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1. Curved wall ABC in Figure 1 is a quarter circle 9 ft wide (into the paper). Compute the (a) horizontal F_H and (b) vertical F_V hydrostatic forces on the wall and (c) the line of action (i.e., the angle θ) of the resultant force F_R. ($\gamma_{water} = 62.4\ lb/ft^3$)

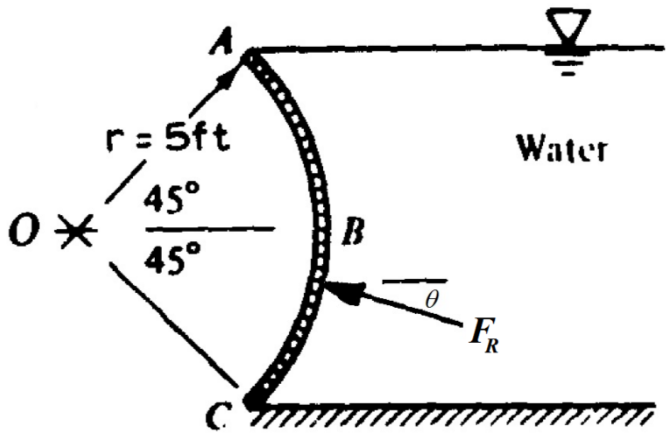

Figure 1

2. For the frictionless cart in Figure 2, compute (a) the *x*-component of the force on the wheels, F_x, caused by deflecting the water jet (ρ = 998 kg/m^3) and (b) the compression of the spring, Δx, if its stiffness is k = 1.6 kN/m. For part (b), use the Hook's law, $F_x = -k\Delta x$. Assume steady state and circular cross sectional area for the water jet.

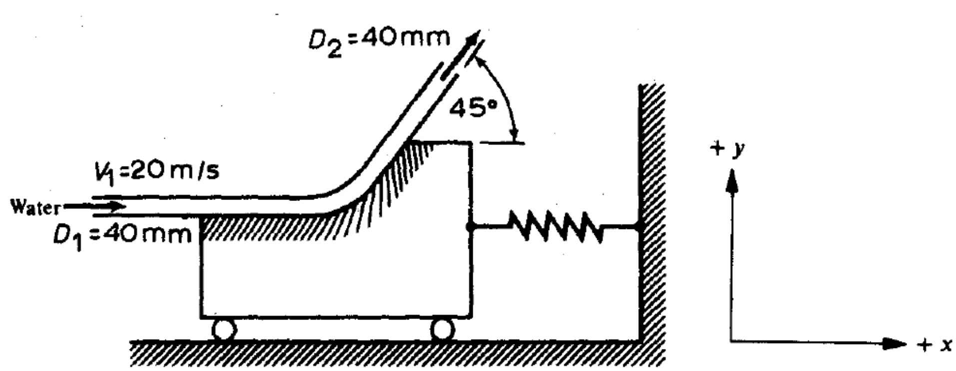

Figure 2

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3. The pressure rise, Δp, across a centrifugal pump in Figure 3(a) can be expressed as $\Delta p = f(D, \omega, \rho, Q)$, where D is the impeller diameter, ω the angular velocity of the impeller (unit for ω is T^{-1}), ρ the fluid density, and Q the volume rate of flow through the pump. (a) By using dimensional analysis, show that the two pi terms of this problem are $\Pi_1 = \Delta p/\rho\omega^2 D^2$ and $\Pi_2 = Q/\omega D^3$. (b) A model pump having a diameter of 8 in. is tested in a laboratory using water (ρ = 998 kg/m^3). When operated at an angular velocity of 40π rad/s the model pressure rise as a function of Q is shown in Figure 3(b). Use this curve to predict the pressure rise across a geometrically similar pump (prototype) for a prototype flowrate of 6 ft^3/s. The prototype has a diameter of 12 in. and operates at an angular velocity of 60π rad/s. The prototype fluid is also water.

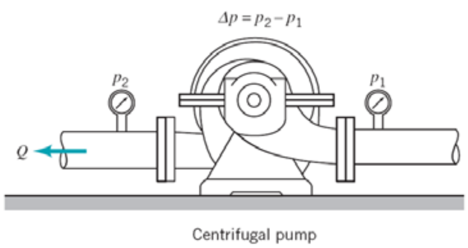

Figure 3(a)

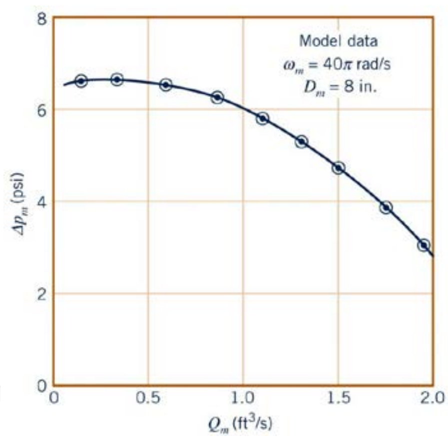

Figure 3(b)

4. If the pump shown in Figure 4 adds a head of 52 ft, determine the flow rate Q for the system. Do not neglect minor losses. Assume f = 0.01 as your first guess then use the equation below for the remaining iterations until f converges to the thousandth decimal place. (Note: 1 psi = 144 lbf/ft^2, g = 32.2 ft/s^2, ρ = 1.94 slugs/ft^3, μ = 2.34 ×10^{-5} lbf·s/ft^2, γ = 62.4 lbf/ft^3, ε = 0.00016 ft and D = 2 ft)

$$\frac{1}{\sqrt{f}} = -1.8\log\left[\left(\frac{\varepsilon/D}{3.7}\right)^{1.11} + \frac{6.9}{Re}\right]$$

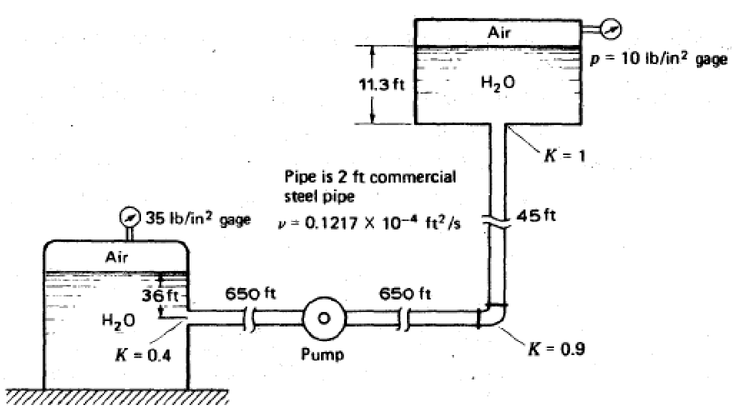

Figure 3

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5. The fixed keel of a Columbia 22 sailboat is about 38 in long as shown in Figure 5. Moving in Lake Ontario at a speed of (a) 2 knots and (b) 10 knots, what is the skin friction drag D_f from the keel, respectively? The water is at 40°F (ν = 1.664 × 10^{-5} ft^2/s and ρ = 1.94 $slugs/ft^3$). Solve this problem using rectangular plate of length 38 in and width 24.5 in, which is the average width of the keel. Transition takes place at Reynolds number of 5×10^5. Note: 1 knot = 1.689 ft/s. See the Appedix A at the end of this exam for the friction drag coeeficient, C_f.

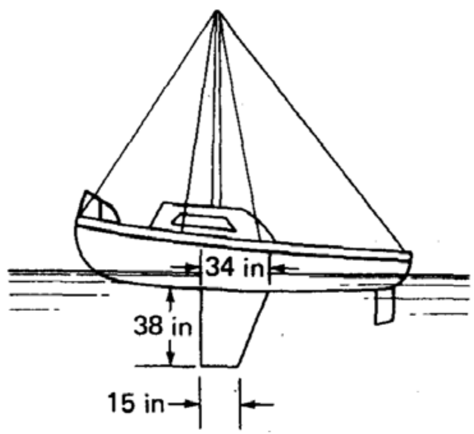

Figure 5

6. A heavy sphere attached to a string should hang at an angle θ when immersed in a stream of velocity U, as shown in Figure 6(a). Knowing that the sphere should hang so that the string tension T balances the resultant of drag and net weight as shown in Figure 6(b), find (a) the net weight W, (b) the drag, and (c) the angle θ if the sphere is steel (ρ_s= 7,844 kg/m^3) and diameter 3 cm and the flow is sea-level standard air (ρ_{air} = 1.225 kg/m^3 and μ_{air} = 1.78 × 10^{-5} kg/m·s) at U = 40 m/s. (Volume $V = \pi D^3/6$ for a sphere of diameter D). Neglect the string drag and the buoyancy force on the sphere, and use the Appendix B of this exam for the drag coefficient C_D if necessary.

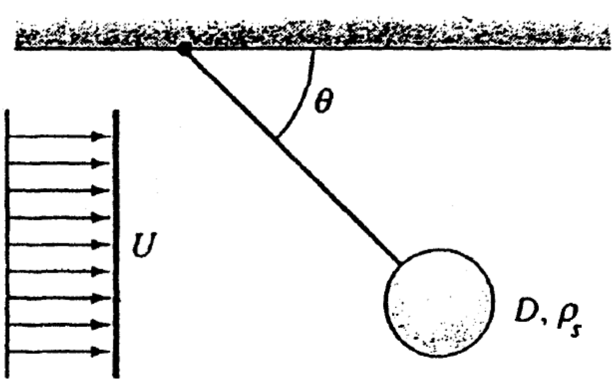

Figure 6(a)

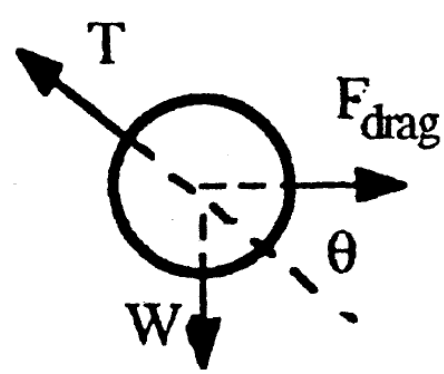

Figure 6(b)

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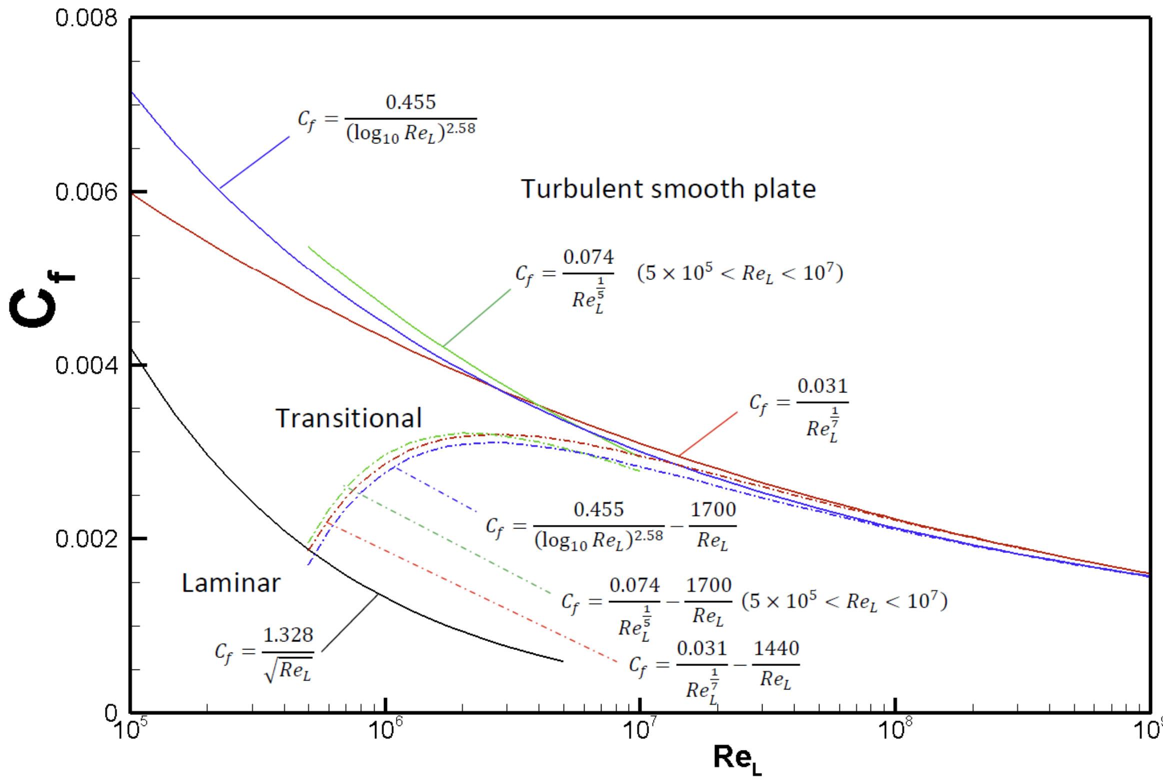
Appendix A. Friction drag coefficient for flat plate



Appendix B. Drag coefficient for a smooth sphere and a smooth cylinder