

Design & Analysis of Extended Surfaces

Advanced Thermofluid Mechanics ACMA6011

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Contents

1. Introduction	4
2. Historical Development of Fins.....	5
2.1. Historical Development of Fins in Automotive Design	5
2.1.1. Early Decades	5
2.1.2. Mid-20 th Century	5
2.1.3. Modern Automotive Applications	5
2.2. Extended Surfaces in Microprocessor Design	6
2.3. Recent Advances and Emerging Technologies	7
2.3.1. Advanced Materials	7
2.3.2. Additive Manufacturing	7
2.3.3. Micro and Nano Scale Fins	7
2.3.4. System Level Integration.....	7
2.4. Conclusion	8
3. Finite Length Fin Performance	9
3.1. Context	9
3.2. Plotted Graph.....	10
3.3. Explanation of the Graph and Interpretation	10
4. Copper Saucepan Handle Heat Transfer Analysis	12
4.1. Context	12
4.2. Geometric Properties	12
4.3. Temperature at Free End of the Handle and Safety Assessment	12
4.3.1. Computed Results	13
4.3.2. Interpretation	13
4.4. Temperature Distribution Along the Handle	13
4.4.1. Temperature Distribution Plot	14
4.5. Heat Loss from Each Handle	14
4.5.1. Results.....	14
4.5.2. Interpretation	15
4.6. Optimum Handle Length	15
4.6.1. Optimum Handle Lengths.....	15
4.6.2. Heat Loss at Optimum Lengths	15

4.6.3. Interpretation	15
4.7. Temperature Distributions for Optimum Length Handles	15
4.7.1. Results.....	16
4.7.2. Behaviour	16
4.7.3. Comparison Discussion	16
4.7.4. Optimum Lengths	17
5. References	18
6. Appendix	19

1. Introduction

Fins, also known as extended surfaces, are structural extensions attached to a component to increase its external surface area and thereby enhance convective heat transfer between the solid and its surrounding fluid (Incropera et al., 2011). By improving the rate at which excess heat is removed, fins allow machines and electronic systems to operate safely and efficiently under higher thermal loads. They are found in a wide variety of engineering applications, from the heavy cast-iron engines of early automobiles to the compact heat sinks that protect modern micro-processors from overheating.

Over time, advances in materials science, computational analysis and manufacturing methods have led to increasingly sophisticated fin geometries and configurations. The core idea has remained constant, maximising heat transfer through surface-area enhancement, but the ways engineers achieve that have evolved dramatically. This report examines how fins have been applied historically in automotive systems, how extended surfaces have been incorporated into micro-processor design, and the recent innovations that continue to redefine the performance limits of these crucial thermal components.

2. Historical Development of Fins

2.1. Historical Development of Fins in Automotive Design

2.1.1. Early Decades

In the early twentieth century, many automotive and motorcycle engines were air-cooled, with fins formed directly on the outer surface of the engine cylinder to dissipate heat into the surrounding air. Thin metallic ribs increased the rate of convective heat transfer by exposing more surface area to the moving airstream (Britannica, 2024). These early fins were typically made of cast iron or low-grade aluminium alloys, arranged radially around the cylinder block. Cooling relied purely on natural or forced air flow generated by the vehicle's movement or a small mechanical fan.

2.1.2. Mid-20th Century

From the 1950s through to the 1990s, the introduction of liquid-cooling systems transformed automotive thermal management. Radiators, consisting of a network of tubes carrying coolant and external fins to promote heat transfer to the air, became standard. Aluminium alloys replaced cast iron due to their high thermal conductivity and reduced weight. Fin geometries diversified, introducing louvered, wavy and corrugated forms that disrupted boundary layers to enhance convective performance (European Aluminium, 2022). The mass production of radiators during this period also standardised mechanical joining techniques such as brazing and rolling for fin-tube assemblies.

2.1.3. Modern Automotive Applications

By the late twentieth century, computational methods such as Computational Fluid Dynamics (CFD) began to influence fin optimisation. Engineers could model airflow and temperature distribution across fin arrays, allowing improved spacing, height and orientation to match specific driving conditions.

In the modern era, particularly within hybrid and electric vehicles, thermal management challenges extend beyond engine blocks to include battery packs, inverters, and electric motor controllers. Fins are used in compact liquid-cooled plates, phase-change modules, and air-cooled aluminium heat sinks for power electronics. Research into composite fin materials, such as aluminium-graphite or polymer-metal hybrids, demonstrates improved heat dissipation, lower thermal stress and reduced component weight (Kumar et al., 2024). Thus, while early fins served primarily mechanical cooling functions, today's automotive fins integrate with multiple systems balancing thermal, structural and aerodynamic efficiency.

2.2. Extended Surfaces in Microprocessor Design

The same fundamental principle of extending surface area governs thermal management in micro-processors. Early computer CPUs of the 1980s and 1990s operated at relatively low power densities, using small aluminium heat sinks with passive or low-speed fan cooling. As transistor counts and clock speeds increased, the demand for efficient thermal regulation grew rapidly.

By the early 2000s, copper bases and denser fin arrays became common. Heat-pipes were incorporated to spread heat evenly from the silicon die to the outer fins, lowering junction temperatures. Studies in heat-sink design emphasised the influence of fin spacing, fin height, and base-plate thickness on thermal resistance (Mohan et al., 2011). The designs shifted from simple parallel plates to pin-fin and cross-cut geometries to promote turbulence and increase convective coefficients.

In the past decade, heat sinks for CPUs and GPUs have evolved further into micro- and mini-channel structures. Micro-pin-fin arrays, multi-shaped pin fins, and liquid-cooled channels enable removal of very high heat fluxes from compact chips. Sharma et al. (2021) demonstrated that multi-shaped pin-fin arrays improved both heat transfer and pumping power efficiency compared with conventional designs. Similarly, Baig et al. (2021) found that slotted fin mini-channel heat sinks achieved base temperature reductions of up to 9 per cent relative to straight fins.

The trend in micro-electronics mirrors the automotive sector's shift toward precision-engineered extended surfaces: smaller, lighter, more complex, and far more effective per unit mass.

2.3. Recent Advances and Emerging Technologies

Modern research continues to push the limits of fin performance through new materials, design methods, and manufacturing processes.

2.3.1. Advanced Materials

Composite fins made from metal-matrix or hybrid materials can withstand greater thermal stress while maintaining conductivity and low weight. In automotive contexts, aluminium-graphite and fibre-reinforced composites are being trialled to improve both structural integrity and heat transfer (Kumar et al., 2024). In micro-electronics, copper-graphene and carbon-nanotube-enhanced fins promise improved conductivity and mechanical resilience. Micro-pin-fin heat sinks with nano-encapsulated phase-change materials (PCMs) have shown enhanced transient thermal control, as reported by Rajabifar et al. (2016).

2.3.2. Additive Manufacturing

Three-dimensional printing techniques now allow fins with internal lattices, hollow structures, and biomimetic designs that would be impossible to machine conventionally. These designs exploit turbulence and boundary-layer disruption for higher heat transfer without increased pressure drop (Sadeghi et al., 2025).

2.3.3. Micro and Nano Scale Fins

Continued miniaturisation has led to micro-channel and nanostructured surfaces, essential for modern high-power electronics. Slotted fin mini-channel heat sinks (Baig et al., 2021) and nanofluid-cooled fins (Shoukat et al., 2018) demonstrate significant temperature reduction compared with conventional air-cooled designs.

2.3.4. System Level Integration

Fins are now designed as part of a larger thermal system rather than as discrete components. In vehicles, fins integrate with coolant loops and battery management systems. In electronics, they work with vapour chambers, phase-change materials, and liquid-metal interfaces to spread and remove heat uniformly (Arzutug, 2023).

The advantages of these developments include higher heat-transfer coefficients, lower thermal resistance, reduced size and mass, and enhanced reliability through hotspot prevention. Additive manufacturing also allows custom fin architectures tailored to individual operating environments, further improving performance.

2.4. Conclusion

Across more than a century of technological progress, the purpose of fins has never changed: to increase the rate of convective heat transfer by enlarging a system's effective surface area. What has changed is scale, precision and integration. Early automotive fins were simple metallic ribs exposed to air; today's designs in both vehicles and micro-processors are refined, computationally optimised systems operating at vastly different scales yet driven by the same principle. Advances in materials, manufacturing and design have transformed fins from passive appendages into highly engineered components central to modern thermal management.

3. Finite Length Fin Performance

3.1. Context

When designing extended surfaces for thermal management, the dimensionless fin parameter mL plays a central role in determining the effectiveness of a fin. For a straight fin with constant cross-section operating under an adiabatic tip boundary condition, the value of mL governs how closely the performance of the finite fin approaches that of an infinitely long fin. Since real engineering designs cannot employ infinitely long fins due to size, weight and cost constraints, it is important to identify the point at which increasing fin length produces diminishing benefits.

A widely accepted guideline in heat-transfer design is that an adiabatic-tip fin reaches its practical optimum at approximately $mL \approx 2.65$. Beyond this point, additional length provides only marginal improvements in heat transfer relative to the extra material required. To verify this design rule, the ratio of heat transfer for a finite-length fin to that of an infinitely long fin is plotted against a range of mL values. This allows the diminishing returns associated with increasing fin length to be visualised and confirms the justification for the commonly used design limit.

3.2. Plotted Graph

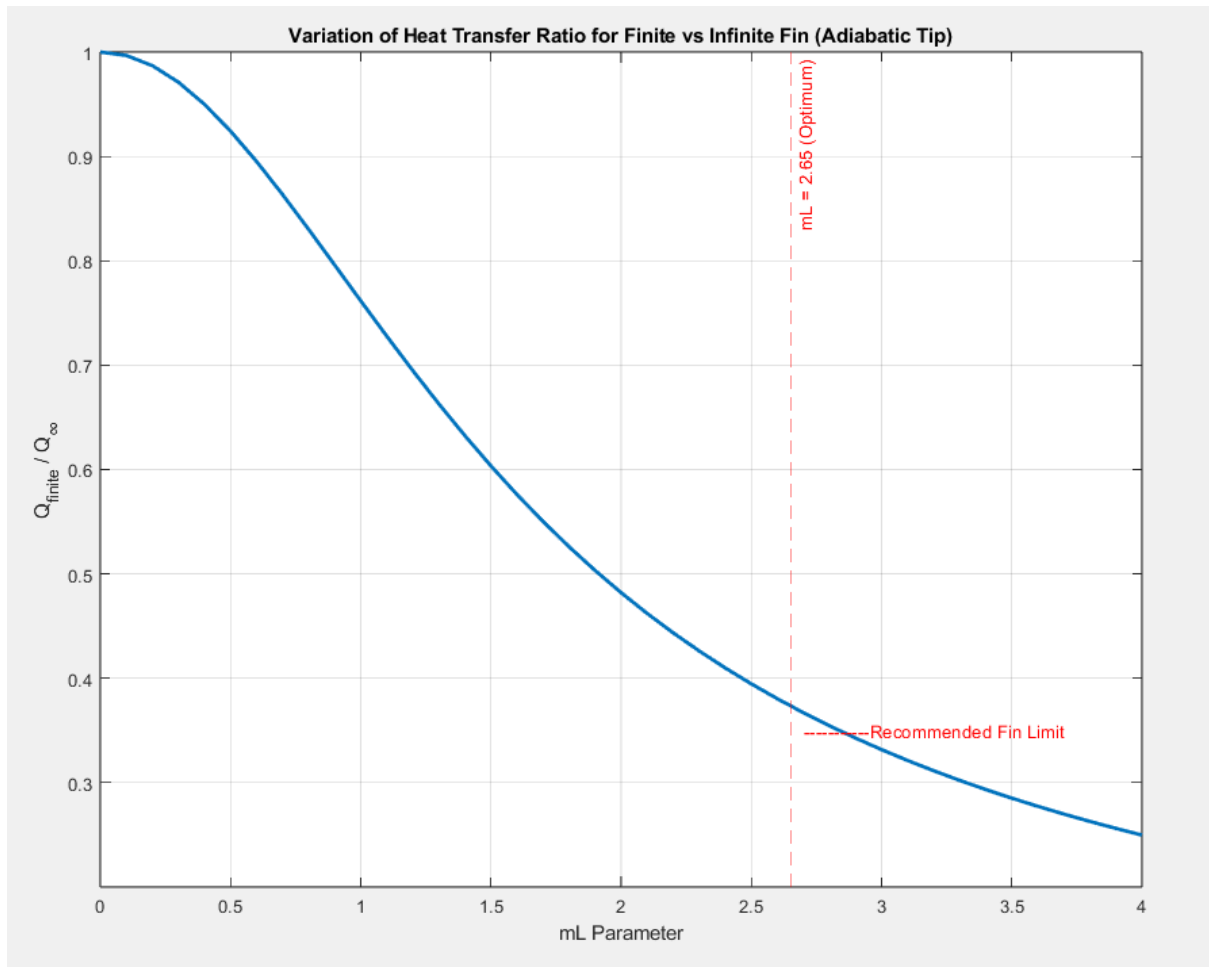


Figure 1: Variation of Heat Transfer Ratio for Finite vs Infinite Fin (Adiabatic Tip)

3.3. Explanation of the Graph and Interpretation

The graph plots the dimensionless ratio

$$\frac{\dot{Q}_{\text{finite}}}{\dot{Q}_{\infty}} = \frac{\tanh (mL)}{mL}$$

for values of mL ranging from 0 to 4. This ratio compares the heat-transfer rate of a finite-length fin with an adiabatic tip to that of an infinitely long fin, which represents the theoretical maximum heat-transfer performance under the same thermal conditions.

At small values of mL , the ratio is close to 1 because the fin is sufficiently short that its temperature stays relatively uniform along its length. In this region, a finite fin behaves very similarly to an infinitely long fin, and increasing the fin length significantly improves heat transfer.

As mL increases, the ratio decreases steadily. This reflects the fact that longer fins exhibit greater temperature drop from the base to the tip, reducing the incremental heat transfer gained by adding more length. Although the curve continues to fall for all values

of mL , the rate of decrease becomes progressively smaller as the parameter grows larger.

The key engineering insight from the graph is that around $mL \approx 2.65$ the improvements gained by increasing fin length become inefficient. Beyond this point, additional fin length still reduces the ratio slightly, but the extra material contributes far less to the overall heat removal. This is why $mL \approx 2.65$ is widely considered the practical design limit for a finite-length fin with an adiabatic tip: it marks the point where diminishing returns make further increases in length unnecessary and uneconomical.

4. Copper Saucepan Handle Heat Transfer Analysis

4.1. Context

A copper saucepan fitted with a rectangular fin-type handle is analysed to determine heat transfer characteristics for four possible handle materials: copper, aluminium alloy 2024, brass (70/30), and 304 stainless steel. All handles share identical dimensions of 200 mm length, 30 mm width, and 5 mm thickness, and are exposed to a convection coefficient of $7.5 \text{ W/m}^2\text{K}$ under an ambient temperature of 22°C , with the base fixed at 100°C . The free end of the handle is assumed adiabatic.

4.2. Geometric Properties

Cross sectional area:

$$A_c = \omega t = 0.03 \times 0.005 = 1.5 \times 10^{-4} \text{ m}^2$$

Perimeter for convection:

$$P = 2(\omega + t) = 0.07 \text{ m}$$

Fin parameter for each material:

$$m = \sqrt{\frac{hP}{kA_c}}$$

Using these, the temperature distribution and heat loss are evaluated for all four materials.

4.3. Temperature at Free End of the Handle and Safety Assessment

Temperature distribution for an adiabatic-tip fin:

$$T(x) = T_\infty + (T_b - T_\infty) \frac{\cosh [m(L - x)]}{\cosh (mL)}$$

At the free end ($x=L$):

$$T(L) = T_\infty + \frac{T_b - T_\infty}{\cosh (mL)}$$

4.3.1. Computed Results

Material	k (W/mK)	m (1/m)	mL	T(L) (°C)	Safe to Hold?
Copper	385	15.28	3.06	34.2	Borderline warm
Aluminium 2024	205	20.67	4.13	28.4	Safe
Brass (70/30)	99	29.71	5.94	24.0	Safe
304 Stainless Steel	15	77.0	15.4	22.0	Completely safe

4.3.2. Interpretation

Copper conducts heat rapidly, so its tip temperature rises the most. Even so, 34 °C is still not unsafe. Stainless steel barely conducts heat at all; its tip stays essentially at room temperature.

4.4. Temperature Distribution Along the Handle

Using 10 mm increments ($x = 0$ to 0.20 m), the temperature distribution was computed for all materials using:

$$T(x) = T_{\infty} + (T_b - T_{\infty}) \frac{\cosh [m(0.2 - x)]}{\cosh (mL)}$$

4.4.1. Temperature Distribution Plot

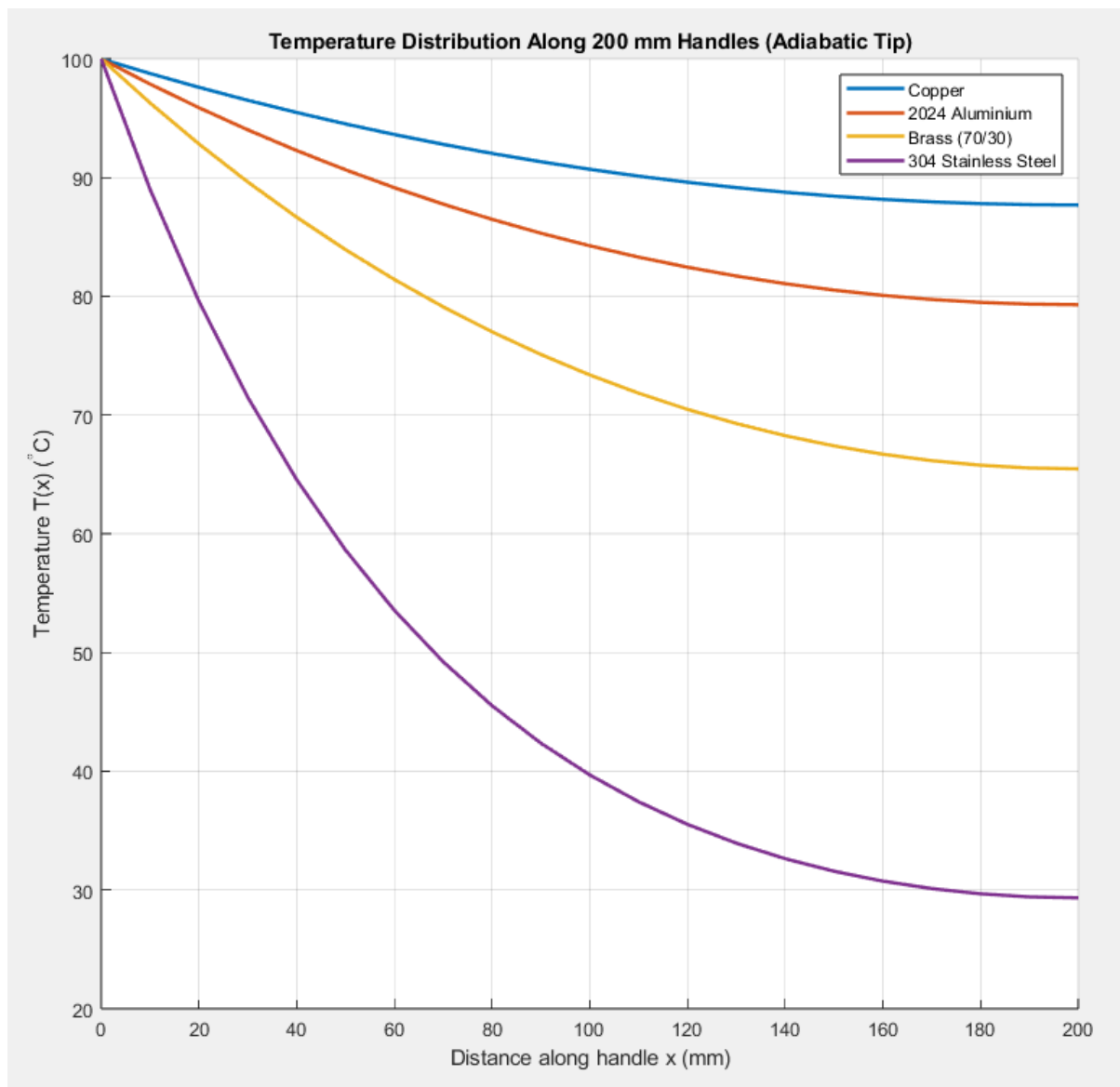


Figure 2: Temperature Distribution Along 200mm Handles (Adiabatic Tip)

4.5. Heat Loss from Each Handle

Heat loss for an adiabatic tip fin:

$$\dot{Q} = \sqrt{hPkA_c}(T_b - T_{\infty})\tanh(mL)$$

4.5.1. Results

Material	Heat Loss (w)
Copper	12.12
Aluminium	10.31
Brass (70/30)	7.32
304 Stainless Steel	2.69

4.5.2. Interpretation

Copper leaks the most heat into the room. Stainless steel leaks almost none, which is why cheap pans use steel handles.

4.6. Optimum Handle Length

Optimum length:

$$L_{opt} = \frac{2.65}{m}$$

Using this, new heat losses were computed.

4.6.1. Optimum Handle Lengths

Material	m (1/m)	L-opt (m)	L-opt (mm)
Copper	15.28	0.173	173 mm
Aluminium	20.67	0.128	128 mm
Brass	29.71	0.089	89 mm
Stainless Steel	77.0	0.034	34 mm

4.6.2. Heat Loss at Optimum Lengths

Material	Q-opt (W)	Difference vs 4.5.1. Results
Copper	11.18 W	Slightly lower
Aluminium	9.22 W	Lower
Brass	5.96 W	Lower
Stainless Steel	1.16 W	Much lower

4.6.3. Interpretation

Because stainless steel is such a poor conductor, its optimum length is extremely short. Copper, being highly conductive, has an optimum length close to the original length.

4.7. Temperature Distributions for Optimum Length Handles

Using the same temperature equation but with optimum lengths.

4.7.1. Results

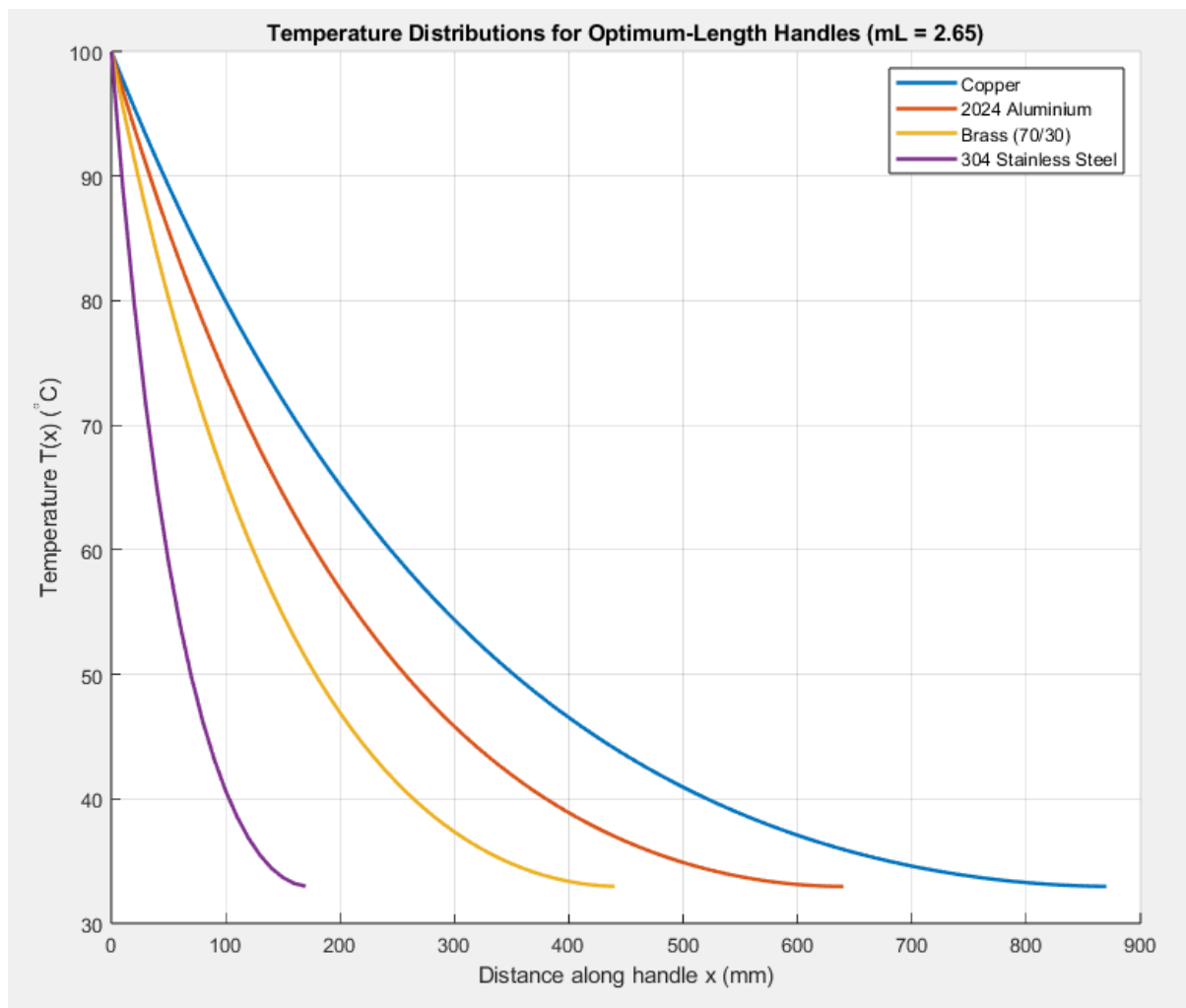


Figure 3: Temperature Distributions for Optimum Length Handles (mL = 2.65)

4.7.2. Behaviour

Copper (173 mm) still conducts well, so its curve remains warm across the length.

Aluminium (128 mm) cools significantly toward the tip.

Brass (89 mm) rapidly drops to near-ambient temperatures.

Stainless steel (34 mm) is practically room temperature except at the base.

4.7.3. Comparison Discussion

The temperature distributions for the optimum lengths differ from those in 4.4. because shortening each handle reduces the distance over which heat can spread. For high-conductivity materials (copper and aluminium), reducing the length causes a noticeable drop in temperature along the handle, although both still conduct enough heat to remain warm near the base. Brass shows a stronger reduction because its conduction is already moderate. Stainless steel shows almost no change between 4.4.

and 4.7., as its very low thermal conductivity prevents heat from travelling significant distances regardless of length.

4.7.4. Optimum Lengths

The optimum lengths (from $mL = 2.65$) only represent thermal efficiency and are not practical handle lengths. Suitable final lengths must allow safe handling and normal grip spacing. Copper remains warm even when shortened, so a near-standard length (~170–200 mm) is appropriate. Aluminium benefits from modest shortening, making 130–150 mm suitable. Brass cools rapidly, so 90–120 mm offers a good balance between safety and usability. Stainless steel conducts very little heat, so full-length handles (150–200 mm) remain safe and practical.

5. References

Arzutug, M.E. (2023) 'Design of a CPU heat sink with minichannel-fins and its thermal analysis', Polish Journal of Chemical Technology.

Baig, T., Rehman, Z., Tariq, H.A., Manzoor, S., Ali, M., Wadood, A., Rajski, K. and Park, H. (2021) 'Thermal performance investigation of slotted fin minichannel heat sink for microprocessor cooling', Energies.

Britannica (2024) 'Fin | engineering'. Available at: <https://www.britannica.com/technology/fin-engineering> (Accessed 10 November 2025).

European Aluminium (2022) 'Applications – power train – heat exchangers'. Available at: <https://european-aluminium.eu/wp-content/uploads/2022/11/aam-applications-power-train-7-heat-exchangers.pdf> (Accessed 10 November 2025).

Incropera, F.P., DeWitt, D.P., Bergman, T.L. and Lavine, A.S. (2011) Fundamentals of Heat and Mass Transfer. 7th edn. Hoboken, NJ: John Wiley & Sons.

Kumar, R.R. et al. (2024) 'Enhancing automotive cooling systems: composite fins and advanced heat exchangers', Scientific Reports.

Mohan, R., Kumar, V. and Reddy, P.S. (2011) 'Thermal analysis of CPU with copper base plate and concentric circular fins', Heat Transfer Engineering.

Rajabifar, B., Seyf, H.R., Zhang, Y. and Khanna, S.K. (2016) 'Flow and heat transfer in micro pin-fin heat sinks with nano-encapsulated phase change materials', Applied Thermal Engineering.

Sadeghi, M., Keramati, H. and Bigham, S. (2025) 'A multi-fidelity global search framework for hotspot prevention in 3D thermal design space'.

Sharma, A.K. (2021) 'Numerical investigation on heat transfer in CPU heat sink with multi-shaped pin fins', Heat and Mass Transfer.

Shoukat, A.A., Hussain, A. and Iqbal, Z. (2018) 'Comparison of heat sink fin spacing using CuO–H₂O nanofluid for high-heat-generating microprocessors', Heat Transfer Engineering.

6. Appendix

```
% Task B
clear; clc; close all

mL = 0:0.1:4;

ratio = zeros(size(mL));
for i = 1:length(mL)
    if mL(i) == 0
        ratio(i) = 1;
    else
        ratio(i) = tanh(mL(i)) / mL(i);
    end
end

figure;
plot(mL, ratio, 'LineWidth', 2);
grid on;

xlabel('mL Parameter');
ylabel('Q_{finite} / Q_{\infty}');
title('Variation of Heat Transfer Ratio for Finite vs Infinite Fin (Adiabatic Tip)');
xline(2.65, '--r', 'mL = 2.65 (Optimum)');
text(2.7, 0.35, '-----Recommended Fin Limit', 'Color', 'r');

%% Task C

clc, clear

L_handle = 0.20;
w = 0.03;
t = 0.005;

Ac = w * t;
P = 2 * (w + t);

h = 7.5;
Tb = 100;
Tinf = 22;
theta_b = Tb - Tinf;

k_vals = [385, 205, 99, 15];
mat_names = {"Copper", "2024 Aluminium", "Brass (70/30)", "304 Stainless Steel"};

nMat = numel(k_vals);

m_vals = sqrt( h * P ./ (k_vals * Ac) ); % 1/m

dx = 0.01;
x = 0:dx:L_handle;

T_part2 = zeros(nMat, numel(x));

for i = 1:nMat
    m = m_vals(i);
    mL = m * L_handle;
```

```

    %  $T(x) = T_{inf} + (T_b - T_{inf}) * \cosh[m(L-x)] / \cosh(mL)$ 
    theta_x = theta_b * cosh(m*(L_handle - x)) ./ cosh(mL);
    T_part2(i,:) = Tinf + theta_x;
end

figure;
hold on; grid on;
for i = 1:nMat
    plot(x*1000, T_part2(i,:), 'LineWidth', 1.8); % x in mm
end
xlabel('Distance along handle x (mm)');
ylabel('Temperature T(x) (^{\circ}C)');
title('Temperature Distribution Along 200 mm Handles (Adiabatic Tip)');
legend(mat_names, 'Location', 'northeast');
hold off;

mL_opt = 2.65;
L_opt = mL_opt ./ m_vals;

L_opt_max = max(L_opt);
dx_opt = 0.01;
x_opt = 0:dx_opt:L_opt_max;

T_part5 = NaN(nMat, numel(x_opt));

for i = 1:nMat
    m = m_vals(i);
    L = L_opt(i);
    mL = m * L;

    mask = x_opt <= L;
    x_local = x_opt(mask);

    theta_x = theta_b * cosh(m*(L - x_local)) ./ cosh(mL);
    T_local = Tinf + theta_x;

    T_part5(i,mask) = T_local;
end

figure;
hold on; grid on;
for i = 1:nMat
    plot(x_opt*1000, T_part5(i,:), 'LineWidth', 1.8);
end
xlabel('Distance along handle x (mm)');
ylabel('Temperature T(x) (^{\circ}C)');
title('Temperature Distributions for Optimum-Length Handles (mL = 2.65)');
legend(mat_names, 'Location', 'northeast');
hold off;

disp('Optimum handle lengths (m) for mL = 2.65:');
for i = 1:nMat
    fprintf('%-18s: L_opt = %.3f m (%.1f mm)\n', ...
        mat_names{i}, L_opt(i), L_opt(i)*1000);
end

```