# MULTI-RESOLUTION PROTOTYPING OF LI-ION BATTERIES

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# INTRODUCTION

## Objective

The objective of this research is to apply the ideas of multi-resolution numerical simulations to prototyping and analysis of Li-ion batteries considered for hybrid vehicle systems.

## Approach

Execution of detailed, fully resolved simulations to calculate the fluid and thermal fields in domains with complex internal structure such as the multi-cell Li-ion battery, is a very resource-intensive process in terms of domain gridding, computational capacity, and lack of ability to change internal configurations without having to re-do the entire flow domain. Multi-resolution approach sidesteps these difficulties by partitioning a complex system into interacting sub-components which are represented by reduced models of varying levels of fidelity. In the case of a Li-ion battery, the computational domain was divided into inflow and outflow coolant manifolds connected by reduced models of individual cells. Flow in the manifolds was modeled using CFD simulations. Reduced models were represented by Artificial Neural Networks (ANNs). Using CFD simulation data, the ANNs were trained to predict mass flow rates and maximum temperatures at battery cells at three representative positions in a pack. The ANNs were coupled to a thermo-flow solver that simulated flow-thermal characteristics in the whole systems.

## DISCUSSION

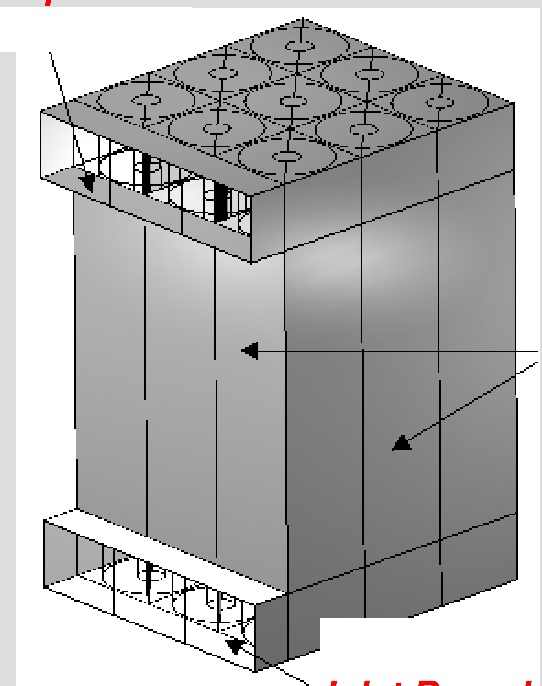
- Hybrid simulations can significantly accelerate the analysis of cooling characteristics of Li-ion batteries.

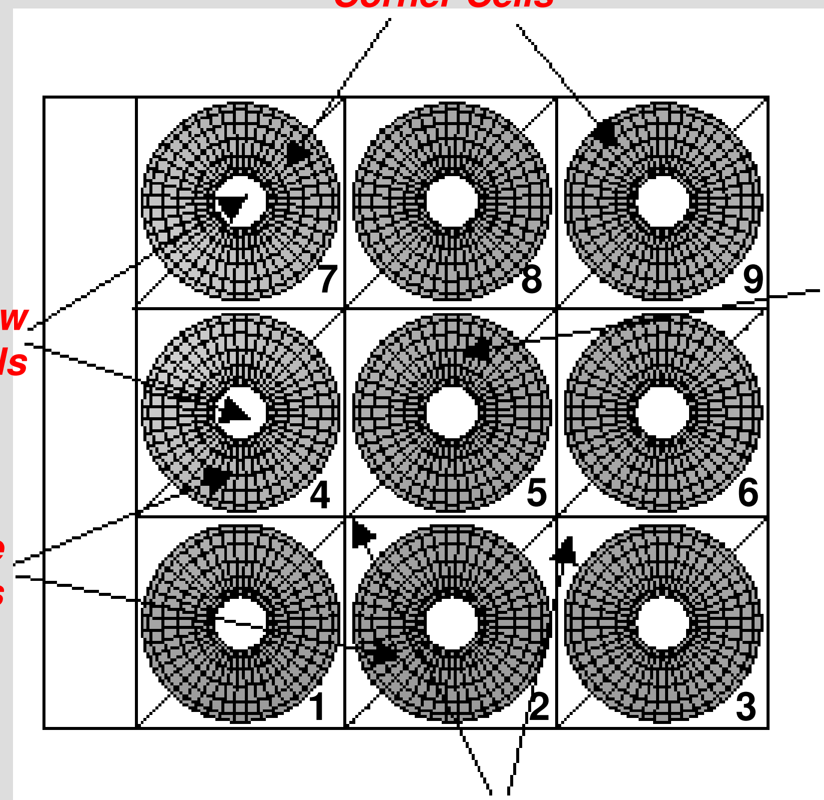
- Heat removal predicted by multi-resolution analysis was within 4% of full-scale CFD predictions, and total coolant mass flow was within 2%.

- For the cases studied, hybrid analysis was approximately 20 times faster than full CFD. In practical terms this translates to an overnight simulation compared to one that would take nearly a month on a single processor machine.

- Flow and thermal fields change qualitatively depending on the number of cells in a representative battery:
  - 9 cell battery pack had basically uniform pressure and velocity fields resulting in essentially uniform thermal fields. Difference between full CFD and hybrid approach predictions of maximum cell temperature were in the range 4-6K.
  - 144 cell battery pack exhibited two recirculation zones leading to formation of two hot spots. Difference between full CFD and hybrid approach predictions of maximum cell temperature were in the range 2-9K.

# Battery Models: CFD Approach



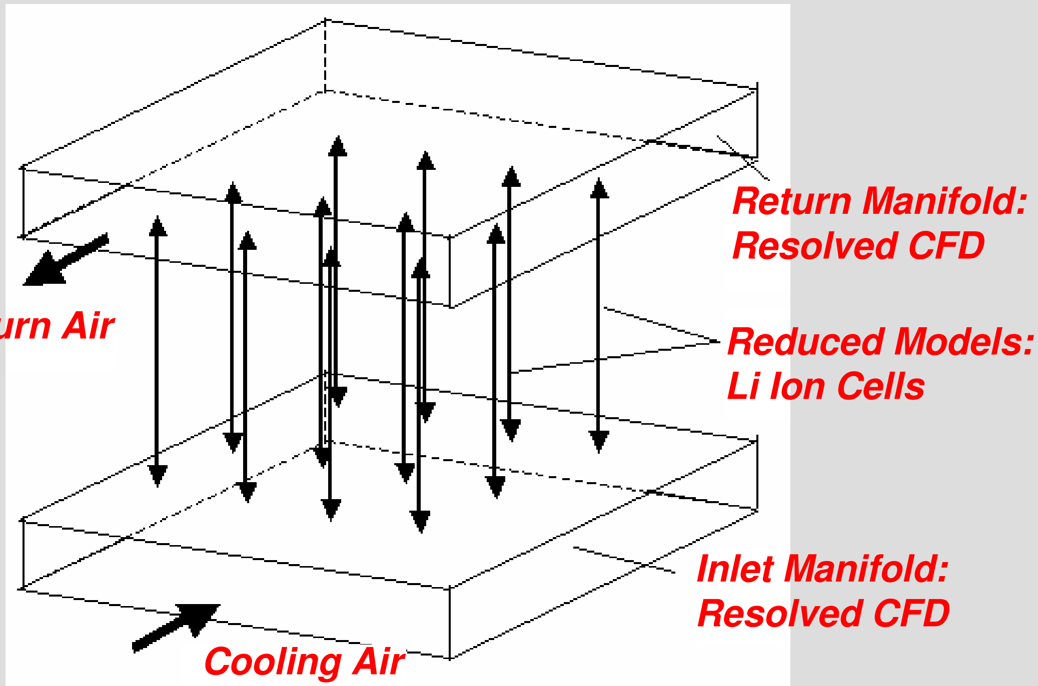




*External Boundary Conditions*

*Internal Gridding*

## *General Layout of the Nine Cell CFD Domain*

# Battery Models: Hybrid ANN-CFD Approach




***Domain Partitioning:***
***Representation by CFD and Reduced Models***

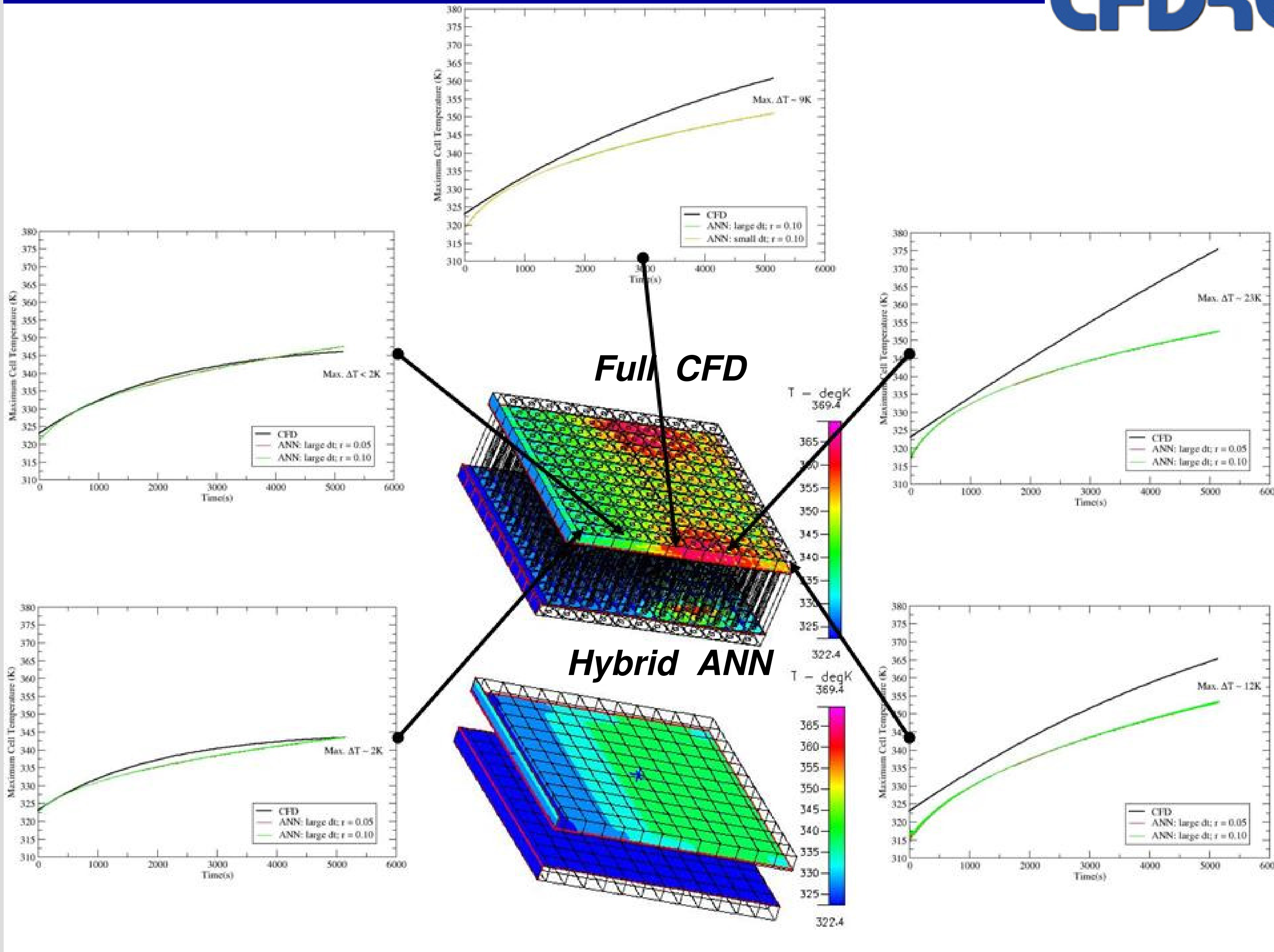
- 9-cell pack = 27 ANNs
- 144-cell pack = 432 ANNs

***Reduced Models of Cells***

- Artificial Neural Networks (ANNs)
- 3 ANNs represent each cell:
  - mass flow into inlet manifold
    mdot = f(local $\Delta$P)
  - mass flow into outlet manifold
    mdot = f(local DP)
  - max. cell temperature
    $T_{max}$ = f(mdot, $heat_{gen}$, time)
- Using symmetry, ANNs trained for 3 representative locations:
  - center, side, corner
- These models can be used to simulate a large class of battery pack configurations

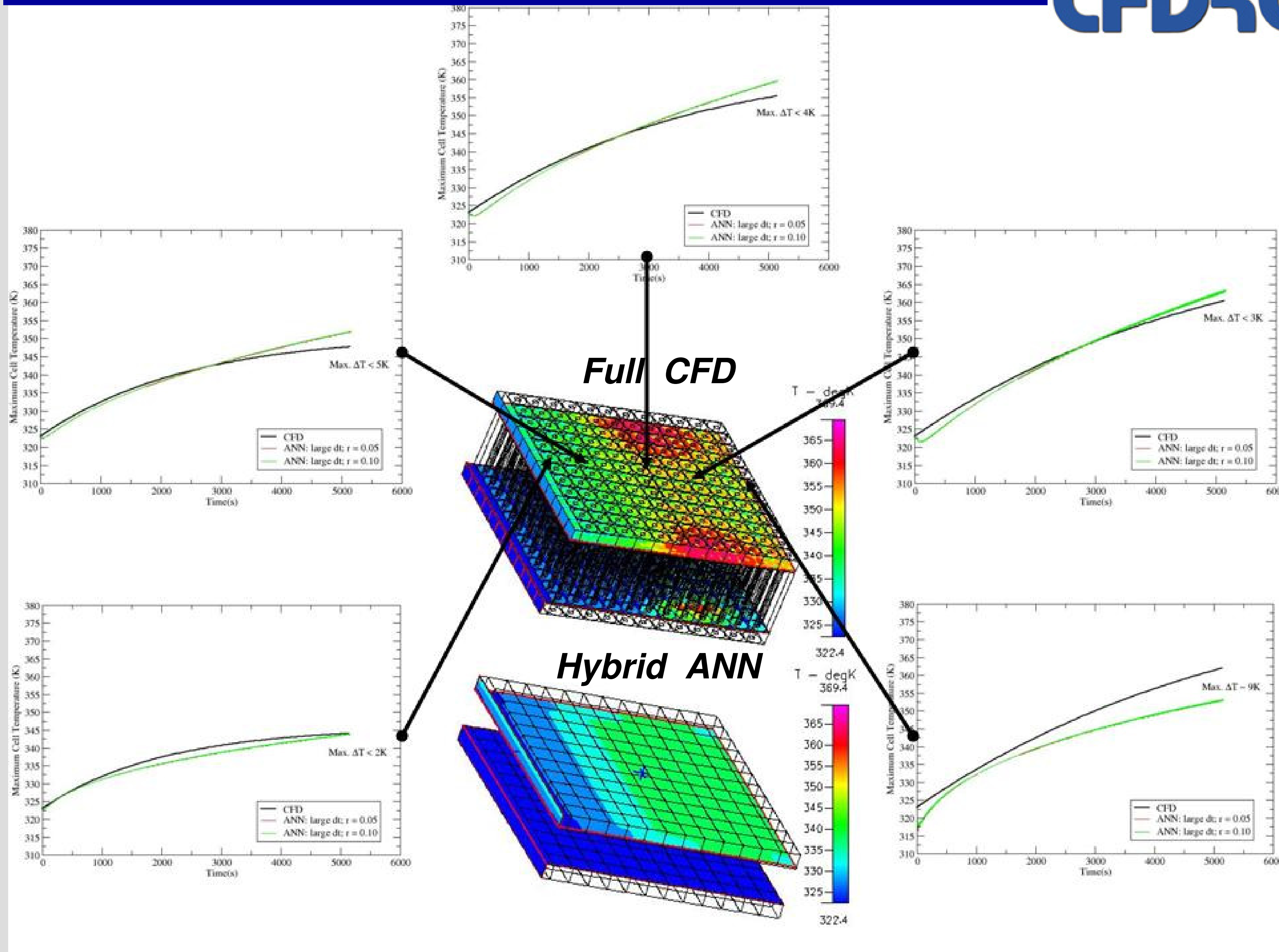
## *Model Arrangement and Connectivity*

## Comparison of Local Quantities for 144-Cell Pack



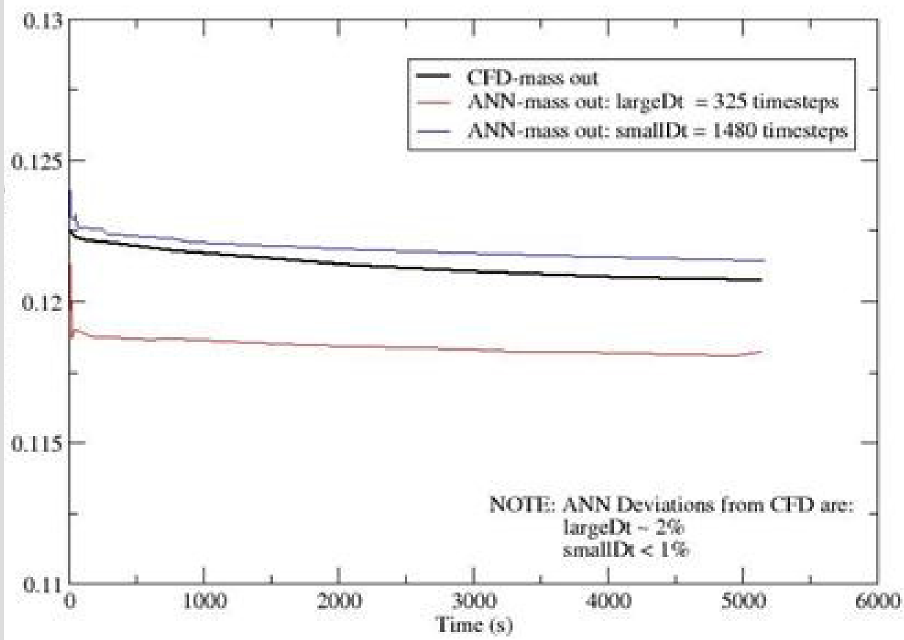

***Maximum Pack Centerline Cell Temperatures***

# Comparison of Local Quantities for 144-Cell Pack

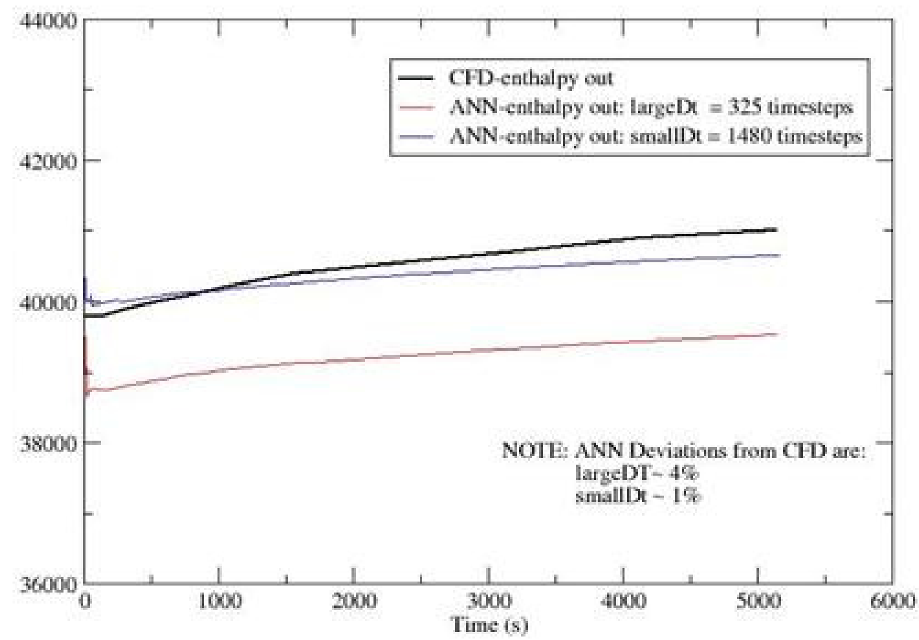



***Maximum Pack Centerline Cell Temperatures***

# Comparison of Average Quantities




Outlet Mass Flow




Outlet Enthaply Flow

***Maximum Mass and Enthalpy Flows at the Pack Outlet***