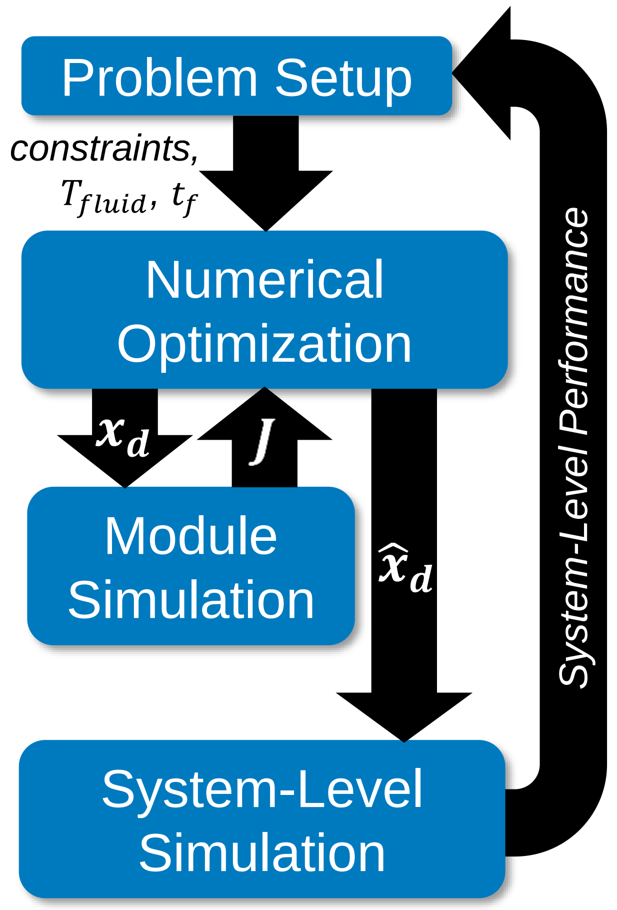
Optimal Design of a Phase-Change Thermal Energy Storage Device

Research Assistants: Michael A. Shanks
Principal Investigator(s): Dr. Neera Jain
Contact email: *shanks5@purdue.edu, neerajain@purdue.edu*

Project Objective

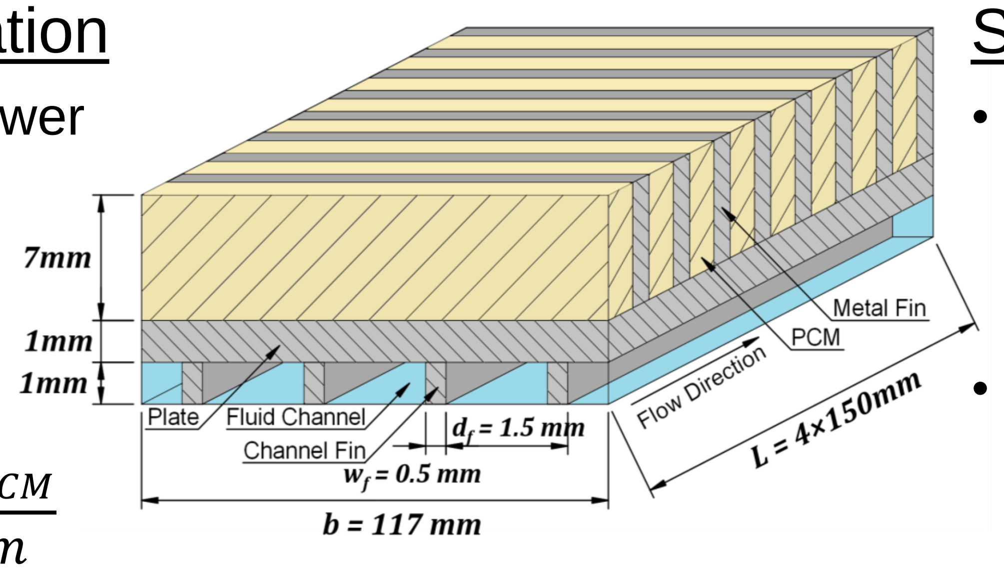
- Thermal energy storage (TES) modules integrated into thermal management systems (TMS) can provide robustness against highly transient heat loads from increasingly electrified air vehicles
- **We develop an iterative design approach with repeated optimization and simulation to size the TES to achieve robustness to transients**
- Our device consists of phase-change material (PCM) embedded in a plate-fin heat sink
- Power density is maximized by optimizing the volume of PCM, and the metal fin/PCM volume ratio can be tuned to achieve a desired heat transfer rate scaled to our TMS testbed



Approach

Numerical Optimization

Objective: Maximize power density by repeatedly simulating the TES for t_f = 50 seconds with a constant T_{fluid}



maximize $J(x_d) = \frac{\Delta q_{PCM}}{t_f m}$

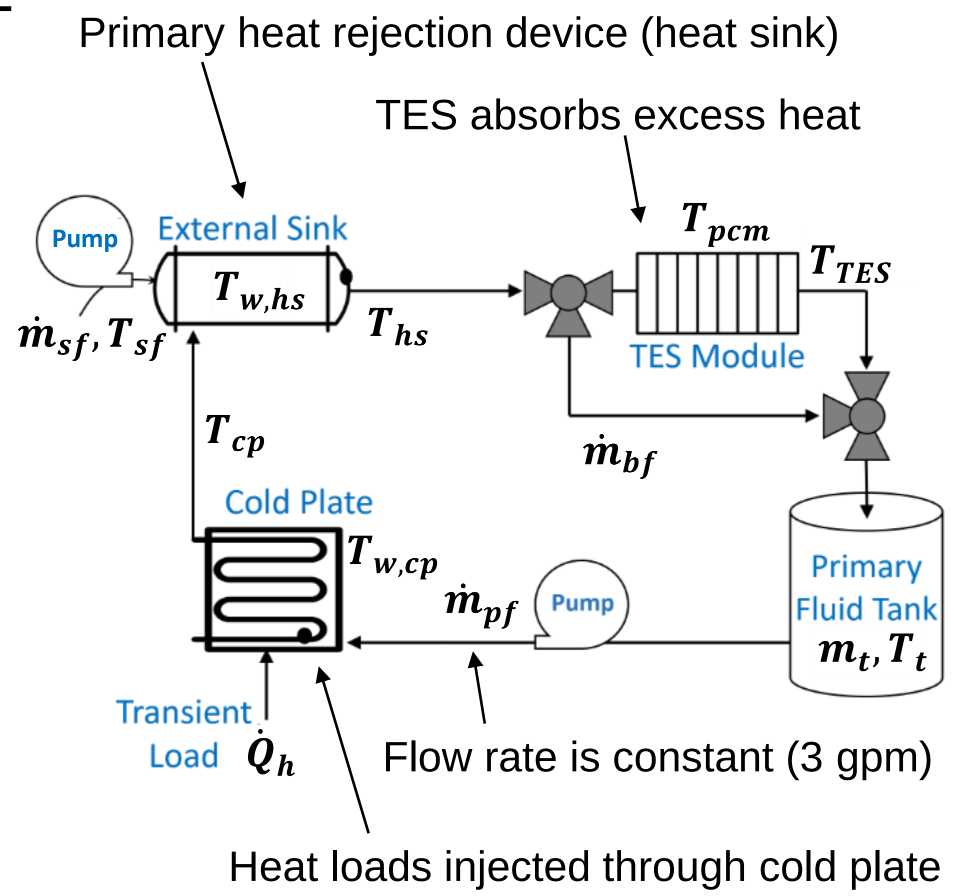
subject to $\frac{\Delta q_{PCM}}{t_f} > 1.5$ kW ← Need to specify a minimum average power to avoid the trivial result where mass is minimized

$15\% \leq \phi \leq 85\%$ ← Metal fin fraction (ϕ) bounds based on manufacturing limits

$50 \text{ mm} \leq b \leq 200 \text{ mm}$
$50 \text{ mm} \leq L \leq 600 \text{ mm}$
$5 \text{ mm} \leq h_{PCM} \leq 200 \text{ mm}$
} Geometric parameters determine the volume of PCM and cross-sectional area for heat transfer

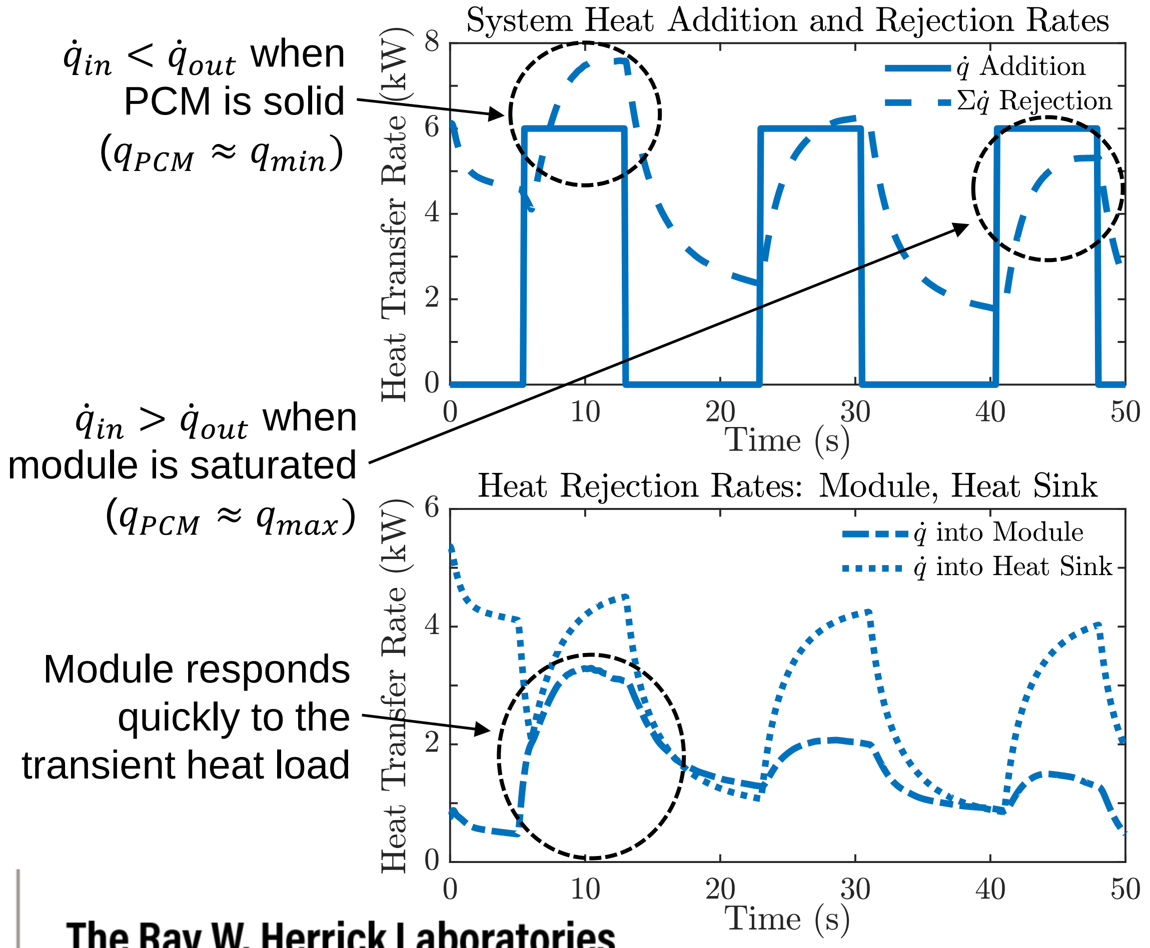
System Level Simulation

- Integrate the optimized design $\hat{x}_d$ into a notional thermal loop model based on physical testbed
- Starting with the PCM fully solid, inject transient heat pulses through the cold plate until the PCM is fully melted
- Analyze TES contribution to heat rejection over time compared to the heat transfer through the external heat sink



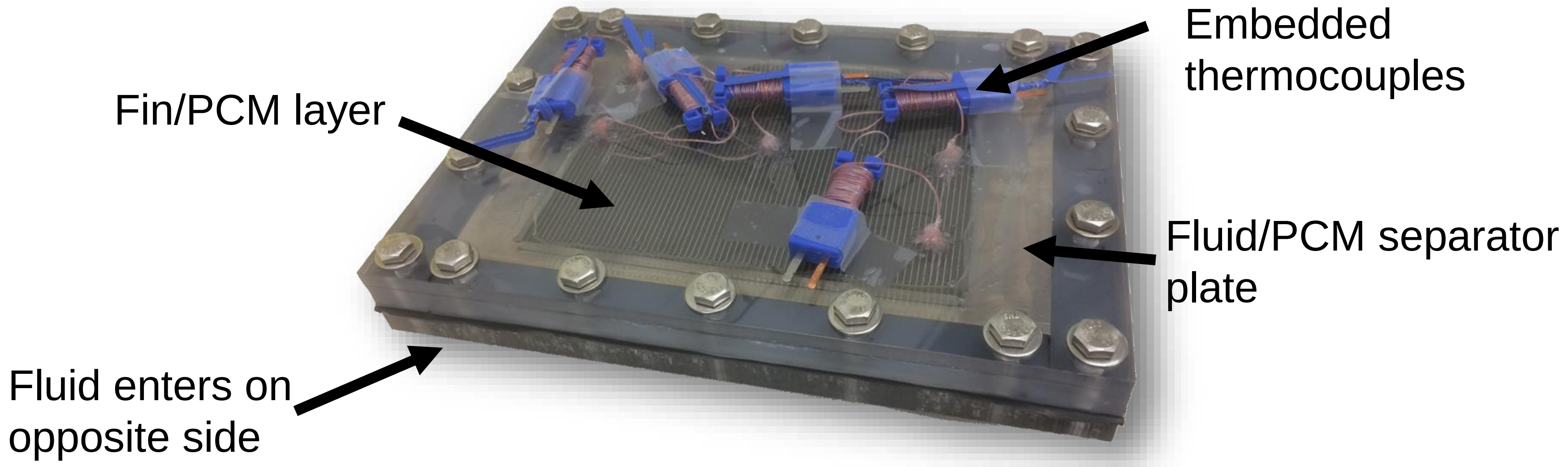
Results

- Heat is added in three transient pulses of 6 kW lasting for 8 seconds each
- System can easily reject the first pulse using both the heat sink and module
- Module performance drops over time as PCM melts. Without the module acting as a buffer, the primary heat sink cannot completely reject the third heat pulse



Future Work

Following the design process presented in this poster, a prototype TES module was fabricated according to the design parameters optimized for our single-phase cooling loop testbed. Using temperature data from this module, the simulation models will be calibrated and used to develop a logic-based controller to achieve robustness to transient loads and validate our design approach.



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