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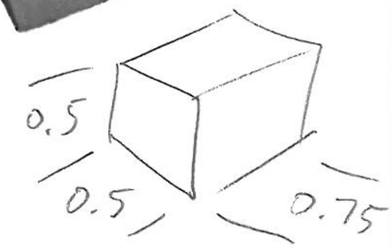
MAE 423 HEAT AND MASS TRANSFER
EXAM 2 - SPRING 2013

Name: Answer Key

You are allowed one sheet of notes.

1. A Styrofoam cooler has an internal size of 0.5 m × 0.75 m × 0.5 m and a wall thickness of 40 mm, with thermal conductivity $k = 0.033$ W/m K. If the temperature inside the cooler is 5° C and the outside temperature is 20° C, what is the heat transfer rate?



$$S = 4 \times \frac{0.5 \times 0.75}{0.04} + 2\,\frac{0.5 \times 0.5}{0.04}$$

$$+ 4 \times 0.54 \times 0.75 + 8 \times 0.54 \times 0.5$$

$$+ 8 \times 0.15 \times 0.04$$

$$= 37.5 + 12.5 + 1.62 + 2.16 + 0.048$$

10 $$= 53.83$$

$$q = kS\Delta T = 0.033 \times 53.83 \times (20-5)$$

$$\boxed{q = 26.6 \text{ W}}$$

2. A 1 m × 1 m flat plate at 60° C is exposed to a lateral flow of air at 20° C with a velocity of 5 m/s. What average convection heat transfer coefficient ($\overline{h_c}$) should be used for the heat transfer calculation?

For dry air at $t_f = \frac{T_s + T_\infty}{2} = \frac{60+20}{2} = 40°C$

$\nu = 17.6 \times 10^{-6}\ m^2/s$ $\quad Pr = 0.71$ $\quad \rho = 1.092$

$k_f = 0.0265\ \frac{W}{mK}$ $\quad \mu = 19.123 \times 10^{-6}$

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$$Re = \frac{U_\infty L}{\nu} = \frac{5 \times 1}{17.6 \times 10^{-6}} = 284\ 000$$

For laminar flow $Re_L < 500\ 000$ & $Pr > 0.5$

$$\overline{Nu}_L = 0.664\ Re_L^{0.5}\ Pr^{0.33}$$

$$= 0.664\ (284\ 000)^{0.5}\ (0.71)^{0.33}$$

$$\overline{Nu}_L = 316.0$$

$$\overline{h}_c = \frac{\overline{Nu}_L k_f}{L} = \frac{316.0 \times 0.0265}{1}$$

$$\boxed{\overline{h}_c = 8.38\ \frac{W}{m^2 K}}$$

3. Draw a picture to demonstrate the difference between the discretized control volumes used in the Finite Difference Method (as described in Chapter 3) and those used in the Finite Volume or Finite Element Method (as performed using Siemens NX for the homework problem).

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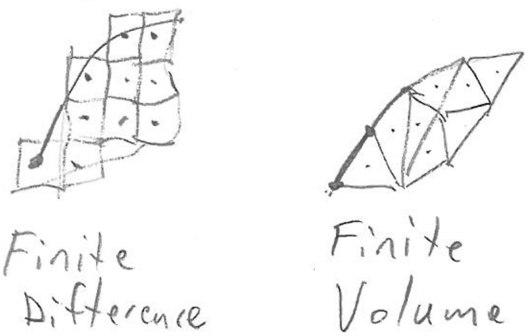

4. What is the primary means that an analyst has to control the accuracy of results in a numerical simulation of conductive heat transfer in a complex shape? I.e., what can be changed in a Finite Difference or Finite Volume model to make the results more accurate?

2 - Make the mesh finer. Use more elements. Use smaller elements

5. Draw a diagram to show velocity and thermal boundary layers over the edge of a plate.

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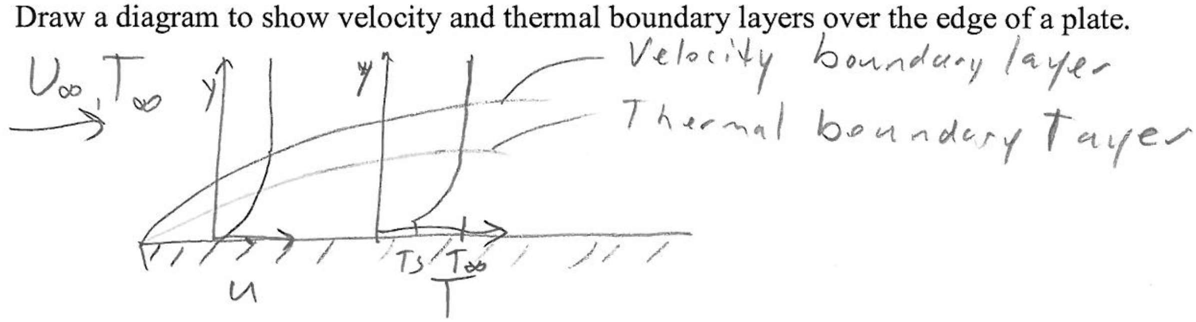

6. Which two dimensionless parameters can be used to relate the solution of the force balance partial differential equation to the energy balance partial differential equation for convection heat transfer to a moving fluid?

- Prandtl number

2 - Reynold's number

7. An aluminum heat sink for the CPU of a computer is made up of a 12 × 10 array of pin fins, each having a 2 mm × 3 mm cross-section and length of 25 mm on a 50 mm × 50 mm base. If the thermal conductivity of the aluminum is $k = 237$ W/m K and the average convection heat transfer coefficient is $\overline{h_c} = 150\ \text{W/m}^2$ K, using the assumption of infinitely long fins, what percentage improvement is achieved in heat removal over simply exposing the surface of the 30 mm × 30 mm CPU? If 100 W of heat is generated by the CPU, how hot will it get in a 20° C environment?

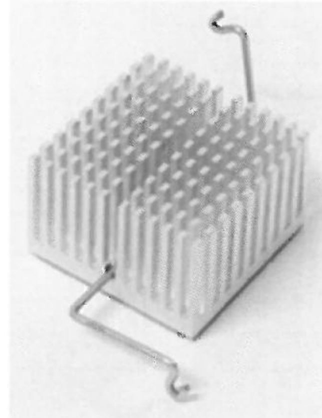

Image from Wikimedia Commons

$$q_{fin} = M\theta_s = \sqrt{\bar{h}_c P k A}\ \theta_s$$

$$= \sqrt{150 \times \underbrace{(2\times 0.002 + 2\times 0.003)}_{0.01} \times 237 \times \underbrace{0.002\times 0.003}_{6\times 10^{-6}}}\ \theta_s = 0.04618\,\theta_s\ \text{W}$$

(0.00178)

$$q_{total} = 12\times 10 \times 0.04618\,\theta_s + 150 \times (0.05\times 0.05 - 12\times 10\times 0.002\times 0.003)\,\theta_s$$

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$$= (5.5416 + 0.267)\,\theta_s$$

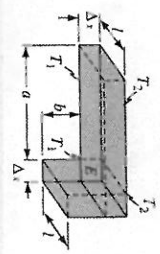
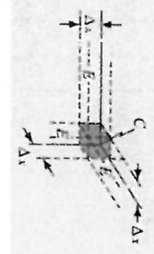
$$= 5.8086\,\theta_s$$

$$q_{CPU} = 150 \times \underbrace{0.03\times 0.03}_{9\times 10^{-4}}\,\theta_s = 0.135\,\theta_s$$

$$\text{Improvement} = \frac{5.8086 - 0.135}{0.135} \times 100\% = 4200\%$$

$$100 = 5.8086\,(T_s - 20)$$

$$\boxed{T_s = 37\,^\circ C}$$

Conduction through two plane sections and the edge[a] section of two walls of thermal conductivity k, with inner- and outer-surface temperatures uniform		$\frac{al}{\Delta x} + \frac{bl}{\Delta x} + 0.54l$
Conduction through the corner section C of three[a] homogeneous walls of thermal conductivity k, inner- and outer-surface temperatures uniform		$(0.15\ \Delta x)$ if Δx is small compared to the lengths of walls

(Continued)

TABLE 28 Dry air at atmospheric pressure

Temperature, T			Density, ρ (kg/m^3)	Coefficient of Thermal Expansion, $\beta \times 10^3$ (1/K)	Specific Heat, c_p (J/kg K)	Thermal Conductivity, k (W/m K)	Thermal Diffusivity, $\alpha \times 10^6$ (m^2/s)	Absolute Viscosity, $\mu \times 10^6$ (N s/m^2)	Kinematic Viscosity, $\nu \times 10^6$ (m^2/s)	Prandtl Number, Pr	$\frac{g\beta}{\nu^2} \times 10^{-8}$ (1/K m^3)
°F	K	°C	$\times 6.243 \times 10^{-2}$ = (lb$_m$/ft^3)	$\times 0.5556$ = (1/R)	$\times 2.388 \times 10^{-4}$ = (Btu/lb$_m$ °F)	$\times 0.5777$ = (Btu/h ft °F)	$\times 3.874 \times 10^4$ = (ft^2/h)	$\times 0.6720$ = (lb$_m$/ft s)	$\times 3.874 \times 10^4$ = (ft^2/h)		$\times 1.573 \times 10^{-2}$ = (1/R ft^3)
32	273	0	1.252	3.66	1011	0.0237	19.2	17.456	13.9	0.71	1.85
68	293	20	1.164	3.41	1012	0.0251	22.0	18.240	15.7	0.71	1.36
104	313	40	1.092	3.19	1014	0.0265	24.8	19.123	17.6	0.71	1.01
140	333	60	1.025	3.00	1017	0.0279	27.6	19.907	19.4	0.71	0.782
176	353	80	0.968	2.83	1019	0.0293	30.6	20.790	21.5	0.71	0.600
212	373	100	0.916	2.68	1022	0.0307	33.6	21.673	23.6	0.71	0.472
392	473	200	0.723	2.11	1035	0.0370	49.7	25.693	35.5	0.71	0.164
572	573	300	0.596	1.75	1047	0.0429	68.9	29.322	49.2	0.71	0.0709
752	673	400	0.508	1.49	1059	0.0485	89.4	32.754	64.6	0.72	0.0350
932	773	500	0.442	1.29	1076	0.0540	113.2	35.794	81.0	0.72	0.0193
1832	1273	1000	0.268	0.79	1139	0.0762	240	48.445	181	0.74	0.00236

Source: K. Raznjević, *Handbook of Thermodynamic Tables and Charts*, McGraw-Hill, New York, 1976.