AME 431: PROJECT 1

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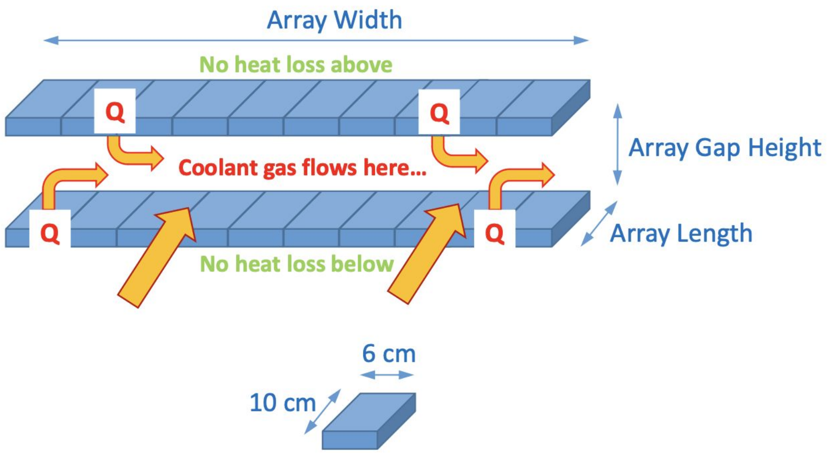
Problem Statement

Design a Heat Sink for Flight Computer Cooling



Approach

1. Find ΔT

$$\Delta T = (T_{max} - T_{bulk\ gas})$$

2. Find Gas Flow given Q_{fluid}

$$\dot{Q} = \dot{m} c_p \Delta T$$

Approach

3. Find Fin area and channel area

$$A_{fin} = n_{fin} * 4tL$$

$$A_{unfin} = L_{full} * w_{full} - n_{fin}t^2$$

$$A_c = height * \frac{width - n_{fin} * t}{n_{fins} - 1}$$

4. Find Velocity

$$\dot{m} = \rho A_c V$$

Approach

5. Length of Channel and Diameter

$$L_{channel} = \frac{width - n_{fin} * t}{n_{fin} - 1}$$

$$D_h = \frac{4 * A_c}{2 * L_{channel} + 2 * height}$$

6. Reynold's number and Prandtl number

$$Re = \frac{V * D_h}{\mu}$$

$$Nu = \frac{\left(\frac{f}{8}\right) RePr}{1.07 + 12.7 \left(\frac{f}{8}\right)^{0.5} \left(Pr^{\frac{2}{3}} - 1\right)}$$

Approach

7. Heat transfer coefficient

$$h = \frac{kNu}{D_h}$$

8. Pressure Drop

$$\Delta P = f\left(\frac{L}{D_h}\right)(\rho * V)$$

Approach

9. Find Q_{fin}

$$Q_{fin} = k_{material} * A_{fin} * \frac{T_b - T_{inf}}{L_{fin}}$$

10. Weight

$$Weight = \rho * w * l * h * n_{fin}$$

STEP 1

Step 1A: Find ΔT

ΔT is determined by finding the max difference between the computer surface and bulk gas. The maximum computer surface temperature is 60℃ and the minimum bulk gas temperature is -20℃. Thus the ΔT we will use is (60 - (-20)) = **80 ℃**

Step 1B: Find Gas Flow given Q_fluid

Q_fluid by definition must be 1200 W. Given ΔT and this, the gas flow can be calculated by Q_dot = m_dot · c_p · ΔT where c_p = 1003.92 J/kg·K (interpolated at N2 = -20℃)
-> 0.0149 kg/s

Assumptions:

1.) Heat sinks square shaped
2.) Take everything at the inlet temperature -20℃

FIN 1 - ALUMINIUM + 350 µm - Sean

A_fin = n_fin * 4 * t * L (start with 50 fins) -> 50 * 4 * 0.00035 m * 0.47 m= 0.0329 m^2

A_unfin = L_full*w_full - n_fin * (t^2) = (0.47m * 0.23 m) - (50 * 0.00035 m ^2) = 0.11 m^2

A_c = 0.05 * ((0.23 m - 50 * 0.00035 m) / (50-1)) = 2.17 * 10^-4 m^2

m_dot = ρ * A_c * V (where m_dot = 0.0149 kg/s and ρ = 1.36 kg/m^3) -> **V = 50.5 m/s**

FIN 1 - ALUMINIUM + 350 μm

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L_channel = (0.23 m - 50 * 0.00035 m) / (50-1) = 0.00434 m

D_h = 4A_c / p = 4 * 2.17 * 10^-4 m^2 / (2*0.00434 + 2 *0.05) = 0.00798 m

Re = V*D / μ = (μ = 1.54 * 10^-5, V = 50.5 m/s) = 26,172.18
Thus flow is **turbulent.**

f = (0.790 ln(Re) - 1.64)^(-2) = 0.0244 (for turbulent flow in smooth tubes)

(Pr = 0.6934 by interpolation)

$$\mathrm{Nu} = \frac{(f/8)\mathrm{Re}\,\mathrm{Pr}}{1.07 + 12.7(f/8)^{0.5}(\mathrm{Pr}^{2/3} - 1)} = 65.8$$

h = k*Nu / D (where k = 0.0223 by interpolation and A-16) = 183.8 W/m^2K

FIN 1 - ALUMINIUM + 350 μm

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$\Delta P = f\,(L/D)\,(\rho * V^2/2) = 0.0244 * (0.47/0.00798)(1.36 * 50.5\ m/s) = 97\ Pa$

Assuming ideal efficiency $Q_{fin} = Q_{fin,max}$

$Q_{surf} = Q_{fin} = k_{Aluminum} * A_{fin} * (T_b - T_{inf}) / L_{fin}$ will be equal to 1327.2 W. Reworking all the previous values with various n_{fin} values, results in an ideal number of fins **= 33**

Thus the Q_{actual} with 33 fins is 875.952 W. Knowing the ideal heat transfer rate is 1200 W, the real efficiency can be calculated by $Q_{actual} / Q_{ideal} = \eta_{fin} = 0.730$.

Weight = ρ_{Al} * (width * length * height) * n_{fins} = 2739 * (0.00035 * 0.47 * 0.05) * 33 = 0.74 kg

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FIN 2 - Aluminum 700 µm - Alex

Material	Aluminum
Thickness (µm)	700
Spacing (m)	0.0102
ΔP (Pa)	201.05
Number of Fins	22
Efficiency	97.33%

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% Constants and Parameters
Q_dot = 1200;
T_surface = 60;
T_inlet = -20;
delta_T = T_surface - T_inlet;
c_p = 1003.92;
rho = 1.3618;
mu = 1.54e-5;
k = 0.0223;
k_mat = 237;
P_in = 102000;
P_out = 101325;
L_fin = 0.47;
W_fin = 0.23;
H_fin = 0.05;
m_dot = 0.0149;

% Parameters to iterate, changing thcikness to be optimal
t_fin_values = 0.0007; % CHANGE
max_N_fin = 200;
tolerance = 1e-3;

% Initialize tracking variables
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Command Window

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Optimal Configuration:
Number of fins: 22
Fin thickness (t_fin): 0.0007 m
Fin spacing (s_fin): 0.010219 m
Hydraulic diameter (D_h): 0.01697 m
Reynolds number (Re): 32133.7685
Nusselt number (Nu): 70.2538
Heat transfer coefficient (h): 92.3205 W/m²·K
Actual heat transfer (Q_actual): 1167.936 W
Pressure drop (delta_P): 201.0481 Pa
Flow cross-sectional area per channel (A_flow): 0.00051095 m²
Flow velocity (u): 21.4137 m/s
fx >>
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FIN 3/4 - Copper - Henry/Karl

Material	Copper
Thickness (μm)	80
Spacing (m)	0.0067
ΔP (Pa)	29.08
Number of Fins	35
Efficiency	29.94%

Material	Copper
Thickness (μm)	160
Spacing (m)	0.001
ΔP (Pa)	104.9
Number of Fins	42
Efficiency	79.38%

Cost

Aluminum ($\$2.12\ per\ kg$)

Copper ($\$6.36\ per\ kg$)

	Aluminum, 350 μm	Aluminum, 700 μm	Copper, 80 μm	Copper, 160 μm
Weight (kg)	0.74	0.99	0.59	1.15
Cost ($)	1.58	2.10	3.75	7.29

Conclusion 1: Copper is far too expensive.

Table Values

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Material	Aluminum	Aluminum	Copper	Copper
Thickness (μm)	350	700	80	160
Spacing (m)	0.0068	0.0102	0.0067	0.001
ΔP (Pa)	627.62	201.05	29.08	104.9
Number of Fins	33	22	35	42
Efficiency	73.00%	97.33%	29.94%	79.38%

Al_350 = 0.73/1.58 = 46.2%/$
Al_700 = 0.9733/2.1=46.3%/$

Conclusion 2: You get **slightly** more efficiency per dollar with the 700 μm aluminum.

Results

ITEM	FINAL INFORMATION
TEAM MEMBERS	Alex Suvorov, Karl Jackle, Henry Glover, Sean Yamaguchi
PROJECT UNDERTAKEN	Flight Computer Heat Sink
MATERIAL/TOTAL WEIGHT	Aluminum, 0.0901 kg
NUMBER OF HEAT UNITS	22 fins, thickness of 700 μm, 21 channels, 0.0102 wide
COOLANT USAGE	0.0149 kg/s ; $1,029.89/day
FIN EFFICIENCY	η = 97.33 %