# MathWorks Products Save Money and Accelerate Fuel-Injection Technology Development at Ricardo

Ricardo Consulting Engineers, which began over 80 years ago as a developer of internal combustion engines, has expanded into fuel cells, powertrain engineering, vehicle engineering, and fuel and lubricant development. A few years ago the company, which is based at Shoreham-on-Sea in England, began investigating gasoline direct injection (G-DI) engines.

G-DI engines differ from other fuel-injected systems in that the fuel is injected directly into the combustion chamber, where it can form a stratified (non-uniform) mixture with the air. This system has the potential to give the engine improved performance and economy while still meeting European emission standards. Ricardo knew, however, that these advantages could only be realized with control strategies developed to optimize the appropriate fuel/air mixture.

Ricardo recently developed control strategies for a Mitsubishi vehicle with a production G-DI engine. The controls needed to enable the Mitsubishi vehicle to meet European emissions standards, which are much stricter than Japanese standards. Ricardo saved considerable development time and expense by using Stateflow®, Simulink®, and MATLAB®.

## The Challenge

The performance and fuel economy of a G-DI engine are best enhanced by optimizing the control switches that handle the transition between the engine's operational modes.

This process is one of the most time-consuming, and therefore most expensive, aspects of designing a G-DI control system. Each transition between operational modes requires a change in fuel mixture, and physical switches must control this fuel-mixture change as well as the transition itself. Moreover, switching is far from instantaneous (in some cases the transition takes almost four seconds), which means that each switch must actually be a controlled process.

Ricardo engineers had defined six main operational modes in the design of the Mitsubishi control system: crank, run a homogeneous air-fuel mixture, run a stratified air-fuel mixture, NOx trap regeneration, overrun, and engine stop.

As they set out to optimize these control systems, the team confronted a series of trade-offs. For example, the stratified run mode offers good fuel economy. In this mode, however, NOx emissions can build up within the after-treatment system. These emissions need to be purged by occasionally

**The Challenge**

To improve automotive engine performance and economy by developing efficient operational control systems for gasoline direct injection (G-DI) engines

**The Solution**

Model the engine management strategies in Simulink and use Stateflow to incorporate mode switches to handle transitions between operational modes

**The Results**

- Emissions reduced by approximately 50 percent
- Accelerated design, saving time and expense
- Models that can be reused on other engines

The MATH WORKS

*"Many of our control engineers believe that MATLAB, Simulink, and Stateflow are class-leading products, so these software tools will be key to Ricardo's future business development."*

—Nick Owen, Technology Department Manager, Ricardo Consulting Engineers

enriching the air-and-fuel mixture. In addition, great care must be exercised when switching between modes because the enriching can cause an increase in the engine output torque, and this would be noticeable to the driver.

To exploit the fuel-economy benefits of the stratified mode while preventing NOx build-up, Ricardo needed to model the entire system and test various strategies.

## The Solution

"Simulink and Stateflow helped us to simplify the development of the necessary control algorithms," says Dr. Ray Heath, Principal Engineer at Ricardo.

The Ricardo team used Simulink and Stateflow to model each of the six operational modes that they had identified. The switches were developed as Simulink block diagrams. (For engine management strategies, there are huge advantages in being able to build a model using Simulink's hierarchical block diagrams. Models remain manageable because only the relevant level of detail is exposed.) The transitions between operational modes were developed as state diagrams using Stateflow.

Stateflow eased the transition from one operational mode to another and also allowed the Ricardo team to view the simulation on-screen as the states changed. The engineers were able to model and then visualize this complex logic, which again assisted in the understanding of the model. Comments Heath, "I particularly like the way in which Stateflow simplifies the handling of multiple operational modes within one model. Being able to watch the states change as the simulation is running certainly helps you see what is happening when the model becomes more complex."

"We initially chose to buy Stateflow for the G-DI project because the client wanted to see results quickly, but having used Stateflow once, we have witnessed the advantages, and are planning to use it far more widely."

Adds Nick Owen, Ricardo's Technology Department Manager, "The majority of our projects at Shoreham could benefit from MathWorks products like Stateflow and Simulink. The G-DI project is only one example of the flexibility and power that lead us to use them."

## The Results

- **Significantly improved engine performance.** The new control algorithm developed by Ricardo reduced emissions on the Mitsubishi G-DI by approximately 50%.
- **Accelerated design, saving time and expense.** Using MATLAB, Simulink, and Stateflow, Ricardo sped the development of the operational control systems for the G-DI engines, with considerable cost savings.
- **Models that can be reused on other engines.** Simulink fully supports Ricardo's modular approach to design, allowing the engineers to model different engines simply by replacing or altering some of the original Simulink blocks. This helps maintain quality and saves time and cost for Ricardo and its clients.

**To find out more:**
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### Application Areas

Automotive
Control design
Engine design

### MathWorks Products Used

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3 Apple Hill Drive
Natick, MA 01760-2098 USA
Tel: 508-647-7000
Fax: 508-647-7101
E-mail: info@mathworks.com
www.mathworks.com



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