Model-Based Engine Calibration

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The MathWorks
Model-Based Calibration: Outline

- The concept
- Example applications today
  - Gasoline application for passenger cars
  - Diesel application for off-road
- Future directions
- This is of interest to engineers involved in
  - Calibration
  - Dynamometer testing
  - Engine control strategy design
  - ECU software and hardware validation
  - Vehicle simulation that includes powertrain
Setting The Scene

Who is driving engine development?
- Customers: better performance, better economy
- Regulators: lower emissions
- Hardware designers: more controllers, fewer compromises
- Competition: lower cost of development

The result is…
- Tougher performance targets
- More complexity
- More pressure to reduce development costs
Calibration
(The Narrow Definition)

- Calibration software is for editing values in lookup tables
Model-Based Calibration

Experiment Design → Data Collection → Data Modelling

Calibration → Implementation
Gasoline Application: Problem Statement

- 2.2 litre gasoline engine with dual independent variable valve timing
- Find best settings of spark timing, inlet cam timing and exhaust cam timing (versus speed and load)
- Objective is best brake specific fuel consumption
- Constraint is exhaust temperature
Gasoline Application: Design of Experiments

- Space-filling design with 253 spark sweeps
Design of Experiments

Benefits

- Significant reductions in experimental time and money
- Collect the most statistically useful data
- Identify the effect of variable interactions
- Produce accurate statistical models

Technology

- Optimal (e.g. v-optimal, d-optimal)
  - Use your knowledge of the response and constraints
- Space filling (e.g. Latin hypercube)
  - Cover the input space efficiently
  - For when you’re not sure what response or constraints to expect
- Classical (e.g. central composite, full factorial)
  - Traditional approaches to design of experiments
Gasoline Application: Modelling

- Models of torque and exhaust temperature
Modelling

Benefits
- Statistical modelling captures the shape of responses and confidence levels
- Modelling tools help to identify bad data
- Models can be reused throughout the design process

Technology
- Multivariable polynomials, splines
- Growth models
- Radial basis functions
- User-defined models
Gasoline Application: Optimisation

### Optimization Output

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<thead>
<tr>
<th>L</th>
<th>N</th>
<th>S</th>
<th>EXH</th>
<th>INT</th>
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<th>Constraint</th>
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### Algorithm Statistics

- Iterations: 26
- FuncCount: 200
- stepsize: 1
- algorithm: medium
- 1storder: 0.005
- 2ndorder:
- message: Optimisation

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### Objective Functions

- BTQ
- S
- EXH
- INT

- Graphs showing trends in variables and functions over different values of S, EXH, and INT.
Calibration Optimisation

Benefits
- Move the table-filling process away from the test bed
- Regenerate calibrations when objectives, constraints or strategies change… without additional testing
- Explore trade-off possibilities interactively
- Produce initial calibrations using engine simulation software, before hardware is available

Technology
- Sophisticated optimisation routines for point-by-point, drive cycles
- User-configurable objectives and constraints
- Easy table filling from optimisation results
- Scripting interface to Optimization Toolbox, GADS Toolbox
Gasoline Application: Results

- Tables of best spark timing, inlet cam timing, exhaust cam timing and torque
Diesel Application: Problem Statement

- 9.0 litre diesel engine with cooled EGR and variable geometry turbocharger
- Find best settings of injection timing, fuel quantity, EGR and turbo rack position (versus speed and torque)
- Objective is best brake specific fuel consumption
- Constraints are exhaust temperature, NOx and peak cylinder pressure
Diesel Application: Design of Experiments

- V-optimal design with 65 injection timing sweeps, constraints on inputs versus speed
Diesel Application: Modelling

- Models of torque, NOx, exhaust temperature and peak cylinder pressure
Diesel Application: Modelling

- Models can be exported to Simulink
Diesel Application: Optimisation

Optimization Output

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Algorithm Statistics

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| Option     | Optimization termin...

Free Variable Values

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Objective Functions

- bhp
- basefuelmass
- fuelpress
-egrift
Diesel Application: Results

- Tables of best injection timing, fuel quantity, EGR and turbo rack position
Future Directions

- Producing ballpark calibrations using engine simulation
- Prototyping algorithms for engine control
- Validating and verifying ECU software and hardware
- Increasing test automation
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- Tish Sheridan
- Jos Martin
- Richard Lang
- Jon Cherrie
- Pete Maloney
Questions???

- Paper in the proceedings
- Stop by the booth for a demonstration
- E-mail: david.sampson@mathworks.co.uk