PHYS-113(3) (Kaldon-10717)
WMU - Fall 2001
Final Exam - 200,000 points

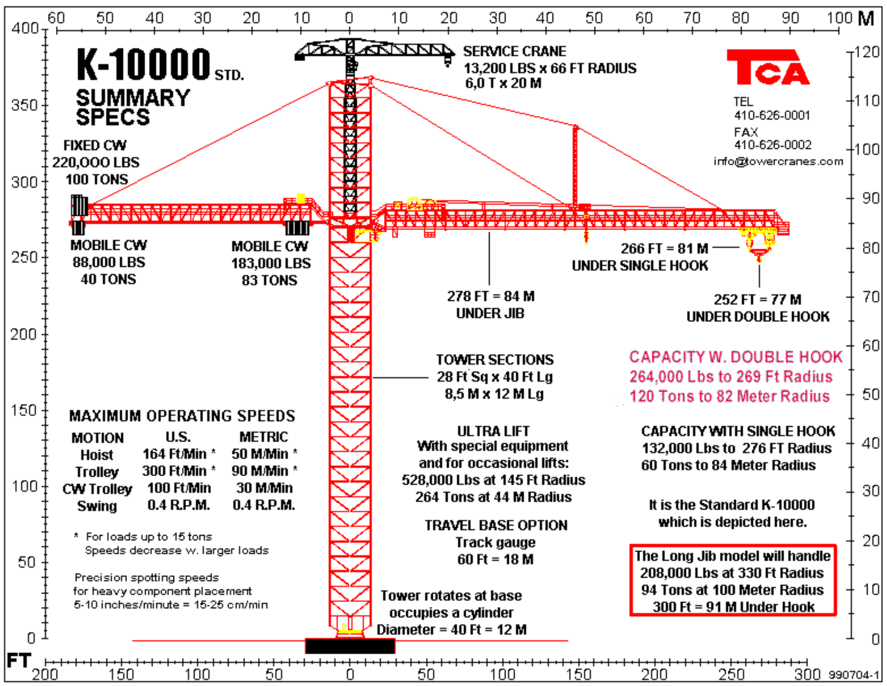
Name ____

Check-Out: ☐ Q ☐ X ☐ T ☐ WS ☐ ___
Section: 3a (A to G) 3b (H to M) 3c (N to S) 3d (T to Z) Rev. 12/04/01·Rev.7

State Any Assumptions You Need To Make -- Circle Any Final Answers
Use Your Time Wisely - Work on What You Can - Be Sure to Write Down Equations
Show All Work - Feel Free to Ask Any Questions

The Krøll 10000 – The Most Powerful Tower Crane in the World (50,000 points)

1.) Well, folks, this is one *seriously* BIG machine and having found a web site run by Tower Cranes of America, Inc., it would do a disservice to a machine of this size without devoting nearly a whole page to its impressive specifications. (Dr. Phil saw this thing in use on TLC's *Monster Machines* the other night.) Now, don't get all nervous and think you have to memorize all this data to do the problems – I just wanted to give you a look at this puppy. At the end of its arm, it can lift 100 metric tons (1 metric ton = 1000 kg = 2200 lbs) nearly 300 feet into the air and swing it over an area larger than six football fields. That beats the next biggest tower crane by a factor of nearly four. The total weight of the entire K-10000 Standard in its typical configuration is 2,114,600 pounds (mass = 959,200 kg). Kroll Towercranes of Denmark make this machine, TCA owns at least two.

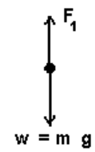


Information courtesy of Tower Cranes of America, Inc. on the WWW athttp://www.towercrane.com
Contact TCA, Inc., if you have need to rent one – their web site says they have two ready for immediate delivery, but you know the Web – might be out of date.

The Krøll 10000 can lift a 100. metric ton ($m = 100{,}000\ kg$) load 252. feet (77.0 meters) in the air in 705.0 seconds. (a) What is the speed of the moving load?

$$v = \frac{d}{t} = \frac{77.0m}{705.0\sec} = 0.1092\sec$$

(b) Find the force F_1 that the crane has to supply to lift the 100. metric ton load at a constant speed. *Hint: It is always good to include a Free Body Diagram. (It also ensures Full Points!)*



$$\sum F_y = F_1 - mg = 0$$
$$F_1 = mg = (100{,}000kg)(9.81m/s^2)$$
$$= 981{,}000N$$

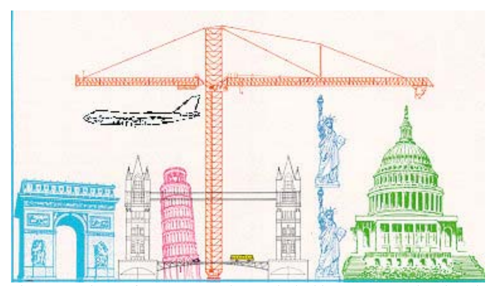
(c) Find the work that the crane does to the load to lift it 252. feet (77.0 meters).

$$W = Fd = (981{,}000N)(77.0m) = 75{,}540{,}000J$$

(d) Find the change in the potential energy of the load as it is lifted 252. feet (77.0 meters).

$$\Delta U_g = mgh_f - mgh_i = mgh_f$$
$$= (100{,}000kg)(9.81m/s^2)(77.0m) = 75{,}540{,}000J$$

(e) Find the power that the crane lift motor has to supply to do the total work of lifting the load from ground to 252. feet (77.0 meters).



Size Comparisons of K-10000 to Other Typical Objects… L'Arc de Triomphe, London Tower Bridge, Leaning Tower of Pisa, 2×Statue of Liberty, Capitol, 747.

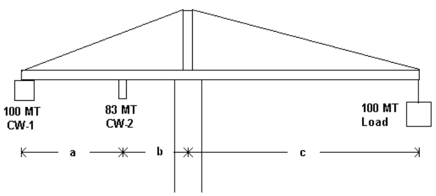
$$P = \frac{W}{t} = \frac{75{,}540{,}000J}{705.0\sec} = 107{,}100W$$

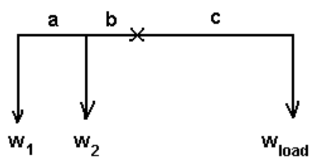
A Crane as Big as the K-10000 Deserves a BIGGER Problem… (50,000 points)

2.) (a) The entire Krøll 10000 tower crane turns on its pedestal base at a rate of 0.400 r.p.m. Find ω in the proper SI units.

$$\omega = \frac{0.400 rev}{60.0 \sec} = \frac{0.400(2\pi\, rad)2\pi\, rad}{60.0 ec}$$
$$= 0.04189 rad / \sec$$

(b) With a 100. metric ton load (100,000 kg) on the right side of the crane, you better have a counterweight on the left side of the crane so that the whole thing doesn't topple over. We'll simplify the problem as follows: We'll ignore the mass of the horizontal crane beam by assuming that the tension from the cables holds it up. The load is located at *c = 77.0 m* from the center tower. On the left is a fixed Counterweight-1 of 100,000 kg located at *a + b = 55.0 m*. The movable Counterweight-2 of 83,000 kg is located at *b* from the center tower. Find *b*. *Hint: Use the tower as your pivot.*





$$\sum \tau = w_1(a+b) + w_2 b - w_{load}\, c = 0$$
$$m_1 g(55.0m) + m_2 g b - m_{load} g(77.0m) = 0$$
$$m_2 g b = m_{load} g(77.0m) - m_1 g(55.0m)$$
$$b = \frac{m_{load} g(77.0m) - m_1 g(55.0m)}{m_2 g}$$
$$= \frac{m_{load}(77.0m) - m_1(55.0m)}{m_2}$$
$$= \frac{(100{,}000kg)(77.0m) - (100{,}000kg)(55.0m)}{(83{,}000kg)}$$
$$= 26.51m$$

(c) Again ignoring the horizontal crane beam and the vertical tower, find the moment inertia *I* of the turning crane based on the three masses described in (b). *If you didn't get an answer to (b), use b = 20.0 meters.*

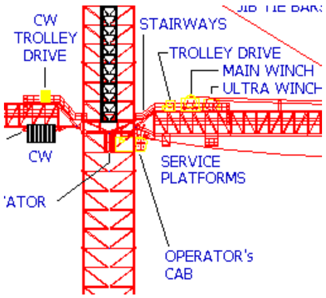
(d) What is the rotational K.E. of the tower? *Requires answers to (a) & (c).*

$$I = \sum m_i r_i^2 = m_1(55.0m)^2 + m_2 b^2 + m_{load}(77.0m)^2$$
$$= (100{,}000kg)(55.0m)^2 + (83{,}000kg)(26.51m)^2 + (100{,}000kg)(77.0m)^2$$
$$= 302{,}500{,}000 kg\cdot m^2 + 58{,}330{,}000 kg\cdot m^2 + 592{,}900{,}000 kg\cdot m^2$$
$$= 953{,}730{,}000 kg\cdot m^2$$

(e) The Krøll 10000 is run by a single operator up on the crane, 83.0 meters up. Now the operator has to ride an elevator to get up and down. Suppose one wanted to put running water for the operator. What is the minimum gauge pressure needed in the water tank on the ground for water to come out up at top?

Minimum gauge pressure means the water just makes it out of the tube at essentially zero sped.

$$P_1 + \rho g h_1 + \tfrac{1}{2}\rho v_1^2 = P_2 + \rho g h_2 + \tfrac{1}{2}\rho v_2^2$$
$$P_1 = P_2 + \rho g h_2$$
$$P_1 - P_2 = \rho g h_2$$
$$= (1000 kg/m^3)(9.81 m/s^2)(83.0m)$$
$$= 814{,}200 Pa = 8.038 atm$$



Car Problems (50,000 points)

3.) (a) Joe is heading to work, driving his 2002 Ford Guzzler™ S.U.V. (3875 kg) at 77.0 mph (34.4 m/s). He's not paying attention to where he is going – there's the new XM Satellite radio to program its 150 channels and he has to connect his cell phone to his FAX machine, and he's watching *Regis and Kelly* on the in-dash TV – and crosses the centerline, running into Jill in her 2002½ Chrysler Ostentatious™ (3760 kg), who is late for work and trying to eat a McDonald's Hot Cakes and Sausage Big Breakfast while driving 83.0 mph (37.1 m/s) the other way. Find the speed of the wreck right after the totally inelastic collision (and before the lawyers arrive).

$$p_{before} = p_{after}$$
$$m_1 v_1 - m_2 v_2 = (m_1 + m_2) V$$
$$V = \frac{m_1 v_1 - m_2 v_2}{(m_1 + m_2)}$$
$$= \frac{3875kg(34.4m/s) - 3760kg(37.1m/s)}{(3875kg + 3760kg)}$$
$$= -0.8115m/s$$

(b) The Guzzler's airbags save Joe's life and so he gets another Guzzler. On the wet pavement of Easy Street (coefficients of friction are 0.350 and 0.495), he floors the accelerator and accelerates at 3.43 m/s² while spinning both tires. Show what kind of friction is providing the force that is accelerating his S.U.V.

spinning tires = kinetic friction

$$F_{f,k} = \mu_k F_N = \mu_k mg$$
$$a = \frac{F_{f,k}}{m} = \frac{\mu_k mg}{m} = \mu_k g = (0.350)(9.81m/s^2) = 3.434m/s^2$$

(c) Jill is also unhurt in her collision and so she gets another Ostentatious. She is cruising down Easy Street at 45.0 mph (20.1 m/s) when a traffic light turns red when she is 45.0 meters from the intersection. Can she safely stop in time?

Can test for minimum stopping distance = maximum static friction

$$a_{\max,s} = -\mu_s g = -(0.495)(9.81m/s^2) = -4.856m/s^2$$
$$v^2 = v_0^2 + 2a(x - x_0)$$
$$0 = v_0^2 + 2a\,x$$
$$2a\,x = -v_0^2$$
$$x = \frac{-v_0^2}{2a} = \frac{-(20.1m/s)^2}{2(-4.856m/s^2)} = 41.60m$$

(d) Joe's Guzzler has a 384 horsepower engine (286,500 Watts). 716,300 Joules of Total Energy are produced by the engine each second. How much energy does this engine waste each second?

$$P = \frac{W}{t}\ ;\ W = P\,t = (286{,}500W)(1.00\,\text{sec}) = 286{,}500J$$
$$Q_H = W + Q_C$$
$$Q_C = Q_H - W = 716{,}300J - 286{,}500J = 429{,}800J$$

(e) Joe's engine has operating temperatures of 98.6°C and 800. K. What is the Second Law Efficiency of this engine?

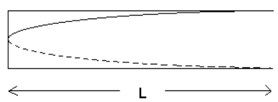
$$\varepsilon_{actual} = \frac{W}{Q_H} = \frac{286{,}500J}{716{,}300J} = 0.4000$$
$$T_C = 98.6°C = 371.6K$$
$$\varepsilon_{Carnot} = 1 - \frac{T_C}{T_H} = 1 - \frac{371.6K}{800.K} = 1 - 0.4645 = 0.5355$$
$$\varepsilon_{2nd\ Law} = \frac{\varepsilon_{actual}}{\varepsilon_{Carnot}} = \frac{0.4000}{0.5355} = 0.7470$$

Luxurious and Rapid Travel Over the Atlantic Puddle… Again! (50,000 points)

4.) (a) Now that the Anglo-French Concorde is once again flying, it's fun to take a closer look at this amazing aircraft. The Concorde cruises at 2.02 times the speed of sound (1336 m.p.h. = 597 m/s) at 16,765 meters altitude (55,000 feet). At that speed each of the four Rolls-Royce Snecma Olympus 593 Mark 610 engines are producing 10,000 lbs. (44,950 N) of thrust. Since we're cruising at a constant speed, use the high speed air resistance equation $F_{drag} = C\,v^2$ and find the constant C for the Concorde. *If you're stumped, try a free body diagram for an airplane in level flight… Make sure you have the correct S.I. units!*

$$F_{thrust} = 4(44{,}950N) = 179{,}800N$$
$$F_{drag} = Cv^2$$
$$C = \frac{F_{drag}}{v^2} = \frac{179{,}800N}{(597m/s)^2} = 0.5045N\cdot s^2/m^2 = 0.5045kg/m$$

(b) It is important in supersonic aircraft that the air is slowed to subsonic speeds before entering the engines. One way to do that is to set up a standing sound wave in the intake. That would be a standing wave with a node at the engine end and an anti-node at the open end. What is the wavelength λ of the fundamental shown for a length L = 3.80 meters?



$$L = \frac{\lambda}{2}\ ;\ \lambda = 2L = 2(3.80m) = 7.600m$$

As noted in class, the Concorde is made of aluminum, $\alpha = 24 \times 10^{-6}\ °C^{-1}$. The plane is 204.5 feet (62.19 m) long on the ground at room temperature, 68°F = 20°C. It is 24.0 cm longer at speed when it is hot. (c) Find the temperature when it is hot.

$$\Delta L = \alpha L_0 \Delta T$$
$$\Delta T = \frac{\Delta L}{\alpha L_0} = \frac{0.240m}{(24\times10^{-6}\,°C^{-1})(62.19m)} = +160.8°C$$

The total empty mass of the plane is 79,000 kg. Not all the plane is hot – otherwise the passengers wouldn't be comfortable sipping their champagne. If we count the mass of the expanded aluminum as 31,500 kg and specific heat as $c_{Al} = 900.\ J/kg\cdot°C$, then (d) how much energy was needed to heat the Concorde at speed? *If you didn't get an answer to (c), then use $T_H = 700.\ K$.*

$$Q = mc\Delta T = (31{,}500kg)(900.\,J/kg\cdot°C)(+160.8°C)$$
$$= 4{,}559{,}000{,}000J$$

(e) The British and French Concorde pilots are very calm when flying. Normal blood pressure is 120 mm·Hg systolic and 80 mm·Hg diastolic (gauge pressures P_1 = 16,000 Pa and P_2 = 10,700 Pa, respectively) in the brachial artery in the arm. The simplest model of the blood pulsing along would use the difference of these pressures to supply the "kinetic pressure" term of Bernoulli's equation. Blood may be thicker than water, but that's viscosity, not mass-to-volume ratio, so we'll use the same density as salt water, $\rho = 1030\ kg/m^3$. How fast would the blood be moving, v_2, using this simple model?

Technically we should be using absolute pressures in Bernoulli's equation, but since our pressures are positive gauge pressures above the outside air pressure, P_0, adding P_0 to both sides of the equals sign doesn't change the final math.

$$P_1 + \rho g h_1 + \tfrac{1}{2}\rho v_1^2 = P_2 + \rho g h_2 + \tfrac{1}{2}\rho v_2^2$$
$$P_1 = P_2 + \tfrac{1}{2}\rho v_2^2$$
$$\tfrac{1}{2}\rho v_2^2 = P_1 - P_2$$
$$v_2^2 = \frac{2(P_1 - P_2)}{\rho}$$
$$v_2 = \sqrt{\frac{2(P_1 - P_2)}{\rho}} = \sqrt{\frac{2(16{,}000Pa - 10{,}700Pa)}{1030kg/m^3}}$$
$$= 3.208m/s$$

Have a First Class Vacation!