1. Consider turbulent flow of an incompressible fluid past a flat plate. The boundary layer velocity profile is assumed to be $u/U = (y/\delta)^{1/7} = Y^{1/7}$ for $Y = y/\delta \le 1$ and u=U for Y>1. This is a reasonable approximation of experimentally observed profiles, except very near the plate where this formula gives $\partial u/\partial y = \infty$ at y=0. Also assume that the shear stress agree with the experimentally determined formula:

$$\tau_w = 0.0225\rho U^2 \left(\frac{\nu}{U\delta}\right)^{1/4}$$

Determine: (1). the boundary layer thickness,
(2). the momentum thickness,
(3). the displacement thickness
(4). the wall shear stress τ_w
(5). the friction drag coefficient C_{Df}

2. The concentric cylinder device of the type shown in Fig.2 is commonly used to measure the viscosity, μ , of liquids by relating the angle twist, θ , of the inner cylinder to the angular velocity, ω , of the outer cylinder. Assume that

$$\theta = f(\omega, \mu, K, D_1, D_2, \ell)$$

where K depends on the suspending wire properties and has the dimension FL. The following data were obtained in a series of tests for which μ =0.01 lb.s/ft², K=10 lb.ft, ℓ =1 ft, and D_1 and D_2 were constant.

θ (rad)	ω (rad/s)
0.89	0.30
1.50	0.50
2.51	0.82
3.05	1.05
4.28	1.43
5.52	1.86
6.40	2.14

Determine from these data, with the aid of dimensional analysis, the relationship between θ , ω and μ for this particular apparatus.

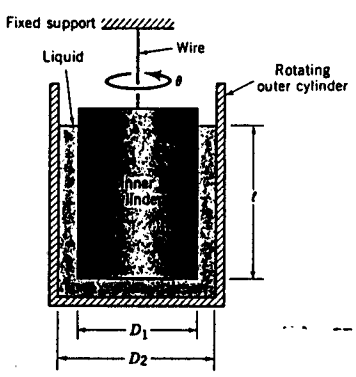

Fig. 2

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3. We consider a laminar flow in an annulus. Fig.3 shows a cross-sectional view of an annular duct. The annular flow area is bounded by the inside surface of the outer duct (radius R_1) and the outside surface of the inner duct (radius R_2). We also define the ratio of these diameters as

$$\kappa = \frac{R_2}{R_1}$$

(1). determine the velocity distribution for fully developed flow.
(2). determine the hydraulic diameter
(3). give the friction factor f in terms of the pressure gradient in the axial direction.
(4). determine the friction factor as a function of Reynolds number ($Re = \frac{\rho V(2R)}{\mu}(1-\kappa)$, V is average velocity).

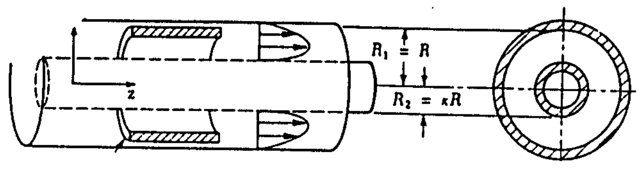

Fig.3

4. Make a comparison between the energy equation and Bernoulli equation. (15%)

5. The U-tube of Fig.5 contains mercury and rotates about the off-center axis a-a. At rest, the depth of mercury in each leg is 150 mm as illustrated. Determine the angular velocity for which the difference in heights between the two legs is 75 mm. (15%)

6. A constant-thickness film of viscous liquid flows in laminar motion down a plate inclined at angle θ, as in Fig. 6. The velocity profile is

$$u = Cy(2h-y) \qquad v = w = 0$$

Find the constant C in terms of specific weight and viscosity and the angle θ, and the volume flux Q per unit width in terms of these paramters. (20%)

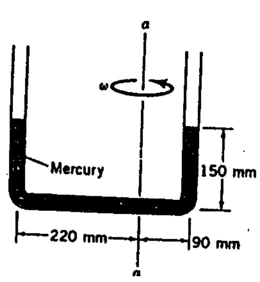

Fig. 5

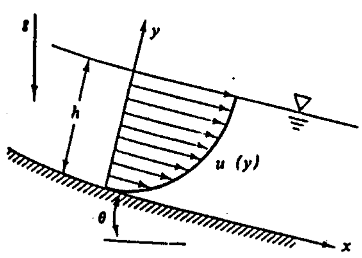

Fig. 6