# REAL TURBOJET WITH AFTERBURNER

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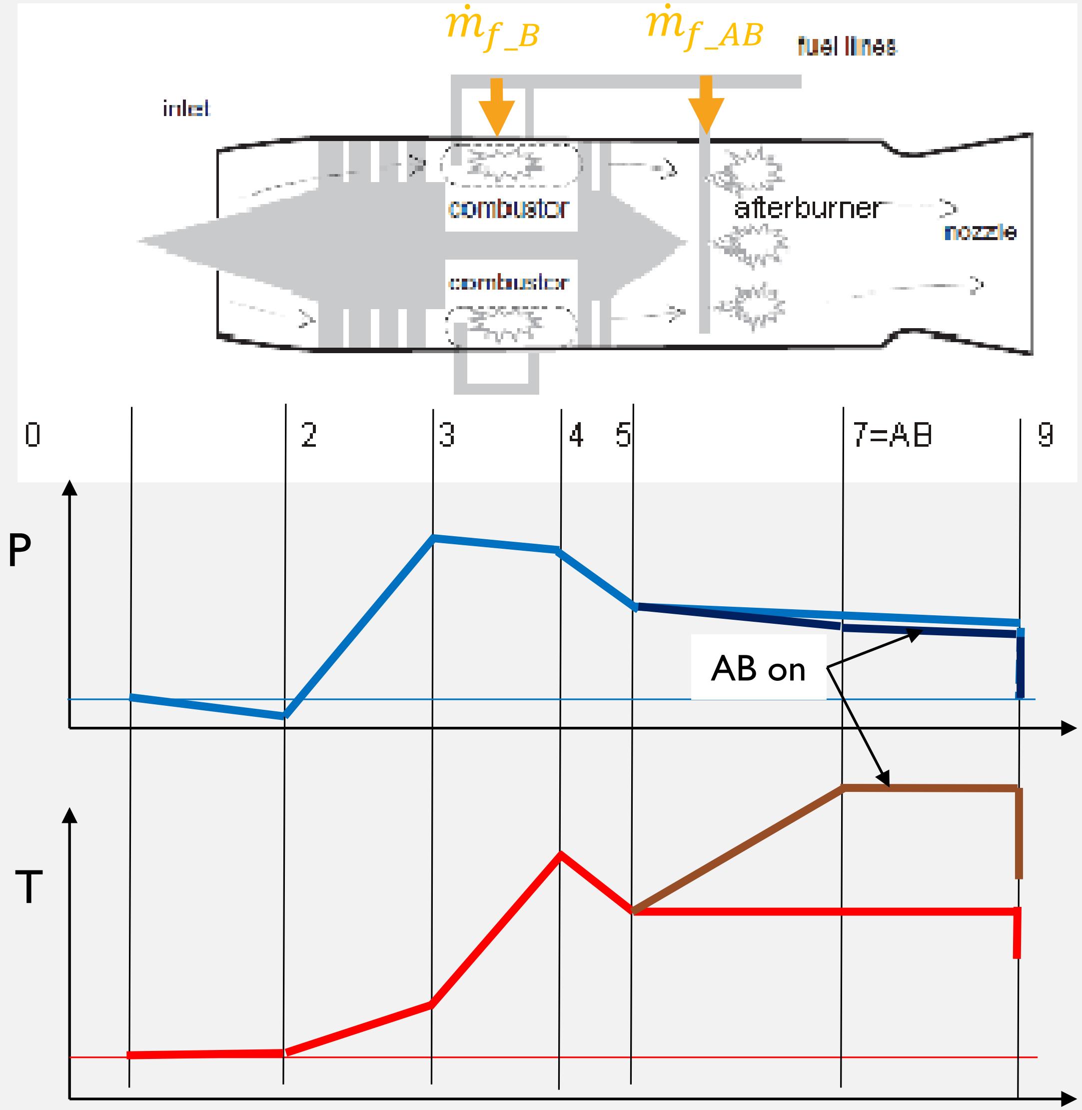
# LITERATURE:


- **Jack D. Mattingly, Elements of Propulsion: Gas Turbines and Rockets, AIAA Education Series 2006 (Chapter 7)**
- **Jack D. Mattingly, Elements of Gas Turbine Propulsion, Tata McGraw Hill Education Private Limited, 2013 (Chapter 7)**
- **Gordon C. Oates, Aerothermodynamics of Gas Turbine and Rocket Propulsion, AIAA Education Series, 1997 (Chapter 7)**

# TURBOJET ENGINE WITH AFTERBURNER




**AB on**

- Temperature in section 7(AB) increases and by this in section 9
- Pressure in section 7(AB) slightly goes down due to additional pressure losses caused by burning process in the afterburner
- Engine outlet gas velocity increases by higher outlet gas temperature
- Outlet gas density goes down by temperature rise, therefore the outlet area should grow when AB is on (will be shown)

**THTUST**

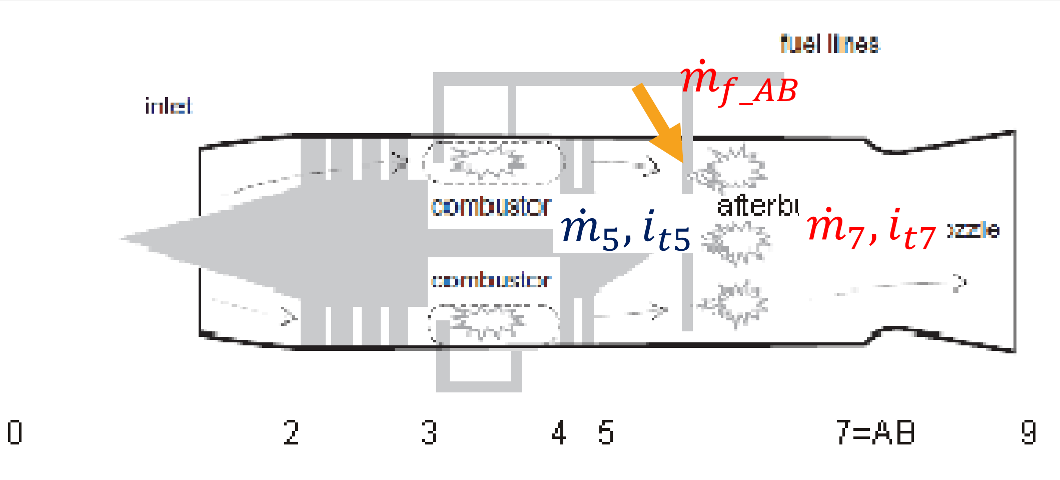
$$T_{AB} = \dot{m}_{9\_AB}V_{9\_AB} + A_{9\_AB}\left(P_{9\_AB} - P_a\right) - \dot{m}_0 V_0 = \dot{m}_{9\_AB}V_{eff\_AB} - \dot{m}_0 V_0$$

$$\dot{m}_{9\_AB} = \dot{m}_0 + \dot{m}_f \qquad \dot{m}_f = \dot{m}_{f\_B} + \dot{m}_{f\_AB}$$

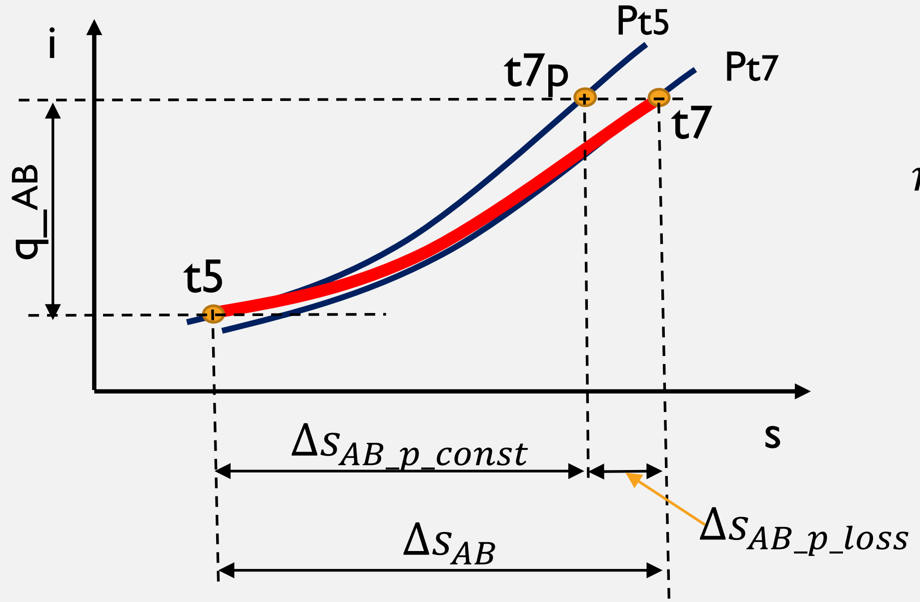
**SPECIFIC FUEL CONSUMPTION**

$$SCF_{AB} = \dot{m}_f / T_{AB}$$

# AFTERBURNER




$$q_{AB} = Cp_{AB}(T_{t4} - T_{t3})$$




**Energy balance:**

$$\eta_{AB}\dot{m}_{f\_AB}FHV = \dot{m}_7 i_{t7} - \dot{m}_5 i_{t5} = \dot{m}_7 Cp_{AB}T_{t7} - \dot{m}_5 Cp_T T_{t5}$$

**Afterburner efficiency**

$$\eta_{AB} = \frac{heat\ added\ to\ the\ gas\ flow\ through\ the\ afterburner}{heat\ contained\ in\ fuel\ suplied\ to\ afterburner}$$

$$\eta_{AB}\dot{m}_{f\_AB}FHV = \dot{m}_5 Cp_{AB}(T_{tAB} - T_{t5})$$

Afterburner fuel mass flow

$$\dot{m}_{f\_AB} = \frac{\dot{m}_5 Cp_{AB}(T_{tAB} - T_{t5})}{\eta_{AB}FHV}$$

Afterburner fuel-air ratio

$$f_{AB} = \frac{\dot{m}_{f\_AB}}{\dot{m}_0} = \frac{Cp_{AB}(1 + f_B)(T_{t4} - T_{t3})}{\eta_B FHV}$$

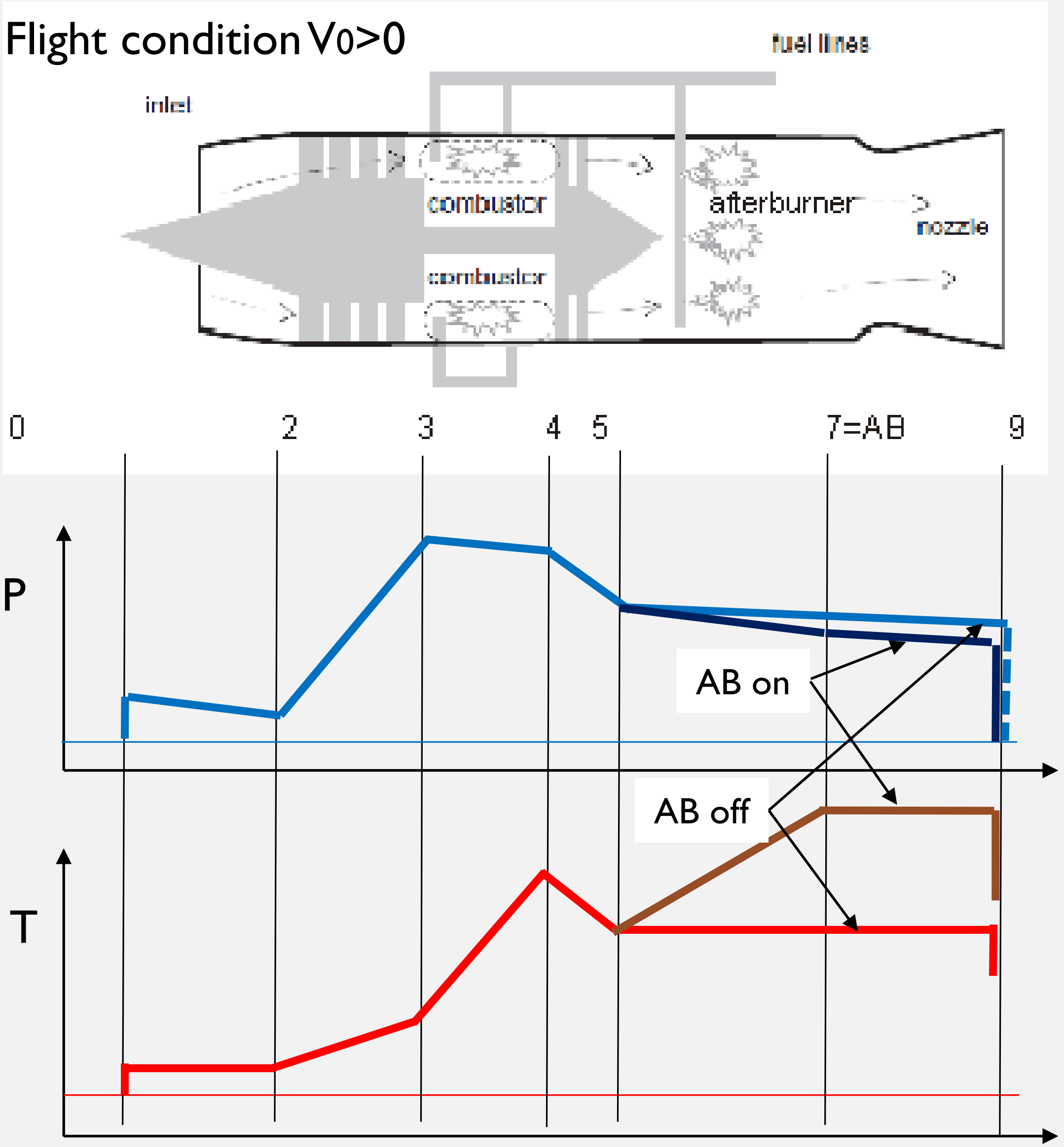
**Pressure losses:** $\pi_{AB} = \frac{P_{t7}}{P_{t5}}$

Additional pressure losses for AB ON are caused by burning process,

**Entropy increase in the afterburner:**

$$\Delta s_{AB} = cp_{AB} ln\frac{T_{tAB}}{T_{t5}} - R_{AB} ln\frac{P_{t7}}{P_{t5}}$$

# TURBOJET ENGINE WITH AFTERBURNER

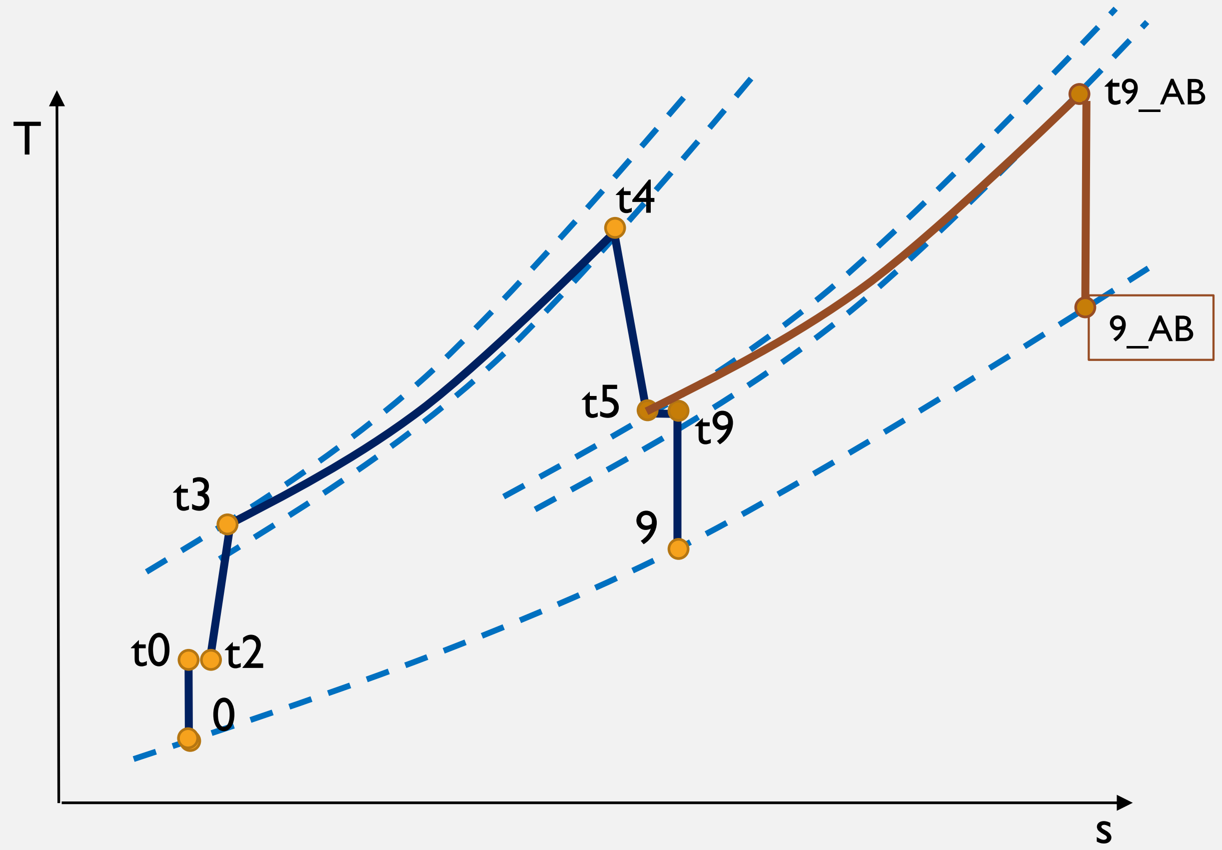



**AB off** Outlet gas speed

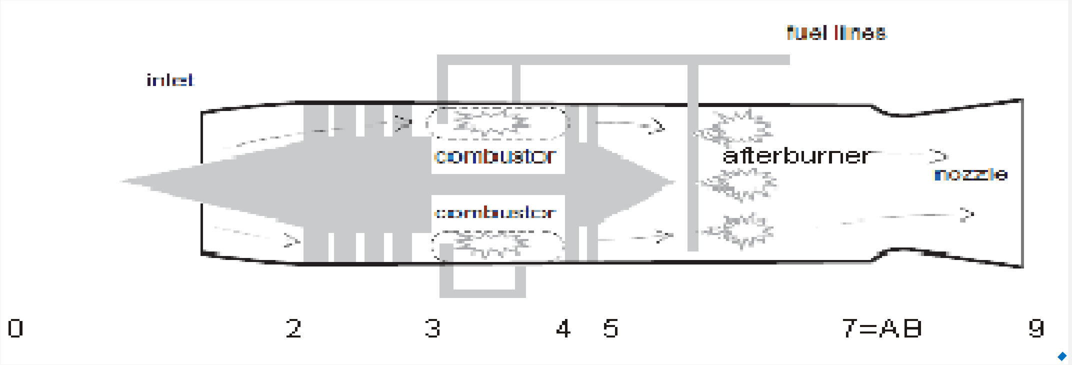
$$c_9 = \sqrt{2Cp_t(T_{9t} - T_9)}$$

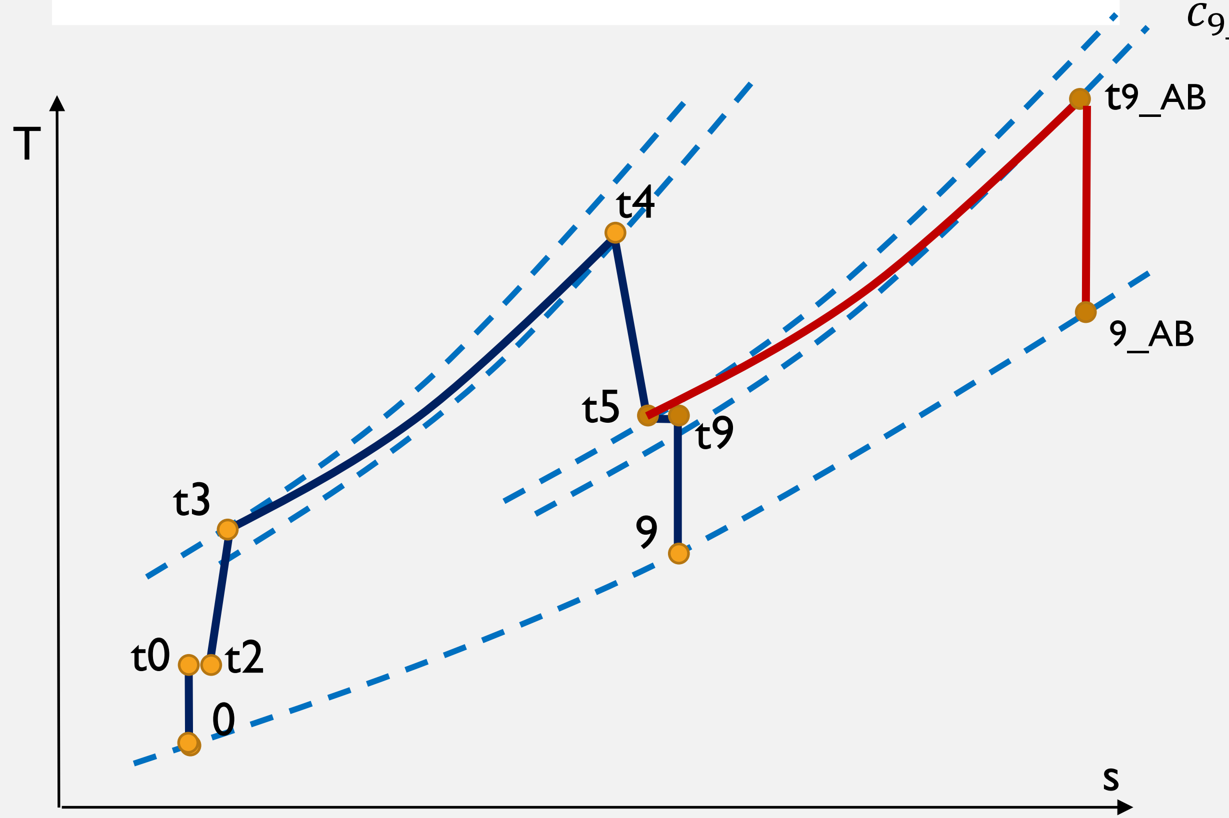
**AB on** Outlet gas speed

$$c_{9\_AB} = \sqrt{2Cp_{AB}(T_{9t\ AB} - T_{9\ AB})}$$



# AB_ON – AB_OFF OUTLET GAS VELOCITY




**AB OFF**

$$c_9 = \sqrt{2Cp_t(T_{t9} - T_9)} \quad c_9 = \sqrt{2Cp_tT_{t9}(1 - (P_9/P_{t9})^{(k_t-1)/k_t})}$$

**AB ON**

$$c_{9\_AB} = \sqrt{2Cp_{AB}(T_{9t\ AB} - T_{9\ AB})}$$

$$c_{9\_AB} = \sqrt{2Cp_{AB}T_{t9\_AB}\left(1 - \left(P_9/P_{t9\_AB}\right)^{(k_{AB}-1)/k_{AB}}\right)}$$

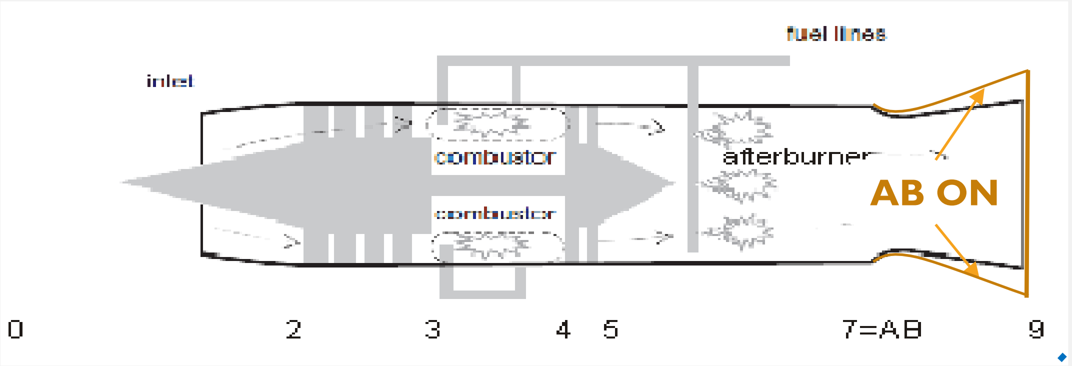
For assumption that:

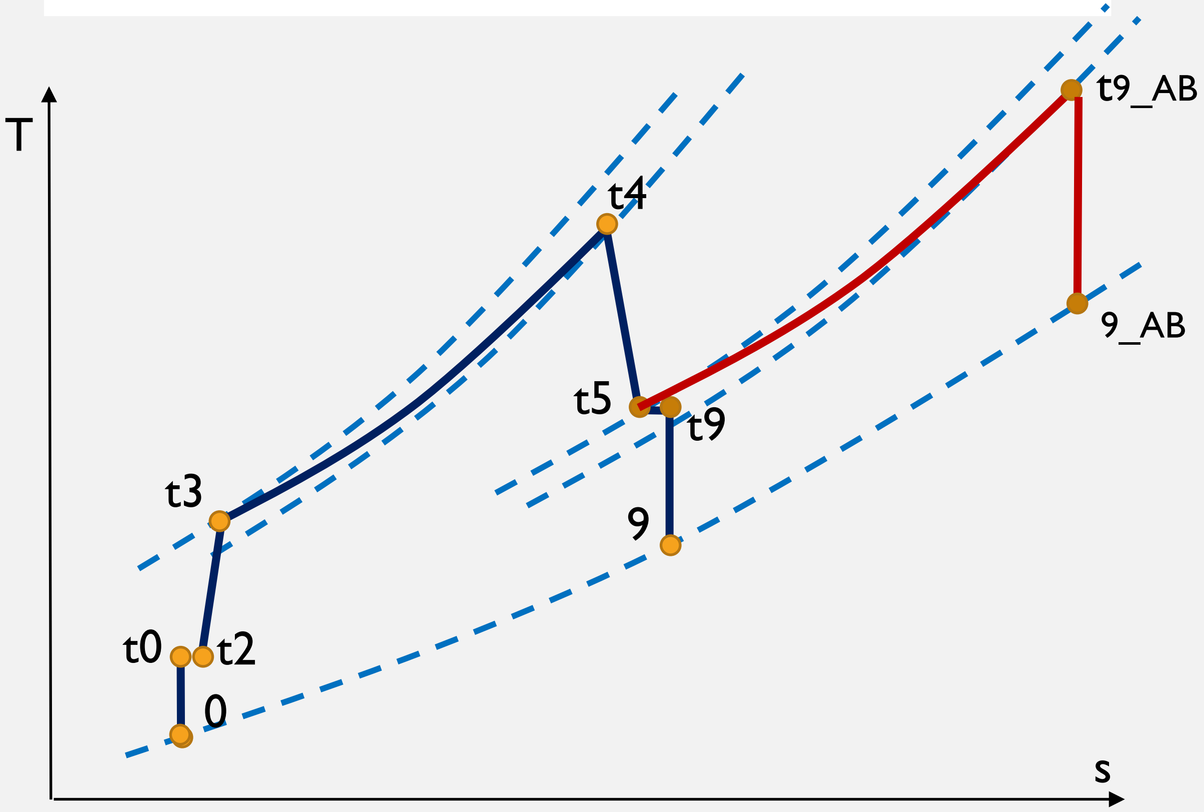
- Gas parameters are similar $Cp_{AB} = Cp_t, k_{AB} = k_t$
- Pressure ratio in propeling nozzle is similar $P_9/P_{t9\_AB} = P_9/P_{t9}$

$$\frac{c_{9\_AB}}{c_9} \cong \sqrt{\frac{T_{tAB}}{T_{t5}}}$$

Engine outlet gas speed grow after **afterburner on** is proportional to the square root from the temperature in the afterburner to the temperature after the turbine.

# AB_ON – AB_OFF OUTLET NOZZLE EXIT AREA




**AB OFF**

$$A_9 = \dot{m}_9/(\rho_9 C_9) \qquad \rho_9 = \frac{P_9}{R_t T_9} = \frac{P_9}{R_t T_{t9} (P_9/P_{t9})^{(k_t-1)/k_t}}$$

**AB ON**

$$A_{9\_AB} = \dot{m}_{9\_AB}/\left(\rho_{9\_AB} C_{9\_AB}\right)$$

$$\rho_{9\_AB} = \frac{P_{9\_AB}}{R_{AB} T_{9\_AB}} = \frac{P_{9\_AB}}{R_{AB} T_{t9\_AB} \left(P_9/P_{t9\_AB}\right)^{(k_{AB}-1)/k_{AB}}}$$

Assumed that:

- Outlet mass flow is almost the same $\dot{m}_{9\_AB} = \dot{m}_9$
- Gas parameters are similar $Cp_{AB} = Cp_t, k_{AB} = k_t$
- Pressure ratio in propeling nozzle is similar $P_9/P_{t9\_AB} = P_9/P_{t9}$
- $T_{t9} = T_{t5}$ for AB OFF engine mode

$$\frac{A_{9\_AB}}{A_9} \cong \sqrt{\frac{T_{tAB}}{T_{t5}}}$$

Engine outlet nozlle area grows after **afterburner on.** The growth is proportional to the square root on the temperature in the afterburner to the temperature after the turbine.

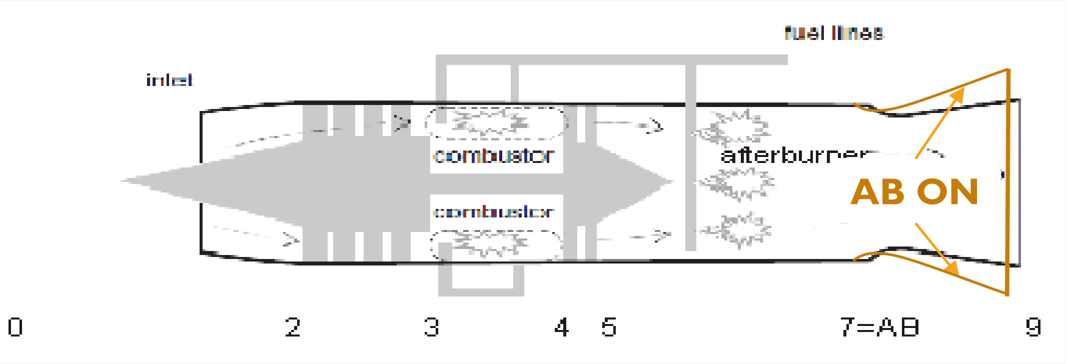
# AFTERBURNER

# EXAMPLE OF AFTERBURNER TURBOJET ENGINE CALCULATION

Given:

| | Parameter | Value |
|---|---|---|
| 1 | 'Ambient temperature [K]' | 217 |
| 2 | 'Ambient pressure [kPa]' | 22 |
| 3 | 'Flight speed' | 1.5000 |
| 4 | 'air mass flow [kg/s]' | 20 |
| 5 | 'CPR' | 15 |
| 6 | 'TIT [K]' | 1400 |
| 7 | 'TAB [K]' | 1750 |
| 8 | 'Inlet pressure losses' | 0.9500 |
| 9 | 'Burner pressure losses' | 0.9800 |
| 10 | 'AB OFF pressure losses' | 0.9750 |
| 11 | 'AB ON pressure losses' | 0.9500 |
| 12 | 'Nozzle pressure losses' | 0.9700 |
| 13 | 'compressor efficiency' | 0.8200 |
| 14 | 'turbine efficiency' | 0.8900 |
| 15 | 'Burner efficiency' | 0.9800 |
| 16 | 'Afterburner efficiency' | 0.9500 |
| 17 | 'Mechanical efficiency' | 0.9900 |

Afterburrner ON vs. OFF performance comparison




| | Parameter | Unit | AB OFF | AB ON |
|---|---|---|---|---|
| 1 | 'Thrust' | 'kN' | 12.2849 | 19.8670 |
| 2 | 'Specific Thrust' | 'N*s/kg' | 614.2442 | 993.3517 |
| 3 | 'fuel cons.' | 'kg/s' | 0.3629 | 0.8190 |
| 4 | 'Specific fuel consump' | 'kg/N/h' | 0.1064 | 0.1484 |
| 5 | 'therm. efficiency' | '-' | 0.5777 | 0.5070 |
| 6 | 'prop. efficiency' | '-' | 0.6036 | 0.3047 |
| 7 | 'overall efficiency' | '-' | 0.3487 | 0.1545 |

Nozzle exit area for AB ON/OFF

| | Description | param | value | relative error |
|---|---|---|---|---|
| 1 | 'Exact method' | 'A9AB_A9' | 1.4296 | 0 |
| 2 | 'Aproximate method' | 'A9AB_A9_app' | 1.3111 | -0.0829 |

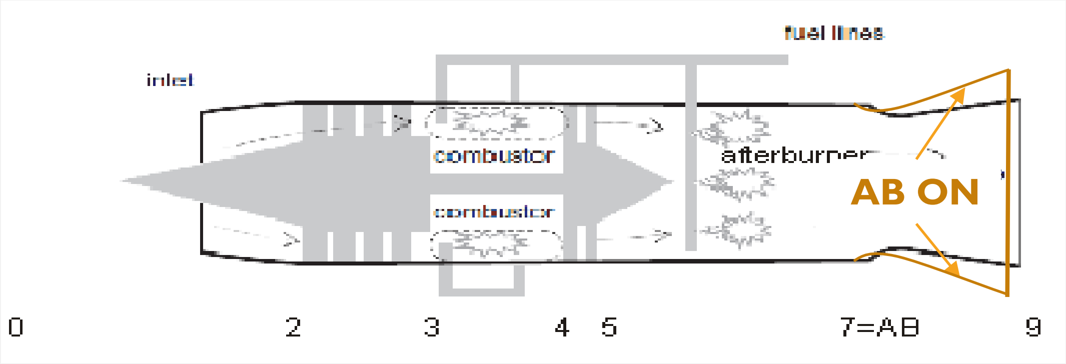
$$\text{A9AB\_A9\_app} = \sqrt{\frac{T_{tAB}}{T_{t5}}}$$

**For Afterburner on:**

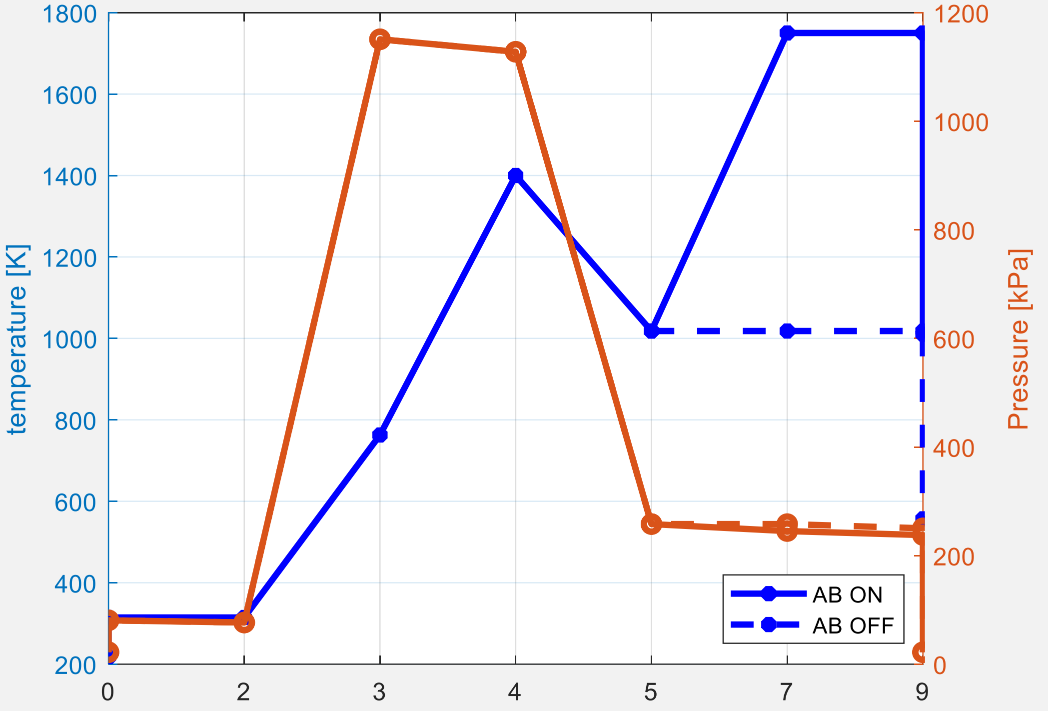
- Thrust and Specific thrust grow about 60%
- SFC grows about 50%
- engine exit area grows about 40%, caclation with simplified formula gives 8% lower result

# EXAMPLE OF AFTERBURNER TURBOJET ENGINE CALCULATION

Temperature and pressure comparison in engine cutsections:




| | Section | Temp. [K] AB_OFF | Temp. [K] AB_ON | Pressure [kPa] AB_OFF | Pressure [kPa] AB_ON |
|---|---|---|---|---|---|
| 1 | '0' | 217 | 217 | 22 | 22 |
| 2 | 't0' | 315 | 315 | 81 | 81 |
| 3 | 't2' | 315 | 315 | 77 | 77 |
| 4 | 't3' | 763 | 763 | 1151 | 1151 |
| 5 | 't4' | 1400 | 1400 | 1128 | 1128 |
| 6 | 't5' | 1018 | 1018 | 258 | 258 |
| 7 | 't7' | 1018 | 1750 | 252 | 245 |
| 8 | 't9' | 1018 | 1750 | 244 | 238 |
| 9 | '9' | 560 | 1010 | 22 | 22 |



# THANKS FOR YOUR ATENTION

Questions and Comments ?

1. …….
2. …….
3. …….