Combining Optimisation with Dymola to Calibrate a 2-zone Predictive Combustion Model.

Mike Dempsey

Optimised Engineering Design Conference 2016

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Software, Consultancy, Training

- Based in Leamington Spa, UK
  - Office in Cape Town, South Africa
- Experts in Systems Engineering, Modelling and Simulation
- Business Activities
  - Engineering consultancy
  - Software sales and support
  - Modelica library developers
  - FMI tool developers
  - Training services
    - Dassault Systemes Certified Education Partner
- Global customer base
  - Europe, USA, India, South Korea, Japan

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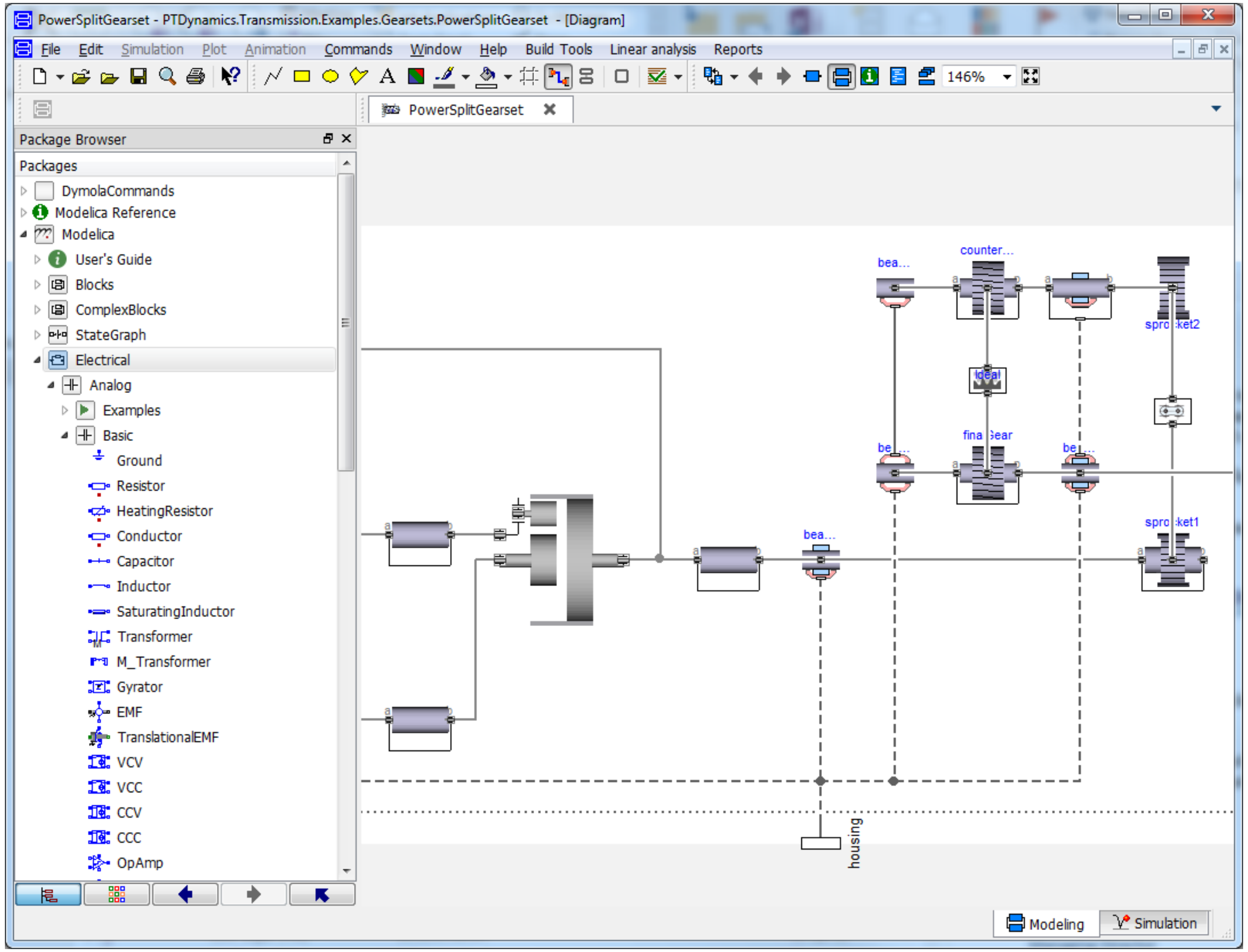
What is Dymola?

- Built on open standards:
  - Modelica Modelling Language
  - Functional Mock-up Interface
- Component orientated modelling approach
- Enables multi-domain modelling and simulation of complex dynamic systems
  - Mechanical, Electrical, Hydraulic, Pneumatic, ThermoFluids, Thermal, Control
- Extensive range of applications libraries for Automotive covering the whole vehicle
- Developed by Dassault Systemes
  - Part of CATIA brand



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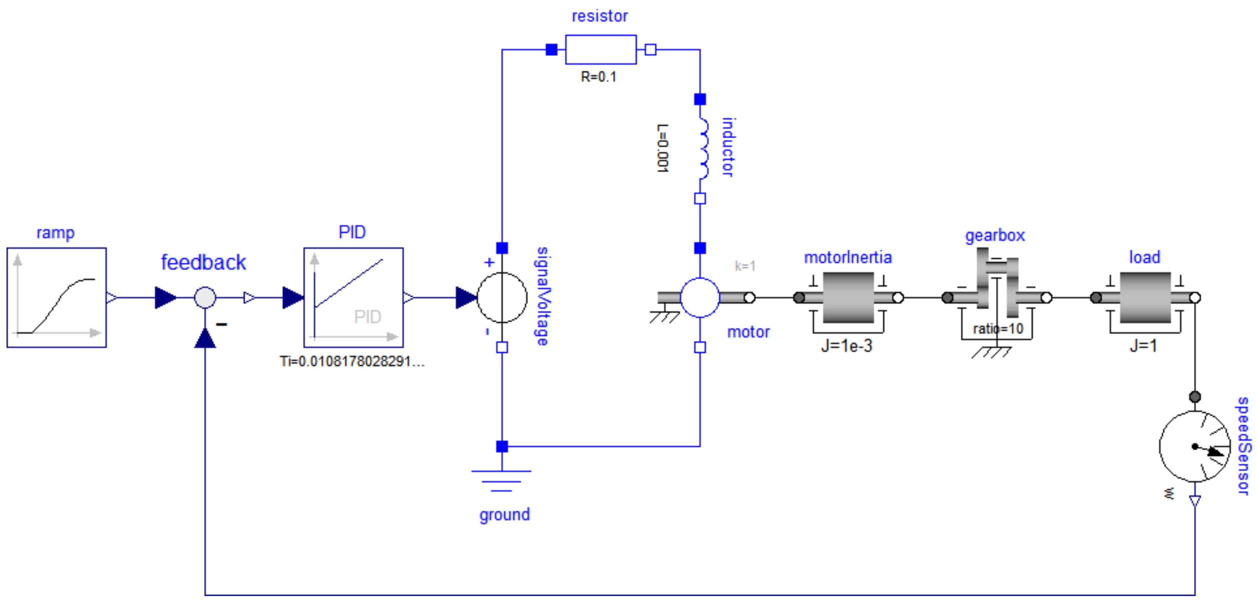
Component Orientated Modelling

- Modelling and simulation of systems integrating multiple physical domains
  - Mechanics (1D, MultiBody), 1D Thermofluids, Control, Thermal, Electrical, Magnetics and more
- Promotes extensive model reuse at component and system level
  - Components represent physical parts: valves, gears, motor
  - Connections between parts describe the physical connection (mechanical, electrical, thermal, signal, etc.)
- Store your own component and system models in libraries to easily share and reuse them across the business



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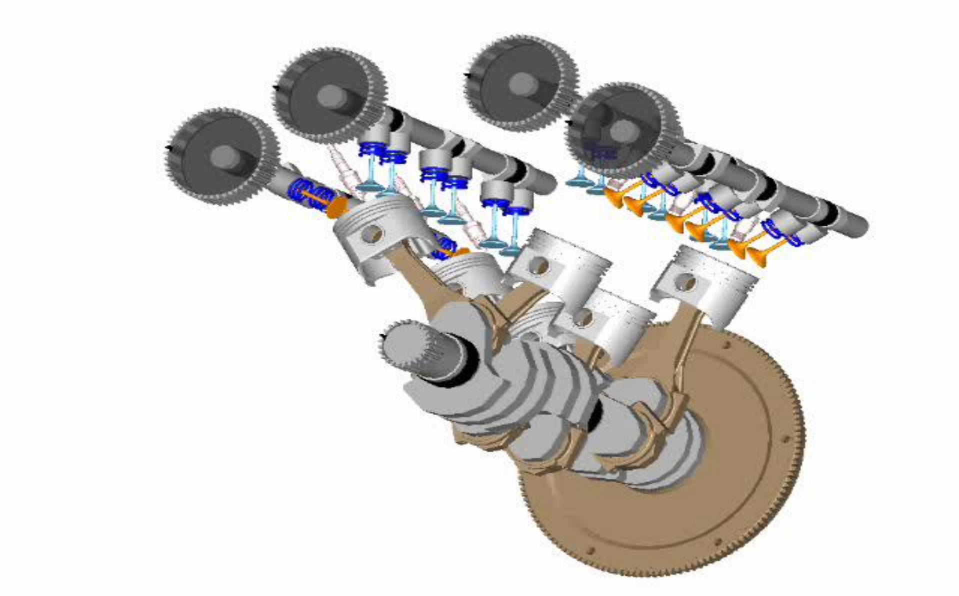
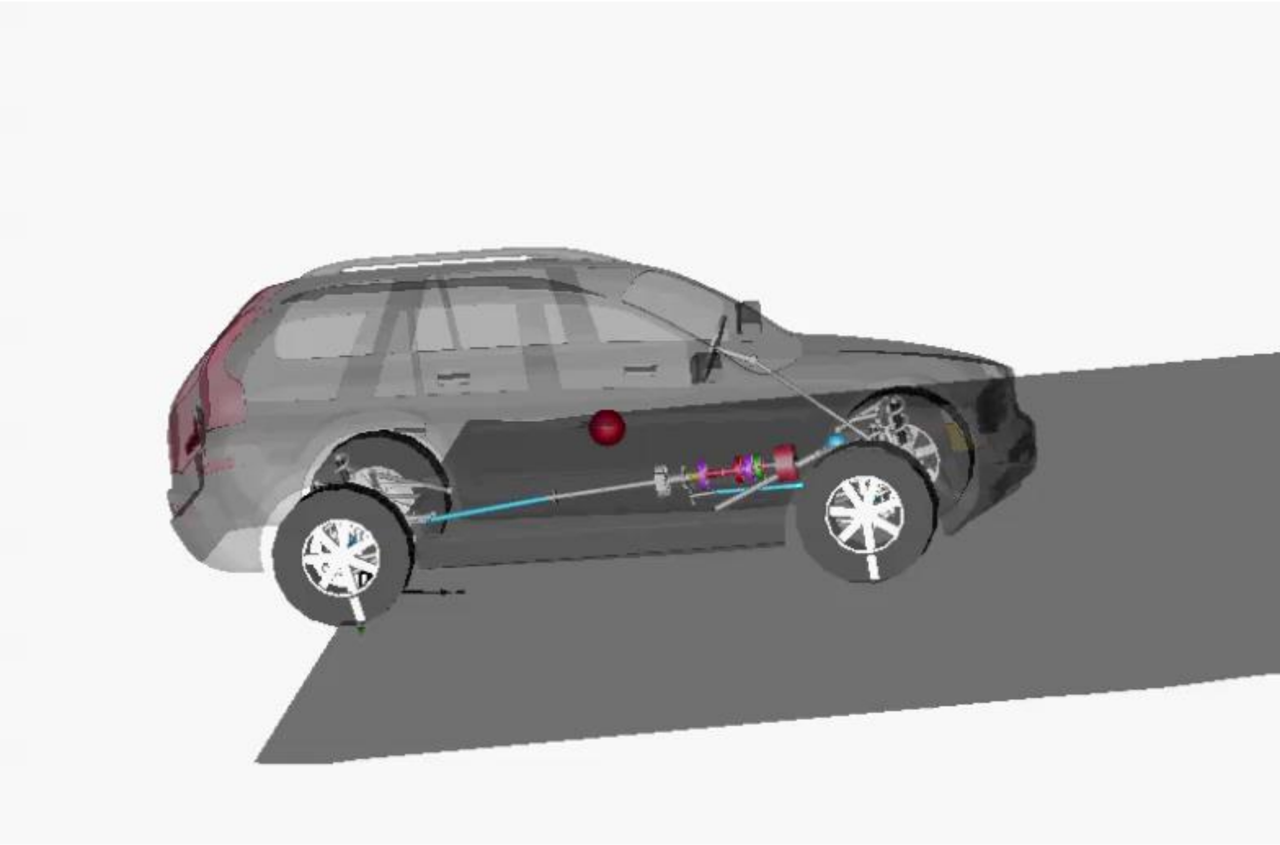
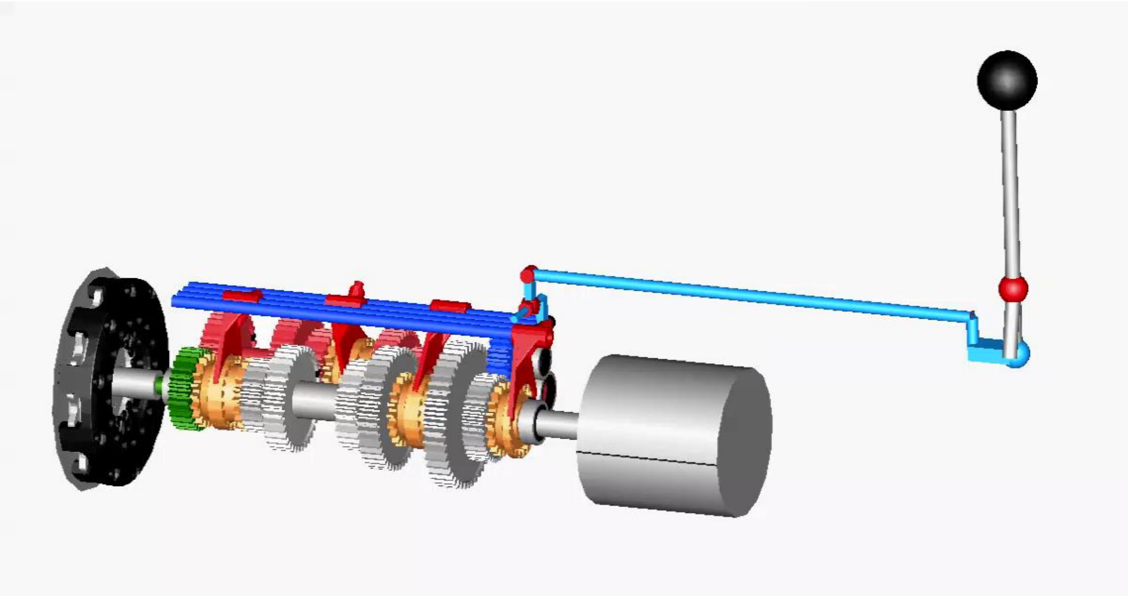
Automotive Applications







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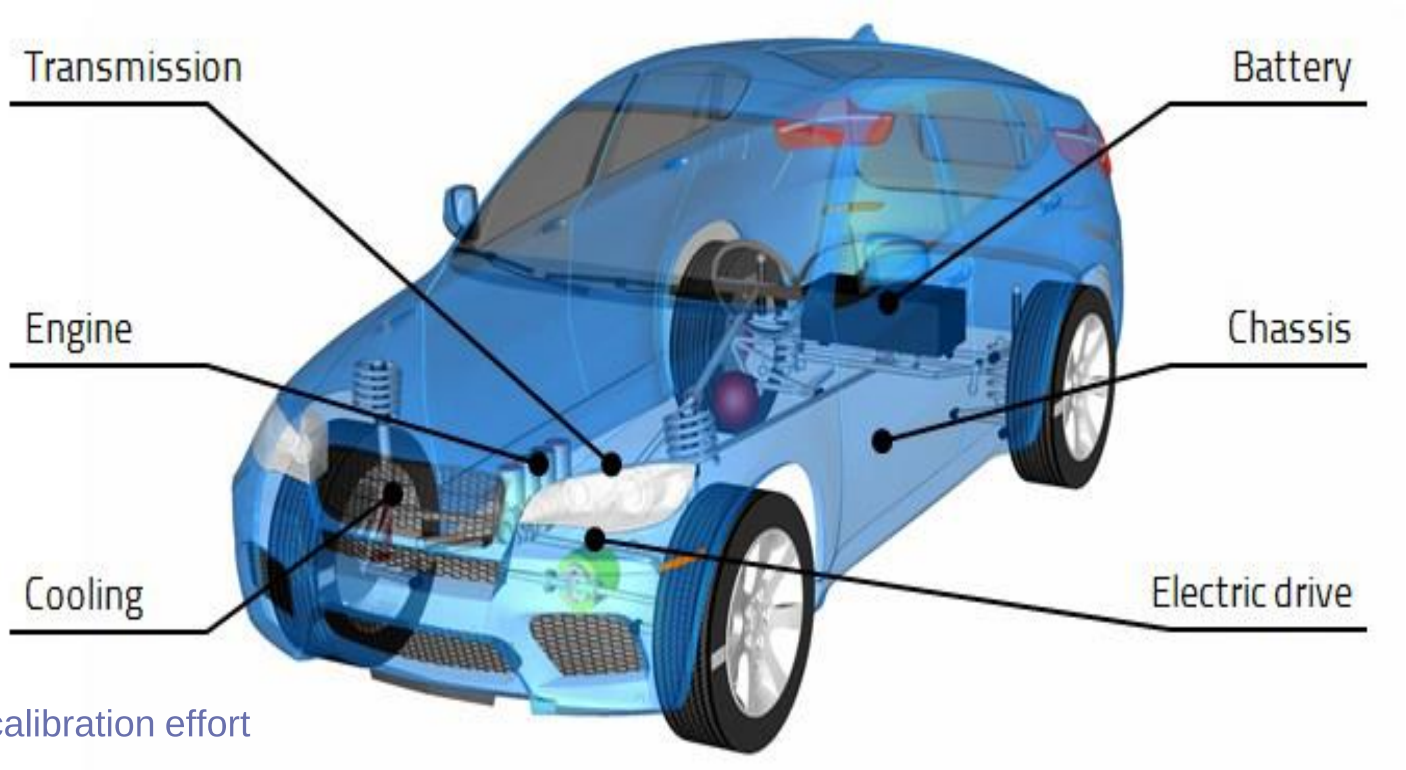
Challenges

- Market demands
  - Improved fuel economy
  - Lower emissions
  - Improved reliability
  - Noise quality
  - Driveability
  - Performance
- Engineering solutions
  - More active systems
    - Increases complexity
  - Better control of existing systems
    - Increasingly complex control requiring large calibration effort
  - Tighter integration of all vehicle systems
- Management demands
  - Faster time to market
  - Lower development and manufacturing cost



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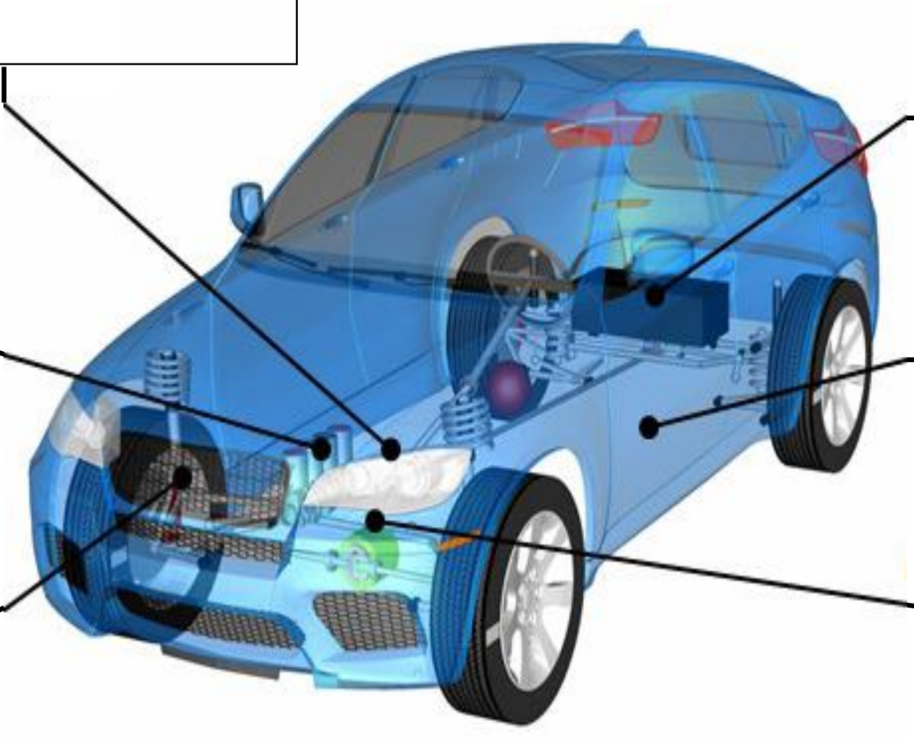
Vehicle Modelling

DYMOLA focuses on physical modelling using Modelica and the integration of these models into the design process

- Gearbox and Driveline
  - Mechanics
  - Thermal
  - Hydraulics
  - Electrification
  - Control
  - Cooling

- Engine
  - Air flow
  - Mechanics
  - Cooling system
  - Fuel system
  - Control system
  - Electrification
  - Hydraulics

- Thermal Management
  - Engine Cooling
  - HVAC
  - Battery Cooling
  - Power Electronics Cooling



- Battery
  - Electrical
  - Thermal
  - Cooling
  - Control

- Chassis
  - Mechanics
  - Active systems
  - Control

- Electric Drive
  - Electrical
  - Thermal
  - Control

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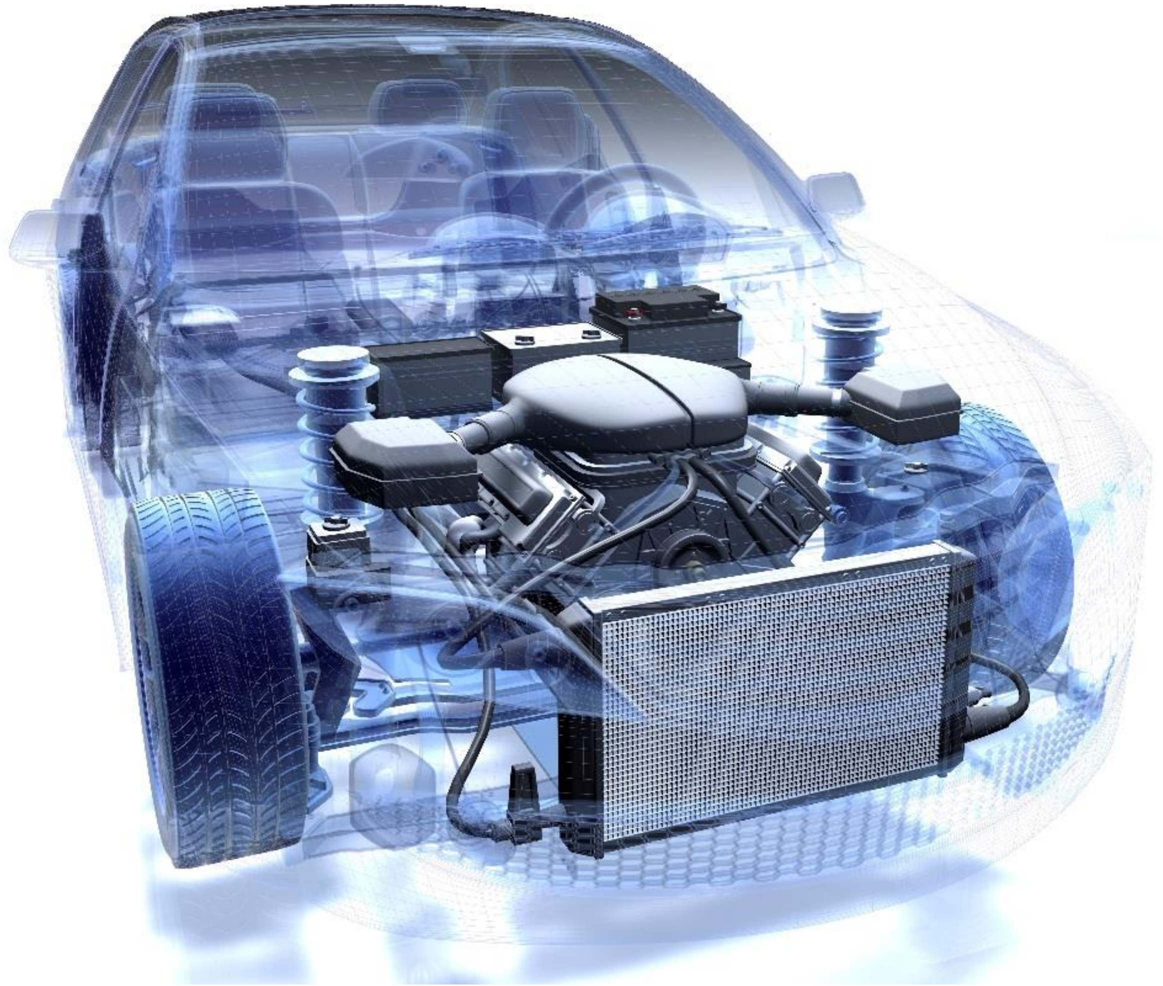
The need for physical modelling

- Automotive products are complex systems covering many domains
  - Mechanical, Electrical, Hydraulic, Pneumatic, Thermal, Chemical, Control, Magnetic, …
- No longer sensible to wait for prototypes to verify that all these systems interact in a good way
- It’s not practical, or perhaps even possible, to fully verify and validate control systems using prototypes
- Need to use predictive models and not just functional ones to make simulation useful from an early stage of the project
- Need a complete virtual test environment



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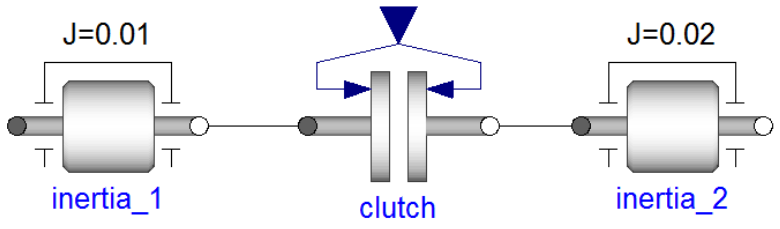
Functional and Predictive models

- A Functional model is one that captures the key function of the model
- A Predictive model allows us to predict the behaviour and explore it's characteristics



- The clutch is there to make sure the two inertias rotate at the same speed when engaged
- Functional model
  - Would reduce the relative speed across the clutch in a predefined manner
  - The controlling parameter would be the engagement time
- Predictive model
  - Would include a model for friction and the torque transfer would be a function of the clutch clamp load, relative speed, temperature, …
  - The parameters would include the geometry and friction characteristics
  - The engagement time could be predicted under different operating scenarios

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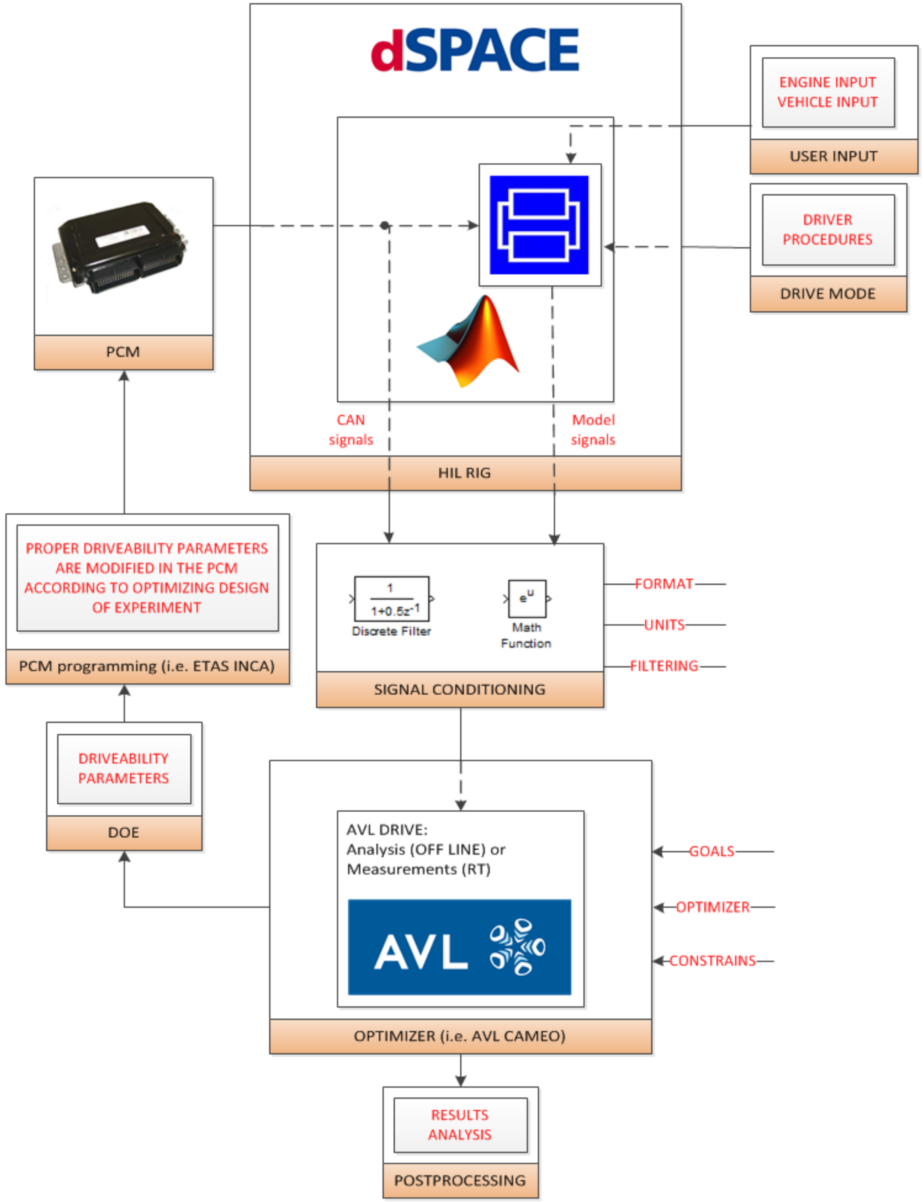
MORSE project

- MOdel-based Real-time Systems Engineering (MORSE)
  - Collaborative research project with Ford and AVL Powertrain
  - Co-funded by Innovate UK as part of the “Towards zero prototyping” competition
    - UK government organisation
  - 2 year project, started in January 2015
- The project is aiming to address some of the challenges of validating the functional requirements of electronic control systems using real-time simulation of multi-domain physical models created in Dymola
  - Models are being developed using the Engines and Powertrain Dynamics Libraries from Claytex



Ford Go Further · AVL · Innovate UK Technology Strategy Board

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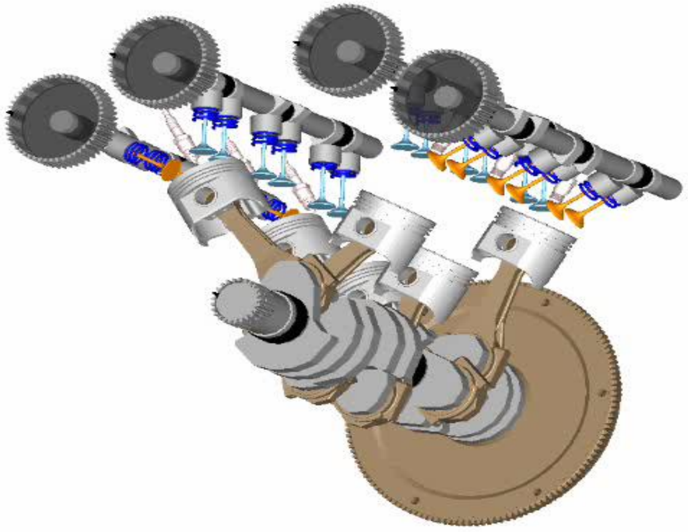
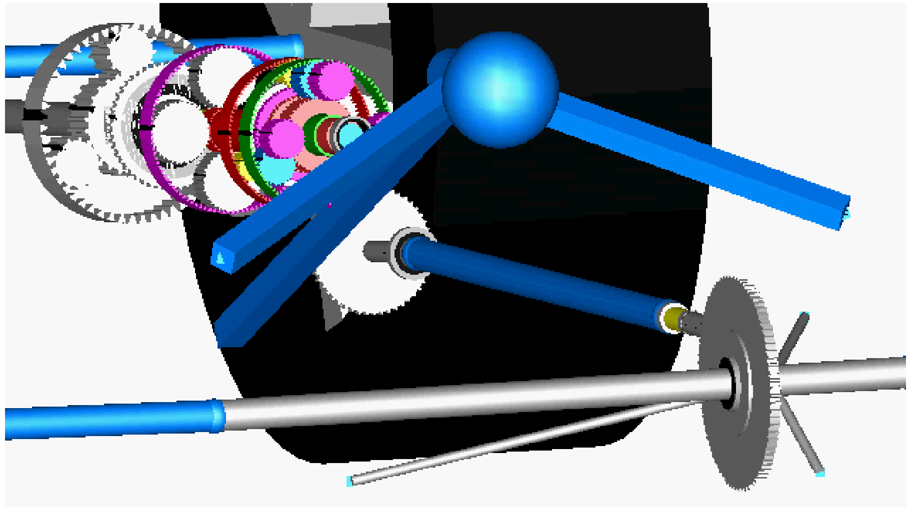
MORSE – Work Packages

- WP1 - Engines Library
  - More predictive combustion model
  - Explore the possibilities for shockwave modelling
  - Enhancements to the cooling, lubrication and fuel system models
  - Performance improvements so that models simulate faster
- WP2 - Powertrain Dynamics Library
  - Addition of thermal effects to all friction models, clutch models, torque converters, etc.
  - Addition of thermo-hydraulic models for actuation
  - Improved gear mesh model to give varying stiffness based on the number of teeth in contact
- WP3 Automatic Model Reduction and Parametrisation Tools
  - Develop ways to easily generate models suitable for HiL based on high fidelity models
  - Develop a tool/method to capture, categorise and set parameters for these large, complex systems
- WP4 – Driveability calibration optimisation process for MIL/SIL
- WP5 – Driveability calibration optimisation process for HiL
- WP6 – Automated Gasoline OBD Validation





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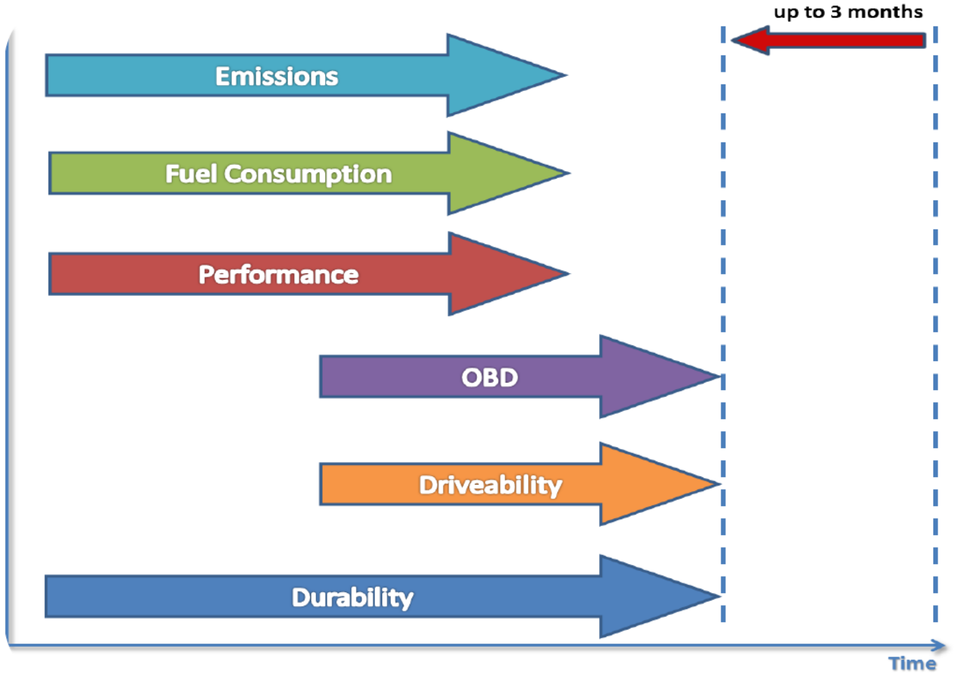
MORSE Benefits

- Develop tools and techniques that use physical models to enable calibration and validation of Powertrain control system to start earlier in the design process
  - Working on SiL, MiL and HiL approaches for driveability calibration in a virtual environment
  - Focus on HiL for OBD validation
- Ford anticipates savings of £1.2m/year in the UK alone
  - Realised through a reduction in the number of physical prototypes required to complete calibration
- Use of AVL DRIVE for virtual calibration of driveability
- Enhancements to the Engines and Powertrain Dynamics Libraries will be included in future releases over the next 1-2 years



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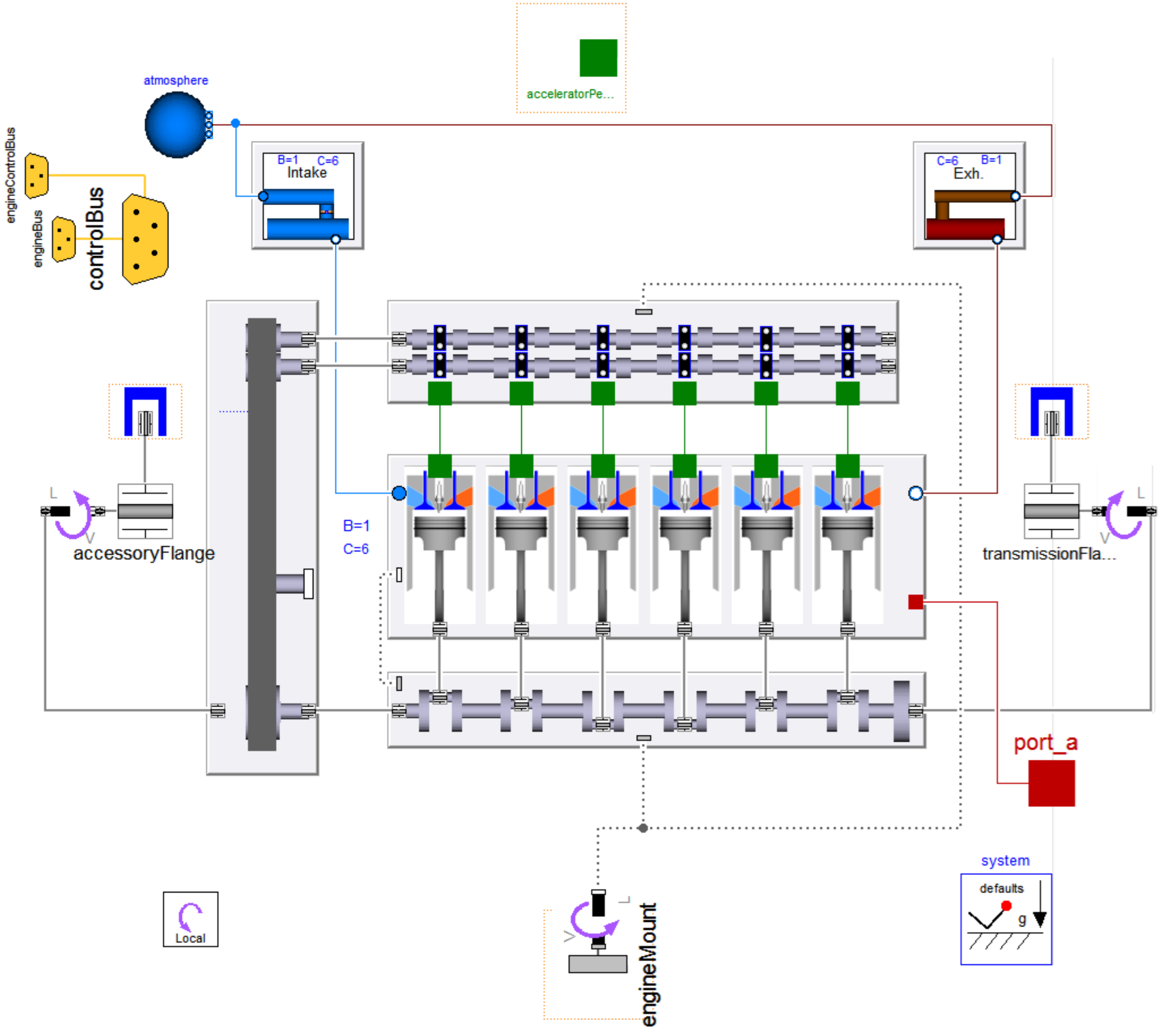
Engines Library

- Mean value and Crank angle resolved engine models
  - Wiebe model for crank angle resolved models
  - Open and expandable making it easy to add your own combustion models
- 1D thermofluid models of intake and exhaust
  - Models for emissions control, turbochargers, superchargers, egr, ...
- Mechanics modelled using 1D/MultiBody hybrid approach
  - Detailed mechanical models possible including all bearings effects, torsional compliance, etc.
- Thermal network to model heat transfer through engine and 1D thermofluid coolant system models
- Engine architecture with templates for various engine configurations
  - Open and extendible to easily plugin new ideas



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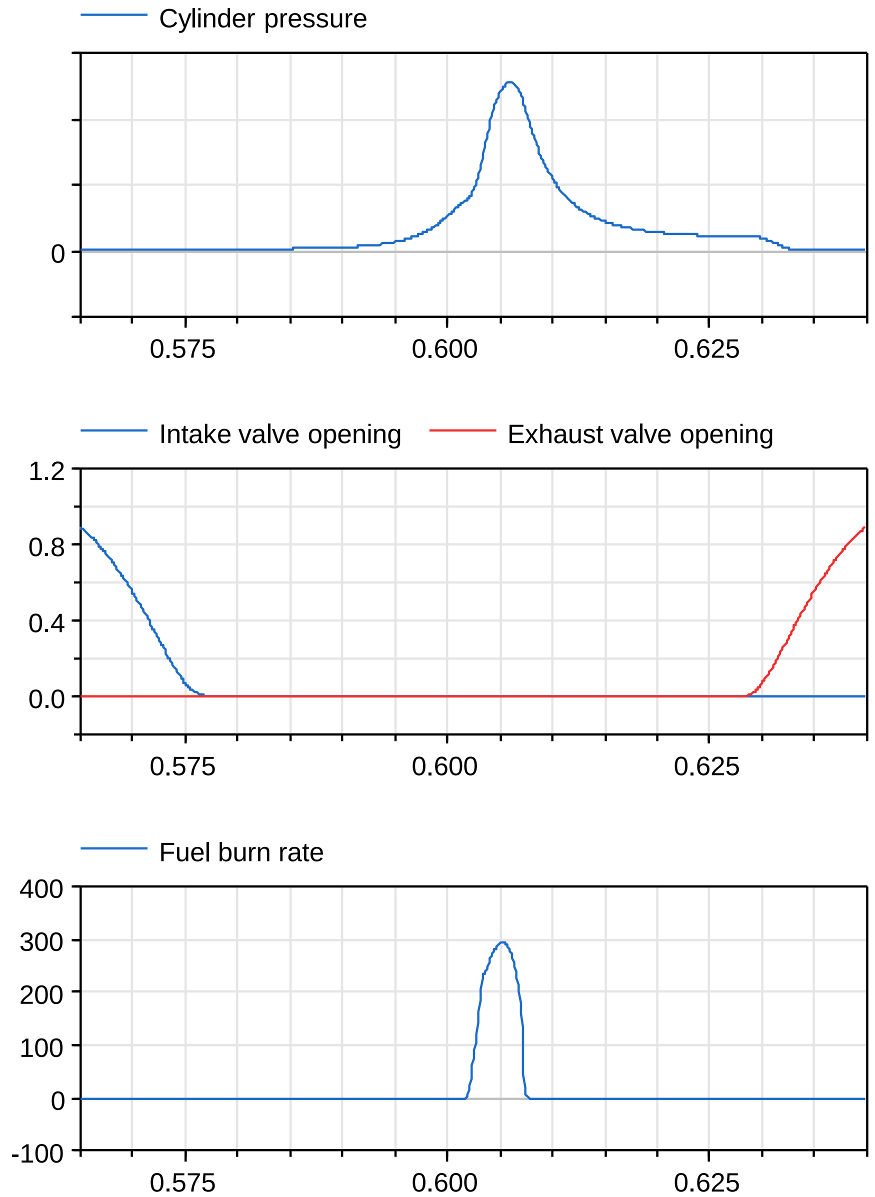
"More Predictive" combustion model

- Major task to support the objectives of the MORSE project
  - We are not trying to develop a completely predictive model as the computation time would be far too slow for our needs
- A predictive model will allow simulation to be used earlier in the development process
  - The model needs to give reasonable results with limited data
  - Must capture the right trends
    - i.e. predict the response to ignition timing changes, afr changes, etc.
- A predictive combustion model has been implemented using entrainment approach
  - Predicts the burn rate for fuel
  - Gives us cylinder pressure, torque, exhaust gas temperature



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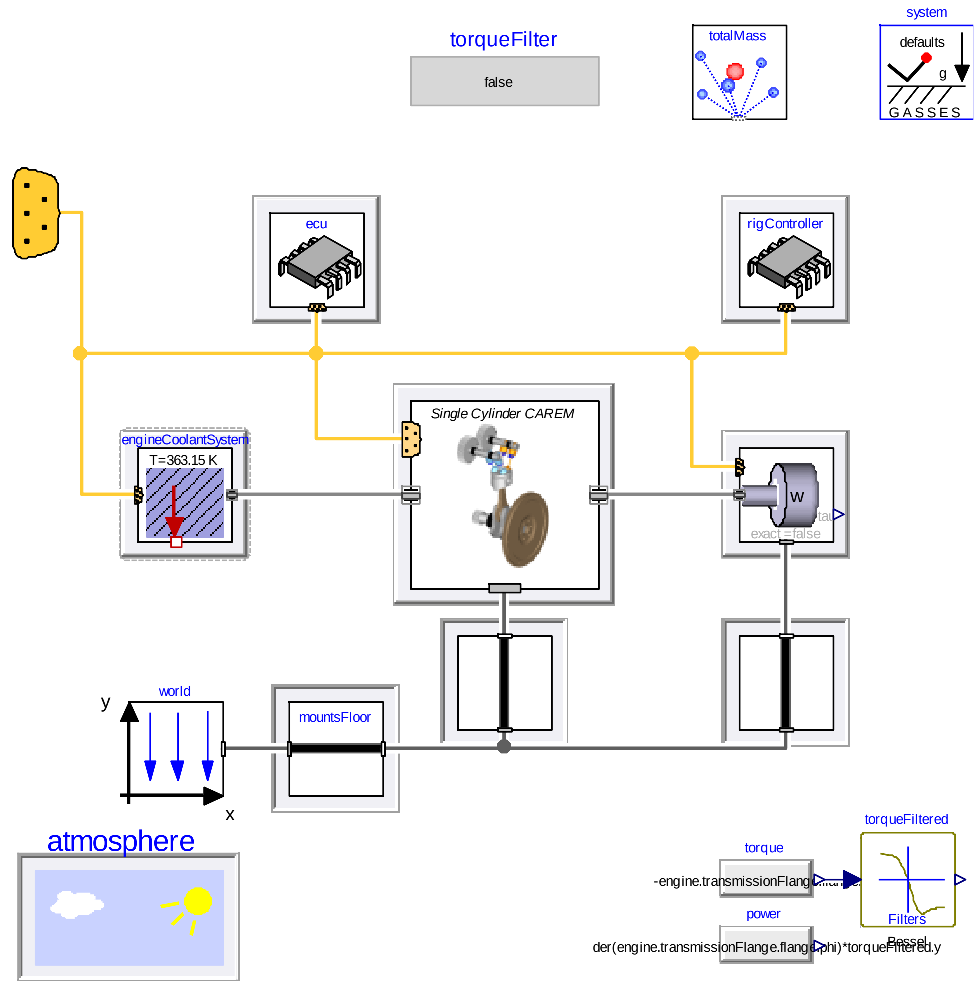
Model details and calibration

- Model includes thermodynamics, turbulence, ignition delay and entrainment factors
  - 39 parameters of which:
    - 10 are geometrical: bore, stroke, bowl diameter and depth, compression ratio
    - The rest cannot be directly measured
- To calibrate the model to a given engine we need test data from a range of operating points
  - Idle, full-load, part-load across the engine speed range
- Complete single cylinder engine model is too complicated to use for this calibration
  - 26559 equations
  - 106 states



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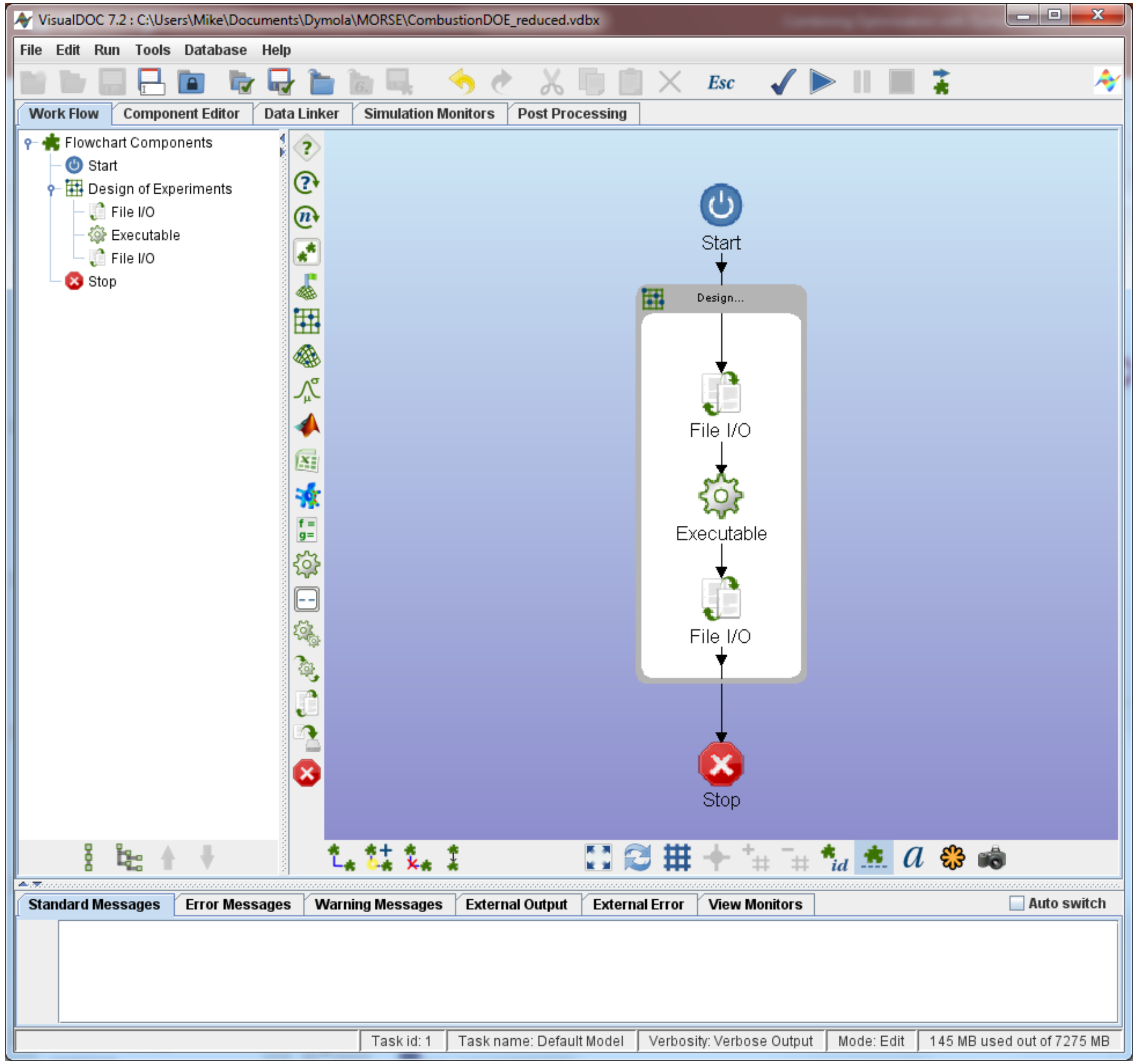
Calibration of the combustion model

- From engine test data we can calculate what the actual burn rate is
- Create a simple model that only includes the combustion model
  - Apply the boundary conditions measured in the tests
  - Calculate the burn rate
- Calibration comes in a number of steps
  1. Understand which of the unmeasurable parameters has the biggest influence on the burn rate
  2. Run optimisation on a small number of operating points to calibrate the "unknown" parameters
  3. Run validation on a larger number of operating points to validate the calibration
- VR&D VisualDoc is being used for the calibration tasks
  - DOE and optimisation tasks
  - Automation of the workflow



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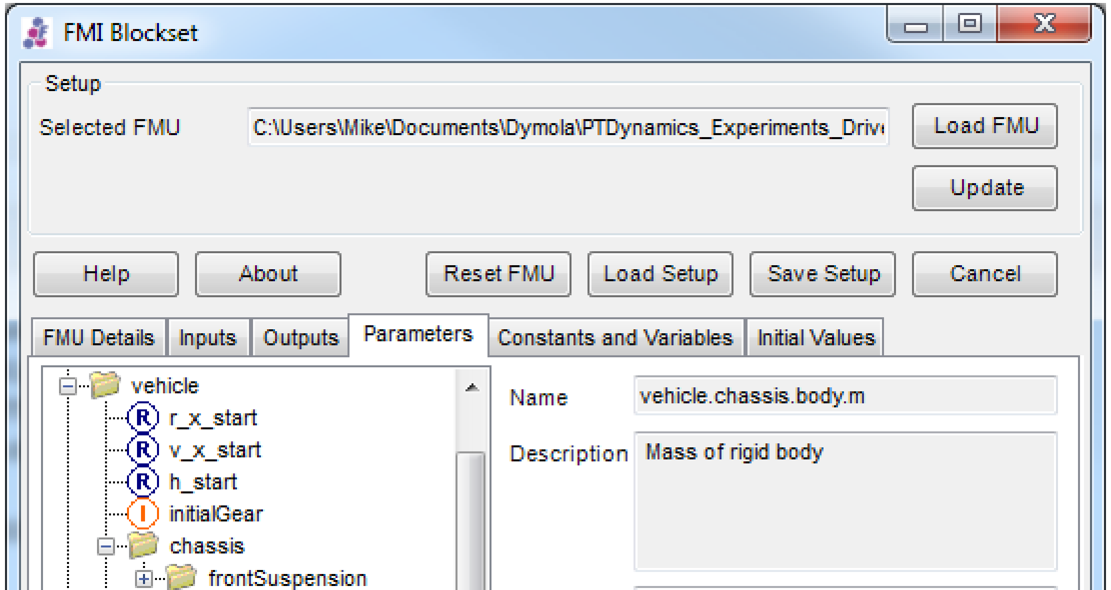
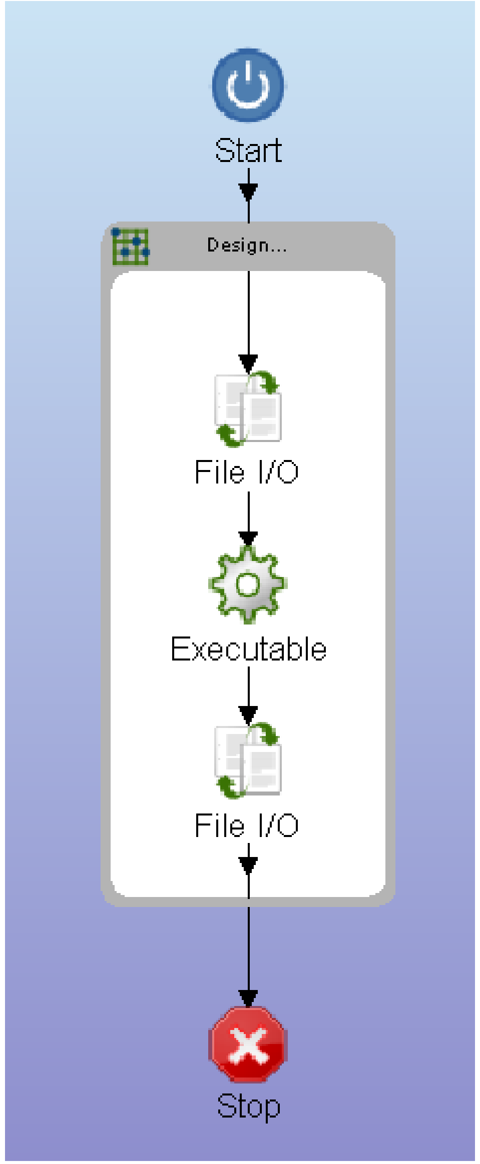
Coupling models to VisualDoc

- VisualDoc provides built-in interfaces to a limited number of 3rd party programmes
  - It does provide the ability to run any executable
  - It can also read and edit information in text files
- Using these capabilities we can couple VisualDoc to our FMI Blockset
- FMI Blockset
  - Developed by Claytex and supports the Functional Mock-up Interface standard
    - FMI is an open standard for model exchange supported by 80 different tools
  - Allows models that are FMI compliant to be simulated in Simulink, Microsoft Excel and directly in Windows





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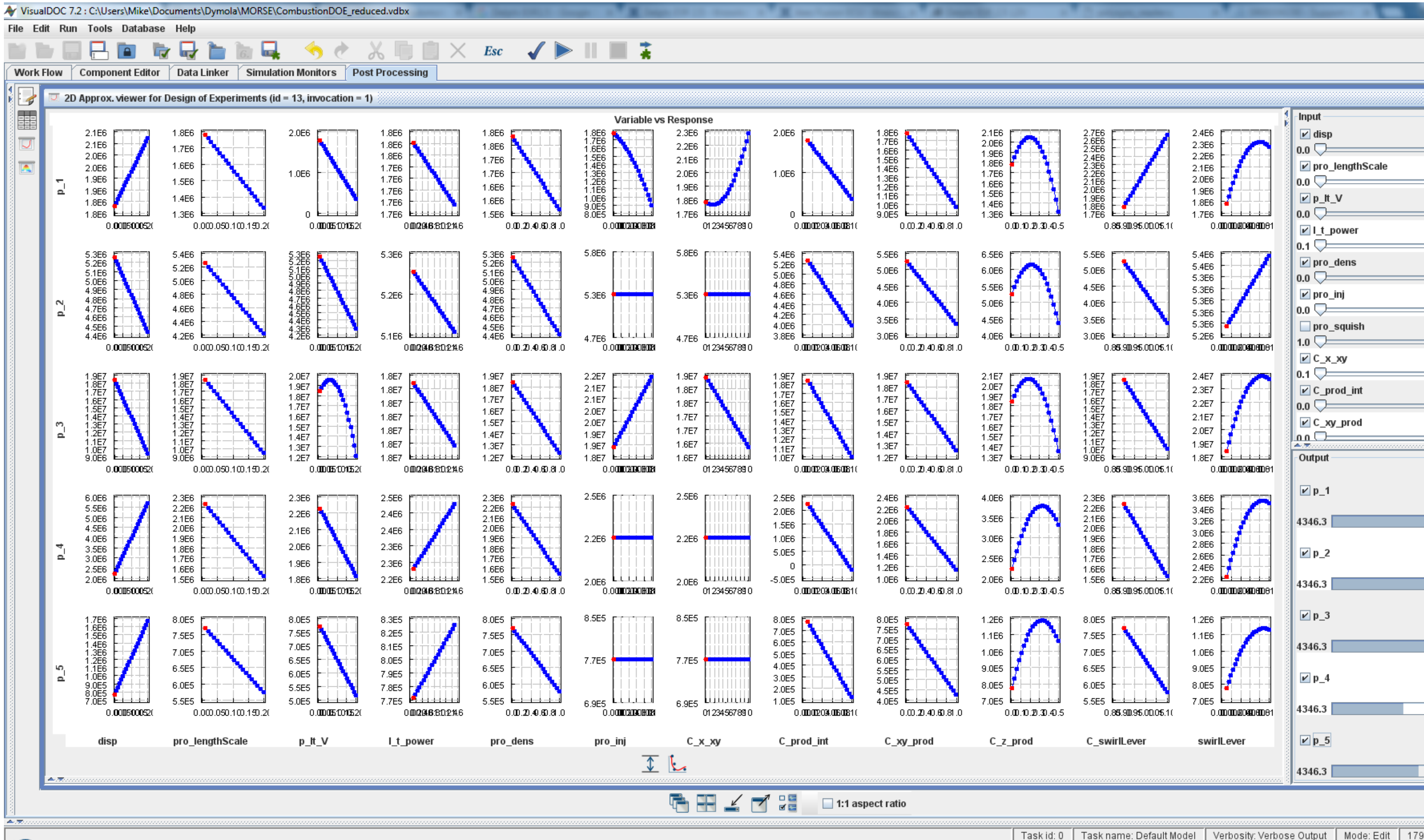
DOE results

- We want to understand which parameters have the biggest effect on different phases of combustion
- Split the combustion process into 5 phases
- Immediately obvious that some parameters do not have any effect on some phases
- Using this information to define the optimisation problem and split it into manageable steps



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Next steps

- Complete the DOE studies to analyse the sensitivity to the different parameters
- Define the optimisation process to calibrate the model using a small number of full and part-load operating points
- Validate the calibration against a larger number of full and part-load operating points
- Use VisualDoc to automate the calibration and validation tasks into one workflow
- Integrate the completed combustion model into a full vehicle model

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Thank you

Mike Dempsey

mike.dempsey@claytex.com
01926 885900
http://www.claytex.com

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