FURTHER EXERCISES ON THERMAL MACHINES

EXERCISE 1

A stream of G = 5 kg/s of air flows in a duct, in total conditions P_T = 1.5 bar and T_T = 400 K and static temperature $T = T_T/2$. It is required to compute:

- The Mach number of the stream, and the section of the duct in the aforementioned conditions.
- The section of the duct required to bring the stream up to sonic conditions (Mach N. = 1), assuming isentropic transformation.
- The section of the duct required to reach P = 1 bar.

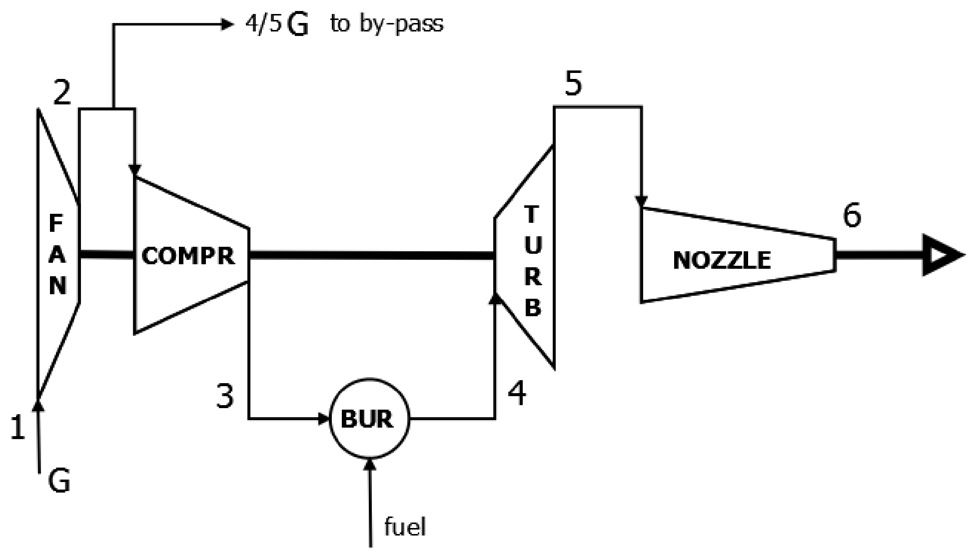
Results: S_in = 0.03415 m^2; S_sonic = 0.016494 m^2; S_1bar = 0.017242 m^2

EXERCISE 2

A schematic of a turbo-fan engine for aeronautic propulsion is reported in the figure. The turbine is used to activate the compressor and the fan. The exhaust gases from the turbine are sent to the nozzle where they are accelerated. The sucked flow rate, Gtot = 120 kg/s, is first operated in the fan, that provides a compression ratio β1=2. 80% of the flow rate is sent to the by-pass duct, while only the 20% of the sucked flow rate is sent to the compressor. The pressure at the exit of the compressor is Pmax = 25 bar. Assume the flow in the full machine keeps the same thermo-physical properties of the air, sucked in ambient conditions (P1=1bar, T1= 20 °C; Cp_{AIR} = 1000 J/kgK; γ_{AIR} = 1.4, R_{AIR} = 287 J/kgK). Assume that all the components are ideal. Requirements:

1. To represent the thermodynamic transformations undergone by the fluid from point 1 to 6 in the T-s diagram.
2. To compute the flow rate of the fuel (LHV = 40000 kJ/kg) required to have a temperature at the turbine inlet T4 = 1450 K
3. To evaluate the thermodynamic conditions at the turbine exit.
4. To compute the velocity at the exit of the nozzle, assuming atmospheric pressure at the exhaust.

Results: GFUEL = 0.436 kg/s ; P5 = 2.64 bar; T5 = 762.5 K; V6 = 607.7 m/s



EXERCISE 3

A centrifugal compressor operates with air with the following geometric and operating parameters:

- impeller diameter: D2=0.4 m;
- angular speed: n = 20000 rpm;
- rotor exit blade angle: β2=-45°;
- intake total conditions: P_T1 = 1bar; T_T1 = 20°C;
- total-total compression ratio : P_T2/P_T1 = 2.8;
- total-total isentropic efficiency : η_{IS} = 0.75;
- mass flow rate: G=5 kg/s;

Assuming that the diffuser induces negligible losses (ideal thermodynamic behavior), compute:

1) the velocity triangle at the impeller exit;
2) the blade span at the exit of the impeller;
3) the index of the polytropic transformation that approximates the real one.

Results: V2t = 320.425 m/s; alpha2 = 73°; alt2 = 0.025 m ; n_trasf = 1.575

EXERCISE 4

The HP section of a steam turbine is composed by an ideal and optimized Curtis stage. The steam (assumed as perfect gas with Cp=2.0 kJ/kgK, MM=18 kg/kmol; γ=1.33) expands from stagnation conditions: $P_{T,in}$=150 bar; $T_{T,in}$=800 K to downstream stage conditions equal to P_{out} = 80 bar. The mean diameter of the machine is D_m = 1.0 m, the blade height at the stator exit is h = 0.025*D_m and the shaft rotates at 3000 rpm. Assigning constant meridional velocity component across the machine, it is required to determine the velocity triangles and the power released by the stage.

Results: Vm = 259.5106 m/s; beta1 = 61.2°; W = 101.8 MW