Turbojet Design Point Simulator

Aim: Program a numerical simulator to predict turbojet design point performances.

Use any convenient programming language to write a code that is capable of predicting turbojet performances given a set of design parameters and component efficiency targets.
The design parameters will be:

- Flight mach number (M_0 [2]).
- Flight altitude (h [11000 m]) or, equivalently, atmospheric ambient conditions (T_0 [216.5 K] and p_0).
- Turbine entry temperature (T_{t_4} [1373 K]).
- Compressor temperature ratio ($\tau_c = T_{t_3}/T_{t_2}$ [2]).

The component efficiency targets are given by:

- Intake (ε_i [0.075]), burner (ε_b [0.06]) and turbine-nozzle duct (ε_n [0.02]) pressure loss coefficients.
- Compressor (η_{c_p} [0.88]) and turbine (η_{t_p} [0.93]) politropic efficiencies.
- Nozzle velocity coefficient (ϕ [0.98])
- Turbine cooling bleed (x [0.07]).

The simulator should be able to compute:

- Specific thrust (Ψ).
- Thermal (η_{th}), propulsive (η_{pr}) and overall (η_O) efficiency.
- Thrust specific fuel consumption (C_{TS}).

The numbers in brackets are reference values to be used for code debugging.

Project evaluation:

Each group will prepare a 15-20 minutes presentation. The presentation should cover the following aspects:

1. Code explanation, including an engine diagram, list of hypotheses made, solver flowchart diagram...
2. Demonstration of the simulator.
3. Comparison with an approximate hand-made computation assuming the gas is calorically perfect, no cooling bleed and negligible fuel addition, but retaining component efficiencies and pressure losses.
4. Results presentation and discussion focused on engine performance optimisation. In particular, $\Psi(M_0, \Delta T_c, T_{t,4})$ and $C_{TS}(M_0, \Delta T_c, T_{t,4},)$ charts. $\Delta T_c = T_{t_3} - T_{t_2} \in [100, 800]\,\mathrm{K}$, $T_{t_4} \in [1000, 1800]\,\mathrm{K}$ and $M_0 \in [0, 3]$.

Use the following approximate expansions to account for gas property variations with temperature and fuel/air ratio, valid for kerosene:

- Constant pressure specific heat: $\dfrac{c_p}{r} = \dfrac{\left(\frac{c_p}{r}\right)_{air} + \alpha\left(\frac{c_p}{r}\right)_{fuel}}{1+\alpha}$
  - $r = 287.15\,\mathrm{J/kg\,K}$
  - $\left(\dfrac{c_p}{r}\right)_{air} \approx 3.5 - 2.8\cdot 10^{-5}\,T + 2.24\cdot 10^{-8}\,T^2 + \left(\dfrac{3090}{T}\right)^2 \dfrac{\exp(3090/T)}{(\exp(3090/T)-1)^2}$
  - $\left(\dfrac{c_p}{r}\right)_{fuel} = 4.47659 + 8.01994\cdot 10^{-3}\,T - 1.8373\cdot 10^{-6}\,T^2$
- Enthalpy: $\dfrac{h}{r} = \displaystyle\int_0^T \frac{dh}{r} = \frac{\left(\frac{h}{r}\right)_{air} + \alpha\left(\frac{h}{r}\right)_{fuel}}{1+\alpha}$
  - $\left(\dfrac{h}{r}\right)_{air} = 3.5\,T - 1.4\cdot 10^{-5}\,T^2 + 7.467\cdot 10^{-9}\,T^3 + \dfrac{3090}{\exp(3090/T)-1}$
  - $\left(\dfrac{h}{r}\right)_{fuel} = -149.054 + 4.47659\,T + 4.00997\cdot 10^{-3}\,T^2 - 6.12432\cdot 10^{-7}\,T^3$
- Pressure ratio: $\Phi = \displaystyle\int_0^T \frac{dh}{rT} = \frac{\Phi_{air} + \alpha\Phi_{fuel}}{1+\alpha}$
  - $\Phi_{air} = 3.5\,\log T - 2.8\cdot 10^{-5}\,T + 1.12\cdot 10^{-8}\,T^2 + \dfrac{3090}{T\,(\exp(3090/T)-1)} - \log\dfrac{\exp(3090/T)-1}{\exp(3090/T)}$
  - $\Phi_{fuel} = 4.47659\,\log T + 8.01994\cdot 10^{-3}\,T + 9.18648\cdot 10^{-7}\,T^2$

For the fuel effective lower heating value, use

- $\dfrac{h_f}{r} = \dfrac{h_{f_0}}{r} - \dfrac{\Delta h_{f_c}}{r}$
  - $h_{f_0} = 4.3095\cdot 10^7\,\mathrm{J/kg}$
  - $\dfrac{\Delta h_{f_c}}{r} = -1607.2 + 4.47659\,T + 4.00997\cdot 10^{-3}\,T^2 - 6.12432\cdot 10^{-7}\,T^3$

All dimensional quantities must be used in SI (international system of units).