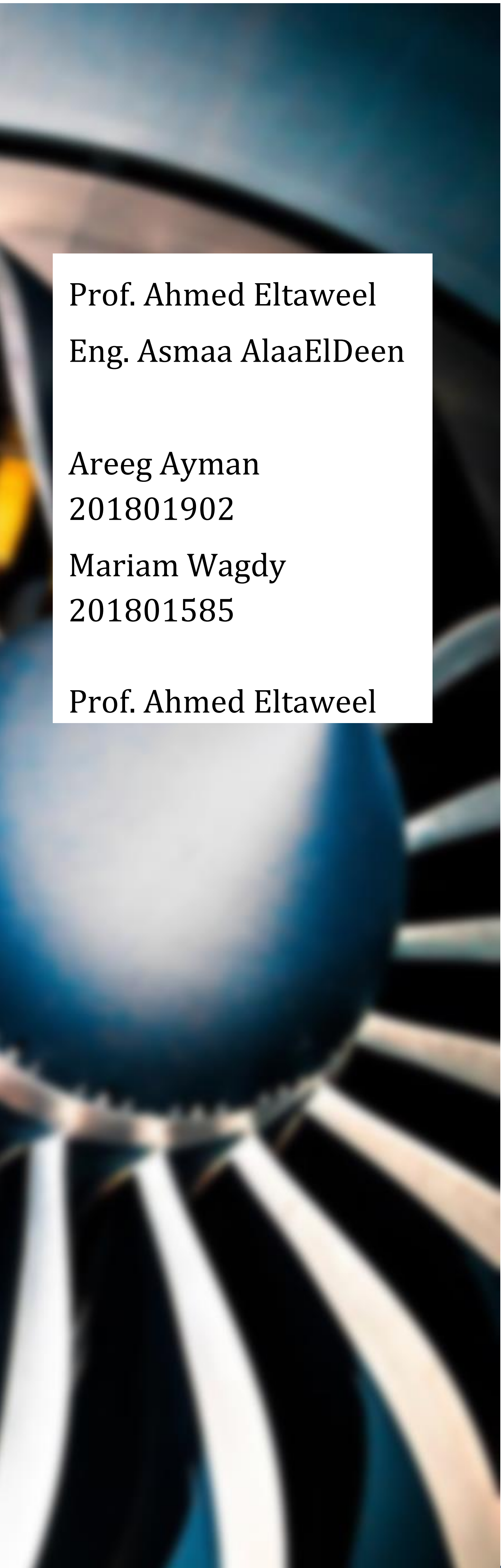
Jet Engine Design

Gas Turbine Engines SPC 417
Project



Prof. Ahmed Eltaweel

Eng. Asmaa AlaaElDeen

Areeg Ayman
201801902

Mariam Wagdy
201801585

Prof. Ahmed Eltaweel

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Thrust Required

Let W_0 = initial gross weight of the airplane, W_f = final gross weight of the airplane. The total distance covered throughout the fl ight is equal to the integral of the equation above from s = 0, where W = W0 (full fuel tank), to s = R, where W = W1 (empty fuel tank):

$$R = \int_{w_1}^{w_o} \frac{V_\infty \, dW}{TSFC \; T_A}$$

Maximum range for a jet airplane occurs when the airplane is flying at a velocity such that $C_L^{1/2}/CD$ is at its maximum.

$$R = \int_{w_1}^{w_o} \sqrt{\frac{2}{\rho_\infty \, S}} \frac{\frac{C_L^{\frac{1}{2}}}{C_D}}{TSFC} \frac{dW}{W^{\frac{1}{2}}}$$

$$R = 2\sqrt{\frac{2}{\rho_\infty \, S}} \frac{\frac{C_L^{\frac{1}{2}}}{C_D}}{TSFC} (W_o^{\frac{1}{2}} - W_f^{\frac{1}{2}})$$

To obtain maximum range for a jet airplane, we want the following:
1. **Minimum** thrust-specific fuel consumption TSFC
2. **Maximum** fuel weight Wf
3. Flight at **maximum** $C_L^{1/2}/C_D$

Segment	**Takeoff**	**Climb**	**Cruise**
Mach Mo	0.286		0.89
H [m]	0	6000	8700
Estimated average aircraft weight (W) [Kg]	140301.25	137503.75	113725
Rate of climb [m/s]	6.35	10	0
Velocity [m/s]	97.3258	216	271.5568
Percentage of fuel weight	0.1		0.8
Angle of attack [degrees]	10	0	0
Density of air [kg/m^3]	1.225	0.660	0.4844
Temperature [C]	288.1	249.2	231.68
Pressure [pa]	101325	47217	32212.4
Speed of sound [m/s]	340.3	316.5	305.12

$$\frac{Excess\ thrust}{weight} = rate\ of\ climb$$

$$Rate\ of\ Climb\ (R/C) = V_\infty \sin\theta$$

Segment	**Takeoff**	**Climb**	**Cruise**
Flight Path Angle (θ)*[deg]*	0	2.653530867	0

$$C_D = 0.01 + 0.065\, C_L^2$$

$$q * S = \frac{1}{2}\rho V^2 S$$

TAKEOFF

For takeoff, over most of the ground roll, T is reasonably constant (this is particularly true for a jet-powered airplane). Also, W is constant. However, both Land D vary with velocity.

Also, experience has shown that the coefficient of rolling friction $\mu_r$varies from 0.02 for a relatively smooth, paved surface to 0.10 for a grass field. We can simplify further by assuming that thrust is much larger than either D or R during takeoff.

$$T = D + \mu_r(W - L) + m\frac{dV}{dt}$$

Assuming constant acceleration and using kinematic equations,

$$L - W = m\frac{V^2}{r_c}$$

$$C_L = \frac{m}{qS}\left(\frac{V^2}{6371000} + g\right)$$

$$T = ma + D + \mu_r(W - L)$$

CLIMB:

$$T - D - W\sin\theta = m\frac{dV}{dt}$$

$$T = qSC_D + W\sin\theta + m\frac{dV}{dt}$$

$$(v_{\infty 2}^2 - v_{\infty o}^2)\ cos^2\theta = \frac{2ah}{tan\,\theta}$$

$$a_1 = -0.024577987$$

$$a_2 = 0.222180294$$

$$L - W\cos\theta = m\frac{V^2}{r_c}$$

Assume: $r_c = \frac{h}{\cos\theta} + 6371000$

$$C_L = \frac{m}{qS}\left(\frac{V^2}{\frac{h}{\cos\theta} + 6371000} + g\cos\theta\right)$$

$$T = qS(0.01 + 0.065\, C_L^2) + mg\sin\theta + ma$$

CRUISE:

$$T_r = D$$

Segment	**Takeoff**	**Climb**	**Cruise**
Thrust Required [N]	**1207080.087**	**557392.9262**	**298893.2698**
Thrust must be available [N]	**1207080.087**	**1932430.426**	**298893.2698**

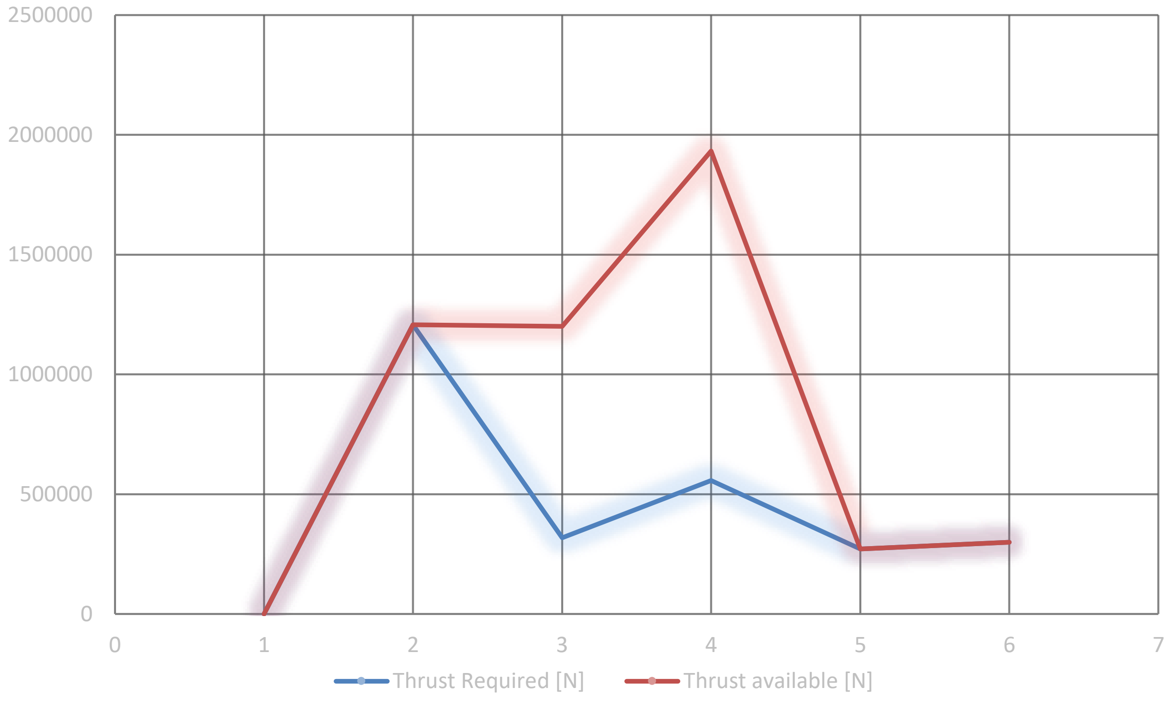
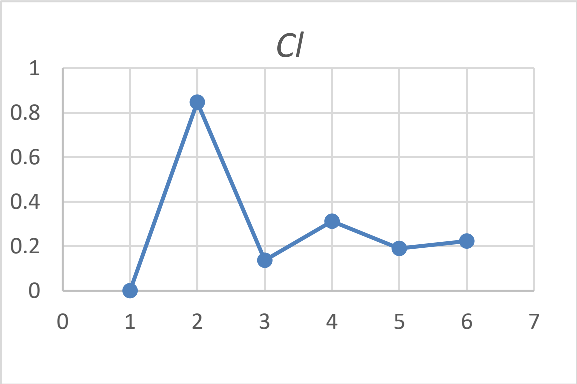
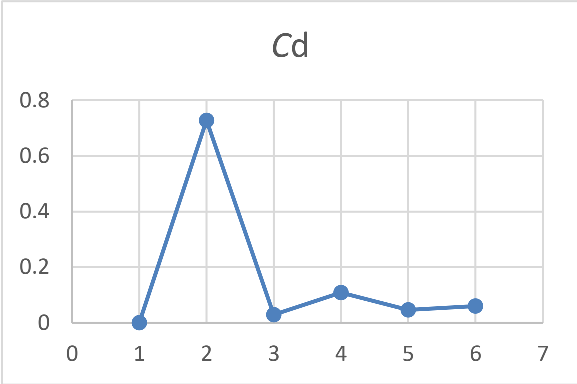
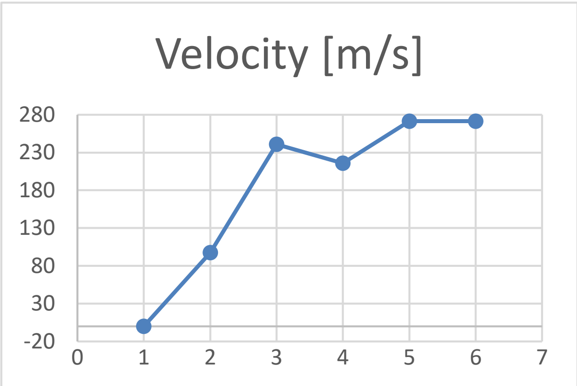


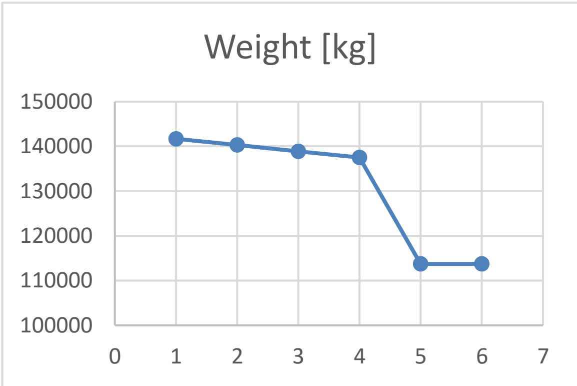
Рисунок 1 Thrust Required at different stations and thrust that must be available, 1-3: takeoff, 3-5: climb, 5-6: cruise

Рисунок 2 Thrust Required at different stations and thrust that must be available, 1-3: takeoff, 3-5: climb, 5-6: cruise

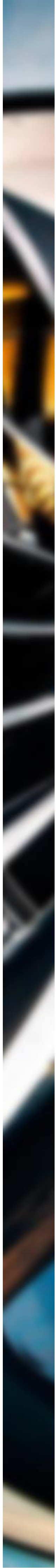






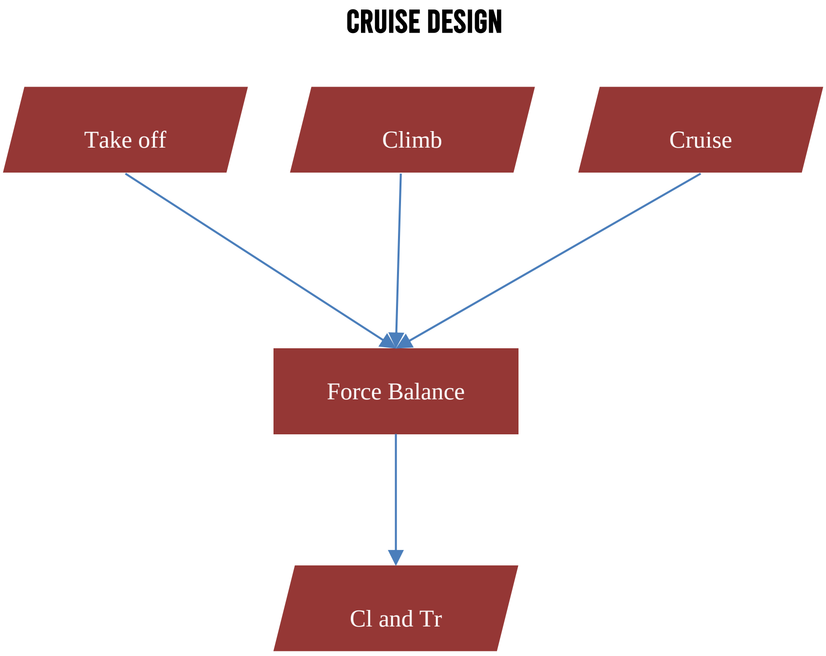


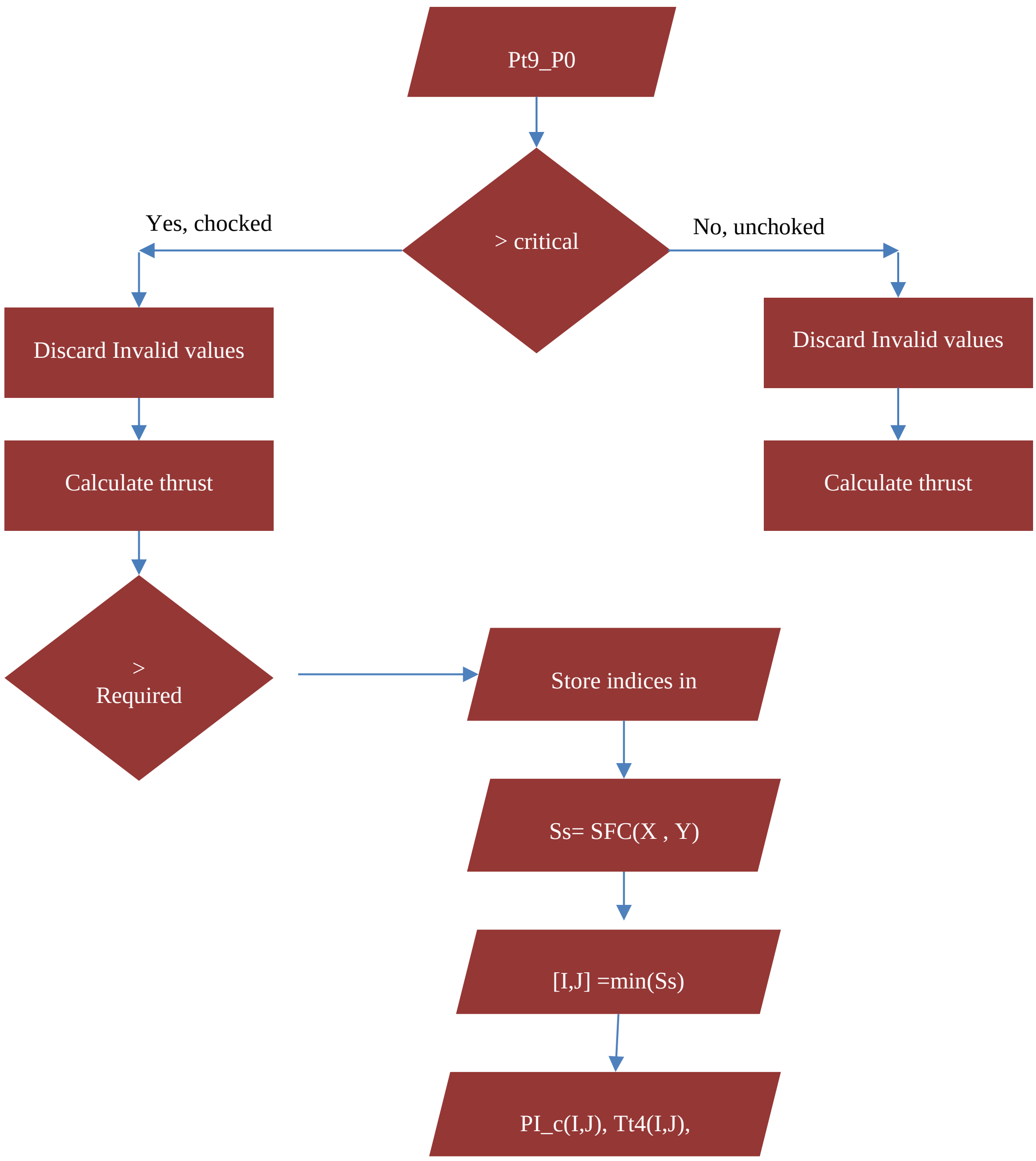
Point	**1**	**2**	**3**	**4**	**5**	**6**
	Takeoff		Climb			Cruise
	first	average	first	average	final	
Mach Mo	0	0.286	0.708198648	0.682464455	0.873650549	0.89
H [m]	0	0	0	6000	8700	8700
Estimated average aircraft weight (W) [Kg]	141700	140301.25	138902.5	137503.75	113725	113725
Rate of climb [m/s]	0	0	6.35	10	0	0
Velocity [m/s]	0	97.3258	241	216	271.5568	271.5568
Vt	0	97.3258	240.9163288	215.7683943	271.5568	271.5568
Vn	0	0	6.35	10	0	0
Percentage of fuel weight	0.1					0.8
Angle of attack [degrees]	10		0			
Density of air [kg/m^3]	1.225	1.225	1.225	0.66	0.5669	0.4844



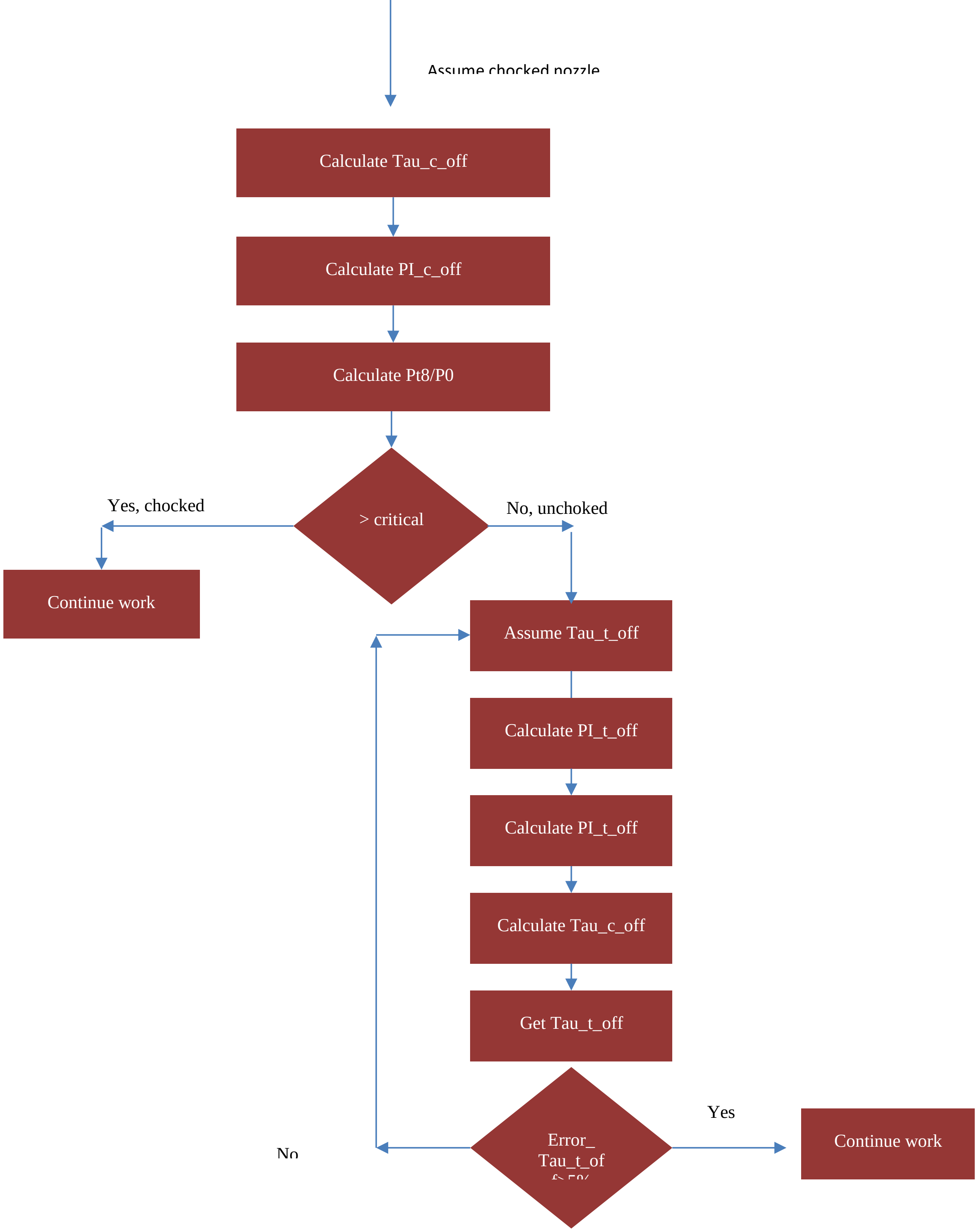
Temperature [C]	288.1	288.1	288.1	249.2	240.46	231.68
Pressure [pa]	101325	101325	101325	47217	39140.8	32212.4
Speed of sound [m/s]	340.3	340.3	340.3	316.5	310.83	305.12
Flight Path Angle [rad]	0	0	0.026351597	0.04631285	0	0
Flight Path Angle [degree]	0	0	1.509835314	2.653530867	0	0
acceleration[m/s]	0	0	-0.024577987	0.223000538	0	0
q	0	5801.790699	35574.6125	15396.48	20902.48046	17860.57776
Cl		0.847247818	0.136750944	0.312563924	0.190620277	0.223085538
Cd		0.727828865	0.028700821	0.107696206	0.04633609	0.059767157
Thrust Required [N]		**1207080.087**	318341.8792	**557392.9262**	271190.9796	**298893.2698**
L		1376355.263	1362161.321	1347467.575	1115642.25	1115642.25
D		1182359.007	285885.7621	464279.8962	271190.9796	298893.2698
Thrust available [N]		**1207080.087**	1200372.754	**1932430.426**	271190.9796	**298893.2698**
muo-r	0.02					

Design Procedure




Pt9_P0
> critical
Yes, chocked
No, unchoked
Discard Invalid values
Calculate thrust
Discard Invalid values
Calculate thrust
>
Required
Store indices in
Ss= SFC(X , Y)
[I,J] =min(Ss)
PI_c(I,J), Tt4(I,J),

OFF-DESIGN


Assume chocked nozzle
Calculate Tau_c_off
Calculate PI_c_off
Calculate Pt8/P0
> critical
Yes, chocked
No, unchoked
Continue work
Assume Tau_t_off
Calculate PI_t_off
Calculate PI_t_off
Calculate Tau_c_off
Get Tau_t_off
Error_
Tau_t_of
No
Yes
Continue work

Engine Design

CRUISE: DESIGN

Compressor Pressure ratio: 38.6

Burner Exit Temperature: 1169.68

Minimum SFC: 2.9274e-05 Kg/N

Mass flow rate of air: 189.8385 Kg/s

Specific Thrust: 393.6152 N/Kg

Fuel to air ratio 0.011523

Theraml Efficiency: 0.3687

Propulsive Efficiency: 0.58782

Overall Efficiency: 0.21673

Compressor Isentropic efficiency: 0.82472

Turbine Isentropic efficiency: 0.93423

V9/V0: 1.6962

Range: 5.15E+05 m

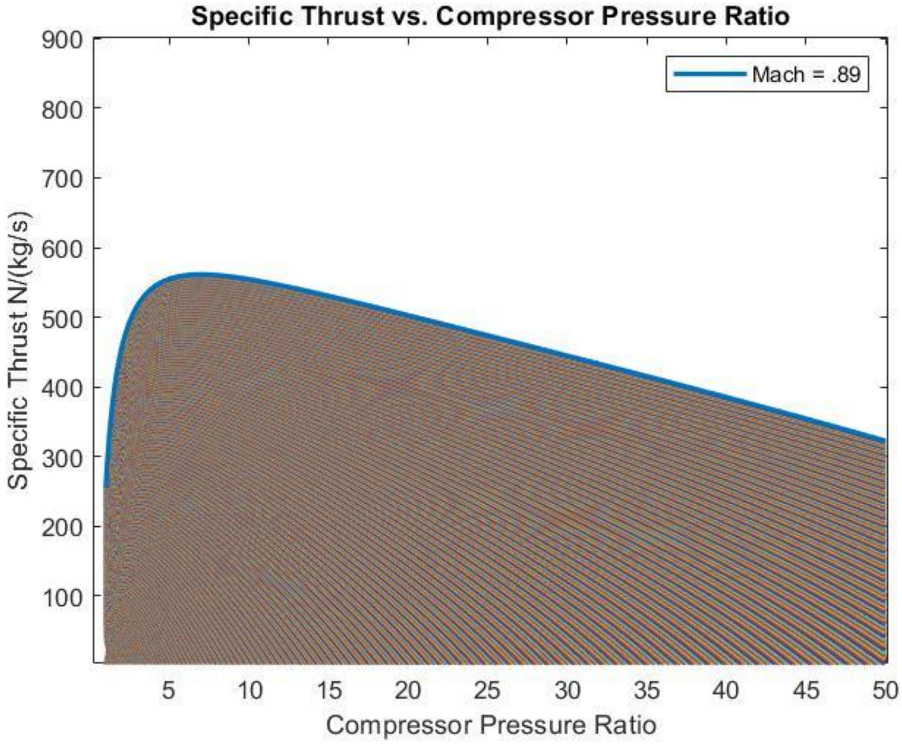


Рисунок 3 Contours of different values of Tt4, and how Specific thrust varies with PI compressor

Рисунок 4 Contours of different values of Tt4, and how Specific thrust varies with PI compressor

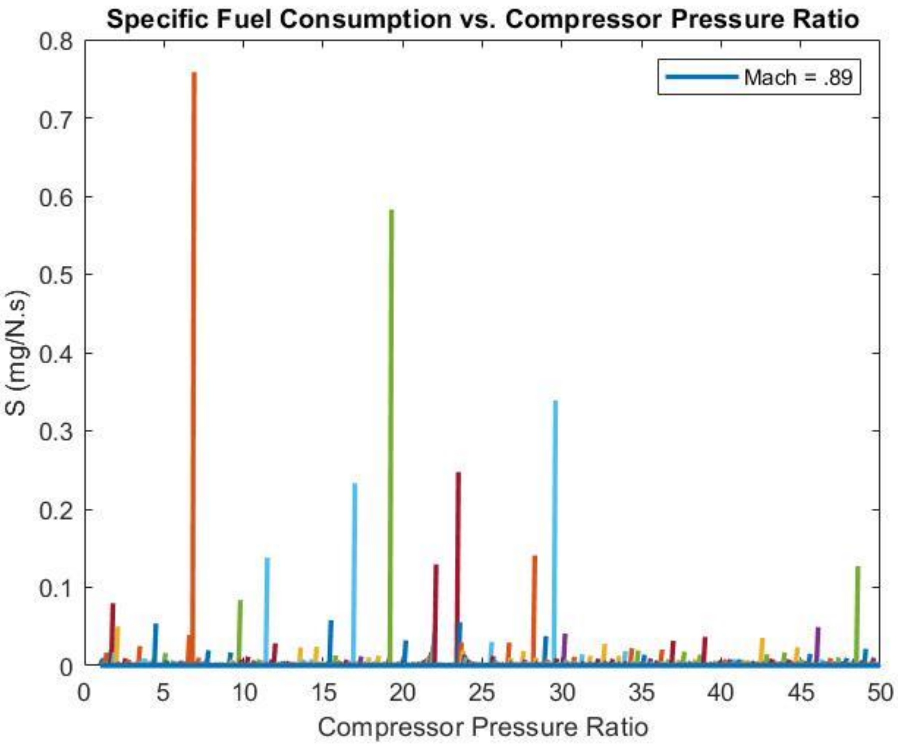


Рисунок 5 Contours of different values of Tt4, and how Specific fuel consumption varies with PI compressor

Рисунок 6 Contours of different values of Tt4, and how Specific fuel consumption varies with PI compressor

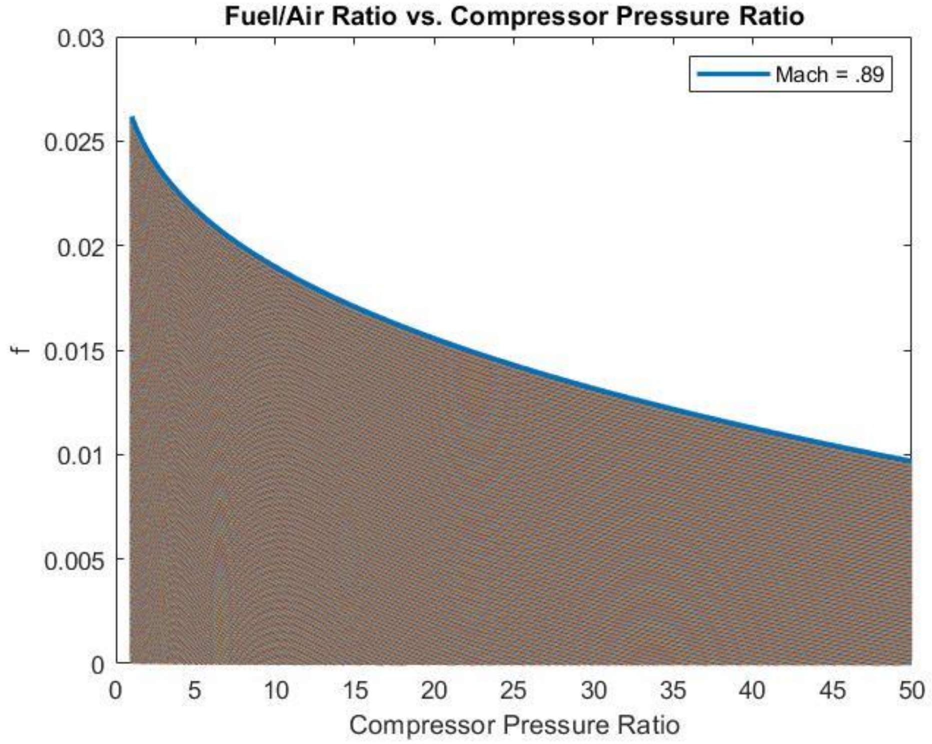


Рисунок 7 Contours of different values of Tt4, and how fuel to air ratio varies with PI compressor

Рисунок 8 Contours of different values of Tt4, and how fuel to air ratio varies with PI compressor

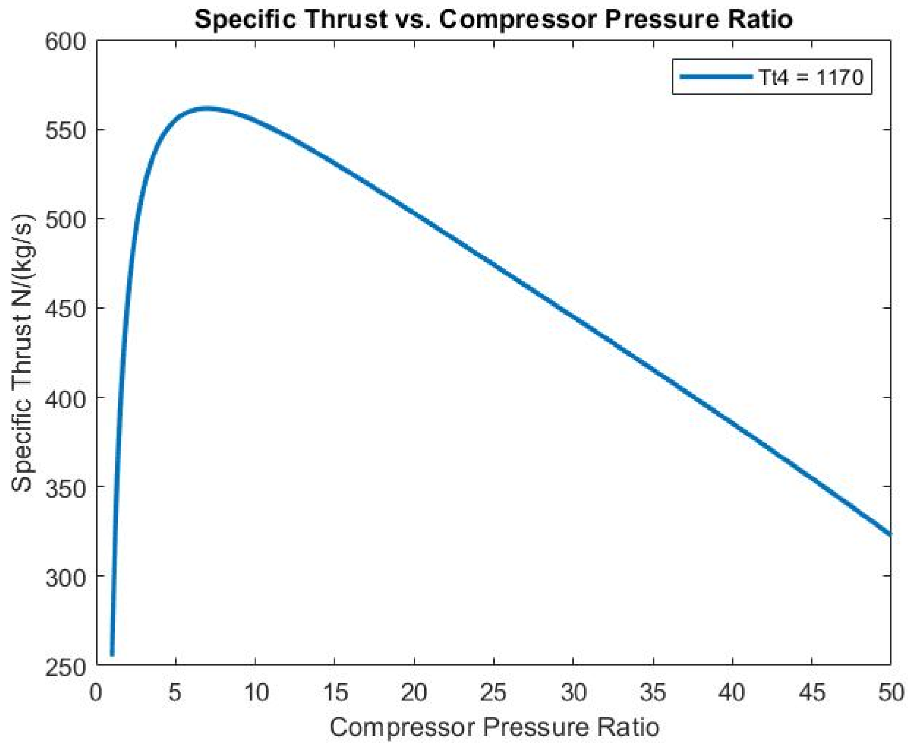


Рисунок 11 Variation of specific Thrust with PI compressor for maximum Tt4

Рисунок 12 Variation of specific Thrust with PI compressor for maximum Tt4

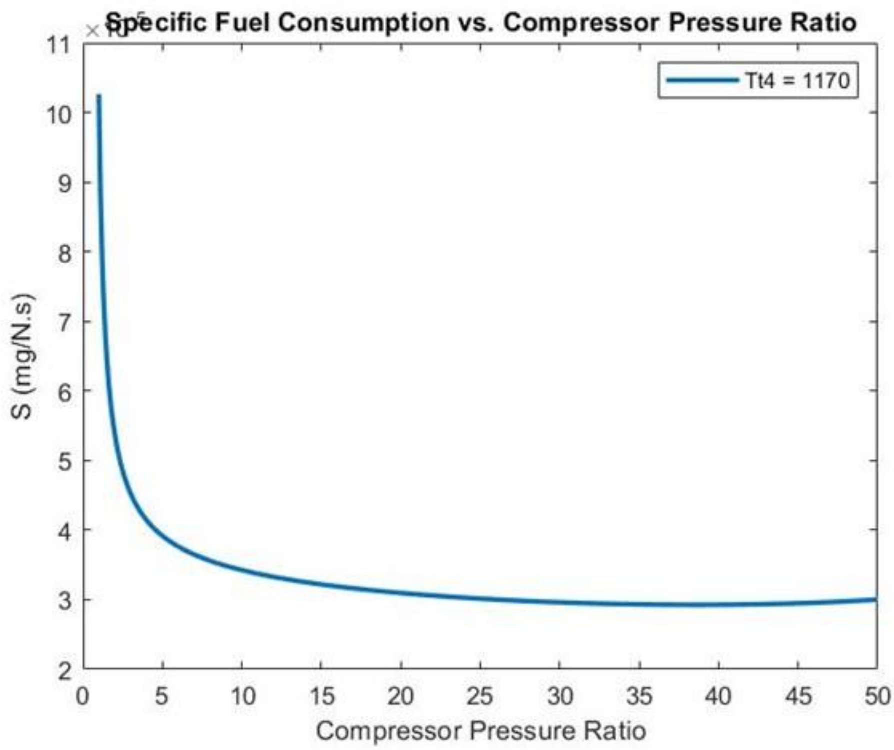


Рисунок 9 Variation of specific Fuel Consumption with PI compressor for maximum Tt4

Рисунок 10 Variation of specific Fuel Consumption with PI compressor for maximum Tt4

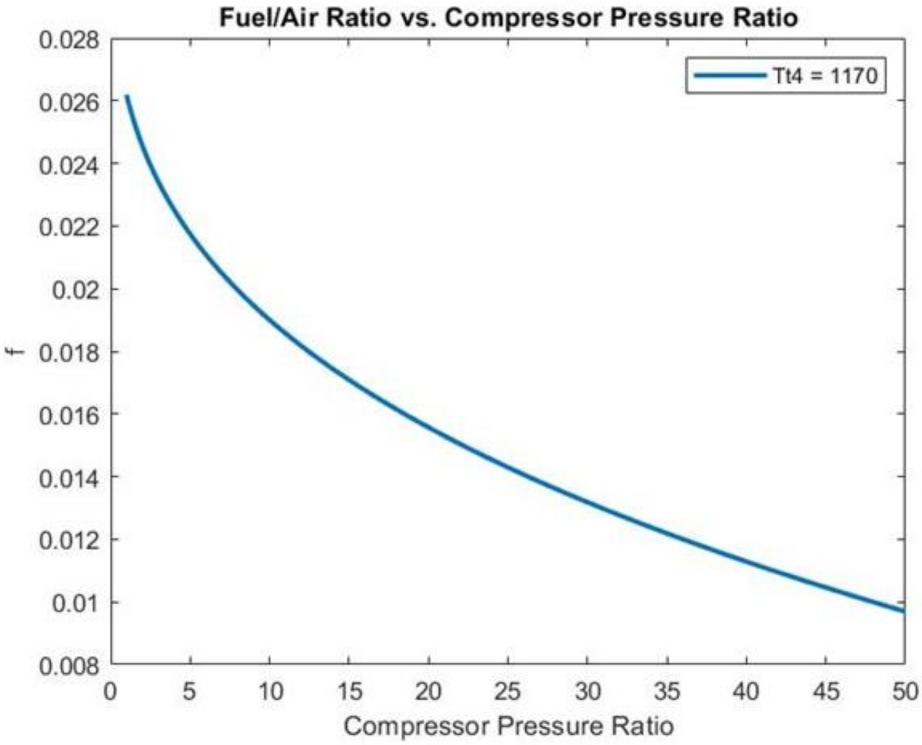


Рисунок 13 Variation of specific Thrust with PI compressor for maximum Tt4

Рисунок 14 Variation of specific Thrust with PI compressor for maximum Tt4

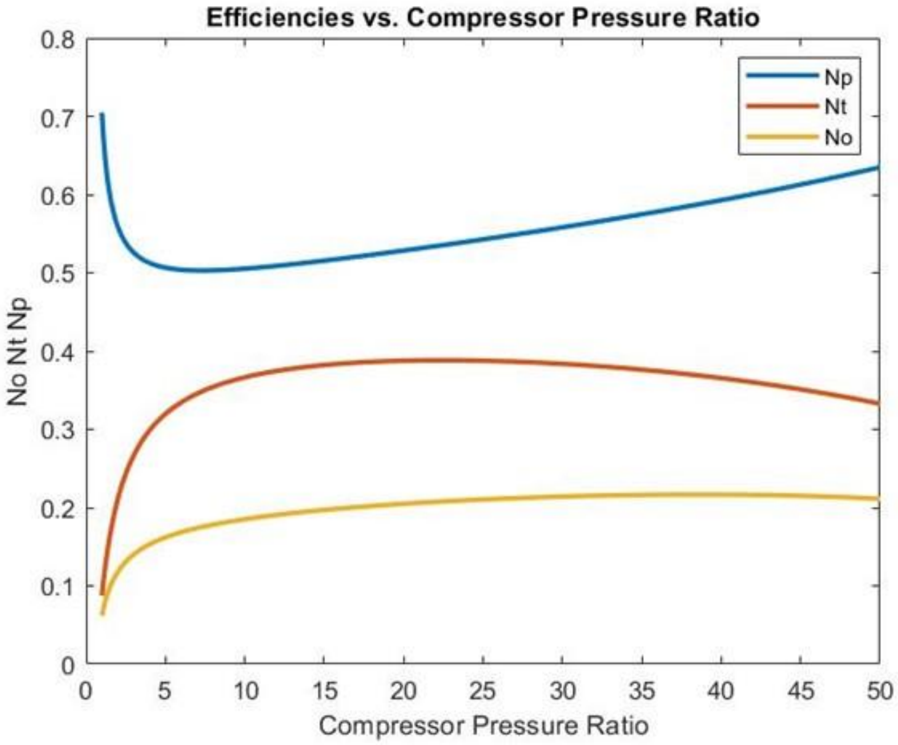


Рисунок 15 Variation of efficiencies with PI compressor for maximum Tt4

Рисунок 16 Variation of efficiencies with PI compressor for maximum Tt4