HEAT TRANSFER

EXAM II June 8, 2012

I. 簡答題 (30%)

1. In what conditions is there no convection heat transfer?
2. What is the relationship among Prandtl number (Pr), thermal and momentum boundary layer thicknesses (δ and δ_T)?
3. In a tube flow problem with contant wall heat flux or wall temperature, the Nusselt number is constant in the fully-developed region for both the temperature and velocity fileds, which means the effect of convective heat transfer is not significant. Why is that?
4. What are the objectives of nondimensionalization?
5. What problem will be create when the viscous term is neglected in the momenturm equation?
6. In the last question, how is this problem solved?
7. For a uniformflow passing a flat plate, the momentum integral equation is used to solve the velocity field. It is assumed that $u/U_\infty = a + b(y/\delta) + c(y/\delta)^2$. What should the boundary conditions be given to determine the constants a, b, and c.
8. Considering a boundary layer of natural convection along a vertical plate, why is dp/dx equal to $-\rho g$? The x direction is the vertical one.
9. What is the film temperature? Why is it useful in solving the problems of convective heat transfer?
10. A uniform flow ($u = U_\infty$, $v = 0$) passes a flat plate with a uniform temperature T_w. In the dimensionless analysis of temperature field, why is the velocity scale is implicit for $Pr > 1$? What is the velocity scale of u for $Pr \leq 1$?

II. Explain the following terms: (15%)

(1) Film temperature

(2) Prandtl number

(3) Boussinesq approximation

(4) Mixed convection:

(5) Nusselt number

III. The following problems are related to the dimensional analysis of the momentum and energy equations inside the boundary layer over a flat plate.

(1) In the following equation, why is $\partial^2 u^*/\partial x^{*2}$ neglected, and why is $(L^2/\delta^2)/Re$ set to be one? (3%)

$$u^*\frac{\partial u^*}{\partial x^*} + v^*\frac{\partial u^*}{\partial y^*} = -\frac{\partial p^*}{\partial x^*} + \frac{1}{Re}\left(\frac{\partial^2 u^*}{\partial x^{*2}} + \frac{L^2}{\delta^2}\frac{\partial^2 u^*}{\partial y^{*2}}\right)$$

(2) What can the following equation be simplified to? Why? (3%)

$$u^*\frac{\partial v^*}{\partial x^*} + v^*\frac{\partial v^*}{\partial y^*} = -\frac{L^2}{\delta^2}\frac{\partial p^*}{\partial y^*} + \frac{1}{Re}\left(\frac{\partial^2 v^*}{\partial x^{*2}} + \frac{L^2}{\delta^2}\frac{\partial^2 v^*}{\partial y^{*2}}\right)$$

(3) The boundary conditions for $y \to \infty$ are $u = U_\infty$, $v = 0$, $T = T_\infty$, $P = P_\infty$. When the boundary layer theory is applied, how can these conditions be modified? (3%)

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

(a) What's meaning of "fully-developed" of the temperature and velcoity fields inside the duct ? (4%)

(b) Prove $\dfrac{\partial T}{\partial z} = \dfrac{dT_w}{dz} = \dfrac{dT_m}{dz} = \text{constant}$, where T_m is the bulk fluid temperature and T_w is the wall temperature. (6%)

(c) 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%)

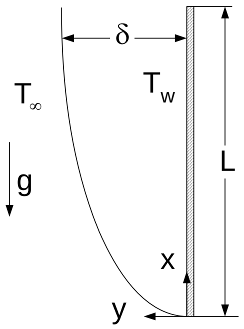
V. Heat loss from a steam pipe in windy air.
A long 10-cm-diameter steam pipe whose external surface temperature is 110°C passes through some open area that is not protected agrainst the winds. Determine the rate of heat loss from the pipe per unit of its length when the air is at 1 atm pressure and 10°C and the wind is blowing across the pipe at a velocity of 8 m/s.(10%)

$$Nu = 0.3 + \frac{0.62\,Re^{1/2}\,Pr^{1/3}}{\left[1+(0.4/Pr)^{2/3}\right]^{1/4}}\left[1+\left(\frac{Re}{282000}\right)^{5/8}\right]^{4/5}$$

$$Nu = \frac{hD}{k}, \quad Re = \frac{VD}{\nu}$$

T, °C	$\nu \times 10^5$ m²/s	k, W/mK	Pr
50	1.798	0.02735	0.7228
60	1.896	0.02808	0.7202
70	1.995	0.02881	0.7177

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



(1) In the boundary layer, what are the two forces, which determine the velocity profile in the layer? How do these two forces determine the velocity profile? (4%)

(2) Derive the momentum equation in the boundary layer,

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=\rho\beta\left(T-T_\infty\right)g+\mu\frac{\partial^2 u}{\partial y^2}, \qquad (a)$$

from the equation,

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{dp}{dx}-\rho g+\mu\frac{\partial^2 u}{\partial y^2}.$$

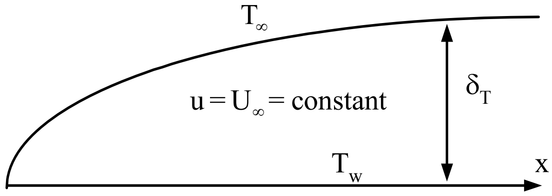
Hint: $\beta = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_p$ (5%)

(3) Derive the following dimensionless equation,

$$u^*\frac{\partial u^*}{\partial x^*}+v^*\frac{\partial u^*}{\partial y^*}=\theta+\frac{1}{\sqrt{Gr}}\left(\frac{L^2}{\delta^2}\right)\frac{\partial^2 u^*}{\partial y^{*2}}$$

from Equation (a). (6%)

VII. 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.



(a) Derive the integral equation of energy. (7%)

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

(b) Derive the experssions of heat-transfer coefficient h and the local Nusselt number Nu_x under the condition that $(T - T_w)/(T_\infty - T_w) = y/\delta_T$. The local Nusselt number must be expressed in terms of Prandtl and local Reynolds numbers. Hint: $Nu_x = hx/k$, $Re_x = xU_\infty/\nu$. (8%)