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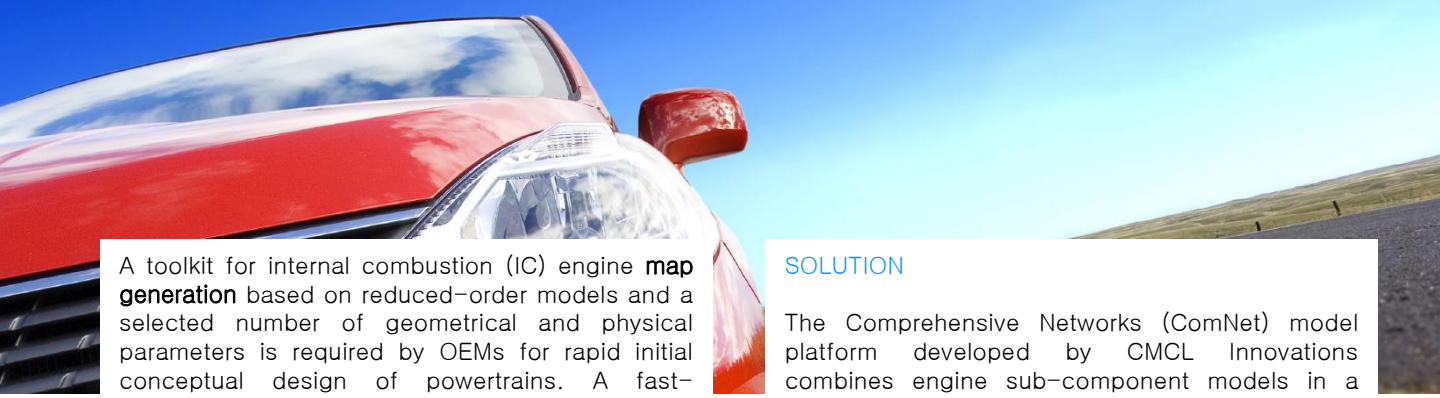
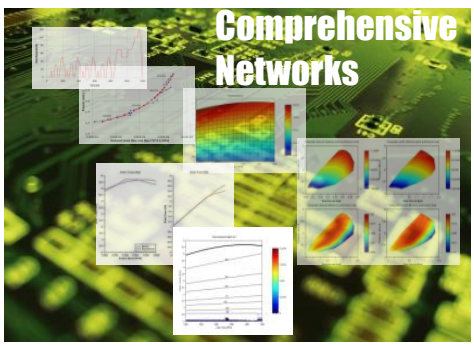
Rapid engine map generation and automatic model calibration for downsized IC engines



A toolkit for internal combustion (IC) engine **map generation** based on reduced-order models and a selected number of geometrical and physical parameters is required by OEMs for rapid initial conceptual design of powertrains. A fast-response model (i.e. low CPU expense) for simulation also finds application in data-driven real-time control systems of vehicles. When coupled with a tool for **sensitivity analysis** and rapid **parameter estimation**, it allows model-based engine development and offers the OEMs the flexibility to design and test new engine concepts and operating conditions.

THE CHALLENGE

- To develop fast-response models to generate engine performance and CO_2 footprint maps for naturally aspirated and downsized engines
- To validate the models against measured engine data using statistical parameter estimation
- To assess the influence of model parameters and operating conditions on the overall model response



SOLUTION

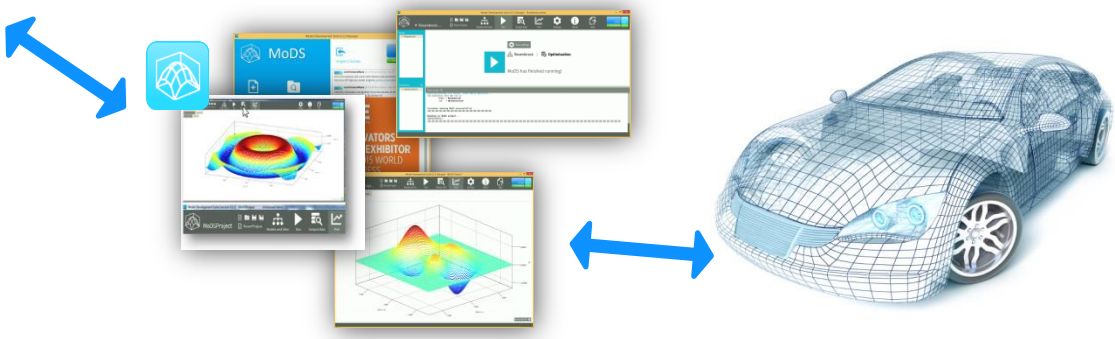
The Comprehensive Networks (ComNet) model platform developed by CMCL Innovations combines engine sub-component models in a comprehensive system. The main sub-components, such as the combustion chamber, the compressor and the turbine, are simulated using **mean value models**.

The use of ComNet, together with a rigorous selection of sensitive design parameters and the implementation of a quick response algorithm for **curve-fitting**, results in a major CPU time reduction while retaining simulation accuracy.

A fully comprehensive range of performance maps is produced for all the subcomponents and the overall system. Fuel consumption, torque and power response to the full range of engine loads and speeds are some of the outputs ComNet can produce.

CMCL's proprietary software Model Development Suite (MoDS) was coupled to provide efficient curve fitting, uncertainty propagation and sensitivity analysis on models developed for different IC engines using the ComNet toolkit.

A progressive down-selection of the most sensitive variables was carried out and led to reduced decision variable arrays and more selective boundaries for the variables. MoDS was then used to perform parameter optimisation, as well as to produce surrogate models to further expand the ComNet tool capabilities.



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RESULT

Very accurate match of engine performance, as shown in Figure 1, coupled with a considerable reduction in computational time, is achieved by ComNet. Engine performance data from a representative automotive engine, in both its naturally aspirated and turbocharged versions, was used in this case for model validation. Simulation of the engine performance characteristics for the full engine operational range is achieved in under 1 sec on a 3.40 GHz Intel® Core ™ processor. In addition to this, ComNet offers the user the flexibility to select between different conventional and alternative fuels, boosting types and fuel injection strategies.

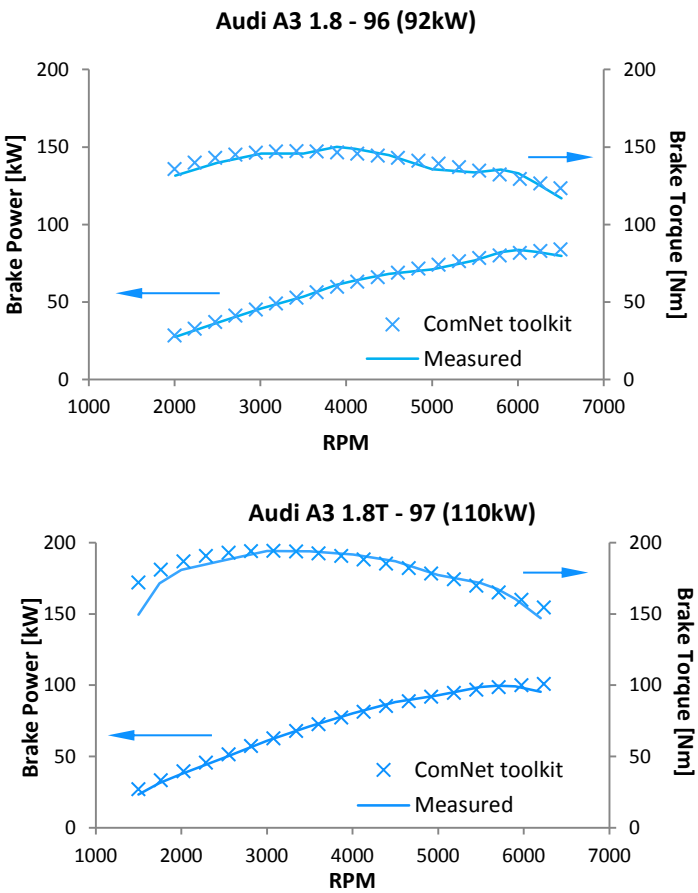

Figure 1: ComNet toolkit response and comparison with measured data from OEMs

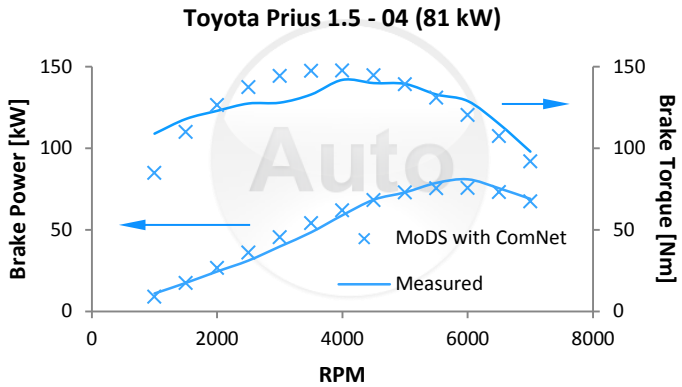

Figure 2: Comparison of measured data from OEMs with maps produced by MoDS with automatic calibration of ComNet

In the examples presented in Figure 1, the match with measured engine maps is achieved by adjusting the model parameters manually. This normally requires a thorough understanding of the engine geometry and operating conditions, and a lengthy search of the relevant parameters and calibration.

In Figure 2, this exercise of model calibration is automated by coupling ComNet with MoDS, by setting initial values for the system variables and parameters, and conservative boundaries for them. This procedure does not require specific expertise in engine design and computational modelling. Without performing any manual tweaking of the model parameters or implementing any lengthy trial and error methods, the coupling of MoDS with the ComNet executables leads through a limited number of iterations, and a considerable shorter time, to the selection of the most sensitive manipulated variables. Through the implementation of its built-in statistical analysis and optimisation tools MoDS is also able to identify local and global minima of the integrated models, and achieve a good match with the target maps.

- A mean-value model-based tool for the rapid design of internal combustion (IC) engines was developed for implementation in engine's initial concept design and vehicle's driveline control.
- The mean-value model coupled with MoDS offers automated parameter estimation, uncertainty propagation and sensitivity analysis.

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