Exercise 5.1

Consider steady, parallel flow of atmospheric air over a flat plate. The air has a temperature and free stream velocity of $300K$ and $25m/s$

a) Evaluate the boundary layer thickness at distances of $x = 1, 10, 100mm$ from the leading edge.

b) If a second plate were installed parallel to and at a distance of $3mm$ from the first pate, what is the distance from the leading edge at which boundary layer merging would occur?

c) Evaluate the surface shear stress and the y-velocity component at the outer edge of the boundary layer for the single plate at $x = 1, 10, 100mm$

d) Comment on the validity of the boundary layer model

TABLE 7.1 Flat plate laminar boundary layer functions [3]

$\eta = y\sqrt{\frac{u_\infty}{\nu x}}$	f	$\frac{df}{d\eta} = \frac{u}{u_\infty}$	$\frac{d^2 f}{d\eta^2}$
0	0	0	0.332
0.4	0.027	0.133	0.331
0.8	0.106	0.265	0.327
1.2	0.238	0.394	0.317
1.6	0.420	0.517	0.297
2.0	0.650	0.630	0.267
2.4	0.922	0.729	0.228
2.8	1.231	0.812	0.184
3.2	1.569	0.876	0.139
3.6	1.930	0.923	0.098
4.0	2.306	0.956	0.064
4.4	2.692	0.976	0.039
4.8	3.085	0.988	0.022
5.2	3.482	0.994	0.011
5.6	3.880	0.997	0.005
6.0	4.280	0.999	0.002
6.4	4.679	1.000	0.001
6.8	5.079	1.000	0.000

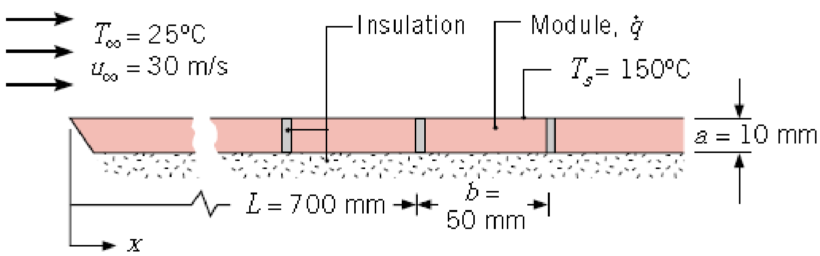
Exercise 5.2

A flat plate of width $W = 1m$ is maintained at a uniform surface temperature of $T_s = 150C$ by using independently controlled, heat-generating rectangular modules of thickness $a = 10mm$ and length $b = 50mm$. Each module is insulated from its neighbors, as well as on its back side. Atmospheric air at $25C$ flows over the plate at a velocity of $30m/s$. The thermophysical properties of the module are $k = 5.2W/mK$, $c_p = 320J/kgK$, and $\rho = 2300kg/m^3$.

a) Find the required power generation $\dot{q}W/m^3$, in a module positioned at a distance $L = 700mm$ from the leading edge

b) Find the maximum temperature T_{max} in the heat-generating module

Note: Air properties are $k_{air} = 0.0308W/mK$, $\nu = 22.02 \cdot 10^{-6}m^2/s$, $Pr = 0.698$



Exercise 5.3

A long, cylindrical, electrical heating element of diameter $D = 10mm$, thermal conductivity $k = 240W/mK$, density $\rho = 2700\text{kg/m}^3$ and specific heat $c_p = 900J/kgK$ is installed in a duct for which air moves in cross flow over the heater at a temperature and velocity of $27°C$ and $10m/s$ respectively.

- Neglecting radiation, estimate the steady-state surface temperature when, per unit length of the heater, electrical energy is being dissipated at a rate of $1000W/m$. To estimate the thermophysical properties use $T_f = 450K$.
- If the heater is activated from an initial temperature of $27°C$, estimate the time required for the surface to come within $10°C$ of its steady state value.

Exercise 5.4 [Difficult] FOR REVISION

A photovoltaic solar panel consists of a sandwich of (top to bottom) a $3mm$ thick ceria-doped glass($k_g = 1.4W/mK$), a $0.1mm$ thick optical grade adhesive ($k_a = 145W/mK$), a very thin silicon semiconducting material, a $0.1mm$ thick solder layer ($k_s = 50W/mK$) and a $2mm$ thick aluminum nitride substrate ($k_{an} = 120W/mK$). The solar-to-electrical conversion efficiency within the semiconductor depends on the silicon temperature, T_{si} and is described by the expression $\eta = 0.28 - 0.001T_{si}$, where T_{si} is in C for $25C < T_{si} < 250C$. Ten percent of the solar irradiation is absorbed at the top surface of the glass, while 83% of the solar irradiation is transmitted to and absorbed by the silicon (the remaining 7% is reflected away from the cell). The glass has an emissivity of 0.9. Consider an $L = 1m$ long, $w = 0.1m$ wide solar cell that is placed on an insulated surface. Air at $25C$ flows over the solar cell, parallel to the long direction, with a velocity of $4m/s$. The temperature of the surroundings is also $25C$. The solar irradiation is $G = 700W/m^2$. The boundary layer is tripped to turbulent condition at the leading edge of the panel at therefore the correlation for the turbulent case must be used to estimate the average value of Nu regardless of the Re_L value:

$$\overline{\mathrm{Nu}}_L = 0.037\,\mathrm{Re}_L^{4/5}\mathrm{Pr}^{1/3}$$

a) Draw the thermal circuit that represents the entire problem. Do not forget radiation heat transfer to the environment. Note that no radiation penetrates deeper than the silicon layer. Also, assume that the stack is sitting on a perfect insulating layer.

b) Determine the temperature of the silicon layer and the electric power produced by the solar cell.