1. Using the various physical parameters and material properties encountered while learning fluid mechanics, please write down and explicitly state the definition of the following dimensionless groups. Please also describe or explain the physical meaning of these dimensionless groups or numbers.

   (i) Froude number, *Fr* (2 pts),

   (ii) Mach number, *Ma* (2 pts),

   (iii) Weber number, *We* (2 pts),

   (iv) Reynolds number, *Re* (2 pts),

   (v) Knudsen number, *Kn* (2 pts).

2. Please describe the meaning and explain the purpose of the hydraulic diameter (10 pts). Under fully developed flow conditions, please show that the hydraulic diameter, D_h, for a duct of arbitrary shape equals to $D_h = 4A_c / P$, where A_c is the cross-sectional area and P is the wetted perimeter (10 pts).

   HINT: You may need the Poiseuille velocity distribution inside a circular duct, i.e.,

   $$u(r) = \frac{1}{4\mu}\left(-\frac{dp}{dz}\right)(R^2 - r^2),$$

   where μ is the fluid viscosity, R is the radius of the circular duct, and $-dp/dz$ is the pressure gradient.

3. (20 pts) Consider a steady uniform flow over a large flat plate. We use a two-dimensional *x*-*y* coordinate system to describe this flow. While the *y*-axis is perpendicular to the surface of the flat plate, the *x*-axis of the coordinate system coincides with the surface of the plate such that the surface of the plate is located at y=0; the leading edge of the plate is specified at x=0. The governing boundary layer equations for this flow condition are given by

   $$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0,$$

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$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \frac{\mu}{\rho}\frac{\partial^2 u}{\partial y^2} + U\frac{dU}{dx},$$

where u and v are respectively the x and y velocity components, μ is the fluid viscosity, ρ is the fluid density, and $U=U(x)$ is the uniform flow velocity which in general can be a function of the x-coordinate. The set of governing equations is subjected to the boundary conditions of $u=0$ and $v=0$ at $y=0$ as well as $u=U$ at $y=\delta$ with δ being the boundary layer thickness. Using the above governing boundary layer equations with the accompanying boundary conditions, please derive the Karman momentum integral equation, that is,

$$\frac{d}{dx}[U^2\theta] + \delta^* U\frac{dU}{dx} = \frac{\tau_w}{\rho},$$

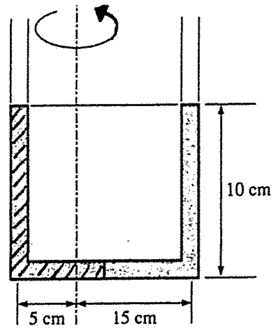
in which δ^* is the displacement thickness, θ is the momentum thickness, and τ_w is the wall shear stress evaluated at the surface of the flat plate.

HINT: You may need the Leibnitz' rule, i.e.,

$$\frac{d}{dt}\int_{\alpha(t)}^{\beta(t)} f(x,t)dx = \int_{\alpha(t)}^{\beta(t)} \frac{\partial f}{\partial t}dx + f(\beta,t)\frac{d\beta}{dt} - f(\alpha,t)\frac{d\alpha}{dt}.$$

4. (a) (5 pts) How will you design and conduct an experiment to prove the non-slip condition?

(b) (10 pts) A U-tube, as shown in the figure, contains water in the right arm and the other liquid in the left arm. It is observed that when the U-tube rotates at 25 rpm about the axis that is 15 cm from the right arm and 5 cm from the left arm. The liquid levels in both arms become the same. Please determine the density of the fluid in the left arm.



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5. Consider a wind turbine with a 100-m blade span subjected to 20 km/h steady wind. If the combined turbine-generator efficiency of the wind turbine is 35%, determine

(a) (8 pts) The power generated by the turbine,

(b) (7 pts) The horizontal force exerted by the wind on the supporting mast of the turbine.

Take the density of air to be 1.24 kg/m^3, and disregard frictional effects.

6. A problem of compressible flow

(a) (10 pts) Please list the assumptions and derive the equation of the stagnation pressure for the isentropic flow of an ideal gas.

$p_0/p = [1 + (k\text{-}1)/2\ \mathrm{M}^2]^{k/(k-1)}$

where k is the specific heat ratio of air and M is Mach number.

(b) (5 pts) Please estimate the stagnation temperature if the flight speed of an aircraft in air is M = 2.0 and environmental temperature is 0 °C.

(c) (5 pts) Explain why the supersonic aircraft often choose the configurations of very sharp noses and wing leading edges, compared to subsonic aircraft.

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