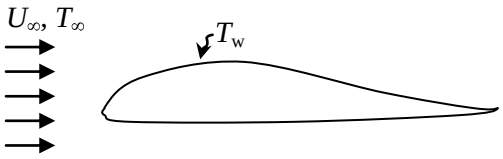
Problem Set # 7

Given: Monday, Oct. 29 **Recommended Completion Date:** Monday, Nov. 05
Do not submit for grading

Problem 1: Consider forced convection from a slender streamlined object in cross flow, as shown in the figure. The total surface area of the object is A_s = 0.02 m^2. The surface of the object is maintained at a constant temperature of T_w = 75°C by means of electrical heating. The fluid temperature far from the object is also constant at T_∞ = 25°C. Experiments yield the following data on the free stream velocity, U_∞, and the total rate of heat loss, q_{total}:
Run 1: U_∞ = 5 m/s; q_{total}= 200 W
Run 2: U_∞ = 24.02 m/s; q_{total}= 600 W

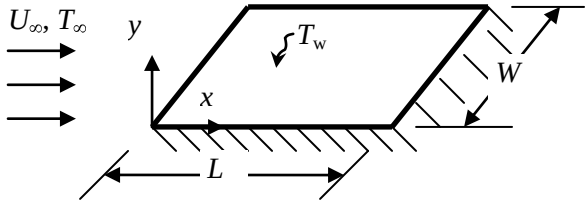
a) Calculate the heat transfer coefficient for Run 1 and Run 2.
b) Calculate the total rate of heat loss from the object when U_∞, = 13.46 m/s
c) The following fluid properties are known: ρ = 1 kg/m^3; c_p = 1000 J/kg-°C; k = 0.025 W/m-°C. The total friction drag in Run 1 is found to be 0.01 N. Calculate the dynamic viscosity of the fluid.



Ans.: *(a)* h_1 =200 W/m^2-°C; h_2 = 600 W/m^2-°C ; *(b)* q_{total}= 400.02 W; (c) $\mu = 8.84\times 10^{-6}$ kg/m-s

Problem 2: A smooth flat plate is aligned with a cross flow of a fluid, as shown in the figure. The length of the plate in the flow direction is L = 1 m, and its width is W = 1m. The plate is maintained at a constant temperature of T_w = 50°C by electrical heating. Only the top surface of the plate is exposed to the fluid flow, and the bottom surface is very well insulated. Experimental data show the followings:
Run 1: Laminar flow throughout: $U_{\infty,1}$ = 2 m/s; $T_{\infty,1}$ = 10°C; Drag$_1$ = 8.4×10^{-3} N; and $q_{total,1}$ = 168 W
Run 2: $U_{\infty,2}$ =? m/s; $T_{\infty,2}$ = 10°C; Drag$_2$ = 0.5854 N; and $q_{total,2}$ = 1170.8 W

a) What is the free-stream velocity in Run 2? (hint: use Chilton-Colburn analogy)
b) Additional measurements yield the following fluid properties: ρ = 1 kg/m^3; c_p = 1000 J/kg-°C. using Run 1 data and the Blasius-Pohlhausen similarity solutions (exact solutions), determine the dynamic viscosity,μ, and the thermal conductivity, k, of the fluid.
c) In Run 2, what is the total rate of heat loss from the plate in the region 0.1 m $\le x \le$ 1.0 m?



Ans.: *(a)* $U_{\infty,2}$ = 20 m/s; *(b)* $\mu = 2\times 10^{-5}$ kg/m-s; k = 0.02 W/m-°C; (c) q_{total} $_{0.1\,m\le x\le 1\,m}$ = 1002.82 W.

Problem 3: A solid is convectively cooled by a cross flow in U_∞ = (10+0.05 t) m/s, where t is the time in seconds after the initiation of the cooling. The volume of the solid is 8×10^{-6} m^3 and its surface is 2×10^{-3} m^2. The initial temperature of the solid, just before it is exposed to the convective cooling, is T_i = 420°C. the free-stream temperature remains constant throughout the cooling process at T_∞ = 20°C. The thermophysical properties of the fluid and the solid may be assumed to remain constant throughout the cooling process at the following values:

Fluid properties: ρ = 1 kg/m^3; c_p = 1000 J/kg-°C; $\mu = 2 \times 10^{-5}$ kg/m-s; k = 0.02 W/m-°C
Solid properties: ρ = 2000 kg/m^3; c_p = 500 J/kg-°C; k = 400 W/m-°C

Measurements indicate the followings: (i) the temperature inside the solid is (essentially) spatially uniform throughout the process; (ii) at t = 0 s, $T = T_i$ = 420°C and dT/dt = -5.4°C/s; and (iii) at t = 60 s, T = 188.9 °C and dT/dt = -2.6 °C/s.

a) Using the given data, and assuming that the general form Nu = C $Re^m Pr^n$ is instantaneously applicable throughout the cooling process determine the specific form of the variation of the heat transfer coefficient, h, with U_∞.
b) Predict the temperature of the solid at t = 100 s.

Ans.: *(a)* $h = 17.08 \times (U_\infty)^{1/2}$; *(b)* T = 108.63°C.

Selected Problems from the Textbook

Please do the following problems (6th Edition):

7.24
7.42
7.88

Or Please do the following problems (7th Edition):

7.24
7.47
7.94