Problem Set – 6

ME 231-A

1. A small low-speed wind tunnel (Fig. 1) is being designed for calibration of hot wires. The air is at 19 °C. The test section of the wind tunnel is 30 cm in diameter and 30 cm in length. The flow through the test section must be as uniform as possible. The wind tunnel speed ranges from 1 to 8 m/s, and the design is to be optimized for an air speed of V = 4.0 m/s through the test section. (a) For the case of nearly uniform flow at 4.0 m/s at the test section inlet, by how much will the centerline air speed accelerate by the end of the test section? (b) Recommend a design that will lead to a more uniform test section flow.

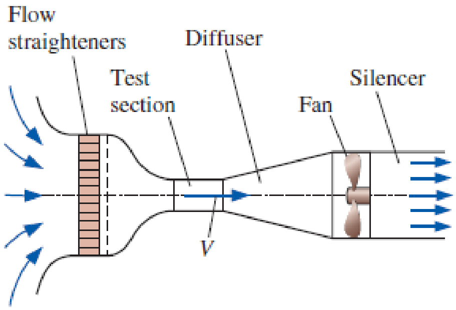

Fig. 1

2. A box fan sits on the floor of a very large room (Fig. 2). Label regions of the flow field that may be approximated as static. Label regions in which the irrotational approximation is likely to be appropriate. Label regions where the boundary layer approximation may be appropriate.
Finally, label regions in which the full Navier– Stokes equation most likely needs to be solved (i.e., regions where no approximation is appropriate).

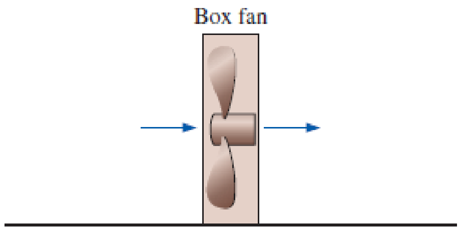

Fig. 2

3. On a hot day (T = 30 °C), a truck moves along the highway at 29.1 m/s. The flat side of the truck is treated as a simple, smooth flat–plate boundary layer, to first approximation. Estimate the x-location along the plate where the boundary layer begins to transition to turbulence. How far downstream from the beginning of the plate do you expect the boundary layer to become fully turbulent?

4. (a) Static pressure P is measured at two locations along the wall of a laminar boundary layer (Fig. 3). The measured pressures are P_1 and P_2, and the distance between the taps is small compared to the characteristic body dimension ($\Delta x = x_2 - x_1 << L$). The outer flow velocity above the boundary layer at point 1 is U_1. The fluid density and viscosity are ρ and μ, respectively. Generate an

approximate expression for U_2, the outer flow velocity above the boundary layer at point 2, in terms of P_1, P_2, Δx, U_1, ρ and μ.

(b) Consider two pressure taps along the wall of a laminar boundary layer as in Fig.3. The fluid is air at 25°C, U_1 = 10.3 m/s, and the static pressure P_1 is 2.44 Pa greater than static pressure P_2, as measured by a very sensitive differential pressure transducer. Is outer flow velocity U_2 greater than, equal to, or less than outer flow velocity U_1? Explain. Estimate U_2.

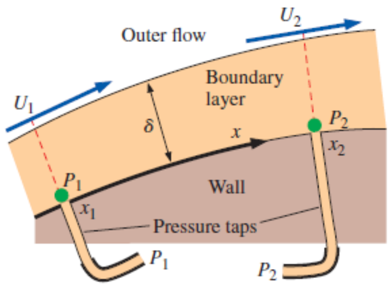

Fig. 3

5. Calculate the value of shape factor H for the limiting case of a boundary layer that is infinitesimally thin (Fig. 4). This value of H is the minimum possible value.

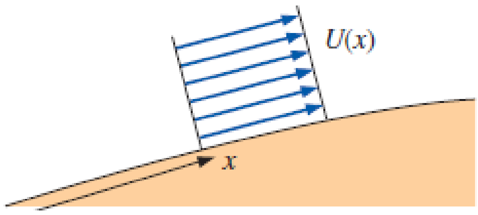

Fig. 4

6. (a) A laminar flow wind tunnel has a test section that is 30 cm in diameter and 80 cm in length. The air is at 20 °C. At a uniform air speed of 2.0 m/s at the test section inlet, by how much will the centerline air speed accelerate by the end of the test section?

   (b) Repeat the calculation of 6 (b), except for a test section of square rather than round cross section, with a 30 cm × 30 cm cross section and a length of 80 cm. Compare the result to that of (a).

7. In order to avoid boundary layer interference, engineers design a “boundary layer scoop” to skim off the boundary layer in a large wind tunnel (Fig. 5). The scoop is constructed of thin sheet metal. The air is at 20 °C, and flows at V = 45.0 m/s. How high (h) should the scoop be at downstream distance x = 1.45 m?

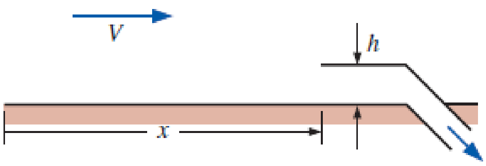

Fig. 5

8. (a) The streamwise velocity component of a steady, incompressible, laminar, flat plate boundary layer of boundary layer thickness d is approximated by the simple linear expression, $u = Uy/ \delta$ for $y < \delta$, and $u = U$ for $y > \delta$ (Fig. 6). Generate expressions for displacement thickness and momentum thickness as functions of d, based on this linear approximation. Compare the approximate values of δ^*/ δ and θ / δ to the values of δ^*/ δ and θ/ δ obtained from the Blasius solution.

   (b) For the linear approximation of Prob. 6 (a), use the definition of local skin friction coefficient and the Kármán integral equation to generate an expression for δ /x. Compare your result to the Blasius expression for δ /x.

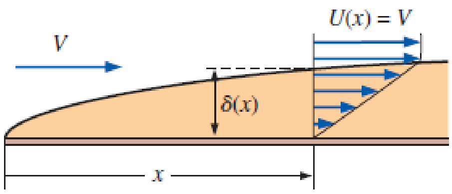

Fig. 6

9. Flow straighteners are arrays of narrow ducts placed in wind tunnels to remove swirl and other in-plane secondary velocities. They can be idealized as square boxes constructed by vertical and horizontal plates, as in Fig. 7. The cross section is a by a, and the box length is L. Assuming laminar flat-plate flow and an array of $N \times N$ boxes, derive a formula for (a) the total drag on the bundle of boxes and (b) the effective pressure drop across the bundle.

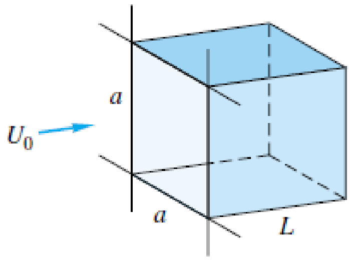

Fig. 7

10. Helium at 20°C and low pressure flows past a thin flat plate 1 m long and 2 m wide. It is desired that the total friction drag of the plate be 0.5 N. What is the appropriate absolute pressure of the helium if U = 35 m/s?

11. A 2.2-cm-outer-diameter pipe is to span across a river at a 30-m-wide section while being completely immersed in water. The average flow velocity of water is 4 m/s and the water temperature is 15 °C. Determine the drag force exerted on the pipe by the river, Use Fig. 11-34, appropriately.

12. The drag coefficient of a car at the design conditions of 1 atm, 25 °C, and 90 km/h is to be determined experimentally in a large wind tunnel in a full-scale test. The height and width of the

car are 1.25 m and 1.65 m, respectively. If the horizontal force acting on the car is measured to be 220 N, determine the total drag coefficient of this car.

13. The resultant of the pressure and wall shear forces acting on a body (Fig. 8) is measured to be 580 N, making 35° with the direction of flow. Determine the drag and the lift forces acting on the body.

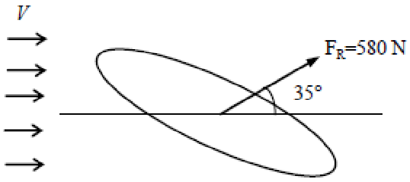

Fig. 8

14. A wind turbine with two or four hollow hemispherical cups connected to a pivot is commonly used to measure wind speed. Consider a wind turbine with four 8-cm-diameter cups with a center-to-center distance of 40 cm, as shown in Fig. 9. The pivot is stuck as a result of some malfunction, and the cups stop rotating. For a wind speed of 15 m/s and air density of 1.25 kg/m3, determine the maximum torque this turbine applies on the pivot.

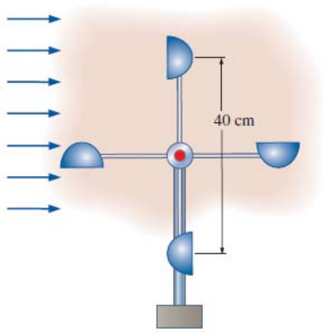

Fig. 9

15. A 7-m-diameter hot air balloon that has a total mass of 350 kg is standing still in air on a windless day. The balloon is suddenly subjected to 40 km/h winds. Determine the initial acceleration of the balloon in the horizontal direction. Take $C_D = 0.2$.

16. Consider laminar flow of a fluid over a flat plate. Now the free-stream velocity of the fluid is tripled. Determine the change in the drag force on the plate. Assume the flow to remain laminar.

17. The top surface of the passenger car of a train moving at a velocity of 95 km/h is 2.1 m wide and 8 m long. If the outdoor air is at 1 atm and 25 °C, determine the drag force acting on the top surface of the car.

18. The forming section of a plastics plant puts out a continuous sheet of plastic that is 1.2 m wide and 2 mm thick at a rate of 18 m/min. The sheet is subjected to airflow at a velocity of 4 m/s on both top and bottom surfaces normal to the direction of motion of the sheet (Fig. 10). The width

of the air cooling section is such that a fixed point on the plastic sheet passes through that section in 2 s. Using properties of air at 1 atm and 60 °C, determine the drag force the air exerts on the plastic sheet in the direction of airflow.

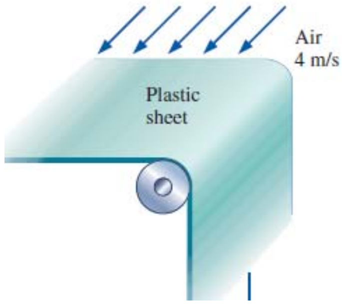

Fig. 10

19. 6-mm-diameter electrical transmission line is exposed to windy air. Determine the drag force exerted on a 160-m-long section of the wire during a windy day when the air is at 1 atm and 15 °C and the wind is blowing across the transmission line at 65 km/h. Use Fig. 11-34 appropriately.

20. A small airplane has a total mass of 1800 kg and a wing area of 42 m^2. Determine the lift and drag coefficients of this airplane while cruising at an altitude of 4000 m at a constant speed of 280 km/h and generating 190 kW of power.

21. A tennis ball with a mass of 57 g and a diameter of 6.4 cm is hit with an initial velocity of 105 km/h and a backspin of 4200 rpm (Fig. 11). Determine if the ball falls or rises under the combined effect of gravity and lift due to spinning shortly after hitting. Assume air is at 1 atm and 25 °C.

Fig. 11

22. A long 5-cm-diameter steam pipe passes through some area open to the wind. Determine the drag force acting on the pipe per unit of its length when the air is at 1 atm and 10 °C and the wind is blowing across the pipe at a speed of 50 km/h. Use Fig. 11-34 appropriately.

23. Dust particles of diameter 0.06 mm and density 1.6 g/cm^3 are unsettled during high winds and rise to a height of 200 m by the time things calm down. Estimate how long it takes for the dust particles to fall back to the ground in still air at 1 atm and 30 °C, and their velocity. Disregard the

initial transient period during which the dust particles accelerate to their terminal velocity, and assume Stokes law to be applicable.

24. Consider a blimp that can be approximated as a 3-m diameter, 8-m long ellipsoid and is connected to the ground (Fig. 12). On a windless day, the rope tension due to the net buoyancy effect is measured to be 120 N. Determine the rope tension when there are 50 km/h winds blowing along the blimp (parallel to the blimp axis).

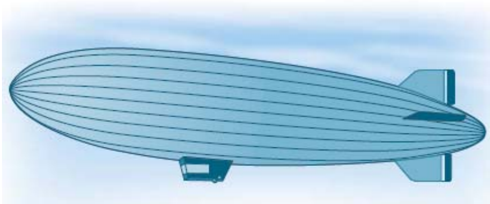

Fig. 12

25. One of the popular demonstrations in science museums involves the suspension of a ping-pong ball (smooth sphere) by an upward air jet (Fig. 13). Children are amused by the ball always coming back to the center when it is pushed by a finger to the side of the jet. Explain this phenomenon using the Bernoulli equation. Also determine the velocity of air if the ball has a mass of 3.1 g and a diameter of 4.2 cm. Assume the air is at 1 atm and 25 °C. Use Fig. 11-34 appropriately.

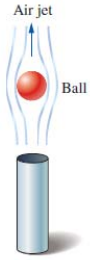

Fig. 13

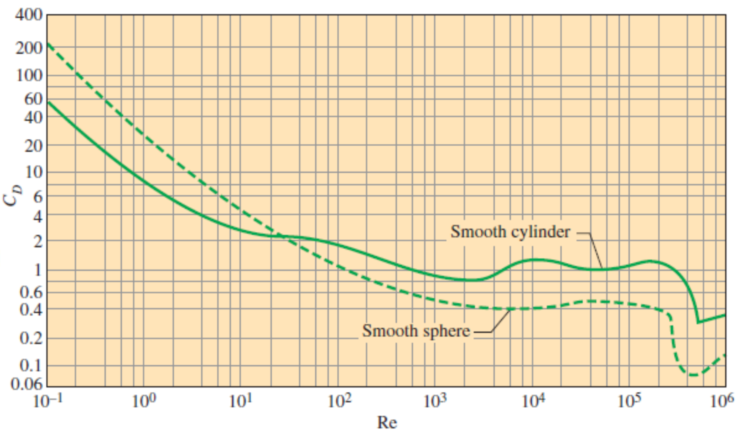

Fig. 11-34: Drag coefficient for cylinder and sphere