Problem 1
In a food-processing plant, honey (viscosity $\mu = 5$ kg·m$^{-1}$·s$^{-1}$) is pumped through an annular tube (length $L = 2$ m; inner radius: $R_i = 5$ mm; outer radius: $R_o = 25$ mm). The applied pressure difference between the inlet and outlet sections of the tube is $\Delta p = p_{in} - p_{out} = 125$ kPa.

The theoretical velocity profile for laminar flow through an annulus is:

$$v_z(r) = \frac{1}{4\mu} \left( \frac{\Delta p}{L} \right) \left[ R_i^2 - r^2 - \frac{R_o^2 - R_i^2}{\ln\left(\frac{R_o}{R_i}\right)} \ln\left(\frac{r}{R_i}\right) \right]$$

1- Show that the no-slip condition is satisfied by this expression on the inner and outer surfaces of the annulus
2- Find the location in the flow at which the shear stress is zero [solution: $r = 13.7$ mm]
3- Derive expressions and calculate the viscous forces acting on the inner and outer surfaces [solution: $F_i = 63.4$ N; $F_o = -172$ N]
4- Compare your results from part 3 to the force $\Delta p \pi (R_o^2 - R_i^2)$. What can you conclude?

Problem 2
You intend to gently place several steel needles (specific gravity: $SG = 7.83$) on the free surface of the water (surface tension $\sigma = 72.8 \times 10^{-3}$ N/m; density $\rho = 1000$ kg/m$^3$) in a large tank. The needles come in two lengths: $L = 5$ and 10 cm. Needles of each length are available with diameters $D = 1, 2.5$ and 5 mm.

1- Express mathematically the condition of static equilibrium for a needle of length $L$ and diameter $D$
2- Determine which needles (if any) will float on the surface of the water [solution: 1-mm needles only]

Problem 3
An important dimensionless parameter concerned with very high-speed flow is the Mach number, defined as $Ma = V/c$, where $V$ is the speed of the object (e.g., airplane, projectile) and $c$ is the speed of sound in the fluid surrounding the object.
1- For a projectile traveling at $V = 800$ mph through air at $50^\circ$F and standard atmospheric pressure, what is the value of the Mach number? (air properties can be obtained from the tables at the end of the textbook)

2- Can compressibility effects be neglected for the flow of air around the projectile?