Code No._____

Fluid Mechanics Ph.D Qualifier Exam

Department of Mechanical Engineering
Michigan State University

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Directions: Closed book

All problems carry equal weight.   In order to receive full credit for a
solution, you must show all work clearly.

Exam prepared by Profs. P. Lillehoj and G. Brereton

Problem 1.

Stokes flow (also called creeping flow) is a fluid flow at very low Reynolds number ($Re \ll 1$) and can be used to describe the movement of aerosol particles and microorganisms. The drag force F_D on an object in a creeping flow is a function of its velocity V, a characteristic length scale L of the object and the fluid viscosity μ.

(a) Using the Pi theorem, find the dimensionless parameters that describe a relationship for F_D as a function of the independent variables, showing your work.

(b) Consider a water flee 1 mm in diameter. A 100× full scale model is tested in glycerin ($\mu = 1.5$ kg/m.s) at $V = 30$ cm/s. If the measured drag force on the model is 1 N, what is the drag force of the actual water flee if it moves at 2 cm/s in water ($\mu = 0.001$ kg/m.s)?

Problem 2.

A nozzle (3 cm in diameter) connected to a fire hose is held by firefighters with water ($\rho = 998$ kg/m^3) flowing at 2 m^3/min at an angle of 30° to the horizontal. Assume the flow is steady and incompressible.

(a) Determine the average water exit velocity (in m/s).

(b) Calculate the horizontal force (in N) exerted on the firefighters by the water jet. Neglect frictional effects and minor losses.
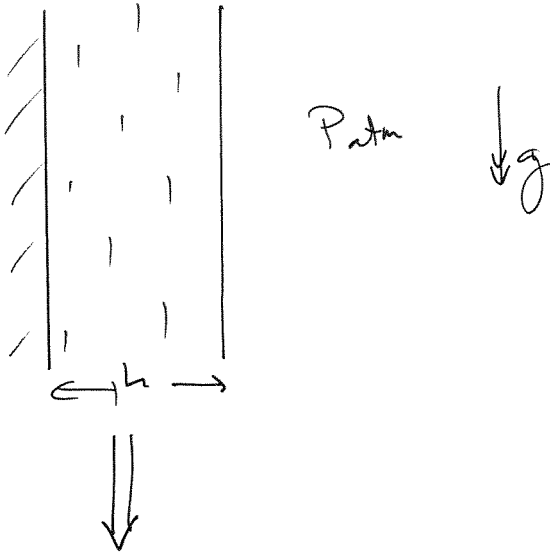
Problem 3.

The differential x-momentum equation for steady, fully developed, incompressible flow of a Newtonian fluid in a two-dimensional Cartesian inertial frame is

$$0 = -\frac{1}{\rho}\frac{\partial p}{\partial x} + f_x + \nu\frac{\partial^2 u}{\partial y^2}$$

where f_x is the body force in the x-direction. Consider the problem of a liquid layer of thickness h flowing down a long flat vertical surface under gravity. The outside of the sheet is exposed to air at atmospheric pressure.

(a) What are the boundary conditions on u?

(b) Find an expression for u as a function of y.

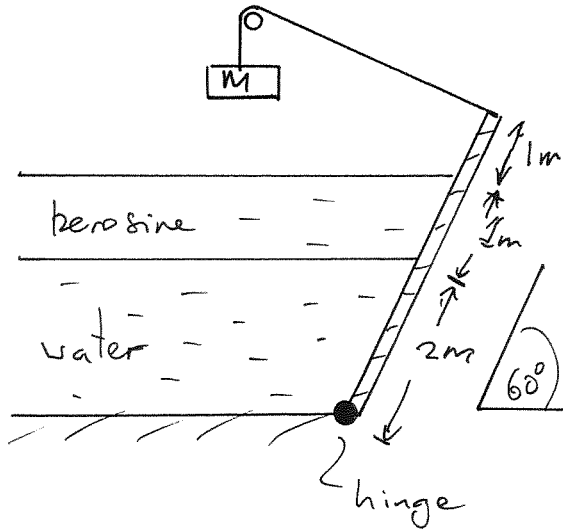(c) At what value of y is u equal to its average value?

Problem 4.

Water flows up the inclined (at 30°) pipe as shown. If the volumetric flow rate is 0.02 m³/s, determine the height h to which the water will rise in the pitot tube.
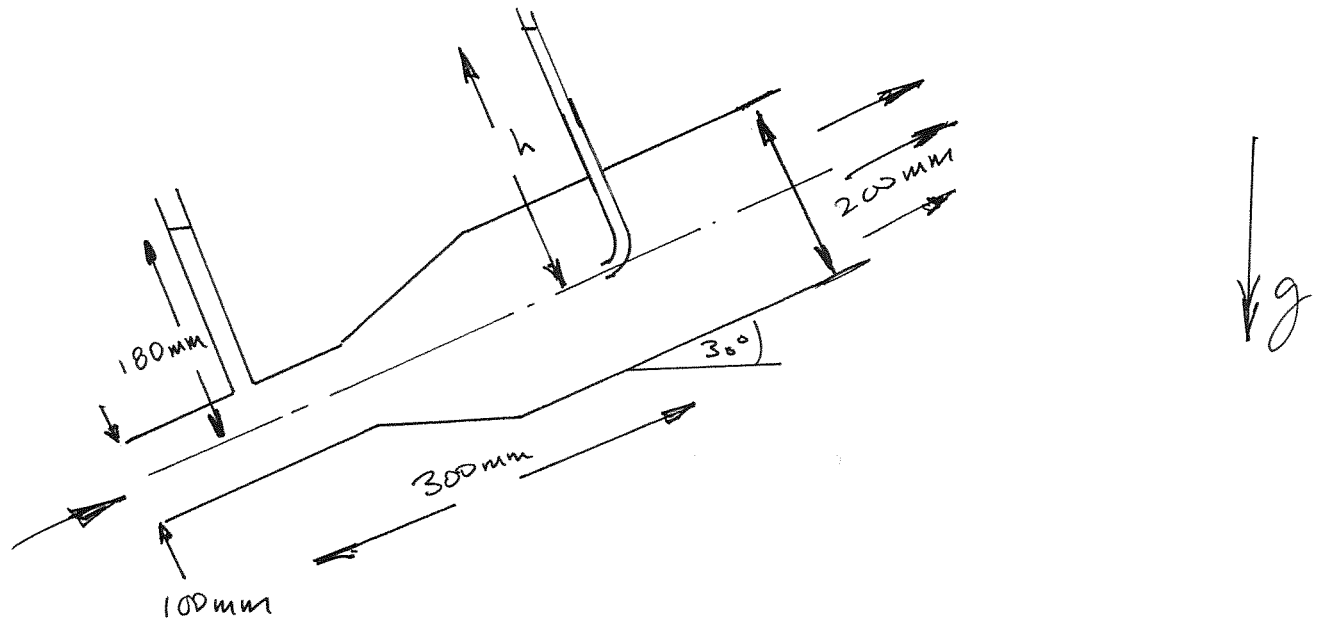
Problem 5.

The container shown is filled with water and kerosine to the depths given. What mass M is required to keep the gate in place? Assume $\rho_{water} = 1000$ kg/m³ and $\rho_{ker} = 814$ kg/m³.