TURBOFAN ENGINE with MIXED STREAMS

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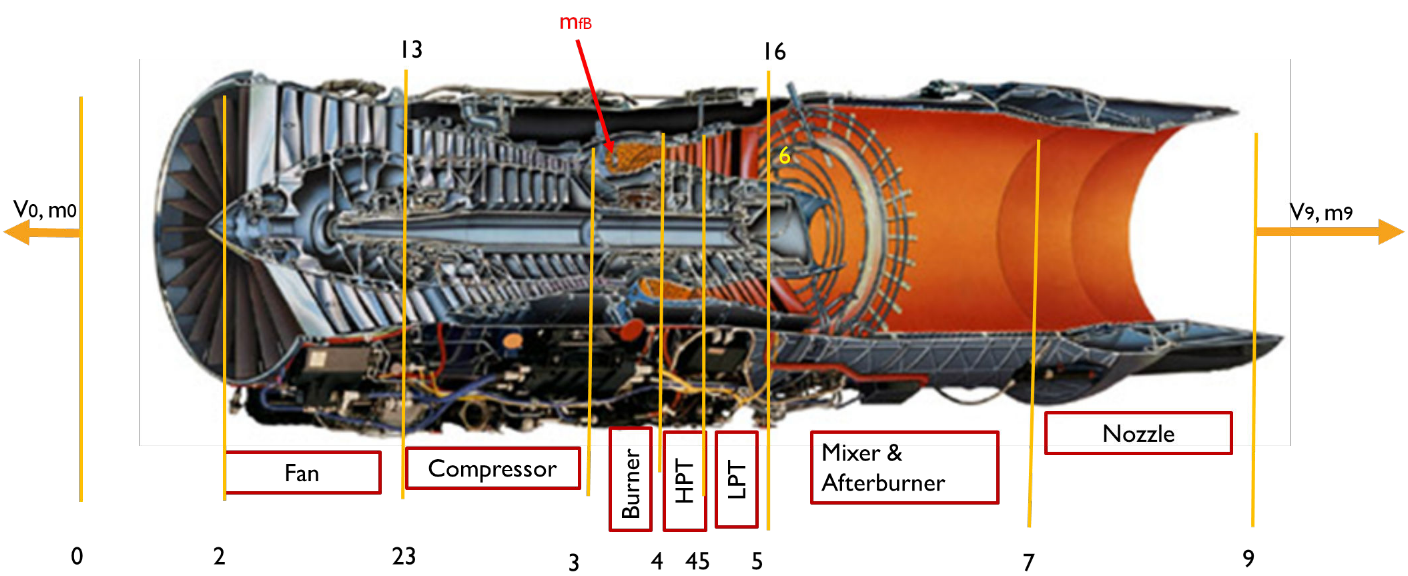
TURBOFAN ENGINE with MIXED STREAMS

En example of turbofan mixed stream engin calculation is presented. The assumption is that the engine nozzle expanison is to ambient pressure. The engine scheme is presented below



Given

Flight conditions: T0=217 K, P0=22 kPa, M0=0.9, fan pressure ratio 3.8, compressor pressure ratio 15, Turbine inlet temperature Tt4=1500 K, mass flow m=60 kg/s.

Engine losses coefficients:

Inlet pressure losses coefficient σ_{IN} 0.97, burner pessure losses coefficient σ_B 0.98, internal duct pressure losses $\sigma_{D\,\text{int}}$ 0.99, external duct pressure losses $\sigma_{D\,\text{ext}}$ 0.97, nozzle pressure losses coefficient σ_N 0.97, fun efficiency η_F 0,89, compressor efficeincy η_C 0.85, high pressure turbine (HPT) efficiency η_{HPT} 0.87, low pressure turbine (LPT) efficiency η_{LPT} 0.89, burner efficiency η_B 0.99, mechanical efficiency low pressure spool $\eta_{M\ LP}$= 0.995, mechanical efficiency high pressure spool $\eta_{M\ HP}$= 0.99, mixer pressure losses coefficient σ_{MIX} 0.95.

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 = 0.9000
```

Air Mass flow [kg/s]

```
m0 = 60
```

Turbine inlet temperature [K]

```
Tt4 = 1500
```

Fan pressure ratio

```
FPR = 3.8000
```

Compressor pressure ratio

```
CPR = 15
```

Ambient conditions

Static temperature [K]

```
T0 = 217
```

Static pressure [Pa]

```
P0 = 22000
```

1) Evaluate BPR to Pt6=Pt16

Calculation in loop to determine BPR to fulfil condition that Pt6=Pt16

BPR is assumed as a range from 0:1 with a step of 0.1

```
BPR = 1×11
         0    0.1000    0.2000    0.3000    0.4000    0.5000    0.6000    0.7000 ···
```

Section 0

Total temperature [K]

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

```
Tt0 = 252.1540
```

Total pressure [Pa]

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

```
Pt0 = 3.7209e+04
```

Speed of sound [m/s]

$a_0 = \sqrt{k * R * T_0}$ - like for ideal engine

```
a0 = 295.2805
```

Flight speed [m/s]

$V_0 = M_0 * a_0$ - like for ideal engine

```
V0 = 265.7525
```

Section 2 Compressor inlet

Total temperature [K]

$T_{t2} = T_{t0}$ - like for ideal engine

```
Tt2 = 252.1540
```

Total pressure [Pa]

$P_{t2} = \sigma_{IN} * P_{t0}$

```
Pt2 = 3.6092e+04
```

Section 25/13 - Fan outlet

Total temperature [K]

$$T_{t25} = T_{t13} = T_{t2} * \left(1 + \frac{\mathrm{FPR}^{\frac{k-1}{k}} - 1}{\eta_F}\right)$$

```
Tt25 = 383.7205

Tt13 = 383.7205
```

Total pressure [Pa]

$P_{t25} = P_{t13} = P_{t2} * \mathrm{FPR}$

```
Pt25 = 1.3715e+05
```

FAN

Fan work   [J/kg]

$$W_F = c_p * (T_{t25} - T_{t2})$$

```
WF = 1.3222e+05
```

Fan power   [W]

$$P_F = m_p * W_F$$

```
PF = 7.9335e+06
```

START LOOP CALCULATION:

STREAM SPLIT

Internal duct mass flow   [kg/s]

$$m_{25} = m_0 * \frac{1}{1 + \mathrm{BPR}}$$

External duct mass flow   [kg/s]

$$m_{13} = m_0 * \frac{\mathrm{BPR}}{1 + \mathrm{BPR}}$$

INTERNAL DUCT / CORE ENGINE

Section 3 - Compressor outlet / Burner inlet

Total temperature   [K]

$$T_{t3} = T_{t25} * \left(1 + \frac{\mathrm{CPR}^{\frac{k-1}{k}} - 1}{\eta_C}\right)$$

Total pressure   [Pa]

$$P_{t3} = P_{t25} * \mathrm{CPR}$$

COMPRESSOR

Compressor work   [J/kg]

$$W_C = c_p * (T_{t3} - T_{t25})$$

Compressor power   [W]

$$P_C = m_{25} * W_C$$

Section 4 Burner outlet / Turbine inlet

Total temperature   [K]

$$T_{t4}$$

Total pressure   [Pa]

$P_{t4} = \sigma_B * P_{t3}$

BURNER

Fuel-air ratio

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

Fuel mass flow   [kg/s]

$$m_{fB} = m_{25} * f_B$$

Section 45   High Pressure Turbine (HPT) outlet / Low Pressure Turbine (LPT) inlet

Total temperature   [K]

$$T_{t45} = T_{t4} - \frac{W_C}{\eta_{M\,\mathrm{HP}} * (1 + f_B) * c_{pt}}$$

Total pressure [Pa]

$$P_{t45} = P_{t4}\left(\frac{\eta_{T\,\mathrm{HP}} + \frac{T_{t45}}{T_{t4}} - 1}{\eta_T}\right)^{\frac{\mathrm{kt}}{\mathrm{kt}-1}}$$

High pressure turbine pressure ratio

$$H\mathrm{PT\ PR} = \frac{P_{t4}}{P_{t45}}$$

Section 5   LPT outlet / Nozzle inlet

Total temperature   [K]

$$T_{t5} = T_{t45} - \frac{(1 + \mathrm{BPR})W_F}{\eta_{M\,\mathrm{LP}} * (1 + f_B) * c_{pt}}$$

Total pressure [Pa]

$$P_{t5} = P_{t45}\left(\frac{\eta_{\mathrm{LPT}} + \frac{T_{t5}}{T_{t45}} - 1}{\eta_{\mathrm{LPT}}}\right)^{\frac{\mathrm{kt}}{\mathrm{kt}-1}}$$

Low pressure turbine pressure ratio

$$\mathrm{LPT\ PR} = \frac{P_{t45}}{P_{t5}}$$

Section 6 Core engine mixer inlet

Total pressure [Pa]

$P_{t6} = \sigma_{D\,int} * P_{t5}$

Section 16 Bypass flow engine mixer inlet

Total pressure [Pa]

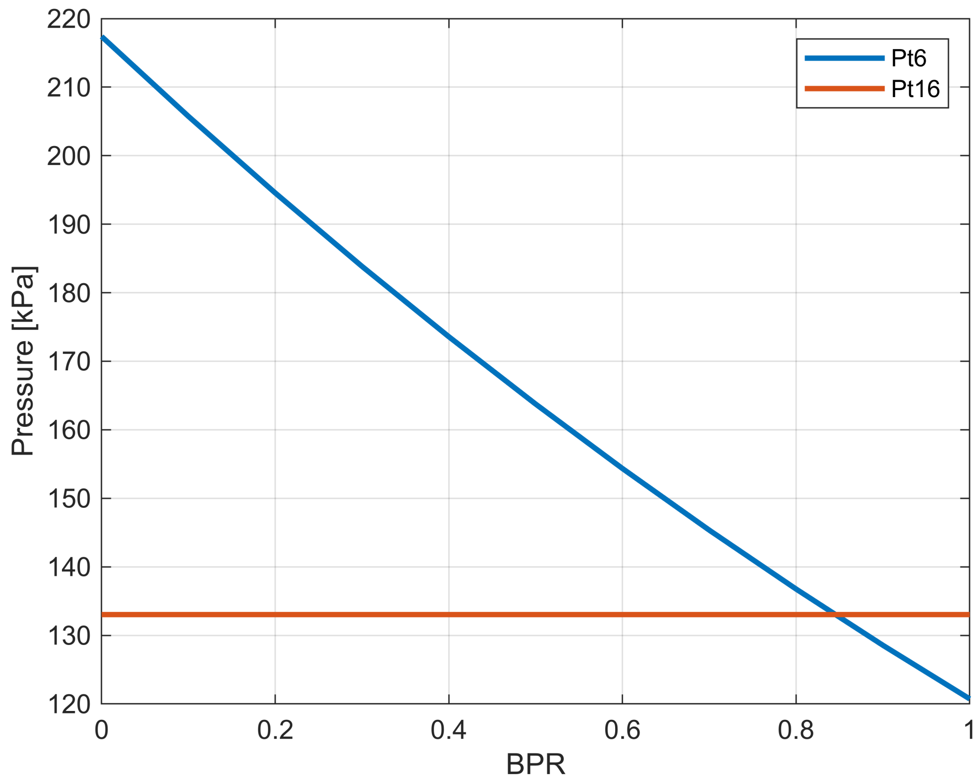
$P_{t16} = \sigma_{D\,ext} * P_{t13}$

The end of loop calculation

Pt16 vs P6 comparison

tabela1 = 11×3 table

	BPR	Pt6 [kPa]	Pt16 [kPa]
1	0	217.3911	133.0366
2	0.1000	205.7369	133.0366
3	0.2000	194.5588	133.0366
4	0.3000	183.8436	133.0366
5	0.4000	173.5783	133.0366
6	0.5000	163.7501	133.0366
7	0.6000	154.3463	133.0366
8	0.7000	145.3544	133.0366
9	0.8000	136.7622	133.0366
10	0.9000	128.5577	133.0366
11	1	120.7288	133.0366



Presented data shows that BPR about 0.85 fulfil that Pt16=Pt6. This value is assumed to the next calculation

2) Turbofan with mixed flow engine calculation

BPR is assumed 0.85

```
BPR = 0.8500
```

Section 0

Total temperature [K]

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

```
Tt0 = 252.1540
```

Total pressure [Pa]

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

```
Pt0 = 3.7209e+04
```

Speed of sound [m/s]

$a_0 = \sqrt{k * R * T_0}$ - like for ideal engine

```
a0 = 295.2805
```

Flight speed [m/s]

$V_0 = M_0 * a_0$ - like for ideal engine

```
V0 = 265.7525
```

Section 2 Compressor inlet

Total temperature [K]

$T_{t2} = T_{t0}$ - like for ideal engine

```
Tt2 = 252.1540
```

Total pressure [Pa]

$P_{t2} = \sigma_{IN} * P_{t0}$

```
Pt2 = 3.6092e+04
```

Section 25/13 - Fan outlet

Total temperature [K]

$$T_{t25} = T_{t13} = T_{t2} * \left(1 + \frac{\mathrm{FPR}^{\frac{k-1}{k}} - 1}{\eta_F}\right)$$

```
Tt25 = 383.7205
Tt13 = 383.7205
```

Total pressure [Pa]

$P_{t25} = P_{t13} = P_{t2} * \mathrm{FPR}$

```
Pt25 = 1.3715e+05
Pt13 = 1.3715e+05
```

FAN

Fan work [J/kg]

$W_F = c_p * (T_{t25} - T_{t2})$

```
WF = 1.3222e+05
```

Fan power [W]

$P_F = m_p * W_F$

```
PF = 7.9335e+06
```

STREAM SPLIT

Internal duct mass flow [kg/s]

$$m_{25} = m_0 * \frac{1}{1 + \text{BPR}}$$

```
m25 = 32.4324
```

External duct mass flow [kg/s]

$$m_{13} = m_0 * \frac{\text{BPR}}{1 + \text{BPR}}$$

```
m13 = 27.5676
```

INTERNAL DUCT / CORE ENGINE

Section 3 - Compressor outlet / Burner inlet

Total temperature [K]

$$T_{\text{t3}} = T_{\text{t25}} * \left(1 + \frac{\text{CPR}^{\frac{k-1}{k}} - 1}{\eta_C}\right)$$

```
Tt3 = 910.9227
```

Total pressure [Pa]

$$P_{\text{t3}} = P_{\text{t25}} * \text{CPR}$$

```
Pt3 = 2.0573e+06
```

COMPRESSOR

Compressor work [J/kg]

$$W_C = c_p * (T_{\text{t3}} - T_{\text{t25}})$$

```
WC = 5.2984e+05
```

Compressor power [W]

$$P_C = m_{25} * W_C$$

Section 4 Burner outlet / Turbine inlet

Total temperature [K]

$$T_{\text{t4}}$$

```
Tt4 = 1500
```

Total pressure [Pa]

$$P_{\text{t4}} = \sigma_B * P_{\text{t3}}$$

```
Pt4 = 2.0161e+06
```

BURNER

Fuel-air ratio

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

```
fB = 0.0166
```

Fuel mass flow [kg/s]

$$m_{fB} = m_{25} * f_B$$

```
mfB = 0.5386
```

Section 45 High Pressure Turbine (HPT) outlet / Low Pressure Turbine (LPT) inlet

Total temperature [K]

$$T_{t45} = T_{t4} - \frac{W_C}{\eta_{M\,\text{HP}} * (1 + f_B) * c_{pt}}$$

```
Tt45 = 1.0500e+03
```

Total pressure [Pa]

$$P_{t45} = P_{t4}\left(\frac{\eta_{T\,\text{HP}} + \frac{T_{t45}}{T_{t4}} - 1}{\eta_T}\right)^{\frac{\text{kt}}{\text{kt}-1}}$$

```
Pt45 = 3.6683e+05
```

High pressure turbine pressure ratio

$$H\text{PT PR} = \frac{P_{t4}}{P_{t45}}$$

```
HPT_PR = 5.4961
```

Section 5 LPT outlet / Nozzle inlet

Total temperature [K]

$$T_{t5} = T_{t45} - \frac{(1 + \text{BPR})W_F}{\eta_{M\,\text{LP}} * (1 + f_B) * c_{pt}}$$

```
Tt5 = 843.3532
```

Total pressure [Pa]

$$P_{t5} = P_{t45}\left(\frac{\eta_{\text{LPT}} + \frac{T_{t5}}{T_{t45}} - 1}{\eta_{\text{LPT}}}\right)^{\frac{\text{kt}}{\text{kt}-1}}$$

```
Pt5 = 1.3395e+05
```

Low pressure turbine pressure ratio

$$\text{LPT PR} = \frac{P_{t45}}{P_{t5}}$$

```
LPT_PR = 2.7385
```

Section 6 Core engine mixer inlet

Total pressure [Pa]

$$P_{t6} = \sigma_{D\,int} * P_{t5}$$

```
Pt6 = 1.3261e+05
```

Total temperature [K]

$$T_{t6} = T_{t5}$$

```
Tt6 = 843.3532
```

Mass flow

$$\dot{m}_6 = \dot{m}_{25} + \dot{m}_{fB}$$

```
m6 = 32.9710
```

Section 16 Bypass flow engine mixer inlet

Total pressure [Pa]

$$P_{t16} = \sigma_{D\,ext} * P_{t13}$$

```
Pt16 = 1.3304e+05
```

Total temperature [K]

$$T_{t16} = T_{t13}$$

```
Tt16 = 383.7205
```

Mass flow

$$\dot{m}_{16} = \dot{m}_{13}$$

```
m16 = 27.5676
```

Section 7 Mixer exit

Mixer inlet pressure is calculated by mass flow averaging formula:

$$P_{av} = \frac{P_{t6} * \dot{m}_6 + P_{t16} * \dot{m}_{16}}{\dot{m}_6 + \dot{m}_{16}}$$

```
Pav = 1.3281e+05
```

Outlet mixer pressure is

$$P_{t7} = \sigma_{MIX} * P_{av}$$

```
Pt7 = 1.2617e+05
```

Mixer outlet mass flow

$$\dot{m}_7 = \dot{m}_{16} + \dot{m}_6$$

```
m7 = 60.5386
```

Outlet temeperature

$$T_{t7} = \frac{c_{pt}\dot{m}_6 T_{t6} + c_p \dot{m}_{16} T_{t16}}{c_{pt}\dot{m}_6 + c_p \dot{m}_{16}}$$

```
Tt7 = 651.2284
```

Section 9 Engine nozzle outlet

Total temperature [K]

$$T_{t9} = T_{t7}$$

```
Tt9 = 651.2284
```

Total pressure [Pa]

$$P_{t9} = P_{t7} * \sigma_N$$

```
Pt9 = 1.2238e+05
```

Static pressure [Pa]

$$P_9 = P_0$$

```
P9 = 22000
```

Static temperature [K]

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

```
T9 = 425.4143
```

Jet stream Mach No

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

```
M9 = 1.7936
```

Speed of sound [m/s]

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

```
a9 = 405.0707
```

Jet speed [m/s]

$$V_9 = M_9 * a_9$$

```
V9 = 726.5381
```

TURBOFAN ENGINE PERFORMANCE CALCULATION

Thrust [N]

$$T = m_{25} * (1 + f_B + \mathrm{BPR}) * V_9 - m_{25} * (1 + \mathrm{BPR}) * V_0$$

```
T = 2.8038e+04
```

Specific thrust [Ns/kg]

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

```
ST = 467.3069
```

Specific fuel consumption [kg/N/s]

$$\mathrm{SFC} = \frac{m_{\mathrm{fB}}}{T} = \frac{f_B}{(1 + \mathrm{BPR}) * \mathrm{ST}}$$

```
SFC = 1.9208e-05
```

Specific fuel consumption [kg/N/h]

$$\mathrm{SFC} = \mathrm{SFC} * 3600$$

```
SFC = 0.0691
```

Thermal efficiency

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

```
etha_th = 0.5985
```

Propulsive efficiency

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

```
etha_p = 0.5376
```

Overall efficiency

$$\eta_o = \frac{V_0 * \mathrm{ST} * (1 + \mathrm{BPR})}{f_B * \mathrm{FHV}} = \eta_{\mathrm{th}} * \eta_p$$

```
etha_o = 0.3218
```

Temperature, pressure vs engine sections plot

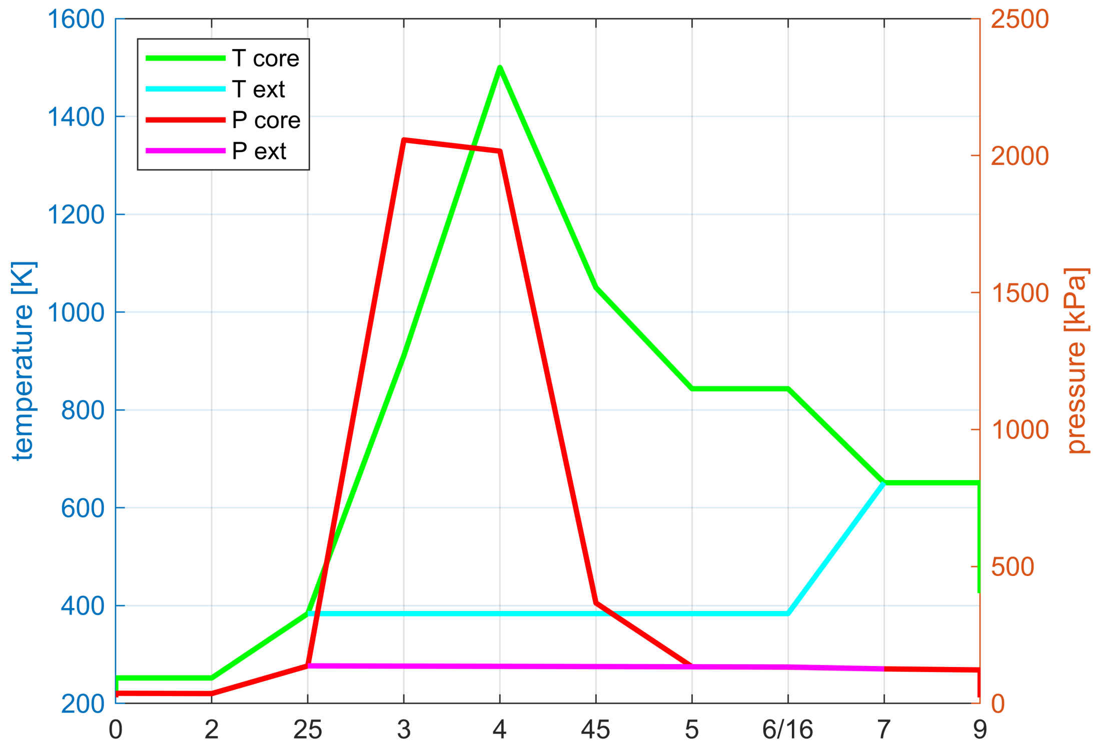


Tabela = 13×3 table

	Section	T [K]	P [kPa]
1	'0'	217	22
2	't0'	252	37.2087
3	't2'	252	36.0924
4	't25'	384	137.1512
5	't3'	911	2.0573e+03
6	't4'	1500	2.0161e+03
7	't45'	1050	366.8300
8	't5'	843	133.9518
9	't6'	843	132.6122
10	't16'	384	133.0366
11	't7'	651	126.1652
12	't9'	651	122.3803
13	'9'	425	22

Temperature - entropy calculation and plot

Entropy growth is calculated from equations:

Inlet entropy grow   [J/kg/K] :

$$\Delta s_{\mathrm{IN}} = -R * \ln(\sigma_{\mathrm{IN}})$$

```
dS_IN = 8.7418
```

Fan entropy grow   [J/kg/K] :

$$\Delta s_F = c_p * \ln \frac{T_{\mathrm{t25}}}{T_{\mathrm{t2}}} - R * \ln(\mathrm{FPR})$$

```
dS_F = 38.8283
```

Compressor entropy grow   [J/kg/K] :

$$\Delta s_C = c_p * \ln \frac{T_{\mathrm{t3}}}{T_{\mathrm{t25}}} - R * \ln(\mathrm{CPR})$$

```
dS_C = 91.6560
```

Combustor entropy grow   [J/kg/K] :

$$\Delta s_B = c_{\mathrm{pB}} * \ln \frac{T_{\mathrm{t4}}}{T_{\mathrm{t3}}} - R_t * \ln(\sigma_B)$$

```
dS_B = 604.3736
```

HPT entropy grow   [J/kg/K] :

$$\Delta s_{\mathrm{HPT}} = c_{\mathrm{pt}} * \ln \frac{T_{\mathrm{t45}}}{T_{\mathrm{t4}}} - R_t * \ln\left(\frac{P_{\mathrm{t45}}}{P_{\mathrm{t4}}}\right)$$

```
dS_HPT = 76.9091
```

LPT entropy grow   [J/kg/K] :

$$\Delta s_{\mathrm{LPT}} = c_{\mathrm{pt}} * \ln \frac{T_{\mathrm{t5}}}{T_{\mathrm{t45}}} - R_t * \ln\left(\frac{P_{\mathrm{t5}}}{P_{\mathrm{t45}}}\right)$$

```
dS_LPT = 35.6854
```

Core duct after turbine entropy grow   [J/kg/K] :

$$\Delta s_{D\,\mathrm{int}} = -\mathrm{Rt} * \ln(\sigma_{D\,\mathrm{int}})$$

```
dS_ID = 2.9146
```

Core mixer entropy down   [J/kg/K] :

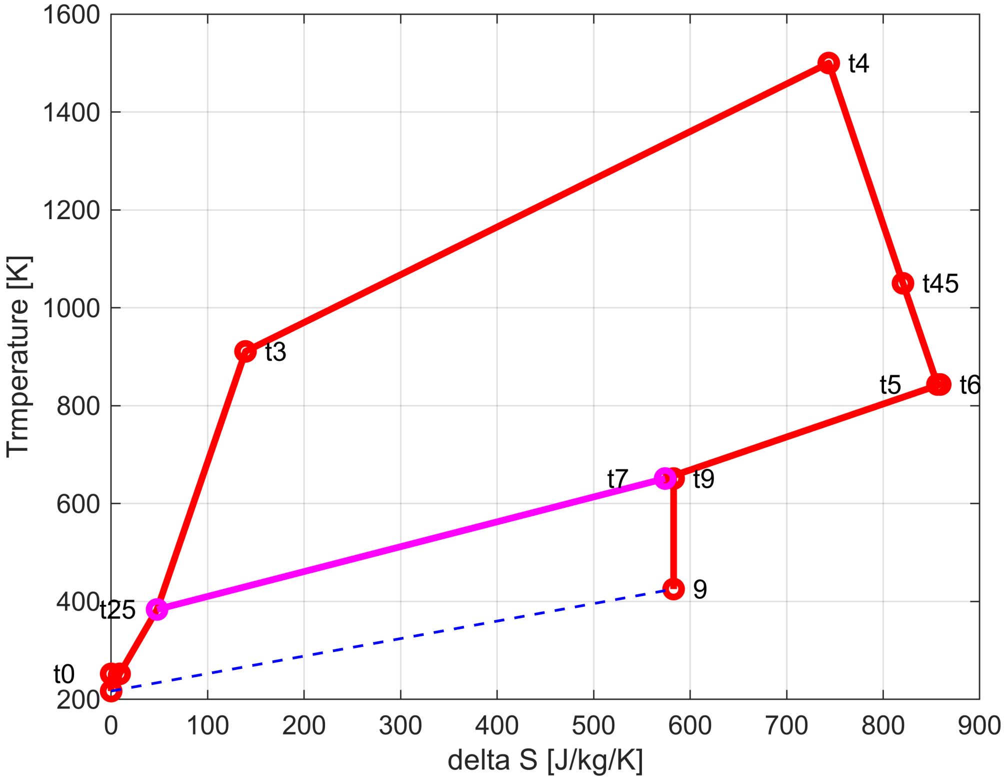
$$\Delta s_{\mathrm{MIX\,INT}} = c_{\mathrm{pt}} * \ln \frac{T_{\mathrm{t7}}}{T_{\mathrm{t5}}} - R_t * \ln\left(\frac{P_{\mathrm{t7}}}{P_{\mathrm{t5}}}\right)$$

```
dS_MIX = -285.1074
```

Engine nozzle entropy grow   [J/kg/K] :

$\Delta s_N = -\text{Rt} * \ln(\sigma_N)$

```
dS_N = 8.8332
```

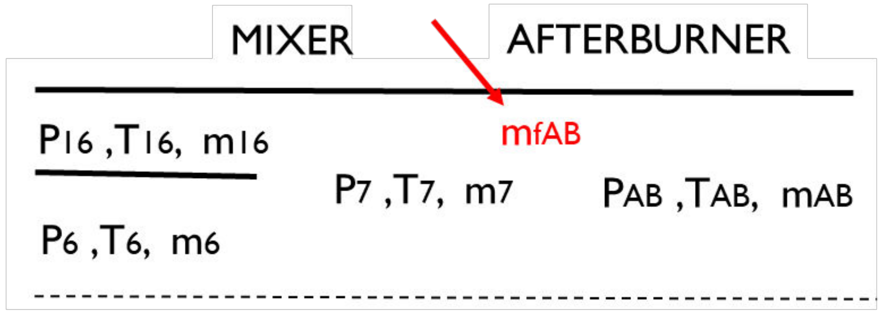


3) MIXED TURBOFAN ENGINE WITH AFTERBURNER (AB-ON)

For engine specified above calculate thermodynamic parameters and its performance, for afterburner ON. T_AB=1800 K, additional pressure losses coefficient σ_{AB} 0,98 and afterburner process efficiency η_{AB} 0,95.

Fumes for the afterburner and the nozzle calculation in AB ON mode kAB=1.29, cpAB=1250 J/kg/K, RAB=295 J/kg/K,

Caclculation done for section 7 for the engine whitout the afterburner is valid. AN-ON influence on calculation for the afterburner (stream mixing is assumed befor afterburning process), therefore all points from 0 to 7 calculated previously are stil valid. New secton AB is introduced, and parameters from section 7 are in the inlet to afterburner calaculation.



Section AB - AFTERBURNER

Total temperature [K]

T_{tAB}

```
TtAB = 1800
```

Total pressure [Pa]

$P_{\mathrm{tAB}} = \sigma_{\mathrm{AB\ ON}} * 7$

```
PtAB = 1.2364e+05
```

Fuel-air ratio

$$f_{\mathrm{AB}} = (1 + f_B + \mathrm{BPR}) * c_{\mathrm{pAB}} * \frac{T_{\mathrm{tAB}} - T_{\mathrm{t7}}}{\mathrm{FHV} * \eta_{\mathrm{AB}}}$$

```
fAB = 0.0546
```

Afterburner fuel mass flow [kg/s]

$m_{\mathrm{fAB}} = m_{25} * f_{\mathrm{AB}}$

```
mfAB = 1.7722
```

Section 9 AB ON

Total temperature [K]

$T_{\mathrm{t9AB}} = T_{\mathrm{tAB}}$

```
Tt9AB = 1800
```

Total pressure [Pa]

$P_{t9AB} = \sigma_N * P_{tAB}$

```
Pt9AB = 1.1993e+05
```

Staticl pressure [Pa]

$P_{9AB} = P_0$

```
P9AB = 22000
```

Static temperature [K]

$$T_{9AB} = T_{t9AB} * \left(\frac{P_{9AB}}{P_{t9AB}}\right)^{\frac{kAB-1}{kAB}}$$

```
T9AB = 1.2294e+03
```

Jet stream Mach No

$$M_{9AB} = \sqrt{\left(\frac{T_{t9AB}}{T_{9AB}} - 1\right) * \frac{2}{k_{AB} - 1}}$$

```
M9AB = 1.7891
```

Speed of sound [m/s]

$$a_{9AB} = \sqrt{k_{AB} * R_{AB} * T_{9AB}}$$

```
a9AB = 683.9992
```

Jet speed [m/s]

$V_{9AB} = M_{9AB} * a_{9AB}$

```
V9AB = 1.2237e+03
```

TURBOJET ENGINE with AFTERBURNER - PERFORMANCE CALCULATION

Total fuel-air ratio

$f = f_B + f_{AB}$

```
f_AB = 0.0712
```

Total fuel consumption [kg/s]

$m_f = m_{fB} + m_{fAB}$

```
mf_AB = 2.3107
```

Thrust [N]

$$T_{AB} = m_{25} * ((1 + f + BPR) * V_{9AB} - (1 + BPR) * V_0)$$

```
T_AB = 6.0306e+04
```

Specific thrust [Ns/kg]

$$\mathrm{ST_{AB}} = \frac{T_{\mathrm{AB}}}{m_0} = \frac{(1 + f + \mathrm{BPR}) * V_{9\mathrm{AB}} - (1 + \mathrm{BPR})V_0}{1 + \mathrm{BPR}}$$

```
ST_AB = 1.0051e+03
```

Specific fuel consumption [kg/N/s]

$$\mathrm{SFC_{AB}} = \frac{m_f}{T_{\mathrm{AB}}}$$

```
SFC_AB = 7.0886e-05
```

Specific fuel consumption [kg/N/h]

$$\mathrm{SFC_{AB}} = \mathrm{SFC_{AB}} * 3600$$

```
SFC_AB = 0.2552
```

Thermal efficiency

$$\eta_{\mathrm{thAB}} = \frac{(1 + f + \mathrm{BPR}) * {V_{9\mathrm{AB}}}^2 - (1 + \mathrm{BPR}){V_0}^2}{2 * f * \mathrm{FHV}}$$

```
etha_th_AB = 0.4482
```

Propulsive efficiency

$$\eta_{\mathrm{pAB}} = \frac{2 * V_0 * \mathrm{ST_{AB}} * (1 + \mathrm{BPR})}{(1 + f + \mathrm{BPR}) * {V_{9\mathrm{ANB}}}^2 - (1 + \mathrm{BPR}){V_0}^2}$$

```
etha_p_AB = 0.1673
```

Overall efficiency

$$\eta_{\mathrm{oAB}} = \frac{V_0 * \mathrm{ST_{AB}}(1 + \mathrm{BPR})}{f * \mathrm{FHV}} = \eta_{\mathrm{thAB}} * \eta_{\mathrm{pAB}}$$

```
etha_o_AB = 0.0750
```

TURBOJET ENGINE AFTERBURNER OFF/ ON COMPARISON

Tabela = 8×4 table

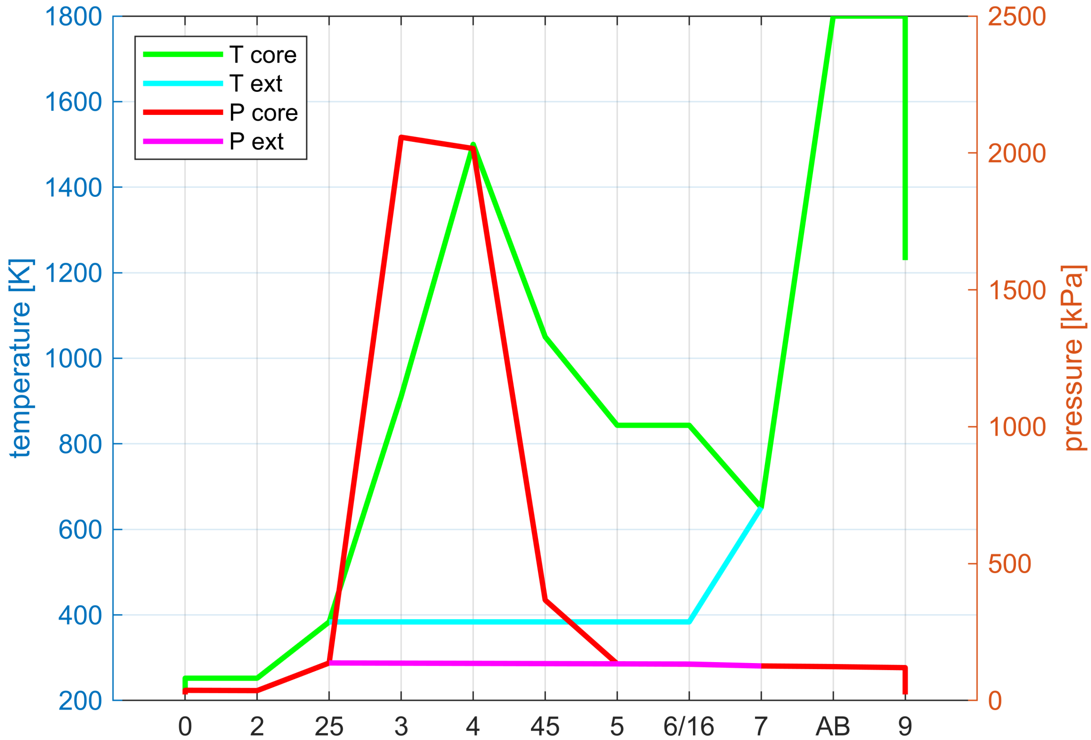
	Parameter	Unit	AB OFF	AB ON
1	'Thrust'	'kN'	28.0384	60.3055
2	'Specific Thrust'	'N*s/kg'	467.3069	1.0051e+03
3	'V9'	'm/s'	726.5381	1.2237e+03
4	'Fuel consumption'	'kg/s'	0.5386	2.3107
5	'Specific fuel consump'	'kg/N/h'	0.0691	0.2552
6	'therm. efficiency'	'-'	0.5985	0.4482
7	'prop. efficiency'	'-'	0.5376	0.1673
8	'overall efficiency'	'-'	0.3218	0.0750

CONCLUSIONS:

Engine with AB ON has:

- higher thrust and specific thust due to higher jet speed (+)
- significantly higher fuel consumption and specific fuel consumption (-)
- lower thermal and overall efficiences (-)

Temperature, pressure vs engine sections plot



Temperature-entropy plot

Entropy growt calculation for section 7 is like for engine with AB_OFF. Additional calculation should be done for AB and propeling nozzle.

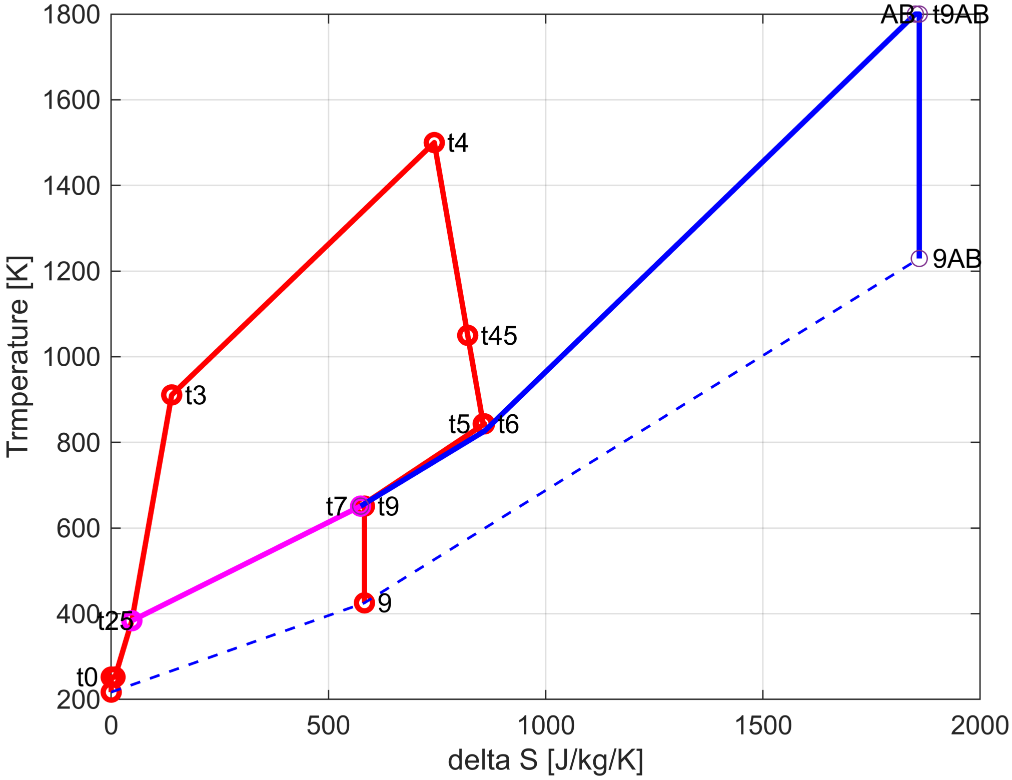
$$\Delta s_{\text{AB}} = c_{\text{pAB}} * \ln\frac{T_{\text{tAB}}}{T_{\text{tAB}}} - R_{\text{AB}} * \ln\left(\frac{P_{\text{tAB}}}{P_{\text{t7}}}\right)$$

```
dS_AB = 1.2768e+03
```

Engine nozzle entropy grow   [J/kg/K] :

$$\Delta s_{N\_\text{AB}} = -R_{\text{AB}} * \ln(\sigma_N)$$

```
dS_NAB = 8.9855
```



Trmperature [K]
delta S [J/kg/K]
1800
1600
1400
1200
1000
800
600
400
200
0
500
1000
1500
2000
t4
t45
t3
t5
t6
t7
t9
9
t25
t0
AB
t9AB
9AB