Birla Institute of Technology and Science, Pilani
ME F212: Fluid Mechanics

Comprehensive exam., **Open Book**, 80 Marks, 9:00-12:00 AM, 19/12/2022

- **Write neatly. Strike out rough work. Write your name and id. clearly.**
- **Partial marks will be awarded only when all the steps are clearly shown.**
- **All final answers are to be highlighted by enclosing in a $\boxed{\text{box}}$.**
- **Use $P_{atm.} = 101325$ Pa, $|\vec{g}| = 9.81$ m/s^2, $\rho_{water} = 10^3$ kg/m^3, $\mu_{water} = 0.001$ Pa.s unless mentioned otherwise.**

1. A mass less sphere of radius r covers a hole at the bottom of a container having a liquid of density ρ up to a height of $2r$ from the bottom of container as shown in figure(1). Atmospheric air exists above the liquid and below the bottom of the container. Gravity points down as shown. What is the minimum angle θ below which the sphere will no more stay on the hole. The volume of the spherical cap (portion of the sphere below the bottom of the container) is $V_{cap} = \frac{\pi}{3}r^3(2 + cos(\theta))(1 - cos(\theta))^2$. (12 marks)

2. A viscous Newtonian fluid film flows steadily down a long tube of radius r_2, the end view of which is shown in figure(2). The film thickness $(r_2 - r_1)$ remains constant in the process. Gravity points along the axis of the tube. Calculate the velocity distribution in the film as a function of radius r, fluid density ρ, viscosity μ, gravity $\vec{g}$, and r_1, r_2. Also calculate the average flow velocity. (12 marks)

3. A 0.01 m thick sheet of water with an in-paper depth of 1 meter is to flow over a hinged plate as shown in figure(3). The plate is being hold by a spring which has an undeformed length of 1 meter when water is not flowing.The spring has a spring constant of $k = 550$ N/m and is bent along the arc of a circle so that its force is always normal to the plate. The distance between the hinge and spring mounting on the plate is 2.1 meter. What water speed $\vec{V}$ will induce a deflection $d\theta = 5°$ in the spring? (12 marks)

4. The total drag force on and power required to move a cruise ship, which has a length of 210 m, need to be calculated. A 1:70 scale model of the cruise ship is built for testing in a water tunnel, the model displaces 0.09 m^3 of water and has a wetted surface area of 5.4 m^2. When tested in the water tunnel at a towing speed 0.1 m/s, the total drag on the model was 4.5 N. Determine the drag on the cruise ship and the speed at which it moves. What power is required to move the cruise ship? Following data is given: $C_D^{\text{viscous}} = 1.328/\sqrt{Re}$ for $Re < 10^6$ and $C_D^{\text{viscous}} = 0.455/(\log_{10}Re)^{2.58}$ for $10^6 < Re < 10^9$. Take $\rho = 1000$ kg/m^3 and $\nu = 10^{-6}$ m/s. (14 marks)

5. A Rankine oval is formed by superimposing a source and a sink placed 2.4 m apart and each having a strength of 9 m^2/s. If the uniform flow around the body has a velocity of 12 m/s and the pressure far from the oval is 101325 Pa, determine the following: (2 marks each)

   (a) Location of stagnation points.
   (b) The equation that defines the boundary of the oval.
   (c) The maximum and minimum velocities on the oval.
   (d) The maximum and minimum pressures on the oval.
   (e) The half width of the oval.

6. A vertical cylinder of length 10 meter and radius equal to 0.2 meter is rotated in anti-clockwise direction with a constant angular velocity of 130 rev/min. Wind of velocity 25 m/s is blowing horizontally around the cylinder. Determine the location of stagnation points (if any) on the surface of the cylinder. What are the maximum and minimum pressure values on the cylinder? What lift force will act on the cylinder due to its rotation and the wind flow? (10 marks)

7. A vertical plate (length = 1.5 m, height = 1 m) is submerged in a flowing, calm water stream having a velocity of 0.25 m/s. Determine the following: (2 marks each)

   (a) Boundary layer thickness at the end of the plate.
   (b) Displacement thickness at the end of the plate.
   (c) Momentum thickness at the end of the plate.
   (d) The total drag force acting on the plate.
   (e) What can be the maximum length of the plate for laminar flow over it?

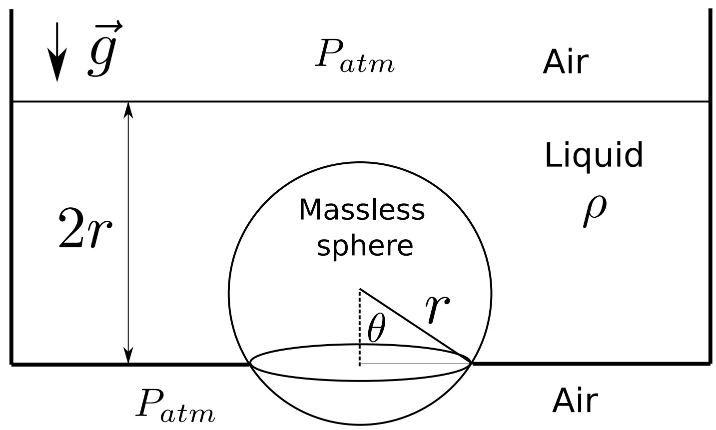

Figure 1: Mass less sphere on a hole

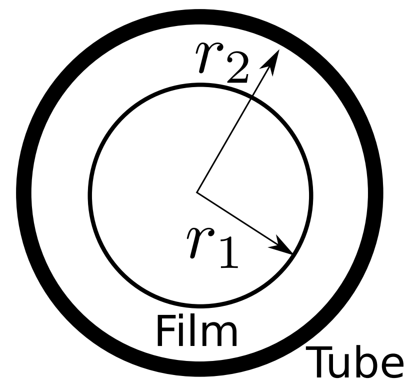

Figure 2: Film flowing inside a tube.

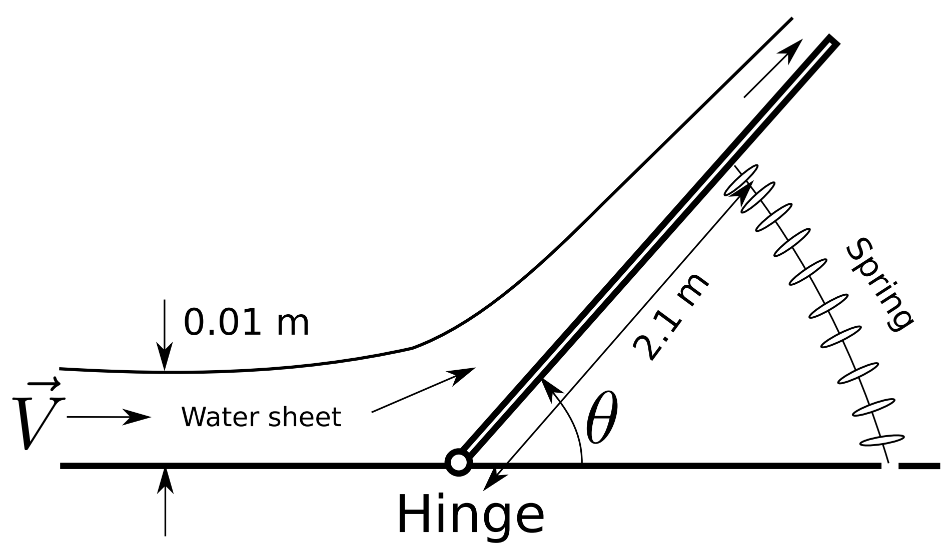

Figure 3: Sheet of water on a hinged plate.