Problem Set #3: Equilibrium Composition and Ramjet Performance

- Homework solutions should be neat and logically presented, see format requirements at http://seitzman.gatech.edu/classes/ae4451/homeworkformat.html.
- For the required problems in this set, YOU MUST include **a sketch** of the flow/system, and *if you employ a control volume analysis*, you must indicate clearly your choice of **control surface**.
- If you use any results or equations from the class notes or text in your solutions, please note and **reference** them (please make sure they are applicable to the problem at hand).
- Try to **solve** the problem **algebraically** first. Only use numbers/values in the final steps of your solution.

1. Hydrogen-Oxygen Rocket Nozzle

Measurements have been taken at the entrance and exit of a rocket nozzle, with the rocket combustion chamber that feeds the nozzle operating on hydrogen (H_2) and oxygen (O_2) with a mass ratio of oxygen to hydrogen equal to 3.50.

	Temperature (K)	Pressure (atm)
Inlet	2897	107
Exit	1266	1.75

For this problem, you can use data from the table below – but do **not** use thermodynamic data for these gases from any other source.

	H ₂ O	OH	Н	0	H ₂	O ₂
MW	18.02	17.01	1.008	16.00	2.016	32.00
<i>К</i> р <i>,f</i> , 2897 к	31.81	1.126	0.113	0.0778	1	1
<i>К</i> р <i>,f</i> , 1266 к	2.162×10 ⁷	0.1567	6.31×10 ⁻⁷	9.33×10 ⁻⁸	1	1
$\Delta ar{h}_{\!f,\ 2897\ m K}$ (kJ/mol)	-252.90	35.38	229.53	256.64	0	0
$\Delta ar{h}_{f,\ 1266\ \mathrm{K}}$ (kJ/mol)	-249.38	37.74	223.67	253.55	0	0
$\overline{h}_{2897 \text{ K}} - \overline{h}_{1266 \text{ K}}$ (kJ/mol)	83.41	56.22	33.90	34.00	66.07	61.81

The formation equilibrium constants are based on a reference pressure of 1 atm.

- a) Is the rocket operating with excess O₂ or H₂ (i.e., is it running oxygen rich or fuel rich)?
- b) What would be the equilibrium composition (in terms of mole fractions) of the propellant entering the nozzle if we assume the only species present are H₂O, OH, and either H₂ (if operating fuel rich) or O₂ (if operating oxygen rich)?

- **c)** What would be the equilibrium composition (in terms of mole fractions) of the combustion products leaving the nozzle if we assume the only species present are the same ones you used in part b)?
- **d)** Assuming the gas velocity entering the nozzle is no more than 50 m/s, estimate the velocity of the gas exiting the nozzle.

2. Ramjet Performance Analysis

A ramjet engine is being used on an aircraft burning a JP fuel with a heating value of 43.5 MJ/kg at a fuel-air ratio of 0.0434. The aircraft is flying at Mach 2.23 and operating (on Earth) at an altitude where the ambient temperature is 214.4 K and the ambient pressure is 13.88 kPa. The product gases exiting the ramjet's nozzle have static properties of 1415 K and 23.80 kPa, a velocity of 1211.9 m/s, and a molecular weight of 28.5.

- **a)** What is the ramjet's thrust-specific fuel consumption (in kg kN⁻¹ hr⁻¹) for the given flight and operating conditions?
- **b)** What are the ramjet's propulsive, thermal and overall efficiencies at these conditions?
- **c)** Assuming the ramjet's combustor is operating with a combustion efficiency of 98.5%, and the averaged specific heat for the combustor is 1.067 kJ/kgK, estimate the stagnation temperature exiting the combustor.

Extra Credit. H₂-O₂ Chemical Equilibrium

Consider a mixture of H₂, O₂, H₂O, OH, H and O at a temperature of 2897 K that was created by burning a mixture that originally contained 80.0% H₂ and 20.0% O₂ by mole. If you need thermochemical data for these species, use the data provided in Problem 1.

- a) What would be the equilibrium composition (in terms of mole fractions) of these species at a pressure of 107 atm?
- **b)** What would be the equilibrium composition (in terms of mole fractions) of these species at a pressure of 10.7 atm?