

# MATLAB EXPO 2018

## Modeling and Simulate Automotive Powertrain Systems

Maurizio Dalbard

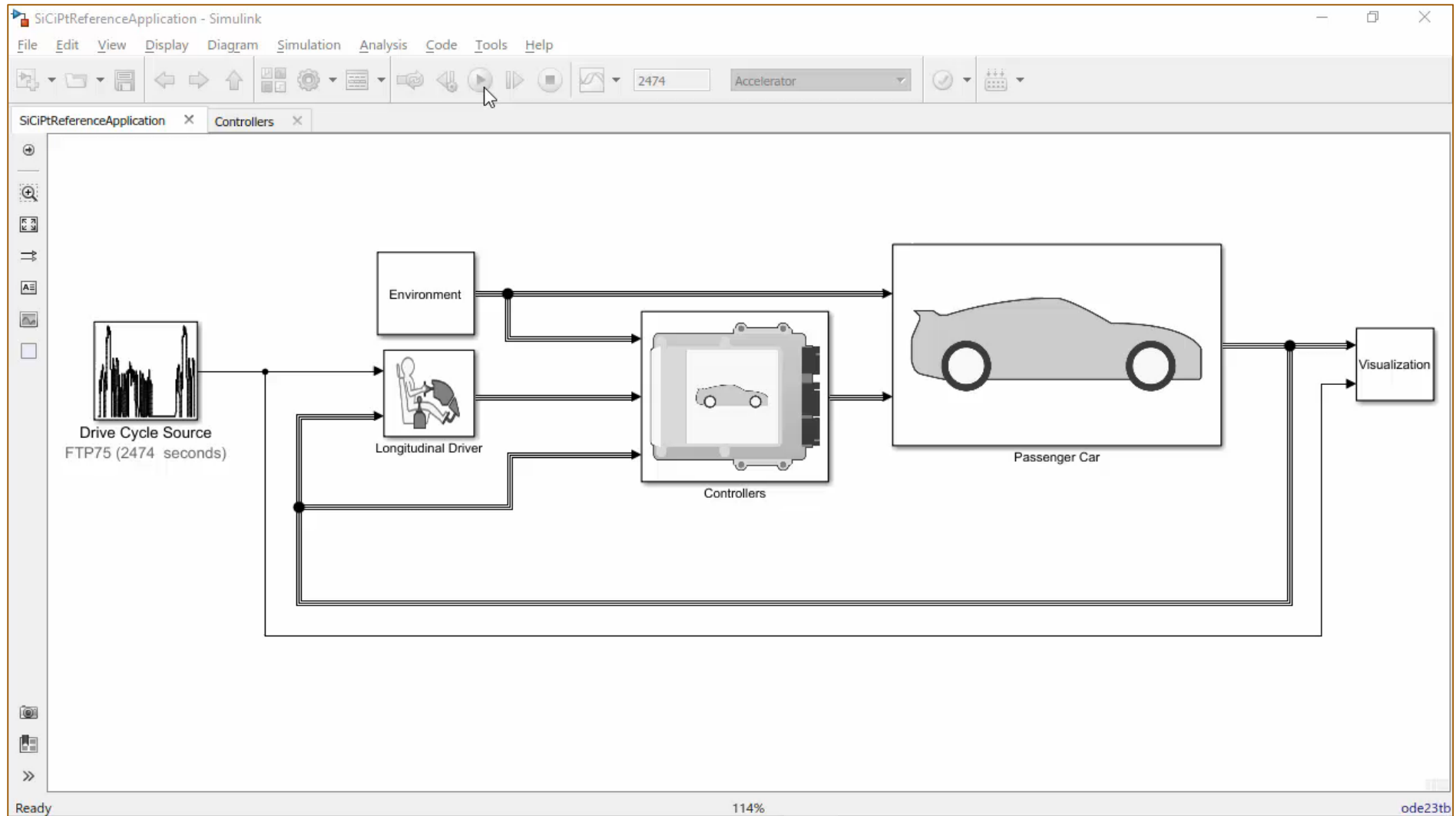


# Model-Based Design Challenges

*It's hard to do good Model-Based Design without good models*

- Insufficient expertise / resources to build right kinds of models
- Limited desktop simulations and adoption of HIL
- Significant impact on development time and cost

# Fuel Economy Simulation



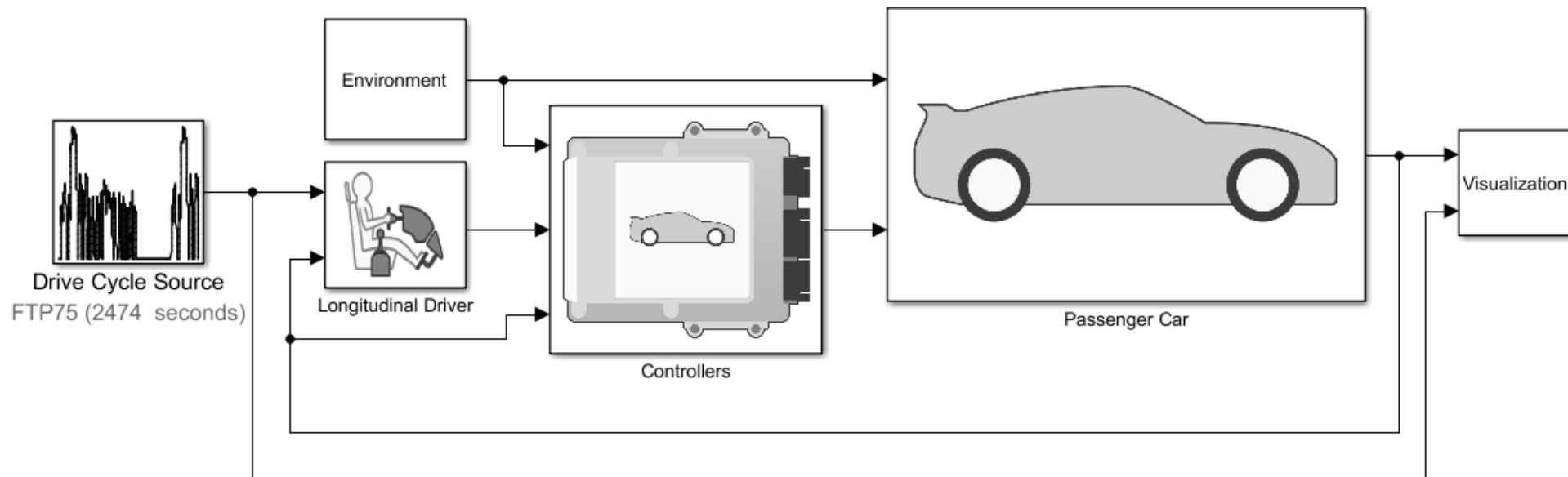
## Key Takeaways

- Perform fuel economy simulations at 50 – 100x real time
- Explore and customize pre-built reference applications
- Reuse models throughout the development cycle

# How to build a Full Vehicle Simulation Model?

# Powertrain Blockset

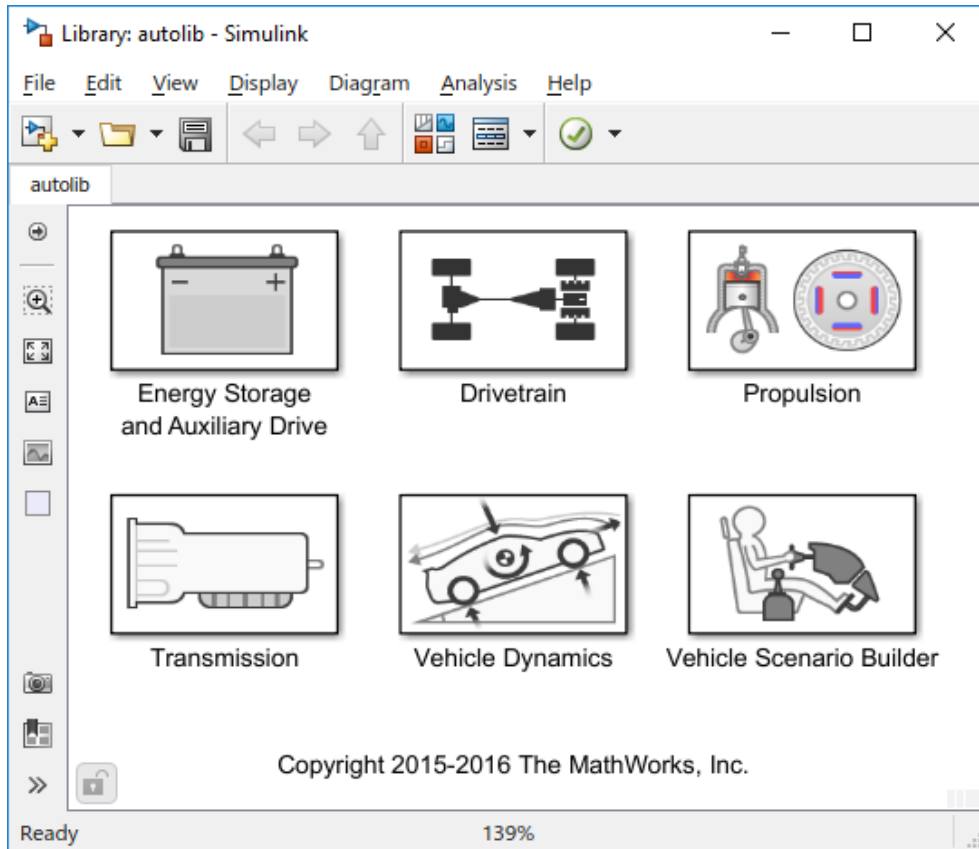
- Goals:
  - Provide starting point for engineers to build good plant / controller models
  - Provide open and documented models
  - Provide very fast-running models that work with popular HIL systems



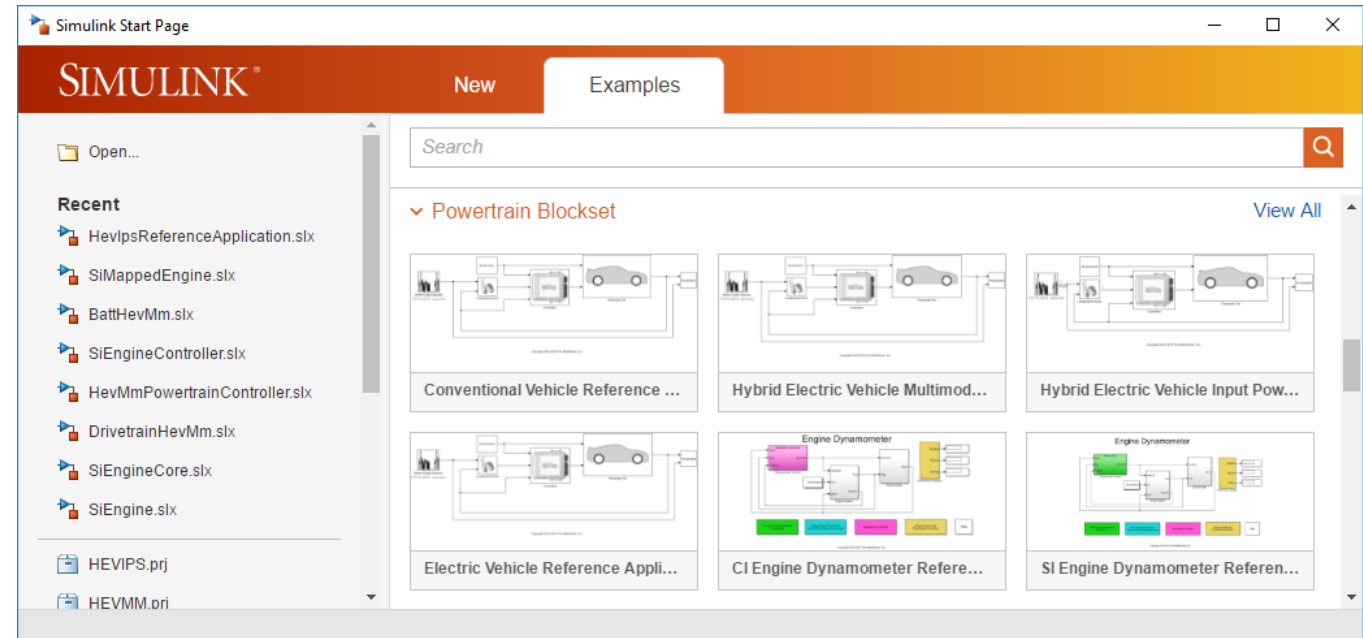
***Lower the barrier to entry for Model-Based Design***

# Powertrain Blockset Features

## Library of blocks

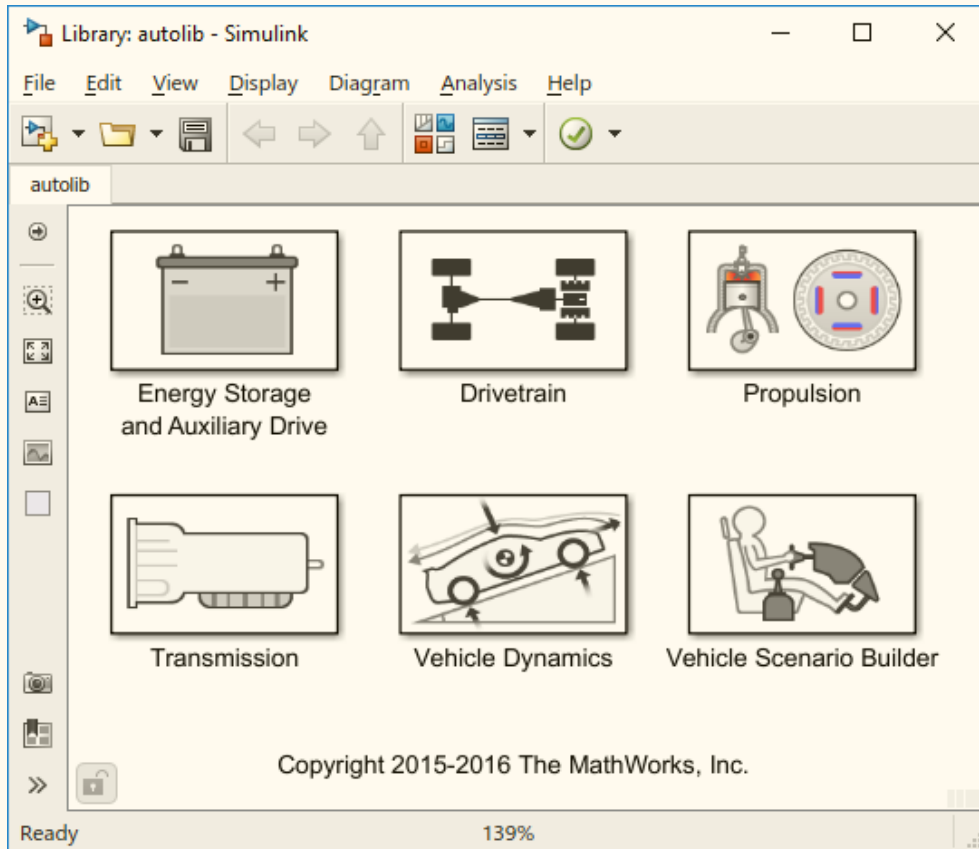


## Pre-built reference applications

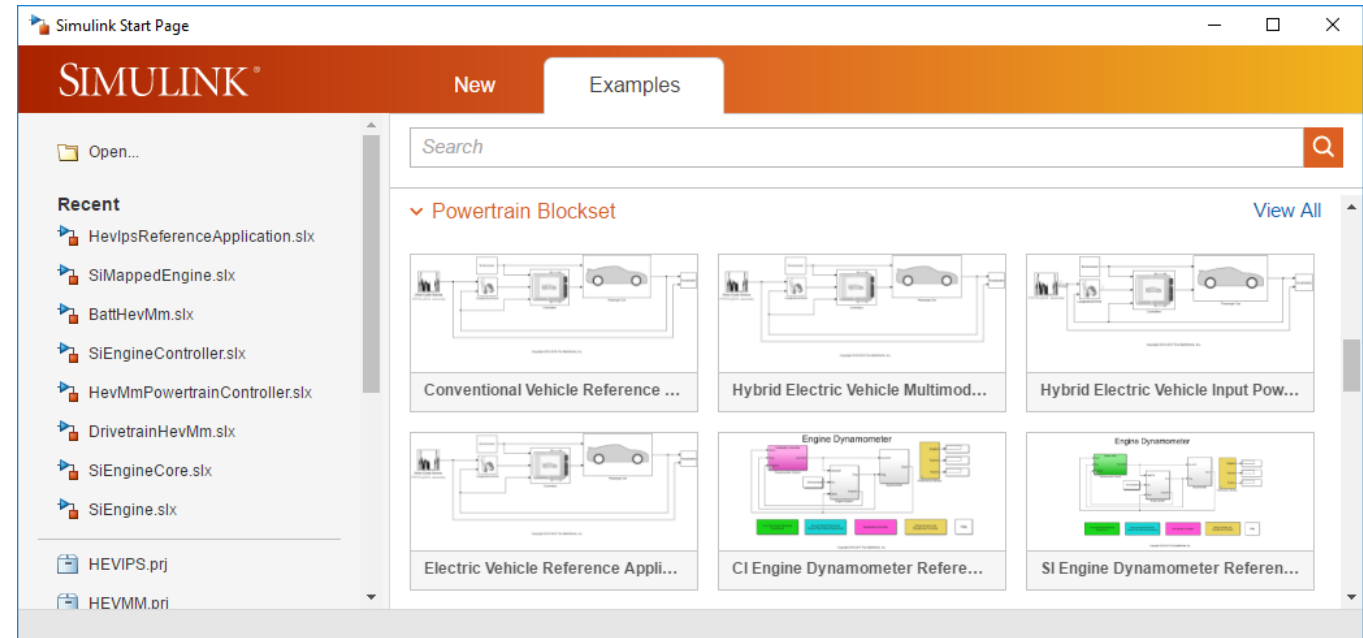


# Powertrain Blockset Features

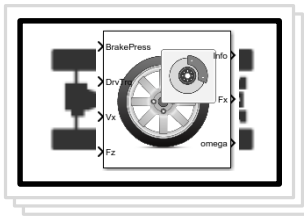
## Library of blocks



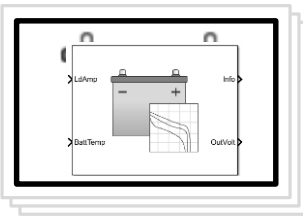
## Pre-built reference applications



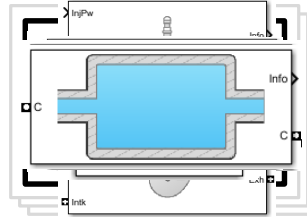




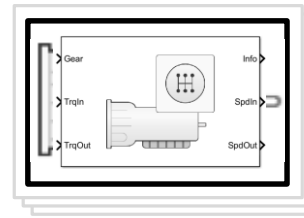
Drivetrain



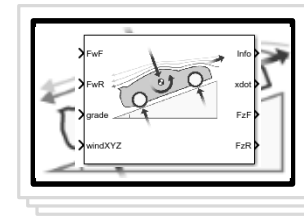
Energy Storage and Auxiliary Drive



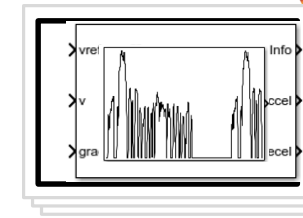
Propulsion



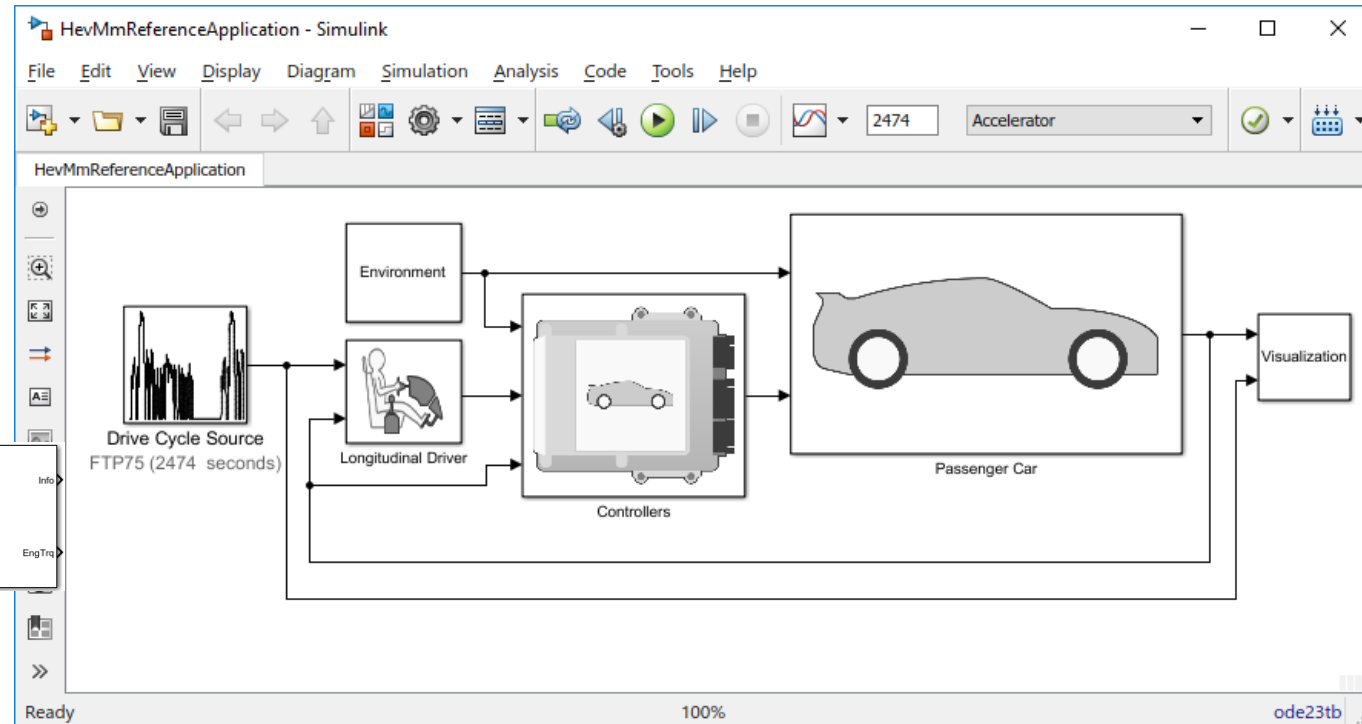
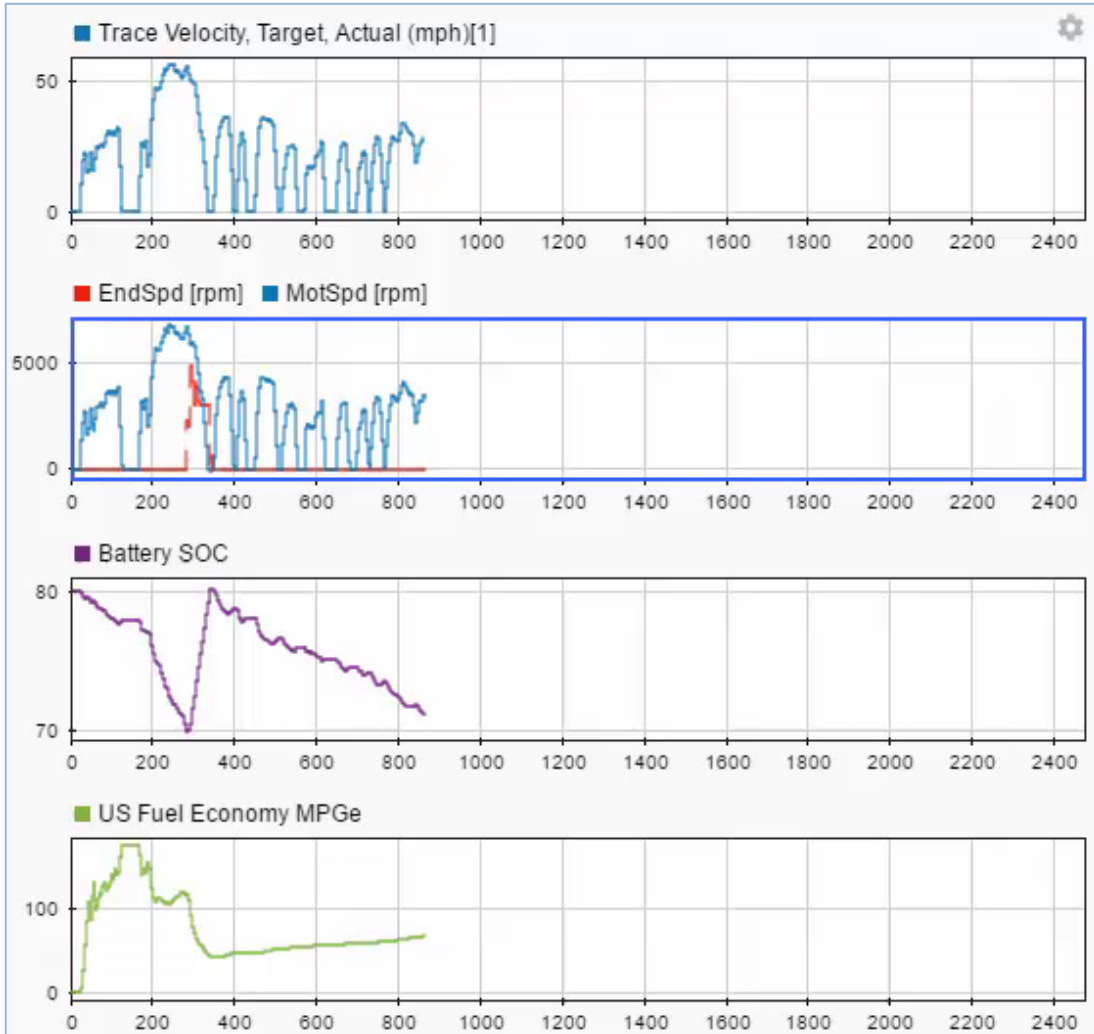
Transmission



Vehicle Dynamics

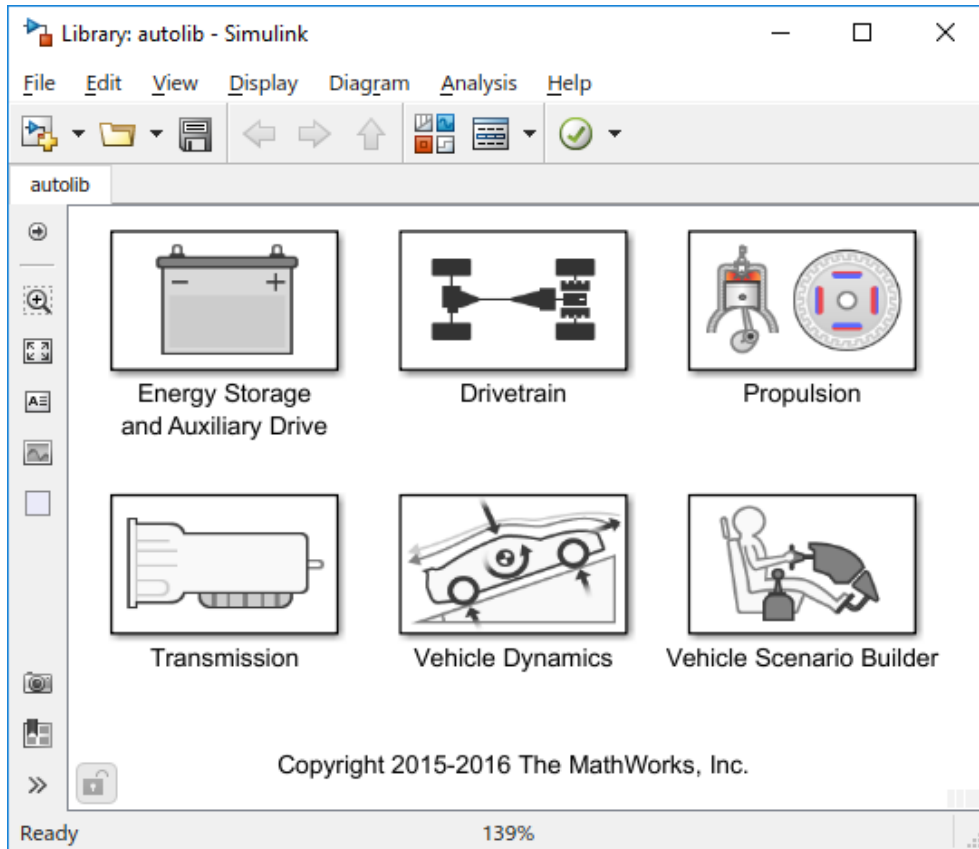


Vehicle Scenario Builder

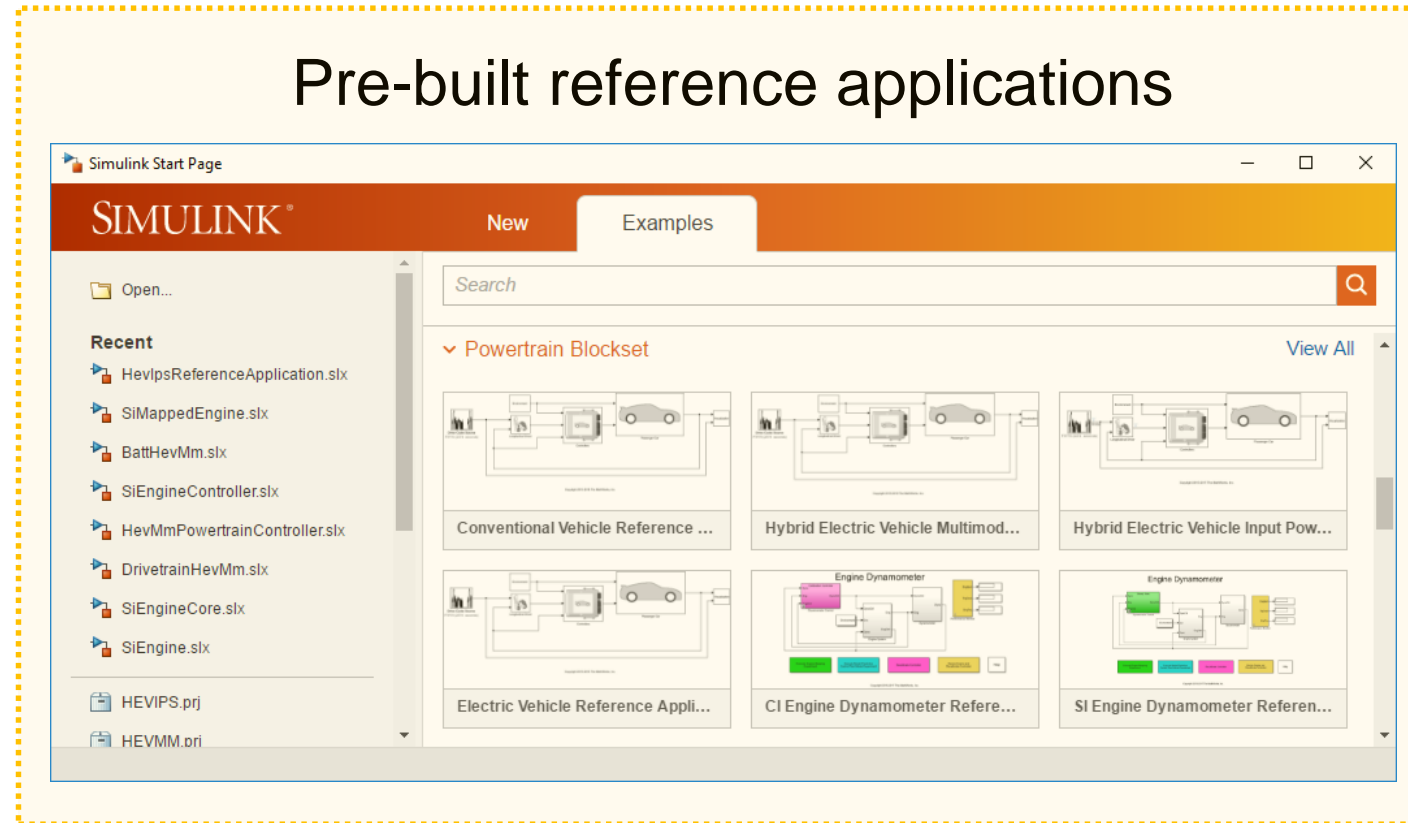


# Powertrain Blockset Features

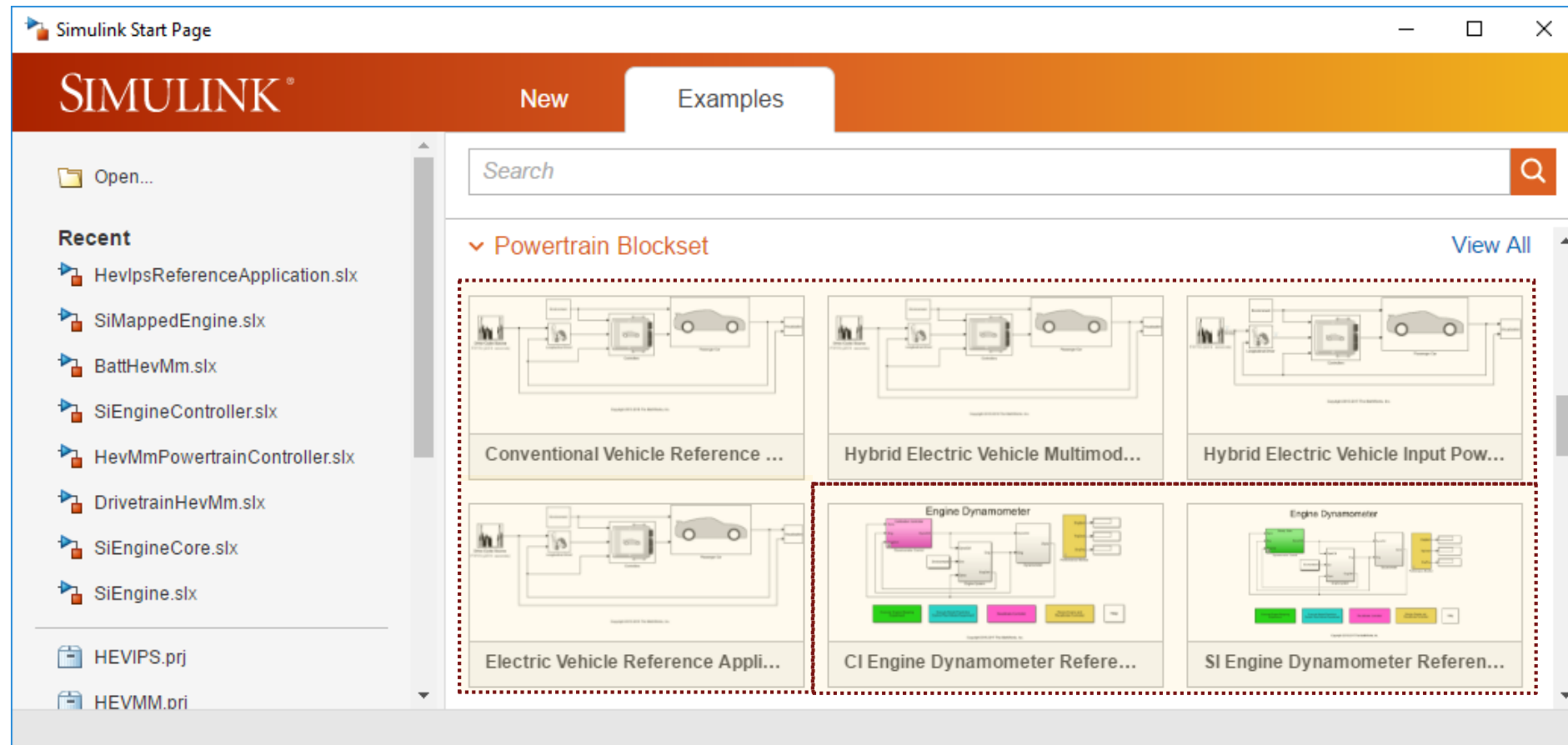
## Library of blocks



## Pre-built reference applications



# Reference Applications



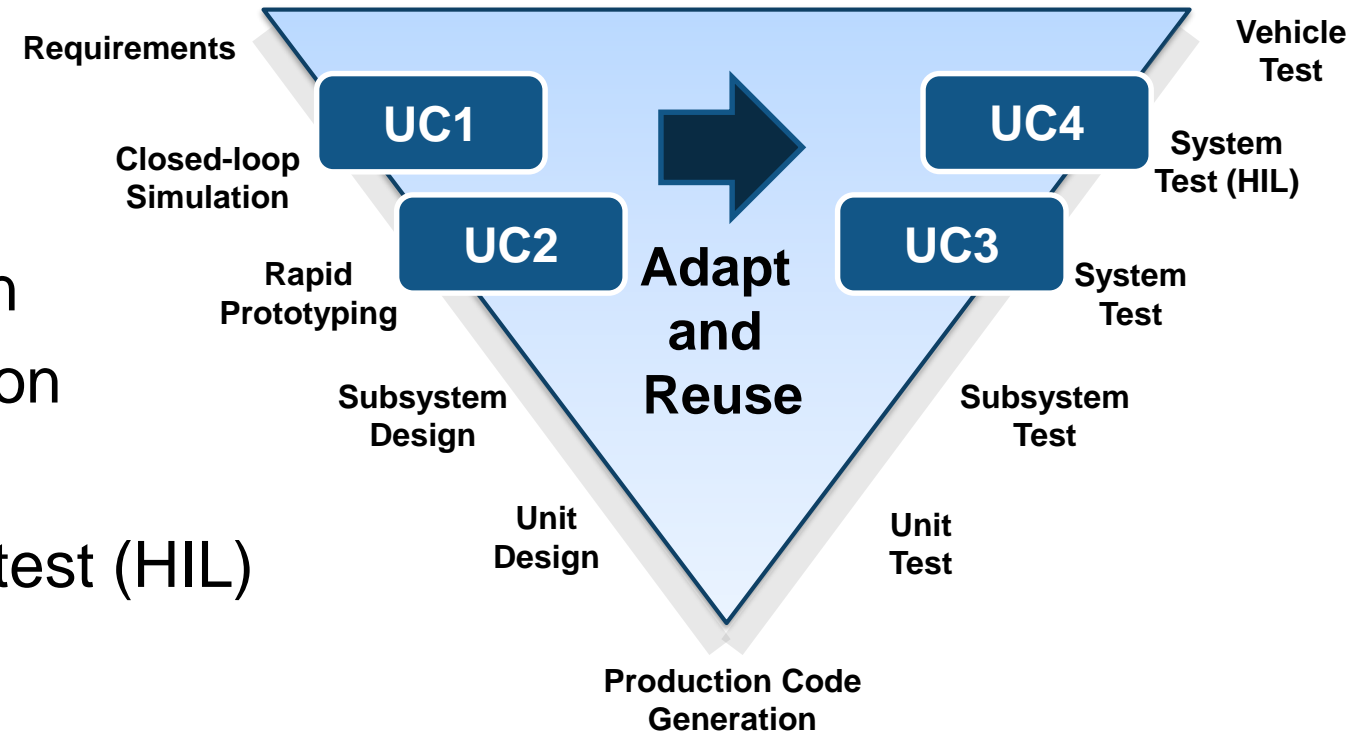
- Full vehicle models (conventional, EV, multi-mode HEV, input power-split HEV)
- Virtual engine dynamometers (compression ignition, spark ignition)

# What we can do with a Full Vehicle Simulation Model?

# Four Use Cases. One Framework.

## Use Cases:

1. System design and optimization
2. Controller parameter optimization
3. System integration test
4. Software-hardware integration test (HIL)



**Engine Modeling and Calibration**

Reduce time on HIL, dyno, vehicle testing

① Engine modeling and calibration

**Design optimization studies**

Explore wider search space with fast simulations

② Design optimization studies

**Multidomain simulation via Simscape**

Integrate & Validate multidomain subsystem models

③ Multidomain simulation via Simscape

**Subsystem Control Design**

Validate controller design via simulation

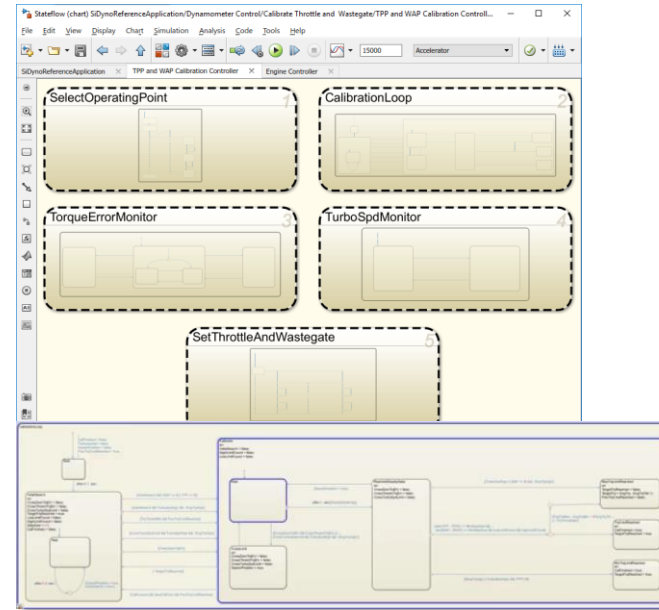
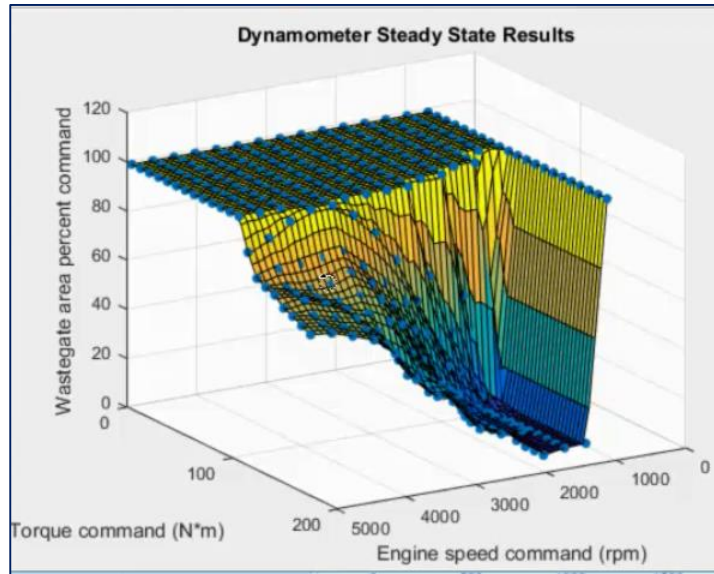
④ Subsystem control design

**Hardware In the Loop (HIL) Testing**

Validate controller in real-time

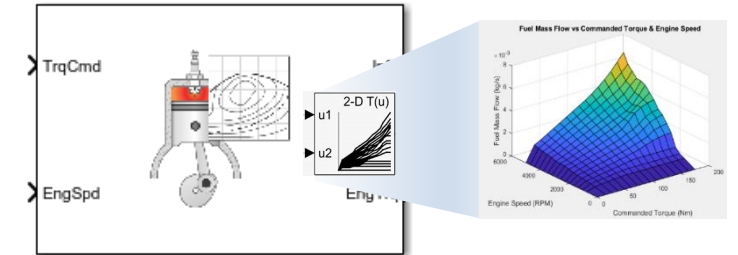
⑤ Hardware-in-the-loop (HIL) testing

# Engine Modeling and Calibration



Design-oriented CAE model

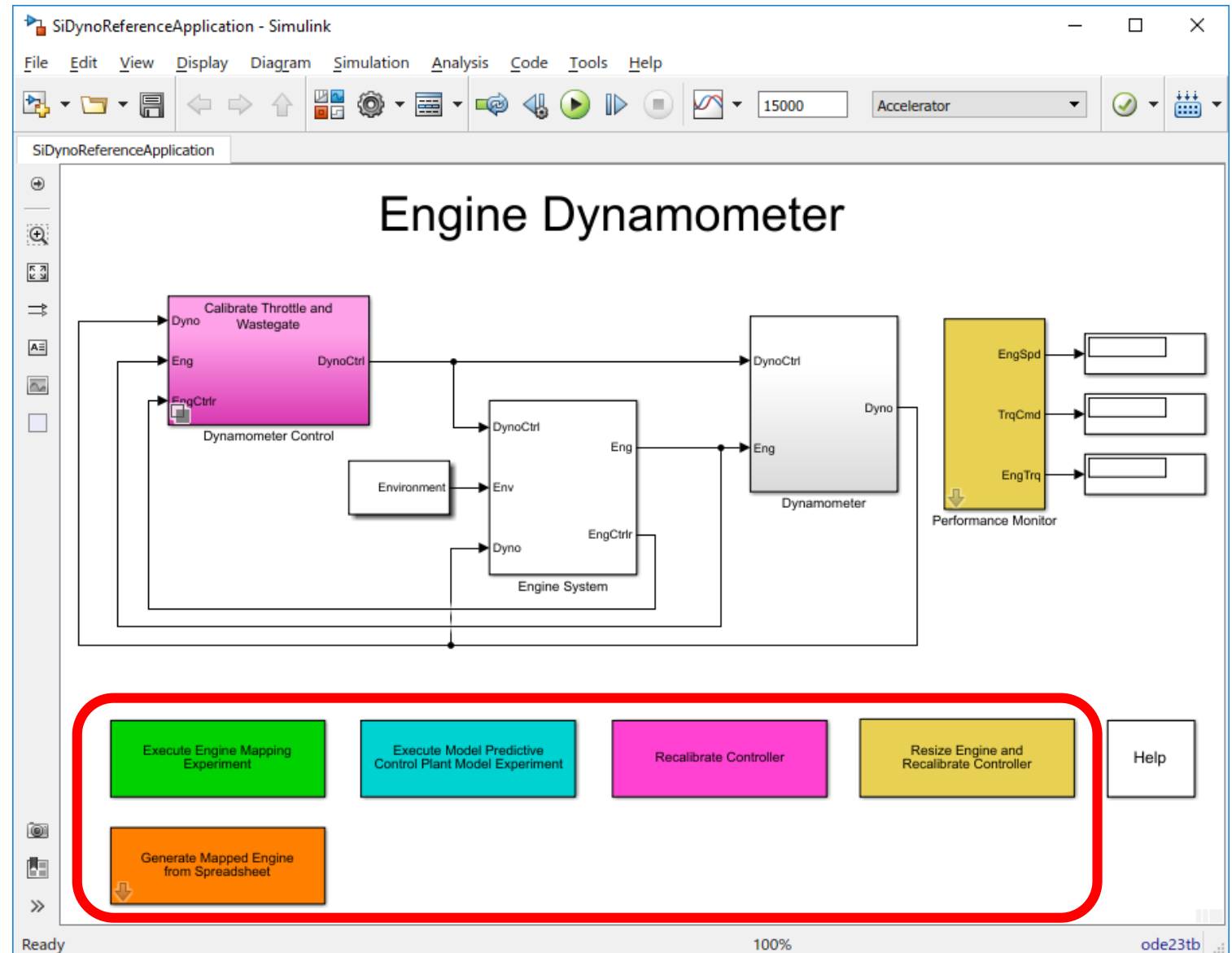
S-Function



Reduce time on HIL, dyno, vehicle testing

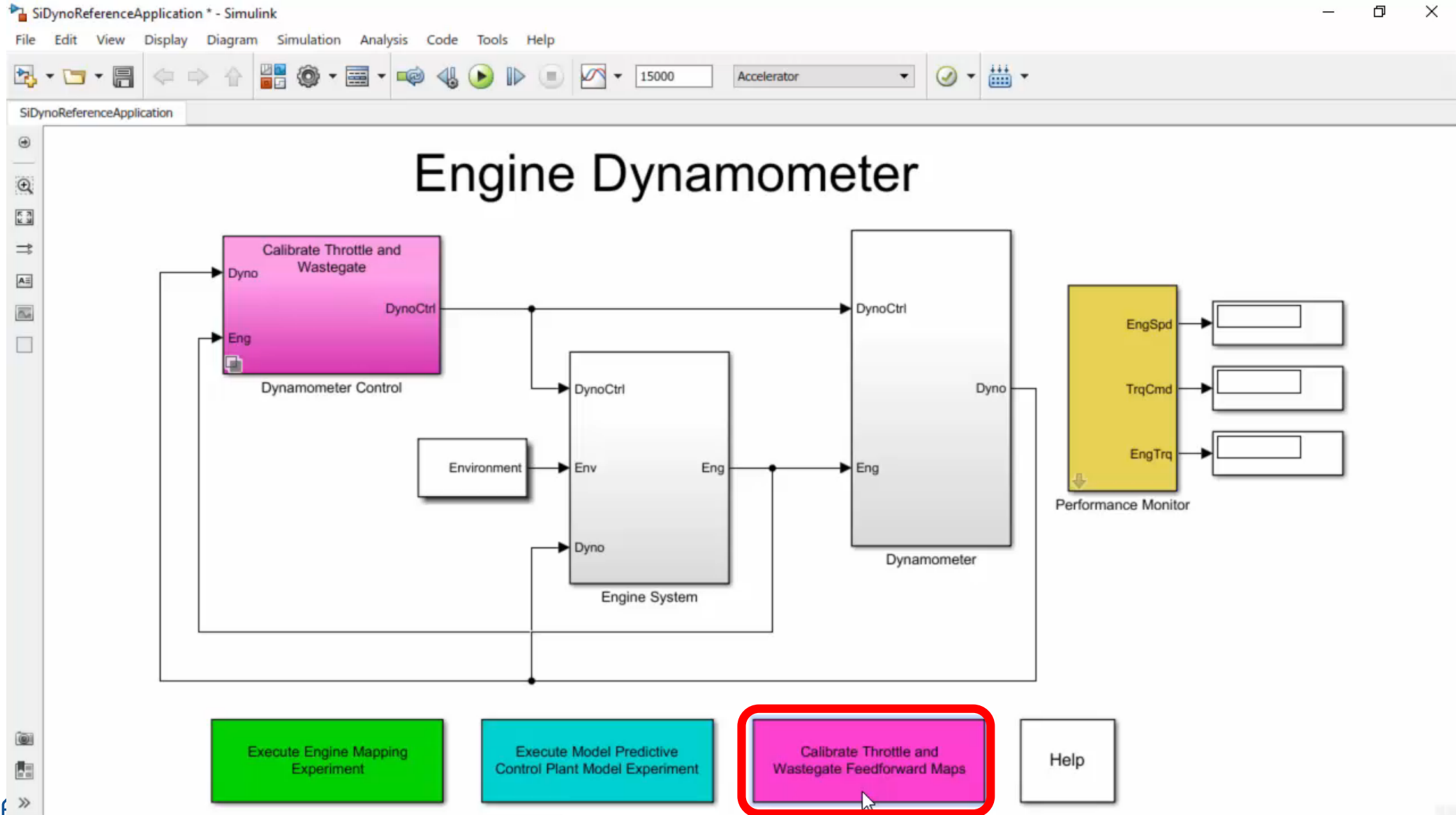
# Engine Modeling and Calibration

- Powertrain Blockset includes virtual engine dynamometer reference applications
- These can be used for a variety of engine controls development and calibration activities
- Includes several pre-defined experiments



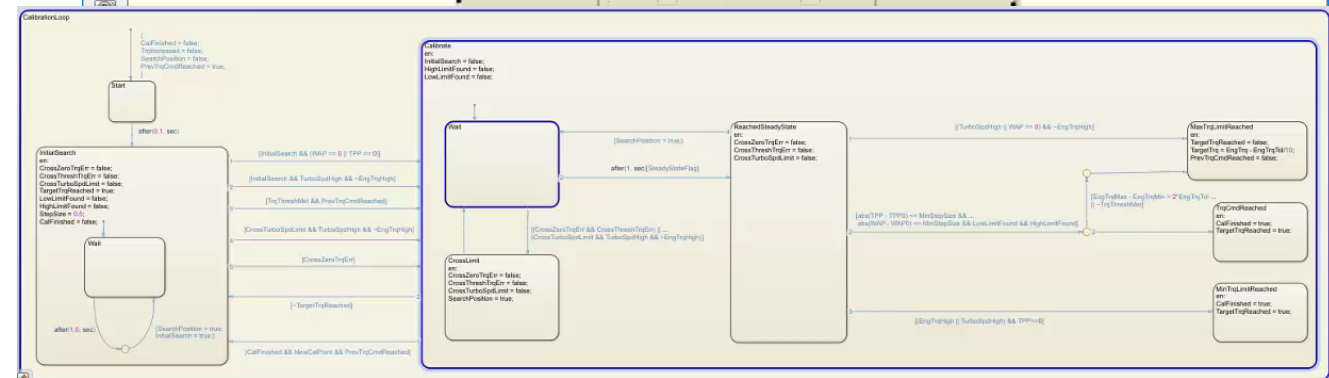
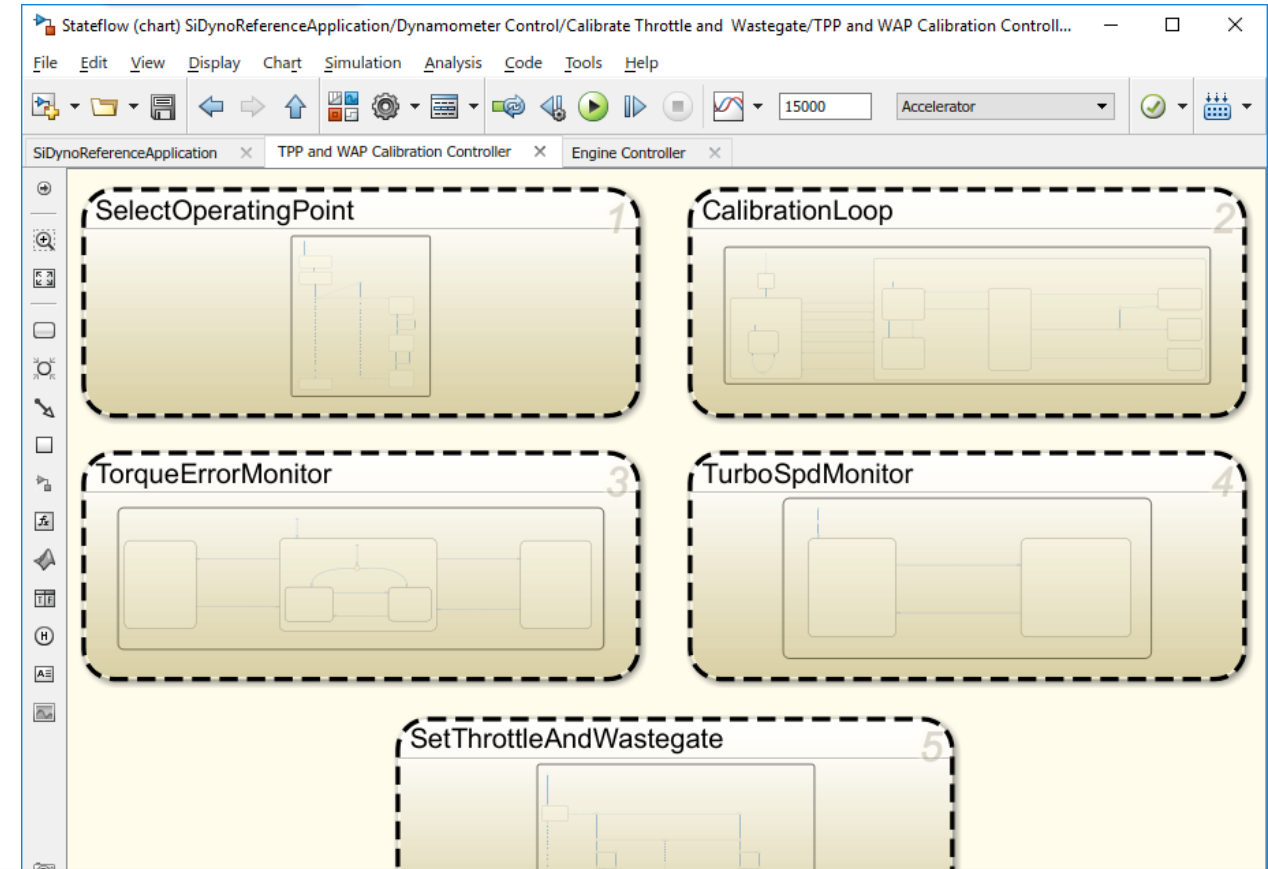


# Automated Calibration Experiment

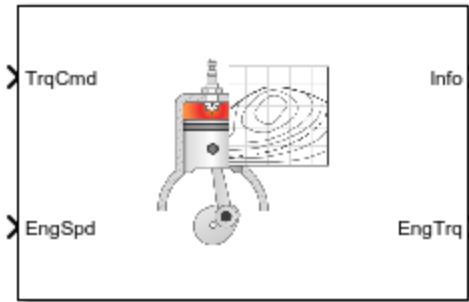


# Executable Test Specification

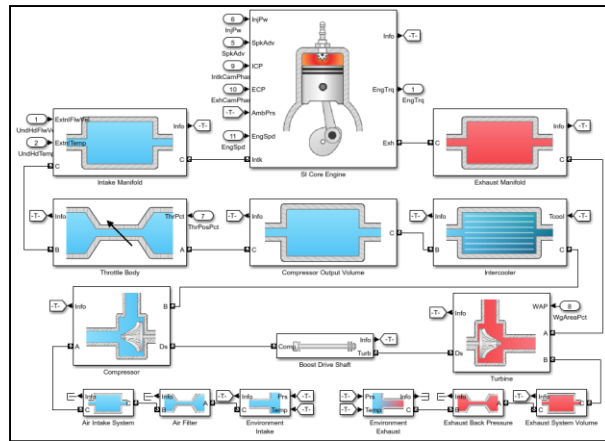
- Describe the calibration procedure as a Stateflow chart (not a Word doc)
- Test the procedure virtually
- Validate / plan calibration procedure with test engineers
- Start testing on real hardware with refined procedure



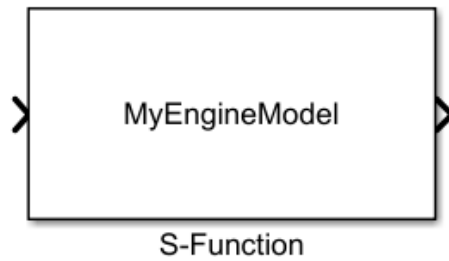
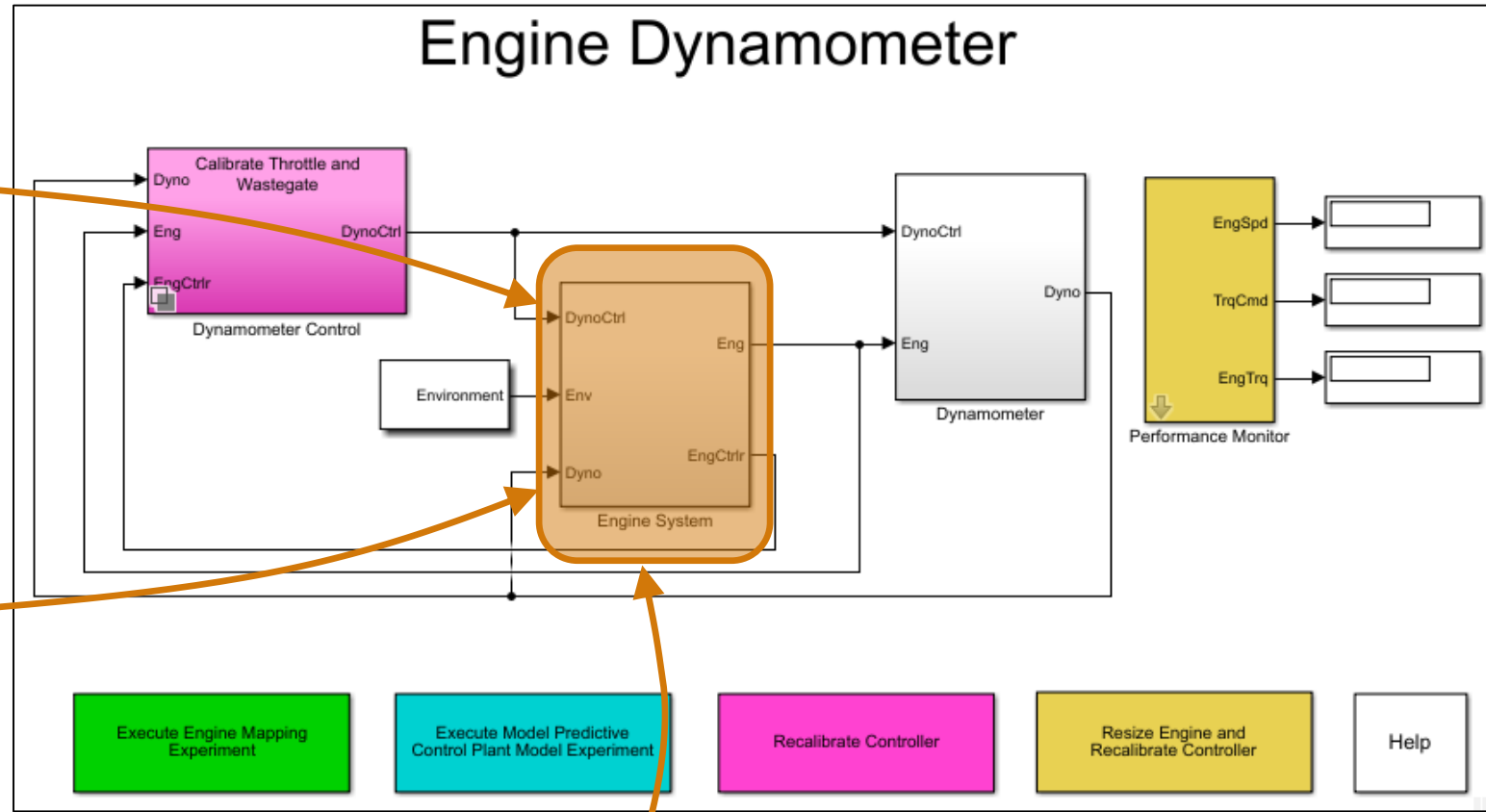
# Flexible Testing Framework



Use Powertrain Blockset mapped engine blocks with your own data

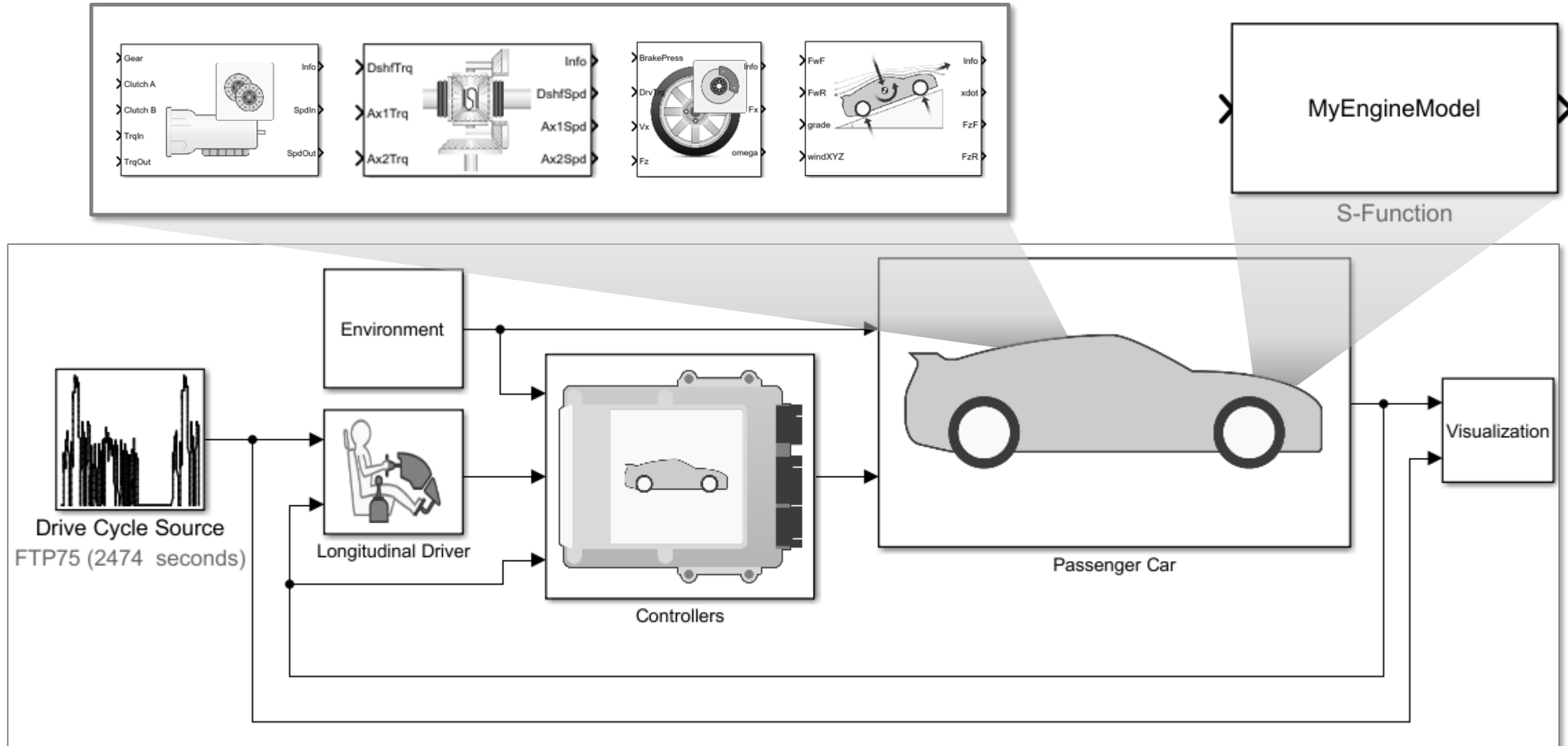


Create custom engine models using Powertrain Blockset library components

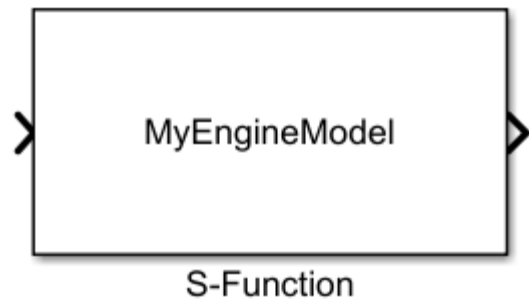


Connect in your own engine model (e.g., 3<sup>rd</sup> party CAE tool)

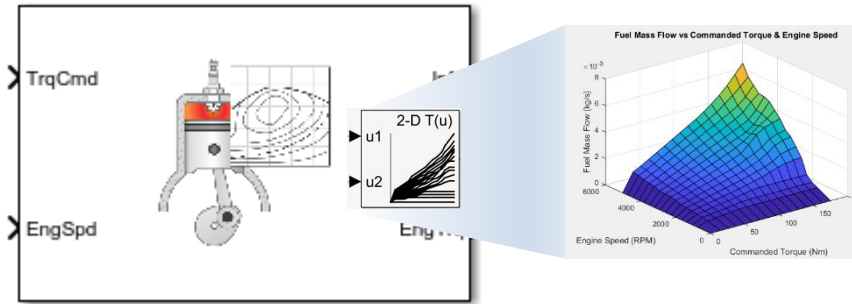
# Controls Validation with Engine Model Co-Simulation



# Controls-oriented Model Creation

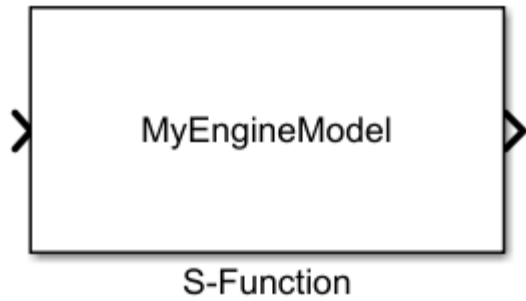


Detailed, design-oriented model

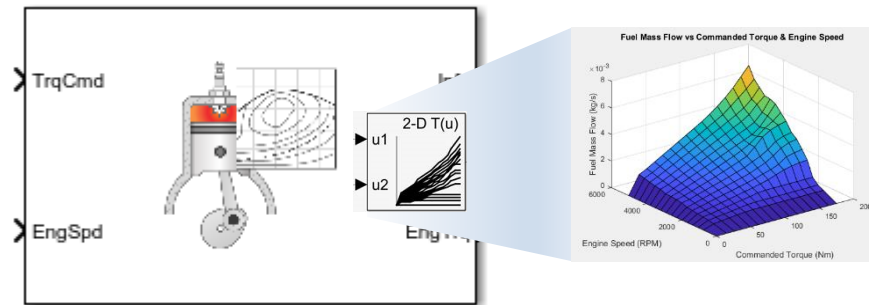
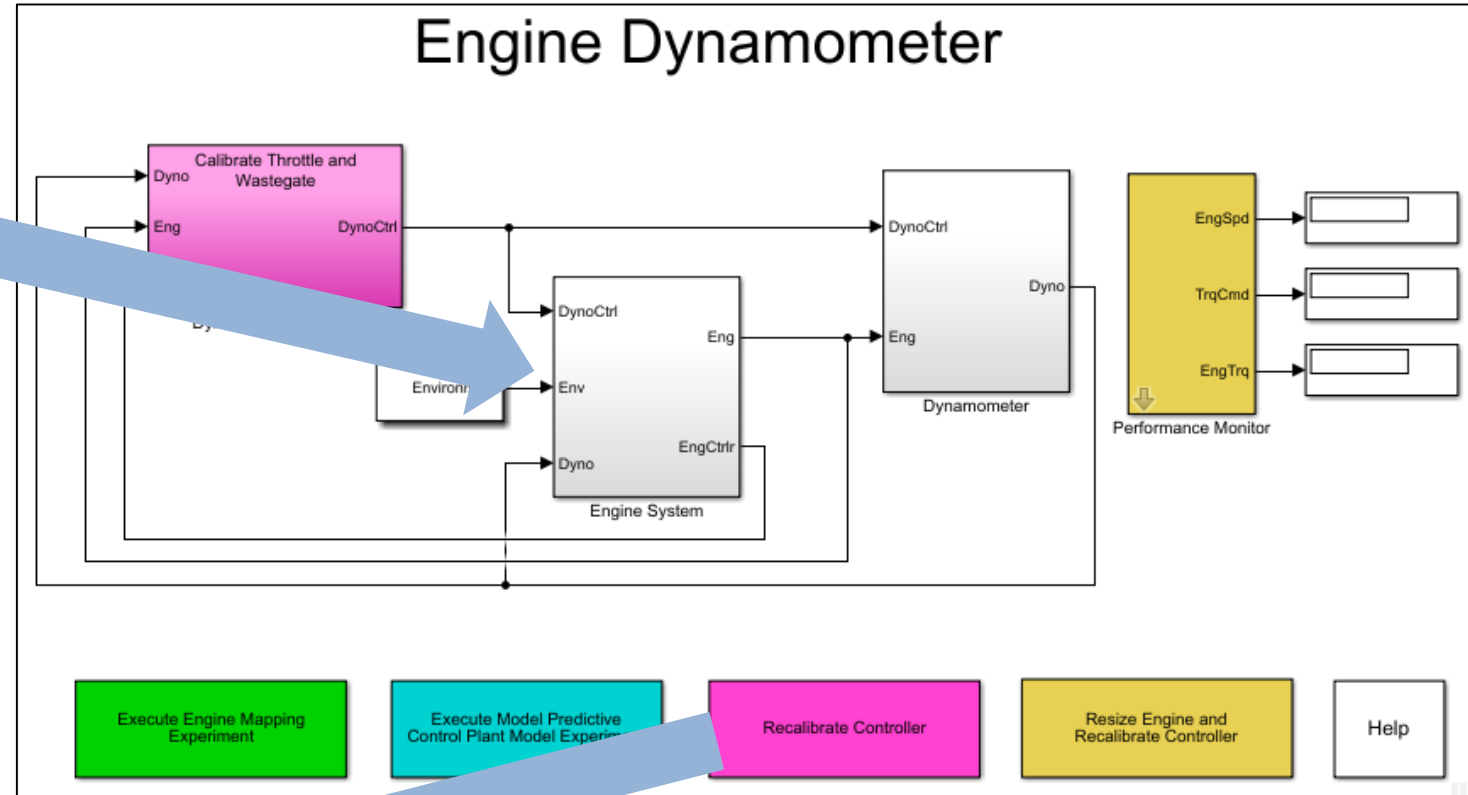


Fast, but accurate controls-oriented model

# Controls-oriented Model Creation



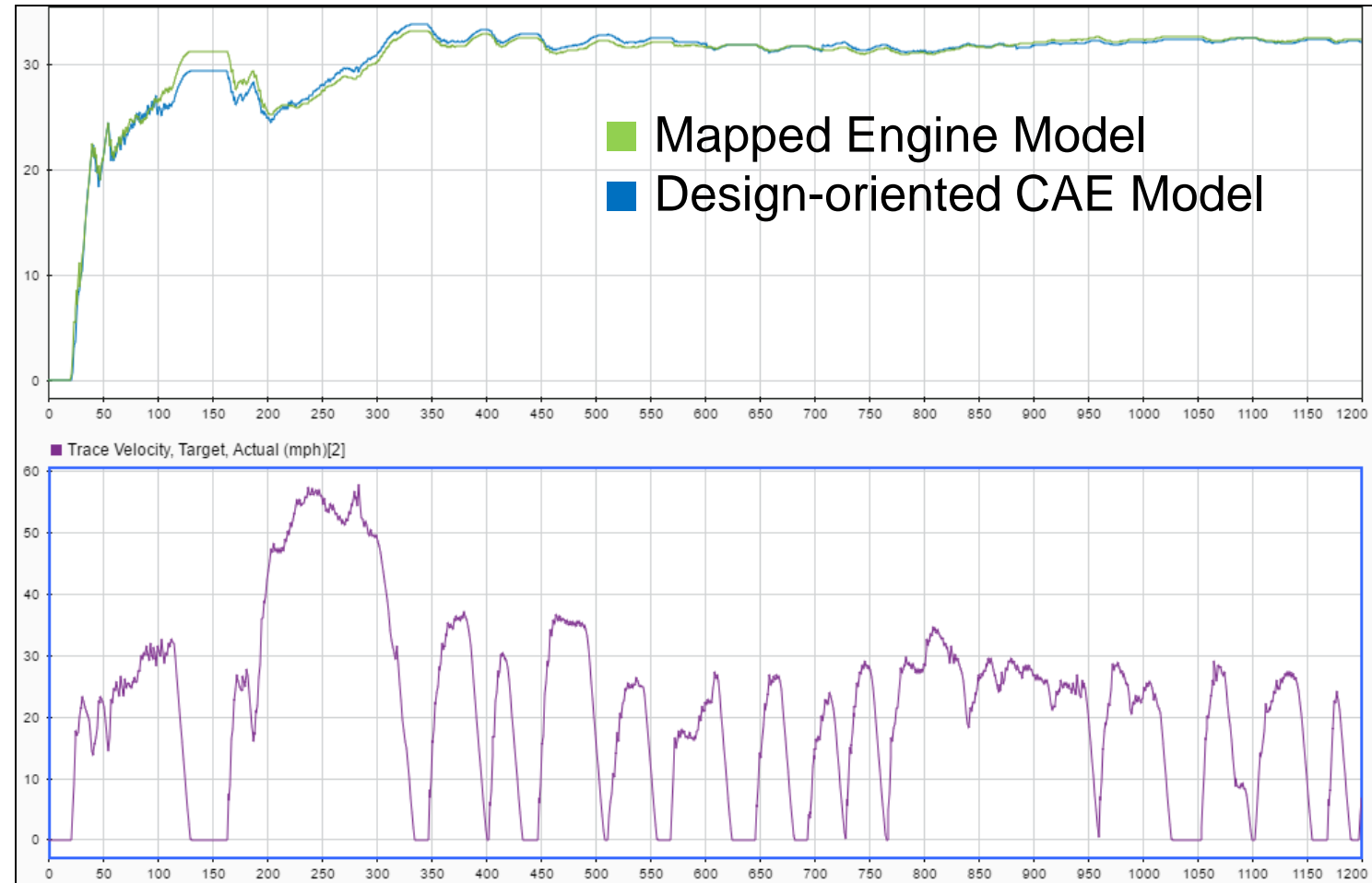
Detailed, design-oriented model



# How Accurate is the Mapped Engine Model?

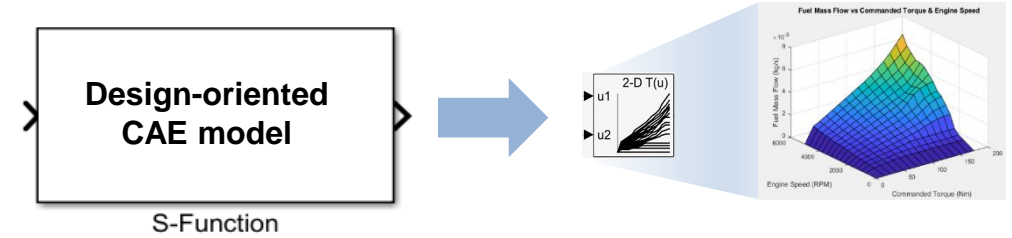
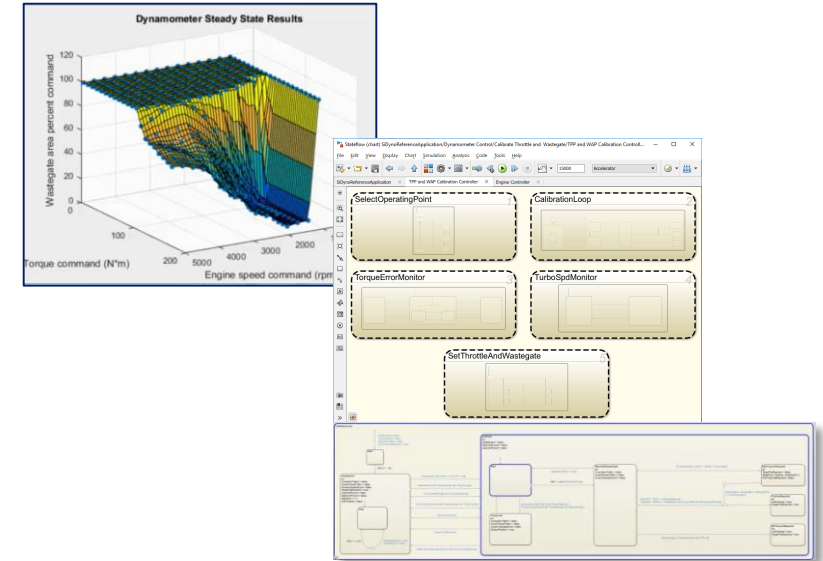
Auto-generated **Mapped Engine Model** vs. co-simulation with **Design-oriented CAE Model**:

- 0.3% fuel economy difference
- 50x faster

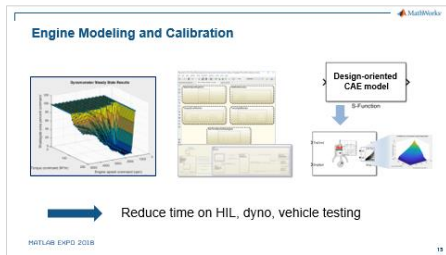


# Engine Modeling and Calibration

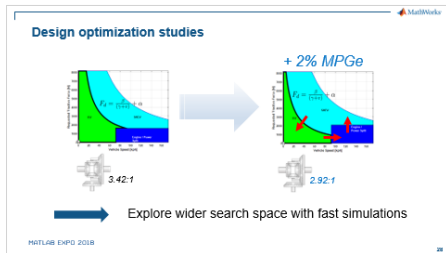
- Calibrate engine control inputs to match torque command
- Define and simulate calibration procedures
- Generate engine maps from CAE models



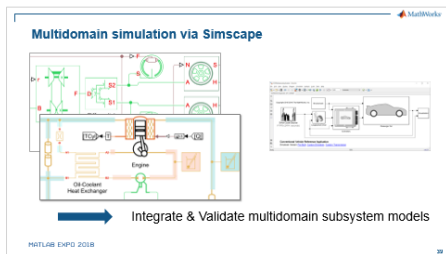




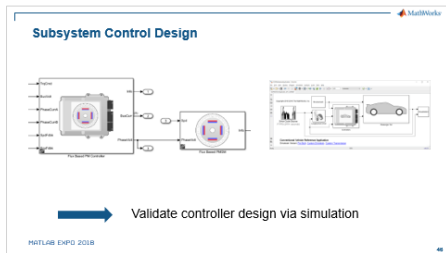
① Engine modeling and calibration



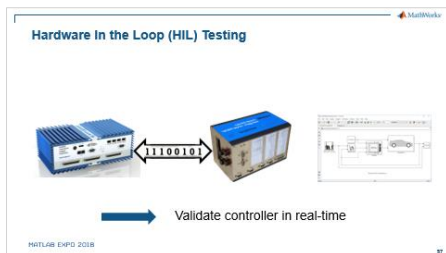
② Design optimization studies



③ Multidomain simulation via Simscape

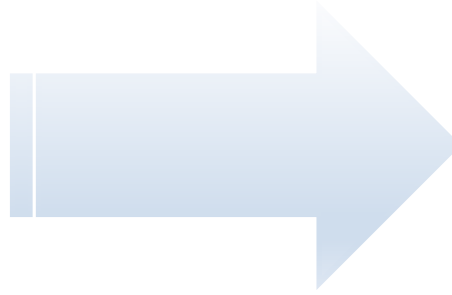
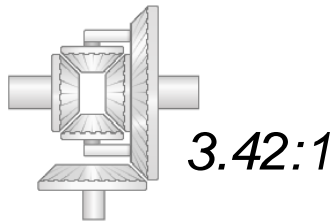
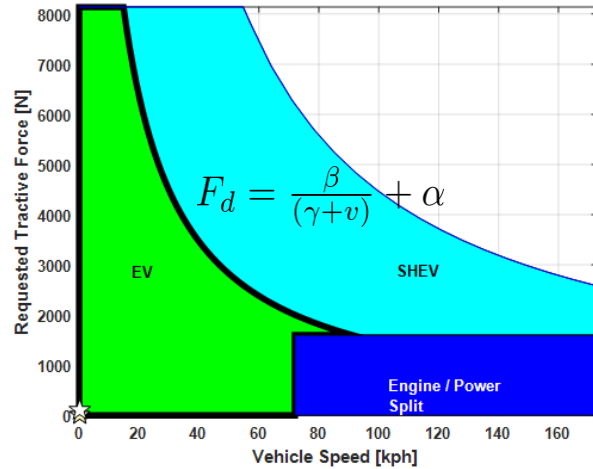


④ Subsystem control design

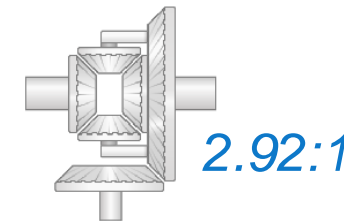
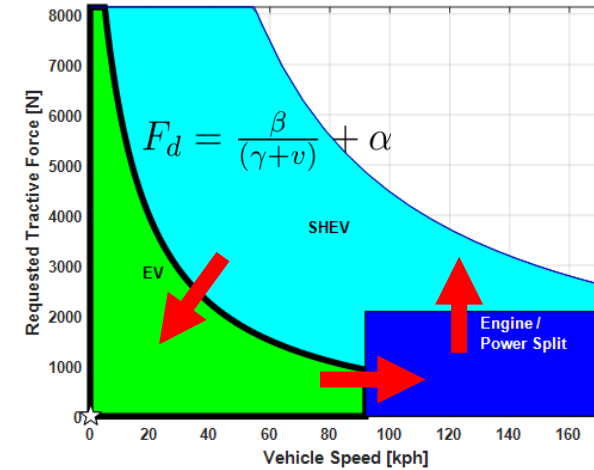


⑤ Hardware-in-the-loop (HIL) testing

# Design optimization studies



+ 2% MPGe



Explore wider search space with fast simulations

# Accessible Optimization Capabilities



- More drive cycles and design parameters
- Using fewer resources

- Simulink Design Optimization UI

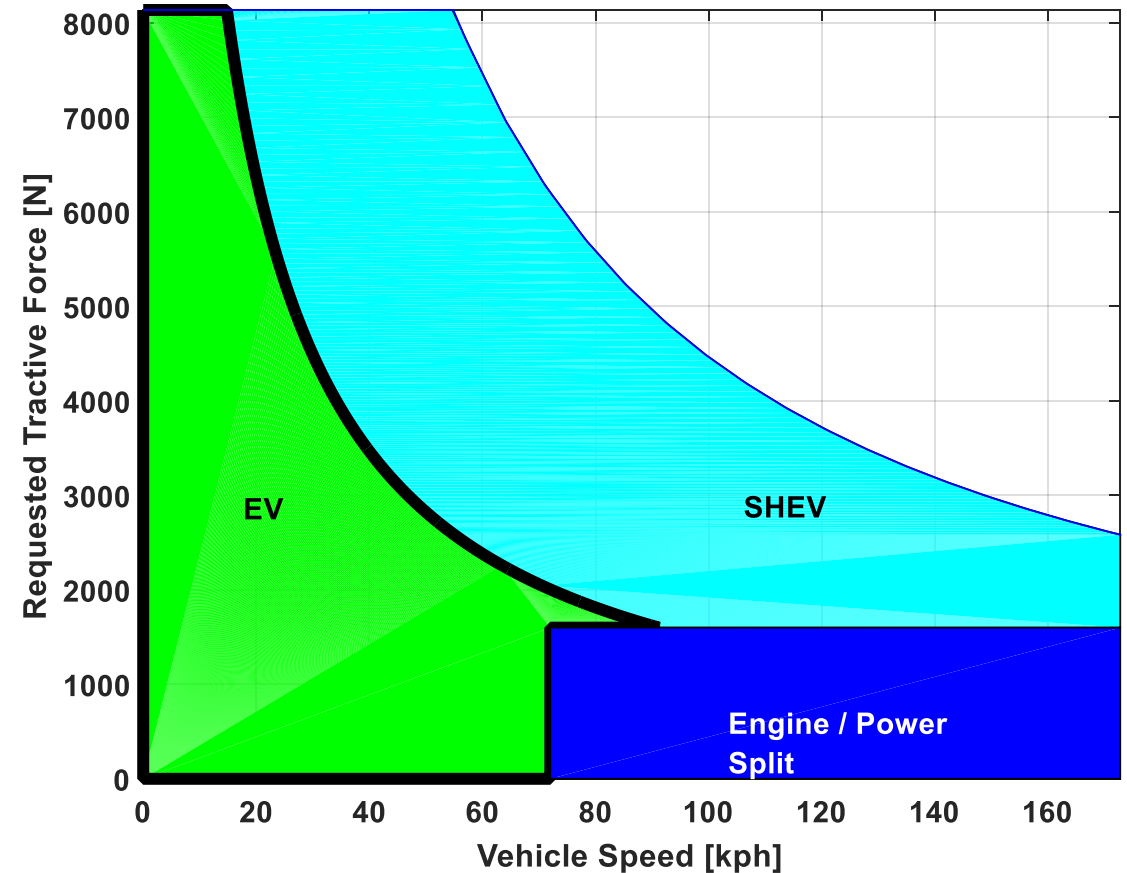
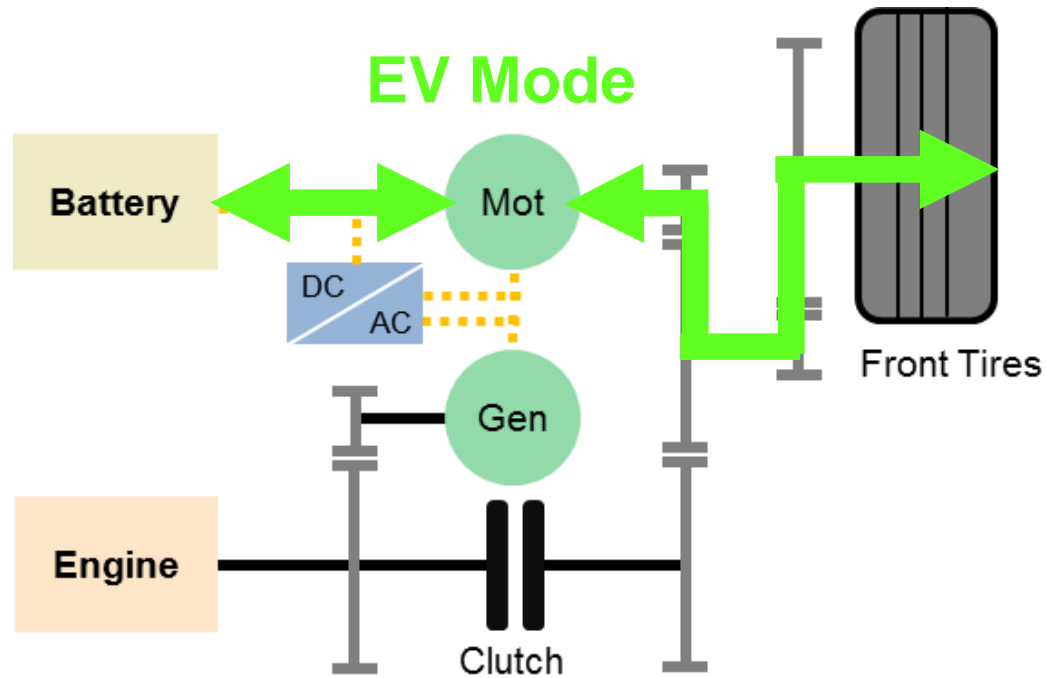
# Multi-Mode HEV Review

SAE International

2013-01-1476  
 Published 04/08/2013  
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 doi:10.4271/2013-01-1476  
 saealtpow.saejournals.org

## Development of a New Two-Motor Plug-In Hybrid System

Naritomo Higuchi, Yoshihiro Sunaga, Masashi Tanaka and Hiroo Shimada  
 Honda R&D Co., Ltd.



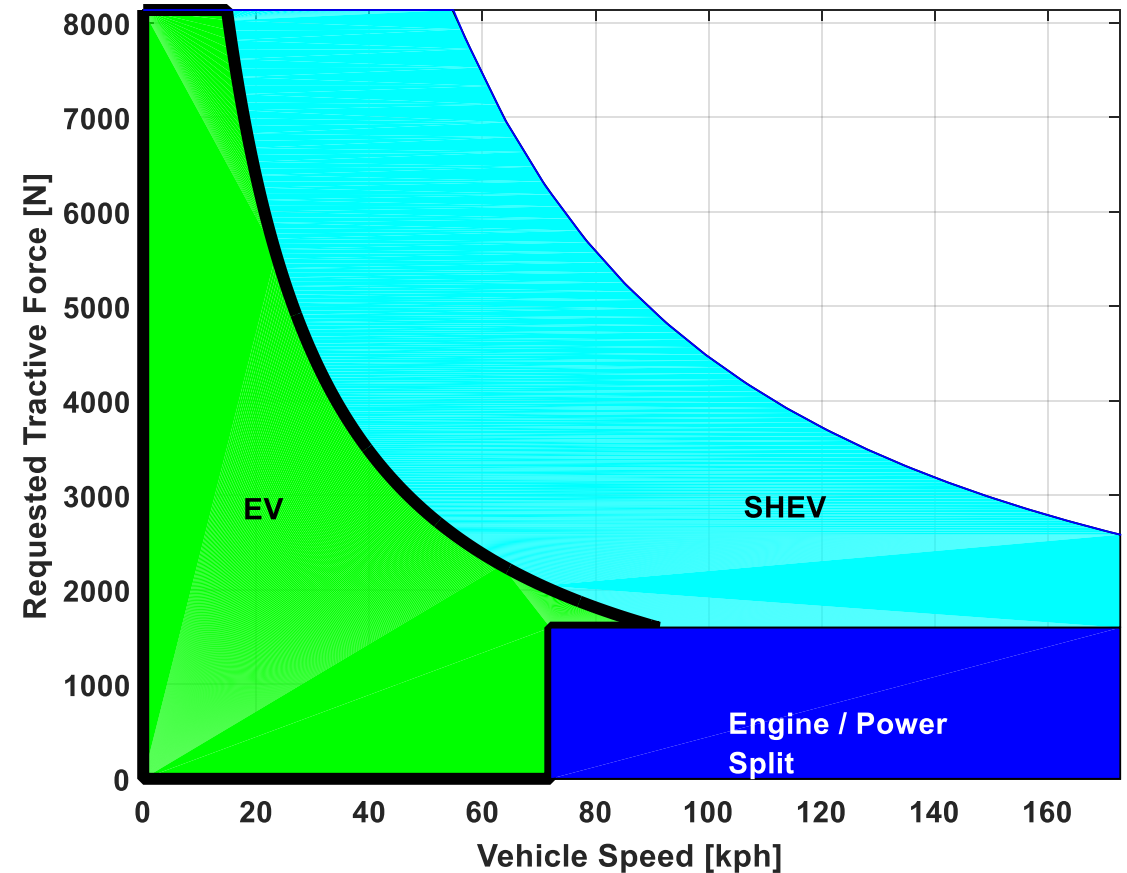
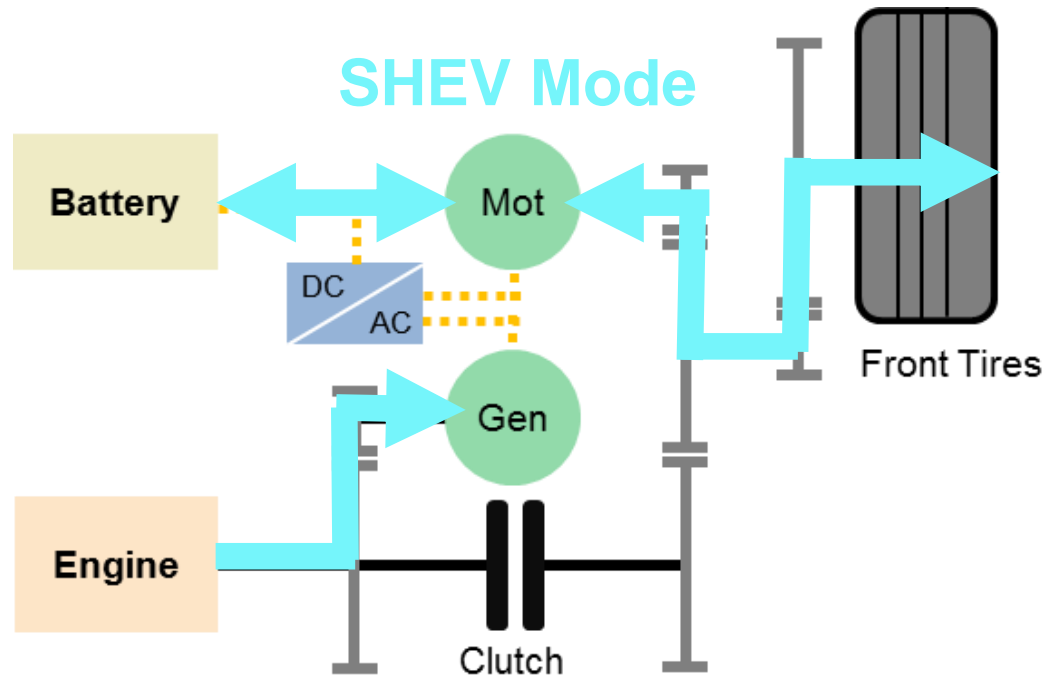
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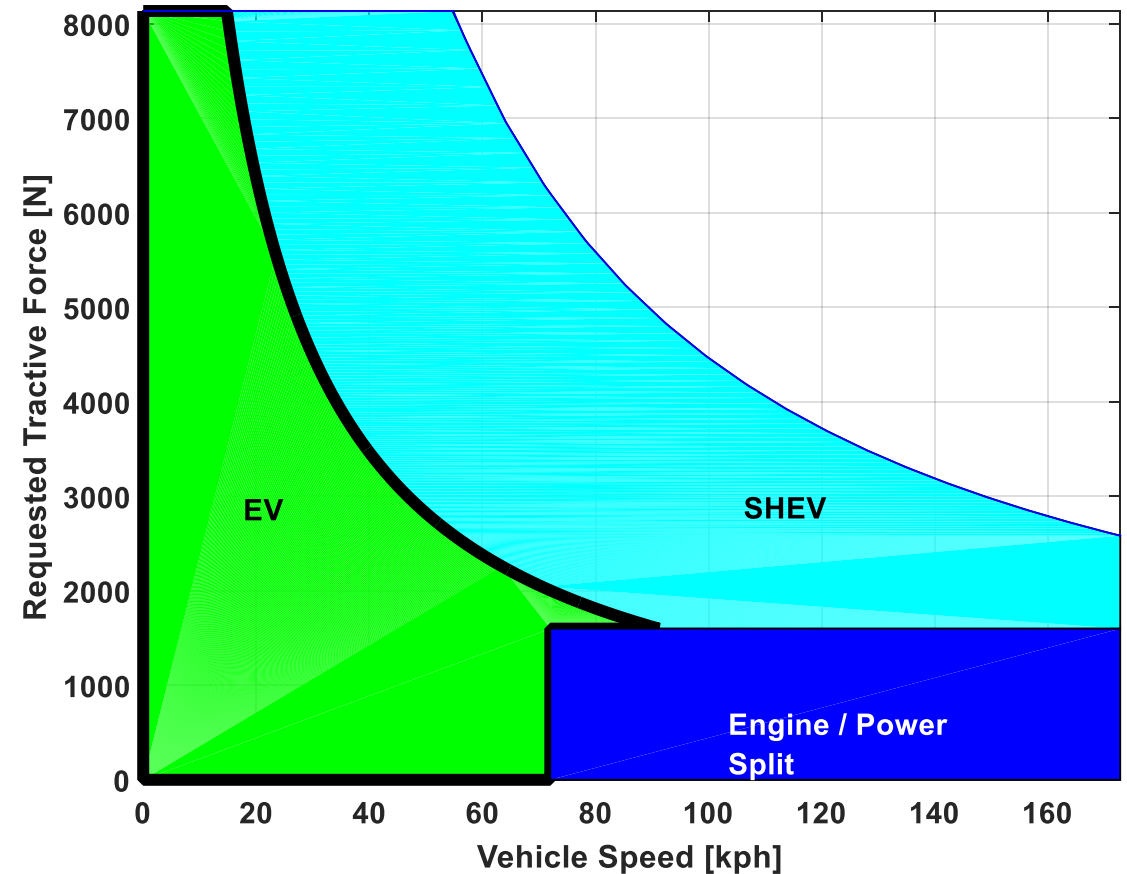
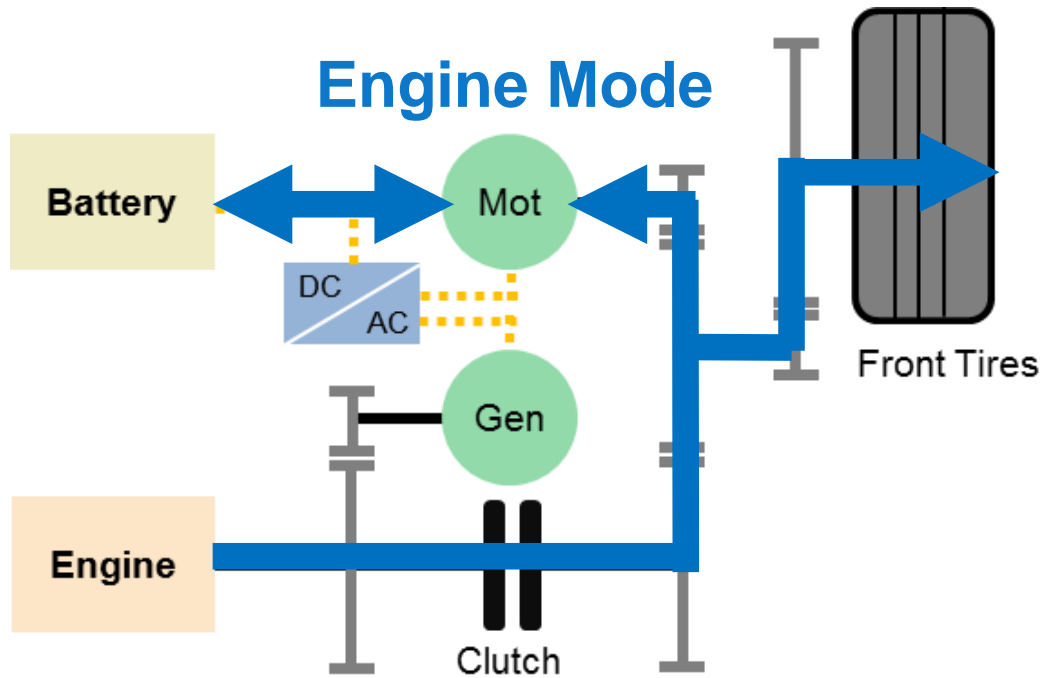
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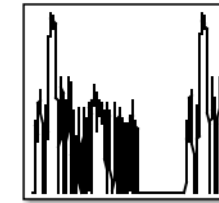
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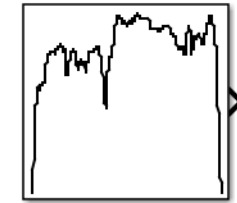


# Design Optimization Problem Statement

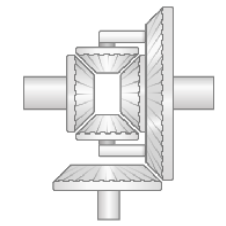
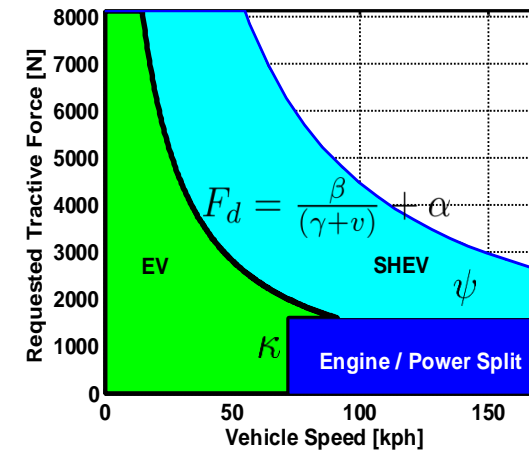
- Maximize MPGe
  - FTP75 and HWFET
  - Weighted MPGe =  $0.55(\text{FTP75}) + 0.45(\text{HWFET})$
  
- Optimize Parameters:
  - 5 control parameters
    - EV, SHEV, Engine mode boundaries
  - 1 hardware parameter
    - Final differential ratio
  
- Use PC
  - Simulink Design Optimization (SDO)
  - Parallel Computing Toolbox (PCT)



Drive Cycle Source1  
FTP75 (2474 seconds)



Drive Cycle Source  
HWFET (765 seconds)

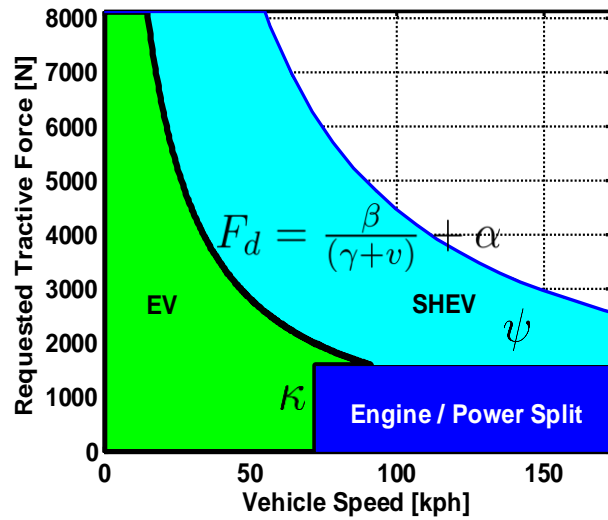


Differential Ratio

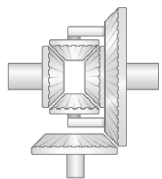


Lenovo ThinkPad T450s  
Dual Core i7 2.60GHz  
12 GB RAM

# Simulink Design Optimization



5 Control mode boundary parameters



Differential gear ratio

RESPONSE OPTIMIZATION - HevMmReferenceApplication\_SDO

Design Variables Set: None

Create Design Variables Set

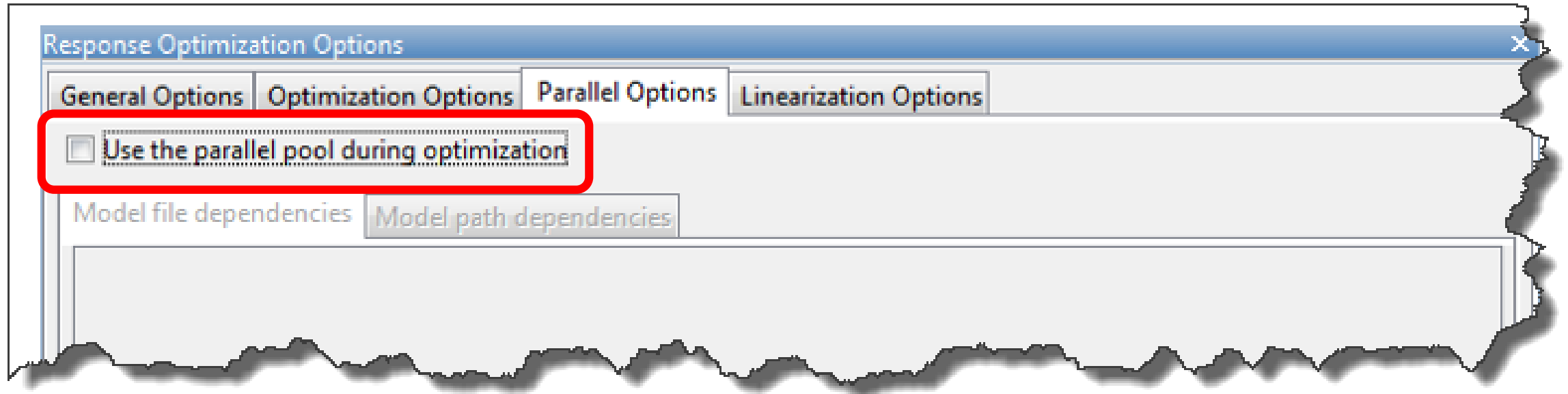
Create Design Variables set: DesignVars

Variable	Value	Minimum	Maximum	Scale
<input checked="" type="checkbox"/> s1_SDO	20	17.3	26.8	32
<input checked="" type="checkbox"/> s2_SDO	1.6	1	2.51	2
<input checked="" type="checkbox"/> q1_SDO	3.908	0	10	4
<input checked="" type="checkbox"/> p1_SDO	1.522	1	2	2
<input checked="" type="checkbox"/> r2_SDO	0	0	1	1
<input checked="" type="checkbox"/> DiffRatio_SDO	3.421	2.5	3.5	4

Update model variables

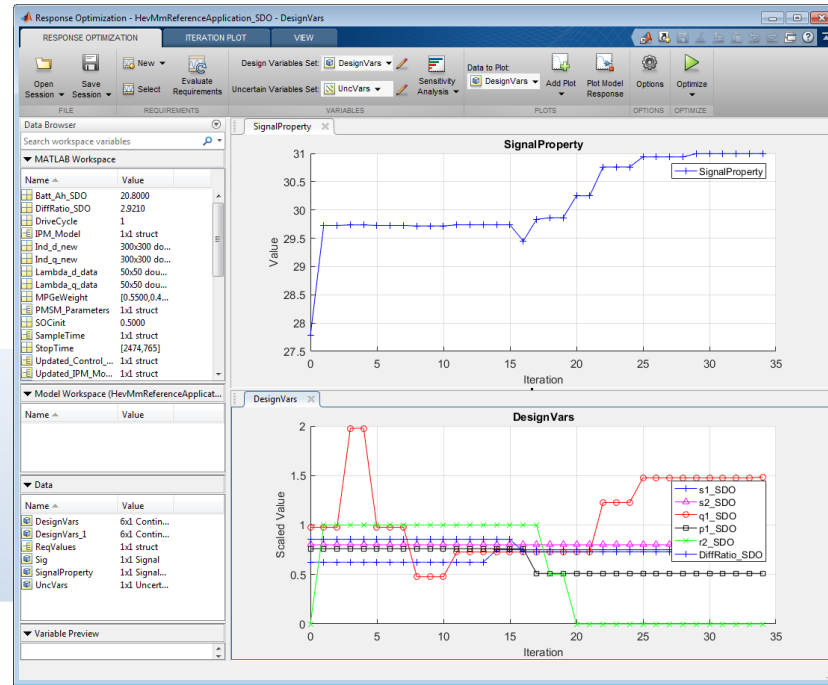
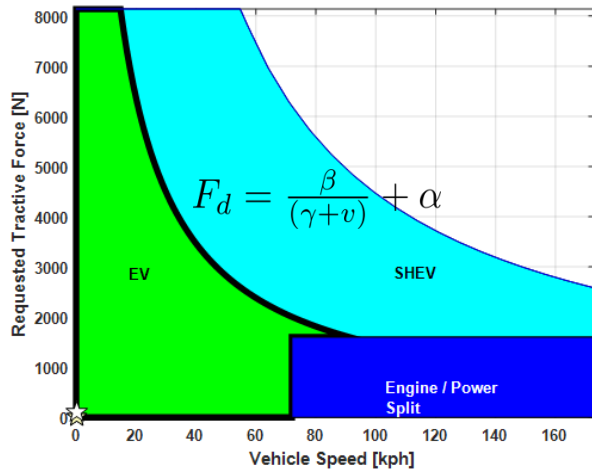


# Simulink Design Optimization

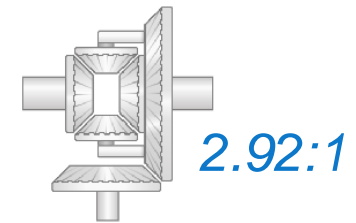
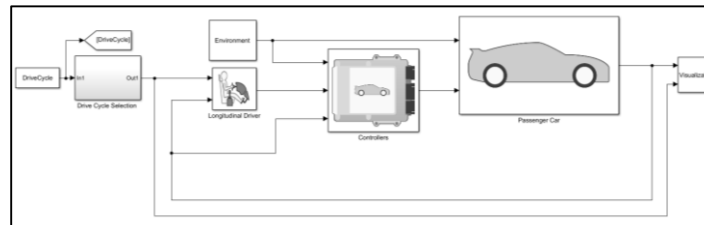
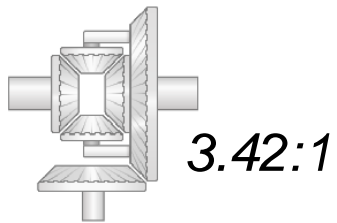
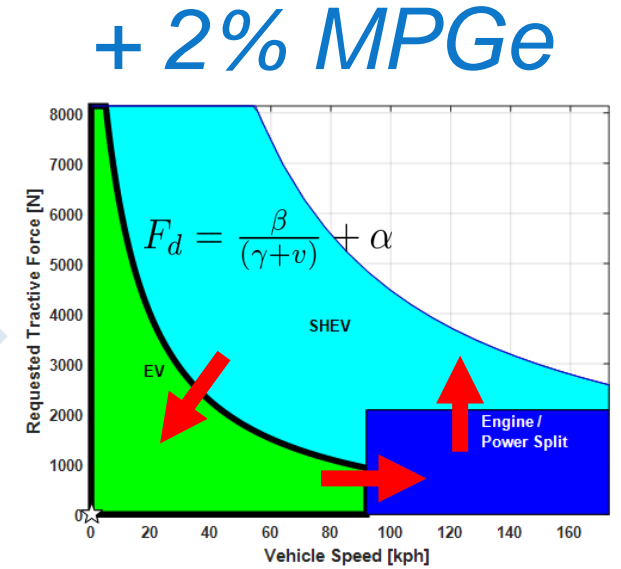


# Optimization Results

Simulink Design Optimization → Response Optimization



~ 12 Hours



# Design optimization studies

- Define Design Optimization studies with minimal setup effort
- Perform Design Optimization studies overnight on your laptop



**Engine Modeling and Calibration**

Reduce time on HIL, dyno, vehicle testing

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① Engine modeling and calibration

**Design optimization studies**

Explore wider search space with fast simulations

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② Design optimization studies

**Multidomain simulation via Simscape**

Integrate & Validate multidomain subsystem models

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③ Multidomain simulation via Simscape

**Subsystem Control Design**

Validate controller design via simulation

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④ Subsystem control design

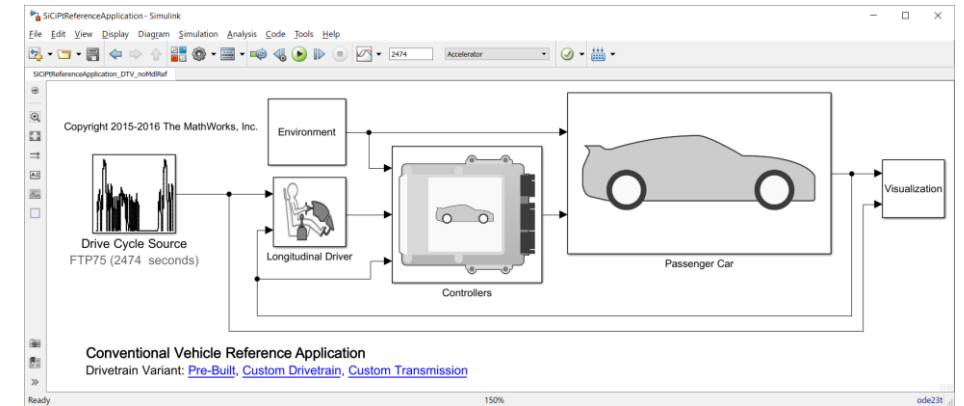
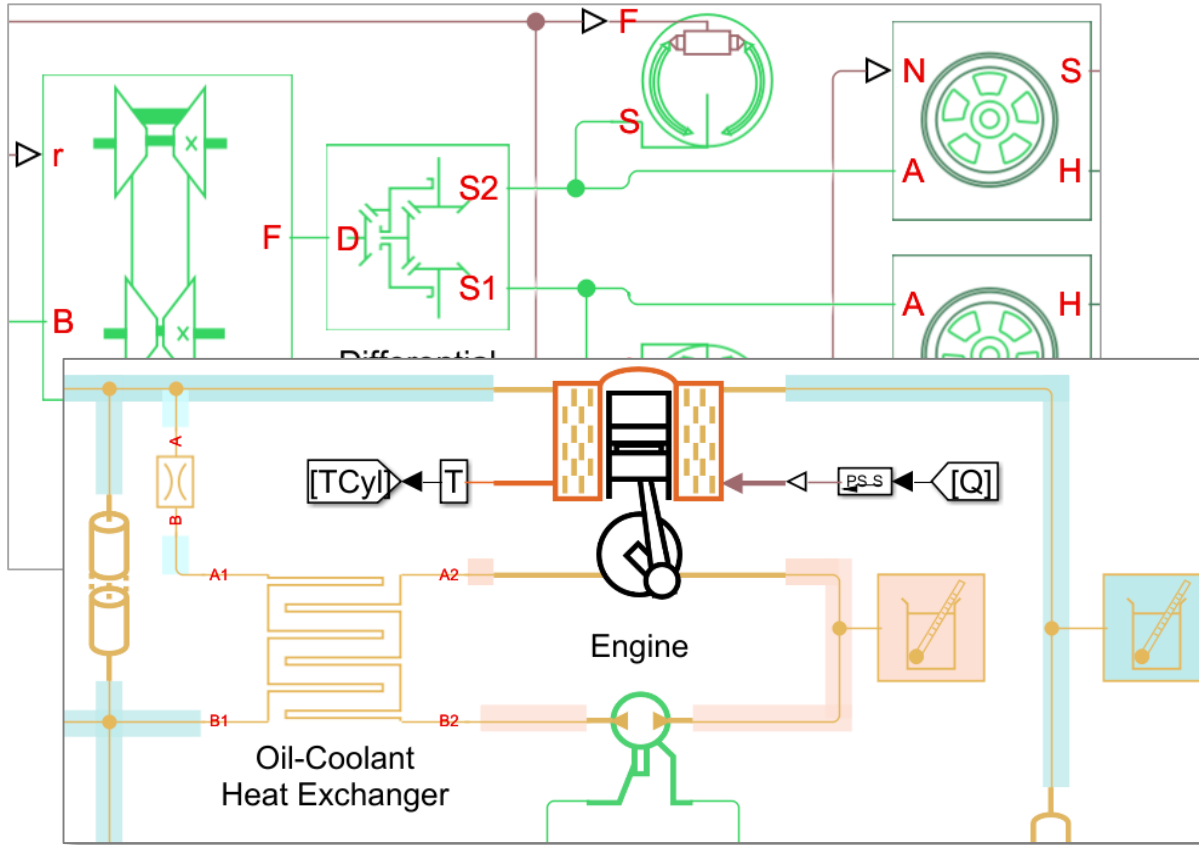
**Hardware In the Loop (HIL) Testing**

Validate controller in real-time

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⑤ Hardware-in-the-loop (HIL) testing

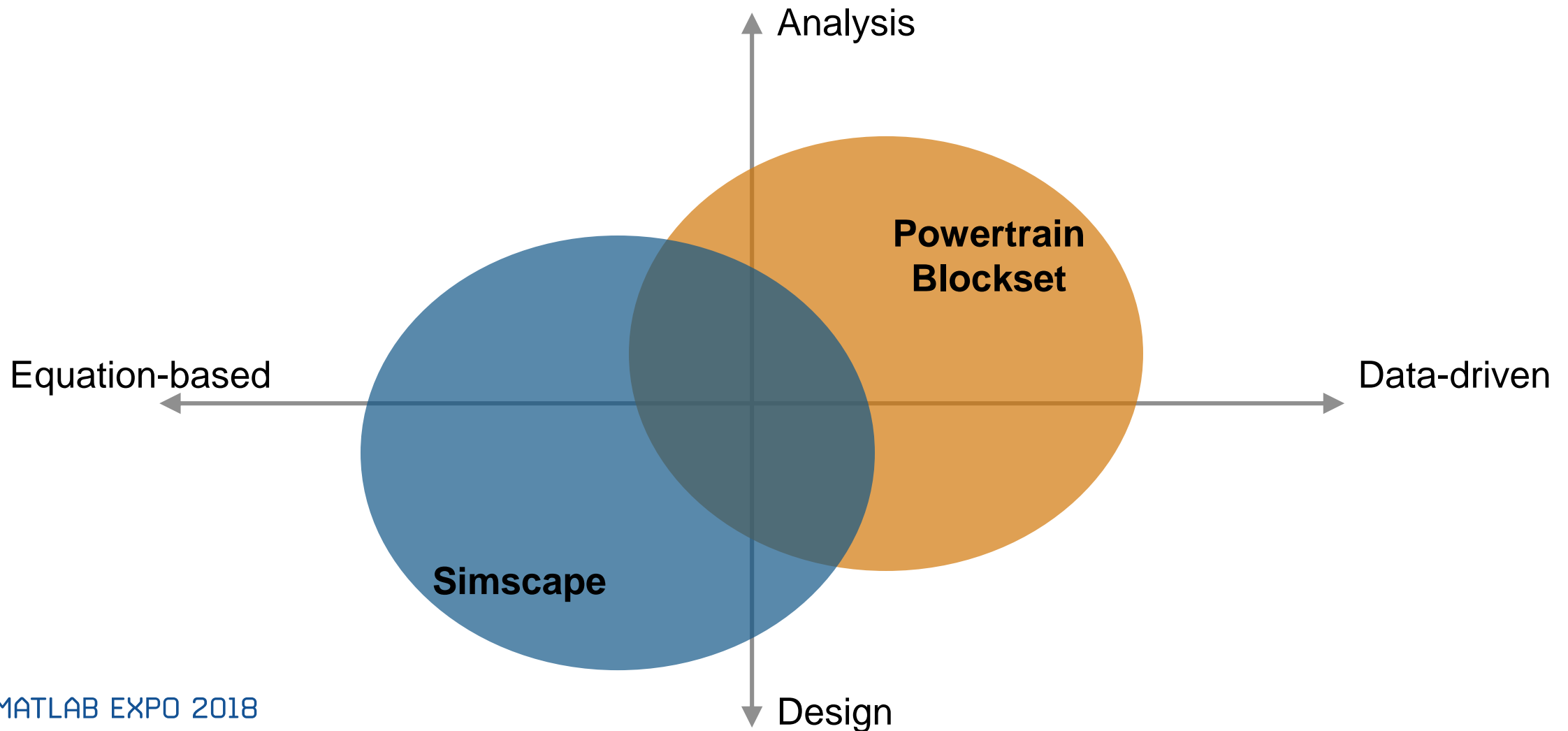
# Multidomain simulation via Simscape



Integrate & Validate multidomain subsystem models

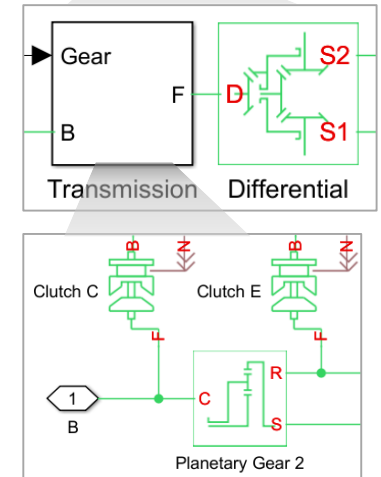
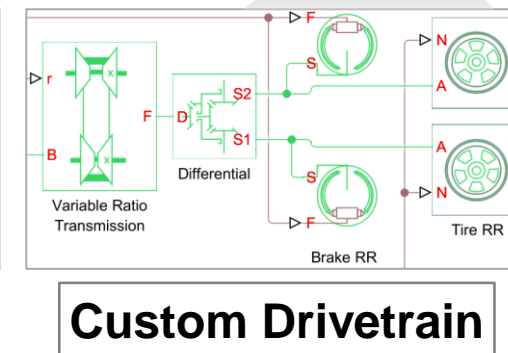
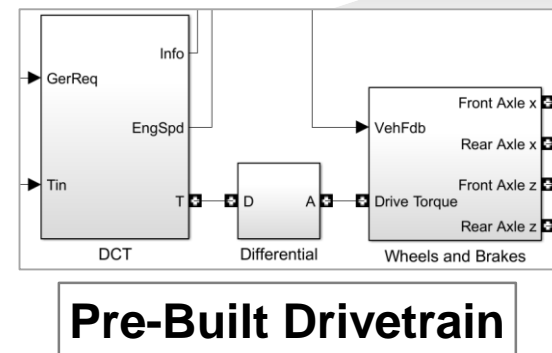
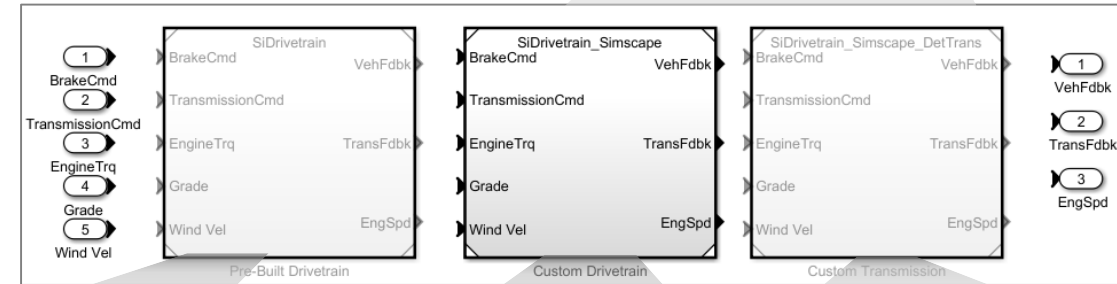
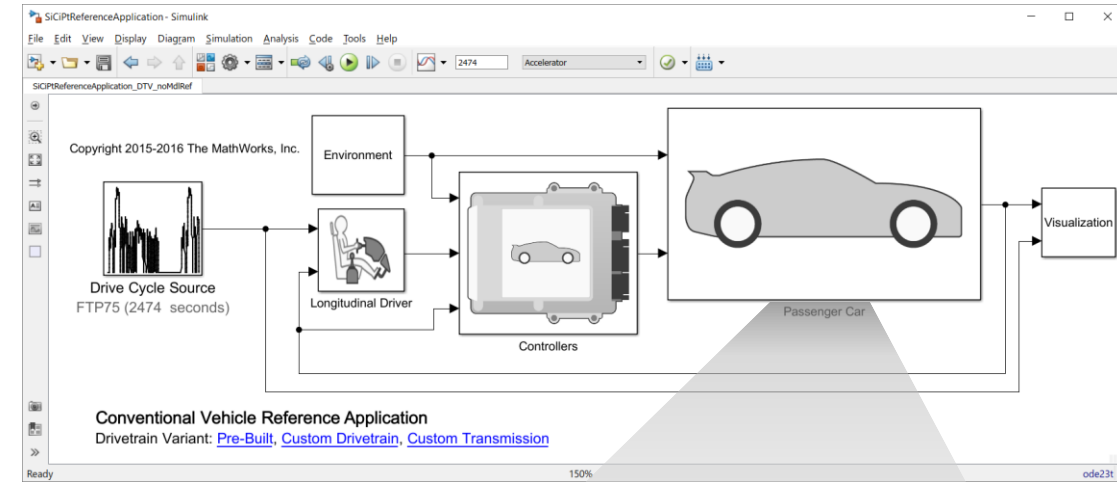
# Powertrain Blockset and Simscape

*Tools have overlap in what they can do, but they have a different emphasis*

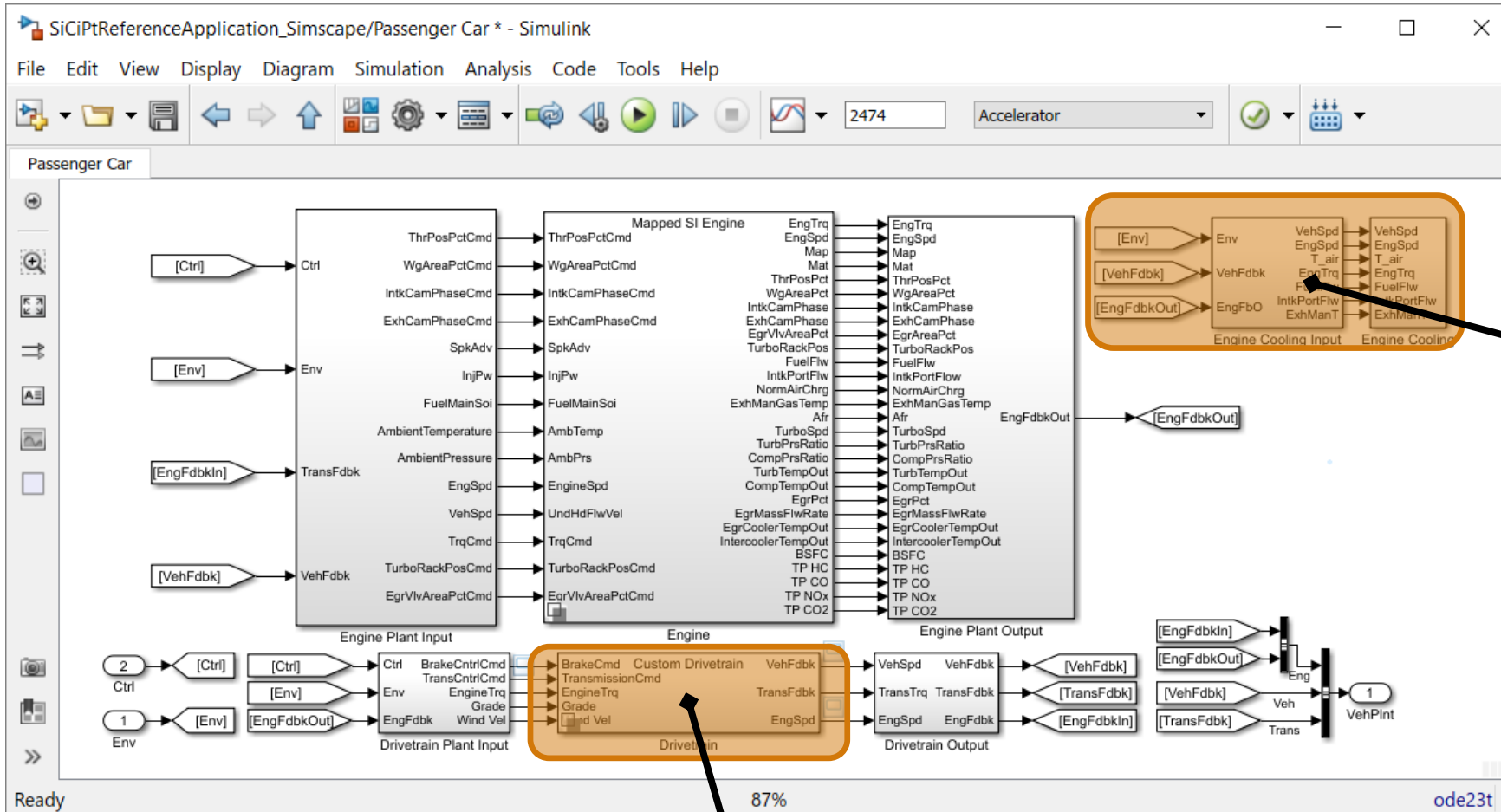


# Custom Drivetrain or Transmission

- Replace portions of reference application with custom models assembled from Simscape libraries
- Use Variant Subsystems to shift back and forth based on current simulation task



# Engine Cooling System



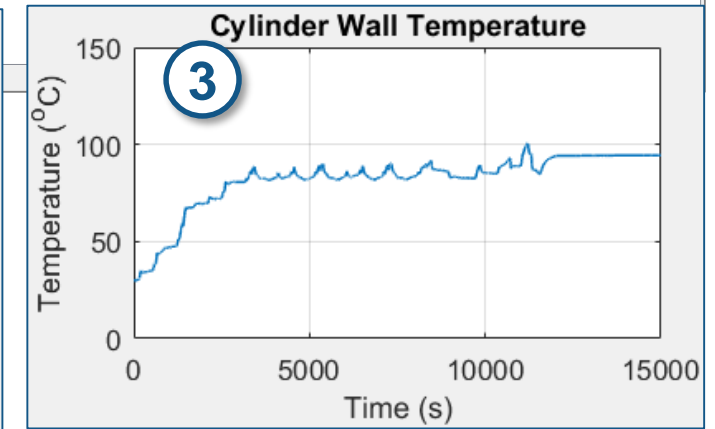
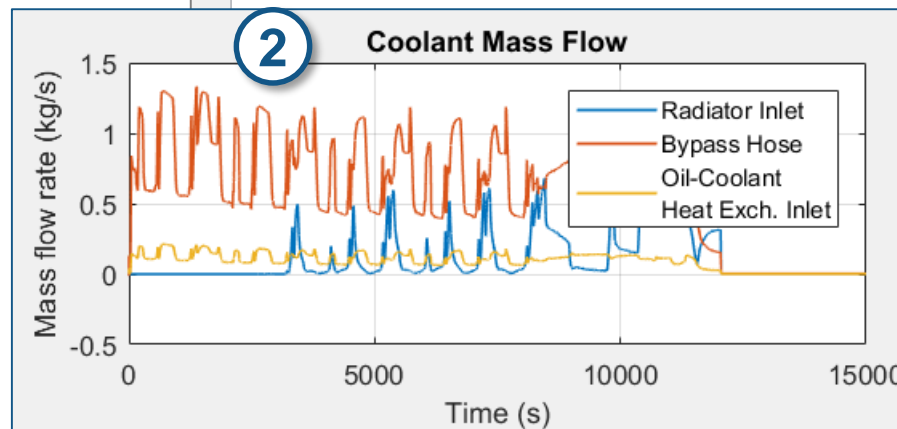
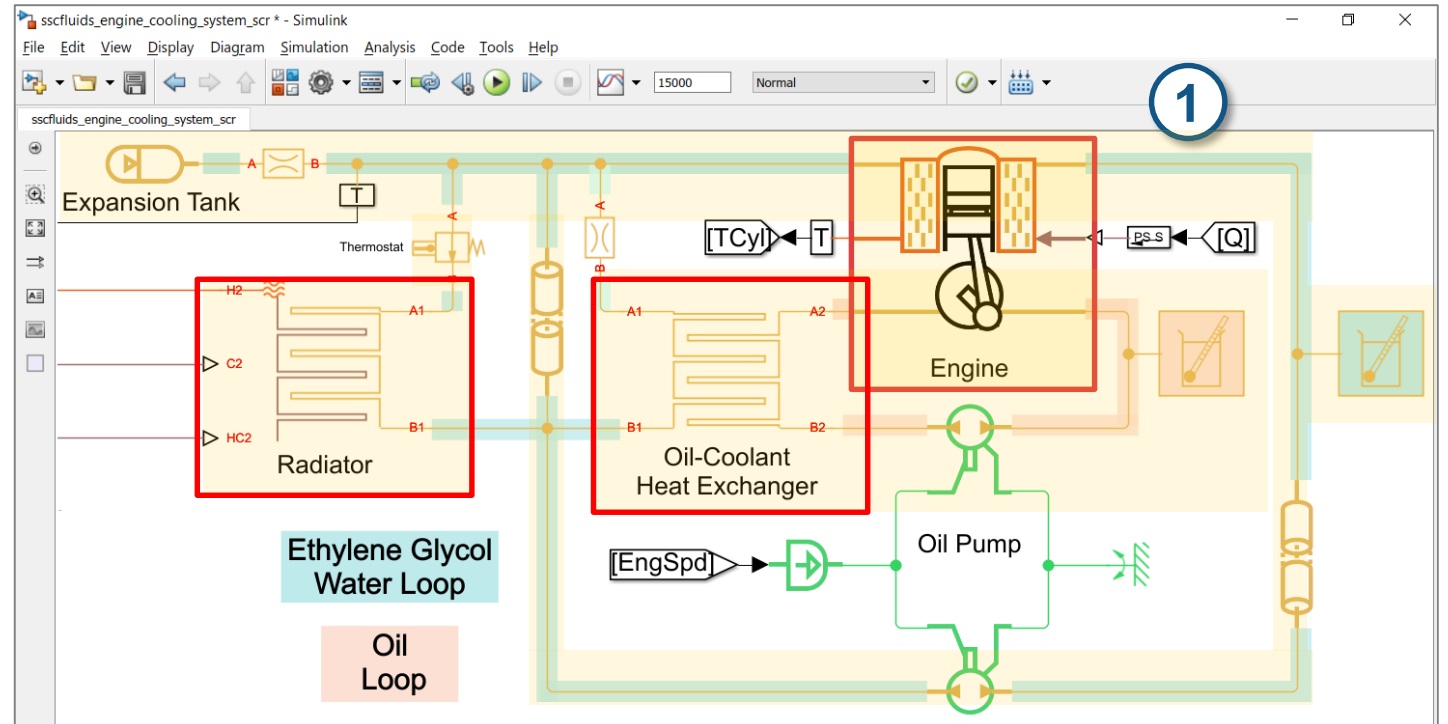
Take customization  
one step further:  
Add Engine Cooling  
Subsystem

Simscape "Custom Driveline" variant



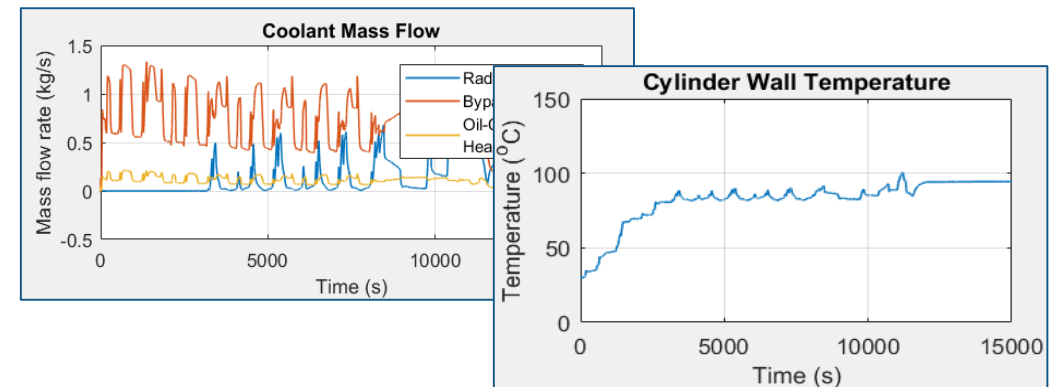
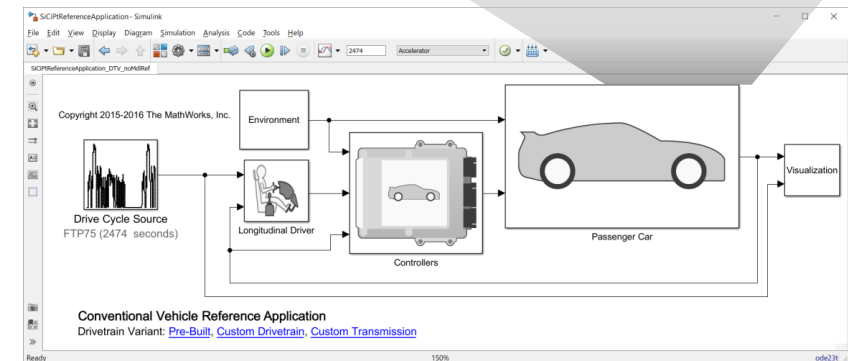
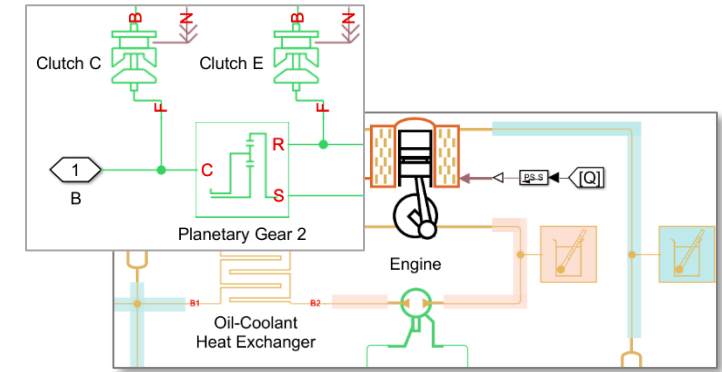
# Conventional Vehicle with Simscape Engine Cooling

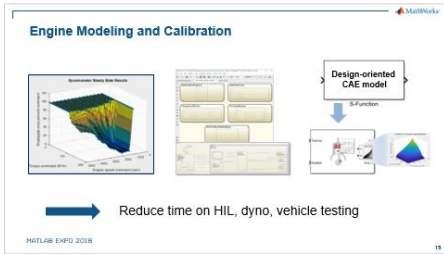
1. Heat rejection calculation
2. Heat distributed between oil and coolant
3. Temperature of cylinder used to validate cooling system performance



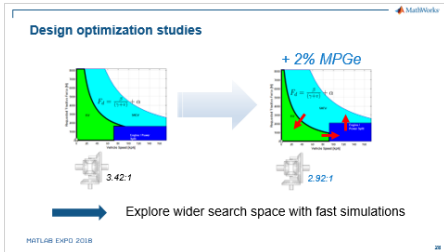
# Multidomain simulation via Simscape

- Create detailed, multi-domain subsystem models with Simscape
- Incorporate them into system level vehicle models from Powertrain Blockset
- Validate subsystem performance with closed loop simulation

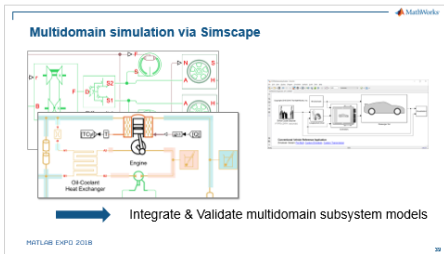




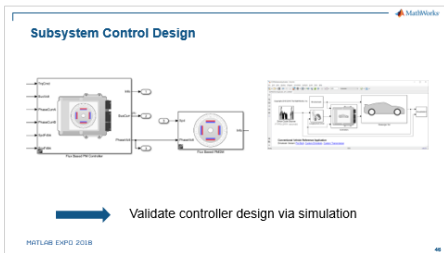
① Engine modeling and calibration



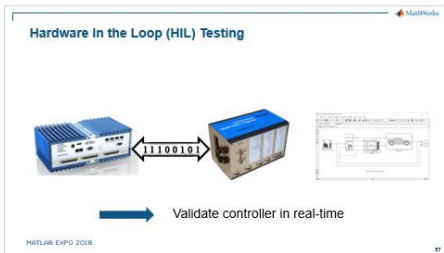
② Design optimization studies



③ Multidomain simulation via Simscape

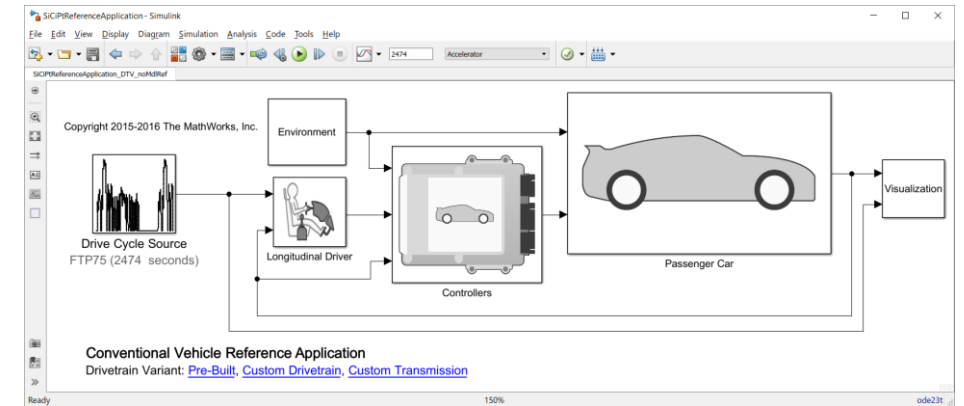
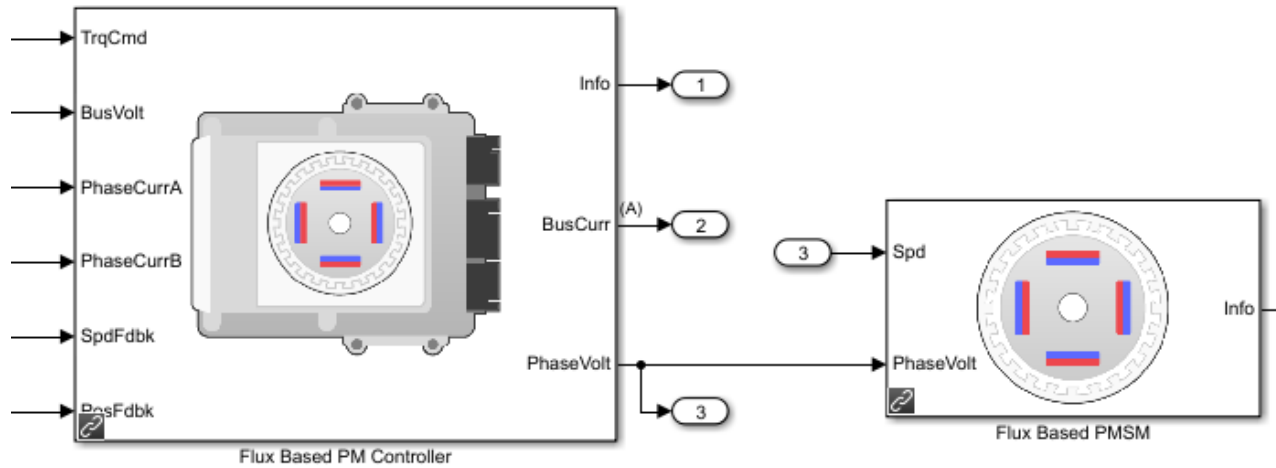


④ Subsystem control design



⑤ Hardware-in-the-loop (HIL) testing

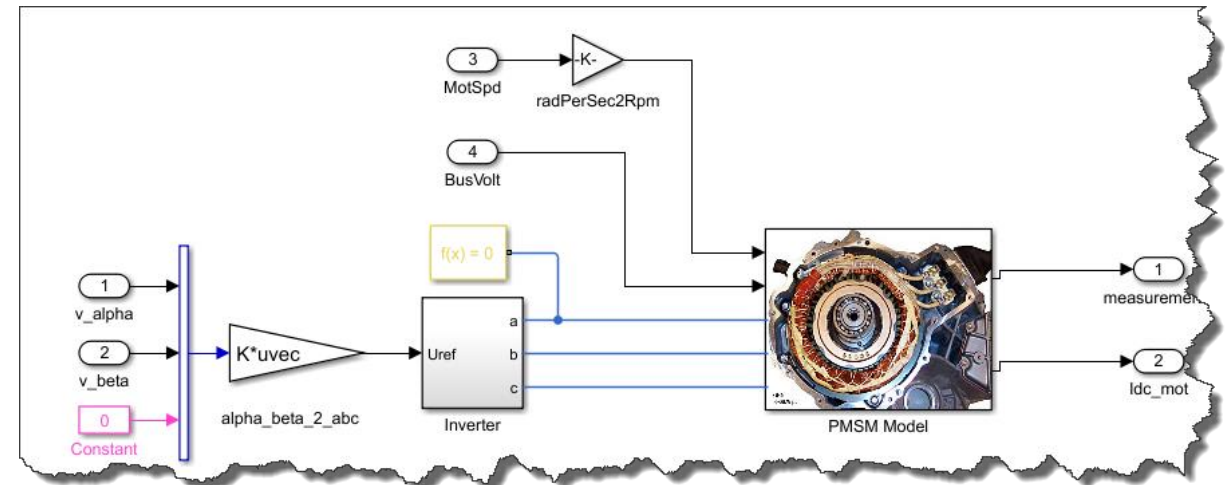
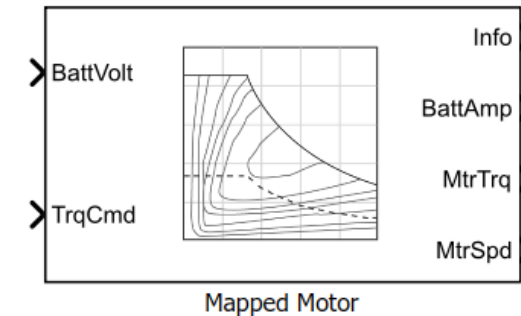
# Subsystem Control Design



Validate controller design via simulation

# Different Motor Models for Different Needs

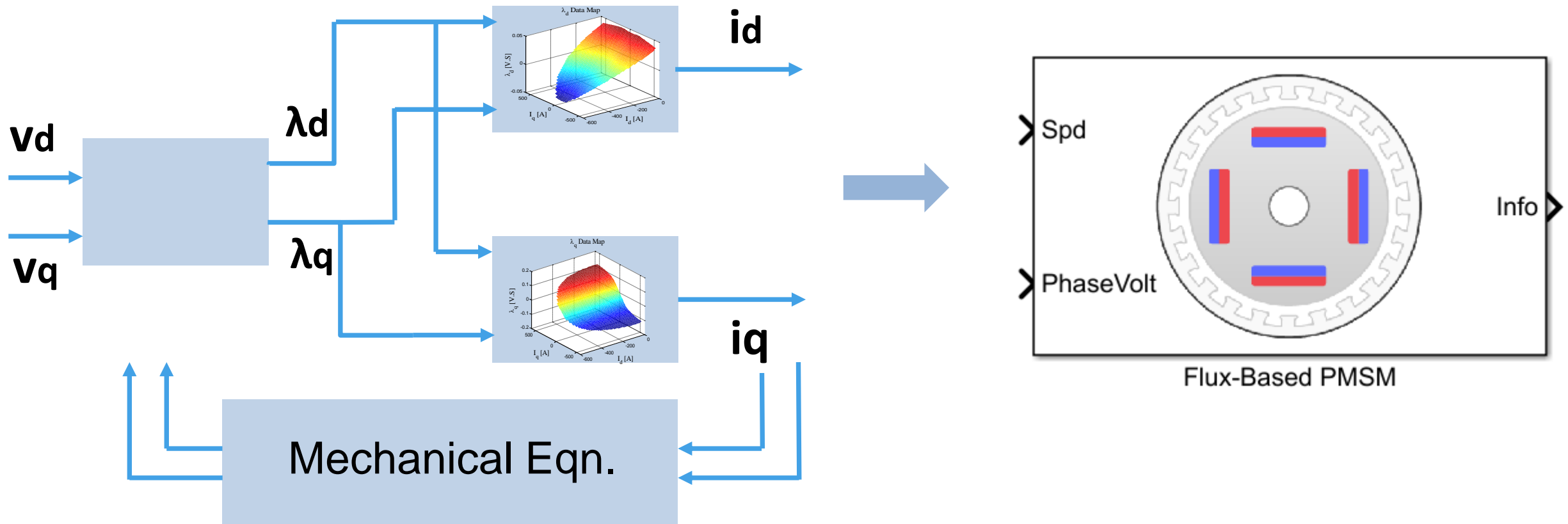
- System Optimization
  - Goal: Estimate fuel economy
  - Requirements: fast simulation speed, simple parameterization
  - Model choice: empirical model
  
- Subsystem Control Design
  - Goal: Study controller interactions
  - Requirements: higher accuracy, inclusion of effects like saturation
  - Model choice: nonlinear saturation



Detailed model = inverter controller + nonlinear motor model

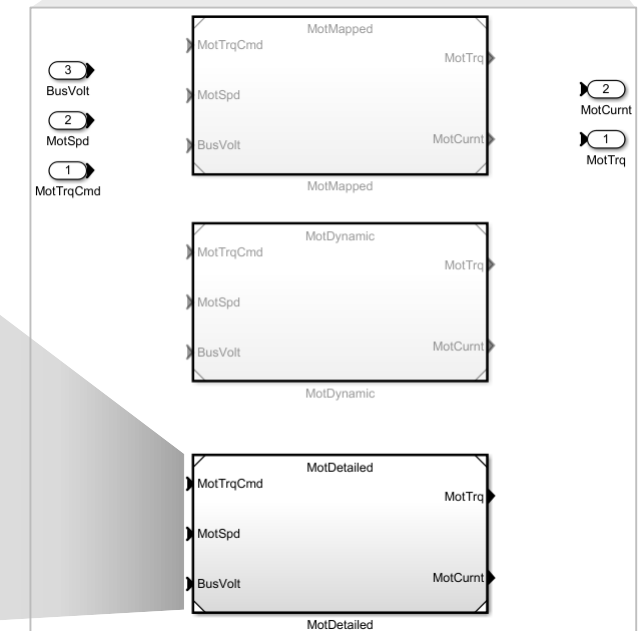
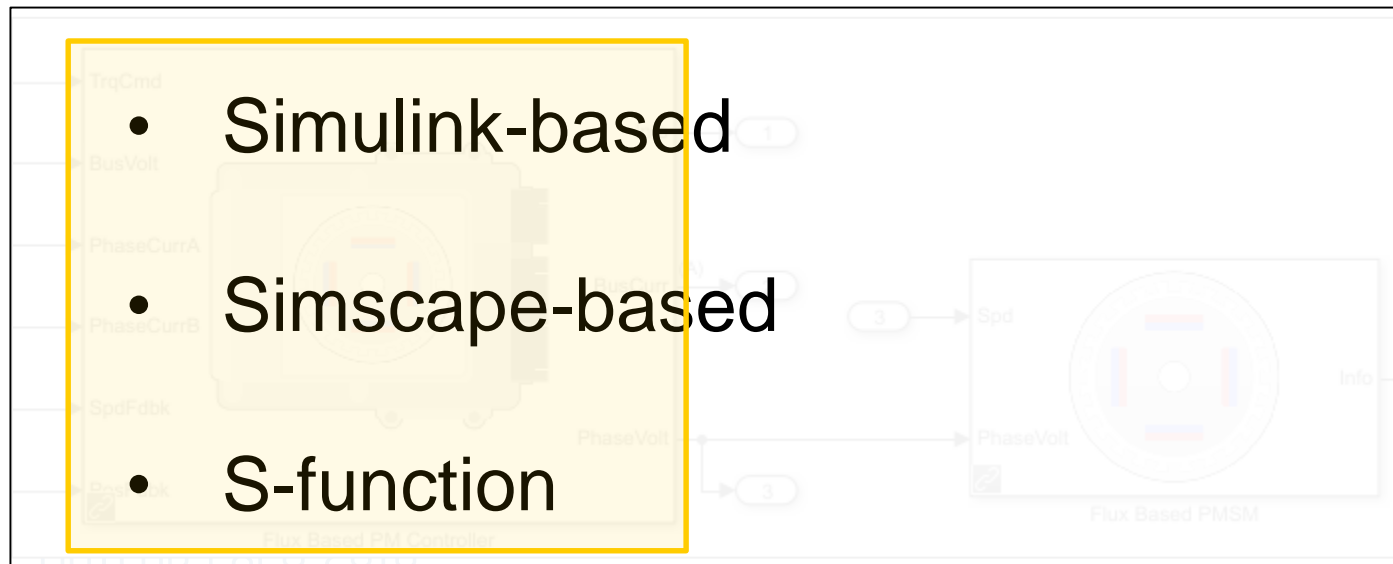
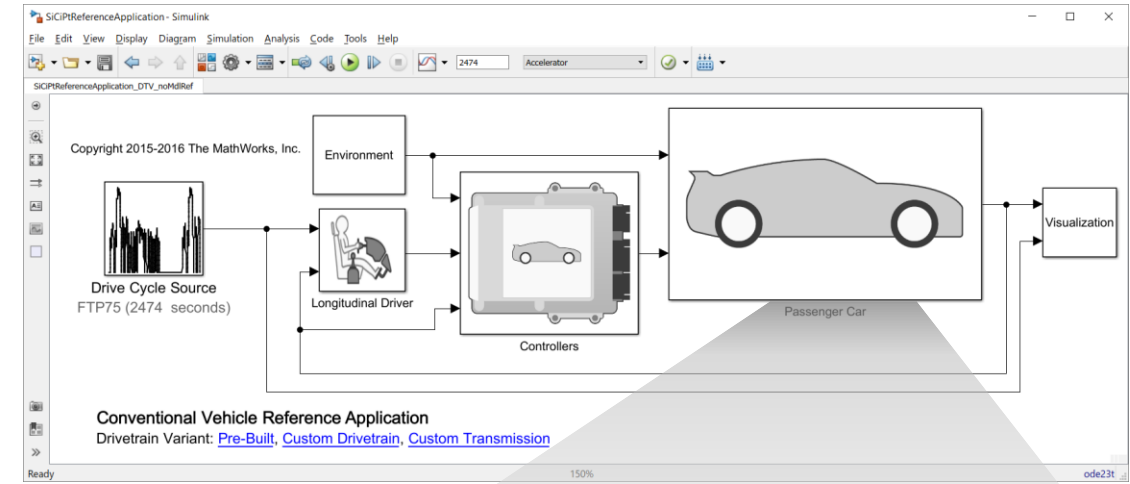
# High Fidelity Detailed Motor Model in Simscape

- FEA simulations or dynamometer data used to obtain non-linear flux table
- Flux-based PMSM model created to capture this effect

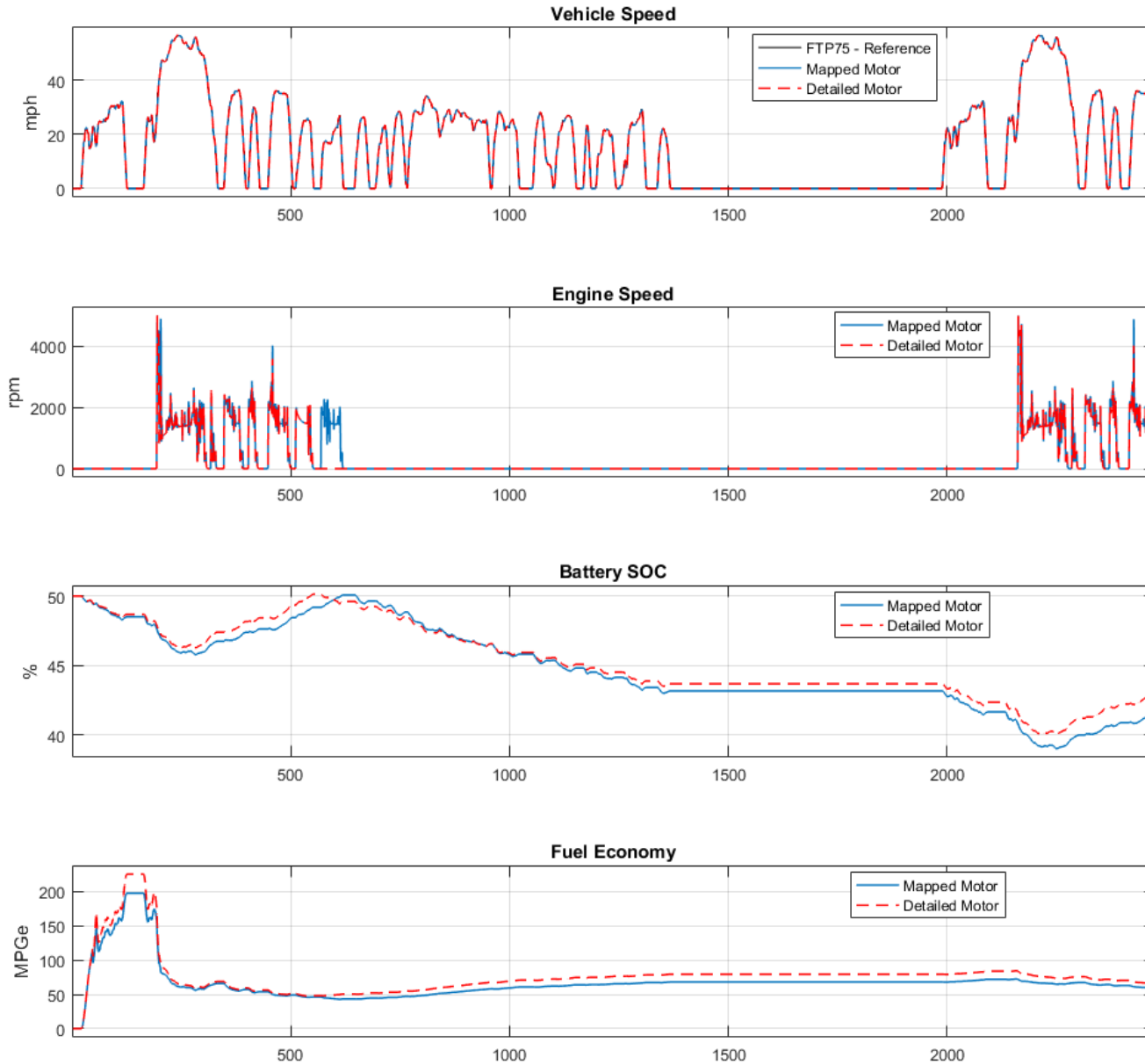


# Including Detailed Subsystem Variants

- Add your own subsystem variants to the existing vehicle models



# Detailed Model Variant Simulation

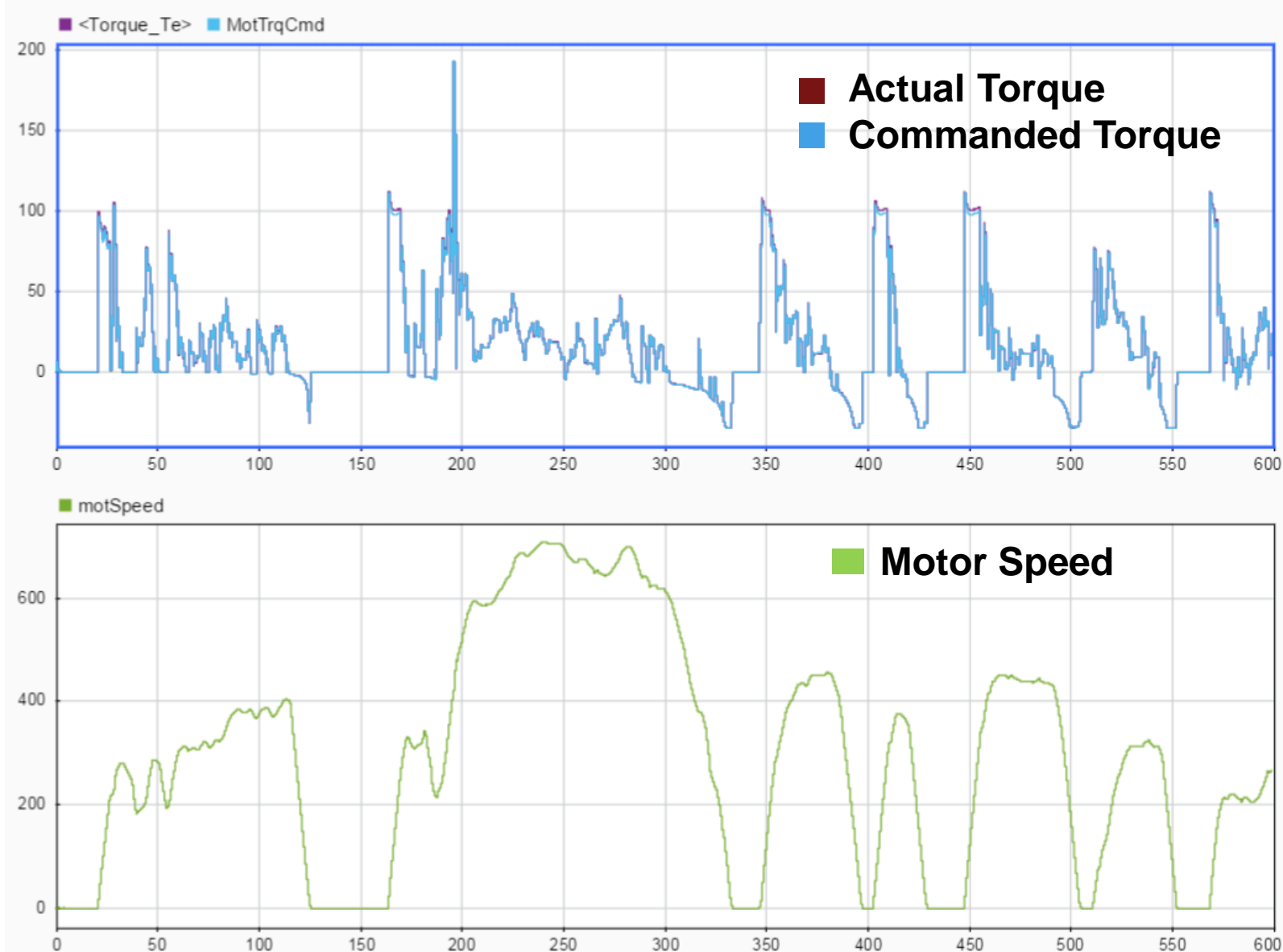


Cycle Name	Final SOC (%)		MPGe	
	Mapped	Detailed	Mapped	Detailed
HWFET	42	44	50.5	51.8
FTP75	41.4	42.8	59.6	66.4

- Detailed variant gives comparable response
- Supervisory controller handles both motor variants
- Motor controller requires further verification



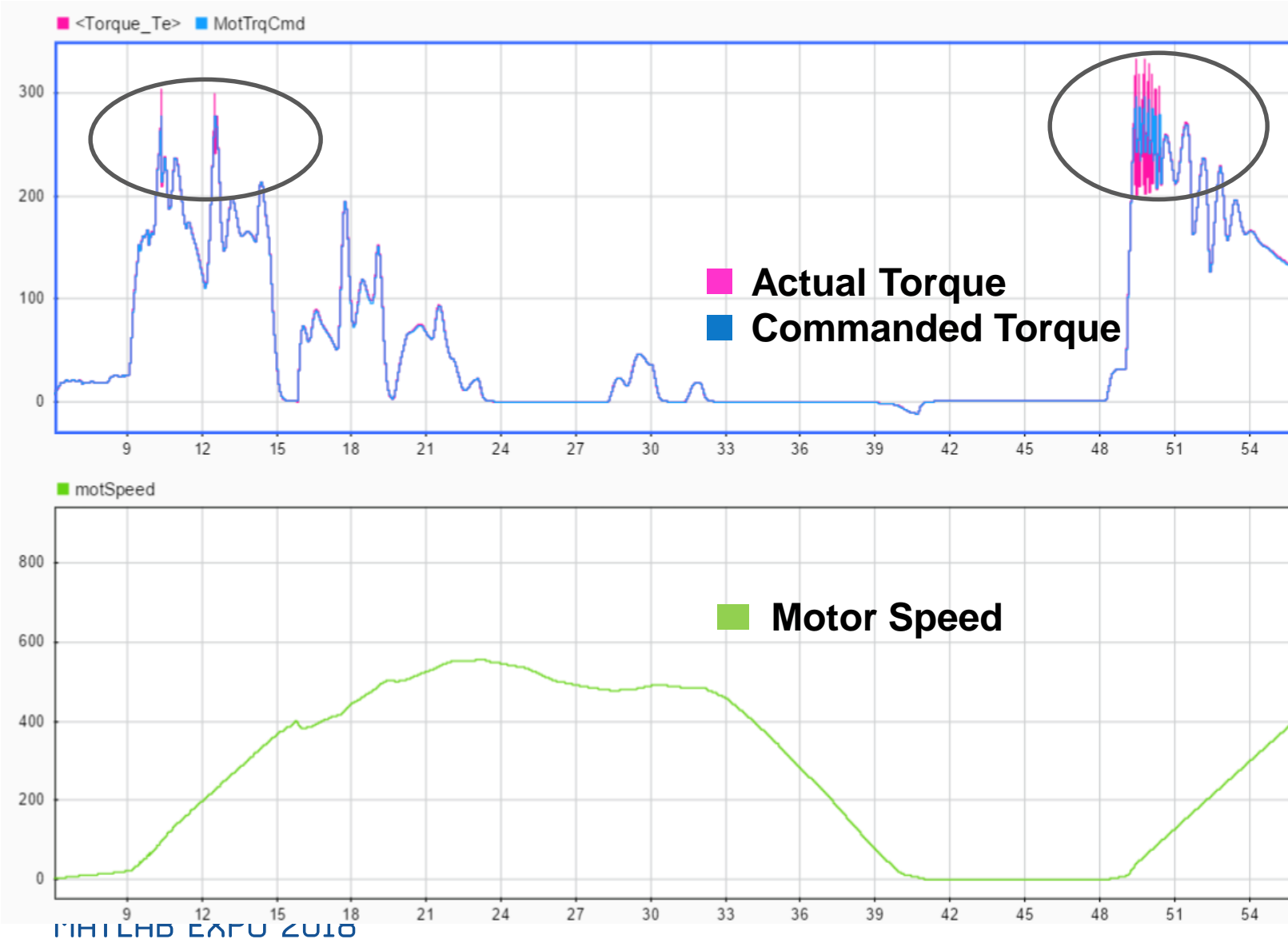
# Torque Control Performance



## FTP75 Drive Cycle

- Motor torque response accurately follows the commanded torque at different speeds

# Torque Control Performance

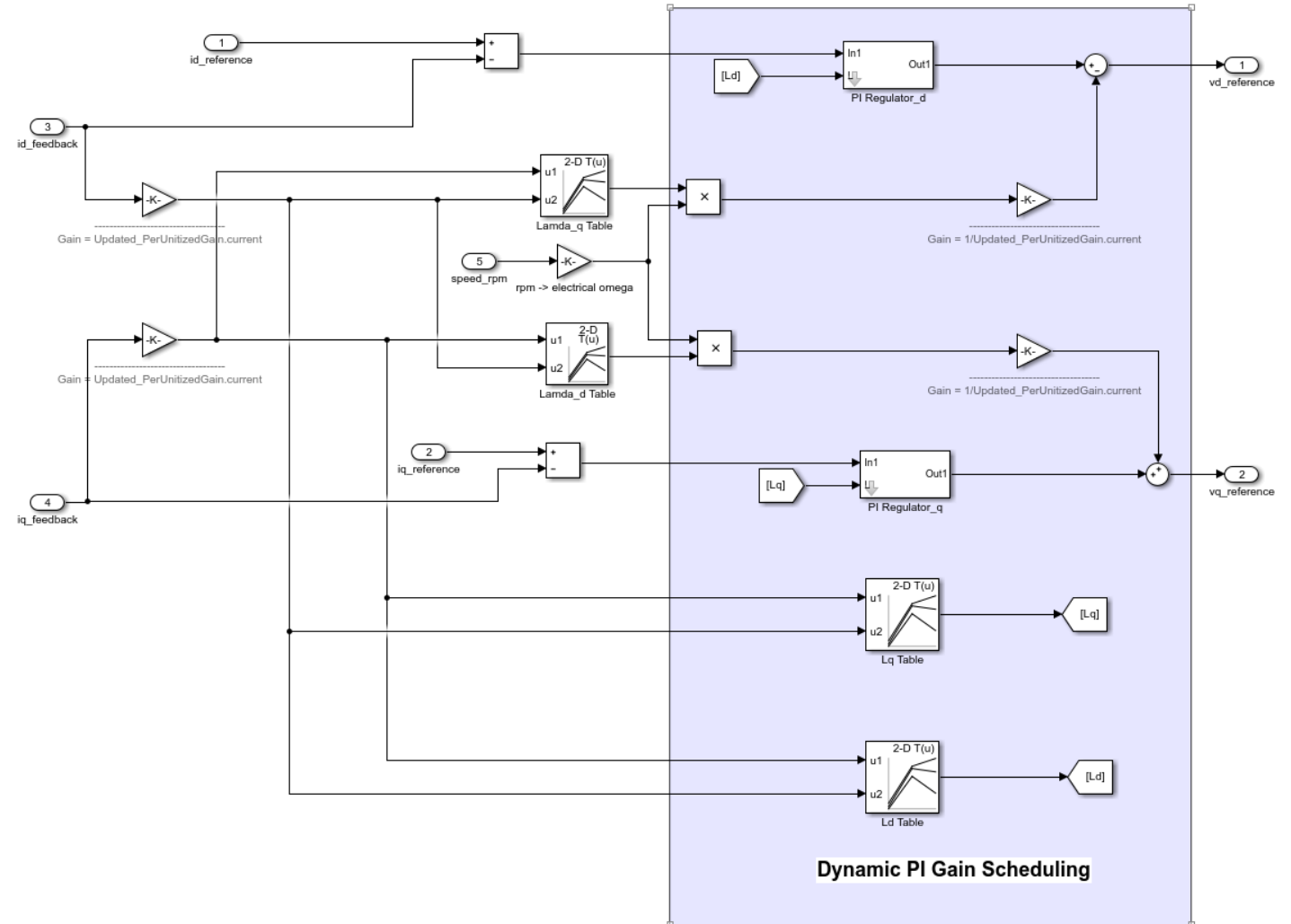
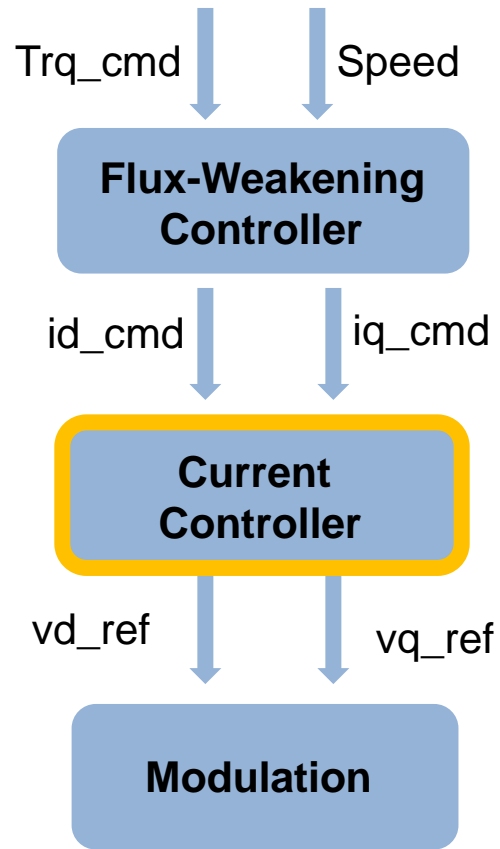


## US06 Drive Cycle

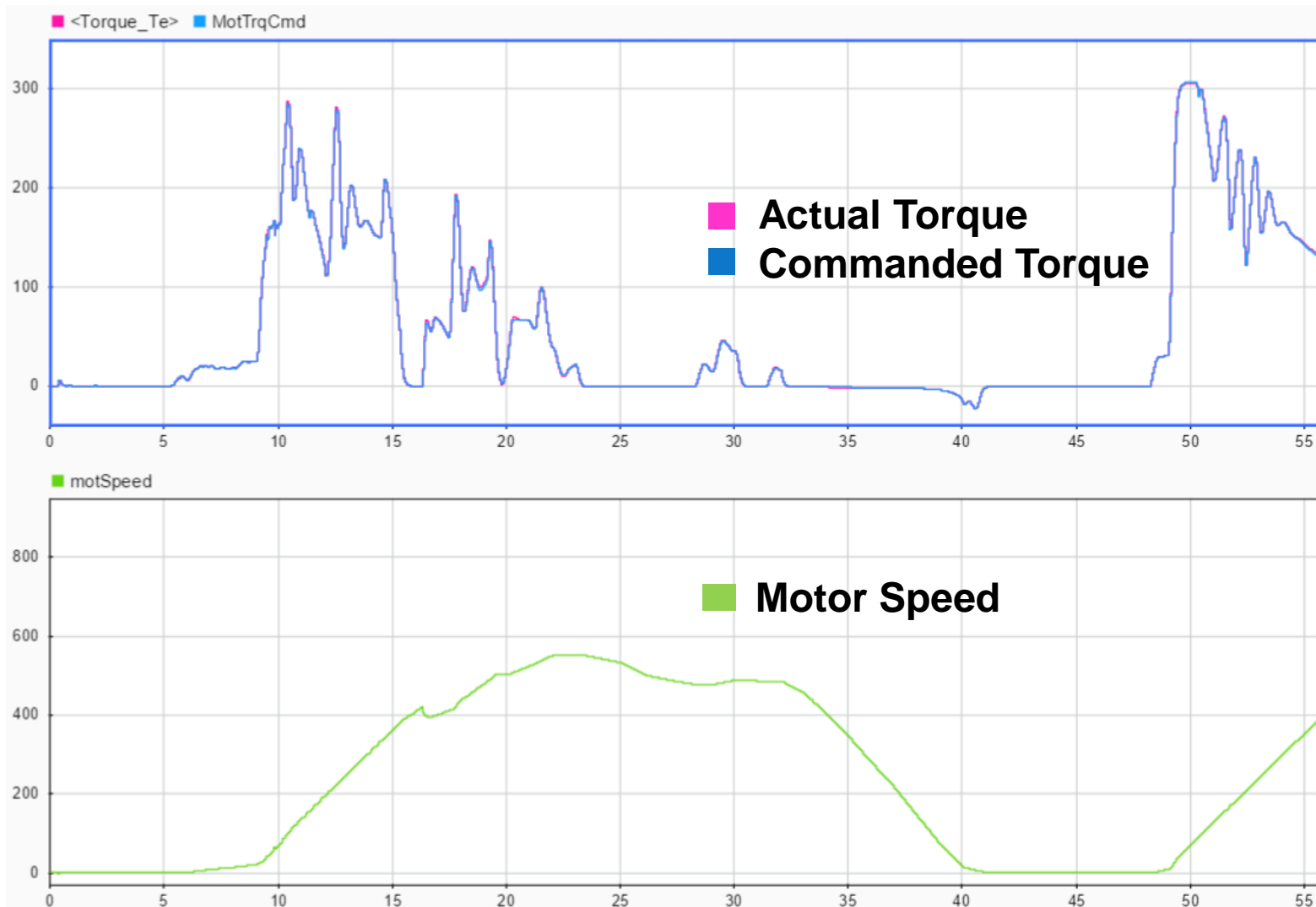
- Much higher power demand reveals a problem
- Motor controller becomes unstable under certain operating conditions

# Controller Enhancements

Current Controller robustness improvement via dynamic gain scheduling



# Torque Control Performance

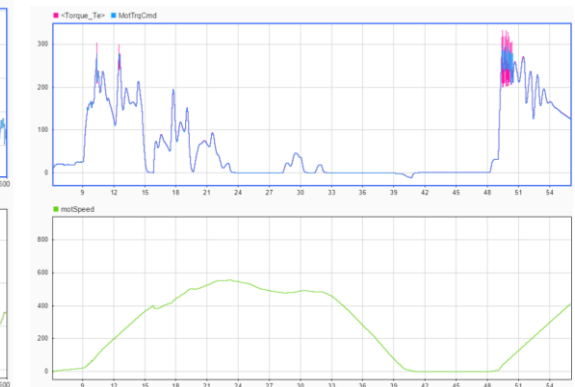
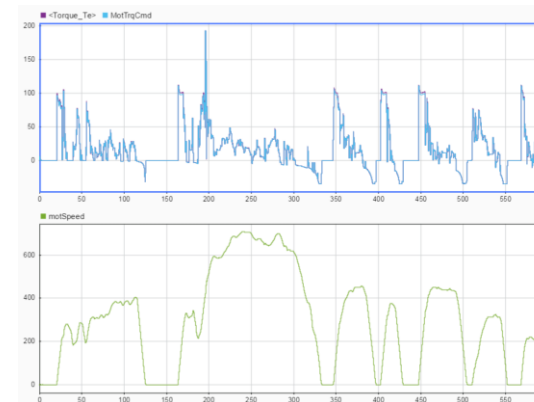
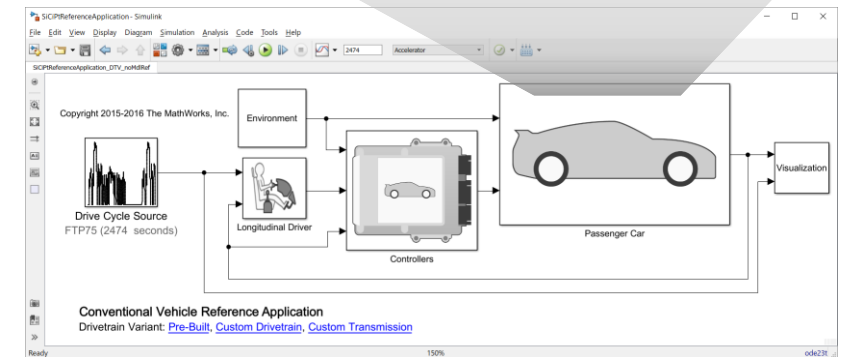
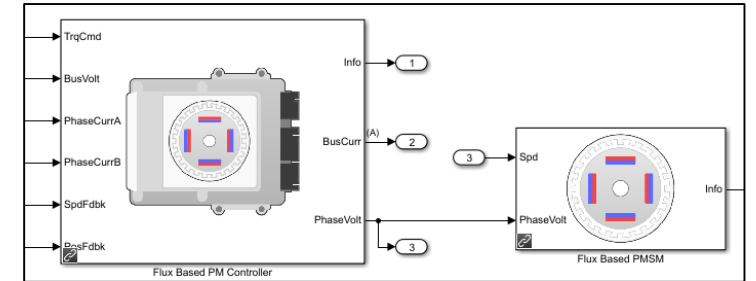


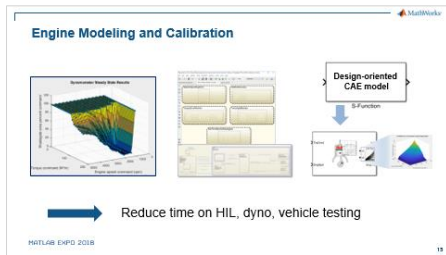
## US06 Drive Cycle

- Even in more extreme maneuvers, improved motor controller is able to provide the commanded torque

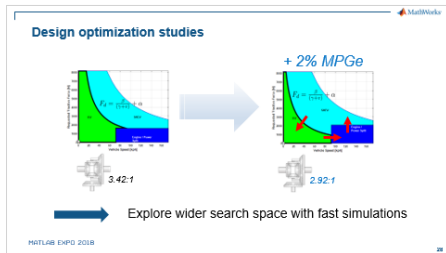
# Subsystem control design

- Easily integrate detailed motor and controller model in system simulation model
- Test interactions between motor and controller with the rest of the vehicle
- Verify subsystem controller meets system level requirements

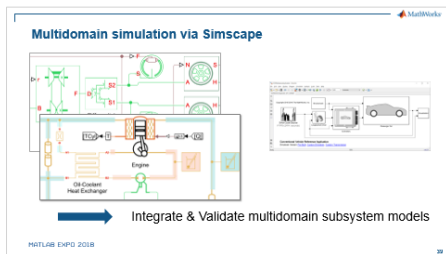




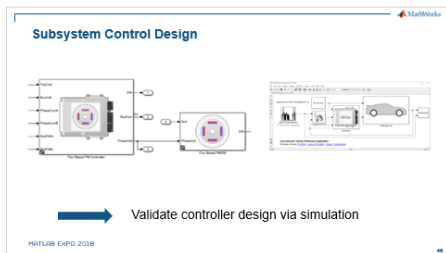
① Engine modeling and calibration



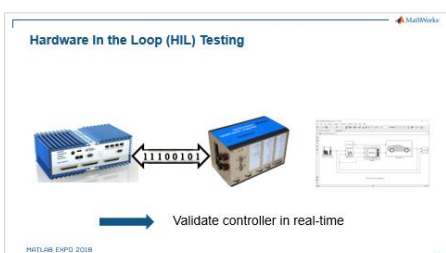
② Design optimization studies



③ Multidomain simulation via Simscape

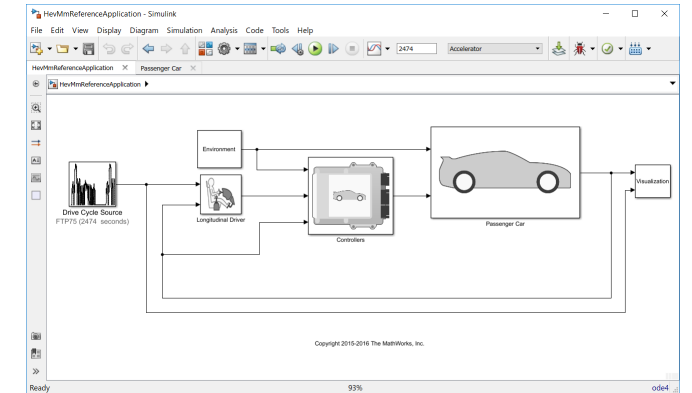
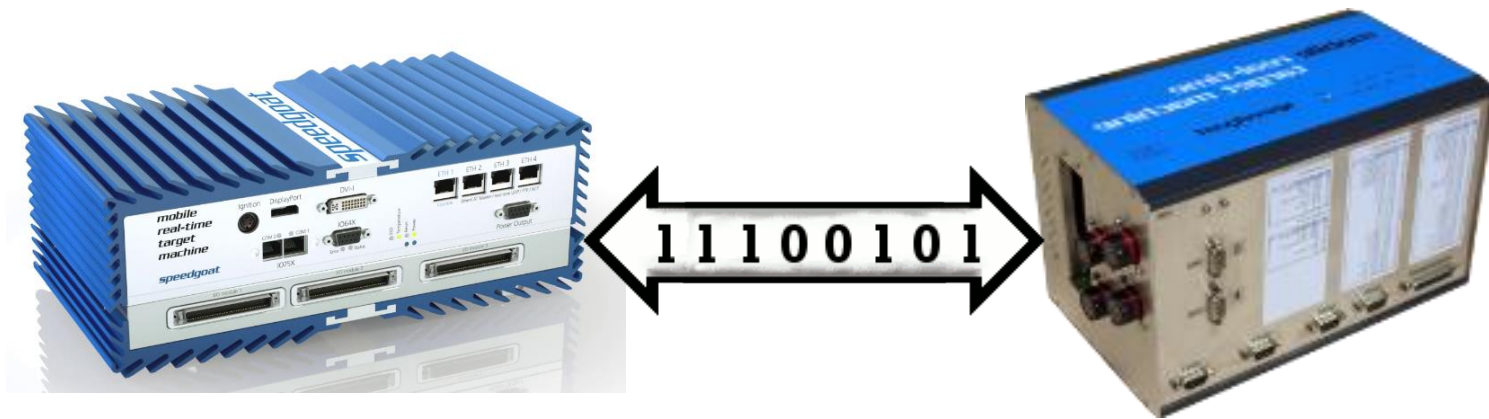


④ Subsystem control design



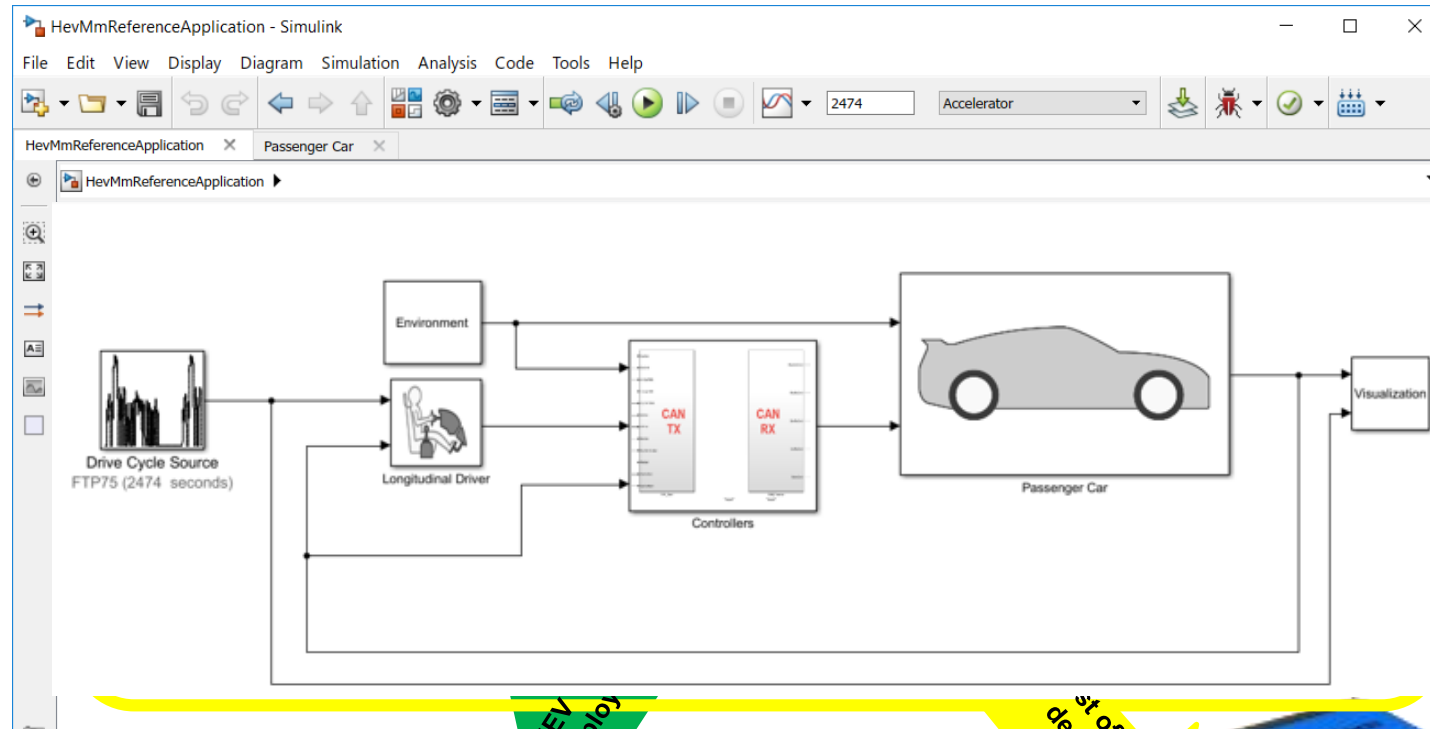
⑤ Hardware-in-the-loop (HIL) testing

# Hardware In the Loop (HIL) Testing



Validate controller in real-time

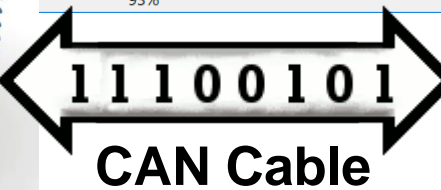
# HIL Testing with Powertrain Blockset HEV Model



Speedgoat Rapid Control Prototyping System



Embedded Controller Hardware



Target Computer Hardware

Speedgoat Hardware in-the-loop System

HEV Deploy

st of model deployed to target

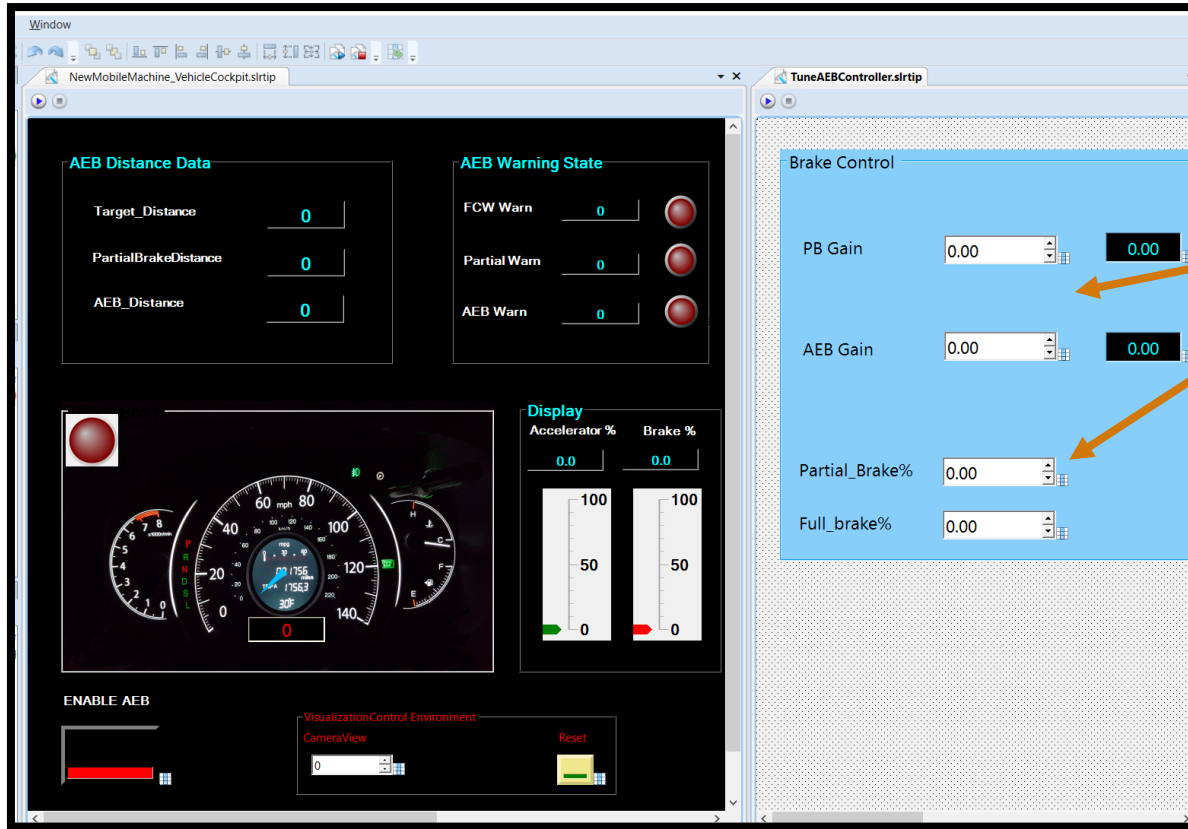
93%



# Powertrain Blockset HIL Testing Physical Setup



# Easily Tune Parameters in Real Time and Save Calibrations



Calibrate parameters at run time in Simulink Real-Time Explorer

Comparison - origCals.dataCalibration vs. newCals.dataCalibration

COMPARISON VIEW

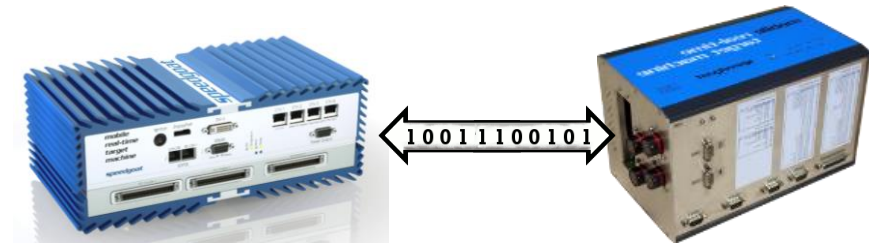
origCals.mat vs. newCals.mat Variable "dataCalibration"

Field Name	origCals.dataCalibration.aeb 1x1 st...	newCals.dataCalibration.aeb 1x1 st...
aeb_gain	0.4000	0.2400
fcw_gain	0.4000	0.4000
fullBrakePercent_0_100	75	90
partialBrakePercent_0_100	25	25
pb_gain	0.4000	0.3000

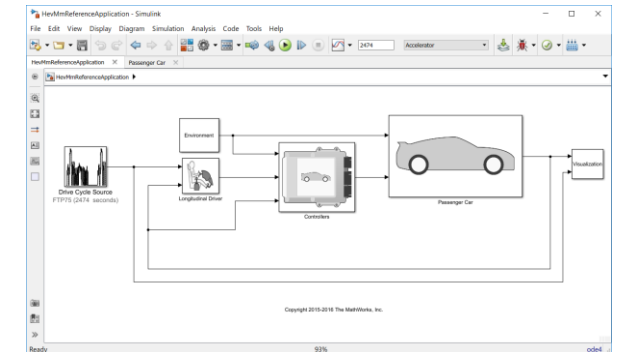
Use Simulink Real-Time API to save and compare calibrations directly from MATLAB

# Hardware-in-the-loop (HIL) testing

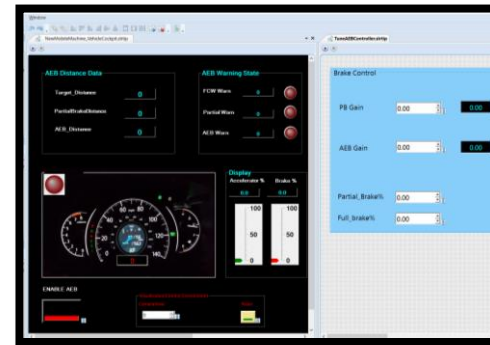
- Validate control algorithm before physical prototypes are available

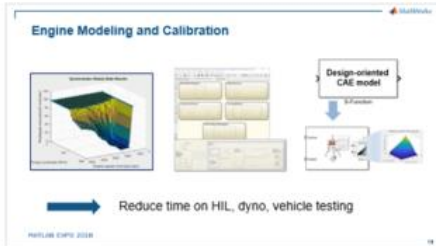


- Reuse the same vehicle models across the V-cycle

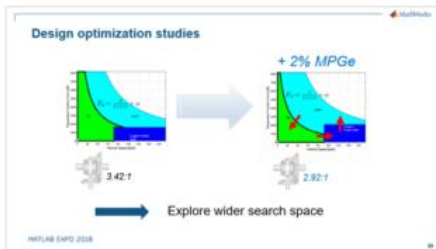


- Tune parameters in real time

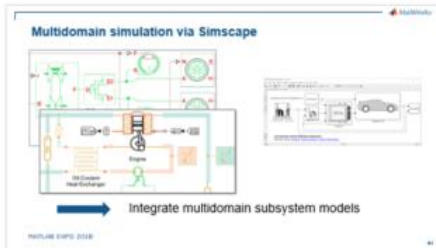




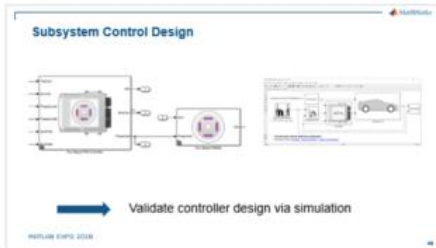
① Engine modeling and calibration  
 → Reduce time on HIL, dyno, vehicle testing



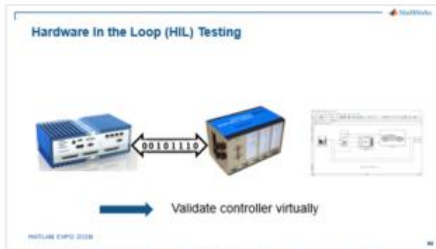
② Design optimization studies  
 → Explore wider search space with fast simulations



③ Multidomain simulation via Simscape  
 → Integrate multidomain subsystem models



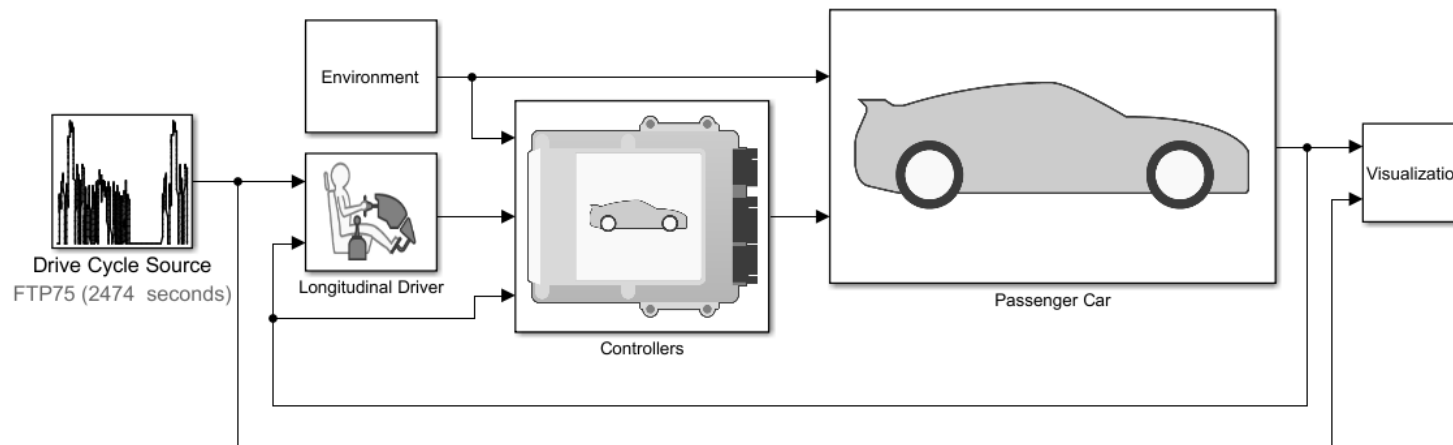
④ Subsystem control design  
 → Validate controller design via simulation



⑤ Hardware-in-the-loop (HIL) testing  
 → Validate controller in real-time

# Key Takeaways

- Perform fuel economy simulations at 50 – 100x real time
- Explore and customize pre-built reference applications
- Reuse models throughout the development cycle



# Thank You!

