CFD Modeling and Optimization of Fin Array Packaging Solutions for Micro-Thermoelectric Generator (μTEG) Devices

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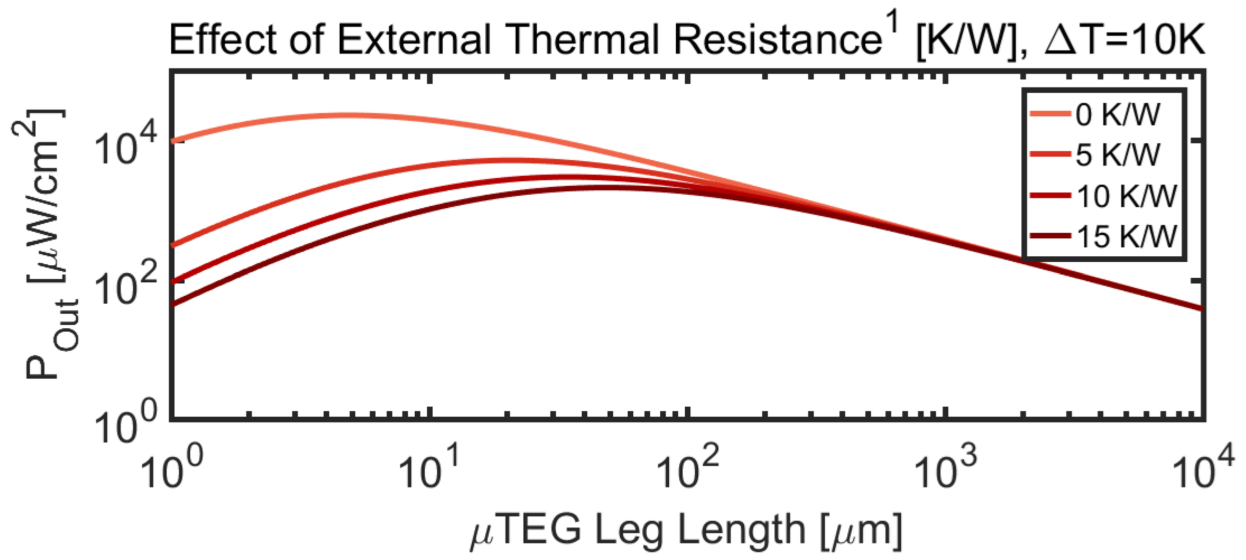
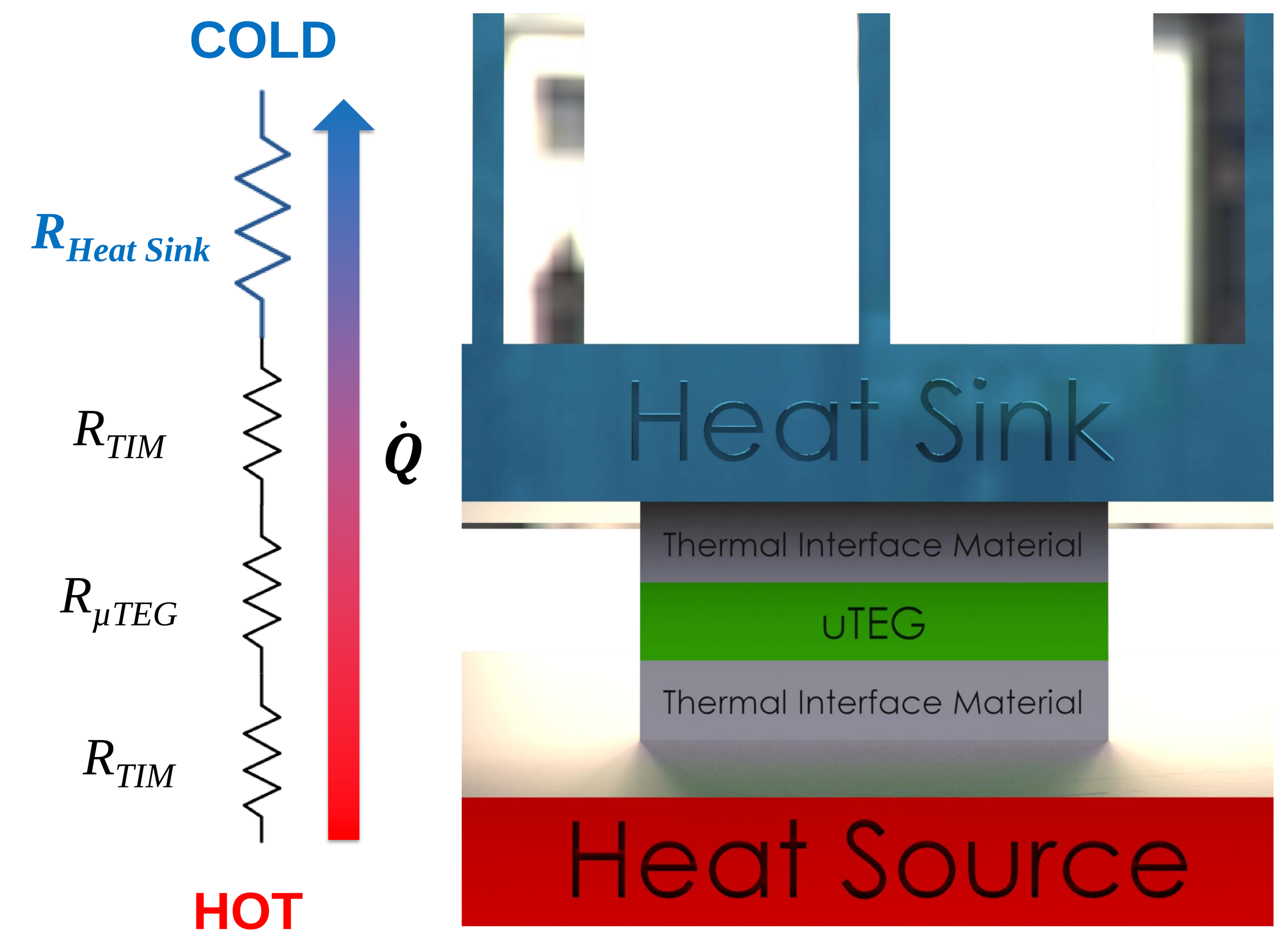
Motivation and Background



Micropelt μTEG[2]

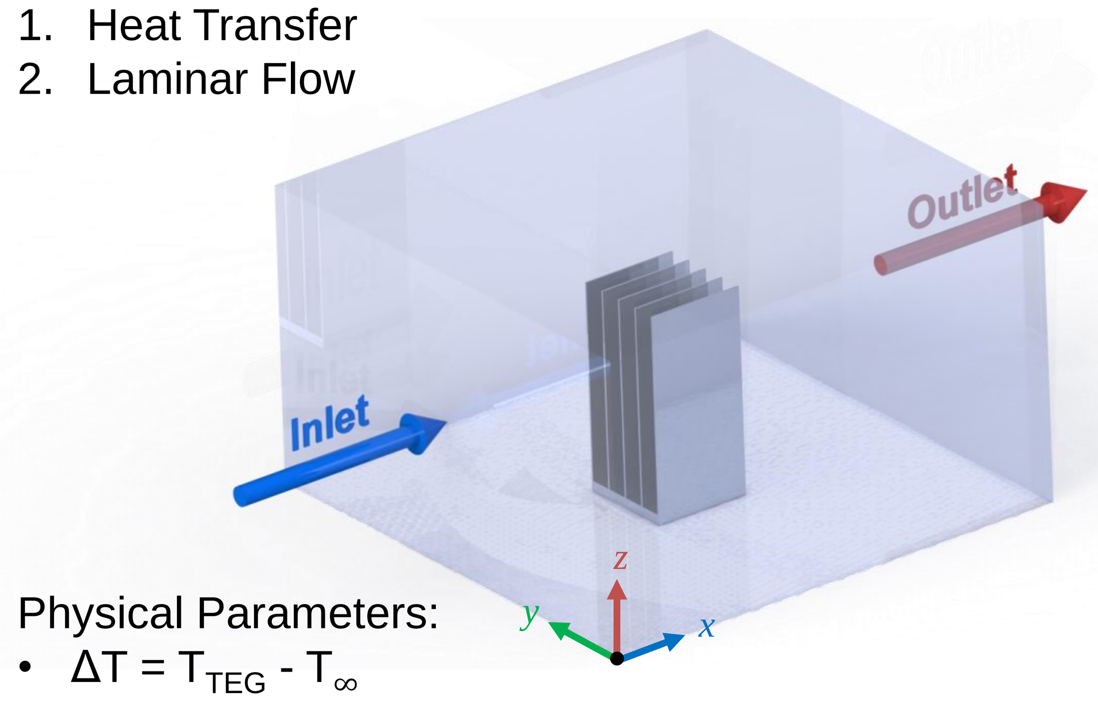
- Prior work[1] demonstrated that optimization of the thermal packaging is critical for successful implementation of μTEGs.
- The packaging's footprint and thermal resistance are key parameters of this study. A thermal resistance of 20 K/W was adopted as the maximum threshold.

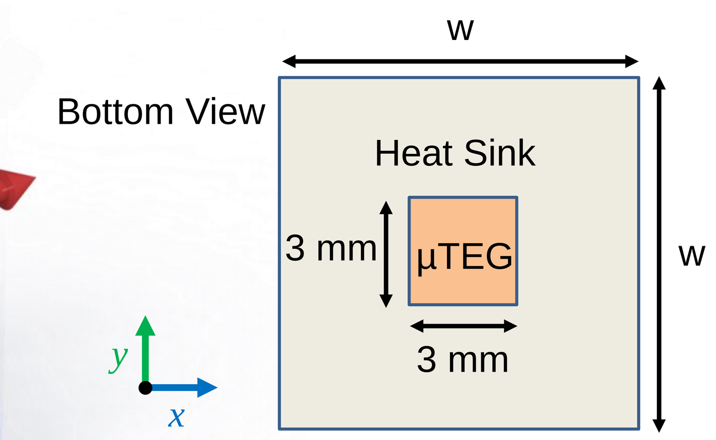


Simulation Parameters

Comsol Multiphysics: Non-Isothermal Flow

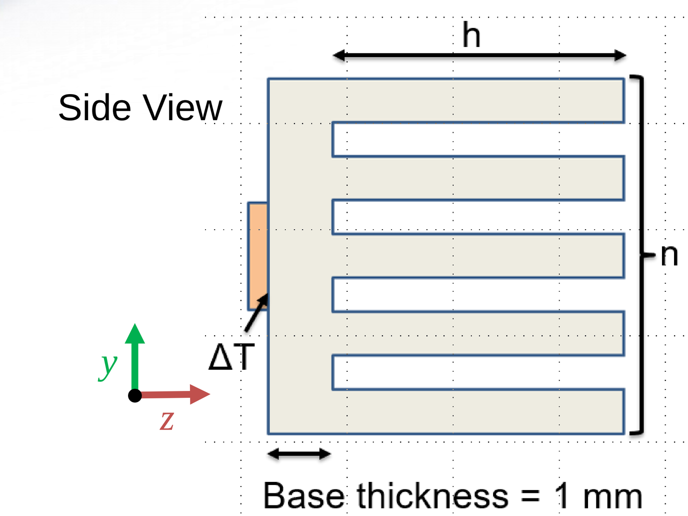
1. Heat Transfer
2. Laminar Flow





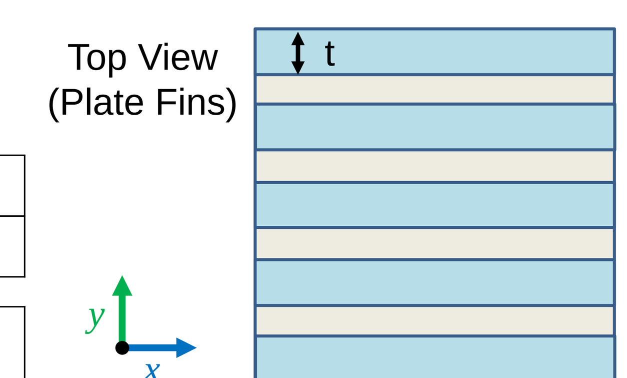
Physical Parameters:

- $\Delta T = T_{TEG} - T_{\infty}$
- h = height of fins
- n = number of fins
- t = thickness of plate fins
- d = diameter of pin fins
- w = width of heat sink's base (footprint)



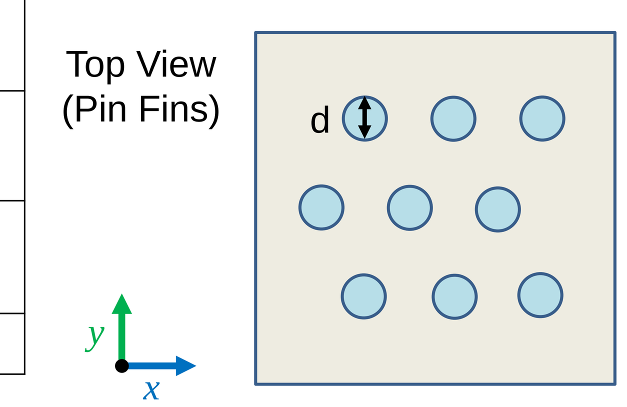
Fin heights were determined using:

- Healing length calculations.
- Max heat fin dimensions: 5x5x5 cm³



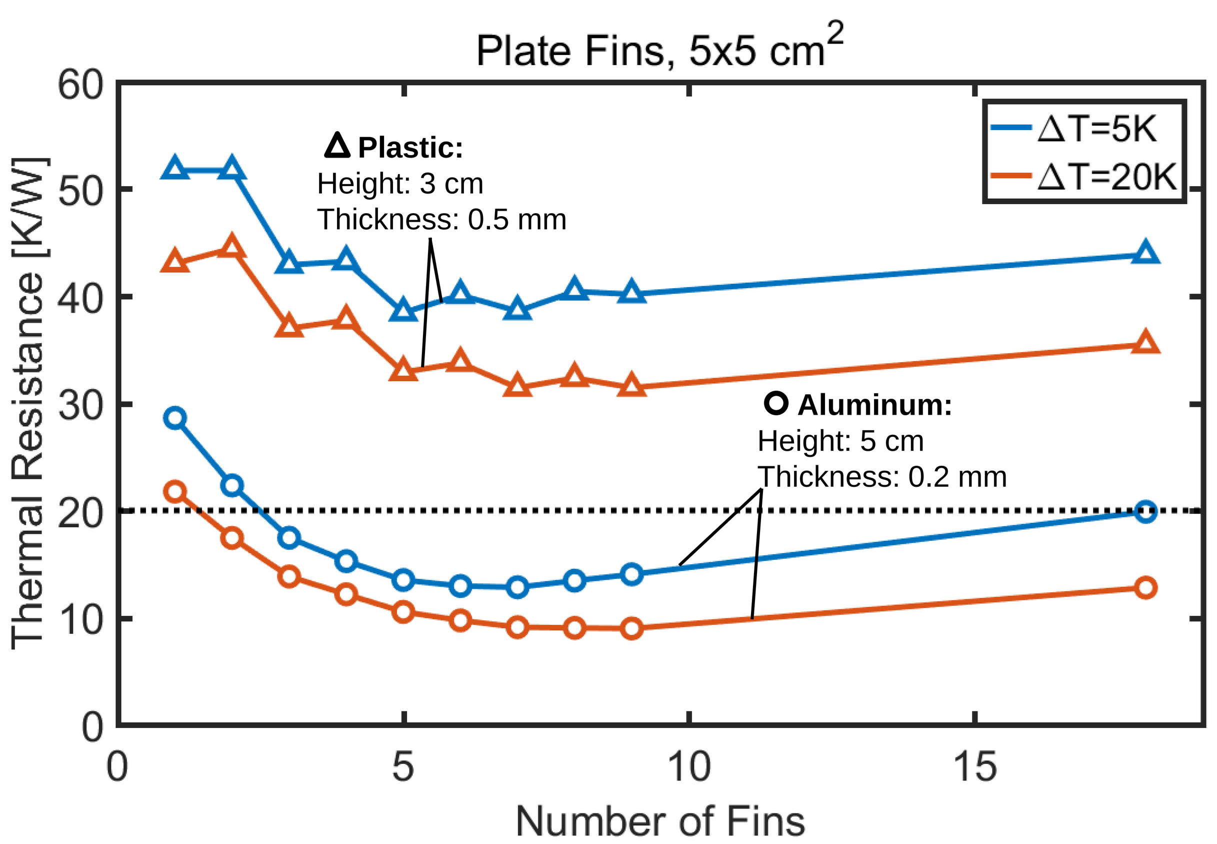
Material	Plastic	Aluminum
Thermal Conductivity [W/m-K]	20	170

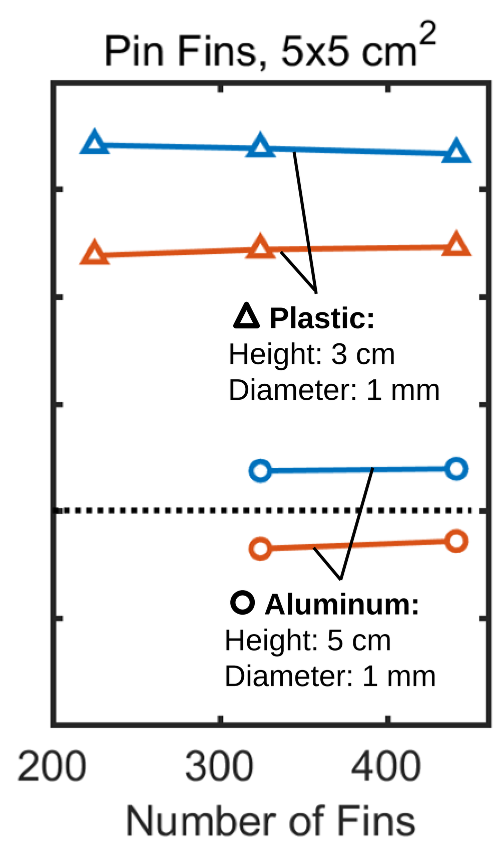
Boundary Conditions	Natural Convection	Forced Convection
Fluid	All walls: no slip	Inlet velocity = v [m/s] Outlet gage pressure = 0 Pa Other walls: no slip
Volume Force	Gravity parallel to x-axis.	Not specified
Temperature	Outer walls = 298 K	Inlet wall = 298 K Other outer walls insulating
	μTEG = 298 K + ΔT	

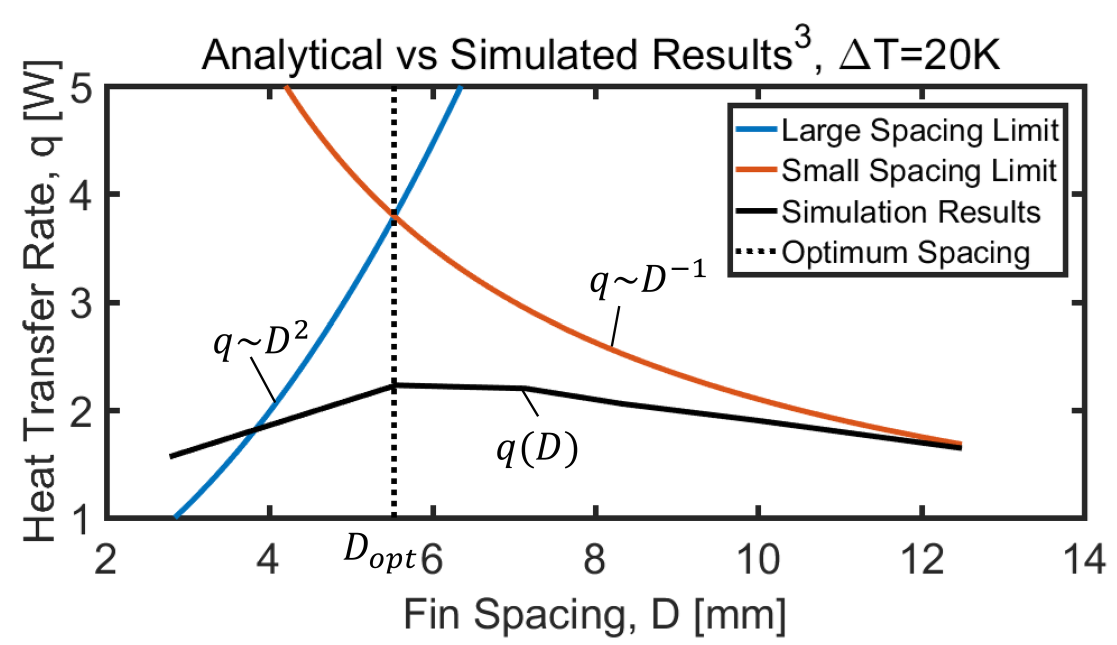


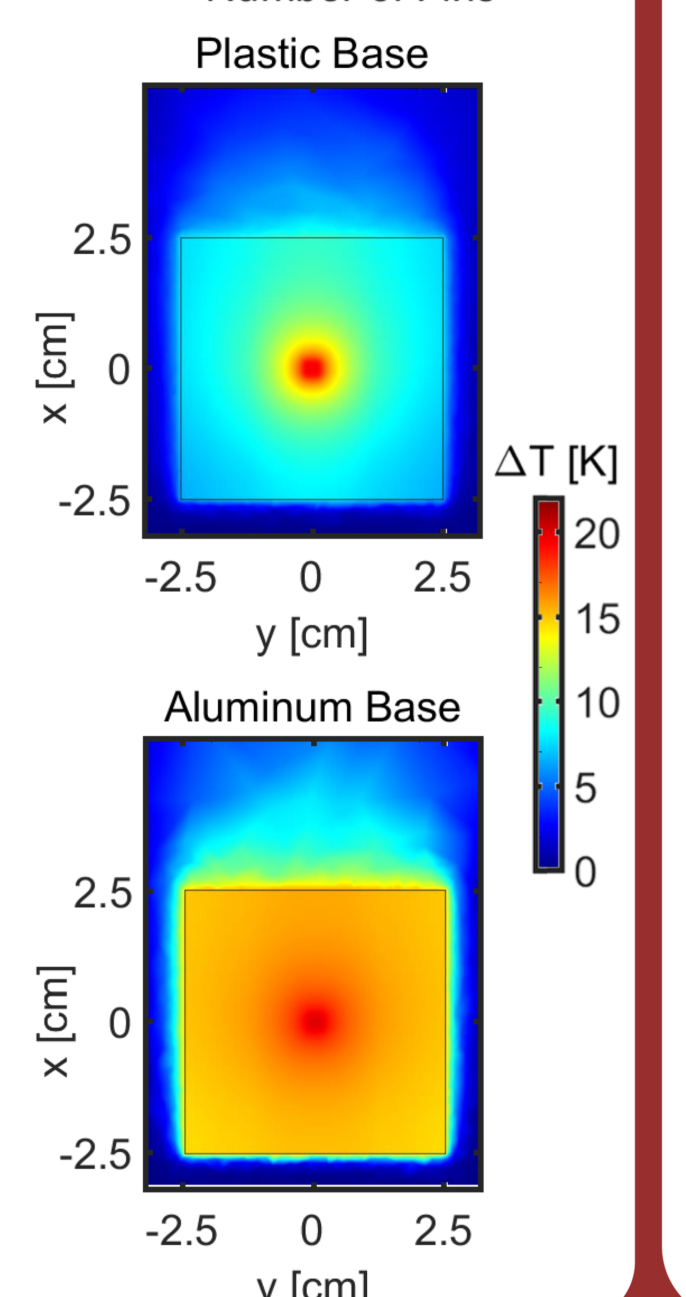
$$Thermal\ Resistance = \frac{\Delta T}{heat\ flux\ through\ \mu TEG * surface\ area\ of\ \mu TEG}$$

Natural Convection



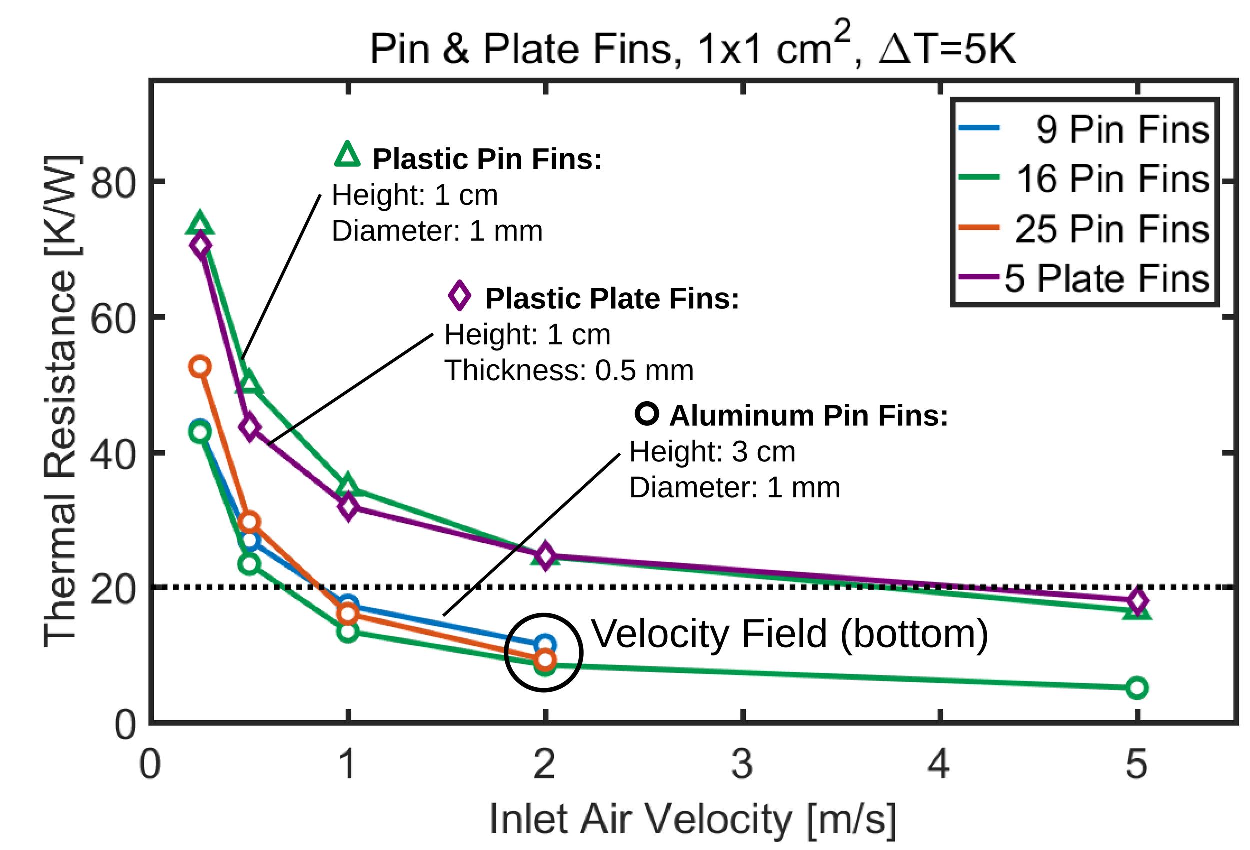


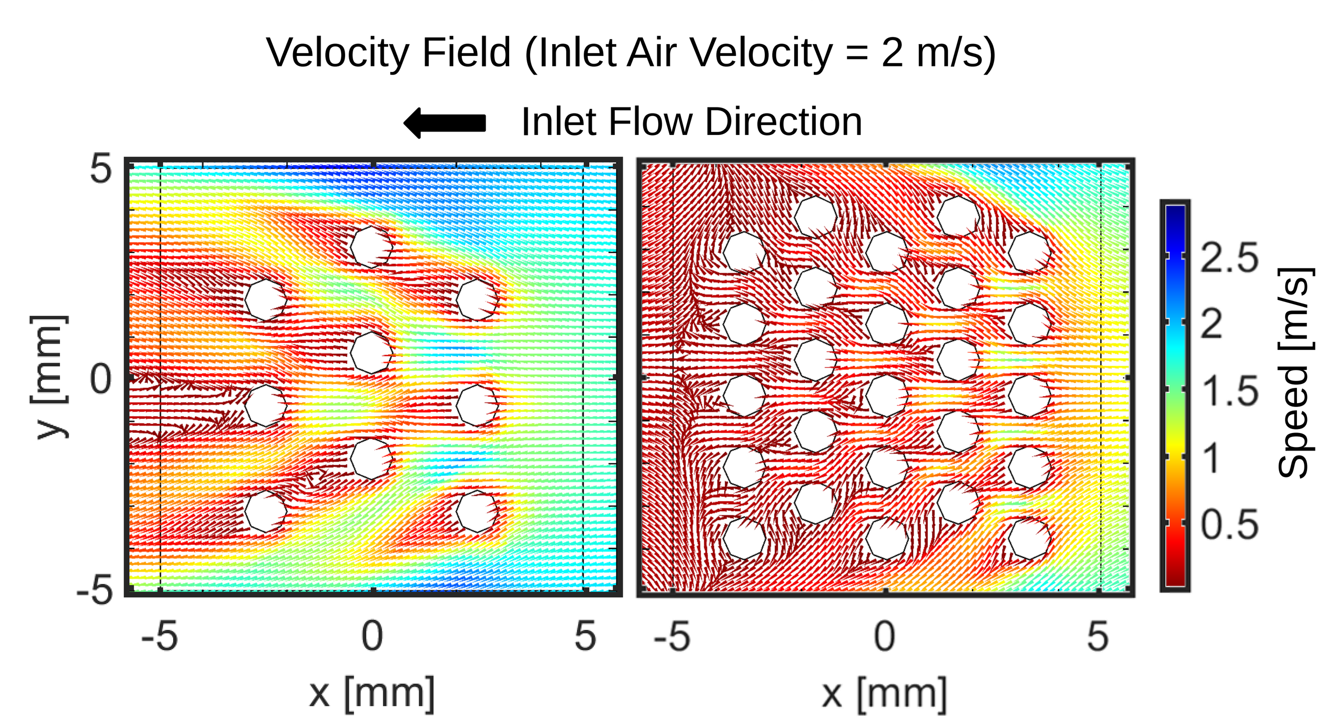




- While plate fins have clearly defined optimum number of fins, pin fins' performance change marginally with increasing number of fins.
- The jagged behavior of the plastic plate fins is a result of the centering of plate fins over the heat source.
- The simulation's results (ΔT = 20 K) agree with the analytical method's prediction[3] of the optimum fin spacing under the assumption that the fins have a uniform surface temperature of 313 K (T_{∞} = 298 K).

Forced Convection





- There is less variation between plate and pin fins in forced convection. Turbulence in staggered pin fins improves performance in forced convection.
- There is only a marginal difference in thermal resistance with higher pin fin densities. For a larger number of fins, the air velocity surrounding the fins reduce dramatically.
- Increased flow separation causes a decrease in the heat transfer coefficient.

Conclusions and Future Work

- Under natural & forced convection, plate fins achieve better performance in ideal conditions. However, unlike plate fins, pin fins do not have a preferred flow direction in the x-y plane. Thus, pin fins are expected to perform better in multi-directional flows.
- Natural Convection (Thermal Resistance < 20 K/W):
  - Al plate and pin fins of 5x5 cm² footprint.
- Forced Convection (Thermal Resistance < 20 K/W):
  - Al plate fins of 1x1 cm² footprint for air velocity > 0.5 m/s.
  - Al and plastic pin fins of 1x1 cm² footprint for air velocity > 5 m/s.
- Further studies are currently being done on more complex designs.

[1]Marc T. Dunham, et. al. *Energy* 93 (2015)
[2] *Micropelt Thermogenerators.* Retrieved from http://micropelt.com/thermogenerator.php
[3]Adrian Bejan. *Convection Heat Transfer.* 3rd ed., Hoboken, NJ, Wiley, 2004.

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