1. Air flows steadily from a large tank through a horizontal hose and exits to the atmosphere via a nozzle, as shown in Figure 1. The diameter of the hose is $D = 0.03$ m, and the diameter of the nozzle exit is $d = 0.01$ m. The pressure inside the tank is maintained at a constant gauge pressure of $p_1 = 3.0$ kPa. The air discharges into the atmosphere under standard temperature and pressure conditions. Assume steady, incompressible flow, negligible viscous losses, and uniform velocity profiles. Please determine (a) (10 pts) the volumetric flow rate Q, and (b) (10 pts) the pressure in the hose p_2.

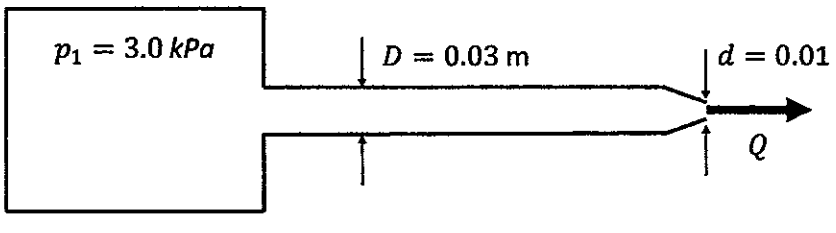

Figure 1

2. How much time is required to fill a cylindrical swimming pool with a diameter of 8 m and a water depth of 1.5 m using a garden hose that supplies water at a constant flow rate of 1.0 L/s? (15 pts)

3. A steady, laminar flow of a viscous, incompressible liquid forms a film of uniform thickness as it flows down an infinitely wide inclined plane. The velocity component normal to the plane is zero. Using the Navier–Stokes equations, derive the relationship between the film thickness and the volumetric flow rate per unit width. Assume that air resistance is negligible, such that the shear stress at the free surface is zero. (15 pts)

4. (30 pts) A rigid spherical ball with mass m_b, density ρ_b, and radius R_b, is attached to a massless, frictionless spring with spring constant, k, in a tank filled with liquid with density, ρ. The spring and the ball are constrained to move in the vertical direction (y-direction) only. Any flow disturbance due to the spring or its anchor is negligible. The ball is displaced from its equilibrium position $y = 0$ to $y = A$ and released, and subsequently oscillates.
   (a) (5 pts) List the force acting on the ball.
   (b) (5 pts) Now assume that the fluid flow in the tank is inviscid and the tank is very large (see Figure 2a), write down the equation describing the motion of the ball (You don't need to solve the differential equation).
   (c) (5 pts) How does your answer in (b) change if the size of the tank's cross section is only slightly larger than the size of the ball (see Figure 2b)? Why?
   (d) (5 pts) How does your answer in (b) change if the fluid flow in the tank is highly viscous? Why? Here, the fluid flow is highly viscous such that the Reynolds number $Re = U_{max}R_b/\nu \ll 1$. Here U_{max} is defined as the maxmimum velocity.
   (e) (5 pts) How does your answer in (d) change if the size of the tank is only slightly larger than the size of the ball? Why?
   (f) (5 pts) Plot the flow pattern including the streamlines and velocity distributions along the line $\overline{AB}$ in cases (d) and (e).

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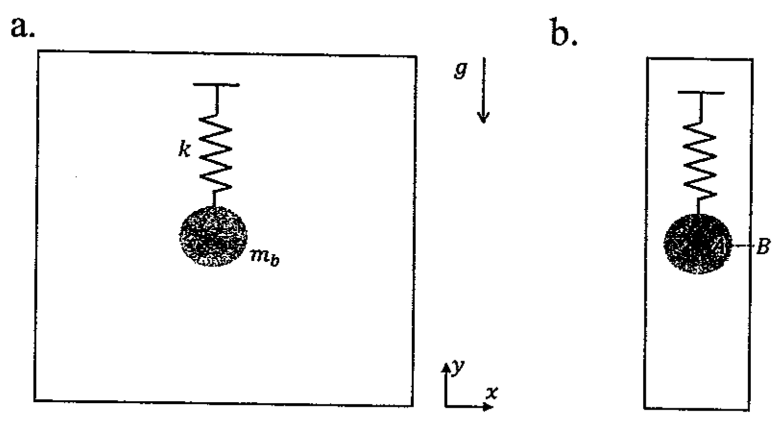

Figure 2

5. (20 pts) A 'big wave' is running through the shallow waters of a bay at an unknown speed C_w. The water in the 'undisturbed' bay is stationary and its original depth h_1 increases to h_2 as the wave passes.
   (a) (15 pts) Assuming constant flow velocity along the water depth, determine the wave speed C_w increases to h_2 as a function of h_1 and h_2 and the gravitational acceleration g. To do this, to avoid a moving control volume, you are suggested to choose a reference frame following the movement of the wave.
   (b) (5 pts) What is the speed of the water in the bay after the wave has passed (i.e., behind the wave)?

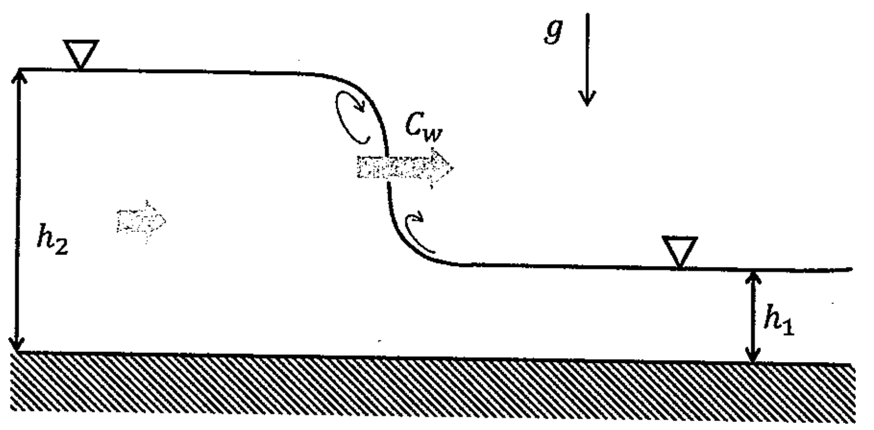

Figure 3

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