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*GM Holden Ltd*

# Cold Engine Emissions Optimization Using Model Based Calibration

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General Motors Holden Ltd.



# Overview

- Cold engine emissions.
- What is model-based calibration?
- Design of experiments.
- Statistical modelling.
- Response model trade-offs and optimisation.
- Implementation.



# Cold Engine Emissions

- “Cold Engine” refers to operation **after** engine start up.
- 20°C emissions tests.
- Catalytic converter has not achieved light-off.
- Engine operation is referred to as “Catalyst Heating.”

## Challenges before light-off

- Minimise exhaust pollutants.
- Achieve acceptable combustion stability.
- Maximise fuel economy.
- Minimise piece costs, e.g. catalytic converter, engine hardware.



# Engine Control Options

- Ignition timing, and fuelling.
- Continuously, variable valve timing for both intake and exhaust.
- Split injection, semi-stratified charge combustion.

Increased complexity means more degrees of freedom !

PFI - 3-4 variables.

DI - 7-8 variables.

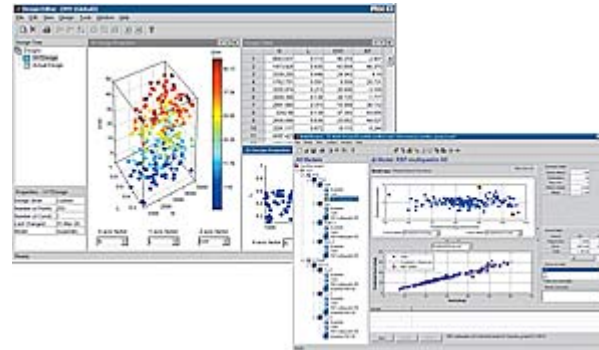
Our brains struggle to visualise 2 or 3 variables at a time !



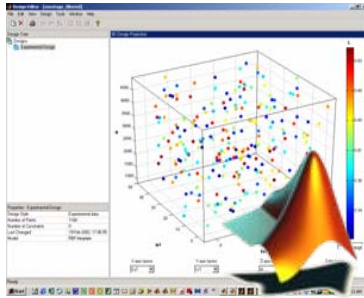
# Model-Based Calibration Toolbox

- An add-on toolbox for MATLAB®
- Specifically developed for engine calibration
- Has been commercially available for approximately 5 years

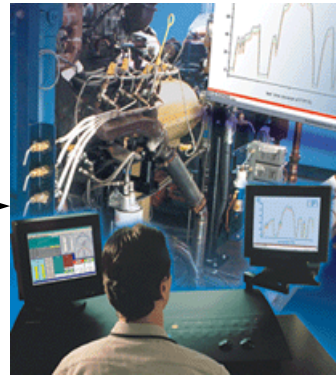
Model-Based Calibration Toolbox provides design tools for calibrating powertrain systems. The toolbox is built on the high-performance technical computing environment of MATLAB® and the modeling capabilities of Simulink®. Model-Based Calibration Toolbox enables the development of optimized calibrations for complex high-degree-of-freedom engines that are difficult to calibrate using traditional methods. Using the toolbox, you can develop a process for systematically generating calibrations that find an optimal balance of engine performance, emissions, and fuel economy.



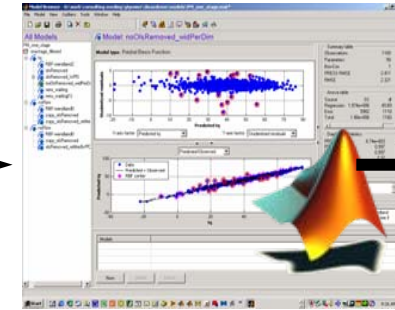
# Model Based Calibration Concept



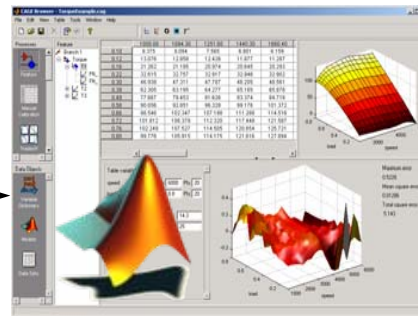
**Experiment Design**



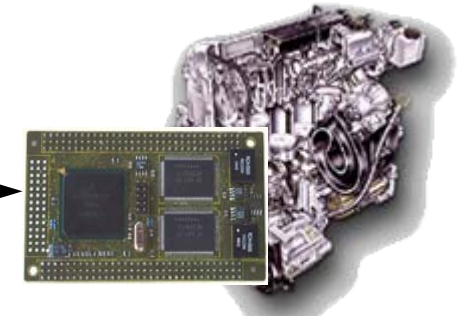
**Data Collection**



**Data Modeling**



**Calibration**



**Implementation**



# Design of Experiments

- Design of experiments is a technique used to select the most statistical useful data.
- Essential for high degree of freedom systems.
- # of points influenced by degrees of freedom and model.

## Benefits

- Significant reduction in test points compared with 'one parameter at a time' or factorial test methods.
- Data collected randomly minimising influence of 'noise' parameters.



# Examples of DOE

## Factorial designs

$L^V = \#$  of points

L = Levels.

V = Variables.

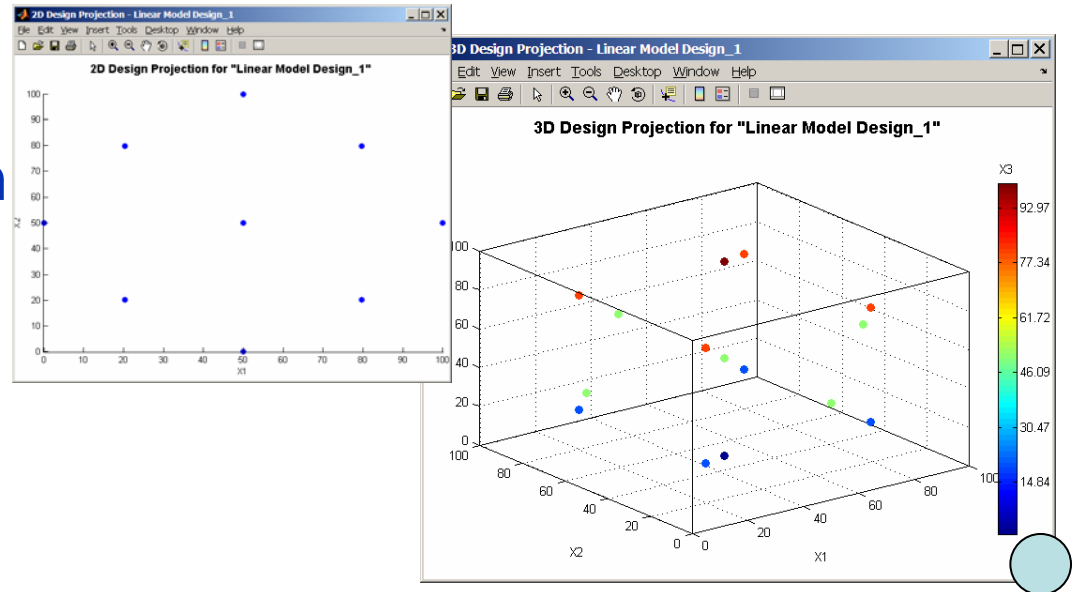
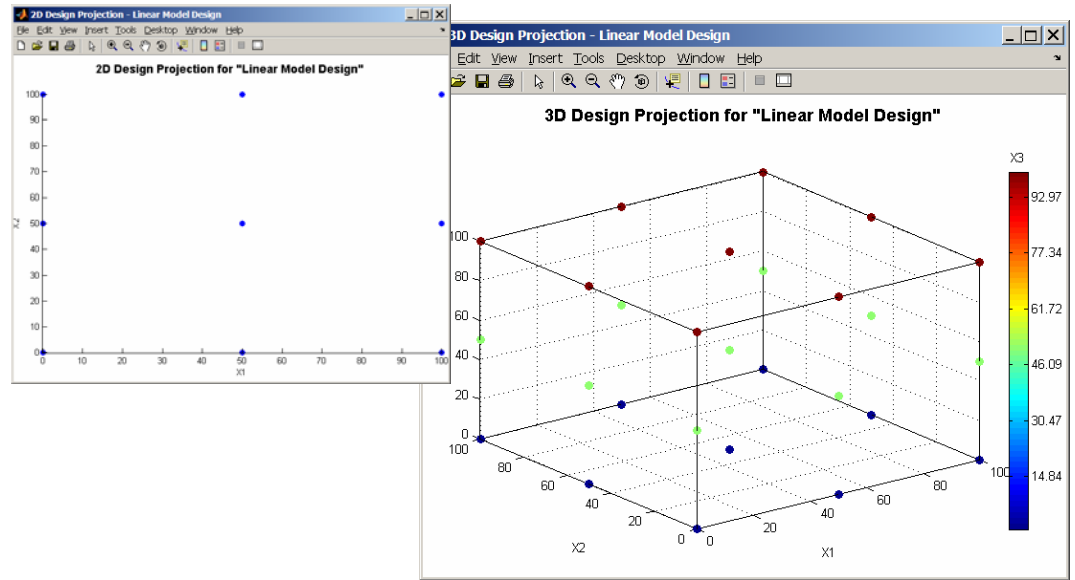
3 levels and 3 variables = 27 points.

## Central Composite Design (CCD)

A classical DOE.

Minimum of 15 points.

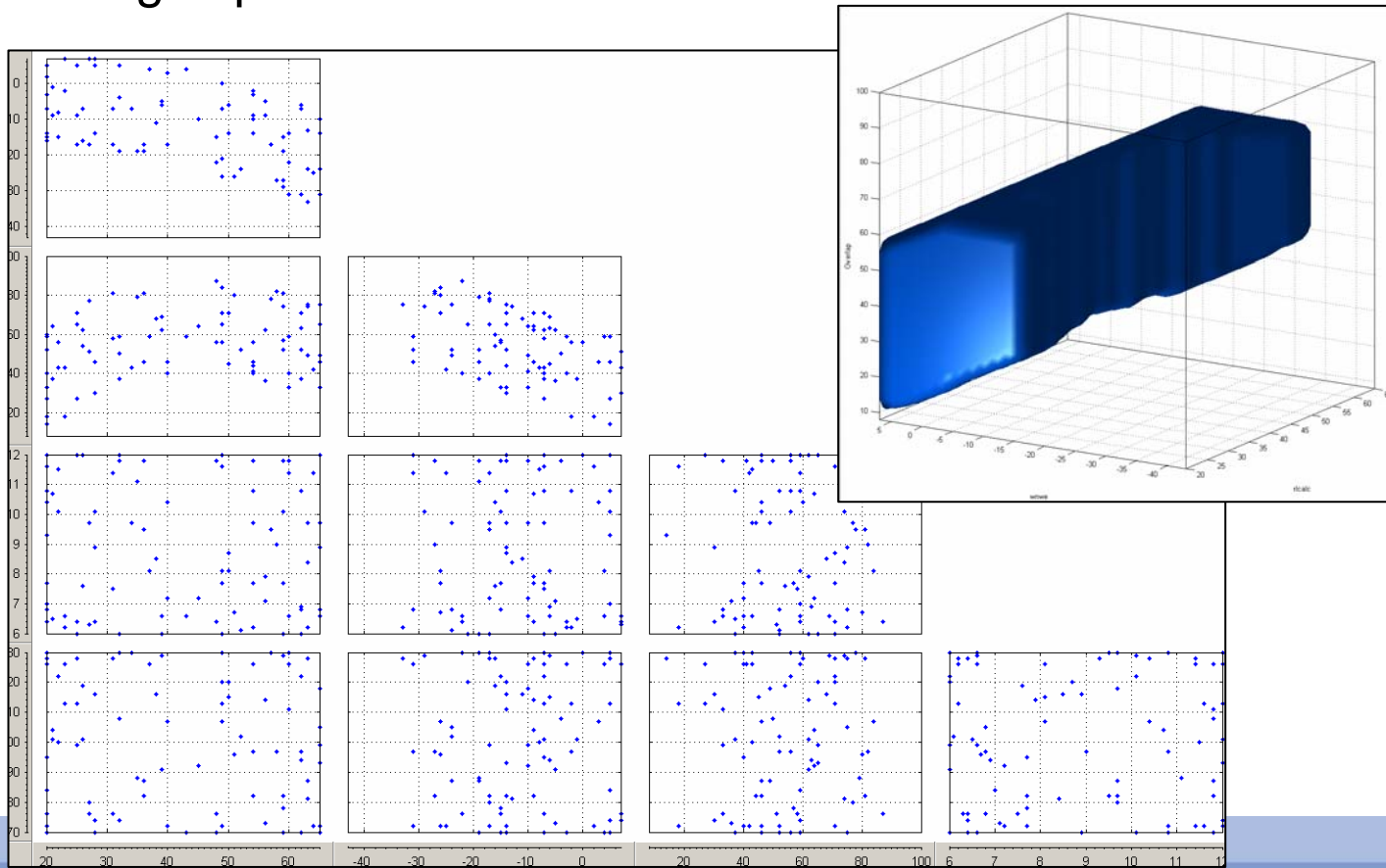
Almost 50 % reduction in test points.



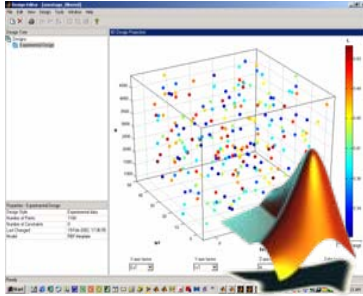


# Optimal designs and augmented space fills

- Computer based design, flexible and useful for constrained design spaces.



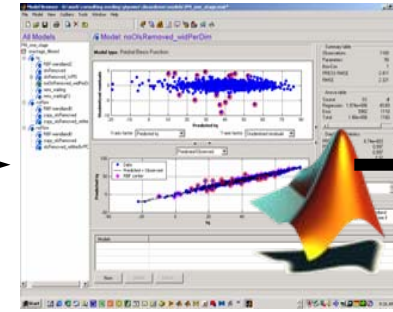
# Model Based Calibration



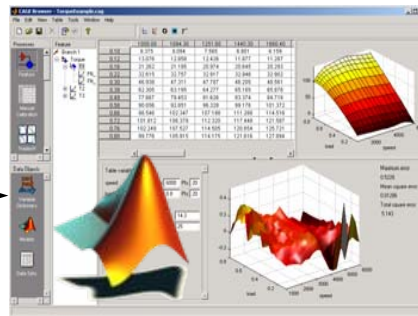
Experiment Design



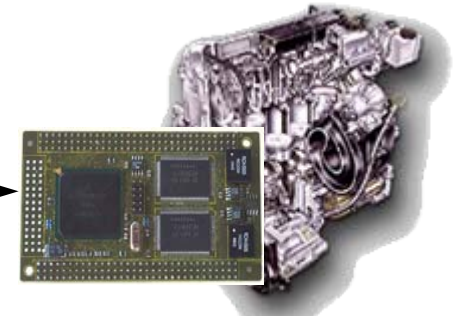
Data Collection



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# Statistical Modelling

- The choice of variables (factors and responses) should be selected based on physical knowledge.
- Models capture the shape of the response and confidence intervals.
- Modelling is split into two parts;
  - Local model.
  - Global model.

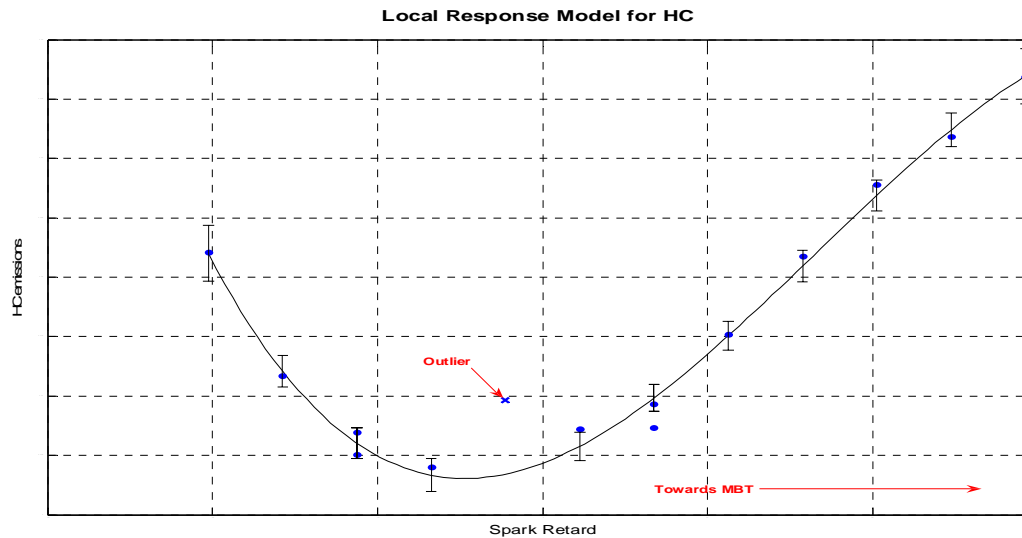
Typical Models are;

- Polynomials.
- Radial Basis Functions (RBF).



# Local Model

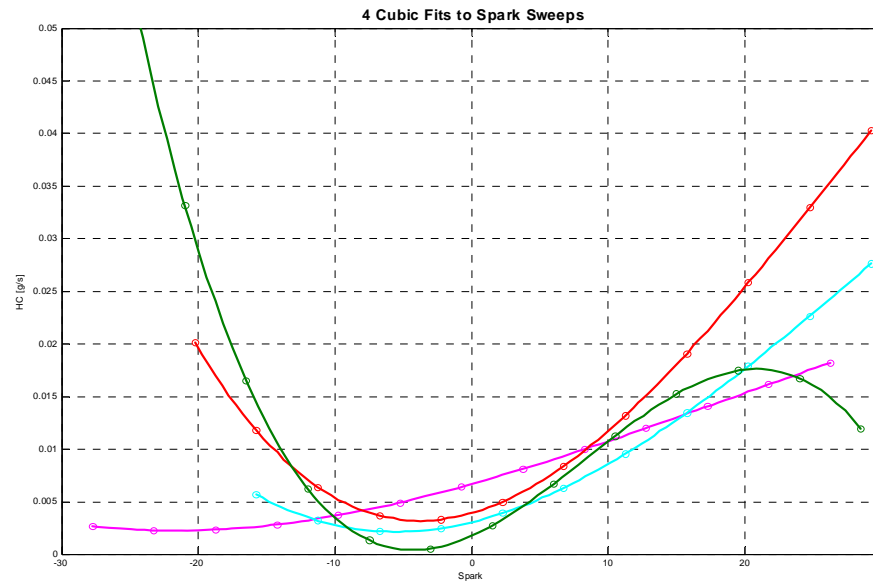
- Local model refers to spark sweep data. Spark is the variable on the x-axis, all other variables are held constant.
- Fitting local models help identify bad data and 'expected' trends.



$$HC = b_0 + b_1 SPARK + b_2 SPARK^2 + b_3 SPARK^3$$

# Global Model

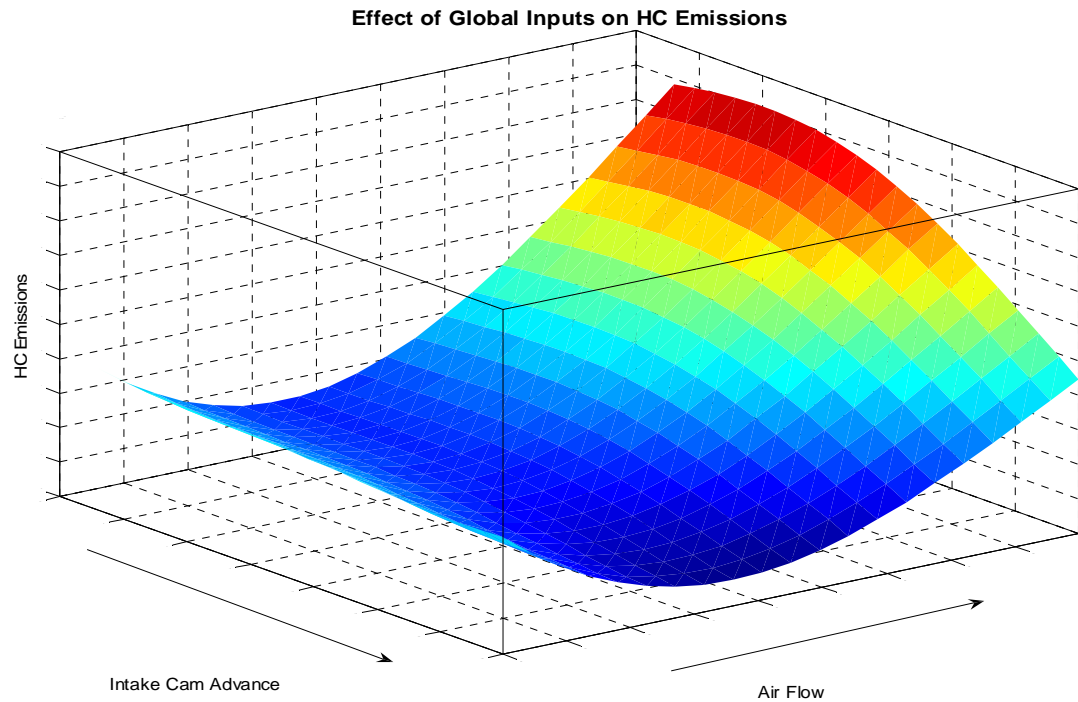
- Coefficients from the local model are fed into the global model.



- A model now represents the local coefficients, enabling reproduction of the spark sweep at any combination of global conditions.

# Response Surface

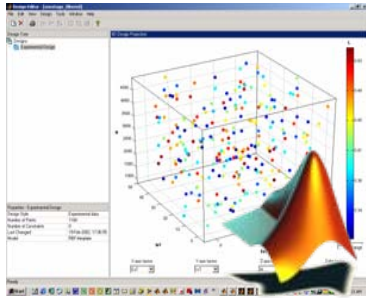
- The response surface can be calculated from the local and global model coefficients.



- Interrogation increases understanding of trends.



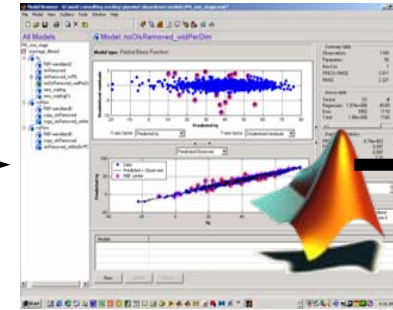
# Model Based Calibration



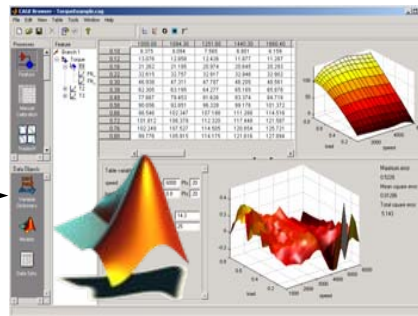
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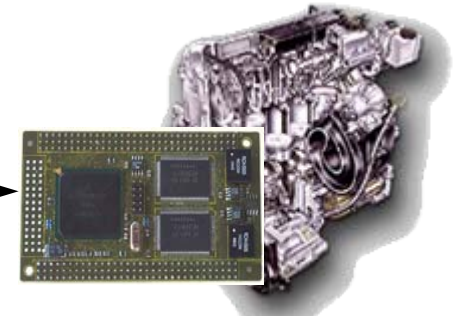
**Data Collection**



**Data Modeling**



**Calibration**



**Implementation**



# Optimisation and Trade-offs

- Optimise controlled variables to meet emissions targets and satisfy customer expectations.
- Optimisation can focus on one response or consist of trade-offs.
- Input variables can be optimised manually considering all responses.
- Optimization Toolbox algorithms can be used for automatic optimisation.

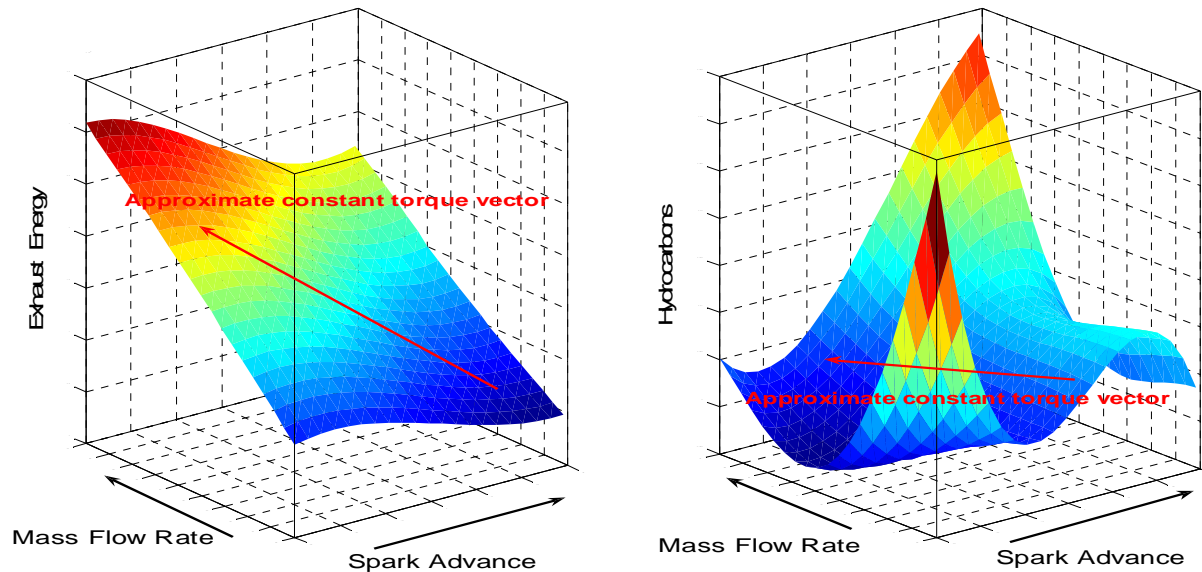




# Single Objective Optimisation

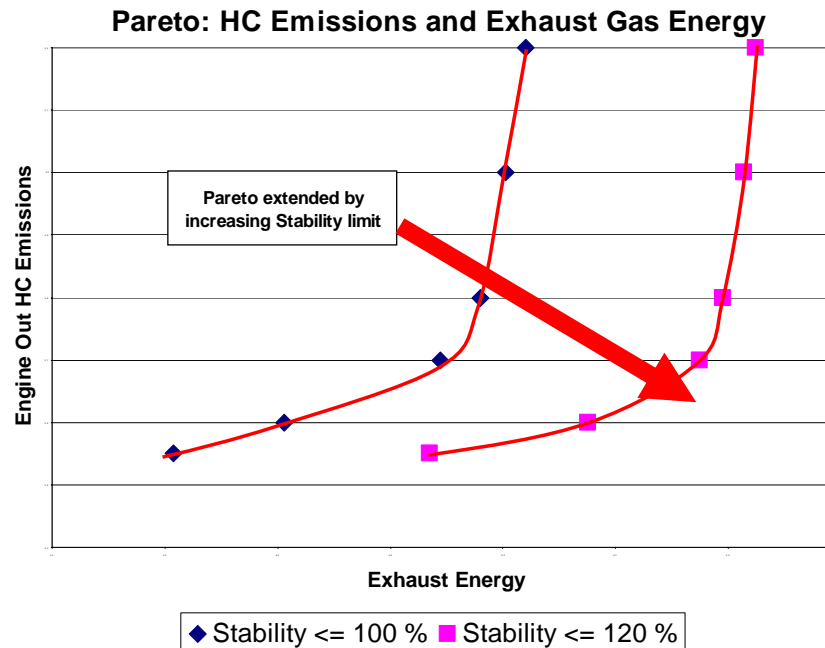
- Appropriate when no trade-off exists or is necessary.
- Constraints are used to limit other responses, e.g. combustion stability.

Exhaust Energy and HC Emissions fn(mass flow rate, spark advance)



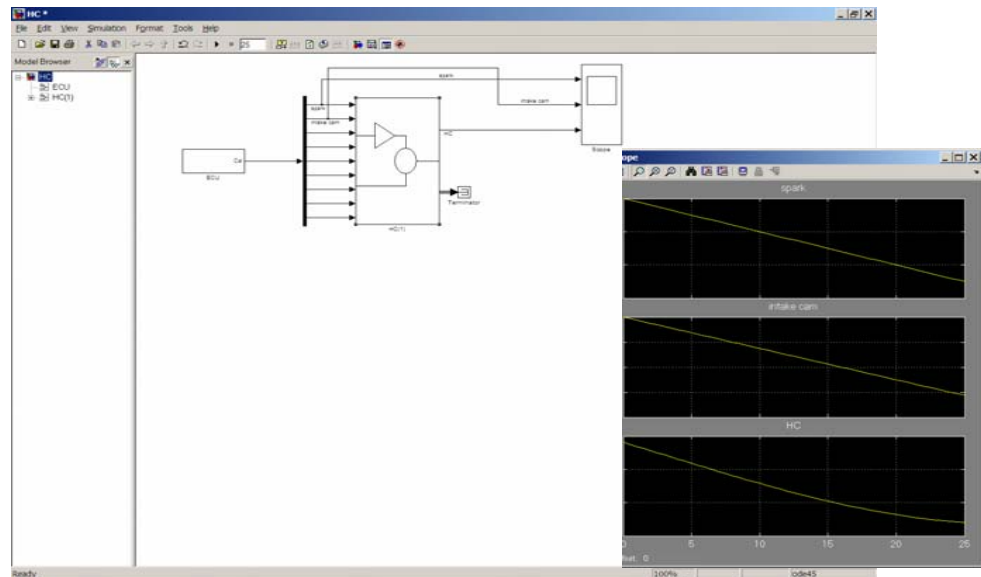
# Multi-Objective Optimisation

- Necessary when optimising one response, results in the deterioration of another.
- Generates a Pareto, more time consuming to select optimum calibration.

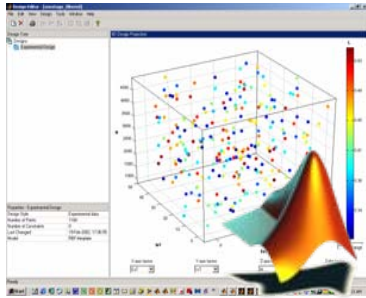


# Re-use of Models

- Collect data once.
- Re-use models as many times as required.
- Constraints can be changed.
- Models are an **engine test bed simulator**.



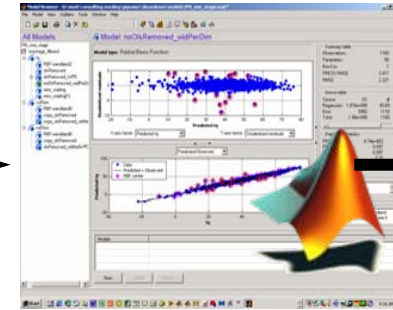
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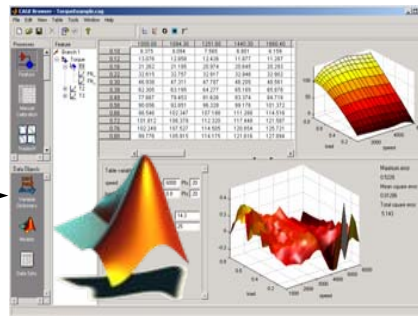
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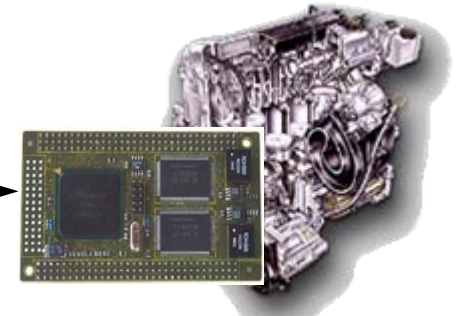
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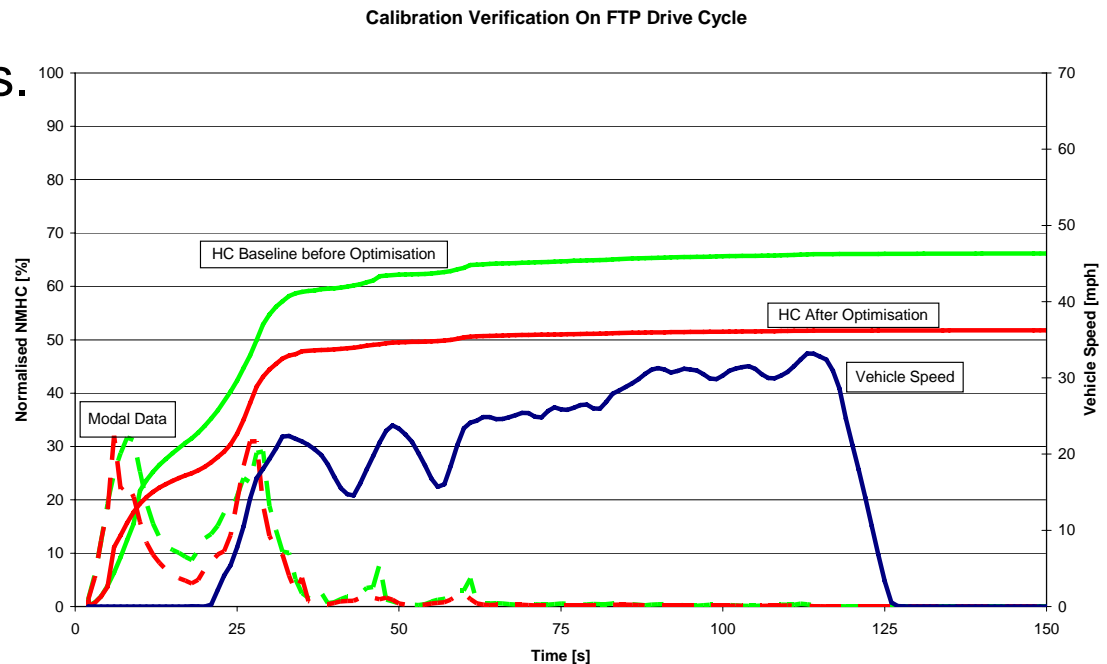


**Implementation**



# Implementation

- Optimum values must translate into ECU maps.
- Take into account strategy deficiencies.
- Can be limited by engine hardware and other calibration areas.
- Cycle analysis.



# Conclusions

- Model-based calibration and design of experiments is a key tool in developing high-technology engines with demanding emissions targets and driveability constraints.
- Use of models allows careful scrutiny of multiple responses and increases understanding of engine operation across all degrees of freedom.
- Use of models as **engine test bed simulator** reduces expensive retesting.
- Experience is a key factor in successful application of this process.



# Acknowledgements

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# Questions?

