



Creation and Validation of a High-Accuracy, Real-Time-Capable Mean-Value GT-POWER Model

Tim Prochnau

**Advanced Analysis and Simulation Department
Engine Group
International Truck and Engine Corporation**

**11th GT-Suite Users' Conference
November 13, 2007**



Outline

- Introduction
- Mean Value Model Approach
- Model Validation
- Brief Model Studies
- Summary/Conclusions
- Future Work



Introduction

- Objective
 - Create and Validate a High-Accuracy, Real-Time-Capable Mean-Value engine model in GT-POWER
 - Model must be capable of simulating next-generation Diesel engine air-handling and fuel systems



Motivation

- Real Time
 - Requirement to run in a HIL system
- High Accuracy
 - Most parameters within 1% of Detailed Model
 - Enables more accurate controls calibration
 - Permits very quick engine hardware or calibration studies
- In GT-POWER
 - Share modeling environment and some parts with detailed models
 - No need for external modeling tools



Mean Value Approach Overview

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- Lumped flow component volumes to permit larger time steps
- Mean-value cylinder model
 - One object replaces multiple cylinders
 - Empirical parameters instead of crank-angle resolved models
- Neural Networks
 - In-cylinder processes trained to detailed model using DOE
 - Results Imposed onto Mean Value model
 - Maps used for Indicated Efficiency, Volumetric Efficiency, Exhaust Energy Fraction

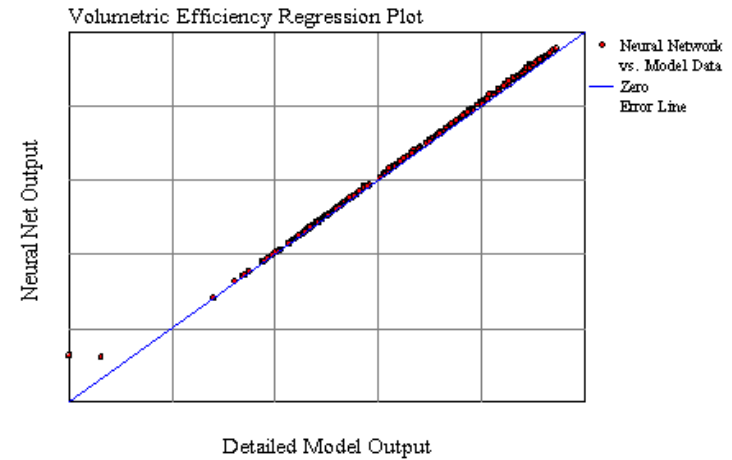
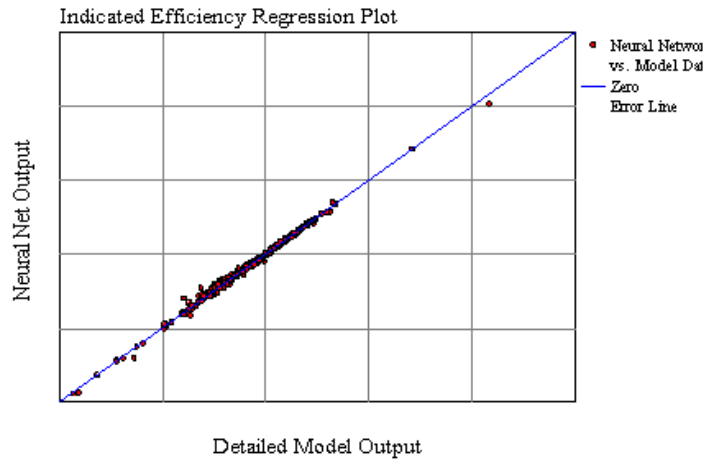


Neural Network Training

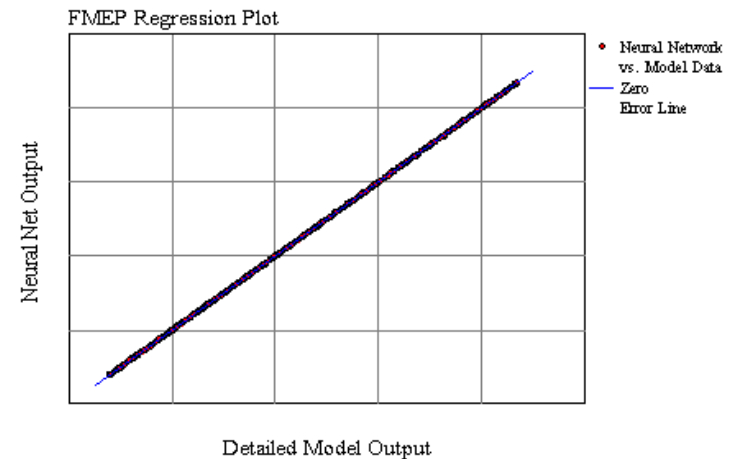
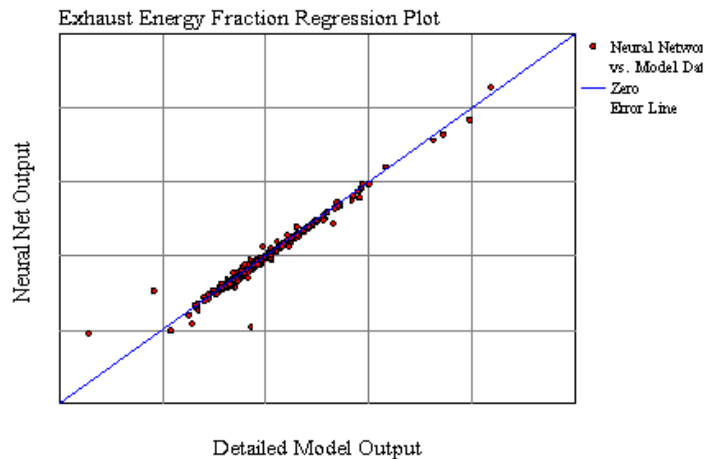
- Detailed Model Training DOE Setup
 - D-Optimal Latin Hypercube, 2000 points
 - 7 Input Factors: Engine Speed, Fueling Rate, Boost Pressure, Back Pressure, Intake Manifold Temperature, EGR Valve Opening
 - Wide Factor Ranges to accommodate extremes of engine operation
- Neural Network Models
 - Much improved results from new 3-layer Feed-Forward Model – eliminates need for external model calibration tools



Neural Network Validation



300-point independent data set shown for model validation





Mean Value Modeling Approach

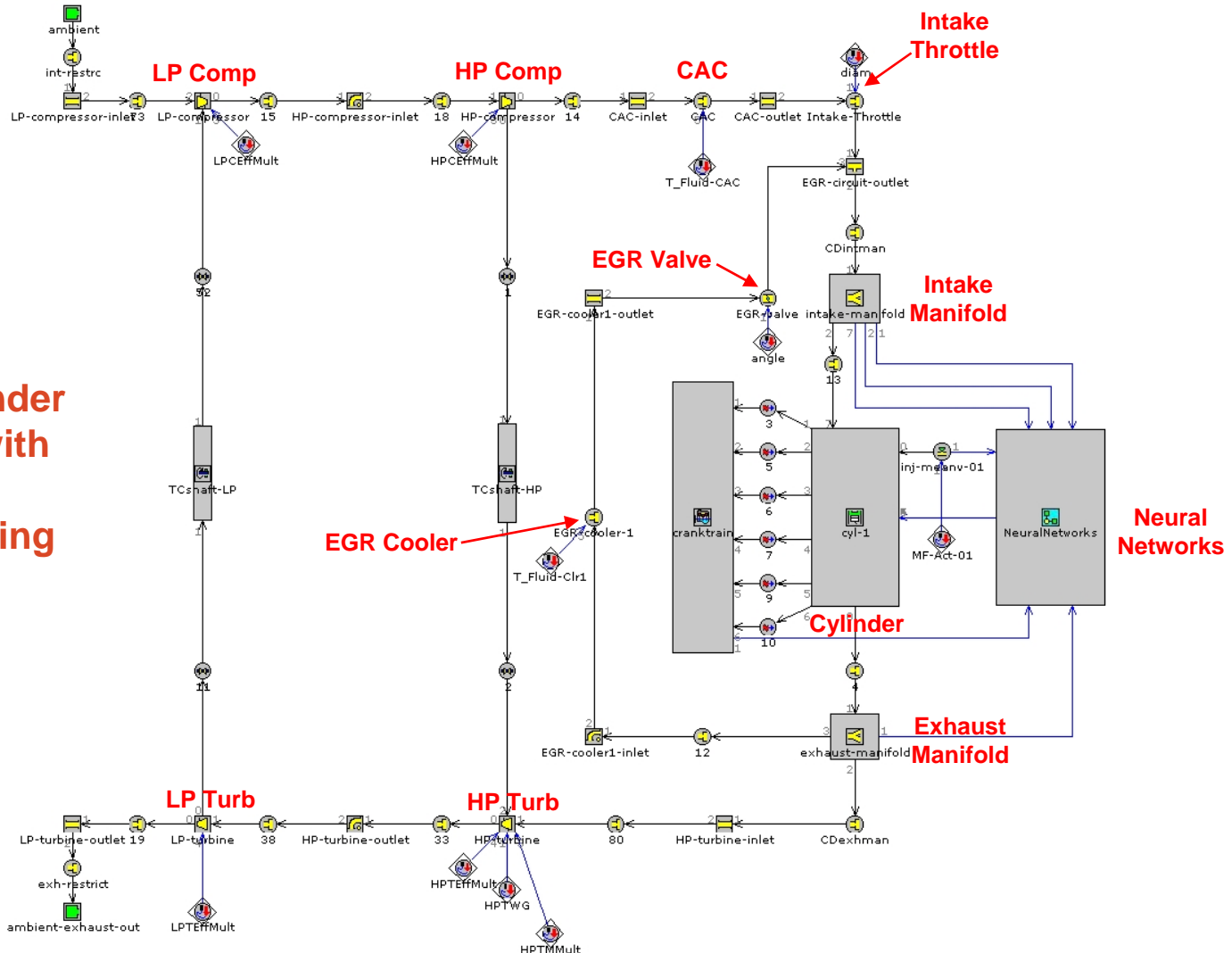
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- RTCoolerConn objects used for Heat Exchangers
 - Easier to calibrate restriction and heat transfer
- Mapped Calibration Parameters
 - Enables accurate air system response across engine operating regime
 - Restrictions
 - Heat transfer
 - Turbo operation
 - Most results very close to detailed model



Mean Value Model

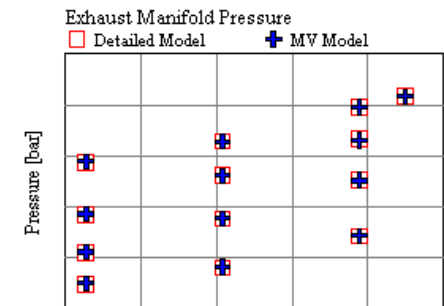
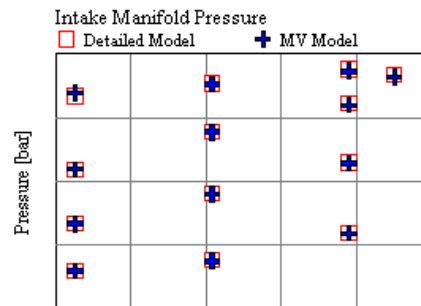
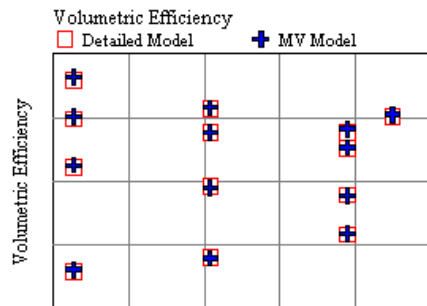
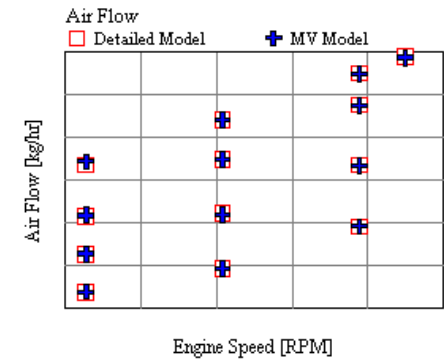
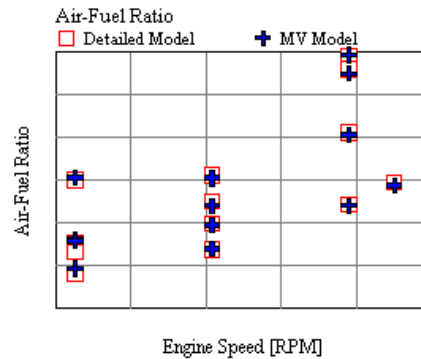
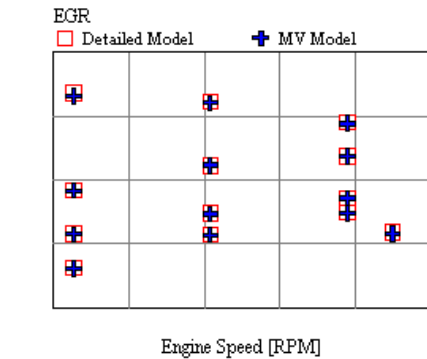
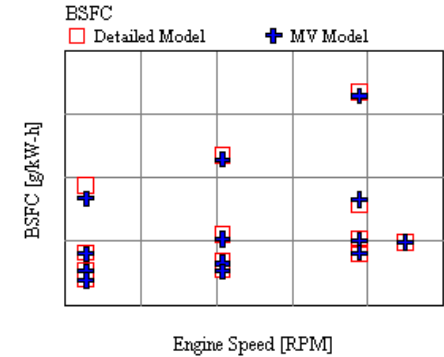
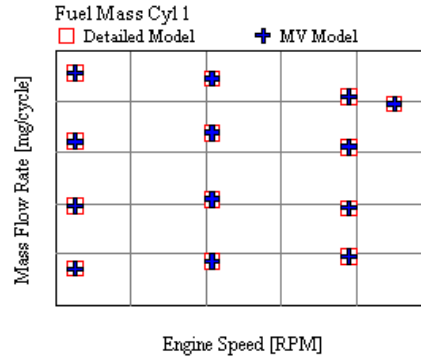
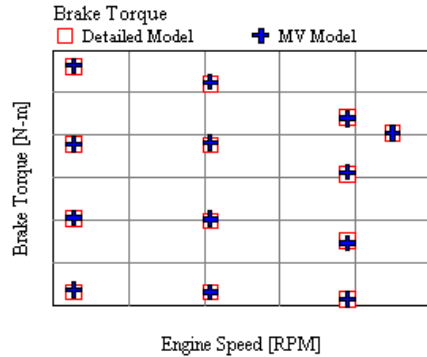
Inline 6-cylinder
DI engine with
2-stage
Turbocharging





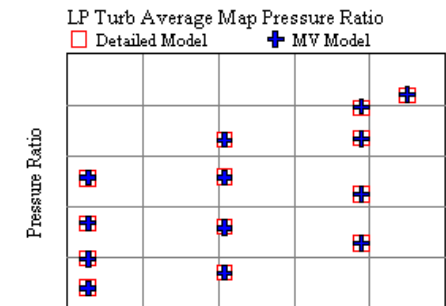
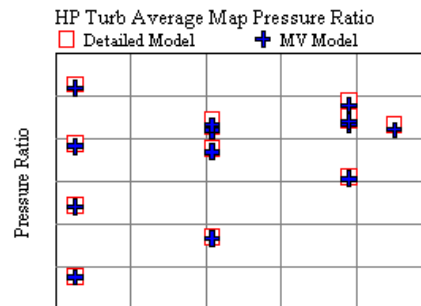
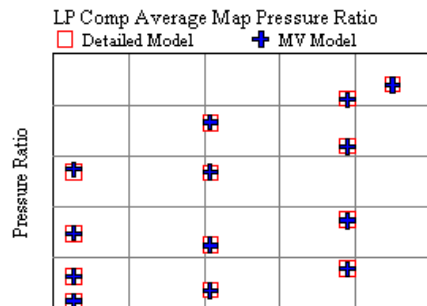
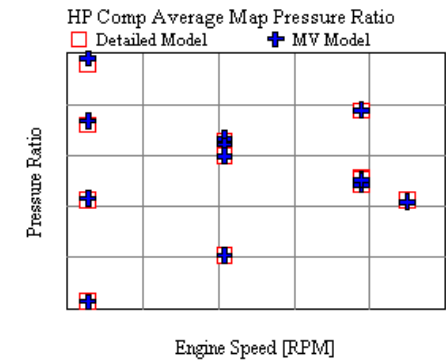
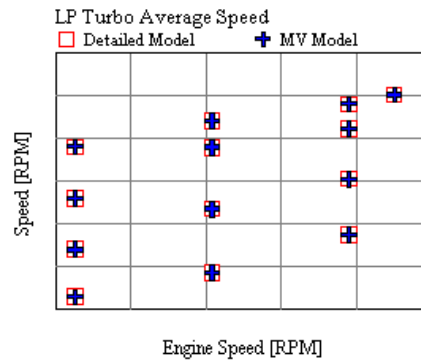
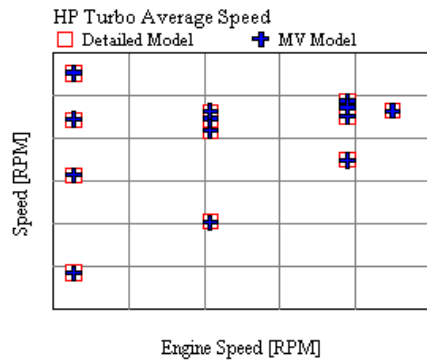
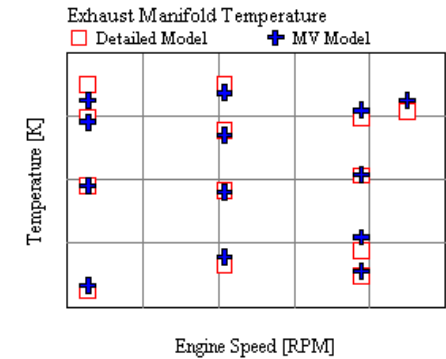
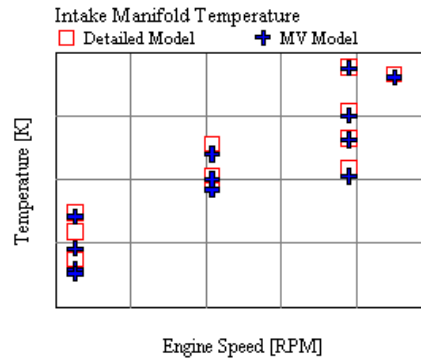
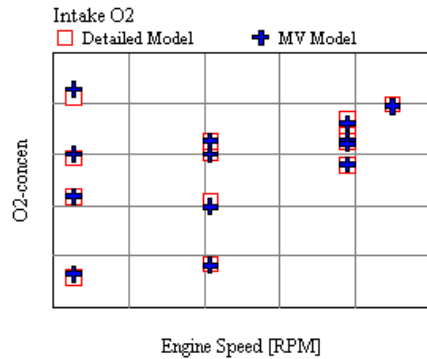
13-Mode Point Calibration

Very good agreement at Steady-State



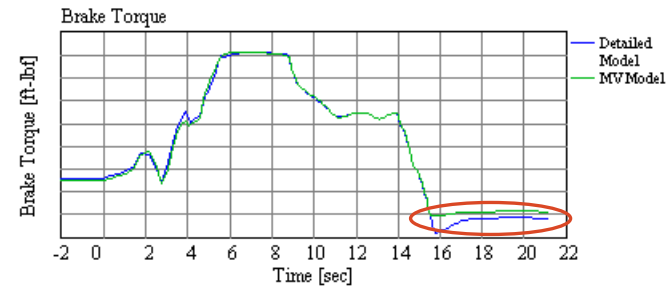
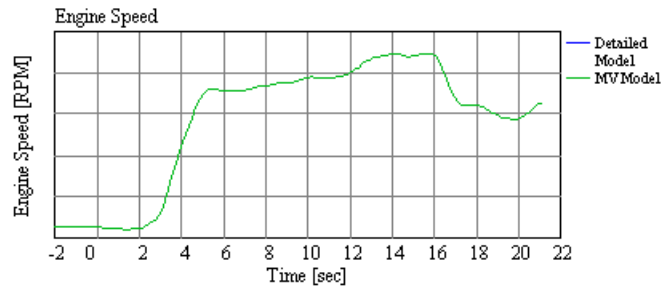


13-Mode Point Calibration

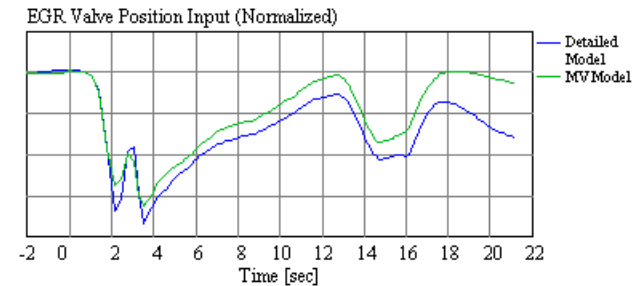
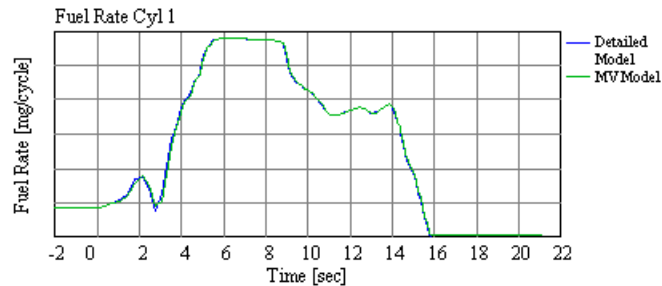




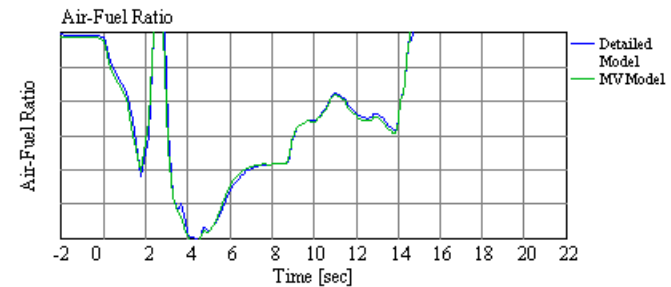
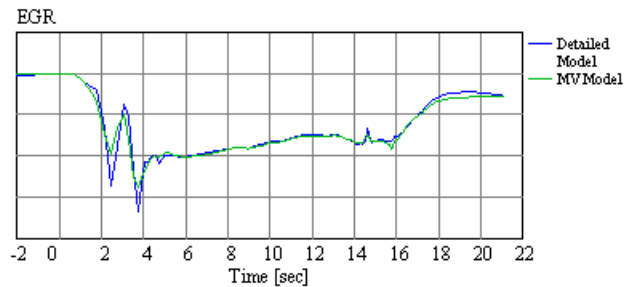
21 seconds of HD FTP Cycle



Mean Value Cylinder cannot handle motoring torque

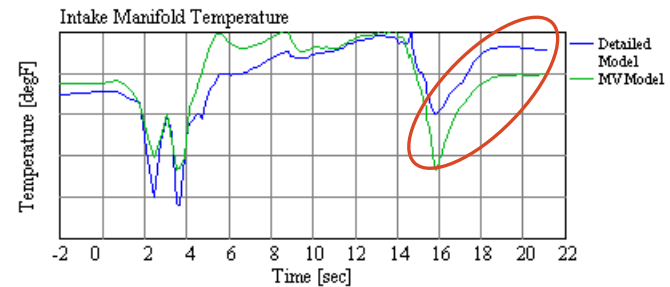
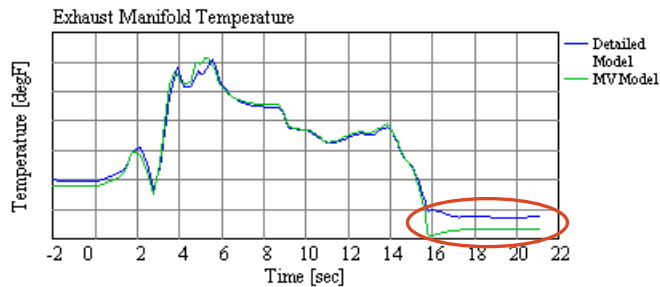
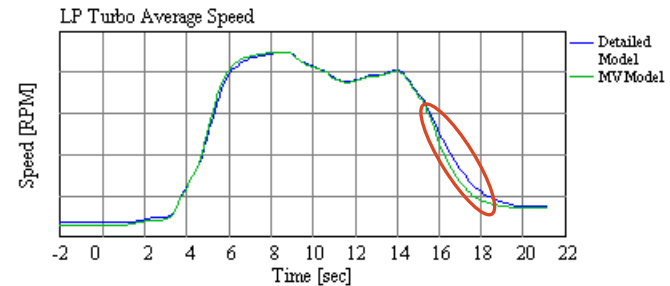
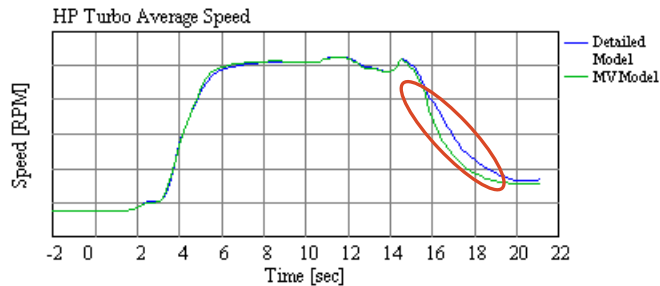
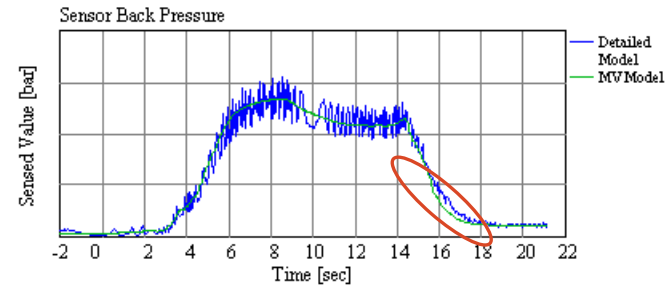
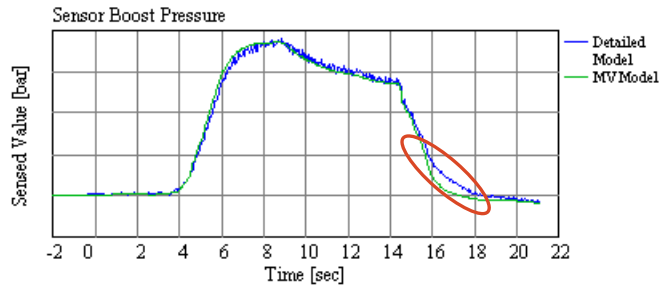


Very good transient agreement is achieved for positive torque





21 seconds of HD FTP Cycle





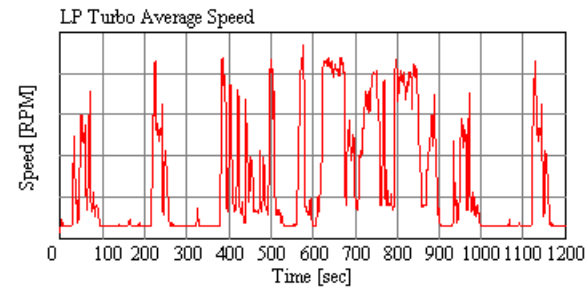
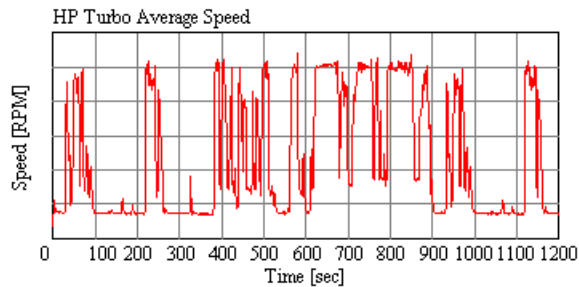
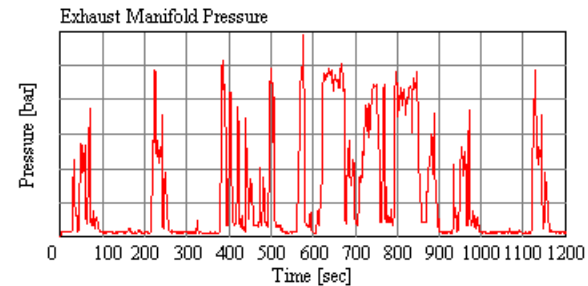
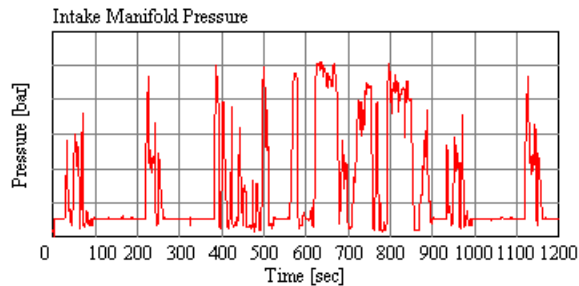
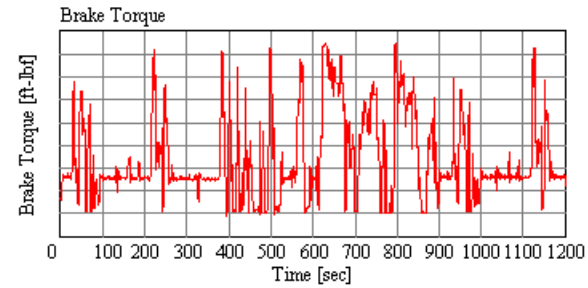
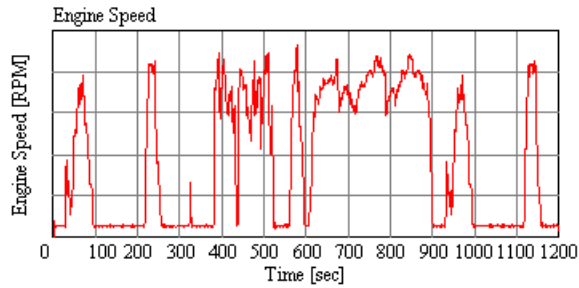
Model Execution Speed

- Mean Value Model used 5 CAD maximum time step
- Single-processor 3.2 GHz standard desktop PC
- Other applications open simultaneously
- Faster execution would be possible by increasing time step, disabling in-cylinder pressure prediction, and reducing flowsplit expansion diameters

Run Time Statistics	Execution/Clock time Ratio	MV/Detailed Execution Speed
21-second portion of US HD FTP Emissions Cycle		
Simulation Environment Elapsed Time	1.00	
Detailed GT-Power Model	70.85	1.0
Mean Value Model in GT-Suite (w/ RLT variables and display windows)	2.37	29.9
Mean Value Model in GT-Suite (w/o RLT variables or display windows)	1.14	62.4
Mean Value Model in GTsuite RT	0.55	129.8
1200-second US HD FTP Emissions Cycle		
Simulation Environment Elapsed Time	1.00	
Mean Value Model in GT-Suite (w/ RLT variables and display windows)	2.27	
Mean Value Model in GT-Suite (w/ RLT variables but w/o display windows)	1.36	

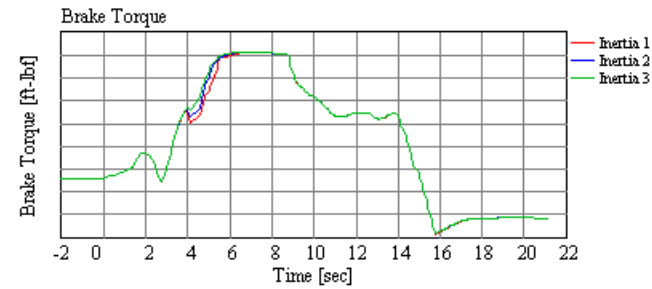
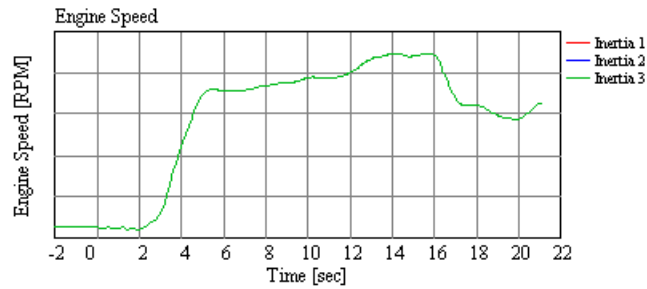


Demonstration: HD FTP Cycle

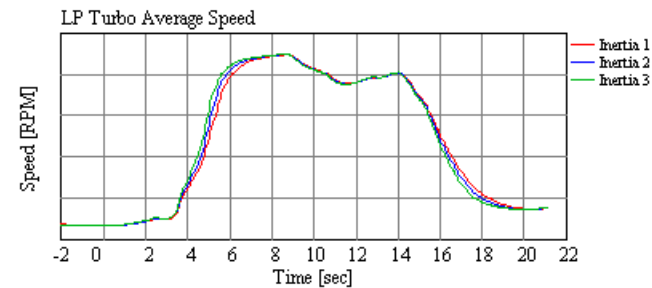
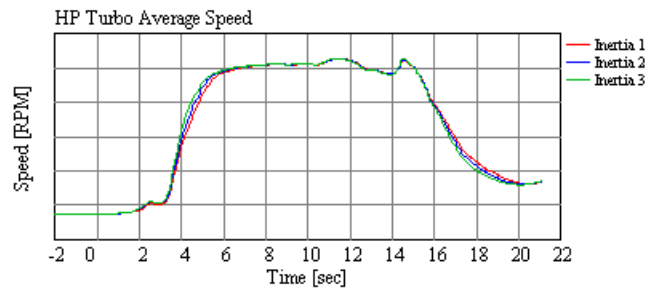
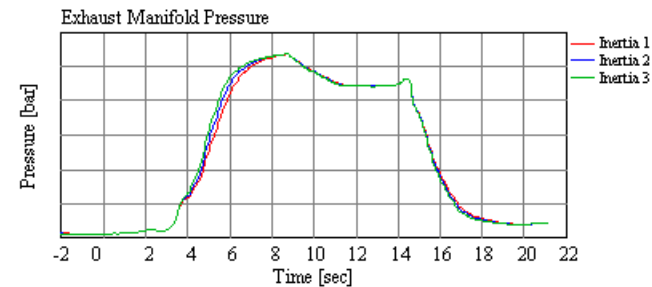
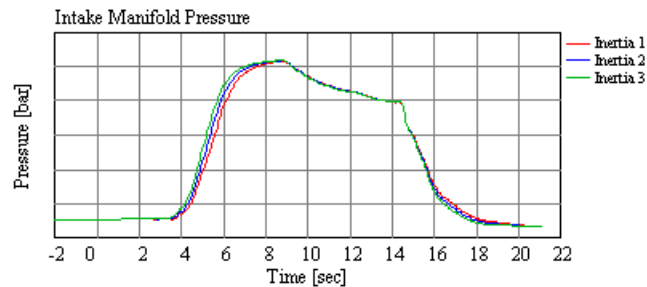




Turbo Inertia Study: Detailed

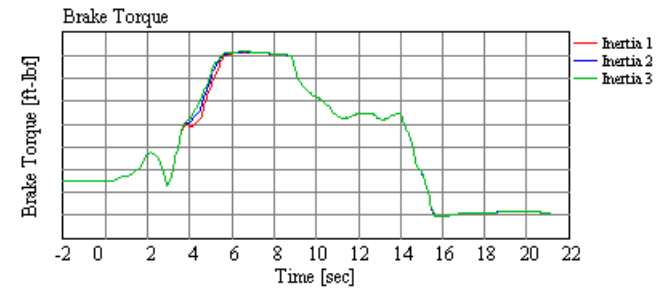
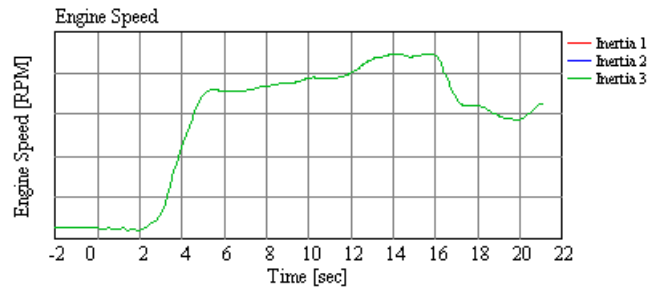


This study ran in 1 hour 34 minutes using the Detailed Model

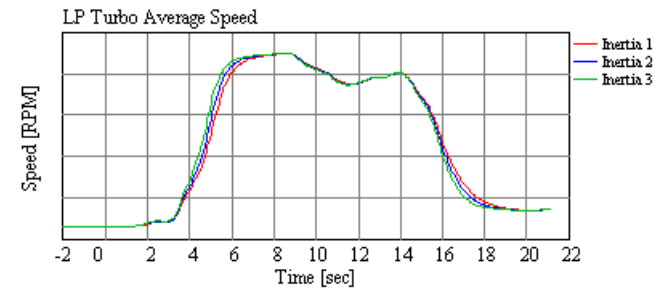
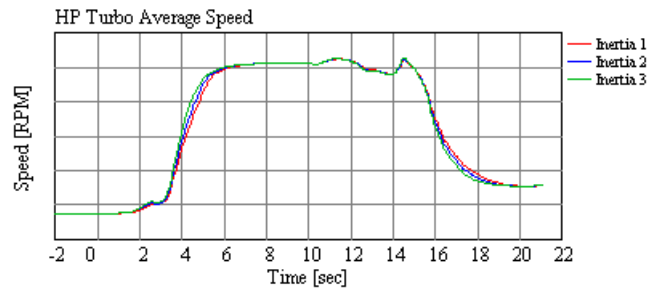
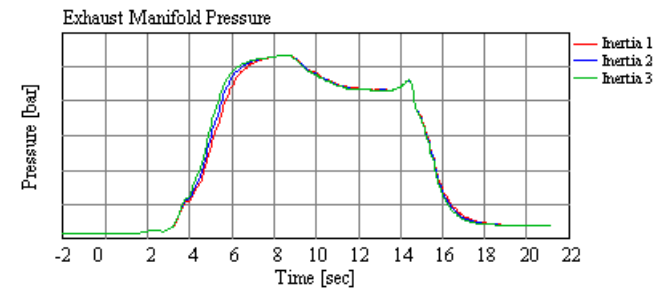
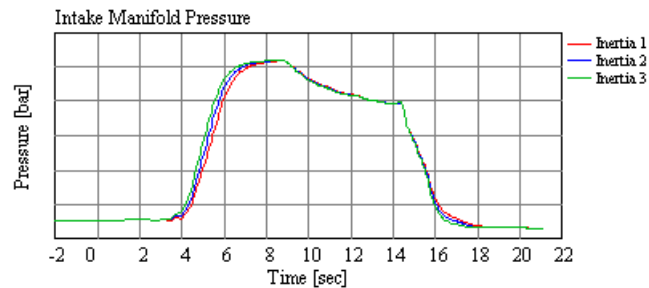




Turbo Inertia Study: Mean Value



This study ran in under 3 minutes using the Mean Value Model





Summary/Conclusions

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- A High-Accuracy, Real-Time-Capable Mean-Value engine model has been created and validated in GT-POWER
- The model is capable of simulating next-generation Diesel engine air-handling and fuel systems
- Very good agreement with detailed model has been achieved at steady-state and over brief transient excursions
- The main limitation is the inability to simulate motoring torque
- The high accuracy of the model also permits very quick engine hardware or calibration studies
- A model calibration methodology is now in place to replicate real-time modeling capability for other engines



Future Work

- Improvements Needed
 - GT-POWER Version 6.2 Build 6 Mean Value Cylinder cannot handle motoring (negative) torque
 - New Mean Value Cylinder object in Build 7 should address this problem
- Future Capabilities
 - Real-Time in-cylinder combustion and emissions models
 - Real-Time Aftertreatment models
 - Automated Model Creation and Calibration