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Parametric Performance Analysis of a Mini Jet Engine

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Abstract: Mini Jet Engines are widely used to power unmanned aeroplanes because they are light, compact with a high power-to-weight ratio. In the mini jet engine, the main operating variables are: compressor pressure ratio (π_c) and turbine inlet temperature (T_{t4}). These variables affect the specific thrust (F_s) and specific fuel consumption (S), which represent the main performance parameters. This paper describes the parametric study of a mini jet engine's performance through operating conditions.

Keywords: Mini Jet Engine; Unmanned, Operating Variables; Parametric Study; Performance.

I. INTRODUCTION

The study of propulsion is needed to explain mini-jet engine theory. Jet propulsion is a practical application of Sir Isaac Newton's third law of motion which states that, "for every force acting on a body there is an opposite and equal reaction". The verb propel is defined as "to drive, or cause to move, forward or onward". Propulsion involves an object to be propelled plus one or more additional bodies, called propellant [1]. Energy efficiency could be obtained by different methods, among which is waste-heat recovery [2], combined cycles [3], using energy storage for peaks having and load leveling [4] and in the limit widening the range of fuel specifications to improve thermo economics [5]. 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 [6, 7]. Performance typically focuses on use of cycle efficiency, specific thrust, and specific fuel consumption [8, 9]. Early studies handled the model of the turbojet to evaluate performance parameters [10]. Further investigations were carried out using variable cycles of turbojet engine at supersonic speeds [11]. In the last few years many papers presented thermodynamic and aerodynamic analyses of the behavior of a turbojet operating with and without afterburners [12].

A. Mini Jet Engine

Jet Engine is a machine which converts chemical (Fuel) energy into Thrust. Jet engines are the power source for most of the aircrafts flying now [13]. And mini jet engine technology and deployment was initially welcomed with enthusiasm by the scientific community and industry [14]. They operate as a Brayton cycle that comprises a centrifugal compressor, a regenerator, a combustion chamber and a radial turbine connected to a permanent magnet alternator rotor. Their main features are that the high-speed generator is directly coupled to the turbine rotor and they use power electronics instead of a gearbox and a conventional generator to adapt the power produced to the grid power quality [15]. Research works studied the effects compressor pressure ratio on thrust and other performance parameters [16]. 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 [17]. Some researchers used energy and energy analyses with a turbojet engine over flight altitudes ranging from sea level to15000m to determine the relative effects of operating variables [18]. In mini jet engine, air as the working fluid is used to produce thrust based on the variation of kinetic energy of burnt gases after combustion [19, 20]. Performance typically focuses on use of cycle efficiency, specific thrust, and specific fuel consumption [21, 22]. In addition, Pilavachi [23], Kaikko et al. [24], Katsigiannis and Papadopoulos [25], Nikpey et al. [26] and Caresane et al. [27] studied the use of mini jet engine in typical cogeneration applications for heat production. Alternative integrations, like Bruno et al., using a mini jet engine as power source in combination with a desalination plant, which absorbs the generated heat [28] and Ho et al., studying the performance of an mini jet engine CHP system with absorption chiller, where the heat is used to provide cooling [29], are other typical examples of studies on mini jet engine.

II. DESIGN METHODOLOGY

A. Working Cycle

Mini jet engine operates on the principles of Brayton open gas/air cycle. In Brayton open cycle the engine working fluid exit/exhaust into the atmosphere after expansion in the turbine and/or the exhaust propelling nozzle [30]. For analysis of real cycles, we will consider the behaviour of the realized turbojet engine including component losses, the mass flow rate of fuel through the components, and the variation of specific heats. Our analysis still assumes one-dimensional flow at the entrance and exit of each component. The variation of specific heats will be approximated by assuming a perfect gas with constant specific heat cpa upstream of the main burner (combustor) and a perfect gas with different constant specific heat cpg downstream of the main burner. Block diagram and real cycle of Turbojet is shown Fig.1 and Fig.2 respectively.

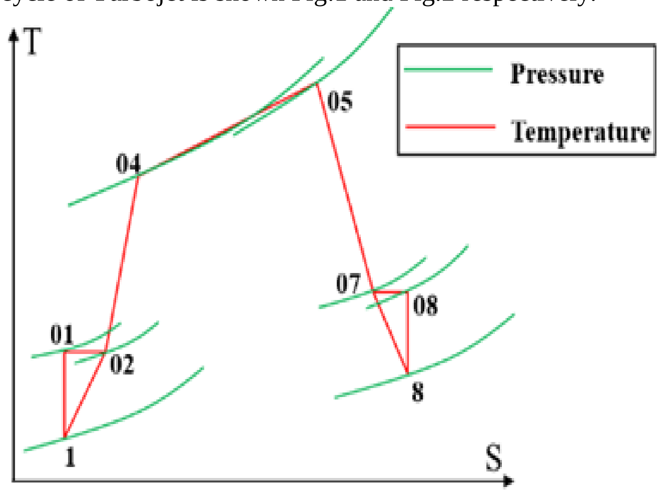

Fig.1. Block Diagram of Mini-Jet Engine.

B. Modelling

The following equations are shown in [1].

$$M_0,\ T_0(\mathrm{K},\ {}^\circ\mathrm{R}),\ \gamma_c, c_{pc}\left(\frac{\mathrm{kJ}}{\mathrm{kg\cdot K}}, \frac{\mathrm{Btu}}{\mathrm{lbm\cdot {}^\circ R}}\right),\ \gamma_t,\ c_{pt}\left(\frac{\mathrm{kJ}}{\mathrm{kg\cdot K}}, \frac{\mathrm{Btu}}{\mathrm{lbm\cdot {}^\circ R}}\right)$$

$$h_{PR}\left(\frac{\mathrm{kJ}}{\mathrm{kg}}, \frac{\mathrm{Btu}}{\mathrm{lbm}}\right),\ \pi_{d\max},\ \pi_b,\ \pi_n,\ e_c,\ e_t,\ \eta_b,\ \eta_m,\ P_0/P_9,\ T_{t4}(\mathrm{K},\ {}^\circ\mathrm{R},)\ \pi_c$$

Inputs:

$$R_c = \frac{\gamma_c - 1}{\gamma_c} c_{pc}$$

$$R_t = \frac{\gamma_t - 1}{\gamma_t} c_{pt}$$

$$a_0 = \sqrt{\gamma_c R_c g_c T_0}$$

$$V_0 = a_0 M_0$$

$$\tau_r = 1 + \frac{\gamma_c - 1}{2} M_0^2$$

$$\pi_r = \tau_r^{\gamma_c/(\gamma_c - 1)}$$

$$\eta_r = 1 \quad \text{for} \quad M_0 \le 1$$

$$\eta_r = 1 - 0.075(M_0 - 1)^{1.35} \quad \text{for } M_0 > 1$$

$$\pi_d = \pi_{d\max}\eta_r$$

$$\tau_\lambda = \frac{c_{pt} T_{t4}}{c_{pc} T_0}$$

$$\tau_c = \pi_c^{(\gamma_c - 1)/(\gamma_c e_c)}$$

$$\eta_c = \frac{\pi_c^{(\gamma_c - 1)/\gamma_c} - 1}{\tau_c - 1}$$

$$f = \frac{\tau_\lambda - \tau_r \tau_c}{h_{PR}\eta_b/(c_{pc}T_0) - \tau_\lambda}$$

$$\tau_t = 1 - \frac{1}{\eta_m(1+f)} \frac{\tau_r}{\tau_\lambda}(\tau_c - 1)$$

$$\pi_t = \tau_t^{\gamma_t/[(\gamma_t - 1)e_t]}$$

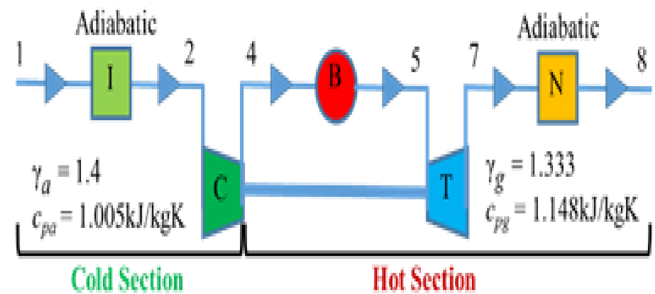

Fig.2. Brayton Cycle.

Equations:

$$\eta_t = \frac{1 - \tau_t}{1 - \tau_t^{1/e_t}}$$

$$\frac{P_{t9}}{P_9} = \frac{P_0}{P_9}\pi_r \pi_d \pi_c \pi_b \pi_t \pi_n$$

$$M_9 = \sqrt{\frac{2}{\gamma_t - 1}\left[\left(\frac{P_{t9}}{P_9}\right)^{(\gamma_t - 1)/\gamma_t} - 1\right]}$$

$$\frac{T_9}{T_0} = \frac{\tau_\lambda \tau_t}{(P_{t9}/P_9)^{(\gamma_t - 1)/\gamma_t}} \frac{c_{pc}}{c_{pt}}$$

$$\frac{V_9}{a_0} = M_9\sqrt{\frac{\gamma_t R_t T_9}{\gamma_c R_c T_0}}$$

$$\frac{F}{\dot{m}_0} = \frac{a_0}{g_c}\left[(1+f)\frac{V_9}{a_0} - M_0 + (1+f)\frac{R_t T_9/T_0}{R_c V_9/a_0}\frac{(1 - P_0/P_9)}{\gamma_c}\right]$$

$$S = \frac{f}{F/\dot{m}_0}$$

$$\eta_T = \frac{a_0^2[(1+f)(V_9/a_0)^2 - M_0^2]}{2g_c f h_{PR}}$$

$$\eta_P = \frac{2g_c V_0(F/\dot{m}_0)}{a_0^2[(1+f)(V_9/a_0)^2 - M_0^2]}$$

$$\eta_O = \eta_P \eta_T$$

Outputs:

$$\frac{F}{\dot{m}_0}\left(\frac{\mathrm{N}}{\mathrm{kg/s}}, \frac{\mathrm{lbf}}{\mathrm{lbm/s}}\right), f,\ S\left(\frac{\mathrm{mg/s}}{\mathrm{N}}, \frac{\mathrm{lbm/h}}{\mathrm{lbf}}\right),$$

$\eta_T,\ \eta_P,\ \eta_O,\ \eta_c,\ \eta_t,$ etc.

C. Parametric Study

Parametric cycle analysis is also called design point analysis or on-design analysis because each plotted engine is operating at its so-called design point. The main objective of parametric cycle analysis is to relate the engine performance parameters (primarily thrust F and thrust specific fuel consumption TSFC) to design choices (compressor pressure ratio, fan pressure ratio, bypass ratio, etc.), to design limitations (burner exit temperature, compressor exit pressure, etc.), and to flight environment (Mach number, ambient temperature, etc.). From parametric cycle analysis, we can easily determine which engine type (e.g., turbofan) and component design characteristics (range of design choices) best satisfy a particular need.

D. Parameters and Inputs

TABLE I: Inputs for Parametric Cycle Analysis

Parameters	
Inlet Mach number (M_0)	0-0.4
Compressor pressure ratio (πc)	2-4
Inputs	
Inlet temperature (T_0)	298 K
Turbine inlet temperature (T_{t4})	1000 K
Diffuser total pressure ratio ($\pi_{d\ max}$)	0.95
Burner total pressure ratio (π_b)	0.94
Nozzle total pressure ratio (π_n)	0.96
Compressor polytropic efficiency (e_c)	0.9
Turbine polytropic efficiency (e_t)	0.9
Burner Isentropic efficiency (η_b)	0.98
Combustor pressure loss (η_m)	0.99
Static pressure ratio of inlet to nozzle (P_0/P_9)	1 (Unchoked)
Fuel low heating value (h_{PR})	42.8 MJ/kg

III. RESULTS

Results of this paper is as shown in bellow Figs.3 to 10.

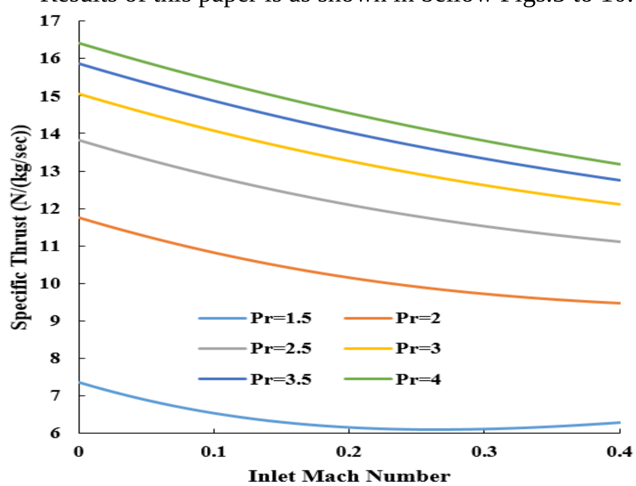

Fig.3. Variation of specific thrust with inlet Mach number.

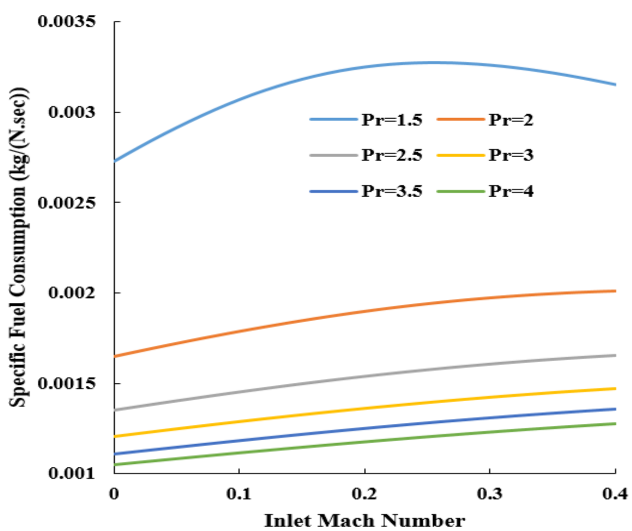

Fig.4. Variation of specific fuel consumption with inlet Mach number.

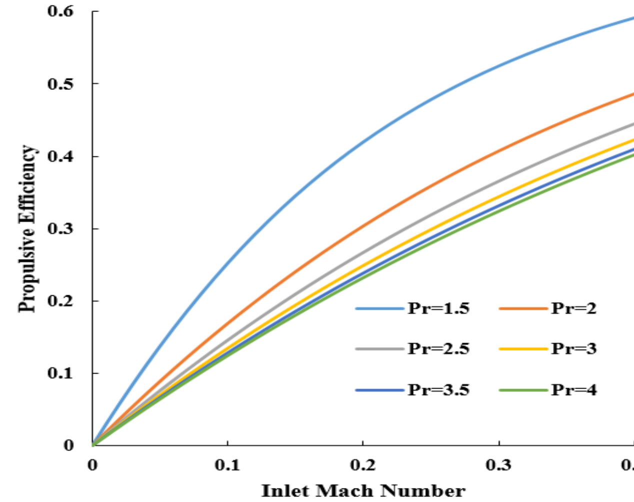

Fig.5. Variation of propulsive efficiency with inlet Mach number.

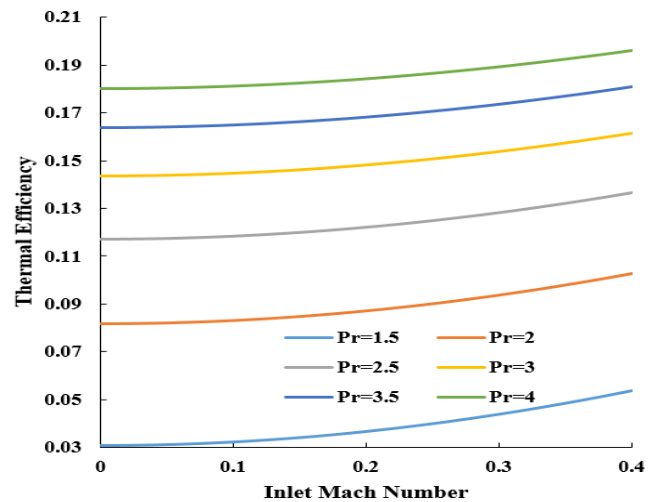

Fig.6. Variation of thermal efficiency with inlet Mach number.

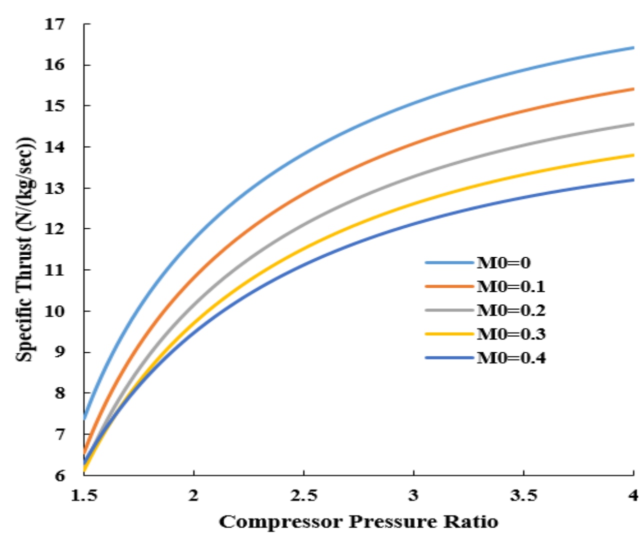

Fig.7. Variation of specific thrust with compressor pressure ratio.

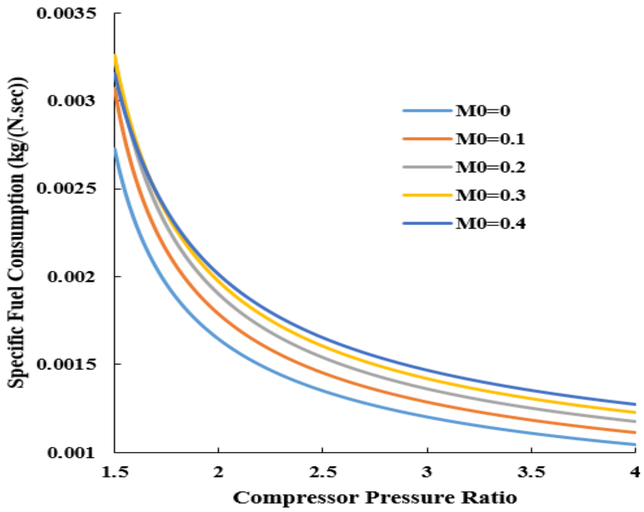

Fig.8. Variation of specific fuel consumption with compressor pressure ratio.

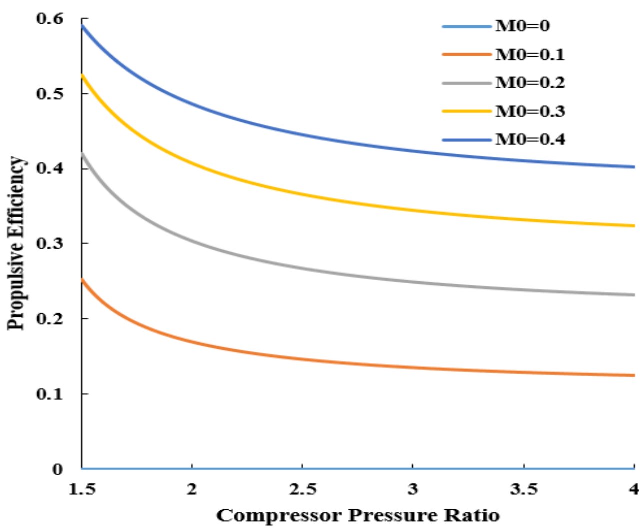

Fig.9. Variation of propulsive efficiency with compressor pressure ratio.

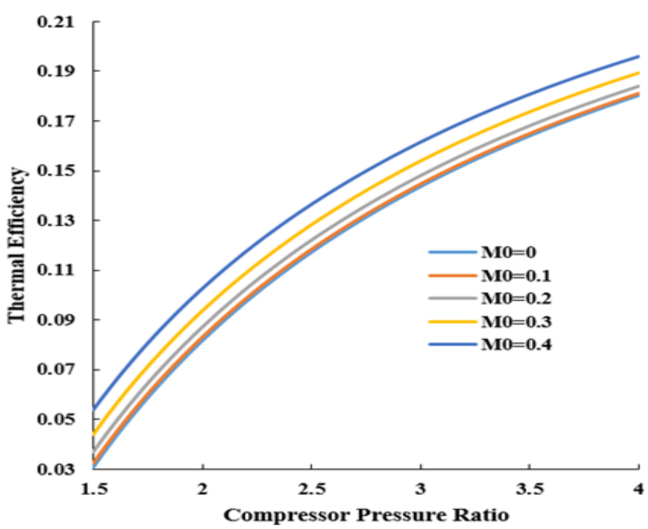

Fig.10. Variation of thermal efficiency with compressor pressure ratio.

IV. CONCLUSIONS AND DISCUSSIONS

The variation of compressor pressure ratio (1.5-4), Mach number (0-0.4) and specific thrust is shown in Fig. 3 and Fig7. At this ranges, specific thrust decreases when Mach number are increased and pressure ratio are decreased. Fig.4 and Fig. 8 also shows the SFC variation with compressor pressure ratio and inlet Mach number. In this figures SFC decreases when pressure ratio is increased, and Mach number is fixed. When the pressure ratio is fixed and increasing Mach number, the SFC increases. The minimum SFC is found at maximum pressure ratio and minimum Mach number. By increasing compressor pressure ratio, propulsive efficiency decreases and thermal efficiency increases as shown in Fig. 5, Fig. 6, Fig. 9 and Fig. 10. At these figures, both propulsive efficiency and thermal efficiency increase when the inlet Mach number is increased.

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