy flows for the components and the overall engine. The highest exergy efficiencies in the gas turbine were obtained as 67.8% and 79.4% under idle and partial load-1 conditions, respectively, whereas the highest values under partial load-2 and full load were calculated as 81% and 80.6% in the combustor, respectively. The greatest exergy destruction occurred in the combustor under all load conditions, with values found to be 35 kW, 40.3 kW, 36.6 kW, and 47.9 kW, respectively. Coban et al. [9] carried out component-based exergy and exergoeconomic analyses of a small-scale turbojet engine operating with conventional jet fuel and biofuel. In the case of biofuel, exergy efficiencies were found to be 74.52% for the air compressor, 47.68% for the combustor, and 99.00% for the high-pressure turbine. When conventional jet fuel was used, these values were 75.22%, 48.34%, and 98.44%, respectively, indicating that performance differences between the two fuels were limited. Sohret and Caliskan [10] dealt with the exergy, sustainability, and environmental performance of a turbojet engine designed for UAVs and determined that the lowest exergetic efficiency was 7.65 % for the overall engine. On the other hand, among the components, the highest entropy generation rate was found to be 179.014 $kW \cdot K^{-1}$ in the combustor, whereas the lowest value was 0.344 $kW \cdot K^{-1}$ in the gas turbine. Liu et al. [11] proposed a power generation and thermal management system that integrates a Rankine cycle and direct hydrogen expansion cycle for the combined utilization of exhaust gas thermal exergy and hydrogen cold energy exergy in liquid hydrogen-fueled turbojet engines. The results demonstrated that there exists an optimal separation temperature ratio and condensation pressure in the Rankine cycle to maximize total net power output and that the effect of para-ortho hydrogen conversion on net power is negligible, whereas it significantly reduces exergy efficiency. In the working fluid comparison, the best mixture was C_2H_6/Xe (0.6/0.4), achieving a maximum net power of 2717.9 kW and an exergy efficiency of 33.1%.

This study aims to examine the effect of micro turbojet engine design variables and fuel lower heating value on energy and exergy parameters. The novelty of the study is that it is the first time in the literature that an exergetic evaluation is carried out for this jet engine model generating 240 N of thrust under the specified variables. In the study, the effects of compressor and turbine isentropic efficiencies, combustor pressure ratio, and fuel parameters on thrust, SFC, and thermal efficiency are examined. Subsequently, the effects of these variables on exergy destruction, exergy efficiency, and improvement potential specific to the jet engine and its components are investigated.

2. SYSTEM DECRIPTION

Micro jet engines are one of the most commonly employed thermal systems and are utilized as the primary propulsion source in aviation. Their use is increasingly growing in many areas such as small aircraft and missile technology [12]. A turbojet engine is designed to provide thrust to an aero-vehicle. The thrust is generated by the movement of combustion gases towards the exhaust outlet of the engine at high speed. The operating principle of the jet engine is based on compressing air throughout the compressor, and this compressed air is mixed and burnt with fuel in the combustor. Lastly, the burnt gases are expanded through the turbine to drive the compressor and several components. Fig. 1 shows the turbojet engine and its main components.

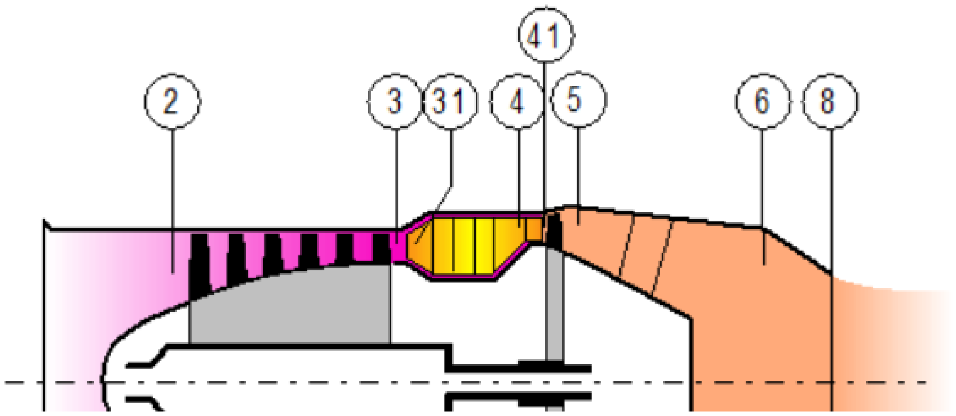

Figure 1. Cross-section of typical turbojet engine with station numbers [13]

Table 1 expresses the basic parameters of the turbojet engine such as thrust, fuel flow, air flow rate, exhaust gas temperature and component efficiencies at the highest power.

Table 1. Main features of jet engine at highest power

Specifications	Value
Net propulsion (N)	240
RPM	118000
Overall pressure ratio	3,8
Air mass flow (kg/s)	0.47
Fuel flow (kg/s)	0.0107
Exhaust gas temperature (K)	783-973
Exhaust velocity (m/s)	362
Spool number	1
Compressor isentropic efficiency	0.8
Turbine isentropic efficiency	0.8
Combustor pressure ratio	0.97
Mechanical efficiency	0.85

Fig. 2 illustrates the T-S (temperature-entropy) and P-V (pressure-volume) diagrams for the jet engine at the actual cycle. As can be seen, the temperature at the compressor outlet is approximately 450 K, whereas the pressure value is measured as 381 kPa. The maximum temperature is observed as 1300 K. In the case of an actual cycle, the pressure ratio in the combustion chamber decreases from 381 kPa to 369 kPa.

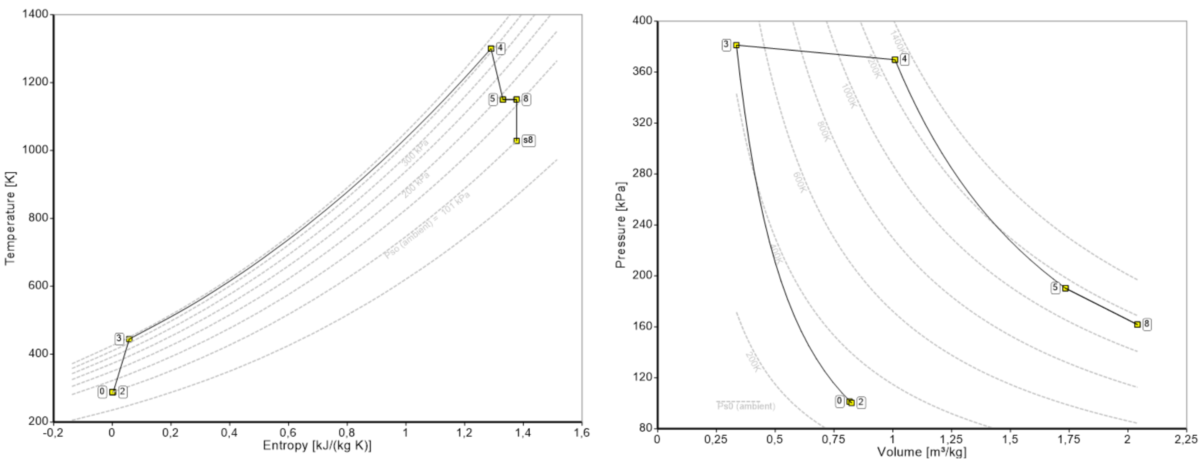

Figure 2. Diagrams of presssure–temperature and temperature-entropy regarding the engine [13]

2. METHODOLOGY

Exergy expresses the amount of usable work that can be obtained from the current state of a turbojet engine as other systems. Through exergy analysis, the inefficiencies of the system and related components are evaluated by considering their locations, sources, and magnitudes (exergy destruction) [14]. Before initiating the analyses, it could be said that there are several assumptions adopted throughout the study: (i) The air and combustion products are treated as ideal gases. (ii) The turbojet engine is considered to operate under steady-state conditions. (iii) Complete combustion was assumed to occur. (iv) The variations in kinetic and potential exergy were regarded as negligible. (v) The lower heating value of kerosene fuel is 42800 kJ/kg [6, 10, 15]. On the other hand, temperature, pressure, work, and efficiency relations for compressor, combustor, and turbine units are expressed in this section.

2.1.Compressor

Compressors are units where air is compressed, consisting of a rotor and a stator. It is emphasized that the compressor has always played a critical role in the success of gas turbine engines and that its development requires high effort and cost [16]. The relationships between compressor outlet temperature, compressor work, and isentropic efficiency are detailed here [17].

$$m_{a,in} = m_{a,out} \tag{1}$$

$$T_{out} = T_{in}\left[1+\frac{(\pi_c^{(\gamma c-1)/\gamma c}-1)}{\eta_c}\right] \tag{2}$$

$$W_c = m_a c p_a (T_{out} - T_{in}) \tag{3}$$

$$\eta_{isan,c} = \frac{h_{out,s}-h_{in}}{h_{out}-h_{in}} \tag{4}$$

where π_c, W_c and $\eta_{isan,c}$ represent compressor pressure ratio, compressor work and isentropic efficiency respectively [18, 19].

2.2.Combustor

It is the section where compressed air is injected with fuel and combustion takes place. Here, a significant increase in air temperature occurs. The combustor is located between the compressor and the turbine, and it transmits the combusted gases to the turbine [16]. The combustor is subjected to the first law of thermodynamics with equation 6.

$$m_{gas} = m_a + m_f \tag{5}$$

$$m_a c_{p,a} T_{in} + \eta_{cc} m_f Q_{LHV} = m_{gas} c_{p,gas} T_{out} \tag{6}$$

$$f = \frac{c_{p,gas} T_{out} - c_{p,a} T_{in}}{\eta_{cc} Q_{LHV} - c_{p,gas} T_{out}} \tag{7}$$

$$P_{out} = \pi_{cc} P_{in} \tag{8}$$

where f and P_{out} denote fuel-to-air ratio and outlet pressure of combustor. Moreover, π_{cc} and Q_{LHV} mean pressure ratio of combustor and lower heating value of kerosene in turn [18, 19].

2.3.Turbine

Turbines are machines that extract energy from fluid flow and convert it into mechanical or electrical energy [16]. The relationships between turbine outlet pressure, turbine work, and isentropic efficiency are detailed here.

$$m_{gas,in} = m_{gas,out} \tag{9}$$

$$P_{out} = P_{in} \left[1 - \frac{1}{\eta_t} \left(1 - \frac{T_{out}}{T_{in}} \right) \right]^{\gamma_g / \gamma_g - 1} \tag{10}$$

$$W_t = m_{gas} c_{p,gas} \left(h_{in} - h_{out} \right) \tag{11}$$

$$\eta_{isan,t} = \frac{h_{in} - h_{out}}{h_{in} - h_{out,s}} \tag{12}$$

where P_{out}, W_t ve $\eta_{isan,t}$ represent turbine outlet pressure ratio, turbine work and its isentropic efficiency respectively [18, 19].

In this study, three fundamental parameters for the turbojet engine, which are thrust, specific fuel consumption, and thermal efficiency are computed. The formulas are mentioned below.

$$\tau_{net} = m_{a,core}\left((1+f)V_e - V_i\right) \tag{13}$$

where τ_{net} and V_e represent net thrust and exhaust velocity, respectively [19].

$$SFC = \frac{\dot{m}_f}{\tau_{net}} \tag{14}$$

where SFC and $\dot{m}_f$ are specific fuel consumption and fuel flow, respectively [19].

$$\eta_{th} = \frac{TP}{\dot{m}_f Q_{LHV}} \tag{15}$$

where η_{th} and TP denote thermal efficiency and total power of jet engine [19].

2.4. Exergetic formula

This study examines three different exergetic parameters, which are exergy destruction, exergy efficiency, and improvement potential. It is observed that kinetic and potential exergy values are generally neglected in calculations since they are relatively small in gas turbine systems. Eq. 16 expresses several types of exergy.

$$\dot{E}x = \dot{E}x^{PH} + \dot{E}x^{CH} + \dot{E}x^{PT} + \dot{E}x^{KN} \tag{16}$$

If the specific heat capacity is considered as constant, several simplifications become possible which leads the specific physical exergy of air to be expressed as follows. [20, 21]:

$$\varepsilon^{PH} = C_{p,a}(T - T_0 - T_0 \ln\frac{T}{T_0}) + R_a T_0 \ln\frac{P}{P_0} \tag{17}$$

2.4.1. Exergy destruction rate ($\dot{E}x_{dest}$)

The parameter that represents the irreversibility within a component is known as the exergy destruction rate. Under steady-state conditions, it is determined by the discrepancy between the fuel exergy and the product exergy. Its mathematical expression is presented as below [22]:

$$\dot{E}x_{dest,k} = \dot{F}_k - \dot{P}_k \tag{18}$$

2.4.2. Exergy efficiency (η_{ex})

Exergy efficiency could be linked to exergy destruction, which reflects irreversibility in the system. For a component-level evaluation, the exergy efficiency can be written in the following form [20]:

$$\eta_{ex} = \frac{\dot{E}x_{out}}{\dot{E}x_{in}} = 1 - \frac{\dot{E}x_{dest}}{\dot{E}x_{in}} \tag{19}$$

where ''out'' represents product and ''in'' denotes fuel.

2.4.3. Improvement potential rate ($\dot{I}P$)

The highest exergy efficiency in a system is achieved when the discrepancy between input and output exergy values, namely, exergy destruction, is minimized. In this regard, Van Gool revealed an exergy parameter that helps evaluate different systems [23]. The parameter is called as improvement potential rate, and its formula is given below.

$$\dot{I}P = (1 - \eta_{ex})(\dot{E}x_{in} - \dot{E}x_{out}) \tag{20}$$

In this study, the specifications of a micro turbojet engine producing 240 N thrust were introduced into the Gasturb-14 gas turbine programme. Subsequently, thanks to the obtained temperature and pressure values, thermodynamic metrics were computed with energy and exergy equations encoded in the MATLAB environment.

3. RESULTS AND DISCUSSION

In this section, the influences of fuel calorific value, combustor pressure ratio, compressor and turbine isentropic efficiency on the performance of the overall engine and its components are investigated. In the first step, parameters of jet engine performance such as thrust, specific fuel consumption, and thermal efficiency are analyzed within the determined variable ranges, whereas in the second section, the effect on three exergetic parameters (exergy destruction, exergy efficiency, and improvement potential) is sought to be understood. Namely, Fig.3 shows the effect of compressor efficiency whereas Fig.4 depicts the influence of turbine efficiency on engine performance. Moreover, Fig.5 illustrates the influence of lower calorific value of the fuel, whereas in Fig.6, the influence of combustor pressure ratio on the overall engine is plotted. On the other hand, Figs.7-10 present exergetic findings for individual components and whole engine.

Fig.3 presents the influences of isentropic efficiency regarding the compressor on TJE thrust, thermal efficiency, and specific fuel consumption. According to this figure, increasing isentropic efficiency has a positive effect on engine performance. Namely, increasing isentropic efficiency increases thrust between 241.8 N and 280 N. Similarly, thermal efficiency varies between 18.3% and 22.1%. SFC drops from 44.25 g/kN.s to 39.38 g/kN.s. In other words, enhancing isentropic efficiency increases thrust by 15.79%, thermal efficiency by 3.8%, and SFC by about 11%.

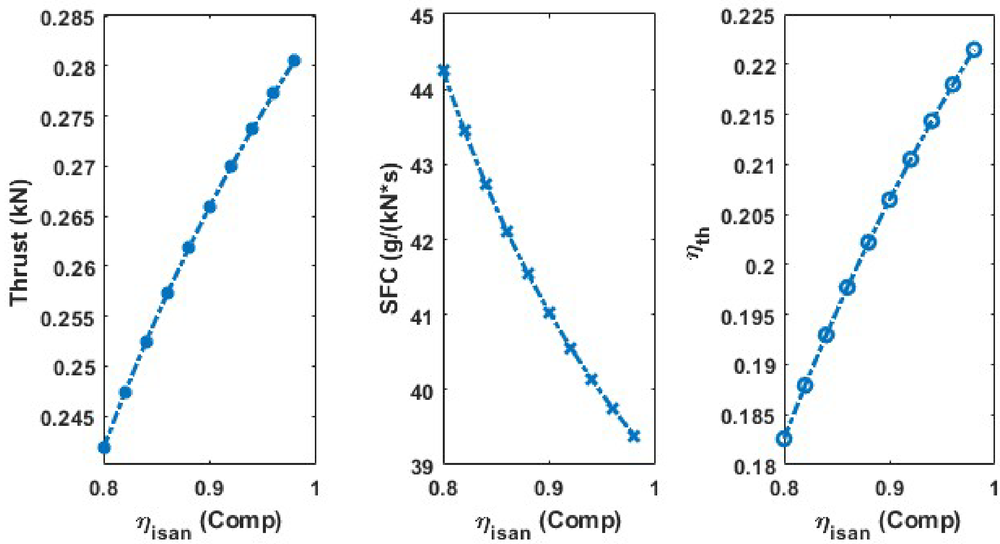

Figure 3. Effect of compressor isentropic efficiency on engine performance parameters

In Fig.4, the influence of isentropic efficiency of turbine on engine performance variables is examined. By improving isentropic efficiency of the turbine from 80% to 98%, the thrust increases from 241.8 N to 276.6 N and the thermal efficiency increases from 18.3% to 22.24%. As expected, SFC improves from 44.25 g/kN.s to 38.68 g/kN.s. It can be understood that isentropic efficiency significantly affects engine performance. In other words, enhancing isentropic efficiency increases thrust by 14.39%, thermal efficiency by 3.94%, and SFC by about 12.58%.

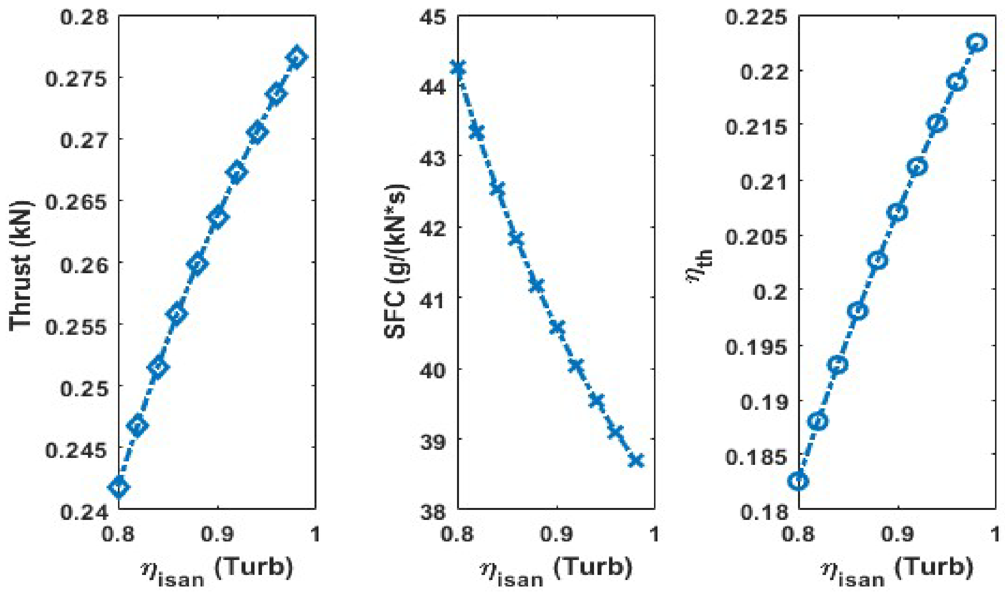

Figure 4. Effect of turbine isentropic efficiency on engine performance parameters

Fig.5 illustrates the effect of the lower heating value of fuel on performance parameters. While varying the calorific value of the fuel at ten different points between 40 MJ/kg and 50 MJ/kg significantly reduces specific fuel consumption, it has minimal impact on net thrust and thermal efficiency. By improving the lower heating value of the fuel, the thrust slightly diminishes from 242.84 N to 239.97 N and the thermal efficiency increases from 18.23% to 18.35%. It corresponds to 1.18% of thrust decrement and 0.12% of efficiency increment. Moreover, SFC of the jet engine decreases by approximately 20.82% from 47.83 g/kN.s to 37.87 g/kN.s. It can be understood that the environmental impact of the engine is reduced by decreasing SFC.

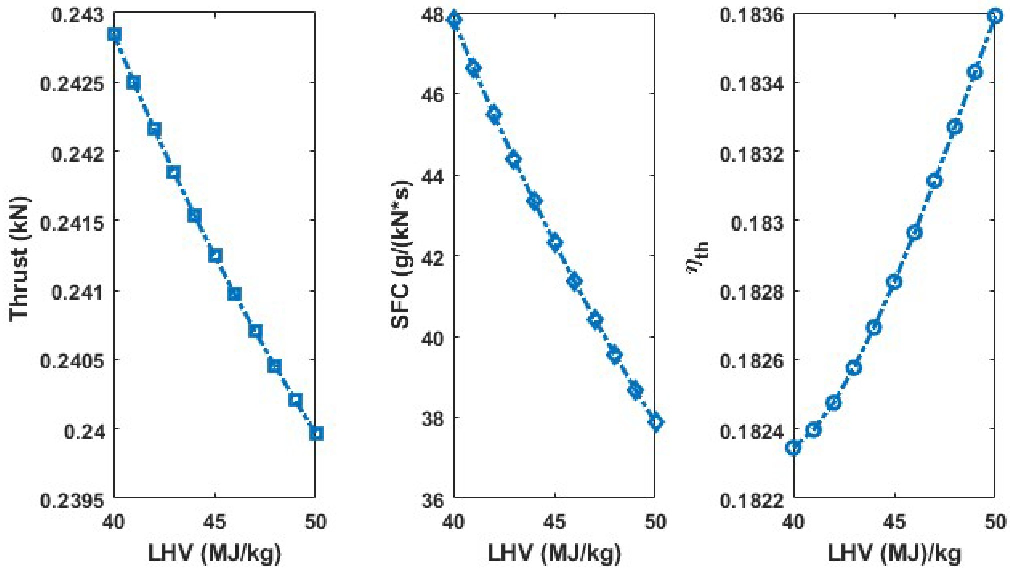

Figure 5. Effects of LHV on performance parameters of whole jet engine

Fig.6 addresses the influence of combustor pressure ratio (CPR) on performance parameters. As can be seen from the figure, increasing CPR positively affects engine performance variables. In other words, with increasing CPR, thrust increases between 220.3 N and 247.2 N. Similarly, thermal efficiency varies between 16.1% and 18.8%. SFC decreases from 48.57 g/kN.s to 43.27 g/kN.s. Namely, with increasing CPR, thrust increases by 12.2%, thermal efficiency increases by 2.7%, and SFC decreases by 10.91%.

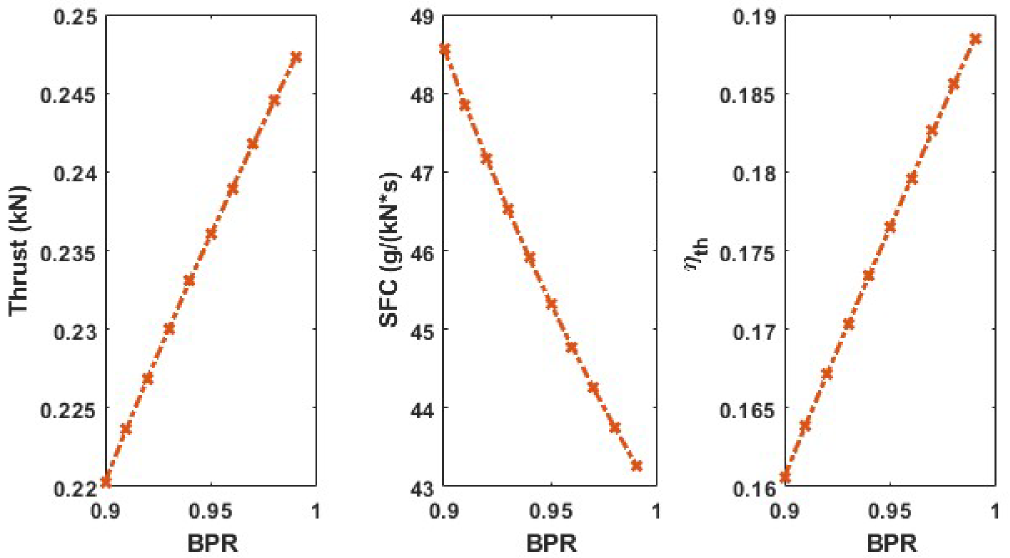

Figure 6. Effects of CPR on performance parameters of whole jet engine

3.1. Exergetic results regarding turbojet engine

In this section, the results of exergy analysis at the design point and under different design variables are shared. Table 2 incorporates outcomes of the exergy analysis regarding the turbojet engine. As can be understood, the exergy efficiencies of the air compressor, combustor, and turbine are measured as 86.82%, 65.42%, and 93.95%, respectively. Since the combustor enjoys the lowest efficiency, exergy destruction and improvement ratio which are higher are observed in this component.

Table 2. Exergy results of turbojet engine

Component	$\dot{E}x_F$ **(kW)**	$\dot{E}x_P$ **(kW)**	$\dot{E}x_{dest}$ **(kW)**	η_{ex} **(%)**	$\dot{E}x_{IP}$ **(kW)**
Air compressor	78,194	67,877	10,297	86,82	1,356
Combustor	556,541	364,119	192,421	65,42	66,528
Gas turbine	97,885	91,969	5,915	93,956	0,357

Fig.7 depicts the exergy destruction, exergy efficiency, and improvement potential calculations with changes in the isentropic efficiency of the compressor. According to this, while the exergy destruction diminishes from 10.29 kW to 0.87 kW, the exergy efficiency improves from 86.82% to 98.63%. In contrast, the improvement potential decreases from 1.356 kW to 0.0118 kW.

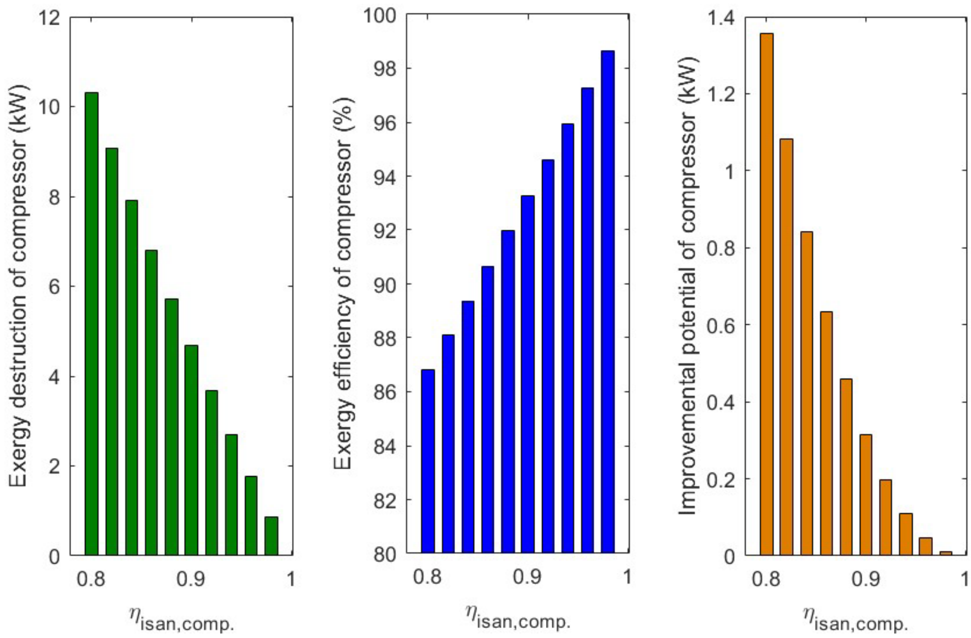

Figure 7. Variation of exergetic metrcis of compressor with influence of isentropic efficiency

In Fig.8, the effects of LHV on the combustor exergy efficiency are investigated. It is observed that by changing the calorific value of the fuel at ten different points between 40 MJ/kg and 50 MJ/kg, the exergy efficiency of combustor increases from 61.17% to 75.56%. Moreover, exergy destruction diminishes from 229.1 kW to 117.985 kW whereas improvement potential of combustor drops from 87.7 kW to 28.82 kW due to increasing efficiency.

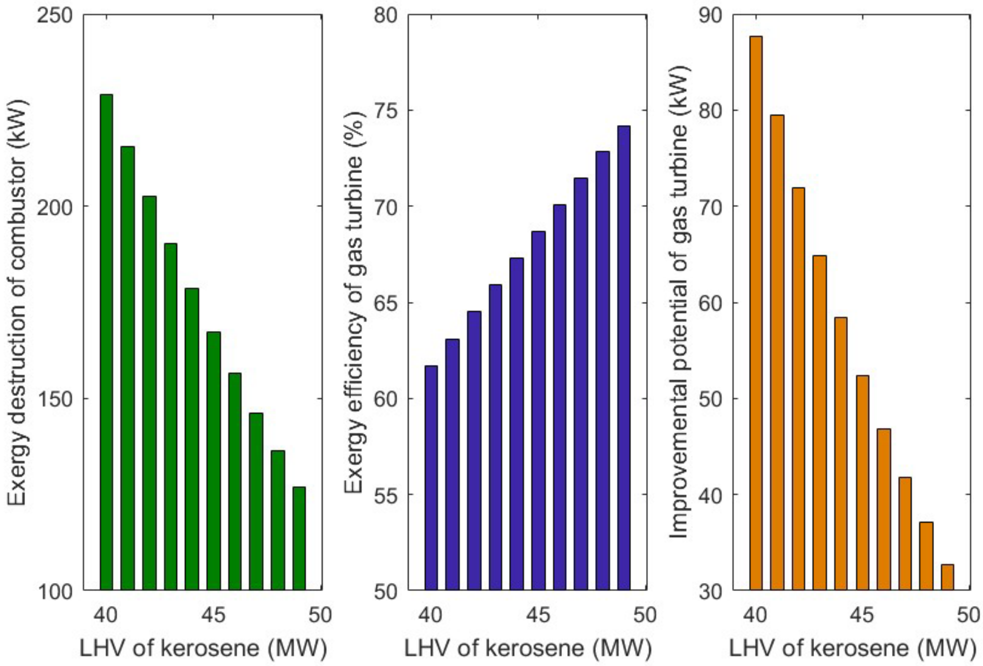

Figure 8. Variation of exergetic metrcis of combustor with lower heating value of fuel

Table 3 presents the effects of combustor pressure ratio on the three exergetic metrics mentioned. According to this, exergy destruction diminishes from 191.801 kW to 188.048 kW whereas the improvement potential decreases from 66.09 kW to 63.53 kW. Furthermore, increasing CPR enhances exergy efficiency of combustor from 65.53% to 66.21%. In other words, it is understood that this variable is beneficial for the combustor efficiency.

Table 3. Variation of exergetic metrcis with influence of combustor pressure ratio

Combustor pressure ratio	$\dot{E}x_{dest}$ (kW)	η_{ex} (%)	$\dot{E}x_{IP}$ (kW)
0.9	191,801	0,6553	66,097
0.91	191,366	0,6561	65,798

0.92	190,935	0,6569	65,502
0.93	190,510	0,6577	65,210
0.94	190,089	0,6584	64,922
0.95	189,672	0,6592	64,638
0.96	189,260	0,6599	64,357
0.97	188,852	0,6606	64,080
0.98	188,448	0,6614	63,807
0.99	188,048	0,6621	63,536

Fig.9 illustrates the effect of turbine isentropic efficiency on turbine exergetic parameters. Accordingly, due to higher isentropic efficiency, exergy destruction decreases from 5.915 kW to 0.474 kW. Exergy efficiency increases from 93.95% to 99.48%. In contrast, the improvement potential decreases from 0.357 kW to 0.0024 kW.

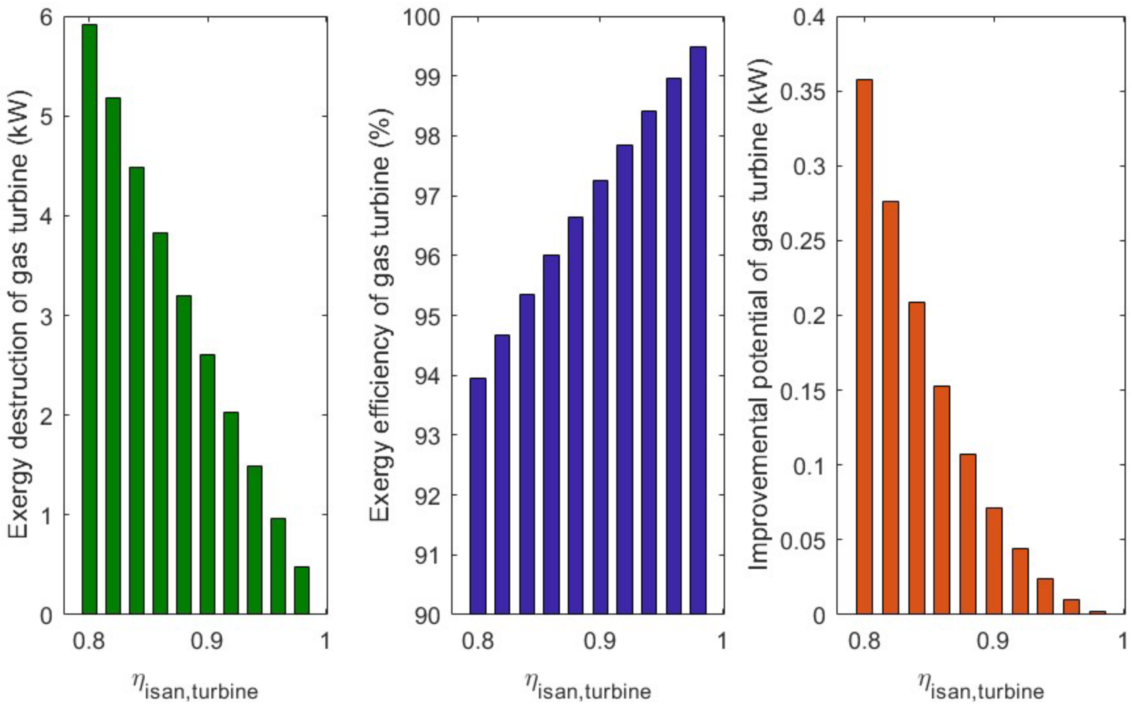

Figure 9. Variation of exergetic metrcis of turbine with influence of isentropic efficiency

Fig.10 presents the effects of four design variables on exergy efficiency of the overall engine. It can be said that increasing all variables increases the exergy efficiency of the micro turbojet engine, thus reducing exergy destruction and irreversibilities in the system. It is observed that the exergy efficiency of jet engine increases from 11.87% to 14.9% thanks to the effect of LHV.

Moreover, it improves from 12.8% to 16.75%, from 12.8% to 16.68% and from 11.12% to 13.93% by increasing the isentropic efficiency of the turbine and compressor and the combustor pressure ratio, respectively.

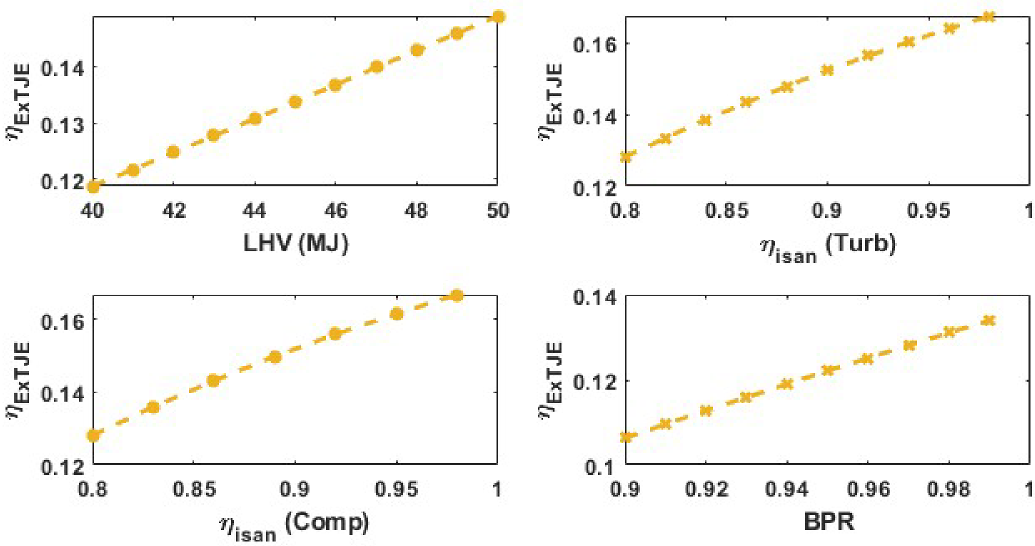

Figure 10. Effect of design variables on the exergy efficiency of the turbojet engine

4. CONCLUSIONS

Technological developments in the aviation industry are becoming more popular for people thanks to unmanned aerial vehicles and applications. This increasing interest allows for more research in aviation engines and thus the development of new concepts. In this study, effects of design variables of a micro-scale turbojet engine (isentropic efficiency, combustor pressure ratio, and fuel parameter) are examined by employing both parametric cycle analysis and exergy analysis. In this context, the analyzed isentropic efficiency is determined as 0.8 to 0.98 for the compressor and turbine, while the combustor pressure ratio was selected as 0.9-0.99 ranges. The lower heating value of the fuel was considered in the range of 40 MW to 50 MW. This allows for a detailed examination of the effects on outputs such as thrust, specific fuel consumption, thermal efficiency, exergy efficiency, exergetic improvement potential, and exergy destruction. To summarize the analysis results:

- With the increase in compressor isentropic efficiency, the jet engine SFC decreases from 44.25 g/kN.s to 39.38 g/kN.s. This corresponds to an 11.03% reduction.
- Due to the increase in fuel lower heating value, SFC decreases from 47.83 g/kN.s to 37.87 g/kN.s. This corresponds to a 20.82% reduction.

- While the increase in compressor isentropic efficiency changes exergy efficiency of the compressor by approximately 11.82%, the increase in turbine isentropic efficiency changes the exergy efficiency of the relevant component by approximately 5.53%.
- The combustor pressure ratio has a limited effect on exergy efficiency. That is, the efficiency increases from 65.53% to 66.21%, which is calculated to be less than 1%.
- With the increase in turbine isentropic efficiency, the exergy efficiency of jet engine improves from 12.8% to 16.75%.

This study shows that when design modifications are made to the turbojet engine, it will be possible to compare the effects on performance through exergetic metrics in a simulation environment. In the future study, the calculated exergetic parameters can be optimized based on the determined input variables so as to observe efficient operating points. Additionally, exergetic outputs can be forecasted from input variables by performing machine learning analysis.

DECLARATION OF ETHICAL STANDARDS

The authors of the paper submitted declare that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Mehmet Kırmızı: Conceptualization, Data Visualization, Manuscript Writing - Review & Editing
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CONFLICT OF INTEREST

There is no conflict of interest in this study.

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