Fluid Mechanics (ME 201)

Instructor: Dr. Sudhakar Yogaraj

School of Mechanical Sciences, IIT Goa.

Tutorial 8 – Boundary layers

1. A bacterium and a huge whale move through water at velocities of 0.01 mm/s and 10 m/s respectively. A large dragonfly cruise through the air at 7 m/s. The relevant length scales for these cases, respectively, are 500 μm, 30 m and 2 cm. Assume kinematic viscosities of air/water at 20^{o}C. Which of the following correctly describe these flowfields?
   - (a) viscous dominant
   - (b) laminar boundary layer
   - (c) turbulent boundary layer

2. For flow around a sphere the boundary layer becomes turbulent around $Re_D \approx 2.5 \times 10^5$. Find the speeds at which (a) an American golf ball (D=4.276 cm), (b) a British golf ball (D=41.1 mm), and (c) a soccer ball (D=22.225 cm) develop turbulent boundary layers. Assume $\nu = 1.5 \times 10^{-5}$ m^2/s.

3. The velocity profile of a laminar boundary layer over is often approximated by the following equations,

$$\text{Parabolic: } \frac{u}{U} = 2\left(\frac{y}{\delta}\right) - \left(\frac{y}{\delta}\right)^2$$
$$\text{Cubic: } \frac{u}{U} = \frac{3}{2}\left(\frac{y}{\delta}\right) - \frac{1}{2}\left(\frac{y}{\delta}\right)^3$$
$$\text{Sinusoidal: } \frac{u}{U} = \sin\left(\frac{\pi y}{2\delta}\right)$$

   Verify if these profiles satisfy boundary conditions for a laminar boundary layer.

4. For all the velocity profiles, evaluate displacement thickness (δ^*) and momentum thickness (θ) as a function of δ

5. Use cubic and sinusoidal profile mentioned in problem 3, apply momentum integral technique for flow over a flat plate, and verify the following table. Blasius solution is included as a reference.

Profile	$\frac{\delta\sqrt{Re_x}}{x}$	$c_f\sqrt{Re_x}$	$C_{Df}\sqrt{Re_l}$
Blasius	5.00	0.664	1.328
Parabolic	5.48	0.730	1.460
Cubic	4.64	0.646	1.292
Sinusoidal	4.79	0.655	1.310

6. Air flows between two parallel stationary plates that are positioned 2 m apart with a uniform velocity of 10 m/s forms a boundary layer on the walls. The fluid within the core region (outside the boundary layers) flows as if it were inviscid. From advanced calculations it is determined that for this flow the boundary layer displacement thickness is given by $\delta^* = 0.007x^{1/2}$ where δ^* and x are in metres. Determine the velocity $U(x)$ and $p(x)$ of the air outside of the boundary layer.

7. Consider turbulent flow of an incompressible fluid past a flat plate. The boundary layer velocity profile is expressed as $\frac{u}{U} = \eta^{1/7}$ where η is the similarity variable. Once the boundary layer thickness is known, shear stress at the wall can be determined using

$$\tau_w = 0.0225\rho U^2 \left(\frac{\nu}{U\delta}\right)^{1/4} \tag{1}$$

   Determine the boundary layer thickness (δ), momentum thickness (θ), and τ_w as a function of x. Compare the results with those of laminar flows.he

8. The average pressure and shear stress acting on the surface of the 1 m^2 flat plate are as indicated in the figure. Determine the lift and drag generated (i) with shear (ii) without shear.

9. A spoiler is used on race cars to produce a negative lift, thereby giving a better tractive force. The lift coefficient for the airfoil shown is $C_L = 1.1$, and the coefficient of friction between the wheels and the pavement is 0.6. At a speed of 350 kmph, by how much would use of the spoiler increase the maximum tractive force that could be generated between the wheels and ground? Assume that the spoiler is rectangular.

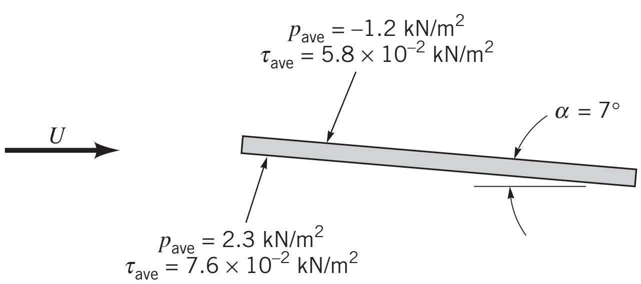

Figure for Problem 8

Figure for Problem 9