Surrogate Model Based Design Optimization Framework for Electric Vehicle Battery Thermal Management Systems

Mechanical & Industrial Engineering
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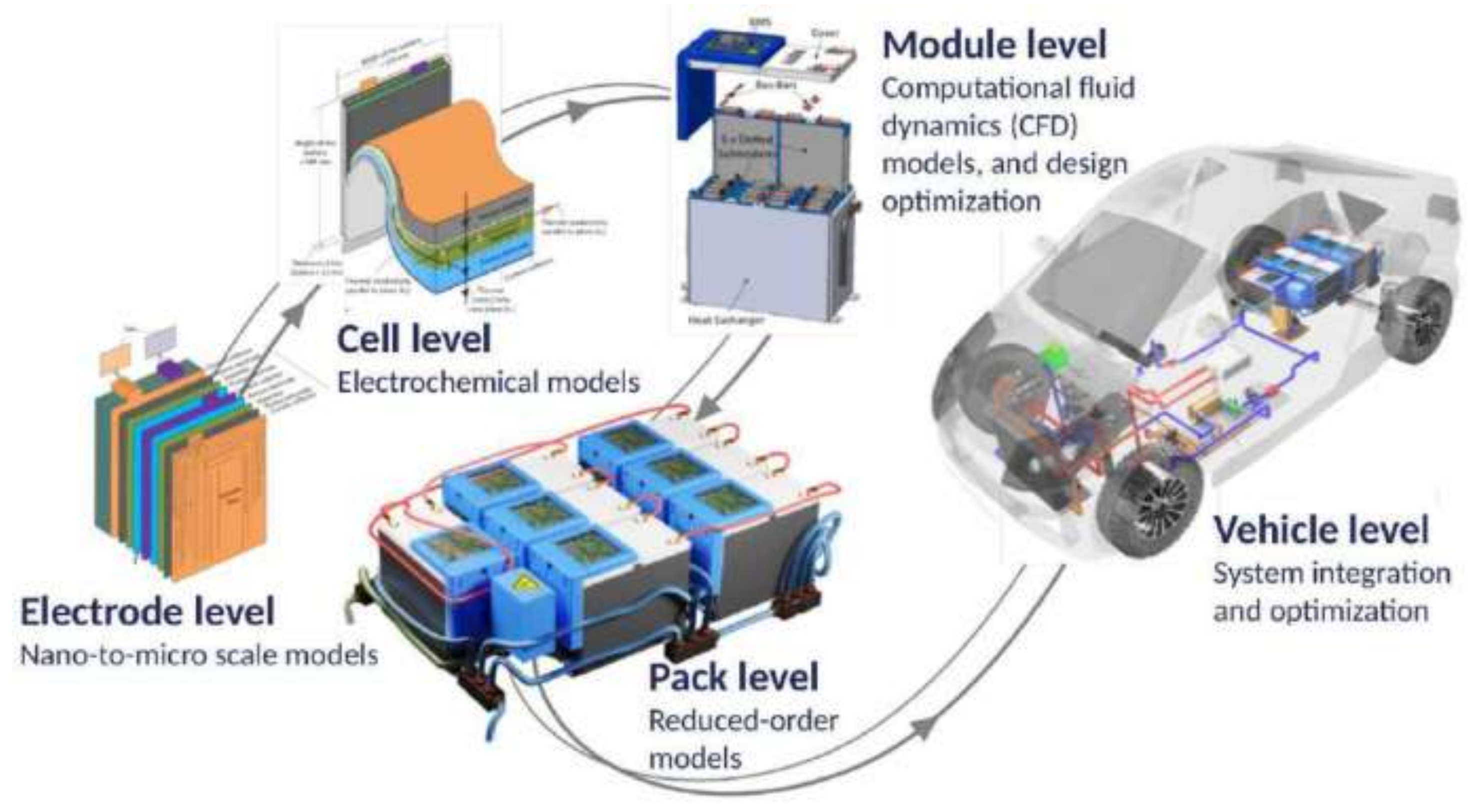
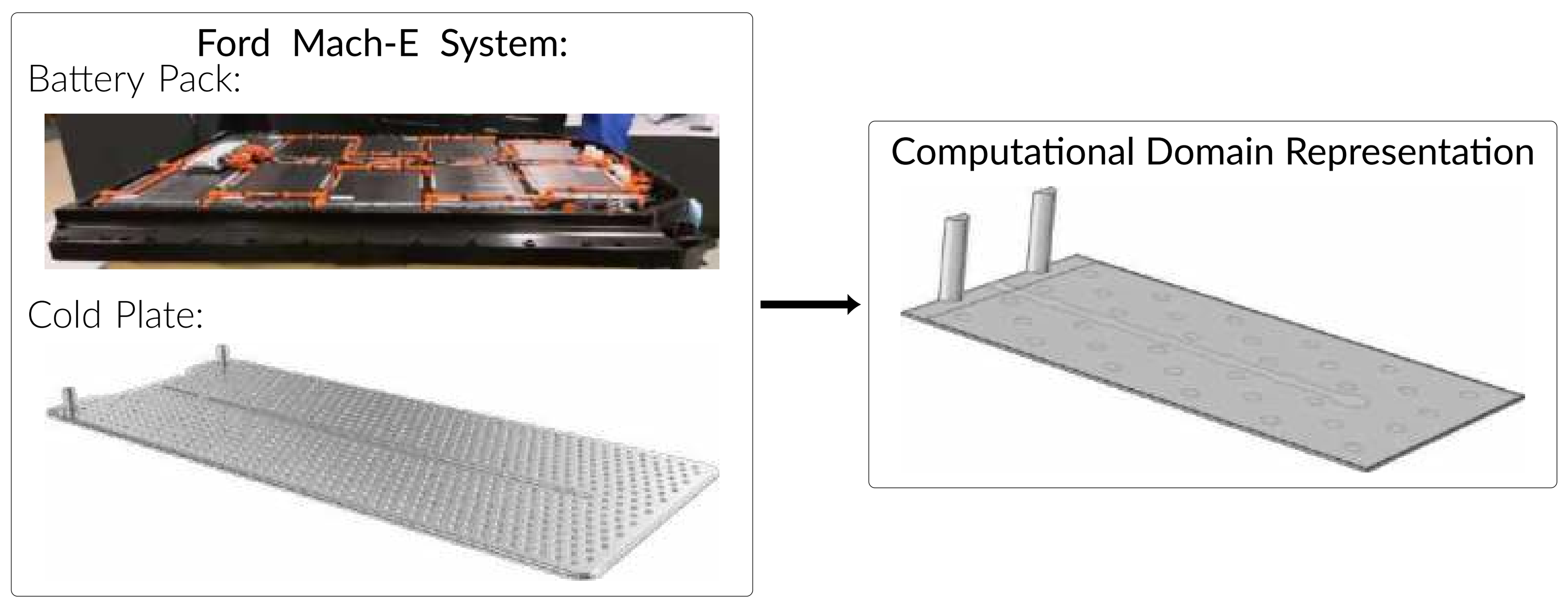
atoms laboratory

Battery Thermal Management Systems



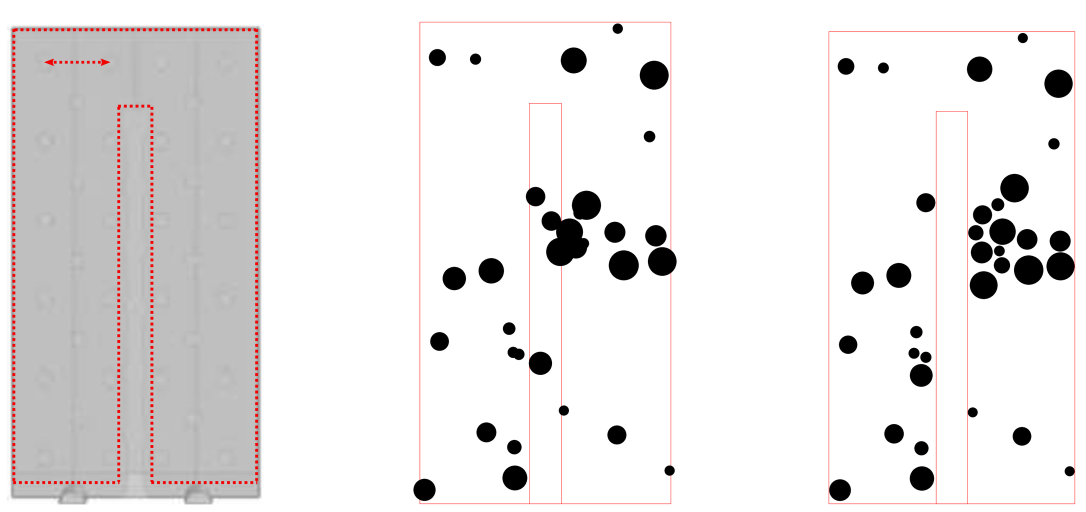
Case Study: Pin-Fin Cold Plates

Numerical models for module-level battery thermal management systems with bottom-cooling pin-fin cold plates, as those commercially available in electric vehicles manufactured by Ford, Rivian, and Lucid Motors.



Design Optimization Formulation

Constraints, design variables, and objectives for the novel design optimization of pin-fin cold plate flow paths (Ebbs-Picken *et al.*, *J. Energy Storage*, 67:107460, 2023).



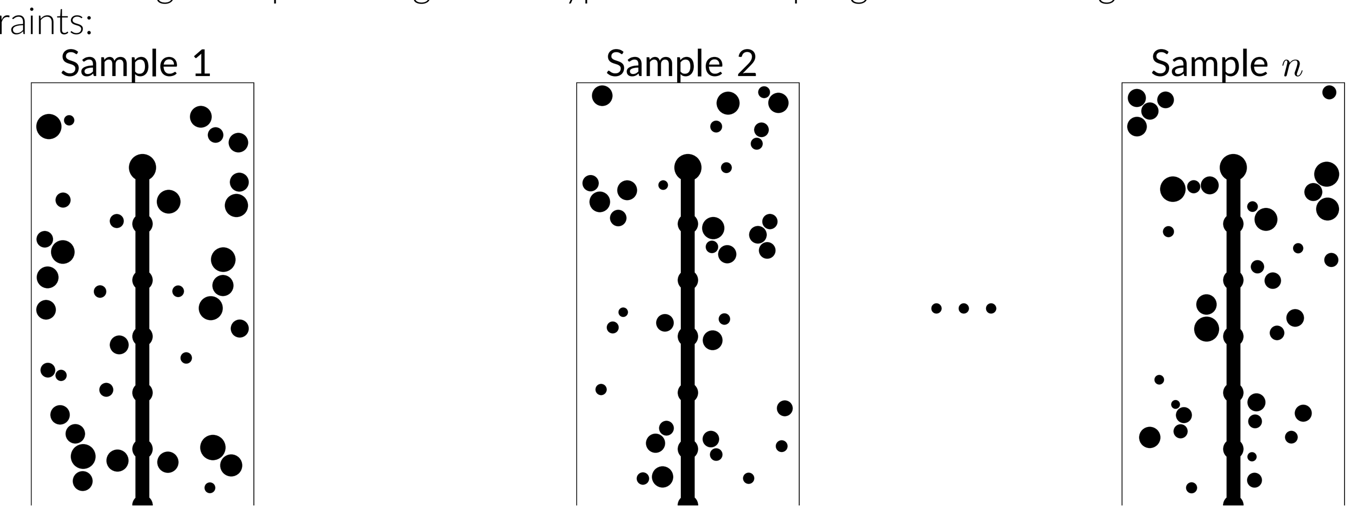
$$\begin{aligned} \text{minimize} \quad & \Delta P,\ V_c,\ T_{\max},\ T_\sigma \\ \text{with respect to} \quad & x_i,\ y_i,\ r_i \in \mathbb{R}^n \\ \text{subject to} \quad & c_1 : x_i, y_i \in dom(\text{plate}) \quad | \quad c_2 : r_{\min} < r < r_{\max} \\ & c_3 : \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \leq 1.025 \cdot (r_i + r_j) \quad \forall \quad i \neq j \end{aligned} \tag{1}$$

Surrogate Modeling Framework

Dense encoder-decoder neural network surrogate models to predict the objectives from the design variables following the process below:

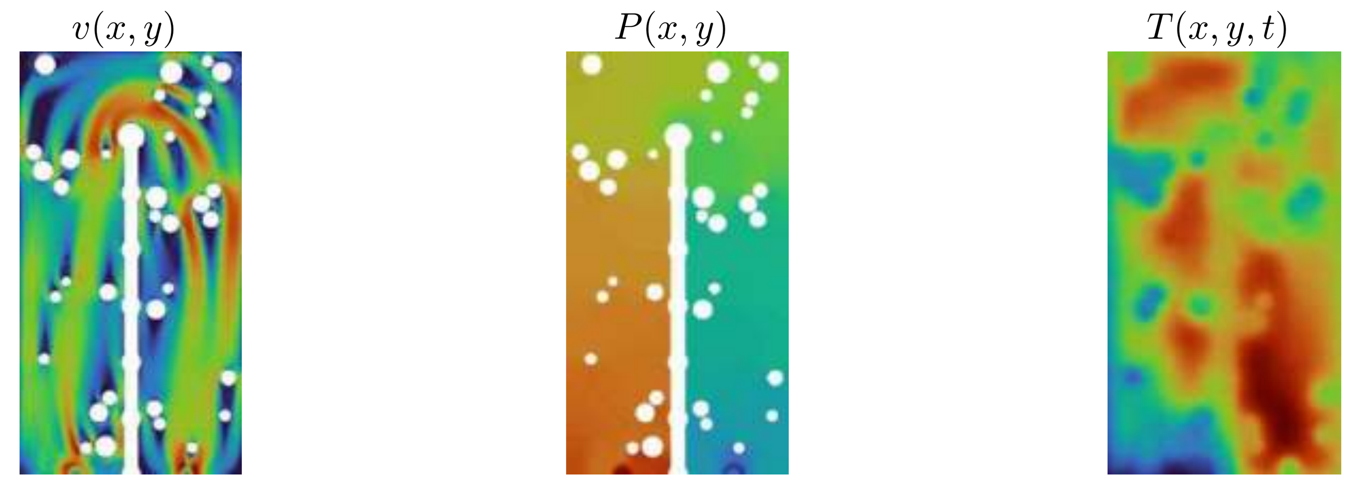
1 Generate Samples

Generated design samples using Latin-Hypercube Sampling from the design variables and constraints:



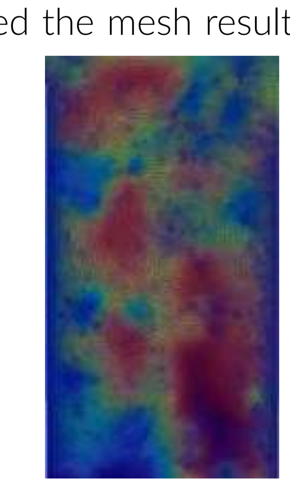
2 Compute Results

Computed the conjugate heat transfer results from the numerical models for each sample point:

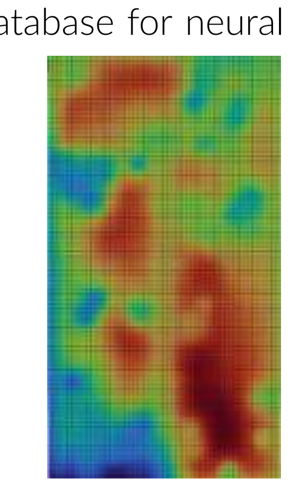


3 Process Mesh Results

Structured the mesh results of each sample to develop a training database for neural networks:

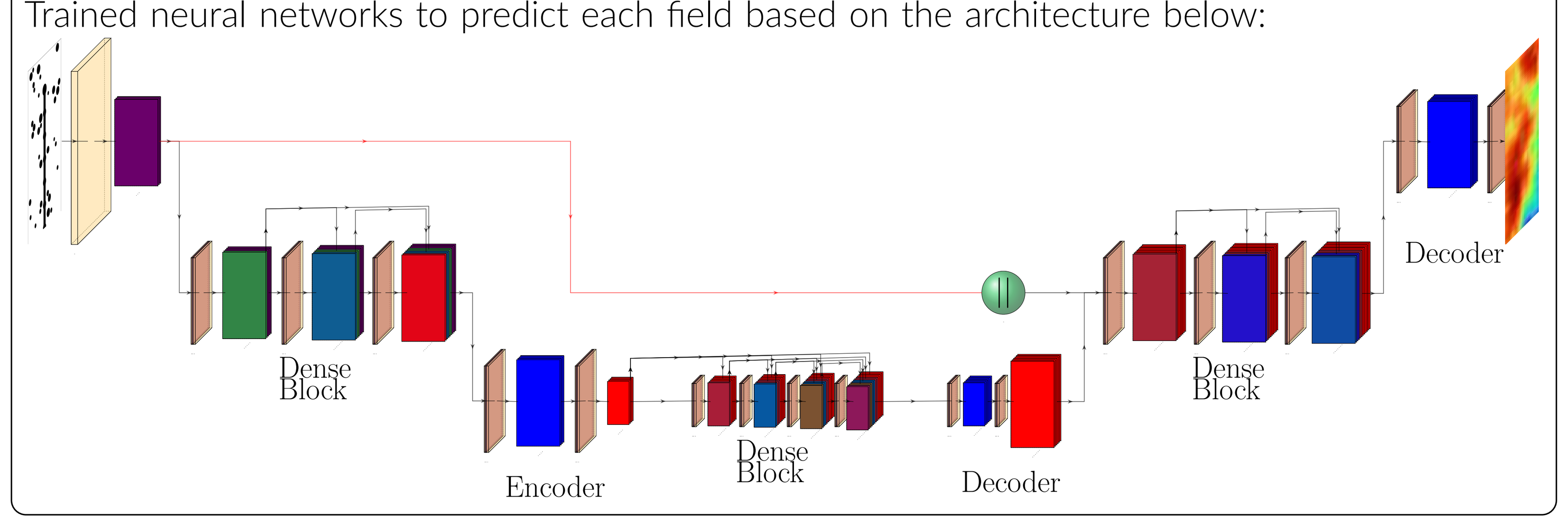


$$Q(c_{\text{struct}}) = \frac{\sum_{j=0}^{n} A(c_{j_{\text{unstruct}}}) \cdot Q(c_{j_{\text{unstruct}}})}{\sum_{j=0}^{n} A(c_{j_{\text{unstruct}}})}$$
$$\forall c_{\text{unstruct}} \in dom(c_{\text{struct}})$$



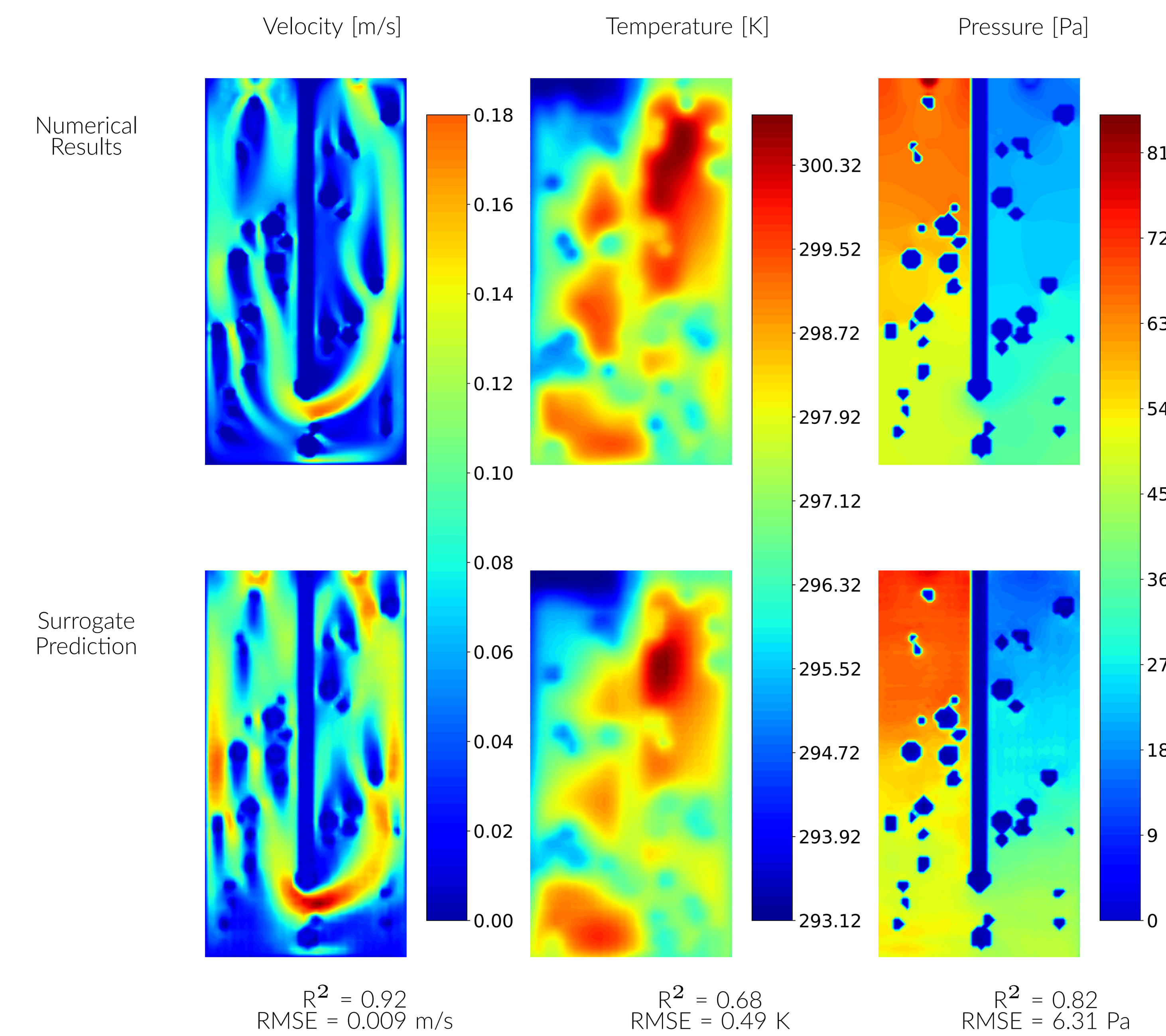
4 Train Dense Encoder-Decoder Neural Networks

Trained neural networks to predict each field based on the architecture below:



Preliminary Results

Surrogate model outputs demonstrate accurate prediction capabilities:



Conclusions and Future Works

Conclusions:

- This generalized framework is applicable across battery thermal management system levels and can be used to accelerate electric vehicle development through design optimization.
- Encoder-decoder neural networks are efficient and accurate surrogate models for cold plate conjugate heat transfer problems.

Future works:

- Use the surrogate models to optimize cold plate flow paths.
- Apply the general optimization framework to other systems including: stationary energy storage and vehicle level thermal management systems.

Acknowledgments

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