MATLAB EXPO 2018

Modeling and Simulate Automotive Powertrain Systems

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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

MathWorks

Trace Velocity, Target, Actual (mph)

EndSpd [rpm] • MotSpd [rpm]

Battery SOC

US Fuel Economy MPGe

Simulink
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)
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
Engine Modeling and Calibration

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., 3rd 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

Fast, but accurate controls-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

Explore wider search space with fast simulations

$F_d = \frac{\beta}{(\gamma + \epsilon)} + \alpha$

- 3.42:1
- 2.92:1

+ 2% MPGe
Accessible Optimization Capabilities

50 - 100x Faster Than Real Time

Efficient Optimization

• More drive cycles and design parameters
• Using fewer resources

Laptop-based Analysis

• Simulink Design Optimization UI
Multi-Mode HEV Review

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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Multi-Mode HEV Review

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Design Optimization Problem Statement

- Maximize MPGe
  - FTP75 and HWFET
  - Weighted MPGe = 0.55(FTP75) + 0.45(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)
Simulink Design Optimization

5 Control mode boundary parameters

Differential gear ratio
Simulink Design Optimization

[Image of Simulink Design Optimization interface with a highlighted option: Use the parallel pool during optimization]
Optimization Results

Simulink Design Optimization → Response Optimization

$F_d = \frac{\beta}{(\gamma + v)} + \alpha$

+ 2% MPGe

~ 12 Hours

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Design optimization studies

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

Mechanical Eqn.)
Including Detailed Subsystem Variants

- Add your own subsystem variants to the existing vehicle models

- Simulink-based
- Simscape-based
- S-function
Detailed Model Variant Simulation

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

<table>
<thead>
<tr>
<th>Cycle Name</th>
<th>Final SOC (%)</th>
<th>MPGe</th>
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<tbody>
<tr>
<td></td>
<td>Mapped</td>
<td>Detailed</td>
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<tr>
<td>HWFET</td>
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<td>44</td>
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<tr>
<td>FTP75</td>
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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

- Trq_cmd → Speed
- id_cmd → iq_cmd
- Flux-Weakening Controller

Current Controller
- vq_ref → vq_ref
- Modulation

Dynamic PI 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
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

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!