

NAME _____ BOX NUMBER _____

Problem 1 (22) _____

Problem 2 (26) _____

Problem 3 (26) _____

Problem 4 (26) _____

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 momentum transfers on a free-body 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

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

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

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

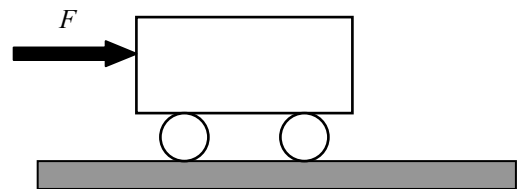
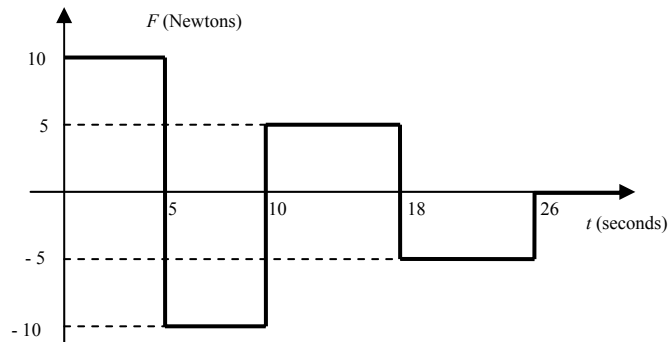
Problem 1 (22 points)

(a) (4) Identify by name all the mechanisms available for transferring linear momentum into or out of a system.

(b) (2) When a pressure force acts on the boundary of a system, it acts in (Circle One)

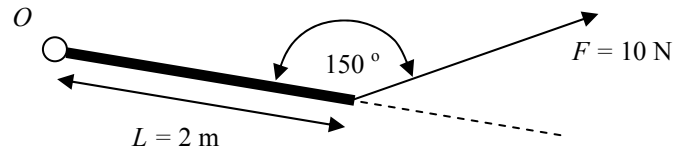
- i. the direction normal to the boundary;
- ii. the direction tangent to the boundary;
- iii. either the direction normal or tangent to the boundary

(c) (4) The time-varying force shown in the graph is applied to drive a rolling cart on a smooth horizontal surface. What is the net change in linear momentum of the cart due to this force after 26 seconds? Assume that the cart rolls without friction and the mass of the cart is 10 kg.



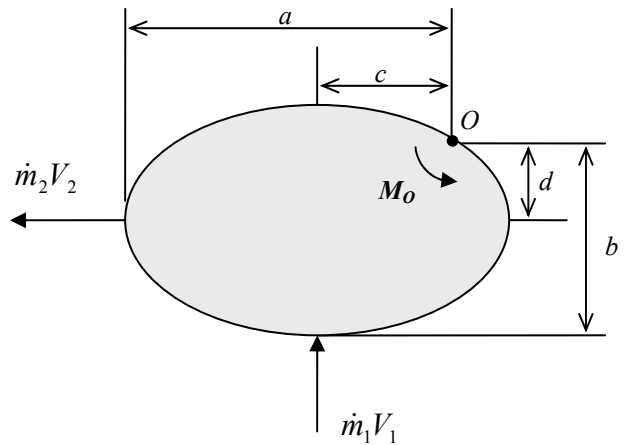
Problem 1 (continued)

- (d) (4) A 2-meter door is free to rotate about the Hinge O under the applied force. What is the resultant moment about point O due to this force? Clearly indicate magnitude *and* direction.

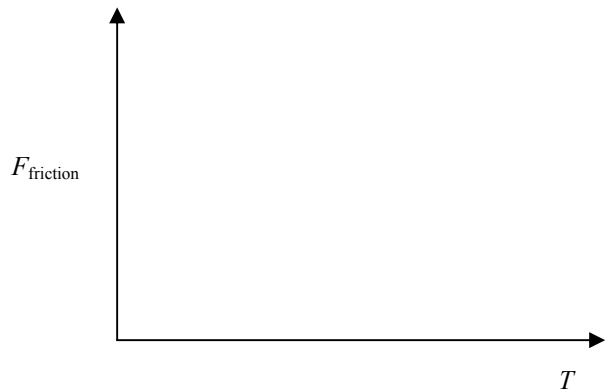
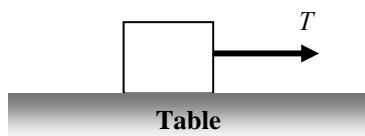


- (e) (4) For the steady-state system shown at right, the Conservation of Angular Momentum Principle about point O , using the right hand rule (CCW is positive), simplifies to one of the following. Circle the correct formulation:

- i) $0 = M_0 - \dot{m}_1 b V_1 + \dot{m}_2 a V_2$
- ii) $0 = M_0 + \dot{m}_1 c V_1 - \dot{m}_2 d V_2$
- iii) $0 = M_0 - \dot{m}_1 c V_1 + \dot{m}_2 d V_2$
- iv) $0 = M_0 + \dot{m}_1 b V_1 - \dot{m}_2 a V_2$



- (f) (4) Suppose that we have a block sitting on *horizontal* table as shown in the figure. The static coefficient of friction is μ_s , and the kinetic coefficient of friction is μ_k . The mass of the block is m and the local acceleration of gravity is g . Initially the tension in the rope is zero and the block is stationary. Slowly, we begin to pull on the block. Plot the magnitude of the friction force exerted **on the table** versus the tension T in the rope.



Problem 2 (26 points)

You have been asked to investigate the performance of a jet-propelled boat using a water channel where the water velocity V_{water} can be varied as required. The boat is placed in the channel and tethered so that it is stationary. The boat is jet-propelled by a pump that develops a constant volumetric flow rate of water, \dot{V}_{pump} . Water enters the aft (front) of the boat through an area of A_1 and leaves at the stern (rear) through an area A_2 .

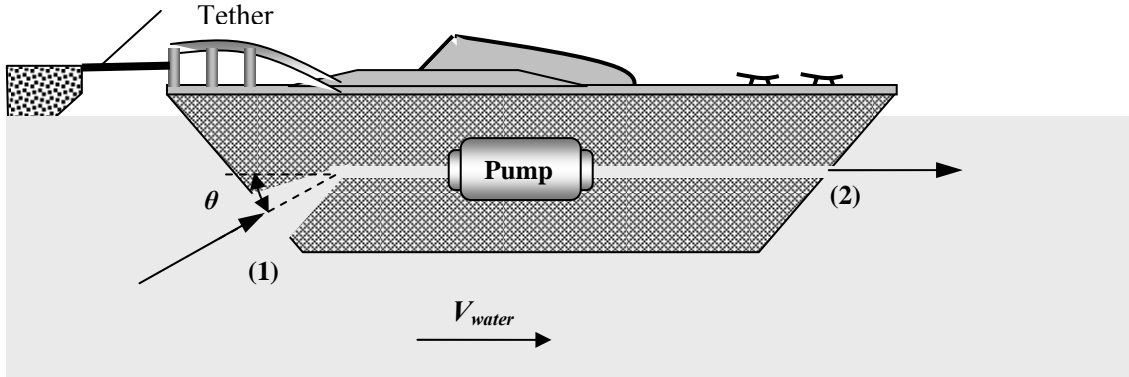
Water flowing over the hull of the boat exerts a drag force on the boat in the direction the water is flowing. This horizontal drag force which includes the net pressure forces on the hull is given by the following equation:

$$F_{drag} = kV_{water}^2$$

where k is a constant.

Assume that the angle θ and water density ρ are both known.

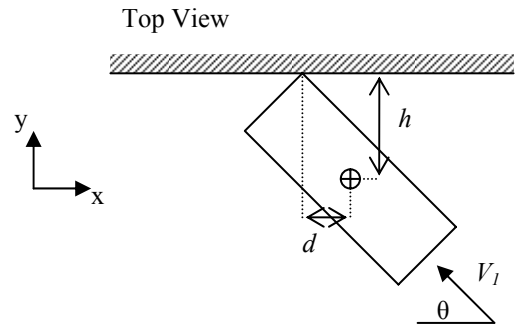
- Find expressions for the water velocities V_1 and V_2 in terms of the pump flow rate, \dot{V}_{pump} .
- Find an expression for the volumetric flow rate through the pump \dot{V}_{pump} as a function of the water velocity in the channel, V_{water} , when the tension in the tether is zero, i.e. $\dot{V}_{pump} = f(V_{water})$.



Problem 3 (26 points)

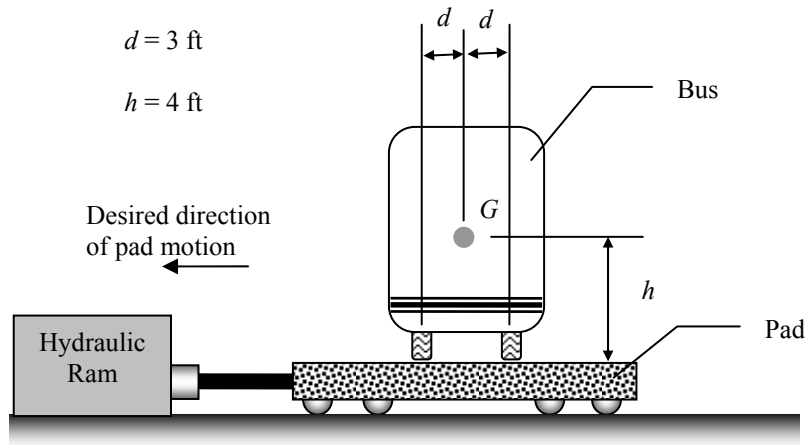
You have been hired by NASCAR to analyze vehicle impacts into the wall. For the crash at right, solve for the average reactions ($R_{x,avg}$ and $R_{y,avg}$) of the wall on the car in terms of the mass of the vehicle m , the initial velocity V_I , the angle θ , the distances h and d , and the time interval $\Delta t = t_2 - t_1$ assuming the vehicle comes to a complete stop during the time interval.

Feel free to assume that the car remains a rectangle during the impact.



Problem 4 (26 points)

As part of a school bus safety test program, school buses are being tested for potential roll-over hazards. To test the bus, it is placed on 1000-pound moveable concrete pad that rolls freely without friction. The horizontal motion of the pad is produced by a hydraulic ram which pulls the pad to left. A 5000-pound school bus is placed on the pad as shown in the figure.



- (a) Assuming the bus does not slip on the pad, determine the minimum value of the horizontal acceleration (dV/dt) of the pad in the direction indicated that will cause the bus to tip, in ft/s^2 .
- (b) Determine the force, in lbf, that the ram must apply to the platform to produce the acceleration found in part (a).
- (c) Determine the minimum static coefficient of friction between the tires and the concrete pad that is required to keep the bus from slipping on the moving pad.

