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ORGINAL ARTICLE

Optimization of gas turbines for sustainable turbojet propulsion

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Abstract Gas-turbines are widely used to power aero planes because they are light, compact with a high power-to-weight ratio. In the turbo jet engine, the main operating variables are: compressor pressure ratio r_p and turbine inlet temperature (*TIT*). These variables affect the specific thrust and specific fuel consumption (*SFC*), which represent the main performance parameters. In addition to the analytical work, a computer program of the General Algebraic Modeling System (GAMS) was used for analysis and optimization. The analysis shows that the specific thrust strongly depends on turbine inlet temperature (*TIT*), where a 10% decrease in *TIT* results in 6.7% decrease in specific thrust and 6.8% decrease in *SFC*. Furthermore, the value of optimum pressure ratio r_f for maximum specific thrust increases with *TIT*. A 10% decrease from design *TIT* results in 11.43% decrease in r_f. The value of optimum pressure ratio for the turbojet engine operating at $Ma=0.8$ and altitude $Alt=13000$ m, and $TIT=1700$ K was found to be 14.

1. Introduction

Energy efficiency could be obtained by different methods, among which is waste-heat recovery [1], combined cycles [2], using energy storage for peak shaving and load leveling [3] and in the limit widening the range of fuel specifications to improve thermo economics [4].

With turbojet engines, air as the working fluid is used to produce thrust based on the variation of kinetic energy of burnt gases after combustion [5,6]. Performance typically focuses on use of cycle efficiency, specific thrust, and specific fuel consumption [7,8].

Early studies handled the model of the turbojet to evaluate performance parameters [9]. Further investigations were carried out using variable cycles of turbojet engine at supersonic speeds [10]. In the last few years many papers presented thermodynamic and aerodynamic analyses of the behavior of a turbojet operating with and without afterburners [11].

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Nomenclature

A	area (unit: m^2)
a	speed of sound (unit: m/s)
Alt	altitude (unit: m)
C_a	inlet air velocity (unit: m/s)
C_5	exit air velocity (unit: m/s)
C_p	constant pressure specific heat (unit: kJ/(kg•K))
F	thrust (unit: N)
F_s	specific thrust (unit: (N•s)/kg)
f_{ac}	actual fuel air ratio
f_{th}	theoretical fuel air ratio
H_v	heating value (unit: kJ/kg)
h	enthalpy (unit: kJ/kg)
Ma	Mach number
m	mass flow rate (unit: kg/s)
ORL	optimum running line
P	pressure (unit: bar)
P_x	pressure at some point x (unit: bar)
R	ideal gas constant (unit: J/(kg•K))
r_f	optimum compressor pressure ratio
r_p	compressor pressure ratio
SFC	specific fuel consumption (unit: kg/(N•s))
T	temperature (unit: K)
T_x	temperature at some point x (unit: K)
TIT	turbine inlet temperature (unit: K)
w_c	compressor work (unit: kJ/kg)
w_{tc}	turbine work needed for driving the compressor (unit: kJ/kg)

Greek letters

γ	ration of specific heats
η	isentropic efficiency
ρ	fluid's density (unit: kg/m^3)

Subscripts

a	air
c	compressor
cc	combustion chamber
d	diffuser
g	gas
j	nozzle
m	mechanical
pr	propulsive
t	turbine

Theoretical and practical engineering developments were necessary for the design, building and testing of an engine with an afterburner [12]. Other research works studied the effects compressor pressure ratio on thrust and other performance parameters [13]. In military applications there were special studies on the factors which determine the proper choice of engine cycle for a combat aircraft to suit the requirements of the designed mission [14]. Some researchers used energy and exergy analyses with a turbojet engine over flight altitudes ranging from sea level to 15000 m to determine the relative effects of operating variables [15].

The main objective of this work is carrying out energy analysis for the different components of the turbo jet engine [16]. Consequently, optimum performance including maximum specific thrust and minimum specific fuel consumption are obtained [17]. This will be done through an analytical method using Excel and a specified software using the language of the General Algebraic Modeling System (GAMS) for comparison [18,19].

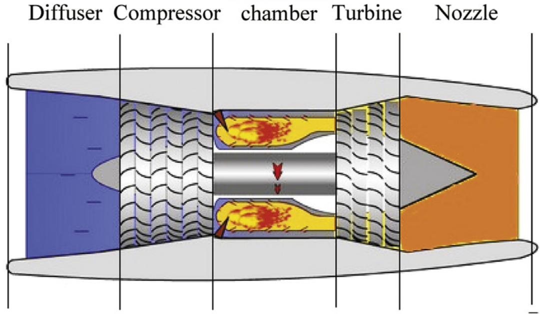

Figure 1 Turbojet engine.

2. Theoretical analysis

A schematic diagram of the turbojet engine and the relevant *T-s* diagram are shown in Figures 1 and 2.

2.1. Overall performance

The heating value of the fuel is: $H_v = 43100$ kJ/kg. The thrust of turbojet engine is produced from summation of momentum and pressure components:

$$F = m(C_5 - C_a) + A_5(P_5 - P_a) \tag{1}$$

To get the specific thrust (F_s), divide Eq. (1) by mass flow

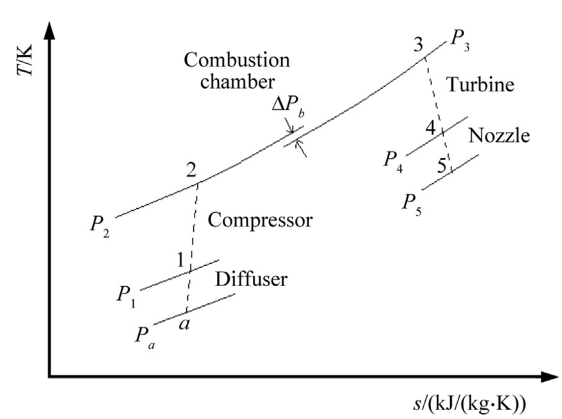

Figure 2 *T-s* diagram.