SKYACTIV TECHNOLOGY engine development is enabling Mazda to commercialize fuel-efficient diesel and gasoline engines that do not rely on downsizing and lean burn. SKYACTIV-G is the world’s first gasoline engine for mass production vehicles to achieve a compression ratio of 14.0:1, resulting in a 15% increase in efficiency and torque. Its diesel counterpart, SKYACTIV-D, has the world’s lowest diesel-engine compression ratio, enabling it to deliver 20% more fuel efficiency while meeting strict exhaust regulations—including Euro6 and automobile exhaust gas regulations in Japan—without using costly exhaust after-treatment that reduces nitrogen oxide (NOx) emission.

Mazda engineers relied on MATLAB®, Simulink®, and Model-Based Calibration Toolbox™ for engine controller design, verification, and calibration.

“SKYACTIV engines incorporate hardware advances that deliver more torque and improve fuel economy,” says Shingo Harada, assistant manager at Mazda. “Model-Based Calibration Toolbox helped us exploit these advances, extracting better fuel efficiency and lower exhaust emissions than would have possible with manual, spreadsheet-based calibration approaches.”

The Challenge
Optimize the efficiency of SKYACTIV engines while meeting strict emissions standards worldwide

The Solution
Use Simulink and Model-Based Calibration Toolbox to accelerate the generation and development of optimal calibration settings, ECU-embeddable models, and engine models for HIL simulation

The Results
- Engine calibration workload minimized
- Model complexity cut in half
- Model accuracy improved

The Challenge
As Mazda engines have grown more complex, it has become increasingly difficult to find optimal calibration settings using traditional approaches. “Trial and error with a spreadsheet and a test cell required extensive lab time, making it difficult to meet delivery schedules,” says Harada. “More importantly, finding an optimal solution in a search space of five or more dimensions is difficult even for experienced calibration engineers, so we could never be certain that we had found the best possible settings.”

Mazda wanted to reduce the SKYACTIV-D’s compression ratio to minimize soot and NOx emissions. To achieve this and other design objectives, engineers required ECU-embeddable statistical models of maximum cylinder pressure and exhaust gas temperature. Initial versions of these models had 40 parameters each and were too complex to run on the ECU. Mazda needed to reduce model complexity without sacrificing accuracy.

The Solution
Mazda used Simulink and Model-Based Calibration Toolbox to define test plans, develop statistical models, and generate ECU-embeddable models for HIL simulation

The Results
- Engine calibration workload minimized
- Model complexity cut in half
- Model accuracy improved

Mazda Speeds Next-Generation Engine Development of SKYACTIV TECHNOLOGY
Using the Calibration Generation (CAGE) tool in Model-Based Calibration Toolbox and a MATLAB based optimization interface developed in-house, the team generated optimal calibrations from the engine models.

To define a realistic operating region for simulation, optimization, and embedded model evaluation, they used Model-Based Calibration Toolbox to create a boundary model.

With Model-Based Calibration Toolbox, Mazda engineers generated embeddable models, including the maximum cylinder pressure model used on the production SKYACTIV-D ECU.

For the same ECU, they generated a total mass of injected fuel as a function of multiple operating-point variables. This model was used with an exhaust temperature model, also generated by Model-Based Calibration Toolbox, to improve the reliability and performance of the fuel mass model. SKYACTIV-D engines meet stringent European and Japanese emission standards and are installed in production vehicles, including the Mazda CX-5.

Engineers working on the SKYACTIV-G engine developed a statistical engine fuel-consumption model using Model-Based Calibration Toolbox. They exported this model to Simulink for use in the development, debugging, and HIL simulation of the engine control logic. The model was reused in automatic transmission fuel consumption simulations, further reducing the model development effort.

The Results

Engine calibration workload minimized. “With traditional methods, getting data when calibrating a new engine required a large amount of testing,” says Harada. “With Model-Based Calibration Toolbox, we reused the existing data and simulated the responses, which enabled us to minimize both the workload to obtain test data and test cell usage.”

Model complexity cut in half. “Our initial embedded maximum cylinder pressure model had 38 parameters. With Model-Based Calibration Toolbox, we reduced that number to 20, which in turn reduced the load on the CPU,” notes Harada. “Similarly, the toolbox enabled us to reduce the number of parameters in our exhaust gas temperature model from about 40 to 20 while maintaining the same level of accuracy.”

Model accuracy improved. “Using a boundary model created with Model-Based Calibration Toolbox, we improved the accuracy of our smoke model and reduced its root-mean-square error (RMSE) by 80%,” says Harada.

“Model-Based Calibration Toolbox not only enabled us to identify optimal calibration settings for the SKYACTIV-D engine, it greatly reduced the engineering effort required. The models it generated accelerated control logic development, provided valuable insights, and made it easy to try new ideas.” —Shingo Harada, Mazda

Industry
- Automotive

Application Areas
- Mathematical modeling
- Algorithm development
- System design and simulation
- Embedded systems
- Control systems

Products Used
- MATLAB®
- Simulink®
- Model-Based Calibration Toolbox™

Learn More About Mazda SKYACTIV TECHNOLOGY
www.mazda.com/mazdaspirt/skyactiv