Unified Engineering Quiz 1 NAME_SOLUTIONS- WAITZ____

Fall 2004

Unified Quiz: Thermodynamics

November 12, 2004

Calculators allowed.
No books allowed.
A list of equations is provided.

- **Put your name on each page of the exam.**
- **Read all questions carefully.**
- **Do all work for each problem on the pages provided.**
- **Show intermediate results.**
- **Explain your work --- don't just write equations.**
- **Partial credit will be given (unless otherwise noted), but only when the intermediate results and explanations are clear.**
- **Please be neat. It will be easier to identify correct or partially correct responses when the response is neat.**
- **Show appropriate units with your final answers.**
- **Box your final answers.**

Exam Scoring

#1 (35%)	
#2 (25%)	
#3 (18%)	
#4 (22%)	
Total	

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1) **(30%, 5 parts * 7% each -- partial credit given)**

a) Explain in physical terms why $c_v<c_p$ for a gas. In your explanation, please include definitions of c_v and c_p and please make reference to different forms of energy and heat and work.

The constant volume specific heat, c_v, is the heat that must be transferred to a kilogram of a substance to raise it's temperature by 1K in a constant volume process. The constant pressure specific heat, c_p, is the heat that must be transferred to a kilogram of a substance to raise it's temperature by 1K in a constant pressure process.

Gases are compressible (that is, by pushing on them it is possible to change their volume). Therefore, when heat is added to a gas at constant pressure (as opposed to constant volume) the gas expands. In doing so, it does work on the surroundings which tends to lower the energy of the system (per the First Law of Thermodynamics), thus it takes more heat to increase the internal energy of a gas for a constant pressure process than for a constant volume process.

a) Describe what internal energy is in physical terms

Internal energy is a measure of the random disordered motion of molecules in a substance.

a) Describe what enthalpy is in physical terms

Enthalpy is the amount of energy that is transferred across a system boundary by a moving flow. This energy is composed of two parts: the internal energy of the fluid (u) and the flow work (pv) associated with pushing the mass of fluid across the system boundary. Because enthalpy is a measure of the energy that is transferred across a system boundary by a flow, it is most useful for flow processes involving open systems, e.g. applications of the steady flow energy equation

1) Continued (30%, 5 parts * 7% each -- partial credit given)

b) What is work?

Work is the transfer of energy across a system boundary by any process other than temperature difference only (which is called heat). It is measured in Joules, just like energy, but it is an energy transfer. It is not a property of the system. It is path dependent (i.e. the amount of energy transferred to or from a system as it goes from state 1 to state 2 depends on the details of the process, not just the beginning and end states).

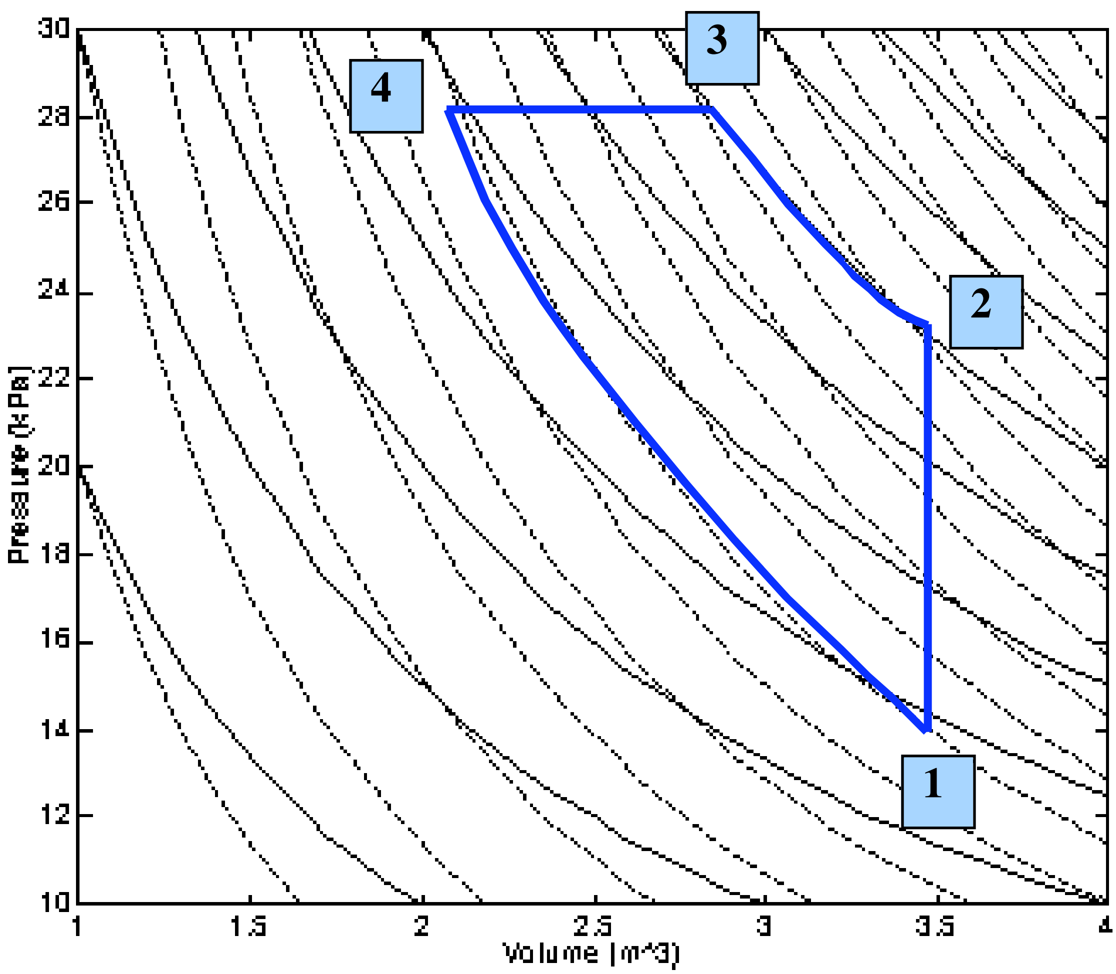
c) When the compression process for an automobile engine is described as adiabatic and quasi-static what are the physical implications relative to the speed and size of the engine, the cylinder design and the properties of the working fluid? (LO# 4, 5)

If the process is quasi-static it means that the speed of the piston is much slower than the amount of time it takes for the gas in the cylinder to reach pressure equilibrium. This time is a function of the speed of sound of the gas and the size of the cylinder. Bigger cylinders and/or slower speeds of sound would require more time to reach equilibrium. If the process is adiabatic, it means that process occurs faster than the time it takes for an appreciable amount of energy to be transferred to the cylinder by virtue of a temperature difference. This time is a function of the thermal diffusivity of the gas, and the cylinder design (e.g. how well insulated it is).

2) (25%, partial credit given)

a) **(5%, partial credit given)** Draw (and label) a thermodynamic cycle consisting of four quasi-static processes involving an ideal gas: (LO# 4, 6)

1-2: constant volume heating
2-3: isothermal compression
3-4: constant pressure cooling
4-1: adiabatic expansion



(dashed lines = adiabats, solid lines = isotherms)

b) **(15%, partial credit given)** Determine the sign of the heat and work transfers and change in internal energy for each leg and the cycle as a whole.

	q (+, - or zero)	**w (+, - or zero)**	**Δu (+, - or zero)**
Leg 1-2	+	0	+
Leg 2-3	-	-	0
Leg 3-4	-	-	-
Leg 4-1	0	+	-
Sum for cycle	-	-	0

c) **(5%, partial credit given)** You are given 2 independent thermodynamic properties at state 1, along with c_p, c_v and R and the following additional information about the cycle:

1-2: constant volume heating
2-3: isothermal compression, compression ratio (v2/v3) = 1.5
3-4: constant pressure cooling
4-1: adiabatic expansion, expansion ratio (v1/v4) = 2

Is enough information given to determine the work of the cycle? If your answer is no, what additional information must be given? If your answer is yes, how would you determine what the work is (i.e. what steps would you go through)? DO NOT SOLVE THE CYCLE TO ANSWER THIS QUESTION!

NAME_SOLUTIONS- WAITZ____

- BLANK PAGE FOR ADDITIONAL WORK -

Yes, enough information is given to solve this problem**. In order to solve the problem, I need to be able to determine the state at each point in the cycle**.

Starting from state 1 (where two properties are given) and going clockwise, given the expansion ratio, (v1/v4) = 2, to state 4—then everything at state 4 is defined (using relationships for adiabatic-quasi-static processes).

So then the pressure at state 3 is known since it is the same as at state 4, but not the volume (yet). The compression ratio (v2/v3) = 1.5 is given, and v2 is the same as v1 since process 2-1 is constant volume. So v3 is known. So the state is fully defined at point 3.

On to state 2: Here the volume is the same as state 1, and the pressure can be determined from the ideal gas relations knowing that temperature is the same as state 3.

Then the work for the cycle can be calculated by applying the First Law to each leg and summing up the work for each leg.

3) (18%, partial credit given) An aircraft is traveling against a headwind. Assume R = 287 J/kg-K, c_p = 1003.5 J/kg-K, c_v = 716.5 J/kg-K, γ = 1.4. (LO# 4)

a) (6%, partial credit given) If the temperature of the atmosphere is 260K and the wind is moving at 10 m/s relative to the ground, what temperature would a thermometer read if it is fixed to the ground?

This is a steady reference frame (air moving by at a constant speed of 10 m/s with a temperature of 260K). The temperature measured by the thermometer is higher than 260K since the flow stagnates (via an adiabatic process with no external work) and the kinetic energy is converted to enthalpy.

$$c_p T_T = c_p T + \frac{c^2}{2}$$

$$\therefore T = 260\text{K}, \quad c = 10\text{m/s} \quad \Rightarrow T_T = 260.05\text{K}$$

b) (6% partial credit given) What temperature would a weather balloon read if it was carried along with the wind?

Since the balloon is moving with the wind, there is no relative velocity difference between the air mass and the frame of reference of the balloon. Therefore the temperature read by the thermometer is the same as the static temperature of the air = 260K.

c) (6%, partial credit given) For a thermometer mounted on an airplane that is flying into the wind at 250m/s relative to the moving air mass, what temperature is read?

First you must put yourself in a steady reference frame (seated on the airplane next to the thermometer). You see flow moving towards you at 250m/s with a temperature of 260. The temperature read by the thermometer is higher than 260K since the flow stagnates (via an adiabatic process with no external work) and the kinetic energy is converted to enthalpy.

$$c_p T_T = c_p T + \frac{c^2}{2}$$

$$\therefore T = 260\text{K}, \quad c = 250\text{m/s} \quad \Rightarrow T_T = 291.1\text{K}$$

4) (22%, partial credit given) For this problem assume the working fluid is an ideal gas with $R=260$ J/kg-K, $c_p= 2800$ J/kg-K, and $c_v = 2540$ J/kg-K. (LO #4)

A cold rocket propellant enters a pump at p = 1MPa, T = 200K and c = 50 m/s. The flow rate is 100 kg/s. The flow leaves the pump at p = 5MPa and c = 60 m/s. Assuming the pump behaves adiabatically and quasi-statically, what are the thermodynamic conditions at the pump exit? What are the rates of work, shaft work and flow work done by the propellant during the pumping process?

$P_1=1\text{x}10^6$ Pa, $T_1 = 200$ K, $c_1 = 50$ m/s, mass flow = 100 kg/s

$P_2=5\text{x}10^6$ Pa, $c_2 = 60$ m/s via a quasi-static, adiabatic process. Therefore pv^{γ}=constant.

$\gamma = c_p/c_v = 1.1$

$p_1 v_1=RT_1 \rightarrow v_1=0.052\ \text{m}^3/\text{kg}$

$pv^{\gamma}=\text{constant} \rightarrow v_2=0.012\ \text{m}^3/\text{kg}$

$p_2 v_2=RT_2 \rightarrow T_2=230.8$ K

Rate of flow work = mass flow * R (T2-T1)

= 100 kg/s * 260 J/kg-K * (230.8 K – 200 K)

= 0.80 MW

Apply the steady flow energy equation:

$$q_{1-2} - w_{1-2} = u_2 - u_1 + \frac{c_2^2}{2} - \frac{c_1^2}{2} \quad \text{or} \quad q_{1-2} - w_{s\,1-2} = h_2 - h_1 + \frac{c_2^2}{2} - \frac{c_1^2}{2}$$

with q = 0 and $du=c_v dT$ and $dh=c_p dT$

$$w_{1-2} = -\left[c_v\left(T_2 - T_1\right) + \frac{c_2^2}{2} - \frac{c_1^2}{2}\right] = -78.8\ \text{kJ/kg}$$

Rate of work = mass flow*w = -7.88 MW

Work = $w_{flow}+w_{shaft}$ therefore

Rate of shaft work = Rate of work minus rate of flow work = -7.88 MW – 0.80 MW = - 8.68 MW

(You could also calculate this using the SFEE in terms of enthalpy as given above.)