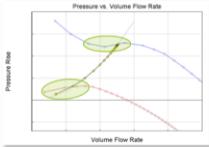




# Cool Innovations: Navigating the Future of Thermal Management

# Leveraging System Agnostic Thermal Simulation

- Faster solution for fans and pumps



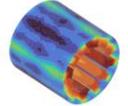
	Supported	Reliable	Fast
Mechanical	✓	✓	✓
Electrical	✓	✓	✓

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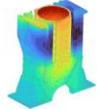
### Faster Thermal FE Solution

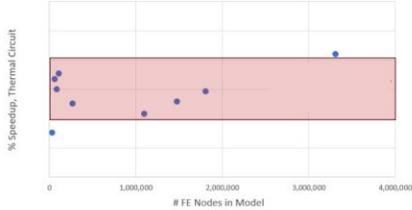
- Thermal FE code optimization
  - Faster time stepping for models with thermal FE parts

ThermalFiniteElement



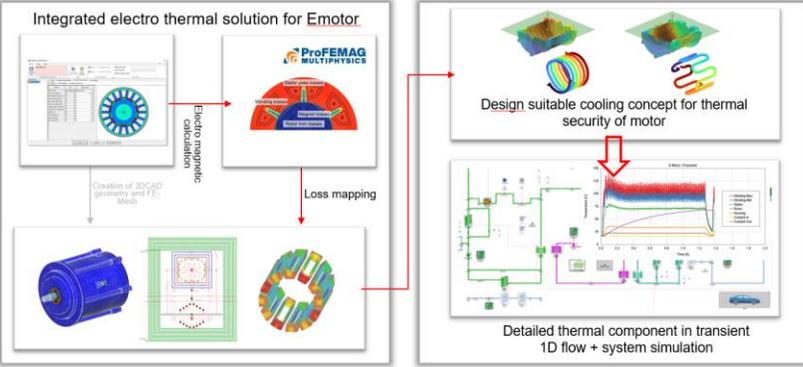
FE Engine Cylinders





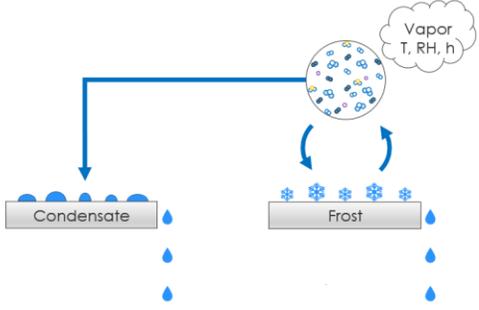
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### Integrated Thermal Component Workflow



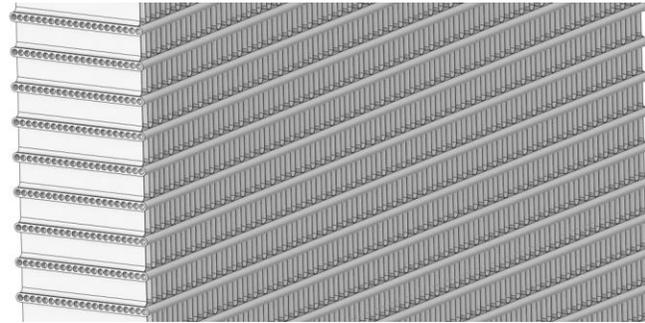
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### Water Cycle – Vapor, Liquid, and Solid

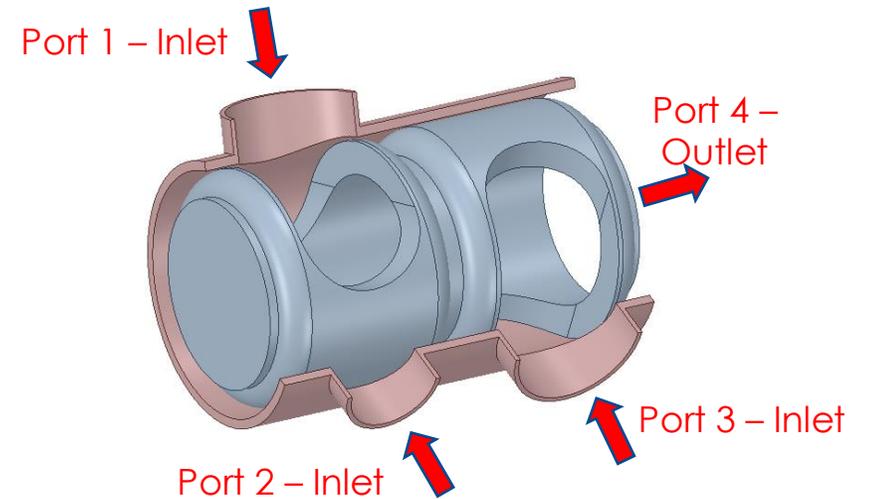


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# Advanced Cooling Technologies



Micro channel heat exchangers & other components



Packaging & integration of functions

materialstoday:  
PROCEEDINGS



Volume 92, Part 2, 2023, Pages 1497-1500

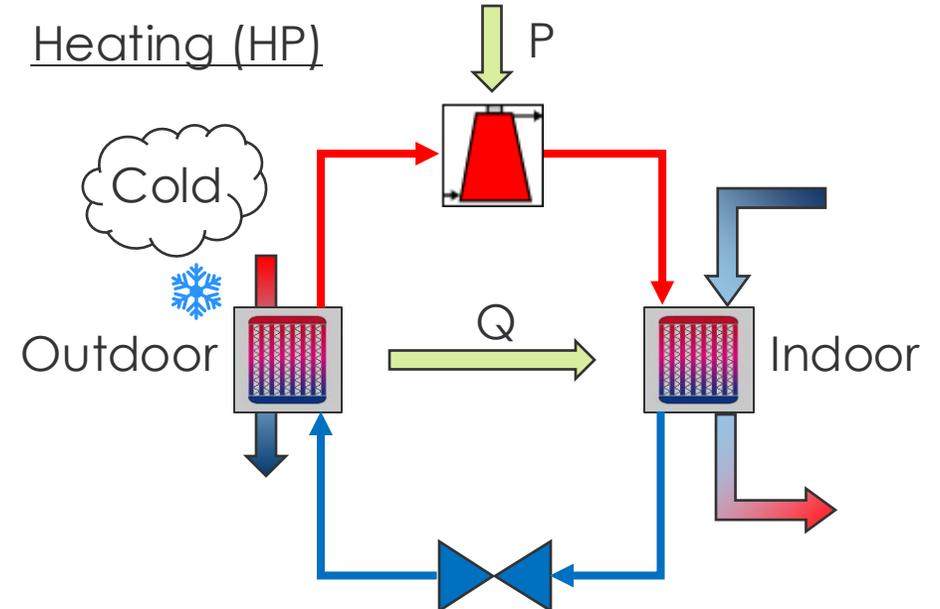
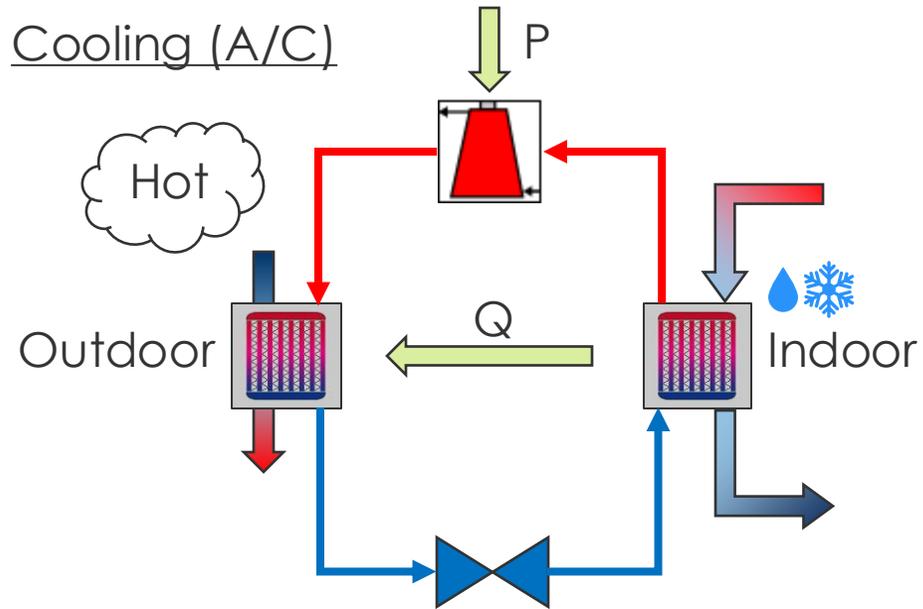
The effectiveness of nanoparticles in coolants a state of the art

H.C.S. Lunga, Thembelani Sithebe, Vasudeva Rao Veerredhi



Advanced coolants & refrigerants

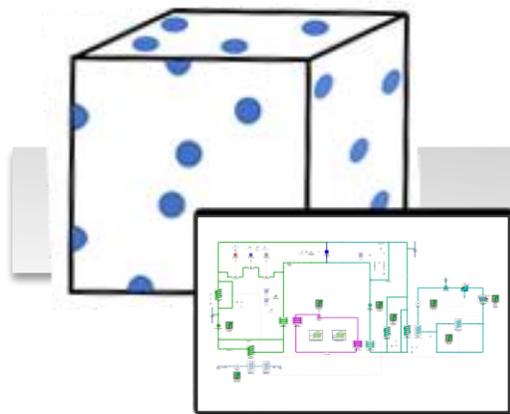
# Heat Pump (HP) Systems



- Advantage:
  - Very efficient – reuse existing HVAC system
  - Positive impact on range
- Challenges:
  - Frost can develop on Indoor (Cooling) or Outdoor (Heating) HX
  - Integration and control
  - Costs

# Machine Learning in Solutions

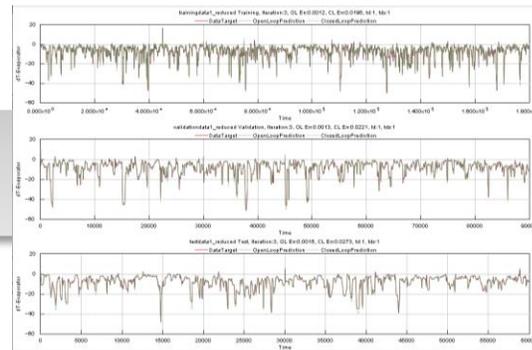
Thermal management model



Design Of Experiment:

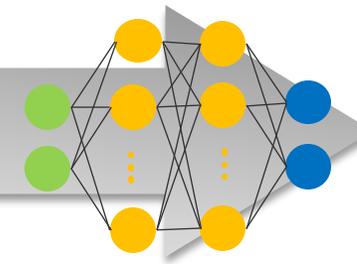
- 5 drive cycle, operating points
- $T_{amb} = [258,313]K$

Training



Neural network for prediction of key thermal management model responses

Meta Model



Responses:

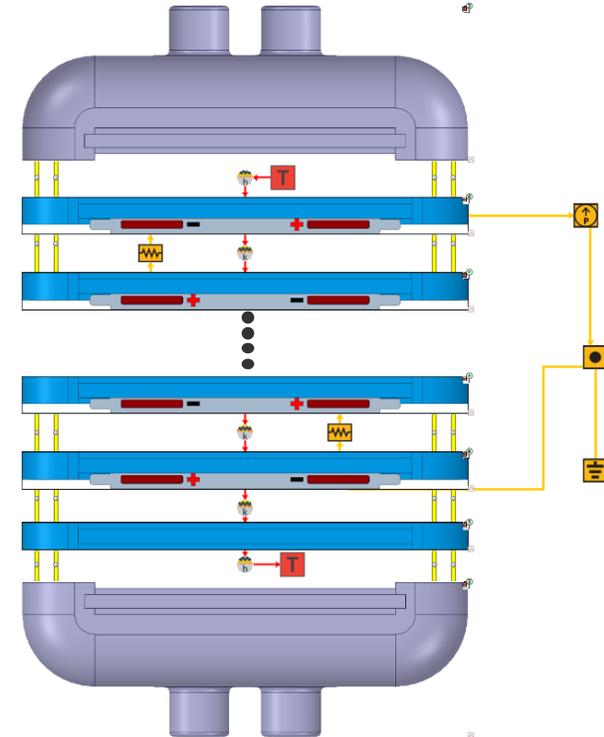
$T_{Bat}, P_{VTM,DC}, P_{VTM,AC}$

Factors:

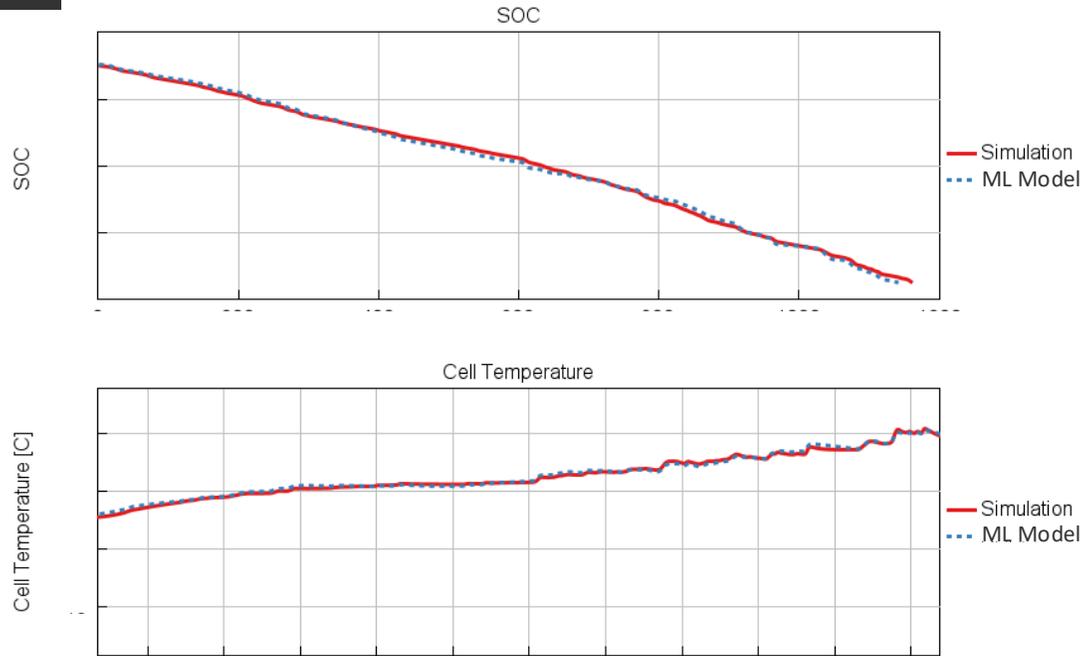
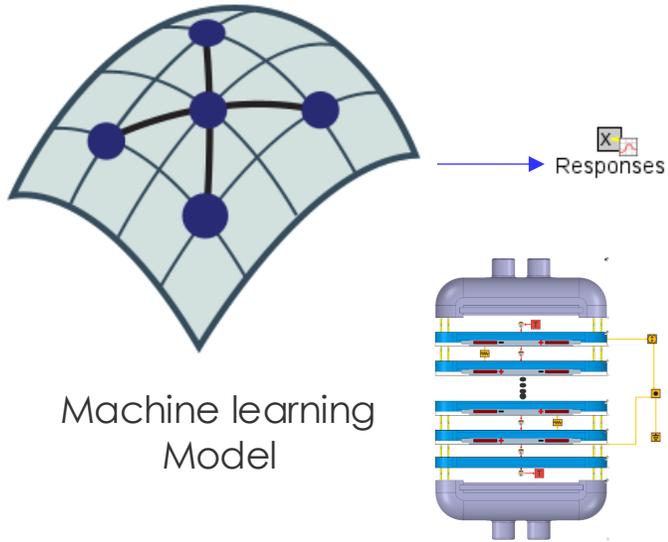
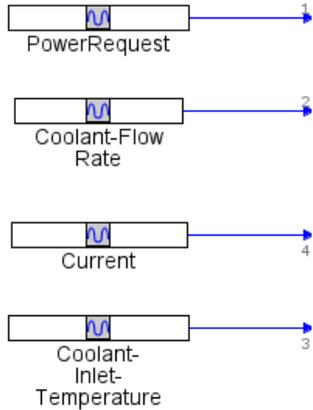
$v_{veh}, P_{total}, T_{amb}, SOC$

# Opportunities when GT Model goes Machine Learning

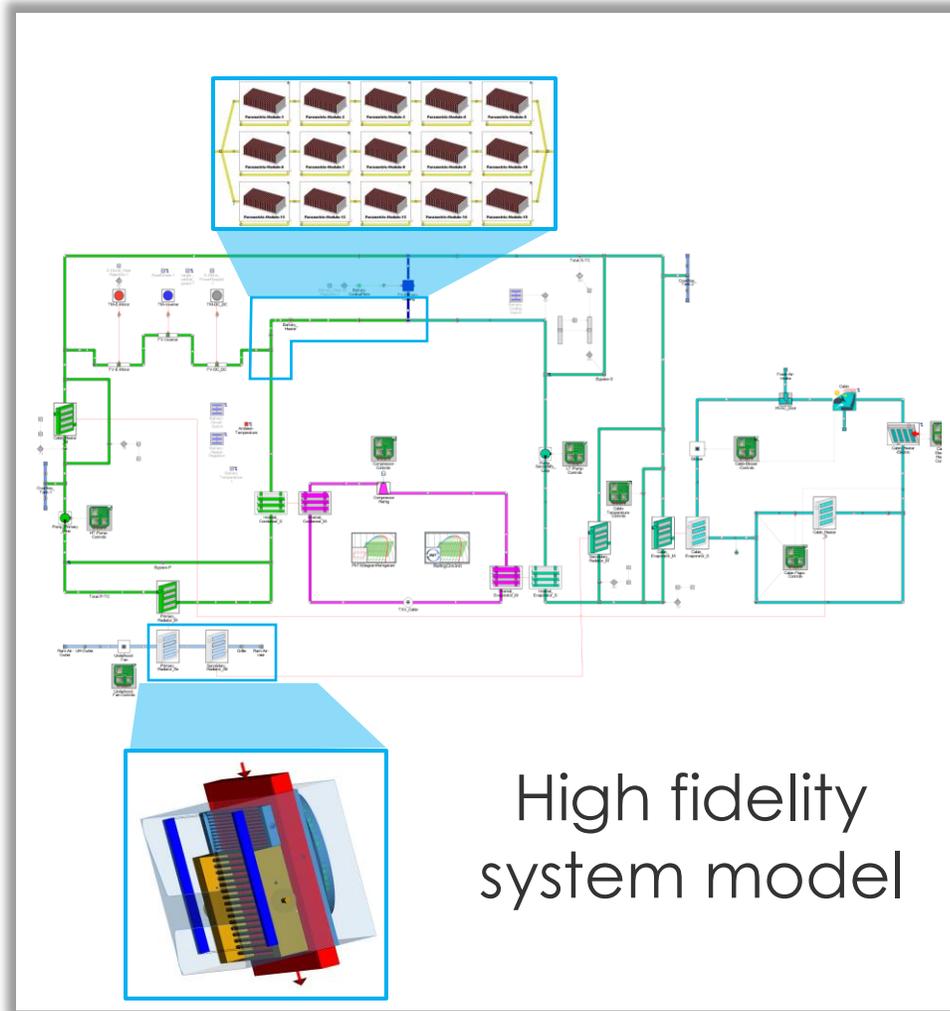
- In GT-SUITE
  - Component aging and wear
  - Component calibration
  - Using information for testing
  - Using information from higher fidelity
  - ...
- With GT-SUITE:
  - Very fast models for embedded systems
  - Virtual sensors
  - Virtual states
  - Detection of faults
  - ...



# Results



# Reduced Order Modeling in GT-SUITE



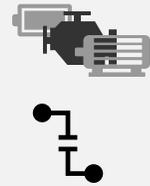
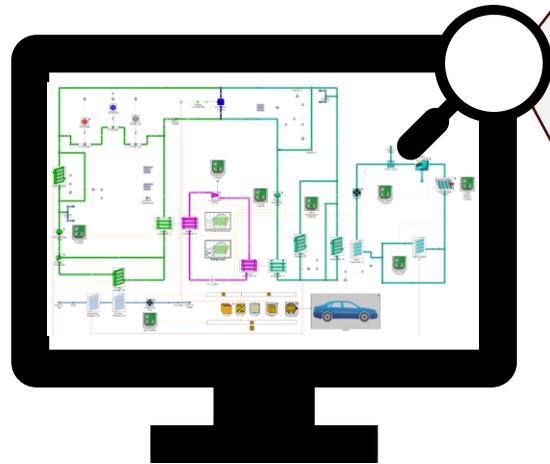
Data driven plant model

- Super fast
- Very easy deployment
- High upfront costs
- Change insensitive

Physics based plant model

- Change sensitive
- RT capable
- Medium upfront cost
- Deployable

# Integration of our work with function development



Variable components  
connected functions



Modular layouts



Advanced controls strategies



Optimization potential



Traffic

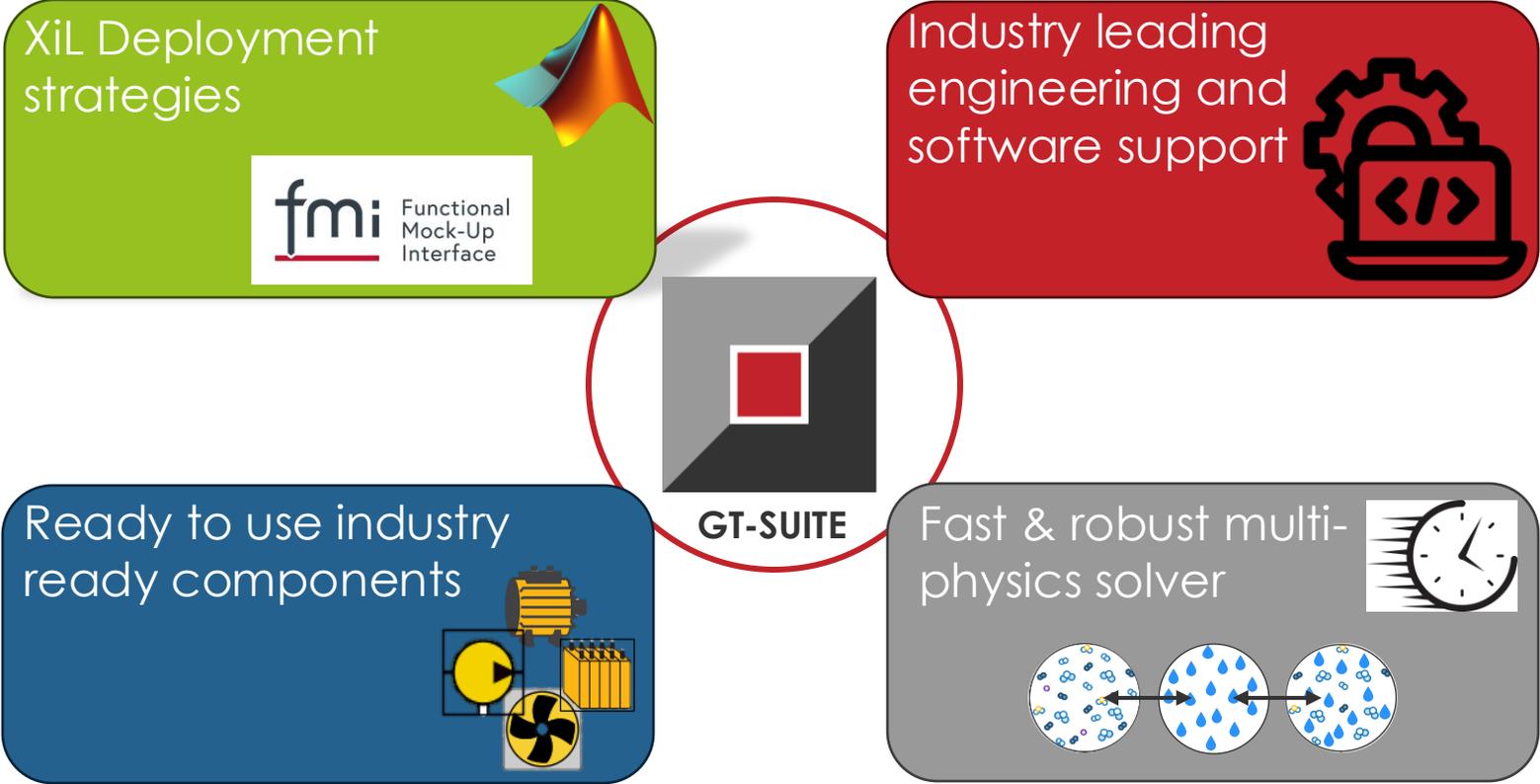


Driver

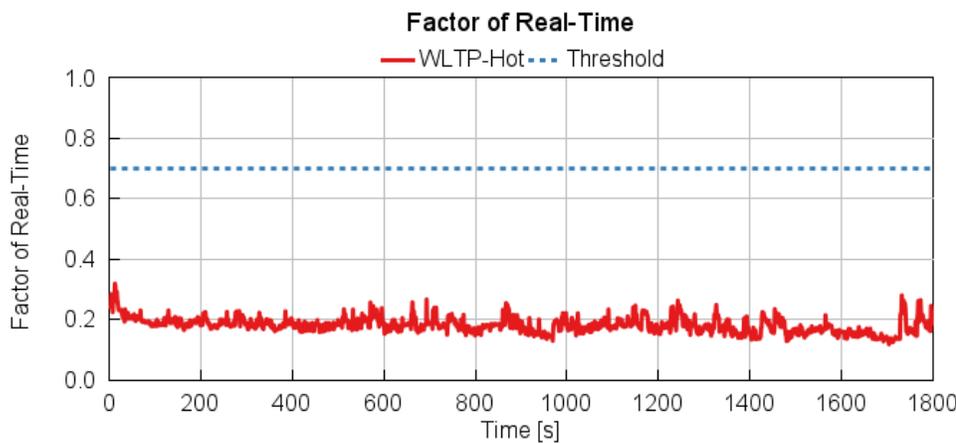


Environment

# GT-SUITE Capabilities for Model Flexibility

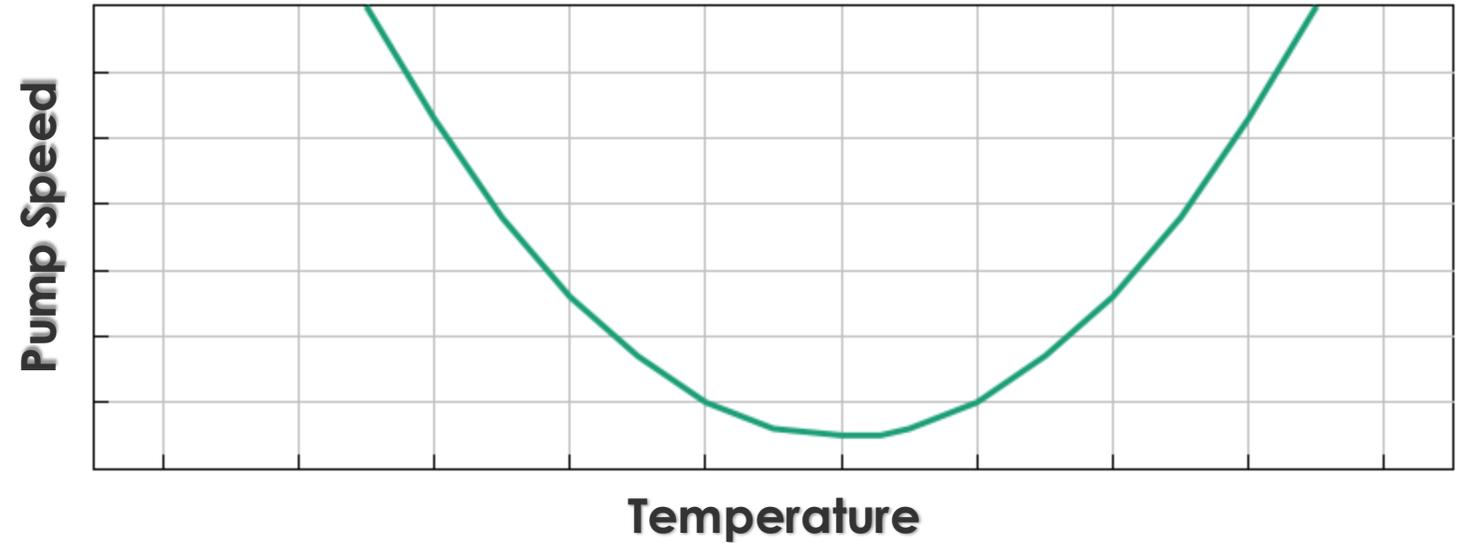
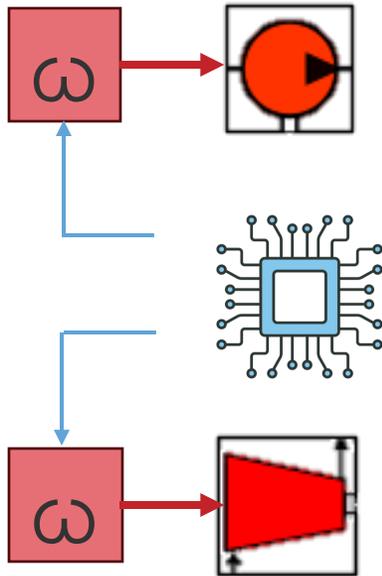


# GT-SUITE on a XiL Simulator



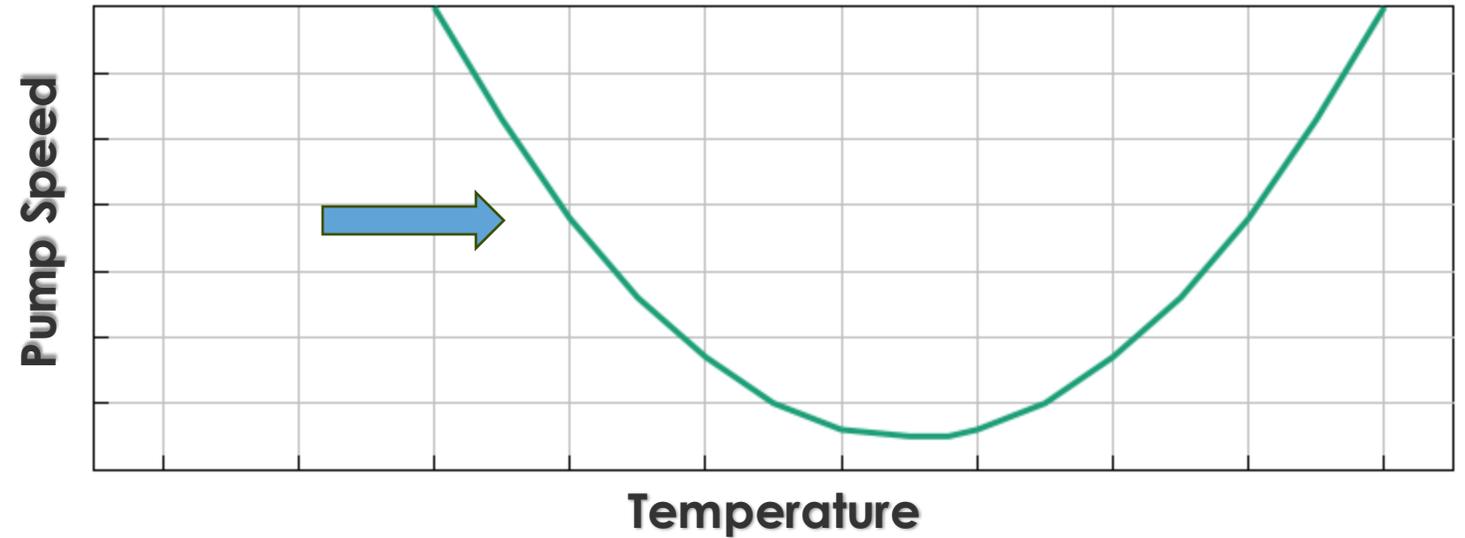
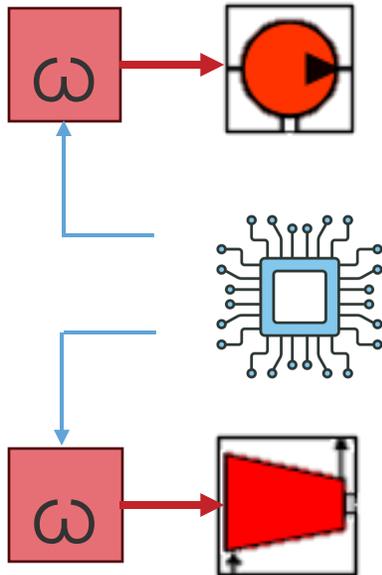
# Control Strategy Test on HiL

Controls Law Validation and Optimization



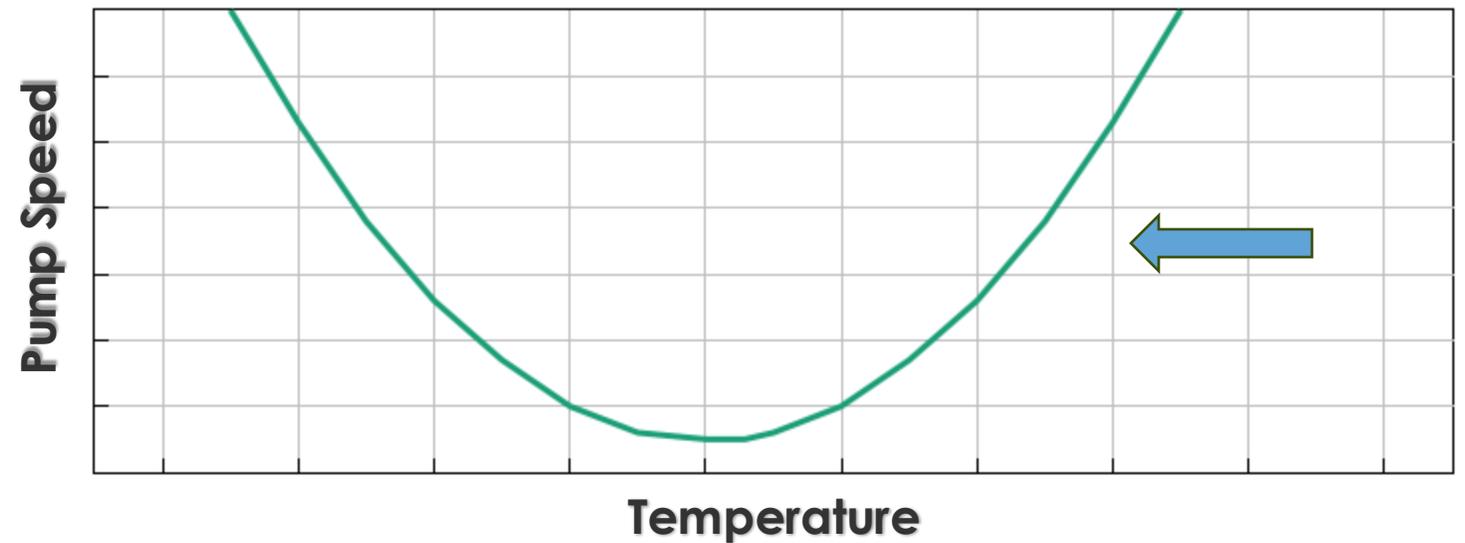
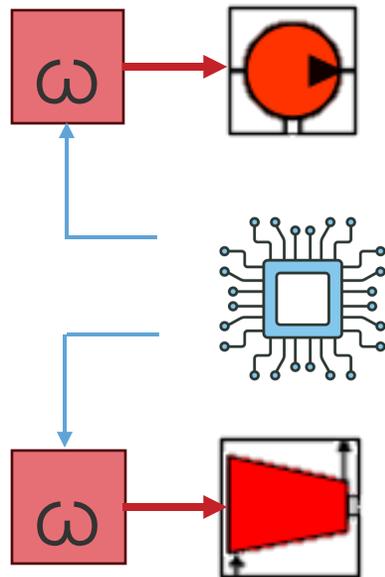
# Control Strategy Test on HiL

Controls Law Validation and Optimization



# Control Strategy Test on HiL

Controls Law Validation and Optimization

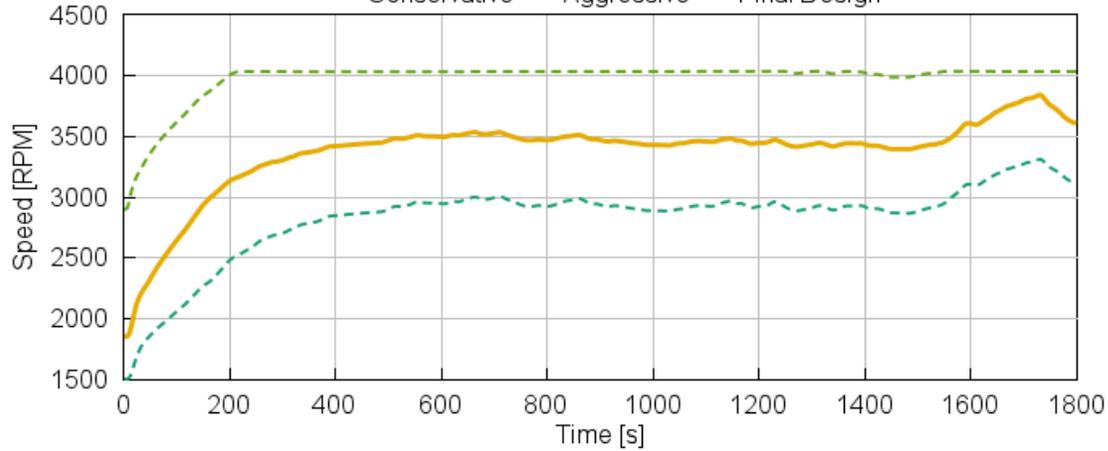


# Setpoint Control Optimization

## Flow Rate

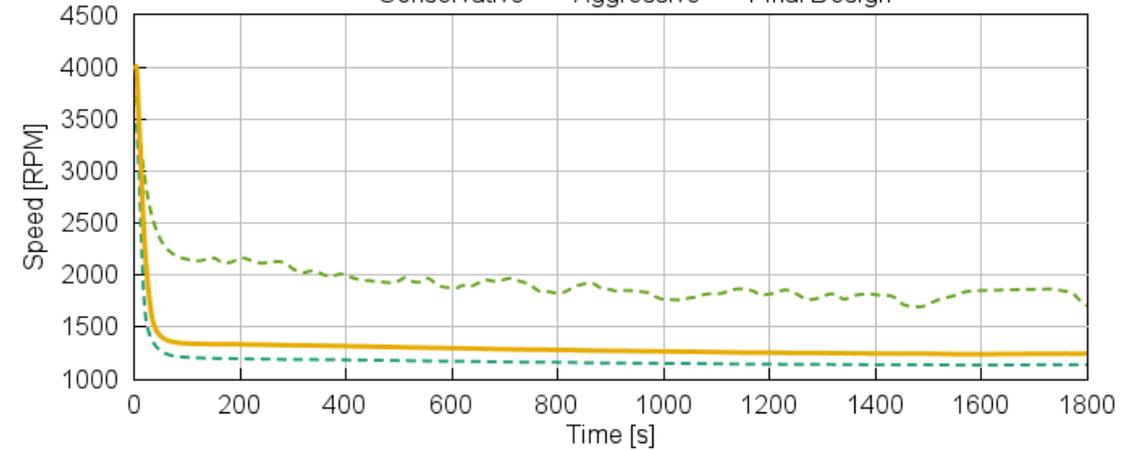
### HT Coolant Circuit Pump

--- Conservative --- Aggressive — Final Design



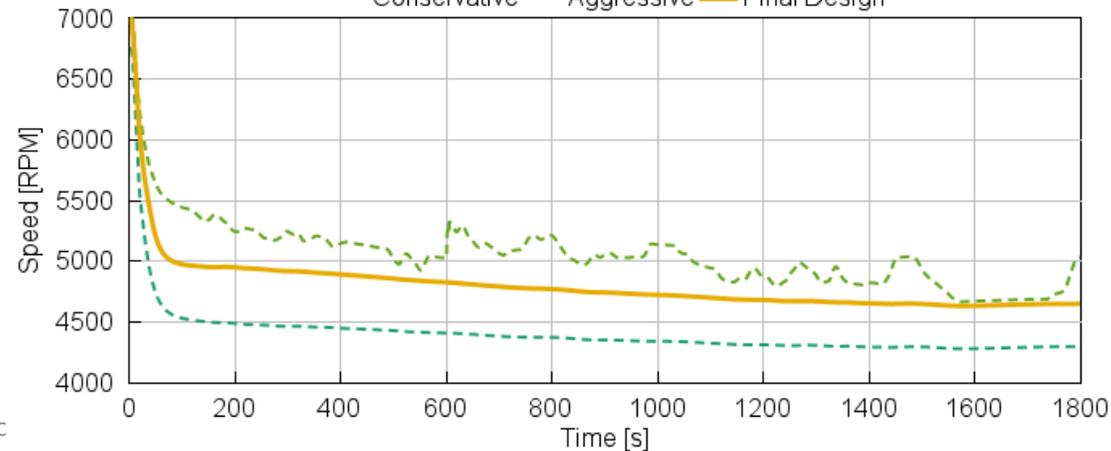
### LT Coolant Pump

--- Conservative --- Aggressive — Final Design



### Compressor

--- Conservative --- Aggressive — Final Design

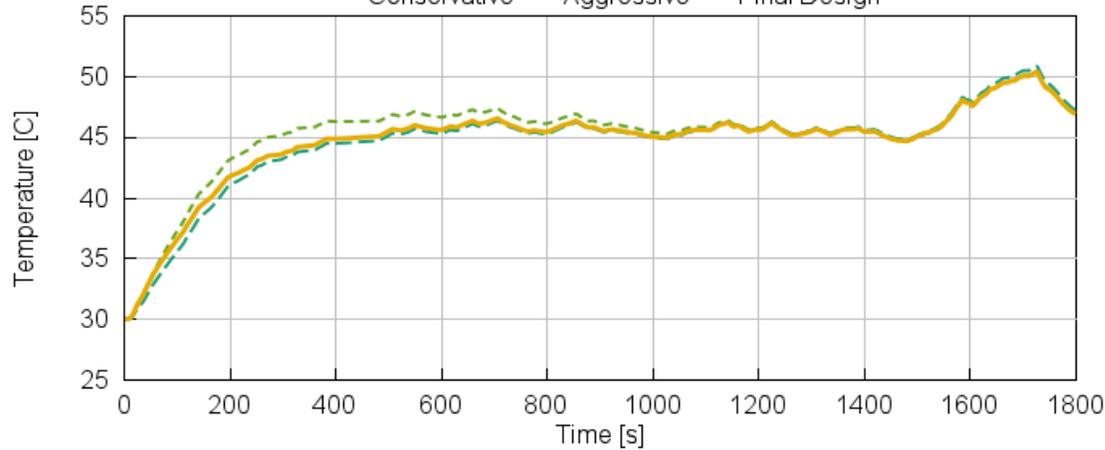


# Setpoint Control Optimization

## Temperatures

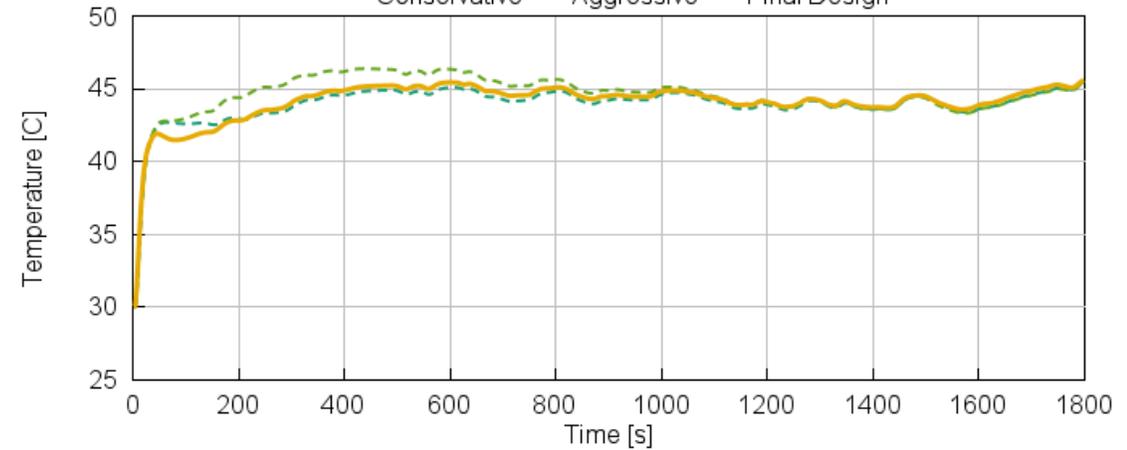
### E-Motor Average Temperature

— Conservative - - Aggressive — Final Design



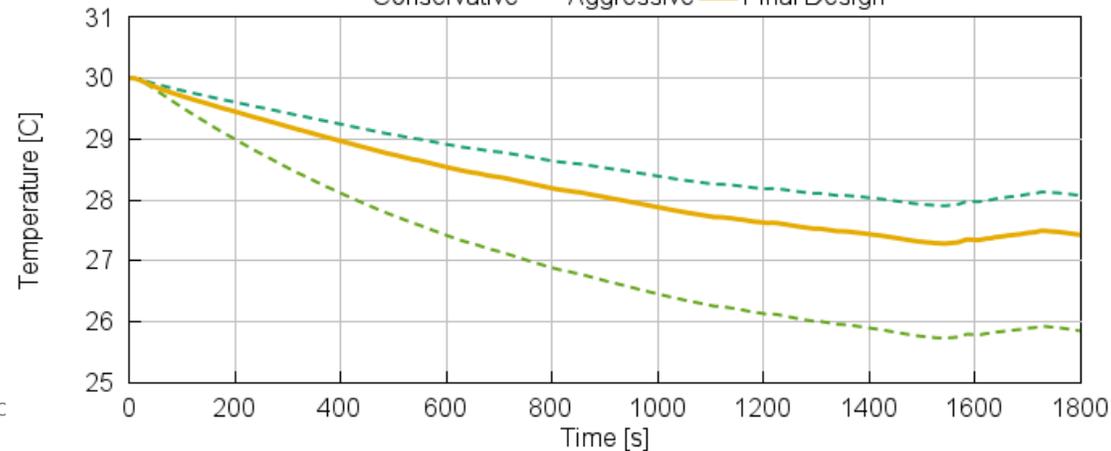
### DCDC Average Temperature

— Conservative - - Aggressive — Final Design

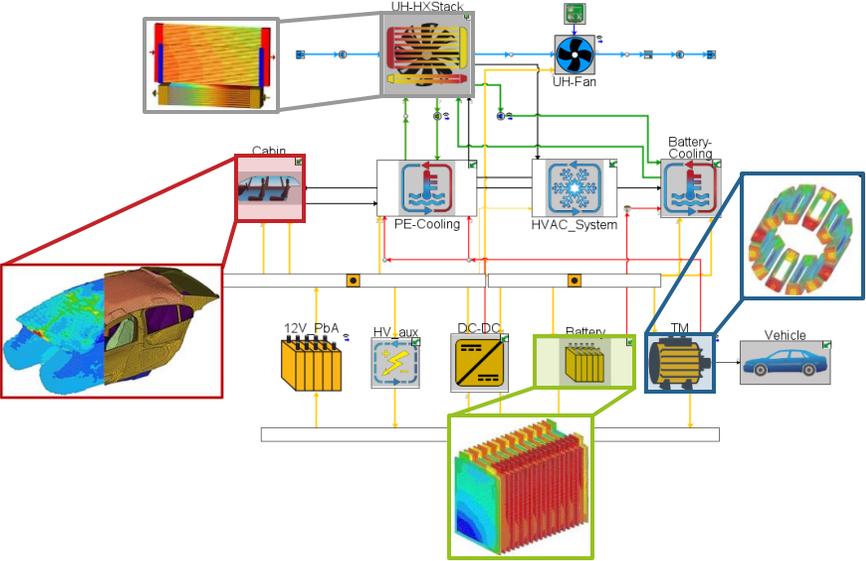
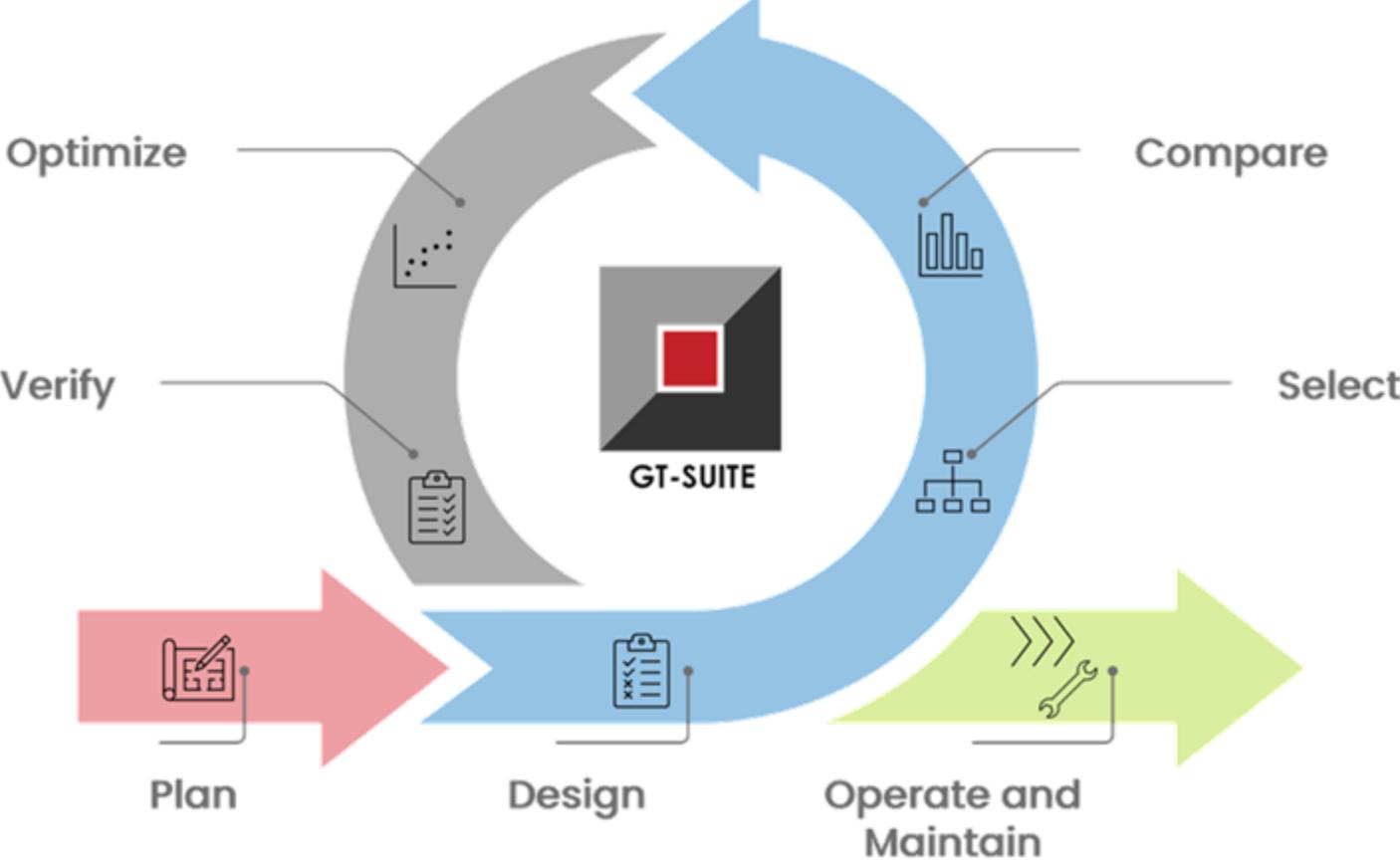


### Battery Plate Average Temperature

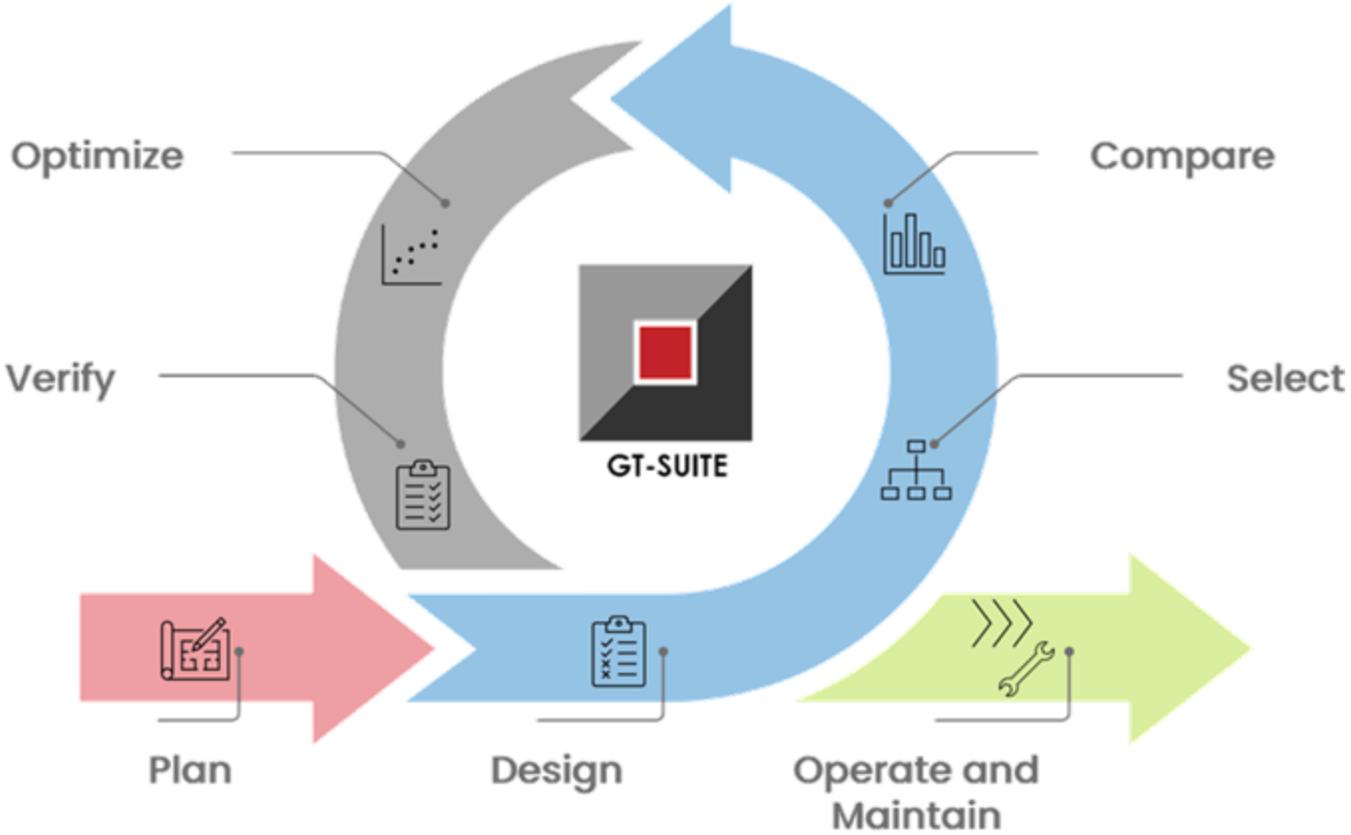
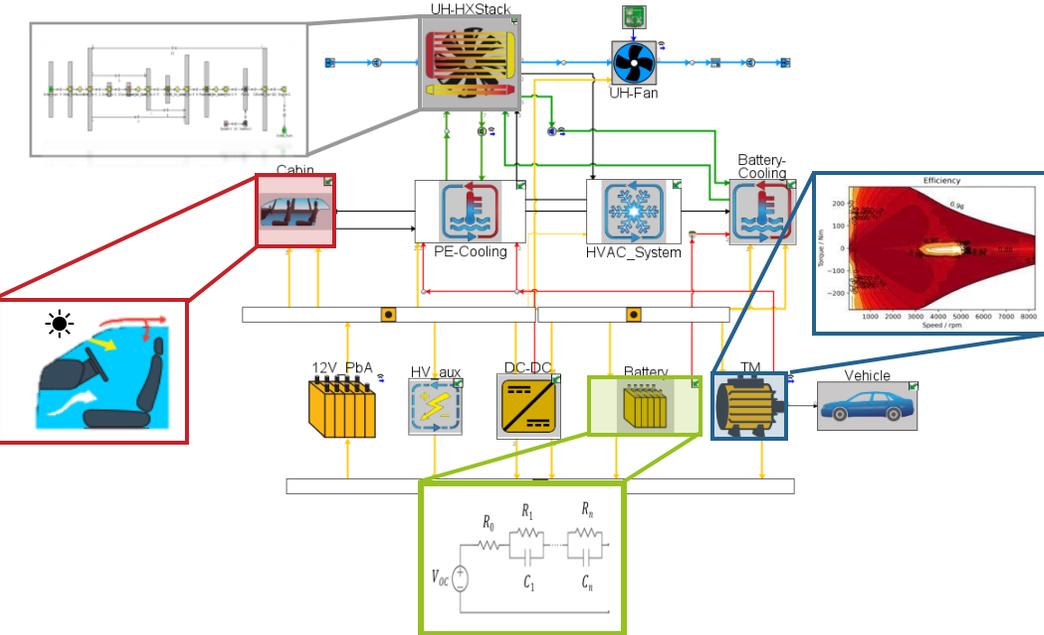
— Conservative - - Aggressive — Final Design



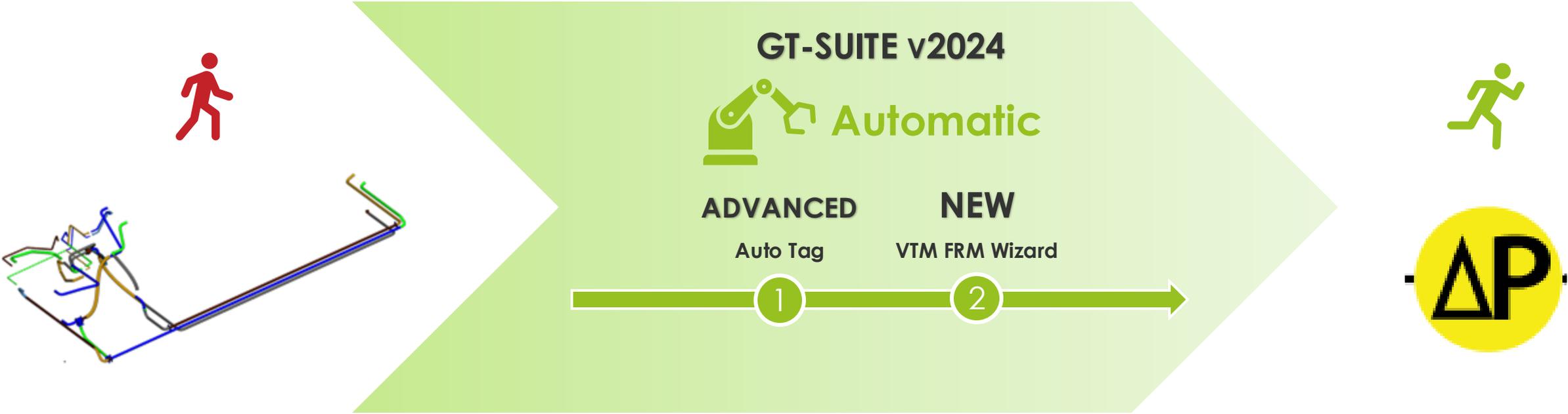
# Detailed System Analysis



# Function Development and Controls



# Volume Reduction for Model Speedup



# Holistic System Simulation Model for XiL

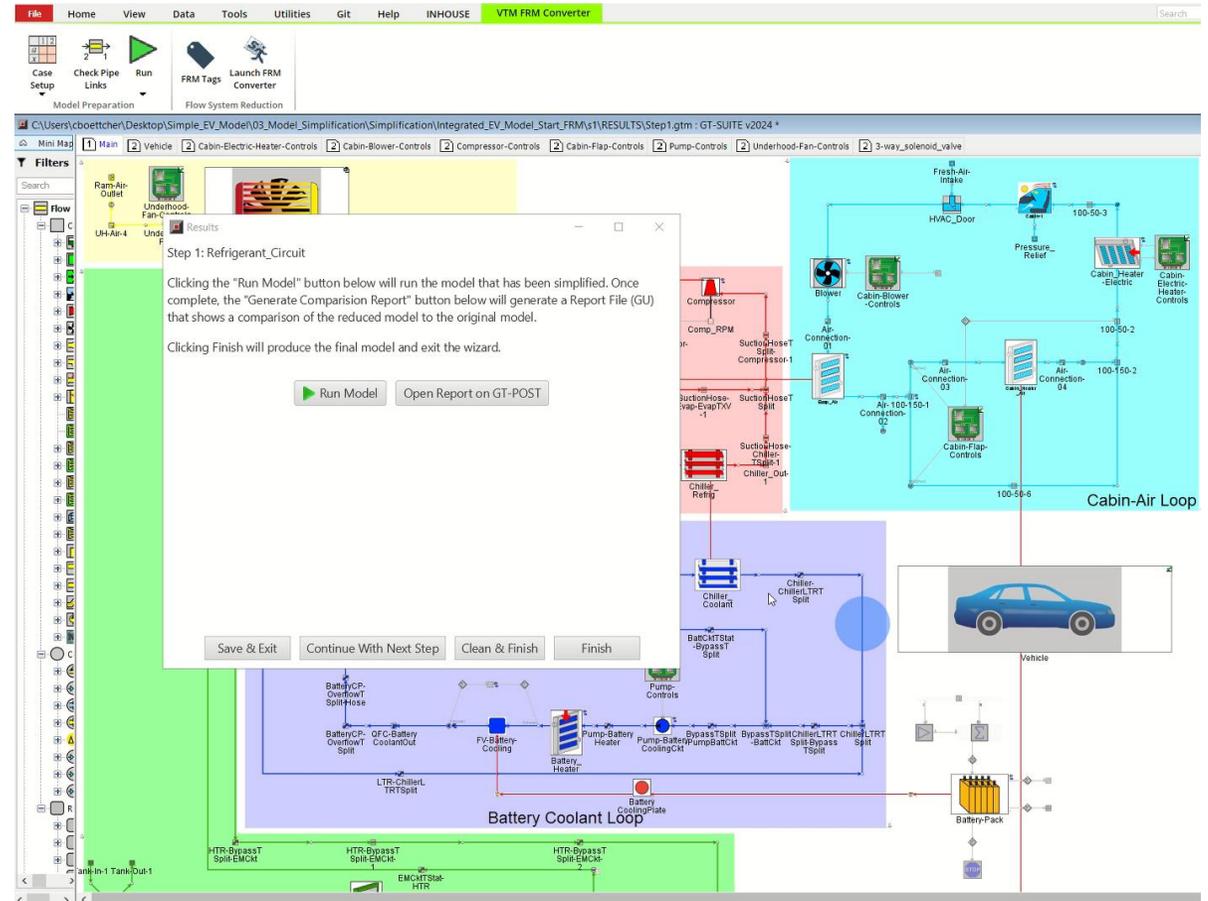
Automatic Identification



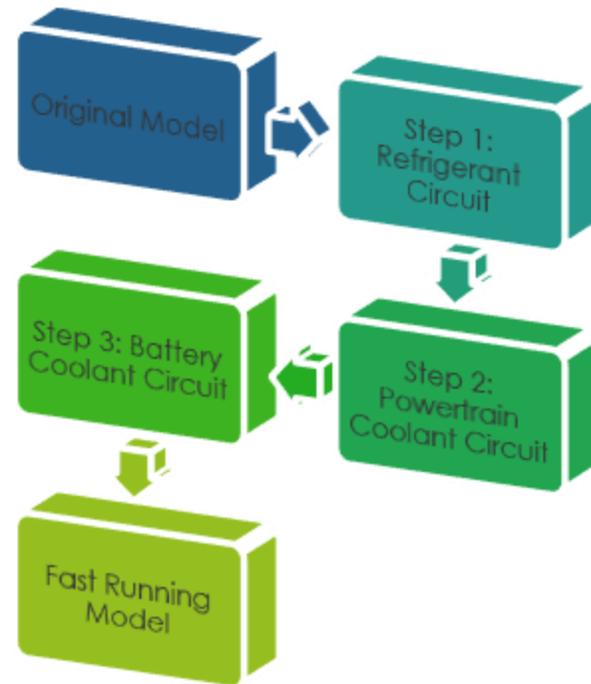
Fast Conversion



Automatic Comparison



# Additional Steps to reduce Model Run Time



## Improved Refrigerant Solver

- Value Added:
  - More stable @ zero flow – Common as heat pump switches mode
  - Reduce thermal team time investment – Faster model development iteration due to quick result feedback
  - Reduce control team time investment – Fast-running physical model is desired for control development and is required for HiL applications

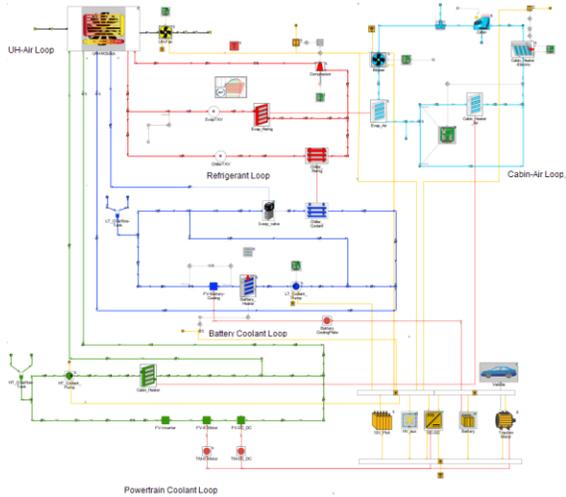
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## Two Fluid NTU Model (Heat Exchanger)

- Fluid temperature blend model
  - Temperature distribution
  - Valid for transient simulations
- Follows trend of  $\epsilon = f(NTU)$
- Value Added:
  - ↓ Subvolumes
  - ↓ Run time
  - Accurate results
  - New HX configurations

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# Conclusion



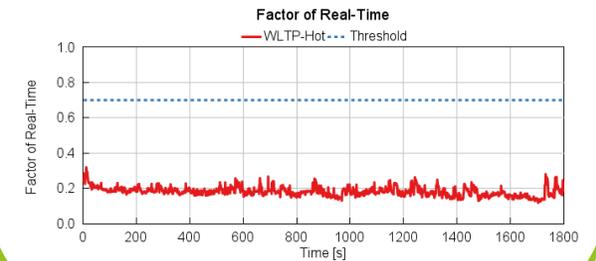
Automatic Identification



Fast Conversion



Automatic Comparison



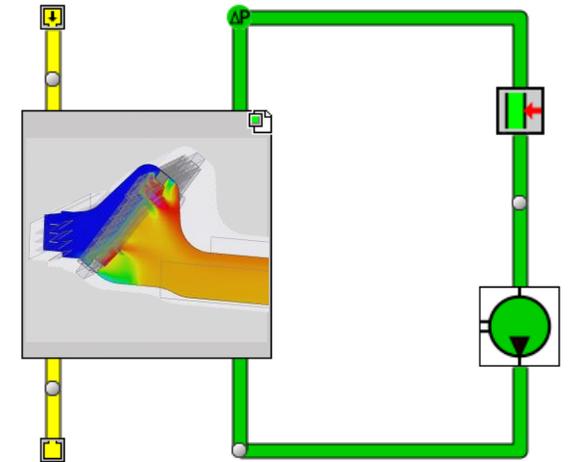
# GT-Auto-3DFlow

Fusion of thermal 1D flow with 3D CFD

Higher accuracy for all geometries & modes

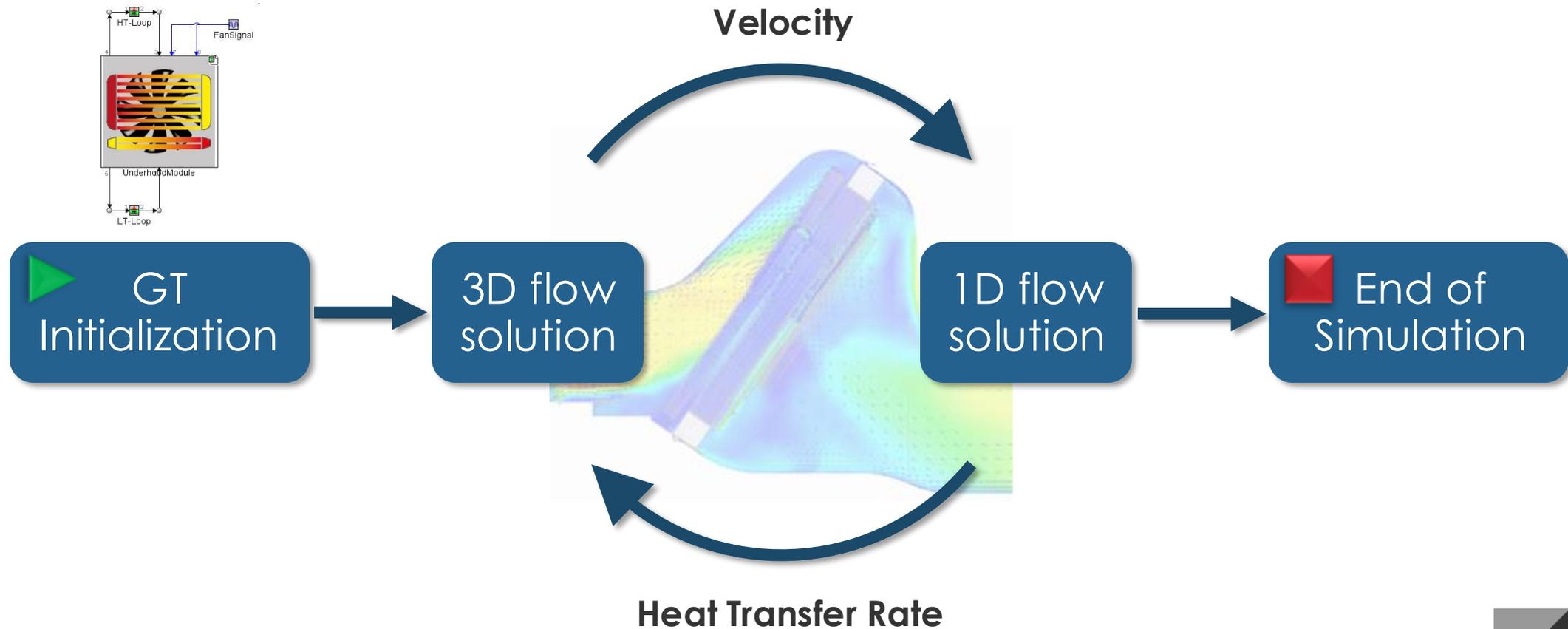
Fast turn-around time using known workflows

Fast, high impact results for your engineering tasks

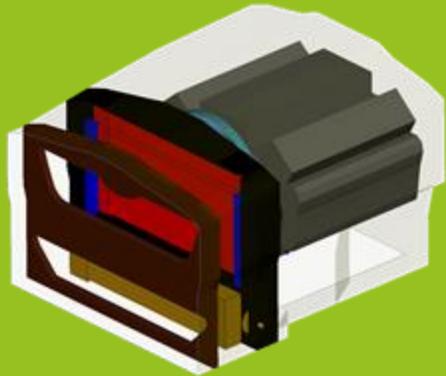


# GT-Auto-3DFlow: Coupled 1D-3D Solution

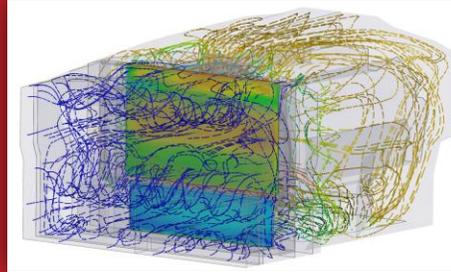
- Integrate with multiple flow domains through GT-SUITE



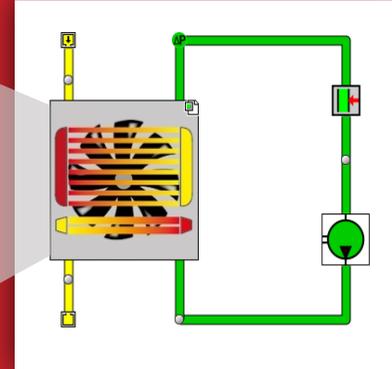
## Optimize Heat Exchanger Sizing and Layout



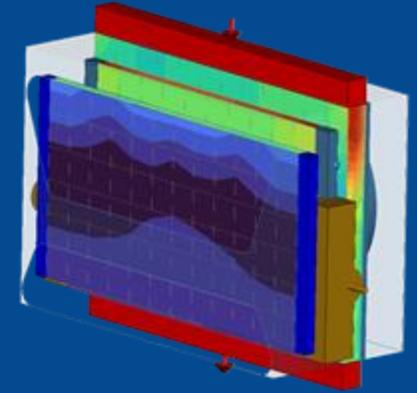
Cool3D  
Geometry Domain  
Setup & Preparation



GT-Auto-3DFlow  
Powered by Simerics



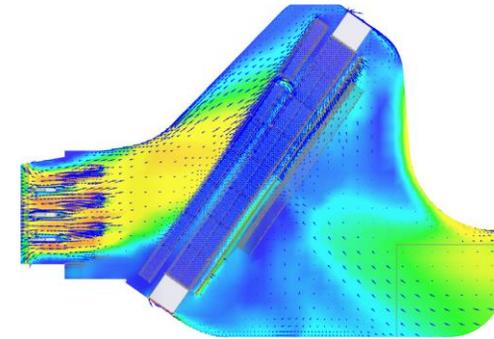
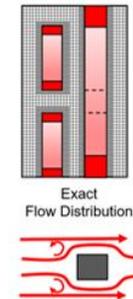
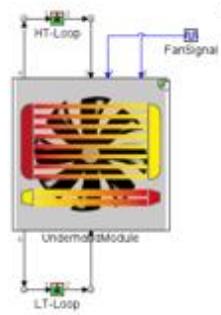
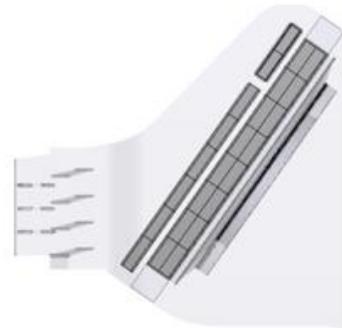
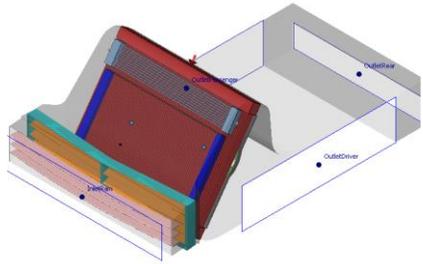
GT-ISE  
Trusted 1D  
GT Flow Solution



GT-POST  
Post-Processing & Analysis

GT 3D SPATIAL FLOW SOLUTION

# Streamlined Solution



Fast building  
of airflow  
environment

Flexible  
placement  
and  
orientation of  
components

Multi-domain  
circuit  
integration

Automatic  
co-simulation  
for an  
accurate 3D  
flow solution

Analyze  
complex flow  
phenomenon

# Summary

