H8.1 A converging nozzle is connected to a large supply tank containing air at 450K and 150 kPa. The nozzle exit area is 30 cm$^2$. The air flows isentropically through the nozzle and discharges into a chamber with pressure of 100 kPa.

a. Determine the mass flow rate of the air [kg/s]
b. If the chamber pressure could be lowered, determine the maximum possible mass flow rate for the air. What chamber pressure(s) will achieve this flow rate?

H8.2 Gas entering a rocket nozzle has a stagnation pressure of 1500 kPa and a stagnation temperature of 3000$^\circ$C. The gas ($k = 1.35, R = 287.0 \text{ Nm/kgK}$) expands isentropically to the ambient pressure. The rocket travels in standard atmosphere at 30,000 m. Determine:

a. Mach number at nozzle exit
b. throat and exit area [m$^2$] for a flow rate of 10 kg/s

c. entropy change across the shock, $s_2 - s_1$ [Btu/lbm$^\circ$R]
d. show static and stagnation states and process on $T-s$ diagram

H8.3 A hypersonic vehicle cruises at an altitude of 100,000 ft. A normal shock stands in front of the stagnation pressure and temperature probes located on the nose of the vehicle. The temperature probe indicates $T_{02} = 8000^\circ R$ behind the shock. Determine:

a. Mach number and speed [mph] of the aircraft
b. static and stagnation pressures behind the shock [psia]
c. entropy change across the shock, $s_2 - s_1$ [Btu/lbm$^\circ$R]
d. show static and stagnation states and process on $T-s$ diagram

H8.4 As discussed in lecture, the behavior of the flow in a converging-diverging nozzle depends on the value of the back pressure, $p_b$. As indicated in attached Fig. H8.4 the behavior can be classified into four Regions (1-4), which are demarcated by three back pressure, $p_b$, values labeled (1), (2), (3) (which also correspond to flow conditions (1), (2), (3)).

Consider a converging-diverging nozzle with $A_e/A_t = 5.0$ that is attached to a reservoir in which air is maintained at 600 kPa and 300 K.

a. For the given nozzle, evaluate $p_b$ (kPa) and $Ma_e$ for the 3 flow conditions (1), (2), (3).

b. Prepare a table summarizing the following for each Region for the given nozzle:
   i. if throat Mach number $Ma_t$ is $<, =, >$ unity
   ii. if $Ma_e$ is $<, =, >$ unity
   iii. if $p_e$ is $<, =, > p_b$
   iv. the range of $p_b$ values associated with each Region
   v. basic description, e.g., isentropic flow, shock in nozzle, underexpanded nozzle, overexpanded nozzle

On "Figure 6-17" ($p/p_o$ vs $x$), sketch a representative pressure distribution for each of the four Regions.
H8.5* Air is supplied to a converging-diverging nozzle from a large tank where the pressure is 790 kPa and the temperature is 150°C. A normal shock wave occurs in the diverging section of the nozzle where the area is 600 mm$^2$ and the Mach number is 1.7. The nozzle exit area is 750 mm$^2$. Assume isentropic flow except across the shock. Consider states (1) and (2), as the states upstream and downstream of the shock, respectively, state (e) as the nozzle exit state. Hint: consider $A_e/A_2^*$ and note $A^*$ is not constant across a shock. Determine:

a. mass flow rate [kg/s]
b. throat area [mm$^2$]
c. nozzle exit pressure [kPa]

H8.6* Measurements are made of compressible flow in a long smooth 7.16 mm i.d. tube. Air is drawn from the surroundings (20°C, 101 kPa) by a vacuum pump downstream. When the downstream pressure is reduced to 626 mm Hg (vacuum) or below, pressure readings along the tube stop changing and become steady. For these conditions, determine:

a. the maximum flow rate possible through the tube [kg/s]
b. stagnation pressure of the air leaving the tube [kPa]
c. entropy change of the air in the tube [kJ/kg K]
d. show static and stagnation states and process on $T–s$ diagram

H8.7* We wish to build a supersonic wind tunnel using an insulated nozzle and constant area duct assembly. Shock free operation is desired, with $Ma_1 = 2.1$ at the test section inlet and $Ma_2 = 1.1$ at the test section outlet. Stagnation conditions are $T_0 = 295$ K and $p_0 = 101$ kPa (abs). Determine:

a. temperature at outlet [K]
b. pressure at outlet [kPa]
c. entropy change through the test section [kJ/kg K]
d. show static and stagnation states and process on $T–s$ diagram