Problem #1 (15 points)

The Nusselt number (Nu) and Rayleigh number (Ra) for heat transfer between a vertical surface of height L at temperature $T_{\text{surface}}$ and a fluid at temperature $T_{\text{fluid}}$ are defined by

$$ Nu = \frac{hL}{k_f}, \quad Ra = \frac{g\beta(T_{\text{surface}} - T_{\text{fluid}})L^3}{\alpha
\nu} $$

where $h$ is the convective heat transfer coefficient (units W/m$^2$˚C), $k_f$ is the thermal conductivity of the fluid (=0.0603 W/m˚C for water), $g$ is the acceleration of gravity, $\beta$ is the thermal expansion coefficient (=2.12 x 10$^{-4}$/˚C for water), $\alpha$ is the thermal diffusivity (=0.0014 cm$^2$/s for water) and $\nu$ is the fluid kinematic viscosity (0.010 cm$^2$/s for water).

(a) What are the units of Nu and Ra in the SI system?
(b) For a wall of height $L = 2$ ft submerged in water with $T_{\text{surface}} = 32$˚C and $T_{\text{fluid}} = 27$˚C, what is the value of Ra?
(c) For a certain configuration, Nu can be estimated by the expression $Nu = 0.10Ra^{1/3}$. For this configuration, using the value of Ra calculated in part (b), what is Nu and what is h?

Problem #2 (15 points)

I calculated the normal stress ($\sigma$, units force/area, i.e. same as pressure) acting on a telephone pole of height $h$ and diameter $d$ caused by a hurricane wind of speed $v$ in air with drag coefficient $C_D$, density $\rho$ and dynamic viscosity $\mu$ (units (mass)/(length * time)) (don’t confuse this $\mu$ with the coefficient of friction already discussed) as follows:

$$ \sigma = \frac{\rho v^2}{2C_D} - \rho gh + \sqrt{\frac{\rho v^3 h}{\mu}} $$

Using “engineering scrutiny,” what “obvious” mistakes can you find with this formula? There are at least 5, but list only the 3 you are most certain of.
Problem #3 (20 points)

A 6 ft long bar of negligible weight has one end supported by a rope and the other end in contact with a vertical wall. There is friction at the contact point with the wall. A 150 lbf weight is hung on the bar as shown in the figure.

(a) Assuming that the friction is sufficient to keep the bar from sliding, what unknown forces are acting on the bar, and in what direction do they act?
(b) Write down all equations needed to solve for these 3 unknown forces (hint: you need 3 equations since there are 3 unknown forces!)
(c) Solve these equations to find the 3 unknown forces
(d) What is the minimum coefficient of friction required to prevent the bar from sliding?

Problem #4 (15 points)

(a) Reanalyze the pin-and-roller link example given in class if the wall, instead of being vertical, is at a 60˚ tilt as shown in the figure. (In this part of the problem, there is no rope at point D.) What are the forces acting at points A and B?
(b) If a rope is attached at point D as shown in the figure, what would be the minimum tension T required to lift the wheel at point B off the tilted wall?
**Problem #5 (20 points)**

Reanalyze the “car on a ramp” example in the lecture notes. Suppose that instead of either of the cases analyzed in class, the rear (downhill) wheels are locked and the front (uphill) wheels are free to spin. (There is no cable attached to the car.)

(a) In terms of a, b, c, θ and W, what coefficient of static friction µs would be required to keep the car from sliding down the ramp?

(b) What would the force parallel to the ramp at point B \( F_{y,B} \) be?

(c) Repeat part (a) and (b) if the configuration is reversed, that is, the front wheels are locked and the rear wheels are free to spin.

**Problem #6 (15 points)**

A 6 ft long bar of negligible weight has one end supported by a pin and one end supported by a rope. A 250 lbf weight is hung on the bar as shown in the figure.

(a) What unknown forces are acting on the bar (hint: there are 3), and in what direction do they act?

(b) Write down all equations needed to solve for these 3 unknown forces (hint: you need 3 equations since there are 3 unknown forces!)

(c) Solve these equations to find the 3 unknown forces