Co-simulation of Transmission Black Box Model & Vehicle Model

Harness Model Development

*Isuzu Technical Center of America*

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Aishwarya Shetty, MBD Engineer, ITCA
Santhosh Pasupathi
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- Strong engineering professional with a Master's degree focused in Automotive Engineering from the University of Michigan
- Experienced Model Based Development Engineer with a demonstrated history of working in the automotive industry, skilled in ETAS - LABCAR, D - Space systems, Simulink, INCA, GT Modeling, IPG Truckmaker and Vehicle Testing & Validation

Aishwarya Shetty
Model Based Development Engineer, Isuzu Technical Center of America

- Graduated with Masters in Mechanical Engineering, University of Michigan- Ann Arbor
- Experience focused on model based development of commercial vehicles
- Actively working on system level vehicle model development and validation of Light & Medium-Heavy duty commercial vehicles (Diesel/Gas/CNG)
- Skilled in modeling platforms such as GT-Suite, IPG Truckmaker, MATLAB-Simulink, MATLAB-Advisor
MODEL BASED DEVELOPMENT

- Approach in which a system model is at the center of the development process
- Supports increasing product complexity and demands for cost/time efficiency
- Common platform development enables model sharing by different departments for different domains:
  - Computer simulation
  - Rapid prototyping
  - Test-bench-based hardware in the loop simulation

**XiL - Model/Powertrain/Hardware in Loop**

Introduction
1D – Map Based Model

- Can be built in very short time
- Requires less data for validation
- Faster than real time
- Low fidelity model
- This approach can be used for basic performance and fuel economy study with less input data for different powertrain configurations

**Figure 2: Map Based Vehicle Architecture**[1]
Introduction

1D – Detailed Model

- Higher fidelity model
- Accurate & repeatable results
- More data required for validation
- Real time simulations
- Used for Hardware-in-loop (HiL) testing

Figure 3: Detailed Vehicle Architecture
Virtual Vehicle Model Objectives

Fuel Economy

Performance

Component Sizing & Optimization

Controls System Development

Drivability

Aftertreatment Analysis
In this presentation, we will be discussing about “\textit{Fuel Economy & Performance simulation study conducted for the medium heavy duty (Class-6) Isuzu FTR truck using the Harness model developed for the detailed transmission black box-vehicle integration.}”

\textbf{Deliverables-}
- Fuel Economy & Performance Estimation

\textbf{Test Cases}
- GM City Cycle
- Interstate 55
- US Assumptions [GM City & Interstate 55]
- Acceleration & performance analysis

\textbf{Scope}
- Basic engine mapping tests were conducted to collect engine data
Map based Transmission

- User inputs the Shift Maps & TC Lockup clutch maps
- Coefficient of performance and Torque ratio maps are added externally as supplied by the supplier
- Map-based model - low fidelity

Map based Engine

- Mechanical Performance Maps
- Air Flow Map
- Fuel Flow Map
- Friction Map

Figure 5: Map Based Vehicle Architecture
Engine Model

- **Engine**: Isuzu- 5.2 ltr- turbocharged intercooled diesel

- **Power & Torque Characteristics**:
  - 215 HP @ 2500 RPM
  - 520 lb-ft @ 1600 RPM

- The following **engine maps** were used in the model:
  - Mechanical Performance Map
  - Friction Map
  - Fuel Consumption Map
  - Airflow Map

*Figure 6: Engine Architecture in GT-Suite* [1]
Transmission Model

- **Transmission**: Allison 2550 RDS - 6 speed automatic

- The black box model consists of:
  - Torque Converter
  - Transmission plant
  - Transmission Controller (TCM)
  - Characterization files

- The Transmission Controls model (TCM) is characterized using portions of a real TCM calibration file that most closely matches the customer requirement

- The plant model includes efficiencies suitable for systems analysis and fuel economy analysis

- Calibrations for the black box model are placed in an encrypted/protected Matlab-based file

- The overall simulation sample time is **0.001 seconds**

*Figure 7: Transmission Black Box Model Architecture [2]*

*Image Ref: Allison Simulation Model Sharing Overview for Outside Customers*
Vehicle Model Setup

- Net Engine Torque
- Engine Demand Torque
- Driver Demand Torque Percent
- Engine Peak Torque
- Engine Torque Limit
- Engine Speed
- Transmission output speed
- Attained Gear
- Torque Converter Speed Ratio
- Selected Shift Pattern
- Transmission output speed
- Achieved Vehicle Speed
- Road Load Torque
- Brake Road Load Torque
- Throttle Percent

Vehicle
Vehicle Model

- **Vehicle:** Isuzu-FTR Class 6 [25950 lbs. GVW]

- **Tire:** Continental HSR2 SA front tire & HDR2 rear tire

- **Final Drive Ratio:** 6.17

- **Total Road Load:**
  
  \[ \text{Road Load Force} = (a + b \, v + cv^2) \]

  - **a** – Includes the effect of rolling resistance
  - **b** – Includes dependence of rolling resistance on velocity & drivetrain losses
  - **c** – Includes aerodynamic drag

*Figure 8: Vehicle Model Architecture in GT-Suite* [1]
Harness Model Setup

- Net Engine Torque
- Engine Demand Torque
- Driver Demand Torque Percent
- Engine Peak Torque

- Engine Torque Limit
- Engine Speed

- Achieved Vehicle Speed
- Road Load Torque
- Brake Road Load Torque
- Throttle Percent

- Attained Gear
- Torque Converter Speed Ratio
- Selected Shift Pattern
- Transmission output speed

: Output signals from GT-Suite and Input signals to Simulink

: Output signals from Simulink and Input signals to GT-Suite (feedback)
Co-simulation Model Setup

Allison Black Box Model (SIMULINK-master)

ITCA Vehicle Model (GT-Suite)

Co-simulation
## Class 6- 25950 lbs. GVW- 6.17 FDR

<table>
<thead>
<tr>
<th>Tests</th>
<th>Harness model Simulation-Normalized*</th>
<th>Field Data-Normalized*</th>
<th>Difference (Field Data vs Detailed Simulation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10mph-Time required (s)</td>
<td>85.59</td>
<td>100.00</td>
<td>-14.4%</td>
</tr>
<tr>
<td>0-20mph-Time required (s)</td>
<td>98.26</td>
<td>100.00</td>
<td>-1.7%</td>
</tr>
<tr>
<td>0-30mph-Time required (s)</td>
<td>100.83</td>
<td>100.00</td>
<td>0.8%</td>
</tr>
<tr>
<td>0-40mph-Time required (s)</td>
<td>102.65</td>
<td>100.00</td>
<td>2.6%</td>
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<td>0-50mph-Time required (s)</td>
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<td>-2.8%</td>
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<td>0-60mph-Time required (s)</td>
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<td>100.00</td>
<td>-1.1%</td>
</tr>
<tr>
<td>Max Speed- Speed achieved (mph)</td>
<td>100.00</td>
<td>100.00</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

### Performance

<table>
<thead>
<tr>
<th>Tests</th>
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<th>Difference (Field Data vs Detailed Simulation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GM City (mpg)</td>
<td>99.26</td>
<td>100.00</td>
<td>0.7%</td>
</tr>
<tr>
<td>Interstate 55 (mpg)</td>
<td>100.00</td>
<td>100.00</td>
<td>0.0%</td>
</tr>
<tr>
<td>US Assumptions (mpg)</td>
<td>99.52</td>
<td>100.00</td>
<td>0.5%</td>
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</table>

*Values have been normalized

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**Figure 12:** Comparison of Performance and Fuel Economy Results of co-simulated detailed transmission model and vehicle model Vs Field Testing Results

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### Class 6- 25950 lbs. GVW- 6.17 FDR

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<tr>
<th>Tests</th>
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<tbody>
<tr>
<td>0-10mph-Time required (s)</td>
<td>46.76</td>
<td>100.00</td>
<td>-53.2%</td>
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<tr>
<td>0-20mph-Time required (s)</td>
<td>70.00</td>
<td>100.00</td>
<td>-30.0%</td>
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<tr>
<td>0-30mph-Time required (s)</td>
<td>82.40</td>
<td>100.00</td>
<td>-17.6%</td>
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<tr>
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<td>0-60mph-Time required (s)</td>
<td>99.29</td>
<td>100.00</td>
<td>-0.7%</td>
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<tr>
<td>Max Speed- Speed achieved (mph)</td>
<td>104.11</td>
<td>100.00</td>
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<tr>
<td>GM City (mpg)</td>
<td>97.15</td>
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<td>2.9%</td>
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<tr>
<td>Interstate 55 (mpg)</td>
<td>89.47</td>
<td>100.00</td>
<td>10.5%</td>
</tr>
<tr>
<td>US Assumptions (mpg)</td>
<td>94.27</td>
<td>100.00</td>
<td>5.7%</td>
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- Time filter was used in map-based model to mimic the turbo lag at low engine speeds

Figure 12: Comparison of Performance and Fuel Economy Results of map based model Vs Field Testing Results
## Results Comparison- Map-based Vs Detailed Simulation

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</table>

*Comparison of Performance and Fuel Economy Results of map based model Vs co-simulated detailed transmission model and vehicle model Vs Field Testing Results

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With the utilization of the Harness model developed for the integration of the Allison transmission black box model and the map-based vehicle model, the following objectives were achieved:

1.) Powertrain studies for FE & performance with different engine & transmission configurations

2.) Different Shift Strategy studies

3.) Final Drive Ratio Optimization

4.) Engine Power-Torque Curve studies to decide the configuration best suited for the vehicle

5.) GPS data was used to simulate the Isuzu standard cycles for durability testing [total miles= 812 approx.]
Benefits of Detailed Model Integration using Harness model:

- Reduces development time & cost
- Early stage of vehicle architectural studies can be conducted without prototyping
- Generates a more reliable final product through the use of computer models for system verification and testing
- Ability to conduct performance testing without hardware damage

Figure 13: Advantages of Detailed Model Integration
Next Steps:

- Integration of Engine FRM model with co-simulated transmission black box model and vehicle model

- Integration of detailed aftertreatment model with co-simulated engine FRM, transmission black box and vehicle model

- Real-time HiL testing of the integrated detailed vehicle model with physical hardware
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Role: BB model supplier and support

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Role: Supplier and support

Burt Krehbiel
Senior Customer Integration & Application Engineer, Allison
Role: Supplier and support

Jonathan Zeman
Vehicle Applications Team Leader, Gamma Technologies
Role: Software Support

Dhaval Lodaya
Project Engineer - Electrified Vehicle Applications, Gamma Technologies
Role: Software Support
References

- Figure 1: ITCA
- Figure 2: Gamma Technologies
- Figure 3: ITCA
- Figure 4: ITCA
- Figure 5: Gamma Technologies
- Figure 6: Gamma Technologies
- Figure 7: Allison
- Figure 8: Gamma Technologies
- Figure 9: ITCA
- Figure 10: ITCA
- Figure 11: ITCA
- Figure 12: ITCA
- Figure 13: ITCA
- Figure 14: ITCA

- [1] GT-Suite Software
- [2] Allison Black Box Model sharing guidelines document
Thank You!