Engine Plant Model Development and Controller Calibration using Powertrain Blockset™

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Key Take-Away’s

- Engine model parameterization is a very non-trivial task
- Engine controller calibration is a very non-trivial task
- MathWorks has tools to help make these two tasks more manageable
Problem Statement

How do I use the Powertrain Blockset engine and controller models for my application so I can:

- Design engine controls?
- Perform fuel economy and emissions studies?
- Create and validate dynamometer test plans?
What we’ll Cover Today

- Parameterizing a Powertrain Blockset engine model
  - Workflow
  - Example: parameterizing a mapped engine model

- Calibrating a Powertrain Blockset engine controller
  - Workflow
  - Example: calibrating an engine controller
What are we Parameterizing and Calibrating?
What we’ll Cover Today

▪ Parameterizing a Powertrain Blockset engine model
  – Workflow
  – Example: parameterizing a mapped engine model

▪ Calibrating a Powertrain Blockset engine controller
  – Workflow
  – Example: calibrating an engine controller
Powertrain Blockset Si Mapped Engine Model

- Contains 2D LUT’s for each model output
- Easy to parameterize
- Great for system level design and development
Parameterizing an Engine Model
- Workflow

- Model-Based Calibration Toolbox provides tools for the process:
  - Creating the Design of Experiments
Parameterizing an Engine Model

- **Workflow**

  - Model-Based Calibration Toolbox provides tools for the process:
    - Creating the Design of Experiments
    - Gather the data
Parameterizing an Engine Model
- Get the data “as calibrated”

Dynamometer Control (Steady State)

Engine System
(Change operating points, fixed calibration)

Data Logger

Measurements
- Air Flow
- Fuel Flow
- Exhaust Temp
- Emissions
- BSFC
Parameterizing an Engine Model
- Workflow

- Model-Based Calibration Toolbox provides tools for the process:
  - Creating the Design of Experiments
  - Gather the data
  - Fitting response surface models (RSM, statistical) to the data
Parameterizing an Engine Model
- Workflow

- Model-Based Calibration Toolbox provides tools for the process:
  - Creating the Design of Experiments
  - Gather the data
  - Fitting response surface models
  - Developing engine performance maps from RSM’s

![Diagram showing the workflow of parameterizing an engine model](image-url)
Parameterizing an Engine Model
- Workflow

- Model-Based Calibration Toolbox provides tools for the process:
  - Creating the Design of Experiments
  - Gather the data
  - Fitting response surface models
  - Developing engine performance maps
  - Validate the result
Launch MBC Toolbox

- From Apps tab
- From command line
  >> mbcmodel
Launch MBC Toolbox
Parameterizing a Mapped Engine Model
- Importing existing data

- Mapped engine model workflow:
  - Importing existing data
Import Data
- Inspect the data

- Look for anomalies or gaps
- Filter data to remove anomalies
- Add derived quantities and unit conversions
- Graphical views speed inspection
Parameterizing a Mapped Engine Model
- Fitting response surface models

- Mapped engine model workflow:
  - Importing existing data
  - Fitting response surface models (RSM, statistical) to the data
Fitting Models to the Data

- Generate response surface models

- Default models automatically fitted to all responses

- Inspect quality of fit

- Try out alternatives
Parameterizing a Mapped Engine Model
- Developing engine performance maps

- Mapped engine model workflow:
  - Importing existing data
  - Fitting response surface models
  - Developing engine performance maps from RSM’s
Calibration Generation Tool

- Fill tables
- Export cal tables
Calibration Generation Tool
- Generating look up tables
Calibration Generation Tool
- Fill tables

- Inspect surfaces
- Adjust table values in extrapolation areas
- Export to MATLAB, Excel or Cal tool
Parameterizing a Mapped Engine Model
- Export and validate result

- Mapped engine model workflow:
  - Importing existing data
  - Fitting response surface models
  - Developing engine performance maps
  - Export and validate the result
Export Calibration Data

Export Tables to MATLAB

% Generated by MATLAB 9.2.0.538062 (R2017a) on 01-May-2017 19:19:54

EngSpd_norm_1.X = [ 0, 750, 1053.5714, 1357.1429, 1660.7143, 1964.2857, 
                  2267.8571, 2571.4286, 2874.9999, 3178.5714, 3482.1429, 3785.7143,  
                  4089.2857, 4392.8571, 4696.4286, 4999.9999, 5303.5714];

EngSpd_norm_1.Y = [ 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15];

TQ_CMD_norm_1.X = [ 0, 15, 26.4285, 37.8571, 49.2857, 60.7143, 72.1429];

TQ_CMD_norm_1.Y = [ 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14];

AirFlowConv_Table_1.X = [ 0, 15, 26.4285, 37.8571, 49.2857, 60.7143, 72.1429];

AirFlowConv_Table_1.Y = [ 0, 750, 1053.5714, 1357.1429, 1660.7143, 1964.2857, 
                        2267.8571, 2571.4286, 2874.9999, 3178.5714, 3482.1429, 3785.7143,  
                        4089.2857, 4392.8571, 4696.4286, 4999.9999, 5303.5714];
Validate the Result
Validate the Result

- Accuracy for 1200 sec of FTP75 sim:
  - % diff in FE was 0.31%

- Run time for 1200 sec of FTP75 sim:
  - PTBS Mapped engine model 28.4 sec
  - GT Power FRM engine model 1449 sec
  - Mapped engine model sim ~51x faster
Parameterizing a Mapped Engine Model

- Summary

- Mapped engine model workflow:
  - Importing existing data
  - Fitting response surface models (RSM, statistical) to the data
  - Developing engine performance maps from RSM’s
  - Validate the result
What we’ll Cover Today

- Parameterizing a Powertrain Blockset engine model
  - Workflow
  - Example: parameterizing a mapped engine model

- Calibrating a Powertrain Blockset engine controller
  - Workflow
  - Example: calibrating an engine controller
What are we Parameterizing and Calibrating?
What are we Calibrating?

- Throttle area percent (TAP)
- Wastegate Fraction
- Intake Cam Advance
- Exhaust Cam Retard
- Lambda
- Spark Advance
Calibrating Optimal Base Engine Control Tables

- Workflow

- Model-Based Calibration Toolbox provides tools for the process:
  - Creating the Design of Experiments
  - Gather the data
  - Fitting response surface models (RSM, statistical) to the data
  - Developing optimal base calibration tables
  - Export calibration to controller
Calibrating Optimal Base Engine Control Tables
- Creating the DoE

- Optimal base engine control calibration workflow:
  - Creating the Design of Experiments

![Diagram showing the process of calibrating optimal base engine control tables](image)
Calibrating Optimal Base Engine Control Tables
- Creating the DoE

I/O of Turbocharged Direct-Injection 1.5L DOHC Engine Model with Dual-Independent Continuously Variable Cam Phasing

**Objective**
- Minimum BSFC
- Exhaust Temperature
- Turbocharger Speed
- Knock limit
- Residual Fraction
- AFR
- Spark Advance
- Waste-gate area
- TAP
- Intake Manifold Pressure

**Constraints**
- Table Breakpoints
- Optimal Tables
- Auxiliary Table

**Output Tables**
- RPM
- Load
- ICP
- ECP
Calibrating Optimal Base Engine Control Tables
- Creating the DoE
Calibrating Optimal Base Engine Control Tables
- Gather the data

- Optimal base engine control calibration workflow:
  - Creating the Design of Experiments
  - Gather the data
Calibrating an Optimal Base Cal Table
- Get the data “from CAE engine models”
Calibrating Optimal Base Engine Control Tables
- Get the data “from calibration sweeps”

**Measurements**
- Air Flow
- Fuel Flow
- Exhaust Temp
- Emissions (EO/TP)
- MAP
- MAT
- A/F
- Turbo Speed
- Turbine press ratio
- Compressor press ratio
- Turbine temp out
- Compressor temp out
- EGR pct.
- EGR cooler temp out
- Intercooler temp out

**Actuator Commands**
- Throttle
- Wastegate
- Injector
- Spark
- Intake cam
- Exhaust cam
- EGR valve
- Turbo

**Dynamometer Control (Steady State)**
- Speed Cmd
- Torque Cmd
- Speed Measured

**Engine**
(Change operating points and sweep Actuator Cmds)

**Dynamometer**

**Data Logger**
Calibrating Optimal Base Engine Control Tables

- Fitting response surface models

- Optimal base engine control calibration workflow:
  - Creating the Design of Experiments
  - Gather the data
  - Fitting response surface models (RSM, statistical) to the data
Calibrating Optimal Base Engine Control Tables
- Generate response surface models from data

- Default models automatically fitted to all responses
- Inspect quality of fit
- Try out alternatives
Calibrating Optimal Base Engine Control Tables
- Develop optimal base calibration tables

- Optimal base engine control calibration workflow:
  - Creating the Design of Experiments
  - Gather the data
  - Fitting response surface models

- Developing optimal base calibration tables from RSMs
Calibrating Optimal Base Engine Control Tables
- Developing calibration tables

- Import response surface models
- Run optimizations
- Analyze tradeoffs and sensitivity
- Fill tables
- Export cal tables
Calibrating Optimal Base Engine Control Tables
- Developing calibrations from response surface models

- Import response surface models
- Run optimizations
- Analyze tradeoffs and sensitivity
- Fill tables
- Export cal tables
Calibrating Optimal Base Engine Control Tables

- Run optimizations

- Define objective
- Define constraints
- Determine operating point weights
How to calculate the weights for a sum optimization
Use MATLAB to calculate weights for a drive cycle

MATLAB program reads measurements from Excel measurement file and calculate weights automatically
Calibrating Optimal Base Engine Control Tables
- Run optimizations

- Evaluate optimization results
- Diagnose optimization convergence issues
Calibrating Optimal Base Engine Control Tables
- Analyze tradeoffs and sensitivity

- Evaluate local sensitivity
- Determine if tradeoffs are needed
Calibration Generation Tool
- Fill tables

- Inspect surfaces
- Export to MATLAB, Excel or Cal tool
Optimal Base Calibrations Completed

Throttle area percent (TAP)
Wasfegate Fraction
Intake Cam Advance
Exhaust Cam Retard

Lambda
Spark Advance
Calibrating Optimal Base Engine Control Tables
- Export and validate the result

- Optimal base engine control calibration workflow:
  - Creating the Design of Experiments
  - Gather the data
  - Fitting response surface models
  - Developing optimal base calibrations

- Export calibration to controller
Export Tables to Calibration Tool
Calibrating Optimal Base Engine Control Tables

- Summary

- Optimal base engine control calibration workflow:
  - Creating the Design of Experiments
  - Gather the data
  - Fitting response surface models
  - Developing optimal base calibrations
  - Export calibration to controller
Key Take-Away’s

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Contact us to Learn More

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