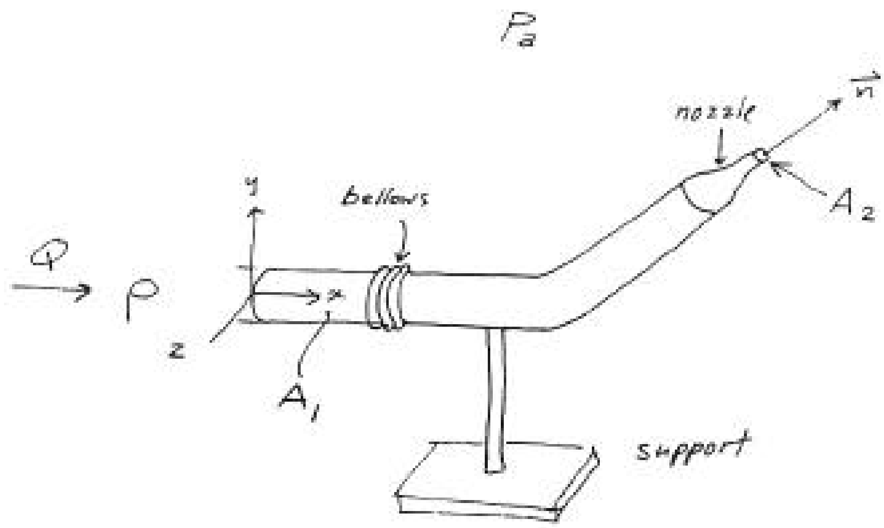
Problem 5.2

Force on fireman's hose



We are interested in how the shape of the nozzle and the direction of the stream affects the force required to hold a fireman's hose. The sketch shows a test rig where a hose-nozzle combination is held firmly by a support. The bellows transmits no force to the parts mounted on the support (the hose to the left of it is supported separately). Water is supplied at a volume flow rate Q ($m^3 s^{-1}$)via a horizontal hose of radius R_1, the flow within being in the x-direction, to a nozzle with a smaller exit radius R_2 and an outward normal vector $\hat{n}_2 = \hat{i}\cos\theta + \hat{j}\sin\theta$. The coordinates are indicated in the figure. The nozzle exit plane is at an elevation h relative to the horizontal supply hose, where y=0. The density of water is ρ, and the atmospheric pressure is p_a. The weight of material (water, hose, and nozzle) between the bellows and the nozzle's exit plane is W.

(a) Assuming that the flow between stations 1 and 2 is incompressible and inviscid, derive an expression for the force $(F_S)_x$ exerted on the fire-hose by the support. Write the answer in terms the given quantities

$$A_1, A_2, \rho, Q, W, h \text{ and } \theta .$$

HINT HINT 2 ANSWER

(b) Demonstrate that $(F_S)_x \le 0$ always, that is, in order to hold the system in place, one must always push on it toward the left, regardless of volume flow rate or angle.

(c) For the simple case $Q=0$ (no flow, but system filled with static liquid to height h), our answer predicts that the external force required to hold it in place is

$$(F_S)_x \approx -\rho g h A_1 \qquad (1)$$

Consider a system mounted on a support with frictionless wheels. The result (1) suggests that if such a system is held in place and filled with water, and the external holding force removed, it will tend to move to the right. Does this make sense? Explain.

ANSWER

(d) Now consider another special case: a straight horizontal pipe, that is, $A_1 = A_2, h = 0$, and $\theta = 0$. In this case part (a) predicts

$$(F_S)_x = 0$$

regardless of the shape of the system between 1 and 2. Explain on physical grounds why this makes sense.

ANSWER