

NAME \_\_\_\_\_ BOX NUMBER \_\_\_\_\_

Problem 1 (38) \_\_\_\_\_

Problem 2 (a) (24) \_\_\_\_\_

Problem 2 (b) (38) \_\_\_\_\_

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 or accounting principles MUST clearly identify the system and show a clear, logical progression from the basic principle(s).**

- **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)/(50 min) ≈ 2 point/minute. That means a 10 point problem is not worth more than 5 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
			O <sub>2</sub>	32.00
Standard Acceleration of Gravity: $g$	= 9.810 m/s <sup>2</sup>	= 32.174 ft/s <sup>2</sup>	N <sub>2</sub>	28.01
Density of liquid water	= 1000 kg/m <sup>3</sup>	= 62.4 lbm/ft <sup>3</sup>	H <sub>2</sub>	2.016
			CO <sub>2</sub>	44.01
		= 1.94 slug/ft <sup>3</sup>		

### Length

$$\begin{aligned}1 \text{ ft} &= 12 \text{ in} = 0.3048 \text{ m} = 1/3 \text{ yd} \\1 \text{ m} &= 100 \text{ cm} = 1000 \text{ mm} = 39.37 \text{ in} = 3.2808 \text{ ft} \\1 \text{ mile} &= 5280 \text{ ft} = 1609.3 \text{ m}\end{aligned}$$

### Mass

$$\begin{aligned}1 \text{ kg} &= 1000 \text{ g} = 2.2046 \text{ lbm} \\1 \text{ lbm} &= 16 \text{ oz} = 0.45359 \text{ kg} \\1 \text{ slug} &= 32.174 \text{ lbm}\end{aligned}$$

### Temperature Values

$$\begin{aligned}(T/\text{K}) &= (T/^{\circ}\text{R}) / 1.8 \\(T/\text{K}) &= (T/^{\circ}\text{C}) + 273.15 \\(T/^{\circ}\text{C}) &= [(T/^{\circ}\text{F}) - 32] / 1.8 \\(T/^{\circ}\text{R}) &= 1.8(T/\text{K}) \\(T/^{\circ}\text{R}) &= (T/^{\circ}\text{F}) + 459.67 \\(T/^{\circ}\text{F}) &= 1.8(T/^{\circ}\text{C}) + 32\end{aligned}$$

### Temperature Differences

$$\begin{aligned}(\Delta T/^{\circ}\text{R}) &= 1.8(\Delta T/\text{K}) \\(\Delta T/^{\circ}\text{R}) &= (\Delta T/^{\circ}\text{F}) \\(\Delta T/\text{K}) &= (\Delta T/^{\circ}\text{C})\end{aligned}$$

### Volume

$$\begin{aligned}1 \text{ m}^3 &= 1000 \text{ L} = 10^6 \text{ cm}^3 = 10^6 \text{ mL} \\&= 35.315 \text{ ft}^3 = 264.17 \text{ gal} \\1 \text{ ft}^3 &= 1728 \text{ in}^3 = 7.4805 \text{ gal} = 0.028317 \text{ m}^3 \\1 \text{ gal} &= 0.13368 \text{ ft}^3 = 0.0037854 \text{ m}^3\end{aligned}$$

### Volumetric Flow Rate

$$\begin{aligned}1 \text{ m}^3/\text{s} &= 35.315 \text{ ft}^3/\text{s} = 264.17 \text{ gal/s} \\1 \text{ ft}^3/\text{s} &= 1.6990 \text{ m}^3/\text{min} = 7.4805 \text{ gal/s} \\&= 448.83 \text{ gal/min}\end{aligned}$$

### Force

$$\begin{aligned}1 \text{ N} &= 1 \text{ kg}\cdot\text{m}/\text{s}^2 = 0.22481 \text{ lbf} \\1 \text{ lbf} &= 1 \text{ slug}\cdot\text{ft}/\text{s}^2 = 32.174 \text{ lbm}\cdot\text{ft}/\text{s}^2 = 4.4482 \text{ N}\end{aligned}$$

### Pressure

$$\begin{aligned}1 \text{ atm} &= 101.325 \text{ kPa} = 1.01325 \text{ bar} \\&= 14.696 \text{ lbf}/\text{in}^2 \\1 \text{ bar} &= 100 \text{ kPa} = 10^5 \text{ Pa} \\1 \text{ Pa} &= 1 \text{ N}/\text{m}^2 = 10^{-3} \text{ kPa} \\1 \text{ lbf}/\text{in}^2 &= 6.8947 \text{ kPa} = 6894.7 \text{ N}/\text{m}^2 \\&[\text{lbf}/\text{in}^2 \text{ often abbreviated as "psi" }]\end{aligned}$$

### Energy

$$\begin{aligned}1 \text{ J} &= 1 \text{ N}\cdot\text{m} \\1 \text{ kJ} &= 1000 \text{ J} = 737.56 \text{ ft}\cdot\text{lbf} = 0.94782 \text{ Btu} \\1 \text{ Btu} &= 1.0551 \text{ kJ} = 778.17 \text{ ft}\cdot\text{lbf} \\1 \text{ ft}\cdot\text{lbf} &= 1.3558 \text{ J}\end{aligned}$$

### Energy Transfer Rate

$$\begin{aligned}1 \text{ kW} &= 1 \text{ kJ}/\text{s} = 737.56 \text{ ft}\cdot\text{lbf}/\text{s} \\&= 1.3410 \text{ hp} = 0.94782 \text{ Btu}/\text{s} \\1 \text{ Btu}/\text{s} &= 1.0551 \text{ kW} \\&= 1.4149 \text{ hp} = 778.17 \text{ ft}\cdot\text{lbf}/\text{s} \\1 \text{ hp} &= 550 \text{ ft}\cdot\text{lbf}/\text{s} = 0.74571 \text{ kW} = 0.70679 \text{ Btu}/\text{s}\end{aligned}$$

### Specific Energy

$$\begin{aligned}1 \text{ kJ}/\text{kg} &= 1000 \text{ m}^2/\text{s}^2 \\1 \text{ Btu}/\text{lbm} &= 25037 \text{ ft}^2/\text{s}^2 \\1 \text{ ft}\cdot\text{lbf}/\text{lbm} &= 32.174 \text{ ft}^2/\text{s}^2\end{aligned}$$

**Problem 1** (38 points)

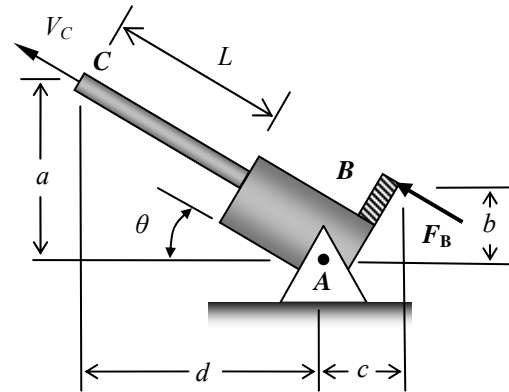
The water cannon at right will be used for dust control during the demolition of the Terre Haute House.

Water enters the cannon through its base at atmospheric pressure with negligible velocity. Water exits the cannon barrel at atmospheric pressure at  $C$  with a very large velocity  $V_C$ . The cannon barrel has cross-sectional area  $A_C$  and length  $L$ .

The cannon full of water has mass  $m$ , and the mass center (center of mass) of the cannon is at  $A$ . The density of water is  $\rho$ .

Determine the reactions at the frictionless pin  $A$  as well as the normal force  $F_B$  applied to the handle  $B$  by the operator to hold the system at steady state.

SET UP but DO NOT SOLVE this problem. Your answer should consist of clear system diagrams, a list of numbered equations, and a list of unknowns.



**Problem 2** (62 points)

**Part (a)** (24 points)

At an international pastry competition, a team of pastry chefs was rushing to get their creation (made completely of sugar!) to the judging table. In their haste, they placed their pastry sculpture onto their transport cart with a relative velocity (sculpture to cart) of 2 m/s. Unfortunately in the ensuing chaos, the pastry sculpture was ultimately destroyed before it could be weighed. The judges have denied any damages claiming the sculpture was “too big.”

The chefs need you to use your Con Apps knowledge to reconstruct the accident.

Video surveillance tapes and examination of the accident scene reveal the following:

Before:  $V_{\text{cart,before}} = 0.5 \text{ m/s}$ ;  $V_{\text{sculpture/cart,before}} = 2.0 \text{ m/s}$

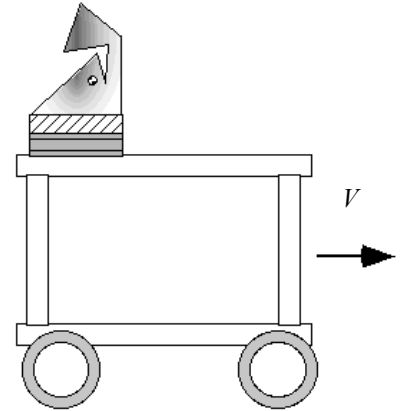
After:  $V_{\text{cart,after}} = 1.0 \text{ m/s}$ ;  $V_{\text{sculpture/cart,after}} = 0$

All velocities are horizontal and to the right.

The sculpture was still intact after it was placed on the cart!

Mass of the cart  $m_{\text{cart}} = 40 \text{ kg}$ .

Sculpture-cart friction coefficients  $\mu_{\text{Static}} = 0.5$  and  $\mu_{\text{Kinetic}} = 0.35$



after pastry sculpture placed on cart

- (i) Determine the mass of the (intact) pastry sculpture from the available information about the behavior of the cart and sculpture.
- (ii) Determine the horizontal impulse of the cart on the pastry sculpture.

**Problem 2 (continued)**

**Part (b)** (38 points)

The chefs are claiming that after the loaded cart got away from them someone could have grabbed the loaded cart and slowed it down! (Most everyone else says not because the sculpture would have slipped off the cart or tipped over.)

For your analysis, assume the following:

- ...loaded cart was moving away from the chefs to the right at 1 m/s,
- ...coefficients of friction between the sculpture and cart were  $\mu_{\text{Static}} = 0.5$  and  $\mu_{\text{Kinetic}} = 0.35$ ,
- ...sculpture dimensions were  $h = 0.75$  m and  $d = 1$  m.
- ...mass of the pastry sculpture was  $m_{\text{Sculpture}} = 17$  kg. (This is *not* the answer to Part (a)).
- ...mass of the cart was  $m_{\text{Cart}} = 40$  kg.

Assuming that someone could have grabbed the cart on the left:

- (i) What is the maximum cart deceleration without the sculpture slipping on the cart?
- (ii) What is the maximum cart deceleration without the sculpture tipping (no slipping)? [Where is the normal force when it starts to tip?]
- (iii) What is the maximum force (direction and magnitude) that could be applied to the cart to slow it down without the sculpture tipping or slipping? [For partial credit, assume a deceleration and solve.]

