1. Water is siphoned from the tank shown in Fig.1. The water barometer indicates a reading of 30.2 ft. Determine the maximum value of h allowed without cavitation occurring. Note that the pressure of the vapor in the closed end of the barometer equals the vapor pressure. (10%)

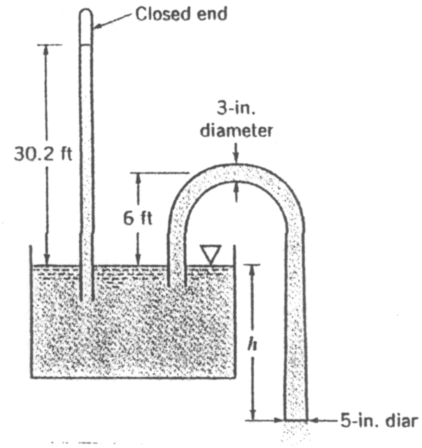

Figure 1.

2. Eleven equally spaced turning vanes are used in the horizontal plane 90° bend as indicated in Fig.2. The depth of the rectangular cross-sectional bend remains constant at 3 in. The velocity distributions upstream and downstream of the vanes may be considered uniform. The loss in available energy across the vanes is $0.2V_1^2/2$. The required velocity and pressure downstream of the vanes, section (2), are 180ft/s and 15 psia. What is the average magnitude of the force exerted by the air flow on each vane? Assume the force of the air on the duct walls is equivalent to the force of the air on one vane. Air density:2.38×10^{-3} slug/ft^3 and 1lbf=1 slug·ft/s^2. (20%)

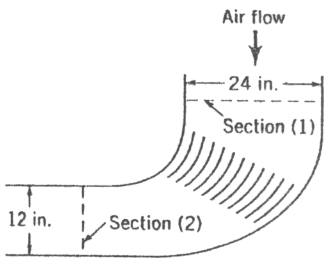

Figure 2.

3. A viscous fluid (specific weight = 76 lbf/ft^3; viscosity =0.02 lbf·s/ft^2) is contained between two infinite, horizontal parallel plates as shown in Fig.3. The fluid moves between the plates under the action of a pressure gradient, and the upper plate moves with a velocity U while the bottom plate is fixed. Determine the velocity distribution between two plates. A U-tube manometer connected between two points along the bottom indicates a differential reading of 0.1 in. If the upper plate moves with a velocity of 0.02 ft/s, at what distance from the bottom plate does the maximum velocity in the gap between the two plates occur? Assume laminar flow. (20%)

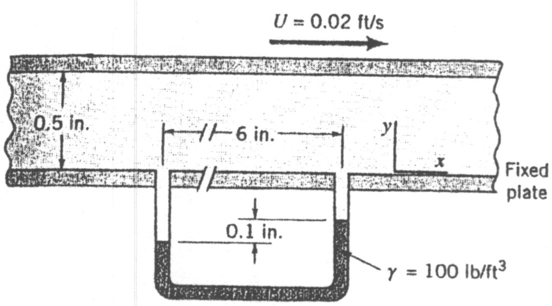

Figure 3.

Problem 4 (15 points)

In 1854 Maxwell wrote of observing the flight characteristics of a thin rectangular body, like a file card, falling through still air. He described the flight as a tumbling motion with a frequency f. Consider a card with dimensions s (span) and c (chord) and a weight per unit area of w (see Fig. P4). When the card is released from the horizontal position, it begins to fall vertically but a flow instability soon causes it to tilt about a horizontal axis. Since the net force is no longer through the mass center, the card rotates. This leads to the observed tumbling motion.

(a) Using dimensional analysis, define a dimensionless tumbling frequency and determine the dimensionless groups upon which it depends.

(b) Now assume that viscous effects are unimportant and that for $s/c > 2$, s is unimportant. How is the result of (a) affected?

(c) Design two **dynamically similar** experiments to be carried out in two fluids of different densities ρ_A and ρ_B. How would the tumbling frequencies in the two experiments be related?

Problem 5 (15 points)

A shaft of radius r_i is held concentrically in a cylindrical case of radius r_o. The shaft is kept stationary and the case is moved at a constant velocity V_o (see Fig. P5). There is no pressure gradient and the flow is laminar and incompressible.

(a) Determine the distribution of shear stress between the inner and outer surfaces, and hence integrate the resulting equation to obtain the velocity distribution.

(b) What force (per unit length) is needed to move the outer cylinder?

Problem 6 (20 points)

Consider a flat porous surface with no lengthwise pressure gradient to which suction is applied for the purpose of sucking off the laminar boundary layer (see Fig. P6). Let us denote by v_0 the downward component of velocity at the surface of the plate ($y = 0$). Then it may be shown that for very small values of v_0/U_∞ compared with unity, the laminar boundary layer becomes constant in both thickness and velocity at large distances from the leading edge, provided that v_0 is constant.

For this case of small v_0/U_∞ and large distance from the leading edge, find

(a) the velocity profile, by relating u/U_∞ to $v_0 y/\nu$;

(b) the displacement thickness Reynolds number $\delta^* v_0/\nu$, where the displacement thickness $\delta^* = \int_0^\infty (1 - u/U_\infty)\, dy$; and

(c) the skin-friction coefficient $2\tau_0/\rho U_\infty^2$, in terms of v_0, U_∞, and ν.

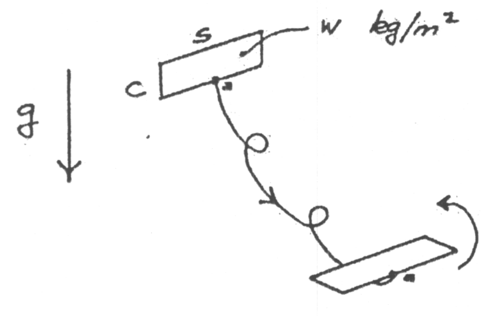

Fig. P4

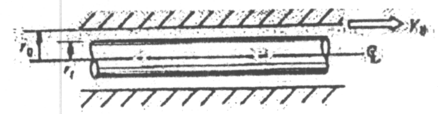

Fig. P5

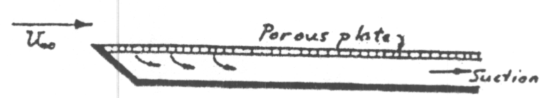

Fig. P6