Electric Vehicle Battery Thermal Management Solution

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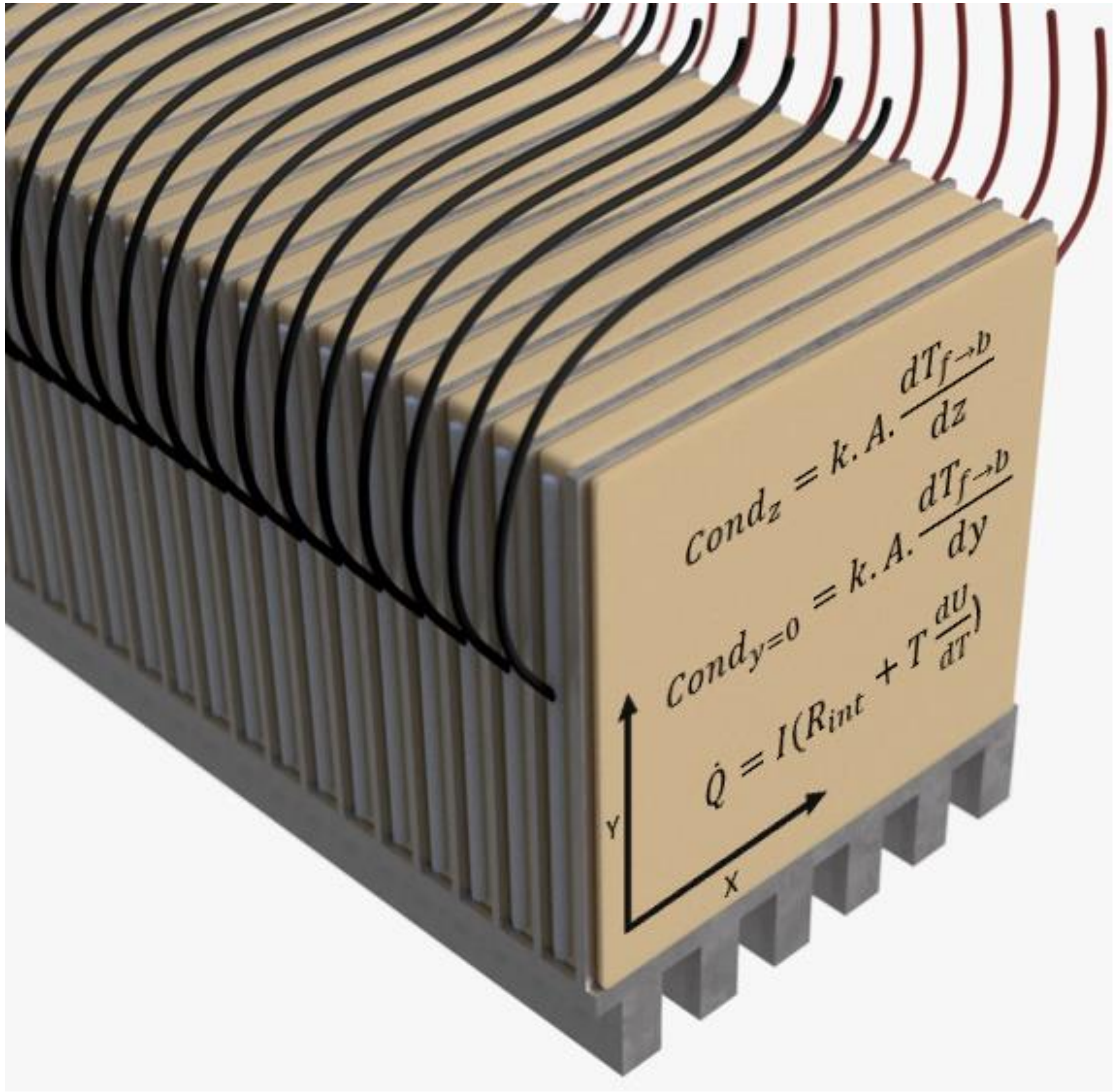
Motivation

- Effects of a high operating temperature on a battery:
  - Faster power fade over time.
  - Faster cell capacity degradation.
  - Efficiency reduction.
  - Increasing likelihood of thermal runaway (Safety).
- Thermal management is needed to optimize the efficiency, reliability, and safety of an EV battery.

Objectives and Expected Outcomes

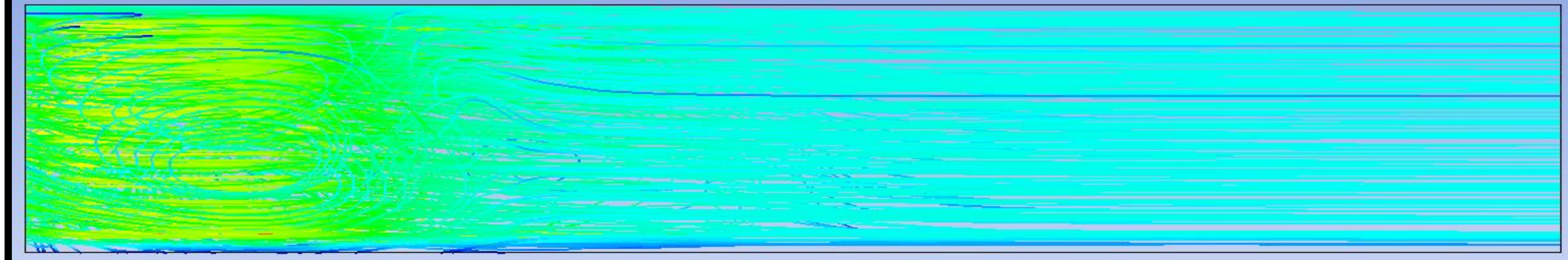
- **Evaluate the effectiveness of a passive fin cooling solution for electric vehicle battery packs.**
    - Create a model of a single prismatic cell of lithium ion battery.
    - Develop a fin model and integrate it with the battery model.
    - Expand solution to a full battery pack.
    - Evaluate the design at different vehicle speeds.
    - Calculate heat dissipation rate and temperature rise as performance metrics.



Updated Assumptions

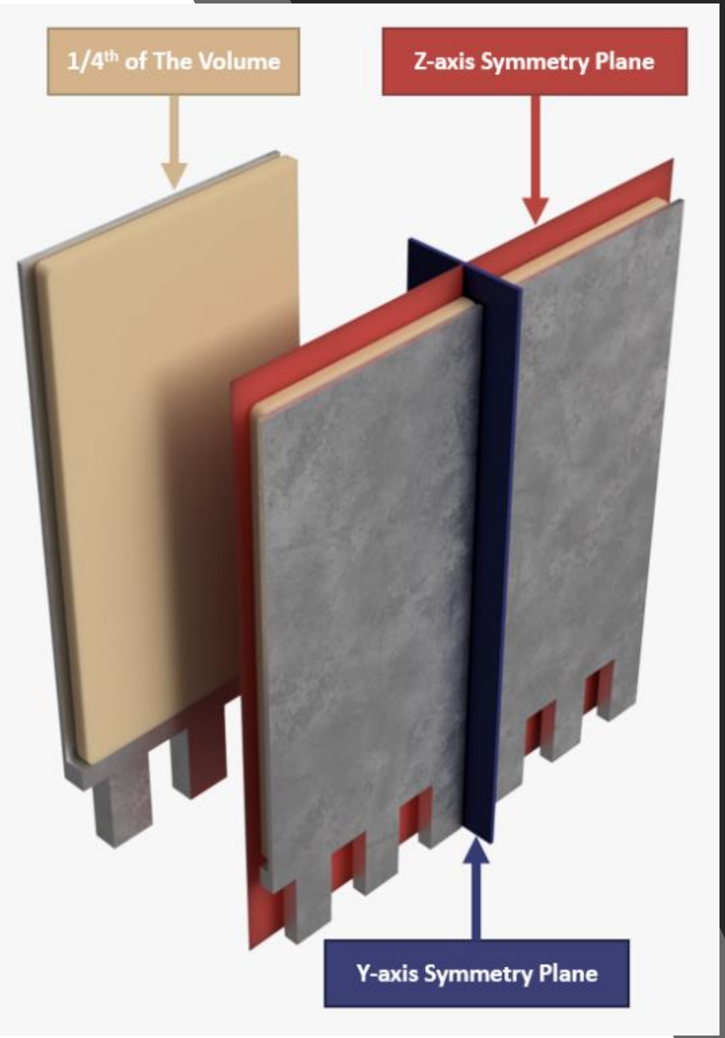
- Turbulent Couette flow modeled in ANSYS as an approximation of flow under the vehicle.
- Forced convection model for plate fin heat sink was used to derive the convective heat transfer rate.
- Heat transfer to the top (through the firewall) assumed zero.
- Conduction is not a function of the battery state of charge (time invariant).
- Constant reversible entropic heat coefficient inside the battery.
- Prismatic fin efficiency equation used to get an equivalent heat transfer rate at the boundary.

Couette Flow Under the Vehicle



ANSYS CFD Results At 80 MPH

Approach: Battery and Fin Model



- A transient 3D model of the battery was developed by writing a differential function to be numerically integrated.
- The heat generation term used the thermo electric equations developed by D. Bernardi et al:

$$\dot{q}_T = I\,(V - U^{avg}) + I.T.\frac{\partial U^{avg}}{\partial T} = I^2 R_{int} + I.T.\frac{\partial U^{avg}}{\partial T}$$

- Direction dependent thermal conduction was used (High conductivity through X and Y, low through Z axis).
- A fin model was developed and integrated into the battery ODE function.
- Symmetry boundary conditions were used to cut the size of the cell and fin model nodes in half in the x direction, and then in half again in the z direction ($1/4^{th}$).
- symmetry boundary conditions were used to scale the solution to a full battery pack.

Approach: Vehicle Power Calculations

$$MechanicalPower = Power_{drag} + Power_{friction} + Power_{Gravity}$$

$$Power_{drag} = V.\left(C_d.A_f.\rho.\frac{V^2}{2}\right)$$

$$Power_{friction} = V.(m.g.RollingResistance)$$

$$Power_{Gravity} = V.Grade.(m.g)$$

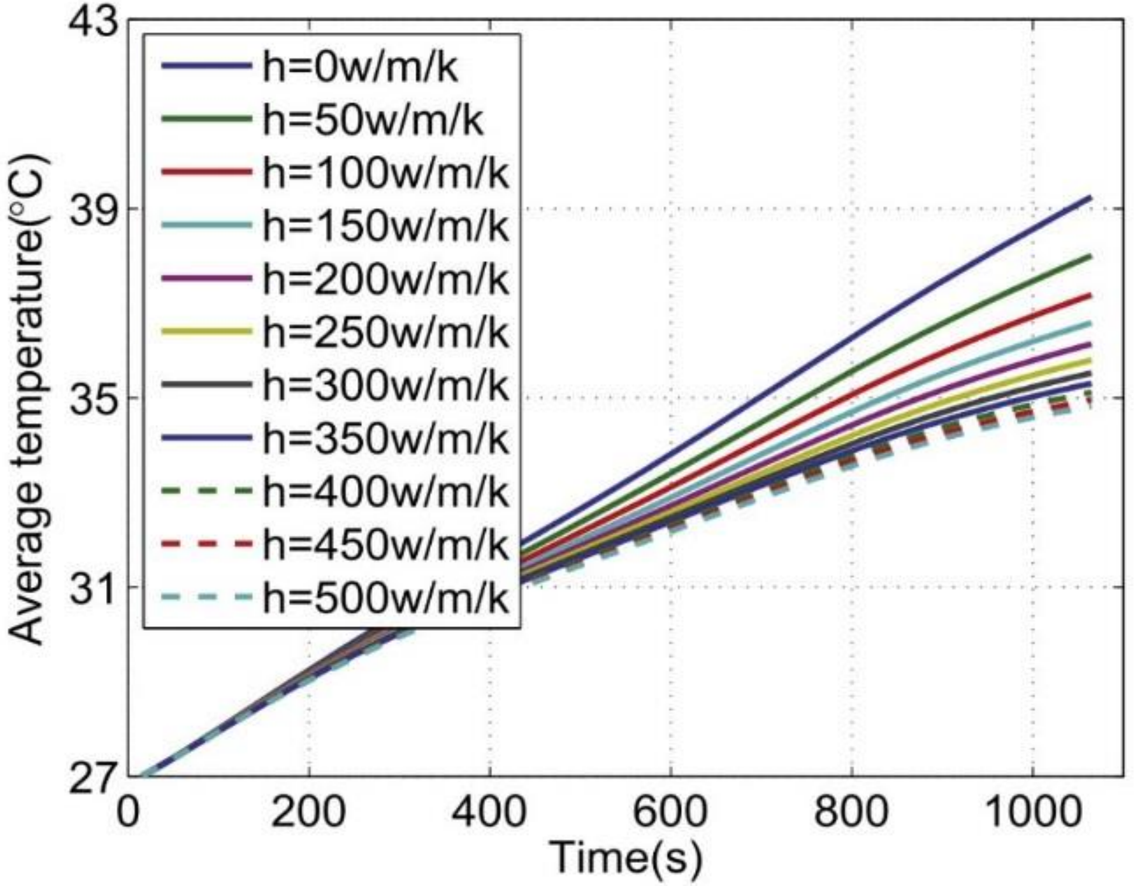
$$Total\ Current(I) = \frac{MechanicalPower}{CarEfficiency}/TotalVoltage$$

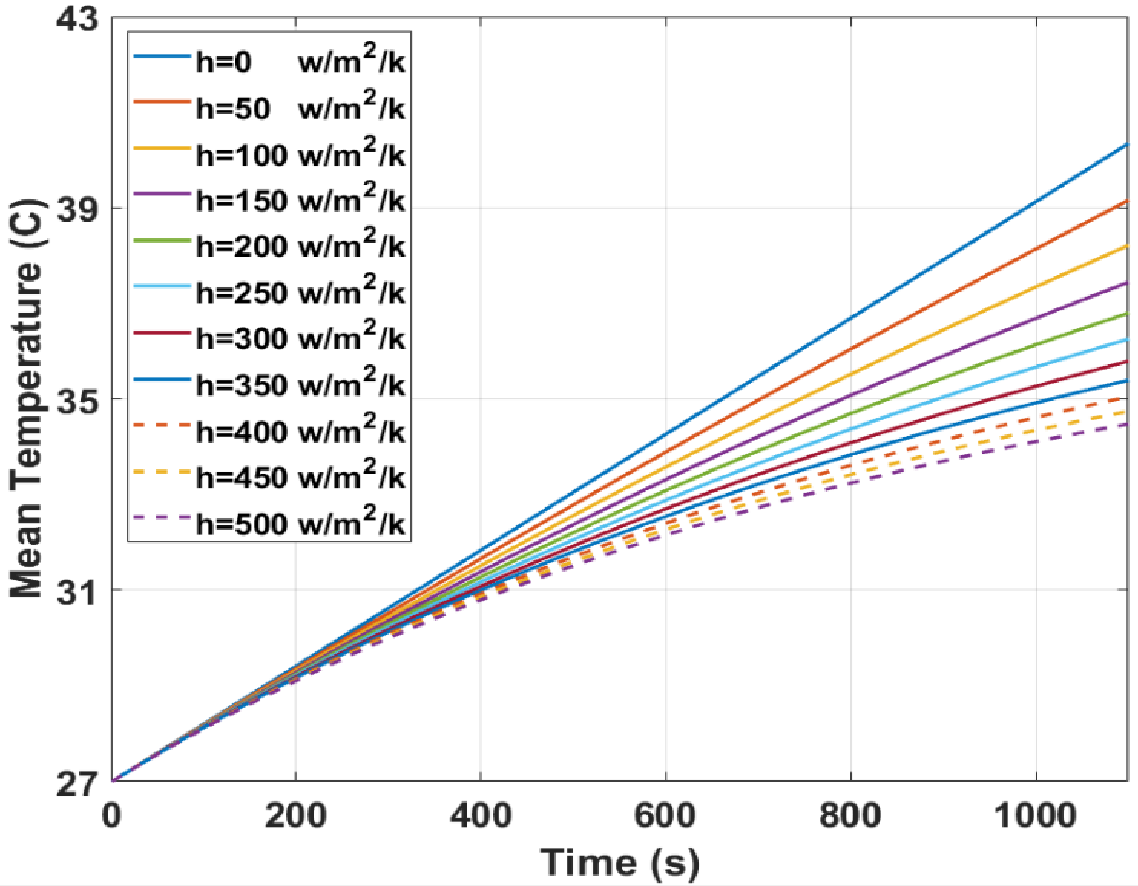
Approach: Fin Convective Heat Transfer Rate

- Turbulent Couette flow was modeled in ANSYS Fluent to approximate the flow profile under the vehicle.
- Nusselt's number Equations for turbulent flow over plate fins were used.
- Fin efficiency equation for prismatic fin shapes was used.
- Reynold's and Prandtl's number were taken at a pressure of one atmosphere and a temperature of 25 C.

- $\boldsymbol{Nu = \left(\frac{1}{\left(\frac{Re\ x\ Pr}{2}\right)^3} + \frac{1}{\left(0.664\ x\sqrt{Re}\ x\ Pr^{\frac{1}{3}}\sqrt{1+\frac{3.65}{\sqrt{Re}}}\right)^3}\right)^{\frac{-1}{3}}}$
- **h =** $\boldsymbol{Nu\frac{k}{L}}$
- $\boldsymbol{\eta_f = \frac{tanh(m.L_c)}{m.L_c}, where;\ m = \sqrt{\frac{2.h}{kt}},\ L_c = L + \frac{t}{2}}$

Results and Discussion: Fixed Convective Heat Transfer Rate Validation

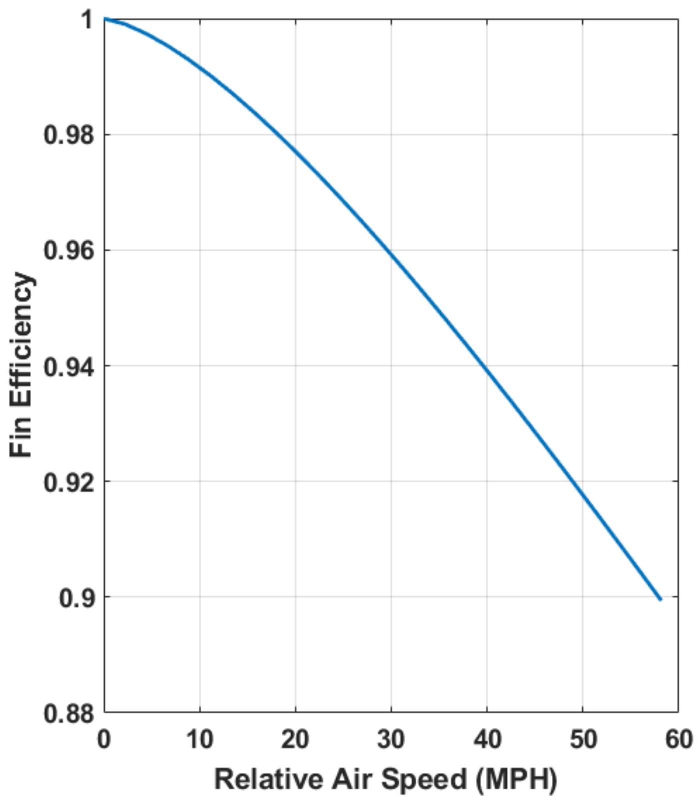


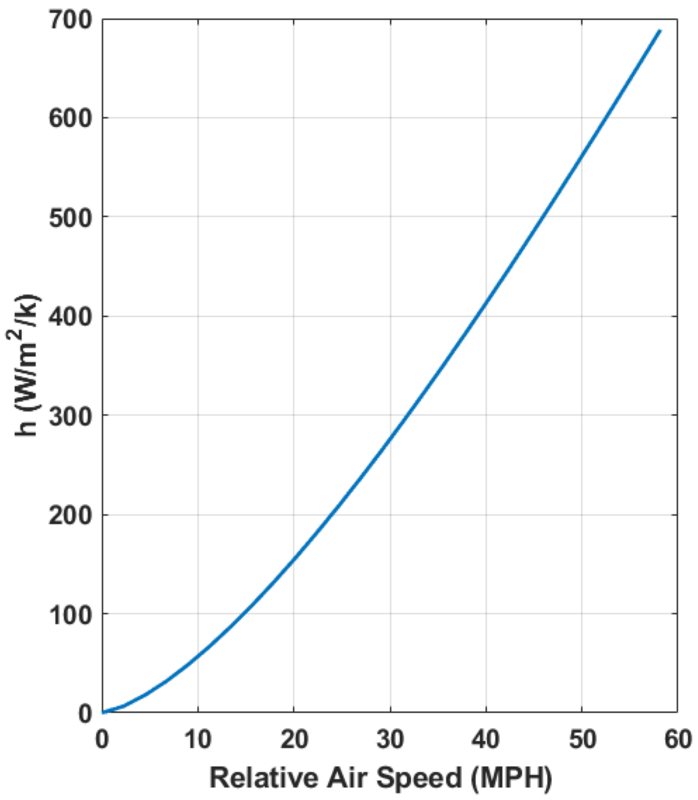


- The battery and fin model was validated by comparing the average transient temperature at different convective heat transfer rates with those of a study that modeled a similar battery.

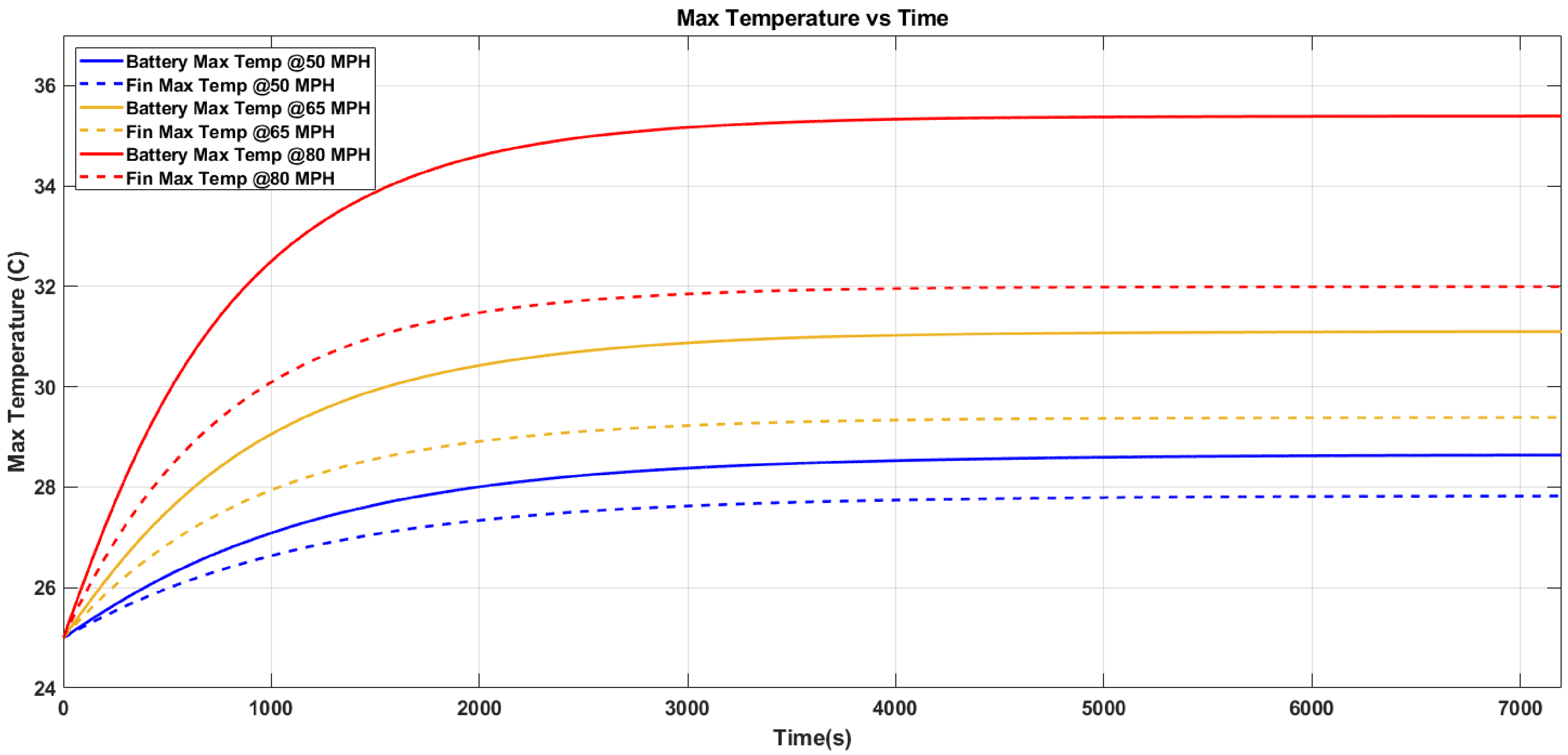
Results and Discussion: Equivalent Convective Heat Transfer Calculation

- ANSYS was used to get the Couette flow distribution under the car and around the fin. The equation for the fin efficiency and Nusselt number of turbulent flow over plate fins was used to get the convective heat transfer rate at different relative air speeds.

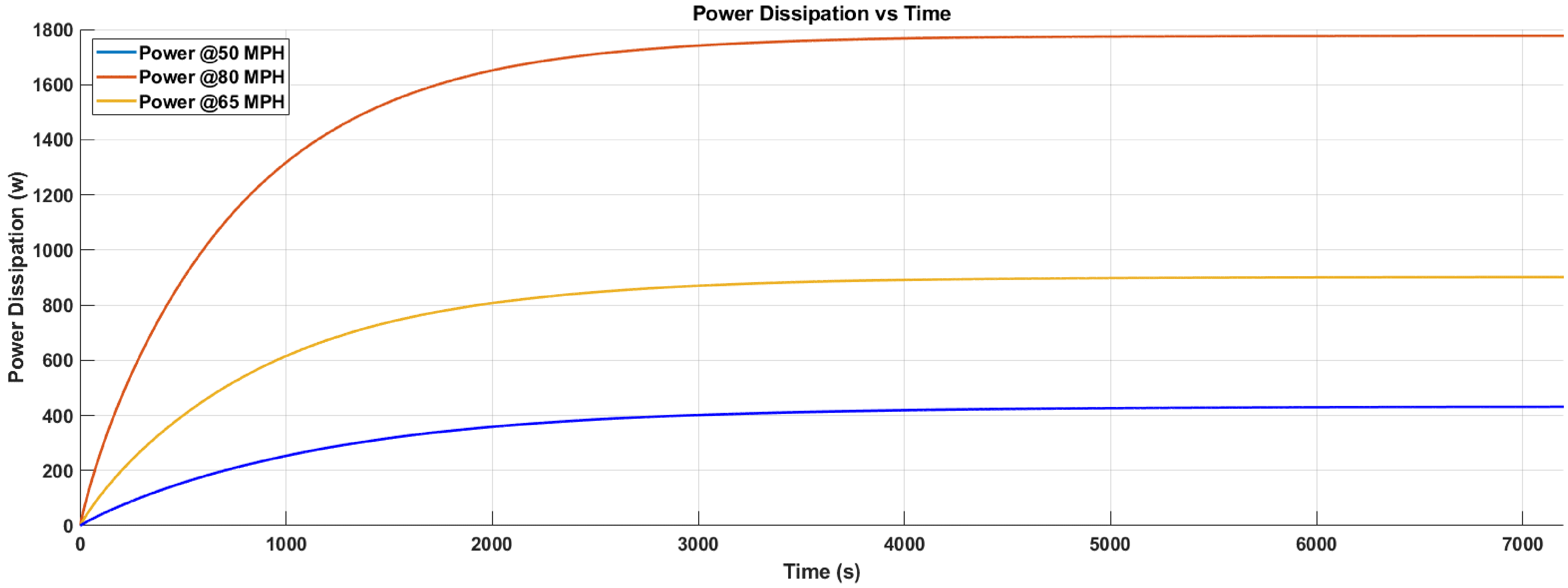




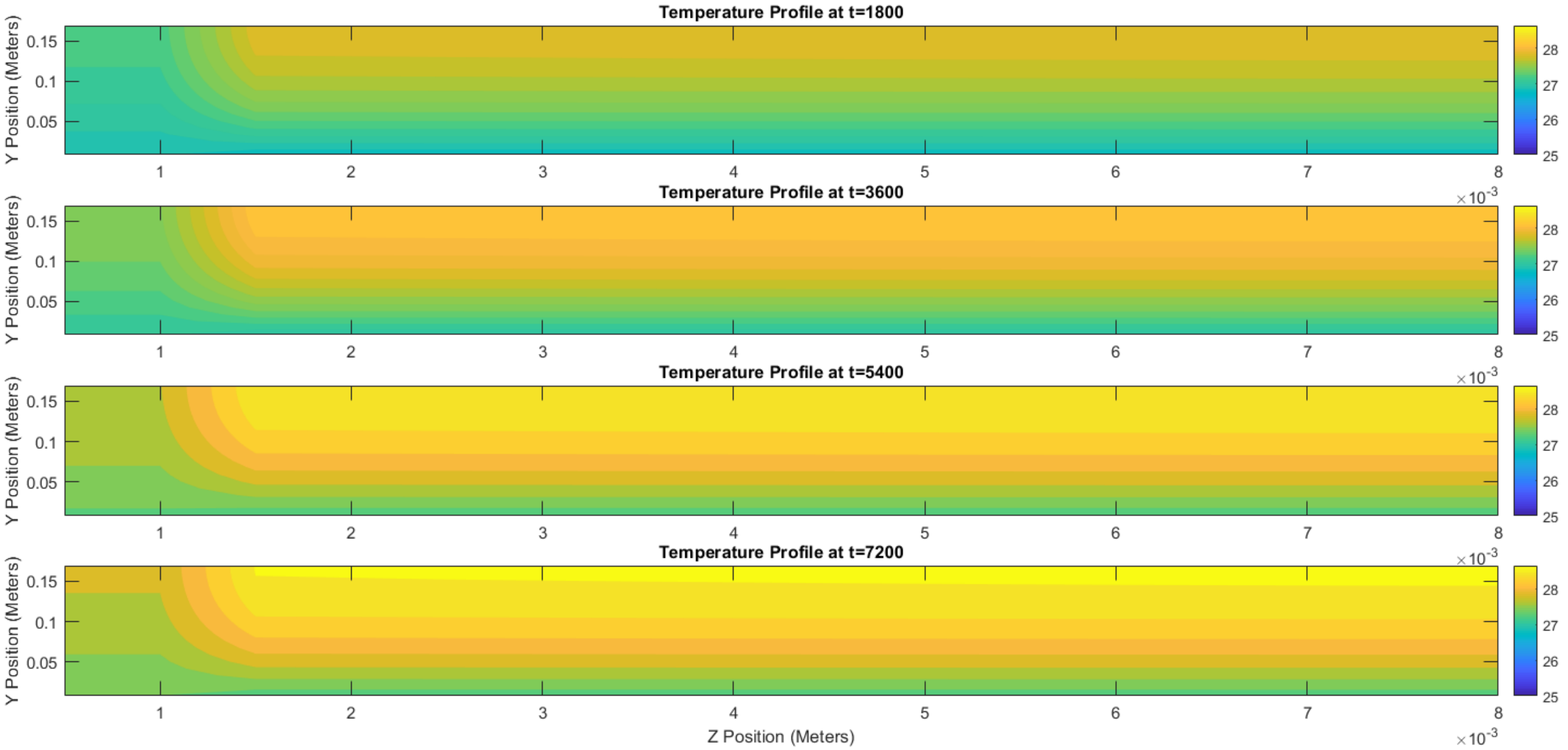
Results and Discussion: Max Battery and Fin Temperatures Over Time



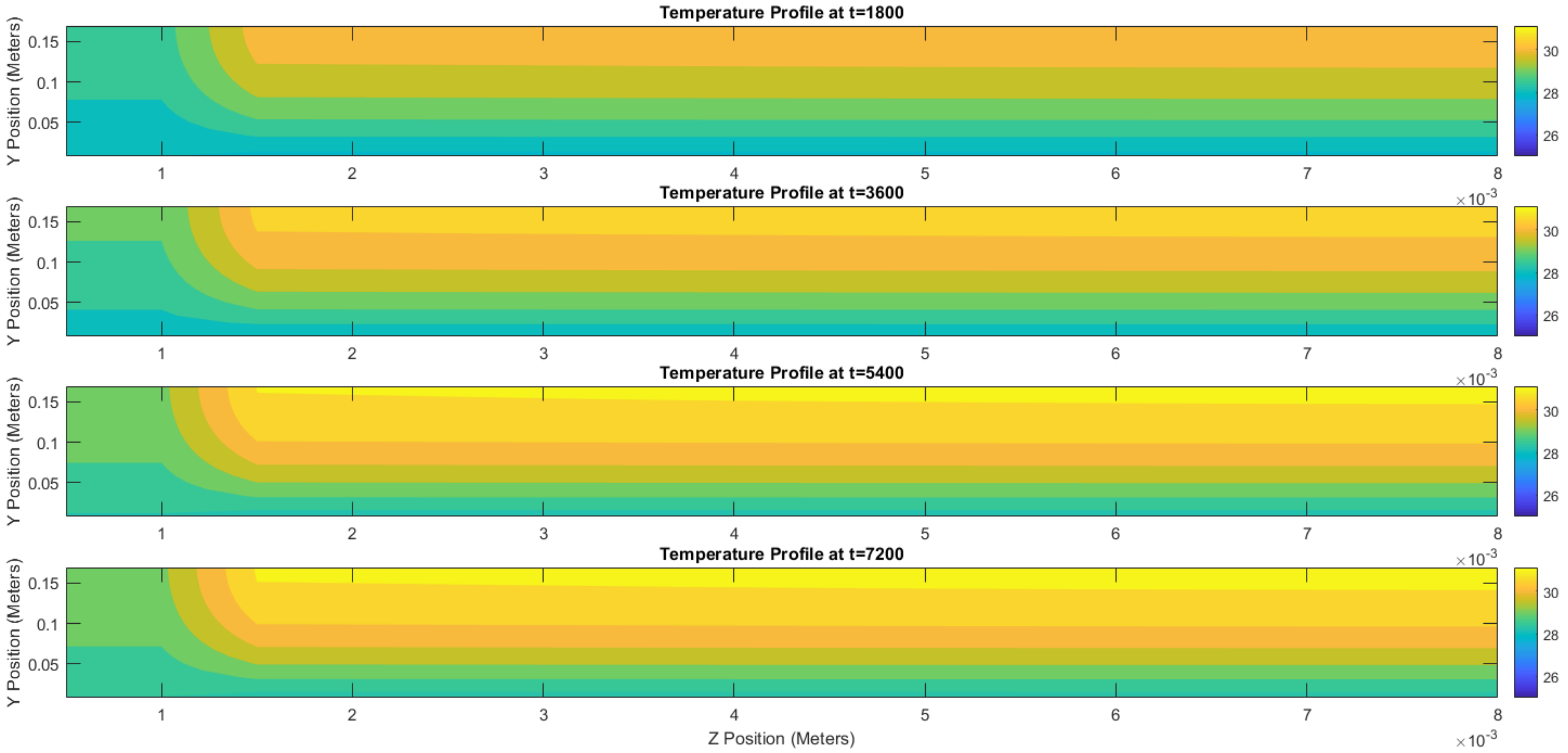
Results and Discussion: Fin Power Dissipation Over Time



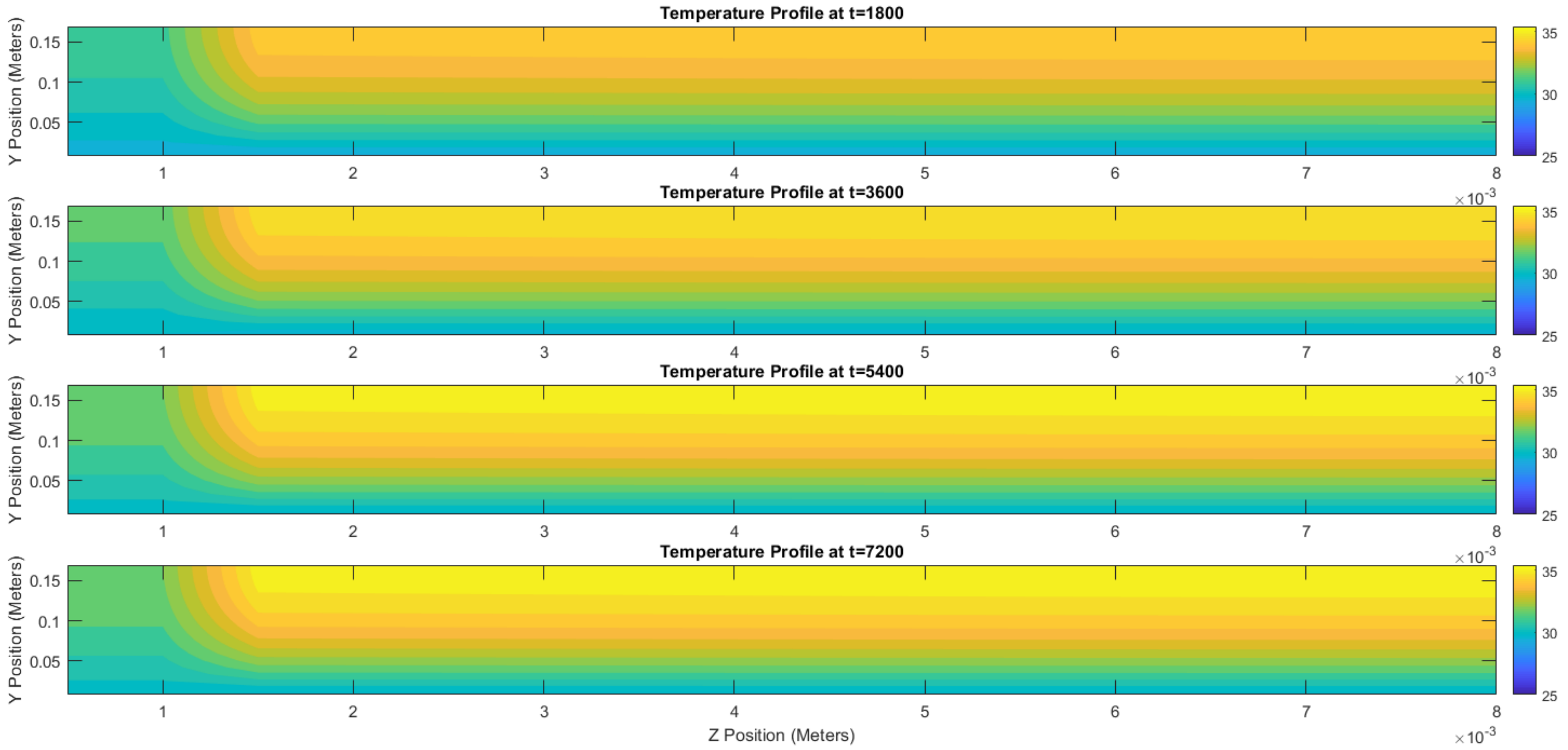
Results and Discussion: Temperature Profile at 50 MPH Vehicle Speed



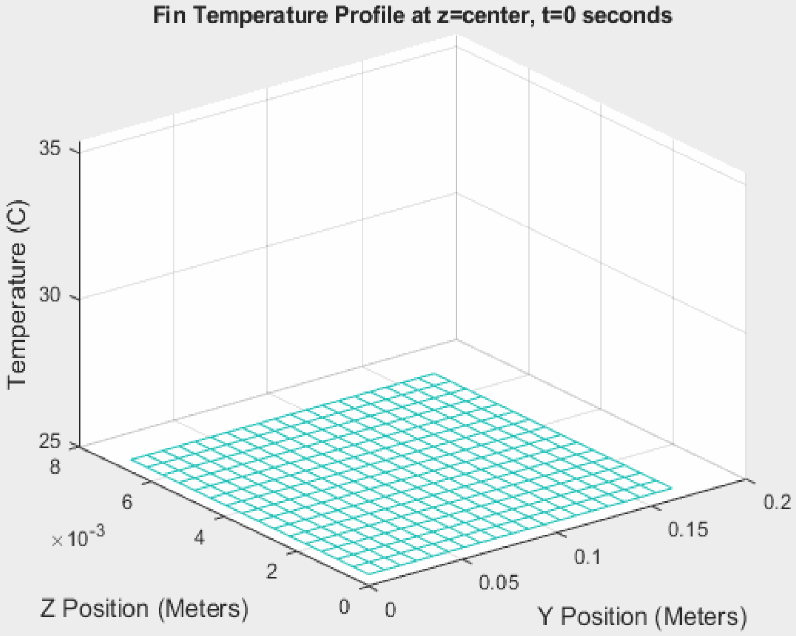
Results and Discussion: Temperature Profile at 65 MPH Vehicle Speed



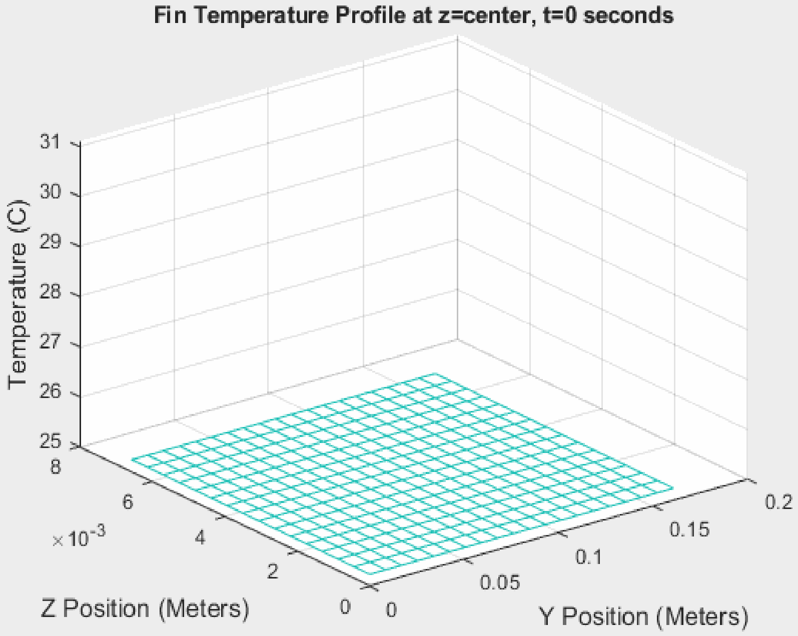
Results and Discussion: Temperature Profile at 80 MPH Vehicle Speed



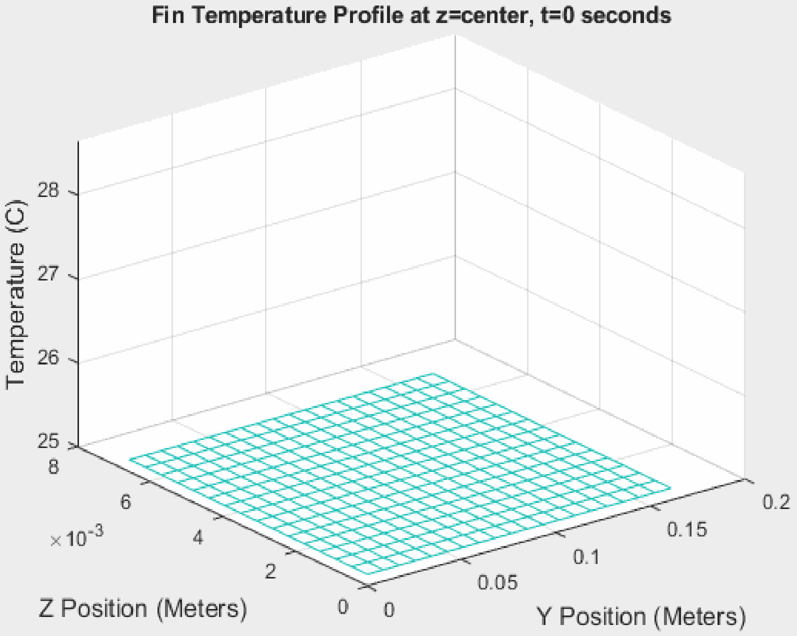
Results and Discussion: Transient Y-Z Temperature Profile at Different Speeds



Transient Y-Z Temperature Profile at 80 MPH



Transient Y-Z Temperature Profile at 65 MPH



Transient Y-Z Temperature Profile at 50 MPH

Conclusion:

- A passive cooling solution for an electric vehicle that relies on a fin under the car could be sufficient in some conditions.
- The design limits the temp rise to 8.5 degrees C with a 94 A discharge current (at 80 MPH), compared to a temp rise of less than 5 degrees using water/glycol liquid cooling or mineral oil jacket cooling.
- Charging speed will be negatively impacted. Since the car is stationary when charging, cooling then will rely on natural convection.
- At low ambient, the battery needs to be heated to maintain its power output, which would be much harder to do with a fin.

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