Energy and Exergy Analysis and Optimization of Turbofan Engine-TF30-P414

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**Abstract**

The turbofan engines are one of the constitutes significant components of the aero engines. In this study, the thermodynamic modeling of the TF30-P414 turbofan engine is developed and validated with reference values. The aims of this research are to determine the effect of the changes in the thrust, fuel mass flow rate, and thermal efficiency with changes of the flight-altitude (H) and the flight-Mach number (Ma). Then, the changing of the exergy efficiency and exergy destruction rate were investigated. The results show that between the different components of the engine in different flight circumstances, the highest exergy destruction occurred in the combustion chamber and the lowest exergy destruction occurred in the nozzle. Also, optimization with the objective function of finding optimum flight conditions to find the highest exergetic efficiency in the flight-Mach number of 1.2 to 2.2 and the flight altitude of 10,000 to 15,000 meters. The results of this optimization reported that the maximum exergetic efficiency happened to the conditions of H=11236 meters and Ma=1.944 with an amount of 32.64%.

**Keywords**

Energy and energy analysis, Flight altitude, Mach number, Turbofan engine

**Nomenclature**

| Symbol | Description |
|--------|-------------|
| \( T_s \) | The inlet temperature of the combustion chamber, \( \text{K} \) |
| \( e_x \) | The specific chemical exergy of the fuel flow, \( \text{kJ.kg}^{-1} \) |
| \( E_i \) | The inlet exergy rate, \( \text{kW} \) |
| \( W_c \) | The power of compressor, \( \text{kW} \) |
| \( \eta_{ecc} \) | The combustor exergy efficiency |
| \( r_p \) | The overall compression ratio |
| \( b_p \) | Bypass ratio |
| \( \eta_{turb} \) | Turbine inlet temperature |
| \( \eta_{cc} \) | Compressor isentropic efficiency |
| \( \eta_{fan} \) | Fan isentropic efficiency |
| \( C_{sp} \) | Specific heat capacity, \( \text{J/kgK} \) |
| \( A_{ex} \) | Nozzle area, \( \text{m}^2 \) |
| \( A_g \) | The area of the input air channel to the engine, \( \text{m}^2 \) |
| \( V_o \) | Flight speed, \( \text{m/s} \) |
| \( g_c \) | Gravity acceleration, \( \text{m.s}^{-2} \) |
| \( m_f \) | Mass flow rate of the airflow, \( \text{kg/s} \) |
| \( m_f \) | Fuel mass flow rate, \( \text{kg/s} \) |
| \( \eta_p \) | The propulsive efficiency |
| \( \eta_{th} \) | Thermal efficiency |
| \( \eta_{ex} \) | The overall exergy efficiency |
| \( \eta_{exT} \) | The exergy efficiency of the turbine |
| \( \eta_{exc} \) | The exergy efficiency of the compressor |
| D | The flight air density, \( \text{kg.m}^{-3} \) |
| \( E_{dc} \) | The exergy destruction rate of the compressor, \( \text{kW} \) |
| EDcc | The exergy destruction of the combustor, \( \text{kW} \) |
| EDn | The nozzle exergy destruction rate, \( \text{kW} \) |
| EDT | The exergy destruction rate of the turbine, \( \text{kW} \) |
| Eo | The outlet exergy rate, \( \text{kW} \) |
| Ex | The chemical exergy of the fuel flow, \( \text{kW} \) |
| Ma | Flight Mach number |
| Pexternal | Pressure in the nozzle discharge, \( \text{kPa} \) |
| Ps | Ambient pressure, \( \text{kPa} \) |
| Qh | Heat transfer rate of combustion chamber, \( \text{kW} \) |
| R | Global constant gas, \( \text{J/kgK} \) |
| T4 | The outlet temperature of the combustion chamber, \( \text{K} \) |
| TSF | Specific thrust, \( \text{g/kNs} \) |
| Vexternal | Flow velocity in the nozzle discharge, \( \text{m/s} \) |
| WT | The turbine power, \( \text{kW} \) |
| \( \eta_{ox} \) | The exergy efficiency of the nozzle |
| FHV | Fuel heat value, \( \text{MJ/kg} \) |
| NOx | Nitrogen oxides |

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INTRODUCTION

The gas turbine (GT) engines are a type of thermal machine based on the Brayton cycle. Thermodynamically, they supplied heat from the fuel ignition with the air and the mechanical power or the propulsion force production. The turbojet engine is the simplest form of air gas turbine engine. At first, the air is initially concentrated in the compressor in these engines. After leaves the compressor, the air moves into the combustion chamber to react with fuel, and the supplied heat from the air and fuel combustion causes a rise in the outlet temperature of the combustor. Accordingly, the flow enthalpy is increased at the turbine entrance. For these two reasons, the turbine can be run. Hence, it discharges at the nozzle, the thrust force is generated due to the velocity and pressure at the nozzle output and output surface area [1-3].

The turbofan engines are one of the constitutes significant components of the aero engines. The turbofan engines are classified into two categories as a mixed-flow turbofan engine or an unmixed-flow turbofan engine. The unmixed flow turbofan is composed of a turbojet core, an axial fan, and a bypass flow. In this configuration, the incoming airflow passes through the axial fan before entering a core compressor, the velocity and pressure of the flow are increased. Then part of the flow of air enters the core compressor, and a portion of the flow is entering the bypass flow. The bypass flow is discharged through the cold path nozzle and the output flow from the turbine through the hot path in the environment. In the turbofan engines, the cold mixed flow, and the core flow enter into the mixer before entering the nozzle, and then, it discharges from the nozzle to the ambient [4, 5].

The thermodynamic analysis evaluated the thermal system efficiency and performance including the energy and exergy analysis. The energy analysis is related to the quantity of energy, but the economic analysis examines the energy quality. The energy is related to energy loss during a process, the production of entropy, and power loss opportunities cause by the Exergy analysis, which can determine the types, the status of location, and the proper size of the exergy losses [6-8].

Recently, Many researchers studied energy and exergy performance via parametric study and the effects of each parameter on energy and exergy efficiency [9, 10]. For instance, Albeigi et al. [11, 12] parametrically worked on a triple cycle combination counting the gas turbine cycle (GT), reheat cycle, and an organic Rankine cycle, by coupling geothermal with a biomass energy source and solar energy source. Also, in their other study, they thermodynamically investigated the effect of organic fluids and pinch temperatures on the Rankine cycle performance by using microturbine.

Sabzehali et al. [13] studied on a new micro-GT engine. They considered the effect of inlet air cooling on the performance of the micro gas turbine engine by changing the parameters such as the temperature difference between the inlet air temperature (IAT) based on International Society of Automation (ISA) standard and turbine inlet temperature (TTT). Subsequently, they optimized the proposed cycle based on the genetic algorithm with two separate objectives, NOx minimization, and thermal efficiency maximization, separately.

In another study, Vadlamudi et al. [14] simulated a simple open cycle gas turbine is modeled to carry out thermodynamic analysis with different open-loop steam cooling techniques to increase the lifespan of the turbine blade’s active cooling.

Turgut et al. [15] explored the exergy analysis of the turbofan engines on the 11,000 meters from the sea level height. They also determined the exergy losses and exergy efficiency of the engine components. Coban et al. [16] inspected the application of thermodynamic rules on a military helicopter engine. The results illustrated that the highest exergy destruction values in the combustion chamber have the highest rather than the other components. Turan et al. [17, 18] considered the impact of reference heights on the exergy efficiency of a turbofan engine with a special economic aid investigation. In their works, the exergy efficiency of a turbofan is composed that at 4000 meters at the 5000 meters, it calculated as 50.3 % and 48.5 %, respectively. They have also conducted a similar study for the engine of a turboshaft engine. Similarly, Etele and Rosen [19] performed the Exergy analysis on a jet engine for flight heights of 15,000 meters of sea level. Bali et al. [20] parametrically, assessed energy and exergy performance of a GT. Rahman et al. [21] studied the parametrically the thermodynamic gas turbine (GT) performance. The efficacy of parameters such as compression ratio of the compressor, the temperature of ambient, fuel consumption ratio with air, and turbine inlet temperature on gas turbine plant performance were investigated. They found that the compressor ratio and fuel consumption ratio with air had a significant impact on the GT thermal efficiency. In another study, the effects of the inlet air temperature on the GT cycle with just adding the cooling system to increase the thermal efficiency have been done [13]. Bali et al. [22] investigated the exergetic economic analyses on an aircraft jet engine. The exergetic efficiency of the engine is calculated for 2421.5 kW output combustion production which was 34.8 %. Bali and Hepbasli [23] examined the energy and exergy analyses of the T56 engine as a turboprop engine in different performance modes of such as power, load, and rotational power of 75 % and 133 %. Also, the energy and exergy performance evaluation of the shaft and shaft power and combustion products are carried out. The results evidenced that the increase in height causes a reduction in exergy efficiency and increased energy efficiency. Bali
engine was calculated [32-34].

Khan et al. [35] applied HAM algorithm for optimal obtained solution in couple stress fluid of a Poiseuille flow for choosing the best expression parameters.

Currently, engineers in different fields such as structure design, aerodynamic design, etc., have done so much in past decade, given the importance of the aircraft engine as a propulsion system, the engine design is one of the most important steps of design, making the engine designers always seek to improve the propulsion efficiency, thermal efficiency, thrust force, and specific fuel consumption. In this study, the dimensionless analysis of the TF30 - P414 engine mixed flow turbofan by using GASTURB software [36] based on off-design were investigated including the changes of energy and exergy efficiency of different components of the TF30-P414 engine with the Mach number and flight altitude were investigated. Also, the cause of the cycle's irreversibility, the destructive exergy calculated in a different component. Correspondingly, the Mach number affects the mass fuel flow rate, and thrust force were investigated. Eventually, the overall efficiency is maximized regarding the optimization by the genetic algorithm.

THERMODYNAMIC MODELING OF THE TURBOFAN CYCLE

The TF30-P414 engine cycle is assumed as a mixed-flow turbofan engine cycle. It is a twin-spool mixed-flow turbofan engine with a high-pressure spool involving the high-pressure turbine (HPT) connected with the high-pressure compressor (HPC), which has mixed with a low-pressure spool involving the low-pressure turbine (LPT) before nozzle with the fan and the low-pressure compressor (LPC) [37]. The turbofan prototypical schematic is presented in Figure 1.

The temperature and pressure of the inlet air play an important role in the temperature and pressure of other parts of the cycle. Also, the real inlet mass flow rate is the function of the velocity and density of the input air. Since
the pressure and temperature are the functions of the flight height, the inlet flow velocity is the function of the flight Mach number. The relative equation has delivered in the following equations. The real air inlet mass flow rate is obtained from Equation (1).

\[ m_r = \frac{W_r}{FHV} \] (1)

The additive heat transference rate to the combustion chamber is evaluated in the following equation;

\[ Q_a = m_r c_p (T_r - T_1) \] (2)

The fuel mass flow rate is equal to the heat ratio of the thermal value per kilogram of fuel and is obtained from Equation (3).

\[ m_f = \frac{Q_a}{FHV} \] (3)

The thrust force in a mixed flow turbofan engine is calculated as follows:

\[ Thrust = m_f (V_e - V_e) + A_e (P_e - P_f) \] (4)

The thrust specific fuel consumption (TSFC) is obtained from Equation (5).

\[ TSFC = \frac{m_f}{Thrust} \] (5)

The thermal efficiency is estimated by Equation (6).

\[ \eta_{TH} = \frac{m_e v_e^2 (v_e^2 + V_e^2)}{S_M} \] (6)

The Propulsive efficiency is the thrust product over the flight speed to the difference of the kinetic energy during the engine and is extracted from Equation (7).

\[ \eta_p = \frac{2 \times Thrust}{m_f (V_e^2 - V_e^3)} V_e \] (7)

The chemical Exergy of the fuel flow is calculated.

\[ m_e \epsilon_e E_x = m_e \epsilon_e \] (8)

The overall efficiency is considered as the multiplied of the propulsive efficiency to thermal efficiency.

\[ \eta_{thrust} = \eta_p \cdot \eta_{th} \] (9)

It should be noticed that the ex for JP10, which is equal to 44927 kJ/kg [8]. The overall thermal efficiency of the turbofan engine is the flight velocity fraction crossed to the thrust force to the chemical exergy of the inlet fuel consumption flow of the engine. The relationships related to the exergy analysis of the cycle components are tabulated in Table 1. Table 2 presents the input data of the TF30 - P414 engine cycle.

The performance results of the TF30 - P414 engine is displayed compared to the reported values [38] in Table 3. The consequences indicate that it has a good agreement for continuing the calculation.

### Table 1. Exergy analysis of cycle components

| Component | Exergy efficiency | Destruction rate of exergy |
|-----------|-------------------|----------------------------|
| Compressor | \[ \eta_{in} = \frac{E_o - E_i}{W_i} \] | \[ E_{isc} = W_i - (E_o - E_i) \] |
| Turbine | \[ \eta_{rot} = \frac{W_i}{E_i - E_o} \] | \[ E_{sort} = E_o - E_i - W_i \] |
| Combustion chamber (CC) | \[ \eta_{isc} = \frac{E_i}{E_i - E_o} \] | \[ E_{isc} = E_o - E_i + E_i \] |
| Nozzle | \[ \eta_{in} = \frac{E_i}{E_i} \] | \[ E_{in} = E_o \] |
| Overall Exergy | \[ \eta = \frac{Fv}{Ex} \] | \[ Ex = E_{in} + E_{ex} + E_{isc} + E_{isc} \] |

### Table 2. The input parameters of the TF30 - P414 engine

| Parameters | Amounts | Units |
|------------|---------|-------|
| \( r_p \) | 19.80 | - |
| \( b_s \) | 0.878 | - |
| \( T_{IT} \) | 1449 | K |
| \( m_e \) | 101.787 | Kg/s |
| \( \eta_{law} \) | 0.91 | - |
| \( FHV \) | 42.076 | MJ/Kg |
| \( \eta_{comb} \) | 0.86 | - |
| \( \eta_{law} \) | 0.88 | - |

### Table 3. The performance results of the TF30 - P414 engine compared to reference values

| Thrust (kN) | TSFC (g/kN/s) |
|------------|---------------|
| Reference value | 56.937 [38] | 25 [27] |
| Present study | 58.80 | 23.924 |
| Deviation (%) | -3.16 | -4.30 |

### RESULTS AND DISCUSSION

**Parametric thermal study**

The real airflow of the engine on flight Mach is given in Figure 2a. At any constant altitude, the Mach number increasing and the rapidly speed increases with the velocity increases, the real flow rate of the incoming air to the engine increases. Also, increasing the altitude in a constant Mach due to the decrease in the ambient air density according to the Equation (1), the real input airflow decreases. The power of the thrust force is
represented in terms of flight-Mach number and flight altitude in Figure 2b. Increasing the flight-Mach number in the constant flight height increases the real input air mass flow to the engine, and according to Equation (4), the engine thrust force also increases, on each Mach number, the flight height, the real flow of the input air should be reduced, as well the engine thrust force reduces. The variation of the fuel flow is shown in Figure 2c. At any constant height with the augmenting flight Mach number, the real air mass flow rate flow of the incoming airflow to the engine increases, so the required heat transfer rate \( Q_H \) is increased where the inlet and outlet combustion chamber temperatures are required. Accordingly, the heat value per fuel is increased when the \( Q_H \) is constant. The real air mass flow rate to the engine lessens with the constant flight Mach number and decreasing of the flight altitude, so it requires less heat to deliver the incoming air into the combustion chamber to the temperature of the turbine. So, the heating rate is decreased and the consumption of fuel is reduced in exchange of the constant heat value for the fuel mass flow rate. Variations of specific fuel consumption in terms of altitude and Mach number are presented in Figure 2d. By increasing the Mach number at any constant height, the intensity increased the fuel consumption which is higher than the intensity of increasing the thrust force, so the motor fuel consumption has increased.

The variation of thermal efficiency and change of propulsive efficiency in terms of the height and Ma are shown in Figure 3.

**Parametric exergy analysis**

In this study, the effect of flight-Mach number, flight altitude on the overall exergy efficiency and fuel flow consumption of the TF30P414 engine were investigated. Also, the efficacy of Ma at the constant flight height of
10,000 m on the energetic efficiency and exergy losses of the parts of the proposed cycle is examined. The thermodynamic properties of the flow at different components of the engine per flight Mach number variation at a constant altitude of 10,000 m are represented in Tables 3-6, respectively.

The performance changes of the TF30 engine components with flight - Mach are represented at an altitude of 10,000 m in Figure 4. Furthermore, the flight Mach number rises the exergy efficiency of the peak pressure compressor and the combustion chamber and it has an exergy efficiency near 100%. Also, the exergy efficiency of HPT, LPC, and HPC is in the range of 80 and 98.69% on the different flight Mach numbers. The exergy efficiency of the combustion chamber at different flight Mach numbers has a value ranging between 75 and 80%. The variation of the exergy destruction rate (E.D.) of the TF30 engine components with flight Mach number at a constant height of 10,000 meters is shown in Figure 5. The results showed that the E.D. rate in the combustion chamber was much higher than the other components. The E.D. rate at the nozzle is also very low and close to zero. In addition, with different flight Mach numbers, the

| Flow stations | M (kg/s) | T (K) | P (kPa) | h (J/kg) | e (J/kg) |
|---------------|----------|-------|---------|----------|----------|
| HPC inlet     | 24.63    | 239.76| 33.638  | -46528   | 28074.2  |
| Combustor inlet| 24.63    | 499.36| 359.151 | 208143   | 28070.066|
| HPT inlet     | 25.325   | 1430.1| 337.969 | 1330000  | 1330000  |
| LPT inlet     | 25.325   | 1218.82| 159.834 | 1072000  | 852382   |
| Mixer inlet   | 25.325   | 1192.93| 143.516 | 556843   | 410942   |
| Nozzle inlet  | 46.95    | 816.36| 92.76   | 556843   | 410942   |
| Nozzle outlet | 46.95    | 699.733| 51.033  | 556843   | 410942   |

Table 3. The flow characteristics of the different parts of the engine are at a height of 10,000 m and Ma = 0.8

| Flow stations | M (kg/s) | T (K) | P (kPa) | h (J/kg) | e (J/kg) |
|---------------|----------|-------|---------|----------|----------|
| HPC inlet     | 36.357   | 237.84| 53.068  | -10631.1 | 63422.4  |
| Combustor inlet| 36.357   | 567.73| 566.67  | 279760   | 340062   |
| HPT inlet     | 37.315   | 1430.2| 533.13  | 1319000  | 1133000  |
| LPT inlet     | 37.315   | 1119.69| 266.015 | 1034000  | 843108   |
| Mixer inlet   | 37.315   | 1115.21| 196.65  | 967948   | 775964   |
| Nozzle inlet  | 69.237   | 812.59| 142.99  | 551982   | 435153   |
| Nozzle outlet | 69.237   | 696.144| 78.65   | 551982   | 435153   |

Table 4. The flow characteristics of the different parts of the engine are at a height of 10,000 m and Mach 1.2

| Flow stations | M (kg/s) | T (K) | P (kPa) | h (J/kg) | e (J/kg) |
|---------------|----------|-------|---------|----------|----------|
| HPC inlet     | 75.101   | 321.45| 90.309  | 39626.3  | 111772   |
| Combustor inlet| 75.101   | 661.5 | 964.28  | 379398   | 437792   |
| HPT inlet     | 58.456   | 1429.50| 906.982 | 1315000  | 1163000  |
| LPT inlet     | 58.456   | 1148.64| 328.85  | 980182   | 823725   |
| Mixer inlet   | 58.456   | 1104.84| 272.99  | 902557   | 744698   |
| Nozzle inlet  | 108.591  | 807.58| 233.90  | 545512   | 462033   |
| Nozzle outlet | 108.591  | 691.384| 128.605 | 545512   | 462032   |

Table 5. The flow characteristics of the different parts of the engine are at a height of 10km and Ma = 1.6

| Flow stations | M (kg/s) | T (K) | P (kPa) | h (J/kg) | e (J/kg) |
|---------------|----------|-------|---------|----------|----------|
| HPC inlet     | 72.579   | 550.394| 119.844| 70138.4  | 141084   |
| Combustor inlet| 72.579   | 717.27 | 1279.59| 439501   | 496694   |
| HPT inlet     | 74.186   | 1428.87| 385.42  | 1312000  | 1180000  |
| LPT inlet     | 74.186   | 1123.79| 396.046 | 947795   | 809687   |
| Mixer inlet   | 74.186   | 1073.3 | 318.825 | 863155   | 723475   |
| Nozzle inlet  | 137.911  | 804.724| 300.394| 541800   | 475414   |
| Nozzle outlet | 137.911  | 688.656| 165.128| 541800   | 475413   |

Table 6. The flow characteristics of the different parts of the engine are at a height of 10km and Ma = 1.8

E.D. of the HPC is greater than the E.D. rate at HPT and the LPT E.D. rate is lower than the HPT E.D. rate. The exergy changes of the TF30 engine fuel flow with the flight-Mach number were represented at a constant flight height of 10,000 meters in the form of the JP10 fuel in Figure 6. Since the flow rate of fuel increases with increasing the Mach number at a constant height of 10,000 meters, according to Equation (8), the chemical exergy of fuel flow increases with increasing the flight Mach number. Exergy fuel flow changes of the TF30 engine with a flight height at Mach number 2 constant per JP10 fuel are shown in Figure 6.

The exergy rate of the incoming fuel flow reduced because of the reduction in the mass flow rate of the fuel by increasing the flight altitude at constant flight Mach number.

The performance changes of the TF30 engine components with flight - Mach at an altitude of 10,000 m are represented in Figure 4. Furthermore, the exergy efficiency reaches nearly to 100% when the flight Mach number rises the exergy efficiency of the compressor peak pressure and the combustion chamber increases. Also, the exergy efficiency of HPT, LPC, and HPC is in the range of 80 and 98.69% at different flight Mach numbers.
The changes in the $\eta_{ex}$ of the TF30 engine parts with $Ma$ at a constant height of 10,000 meters numbers. The exergy efficiency of the combustion chamber at different flight Mach numbers has a value ranging between 75 and 80 %. The variation of the exergy destruction rate (E.D.) of the TF30 engine components with flight Mach number at a constant height of 10,000 meters is shown in Figures 5. The results showed that the E.D. rate in the combustion chamber was much higher than the other components. The E.D. rate at the nozzle is also very low and close to zero. In addition, at different flight Mach numbers, the E.D. of the HPC is greater than the E.D. rate at HPT and the LPT E.D. rate is lower than the HPT E.D. rate. The exergy changes of the TF30 engine fuel flow with the flight-Mach number at a constant flight height of 10,000 meters in the form of the JP10 fuel are represented in Figure 6. Since the flow rate of fuel increases with an increase in the Mach number at a constant height of 10,000 meters, according to Equation (8), the chemical exergy of fuel flow increases with an increase in the flight Mach number. Exergy fuel flow changes of the TF30 engine with a flight height at Mach number 2 constant per JP10 fuel are shown in Figure 6. Since an increase in the flight altitude with each constant flight Mach number reduces the fuel mass flow rate, the efficacy of the flight Mach number reduces the Exergy rate of the incoming fuel flow. The exergy efficiency changes with the Mach number at a constant flight height of 10,000 meters in the form of JP10 fuel are represented in Figure 6. By increasing the Mach number, the thrust force and flight speed are increased at a constant height of 10,000 meters and the intensity of increasing the cross of the flight speed and thrust force is higher than the intensity of the increase in the energy rate of the fuel flow; thus, increasing the Mach number at a flight height of 10,000 meters, the exergy efficiency of the TF30 engine increases. The $\eta_{ex}$ of the TF30 engine with flight Mach number of constant two for the JP10 fuel is illustrated in Figure 6. The findings show the highest and lowest exergy efficiency of the TF30 engine is at $Ma = 2$ and $H = 10$ km, and $Ma = 2$ and $H = 20$ km, respectively.

**Optimization**

Teaching–learning-based optimization (TLBO) is derived from the teaching and learning process. It is based on the influence of the teacher on the students' efficiency in a class. TLBO was performed during two-approach steps. The input parameters of the algorithm are the lower and upper bounds of the variables, the amount of production, and the fitness function. TLBO is considered
to be the basis of the optimization approach. First, the members of the class are generated for the Variables boundary. The best response is chosen according to the fitness function of the instructor [39].

**Instructor phase**

The first stage is called the training phase, the instructor tries to influence the level of knowledge of the members. The class raised its mean to increase the ability of the class. This random process depends on many aspects. The parameters at any interaction \( i \), \( M_i \), and \( T_i \) are the mean level of class and Teacher at any iteration. \( T_i \) will be near to the \( M_i \) after teaching development and it is named \( M_{new} \). So, The difference and the mean of these two parameters subtract from each other. This subtraction is defined as follows:

\[
\text{difference} - \text{mean} = r_i (M_{new} - T_i, M_i)
\]

where, \( r_i \) is a random number in the range of 0 to 1 and \( T_i \) is the educational factor which can be determined the education quality and Master's ability to transfer knowledge.

**Learner phase**

At this stage, the population (who are a classmate) develops their knowledge by working together. One of the most important features of this algorithm is the lack of dependence on the parameters. Because the algorithm has the lowest possible number of parameters and hence, it can have a particular advantage. The acquaintance of learners improves with input teacher feedback and also among of their interaction. Arbitrarily, the learners cooperate with other learners in a group to learn or discuss the project, the presentation, etc. so it can help interactively and they exchange the information together [39, 40]. Learner modification is articulated as:

For \( i=1:Pn \)

Arbitrarily choose two learners \( X_i \) and \( X_j \), where \( i \neq j \)

If \( f(X_i) < f(X_j) \)

\[
X_{new,i} = X_{old,i} + r_i (X_j - X_i)
\]

\[ Else \]

\[
X_{new,i} = X_{old,i} + r_i (X_j - X_i)
\]

\[ End \ If \]

End For

Accept \( X_{new} \) if it gives a better function value. If the fitness function improved, this effect would be accepted. The above process is repeated until the optimal response or estimation of stopped conditions. The flowchart of the TLBO approach is shown in Figure 7.

In this section, the TF30-P414 turbofan engine is optimized. The optimization approach is produced by the TLBO algorithm with the objective function such as TIT, bypass ratio, and the flight altitude with the JP10 as a fuel. The range of bypass ratio is 0.4-0.9, TIT is 1400-1600 (K), flight-Mach number is 1.2-2, and flight altitude is in the range of 10000-15000 meters.

![Figure 7. TLBO flowchart](image)

The optimization design variables are shown in Table 7. TSFC and thrust are the design constraints of optimization. The low and high values of TSFC are 10 and 40 g/kN, respectively, also the low and high values of thrust are 25 and 30 kN, respectively. The values of the design constraints are shown in Table 8.

Subsequently, the amounts of optimized design variables are indicated in Table 9. Also, the amounts of design constraints are thrust=29.4 kN and TSFC=39.9 (g/kN). Finally, the amount of optimized performance of the TF30-P414 engine is \( M_a = 1.176 \) (kg/s), \( \eta_{Th} = 54.08\% \), \( \eta_P = 84.4\% \), \( \eta_{Overall} = 45.66\% \), and \( \eta_{ex} = 32.64\% \).

**TABLE 7. The optimization design variables**

| Parameters    | Low values | High values |
|---------------|------------|-------------|
| Bypass ratio  | 0.4        | 0.9         |
| TIT (K)       | 1400       | 1600        |
| Flight-Mach number | 1.2    | 2           |
| Flight altitude (m) | 10000  | 15000       |

**TABLE 8. The design constraints**

| Parameters     | Low values | High values |
|----------------|------------|-------------|
| TSFC (g/kN)    | 10         | 40          |
| Thrust (kN)    | 25         | 30          |
CONCLUSION

In this paper, the TF30-P414 turbofan engine is thermodynamically investigated. At first, it has been validated with the datasheet of the TF30-P414 turbofan engine. Then, the effect of the changes in the thrust fuel consumption, mass flow rate, and thermal efficiency with the flight altitude and the flight Mach number changes were investigated. Furthermore, the exergy efficiency and destruction rate of exergy were inspected with flight - Mach number and flight altitude in each component. Finally, for finding the best condition of flight altitude and flight-Mach number, optimization has been operated. The results are reported as follows:

1. As a result of the thrust force and consumed-fuel flow rate, as well as the fuel consumption and the engine thrust, the real air inlet flow rate, grows if the Flight-Mach number increases at the constant flight altitude.

2. Increasing the flight altitude by the constant Flight – Mach number, the real flow of air to the engine is reduced due to the reduction in the air density, so the engine thrust force is reduced. Also, the consumed flow rate of fuel is reduced.

3. At any constant flight altitude, the chemical exergy rate increases due to the increase in the thrust-specific fuel consumption (TSFC). However, the increasing intensity of the chemical exergy rate of fuel flow in return for increasing the Mach number, consequently, the engine exergy efficiency is increased by increasing the Mach number at constant flight altitude.

An Optimization has been done to find the optimized Mach number and flight altitude for the exergy efficiency maximization in the range of 1.2 to 2 and 10,000 m to 15,000 m respectively by using a single-purpose optimization algorithm named as teaching-learning-based optimization method (TLFO). The findings indicate that the uppermost exergy efficiency happened in the flight altitude of 11236 m and the Mach number of 1.994. The maximum exergy efficiency was calculated at 32.64%.

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در این مطالعه ابتدا اقدام به مدلسازی ترمودینامیکی موتور توربوفن TF30 و اختصاصی مقادیر آن با مقادیر مرجع پرداخته شد. سپس تأثیر تغییرات

تراس، دیی سوخت منجر به هوا طراحی و راندمان‌های جراحی و اثری به تغییرات ارتفاع و مایع پرپاژی مورد بررسی قرار گرفته. پس از آن به

بررسی تغییرات راندمان اکتریزی و نرخ تغییر اکتریزی با تغییرات مایع و ارتفاع پرپاژی پرداخته شد. در این مطالعه مشاهده شد با افزایش عد مایع در هر ارتفاع

تاثیر مقاله، دیی سوخت منجر به هوا طراحی و راندمان اکتریزی افزایش می‌یابد. همچنین نتایج حاکی از آن است که از بین اجزای مختلف موتور در

وضعیت‌های پوژوی مختلف نهایی نمود که اکتریزی در محیط‌های اجرا و کمتر تغییر اکتریزی در نواز اندازه‌ی منجر و کمترین بهینه در تغییر

اکتریزی کلی موتور در ارتفاع پوژوی 10000 متری به ترتیب در مایع پرپاژی 8/3 و 1/2 اندازه‌ی منجر به بهینه‌سازی با هدف پیچیدن شرایط پروپاژی بهینه با تابع

هدف بهینه‌سازی نمودن راندمان اکتریزی کلی موتور در محیط‌های پرپاژی 1/2 تا 1/2 و ارتفاع پرپاژی 10000 تا 15000 متری انجام شد. نتایج این بهینه‌سازی

حاکی از آن است که بهینه‌سازی کلی موتور در ارتفاع پرپاژی 13236 متری و مایع پرپاژی 1944/1 می‌باشد که مقادیر آن 33/64 درصد است.