

The optimization of a jet turbojet engine by PSO and searching algorithms

Sorush Niknamian

PhD in Cell and Molecular Biology and Military Medicine, Liberty University (LU), USA, so.ninamian@gmail.com

Abstract

The turbojet engine operates on the ideal Brayton cycle (gas turbine) and consists of six main parts: diffusers, compressors, combustion chambers, turbines, afterburners and nozzles. Using computer code writing in MATLAB software environment, exergy analysis on all selected turbojet engine components, exergy analysis on J85-GE-21 turbojet engine for selective height of 1000-8000 meters above sea level at speeds of 200 m/s and temperatures of 10°C, 20°C and 40°C have been provided and then, according to the system functions, the system is optimized based on the PSO method. For the purpose of optimization, variables of Mach number, efficiency of the compressor, turbine, nozzle and compressor pressure ratio are considered in the range of 0.6 to 1.4, 0.8 to 0.95, 0.8 to 0.95 and 7 to 10, respectively. The highest exergy efficiency of different parts of the engine at sea level with an inlet air velocity of 200 m/s corresponds to a diffuser with 73.1%. Then, the nozzle and combustion chamber are respectively 68.6% and 51.5%. The lowest exergy efficiency is related to compressor with 4%. After that, the afterburner is ranked second with 11.6%. Also, the values of entropy produced and the efficiency of the second law before optimization were 1176.99 and 479 w/k respectively and the same values after optimization were 1129 and 51.4 w/k respectively which is identified. After the optimization process, the amount of entropy produced is reduced and the efficiency of the second law of thermodynamics has increased.

© 2021 Author(s).

Keywords: Brayton Cycle, Plane, Exergy Analysis, Turbojet Engine, Exergy Efficiency, Optimization

1. Introduction

The mounted engine on airplane is utilized for producing of thrust force. The output gases, which exit forcefully from the engine nozzle at the rear side of engine of airplane, cause airplane to move quickly forward and this is led to passing air flow over the wing of airplane. Given the airplane wing is similar to airfoil, the surface area over the wing is greater than the same area under it. As a result, the pressure on the wing will be smaller than under the wing and a force will be exerted under it to move it up and it is called lift force and causes the airplane to go up the ground level. Today, gas turbine engines are utilized in many modern airplanes to produce the needed thrust force for motion because they are light-weight and compressive and power-to-weight ratio is high in them.

* Corresponding author.

E-mail address: so.ninamian@gmail.com (Sorush Niknamian)

Gas turbines in airplanes operate within an open cycle called jet thrust cycle. The ideal jet thrust cycle differs from simple ideal Brayton cycle in that the existing gases in thrust cycle are not expanded up to the level of ambient pressure, but they are expanded to the level of pressure in which the produced power by the turbine is the same as the quantity that is necessary for operation of compressor and other accessories including generator and hydraulic pump. In other words, the net output work of jet thrust cycle is zero [1].

The gas turbine is used as a general term for types of turbine engines and within range of jet engines it includes turbojet, turbofan, and turboshaft and all turbine engines that operate by jet mechanism. One can refer to other thrust systems that produce fluid acceleration of thrust but exclude from turbine such as ramjet, pulsejet and rocket jets each of which operates by separate mechanisms and principles and possesses different structure.

The exergy analysis has been presented on elements of turbojet engine in several studies done by domestic and foreign researchers. Ehyaei [2] examined analysis of exergy on turbo engine for jet (model: J85-GE-21) with afterburner. This turbojet engine operates according to ideal Brayton cycle (gas turbine) and comprises of six main parts i.e. diffuser, compressor, combustion chamber, afterburner, and nozzle. The exergy analysis was conducted on all parts of the selected turbojet engine at two different seal levels and height (11'000 m) using little information derived from cabin indicators and by writing computer code. The maximum exergy efficiency is related to compressor with 96.72% at sea level. Then, nozzle and turbine are placed at next ranks with 93.70% and 92.31%, respectively. The efficiency of all engine parts and total efficiency are reduced by decrease in velocity of input air to the engine at two aforesaid height levels. The minimum exergy is for afterburner (45.81%) at sea level. Then, combustion chamber is placed at second position (80.42%). Given constant air pressure, following to rise of temperature of input air in the engine, total efficiency of turbojet engine is reduced up to 45%, as temperature is increased one degree [2].

In a study that was carried out by Turan [3]; Baklacioglu, Aydin, Turan [4]; Şöhret, Ekici, Altuntaş, Arif, Hikmet [5], the advanced analysis of exergy was done to assess performance of a military turbojet engine or an afterburner system and splitting of exergetic loss under avoidable/ unavoidable and endogenous/exogenous modes. The ordinary and advanced exergy analysis has been presented on a turbojet engine of a military airplane in this study and important exergy parameters are defined for engine parts within this framework. While exergetic loss rates are divided into endogenous/ exogenous and avoidable/ unavoidable parts in engine parts. Likewise, the interdependencies are obtained between engine parts and real dependent improvement potentials on operational conditions by this analysis. As a result of this study, the values of exergetic efficiency of engine are derived as 39.41% in MIL mode (performance of maximum thrust of engine without fuel combustion in afterburner) and 17.90% in afterburner (AB) mode (maximum performance of engine thrust with fuel combustion in afterburner) respectively. This system has small improvement potential because the amounts of unavoidable exergetic loss are 93% in MIL mode and 98% in AB mode. It seems there is weak relationship among the elements because the endogenous exergetic loss is 83% in MIL mode and 94% in AB mode. Finally, it can be concluded that according to the given results, it should be focused in low-pressure compressor, high-pressure compressor, combustion chamber and exhaust of engine afterburner [6].

Yucer [7] conducted thermodynamic analysis on performance of load unit for a jet engine of gas turbine at small scale using the exergetic analysis technique. To perceive performance of this jet engine, several tests were carried out under four various types of load (neutral, load in first part, load in second part, and full loading). The maximum exergetic efficiency is 69% for a compressor and 72% in combustion chamber and 79% in a gas turbine under loading mode at first part and also 72% for compressor, 80.6% in combustion chamber and 72% in gas turbine under loading mode for the second part and 75% in compressor, 81% for combustion chamber and 77% in gas turbine under full loading mode.

2. Methodology

Initially, equations have been written for energy and exergy of the system in the current study and based on which energy is modeled in MATLAB medium. Then parameters of system are optimized according to the given model such as pressure ratio and air-to fuel ratio based on PSO and searching algorithms. Again by proposing of the given constraints and based on their variance in searching algorithms, the optimized points are obtained including maximum

efficiency in first thermodynamic law and by minimization of the produced entropy and also in PSO algorithms based on reproductive genetics of the above-said optimized values. Then, after validation of results, the optimal results are compared with each other in two algorithms at above. It can be implied about innovation of this system that two searching and PSO algorithms have not been so far compared for jet engines and their results. The computer games have positive effect on growing creativity in preschool children.

3. Result

The value of given exergy on turbojet engine (J85-GE-21 is presented for the selected height (7'500 m) higher than sea level at velocity of 200 m/s and at 10, 20, and 40° C.

Then, the above-said system is optimized according to PSO technique based on target functions.

The efficiency and loss of exergy and rate of produced entropy are calculated for different parts of engine at sea level and their quantities are given in table 1.

Table 1. Efficiency based on first thermodynamic law, loss of exergy and rate of produced entropy for parts of engine at sea level at input air speed

Component	$\eta_{\Pi}(\%)$	$E'_D(\text{kW})$	$S'_{\text{gen}}\left(\frac{\text{kW}}{\text{K}}\right)$
Diffuser	73.1	22.85	7.66
Compressor	4.00	38.01	12
Combustion chamber	51.50	2596.03	870
Turbine	25.7	112.25	38
After Burner	11.6	404.68	136
Exhaust Nozzle	68.6	967.54	325

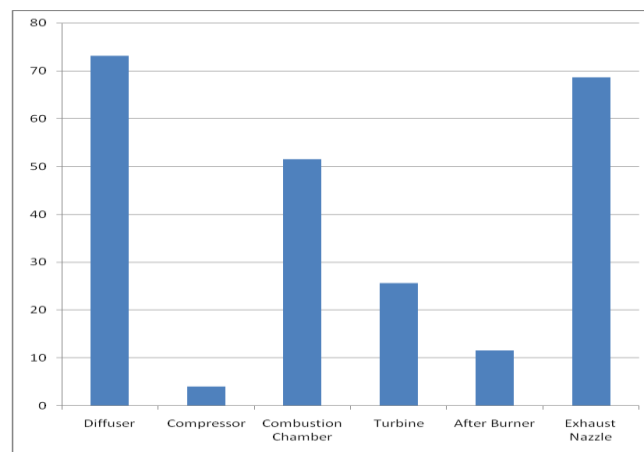


Fig 1. Efficiency of exergy in different parts of engine at sea level and with velocity of input air (200 m/s)

Table 2. The values of produced entropy and efficiency in the second thermodynamic law before and after optimization

Values	Before optimization	After optimization
$S'_{\text{gen}}\left(\frac{\text{W}}{\text{K}}\right)$	1176.99	1129
$\eta_{\Pi}(\%)$	47.9	51.4

As it characterized in above-said table, after process of optimization, the amount of produced entropy has been reduced and efficiency of the second thermodynamic law was increased. The entropy was reduced about 4.25% and efficiency was increased 73% based on the second thermodynamic law. Table 3 shows optimal values for variables of cycle at different heights. With respect to this table, it can be found that the amounts of produced entropy have been reduced by rising height and efficiency was increased according to the second thermodynamic law.

Table 3. The optimal values of cycle at different heights

H	$S_{\text{gen}} \left(\frac{\text{W}}{\text{K}} \right)$	$\eta_{\Pi}(\%)$	M	$\eta_c(\%)$	$\eta_T(\%)$	$\eta_N(\%)$	r_c
1000	1189.9	47.7	0.6	88	80	80	7
3000	1142.8	50.06	0.6	92	80	86	7
5000	1101.2	53.23	0.99	94	94	94	9.98

The amount of produced entropy is reduced from 1189.9 W/K to 1101.2 W/K following to rise of height from 1000 m to 3000 m. Similarly, the efficiency has been reduced according to the second thermodynamic law. Of course, decrease in temperature is also led to reduced efficiency of cycle based on the second thermodynamic law.

4. Analysis of Result

The equations of energy and exergy of system were initially written in this study and based on which the energy was modeled in MATLAB medium; afterwards, the system parameters were optimized according to the given model such as pressure ratio and air-to-fuel ratio based on PSO and genetic algorithms. Regarding importance and necessity of conducting this study, it can be mentioned that with respect to unstable nature of reversible energies, the strategies of world studies have been presented in field of energy in two forms during 20 recent years: 1) Utilization from reversible energies and 2) Optimization of energy consuming systems in reduction of energy consumption for which the current research has dealt with thermodynamic optimization of turbojet cycle. Among the given constraints in this system, one can refer to the selected height (7'500 m higher than sea level), the chosen velocities (200 m/s) and temperatures (10, 20 and 40° C). The system variables for optimization have been considered as Mach Number, efficiency of compressor, efficiency of turbine, efficiency of nozzle and pressure ratio of compressor based on variance of optimal values including maximum efficiency in the first thermodynamic law, minimization of produced entropy given a stable and one-dimensional system. The highest exergetic efficiency belongs to diffuser (73.1%) and then nozzle and combustion chamber are ranked with 68.6% and 51.5%, respectively. The lowest exergetic efficiency is related to compressor (4%) and then afterburner (11.6%) is placed at second position. The highest exergetic loss belongs to combustion chamber (2596.3 kW). Afterwards, nozzle and afterburner are placed with amounts of 967.54 kW and 404.68 k/W, respectively. The combustion chamber is placed at the first position in terms of irreversibility of processes. Due to quick change in cross section, the exhaust nozzle is placed at second position in terms of irreversibility. Therefore, combustion process is extremely irreversible in engine. The afterburner is placed at third rank as well.

Based on PSO (Particle Swarming Optimization) algorithm at the beginning of optimization, Pareto chart is drawn for turbojet engine at 3'500 m higher than sea level based on efficiency of the second thermodynamic law and the produced entropy that indicated reverse relationship between these two important variables. In other words, the produced entropy is reduced by rise of efficiency in the second thermodynamic law and inversely it shows logical relationship between these two parameters. Based on PSO and genetic algorithms and after optimization, amount of produced entropy has been reduced from 1176.99 W/K to 1129 W/K and the efficiency of the second thermodynamic law from 47.9% to 51.4% and this indicates successful optimization. Similarly, following to rise of height from 1000 m to 5000 m, rate of efficiency in the second thermodynamic law has been increased from 47.9% to 51.4%. Likewise, given sensitivity analysis and change in variables of system efficiency of the second thermodynamic law varies as follows.

Table 4. Variables of system for efficiency of the second thermodynamic law

The relevant variable	Efficiency of the second thermodynamic law
Rise of compressor pressure ratio	Reduced efficiency
Rise of Mach Number	Reduced efficiency
Rise of temperature	Increased efficiency
Rise of height from 1000 m to 5000 m	Increased efficiency
Increase and decrease in efficiency of compressor	Fixed efficiency

5. The practical suggestions

One of the suggestions that can be utilized according to findings of this study is that in addition to analysis of above-said cases one can also imply optimization and correction of the following cases. The compressor is the first part of engine core. The compressor is composed of one of the fans that are built from many blades connected to the shaft. The compressor makes the air flow compressed through it by reducing spaces. The fan has favorable effect therefore selection of suitable fan based on requirements can positively affect rise of efficiency of the system. Likewise, nozzle acts as exhaust for engine. The energy acquired from output air flow out of the turbine is discharged at this unit. In addition to energy, the cold air flow which is passed along core of engine provides double energy. Combination of hot and cold air flows exits from the engine creates thrust for engine and airplane. Nozzle may include a unit called mixer where air flow comes out of engine core at high temperature and it is mixed with air flow with lower temperature passing along the engine. The mixer contributes the engine to produce lesser noise.

References

- [1] Anjiri Dezfuli- Abdul Hassan (2010). Analysis of exergy in turbojet engine. MA thesis, Islamic Azad University, Dezfoul branch.
- [2] Ehyaei, M. A., Angiridezfuli. Rosen, M. A., (2013) ' Exergetic Analysis Of An Aircraft Turbojet Engine With After burner', Thermal Science, Vol 17, No. 4, pp. 1181-1194
- [3] Turan, O. (2016) ' Energy and Exergy (ENEX) Analyses of a MD-80 Aircraft, IJMERR', Vol 5, No.3, pp. 206-209
- [4] Baklacioglu, T., Aydin, H., Turan, O. (2016) ' Energetic and exergetic efficiency modeling of a cargo aircraft by a topology improving neuro-evolution algorithm', Energy, Vol 103, pp. 630-645
- [5] Şöhret, Y. Ekici, S. Altuntaş, Ö. Arif, H. T. Hikmet, K. (2016) ' Exergy as a useful tool for the performance assessment of aircraft gas turbine engines', Progress in Aerospace Sciences, Vol 83, pp.57-69
- [6] Balli, O. (2017). Advanced exergy analyses to evaluate the performance of a military aircraft turbojet engine (TJE) with afterburner system: splitting exergy destruction into unavoidable/avoidable and endogenous/exogenous. *Applied Thermal Engineering*, 111, 152-169.
- [7] Yucer, C. T. (2016). Thermodynamic analysis of the part load performance for a small scale gas turbine jet engine by using exergy analysis method. *Energy*, 111, 251-259.