Due: In class, Friday **October 7, 2022**	**Name(s)** (*Each* student must submit; list anyone you worked with)	**PSU ID (abc123)**
	Student submitting:	
	Worked with:	
	Worked with:	

ME 420
Fall Semester, 2022
Homework Set # 5

Professor J. M. Cimbala

For instructor or TA use only:		
Problem	**Score**	**Points**
1		10
2		40
3		50
Total:		**100**

1. (10 pts) A rocket nozzle is being designed for conditions in which the stagnation pressure is 975 kPa and the atmospheric pressure is 20.3 kPa. The ratio of specific heats for the exhaust gases is 1.36. Calculate the area ratio A_e/A^* of the nozzle (the diverging part after the throat) that would yield ideally expanded conditions through the entire nozzle (no shocks).

2. (40 pts) Air flows from a large tank at 765 kPa and 483 K into an axisymmetric converging-diverging nozzle. The coordinates for radius r as a function of x for the nozzle are provided in an Excel file on the course website. Give all answers to four significant digits.

(a) Calculate the Mach number and pressure (in kPa) at the exit of the nozzle for the case in which the flow is choked at the throat, but just barely, such that the flow in the diverging portion of the nozzle is ***subsonic***. [Condition C in our class notes.]

(b) Carefully plot Mach number, pressure (in kPa), temperature (in K), and density (in kg/m^3) as functions of axial distance x from the entrance to the exit of the converging-diverging nozzle. This problem needs to be solved using software of your choice. Do not print out these plots yet since you will be adding to them.

(c) Repeat Part (a) for the case in which the back pressure is low enough that the flow is ***supersonic*** everywhere in the diverging portion of the nozzle. [Condition F in our class notes.]

(d) Repeat Part (b), but for the supersonic case. Put both the subsonic and supersonic cases on the ***same plot***, with a clear legend to label the curves. In the end, you should have four plots total: M, P, T, and ρ vs. x, each plot having two curves.

3. (50 pts) In class, when deriving equations for a normal shock, we developed equations for both the ***Fanno curve*** and the ***Rayleigh curve***. These are often plotted *together on the same plot* on a ***Mollier diagram***, which is a plot of specific enthalpy h (vertical axis) vs. specific entropy s (horizontal axis). We start with an (arbitrary) initial state 1 (upstream of the stationary normal shock): $M_1 = 3.40$, $T_1 = 258$ K, and $s_1 = 1590$ J/(kg K) with air as our gas.

(a) Consider the **Fanno curve**. At the given initial (upstream) conditions, and for a range of values of M_2, calculate T_2/T_1 and P_2/P_1, and then for each M_2, calculate s_2 by utilizing the appropriate entropy equation for an ideal gas. Also calculate h_2 for each M_2. Plot the *Fanno curve* on an *h*-*s* plot.

(b) Now consider the **Rayleigh curve**. Repeat Part (a), but plot the *Rayleigh curve* ***on the same plot***. Be sure to include a legend so the grader knows which curve is which.

(c) Your two curves should intersect at only two points. Discuss the significance of these two intersection points. Also, for both curves, discuss the significance of the point on the plot where $M_2 = 1$.

(d) Assume that a stationary normal shock forms at the given (upstream) conditions of the problem statement. From your analysis above, calculate the following properties downstream of the shock: M_2, T_2, h_2, and s_2. *Note*: If you do everything correctly, these values should be the same whether from your Fanno curve or your Rayleigh curve.

(e) Use the online Compressible Aerodynamics Calculator to determine the downstream Mach number M_2 and the pressure ratio P_2/P_1 for a stationary normal shock at the conditions given in the problem statement. Do the results agree with your conclusions from Part (d)?