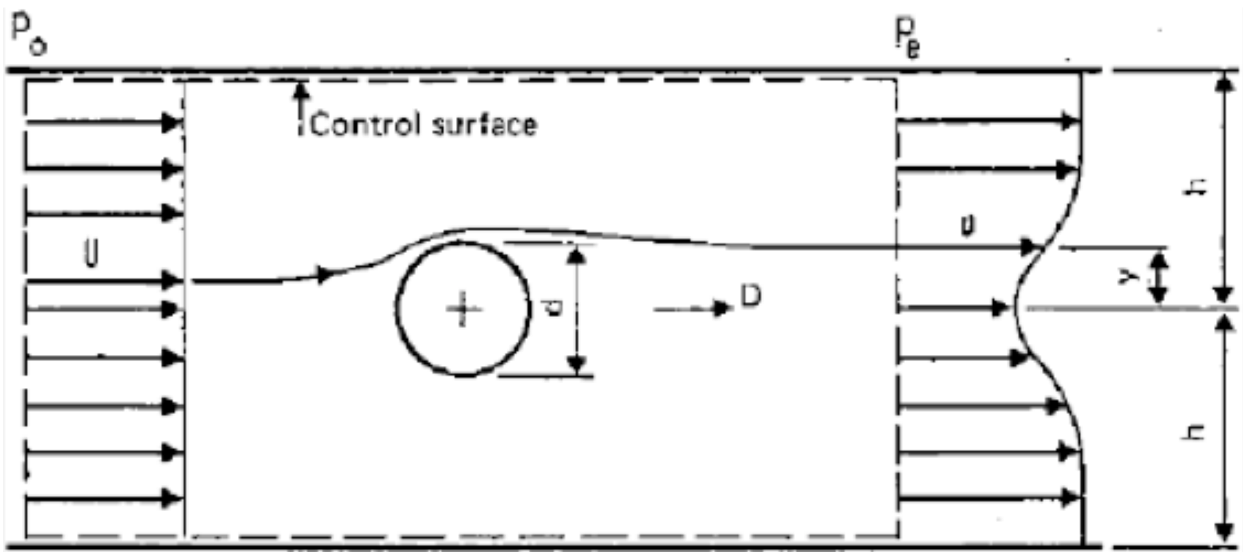
CBE 30355 TRANSPORT PHENOMENA I

First Hour Exam
10/4/16

This test is closed books and closed notes

Problem 1). (20 pts) In Senior Laboratory one of the experiments used to be measuring the drag on a cylinder at high Re. One of the techniques used is called a "wake traverse", in which we measure both the uniform velocity U upstream of the cylinder, and the non-uniform velocity u(y) downstream of the cylinder. We also measure the upstream pressure p_0 and the downstream pressure p_e. The diagram from the lab manual is given below.



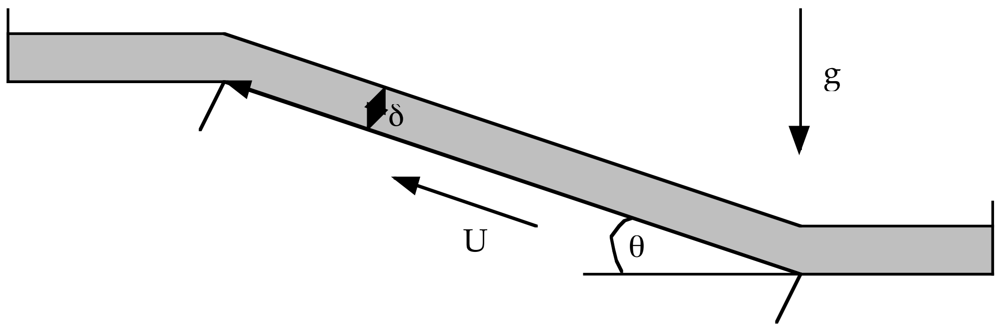
a. Write down in words the integral momentum balance around the control surface depicted above.

b. Is there more momentum convected into or out of the control volume (e.g., upstream vs. downstream)?

c. Given that we can neglect any drag on the side walls of the control surface, develop an explicit integral expression (e.g., involving an integral over y from y = -h to y = +h) for the drag per unit length (into the paper) D exerted by the fluid on the cylinder in terms of p_0, p_e, U and u. Both p_0 and p_e may be taken to be constant over the inlet and outlet, respectively, and they are *not* equal!

Hint: This problem is pretty much identical to the sluice gate problem you solved for homework, except here the upstream and downstream pressures are measured (no gravity), and the downstream velocity profile is non-uniform, and thus must be left in integral form in the momentum balance. In lab it's this downstream velocity measurement that's the tricky part of the experiment...

Problem 2). (20 points) Flow Down an Incline: Two reservoirs containing a viscous fluid are connected by an incline as shown below. On the incline you have a belt moving upwards with velocity U, dragging fluid with it, and gravity is pulling the fluid back down the other way. Eventually the system reaches steady state where the net flow rate of the fluid is zero (the two effects balance). For a given belt velocity, angle, and material properties, what is the fluid depth δ on the belt at steady-state? You may regard the upper surface as stress-free. (Hint: the problem is *a lot easier* if you render it dimensionless!)



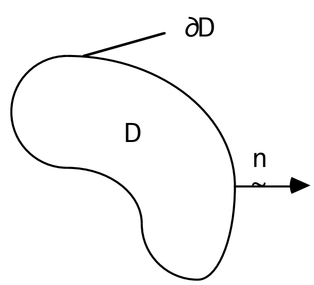
Problem 3. (20 pts) Consider the arbitrary fluid element depicted below. A fluid with thermal energy per unit volume $\rho C_p T$ (where T is the temperature and C_p is the heat capacity per unit mass) is flowing through the element with velocity $\underset{\sim}{u}$. In addition to convective heat transfer, we also have the conductive (diffusive) heat transfer flux, given by Fourier's Law of heat conduction:

$$\underset{\sim}{q} = -k \underset{\sim}{\nabla} T$$

which is analogous to the shear stress from Newton's law of viscosity. Here k is the thermal conductivity. There is also a source of thermal energy (heat generation) per unit volume S. due to chemical reactions or other sources. Both the velocity $\underset{\sim}{u}$ and the temperature T may be functions of position and time, but physical properties such as k, ρ, and C_p are taken to be constant.

a. Given the statement that thermal energy is conserved, derive an integral equation governing the thermal energy in the arbitrary control volume depicted below.

b. Using the results of part a, derive the microscopic equation governing energy transport in a flowing liquid analogous to the Navier Stokes equations. You will use this equation *a lot* next term!



Problem 4). (20 pts total) Transport Glossary / Index Notation / Short Answer

a. (6pts) Briefly identify the physical mechanism described by each of the following terms:

1. $\mu \dfrac{\partial^2 u_x}{\partial y^2}$

2. $\dfrac{\partial u_i}{\partial x_i} = 0$

3. $\rho \dfrac{v_r v_\theta}{r}$

b. (4 pts) Write out Bernoulli's Equation. What is it a statement of (e.g., where does it come from)?

c. (2pts) Using index notation, show how you can decompose the rate of strain tensor into symmetric and anti-symmetric parts.

d. (2 pts) Does Poiseuille's Law govern pressure drop / flow rate relationships for your typical house plumbing system? Briefly (quantitatively) justify your answer.

e. (2 pts) Match up the kinematic viscosities of the following materials:

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

f. (2 pts) Briefly explain how a manometer works.

g. (2pts) Why is the relaxation time important in the study of the rheology of a complex material such as a polymer melt?