CBE 30355 TRANSPORT PHENOMENA I

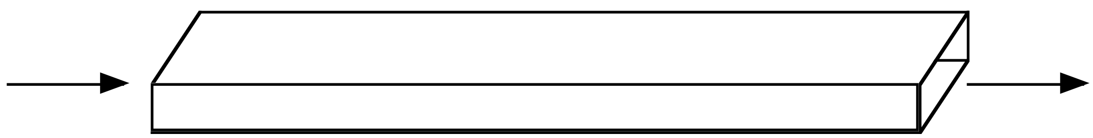
First Hour Exam
10/4/18

This test is closed books and closed notes

Problem 1. (20 points) Plane Poiseuille Flow: A problem which is currently being investigated in bioengineering laboratories is the phenomenon of cell adhesion to surfaces in the presence of hydrodynamic stresses. This is very important in the design of biocompatible materials, for example. To study this, a researcher has built a rectangular flow cell which is 50μm deep, 1mm wide, and 2cm long. The objective is to have a wall shear stress (e.g., stress at the lower wall - the 1mm x 2cm surface - where cell adhesion is being studied) of 5 dyne/cm^2 (cgs units for stress). Due to the ratio of length scales, you can assume unidirectional plane-Poiseuille flow.

a. What is the pressure required of the pump? Using a force balance over the appropriate control volume, show that this is independent of the viscosity of the fluid.

b. If the working fluid has the same viscosity as water, what should the flow rate of the pump supplying the fluid be? Give the answer in μl/min (microliters/min).



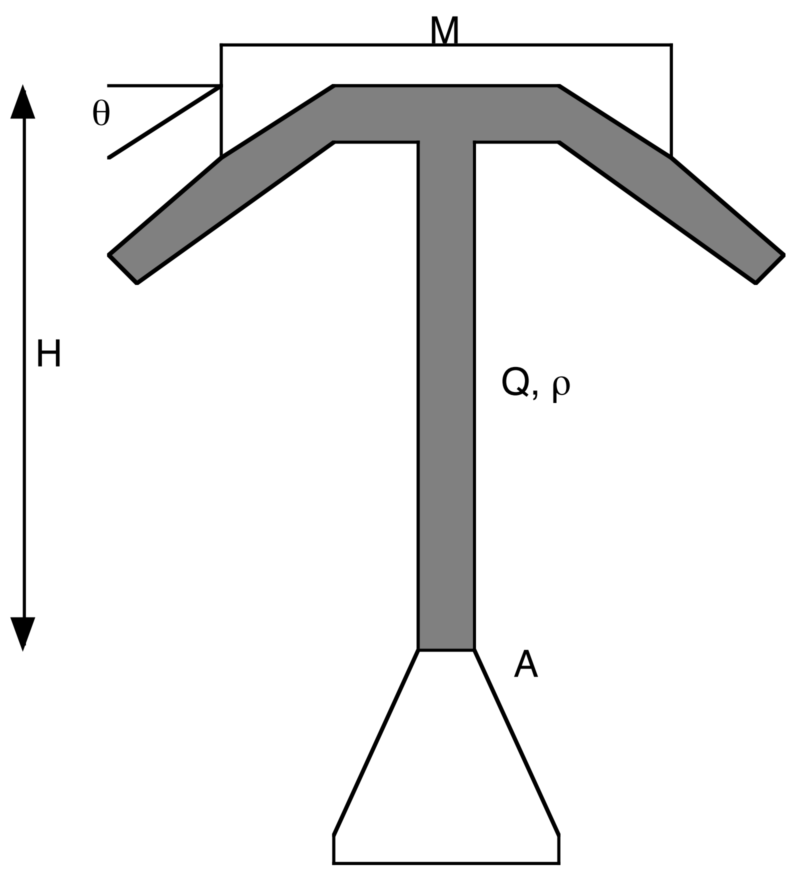
Problem 2. (20 pts) Hydrostatics. Consider the balloon depicted below. At takeoff the balloon volume is actually fairly small, but as it rises the gas in the balloon expands to fill the envelope, eventually reaching its maximum volume V. The weight of the balloon, gas, and payload is fixed at a value M (assuming no leaks!). If we make the well-mixed atmosphere approximation made for Lawnchair Larry (good to about 20km), use the equation governing hydrostatics and the adiabatic gas law to calculate the final altitude of the balloon.

Problem 3. (20 pts) Momentum Balances/Bernoulli's Equation. Consider the plate and mass depicted below. The mass M is supported by the deflection of a jet of water of volumetric flow rate Q and density ρ. The jet emerges from a nozzle of cross-sectional area A. The curvature of the plate deflects the stream backwards by some angle θ.

a. Determine the velocity of the jet at the nozzle U_0.

b. If the pipe supplying the nozzle is really fat (cross-sectional area much greater than A), what is the pressure in the pipe?

c. Using all the provided information (and an integral momentum balance!) calculate the equilibrium height of the plate. Note that the jet slows down as it moves upwards!



Problem 4. (20 pts) Short answer questions:

1. The ratio of the centerline velocity divided by the average velocity:
   a. for laminar channel flow is:
   b. for laminar tube flow is:

2. Provide two physical interpretations for the vector ρu_i .

3. $\rho \dfrac{u_\theta \, u_r}{r}$:
   a. Name a physical phenomenon where it plays an important role.
   b. Which component of the Navier-Stokes equations does it appear in?

4. You put a block of glass of thickness 2mm on a hot surface. The glass has a thermal diffusivity of about 0.004 in cgs units. About how long would you have to wait before the top of the glass warms up? Show the basis of your calculation.

5. Write down the continuity equation for an **incompressible** fluid using index notation.

6. The symmetric part of the rate of strain tensor is usually given the symbol e_{ij}. What is its representation in terms of u_i? (Index notation, please!)

7. Match up the kinematic viscosities of the following materials:

1. Water	A. 17.0 cSt
2. Air	B. 1.0 cSt
3. Glycerine	C. 0.118 cSt
4. Mercury	D. 650 cSt

8. The Reynolds number is probably *the* key dimensionless group in fluid mechanics.
   a. how is it defined for flow through a pipe?
   b. why does it govern the transition from laminar to turbulent flow?

9. Match up the following:

1. $\delta_{ij}\,\delta_{ij}$	A. 1
2. $\delta_{i1}\,\delta_{j2}$	B. 0
3. $\delta_{i1}\,\delta_{i2}$	C. 3
4. $\delta_{i1}\,\delta_{i1}$	D. None of the above

10. What is the most general second order **pseudo** tensor characterized by a single director p_i? (Hint: this is the one we used in the notes to show that rotation of a body of revolution with fore-and-aft symmetry due to a force such as gravity was zero at zero Re)