Aircraft Engine Construction - Ideal ramjet engine

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IDEAL RAMJET

Ramjet engine scheme and assumed cutsection index are presented in the figure below

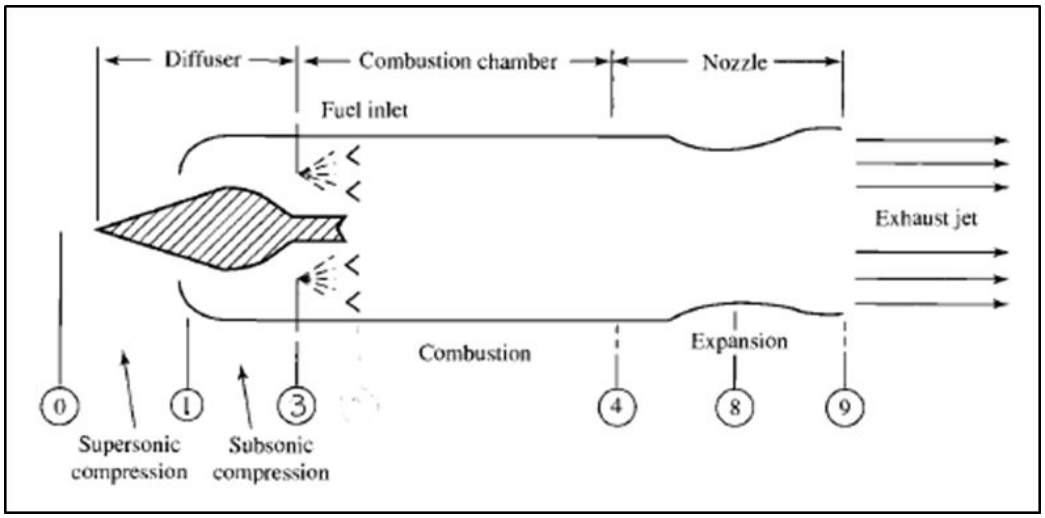


Fig. Rumjest engine

RAMJET SINGLE POINT WORK ANALYSIS

Given

T0=217 K, P0=22 kPa, M0=1.5, Tt4=1500 K, air mass flow m=20 kg/s

Gas parameters:

Air: k=1.4; cp=1005 J/kg/K, R=287 J/kg/K,

Fumes in turbine and nozzle kt=1.33, cpt=1170 J/kg/K, Rt=290 J/kg/K,

For combustion in combustor cpB=1200 J/kg/K,

Fuel heat value: FHV=43 MJ/kg

Flight Mach No

```
M0 = 1.5000
```

Air Mass flow [kg/s]

```
m0 = 20
```

Turbine inlet temperature [K]

```
Tt4 = 1500
```

Ambient conditions

Static temperature [K]

```
T0 = 217
```

Static pressure [Pa]

```
P0 = 22000
```

Section 0

Total temperature [K]

$$T_{t0} = T_0\left(1 + \frac{k-1}{2} M_0^2\right)$$

```
Tt0 = 314.6500
```

Total pressure [Pa]

$$P_{t0} = P_0\left(1 + \frac{k-1}{2} M_0^2\right)^{\frac{k}{k-1}}$$

```
Pt0 = 8.0763e+04
```

Speed of sound [m/s]

$$a_0 = \sqrt{k * R * T_0}$$

```
a0 = 295.2805
```

Flight speed [m/s]

$$V_0 = M_0 * a_0$$

```
V0 = 442.9208
```

Section 1 Engine inlet

Total temperature [K]

$$T_{t1} = T_{t0}$$

```
Tt1 = 314.6500
```

Total pressure [Pa]

$$P_{t1} = P_{t0}$$

```
Pt1 = 8.0763e+04
```

Section 3 - Compressor outlet / Burner inlet

Total temperature [K]

$$T_{t3} = T_{t1}$$

```
Tt3 = 314.6500
```

Total pressure [Pa]

$$P_{t3} = P_{t1}$$

```
Pt3 = 8.0763e+04
```

Section 4 Burner outlet

Total temperature [K]

$$T_{t4}$$

```
Tt4 = 1500
```

Total pressure [Pa]

$$P_{t4} = P_{t3}$$

```
Pt4 = 8.0763e+04
```

BURNER

Fuel-air ratio

$$f_B = c_{pB} * \frac{T_{t4} - T_{t3}}{FHV}$$

```
fB = 0.0331
```

Fuel mass flow [kg/s]

$$m_{fB} = m_0 * f_B$$

```
mfB = 0.6616
```

Section 9 Engine Nozzle outlet

Total temperature [K]

$$T_{t9} = T_{t4}$$

```
Tt9 = 1500
```

Total pressure [Pa]

$$P_{t9} = P_{t5}$$

```
Pt9 = 8.0763e+04
```

Static pressure [Pa]

$$P_9 = P_0$$

```
P9 = 22000
```

Static temperature [K]

$$T_9 = T_{t9} * \left(\frac{P_9}{P_{t9}}\right)^{\frac{kt-1}{kt}}$$

```
T9 = 1.0863e+03
```

Jet stream Mach No

$$M_9 = \sqrt{\left(\frac{T_{t9}}{T_9} - 1\right) * \frac{2}{kt - 1}}$$

```
M9 = 1.5192
```

Speed of sound [m/s]

$$a_9 = \sqrt{kt * Rt * T_9}$$

```
a9 = 647.2958
```

Jet speed [m/s]

$$V_9 = M_9 * a_9$$

```
V9 = 983.3714
```

TURBOJET ENGINE PERFORMANCE CALCULATION

Thrust [N]

$$T = m_0 * (1 + f_B) * V_9 - m_0 * V_0$$

```
T = 1.1460e+04
```

Specific thrust [Ns/kg]

$$ST = \frac{T}{m_0} = (1 + f_B) * V_9 - V_0$$

```
ST = 572.9801
```

Specific fuel consumption [kg/N/s]

$$SFC = \frac{m_{fB}}{T}$$

```
SFC = 5.7732e-05
```

Specific fuel consumption [kg/N/h]

$$SFC = SFC * 3600$$

```
SFC = 0.2078
```

Thermal efficiency

$$\eta_{\text{th}} = \frac{(1 + f_B) * V_9^2 - V_0^2}{2 * f_B * \text{FHV}}$$

```
etha_th = 0.2822
```

Propulsive efficiency

$$\eta_p = \frac{2 * V_0 * \text{ST}}{(1 + f_B) * V_9^2 - V_0^2}$$

```
etha_p = 0.6322
```

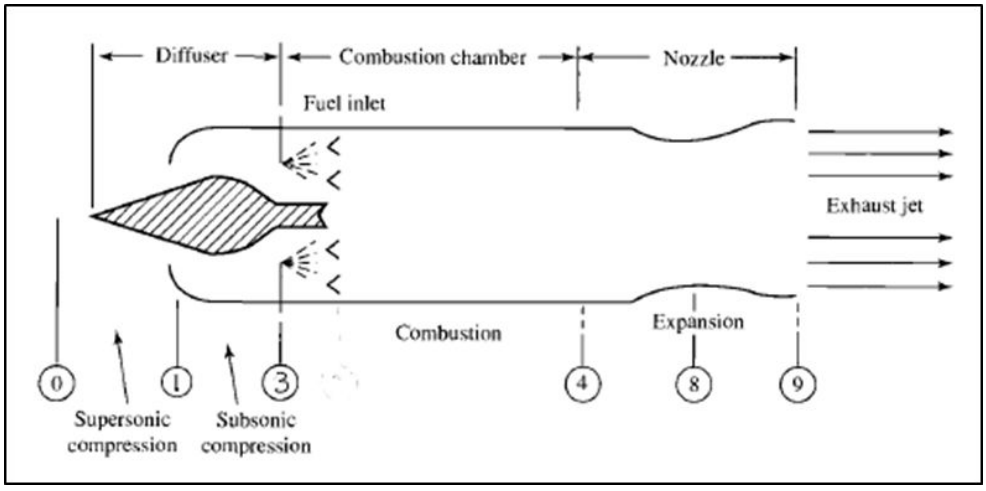
Overall efficiency

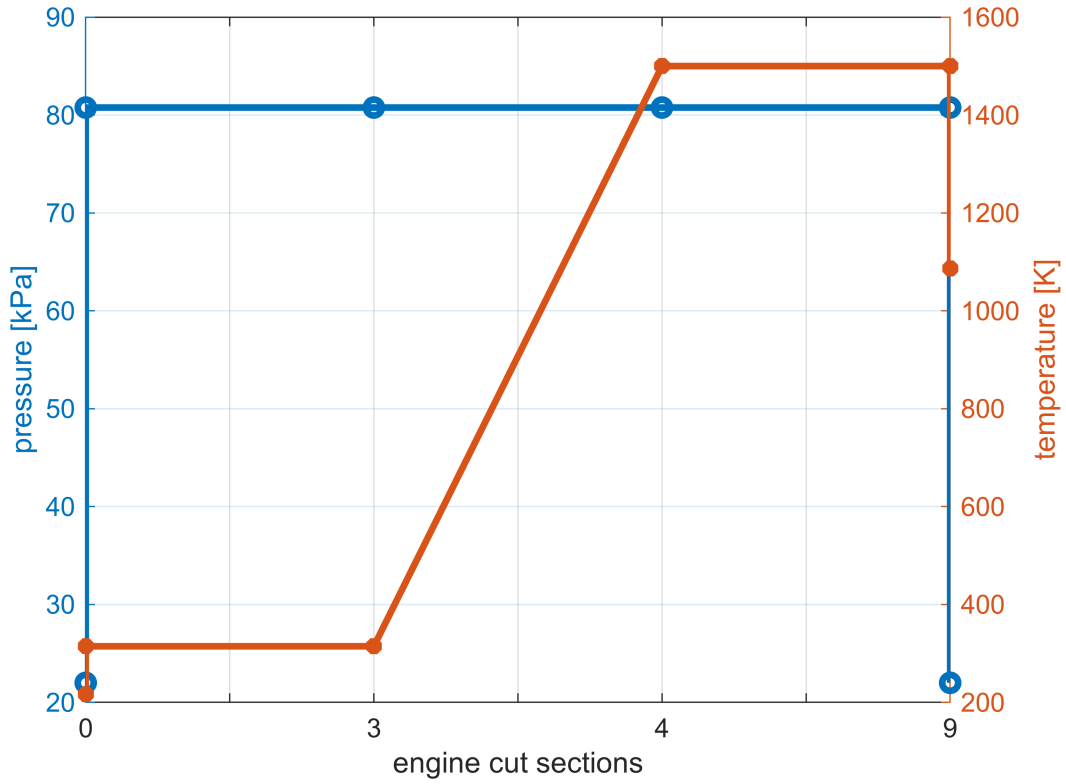
$$\eta_o = \frac{V_0 * \text{ST}}{f_B * \text{FHV}} = \eta_{\text{th}} * \eta_p$$

```
etha_o = 0.1784
```

VISUALIZATION of SINGLE POINT CALCULATION RESULTS

Temperature, pressure vs engine cutsections plot





CONCLUSIONS

- Pressure increases in inlet - ram efect (from sataic to total due to flight speed)
- Pressure decrease in propelling nozzle (from total to static - jet speed is produecd)
- Tepearture increase in inlet and combustor
- Temparture decrease in propeling nozzle

`Tabela = 8×3 table`

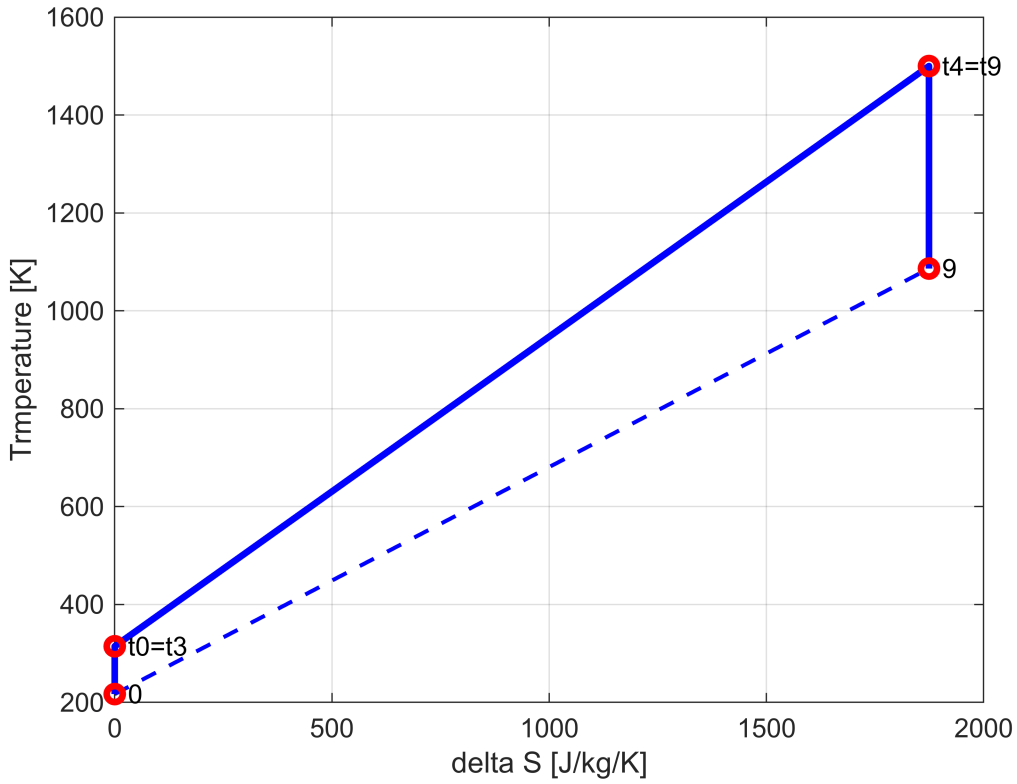
	Parameter	Unit	Value
1	'Thrust'	'kN'	11.4596
2	'Specific Thrust'	'N*s/kg'	572.9801
3	'V9'	'm/s'	983.3714
4	'Fuel consumption'	'kg/s'	0.6616
5	'Specific fuel consump'	'kg/N/h'	0.2078
6	'therm. efficiency'	'-'	0.2822
7	'prop. efficiency'	'-'	0.6322
8	'overall efficiency'	'-'	0.1784

Temperature - entropy plot

Combuctor entropy growth

$$\Delta s = c_{\mathrm{pB}} * \ln \frac{T_{\mathrm{t4}}}{T_{\mathrm{t3}}}$$

```
deltaS = 1.8741e+03
```



CONCLUSIONS

- Ram compression (in the inlet) is isentropic as decompression in the propelling nozzle. The entropy grow is observed in combustion process only

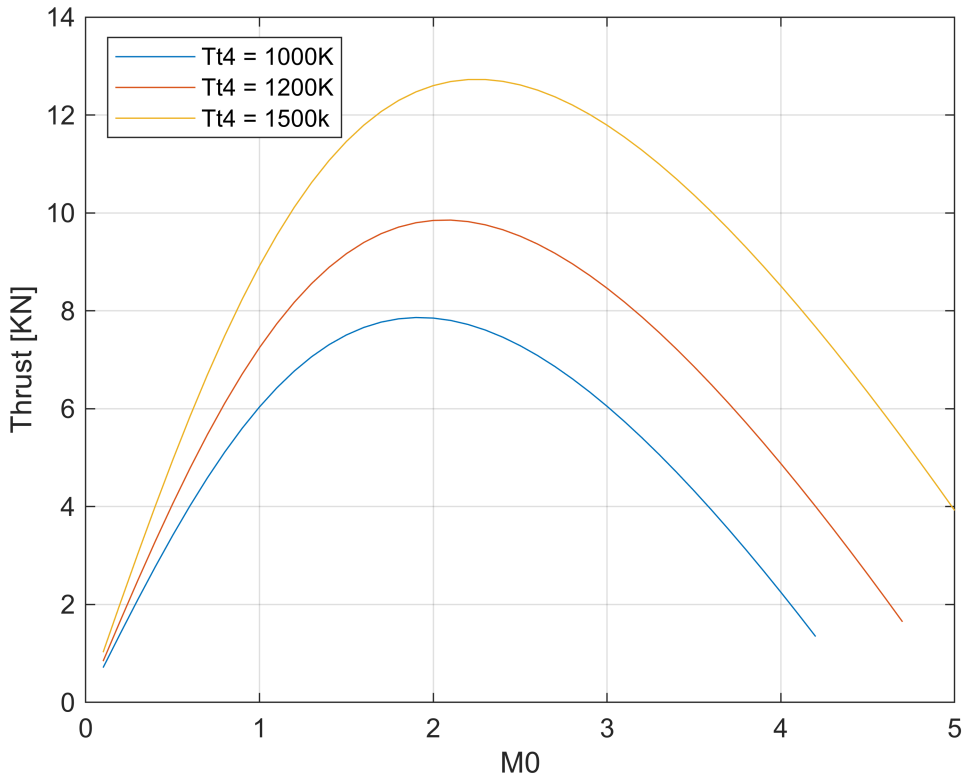
PERFORMANCE OF IDEAL RAMJET

Example of the ideal ramjet calculation for flight speed from 0 to 3 for different Tt4;

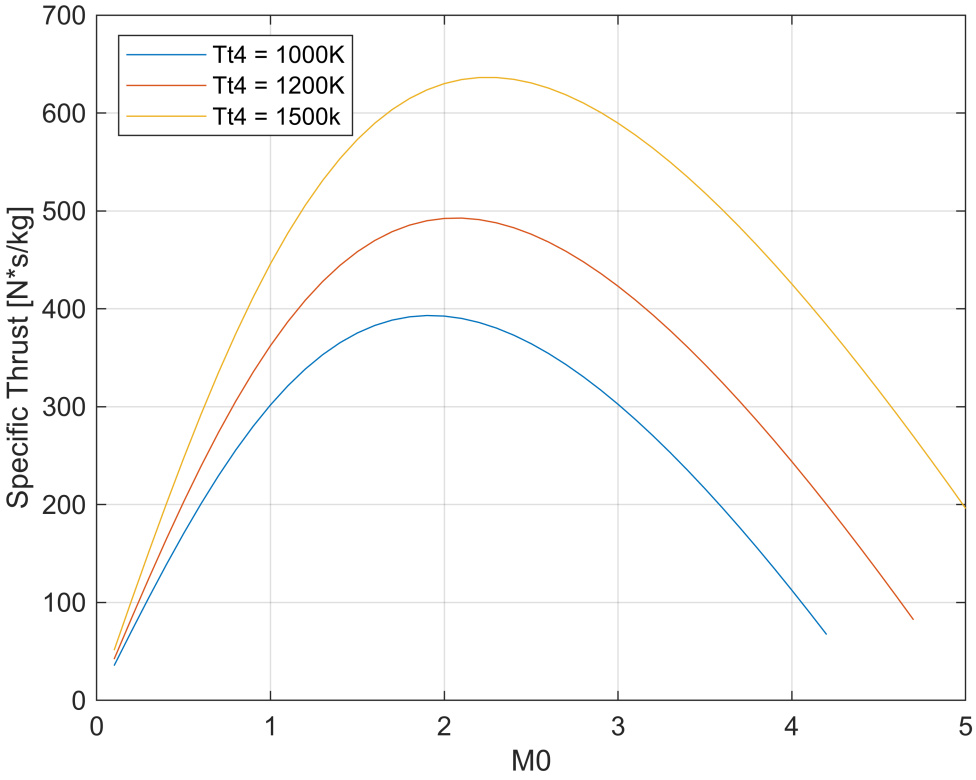
Given

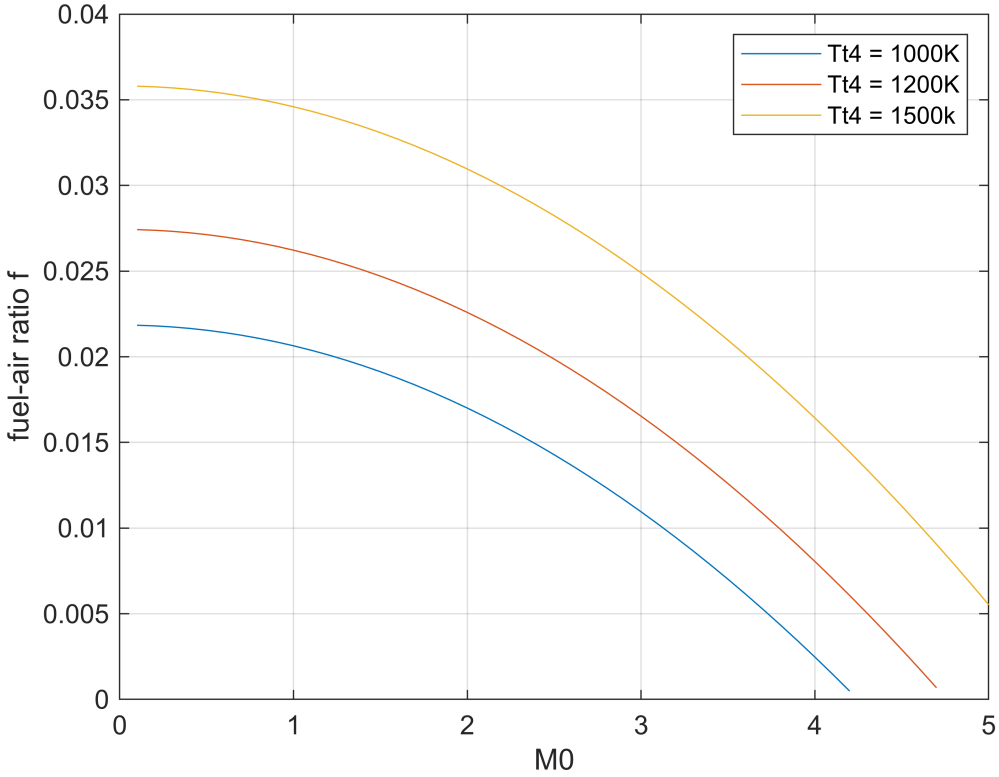
T0=217 K, P0=22 kPa, air mass flow m=20 kg/s

Calculation is done in the loop for M0=[0:0.1:5] first for Tt4=1000K and next for Tt4-1200k and Tt4=1500 K

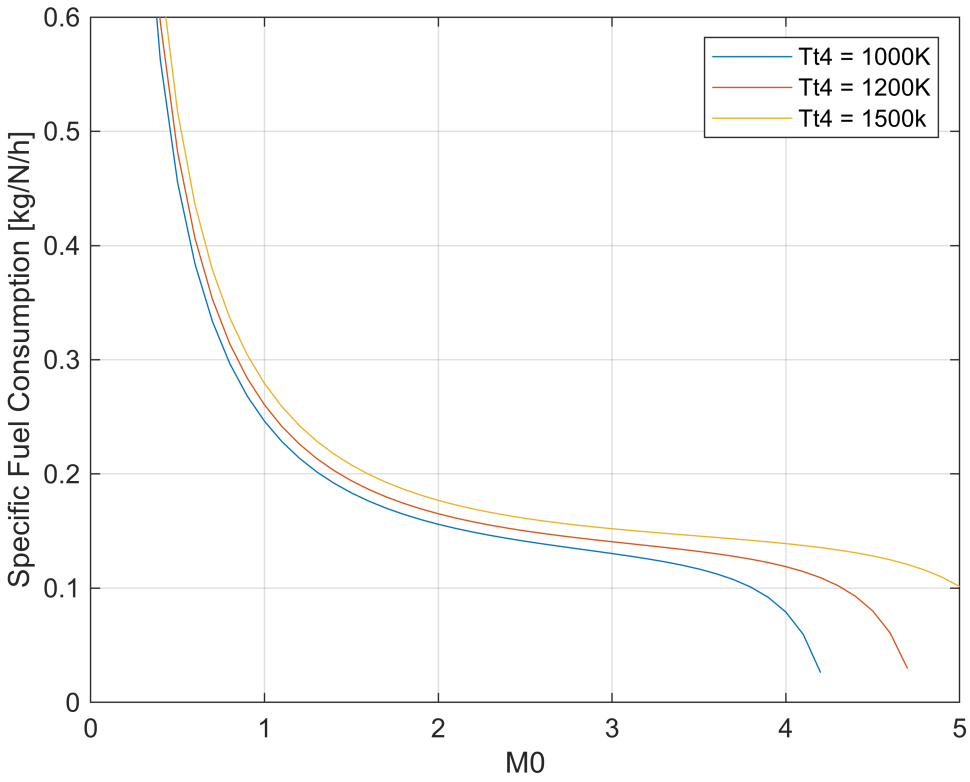


Ramjet engine thrust increases to its maximum with flight speed and then decreases. For higher Tt4 thrust is higher and reaches its maximum value for higher flight speed. Specific thrust vs flight speed relation looks similar.





The fuel to air ratio goes down with flight speed. Additionally it is lower for the lower Tt4. The range of flight speed applicability is lower when Tt4 is lower (the end of range when f reaches 0)


Tt4 = 1000K
Tt4 = 1200K
Tt4 = 1500k
Specific Fuel Consumption [kg/N/h]
M0
0
0.1
0.2
0.3
0.4
0.5
0.6
0
1
2
3
4
5

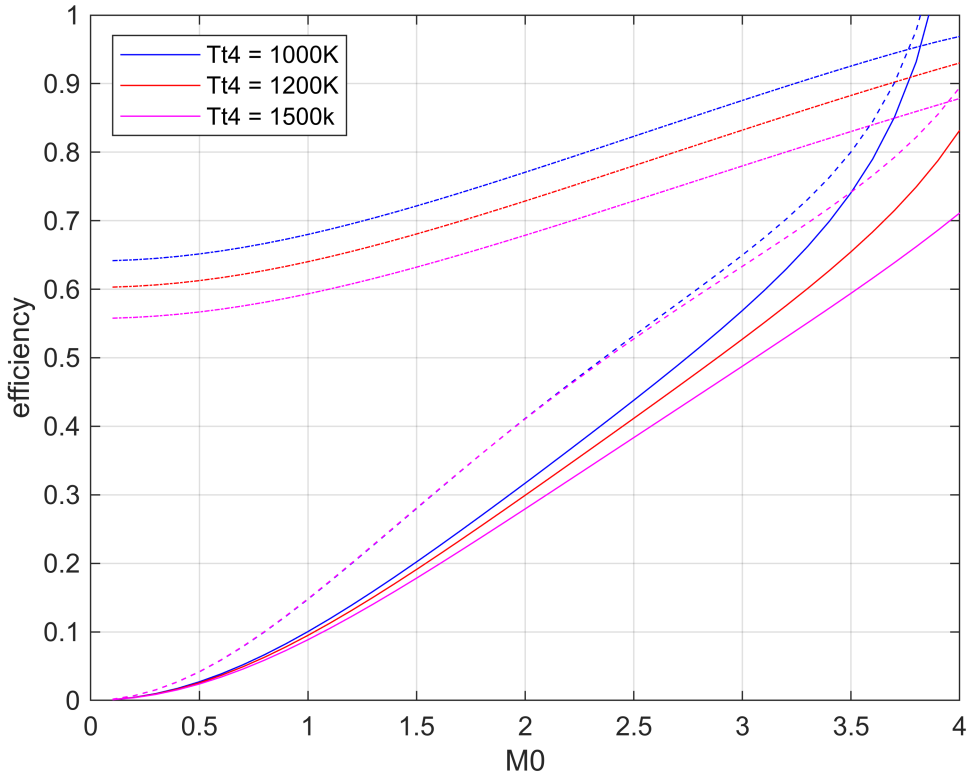

Tt4 = 1000K
Tt4 = 1200K
Tt4 = 1500k
efficiency
M0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.5
1
1.5
2
2.5
3
3.5
4

Figure: Ramjet efficiency - dashed line - thermal efficiency; dashed-dot line - propulsive efficiency; continous line - overal efficiency

All ramjet efficiencies incease with flight speed.

FUNCTIONS