Outline

• Motivation
• Multimodel advantages and disadvantages
• Calibration process steps
  – Determine DoE points and cycle weights
  – DoE factors and bounds
  – Build and execute DoE test plan
  – Export multimodels and boundary models
  – Optimize calibration
  – Export and verify calibration
Motivation

• Current trends…
  – Emissions standards continue to tighten
  – Fuel consumption is becoming even more critical with rising fuel prices
  – Growing diesel engine customer base is demanding more refinement
• To meet these challenges technology is added to engines
  – Multiple injection strategies
  – Variable geometry turbochargers, series and parallel boost systems
  – Larger EGR coolers and cooler bypass valves
  – Variable swirl control
  – Variable valve events
  – Variable compression ratio
  – Etc…
• Calibration degrees of freedom continue to increase
  ➢ Model-based calibration has become absolutely necessary!
• Margin to emissions standards continues to decrease
  ➢ Cycle-based emissions and fuel consumption optimization is required!
  – Tradeoffs between various speed/load points
  – Optimum solution is not a collection of independent local optimizations
  – Requires global models at many speed/load points
• Model-Based Calibration Toolbox (MBC) offers tools to address these needs
Multimodel Advantages and Disadvantages

• Multimodels essentially switch between best local models at discrete speeds and loads

• Advantages
  – Reduces number of modeled inputs by two (speed and load)
  – Can select best model type for each response at each speed/load
  – Achieves maximum model fidelity at each speed and load

• Disadvantages
  – Compared to single-stage: Requires more data
  – Compared to conventional two-stage: Does not utilize data at other speeds and loads to determine trends
  – Cannot interpolate between speeds and loads
Calibration Process Steps

- Identify designed experiment (DoE) operating points
  - Select load axis
  - Cascade vehicle drive cycles to engine operating points
  - Select speed/load (S/L) break points for DoE
  - Calculate weighting factors for each S/L for each drive cycle
- Determine DoE factors, bounds, and resolution
  - Identify factors to be varied
  - Select ranges for each factor at each S/L
  - Build DoE runs based on desired model complexity
- Collect and prepare data for MBC
- Build multimodels for engine responses with boundary models
- Optimize calibration
  - Independent S/L optimization
  - Cycle-based optimization
- Export calibration and verify engine responses
DoE Speed/Load Operating Points

- Cascade vehicle drive cycles to engine operating speed and load
- Requires either vehicle data or detailed vehicle models
- Select load axis – brake torque, indicated torque, etc.
- Select DoE S/L operating points
- Calculate time weights
DoE Factors and Bounds

• Identify factors to be directly varied
  – Do not have to match actual calibration inputs
  – Must offer stable engine operation with minimal baseline calibration
    • Prefer measured rather than modeled feedback
  – For position control, combine multiple actuators into single scale
    • Vane position and waste gate position => “Boost system position”
    • EGR valve and throttle valve => “Air system position”

• Measure responses that could be used as inputs
  – EGR rate, intake oxygen percentage, etc.
DoE Factors and Bounds

- Screening DoE for boost and air system limits
- Build boundary models for one-stage test plan
- Use simple CAGE optimization to find minimum and maximum for each speed and load
Build and Execute DoE Test Plan

- Generic DoE template (each factor 0 to 1)
- DoE for each speed/load based on bounds from screening

Example

- 190 point Halton sequence space-filling design for 6-input, 3rd order polynomial models
- Meets standard error coefficient guidelines of 0.7
- Meets Hat matrix leverage value guidelines of 0.9
- Real DoE should be augmented with additional ~25% of minimum point count (some points should fail if engine limits are being explored)
Build MBC Multimodels

- Import data into MBC
- Filter obvious outliers
- Build two-stage test plan with TWO inputs at the global level

- Multiple models, i.e.
  - Third order polynomial
  - Radial basis function
  - Neural network

- Response models
  - Emissions
  - Fuel consumption
  - Critical engine limits
  - Optional control inputs
  - Combustion Noise
Export Multimodels to CAGE

- New feature in R2008A
- Builds local boundary models
  - Range constraint
  - Convex hull with select critical parameters
  - Ability to preview boundary models is in development

Creates CAGE dataset with average inputs for each speed and load

Creates CAGE tradeoff and builds calibration tables

Creates simple optimization with one objective and boundary models
CAGE Tradeoff Options

- Automatic table setup available
- Option to manually set up tables that match actual calibration break points
- Later, tables can be filled by optimization results
Optimization Step 1 – Independent Local Optimums

• Creates good starting point for cycle optimization
• Gives direction for off cycle speed/load points
• Objective
  – Minimize fuel flow
• Constraints
  – Boundary model
  – Basic emissions limits
  – Critical engine mechanical limits
  – Combustion noise
Optimization Step 2 – Cycle Optimization

Objective
- Minimize cycle-weighted fuel flow

Constraints
- Boundary model
- Basic emissions limits
- Critical engine mechanical limits
- Cycle-weighted emissions limits
- Map gradients to ensure smooth calibration tables
- Combustion noise
Fill Calibration Tables

- Cycle optimization results can be used to fill calibration tables by interpolation and extrapolation
- Extrapolated results may violate engine limits

- Tables can be exported to calibration tool
- Engine must be mapped to verify results
Summary

- Multimodels are useful for complex engine calibrations
  - Select best local models
  - Allow use of cycle objectives and constraints
  - Allow use of gradient constraints
- Usability greatly increased in R2008A
  - Boundary model visualization is in development
- Engine verification is critical for interpolated and extrapolated points
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- Thank you for your attention
- Questions?