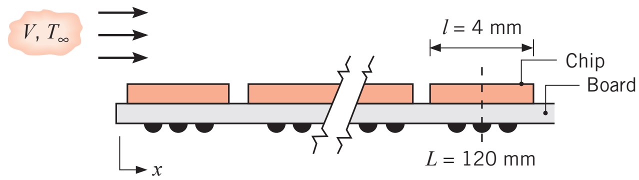
6.39 Forced air at $T_\infty = 25°C$ and $V = 10$ m/s is used to cool electronic elements on a circuit board. One such element is a chip, 4 mm × 4 mm, located 120 mm from the leading edge of the board. Experiments have revealed that flow over the board is disturbed by the elements and that convection heat transfer is correlated by an expression of the form

$$Nu_x = 0.04\, Re_x^{0.85}\, Pr^{1/3}$$



Estimate the surface temperature of the chip if it is dissipating 30 mW.

6.40 Consider the electronic elements that are cooled by forced convection in Problem 6.39. The cooling system is designed and tested at sea level ($p \approx 1$ atm), but the circuit board is sold to a customer in Mexico City, with an elevation of 2250 m and atmospheric pressure of 76.5 kPa.

(a) Estimate the surface temperature of the chip located 120 mm from the leading edge of the board when the board is operated in Mexico City. The dependence of various thermophysical properties on pressure is noted in Problem 6.22.

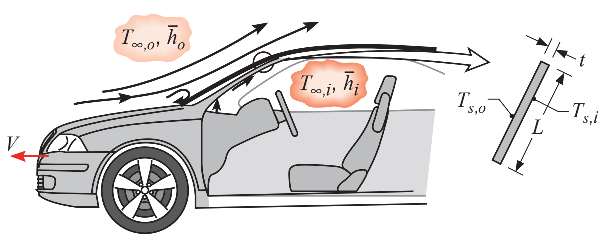
(b) It is desirable for the chip operating temperature to be independent of the location of the customer. What air velocity is required for operation in Mexico City if the chip temperature is to be the same as at sea level?

6.41 Consider the chip on the circuit board of Problem 6.39. To ensure reliable operation over extended periods, the chip temperature should not exceed 85°C. Assuming the availability of forced air at $T_\infty = 25°C$ and applicability of the prescribed heat transfer correlation, compute and plot the maximum allowable chip power dissipation P_c as a function of air velocity for $1 \leq V \leq 25$ m/s. If the chip surface has an emissivity of 0.80 and the board is mounted in a large enclosure whose walls are at 25°C, what is the effect of radiation on the $P_c - V$ plot?

6.42 A major contributor to product defects in electronic modules relates to stresses induced during thermal cycling (intermittent heating and cooling). For example, in circuit cards having active and passive components with materials of different thermal expansion coefficients, thermal stresses are the principal source of failure in component joints, such as soldered and wired connections. Although concern is generally for fatigue failure resulting from numerous excursions during the life of a product, it is possible to identify defective joints by performing accelerated thermal stress tests before the product is released to the customer. In such cases, it is important to achieve rapid thermal cycling to minimize disruptions to production schedules.

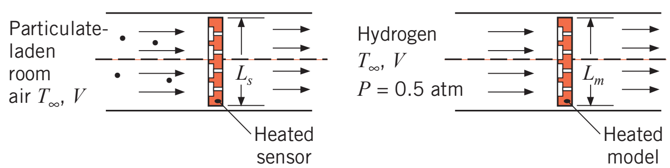
A manufacturer of circuit cards wishes to develop an apparatus for imposing rapid thermal transients on the cards by subjecting them to forced convection characterized by a relation of the form $\overline{Nu}_L = C\,Re_L^m\,Pr^n$, where $m = 0.8$ and $n = 0.33$. However, he does not know whether to use air ($k = 0.026$ W/m·K, $\nu = 1.6 \times 10^{-5}$ m^2/s, $Pr = 0.71$) or a dielectric liquid ($k = 0.064$ W/m·K, $\nu = 10^{-6}$ m^2/s, $Pr = 25$) as the working fluid. Assuming equivalent air and liquid velocities and validity of the lumped capacitance model for the components, obtain a quantitative estimate of the ratio of the thermal time constants for the two fluids. What fluid provides the faster thermal response?

6.43 The defroster of an automobile functions by discharging warm air on the inner surface of the windshield. To prevent condensation of water vapor on the surface, the temperature of the air and the surface convection coefficient ($T_{\infty,i}$, $\overline{h}_i$) must be large enough to maintain a surface temperature $T_{s,i}$ that is at least as high as the dewpoint ($T_{s,i} \geq T_{\text{dp}}$).



Consider a windshield of length $L = 800$ mm and thickness $t = 6$ mm and driving conditions for which the vehicle moves at a velocity of $V = 70$ mph in ambient air at $T_{\infty,o} = -15$°C. From laboratory experiments performed on a model of the vehicle, the average convection coefficient on the outer surface of the windshield is known to be correlated by an expression of the form $\overline{Nu}_L = 0.030\,Re_L^{0.8}\,Pr^{1/3}$, where $Re_L \equiv VL/\nu$. Air properties may be approximated as $k = 0.023$ W/m·K, $\nu = 12.5 \times 10^{-6}$ m^2/s, and $Pr = 0.71$. If $T_{\text{dp}} = 10$°C and $T_{\infty,i} = 50$°C, what is the smallest value of $\overline{h}_i$ required to prevent condensation on the inner surface?

6.44 A microscale detector monitors a steady flow ($T_\infty = 27$°C, $V = 10$ m/s) of air for the possible presence of small, hazardous particulate matter that may be suspended in the room. The sensor is heated to a slightly higher temperature to induce a chemical reaction associated with certain substances of interest that might impinge on the sensor's active surface. The active surface produces an electric current if such surface reactions occur; the electric current is then sent to an alarm. To maximize the sensor head's surface area and, in turn, the probability of capturing and detecting a particle, the sensor head is designed with a very complex shape. The value of the average heat transfer coefficient associated with the heated sensor must be known so that the required electrical power to the sensor can be determined.



Consider a sensor with a characteristic dimension of $L_s = 80\ \mu$m. A scale model of the sensor is placed in a recirculating (closed) wind tunnel using hydrogen as the working fluid. If the wind tunnel operates at a hydrogen absolute pressure of 0.5 atm and velocity of $V = 0.5$ m/s, find the required hydrogen temperature and characteristic dimension of the scale model, L_m.

Reynolds Analogy

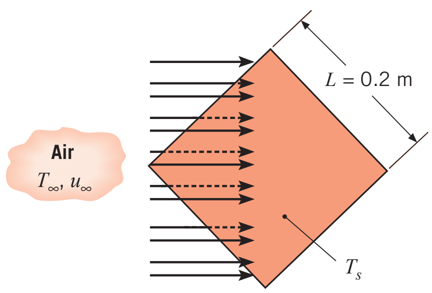
6.45 A thin, flat plate that is 0.2 m × 0.2 m on a side is oriented parallel to an atmospheric airstream having a velocity of 40 m/s. The air is at a temperature of $T_\infty = 20$°C, while the plate is maintained at $T_s = 120$°C. The airflows over the top and bottom surfaces of the plate, and measurement of the drag force reveals a value of 0.075 N. What is the rate of heat transfer from both sides of the plate to the air?

6.46 Atmospheric air is in parallel flow ($u_\infty = 15$ m/s, $T_\infty = 15$°C) over a flat heater surface that is to be maintained at a temperature of 140°C. The heater surface area is 0.25 m^2, and the airflow is known to induce a drag force of 0.25 N on the heater. What is the electrical power needed to maintain the prescribed surface temperature?

6.47 Determine the drag force imparted to the top surface of the flat plate of Example 6.4 for water temperatures of 300 K and 350 K. Assume the plate dimension in the z-direction is $W = 1$ m.

6.48 For flow over a flat plate with an extremely rough surface, convection heat transfer effects are known to be correlated by the expression of Problem 6.32. For airflow at 50 m/s, what is the surface shear stress at $x = 1$ m from the leading edge of the plate? Assume the air to be at a temperature of 300 K.

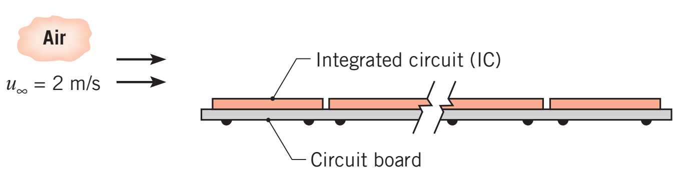
6.49 A thin, flat plate that is 0.2 m × 0.2 m on a side with rough top and bottom surfaces is placed in a wind tunnel so that its surfaces are parallel to an atmospheric airstream having a velocity of 30 m/s. The air is at a temperature of $T_\infty = 20°C$ while the plate is maintained at $T_s = 80°C$. The plate is rotated 45° about its center point, as shown in the schematic. Airflows over the top and bottom surfaces of the plate, and measurement of the heat transfer rate is 2000 W. What is the drag force on the plate?



Top view of thin, flat plate

6.50 As a means of preventing ice formation on the wings of a small, private aircraft, it is proposed that electric resistance heating elements be installed within the wings. To determine representative power requirements, consider nominal flight conditions for which the plane moves at 100 m/s in air that is at a temperature of −23°C. If the characteristic length of the airfoil is $L = 2$ m and wind tunnel measurements indicate an average friction coefficient of $\overline{C_f} = 0.0025$ for the nominal conditions, what is the average heat flux needed to maintain a surface temperature of $T_s = 5°C$?

6.51 A circuit board with a dense distribution of integrated circuits (ICs) and dimensions of 120 mm × 120 mm on a side is cooled by the parallel flow of atmospheric air with a velocity of 2 m/s.



From wind tunnel tests under the same flow conditions, the average frictional shear stress on the upper surface is determined to be 0.0625 N/m^2. What is the allowable power dissipation from the upper surface of the board if the average surface temperature of the ICs must not exceed the ambient air temperature by more than 25°C? Evaluate the thermophysical properties of air at 300 K.