Find your FIT

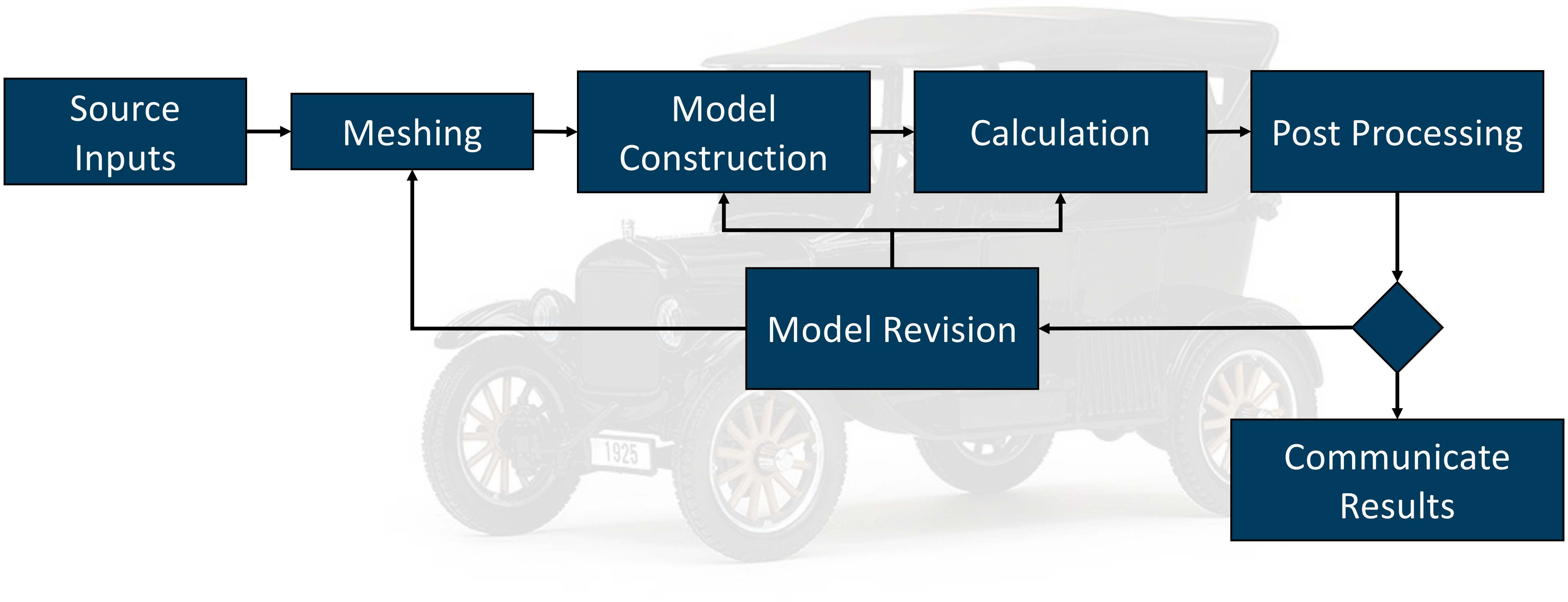
A Comparison of Strategies for Simulating Vehicle Heat Protection Test Cycles in 3D

ThermoAnalytics®

The Thermal Management Process

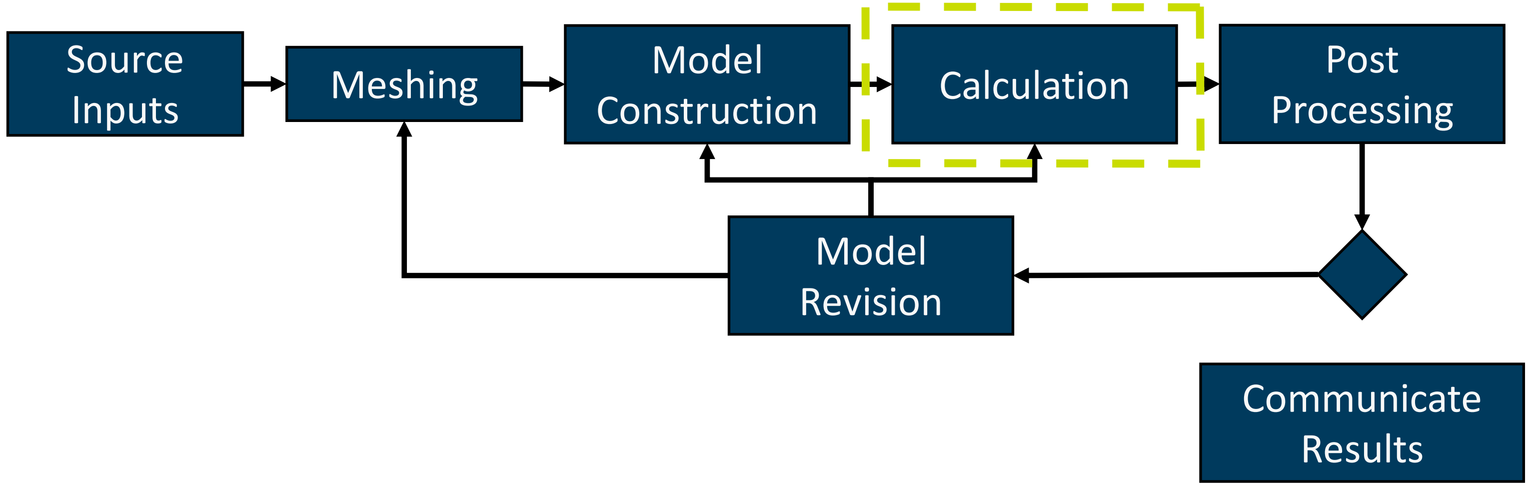
The Thermal Management Process

The ideal process minimizes the cost of each step



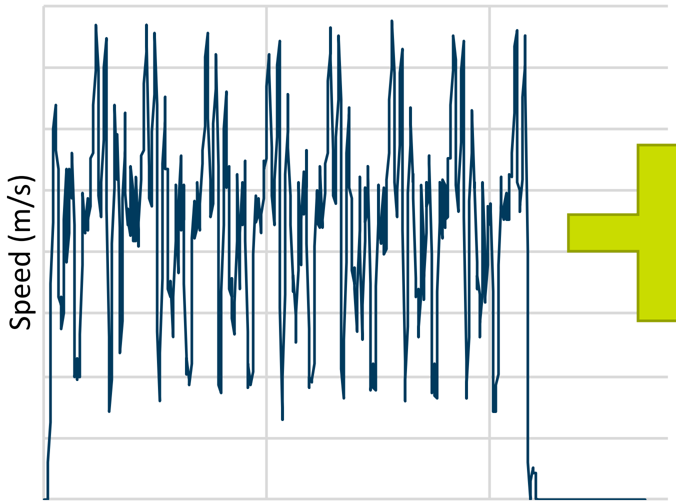
What is the most effective thermal management process?

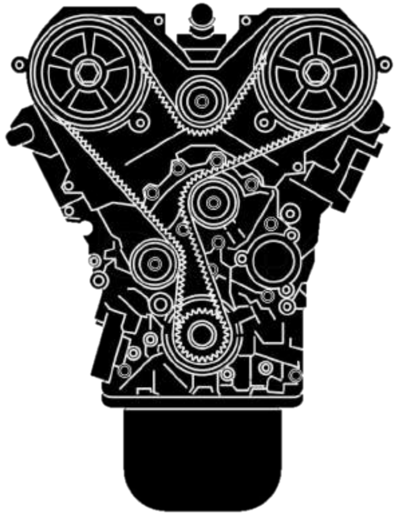
- Needs to support high volume production work
- Easily adapt to specialized jobs
- Minimize resource requirements

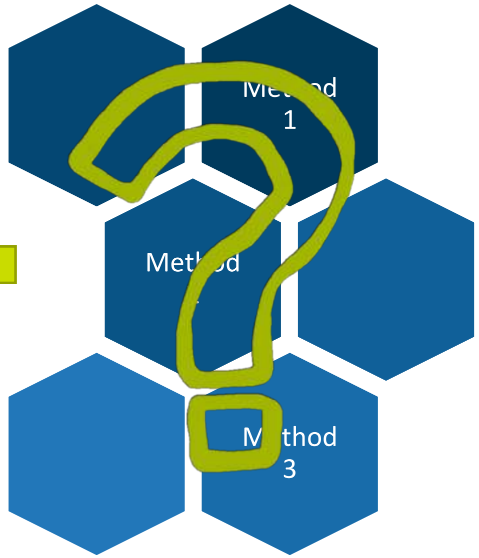


Find your FIT

Calculation







FIT

- Simulation methods
- Approach to evaluation
- Results
- Conclusions

Different Strategies

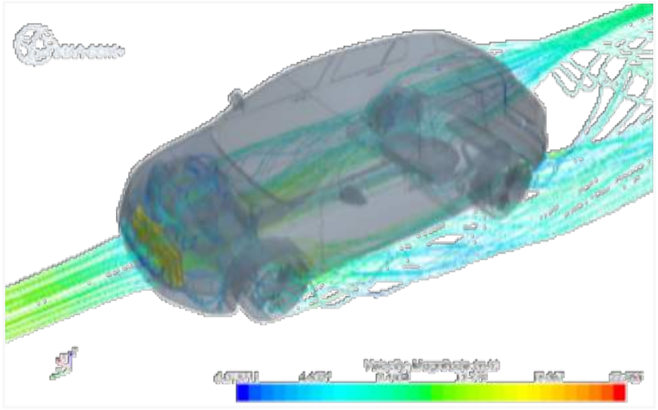
- CHT - Conjugate Heat Transfer
- Step-wise
- Psuedo Transient
- 1D Surrogate
- 2D surrogate

Conjugate Heat Transfer

- Solves as one solution
- Very detailed

CFD Coupling

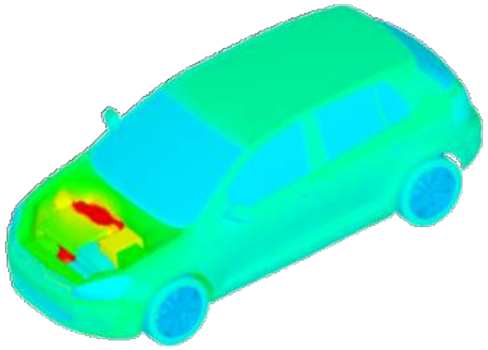
CFD



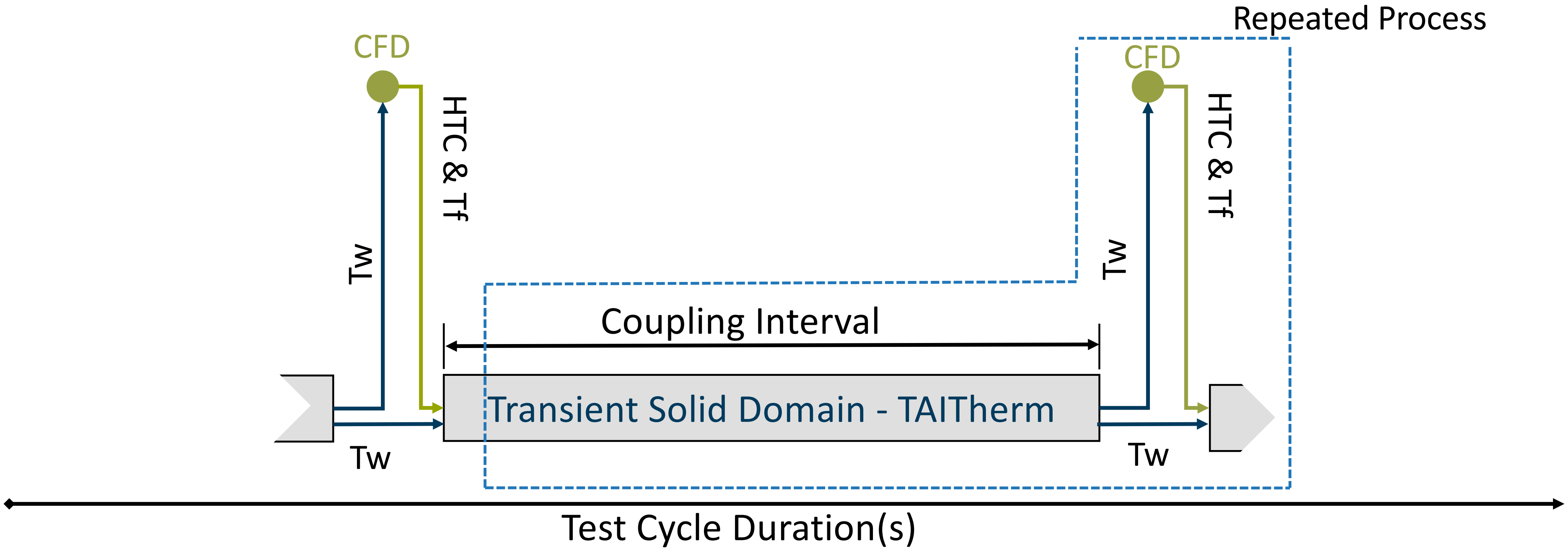
Convection coefficients or fluid velocities
& fluid temperatures
(h and Tfluid)

Surface temps
(Twall)

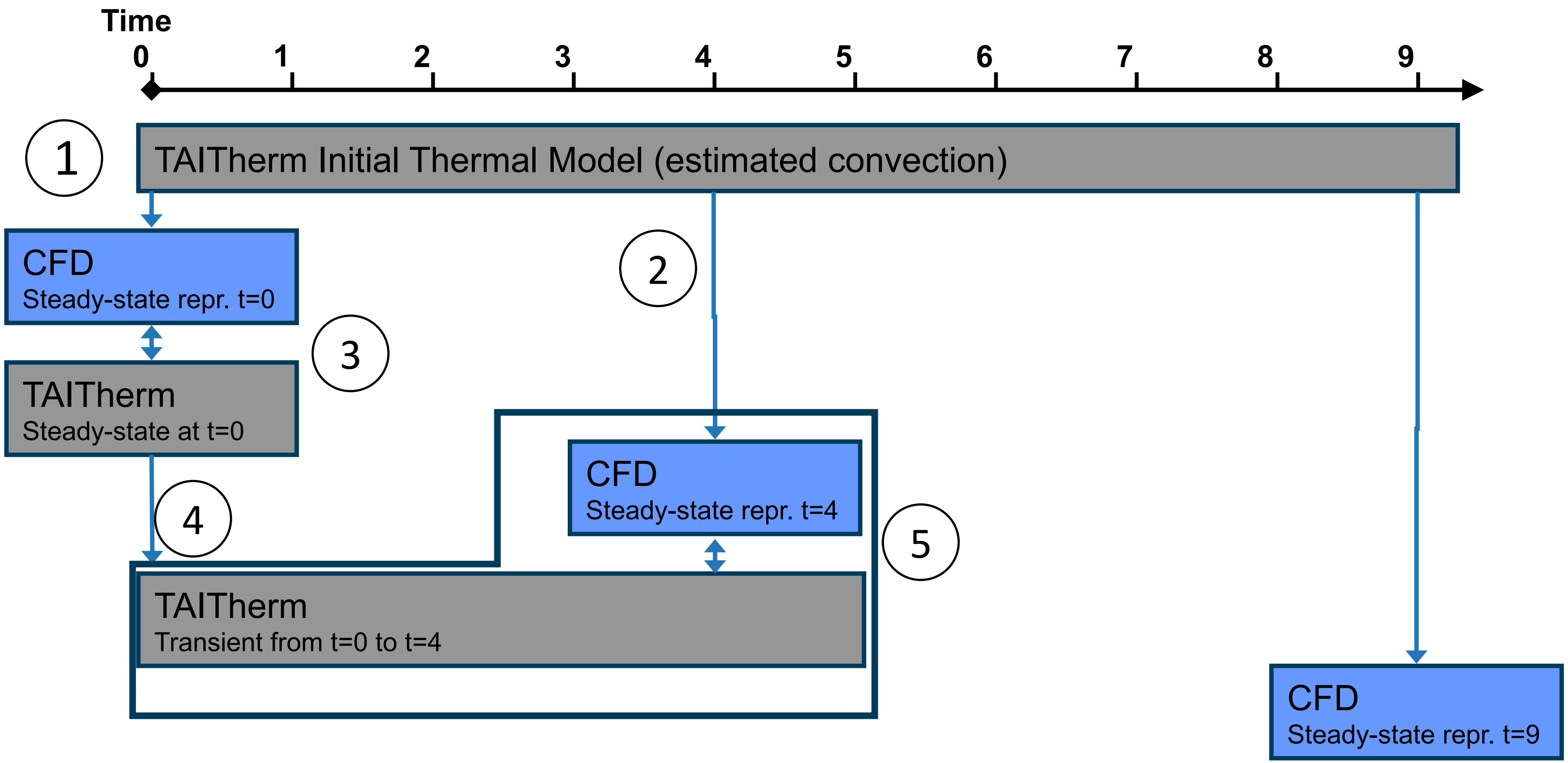
TAITherm

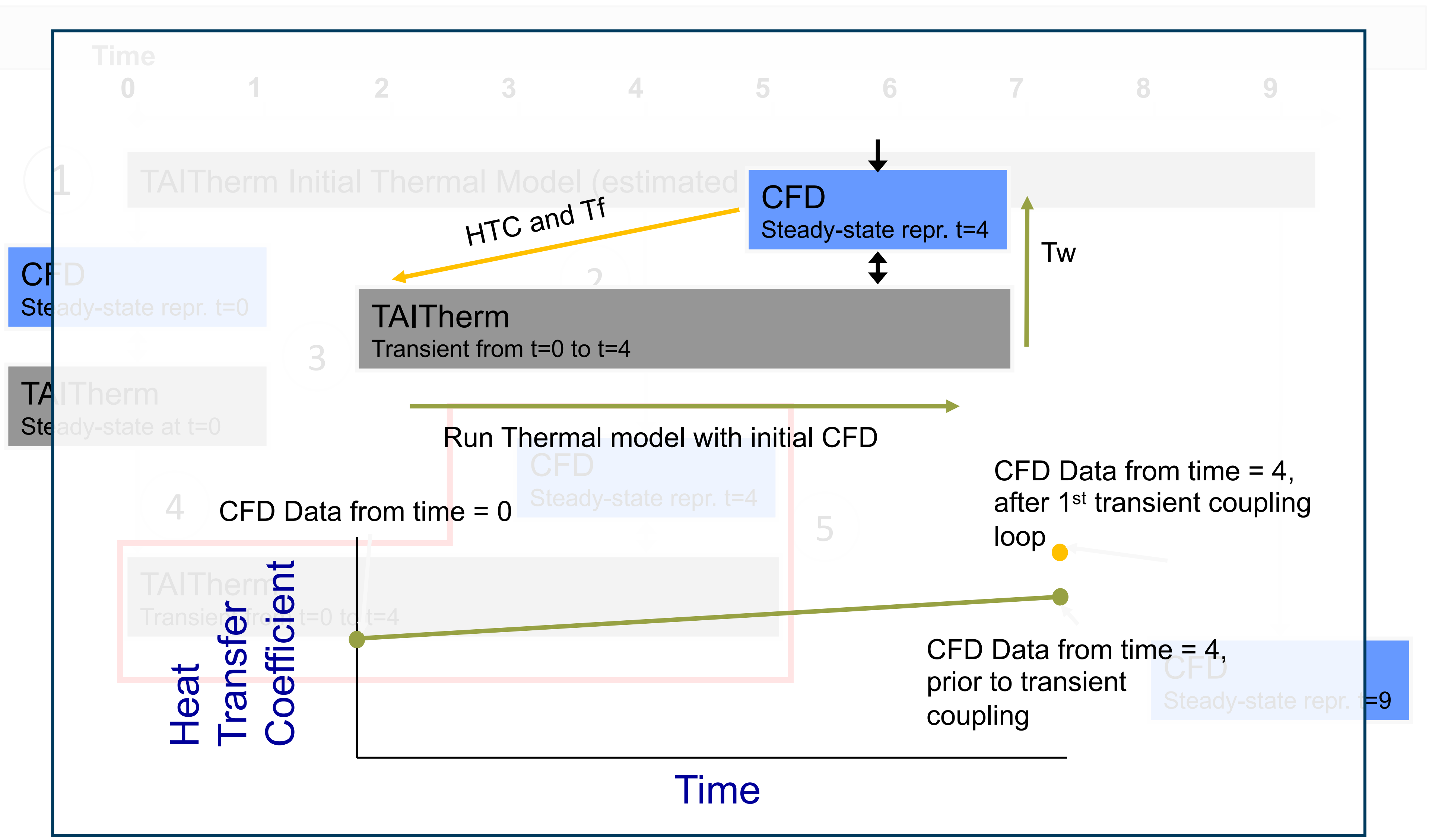


Step Wise

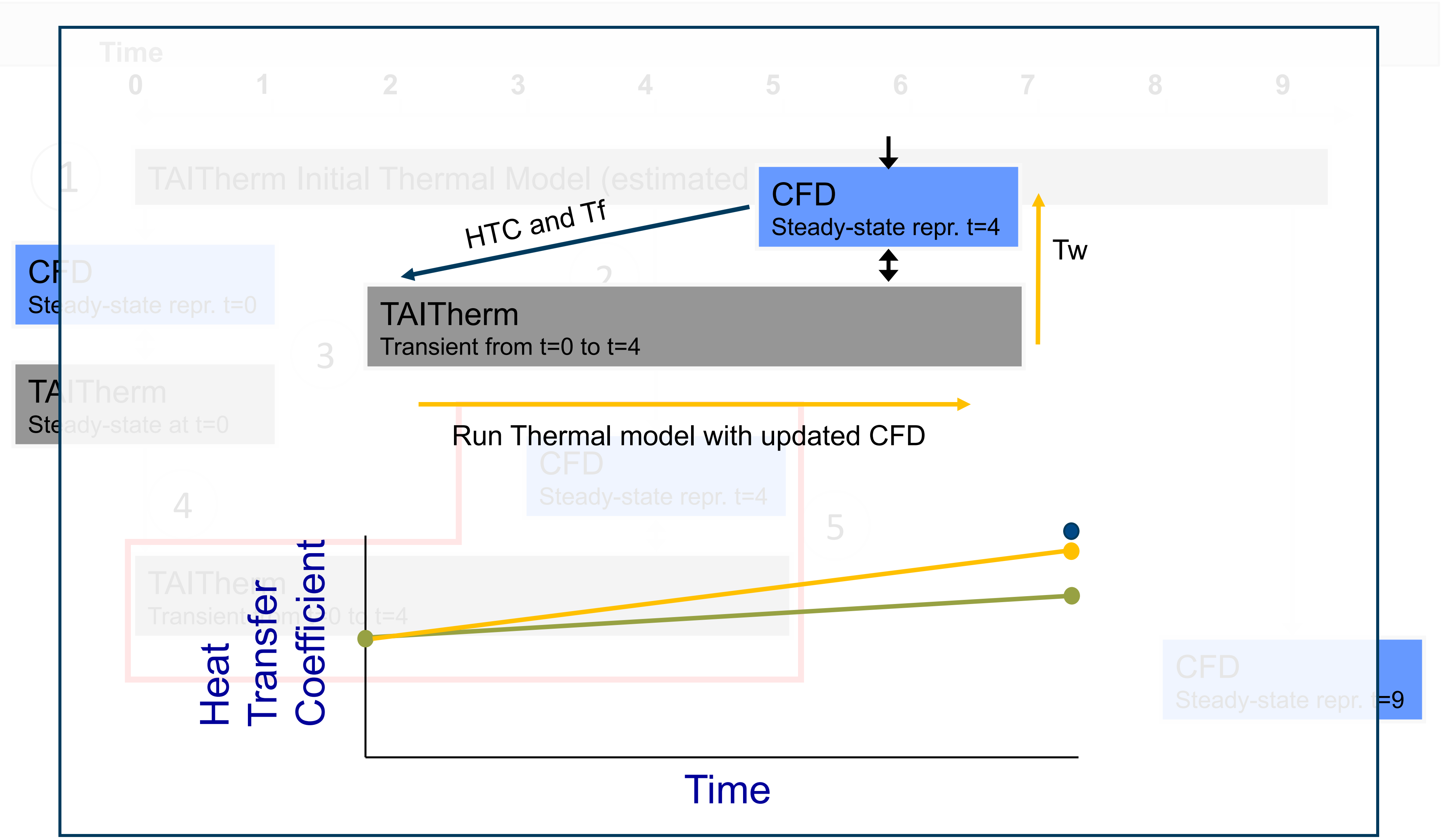

Repeated Process
CFD
HTC & Tf
Tw
CFD
HTC & Tf
Tw
Coupling Interval
Transient Solid Domain - TAITherm
Tw
Tw
Test Cycle Duration(s)

Psuedo-Transient

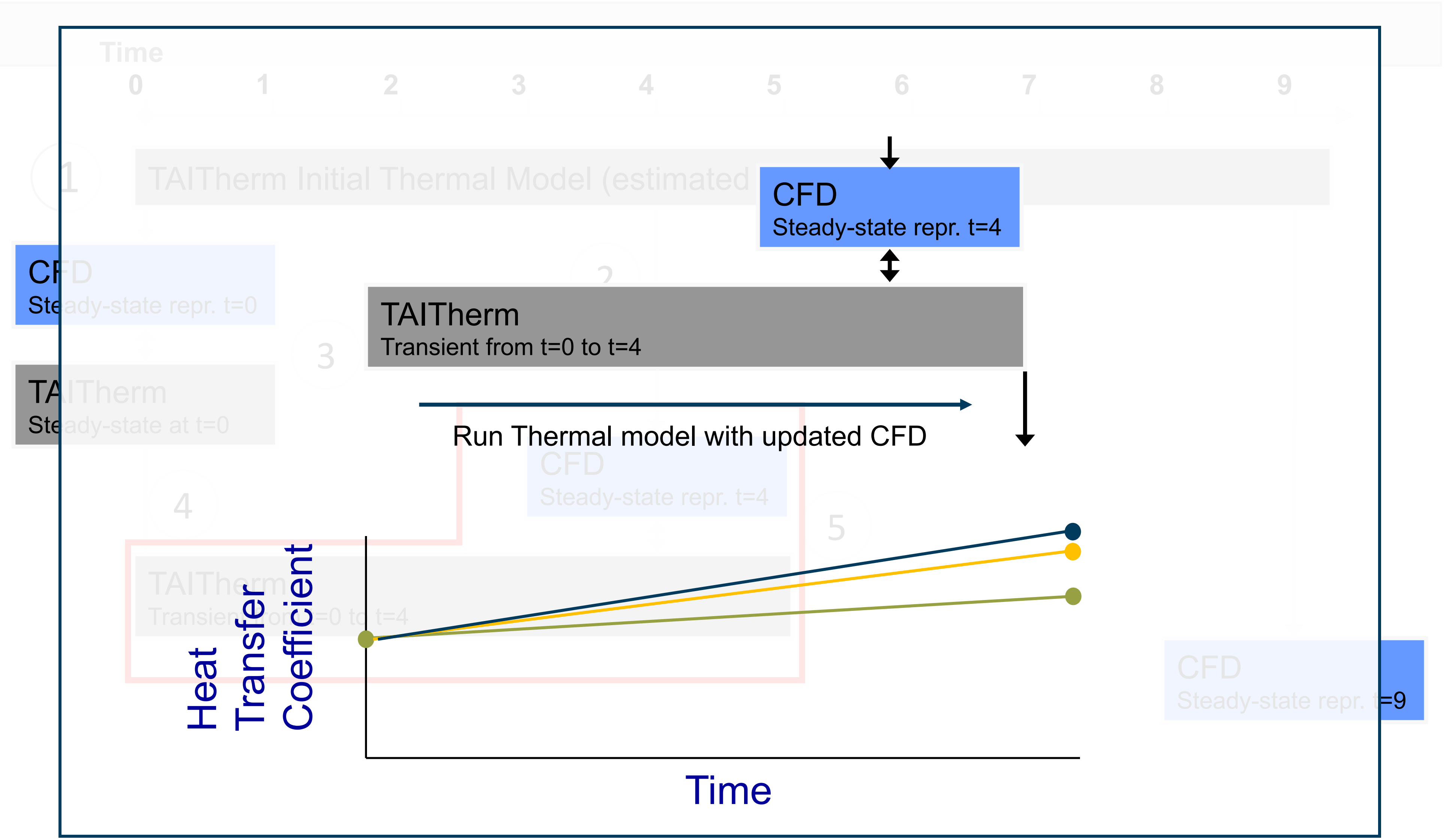



CFD
Steady-state repr. t=4
HTC and Tf
Tw
TAITherm
Transient from t=0 to t=4
Run Thermal model with initial CFD
CFD Data from time = 4, after 1st transient coupling loop
CFD Data from time = 0
CFD Data from time = 4, prior to transient coupling
Heat Transfer Coefficient
Time

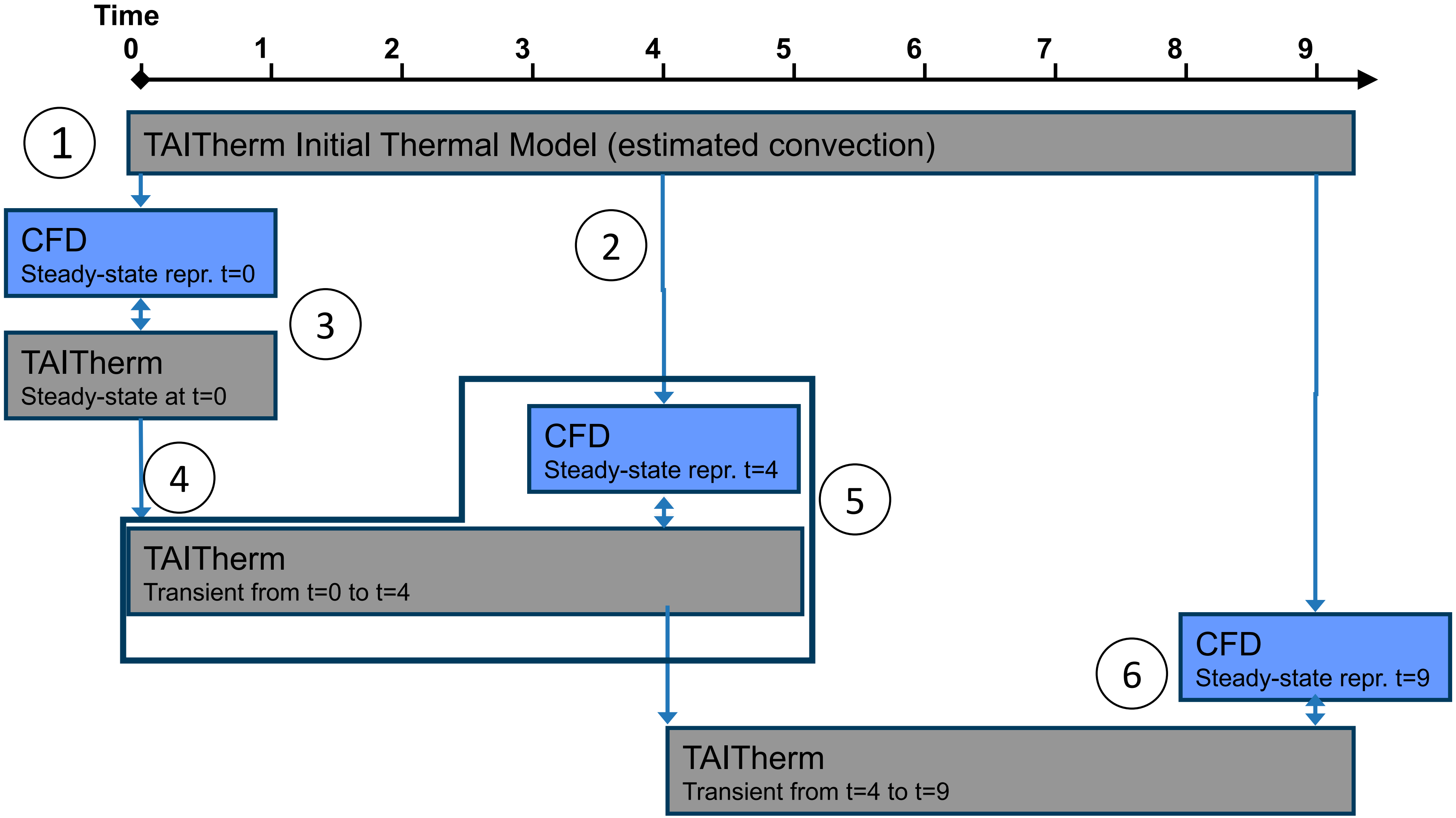
Pseudo-Transient



Pseudo-Transient



Psuedo-Transient



Surrogate Modeling Process

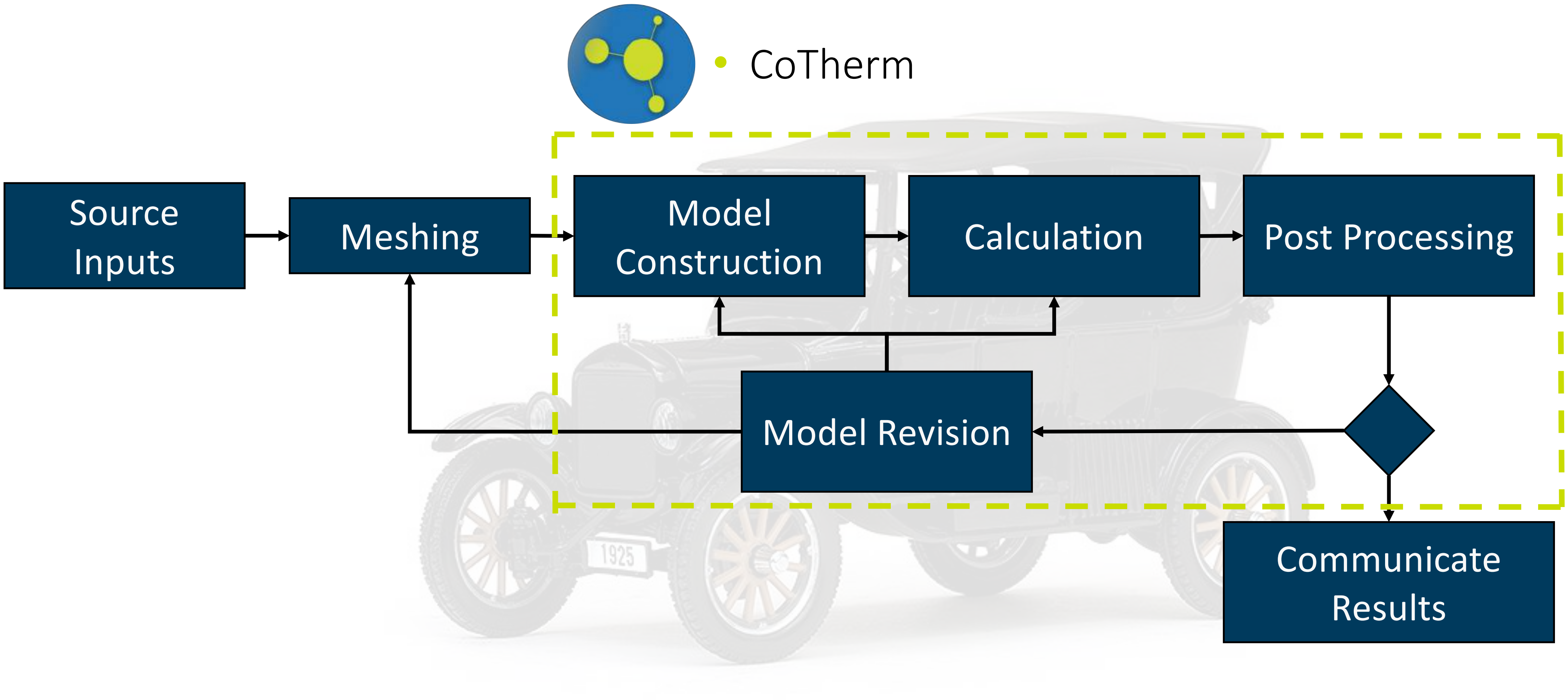
	Sample range of vehicle operating conditions →	Compute a steady state CHT solution at each operating condition →	Fit an equation to the convective boundary conditions →	Run transient thermal model using surrogate model to approximate convective boundary conditions
1D	Uniform Sampling of Vehicle Speed	Coupled CHT solutions	Linear Interpolation	Leveraged Existing Software Features
2D	OLHC of Vehicle Speed and Inlet Temperature	Coupled CHT solutions	Gaussian Anisotropic Kriging	Custom Developed Coupling Harness

	Traditional Conjugate Heat Transfer Simulation	Stepwise Transient	Surrogate Models	Psuedo Transient
Pros	• High Accuracy • Easiest process	• Reduced runtimes • Flexible resource allocation	• Reduced runtimes • Models can be reused • Flexible resource allocation • Flexible post analysis options	• Reduced runtimes • Flexible resource allocation
Cons	• Large computational costs • Inflexible resource allocation	• Steady fluids assumption	• Many samples required • Complex process • Steady sample point assumption	• Complex process • Steady state fluid assumptions

CoTherm

Process automation software from ThermoAnalytics

The Thermal Management Process



Drive Cycle Extension – 1D Surrogate

- CoTherm

- Inputs:
  - Thermal/CFD models
  - Drive cycle data

- Determines coupling points based on Drive Cycle Profile
- Runs steady thermal-CFD cases
- Imports CFD results into transient thermal model
- Runs transient thermal model

- Output:
  - Transient thermal model

Psuedo Transient Method

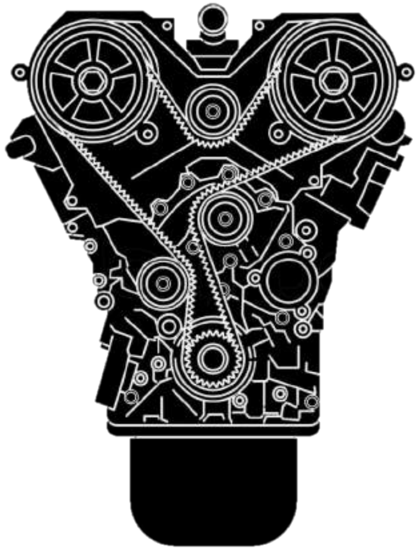
- CoTherm

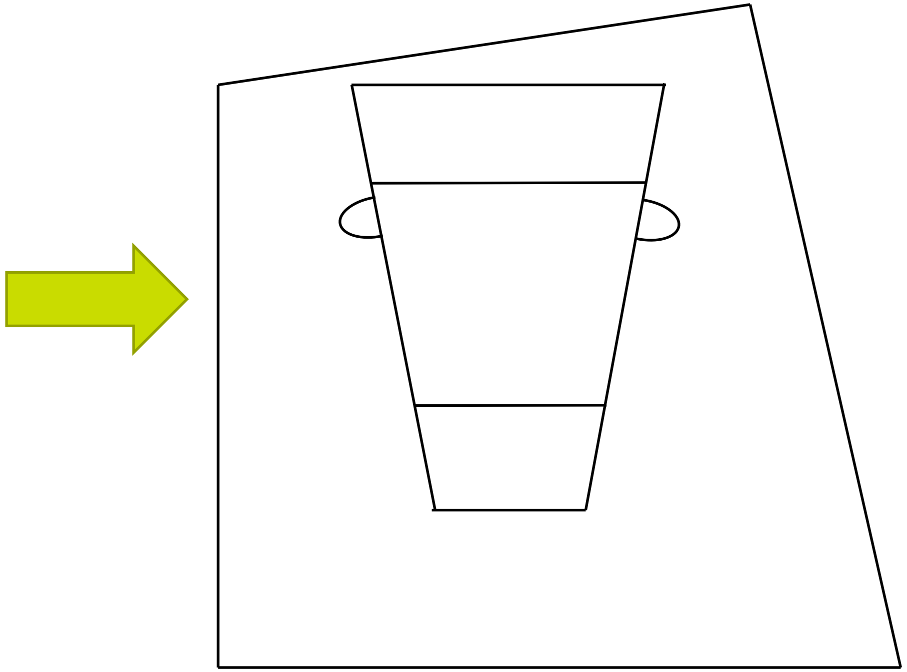
- Inputs:
  - Base Thermal/CFD models
  - Boundary conditions
  - Coupling interval

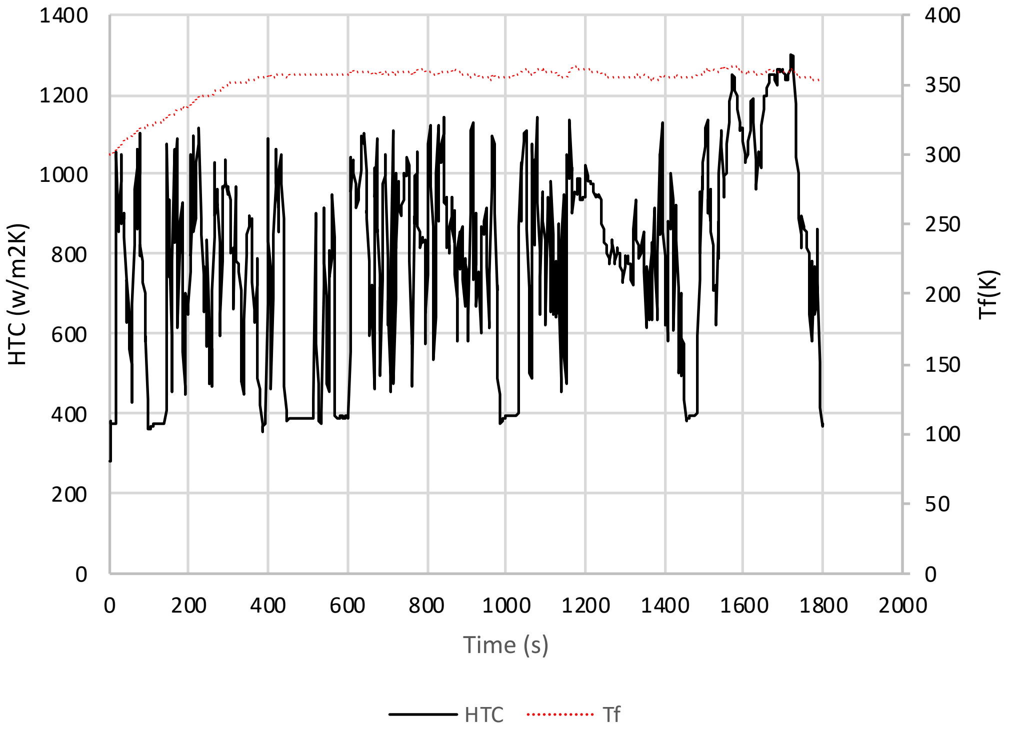
- Automatically sets up SS CFD models
- Couples Thermal and CFD models
- Merges thermal models

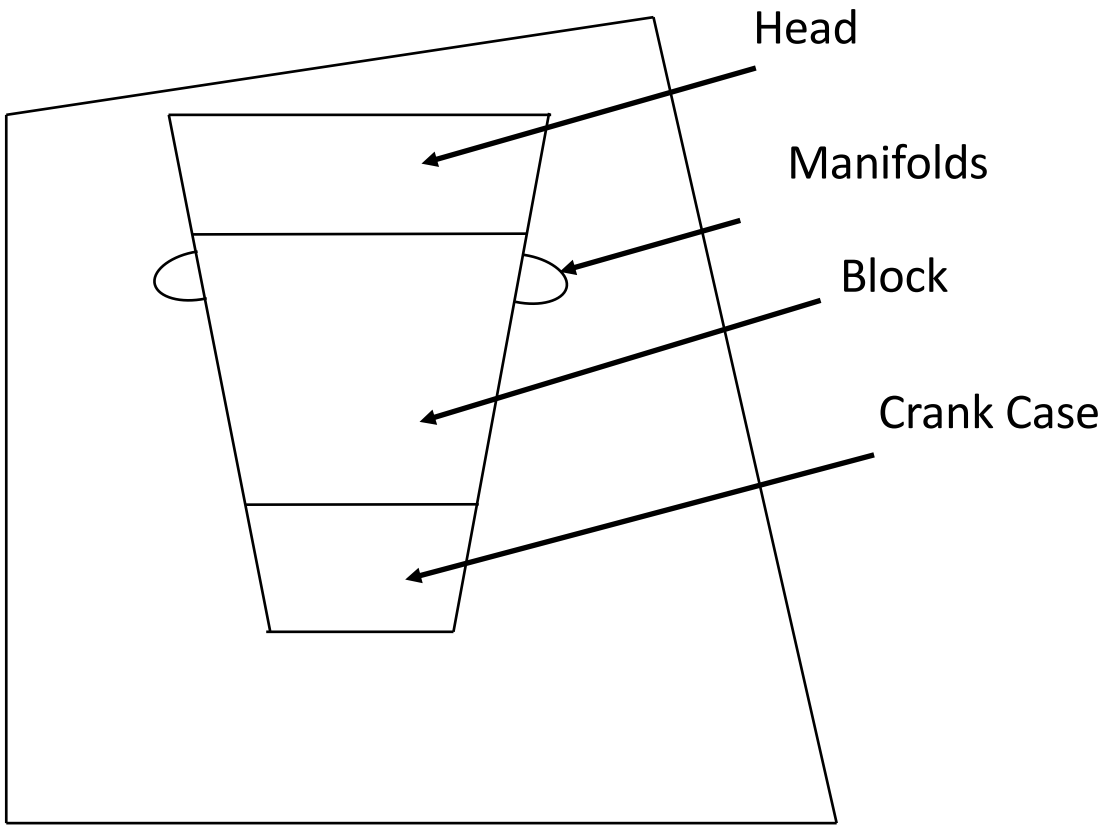
- Output:
  - Merged thermal model with all CFD points

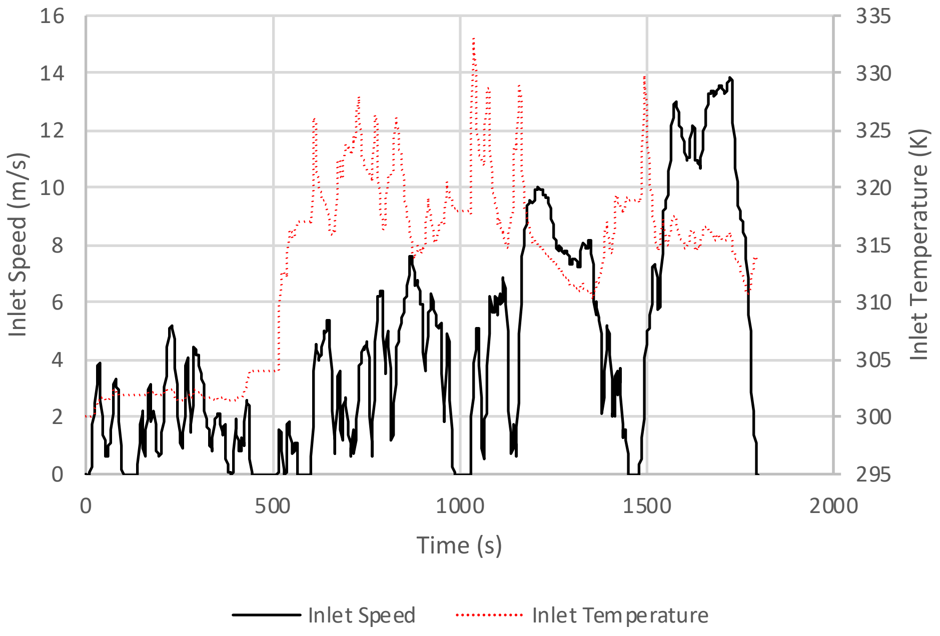
- Selected highly simplified engine bay geometry
    - 34,602 surface elements
    - 275,748 volume elements

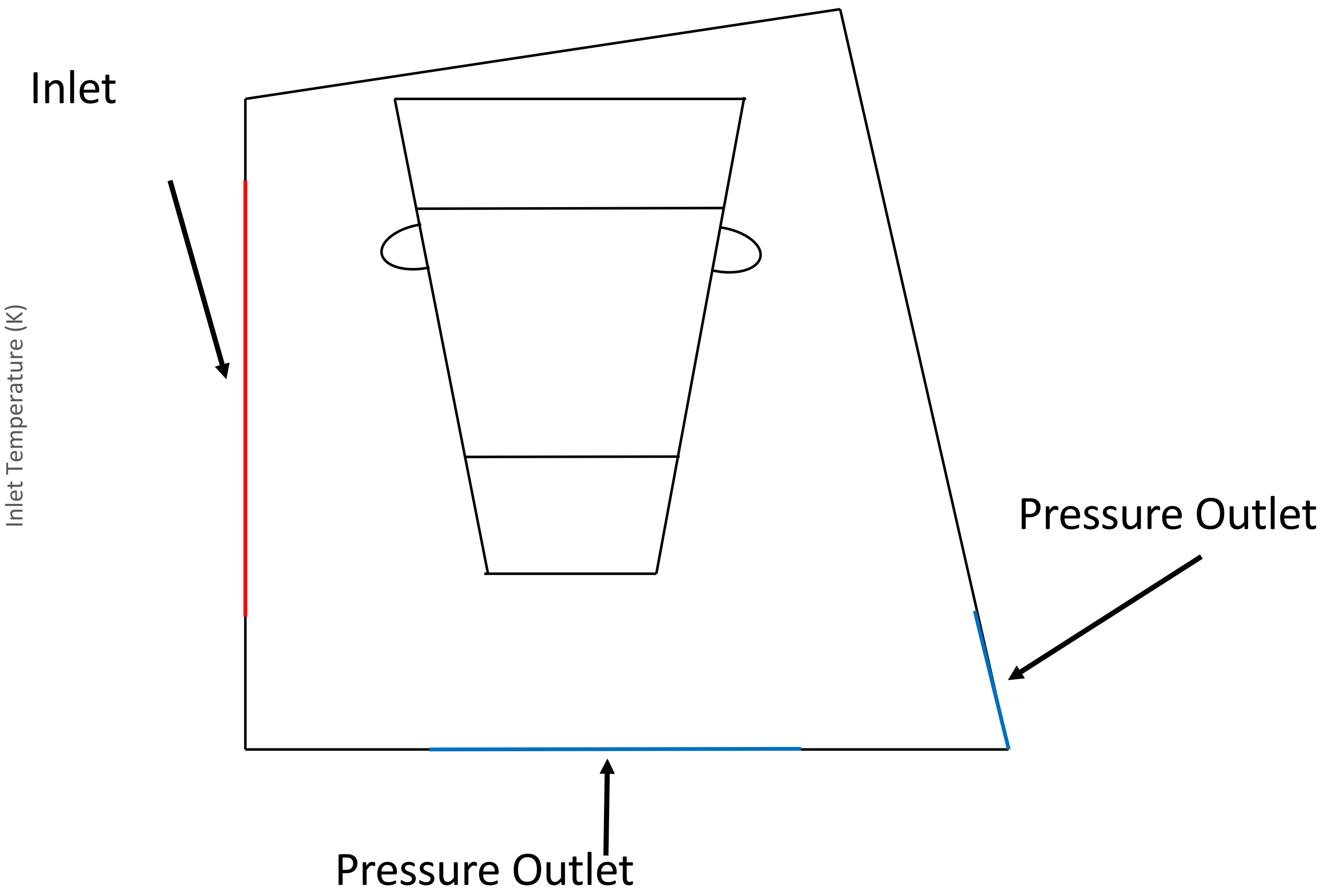


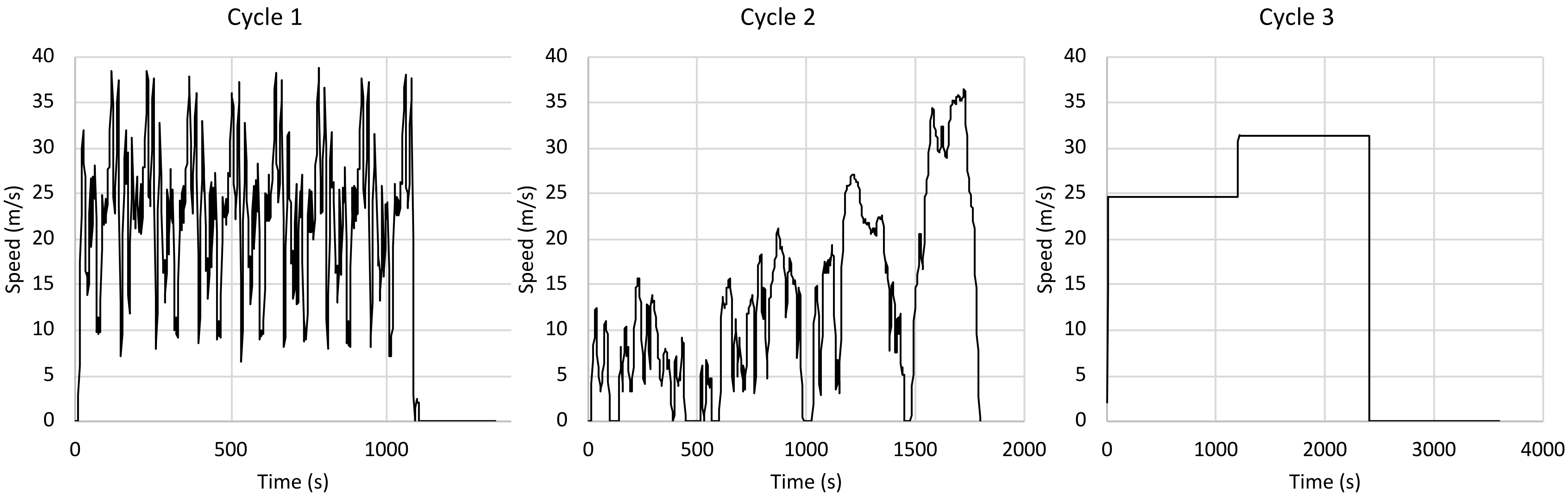



1400
1200
1000
800
600
400
200
0
HTC (w/m2K)
400
350
300
250
200
150
100
50
0
Tf(K)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Time (s)
HTC
Tf

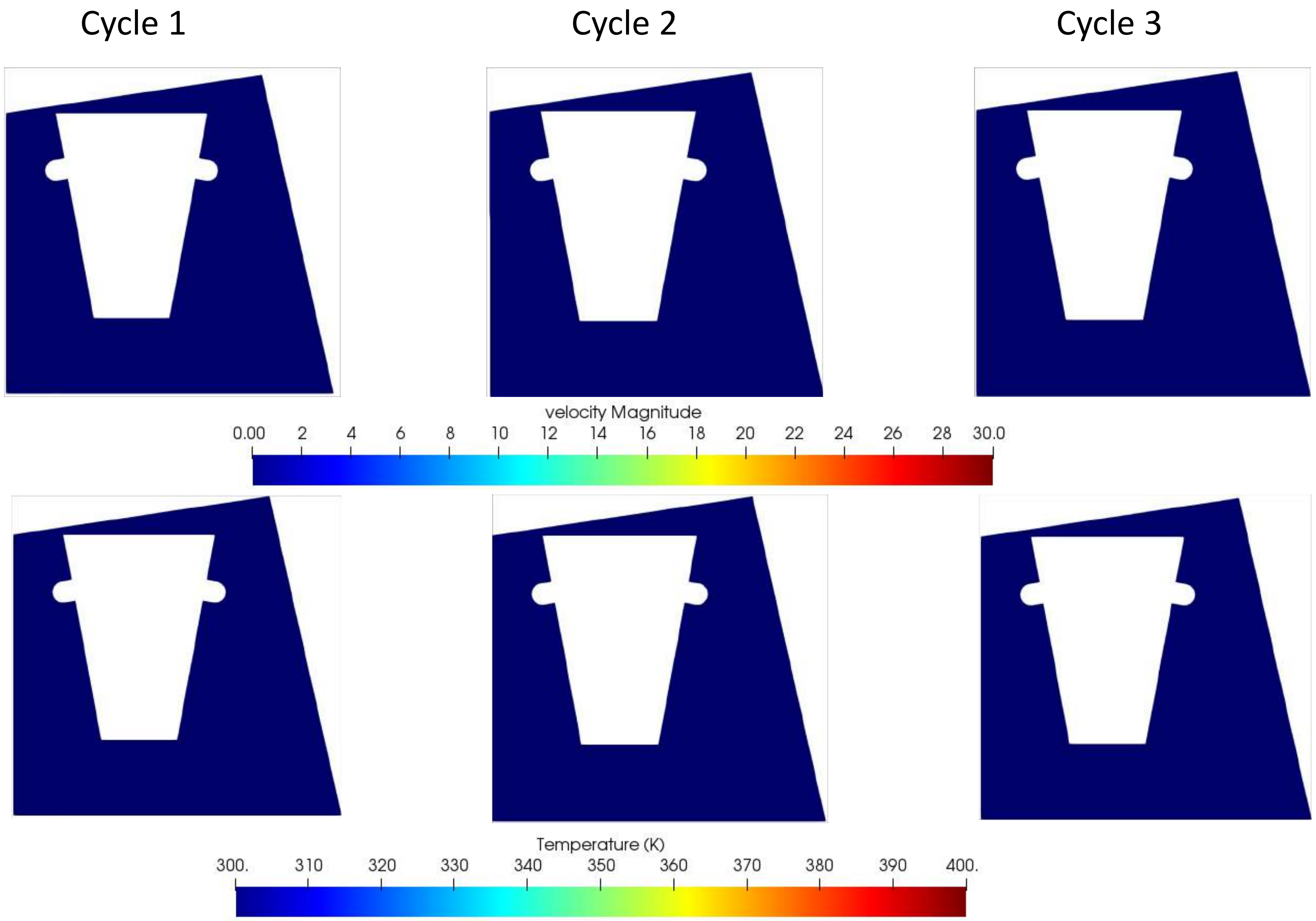

Head
Manifolds
Block
Crank Case

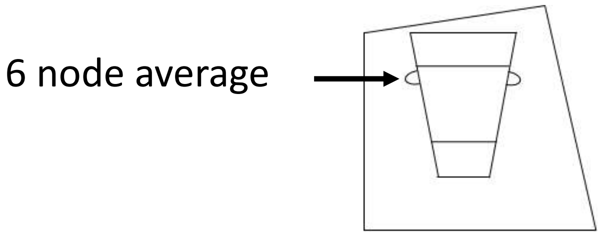

Inlet Speed (m/s)
Inlet Temperature (K)
Time (s)
16
14
12
10
8
6
4
2
0
335
330
325
320
315
310
305
300
295
0
500
1000
1500
2000
Inlet Speed
Inlet Temperature


Inlet
Pressure Outlet
Pressure Outlet

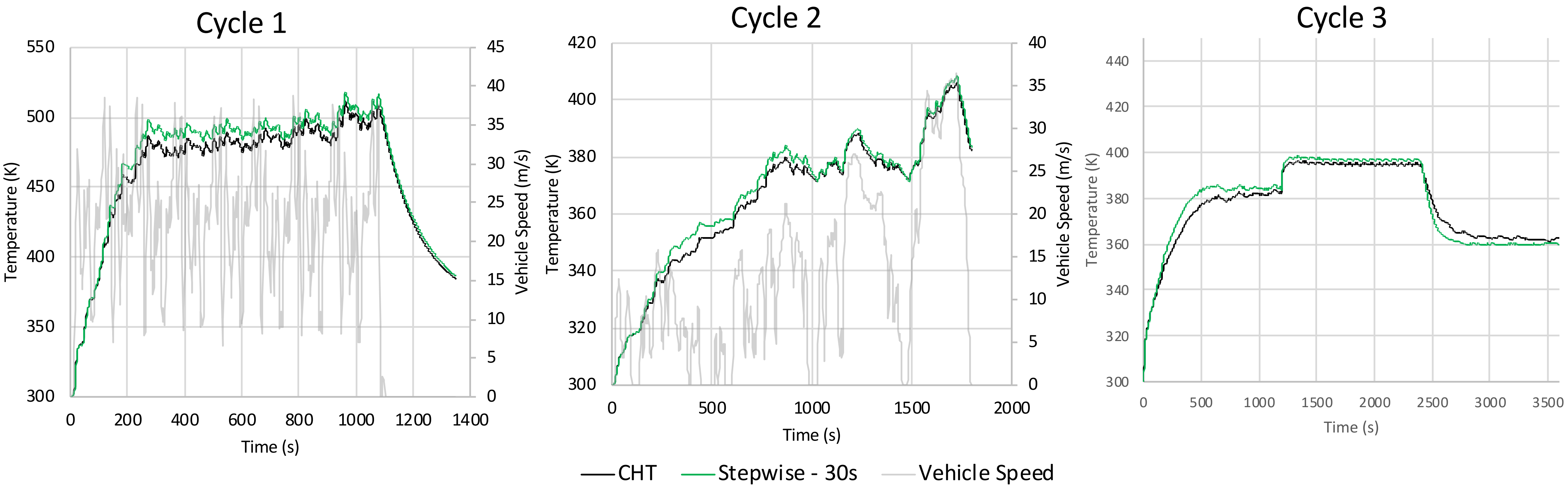


Duration (s)	1350	1800	3600
Max Speed (m/s)	38.8	36.5	31.4
Avg. Speed (m/s)	18.0	12.9	18.6
Volatility	2.98	0.27	0.06


Cycle 1
Cycle 2
Cycle 3
velocity Magnitude
0.00 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30.0
Temperature (K)
300. 310 320 330 340 350 360 370 380 390 400.

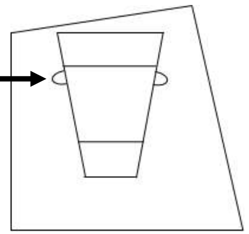


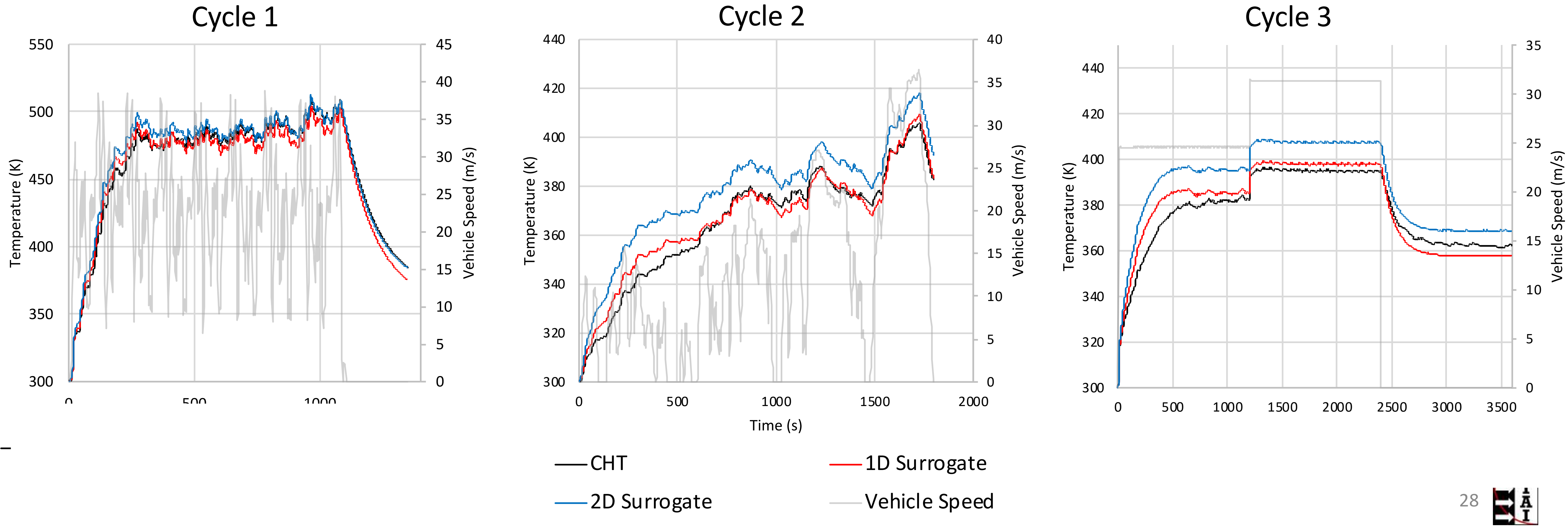
Stepwise Transient Prediction - Temperature



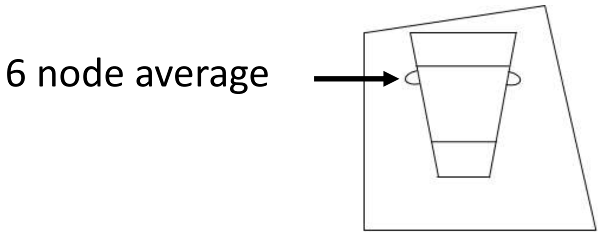
Surrogate Model Transient Prediction – Temperature

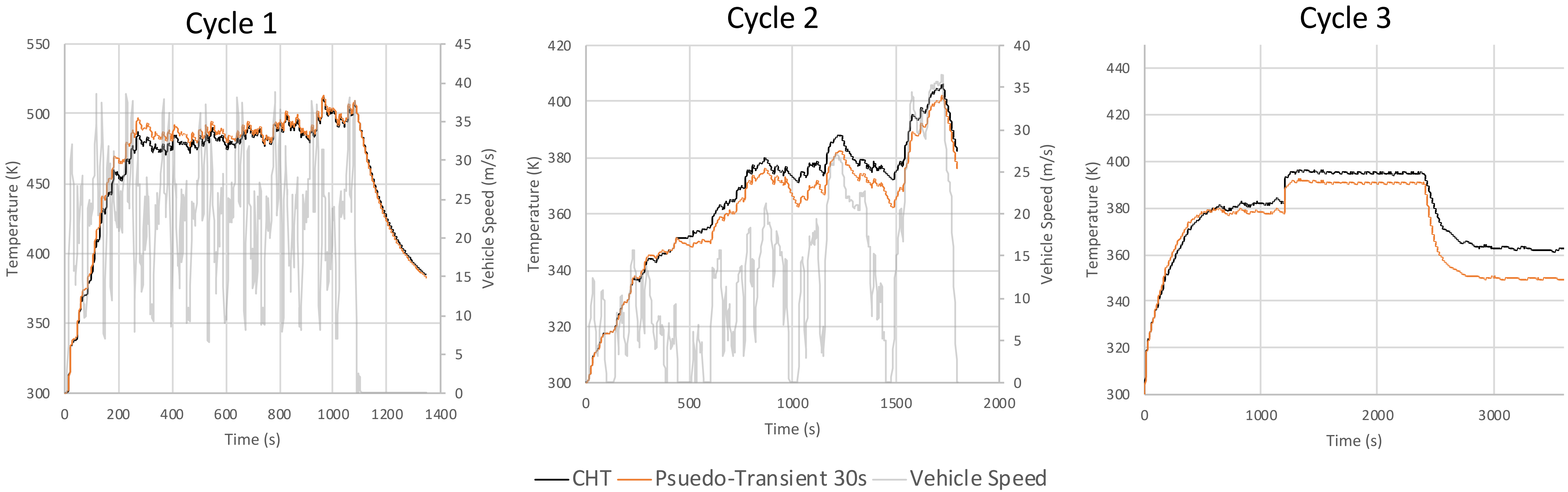
6 node average

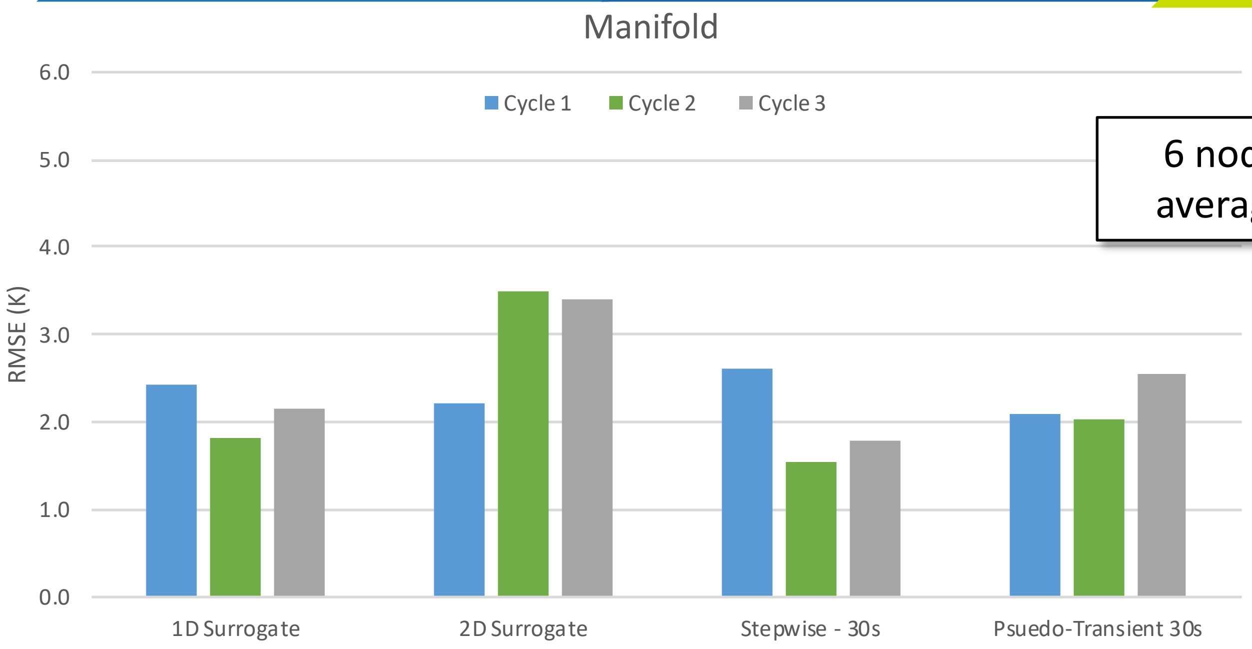




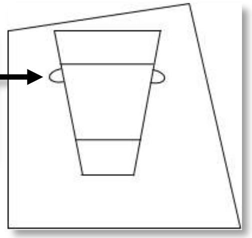
Psuedo Transient Prediction – Temperature



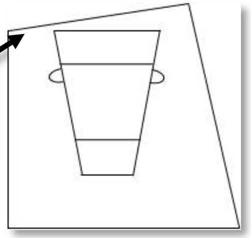


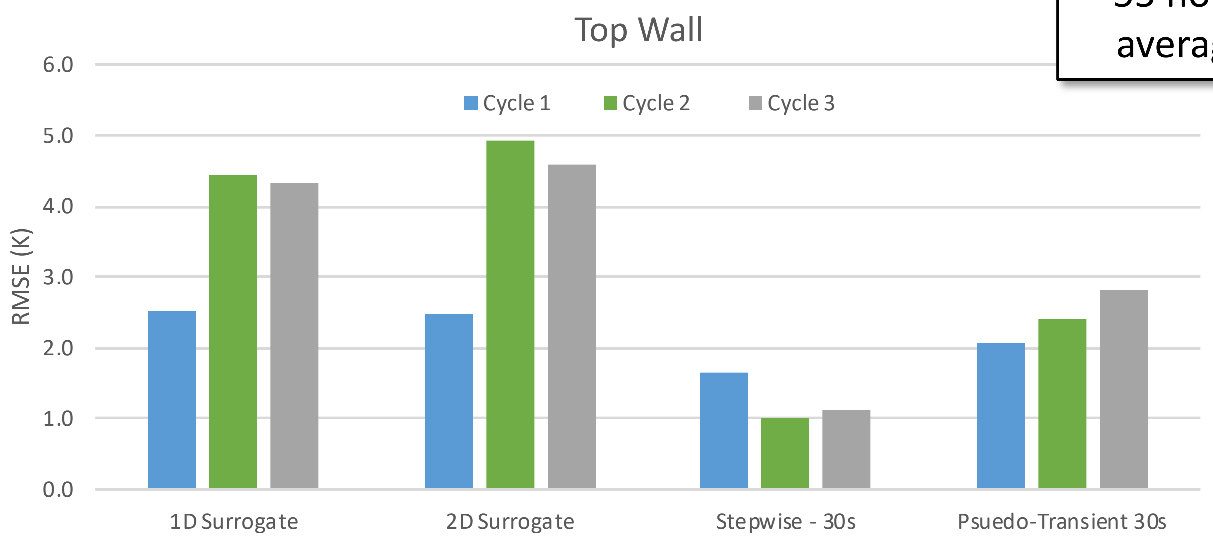


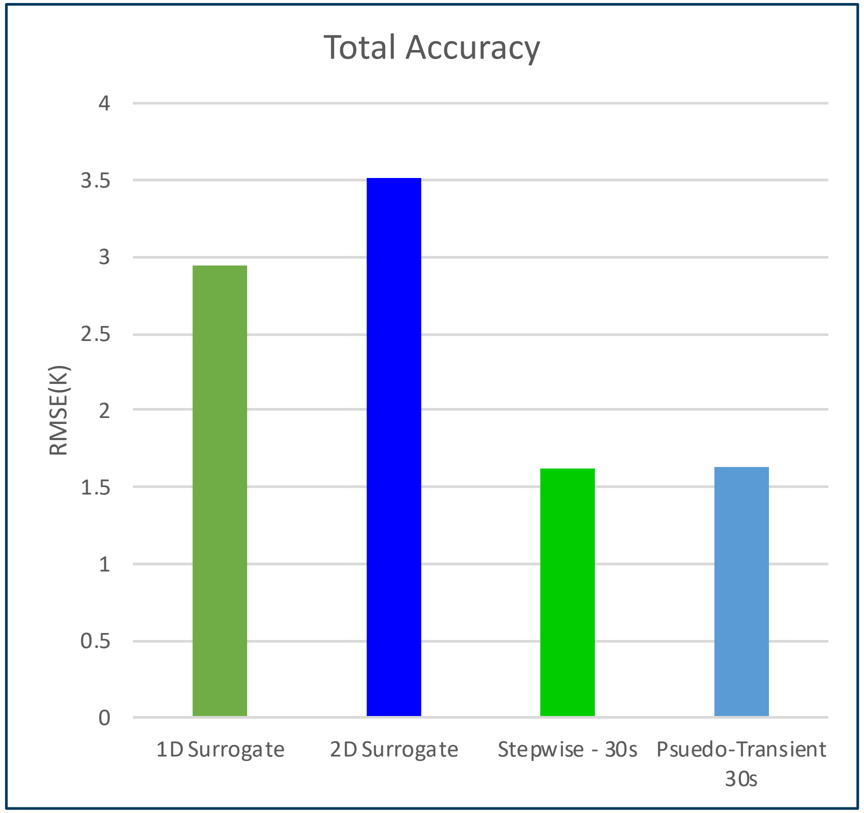
6 node average

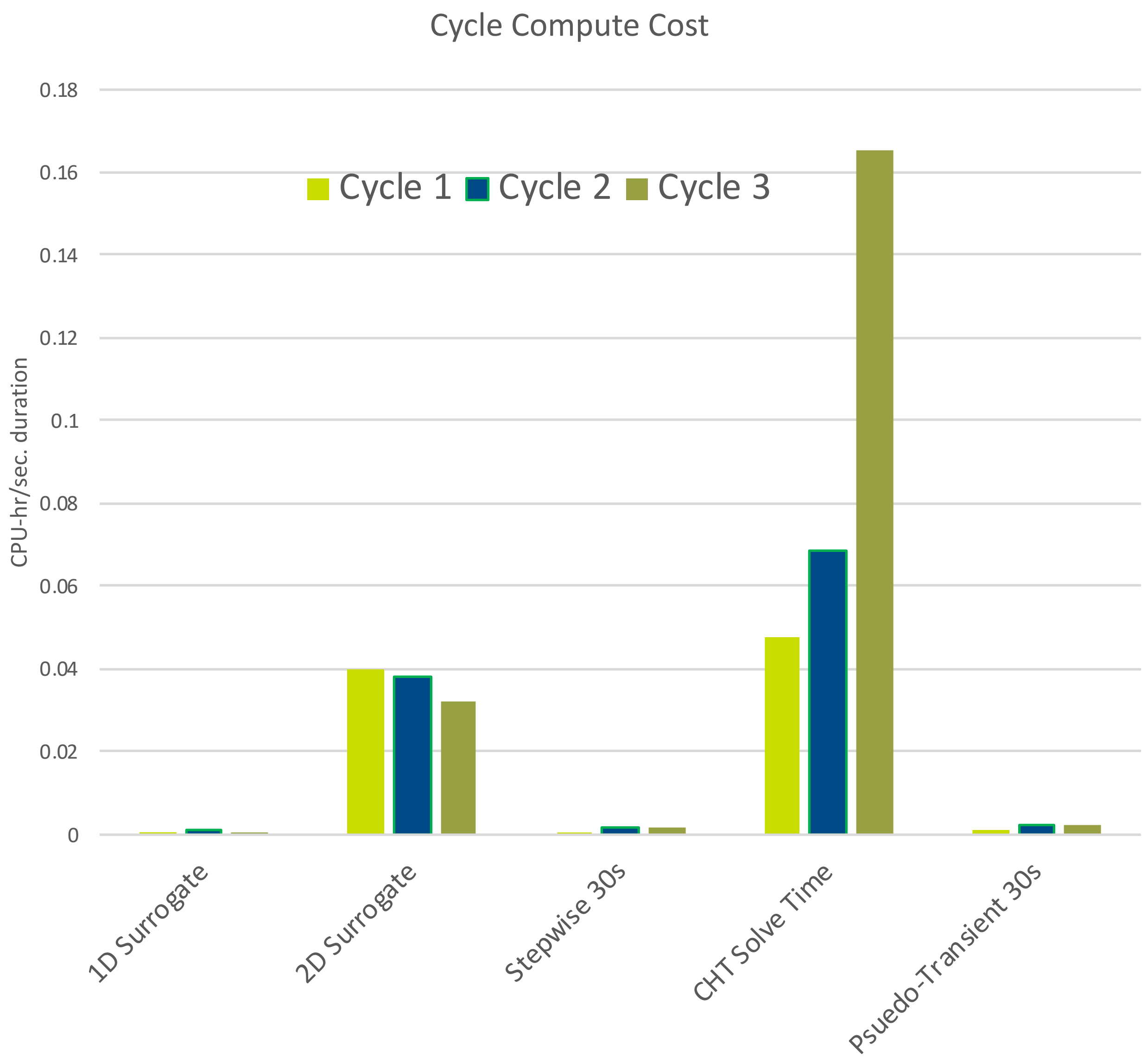


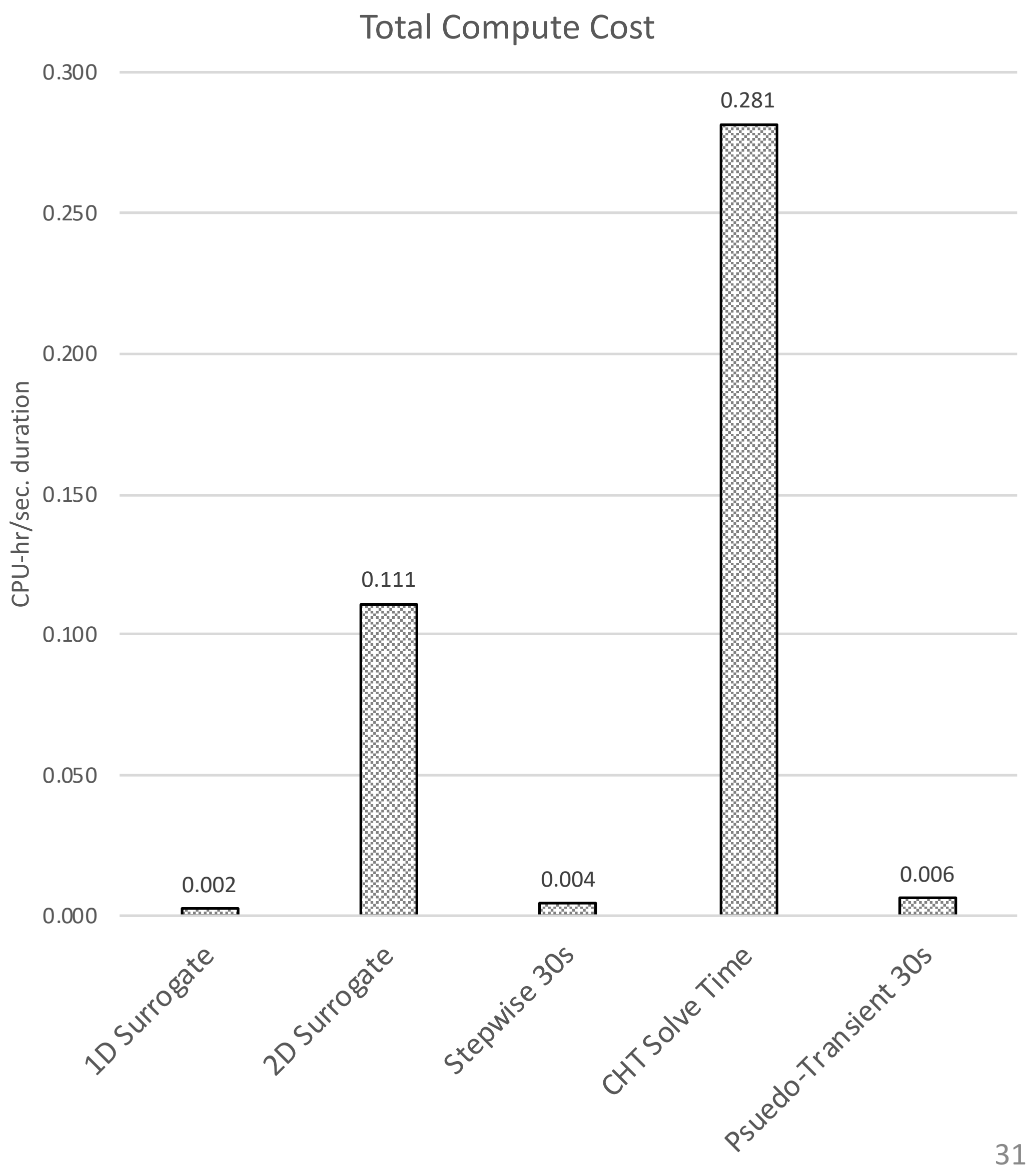
55 node average

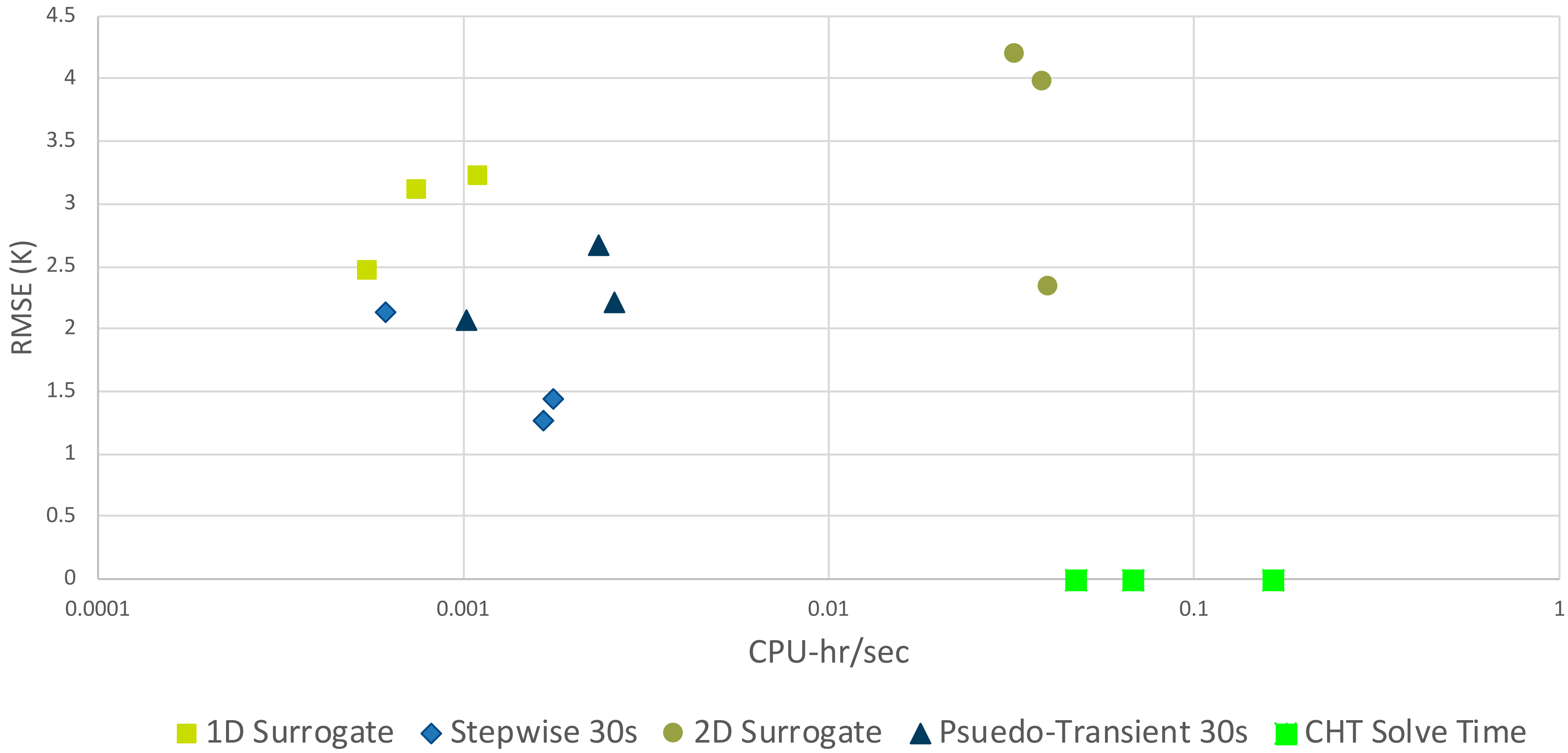




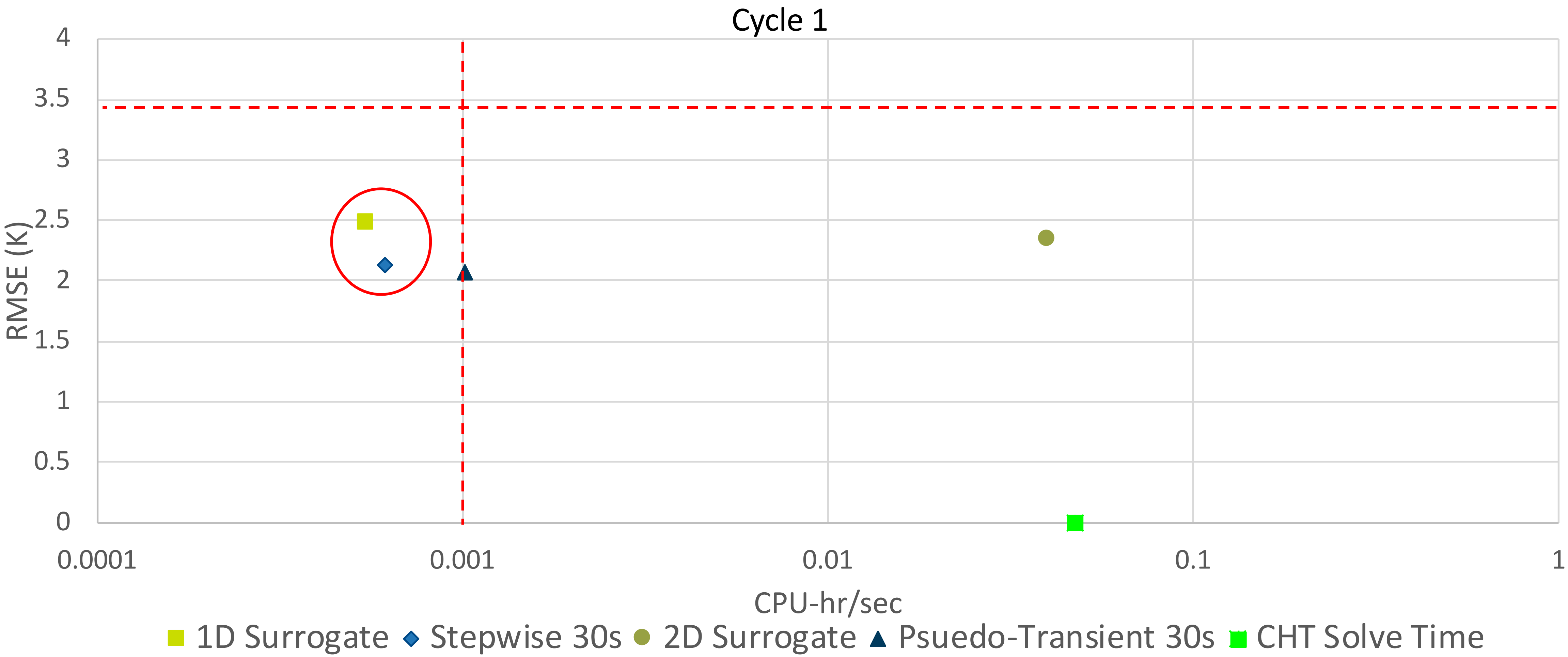



Cycle Compute Cost
Cycle 1
Cycle 2
Cycle 3
CPU-hr/sec. duration
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1D Surrogate
2D Surrogate
Stepwise 30s
CHT Solve Time
Psuedo-Transient 30s

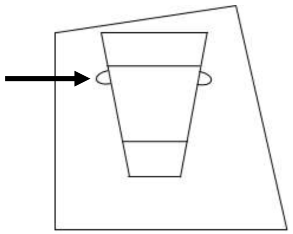

Total Compute Cost
CPU-hr/sec. duration
0.300
0.250
0.200
0.150
0.100
0.050
0.000
0.002
0.111
0.004
0.281
0.006
1D Surrogate
2D Surrogate
Stepwise 30s
CHT Solve Time
Psuedo-Transient 30s



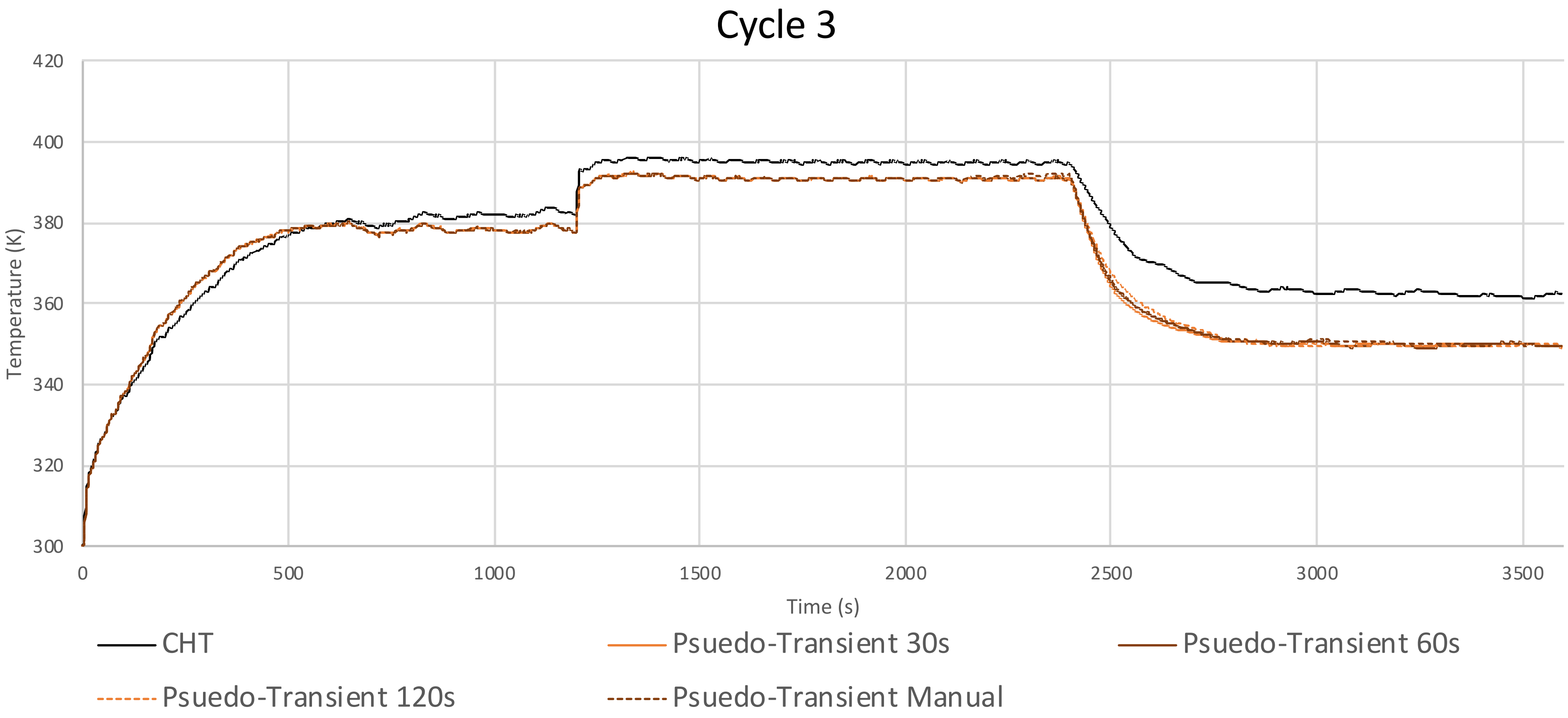
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
RMSE (K)
0.0001
0.001
0.01
0.1
1
CPU-hr/sec
1D Surrogate
Stepwise 30s
2D Surrogate
Psuedo-Transient 30s
CHT Solve Time

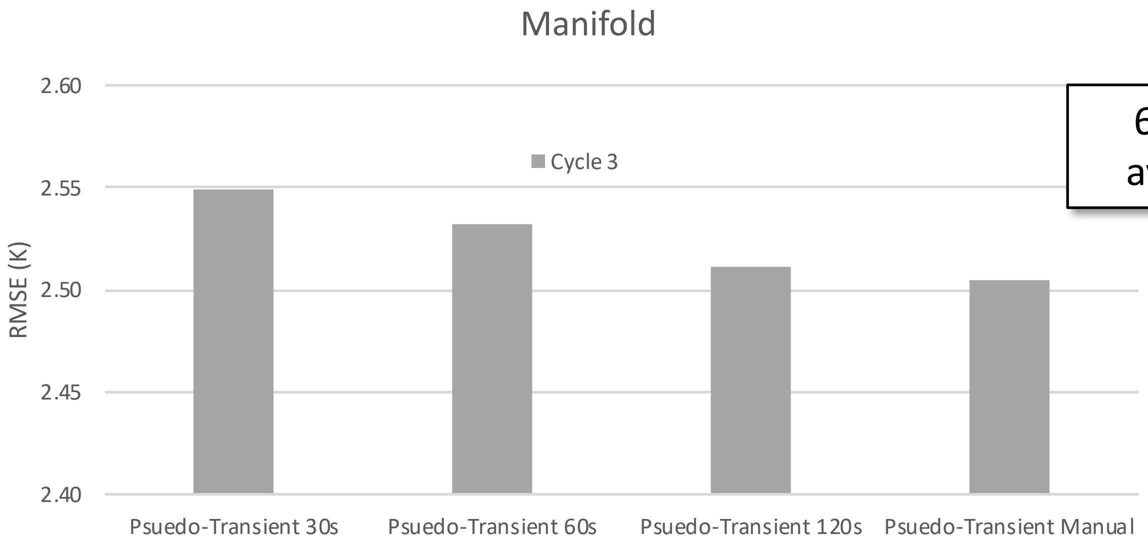

Cycle 1
4
3.5
3
2.5
2
1.5
1
0.5
0
RMSE (K)
0.0001
0.001
0.01
0.1
1
CPU-hr/sec
1D Surrogate
Stepwise 30s
2D Surrogate
Psuedo-Transient 30s
CHT Solve Time

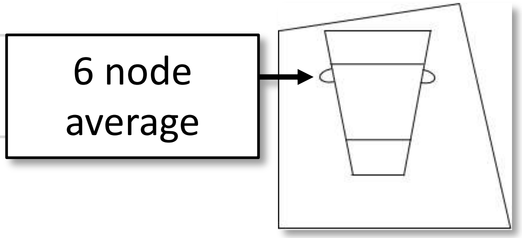
6 node average

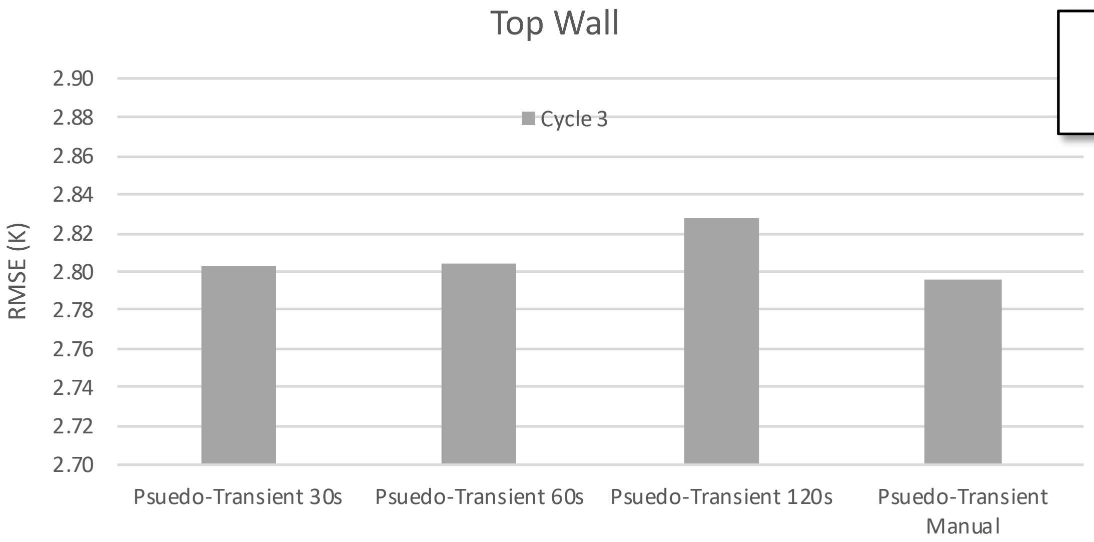


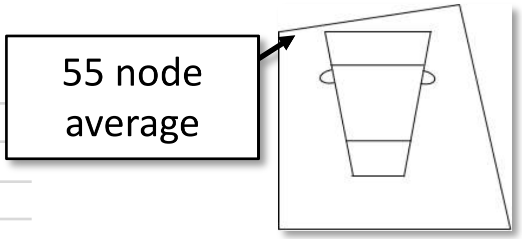
Psuedo Transient Prediction – Temperature

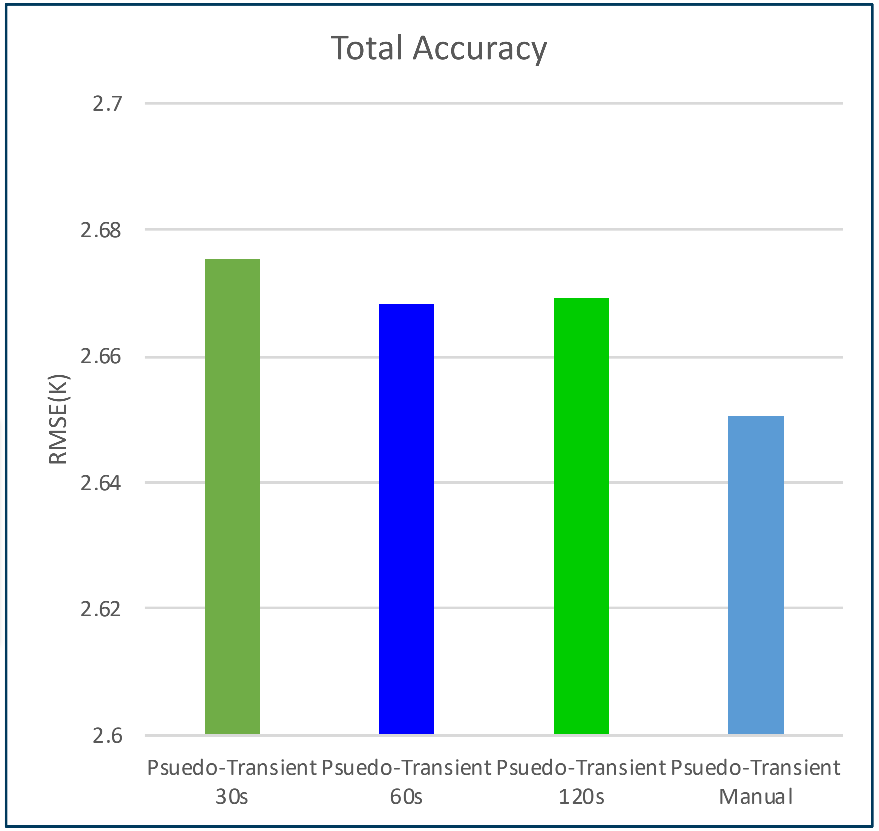


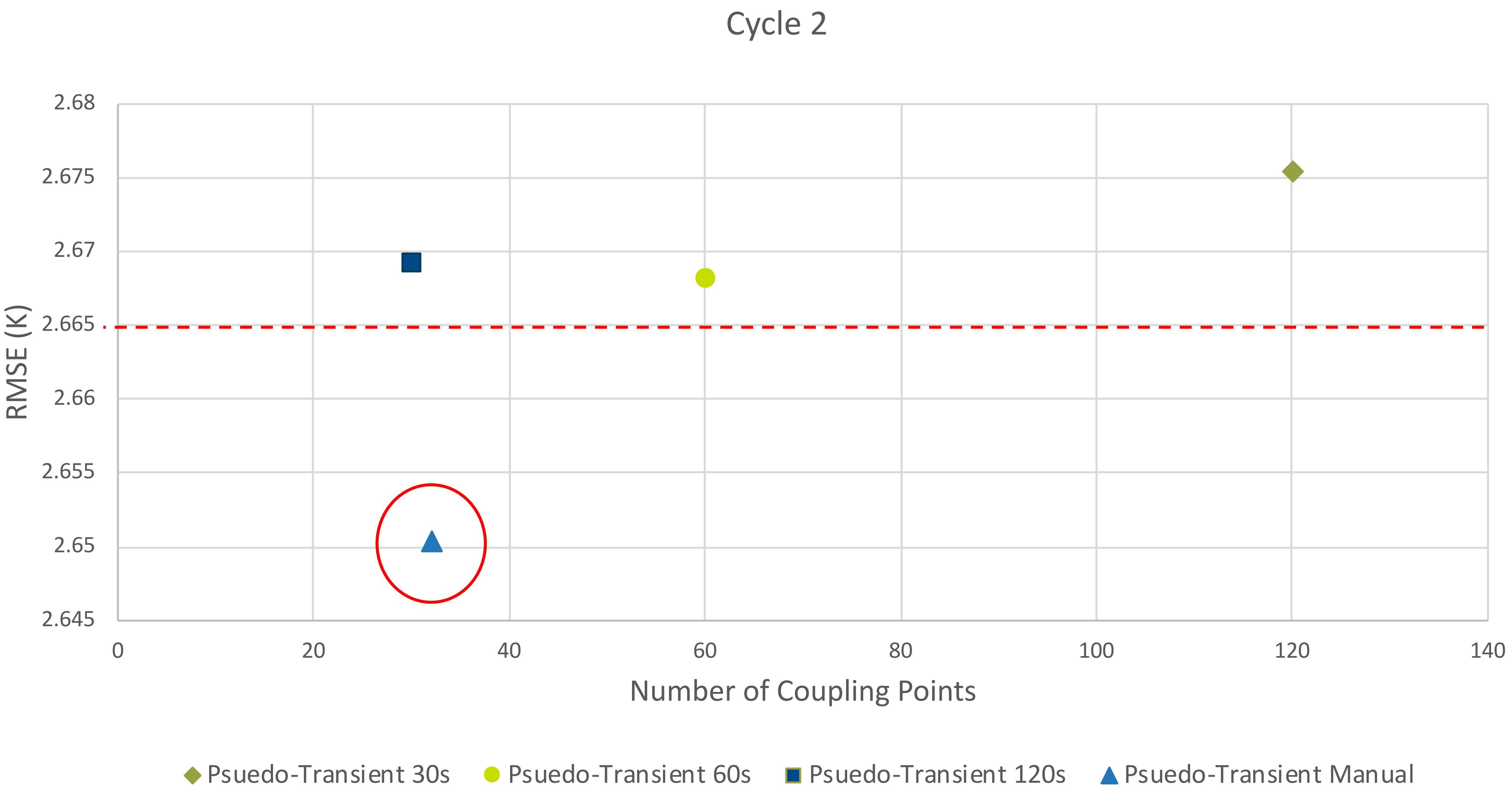

Manifold
2.60
2.55
2.50
2.45
2.40
RMSE (K)
Cycle 3
Psuedo-Transient 30s
Psuedo-Transient 60s
Psuedo-Transient 120s
Psuedo-Transient Manual

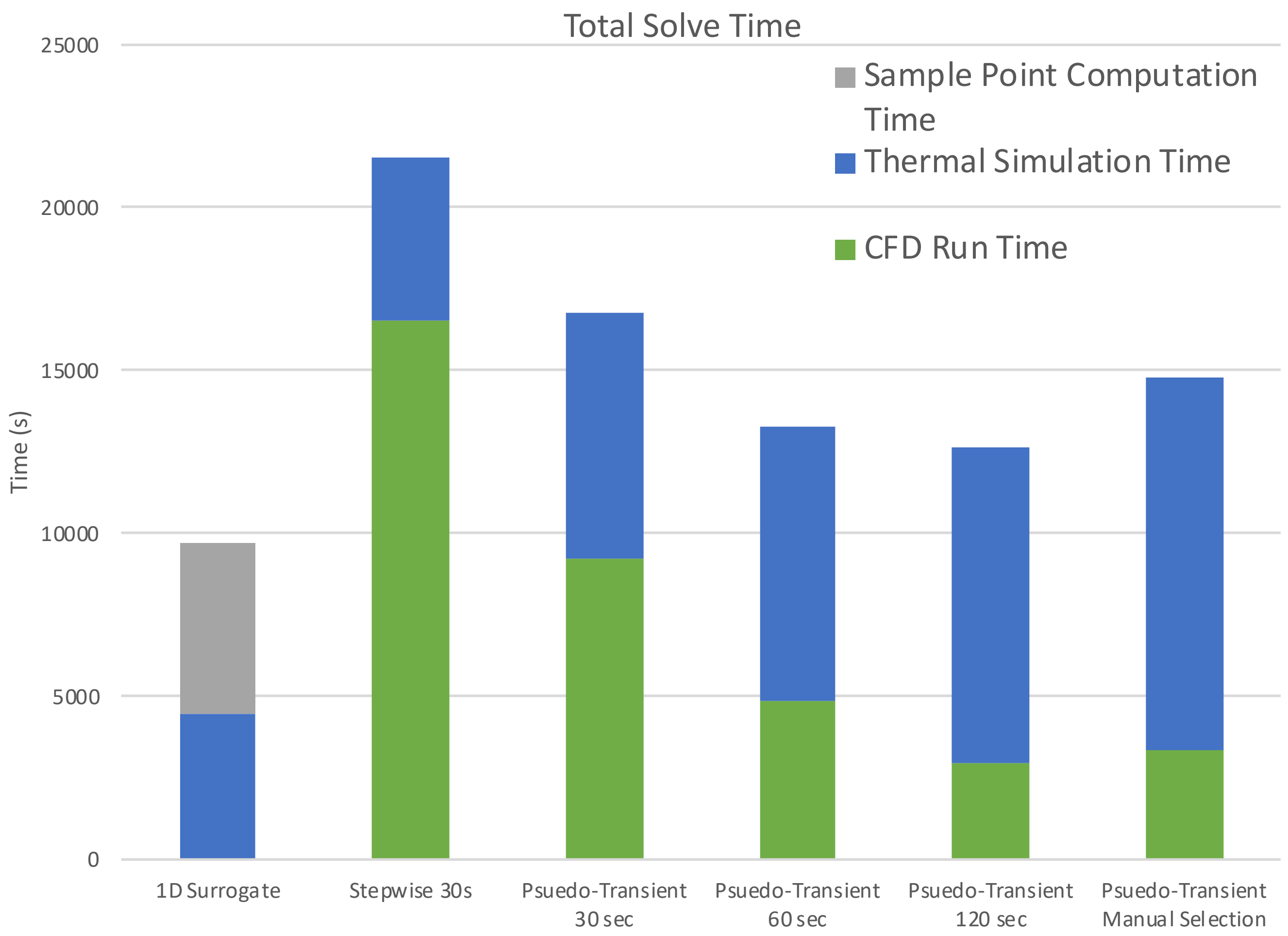

6 node average

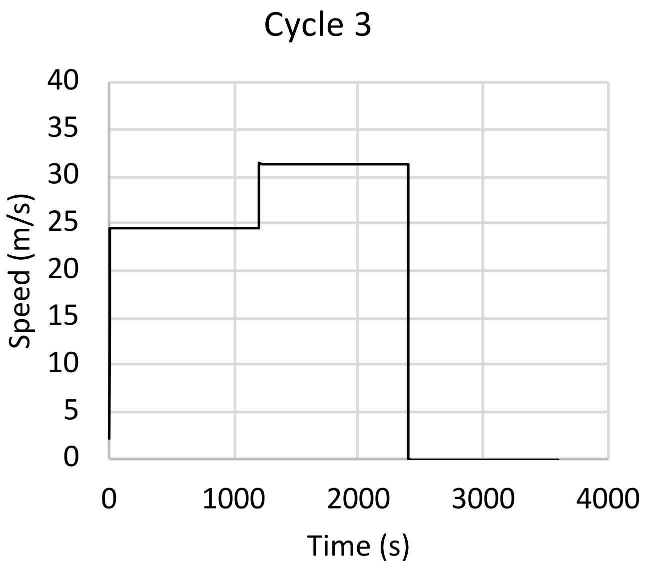

Top Wall
2.90
2.88
2.86
2.84
2.82
2.80
2.78
2.76
2.74
2.72
2.70
RMSE (K)
Cycle 3
Psuedo-Transient 30s
Psuedo-Transient 60s
Psuedo-Transient 120s
Psuedo-Transient Manual


55 node average


Total Accuracy
2.7
2.68
2.66
2.64
2.62
2.6
RMSE(K)
Psuedo-Transient 30s
Psuedo-Transient 60s
Psuedo-Transient 120s
Psuedo-Transient Manual


Cycle 2
RMSE (K)
2.68
2.675
2.67
2.665
2.66
2.655
2.65
2.645
0
20
40
60
80
100
120
140
Number of Coupling Points
Psuedo-Transient 30s
Psuedo-Transient 60s
Psuedo-Transient 120s
Psuedo-Transient Manual

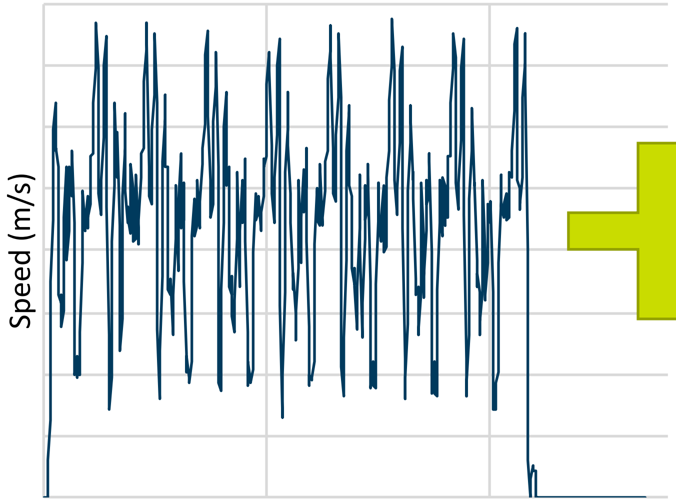

Total Solve Time
Sample Point Computation Time
Thermal Simulation Time
CFD Run Time
Time (s)
25000
20000
15000
10000
5000
0
1D Surrogate
Stepwise 30s
Psuedo-Transient 30 sec
Psuedo-Transient 60 sec
Psuedo-Transient 120 sec
Psuedo-Transient Manual Selection


Cycle 3
Speed (m/s)
40
35
30
25
20
15
10
5
0
0
1000
2000
3000
4000
Time (s)

- Significant cost differences between the methods
- Step-wise and Psuedo-Transient coupling offers a good balance of accuracy and run time
- Finding the number of coupling points that balance accuracy and computational costs is important
- Surrogate models offer significant savings, but sacrifice accuracy

- Further Research
  - Model sizes
  - Time Stepping
  - Other coupling methods
  - Sampling method for surrogate models
  - Surrogate model interpolation methods

Find your FIT



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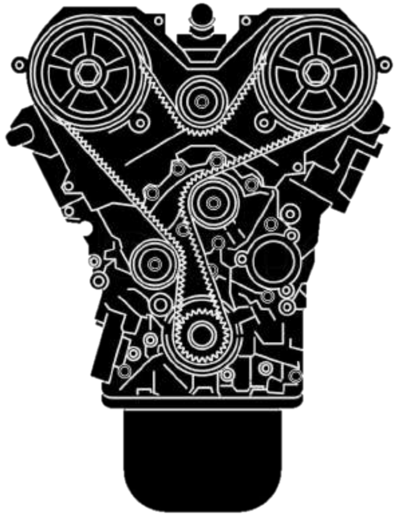

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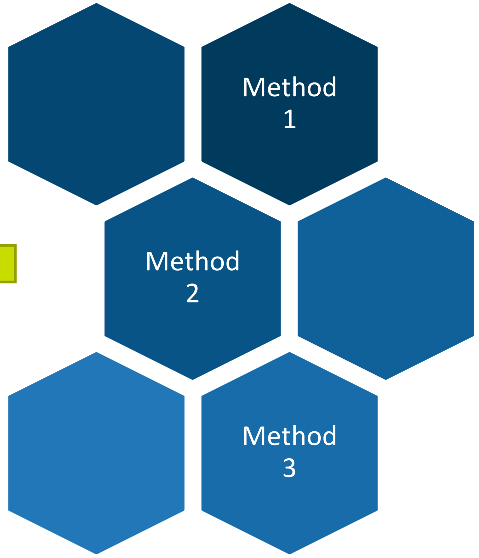

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FIT

techsupport@thermoanalytics.com

Questions?

Thank you for your attention

Technical Support

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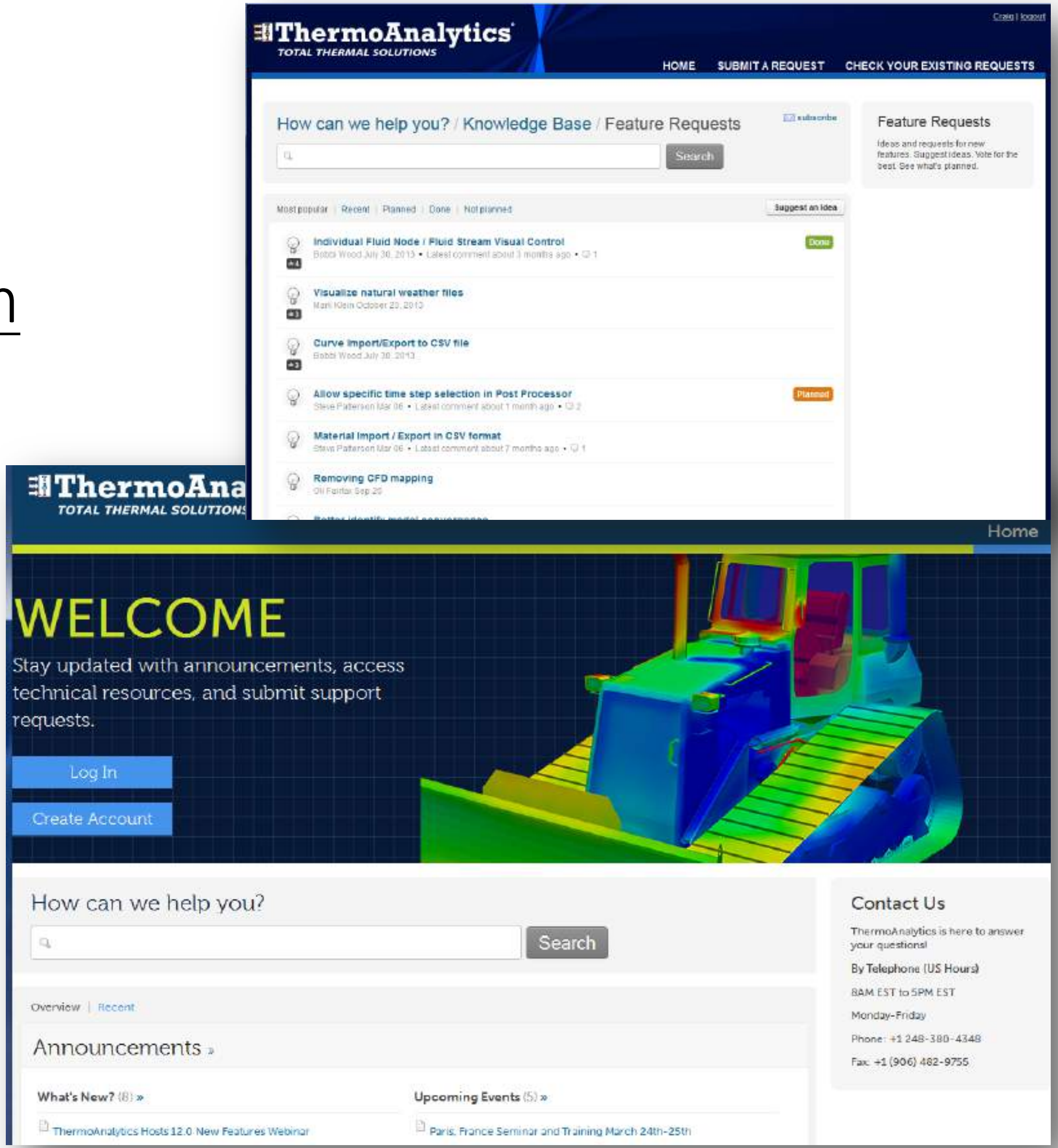
  - Feature Requests



Thanks and References

1. Disch, M., Widdecke, N., Wiedemann, J., Reister, H. et al., "Numerical Simulation of the Transient Heat-Up of a Passenger Vehicle during a Trailer Towing Uphill Drive," SAE Technical Paper 2013-01-0873, 2013
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