

NAME _____ BOX NUMBER _____

Problem 1 (22) _____

Problem 2 (30) _____

Problem 3 (24) _____

Problem 4 (24) _____

Total (100) _____

INSTRUCTIONS

- Closed book/notes exam. (Unit conversion page provided)
- Help sheet allowed. (8-1/2 x 11" sheet of paper, one side)
- Laptops may be used; however, no pre-prepared worksheets or files may be used.

1) Show all work for complete credit.

- Start all problems at the ANALYSIS stage, but clearly label any information you use for your solution.

• Problems involving conservation principles MUST clearly identify the system and show a clear, logical progression from the basic principle(s). For FULL CREDIT, you must clearly show and label all energy transfers on a system diagram for your system.

- Don't expect us to read your mind as to how or why you did something in the solution. Clearly indicate how you arrived at your answer and how you used the given information in the process.
- Always crunch numbers last on an exam. The final numerical answer is worth the least amount of points. (Especially if all we would have to do is plug in the numbers into a well-documented solution.)

2) Useful Rule of Thumb (Heuristic): (100 point exam)/(90 min) ≈ 1 point/minute. That means a 10 point problem is not worth more than 10 minutes of your time (at least the first time around).

3) Please remain seated until the end of class or everyone finishes. (Raise your hand and I'll pick up your exam if you have other work you need or want to do.)

USEFUL INFORMATION	SI	USCS	Molar Mass [kg/kmol; lbm/lbmol]	
Ideal Gas Constant: R_u	= 8.314 kJ/(kmol-K)	= 1545 (ft-lbf)/(lbmol-°R)	Air	28.97
		= 1.986 Btu/(lbmol-°R)	O ₂	32.00
Standard Acceleration of Gravity: g	= 9.810 m/s ²	= 32.174 ft/s ²	N ₂	28.01
Density of liquid water	= 1000 kg/m ³	= 62.4 lbm/ft ³	H ₂	2.016
		= 1.94 slug/ft ³	CO ₂	44.01

Length

$$1 \text{ ft} = 12 \text{ in} = 0.3048 \text{ m} = 1/3 \text{ yd}$$

$$1 \text{ m} = 100 \text{ cm} = 1000 \text{ mm} = 39.37 \text{ in} = 3.2808 \text{ ft}$$

$$1 \text{ mile} = 5280 \text{ ft} = 1609.3 \text{ m}$$

Mass

$$1 \text{ kg} = 1000 \text{ g} = 2.2046 \text{ lbm}$$

$$1 \text{ lbm} = 16 \text{ oz} = 0.45359 \text{ kg}$$

$$1 \text{ slug} = 32.174 \text{ lbm}$$

Temperature Values

$$(T/K) = (T/^{\circ}\text{R}) / 1.8$$

$$(T/K) = (T/^{\circ}\text{C}) + 273.15$$

$$(T/^{\circ}\text{C}) = [(T/^{\circ}\text{F}) - 32] / 1.8$$

$$(T/^{\circ}\text{R}) = 1.8(T/K)$$

$$(T/^{\circ}\text{R}) = (T/^{\circ}\text{F}) + 459.67$$

$$(T/^{\circ}\text{F}) = 1.8(T/^{\circ}\text{C}) + 32$$

Temperature Differences

$$(\Delta T/^{\circ}\text{R}) = 1.8(\Delta T / \text{K})$$

$$(\Delta T/^{\circ}\text{R}) = (\Delta T/^{\circ}\text{F})$$

$$(\Delta T / \text{K}) = (\Delta T/^{\circ}\text{C})$$

Volume

$$1 \text{ m}^3 = 1000 \text{ L} = 10^6 \text{ cm}^3 = 10^6 \text{ mL} = 35.315 \text{ ft}^3 = 264.17 \text{ gal}$$

$$1 \text{ ft}^3 = 1728 \text{ in}^3 = 7.4805 \text{ gal} = 0.028317 \text{ m}^3$$

$$1 \text{ gal} = 0.13368 \text{ ft}^3 = 0.0037854 \text{ m}^3$$

Volumetric Flow Rate

$$1 \text{ m}^3/\text{s} = 35.315 \text{ ft}^3/\text{s} = 264.17 \text{ gal/s}$$

$$1 \text{ ft}^3/\text{s} = 1.6990 \text{ m}^3/\text{min} = 7.4805 \text{ gal/s} = 448.83 \text{ gal/min}$$

Force

$$1 \text{ N} = 1 \text{ kg}\cdot\text{m}/\text{s}^2 = 0.22481 \text{ lbf}$$

$$1 \text{ lbf} = 1 \text{ slug}\cdot\text{ft}/\text{s}^2 = 32.174 \text{ lbm}\cdot\text{ft}/\text{s}^2 = 4.4482 \text{ N}$$

Pressure

$$1 \text{ atm} = 101.325 \text{ kPa} = 1.01325 \text{ bar} = 14.696 \text{ lbf}/\text{in}^2$$

$$1 \text{ bar} = 100 \text{ kPa} = 10^5 \text{ Pa}$$

$$1 \text{ Pa} = 1 \text{ N}/\text{m}^2 = 10^{-3} \text{ kPa}$$

$$1 \text{ lbf}/\text{in}^2 = 6.8947 \text{ kPa} = 6894.7 \text{ N}/\text{m}^2$$

[lbf/in² often abbreviated as “psi”]

Energy

$$1 \text{ J} = 1 \text{ N}\cdot\text{m}$$

$$1 \text{ kJ} = 1000 \text{ J} = 737.56 \text{ ft}\cdot\text{lbf} = 0.94782 \text{ Btu}$$

$$1 \text{ Btu} = 1.0551 \text{ kJ} = 778.17 \text{ ft}\cdot\text{lbf}$$

$$1 \text{ ft}\cdot\text{lbf} = 1.3558 \text{ J}$$

Energy Transfer Rate

$$1 \text{ kW} = 1 \text{ kJ}/\text{s} = 737.56 \text{ ft}\cdot\text{lbf}/\text{s} = 1.3410 \text{ hp} = 0.94782 \text{ Btu}/\text{s}$$

$$1 \text{ Btu}/\text{s} = 1.0551 \text{ kW} = 1.4149 \text{ hp} = 778.17 \text{ ft}\cdot\text{lbf}/\text{s}$$

$$1 \text{ hp} = 550 \text{ ft}\cdot\text{lbf}/\text{s} = 0.74571 \text{ kW} = 0.70679 \text{ Btu}/\text{s}$$

Specific Energy

$$1 \text{ kJ}/\text{kg} = 1000 \text{ m}^2/\text{s}^2$$

$$1 \text{ Btu}/\text{lbm} = 25037 \text{ ft}^2/\text{s}^2$$

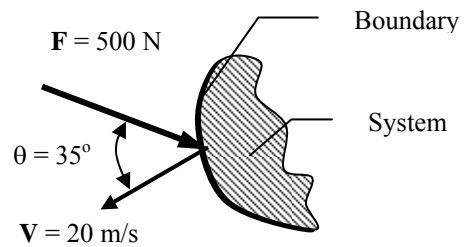
$$1 \text{ ft}\cdot\text{lbf}/\text{lbm} = 32.174 \text{ ft}^2/\text{s}^2$$

Problem 1 (22 points)

- (a) (8) In ES201, the mechanical energy balance (MEB) was initially developed from the conservation of linear momentum. However, the MEB can also be thought of as a special case of the conservation of energy principle. Starting with the rate-form of the conservation of energy principle, what assumptions are required to recover the mechanical energy balance? For FULL CREDIT, you must **name the modeling assumption** and **indicate how it changes the conservation of energy equation**.

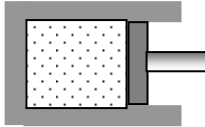
$$\frac{dE_{sys}}{dt} = \dot{Q}_{net,in} + \dot{W}_{net,in} + \sum_{in} \dot{m}_i \left(h_i + \frac{V_i^2}{2} + gz_i \right) - \sum_{out} \dot{m}_e \left(h_e + \frac{V_e^2}{2} + gz_e \right) \Rightarrow \Delta E_K + \Delta E_G + \Delta E_{Spring} = W_{mech,in}$$

- (b) (3) A force \mathbf{F} acts on the surface of a system as shown in the figure. The point of application of the force moves with the velocity \mathbf{V} also shown on the figure. Calculate the mechanical power transferred by the force to the system.



- (c) (3) A 5-hp electric motor requires an input of 4.0 kW of electric power and draws its power from a 110-volt AC power system. Assuming the motor has a power factor of one, calculate the effective current for the motor, in amps.

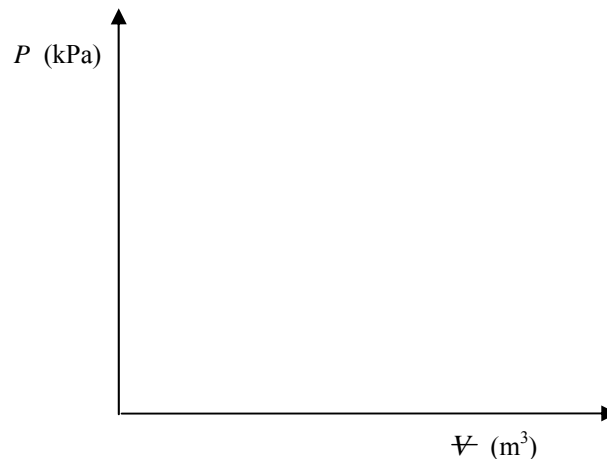
(d) An ideal gas is contained in a simple piston-cylinder device and executes the three-step process shown in the figure.



Process & State Information	
State 1:	$P_1 = 100 \text{ kPa}$; $V_1 = 1.00 \text{ m}^3$; $T_1 = 300 \text{ K}$
Process 1 \rightarrow 2	Constant-pressure (isobaric) expansion
State 2:	$V_2 = 2.00 \text{ m}^3$
Process 2 \rightarrow 3:	Constant-temperature (isothermal) expansion where $PV = C$.
State 3:	$V_3 = 3.00 \text{ m}^3$
Process 3 \rightarrow 4:	Constant-pressure (isobaric) compression
State 4:	$V_4 = V_1 = 1.00 \text{ m}^3$

(d-i) (3) Determine the temperature of the gas at state 2.

(d-ii) (3) Sketch the process on the P - V diagram provided. Clearly label the four states — 1, 2, 3, and 4.

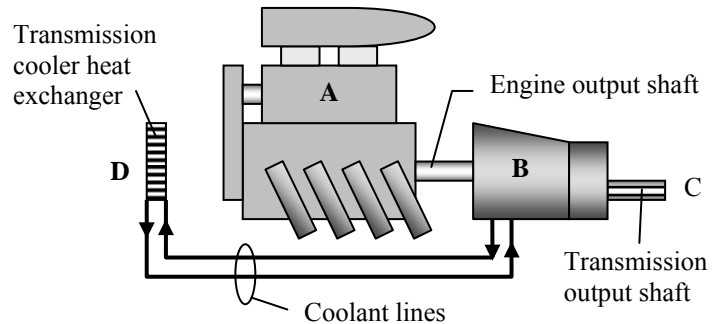


(d-iii) (2) Using your sketch above, identify the *area* on the diagram that represents the work done during process 2-3 by shading or cross-hatching the area.. (We'll look for the answer on the diagram above.)

Problem 2 (30 points)

A 455 cubic inch Pontiac engine (A) is connected to a TH400 automatic transmission (B) which sends power out to the rear wheels (C). A transmission cooler heat exchanger (D) is used to remove heat generated by frictional losses within the transmission. A liquid coolant circulates through a closed loop to transfer the energy from the transmission to the cooler heat exchanger. Steady-state performance data is measured in the lab and the results are shown in the table:

Test Data	
Power Measurements	
Engine output shaft @ 3800 rpm	390.0 hp
Transmission output shaft	350.4 hp
Coolant Temperatures	
Cooler inlet / transmission outlet	300°F
Cooler outlet / transmission inlet	237°F



If needed, you may assume the transmission coolant fluid can be modeled as an incompressible substance with a density of $56.8 \text{ lb}_m/\text{ft}^3$ and a specific heat $0.4286 \text{ Btu}/(\text{lb}_m\text{-}^\circ\text{F})$.

- Determine the **torque** produced by the motor at the engine output shaft, in $\text{ft}\text{-lb}_f$.
- Determine the **heat transfer rate** out of the transmission cooler heat exchanger, in Btu/s . Assume that there is negligible heat transfer from the surfaces of the transmission casing and the coolant lines.
- Determine the **mass flow rate of coolant** through the coolant lines, in lb_m/s . Assume that pressure drops inside the coolant loop circuit are negligible, i.e. pressure inside the coolant loop is uniform.
- Experience has shown that the heat transfer from the transmission casing may *not* be negligible. To check this out, estimate the **heat transfer rate from the surface of the transmission** by convection. Assume that the surface area of the casing is 8.68 ft^2 , the surface temperature is 80°F , the temperature of the surrounding air is 70°F , and the convective heat transfer coefficient is $0.0144 \text{ Btu}/(\text{ft}^2\text{-s}\text{-}^\circ\text{F})$.

Problem 3 (24 points)

In a belated move to surpass the U.S. space program, chipmunks have decided to place a chipmunk in space. The planned launch vehicle for the chipnaut is a potato slingshot as shown in the figure.

For the launch, the chipnaut first climbs out on a limb and takes a position immediately above the potato slingshot. Then his launch crew pulls back the slingshot into the firing position as shown. Once the slingshot is fired, the chipnaut awaits the potato “booster”. When the potato booster arrives, it picks up (impacts) the chipnaut without touching the tree launch platform and carries the chipnaut upward to the heavens.

Your job is to predict how the flight will proceed. You may assume that all motion is in the vertical direction. Additional information is provided below:

Mass of the potato = 1.0 kg

Mass of the chipnaut = 2.0 kg

Elastic Band: Spring Constant $k = 500 \text{ N/m}$

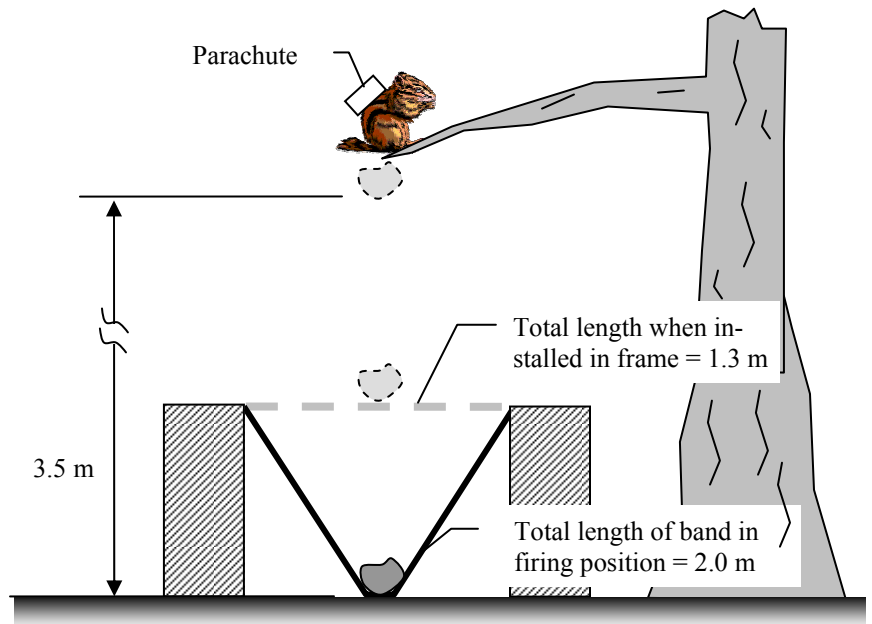
Total length (unstretched) = 1.0 m

Total length installed (with initial stretch) = 1.3 m

Total length stretched for firing = 2.0 m

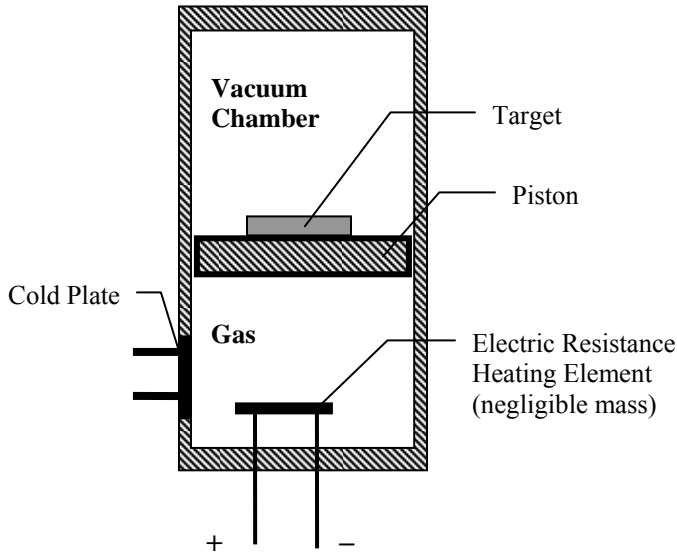
- (a) Determine the velocity, in m/s, of the potato “booster” immediately before it picks up the chipnaut.
- (b) Determine the maximum elevation, in meters, that can be achieved by the “booster” carrying the chipnaut.

(Please note that some chipnauts have been concerned about remaining conscious during the flight. Future test flights will investigate this potential problem.)



Problem 4 (24 points)

The ion sputtering process creates a new surface layer of material on an object by bombarding the surface with ions of the desired material. The top half of the device in the figure is the vacuum chamber and the lower half is the piston-cylinder device used to raise or lower the target. The position of the piston is altered by adding energy to the gas using an electric resistance heating element or removing energy by heat transfer using a cold plate in the cylinder wall. The known information is shown in the table.



Given Information

- $m_p =$ Mass of the piston
- $m_T =$ Mass of the target
- $m_G =$ Mass of the gas
- $A_p =$ Area of the piston
- $T_1 =$ Initial temperature of the gas
- $T_2 =$ Final temperature of the gas
- $P_1 = \left\{ \begin{array}{l} (m_T + m_p) g / A_p, \text{ the initial} \\ \text{pressure in the gas.} \end{array} \right.$
- $z_1 =$ Initial elevation of the piston
- $g =$ Acceleration of gravity
- $c_p \ \& \ c_v =$ Specific heats of the gas
- $W_{\text{elect,in}} =$ Electric work *into* the gas
- $Q_{\text{cold,out}} =$ Heat transfer *out* of the gas and into the cold plate.

Select an appropriate system or systems and determine the change in elevation of the target, $\Delta z = z_2 - z_1$, in terms of some or all of the given information.

Assume that the piston is frictionless and initially stationary. The change in elevation occurs very slowly with negligible change in kinetic energy of the piston. In addition, the piston, the cylinder wall, and the vacuum chamber wall (all the cross-hatched regions) are made of material that provides an adiabatic boundary and does not change temperature. The gas can be modeled as an ideal gas with room temperature specific heats.

