Ankara Yildirim Beyazit University
Faculty of Aeronautics and Astronautics
Department of Aerospace Engineering

Propulsion Systems 2

AEE 431

MATLAB PROJECT REPORT

AUTHORS:

1. Furkan Başköse (21110151002)
2. Muhammed Berati Kiliç (20110111028)
3. Süleyman Sert (20110111036)
4. Züleyha Savci (21110151003)
5. Elif Hazan Efe (21110111002)

November 15, 2024

Contents

1 Introduction

1.1 Question

Create a Matlab script that determines the performance of afterburning and nonafterburning mixed-flow turbofan engines with losses. Your Matlab script must have a user interface, and must be universal – must be able to output correct results with any user input. Table 1 tabulates an example input data.

$c_{pc} = 1004.83$ [J/kg.K]	$\gamma_c = 1.4$	$T_0 = 216.67$ [K]	$\pi_{dmax} = 0.98$
$e_c = 0.90$	$e_f = 0.89$	$e_t = 0.91$	$\pi_n = 0.98$
$\gamma_t = 1.3$	$\eta_b = 0.995$	$\pi_b = 0.96$	$T_4 = 1777.78$ [K]
$\gamma_{AB} = 1.3$	$\eta_{AB} = 0.95$	$\pi_{AB} = 0.96$	$T_{t7} = 2000$ [K]
$M_6 = 0.4$	$\eta_m = 0.99$	$\frac{P_9}{P_0} = 1$	$\pi_f = 2 \rightarrow 5$
$\pi_c = 24$	$\pi_{Mmax} = 0.98$	$c_{pt} = 1235.11$ [J/kg.K]	$c_{pAB} = 1235.11$ [J/kg.K]
$h_{PR} = 42800$ [kJ/kg]	$M_0 = 0.9, 2.0$		

Table 1: Turbofan engine input data

What to plot?

- S vs $F/\dot{m}_0$ for $\pi_f = 2 \rightarrow 5$ with afterburner ON and OFF for both two Mach numbers.
- α vs π_f and τ_t vs π_f (on the same plot) for both two Mach numbers.
- η_{th} vs π_f with afterburner ON and OFF for both two Mach numbers.
- η_p vs π_f with afterburner ON and OFF for both two Mach numbers.
- η_0 vs π_f with afterburner ON and OFF for both two Mach numbers.
- Compare all plots above against the results from PARA software. Data from PARA plots can be extracted by using PlotDigitizer or any other software of your choice.

1.2 Solution Steps

In this study, to analyze the performance of a mixed-flow turbofan engine with and without afterburning, the following solution steps were followed:

1. **Manual Solution:** Initially, manual calculations were performed to establish the fundamental parameters of the engine cycle analysis. This analysis includes calculating thermodynamic ratios, efficiencies, and performance parameters for each component of the engine.
2. **Development of the Matlab Code:** Based on the equations and analyses obtained from the manual solution, a universal cycle analysis code was developed in Matlab. This code allows users to modify engine input parameters and analyze engine performance with ease.

3. **Comparison of Results:** The results obtained from Matlab were compared with results from the PARA software. This comparison aimed to verify the accuracy of the obtained data and enhance the model's reliability. Results from the PARA plots were extracted using tools like PlotDigitizer.

4. **App Development:** In parallel with the Matlab script, a user-friendly application was developed. This application is designed to provide users with a more practical experience by visualizing the cycle analysis. The application is built to allow users to adjust parameters and view results in graphical form through an intuitive interface that integrates the Matlab code.

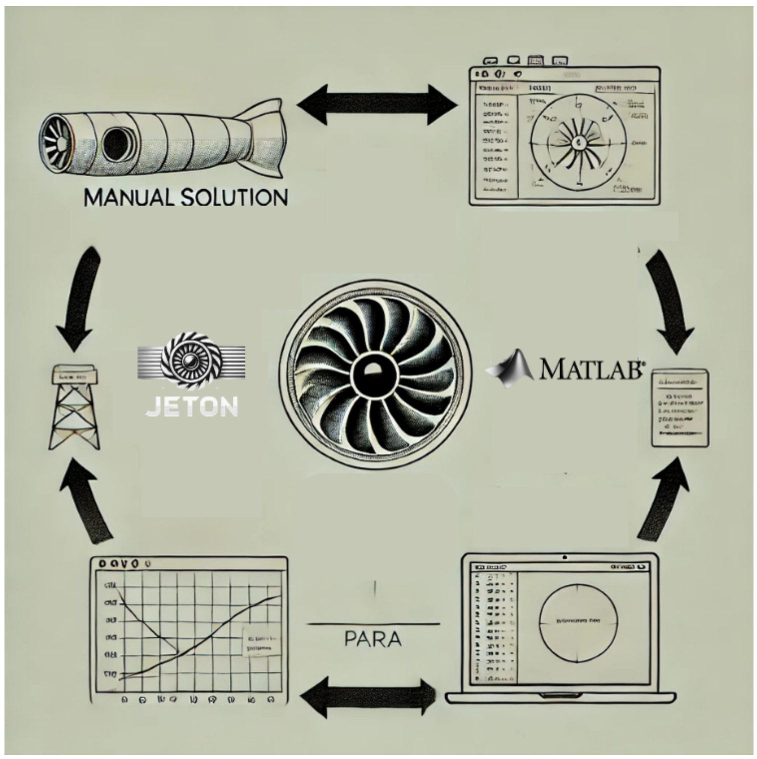

Figure 1: Solution Steps.

In this project, cycle analysis and performance parameters of a mixed-flow turbofan engine were examined in detail, with the objective of improving the efficiency and thrust stability of modern turbofan engines at high speeds. Mixed-flow turbofan engines are particularly prominent in both military and civil aviation, especially for their efficient performance at supersonic speeds. Compared to separate-flow turbofan engines, mixed-flow engines merge bypass air and combustion gases, thus providing higher thrust at high speeds. This characteristic makes them highly suitable for supersonic jets used in military applications.

The project aims to analyze the performance of a mixed-flow turbofan engine under various speeds, fan pressure ratios, and afterburner conditions. The methodology involves performing cycle analysis using Matlab, supported by a user-friendly application (app) that enables users to adjust input parameters and visualize the results dynamically. Over the course of this project, key performance metrics such as thrust, specific fuel consumption, thermal efficiency, and overall efficiency were calculated and assessed.

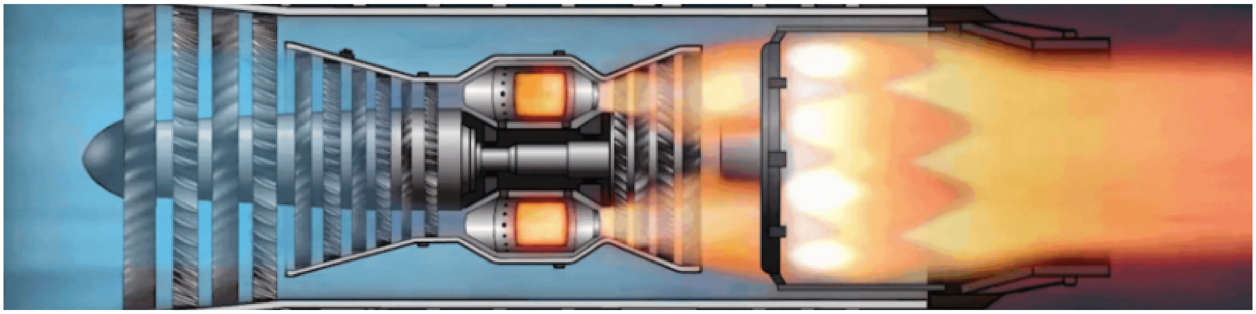

Figure 2: Turbofan with Afterburning

1.3 App Introduction

This section introduces a user interface developed in Matlab, designed to present engine cycle analysis results in an intuitive and user-friendly manner. The app enables users to easily adjust engine input parameters and visualize outputs through various plots. The development of the app was carried out in parallel with the Matlab code for cycle analysis, with a focus on **flexibility and user experience. This approach allows users to experiment with Mach number, fan pressure ratio (π_f), combustion temperatures (T_{t4}, T_{t7}), and afterburner status to assess engine performance dynamically.

Figure 3: JetON App

1.4 Methodology

This section provides a comprehensive explanation of the theoretical principles and computational methods used for engine cycle analysis. The engine cycle calculations cover the ram effect, diffuser, compressor, combustion chamber, turbine, and afterburner components, each of which was analyzed in terms of thermodynamic properties. For each component, temperature ratios (τ), pressure ratios (π), and efficiency values (η) were calculated to analyze the energy transformations throughout the cycle. The following details explain the analysis of each component:

1.4.1 Ram Effect

The ram effect was calculated based on the freestream Mach number, with ram efficiency and pressure ratios (π_r) and temperature ratios (τ_r) derived accordingly.

1.4.2 Diffuser

The diffuser's pressure increase was calculated to convey high-speed flow to the compressor. Diffuser efficiency (η_d) and maximum pressure ratio (π_d) were used, and temperature and pressure ratios were calculated assuming adiabatic processes.

1.4.3 Compressor

Essential to the engine's efficiency, the compressor was analyzed based on fan pressure ratio (π_c) and efficiency (η_c), and the output temperature and pressure ratios were determined.

1.4.4 Combustion Chamber

The increase in temperature in the combustion chamber was calculated based on burner pressure ratio (π_b) and burner efficiency (η_b). The fuel-air ratio and burner efficiency were considered essential parameters.

1.4.5 Turbine

Turbine performance was based on turbine efficiency (η_t) and temperature ratios. Turbine pressure ratio (π_t) and temperature ratio (τ_t) were calculated based on the energy requirements to balance the compressor.

1.4.6 Afterburner

The afterburner provides additional thrust by burning remaining oxygen in the flow with extra fuel. Pressure ratio (π_{AB}), temperature ratio (τ_{AB}), and afterburner efficiency (η_{AB}) were used to determine the temperature and pressure increases in afterburner mode.

A Matlab script was developed to compute temperature, pressure, and efficiency values throughout the cycle and determine engine performance parameters. The script was designed to be modular, calculating each component's performance independently, and allowing dynamic updates for each input.

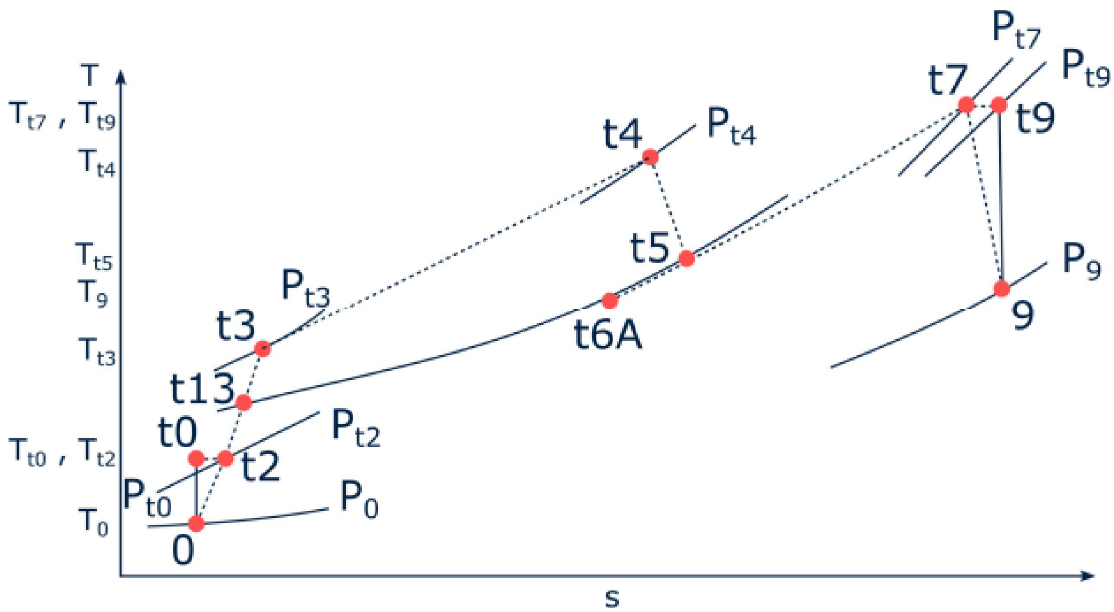

Figure 4: Mixed Flow Turbofan with Afterburner T-s Diagram.

1.5 Results and Discussion

In the Results and Discussion section, the results obtained from the Matlab cycle analysis are presented and compared with literature values and PARA software outputs. Key performance parameters include specific thrust, specific fuel consumption (SFC), thermal efficiency (η_{th}), propulsive efficiency (η_p), and overall efficiency (η_0). The variations of these values with fan pressure ratios (π_f) and Mach numbers are analyzed for both afterburner-on and afterburner-off conditions.

Results from the Matlab model were validated against those from the PARA software to evaluate the accuracy and reliability of the model. Comparisons were made between Matlab and PARA results using extracted data from PARA plots through tools like PlotDigitizer. These comparisons help ensure that the Matlab model provides an accurate representation of mixed-flow turbofan performance under various conditions.

1.6 Appendix

The Appendix section includes the complete Matlab script used in this project, which provides the backbone of the cycle analysis and app functionalities. The script is organized modularly, with independent functions for each calculation step, enabling parameter adjustments and ease of analysis. The script was developed simultaneously with the app, allowing a cohesive integration between the back-end calculations and user interface. This design allows users to conduct cycle analysis dynamically by simply adjusting parameters in the app.

The app interface was designed to integrate each calculation module, allowing users with little to no programming experience to perform engine performance analysis. After entering input parameters, the app enables users to obtain and visualize results with a single click.

—

This structure provides readers with a clear understanding of each project stage and the analyses conducted in each phase. The figures included provide additional support for each section.

2 JetON Application

JetON is a MATLAB-based simulation application designed to evaluate the performance of mixed-flow turbofan engines in both afterburning and non-afterburning configurations across various Mach numbers and pressure ratios. The application provides a user-friendly interface that allows for flexible and comprehensive analysis based on the input parameters from the user. JetON is specifically tailored to analyze key thermodynamic parameters and performance metrics of mixed-flow turbofan engines.

The application is structured into three main sections:

2.1 Introduction Page

The introduction page offers a brief overview of JetON, where the user can see the main functionalities of the application. By clicking the **"Click Here to Ignite Engine"** button, the user can navigate to the main input panel, initiating the analysis process. This page serves as the starting point, providing basic information on how to proceed within the application.

2.2 Input Panel

The input panel contains various sections where users can enter specific parameters for engine analysis. Each parameter set corresponds to a different engine component, providing a systematic way for users to input values:

- **Fan Inputs**: Parameters such as fan pressure ratio (π_f) and fan isentropic efficiency (η_f), which contribute to the compression process.

- **Compressor Inputs**: Parameters including compressor pressure ratio (π_c), isentropic efficiency (η_c), specific heat capacity (c_{pc}), and γ_c, influencing compressor performance.

- **Turbine Inputs**: Values such as turbine exit temperature (T_{t4}), isentropic efficiency (η_t), specific heat capacity (c_{pt}), and γ_t.

- **Afterburner Inputs**: Parameters like afterburner pressure ratio (π_{AB}), combustion efficiency (η_{AB}), specific heat capacity (c_{pAB}), and exit temperature (T_{t7}).

- **Diffuser/Nozzle Inputs**: Values for diffuser and nozzle pressure ratios (π_d and π_n) and isentropic efficiency.

Once all parameters are entered, the user clicks the **"IGNITE"** button to initiate the computation process. Pressing this button triggers the MATLAB-based algorithm that simulates the engine's thermodynamic cycle. The analysis accounts for each component's contribution, calculating parameters such as thrust (F), specific fuel consumption (S), thermal efficiency (η_{th}), propulsive efficiency (η_p), and overall efficiency (η_0).

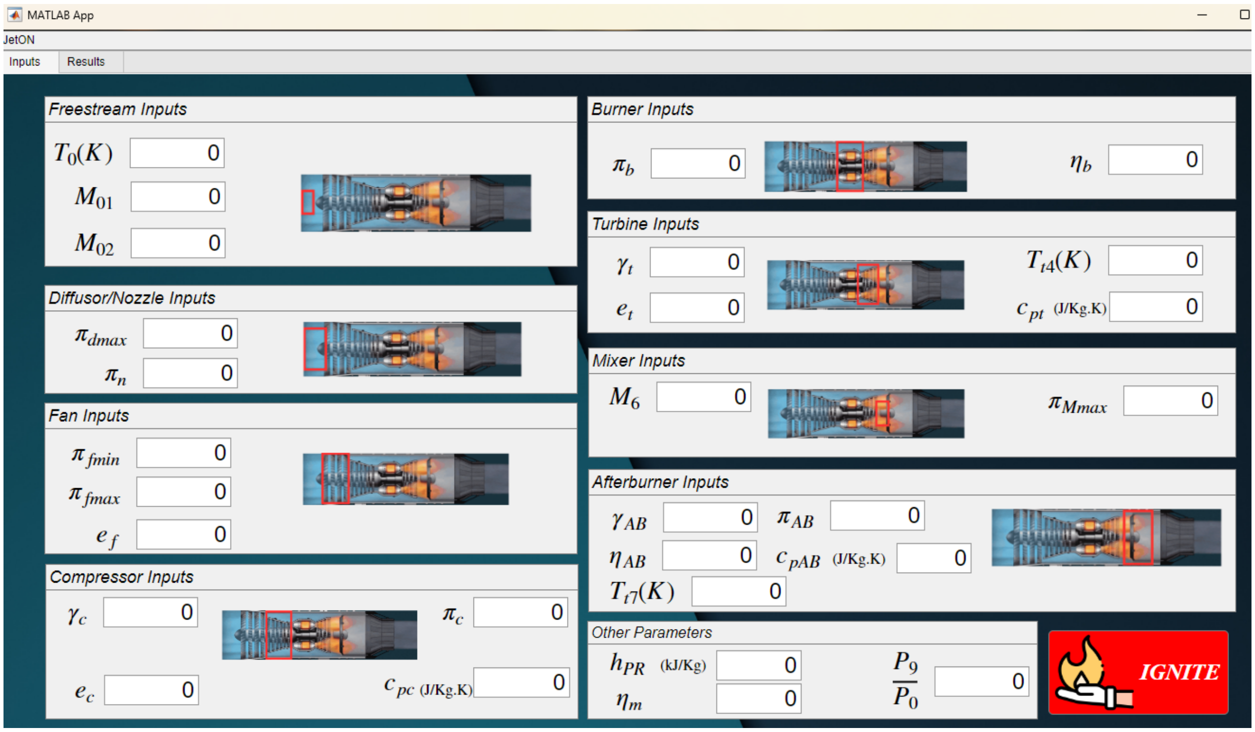

Figure 5: JetON App Input Page

2.3 Results Panel

In the results tab, JetON presents the calculated outcomes based on the user-defined parameters in a graphical format. The result plots include performance analyses across various Mach numbers and fan pressure ratios, covering:

- **Specific Thrust** ($F/\dot{m}_0$) **vs Specific Fuel Consumption** (S): Shows the relationship between thrust and specific fuel consumption for afterburner on and off states for both Mach numbers.

- **Thermal Efficiency** (η_{th}) **vs Fan Pressure Ratio** (π_f): Displays the variation of thermal efficiency with fan pressure ratio.

- **Propulsive Efficiency** (η_p) **vs Fan Pressure Ratio** (π_f): Presents the propulsive efficiency as a function of fan pressure ratio.

- **Overall Efficiency** (η_0) **vs Fan Pressure Ratio** (π_f): Summarizes the overall efficiency parameters.

These result plots are generated using MATLAB's plotting functions and can be viewed by clicking the "Plot" buttons. Additionally, the application provides data for comparison with the PARA software, allowing users to validate the calculated results against other reference tools.

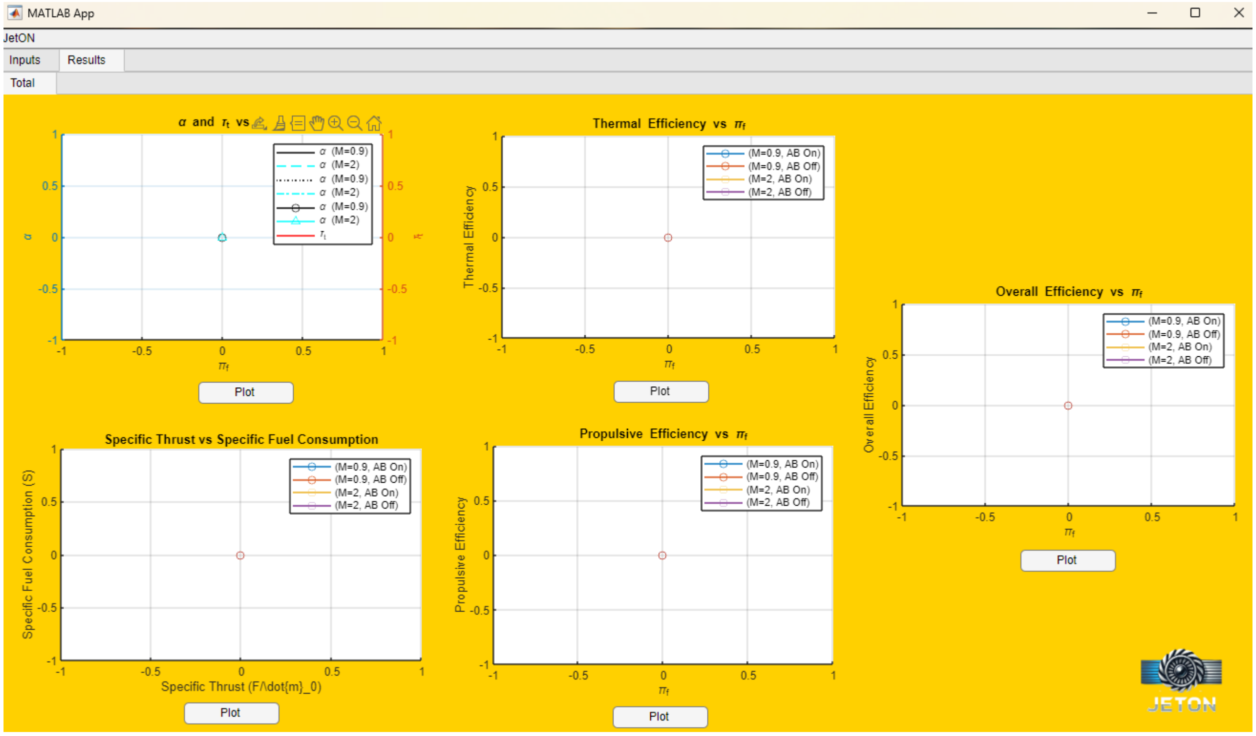

Figure 6: JetON App Results Page

2.4 Application Workflow

JetON operates by running a MATLAB algorithm that processes the user-provided engine parameters, simulates the complete cycle for the engine, and computes performance metrics.

In the background, the MATLAB code follows these steps:

1. **Input Data Processing**: User-entered values are collected to form the foundational inputs for the algorithm.

2. **Engine Cycle Calculations**: For each component (fan, compressor, turbine, afterburner, diffuser/nozzle), the algorithm calculates temperature and pressure ratios and efficiency values to simulate the engine's cycle.

3. **Performance Metric Calculations**: Parameters such as specific thrust, specific fuel consumption, and thermal efficiency are computed.

4. **Visualization of Results**: The analysis results are graphically presented to the user through MATLAB's plotting functions.

JetON enables engineers and researchers to perform quick and effective analyses by allowing users to easily input and adjust the parameters that define engine performance.

3 Methodology

The turbofan mixed exhaust engine is considered as a *real engine*. In a real turbofan mixed exhaust engine, *total pressure* losses occur due to *wall friction* in the inlet and *shock waves* caused by supersonic conditions. In ideal engine processes, the efficiencies of engine components are neglected. However, in this study, the efficiencies of engine components are included, and it is considered that these efficiencies cannot be 100% according to the Second Law of Thermodynamics [2].

Considering these evaluations, hand calculations were performed for $M_0 = 2$ and $\pi_f = 3$ using the given input values in the problem. Based on the obtained results, a MATLAB code was prepared, and verifications were conducted between the hand calculations and the MATLAB results. Firstly, the necessary formulas for hand calculations are presented sequentially [5] , and the calculations are performed according to the order of the equations, which are added to the methodology section. The *fuel/air ratio* and *afterburner fuel/air ratio* values were obtained through iterative methods.

$$R_c = \frac{\gamma_c - 1}{\gamma_c} \cdot cp_c \tag{1}$$

$$R_t = \frac{\gamma_t - 1}{\gamma_t} \cdot cp_t \tag{2}$$

$$R_{AB} = \frac{\gamma_{AB} - 1}{\gamma_{AB}} \cdot cp_{AB} \tag{3}$$

$$a_0 = \sqrt{g_c \cdot \gamma_c \cdot R_c \cdot T_0} \tag{4}$$

$$V_0 = M_0 \cdot a_0 \tag{5}$$

$$\tau_r = 1 + \frac{\gamma_c - 1}{2} \cdot M_0^2 \tag{6}$$

$$\pi_r = \tau_r^{\frac{\gamma_c}{\gamma_c - 1}} \tag{7}$$

$$\eta_r = \begin{cases} 1 & \text{if } M_0 \leq 1 \\ 1 - 0.075 \cdot (M_0 - 1)^{1.35} & \text{if } 1 < M_0 < 5 \\ \frac{800}{M_0^4 + 935} & \text{if } M_0 \geq 5 \end{cases} \tag{8}$$

$$\pi_d = \pi_{d\text{max}} \cdot \eta_r \tag{9}$$

$$\tau_\lambda = \frac{cp_t}{cp_c} \cdot \frac{T_{t4}}{T_0} \tag{10}$$

$$\tau_{\lambda_{AB}} = \frac{cp_{AB}}{cp_c} \cdot \frac{T_{t7}}{T_0} \tag{11}$$

$$\tau_c = \pi_c^{\frac{\gamma_c - 1}{\gamma_c \cdot e_c}} \tag{12}$$

$$\eta_c = \frac{\pi_c^{\frac{\gamma_c - 1}{\gamma_c}} - 1}{\tau_c - 1} \tag{13}$$

$$f = \frac{h_{t4} - h_{t3}}{\eta_b h_{PR} - h_{t3}} \tag{14}$$

$$T_{t3} = T_0 \cdot \tau_d \cdot \tau_r \cdot \tau_c \tag{15}$$

$$\tau_f = \pi_f^{\frac{\gamma_c - 1}{\gamma_c \cdot e_f}} \tag{16}$$

$$\alpha = \frac{\eta_m (1+f)(\tau_\lambda/\tau_r)(1 - (\pi_f/(\pi_c \pi_b))^{(\gamma_t - 1)e_t/\gamma_t}) - (\tau_c - 1)}{\tau_f - 1} \tag{17}$$

$$\tau_t = 1 - \frac{1}{\eta_m \cdot (1+f)} \cdot \frac{\tau_r}{\tau_\lambda} \cdot (\tau_c - 1 + \alpha \cdot (\tau_f - 1)) \tag{18}$$

$$\pi_t = \tau_t^{\frac{\gamma_t}{(\gamma_t - 1) \cdot e_t}} \tag{19}$$

$$\frac{P_{t16}}{P_{t6}} = \frac{\pi_f}{\pi_c \pi_b \pi_t} \tag{20}$$

$$M_{16} = \sqrt{\frac{2}{\gamma_c - 1} \left(\left[\frac{P_{t16}}{P_{t6}} \left(1 + \frac{\gamma_t - 1}{2} M_6^2 \right)^{\gamma_t (\gamma_t - 1)} \right]^{(\gamma_c - 1)/\gamma_c} - 1 \right)} \tag{21}$$

$$\alpha' = \frac{\alpha}{1+f} \tag{22}$$

$$c_{p6A} = \frac{c_{pt} + \alpha' c_{pc}}{1 + \alpha'} \tag{23}$$

$$R_{6A} = \frac{R_t + \alpha' R_c}{1 + \alpha'} \tag{24}$$

$$\gamma_{6A} = \frac{c_{p6A}}{c_{p6A} - R_{6A}} \tag{25}$$

$$\frac{T_{t16}}{T_{t6}} = \frac{T_0 \tau_r \tau_f}{T_{t4} \tau_t} \tag{26}$$

$$\tau_M = \frac{c_{pt}}{c_{p6A}} \frac{1 + \alpha' (c_{pc}/c_{pt})(T_{t16}/T_{t6})}{1 + \alpha'} \tag{27}$$

$$\Phi(M_6, \gamma_6) = \frac{M_6^2 (1 + [(\gamma_t - 1)/2] M_6^2)}{(1 + \gamma_t M_6^2)^2} \tag{28}$$

$$\Phi(M_{16}, \gamma_{16}) = \frac{M_{16}^2 (1 + [(\gamma_c - 1)/2] M_{16}^2)}{(1 + \gamma_c M_{16}^2)^2} \tag{29}$$

$$\Phi = \left[\frac{1 + \alpha'}{\frac{1}{\sqrt{\Phi(M_6, \gamma_6)}} + \alpha' \sqrt{\frac{R_c \gamma_t T_{t16}/T_{t6}}{R_t \gamma_c \Phi(M_{16}, \gamma_{16})}}} \right]^2 \frac{R_{6A} \gamma_t}{R_t \gamma_{6A}} \tau_M \tag{30}$$

$$M_{6A} = \sqrt{\frac{2\Phi}{1 - 2\gamma_{6A}\Phi + \sqrt{1 - 2(\gamma_{6A}+1)\Phi}}} \tag{31}$$

$$\frac{A_{16}}{A_6} = \frac{\alpha' \sqrt{T_{t16}/T_{t6}}}{\frac{M_{16}}{M_6}\sqrt{\frac{\gamma_c R_t}{\gamma_t R_c}\frac{1+[(\gamma_c-1)/2]M_{16}^2}{1+[(\gamma_t-1)/2]M_6^2}}} \tag{32}$$

$$\text{MFP}_{6A} = \frac{M_{6A} \cdot \sqrt{\frac{\gamma_{6A}}{R_{6A}}}}{\left(1 + \frac{\gamma_{6A}-1}{2}M_{6A}^2\right)^{\frac{\gamma_{6A}+1}{2(\gamma_{6A}-1)}}} \tag{33}$$

$$\pi_{Mideal} = \frac{(1+\alpha')\sqrt{\tau_M}}{1 + A_{16}/A_6}\frac{MFP(M_6, \gamma_t, R_t)}{MFP(M_{6A}, \gamma_{6A}, R_{6A})} \tag{34}$$

$$\pi_M = \pi_{Mmax}\pi_{Mideal} \tag{35}$$

Afterburner Off

$$cp_9 = cp_{6A} \tag{36}$$

$$R_9 = R_{6A} \tag{37}$$

$$\gamma_9 = \gamma_{6A} \tag{38}$$

$$\pi_{AB} = 0.96 \tag{39}$$

$$f_{AB} = 0 \tag{40}$$

$$\frac{P_{t9}}{P_9} = P_{0/P9} \cdot \pi_r \cdot \pi_d \cdot \pi_c \cdot \pi_b \cdot \pi_t \cdot \pi_M \cdot \pi_{AB} \cdot \pi_n \tag{41}$$

$$\frac{T_9}{T_0} = \frac{T_{t4} \cdot \tau_t \cdot \tau_M}{T_0} \Big/ \left(\frac{P_{t9}}{P_9}\right)^{\frac{\gamma_9 - 1}{\gamma_9}} \tag{42}$$

Afterburner On

$$c_{p_9} = c_{p_{AB}} \tag{43}$$

$$R_9 = R_{AB} \tag{44}$$

$$\gamma_9 = \gamma_{AB} \tag{45}$$

$$\pi_{AB} = 0.96 \tag{46}$$

$$f_{AB} = \left(1 + \frac{f}{1+\alpha}\right)\frac{h_{t7} - h_{t6A}}{\eta_{AB}h_{PR} - h_{t7}} \tag{47}$$

$$\frac{P_{t9}}{P_9} = P_{0/P9} \cdot \pi_r \cdot \pi_d \cdot \pi_c \cdot \pi_b \cdot \pi_t \cdot \pi_M \cdot \pi_{AB} \cdot \pi_n \tag{48}$$

$$\frac{T_9}{T_0} = \frac{T_{t7}}{T_0} \Big/ \left(\frac{P_{t9}}{P_9}\right)^{\frac{\gamma_9 - 1}{\gamma_9}} \tag{49}$$

Exit Parameters

$$M_9 = \sqrt{\frac{\left(\frac{P_{t9}}{P_9}\right)^{\frac{\gamma_9-1}{\gamma_9}} - 1}{\frac{2}{\gamma_9-1}}} \tag{50}$$

$$\frac{V_9}{a_0} = M_9 \cdot \sqrt{\frac{\gamma_9 \cdot R_9}{\gamma_c \cdot R_c} \cdot \frac{T_9}{T_0}} \tag{51}$$

$$f_0 = \frac{f}{1+\alpha} + f_{AB} \tag{52}$$

$$\frac{F}{\dot{m}_0} = \frac{a_0}{g_c}\left((1+f_0)\cdot\frac{V_9}{a_0} - M_0 + (1+f_0)\cdot\frac{R_9}{R_c}\cdot\frac{T_9}{T_0}\cdot\frac{1-P_0/P_9}{\frac{V_9}{a_0}\cdot\gamma_c}\right) \tag{53}$$

$$S = \frac{f_0}{\frac{F}{\dot{m}_0}} \tag{54}$$

$$\eta_P = \frac{2\cdot g_c \cdot V_0 \cdot \frac{F}{\dot{m}_0}}{a_0^2\left[(1+f_0)\cdot(\frac{V_9}{a_0})^2 - M_0^2\right]} \tag{55}$$

$$\eta_T = \frac{a_0^2\left[(1+f_0)\cdot(\frac{V_9}{a_0})^2 - M_0^2\right]}{2\cdot g_c \cdot f_0 \cdot h_{pr}\cdot} \tag{56}$$

$$\eta_0 = \eta_T \cdot \eta_P \tag{57}$$

Calculation

$$R_c = \frac{1.4-1}{1.4}\cdot 1004.83 = 287.0943$$
$$R_t = \frac{1.3-1}{1.3}\cdot 1235.1 = 285.0254$$
$$R_{AB} = \frac{1.3-1}{1.3}\cdot 1235.1 = 285.0254$$

$$V_0 = 2\cdot 295.102 = 590.208$$
$$\pi_f = 3$$

$$\tau_r = 1 + \frac{1.4-1}{2}\cdot 2^2 = 1.8$$
$$\pi_r = 1.8^{\frac{1.4}{1.4-1}} = 7.8244$$

Given values of M_0 and γ_c, the values of τ_r and π_r have been calculated

$$\eta_r = 1 - 0.075\cdot(2-1)^{1.35} = 0.925$$

Since $M_0 > 1$, the ram recovery (η_r) is calculated using the second formula.

$$\tau_d = 1$$

$$\pi_d = 0.98 \cdot 0.925 = 0.9065$$

The input value π_{di_max} is used along with the calculated η_r to determine π_d.

$$\tau_\lambda = \frac{cp_t}{cp_c} \cdot \frac{T_{t4}}{T_0} = 10.085$$

The value of τ_λ is calculated using the input values c_{pt}, c_{pc}, T_{t4}, and T_0.

$$\tau_{\lambda_{AB}} = \frac{1235.1}{1004.8} \cdot \frac{2000}{216.67} = 11.346$$

The value of $\tau_{\lambda AB}$ is calculated using the input values

$$\tau_c = 3^{\frac{1.4-1}{1.4 \cdot 0.90}} = 2.743$$

The value of τ_c is calculated using the values π_c, γ_c, and e_c.

$$\eta_c = \frac{24^{\frac{1.4-1}{1.4}} - 1}{2.743 - 1} = 0.849$$

$$T_{t3} = 216.67 \cdot 1 \cdot 1.8 \cdot 2.743 = 1069.6$$

$$\tau_f = 3^{\frac{1.4-1}{1.4 \cdot 0.89}} = 1.4229$$

$$\eta_f = \frac{3^{\frac{1.4-1}{1.4}} - 1}{1.4229 - 1} = 0.8788$$

The fuel/air ratio (f) in the main burner needs to be calculated iteratively. The iteration should continue until the error between the reference input f and the iterated f is less than 0.0001. To start the iteration, the value of h_{t3} must be determined. It is calculated using $T_{t3} = 1069.6$K, $f = 0$, and $\tau_d = 1$ (assuming the diffuser is adiabatic).

Iteration 1

With $f = f_{max}/2$ and $T_{t4} = 1777.78$K, the value of h_{t4} is calculated.

$$h_{t4} = 2063 + \frac{(1777.78 - 1770) \cdot (2076.71 - 2063)}{1780 - 1770}$$

Using the values h_{t3} and h_{t4}, f and the error are recalculated. Since the error is greater than 0.0001, a second iteration is required.

Iteration 2

With $f = 0.0234$ and $T_{t4} = 1777.78$K, the new value of h_{t4} is calculated.

For this new h_{t4}, f and the error are recalculated. Since the error is still greater than 0.0001, a third iteration is required.

Iteration 3

With $f = 0.02268$ and $T_{t4} = 1777.78\text{K}$, the next h_{t4} value is calculated.

The error is now less than 0.0001, so $f = 0.0226$ is accepted.

$$\alpha = \frac{0.94(1+0.0226)\left(\frac{10.085}{1.8}\right)\left\{1-\left[\frac{3}{24\cdot 0.96}\right]^{\frac{(1.3-1)0.3}{1.3}}-(2.743-1)\right\}}{1.423-1} = 0.5506$$

MATLAB code that we made found this value as: 0.5547

Using the given values η_m, π_f, π_c, π_b, γ_t, and e_t, along with the calculated values of f, τ_λ, τ_r, τ_c, and τ_f, the bypass ratio is determined.

$$\tau_t = 1 - \frac{1}{0.99\cdot(1+0.0226)}\cdot\frac{1.8}{10.085}\cdot(2.743-1+0.5506\cdot(3-1)) = 0.6516$$

MATLAB code that we made found this value as: 0.6517

$$\pi_t = 0.6516^{\frac{1.3}{(1.3-1)\cdot 0.91}} = 0.18$$

The value τ_t is calculated using the given and calculated values, and π_t is then determined.

$$\eta_t = \frac{1-0.6516}{1-0.6516^{\frac{1}{0.91}}} = 0.9280$$

$$\frac{P_{t16}}{P_6} = \frac{3}{24\cdot 0.96\cdot 0.13} = 1.00102$$

The value P_{t16}/P_{t6} is calculated for use with M_{16}.

$$M_{16} = \sqrt{\frac{2}{1.4-1}\left\{\left[1.00102\left(1+\frac{1.3-1}{2}0.4^2\right)^{\frac{1.3(1.3-1)}{(1.3-1)1.4}}\right]-1\right\}} = 0.388$$

$$\alpha' = \frac{0.5506}{1+0.0226} = 0.5384$$

To use in further calculations, the value of α' is determined.

$$\frac{T_{t16}}{T_{t6}} = \frac{216.67\cdot 1.8\cdot 1.423}{1777.78\cdot 0.6516} = 0.479$$

To calculate the value of τ_m, the $\frac{T_{t16}}{T_{t6}}$ ratio has been calculated.

$$\tau_M = \frac{\frac{1235.11}{1154.52}}{\left(1+0.5384\left(\frac{1004.83}{1235.11}\right)(0.479)\right)}1+0.5384 = 0.8413$$

The value τ_m is calculated bey using T_{t16}/T_{t6}

$$\Phi(M_{16},\gamma_{16}) = (0.388)^2\,\frac{1+\left(\frac{0.4}{2}\right)\cdot(0.388)}{\left(1+((1.4)\cdot(0.388)^2)\right)^2} = 0.1058$$

Likewise

$$\Phi(M_6, \gamma_6) = 0.1123$$

And

$$\Phi = \frac{1 + 0.5384}{\frac{1}{\sqrt{0.1123}} + 0.5384 \frac{(287.0)(1.3)(0.4938)}{(285.025)(1.4)(0.1058)}} \cdot \frac{(285.75)(1.3)(0.8413)}{(285.025)(1.83)} = 0.1165$$

$$M_{6A} = \sqrt{\frac{20.1165}{1 - 2 \cdot 1.33 \cdot 0.1165 + \sqrt{1 - 2(1.33 + 1)0.1165}}} = 0.413$$

$$\frac{A_{16}}{A_6} = \frac{A_{16}}{A_6} = \frac{(0.5276)\sqrt{0.479}}{\frac{0.388}{0.4}\sqrt{\frac{(2.4)(285.025)}{(1.3)(232.091)}} \cdot \frac{1+\left(\frac{1.4-1}{2}\right)(0.388)^2}{1+\left(\frac{1.3-1}{2}\right)(0.4)^2}} = 0.3704$$

$$MFP(M_6, \gamma_t, R_t) = \frac{(0.4) \cdot \sqrt{\frac{(1.3)(1)}{(285.025)}}}{1 + \left[\frac{(1.3-1)}{2}(0.4)^2\right]^{\frac{(1.3+1)}{2(1.3-1)}}} = 0.02467$$

Likewise

$$MFP(M_{6A}, \gamma_{6A}, R_{6A}) = 0.0255$$

$$\pi_{Mideal} = \frac{(1 + 0.5384)\sqrt{0.8413}}{1 + 0.3704} \frac{(0.02467)}{(0.0255)} = 0.996$$

$$\pi_M = (0.98)(0.996) = 0.976$$

$$\frac{P_{t9}}{P_9} = 1 \cdot 7.8244 \cdot 0.9065 \cdot 24 \cdot 0.96 \cdot 0.13 \cdot 0.976 \cdot 0.96 \cdot 0.98 = 19.51$$

Afterburner Off

Using the calculated α', necessary values for c_{p6a}, R_c, R_t, R_{6A}, and γ_{6A} are calculated.

$$cp_{6A} = \frac{1235.11 + 0.5384' 1004.8}{1 + 0.5384} = 1154.52$$

$$R_9 = R_{6A} = 285.75$$

$$\gamma_9 = \gamma_{6A} = 1.33$$

$$\pi_{AB} = 0.96$$

$$f_{AB} = 0$$

$$\frac{T_9}{T_0} = \frac{1777.78 \cdot 0.6516 \cdot 0.8413}{216.67} \Big/ (19.51)^{\frac{1.33-1}{1.33}} = 2.152$$

$$M_9 = \sqrt{\frac{2}{1.33 - 1}\left((19.51)^{\frac{1.33-1}{1.33}} - 1\right)} = 2.57$$

$$\frac{V_9}{a_0} = 2.57 \cdot \sqrt{\frac{1.33 \cdot 285.75 \cdot 2.152}{287.09 \cdot 1.4}} = 3.666$$

$$a_0 = \sqrt{1 \cdot 1.4 \cdot 287.09 \cdot 216.67} = 295.102$$

$$f_0 = \frac{0.0226}{1 + 0.5506} + 0 = 0.014575$$

$$\frac{F}{\dot{m}_0} = \frac{295.102}{1}\left((1 + 0.014575) \cdot 3.666 - 2\right) = 507.408 \quad (Ns/kg)$$

MATLAB code that we made found this value as: 513.1515 (Ns/kg)

$$S = \frac{0.014575}{507.408} = 2.87 \cdot 10^{(-5)} \quad (kg/Ns)$$

MATLAB code that we made found this value as: $2.946 \cdot 10^{-5}(kg/Ns)$

$$\eta_P = \frac{2 \cdot 1 \cdot 2 \cdot 507.408}{295.102\left((1 + 0.014575) \cdot (3.666)^2 - 2^2\right)} = 0.714$$

MATLAB code that we made found this value as: 0.7118

$$\eta_T = \frac{295.102^2\left((1 + 0.014575) \cdot (3.666)^2 - 2^2\right)}{2 \cdot 1 \cdot 0.014575 \cdot 42800 \cdot 10^3 \cdot 1000} = 0.672$$

MATLAB code that we made found this value as: 0.6576

$$\eta_0 = 0.672 \cdot 0.714 = 0.480$$

MATLAB code that we made found this value as: 0.4681

Afterburner On

$$c_{p_{AB}} = c_{p_{AB}} = 1235.11$$

$$R_9 = R_{AB} = 285.025$$

$$\gamma_9 = \gamma_{AB} = 1.3$$

$$\pi_{AB} = 0.96$$

$$T_{t6A} = (1777.78)(0.6516)(0.8413) = 974.56$$

$$\frac{T_9}{T_0} = \frac{2000}{216.67}/(19.51)^{\frac{1.3-1}{1.3}} = 4.65$$

$$f_{AB} = \left(1 + \frac{f}{1+\alpha}\right)\frac{h_{t7} - h_{t6A}}{\eta_{AB} h_{PR} - h_{t7}}$$

(f_{AB})in the afterburner needs to be calculated iteratively.

To start the iteration, the h_{t6A} value must first be determined. T_{t6A} is obtained using the given T_{t4} and the calculated τ_t and τ_m values.

For $T_{t6A} = 974.56\ K$ and $f = 0.0226$, the corresponding h_{t6A} value is calculated as follows:

$$h_{t6Ax} = 1030.83 + \frac{(974.56 - 920) \cdot (1042.51 - 1030.83)}{980 - 920} = 1036.16$$

$$h_{t6Ay} = 1049.41 + \frac{(974.56 - 920) \cdot (1061.41 - 1049.41)}{980 - 920} = 1054.88$$

$$h_{t6A} = 10.4245$$

Iteration 1:

$f_{AB} = \frac{f_{\max}}{2}$ and $T_{t4} = 2000\ K$, then calculate the corresponding h_{t7} value.

Using the obtained h_{t6A} and h_{t7} values, calculate f_{AB} and the error.

Since the result of the iteration is greater than 0.0001, a second iteration is required.

Iteration 2:$f_{AB} = 0.0352 and T_{t4} = 2000\ K,$ then calculate the new h_{t7} value.

Using the new h_{t7} value, calculate f_{AB} and the error again.

Since the result of the iteration is still greater than 0.0001, a third iteration is required.

Iteration 3:$f_{AB} = 0.03528 and T_{t4} = 2000\ K,$then calculate the new h_{t7} value.

Using the new h_{t7} value, calculate f_{AB} and the error.

Since the error is now smaller than 0.0001, f_{AB} is taken as 0.035285.

$$M_9 = \sqrt{\frac{(19.51)^{\frac{1.33-1}{1.33}} - 1}{1.3 - 1} \cdot 2} = 2.562$$

$$f_0 = \frac{0.0226}{1 + 0.5506} + 0.035285 = 0.04986$$

$$\frac{F}{\dot{m}_0} = \frac{295.102}{1}((1 + 0.04986) \cdot 5.305 - 2) = 1053.369 \quad (Ns/kg)$$

MATLAB code that we made found this value as: 1050.6 (Ns/kg)

$$S = \frac{0.04986}{1053.369} = 4.73 \cdot 10^{(-5)} \quad (kg/Ns)$$

MATLAB code that we made found this value as: $4.571 \cdot 10^{-5} (kg/Ns)$

$$\eta_P = \frac{2 \cdot 1 \cdot 2 \cdot 1053.369}{295.102\left((1 + 0.04986) \cdot (5.305)^2 - 2^2\right)} = 0.559$$

MATLAB code that we made found this value as: 0.5585

$$\eta_T = \frac{295.102^2\left((1 + 0.04986) \cdot (5.305)^2 - 2^2\right)}{2 \cdot 1 \cdot 0.04986 \cdot 42800 \cdot 10^3} = 0.521$$

MATLAB code that we made found this value as: 0.5402

$$\eta_0 = 0.559 \cdot 0.521 = 0.291$$

MATLAB code that we made found this value as: 0.3017

4 Results and Discussion

In this section, the following performance parameters and their graphs will be examined. Additionally, these graphs will be compared with data extracted from the PARA software and discussed:

- Bypass ratio vs Fan Pressure Ratio and Turbine Temperature Ratio vs Fan Pressure Ratio for both two Mach numbers.
- Specific Fuel Consumption vs Specific Thrust for Fan Pressure Ratio from 2 to 5, with Afterburner ON and OFF for both two Mach numbers.
- Thermal Efficiency vs Fan Pressure Ratio with Afterburner ON and OFF for both two Mach numbers.
- Propulsive Efficiency vs Fan Pressure Ratio with Afterburner ON and OFF for both two Mach numbers.
- Overall Efficiency vs Fan Pressure Ratio with Afterburner ON and OFF for both two Mach numbers.

4.1 Bypass ratio (α), Turbine Temperature Ratio (τ_T) vs Fan Pressure Ratio (π_F)

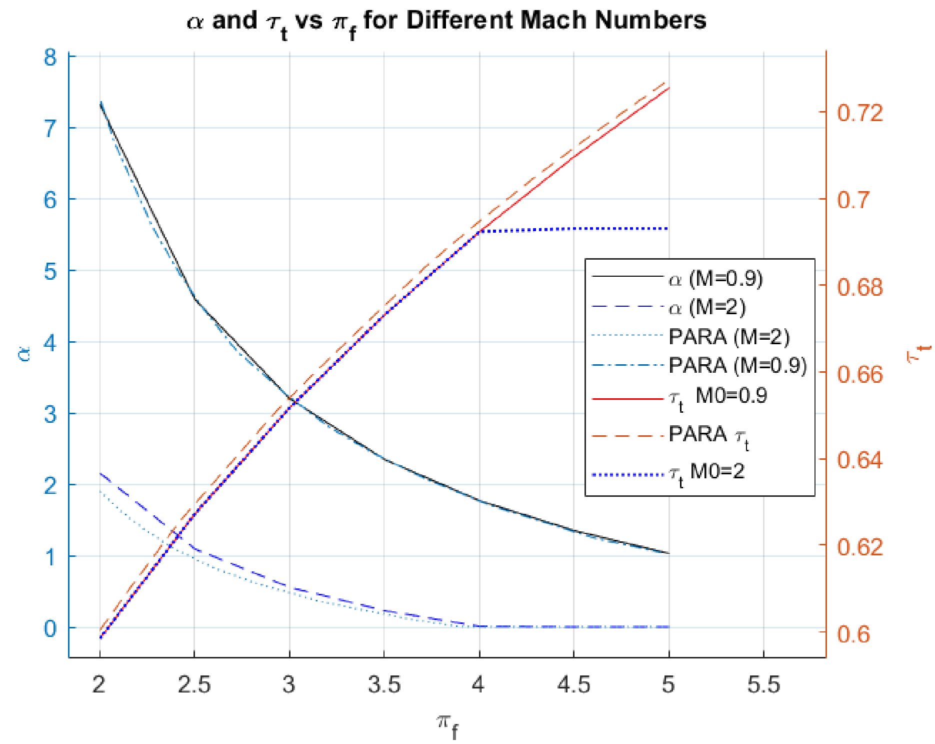

Figure 7: Bypass ratio, Turbine Temperature Ratio versus Fan Pressure Ratio

By looking at figure 7 with increasing fan pressure ratio, bypass ratio for both mach numbers are decreasing. This could be explained by inspecting the bypass ratio formula:

$$\alpha = \frac{\eta_m(1+f)(\tau_\lambda/\tau_r)(1-(\pi_f/(\pi_c\pi_b))^{(\gamma_t-1)e_t/\gamma_t}) - (\tau_c - 1)}{\tau_f - 1}$$

From formula it can be seen that increasing π_f inversely effect the value of the bypass ratio and also increasing π_f means increasing in fan temperature ratio from equation(16) and its also means decreasing in bypass ratio.

In terms of mach number it could be seen that bypass ratio also decreases with increasing mach number. It could be explained by formula again. With the increasing mach number ram pressure ratio is also increasing thus ram temperature ratio is increasing (equation 6) and that leads to reduction in bypass ratio.

Turbine temperature ratio is increasing with π_f and it could be explained by formulation we get with the Kutta condition ($P_{t16} = P_{t6}$) [1] [4] [5] :

$$\pi_f = \pi_c \pi_b \pi_t$$

From expression above, it can be inferred that with increasing π_f we get increasing π_t and therefore increasing τ_t.

Data from PARA is looks like appropriate as tendency but there are few errors anyway. Errors are caused by resolution and rounding of solution. And there is an obvious error for turbine temperature ratio due to negative values occur in the code. These values turned in to zero and that leads to elimination of effect of fan pressure ratio on turbine temperature ratio so values remains constant with increasing π_f for rest.

4.2 Specific Fuel Consumption (S) vs Specific Thrust $(F/\dot{m}_0)$

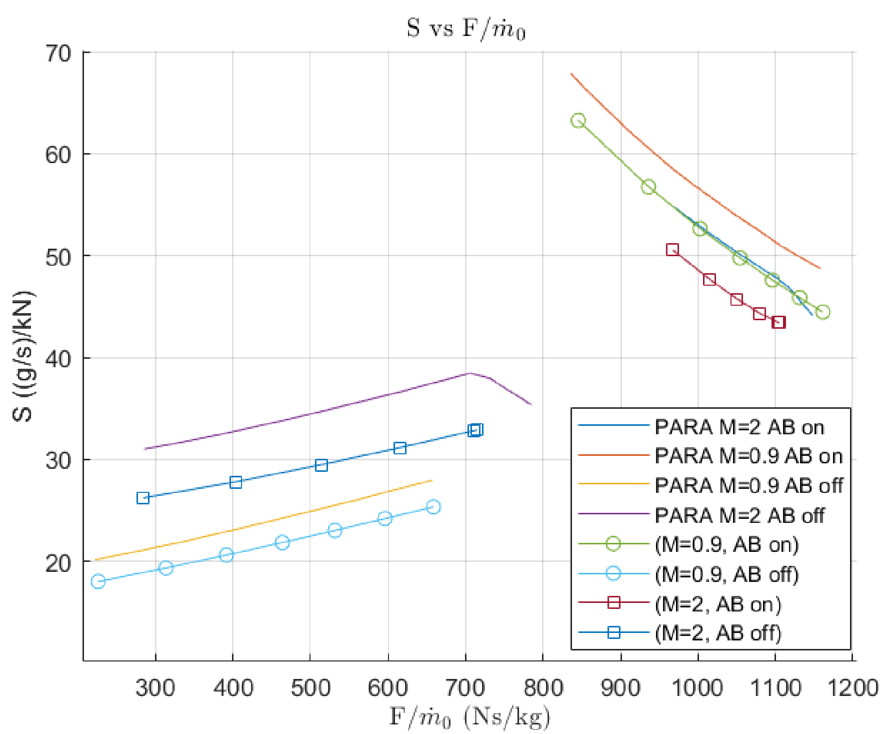

Figure 8: Specific Fuel Consumption vs Specific Thrust for Fan Pressure Ratio

With reference to Figure 8, as the fan pressure ratio increases (in the figure, the fan pressure ratio goes from 2 to 5 with an increment of 0.5 from left to right.), the specific thrust also increases. This can be explained by the increase in fan temperature ratio, τ_f. An increase in τ_f leads to an increase in the temperature entering the mixer, thereby raising the exit temperature. Using equation(51), it can be observed that this gain leads to an increase in exit velocity, and from equation (53), it can be seen that specific thrust also increases accordingly.

For TSFC (Thrust Specific Fuel Consumption), there are two behaviors observed with increasing fan pressure ratio. When the afterburner is off, TSFC increases with an increasing fan pressure ratio. This can be explained by the reduction in the bypass ratio, α. In Figure 7, it can be seen that α decreases non-linearly, with this reduction occurring faster than a linear trend. Using equation(52), it can be observed that f_o increases as a result of the decrease in α. However, specific thrust increases linearly. By analyzing the TSFC equation, we can examine the behavior of TSFC in light of these changes. If we calculate the change in f_o when the fan pressure ratio increases from 2 to 2.5, we see that f_o increases by 49%, while specific thrust increases by 44% over the same interval. Thus, TSFC increases in this case.

When the afterburner is on, TSFC decreases with an increasing fan pressure ratio, which can be explained by the f_{AB} term in the f_o formula (equation 52). To understand this behavior, we should examine equations (19) and (47). With the Kutta condition, it can be inferred that τ_t increases with an increasing π_f. According to equation(47), this increase leads to a reduction in f_{AB}. As a result, f_o decreases, while specific thrust increases, leading to a decrease in TSFC.

With respect to increasing Mach number, specific thrust increases due to the increase in exit velocity as previously discussed. However, in this case, the increase is caused by the increase in ram temperature ratio (equation 6).

For TSFC, increasing Mach number yields two distinct behaviors. When the afterburner is off, TSFC increases with Mach number. This can be attributed to an increase in f_o. As Mach number increases, π_r also rises, leading to an increase in τ_r (equation 6). This in turn causes a decrease in the bypass ratio, which positively impacts f_o. In this case, f_o increases by 82.93%, specific thrust increases by 25.91%, and thus, TSFC decreases.

When the afterburner is on, TSFC decreases with increasing Mach number, which can be explained by an increase in the mixer temperature ratio. As Mach number increases, τ_r rises as discussed earlier. This, in turn, leads to an increase in τ_M (equation 27) and a subsequent decrease in f_{AB} (equation 47). Consequently, with a decrease in f_o, TSFC decreases while specific thrust increases.

Data from PARA is looks like appropriate as tendency but there are obvious errors. Errors could be caused by wrong values obtained in code and also could caused by unknown behavior of PARA software. From some π_f values some values remains constant due to negative values occur in the code. These values turned into zero and that leads to elimination of effect of fan pressure ratio on values for rest of calculations.

4.3 Thermal Efficiency (η_T) vs Fan Pressure Ratio (π_F)

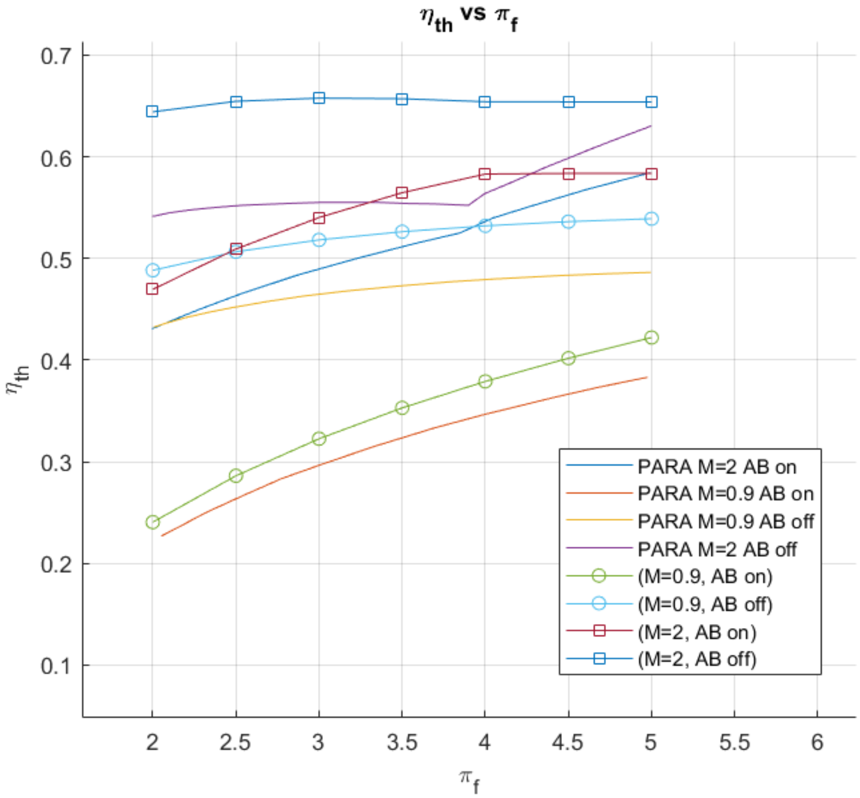

Figure 9: Thermal Efficiency vs Fan Pressure Ratio

In Figure 9 it can be seen that with increasing fan pressure ratio, thermal efficiency is increasing. It can be explained by increasing exit velocity. As we previously discussed, increasing the fan pressure ratio results in greater thrust. Essentially, thrust arises from a change in momentum, so increasing the exit velocity leads to a larger thrust output, as it directly affects the velocity change. Looking back at the thermal efficiency equation, increasing the exit velocity clearly contributes to an increase in thermal efficiency.

$$\eta_T = \frac{a_0^2\left[(1+f_0)\cdot(\frac{V_9}{a_0})^2 - M_0^2\right]}{2\cdot g_c\cdot f_0\cdot h_{pr}}$$

In after burner on cases thermal efficiency is less than the after burner off cases. Its simply due to increased fuel rate. Additional after burner fuel leads to decrease in thermal efficiency by definition [3] (equation 56).

Data from PARA is looks like appropriate as tendency but there are obvious errors. Errors could be caused by wrong values obtained in code and also could caused by unknown behavior of PARA software. From some π_f values some values remains constant due to negative values occur in the code. These values turned into zero and that leads to elimination of effect of fan pressure ratio on values for rest of calculations.

4.4 Propulsive Efficiency (η_P) vs Fan Pressure Ratio (π_F)

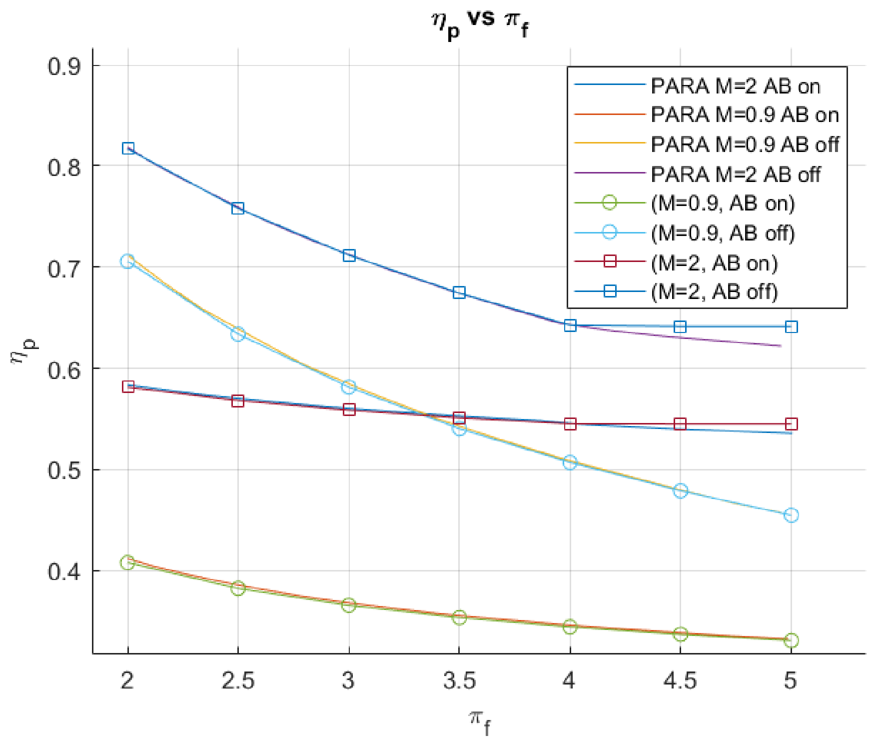

Figure 10: Propulsive Efficiency vs Fan Pressure Ratio

In Figure 10 it can be seen that propulsive efficiency decreases with the increasing fan pressure ratio. Also, we see that increasing the mach number causes to decrease of propulsive efficiency. That could be explained by propulsive efficiency formula:

$$\eta_P = \frac{2 \cdot g_c \cdot V_0 \cdot \frac{F}{\dot{m}_0}}{a_0^2 \left[(1 + f_0) \cdot (\frac{V_9}{a_0})^2 - M_0^2\right]}$$

As the fan pressure ratio π_f increases, exit velocity, as explained before, also increases. Observing the term $\frac{V_9}{a_0}$, which represents the ratio of exit velocity to the speed of sound, we see that it grows as well. With an increase in specific thrust, $\frac{V_9}{a_0}$ continues to rise. However, when examining the specific thrust equation, the denominator contains $\frac{V_9}{a_0}$ in squared form. This causes the denominator to grow faster than the numerator, leading to a reduction in propulsive efficiency with the fan pressure ratio increases.

In terms of mach number it could directly observed that V_0 and also M_0 increase. While mach number inversely effect the denominator and V_0 effect the nominator proportionally, with the higher mach numbers propulsive efficiency would decrease.

Data from PARA is looks like appropriate as tendency but there are few errors anyway. Errors are caused by rounding of solution and also negative alpha value problem for higher mach number mentioned before.

4.5 Overall Efficiency (η_0) vs Fan Pressure Ratio (π_F)

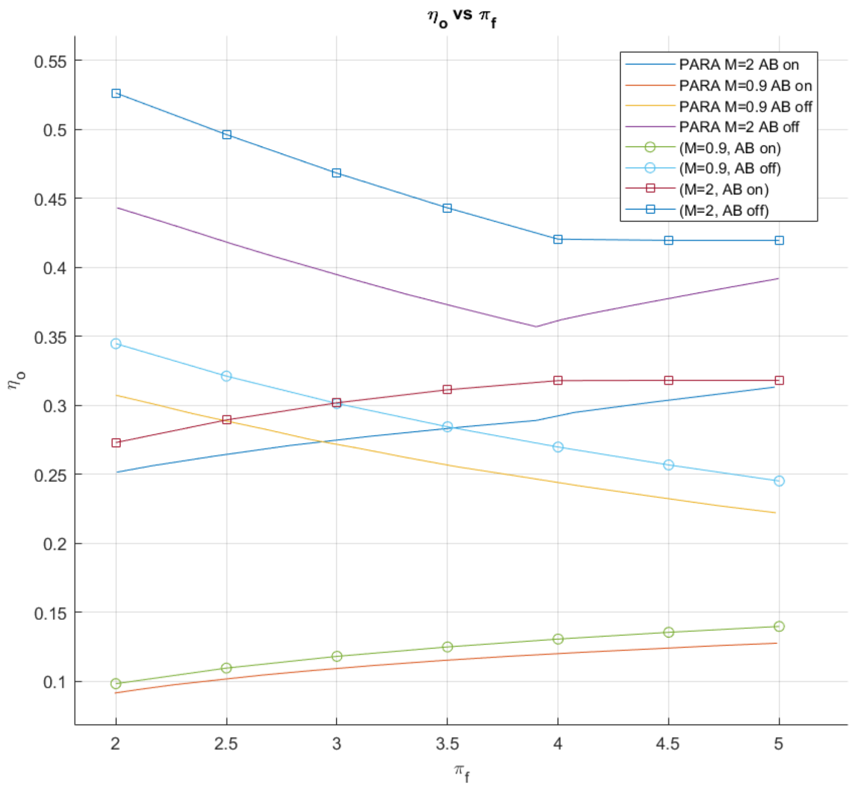

Figure 11: Overall Efficiency vs Fan Pressure Ratio

In figure 11 that could be seen that there is two behavior that depends on after burner. To understand these behaviors we could directly look at the propulsive and thermal efficiencies by definition of overall efficiency.

Data from PARA is looks like appropriate as tendency but there are obvious errors. Errors could be caused by wrong values obtained in code and also could caused by unknown behavior of PARA software but we could easily see that errors come from thermal efficiency for overall efficiency.

References

[1] Kerrebrock, J. L., "Aircraft Engines and Gas Turbines," 2nd ed., MIT Press, Cambridge, MA, 1992.

[2] Çengel, Y. A., and Boles, M. A., "Thermodynamics: An Engineering Approach," 8th ed., McGraw-Hill Education, New York, NY, 2014.

[3] El-Sayed, A. F., "Aircraft Propulsion and Gas Turbine Engines," CRC Press, Boca Raton, FL, 2008.

[4] Anderson, J.D., "Fundamentals of Aerodynamics," 6th ed., McGraw-Hill Education, New York, 2017.

[5] Mattingly, J.D., "Elements of Propulsion: Gas Turbines and Rockets," 2nd ed., American Institute of Aeronautics and Astronautics, Reston, VA, 2012.

5 Appendix

MATLAB Code

```
clear all;
clc;


%%%%%%%%%make them variables%%%%%%%
PARA1;
cpc = 1004.83;
gamma_c = 1.4;
T0 = 216.67;
pidmax = 0.98;
piMmax = 0.98;
ec = 0.90;
ef = 0.89;
et = 0.91;
pin = 0.98;
cpt = 1235.11;
gammat = 1.3;
etab = 0.995;
pib = 0.96;
Tt4 = 1777.78;
cp_AB = 1235.11;
gammaAB = 1.3;
etaAB = 0.95;
piAB = 0.96;
Tt7 = 2000;
hPR = 42800;
M6 = 0.4;
etam = 0.99;
P0_P9 = 1;
pi_fmin=2;
pi_fmax=5;
pi_fresol= 0.5;
pi_fvals = pi_fmin:pi_fresol:pi_fmax;  %% 2 limit variable
m0_first=0.9;
m0_sec=2;
M0vals = [m0_first, m0_sec]  ;        %%[0.9, 2.0]; %%2 variable
pi_c = 24;
gc = 1;
Rc = ((gamma_c - 1) / gamma_c) * cpc;
Rt = ((gammat - 1) / gammat) * cpt;
```

```
a0=sqrt(gamma_c*Rc*T0);

%%%%%%%%%%%%%%%%%
% result matrices
fABmat=zeros(length(M0vals), length(pi_fvals));
T9divt0values= zeros(length(M0vals), length(pi_fvals));
fovalues=zeros(length(M0vals), length(pi_fvals));
foabovalues=zeros(length(M0vals), length(pi_fvals));
v9dia0vals=zeros(length(M0vals), length(pi_fvals));
taumvals=zeros(length(M0vals), length(pi_fvals));
m9vals=zeros(length(M0vals), length(pi_fvals));
m9abvals=zeros(length(M0vals), length(pi_fvals));

alphavalues = zeros(length(M0vals), length(pi_fvals));
tau_tvalues = zeros(length(M0vals), length(pi_fvals));

Specfconsabon_values= zeros(length(M0vals), length(pi_fvals));
Specfconsabof_values= zeros(length(M0vals), length(pi_fvals));

specthrabon_values=zeros(length(M0vals), length(pi_fvals));
specthrabof_values=zeros(length(M0vals), length(pi_fvals));

thermaleffabon_values=zeros(length(M0vals), length(pi_fvals));
thermaleffabof_values=zeros(length(M0vals), length(pi_fvals));

propulseffabon_values=zeros(length(M0vals), length(pi_fvals));
propulseffabof_values=zeros(length(M0vals), length(pi_fvals));

overalleffabon_values=zeros(length(M0vals), length(pi_fvals));
overalleffabof_values=zeros(length(M0vals), length(pi_fvals));


%appendix
 tab = 'Appendix.xlsx';
 inform = readmatrix(tab);

% values for interp
Tvals = inform(:, 1);
fvals = [0, 0.0169, 0.0338, 0.0507, 0.0676];
h_t4vals = [1975.42, 2025.42, 2073.78, 2120.59, 2165.93];
h_t7vals = [2251.53, 2311.27, 2369.05, 2424.98, 2479.14];



% f tables
```

```
f0vals = inform(:, 2);%f=0
f169vals = inform(:, 3);%f=0.0169
f338vals = inform(:, 4);%f=0.0338
f507vals = inform(:, 5);%f=0.0507
f676vals = inform(:, 6);%f=0.0676

[Tvalsinterp, ~, idx] = unique(Tvals);
f0valsinterp = accumarray(idx, f0vals, [], @mean);




%%%%%%%%%%%%%%
% M0 loop
for i = 1:length(M0vals)
    M0 = M0vals(i);
    % fprintf('Mach number (M0): %.1f\n', M0);
   %ram
    tau_r = 1 + ((gamma_c - 1) / 2) * M0^2;
    pi_r = tau_r^(gamma_c / (gamma_c - 1));

    if M0 <= 1
        eta_r = 1;
    else
        eta_r = 1 - 0.075 * (M0 - 1)^1.35;
    end


    % defuser
    pi_d = eta_r * pidmax;

    if M0 <= 1
         tau_d = 1; %highly adiabatic
     else
         tau_d = pi_d^((gamma_c-1)/gamma_c);
    end


    % comp
    tau_c = pi_c^((gamma_c - 1) / (gamma_c * ec));
    %eta_c = (pi_c^((gamma_c - 1) / gamma_c) - 1) / (tau_c - 1)
       ; %?

    %calculation of T_t3
    T_t3 = T0 * tau_r * tau_d * tau_c;
```

```
    % fprintf('Mach number (M0): %.1f\n', M0);
    % fprintf('T_t3: %.2f Kelvin\n', T_t3);

    % h_t3 interpolasyonu
    if T_t3 >= min(Tvalsinterp) && T_t3 <= max(Tvalsinterp)

        h_t3 = interp1(Tvalsinterp, f0valsinterp, T_t3, 'linear');
        % fprintf('for %0.2f K and f=0, h_t3: %0.2f\n', T_t3, h_t3);

    else
        % fprintf('T_t3 de eri Excel dosyas ndaki s cakl k aral  nda de il.\n');
        continue;
    end

   %%%%%%%%%% inspect

    f= 0.0338;
    tolerance = 0.0001;
    max_iter = 100;
    iter = 0;

    delta_f = inf;
    while delta_f > tolerance && iter < max_iter

        h_t4_interp = interp1(fvals, h_t4vals, f, 'linear');
        f_new = (h_t4_interp - h_t3) / (etab * hPR - h_t4_interp);
        delta_f = abs(f_new - f);
        f = f_new;
        iter = iter + 1;
        % fprintf('Iteration %d: f = %.5f, delta_f = %.5f\n', iter, f, delta_f);
    end
    % fprintf('Final f value: %.5f, total iteration: %d\n', f, iter);
%fmat(i,in)=f;


    %%%%%%%% pi_f loop
    for in = 1:length(pi_fvals)
```

```
        tau_lambda= (cpt/cpc)*(Tt4/T0);%
        pi_f = pi_fvals(in);


        tau_f= pi_f^((gamma_c-1)/(gamma_c*ef));  %




        %a= (eta_m*(1+f)*(tau_lambda/tau_r)*(1-(pi_f/(pi_c*pi_b
           )) ^ ((gamma_t-1)*et /gamma_t))-(tau_c-1))/(tau_f-1)
           ; %%
        a= (etam*(1+f)*(tau_lambda/tau_r)*(1-(pi_f/(pi_c*pib))
           ^((gammat-1)*et/gammat))-(tau_c-1))/(tau_f-1); %%
            if a < 0
               a = 0;
            end
        % fprintf('\n a: %.5f, pi_f: %.5f tau_f: %.5f\n', a,
           pi_f, tau_f);




        tau_t= 1 - (tau_r*(tau_c -1 +a*(tau_f-1)))/(etam*(1+f)*
           tau_lambda);


        pi_t=tau_t^(gammat/((gammat-1)*et));

        pt16divpt6= pi_f/(pi_c*pib*pi_t);


        M16= sqrt((2/(gamma_c-1))*(((pt16divpt6*((1+(gammat-1)
           *0.5*M6^2 )^(gammat/(gammat-1))))^((gamma_c-1)/
           gamma_c)) -1 ));

        alphavalues(i, in) = a;
        tau_tvalues(i, in) = tau_t;




%%%%%%%%%%%%%%%%% alpha and Tau_t plot done
```

```
 a_prime= alphavalues(i, in)/(1+f);%
 R6A=(Rt +a_prime*Rc)/(1+a_prime);

% fprintf('\n a: %.5f, a_prime: %.5f\n', a, a_prime);

cp_6A=(cpt+a_prime*cpc)/(1+a_prime);%

gamma6A=cp_6A/(cp_6A-R6A);


Tt16divtt6=(T0*tau_r*tau_f)/(Tt4*tau_t);%T_t16/T_t6

tau_M=(cpt/cp_6A)*((1+a_prime*(cpc/cpt)*(Tt16divtt6))
   /(1+a_prime)); %%
taumvals(i,in)=tau_M;

tau_b=Tt4/T_t3;

T_t6A=T0*tau_r*tau_d*tau_c*tau_b*tau_t*tau_M;

phim6gam6= (M6^2)*(1+ ((gammat -1)/2)*M6^2)/(1+gammat*
   M6^2)^2;
phim16gam16=(M16^2)*(1+ ((gamma_c -1)/2)*M16^2)/(1+
   gamma_c*M16^2)^2;


%Phi= ((1 + a_prime)/(1/phim6gam6^0.5 + a_prime*(((Rc*
   gamma_t)/(Rt*gamma_c))*(Tt16divtt6/phim16gam16))
   ^0.5))*((R6A*gamma_t)/(Rt*gamma6A) * tau_M);
Phi= (((1+a_prime)/( 1/sqrt(phim6gam6) + a_prime*sqrt(
   Rc*gammat*Tt16divtt6/(Rt*gamma_c*phim16gam16))  ))
   ^2)*R6A*gammat*tau_M/(Rt*gamma6A)   ;
M6A= sqrt(2*Phi/(1-2*gamma6A*Phi +sqrt(1-2*(gamma6A+1)*
   Phi)));
A16divA6= a_prime*sqrt(Tt16divtt6) / ((M16/M6)*sqrt(((
   gamma_c*Rt*(1+((gamma_c -1)/2)*M16^2)))/((gammat*Rc
   *(1+((gammat -1)/2)*M6^2)))));


%MFP= (M*sqrt(gamma/R))/((1+ ((gamma-1)/2)*M^2)^((gamma
    +1)/(2*(gamma-1))))
MFPM6t= (M6*sqrt(gammat/Rt))/((1+ ((gammat-1)/2)*M6^2)
   ^((gammat +1)/(2*(gammat-1))));
```

```
        MFPM6A= (M6A*sqrt(gamma6A/R6A))/((1+ ((gamma6A-1)/2)*
           M6A^2)^((gamma6A +1)/(2*(gamma6A-1))));
        pi_Mideal= ((1+a_prime)*sqrt(tau_M))*MFPM6t/((1+
           A16divA6)*MFPM6A);
        pi_M= piMmax*pi_Mideal;

        Pt9divp9=P0_P9*pi_r*pi_d*pi_c*pib*pi_t*pi_M*pin; %AB
           off



        %%%% ABoff - man %%%%
        cp9=cp_6A;
        R9=R6A;




        T9divT0= (Tt4*tau_t*tau_M/T0)/((Pt9divp9)^((gamma6A-1)/
           gamma6A));
        T9divt0values(i,in)=T9divT0;
        M9=sqrt((2/(gamma6A-1))*((Pt9divp9)^((gamma6A-1)/
           gamma6A) -1 ));
        m9vals(i,in)=M9;

        V9diva0=M9*sqrt((gamma6A*R9)*T9divT0/(gamma_c*Rc));
v9dia0vals(i,in)=V9diva0;

        a0=sqrt(gamma_c*Rc*T0);

        f0abof= (f)/(1+a);
        fovalues(i,in)=f0abof;

        specthrabof=(a0)*((1+f0abof)*V9diva0 - M0 + (1+f0abof)*
           R9*T9divT0*(1-P0_P9)/(Rc*V9diva0*gamma_c)); %%%%%%
           look
        specthrabof_values(i, in) = specthrabof;

        specfconsabof=f0abof/specthrabof;
        Specfconsabof_values(i,in)=specfconsabof*10^6;

        propulseffabof= 2*M0*specthrabof/(a0*(((1+f0abof)*
           V9diva0^2) - M0^2));
        propulseffabof_values(i,in)=propulseffabof;
```

```
        % thermaleffabof= (a0^2)*(plusf0abof*v9sq -machsq)/(2*
           f0abof*hPR*1000);
        plusf0abof=1 + f0abof; v9sq=V9diva0^2; machsq=M0^2;


        thermaleffabof= ((a0^2)*(((1+f0abof)*(V9diva0^2)) - M0
           ^2))/(2*f0abof*hPR*1000);
        thermaleffabof_values(i,in)= thermaleffabof;

        % if a>=0
        % thermaleffabof= ((a0^2)*(((1+f0abof)*(V9diva0^2)) -
           M0^2))/(2*f0abof*hPR*1000);
        % thermaleffabof_values(i,in)= thermaleffabof;
        % else
        % thermaleffabof= -1*((a0^2)*(((1+f0abof)*(V9diva0^2))
           - M0^2))/(2*f0abof*hPR*1000);
        % thermaleffabof_values(i,in)= thermaleffabof;
        % end


        overalleffabof= thermaleffabof*propulseffabof;
        overalleffabof_values(i,in)= overalleffabof;



       %%%%abonman!!!!!1!

       RAB= ((gammaAB-1)/gammaAB)*cp_AB;  %Rab?



       Tt6Aabon=Tt4*tau_t*tau_M;



% ht values

ht_values = inform(:, 2:end); % for all ht values



% finding f value
[~, idx1] = min(abs(fvals - f));
if f > fvals(idx1)
    idx2 = idx1 + 1;
```

```
else
    idx2 = idx1 - 1;
end

% valid column
idx1 = max(1, min(idx1, size(ht_values, 2)));
idx2 = max(1, min(idx2, size(ht_values, 2)));

% ht, f
ht1 = ht_values(:, idx1);
ht2 = ht_values(:, idx2);
f1 = fvals(idx1);
f2 = fvals(idx2);

% interp
ht_interp1 = interp1(Tvals, ht1, Tt6Aabon, 'linear', 'extrap');
ht_interp2 = interp1(Tvals, ht2, Tt6Aabon, 'linear', 'extrap');

% interp ht
ht6A = interp1([f1, f2], [ht_interp1, ht_interp2], f, 'linear',
    'extrap');


 % fAB=(1+ f/(1+a)) * ()
fAB=  0.0338;
    tolerance = 0.0001;
    max_iter = 100;
    iter = 0;
%Fab iter
    delta_fAB = inf;
    while delta_fAB > tolerance && iter < max_iter

        h_t7_interp = interp1(fvals, h_t7vals, fAB, 'linear');
        f_newAB = (h_t7_interp - ht6A) / (etab * hPR -
           h_t7_interp);
        delta_fAB = abs(f_newAB - fAB);
        fAB = f_newAB;
        iter = iter + 1;
        % fprintf('Iteration %d: fAB = %.5f, delta_fAB = %.5f\n
           ', iter, fAB, delta_fAB);
    end
    % fprintf('Final fAB value: %.5f, total iteration: %d\n',
       fAB, iter);
fABmat(i,in)=fAB;
```

```
 Pt9divp9AB=P0_P9*pi_r*pi_d*pi_c*pib*pi_t*pi_M*piAB*pin;

T9divT0abon=(Tt7/T0)/ ((Pt9divp9AB)^((gammaAB-1)/gammaAB));

 M9AB=sqrt((2/(gammaAB-1))*((Pt9divp9AB)^((gammaAB-1)/gammaAB)
    -1 ));
m9abvals(i,in)=M9AB;
 V9diva0AB=M9AB*sqrt(gammaAB*RAB*T9divT0abon/(gamma_c*Rc));

 f0abon= (f/(1+a) )+ fAB;
 foabovalues(i,in)=f0abon;


        %%specthrabof=a0*((1+f0abof)*V9diva0 - M0 + (1+f0abof)*
           R9*T9divT0*(1-P0_P9)/(Rc*V9diva0*gamma_c)     );




        specthrabon=a0*((1+f0abon)*V9diva0AB - M0 + (1+f0abon)*
           RAB*T9divT0abon*(1-P0_P9)/(Rc*V9diva0AB*gamma_c)) ;
           %%%%%%look
        specthrabon_values(i,in)=specthrabon;

        Specfconsabon= f0abon/specthrabon;
        Specfconsabon_values(i,in)=Specfconsabon*10^6 ;

        propulseffabon= 2*M0*specthrabon/(a0*(((1+f0abon)*
           V9diva0AB^2) - M0^2));
        propulseffabon_values(i,in)=propulseffabon;

        thermaleffabon=((a0^2)*(((1+f0abon)*V9diva0AB^2) - M0
           ^2))/(2*f0abon*hPR*1000);
        thermaleffabon_values(i,in)=thermaleffabon;

        overalleffabon=thermaleffabon*propulseffabon;
        overalleffabon_values(i,in)=overalleffabon;


       %%%%%%%%%%%%%%%%%%

       %by deadbacco

    end %pif
```

```
end %M0


    % plot
    %taut alpha
figure;
hold on;
yyaxis left
% M 0.9  (alpha  tau_t)
plot(pi_fvals, alphavalues(1, :),'Color', 'k', 'DisplayName', '
   \alpha (M=0.9)');
% Mach 2 i (alpha )
plot(pi_fvals, alphavalues(2, :),'Color', 'b', 'DisplayName', '
   \alpha (M=2)');

plot(xa,ya, 'DisplayName', 'PARA (M=2)');
plot(xaa,yaa, 'DisplayName', 'PARA (M=0.9)');
ylabel(' \alpha ');
ylim([-0.5, 8]);

yyaxis right
plot(pi_fvals, tau_tvalues(1, :),'Color', 'r','DisplayName', '\
   tau_t  M0=0.9'); %for M0=0.9
plot(xt,yt, 'DisplayName', 'PARA \tau_t');
plot(pi_fvals, tau_tvalues(2, :),'linewidth',1.2,'Color', 'b','
   DisplayName', '\tau_t M0=2');
% M0=2' ); %saameeeeee    t?
ylabel('\tau_t');
ylim([0.59, 0.73]);

title('\alpha and \tau_t vs \pi_f for Different Mach Numbers');
xlabel('\pi_f');
xlim([1.5,5.5]);
% ylabel('Values of \alpha and \tau_t');
legend('show');
grid on;
hold off;

% spec th spec fuel

figure;
hold on;

%   (s thr)
```

```
plot(xs,ys, 'DisplayName', 'PARA M=2 AB on ');
plot(x2s,y2s, 'DisplayName', 'PARA M=0.9 AB on');
plot(x3s,y3s, 'DisplayName', 'PARA M=0.9 AB off');
plot(x4s,y4s, 'DisplayName', 'PARA M=2 AB off');
plot(specthrabon_values(1,:), Specfconsabon_values(1, :), '-o',
    'DisplayName', '(M=0.9, AB on)');
plot(specthrabof_values(1,:), Specfconsabof_values(1, :), '-o',
    'DisplayName', '(M=0.9, AB off)');
plot(specthrabon_values(2,:), Specfconsabon_values(2, :), '-s',
    'DisplayName', '(M=2, AB on)');
plot(specthrabof_values(2,:), Specfconsabof_values(2, :), '-s',
    'DisplayName', '(M=2, AB off)');


title('S vs F/$\dot{m}_0$ ', 'Interpreter', 'latex');
xlabel('F/$\dot{m}_0$ (Ns/kg)', 'Interpreter', 'latex');
ylabel('S ((g/s)/kN)');
legend('show');
grid on;
hold off;




% thermal pif

figure;
hold on;


plot(xtyu,termonm2, 'DisplayName', 'PARA M=2 AB on ');
plot(xth,termonm9, 'DisplayName', 'PARA M=0.9 AB on');
plot(xty,termoffm9, 'DisplayName', 'PARA M=0.9 AB off');
plot(xtt,termofffm2, 'DisplayName', 'PARA M=2 AB off');
plot(pi_fvals, thermaleffabon_values(1, :), '-o', 'DisplayName'
   , '(M=0.9, AB on)');
plot(pi_fvals, thermaleffabof_values(1, :), '-o', 'DisplayName'
   , '(M=0.9, AB off)');
plot(pi_fvals, thermaleffabon_values(2, :), '-s', 'DisplayName'
   , '(M=2, AB on)');
plot(pi_fvals, thermaleffabof_values(2, :), '-s', 'DisplayName'
   , '(M=2, AB off)');


title('\eta_{th} vs \pi_f');
xlabel('\pi_f');
```

```
ylabel('\eta_{th}');
legend('show');
grid on;
hold off;


% prop vs pif
figure;
hold on;


plot(xppo,propm2on, 'DisplayName', 'PARA M=2 AB on ');
plot(xpr,propm9on, 'DisplayName', 'PARA M=0.9 AB on');
plot(xpo,propm9off, 'DisplayName', 'PARA M=0.9 AB off');
plot(xpp,propm2off, 'DisplayName', 'PARA M=2 AB off');
plot(pi_fvals, propulseffabon_values(1, :), '-o', 'DisplayName'
    , '(M=0.9, AB on)');
plot(pi_fvals, propulseffabof_values(1, :), '-o', 'DisplayName'
    , '(M=0.9, AB off)');
plot(pi_fvals, propulseffabon_values(2, :), '-s', 'DisplayName'
    , '(M=2, AB on)');
plot(pi_fvals, propulseffabof_values(2, :), '-s', 'DisplayName'
    , '(M=2, AB off)');


title('\eta_p vs \pi_f');
xlabel('\pi_f');
ylabel('\eta_p');
legend('show');
grid on;
hold off;

% over vs pif
figure;
hold on;


plot(xov,Overm2on, 'DisplayName', 'PARA M=2 AB on ');
plot(xover,Overm9on, 'DisplayName', 'PARA M=0.9 AB on');
plot(xloser,Overm9off, 'DisplayName', 'PARA M=0.9 AB off');
plot(xlover,Overm2off, 'DisplayName', 'PARA M=2 AB off');
plot(pi_fvals,overalleffabon_values(1, :), '-o', 'DisplayName',
     '(M=0.9, AB on)');
plot(pi_fvals, overalleffabof_values(1, :), '-o', 'DisplayName'
    , '(M=0.9, AB off)');
```

```
plot(pi_fvals,overalleffabon_values(2, :), '-s', 'DisplayName',
    '(M=2, AB on)');
plot(pi_fvals, overalleffabof_values(2, :), '-s', 'DisplayName'
   , '(M=2, AB off)');


title('\eta_o vs \pi_f');
xlabel('\pi_f');
ylabel('\eta_o');
legend('show');
grid on;
hold off;


 % badmoon;
```