AE 234/711 Aircraft Propulsion
Tutorial 6

1. **Compression** - Ideal vs Real (with dissipation) The fuel-air mixture inside a cylinder is initially occupying a volume $\mathcal{V}_i$. It has a mass m_i, pressure p_i, specific internal energy e_i and a temperature T_i. This mixture needs to be energised by **add**ing energy of magnitude $\mathcal{E}$ to the system. Compare the various ways of adding this energy, through isentropic, isobaric, isochoric and isothermal processes. Calculate the final state for each of these processes. Represent these processes on $T-s$ and $p-v$ plots. Comment on the relative effectiveness of these processes.

2. A ramjet is to propel an aircraft at Mach 3 at high altitude where the ambient pressure is 8.5 kPa and the ambient temperature T_a is 220 K. The temperature of the gases leaving the combustor is 2540 K.
   If all components of the engine are ideal - that is, frictionless - determine the thrust, thermal, propulsion and overall efficiencies of the engine.
   Repeat the calculations for $\eta_d = 0.7$, $\eta_b = 0.95$ and $\eta_n = 0.98$.
   Let the specific heat ratio be $\gamma = 1.4$ and make the approximations appropriate to $f \ll 1$.
   Verify your results with the given plots.

3. Given in the table on the next page are the `JANAF` coefficients that describe the thermodynamic properties of N_2. Plot the variation of c_p vs temperature for $T \in [200,\ 6000]$. Estimate the error in assuming a constant value for c_p. **Compare your results with the tabulated values at https://janaf.nist.gov/tables/N-023.html**
   We typically assume that the thermodynamic properties (h, s etc.) and transport properties (μ, κ etc.) of gases vary in a simple manner, easy for our calculations. However, they vary nonlinearly with temperature.
   US armed forces had put in a lot of effort to compile these properties for individual species. Tabulated data, called the JANAF (**J**oint **A**rmy **N**avy and **A**ir**F**orce) tables, were first available for different temperature levels; later curvefits were generated for these properties.
   The curvefits are of this form

$$\frac{1}{\mathsf{R}} c_p\left(T\right) = a_1 T^{-2} + a_2 T^{-1} + a_3 + a_4 T + a_5 T^2 + a_6 T^3 + a_7 T^4$$

   The following expressions for specific enthalpy and entropy follow from the above express for c_p

$$\frac{1}{\mathsf{R}T} h\left(T\right) = -a_1 T^{-2} + a_2 \frac{1}{T} \ln T + a_3 + \frac{1}{2} a_4 T + \frac{1}{3} a_5 T^2 + \frac{1}{4} a_6 T^3 + \frac{1}{5} a_7 T^4 + b_1 T^{-1}$$
$$\frac{1}{\mathsf{R}} s\left(T\right) = -\frac{1}{2} a_1 T^{-2} - a_2 T^{-1} + a_3 \ln T + a_4 T + \frac{1}{2} a_5 T^2 + \frac{1}{3} a_6 T^3 + \frac{1}{4} a_7 T^4 + b_2$$

   Values of the coefficients for most chemicals at temperatures upto $20,000$ K can be found in the report `NASA/TP-2002-211556`.

200 < T < 1000	a_1	a_2	a_3	a_4
	$2.210371497 \cdot 10^4$	$-3.818461820 \cdot 10^2$	6.082738360	$-8.530914410 \cdot 10^{-3}$
a_5	a_6	a_7	b_1	b_2
$1.384646189 \cdot 10^{-5}$	$-9.625793620 \cdot 10^{-9}$	$2.519705809 \cdot 10^{-12}$	$7.108460860 \cdot 10^2$	-10.76003744
1000 < T < 6000	a_1	a_2	a_3	a_4
	$5.877124060 \cdot 10^5$	$-2.239249073 \cdot 10^3$	6.066949220	$-6.139685500 \cdot 10^{-4}$
a_5	a_6	a_7	b_1	b_2
$1.491806679 \cdot 10^{-7}$	$-1.923105485 \cdot 10^{-11}$	$1.061954386 \cdot 10^{-15}$	$1.283210415 \cdot 10^4$	-15.86640027

Specific enthalpy at 298.15 K for N_2 is 8670.104 J/mol . where $\mathcal{R} = 8.314510$ J/(mol-K) and h is in J/mol. Molecular weight for N_2 is 28.0134 gm/mol.
Data for various other species can also be found at https://janaf.nist.gov/