Using Model Based Design to Support Fuel Consumption Regulations

SAE Hybrid Vehicle Technologies 2010 Symposium
February 11, 2010

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Using Model Based Design to Support Fuel Consumption Regulations

- Why do we need Model Based Design?
- What are the different processes available?
- What process should be selected?
- How can modeling and simulation be used by OEMs?
- Conclusions
Medium & Heavy Duty Fuel Consumption Is Going to Be Regulated

- Fuel Consumption has been increasing over the years to account for 26% of the transportation fuel in 2008
- EISA of 2007 requires DOT to establish fuel economy standards for MD and HD vehicles
- Problematic:
  - Huge number of vehicle applications, with some of them being “one of a kind”
  - Very large number of companies, many of them focusing on low volume specialty applications
  - Not enough testing facilities
  - Testing all options would likely be prohibitively costly for the OEMs

**Objective**: Propose options to support future regulations while minimizing costs and burden to implement the program
Reliance on Modeling & Simulation Is Continuously Increasing

- Reduce cost and time to production
  - Provides math-based environment for more thorough multidisciplinary integration and testing in the virtual environment before hardware builds
  - Evaluate multiple technologies quickly to reduce hardware iterations
  - Promotes parallel and integrated virtual development of control systems and hardware
  - Reduces/eliminates duplicate modeling and analysis work and activities
- Enables fast introduction to market with new technologies and accurate fuel economy
  - Delivers properly integrated, initial designs that balance Fuel Economy, Emissions and Drivability (FEED) requirements.
  - Provides common methods and tools for comparing/evaluating technologies and development of standard processes.
  - Facilitates efficient, seamless link from research to production to maximize reuse of work products and eliminate waste.
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Companies Already Use Model Based Design Approach as Part of Their Vehicle Development Process

System Requirements
- Sim: Simulation
- RP: Rapid Prototyping
- OTRP: On-Target Rapid Prototyping
- PCG: Production Code Generation
- SIL: Software-In-the-Loop
- PIL: Processor-In-the-Loop
- HIL: Hardware-In-the-Loop

System Design
- RP PIL

Software Design

Hardware/Software Integration

Software Integration

Coding

PCG
Any of the Steps Could Potentially be Used for Regulations

Main Model Based Design Steps (1)

Software-in-the-Loop
- Algorithm or Controller Model
- Plant Model
  - Compiled C-code S-Function
  - Execution on Host Computer
  - Non Real Time
  - No I/O

Hardware-in-the-Loop
- Algorithm or Controller Model
- Plant Model
  - Embedded Target
  - PC with I/O Boards
  - I/O

Rapid Control Prototyping
- Algorithm or Controller Model
- Plant Model
  - Code Generation
  - I/O
  - Plant / Prototype

Component-in-the-Loop
- Algorithm or Controller Model
- Plant Model
  - Code Generation
  - Rest of Vehicle is Emulated
  - Entire System is Hardware

(1) Source www.mathworks.com
Example: Japanese Government Uses Different Methods for Different Powertrains

Modeling for Conventional (1)

- Driving Modes
  - Engine
  - Vehicle
  - Transmission

- Gearshift Operation (Pre-assigned Method) (Calculation Method)

- Engine Torque
- Engine Speed
- Fuel Economy (km/l)

Hardware-in-the-Loop for HEVs(1)

- Vehicle Basis
  - JE05 Running Pattern
- Calculation with HILS
  - Engine load
  - Efficiency
  - Engine speed
  - Fuel consumption
- Exhaust Emissions Test
  - Actual Engine Measurement

(1) Source A. Hoshi, Ministry of Land, Infrastructure, Transport and Tourism
Modeling & Simulation (M&S) Process

Characterize Components
- Engine
- Transmission
- Electric Machine
- Tires
- Batteries
- Chassis

Model & Validate Systems
- Generate Model Inputs
- Implement Control Logic
- Validate Systems with Test Data

Simulate Vehicle
- Define Vehicle
- Select Simulation Setup (Drive Cycle, test weight...)
- Fuel Consumption Performance...
Hardware-In-the-Loop (HIL) Process

Example of HIL Usage to Support HEV Truck Regulations in Japan \(^{(1)}\)

Example of HIL Used to Develop and Test Embedded Electronic Controllers \(^{(2)}\)

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\(^{(1)}\) Source JARI, Development of a Fuel Economy and Exhaust Emission Test Method with HILS for Heavy Duty HEVs, SAE 2008-01-1318

\(^{(2)}\) Embry-Riddle University – EcoCAR Competition
Component-in-the-Loop (CIL) Process

Example 1 - Engine

When components or specific physical phenomena cannot be properly modeled, CIL is an effective way to evaluate technologies.

Rest of the Vehicle Modeled & Runs Real Time

Engine behaves as if in vehicle

Example 2 - Battery

CIL is also useful to OEMs to develop and test controllers.
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What Process Should be Selected When?

Examples

- When models for several component technologies have not been developed or validated yet
- When the model needs to be validated

- When a specific component technology has not been validated, but the rest of the vehicle has

- When the plant model of a component has been validated, and a new version of the production controller needs to be evaluated (e.g., new engine ECU, HEV ECU...)

- When all components have been tested and their models validated.
- When changes in vehicle characteristics that do not require further validation (e.g., ratio, tires...)

(1) Source West Virginia Univ. (2) Source Embry-Riddle
Uncertainty Within Each Process Has to Be Addressed

Example: High Altitude Testing Leads to Erroneous Results (1)

![Mean UDDS PM Emissions Graph](image)

Example: Unexpected Axle Torque Measured During Neutral Coastdown (2)

![Graph showing Vehicle Speed, Engine Speed, and Total Axle Torque](image)

(1) Source CRC E-55-1 Inter-laboratory Crosscheck of Heavy-Duty Vehicle D.PDF
(2) Source M. Duoba and all, SAE 2005-01-0685
Uncertainty In-between Processes Has to Be Addressed

Example: Driver Has Significant Impact of Fuel Consumption on a Vehicle Dynamometer, Especially for HEV (1)

- Modeling and simulation might be as uncertain as other methods
- What uncertainty is acceptable?

Example: Driver Has No Impact on Fuel Consumption When Using CIL, but Models and Command Delays Add Uncertainties

(1) Source, ANL APRF
Processes Have to Be Carefully Defined

Example: How do we collect data for models? (e.g. number of engine load points measured to define maps)

Example: What is an acceptable delay between commands and feedback for Component-in-the-Loop?

Example: What do we mean by validation? (How close is close enough)

Engine torque validation of GM 2Mode HEV Tahoe (SAE 2009-01-1307)
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What Level of Modeling Will Ensure Fair Technology Comparison?

- Different models might be necessary to properly represent different technologies.
Any Legacy Code Needs to Be Integrated Easily To Minimize Additional Workload

Legacy models should be integrated using automated processes

Models from Commercial-off-the-shelf-tools should be able to be linked back to the common environment

- As little effort as possible should be requested to the OEMs to integrate their legacy code and data
Proprietary Data Needs to Be Shared

Each Supplier/OEM Provides a Model of Its Component

- The MD and HD industry is composed of many OEMs
- Inputs from numerous OEMs are necessary to model an entire vehicle

Each Expert System is Reused Until Entire Vehicle is Assembled
Intellectual Property Needs to Be Protected

- The component data, both plant and controls, necessary for the simulation of a vehicle are often scattered across several companies.
- All the information should be located at the same place to allow fuel consumption simulation.
- The models should be used by OEMs without providing any access to any of the component data.
- File encryption and database access control would provide further protection.
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Model Based Design Processes Can be Used to Support Regulations in a Cost Effective Manner

- Several processes are available to support regulations, from vehicle dynamometer testing, to Component-in-the-Loop and vehicle simulation
- Use of modeling and simulation (M&S) or a combination of M&S with hardware (e.g., HIL, CIL) is a cost effective way to regulate fuel consumption of Medium and Heavy Duty vehicles, especially for small companies.
- The different steps of any process should be carefully defined
- Any process will still require testing
Can the Approach be Generalized to Light Duty Applications?

- OEMs already have accurate vehicle simulation tools to support conventional vehicles fuel consumption

  => Component-in-the-loop (CIL) could be used to measure emissions

- HEVs and PHEVs require longer testing time and are more difficult to model, but the added uncertainty of the models may be offset by human test driver variability

  => CIL or vehicle modeling could be used

- Electric vehicles require an increasingly long testing time on the dynamometer.

  => Cost could be drastically reduced by using existing vehicle modeling