THERMO
ANALYTICS

Reduce Vehicle Development Costs with Real-world Simulations

Jon Juszkiewicz, Thermal/CFD Engineer

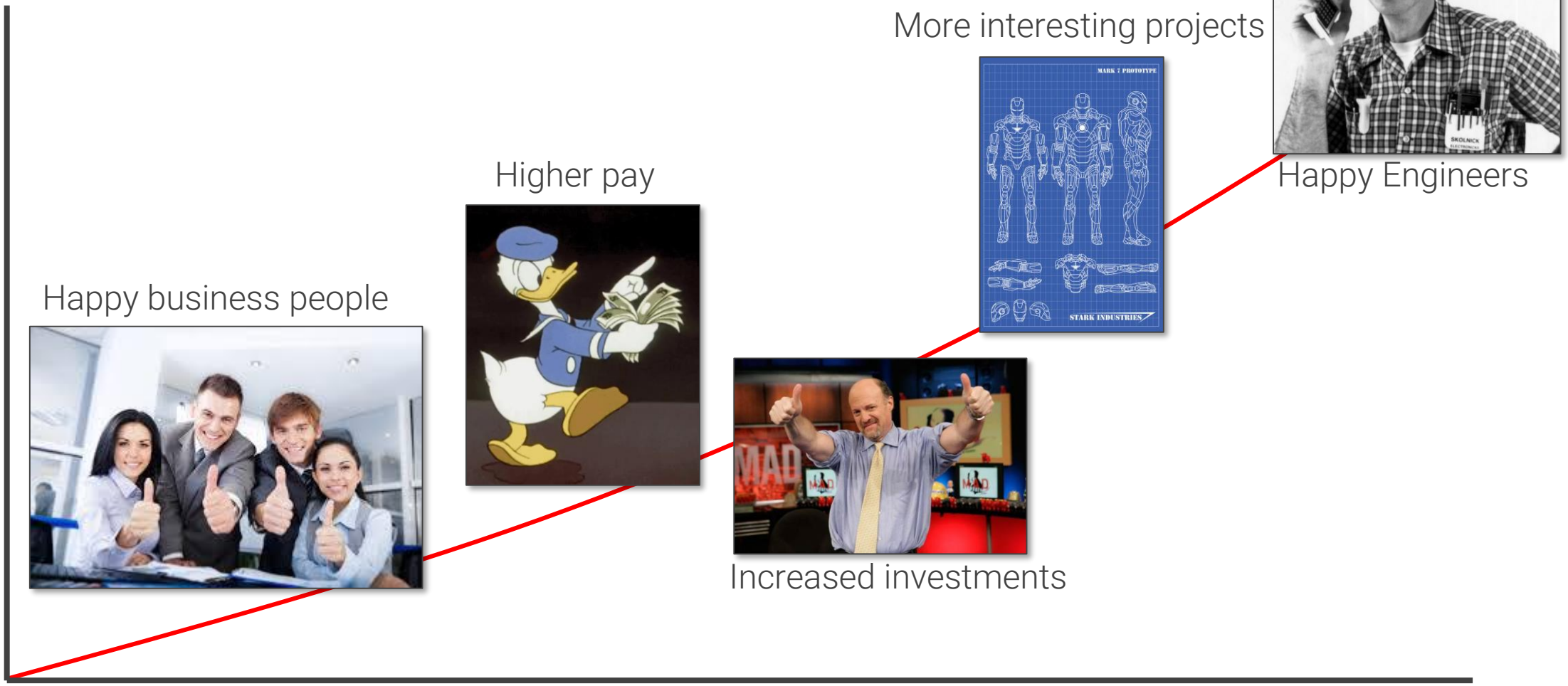
THERMO ANALYTICS

Agenda

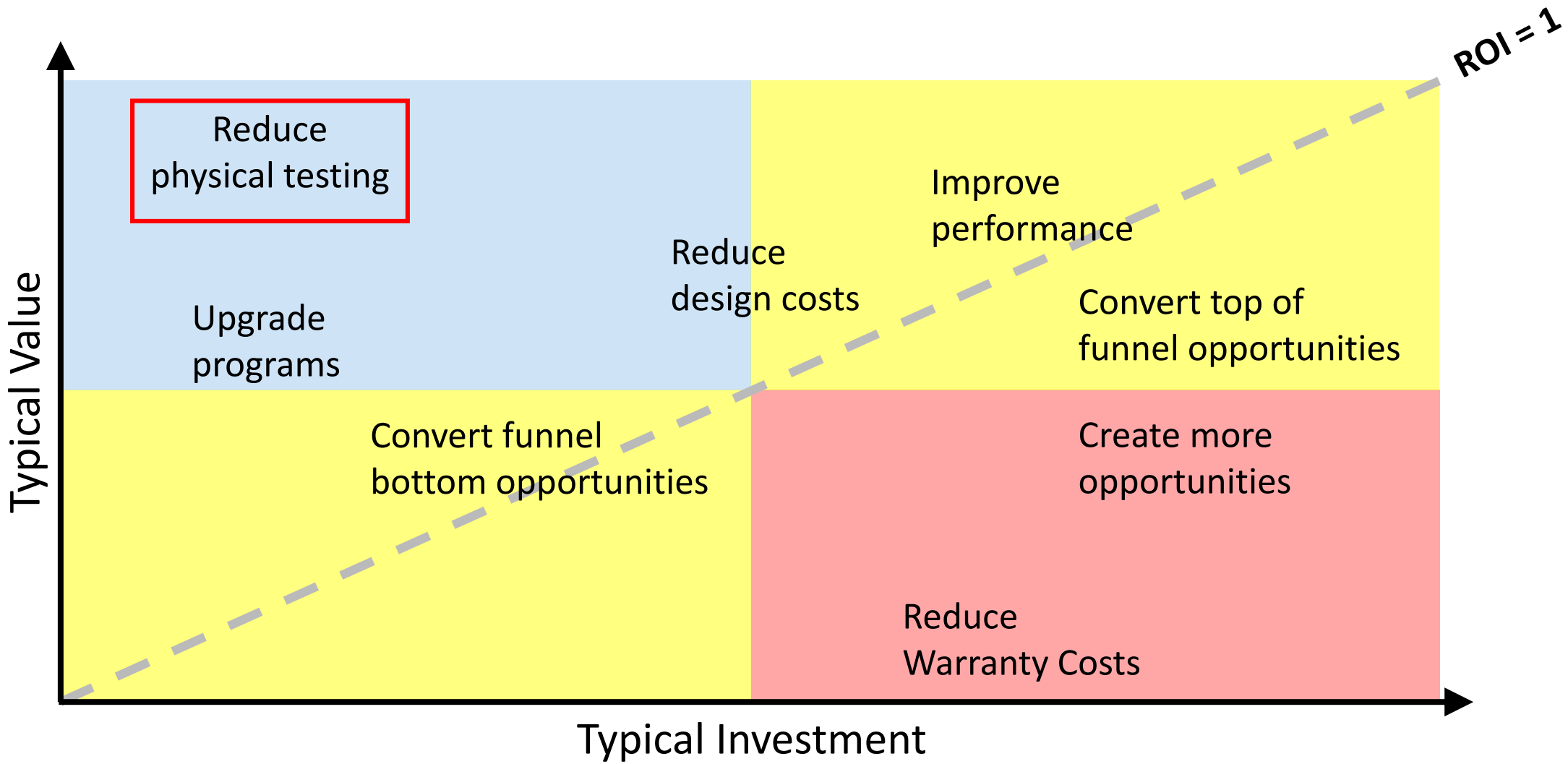
1. Modern Solutions to Age Old Problems – The need for transient simulation
    1. Growth is Good
    2. How Do Engineers Create Growth Opportunities?
    3. Vehicle Thermal Test Cycles
    4. Modern Design Targets
2. The Million Dollar Question and How to Answer It
    1. The $1M Question
    2. Modeling Options
3. A Novel Approach to Drive Cycle Simulation – Theory, History and a Commercial Solution
    1. Theory
    2. Background
    3. A Commercial Solution
4. Case Study –Strategies for Simulating Test Cycles in 3D
5. Conclusions

Modern Solutions to Age Old Problems – The need for transient simulation

Growth is Good



How can Engineers Create Growth?

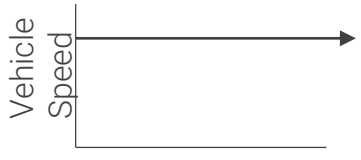


Vehicle Thermal Test Cycles

All these test cycles require transient simulations

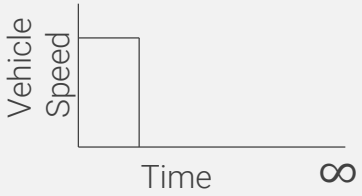
Simulation Method Maturity at a Typical OEM

Test Cycle Complexity



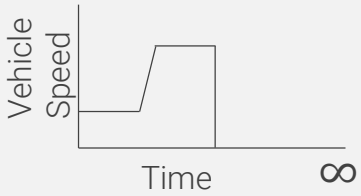
Steady State

Peak excursion tests



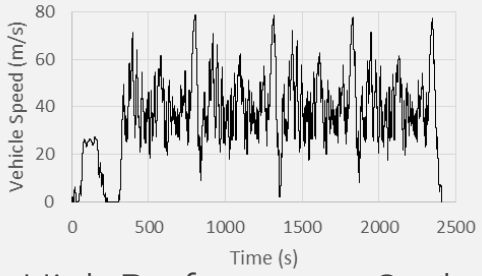
Thermal Soaks

WLTP – WLTC
FTP & SFTP
UDDS
Davis Dam (SAE J2807 Tow Test)



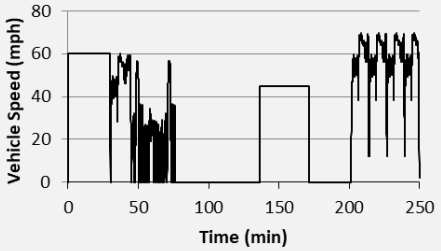
Simple Drive Cycles

Nurburgring
Nardo
Autobahn
Ring road



High Performance Cycles

Delivery Vehicle
Schoolbus route
City cycles
Multi-stop brake cycles

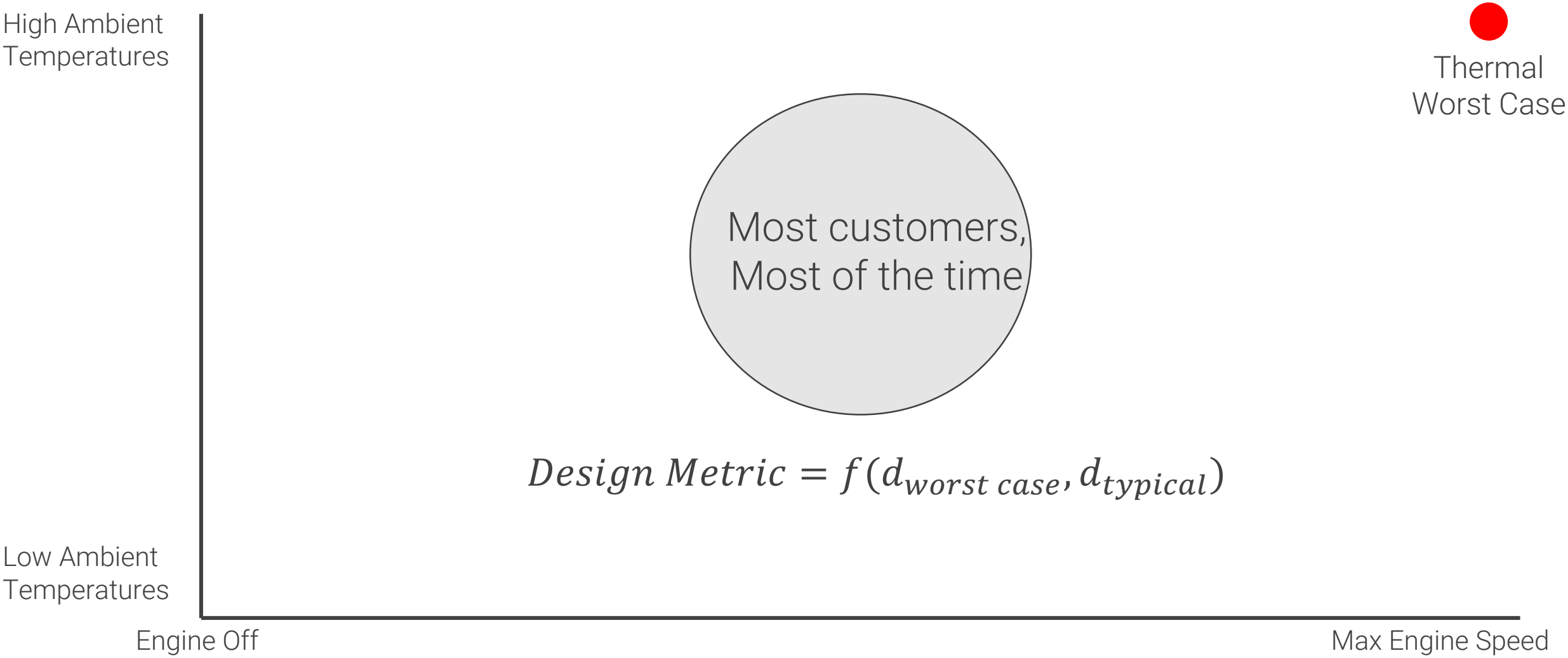


Mixed Cycles

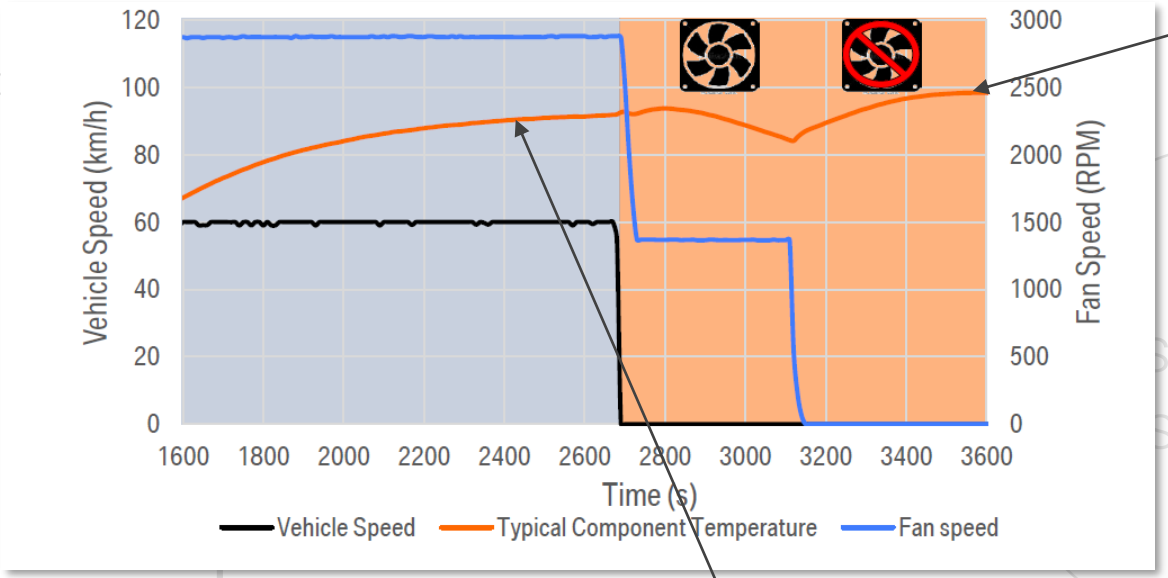
Engineering Approximations of End Customer Behavior

What End Customers Actually Do

Modern Design Targets

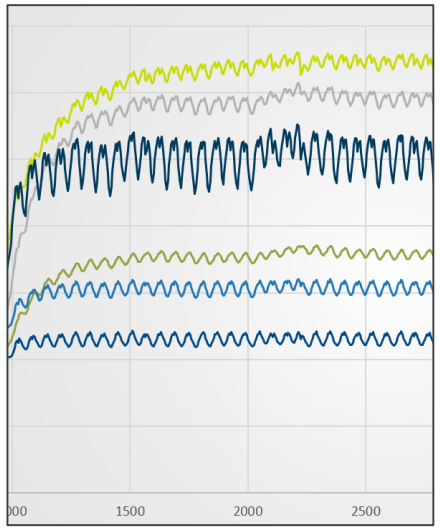


Modern Design Targets



Thermal Worst Case (150 °C)

Does the fan induced cycling or thermal shock cause more part failures?

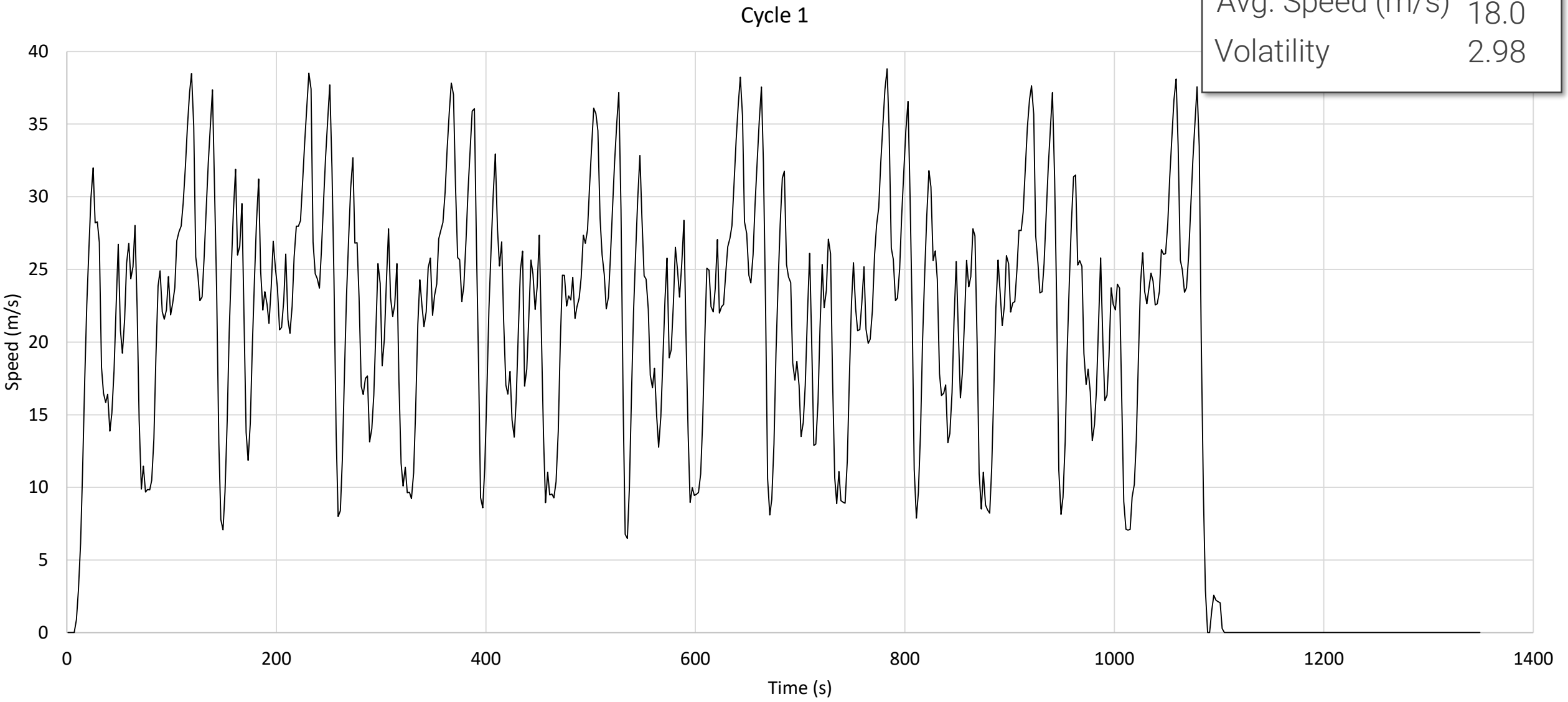


Fan induced temperature cycling (110-130 °C)

The Million Dollar Question and How to Answer It

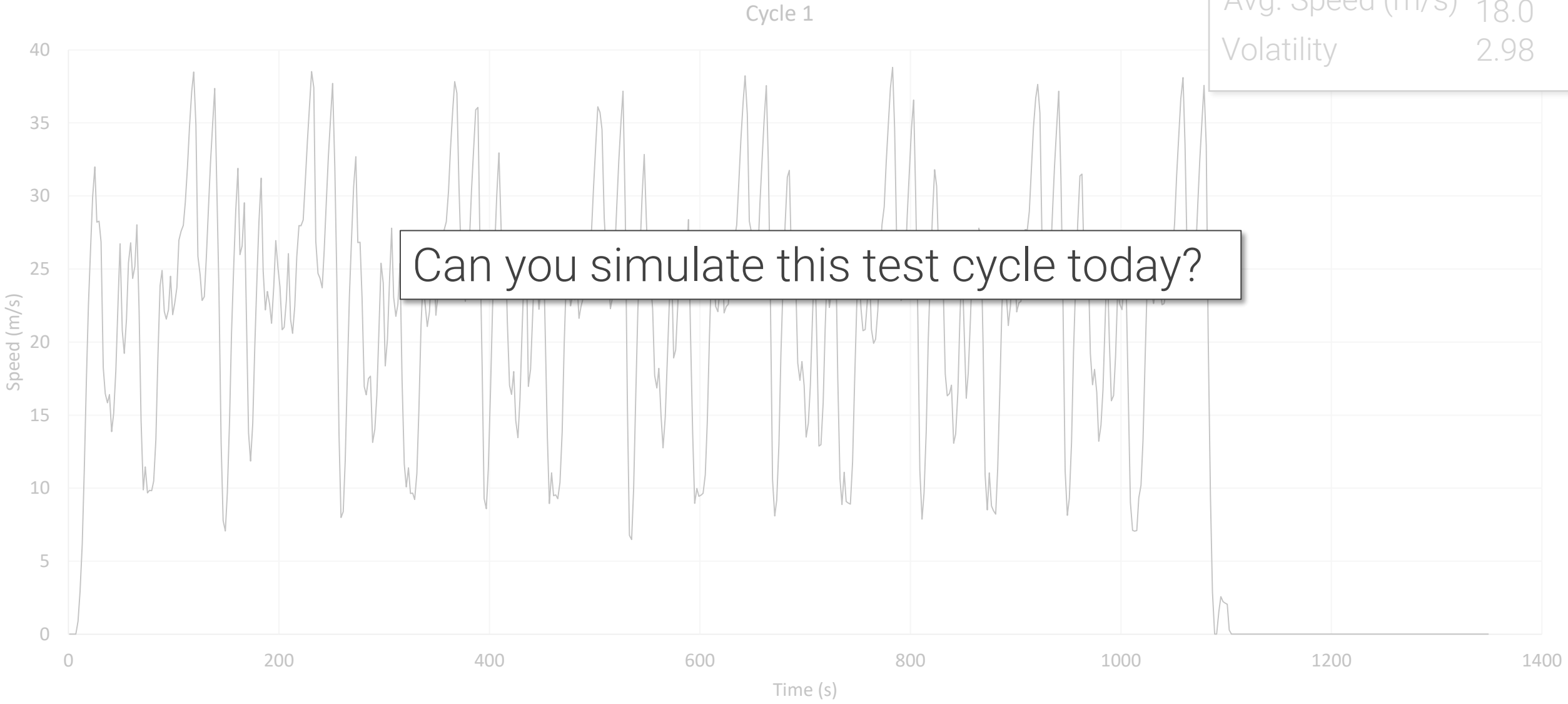
The $1M Question

Duration (s)	1350
Max Speed (m/s)	38.8
Avg. Speed (m/s)	18.0
Volatility	2.98



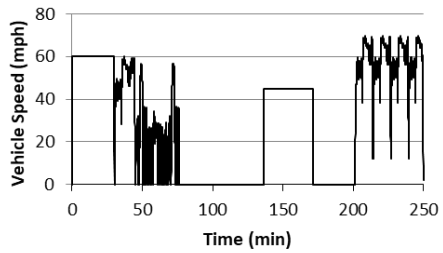
The $1M Question

Duration (s)	1350
Max Speed (m/s)	38.8
Avg. Speed (m/s)	18.0
Volatility	2.98

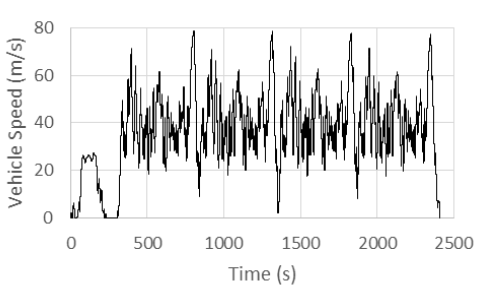


Can you simulate this test cycle today?

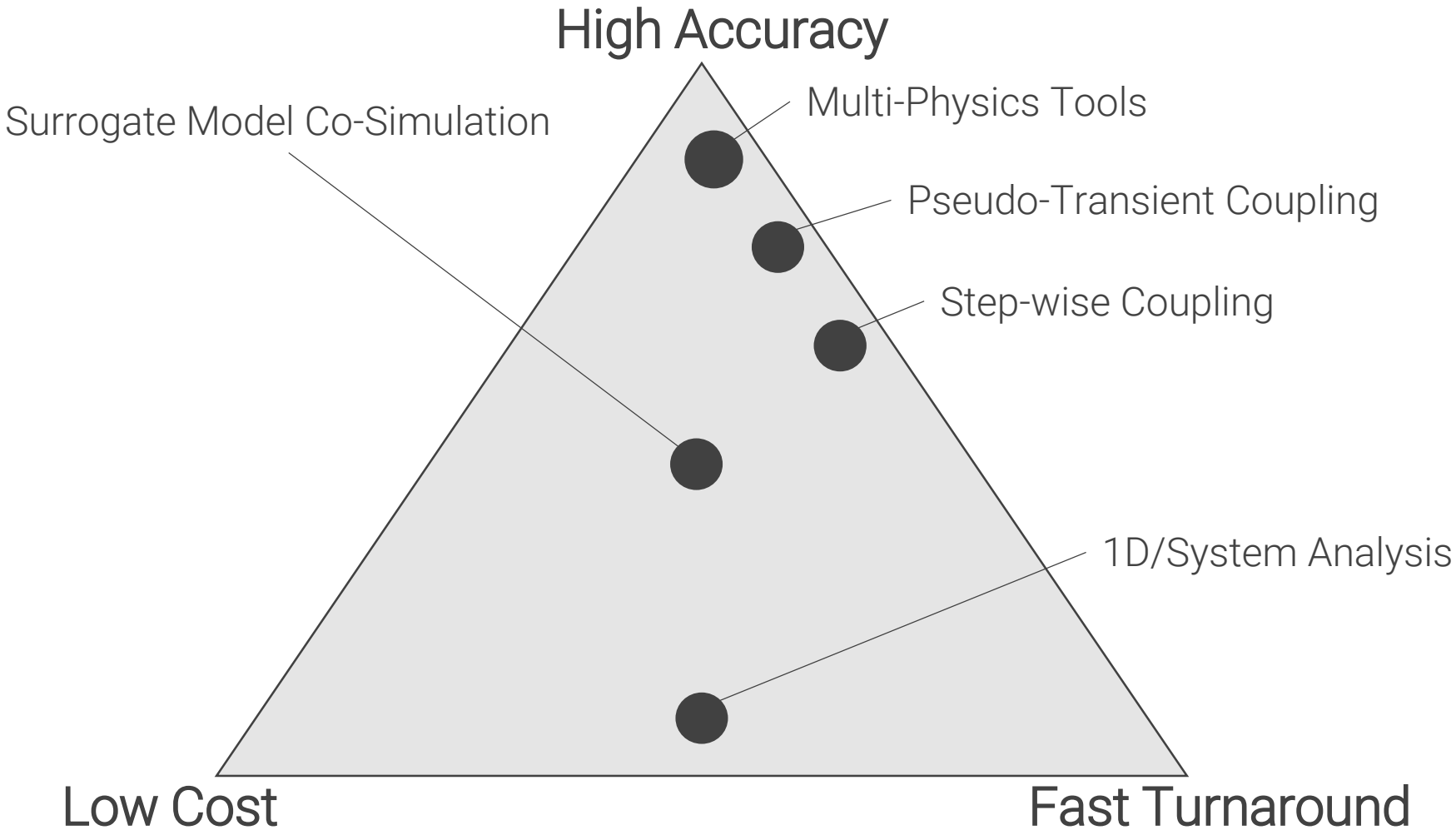
Modeling Options



Mixed Duty Cycles

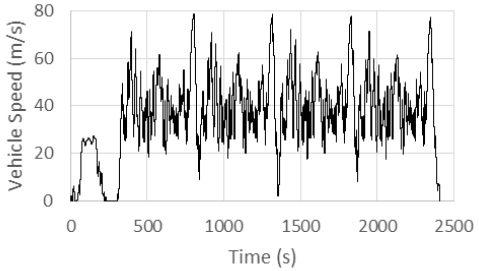


Dynamic Drive Cycles

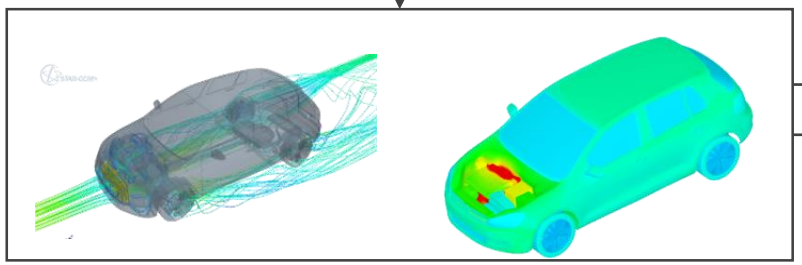


A Novel Approach to Drive Cycle Simulation – Theory, History and a Commercial Solution

Theory



Select a set of representative vehicle parameters



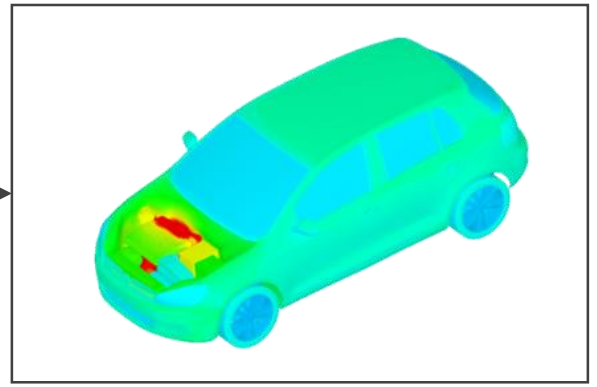
Calculate the steady state CHT solution at each selected speed

Extract HTC & Tf

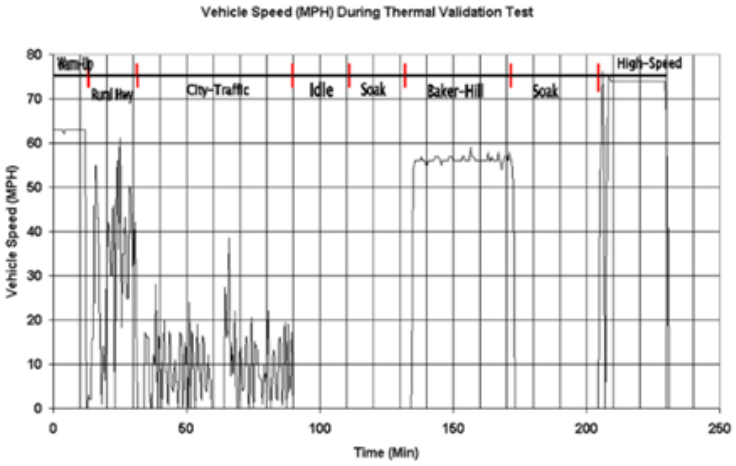
Surrogate Model

Make the samples continuous over the range of speeds with a surrogate model

Solve transient thermal simulation



Background

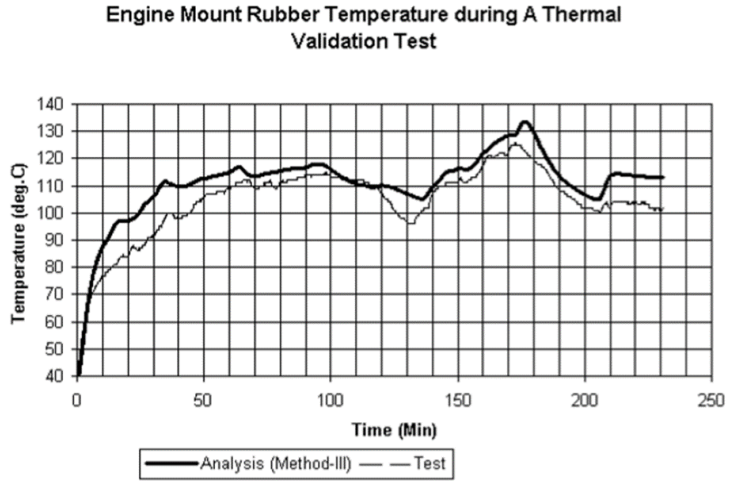


1. Vehicle Speed
2. Fan Speed
3. Radiator Exit Temperature
4. Ambient Air Temperature
5. Exhaust Gas Flow Rate
6. Exhaust Gas Temperature

OLHC Kriging

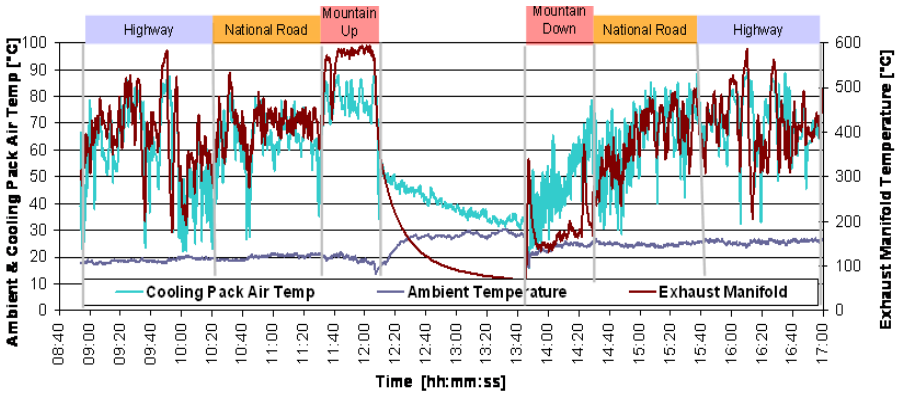
Part Average HTC Curve

Part Average Tf Curve



2007
Kaushik
GM Research

Background



Vehicle Speed

Fan Mass Flow Rate

Fan Air Temperature

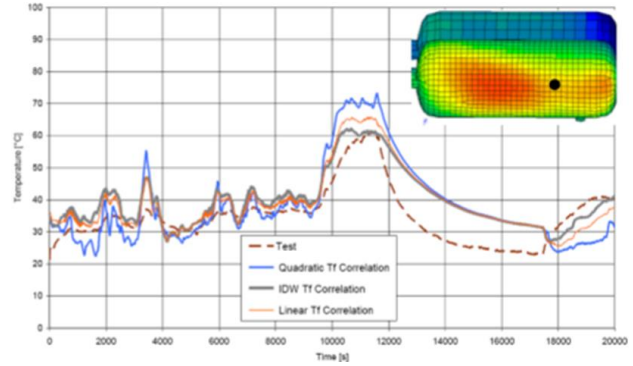
Exhaust Gas Temperature

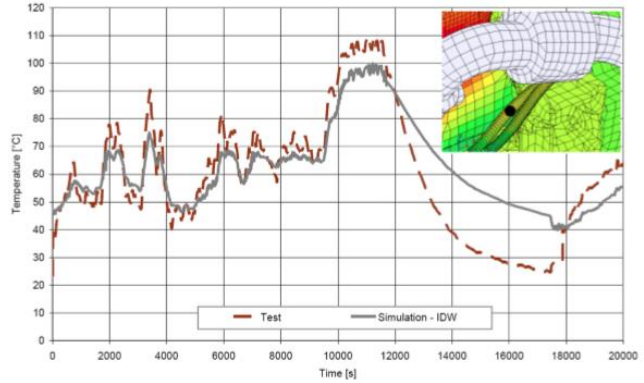
Manual Selection

IDW

Local HTC Surrogate Model

Local Tf Surrogate Model

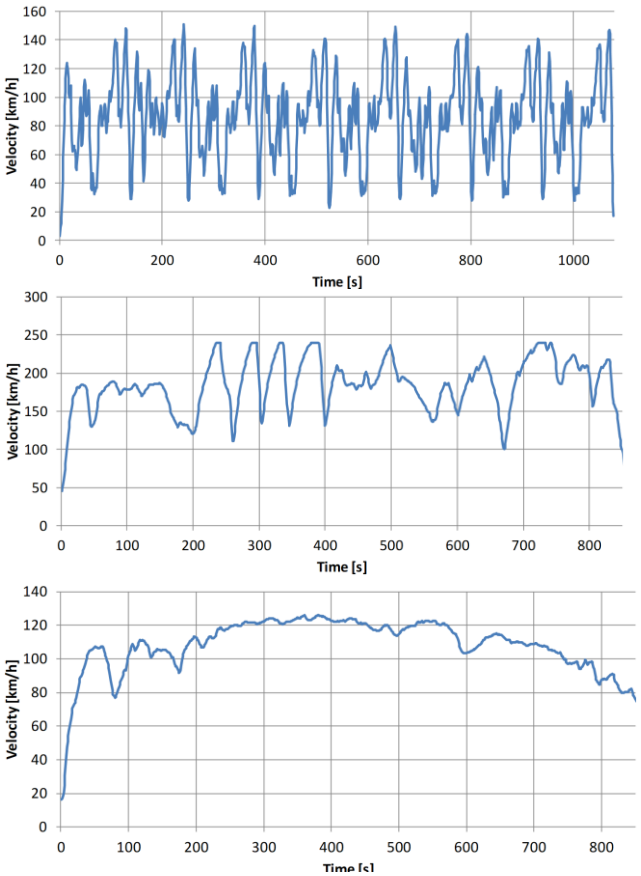




2007
Kaushik
GM Research

2011
Pryor
ThermoAnalytics

Background



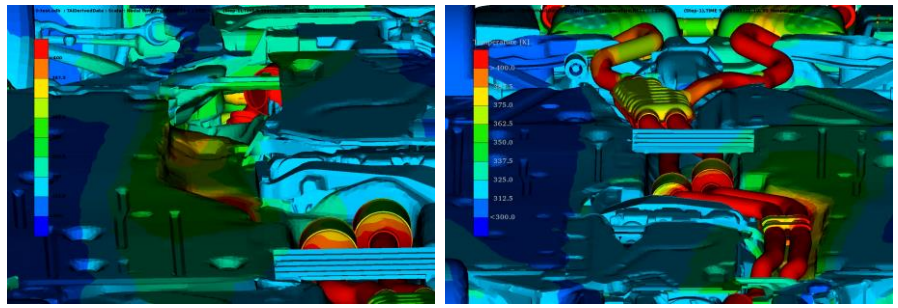
Vehicle Speed

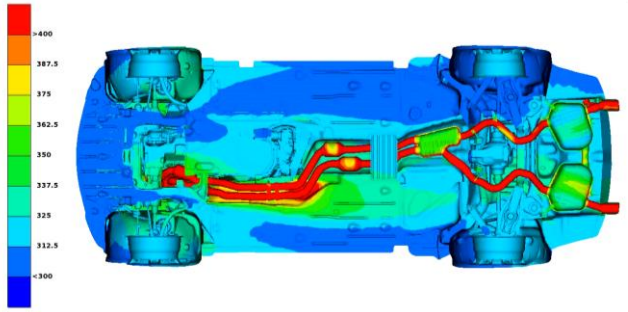
Undisclosed

Linear

Local HTC Surrogate Model

Local Tf Surrogate Model



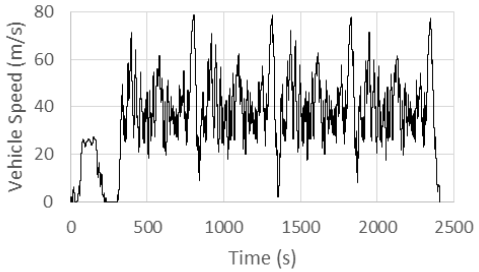


2007
Kaushik
GM Research

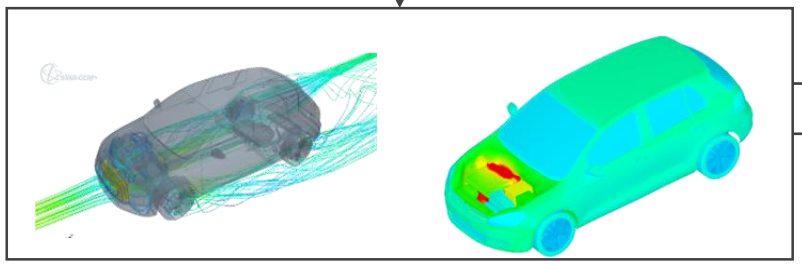
2011
Pryor
ThermoAnalytics

2014
Haehndel
BMW Motorsport

A Commercial Solution



Select a set of representative vehicle parameters



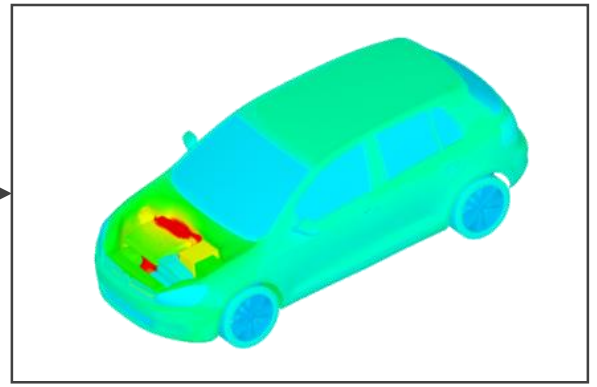
Calculate the steady state CHT solution at each selected speed

Extract HTC & Tf

Surrogate Model

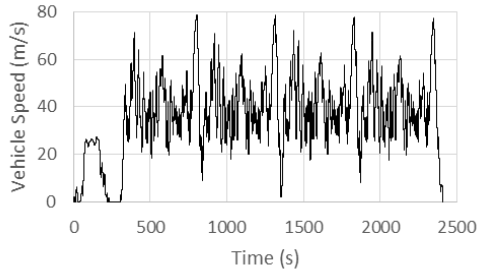
Make the samples continuous over the range of speeds with a surrogate model

Solve transient thermal simulation

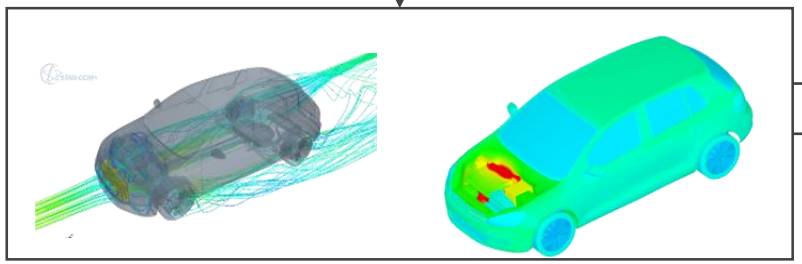


A Commercial Solution

CoTherm



Select a set of representative vehicle parameters



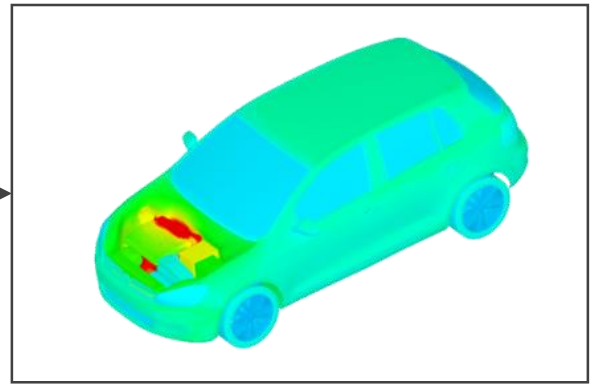
Calculate the steady state CHT solution at each selected speed

Extract HTC & Tf

Surrogate Model

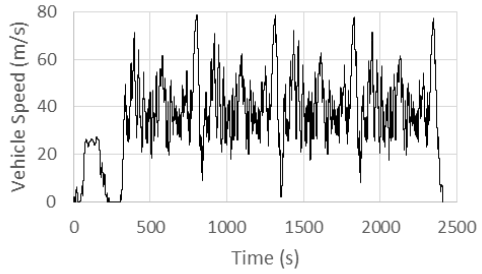
Make the samples continuous over the range of speeds with a surrogate model

Solve transient thermal simulation

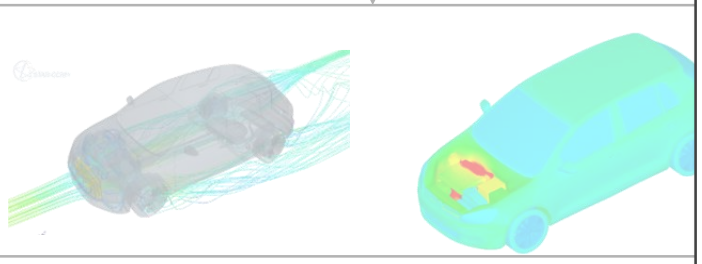


A Commercial Solution

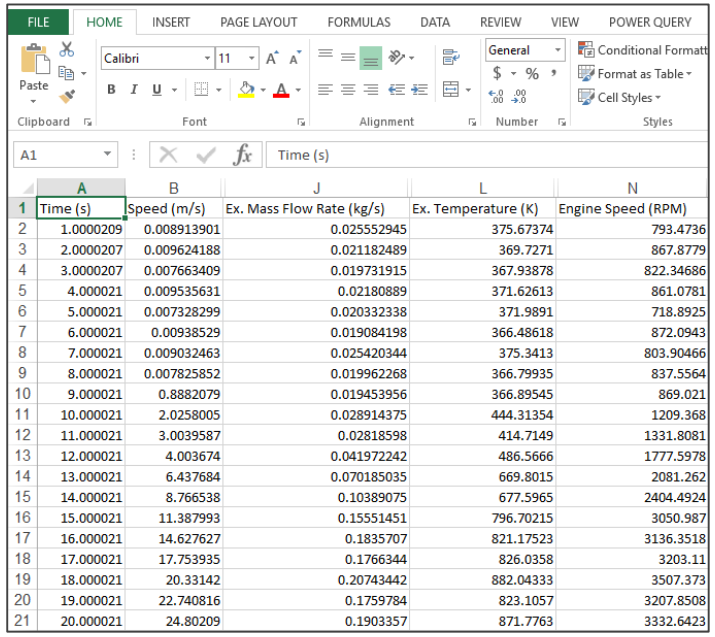
CoTherm



Select a set of representative vehicle parameters

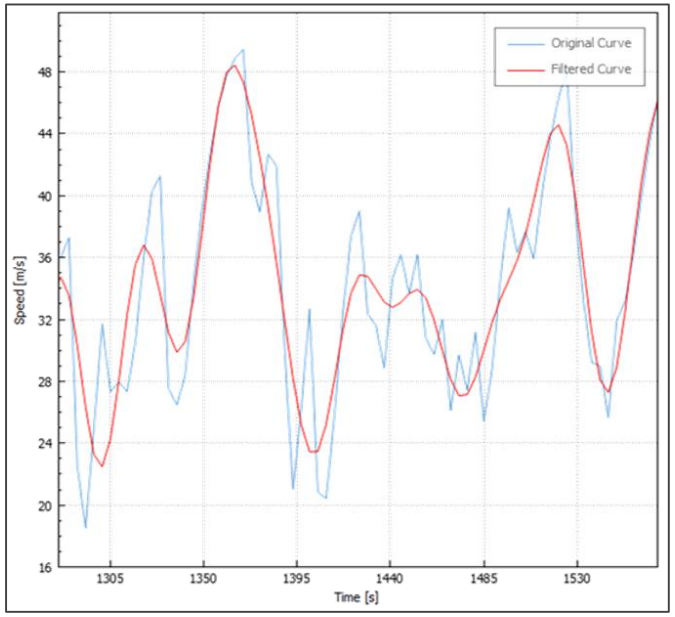


Calculate the steady state CHT solution at each selected speed



	A	B	J	L	N
1	Time (s)	Speed (m/s)	Ex. Mass Flow Rate (kg/s)	Ex. Temperature (K)	Engine Speed (RPM)
2	1.0000209	0.008913901	0.025552945	375.67374	793.4736
3	2.0000207	0.009624188	0.021182489	369.7271	867.8779
4	3.0000207	0.007663409	0.019731915	367.93878	822.34686
5	4.000021	0.009535631	0.02180889	371.62613	861.0781
6	5.000021	0.007328299	0.020332338	371.9891	718.8925
7	6.000021	0.00938529	0.019084198	366.48618	872.0943
8	7.000021	0.009032463	0.025420344	375.3413	803.90466
9	8.000021	0.007825852	0.019962268	366.79935	837.5564
10	9.000021	0.8882079	0.019453956	366.89545	869.021
11	10.000021	2.0258005	0.028914375	444.31354	1209.368
12	11.000021	3.0039587	0.02818598	414.7149	1331.8081
13	12.000021	4.003674	0.041972242	486.5666	1777.5978
14	13.000021	6.437684	0.070185035	669.8015	2081.262
15	14.000021	8.766538	0.10389075	677.5965	2404.4924
16	15.000021	11.387993	0.15551451	796.70215	3050.987
17	16.000021	14.627627	0.1835707	821.17523	3136.3518
18	17.000021	17.753935	0.1766344	826.0358	3203.11
19	18.000021	20.33142	0.20743442	882.04333	3507.373
20	19.000021	22.740816	0.1759784	823.1057	3207.8508
21	20.000021	24.80209	0.1903357	871.7763	3332.6423

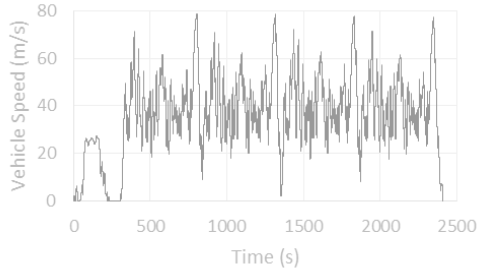
Test Cycle Data Specified Directly in Excel



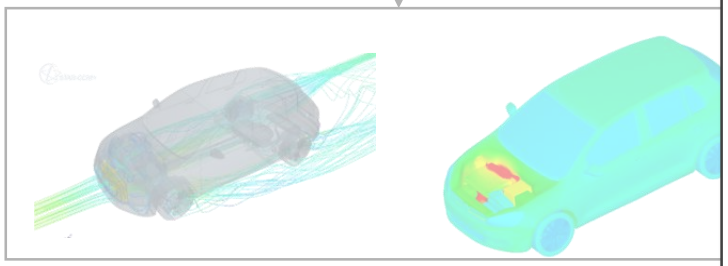
Process Data from Excel Directly in CoTherm

A Commercial Solution

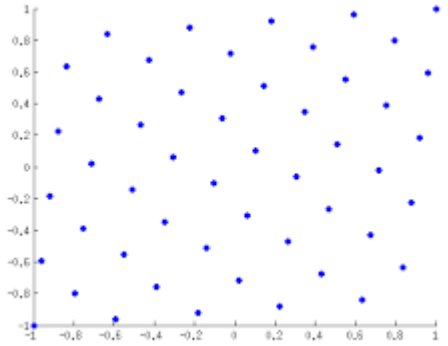
CoTherm

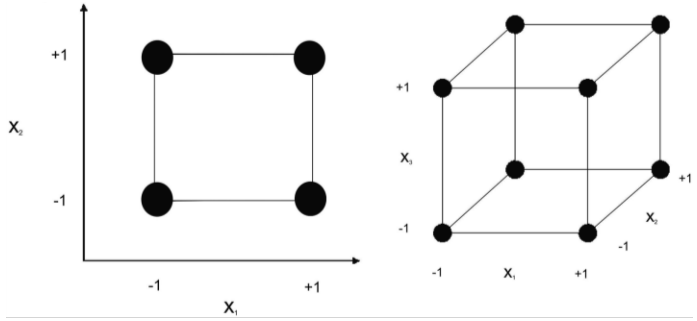


Select a set of representative vehicle parameters

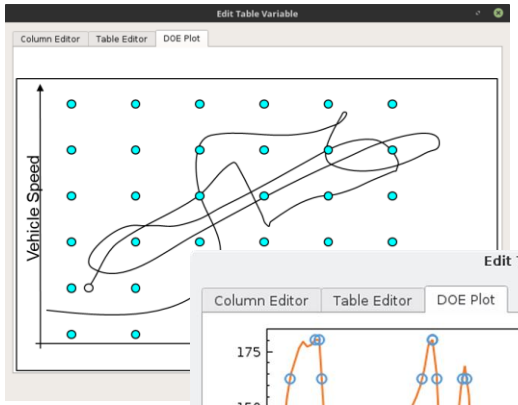


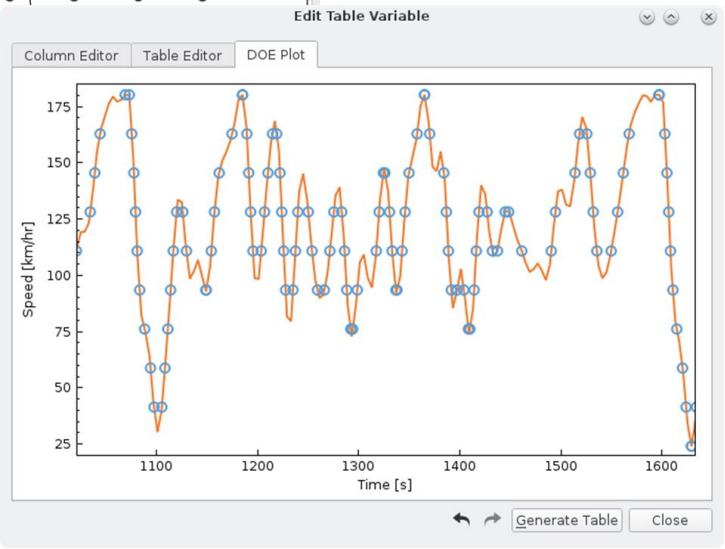
Calculate the steady state CHT solution at each selected speed





Select OLHC or Full Factorial Sampling Plans in Any Number of Dimensions

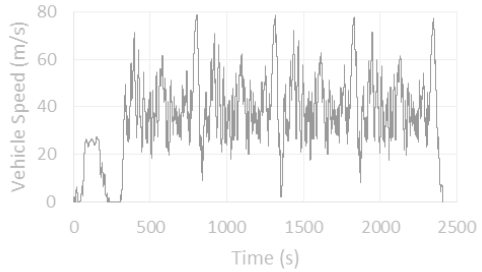




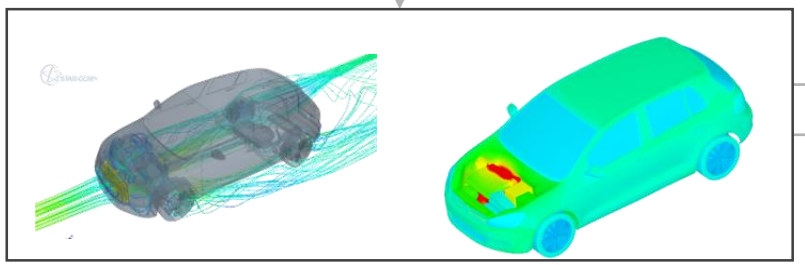
Visualize the Sample Points and Boundary Conditions

A Commercial Solution

CoTherm

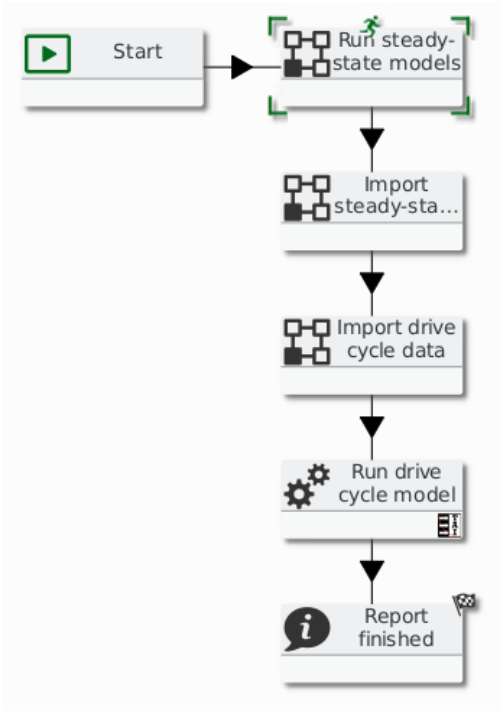


Select a set of representative vehicle parameters

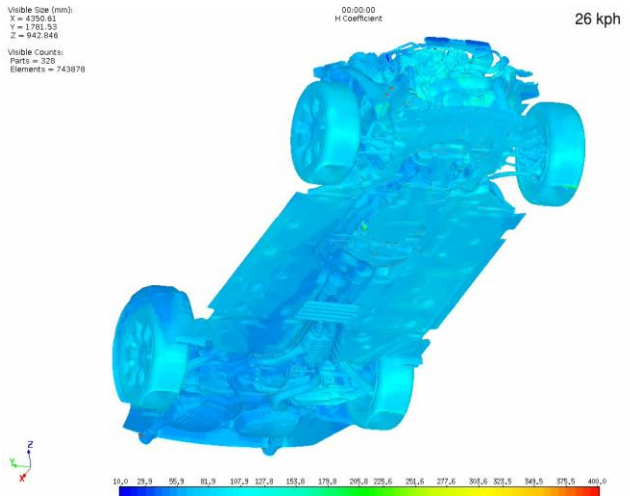


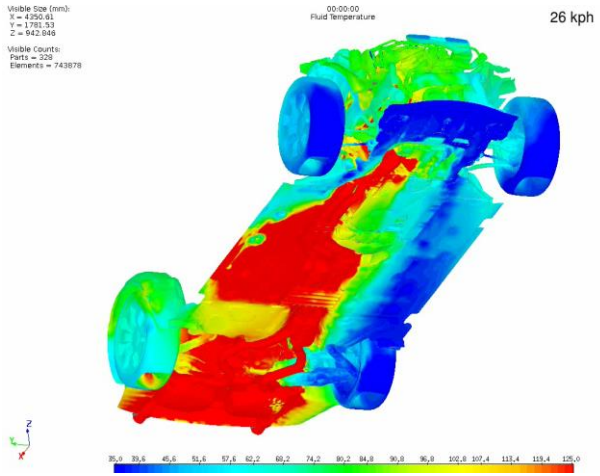
Calculate the steady state CHT solution at each selected speed

Ext



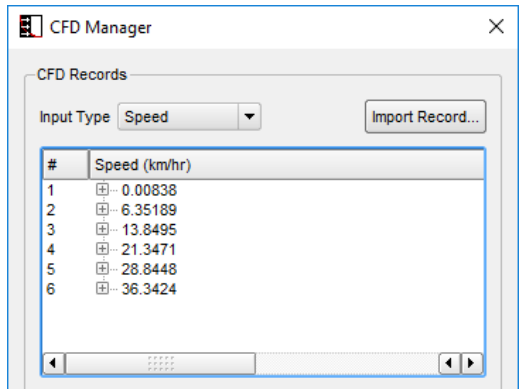
Sample Points are Automatically Calculated Based on Sampling Plan

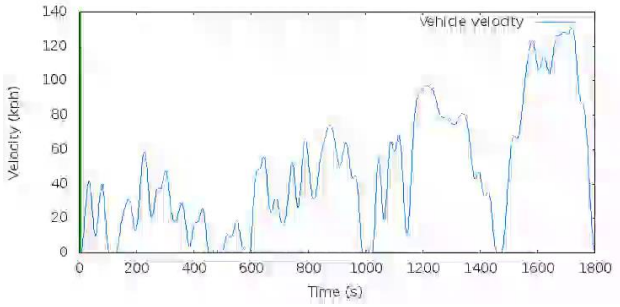


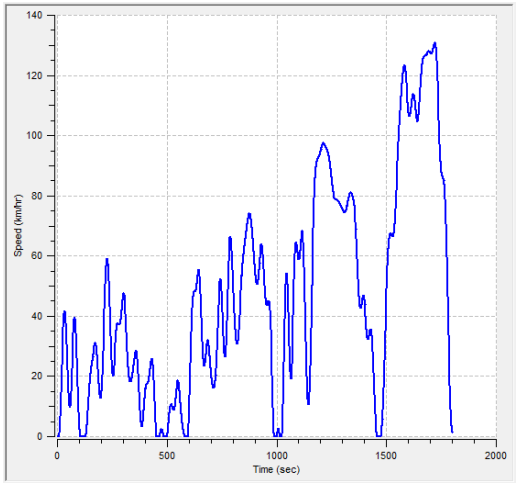


A Commercial Solution

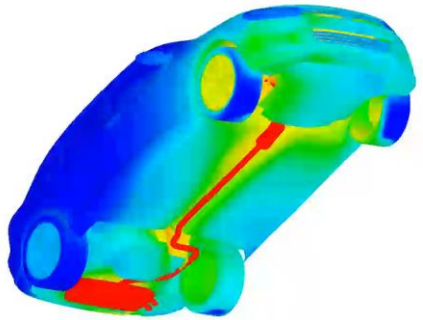
CoTherm

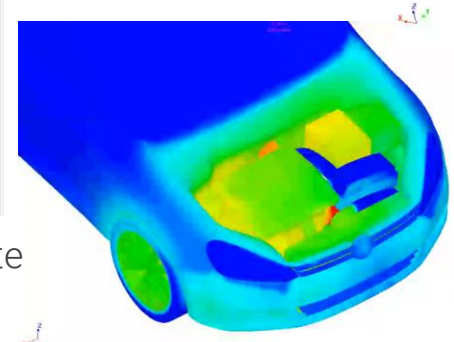






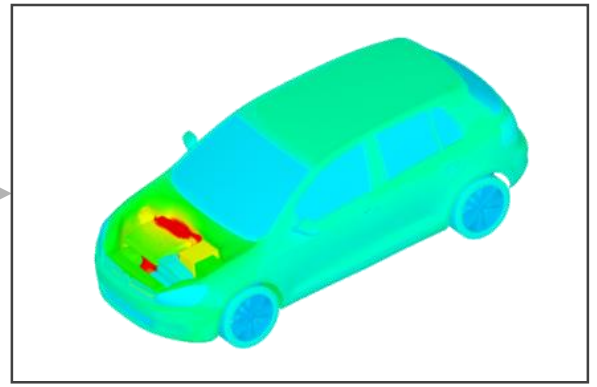
Automatically Create Surrogate Model and Import Boundary Conditions





Simulate Any Drive Cycle Bounded by the Surrogate Model Sample Points

Solve transient thermal simulation

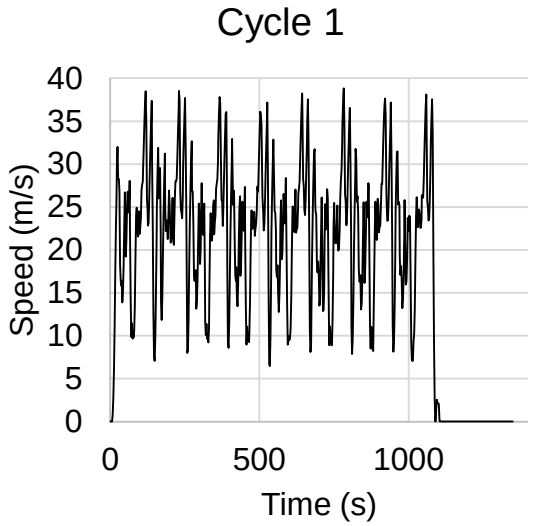


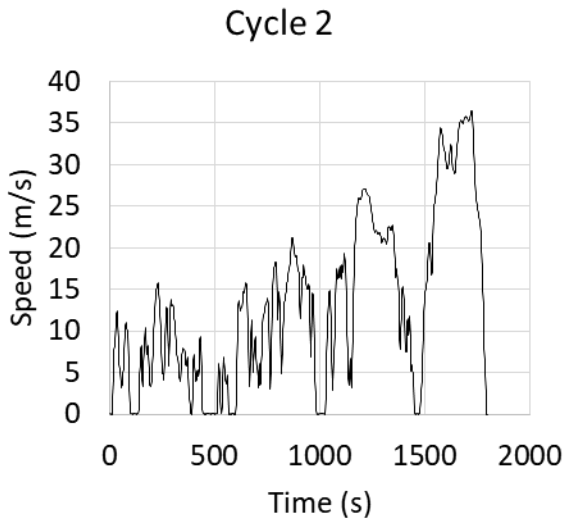
Case Study –Strategies for Simulating Test Cycles in 3D

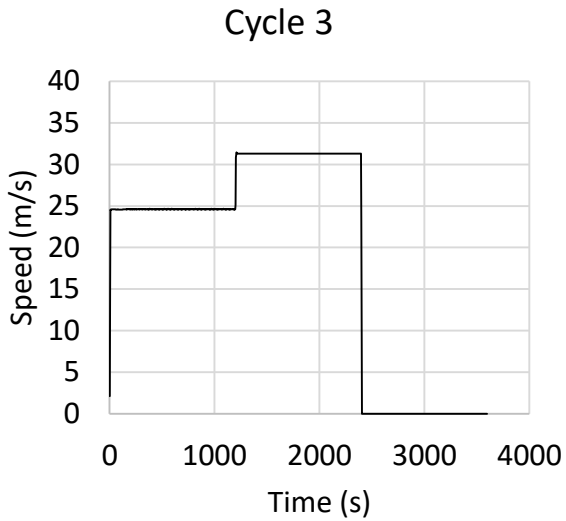
Case Study Introduction

3 Representative Speed profiles Selected

- Speed Profile
- Speed Profile
- Speed Profile



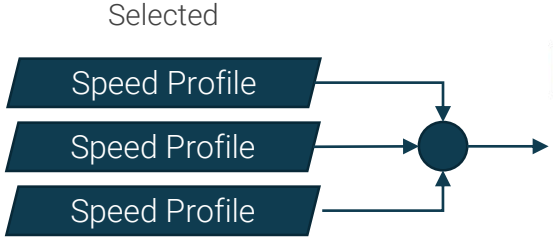


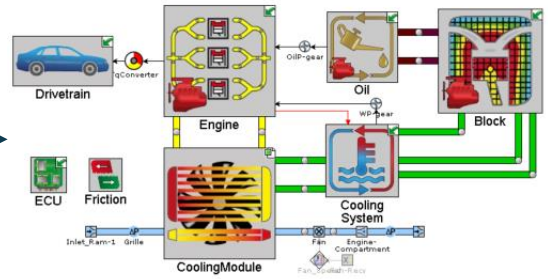


A Comparison of Strategies for Simulating Vehicle Heat Protection Test Cycles in 3D, SAE TMSS, 2018

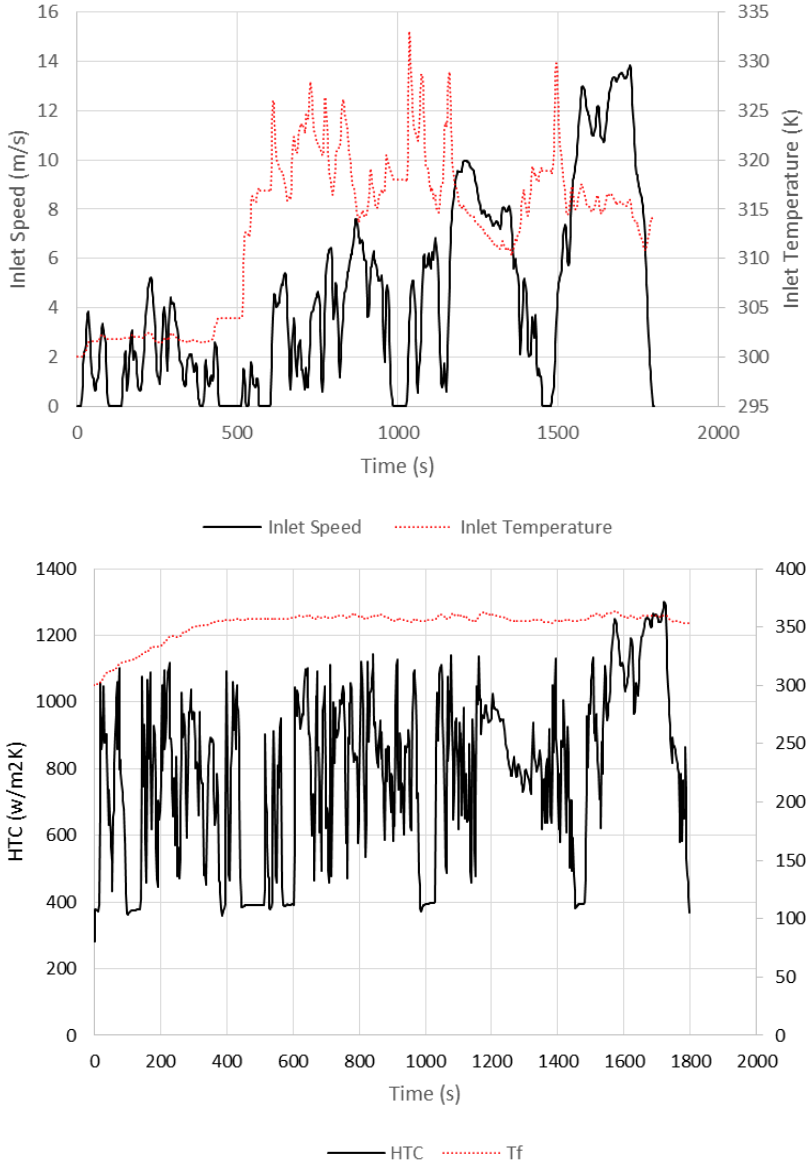
Case Study Introduction

3 Representative Speed profiles Selected





Representative 3D Model Boundary Conditions Created with GT-ISE System Model

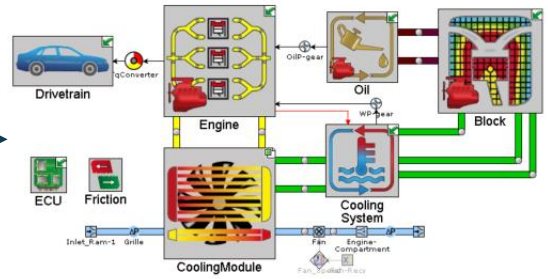


A Comparison of Strategies for Simulating Vehicle Heat Protection Test Cycles in 3D, SAE TMSS, 2018

Case Study Introduction

3 Representative Speed profiles Selected

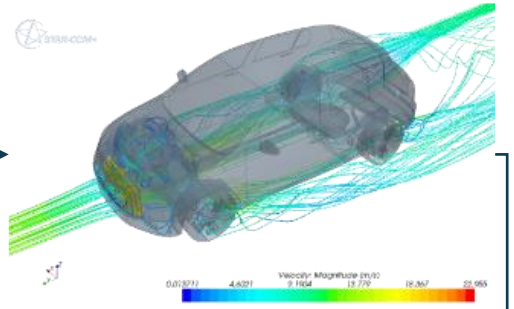
- Speed Profile
- Speed Profile
- Speed Profile



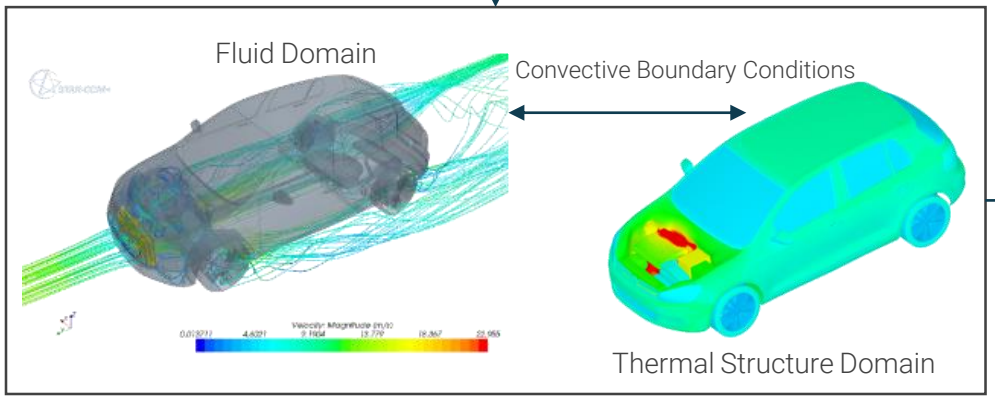
Representative 3D Model Boundary Conditions Created with GT-ISE System Model

Test Cycle Boundary Conditions

Establish a “True” Solution using a CHT simulation



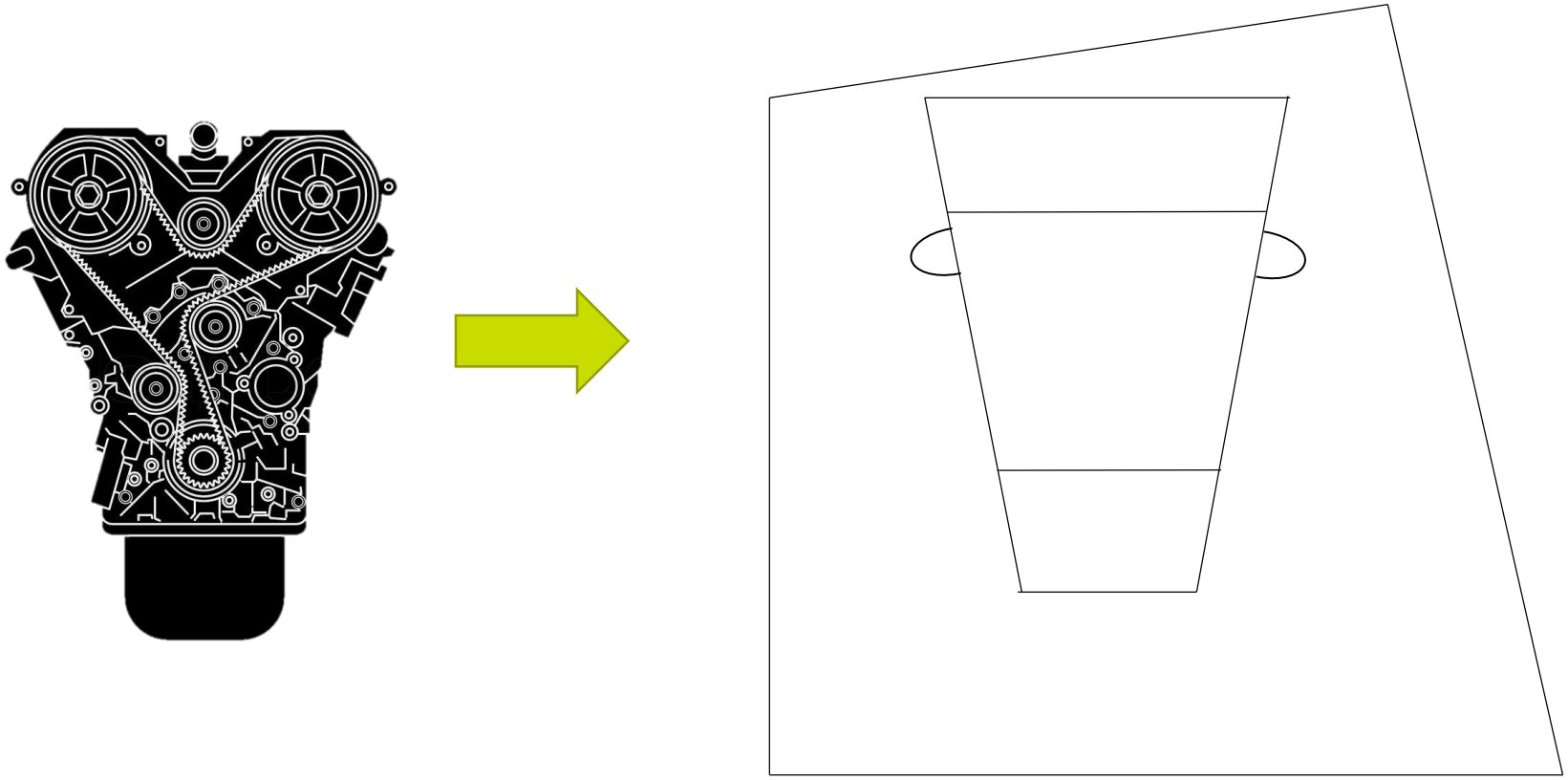
Compare CHT and Coupled Solutions



Simulate the Same Test Cycles With Segregated Domains Using Various Coupling Strategies

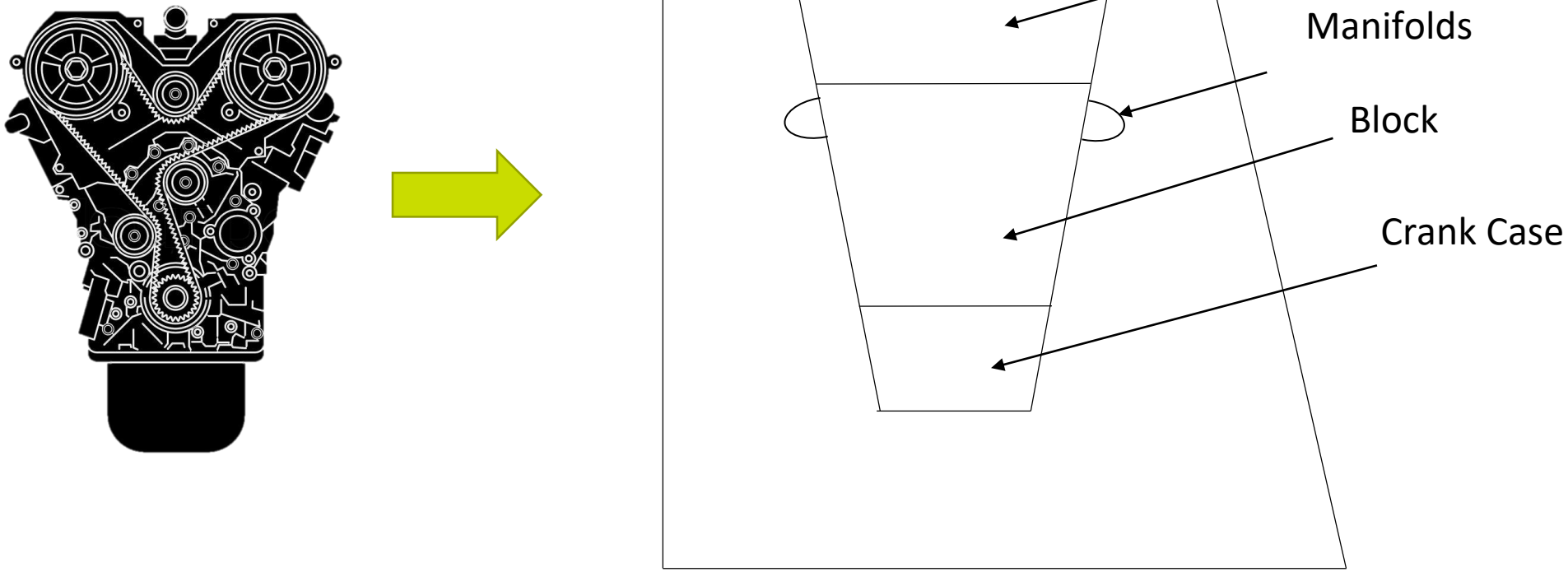
A Comparison of Strategies for Simulating Vehicle Heat Protection Test Cycles in 3D, SAE TMSS, 2018

Case Study Introduction



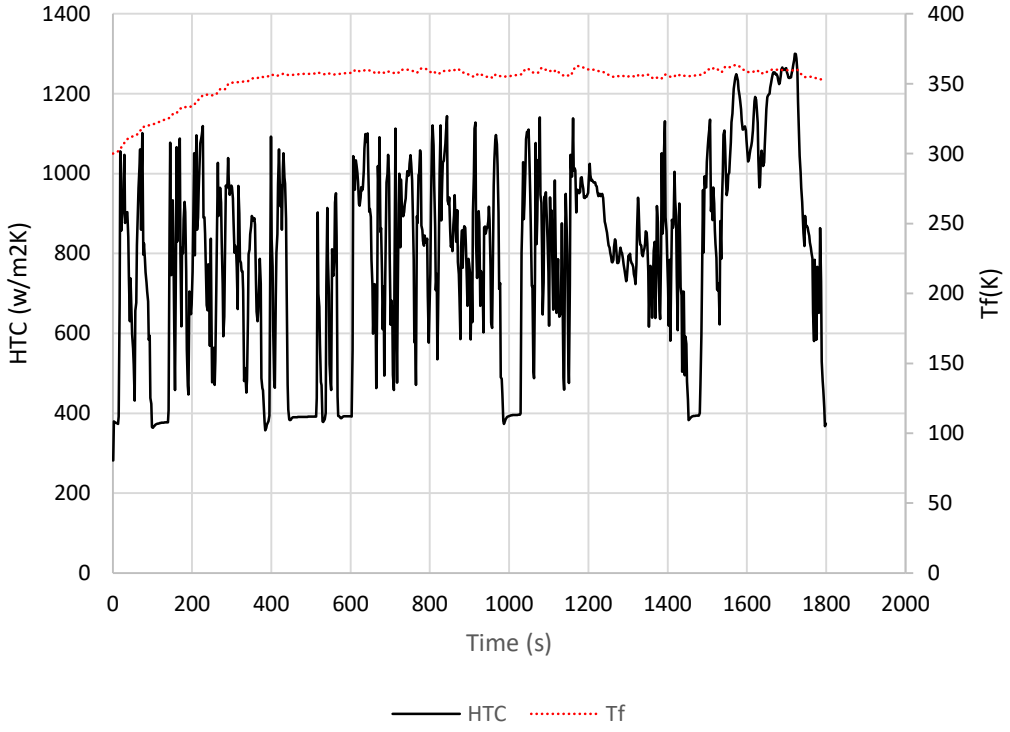
A Comparison of Strategies for Simulating Vehicle Heat Protection Test Cycles in 3D, SAE TMSS, 2018

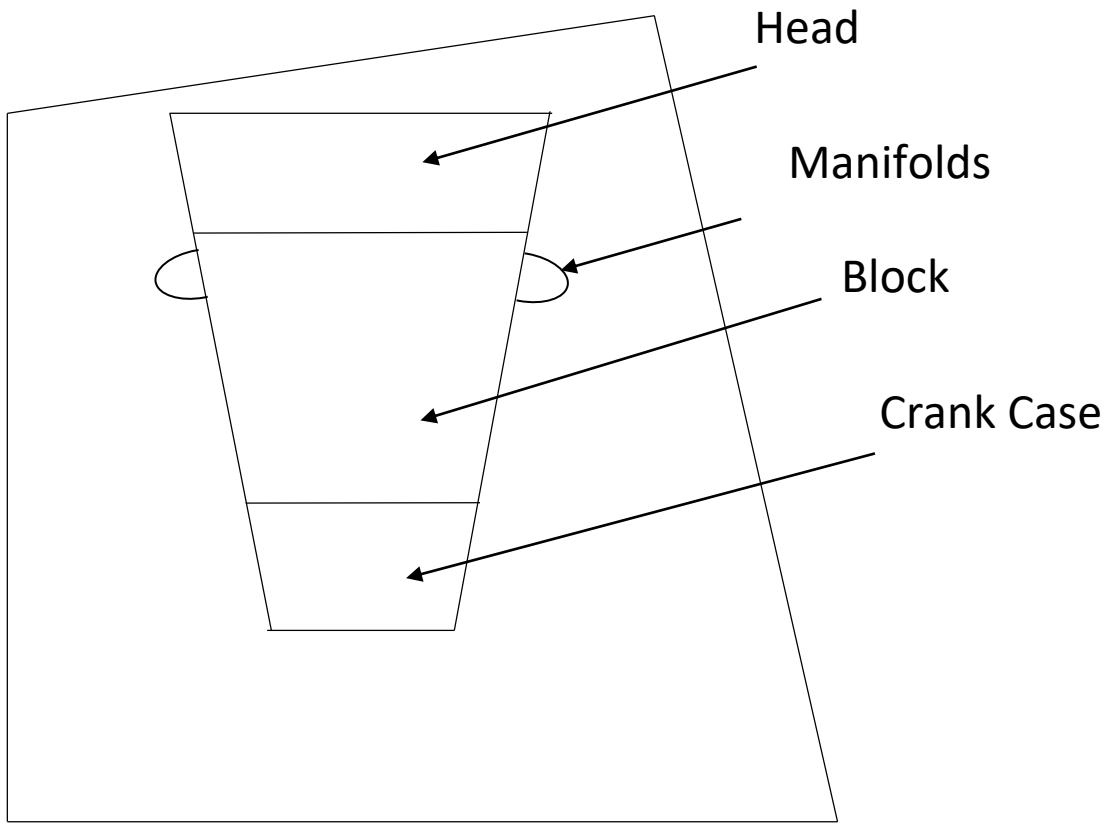
Case Study Introduction



A Comparison of Strategies for Simulating Vehicle Heat Protection Test Cycles in 3D, SAE TMSS, 2018

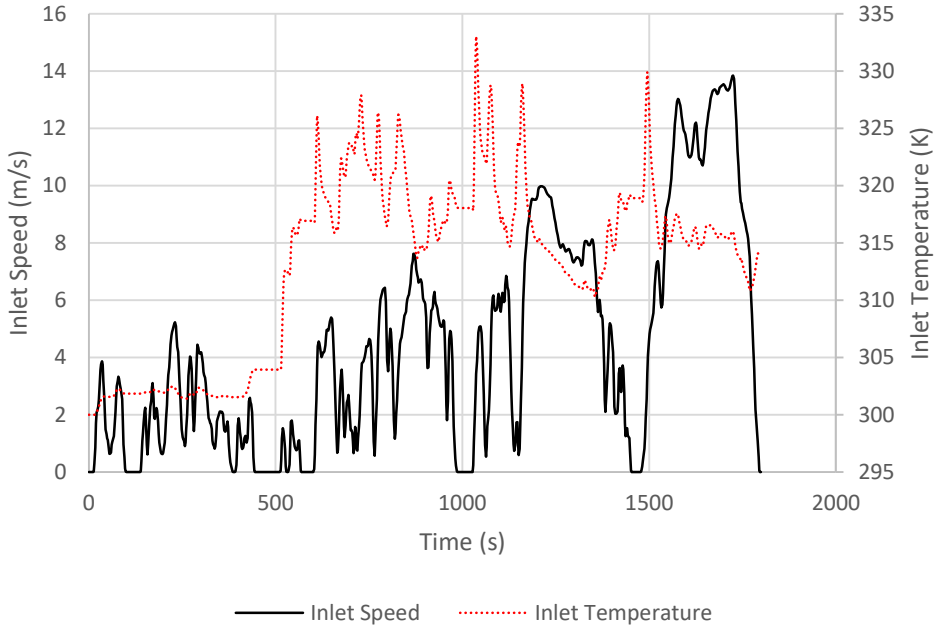
Case Study Introduction

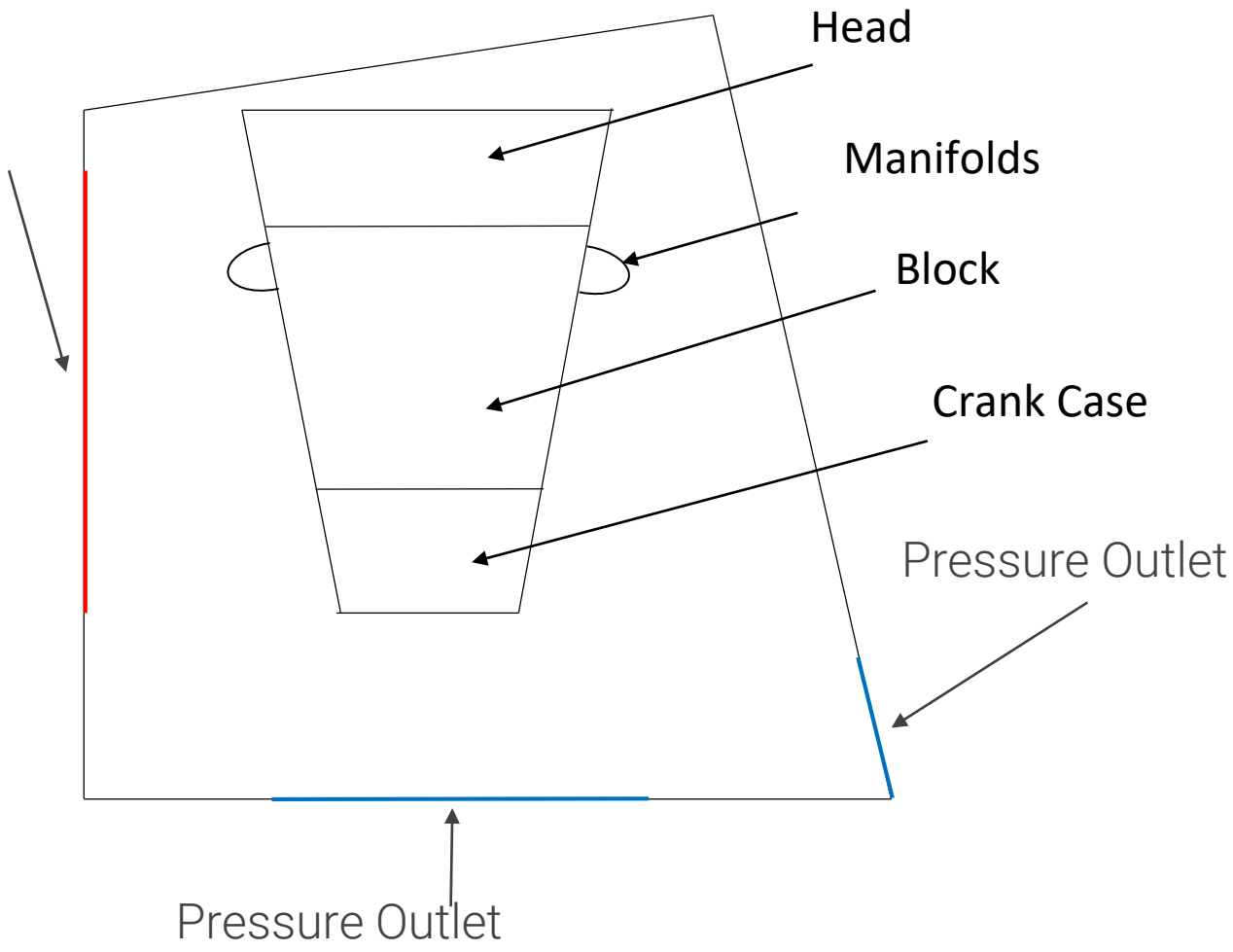




A Comparison of Strategies for Simulating Vehicle Heat Protection Test Cycles in 3D, SAE TMSS, 2018

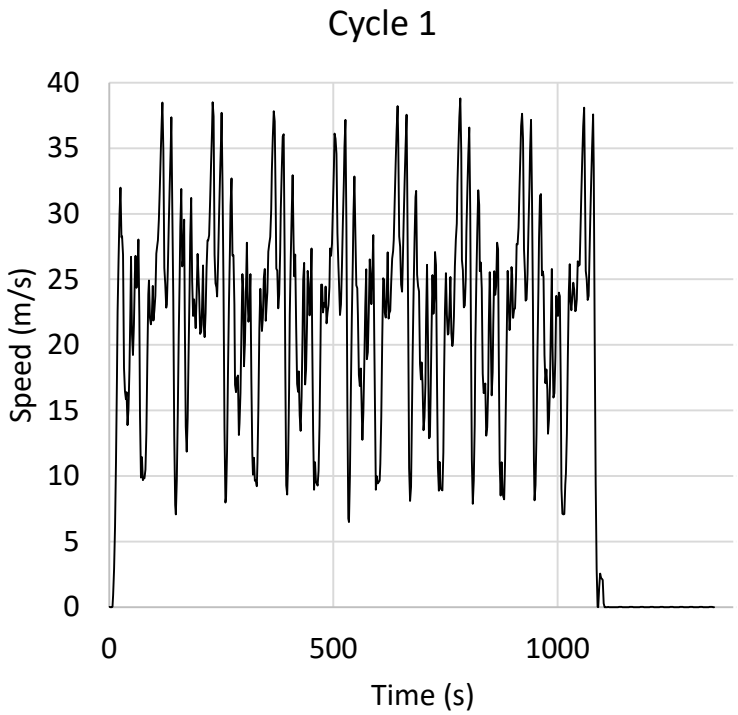
Case Study Introduction

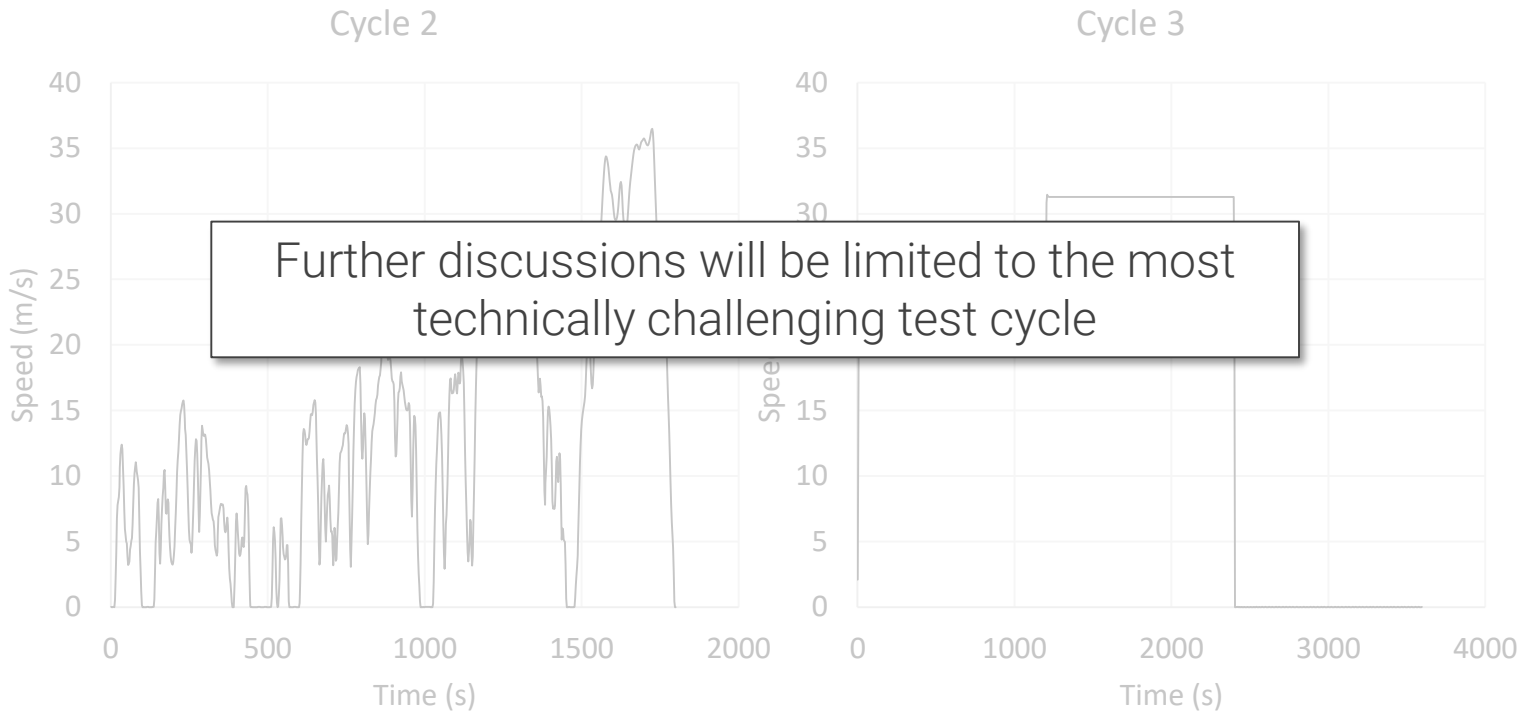




A Comparison of Strategies for Simulating Vehicle Heat Protection Test Cycles in 3D, SAE TMSS, 2018

Case Study Introduction





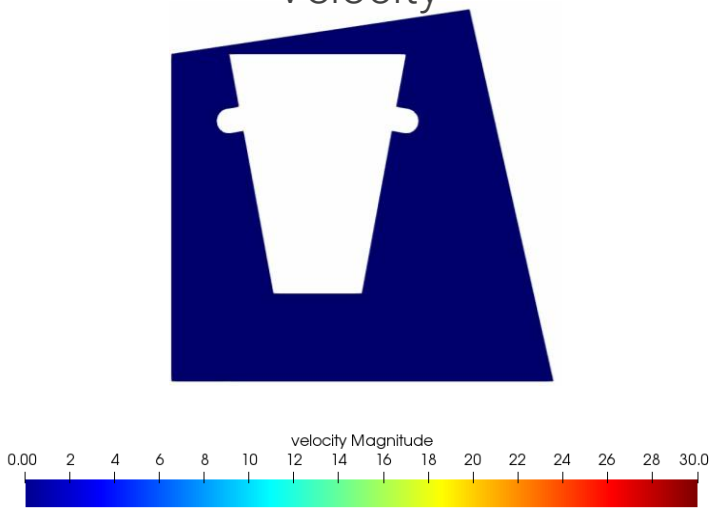
Further discussions will be limited to the most technically challenging test cycle

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

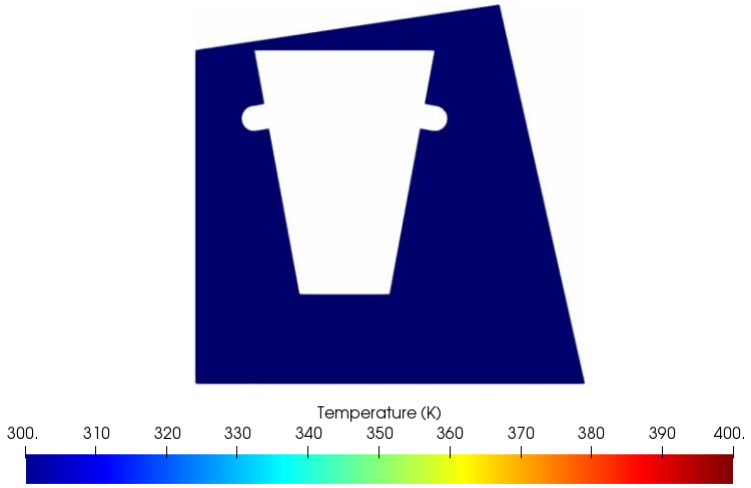
A Comparison of Strategies for Simulating Vehicle Heat Protection Test Cycles in 3D, SAE TMSS, 2018

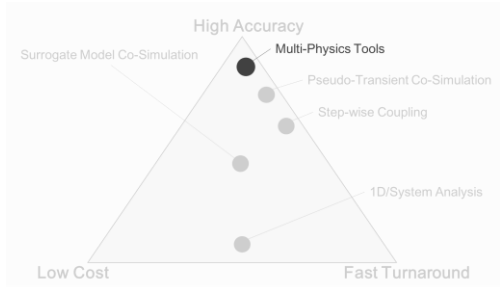
CHT Simulation

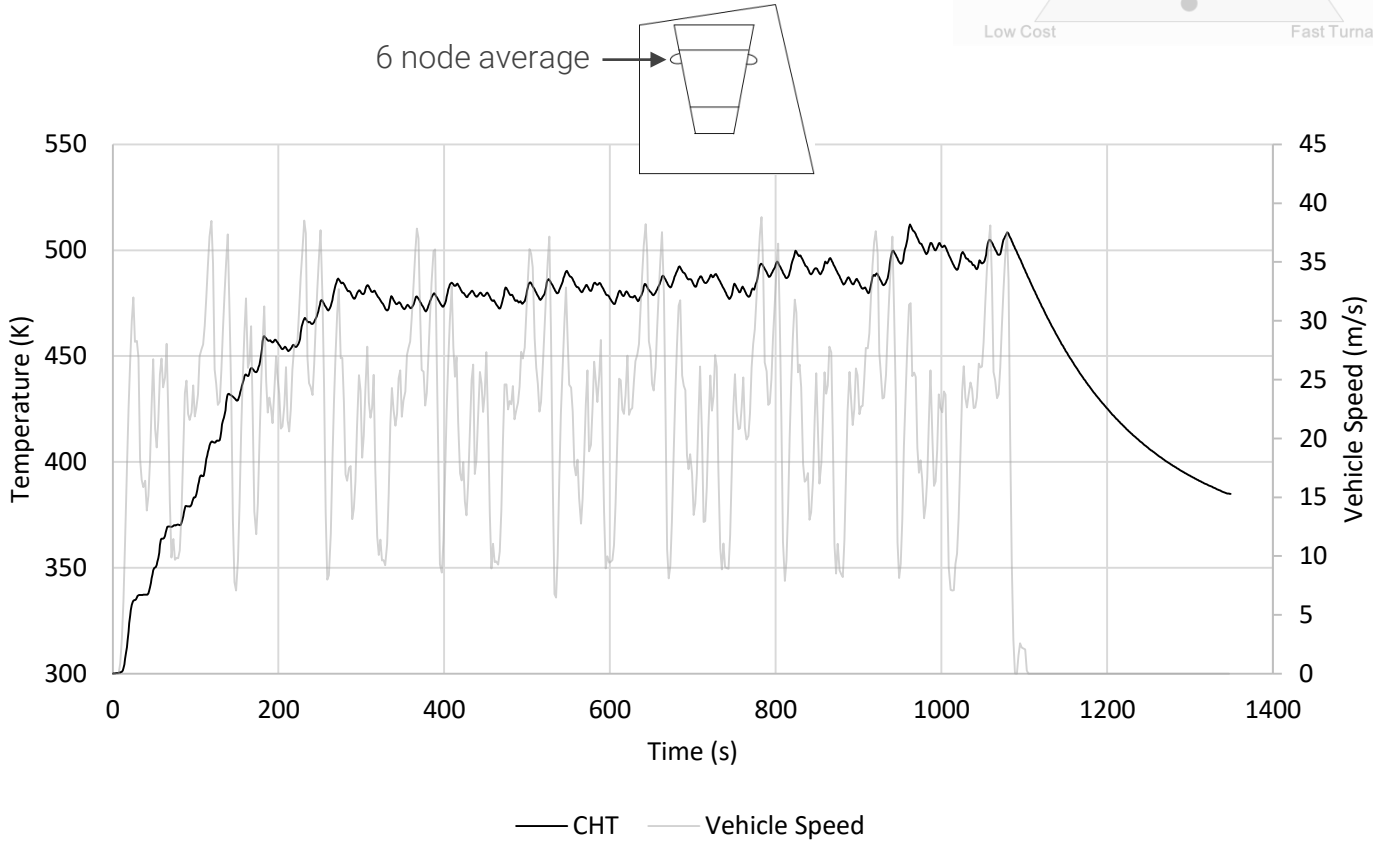
Velocity



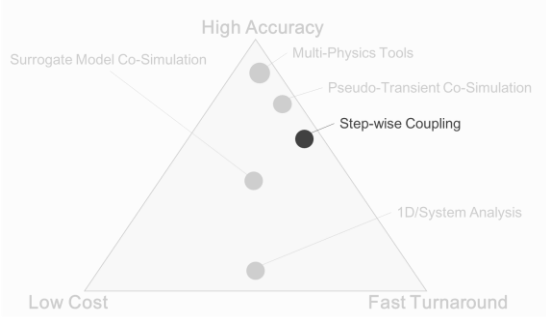
Temperature

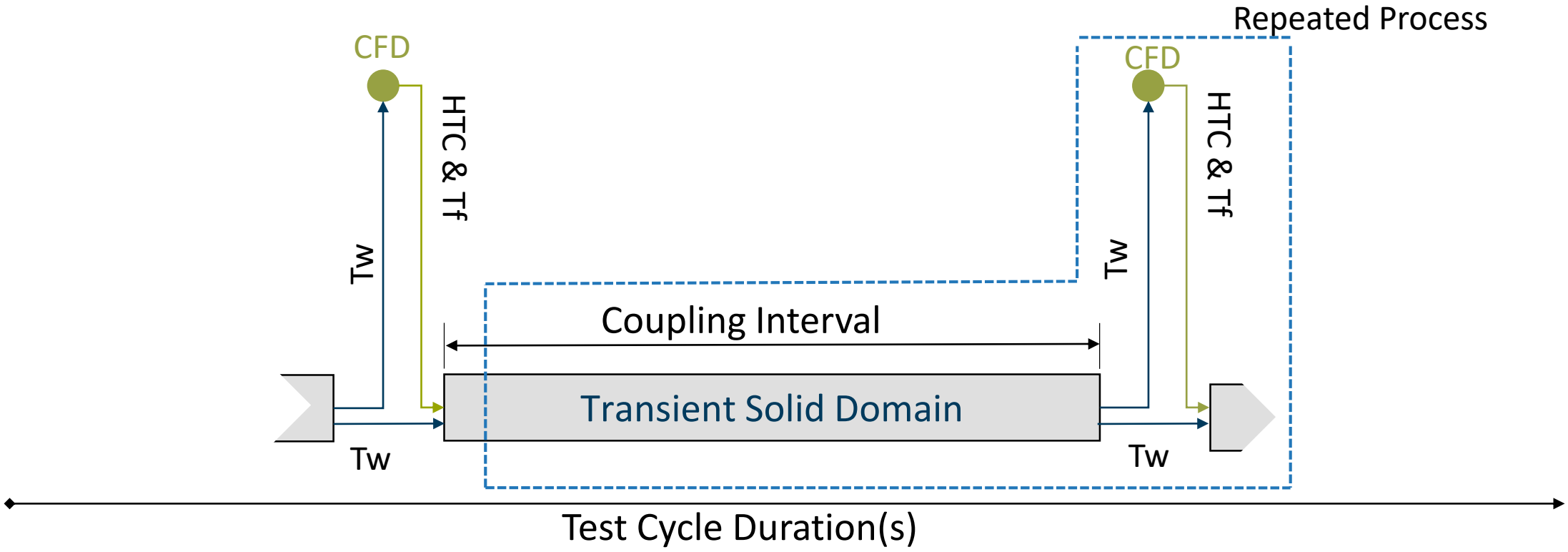




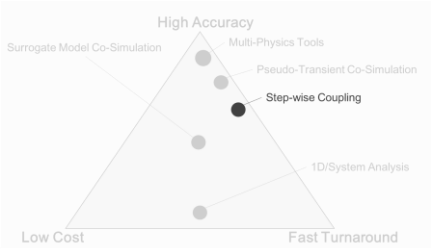


Step-Wise Coupling

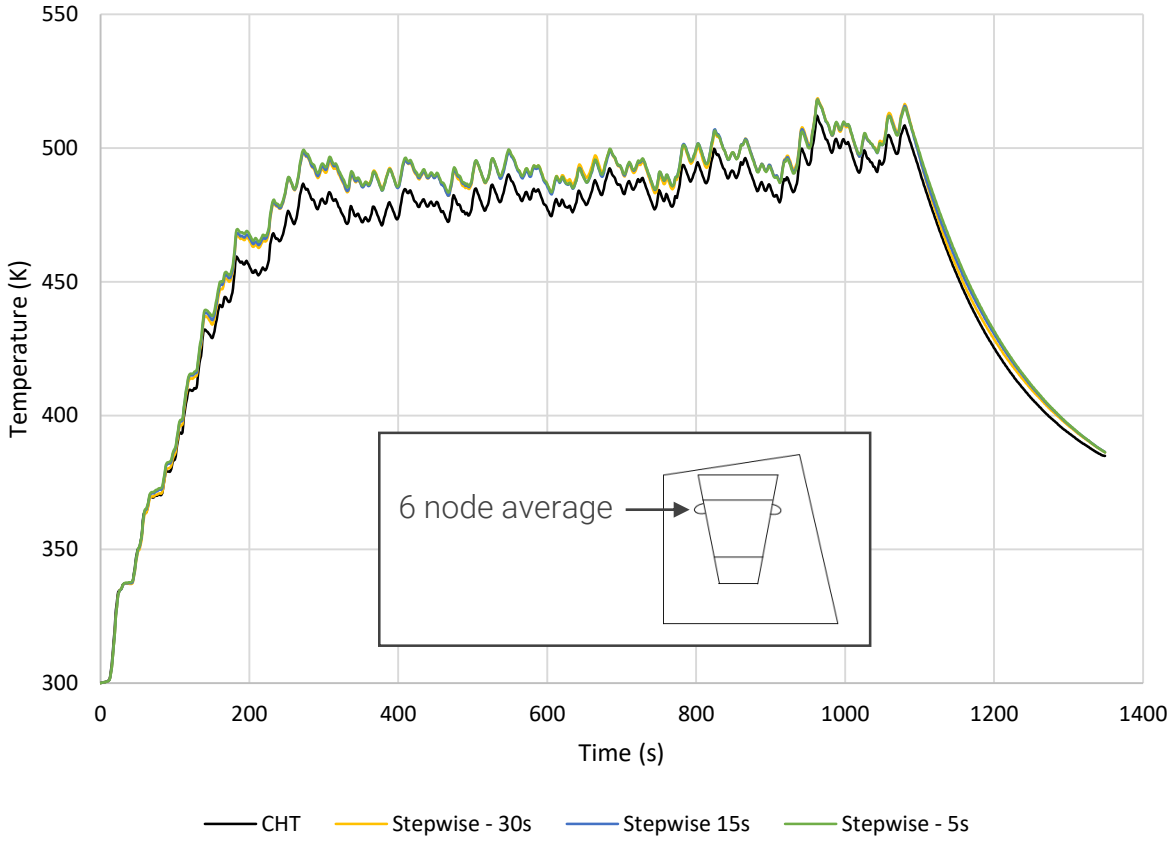




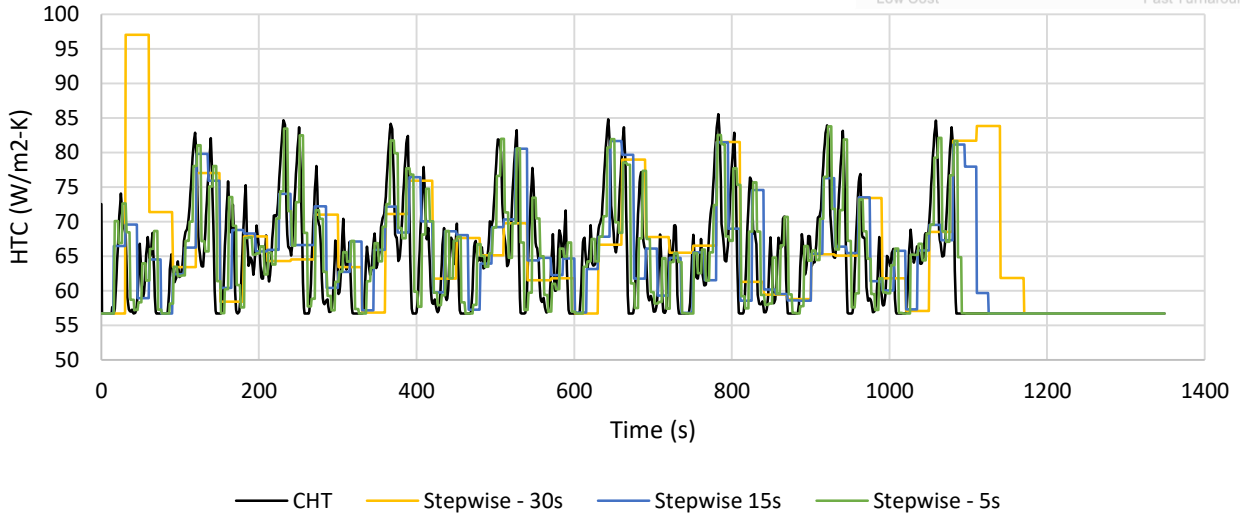
Step-Wise Coupling



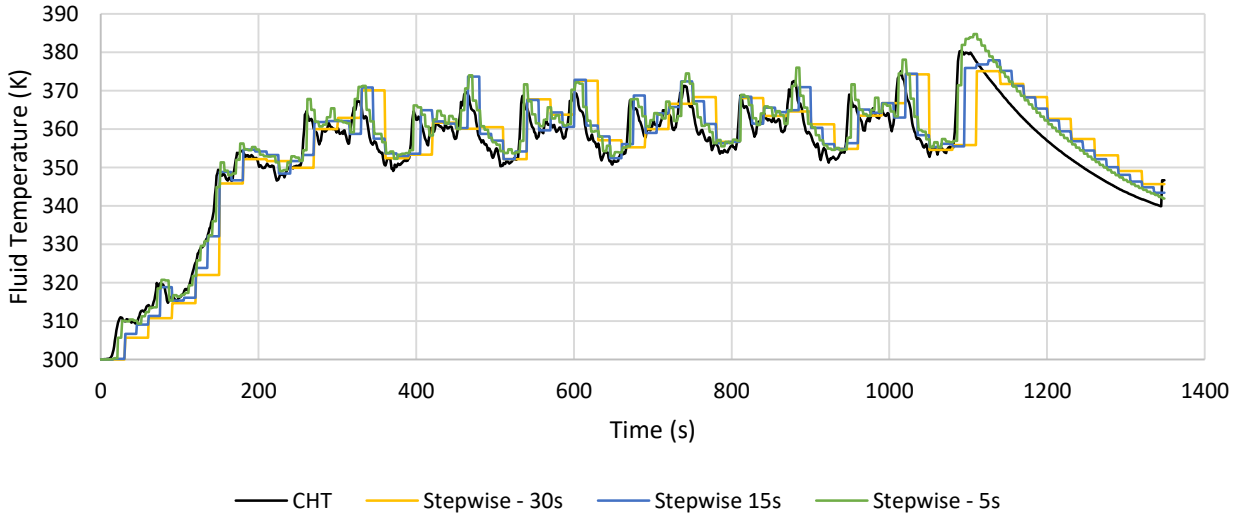
Wall Temperature



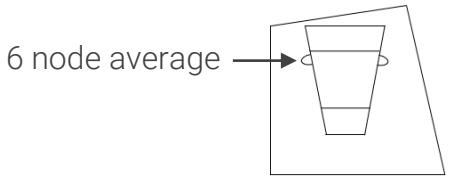
Heat Transfer Coefficient

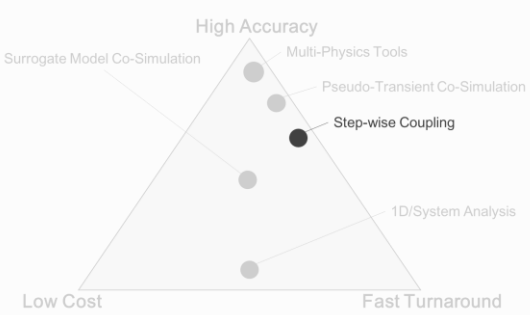


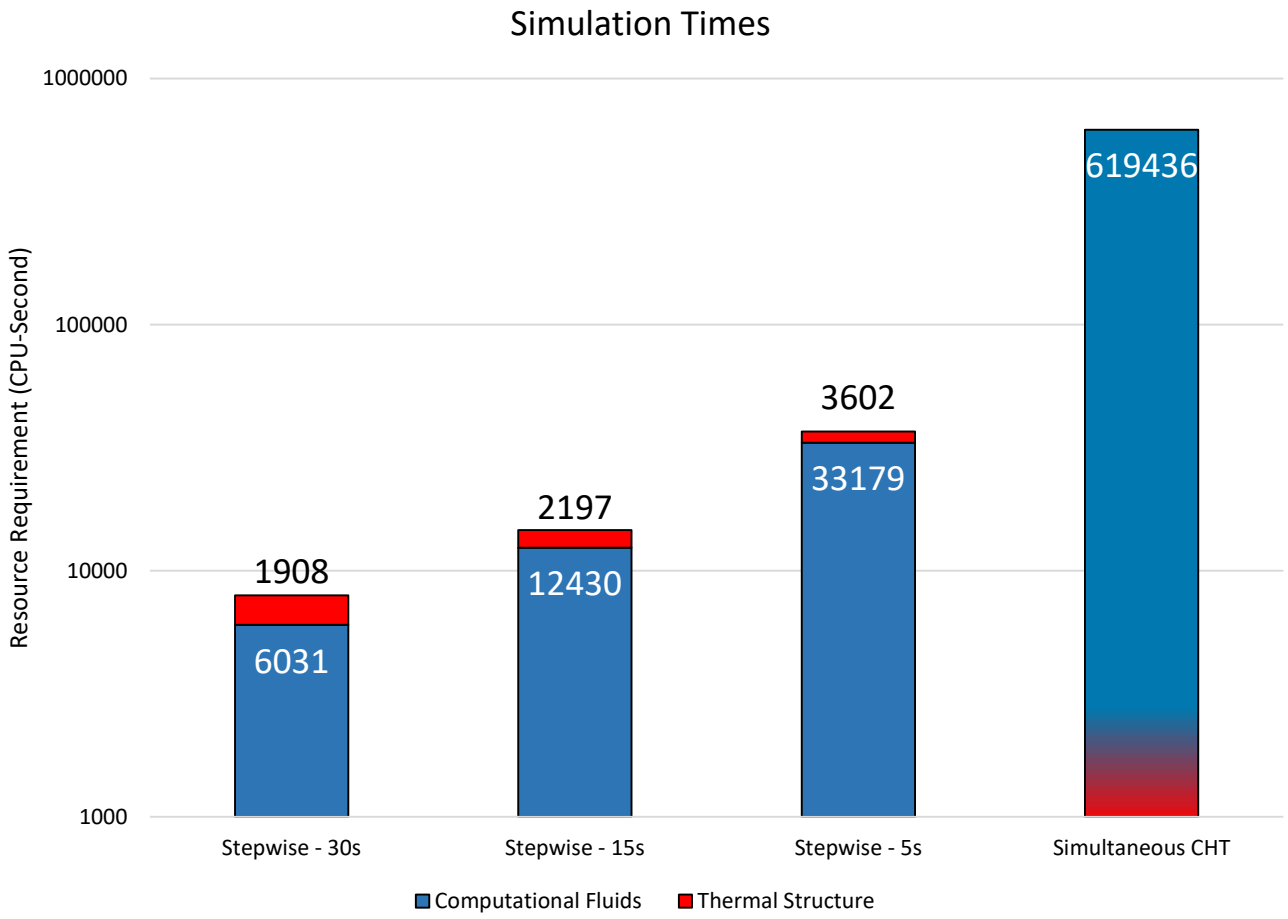
Fluid Temperature

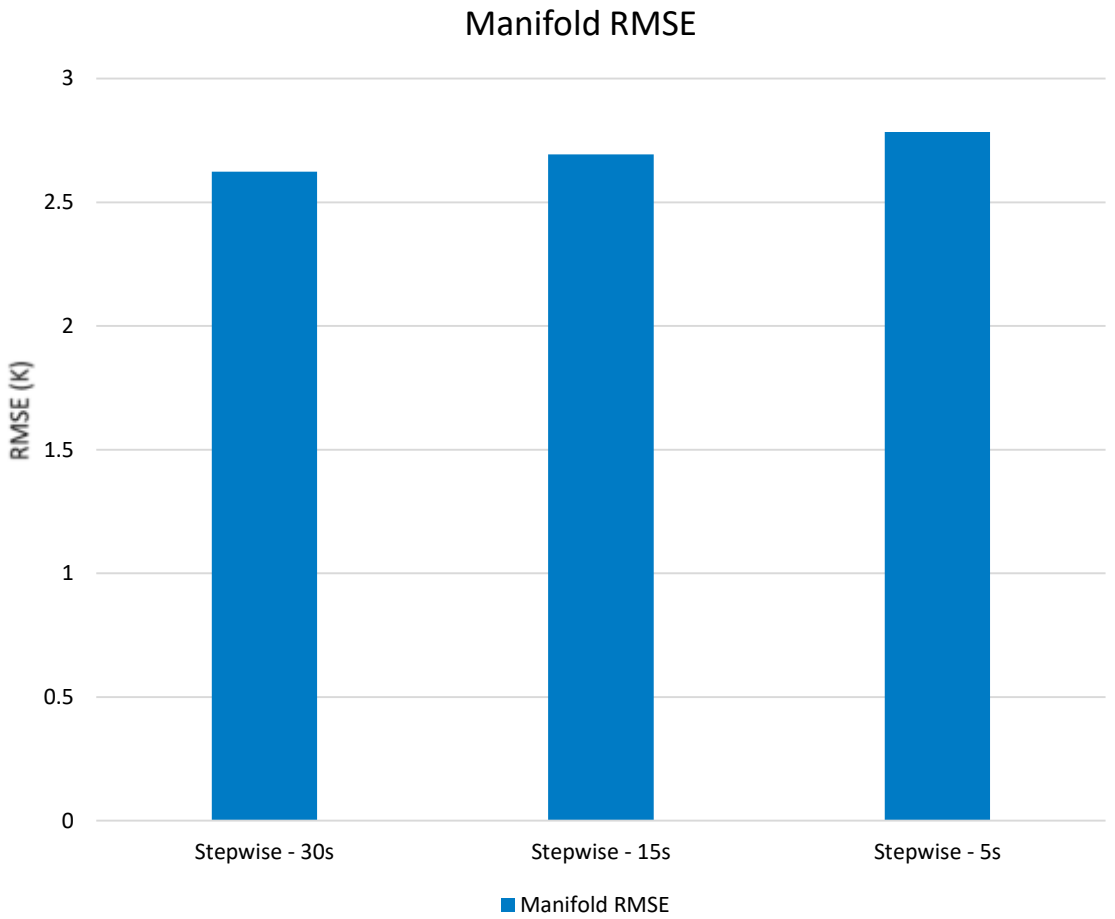


Step-Wise Coupling

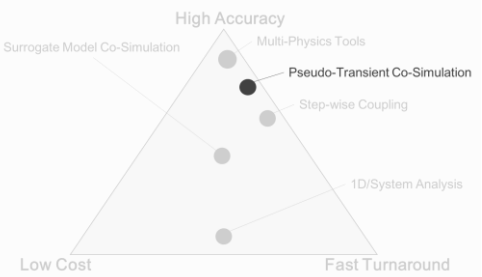


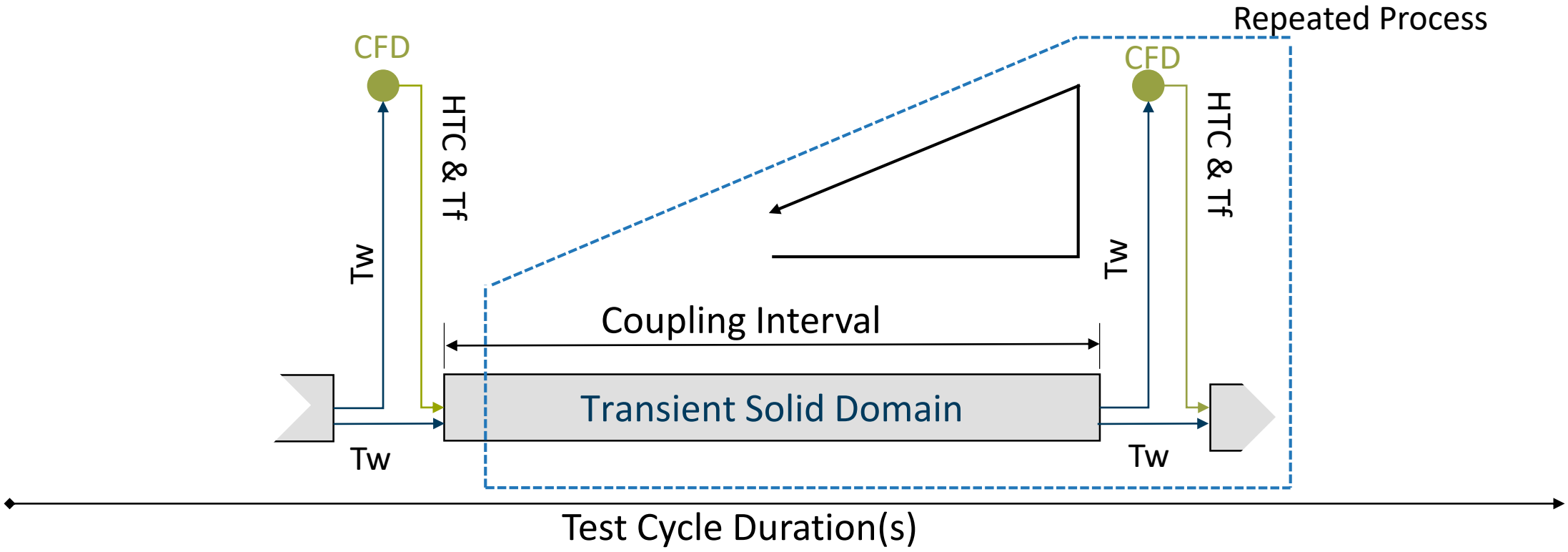




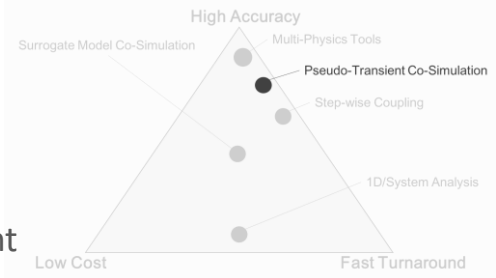


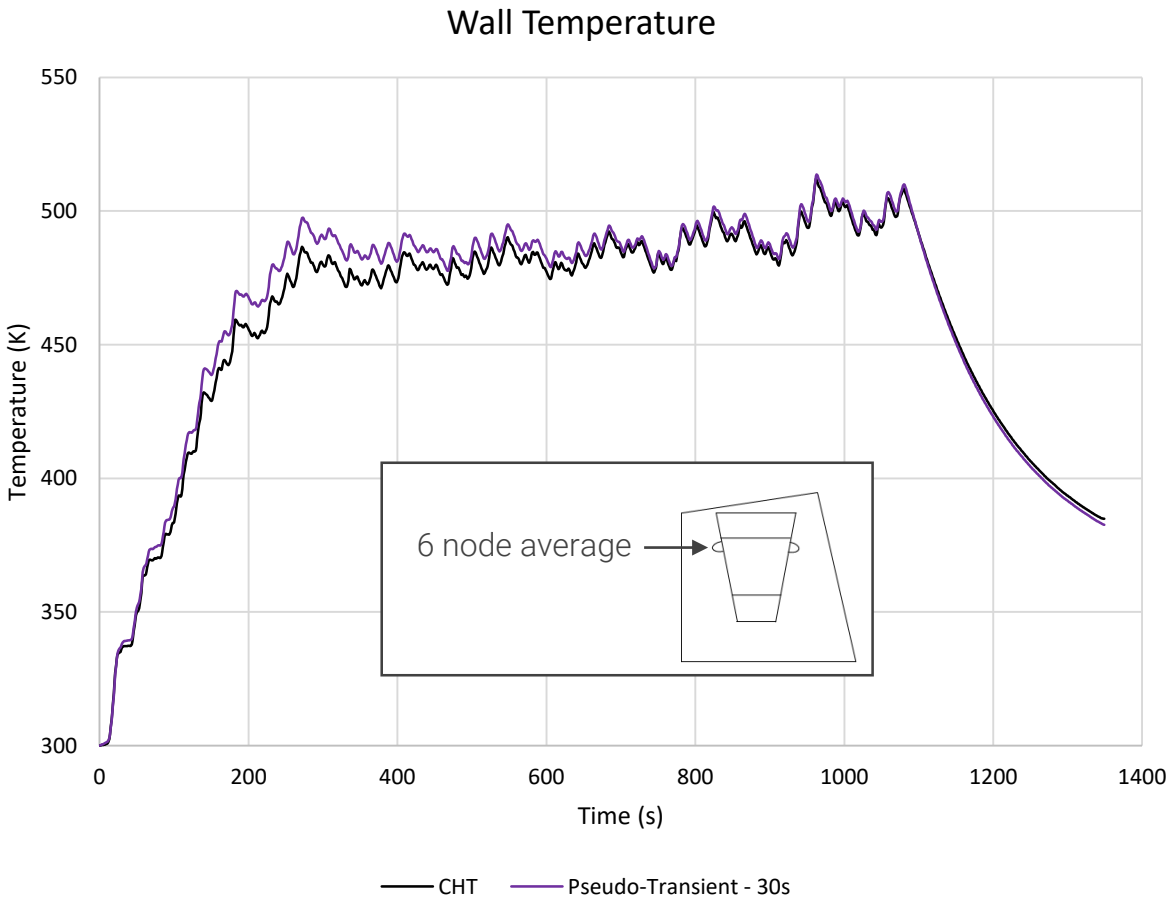
Pseudo-Transient Coupling

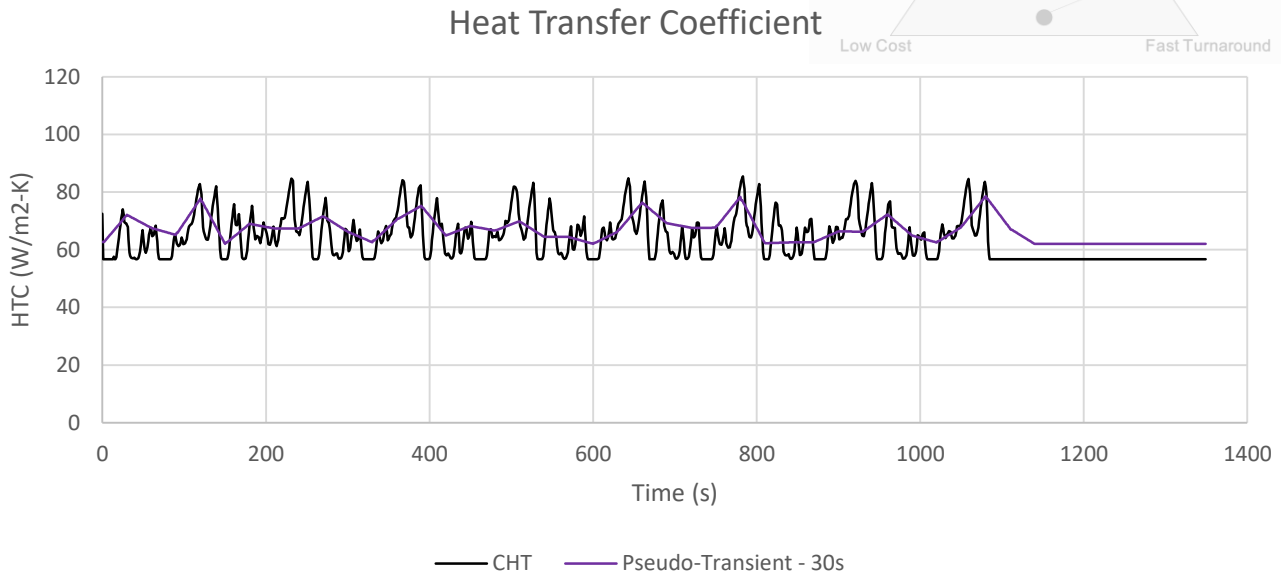


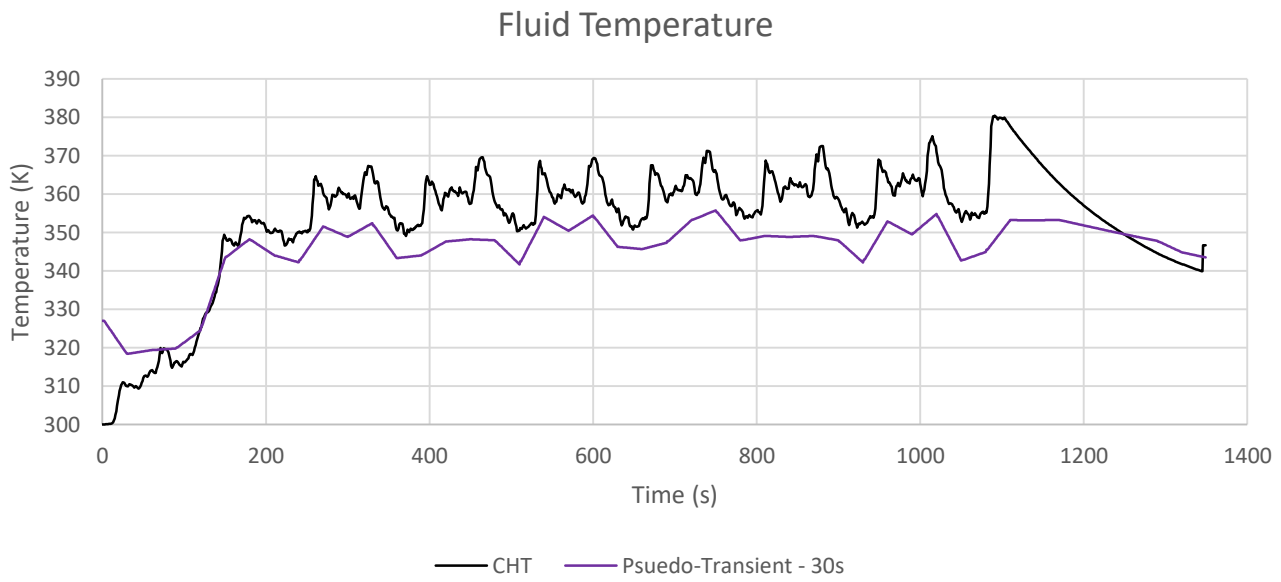


Pseudo-Transient Coupling

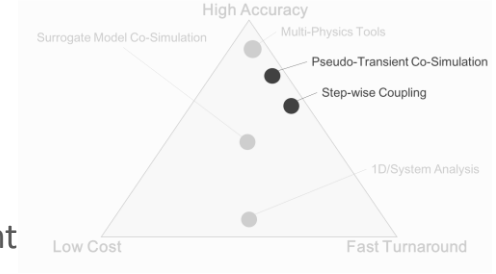


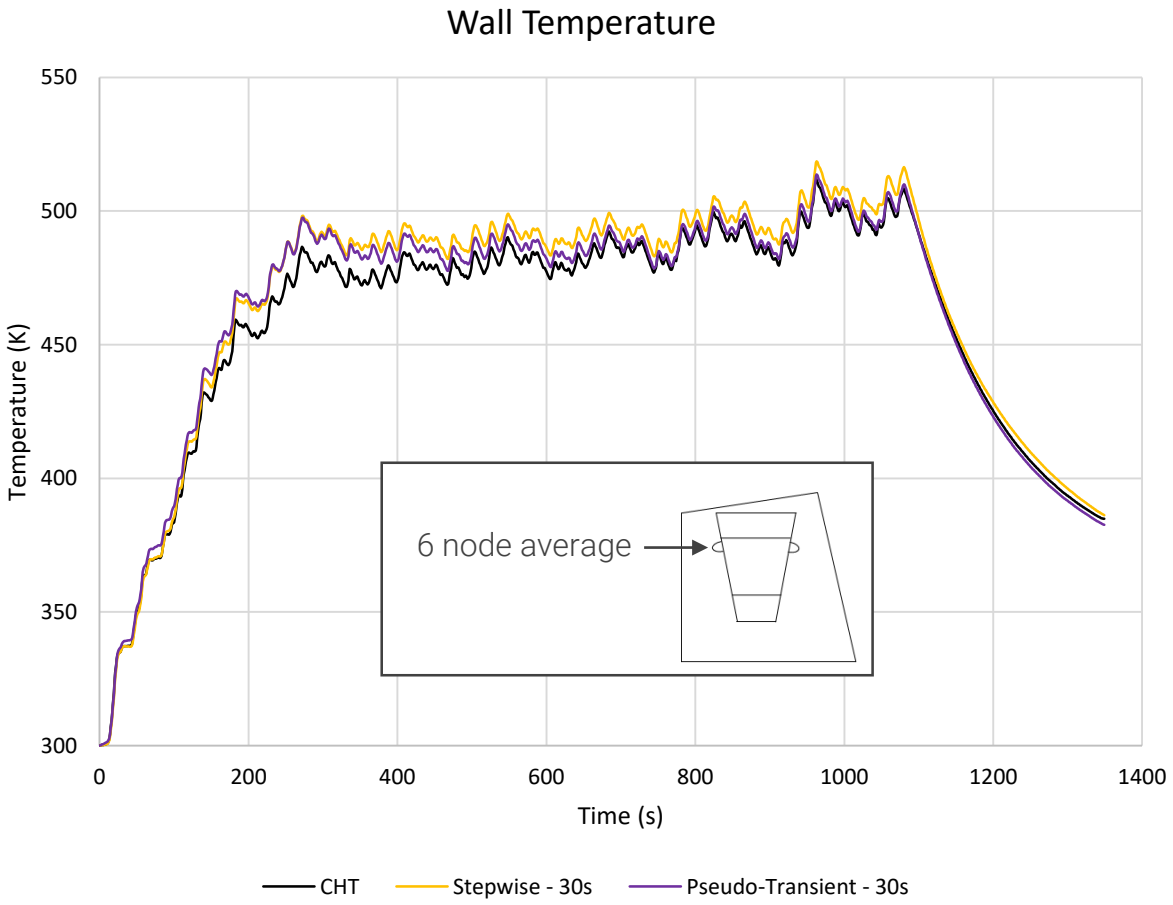


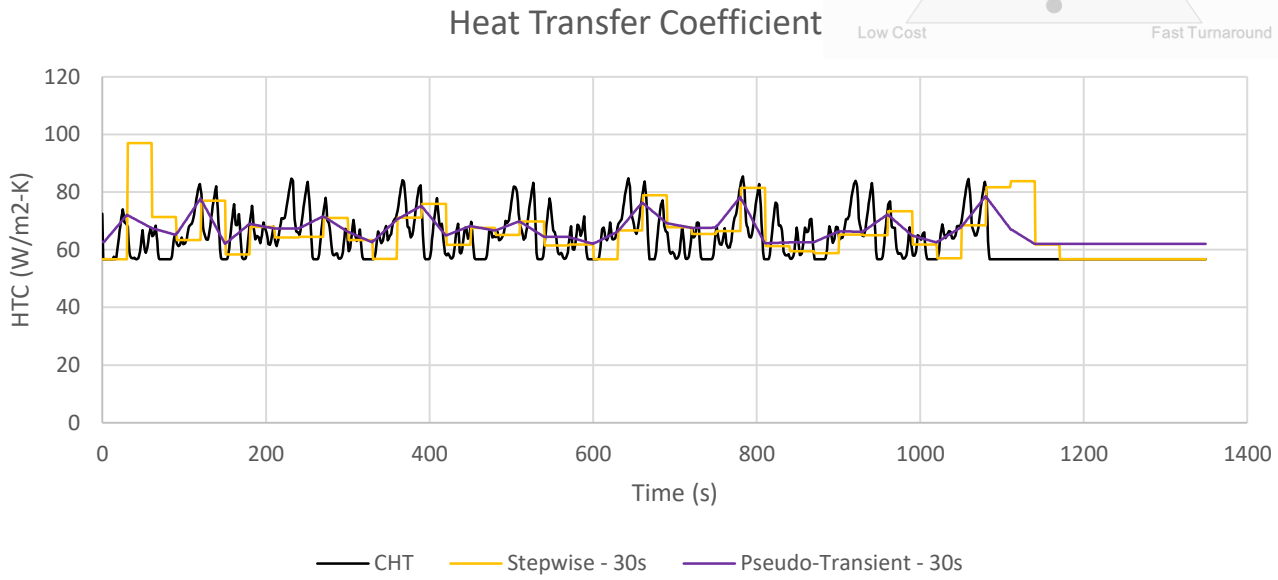


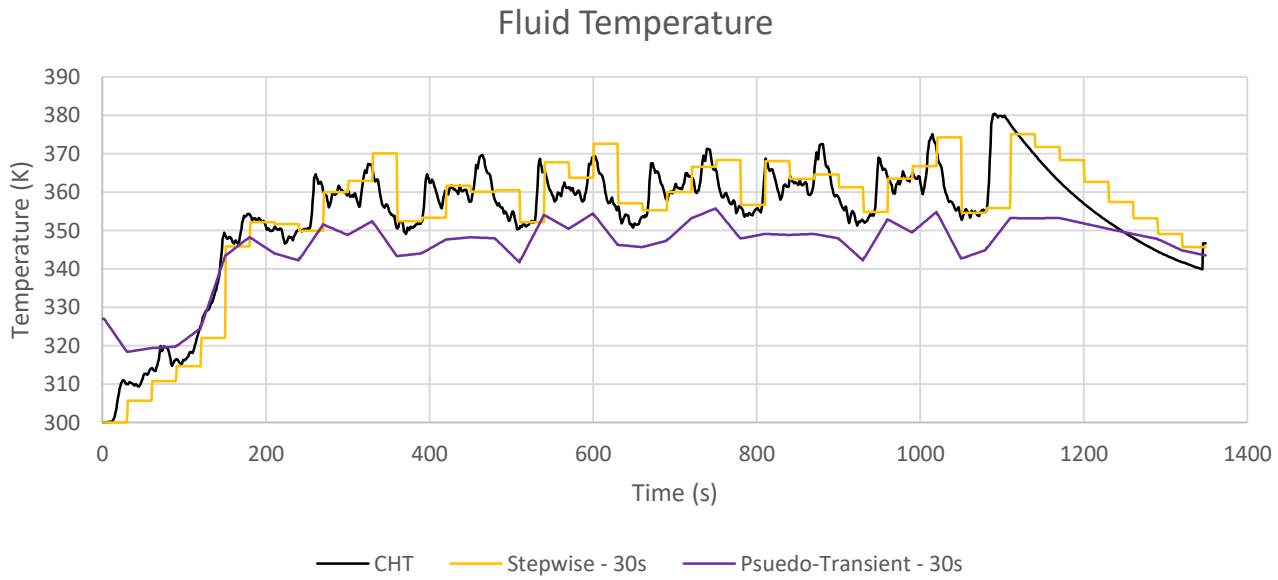


Pseudo-Transient Coupling

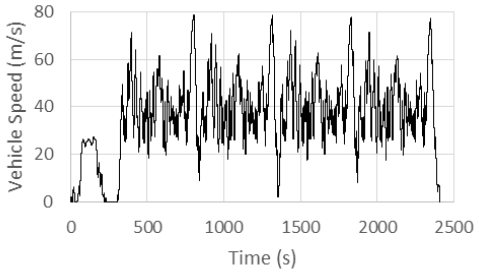




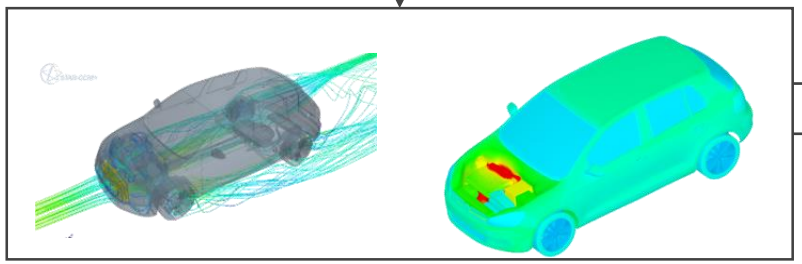




Surrogate Model Co-Simulation



Select a set of representative vehicle parameters



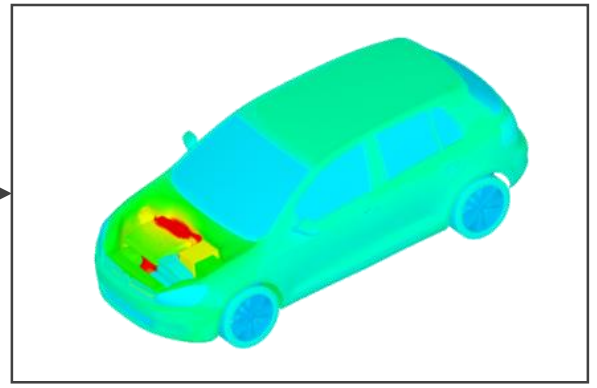
Calculate the steady state CHT solution at each selected speed

Extract HTC & Tf

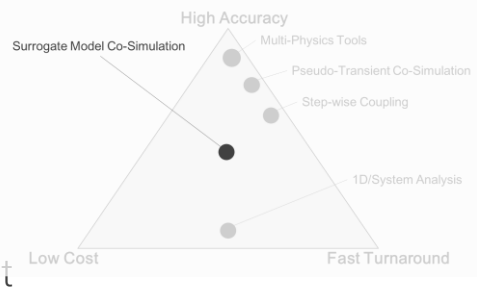
Surrogate Model

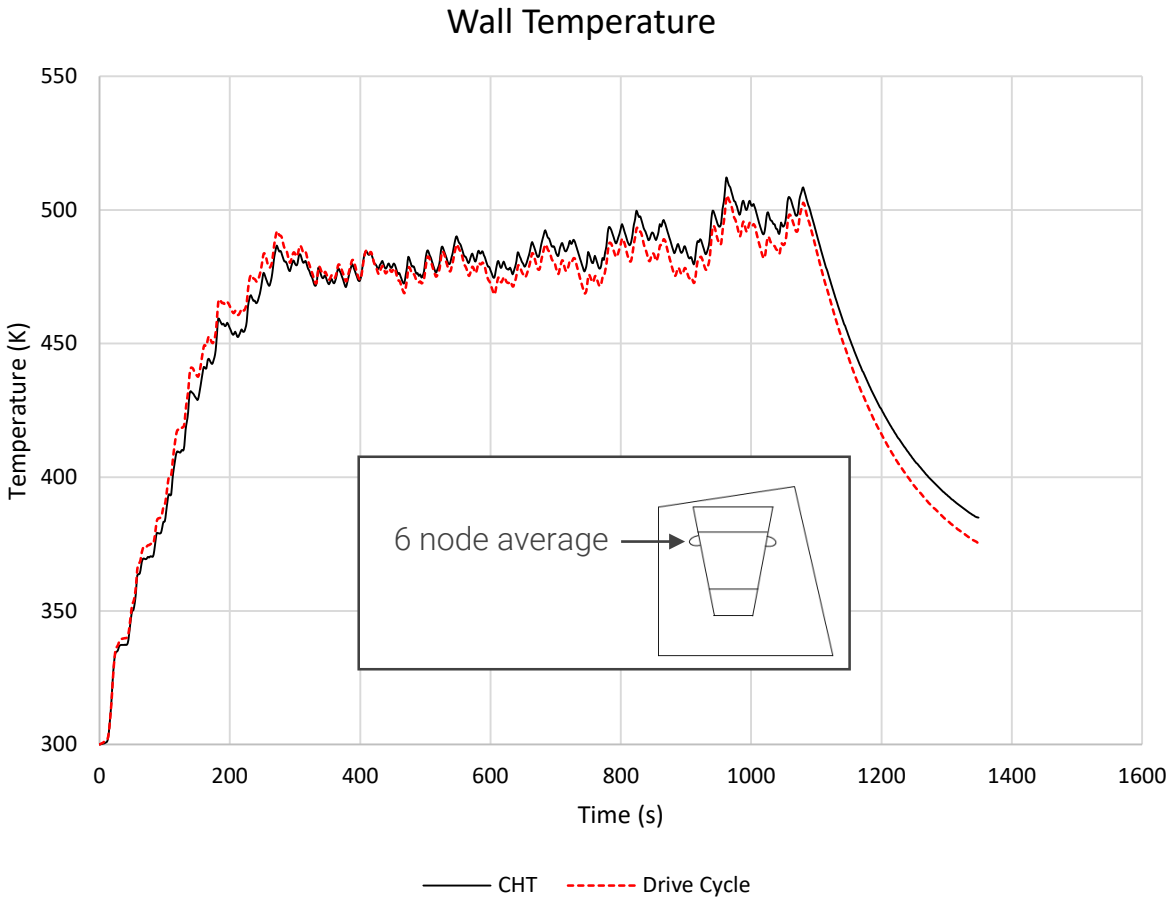
Make the samples continuous over the range of speeds with a surrogate model

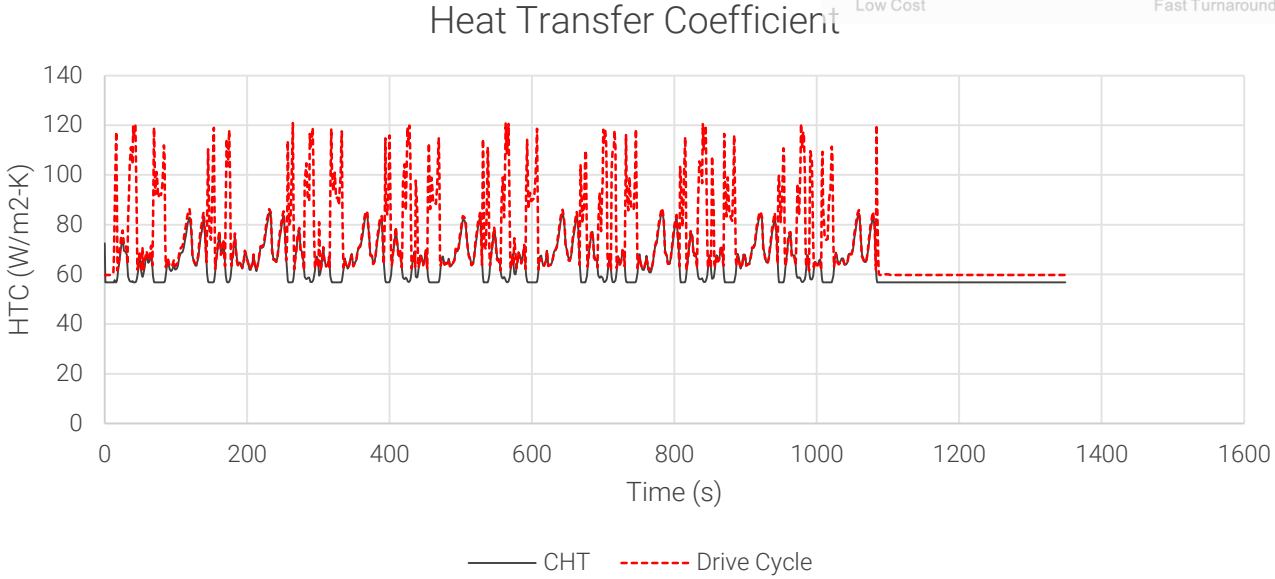
Solve transient thermal simulation

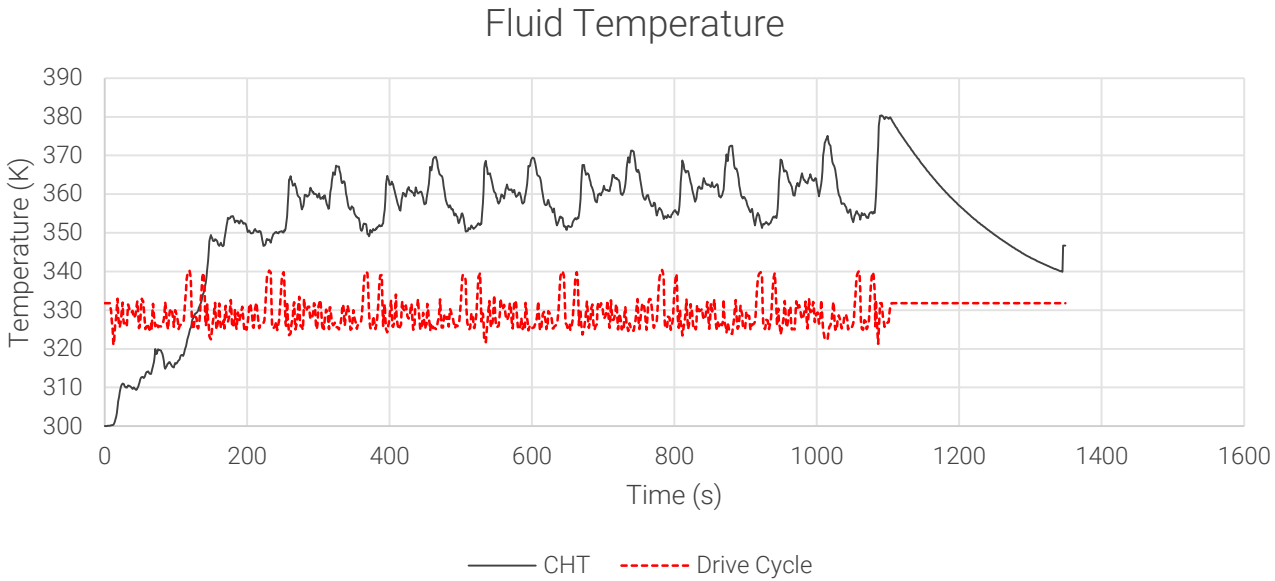


Surrogate Model Co-Simulation

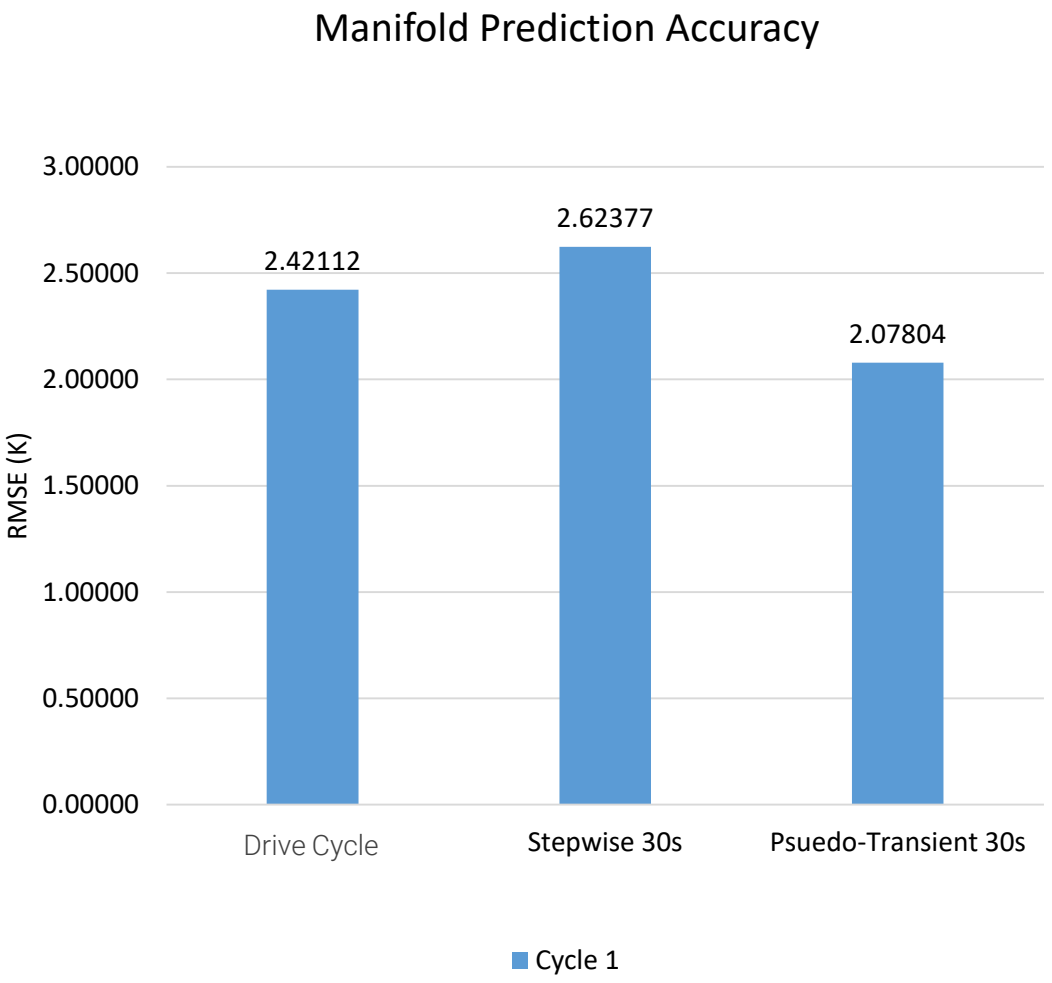




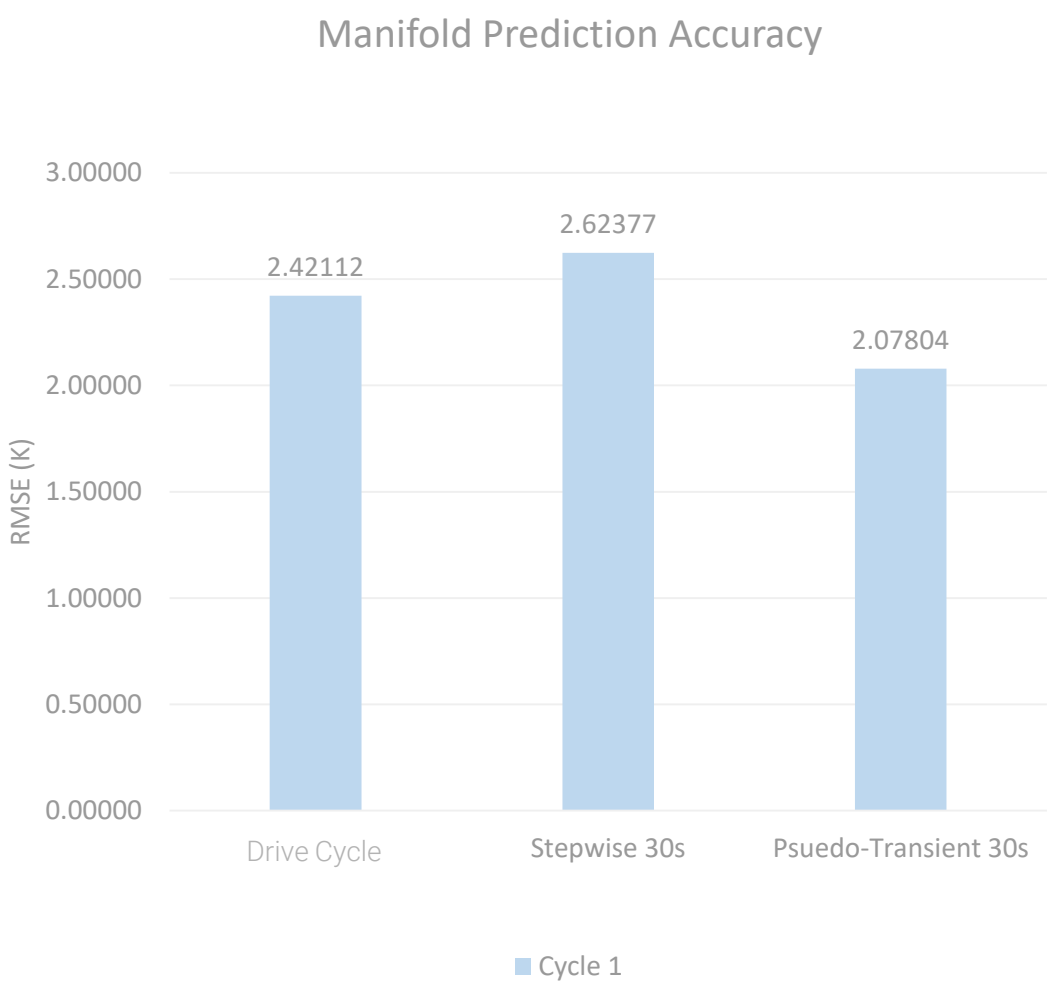


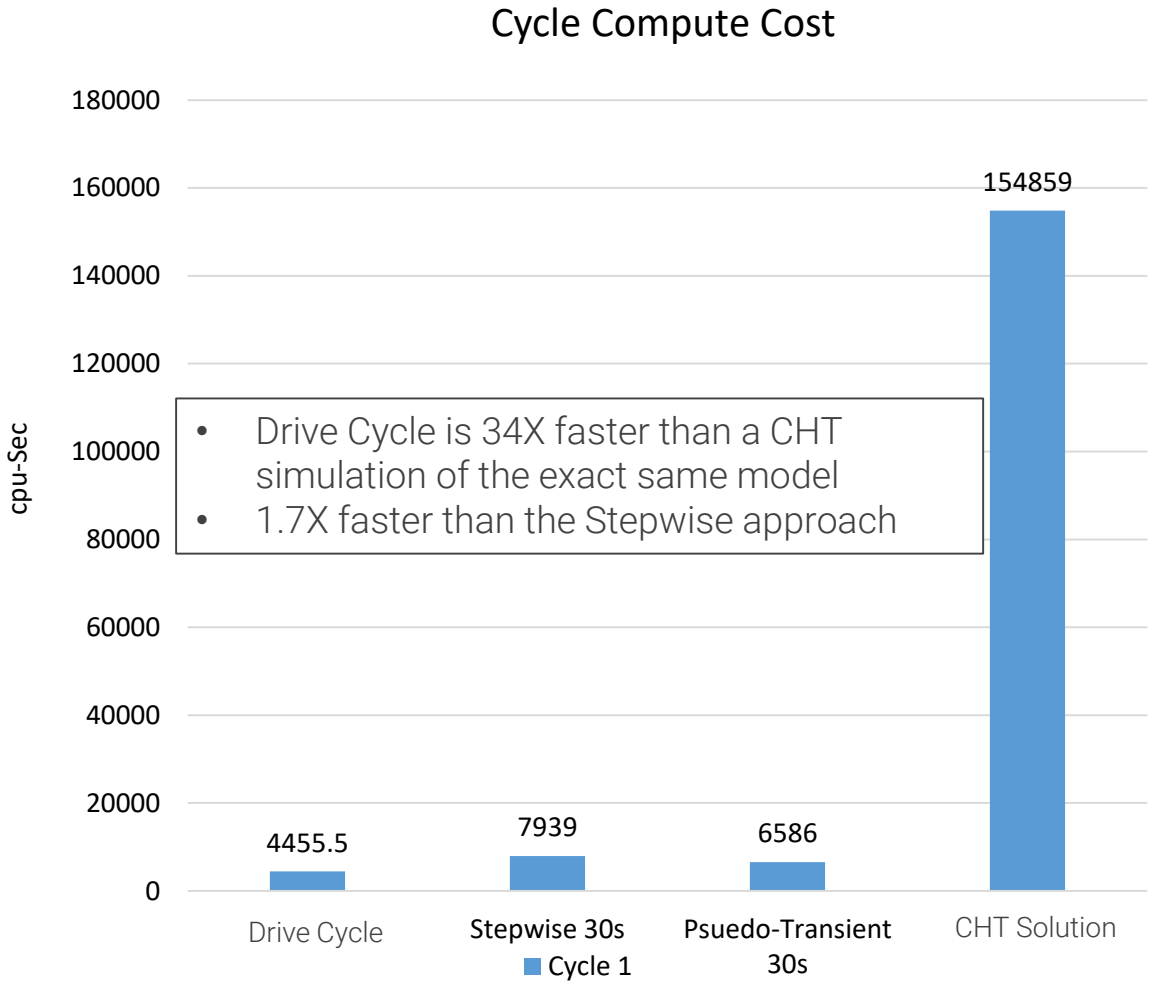


Case Study Conclusions



Case Study Conclusions

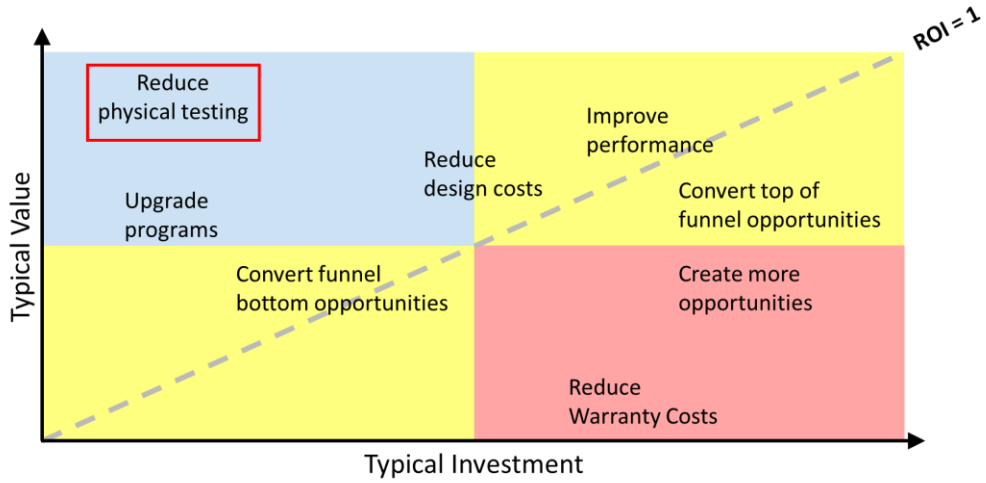


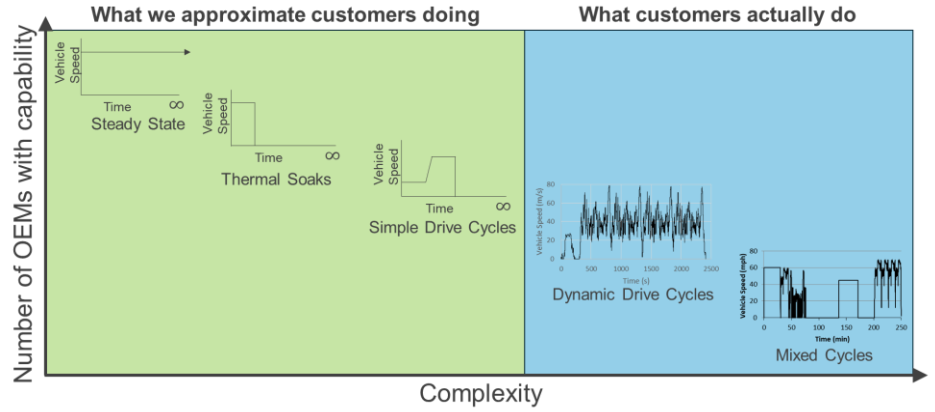


Conclusions

Conclusions

- Reducing physical testing costs create growth opportunities
- Transient modeling capabilities are huge opportunity to reduce testing costs
- TAI's Drive Cycle Extension enables the simulation of any test cycle

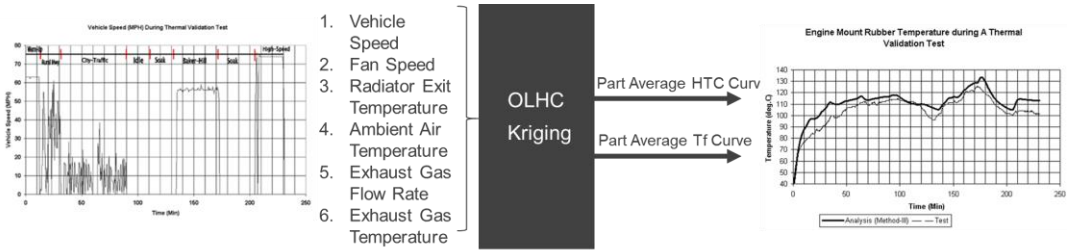


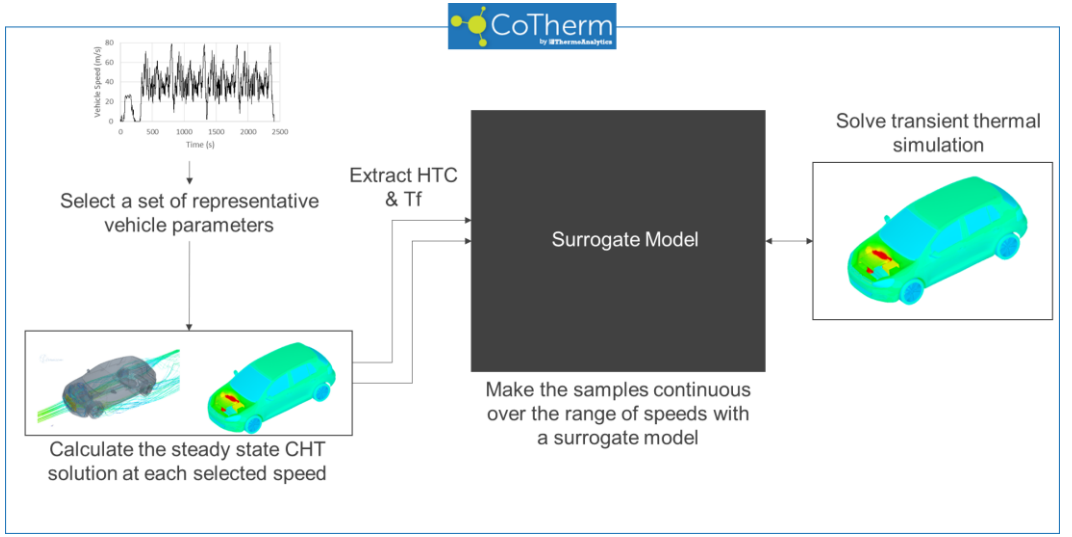


Conclusions

- Reducing physical testing costs create growth opportunities
- Transient modeling capabilities are huge opportunity to reduce testing costs
- TAI's Drive Cycle Extension enables the simulation of any test cycle

- There is a long history of surrogate modeling being used in engineering design
- Proven to be accurate and low cost
- TAI's CoTherm software makes the process simple to use, easy to deploy and highly automated



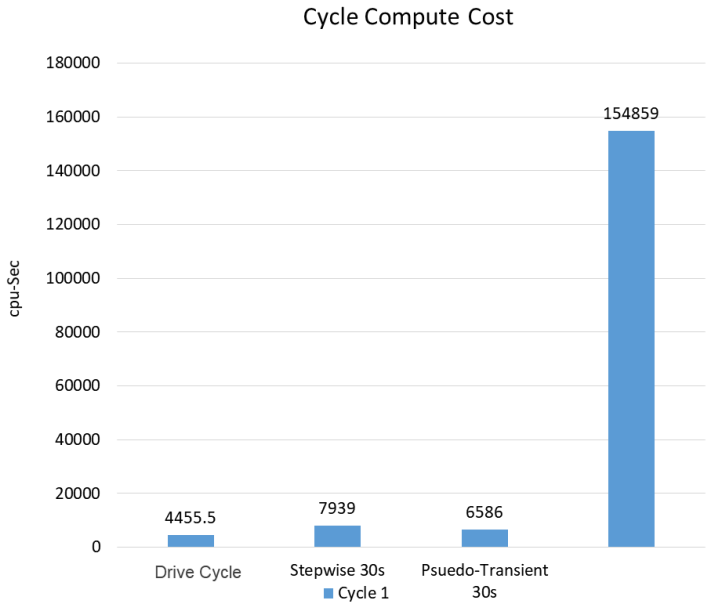


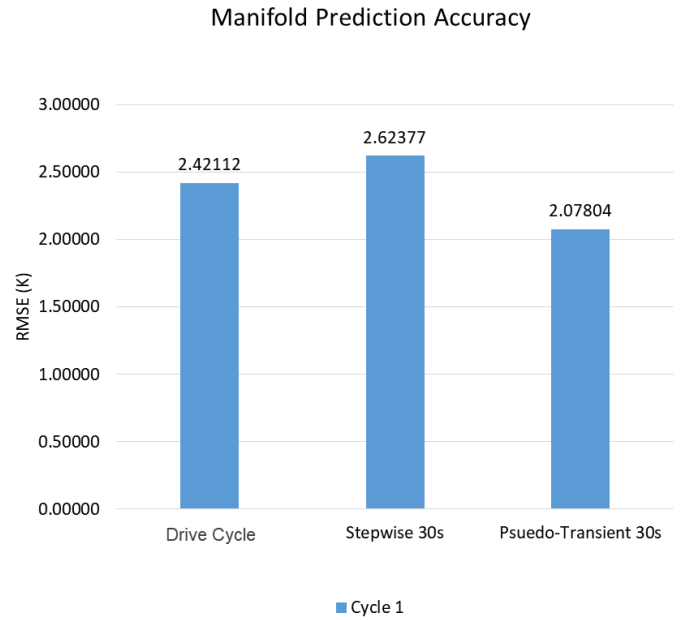
Conclusions

- Reducing physical testing costs create growth opportunities
- Transient modeling capabilities are huge opportunity to reduce testing costs
- TAI's Drive Cycle Extension enables the simulation of any test cycle

- There is a long history of surrogate modeling being used in engineering design
- Proven to be accurate and low cost
- TAI's CoTherm software makes the process simple to use, easy to deploy and highly automated

- The use of surrogate models for convective boundary conditions greatly reduces simulation times
- Surrogate models are as accurate as other coupled simulation methods
- The reduction in run time allows greater number of design studies





Thank you

US Location

ThermoAnalytics HQ
23440 Airpark Blvd.
Calumet, MI 49913

Jon Juszkiewicz

Office: +1 (906) 482-9560 x152
jrj@thermoanalytics.com
www.thermoanalytics.com