(Add a short summary of the concepts you are using to solve the problem)
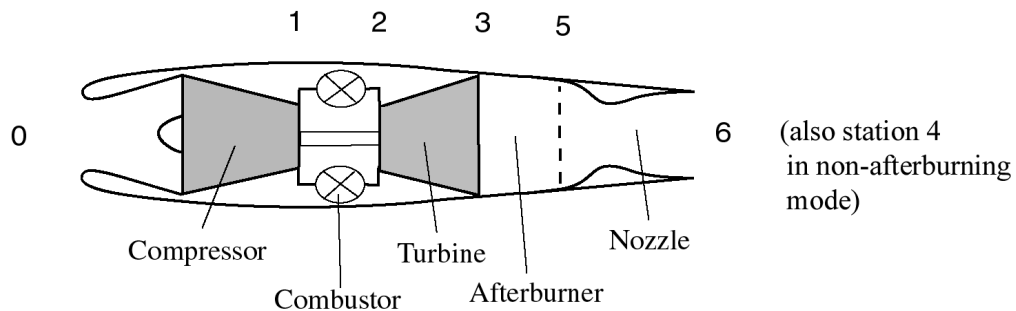
Problem T19

A turbojet engine can be operated with or without afterburning. The cycle is shown in the figure below. Operated without an afterburner, it consists of reversible, adiabatic compression from 0 to 1, constant pressure burning from 1 to 2, then reversible adiabatic expansion through the turbine and the nozzle from 2 to 4, where the pressure at state 4 is atmospheric. The isentropic temperature ratio (T_1/T_0 where T_1 is the temperature at the compressor exit and T_0 is the atmospheric temperature) is τ_s, which is equal to 2. The ratio of maximum temperature to atmospheric temperature is 10. The kinetic energy changes across the turbine and compressor can be neglected, as can any temperature rise produced in the inlet and diffuser ahead of the compressor. If necessary, express your answers in terms of T_0 and c_p. The latter can be assumed constant throughout (the same value for both air and the combustion gas). The fuel mass flow can be neglected.

   a) Sketch the non-afterburning cycle in a T-s diagram and label all states.

   b) What is the thermal efficiency of the non-afterburning cycle?

   c) What is the net mechanical work produced per unit mass flow?

In the afterburning mode, expansion takes place in the turbine from state 2 to state 3, and then the flow is passed through an afterburner where it undergoes constant pressure combustion from state 3 to state 5. The maximum temperature at the afterburner is the same as the maximum temperature at the combustor exit. On leaving the afterburner, the flow expands through a nozzle to atmospheric pressure at state 6.

   d) Sketch states 3, 5 and 6 in the same T-s diagram.

   e) The afterburner entrance is at the turbine exit. What is the afterburner inlet temperature T_3?

   f) The afterburner exit temperature, T_5, is the nozzle inlet temperature. What is the nozzle exit temperature, T_6?

   g) What is the thermal efficiency of the afterburning engine cycle?

$$T_1/T_0 = \tau_s = 2$$
$$T_{max}/T_0 = 10$$

Problem T20

Air flows through an insulated throttle before it enters an ideal turbine as sketched in the figure below. There is a stagnation pressure drop, ΔP_t, across the throttle. The air enters the throttle at a stagnation pressure $P_{t1} = 10$ bar and a stagnation temperature $T_{t1} = 600$ C. The turbine exit stagnation pressure is $P_{t3} = 1$ bar. You can assume air to be an ideal gas with R = 287 J/kg-K and $\gamma = 1.4$.
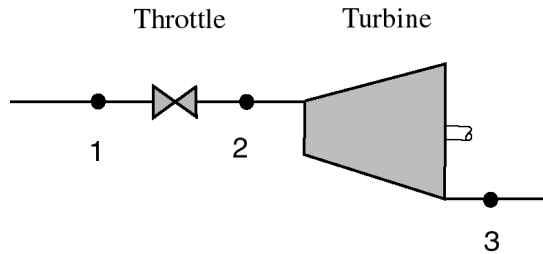
a) Sketch the throttling process from state 1 to state 2 in an *h-s* diagram. Explain the rationale behind your sketch (one to two sentences are needed, possibly with an equation)

b) The throttle (think of a valve) can be operated over a range of conditions. If it is fully opened there is no stagnation pressure drop, $P_{t1} = P_{t2}$. If it is closed as far as possible there is only a small leakage flow so the stagnation pressure change across the turbine is negligible and $P_{t2} = P_{t3}$. Sketch the stagnation states in these two "limiting cases" for the expansion through the overall throttle-turbine combination on the same *h-s* diagram.

c) Assuming that the throttle is fully open ($P_{t1} = P_{t2}$) what is the shaft work, per unit mass of air, produced in the turbine?

d) Assuming that the throttle is closed as far as possible so that $P_{t2} = P_{t3}$ what is the change in entropy across the throttle between stations 1 and 2?