MCL814 Convective Heat Transfer
Major Test
(Open handwritten notes only - books and photocopied notes not permitted)

Max. Marks: 60
Duration: 2 hrs

May 6, 2023

Answer all questions. Marks for each question is indicated. Only what you write on the paper can be evaluated, not what you think. Please write all assumptions and steps explicitly. Often, correct final answer does not assure you marks: the right approach does. Use sketches where necessary.

1. In order to control friction and form drags, a common practice is to allow blowing or suction through the surface on which the boundary layer is formed. This results in a condition where the normal velocity component $v \neq 0$ at the wall. Consider a flat plate boundary layer with suction or blowing. Starting from the most general equations of continuity and momentum in x and y directions, derive the boundary layer equations that would apply to such a problem. State the boundary conditions for solving this problem. (12)

2. Solve the laminar boundary layer for constant free stream velocity U_∞, using the momentum integral equation, using the velocity profile approximated as

$$\frac{u}{U_\infty} = \sin\frac{\pi y}{2\delta}$$

Evaluate the boundary layer thickness δ and friction coefficient C_f using this analysis. Compare the results with the exact (similarity) solution and comment. (12)

3. Consider fully developed flow (both velocity and temperature profiles) between parallel plates with a spacing a between them, with inlet at $x = 0$. Consider a uniform heat flux $\dot{q}''_w$ through both walls, into the fluid. Use the fully developed velocity profile given as $u/\overline{u} = 3/2[1 - (2y/a)^2]$. Derive the analytical expression for the non-dimensional temperature profile $(T - T_w)/(T_m - T_w)$, where $T_w(x)$ is the temperature of the wall and $T_m(x)$ is the mean temperature at any x, in terms of the local Nusselt number $Nu_{2a} = h.2a/k$. (12)

4. Water flows with a velocity $U_\infty = 0.2$ m/s parallel to a plane wall. The following calculations refer to the position $x = 6$ m measured downstream from the leading edge. Properties of water at 20°C are as follows: $k = 0.59$ W/m-K; $\rho = 998.2$ kg/m^3, $C_p = 4182$ J/kg-K; $\nu = 1.004 \times 10^{-6}$ m^2/s.
   (a) A probe is to be inserted in the viscous sublayer to the postion represented by $y^+ = 2.7$. Calculate the actual distance y in mm desired between the probe and the wall.
   (b) Calculate the boundary layer thickness δ, assuming that the entire length x is covered by turbulent boundary layer flow.
   (c) Calculate the heat transfer coefficient $\overline{h}_x$ averaged over the length x. Hint: Use Colburn Analogy.

   (12)

5. In order to solve the problem of laminar natural convection over a vertical flat plate with constant wall heat flux $\dot{q}''_w$, a quadratic temperature profile is to be chosen. For this, it is first assumed that $\delta = \delta_T$. Taking $\eta = y/\delta$, derive the expression for the temperature profile in the form

$$(T - T_\infty) = Q(x)(1 - \eta)^2$$

Express $Q(x)$ in terms of the variables such as g, β, δ, $\dot{q}''_w$ etc. (12)