From: Dallin Romney
Subject: Convection over a Flat Plate

Attachments: 4 figures, 1 table, MATLAB code

Summary
The purpose of this laboratory experiment is to model convection over a flat, heated plate and compare it to experimental results. A flat plate with a heated region was placed in a wind tunnel and the surface temperature was measured at various points. The goal of the analysis was to use the heating power and fluid properties to determine experimental convection heat coefficient and corresponding Nusselt number values, and compare them to theoretical values of h and Nu that are derived from empirical correlations. The results showed that the theoretical and experimental values differed anywhere from about 20-32%. In conclusion, empirical correlation were fair approximations of the convection but not very precise.

Results
Figures 1-3 plot experimental versus theoretical results at x positions along the plate; Figure 1 shows the Nusselt number, Figure 2 shows the convection heat transfer coefficient, and Figure 3 shows the node temperatures. Table 1 shows the calculated experimental and theoretical average Nusselt numbers and heat transfer coefficients. Finally, Figure 4 shows a derivation of the method for determining integration spacing.

Discussion
1. The mean experimental Nu_x is 179.2 and the theoretical one is 118.0; the difference is 34.2%. For h_x, the experimental mean is 33.1 $\frac{W}{m^2K}$ and the theoretical one is 22.9 $\frac{W}{m^2K}$; the difference is 30.8%. Finally, the average experimental surface temperature T_x was 306.6 K and the theoretical average was 313.5 K, with a difference of 2.25%. If considered in °C, the difference is 20.6 %. The theoretical results are very close to the experimental results towards the front of the plate, but diverge towards the back. Assuming the temperature measurements are accurate and the plate is uniformly heated, this probably means the boundary layer flattens earlier than expected. Perhaps the airflow is affected by the wind-tunnel walls nearby.

2. The experimental $\overline{Nu}_L$ is 192.0 and the theoretical one is 130.8. For $\bar{h}_L$, the experimental value is 32.9 $\frac{W}{m^2K}$ and the theoretical one is 22.4 $\frac{W}{m^2K}$. For both, the difference is 31.9%. Also, the weighted average experimental surface temperature $\bar{T}_s$ was 306.7 K and the theoretical average was 313.9 K, with a difference of 2.35%. However, if considered in °C, the difference is 21.5 %.

3. The estimated value of heat loss due to radiation is 1.12 W. The heater power is 8.23 W, so about 13.6 % of it is lost to radiation. Similarly, from a flux standpoint, the estimated heat loss due to radiation is 54.0 W/m^2, which is 13.7% of the total 395.6 W/m^2.

4. The end of the heated surface is at x = 230 mm. Assuming air properties at the same film temperature as the final data point (27.95 °C), the Reynolds number

$$Re_x = \frac{\rho u_\infty x}{\mu} = \frac{1.0133\,\frac{kg}{m^3}\cdot 4.963\frac{m}{s}\cdot 0.230\ m}{1.851\cdot 10^{-5}\frac{kg}{m\cdot s}} = 62489 = 6.25 \cdot 10^4$$

The critical Reynolds number for a flat plate is $Re_c = 5 \cdot 10^5$. Since $Re_x < Re_c$, we expect the entire heated region to be laminar.

Attachment: Figures and Tables

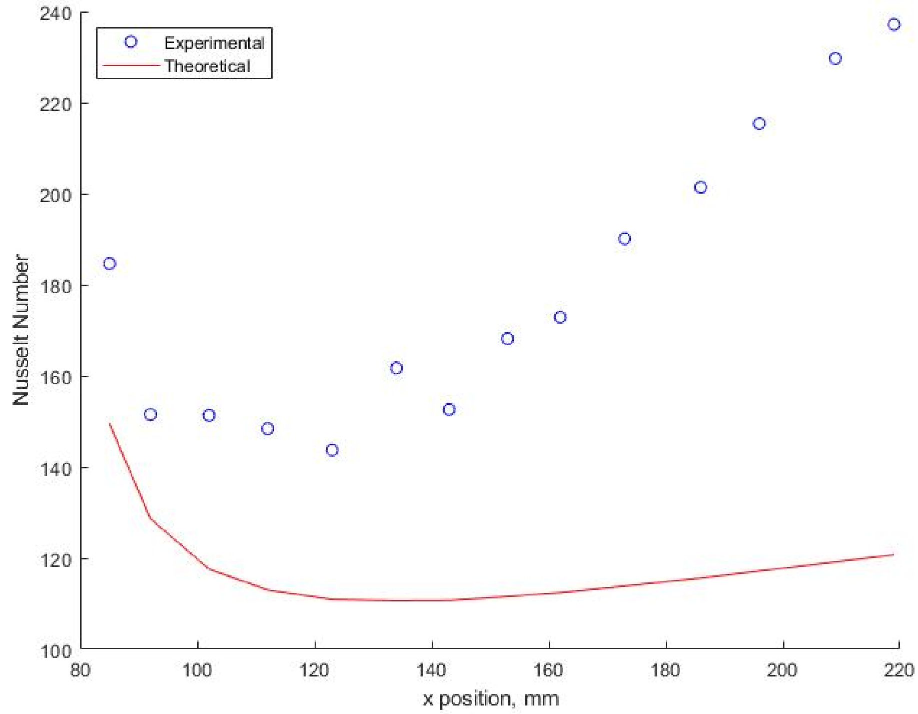

Figure 1. Nusselt number Nu_x vs. x along the heated plate, experimental vs. theoretical

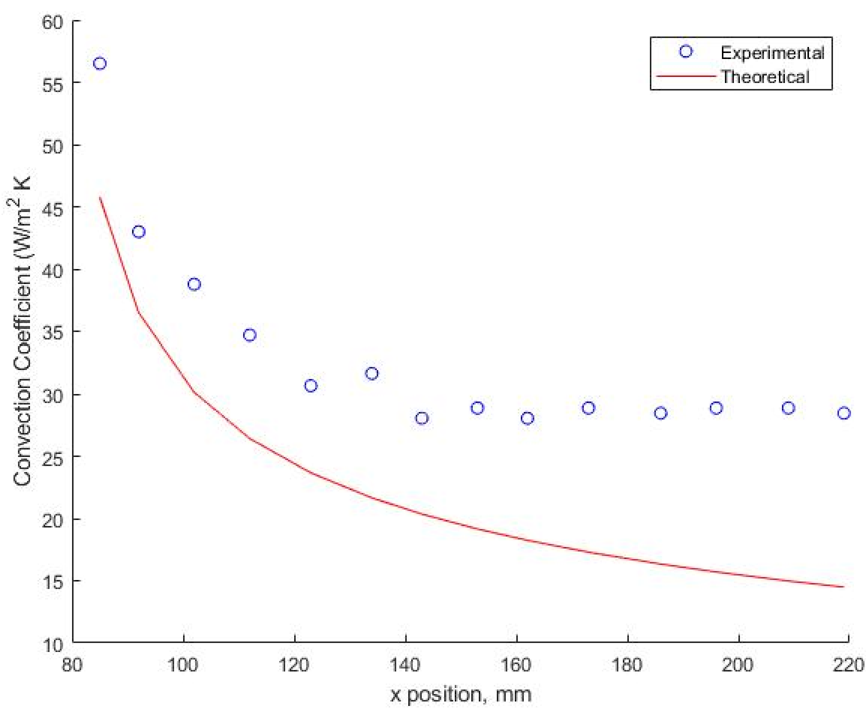

Figure 2. Convection coefficient h_x vs. x along the heated plate, experimental vs. theoretical

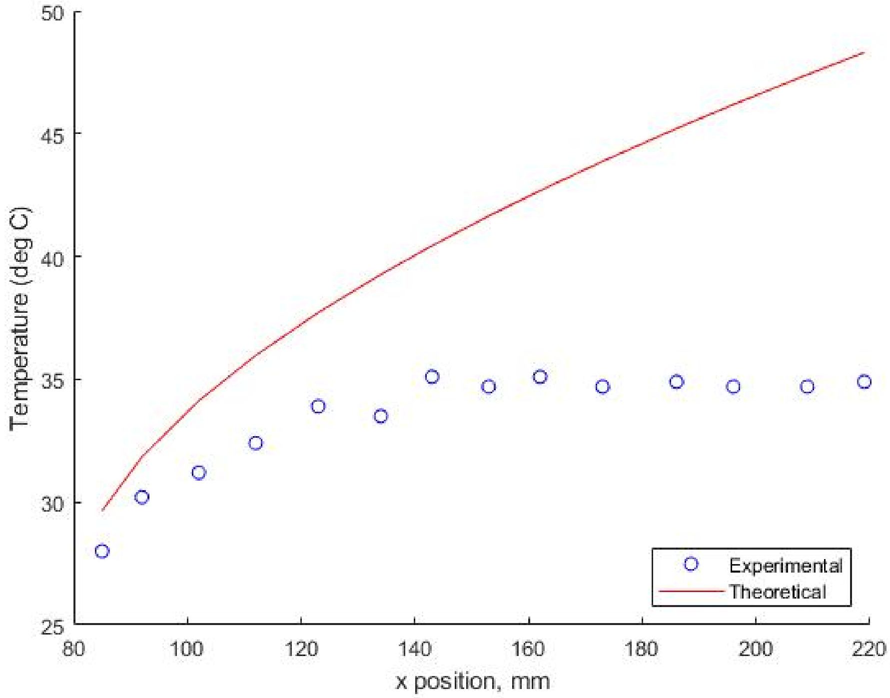

Figure 3. Temperature T_x vs. x along the heated plate, experimental vs. theoretical

Table 1. Experimental vs. theoretical average convection coefficients and Nusselt numbers

	$\overline{Nu}_L$	$\bar{h}_L \ \frac{W}{m^2K}$
Experiment	192.0	32.91
Theory	130.8	22.42

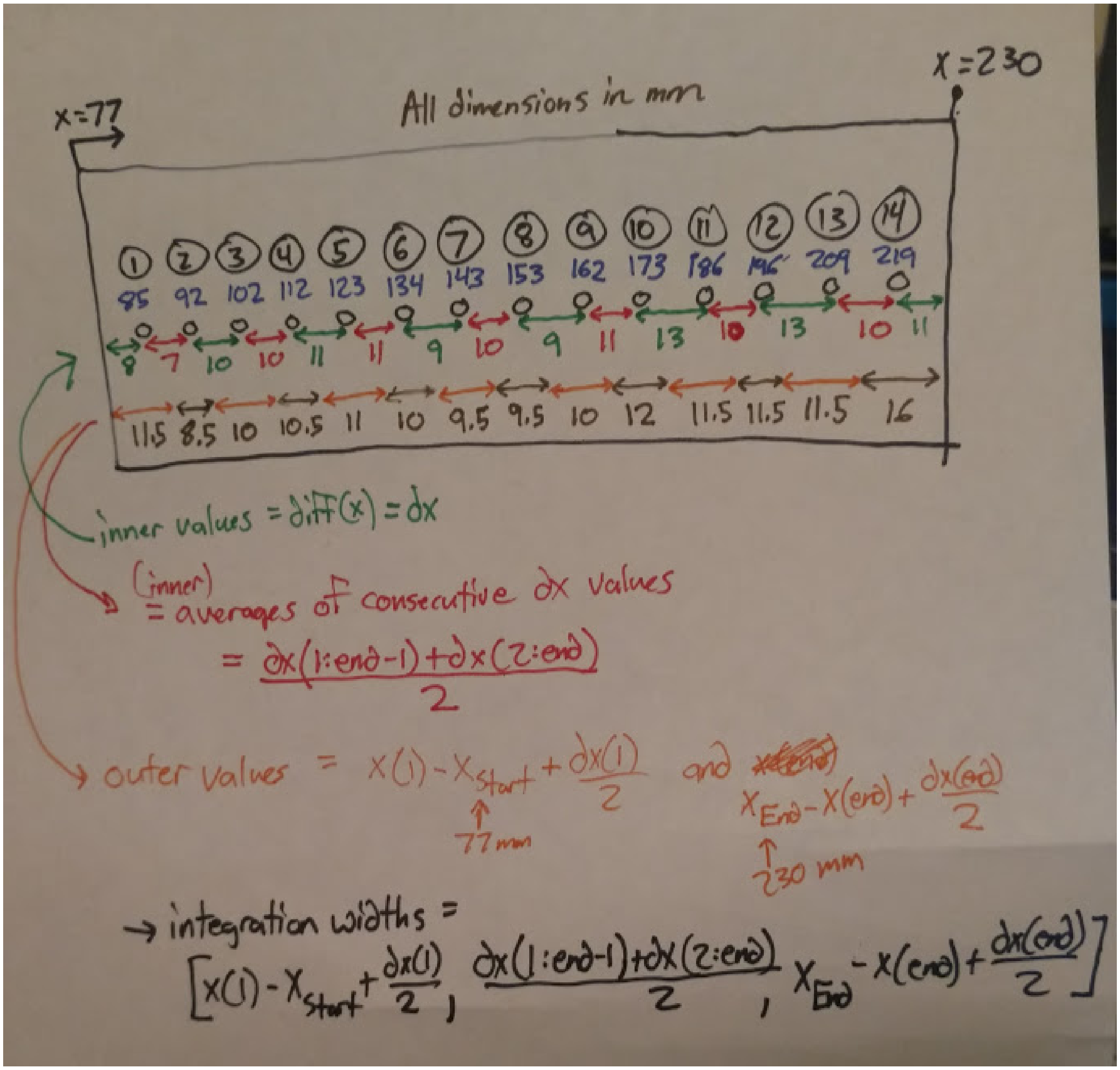

Figure 4. Derivation of integration method