EXAM II
HEAT TRANSFER

June 12, 2015

I. Explain the following terms: (18%)

(1) Prandtl number

(2) Film temperature

(3) Nusselt number

(4) Grashof number

(5) Peclet number

(6) D'Alembert's paradox

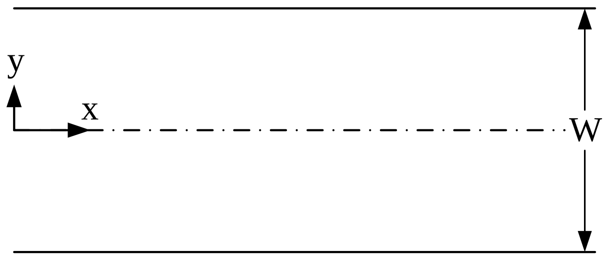
II. 簡答題: (36%)

1. What's the difference between Bi and Nu?
2. The thermal integration of a uiform flow over a heated plate can be written as
$$U_\infty \frac{d}{dx}\left[\delta\left(\frac{3}{20}\zeta^2 - \frac{3}{280}\zeta^4\right)\right] = \frac{3}{2}\frac{\alpha}{\delta\zeta}$$
Why can the equation be simplified as the following one?
$$\frac{3}{20}U_\infty \frac{d}{dx}\left(\delta\zeta^2\right) = \frac{3}{2}\frac{\alpha}{\delta\zeta}$$
3. For the boundary layers of thermal flow problems, what's the difference between water and liquid metal?
4. How do you judge whether two thermal flow problems are physically similar?
5. A uniform flow passes over a flat plate. The temperatures of the flow and the plate are T_∞ and T_W, respectively. Why are the shear stress at y = δ and heat flux (in y-direction) at y = δ_T are zero?
6. In the problem of natural convection, density changes with temperature. The density, appearing in the continuity, momentum and energy equations, makes the problem difficult to solve. Generally, how do people handle this problem?
7. What are the objectives of non-dimensionalization?
8. For a thermal flow in a tube, why is the bulk fluid temperature used instead of the average temperature?
9. Considering a boundary layer of natural convection along a vertical plate, why is dp/dx equal to $-\rho g$?
10. For a uniform flow passing a flat plate, the momentum integral equation is used to solve the velocity field. It is assumed that $u/U_\infty = a + b(y/\delta) + c(y/\delta)^2$. Why can we not use the the boundary condition that $\partial^2u/\partial y^2=0$ at y = 0?
11. In a boundary layer of a uniform passing over a flat plate with constant temperature, T_W, why is the viscous term ($\nu\partial^2u/\partial x^2$ or $\nu\partial^2v/\partial x^2$) or the conduction term ($k\partial^2T/\partial x^2$) in the flow direction (the x direction) neglected physically?
12. In what conditions is there no convection heat transfer?

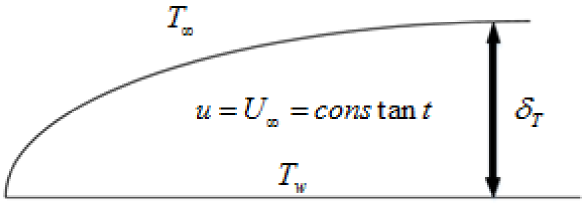
III. Consider the heat transfer in a parallel plate duct with constant wall heat flux.

(a) Prove $\frac{\partial T}{\partial x} = \frac{\partial T_w}{\partial x} = \frac{\partial T_m}{\partial x} = \text{constant}$, where T_m is the bulk fluid temperature and T_w is the wall temperature.(7%)

(b) Derive the expression of Nu for the case of constant wall heat flux in the fully-developed region if it is assumed that $u = U_\infty$ and $v = 0$. (10%)



IV. A steady uniform flow, whose velocity is U_∞, passes over a flat plate. The fluid is at uniform temperature T_∞ and the temperature of the plate is T_w. Assume that $u = U_\infty =$ constant and $v = 0$.



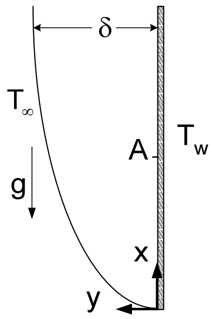
1. Derive the integral equation of energy. (9%)

$$\frac{d}{dx}\int_0^{\delta_T} U_\infty (T_\infty - T)\,dy = \alpha \left.\frac{\partial T}{\partial y}\right)_w$$

2. Assume the temperature distribution as $(T - T_w)/(T_\infty - T_w) = a + b(y/\delta_T)$, Derive the expression of δ_T/x. (8%)

(3) Derive the expression of Nu_x. (4%)

V. A vertical plate with a uniform temperature T_w in an environment at temperature T_∞. Assume Pr = 1.



(1) Draw the temperature and velocity distributions vs. y (i.e. T vs. y and u vs. y) at $x = x_A$. x_A is the x-coordinate of point A. Explain why the velocity profile is like that you draw. (6%)

(2) Prove that the momentum integral equation is (10%)

$$\frac{d}{dx}\left[\int_0^{\delta} \rho u^2 dy\right] = -\mu \left.\frac{\partial u}{\partial y}\right)_{y=0} + \int_0^{\delta} \rho g \beta (T - T_\infty)\,dy$$

VI. The door of a kitchen oven is a vertical rectangular area 0.5 m tall and 0.65 m wide. The external surface of the oven door is at 40°C, while the room air is at 20°C. Calculate the natural convection heat transfer rate from the door to the ambient air. (8%)

$$Nu = \frac{hH}{k} = 0.517 \times Ra_H^{1/4},$$

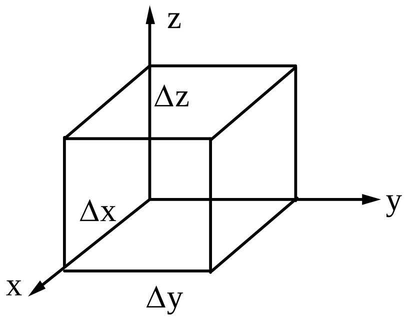
$$Ra_H = \frac{g\beta}{\alpha\nu} H^3 (T_w - T_\infty),$$

where H is 50 cm in this problem.

Pr = 0.72, k = 0.026 W/m·°C,

$$\frac{g\beta}{\alpha\nu} = \frac{90.7}{cm^3 \cdot °C}$$

VII. For a one-dimensional transient problem of heat convection, derive the expression of the energy equation. To derive this equation, consider a small control volume as shown in the following figure. The temperature is function of t and y, i.e., T = T(t, y). Only the velocity in the y direction, v, exists, i.e., u = 0 and w = 0. (8%)



VIII. The following problems are related to the natural convection.

(1) Why is the problem of natural convection more difficult to solve than that of forced convection generally? (3%)

(2) In solving the integral equations, why can equation (a2) be derived from equation (a1)? (3%)

$$\frac{u}{u_x} = \frac{\beta g \delta^2 (T_w - T_\infty)}{4 u_x \nu}\left(\frac{y}{\delta}\right)\left(1 - \frac{y}{\delta}\right)^2 \quad \text{(a1)}$$

$$\frac{u}{u_x} = \frac{y}{\delta}\left(1 - \frac{y}{\delta}\right)^2 \quad \text{(a2)}$$