

H.W # 1

along with the velocity distribution

$$\frac{u}{u_\infty} = \frac{3}{2} \frac{y}{\delta} - \frac{1}{2} \left(\frac{y}{\delta} \right)^3$$

and the expression for the boundary-layer thickness

$$\frac{\delta}{x} = \frac{4.64}{\sqrt{\text{Re}_x}}$$

derive an expression for the y component of velocity v as a function of x and y . Calculate the value of v at the outer edge of the boundary layer at distances of 6 and 12 in from the leading edge for the conditions of Example 5-3.

- 5-4 Repeat Problem 5-3 for the linear velocity profile of Problem 5-2.
- 5-5 Using the linear-velocity profile in Problem 5-2 and a cubic-parabola temperature distribution [Equation (5-30)], obtain an expression for heat-transfer coefficient as a function of the Reynolds number for a laminar boundary layer on a flat plate.
- 5-6 Air at 20 kPa and 5°C enters a 2.5-cm-diameter tube at a velocity of 1.5 m/s. Using a flat-plate analysis, estimate the distance from the entrance at which the flow becomes fully developed.
- 5-7 Oxygen at a pressure of 2 atm and 27°C blows across a 50-cm-square plate at a velocity of 30 m/s. The plate temperature is maintained constant at 127°C. Calculate the total heat lost by the plate.
- 5-8 A fluid flows between two large parallel plates. Develop an expression for the velocity distribution as a function of distance from the centerline between the two plates under developed flow conditions.
- 5-9 Using the energy equation given by Equation (5-32), determine an expression for heat-transfer coefficient under the conditions

$$u = u_\infty = \text{const} \quad \frac{T - T_w}{T_\infty - T_w} = \frac{y}{\delta_t}$$

where δ_t is the thermal-boundary-layer thickness.

- 5-10 Derive an expression for the heat transfer in a laminar boundary layer on a flat plate under the condition $u = u_\infty = \text{constant}$. Assume that the temperature distribution is given by the cubic-parabola relation in Equation (5-30). This solution approximates the condition observed in the flow of a liquid metal over a flat plate.
- 5-11 Show that $\partial^3 u / \partial y^3 = 0$ at $y = 0$ for an incompressible laminar boundary layer on a flat plate with zero-pressure gradient.
- 5-12 Review the analytical developments of this chapter and list the restrictions that apply to the following equations: (5-25), (5-26), (5-44), (5-46), (5-85), and (5-107).
- 5-13 Calculate the ratio of thermal-boundary-layer thickness to hydrodynamic-boundary-layer thickness for the following fluids: air at 1 atm and 20°C, water at 20°C, helium at 1 atm and 20°C, liquid ammonia at 20°C, glycerine at 20°C.
- 5-14 For water flowing over a flat plate at 15°C and 3 m/s, calculate the mass flow through the boundary layer at a distance of 5 cm from the leading edge of the plate.
- 5-15 Air at 90°C and 1 atm flows over a flat plate at a velocity of 30 m/s. How thick is the boundary layer at a distance of 2.5 cm from the leading edge of the plate?
- 5-16 Air flows over a flat plate at a constant velocity of 20 m/s and ambient conditions of 20 kPa and 20°C. The plate is heated to a constant temperature of 75°C, starting at

a distance of 7.5 cm from the leading edge. What is the total heat transfer from the leading edge to a point 35 cm from the leading edge?

- 5-17 Water at 15°C flows between two large parallel plates at a velocity of 1.5 m/s. The plates are separated by a distance of 15 mm. Estimate the distance from the leading edge where the flow becomes fully developed.
- 5-18 Air at standard conditions of 1 atm and 27°C flows over a flat plate at 20 m/s. The plate is 60 cm square and is maintained at 97°C. Calculate the heat transfer from the plate.
- 5-19 Air at 7 kPa and 35°C flows across a 30-cm-square flat plate at 7.5 m/s. The plate is maintained at 65°C. Estimate the heat lost from the plate.
- 5-20 Air at 90°C and atmospheric pressure flows over a horizontal flat plate at 60 m/s. The plate is 60 cm square and is maintained at a uniform temperature of 10°C. What is the total heat transfer?
- 5-21 Nitrogen at 2 atm and 500 K flows across a 40-cm-square plate at a velocity of 25 m/s. Calculate the cooling required to maintain the plate surface at a constant temperature of 300 K.
- 5-22 Plot the heat-transfer coefficient versus length for flow over a 1-m-long flat plate under the following conditions: (a) helium at 1 lb/in² abs, 80°F, $u_\infty = 10$ ft/s [3.048 m/s]; (b) hydrogen at 1 lb/in² abs, 80°F, $u_\infty = 10$ ft/s; (c) air at 1 lb/in² abs, 80°F, $u_\infty = 10$ ft/s; (d) water at 80°F, $u_\infty = 10$ ft/s; (e) helium at 20 lb/in² abs, 80°F, $u_\infty = 10$ ft/s.
- 5-23 Calculate the heat transfer from a 20-cm-square plate over which air flows at 35°C and 14 kPa. The plate temperature is 250°C, and the free-stream velocity is 6 m/s.
- 5-24 Air at 20 kPa and 20°C flows across a flat plate 60 cm long. The free-stream velocity is 30 m/s, and the plate is heated over its total length to a temperature of 55°C. For $x = 30$ cm, calculate the value of y for which u will equal 22.5 m/s.
- 5-25 For the flow system in Problem 5-24, calculate the value of the friction coefficient at a distance of 15 cm from the leading edge.
- 5-26 Air at a pressure of 200 kPa and free-stream temperature of 27°C flows over a square flat plate at a velocity of 30 m/s. The Reynolds number is 10^6 at the edge of the plate. Calculate the heat transfer for an isothermal plate maintained at 57°C.
- 5-27 Calculate the boundary layer thickness at the edge of the plate for the flow system in Problem 5-26. State the assumptions.
- 5-28 Air at 5°C and 70 kPa flows over a flat plate at 6 m/s. A heater strip 2.5 cm long is placed on the plate at a distance of 15 cm from the leading edge. Calculate the heat lost from the strip per unit depth of plate for a heater surface temperature of 65°C.
- 5-29 Air at 1 atm and 27°C blows across a large concrete surface 15 m wide maintained at 55°C. The flow velocity is 4.5 m/s. Calculate the convection heat loss from the surface.
- 5-30 Air at 300 K and 75 kPa flows over a 1-m-square plate at a velocity of 45 m/s. The plate is maintained at a constant temperature of 400 K. Calculate the heat lost by the plate.
- 5-31 A horizontal flat plate is maintained at 50°C and has dimensions of 50 cm by 50 cm. Air at 50 kPa and 10°C is blown across the plate at 20 m/s. Calculate the heat lost from the plate.
- 5-32 Air flows across a 20-cm-square plate with a velocity of 5 m/s. Free-stream conditions are 10°C and 0.2 atm. A heater in the plate surface furnishes a constant heat-flux

- condition at the wall so that the average wall temperature is 100°C . Calculate the surface heat flux and the value of h at an x position of 10 cm.
- 5-33 Calculate the flow velocity necessary to produce a Reynolds number of 10^7 for flow across a 1-m-square plate with the following fluids: (a) water at 20°C , (b) air at 1 atm and 20°C , (c) Freon 12 at 20°C , (d) ammonia at 20°C , and (e) helium at 20°C .
- 5-34 Calculate the average heat-transfer coefficient for each of the cases in Problem 5-31 assuming all properties are evaluated at 20°C .
- 5-35 Calculate the boundary-layer thickness at the end of the plate for each case in Problem 5-33.
- 5-36 A blackened plate is exposed to the sun so that a constant heat flux of 800 W/m^2 is absorbed. The back side of the plate is insulated so that all the energy absorbed is dissipated to an airstream that blows across the plate at conditions of 25°C , 1 atm, and 3 m/s. The plate is 25 cm square. Estimate the average temperature of the plate. What is the plate temperature at the trailing edge?
- 5-37 Air at 0.5 atm pressure and 27°C flows across a 34-cm-square plate at a velocity of 20 m/s. The plate temperature is maintained at 127°C . Calculate the heat lost by the plate.
- 5-38 Helium at 3 atm and 73°C flows across a 35-cm-square plate that is maintained at a surface temperature of 113°C . The free-stream velocity is 50 m/s. Calculate the convection heat lost by the plate.
- 5-39 Air at 1 atm and 300 K blows across a 50-cm-square flat plate at a velocity such that the Reynolds number at the downstream edge of the plate is 1.1×10^5 . Heating does not begin until halfway along the plate and then the surface temperature is 400 K. Calculate the heat transfer from the plate.
- 5-40 Air at 20°C and 14 kPa flows at a velocity of 150 m/s past a flat plate 1 m long that is maintained at a constant temperature of 150°C . What is the average heat-transfer rate per unit area of plate?
- 5-41 Derive equations equivalent to Equation (5-85) for critical Reynolds numbers of 3×10^5 , 10^6 , and 3×10^6 .
- 5-42 Assuming that the local heat-transfer coefficient for flow on a flat plate can be represented by Equation (5-81) and that the boundary layer starts at the leading edge of the plate, determine an expression for the average heat-transfer coefficient.
- 5-43 A 10-cm-square plate has an electric heater installed that produces a constant heat flux. Water at 10°C flows across the plate at a velocity of 3 m/s. What is the total heat which can be dissipated if the plate temperature is not to exceed 80°C ?
- 5-44 Repeat Problem 5-41 for air at 1 atm and 300 K.
- 5-45 Helium at 1 atm and 300 K is used to cool a 1-m-square plate maintained at 500 K. The flow velocity is 50 m/s. Calculate the total heat loss from the plate. What is the boundary-layer thickness as the flow leaves the plate?
- 5-46 A light breeze at 10 mi/h blows across a metal building in the summer. The height of the building wall is 3.7 m, and the width is 6.1 m. A net energy flux of 347 W/m^2 from the sun is absorbed in the wall and subsequently dissipated to the surrounding air by convection. Assuming that the air is 27°C and 1 atm and blows across the wall as on a flat plate, estimate the average temperature the wall will attain for equilibrium conditions.
- 5-47 The bottom of a corn-chip fryer is 10 ft long by 3 ft wide and is maintained at a temperature of 420°F . Cooking oil flows across this surface at a velocity of 1 ft/s and has a free-stream temperature of 400°F . Calculate the heat transfer to the oil and