ENGR 292 Fluids and Thermodynamics

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Review of Last Class

- **Determine the convective heat transfer coefficient h is not an easy task.**
- **Use Patterns defined in Table C-8 to find Nu**
  - by calculating Re for forced convection
  - by calculating Gr for natural convection

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Review of Last Class

- **Forced Convection**
  - Fluid was forced to move over a surface or in a tube by external means such as a pump or a fan.

Table C-8

(A) Flow in circular tubes
(B) Boundary layer on a flat plate
(C) Single circular cylinder or sphere in cross flow

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Review of Last Class

- **Natural Convection**
  - Any fluid motion occurs by natural means such as buoyancy

Table C-8

(D) Natural convection from a horizontal cylinder
(E) Natural convection from vertical surfaces

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Review of Last Class

- **Procedure for Calculating "h" – Forced Convection:**
  1. Determine the geometric parameter L;
  2. Determine the type of the Forced Convection in Table C-8 (A), (B) or (C)
  3. Assume a fluid temperature, $T_f(°K)$ (if it is not given). Look up the thermo-physical properties ($\rho, k, \mu, \upsilon, Pr$) of the fluid used in the convection in Table A-18 (if Pr is not given, use $Pr = \frac{\mu C_p}{k}$)

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Review of Last Class

4. Calculate the Reynolds number (Re) or other information to determine the Flow type – Laminar or Turbulent

$$Re = \frac{vL\rho}{\mu} = \frac{vL}{\nu}$$

Please note:

Critical Reynolds Numbers

- Inside a Pipe
  - $Re_{Cr} = 2000$
- Over a Flat Plate
  - $Re_{Cr} = 500,000$

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Review of Last Class

5. Calculate Nusselt number (Nu)

$$Nu = CRe_L^m Pr^n$$

Find C, m, n as per flow type and thermal boundary layer condition

6. Calculate h

$$h = \frac{(Nu)k}{L}$$

Review of Last Class

- Procedure for Calculating "h" – Natural Convection:
  1. Determine the geometric parameter L;
  2. Determine the type of the Natural Convection in Table C-8 (D) or (E)
  3. Assume a fluid temperature, T_f ($°K$) (if it is not given). Look up the thermo-physical properties ($\rho, k, \mu, \upsilon, Pr$) of the fluid used in the convection in Table A-18

Review of Last Class

- 4. Calculate the Grashof number (Gr)

$$Gr = \frac{g\beta(T_{surface} - T_{\infty})L^3\rho^2}{\mu^2}$$

$\beta = \frac{1}{T_f}$ for gas only $(K = C + 273.15)$

5. Calculate Nusselt number (Nu)

$$Nu = C(Gr \times Pr)^n$$

Find C and n as per the value of $(Gr \times Pr)$

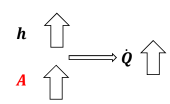
6. Calculate h

$$h = \frac{(Nu)k}{L}$$

Heat Transfer from Finned Surfaces

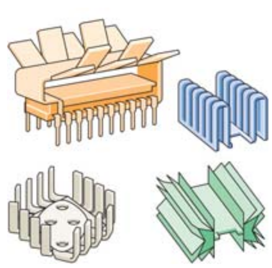
- To Improve the Convective Heat Transfer

$$\dot{Q} = hA(T_{surface} - T_{\infty})$$



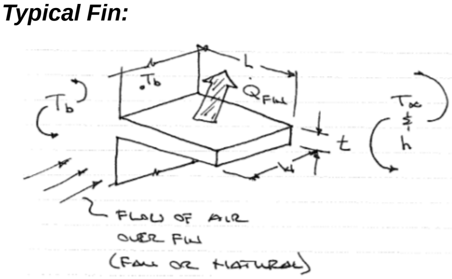
Heat Transfer from Finned Surfaces

- Various Fins – to increase the heat transfer area A:



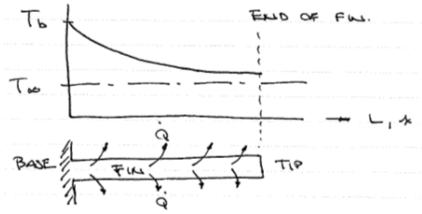
Typical Fin

- Typical Fin:



Fin Efficiency

- **Heat Transfer is not constant over the entire Fin**



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Fin Efficiency

- **Fin Efficiency**

$$\eta_{Fin} = \frac{Actual\ Heat\ Transfer\ Rate\ from\ the\ Fin}{Ideal\ Heat\ Transfer\ Rate\ from\ the\ Fin}$$

Ideal Heat Transfer Rate from the Fin is possible only if the entire fine were at T_b (base temperature)

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Fin Efficiency

- **Fin Efficiency**

$$\eta_{Fin} = \frac{\dot{Q}_{Fin}}{\dot{Q}_{Fin,Max}}$$

$$\dot{Q}_{Fin,Max} = hA_{Fin}(T_b - T_\infty)$$

$$A_{Fin} = A_{Fin\_Sides} + A_{Fin\_Tip}$$

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Heat Transfer from Finned Surfaces

- **Heat Transfer Rate of Fin Surfaces:**

$$\dot{Q}_{Fin} = \eta_{Fin}\dot{Q}_{Fin,Max}$$
$$= \eta_{Fin} h A_{Fin}(T_b - T_\infty)$$

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Heat Transfer from Finned Surfaces

- **To Determine η_{Fin}:**

Calculate $\xi \rightarrow \eta_{Fin}$

(Figure 8-59)

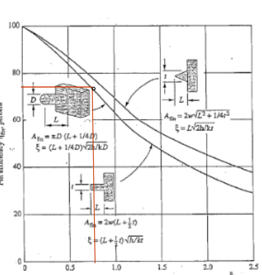

FIGURE 8-59
Efficiency of circular, rectangular and triangular fins on a plain surface of width w (from Gardner).

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Heat Transfer from Finned Surfaces

- **To Determine η_{Fin}:**

Calculate $\xi \rightarrow \eta_{Fin}$

(Figure 8-60)

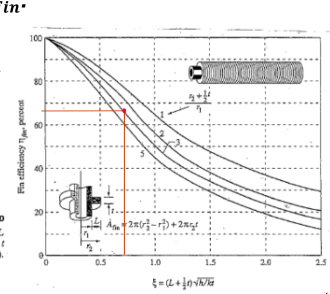

FIGURE 8-60
Efficiency of circular fins of length L and constant thickness t (from Gardner).

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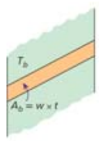
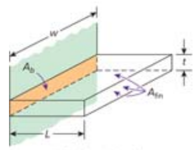
Fin Effectiveness

- **_How good is the Fin compared to No Fin attached :_**



(a) Surface without fins



(b) Surface with a fin
$A_{fin} = 2 \times w \times L + w \times t$
$\cong 2 \times w \times L$

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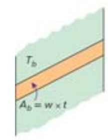
Fin Effectiveness

- **_No Fin attached :_**

$$\dot{Q}_{No\ Fin} = hA_b(T_b - T_\infty)$$

A_b= the area of the Fin's base or root.

T_b= Base temperature of Fin and Wall.



(a) Surface without fins

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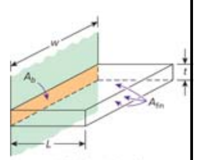
Fin Effectiveness

- **_Fin attached :_**

$$\dot{Q}_{Fin} = \eta_{Fin} h A_{Fin}(T_b - T_\infty)$$



(b) Surface with a fin
$A_{fin} = 2 \times w \times L + w \times t$
$\cong 2 \times w \times L$

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Fin Effectiveness

- **_Fin Effectiveness ε_{Fin}:_**

$$\varepsilon_{Fin} = \frac{\dot{Q}_{Fin}}{\dot{Q}_{No\ Fin}}$$

$$= \frac{\eta_{Fin} h A_{Fin}(T_b - T_\infty)}{hA_b(T_b - T_\infty)} = \frac{\eta_{Fin} A_{Fin}}{A_b}$$

Assume the h is the same for both cases.

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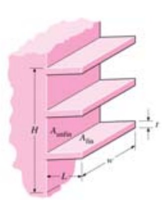
Heat Transfer from Finned Surfaces

- **_Multiple Fins:_**



$A_{no\ fin} = w \times H$
$A_{unfin} = w \times H - 3 \times (t \times w)$
$A_{fin} = 2 \times L \times w + t \times w$
$\cong 2 \times L \times w$ (one fin)

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Heat Transfer from Finned Surfaces

- **_For all the Fins and Surfaces_**

$$\dot{Q}_{Total\ Fin} = \dot{Q}_{UnFin} + \dot{Q}_{Fin}$$
$$= h(A_{UnFin} + \eta_{Fin} A_{Fin})(T_b - T_\infty)$$

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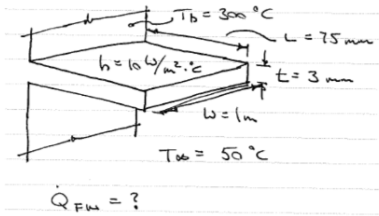
Example 1

- **Calculate $\dot{Q}_{Fin}$**



The Fin is Aluminum: $k \approx 200\ w/m℃$

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Example 1

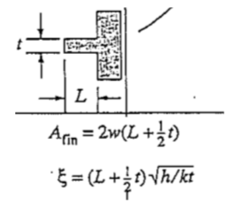
- **Solution:**

From Figure 8-59

$A_{Fin} = 2w(L + \frac{1}{2}t)$

$= 2(1)(0.075 + \frac{1}{2}(0.003))$

$= 0.153m^2$



$\xi = (L + \frac{1}{2}t)\sqrt{h/kt}$

$= \left(0.075 + \frac{1}{2}(0.003)\right)\sqrt{\frac{10}{200 \times 0.003}} = 0.312$

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Example 1

- **Solution:**

$\xi = 0.312$

From Figure 8-59

$\eta_{Fin} \approx 0.88$

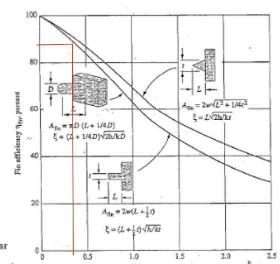

FIGURE 8-59
Efficiency of circular, rectangular and triangular fins on a plain surface of width w (from Gardner).

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Example 1

- **Solution:**

$\dot{Q}_{Fin} = \eta_{Fin} h A_{Fin}(T_b - T_\infty)$

$= (0.88)(10)(0.153)\ (300 - 50)$

$= 336.6\ watts.$

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Example 1

- **Solution:**

Fin Effectiveness

$$\varepsilon_{Fin} = \frac{\eta_{Fin} A_{Fin}}{A_b} = \frac{(0.88)(0.153)}{(0.003)} = 44.9$$

$A_b = w \times t = 1 \times 0.003 = 0.003m^2$

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Heat Sink Selection

- **Example:**

A power transmitter is rated to produce 60 watts at full power. The case can not exceed 90℃, with a air temperature 30 ℃

$$\dot{Q} = \frac{\Delta T}{R}$$

$$R = \frac{\Delta T}{\dot{Q}} = \frac{90 - 30}{60} = 1℃/w$$

Choose a heat sink with $R < 1℃/w$

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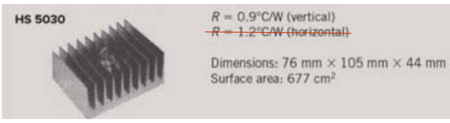
Heat Sink Selection

- **Example:**

Such as HS5030 (vertical), whose R = $\mathbf{0.9}℃/w < \mathbf{1}℃/w$



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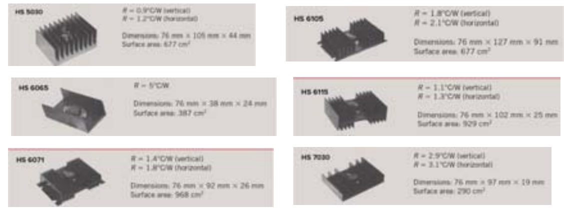
Heat Sink Selection

- **Various Heat Sinks:**



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Heat Transfer in Common Configurations

- ***Heat Transfer in Common Configurations in conduction shape factor :***

$$\dot{Q} = Sk(T_1 - T_2)$$

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Heat Transfer in Common Configurations

- ***Large Plane Wall:***

$$S = \frac{A}{L}$$

$$\dot{Q} = Sk(T_1 - T_2)$$

$$= k\frac{A}{L}(T_1 - T_2)$$

$$R = \frac{1}{kS}$$

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Heat Transfer in Common Configurations

- ***A long cylinder layer :***

$$S = \frac{2\pi L}{ln(\frac{D_2}{D_1})}$$

$$\dot{Q} = Sk(T_1 - T_2)$$

$$= k\frac{2\pi L}{ln(\frac{D_2}{D_1})}(T_1 - T_2)$$

$$R = \frac{1}{kS}$$

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Heat Transfer in Common Configurations

- ***A spherical layer :***

$$S = \frac{2\pi D_1 D_2}{D_2 - D_1}$$

$$\dot{Q} = Sk(T_1 - T_2)$$

$$= k\frac{2\pi D_1 D_2}{D_2 - D_1}(T_1 - T_2)$$

$$R = \frac{1}{kS}$$

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Example 2

8-142 The case-to-ambient thermal resistance of a power transistor that has a maximum power rating of 15 W is given as 25°C/W. If the case temperature of the transistor is not to exceed 80°C, determine the power at which this transistor can be operated safely in an environment at 30°C.

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Example 2

- ***Solution:***

Recall:

$$\dot{Q} = \frac{T_{Case} - T_\infty}{R_{Case-to-\infty}} = \frac{T_{Case} - T_{Ambient}}{R_{Case-to-Ambient}}$$

$$\Delta T = T_{Case} - T_{Ambient} = 80℃ - 30℃ = 50℃$$

$$R_{Case-to-Ambient} = 25℃/W$$

$$\dot{Q} = \frac{\Delta T}{R} = \frac{50℃}{25℃/W} = 2\ W$$

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Example 3

8-143 A 40-W power transistor is to be cooled by attaching it to one of the commercially available heat sinks shown in Table 8-6. Select a heat sink that will allow the case temperature of the transistor not to exceed 90°C in the ambient air at 20°C.

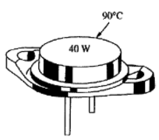

FIGURE P8-143

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Example 3

- ***Solution:***

$$\dot{Q} = \frac{T_{Case} - T_\infty}{R_{Case-to-\infty}}$$

$$= \frac{T_{Case} - T_{Ambient}}{R_{Case-to-Ambient}}$$

$$R_{Case-to-Ambient} = \frac{T_{Case} - T_{Ambient}}{\dot{Q}}$$

$$= \frac{90℃ - 20℃}{40\ W} = 1.7℃/W$$

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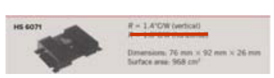
Example 3

- ***Solution:***

For this to work R of the heat sink must be less than $1.75℃/W$



All these above are ok, make a final selection based on size and other factors.

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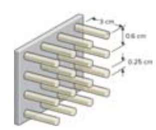
Example 4 – *Check the Solution at ENGR292 Web*

8-150 A hot surface at 100°C is to be cooled by attaching 3-cm-long, 0.25-cm-diameter aluminum pin fins [$k = 237\ W/(m \cdot °C)$] to it, with a center-to-center distance of 0.6 cm. The temperature of the surrounding medium is 30°C, and the heat transfer coefficient on the surfaces is $35\ W/(m^2 \cdot °C)$. Determine the rate of heat transfer from the surface for a 1 m × 1 m section of the plate. Also determine the overall effectiveness of the fins.



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Example 5 - *Check the Solution at ENGR292 Web*

A 0.3 cm thick, 12 cm high and 18 cm long circuit board houses 80 closely spaced logic chips on one side. Each chip dissipates 0.04 W. The board is impregnated with copper fillings, and has an effective thermal conductivity of 20 W/m-°C. All the heat generated in the chips is conducted across the circuit board and is dissipated from the back side of the board to the medium at 40°C with a heat transfer coefficient of 50 W/m^2-°C.

Determine:

a. the temperatures on the two sides of the circuit board (chip side and cooling medium side).

b. In an attempt to improve the heat transfer characteristics of the board/chip system, a 0.2 cm thick, 12 cm high and 18 cm long aluminium plate (k = 237 W/m-°C) with 864, 2 cm long aluminium pin fins of diameter 0.25 cm is attached to the back side of the circuit board with a 0.02 cm thick epoxy adhesive (k = 1.8 W/m-°C).

Now determine the temperatures on the two sides of the circuit board.

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What is next?

- ***Analytical Tools***
  - ***Part -1 (Optional):***
    - ***General Energy Equations***
    - ***Navier-Stokes Equations***
    - ***Lagrangian and Eulerian Reference Frames***
  - ***Part -2 (Optional):***
    - ***Dimensional Analysis***
    - ***Similitude Examples***
    - ***Similitude Examples - Expanded***

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What is next?

- ***Final Review***
  - ***Part -1:***
    - ***Fluid Statics***
    - ***Fluid Dynamics***
  - ***Part -2 :***
    - ***Thermodynamics***
    - ***Heat Transfer***

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