

Model-based Real-time Systems Engineering

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ABSTRACT:

Automotive manufacturers face enormous pressure to increase the range of vehicles/technologies that they offer. In this competitive environment any advances in simulation and virtual engineering offer significant advantages, especially when they reduce the amount of physical testing required. The Model Based Real-time Systems Engineering (MORSE) project looks to push simulation based virtual engineering into new areas to help meet the challenge.

MORSE is collaboration between Ford, AVL and Claytex. The final system to come out of the project will consist of a Powertrain Control Module (PCM) model/hardware, sensor and actuator interfaces and vehicle network model provided by Ford, which will link to a HiL or SiL system running state-of-the-art physical models of both the engine and vehicle (developed by Claytex). AVL will then use their industry standard driveability software (AVL Drive) to assess the vehicle performance. This real-time system will then be used to push the boundaries of virtual engineering to calibrate and validate both new engine diagnostic features and also to develop an automated process to calibrate driveability features that would normally require physical testing.

In this paper we will introduce the technical approach taken in the MORSE project and present some initial results from both desktop based (SiL) tests and the real-time HiL environment. The results presented demonstrate the potential impact of this project in terms of shifting product development efforts towards the virtual environment.

Keywords— Combustion Engine Modelling, Driveline and Transmission Modelling, Hardware - in-Loop testing, Performance / Drivability.

1 INTRODUCTION

MORSE is a two year collaborative project led by Ford in collaboration with the AVL UK and Claytex; co-funded through InnovateUK's Towards Zero Prototyping competition. The aim of the project is to develop predictive engine and vehicle models enabling virtual calibration of driveability control features and validation of On Board Diagnostics (OBD) fault paths. Coupled with advanced tools for model reduction and lifecycle management, MORSE aims to bring virtual calibration to the front of the product development process.

2 MOTIVATION AND BACKGROUND

A modern vehicle may contain 100 Electronic Control Units (ECUs) and 100 million lines of code [1]. The only way to achieve full code coverage and prevent / detect faults in early stages of a vehicle program is by Model-Based Systems Engineering and automated simulation based testing.

Driveability describes the qualitative assessment of the vehicle's response to the driver's input. OEMs face many challenges in delivering driveability, e.g. provide a high driveability quality level for conventional, hybrid and other powertrain concepts, handle the trade-off between emissions, fuel economy, performance and driveability, guarantee an agreed vehicle character (brand DNA), reduce time to market and reduce development costs.

Frontloading of driveability development activities from road, chassis dyno and engine test bed to SiL and HiL lead to a reduction in vehicle testing and number of required prototypes, thus saving costs. Simultaneous driveability development in early phases leads to improved quality and with computer based automatic optimisation, even in a shorter time [2] – [3].

OBD calibration complexity is also growing rapidly; it is no longer possible to carry on using traditional vehicle based test and calibration methods. Not enough prototype vehicles and engineering time are available to complete all required test cases. New sensors and actuators have resulted in increased plausibility diagnostic software and increased Comprehensive Component Monitoring (CCM) content; additionally emission control components are subject to legislation requiring comprehensive and well documented test cases.

Different networks and vehicle interfaces also pose some challenges, e.g. the same engine and PCM (Powertrain Control Module) may be used in different vehicle platforms, different or additional fault paths due to network and vehicle variation and Start / Stop feature comes with additional but also different interfaces, depending on the vehicle.

Having the same vehicle and engine in different markets also means dealing with emission legislation variations and market driven feature content. These result in different software and calibration content requiring additional tests.

Limited time and prototypes to cover all applications and variations mean automation and flexible test environment are essential. To achieve driveability development and OBD testing via fault insertion into the component and system models a flexible modelling environment which allows model classes of different fidelity but with common interfaces is also required.

3 MODELLING ARCHITECTURE

Due to the complexity of physical models involved in this project a new modelling architecture was developed to allow simulation where different parts of the model are allocated to the different cores of the HiL real-time processor. The dSPACE HiL platform which is utilised in this project limits splitting to the top level of the Simulink model. This means the standard Vehicle Modelling Architecture (VMA) [4] previously used by Ford had to be changed in order to take advantage of multi-processor capabilities of the dSPACE HiL simulators. Additionally models of this complex nature require standard input/output interfaces so that each subsystem can be tested separately before final integration. Defining standard subsystem input/output interfaces also provides the possibility of using different modelling resources. For example in certain applications an engine model developed in Simulink may be used. Where using a physical model provides advantages (e.g. OBD fault paths) a Dymola version of the engine model can be integrated without any change in input/output interfaces. To achieve this detail of interface; signals including their time based or angular based behaviour must be defined as part of the standard.

4 DRIVER MODEL

A driver model is necessary to place the plant model in the correct state for calibration purposes, including performing the complex manoeuvres used during driveability assessment. It is also

necessary to ensure the driver model can flexibly operate in many modes, both manual and automatic, to be able to change the drive mode or test cycle live during SiL/HiL operation. This will help the end-user to avoid stopping a test in order to recompile the model when changing the desired drive cycle.

4.1 Simulink/Stateflow driver model

The creation of the driver model has been carried out in Simulink in such a way that a new manoeuvre or drive cycle can be selected and executed at any point in time. By making extensive use of Stateflow charts, the system remains intuitive and readable.

Feedback signals from vehicle model (such as vehicle velocity and acceleration, engine speed, gear selected) are used to allow the driver to work intelligently, modifying the pedal positions to perform the desired manoeuvre.

4.2 Structure of manoeuvres

The end user has a number of manoeuvres, or cases, which can be selected within the model. The user will have an integer parameter that can be used to select different cases within the model, implemented using a standard “case selector” block in Simulink.

4.3 Stateflow state-machine

Separate Simulink Stateflow state-machines are used to implement the drive manoeuvres. Each state-machine contains an initialisation procedure to place the vehicle and engine into a suitable state to begin the desired test. They also contain an exit procedure to ensure the vehicle and engine are returned to a safe and steady state to allow smooth transition between manoeuvres.

5 MODEL TEST HARNESS

The MORSE project involves linking together a number of complex elements to create the complete system. To help with this process AVL created test harnesses for the engine and vehicle models to enable systematic model validation.

When a new version of the engine or vehicle plant models has been created, it is taken through a process to sign it off as ready to integrate with the rest of the system. The first step in the process is to test the model using the harness in Simulink, with the Dymola plant model embedded as an S-function (vehicle or engine), using the correct fixed step solver. If this initial test is successful

an FMU version of the Simulink model is built and the same test of the vehicle or engine is performed in Dymola in closed loop with a fixed step solver. Finally, to complete validation of the model, we compare the results from both environments and make sure there are no errors, as well as assessing the Real Time capability of the model.

5.1 Vehicle Test Harness (VTH)

The Vehicle Test Harness is created based on carrying out a full Tip-in/Tip-out procedure. This procedure was selected as the validation test case as it involves a combination of important processes. The initial portion of the test is used to validate engine start and pull away. After initial pull away the vehicle changes gear (allowing assessment of the shifting behaviour) before beginning the tip-in/tip-out manoeuvre which is used to assess the vehicle performance during acceleration and deceleration. The core tip-in/tip-out sequence is repeated over several gears and pedal positions. At the end of the scenario the vehicle returns to a standstill condition and idle operation can be examined. The test is repeated in Dymola and the results between the two environments are compared. Figure 4 shows a near perfect overlay of the results from Simulink (red) onto the results from Dymola (blue.)

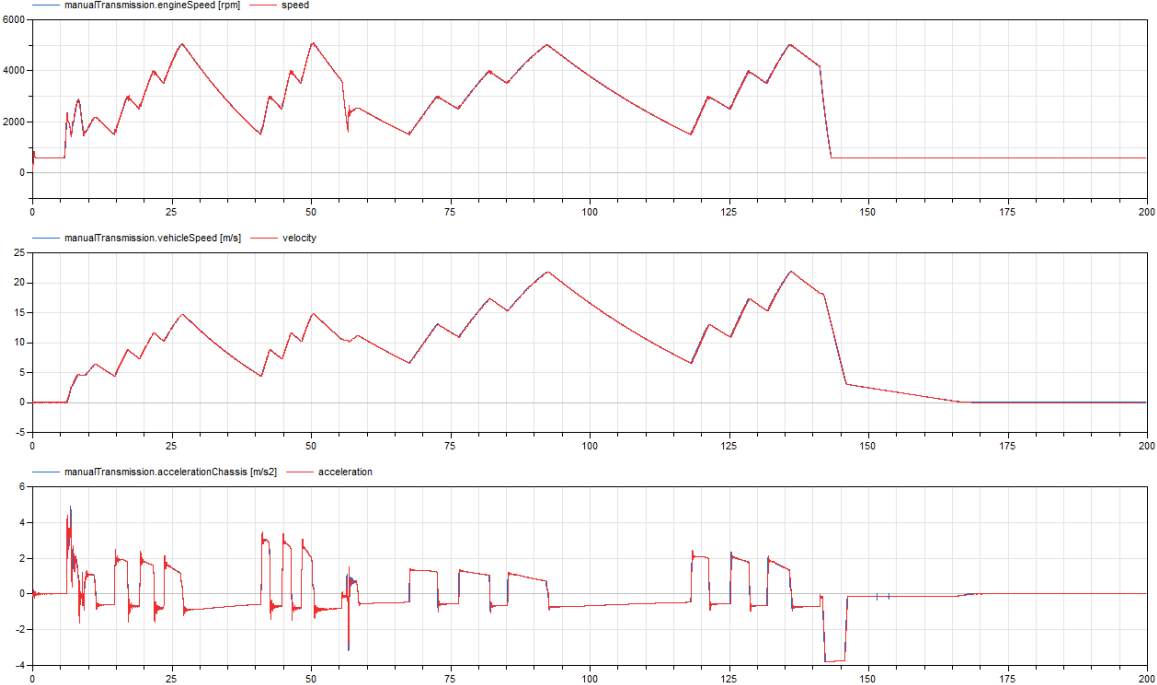


Figure 4: VTH results with comparison

5.2 Engine Test Harness (ETH)

Significantly greater complexity is required in the AVL Engine Test Harness as it must support an I/O interface that is compatible with the Ford PCM. The correct signals must be generated for the multitude of sensors and actuators present on a modern ECU, some of the most complex include injection, spark and cam timing.

The test harness verifies vital engine behaviour, for example engine start, stable idle operation by controlling throttle position (based on engine speed and throttle downstream pressure), Deceleration Fuel Shut-Off (DFSO), engine shut-off and engine restart. To achieve this, the test harness itself must have a certain level of complexity and includes a simple dyno model, which can apply a torque to control the engine to a target speed. The ETH also controls the fuel mass based on engine feedback of manifold conditions, volumetric efficiency and a lambda target.

6 AUTOMATED AVL DRIVE ASSESSMENT

The test system, consisting of a modern engine control unit and advanced physical plant models, enables new areas of virtual calibration. AVL's aim is to create tools and processes that leverage these capabilities to enable automated optimisation of driveability calibration. However to achieve this, it is important to correctly identify the interfaces between all the different software packages and ensure the exploitability of this area of the project for both AVL and Ford.

6.1 Flowchart and process description

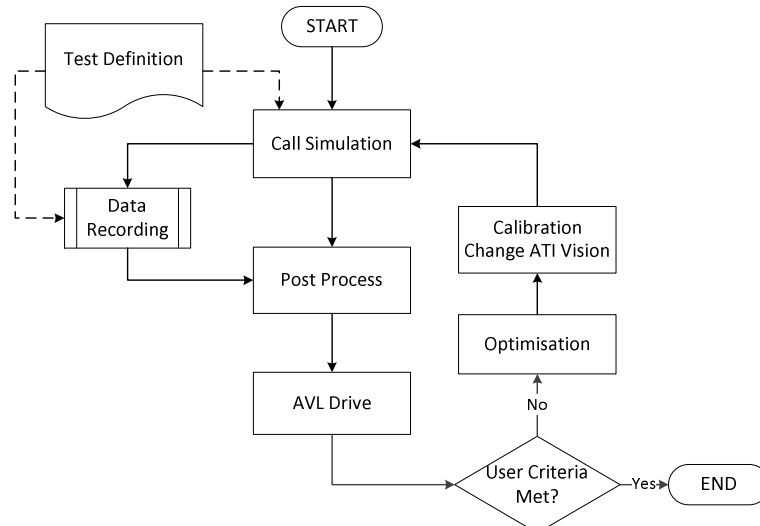


Figure 5: Automation flowchart.

Firstly, results from the simulation environment need to be extracted and presented to the analysis tool (AVL DRIVE) in a suitable format. Secondly AVL DRIVE generates the objective driveability ratings. Finally, a new optimisation process must interpret the analysis of simulation results and turn this into an updated set of test parameters, which can then be pushed to the PCM via a calibration tool to enable re-running of the simulation until a user criteria is met.

The process involved is entirely new, and must be capable of interfacing with many platforms including AVL DRIVE, AVL CAMEO, dSPACE AutomationDesk, Matlab and ATI Vision. Figure 5 shows a representation of this process.

6.2 Automated assessment in the MIL/SIL environment

A partial assessment of the proposed driveability optimisation process has been performed in the MIL/SIL environment. A MATLAB routine has been developed and used to run the SIL workspace with pre-defined settings through a selectable scenario (NEDC cycle, tip-in/tip-out etc.) The simulation outputs are then captured at the end of the manoeuvre and automatically trigger assessment using AVL DRIVE. After assessment, the drive ratings (DR) are used to calculate a new PCM calibration, which is fed into the SiL workspace before beginning the next iteration.

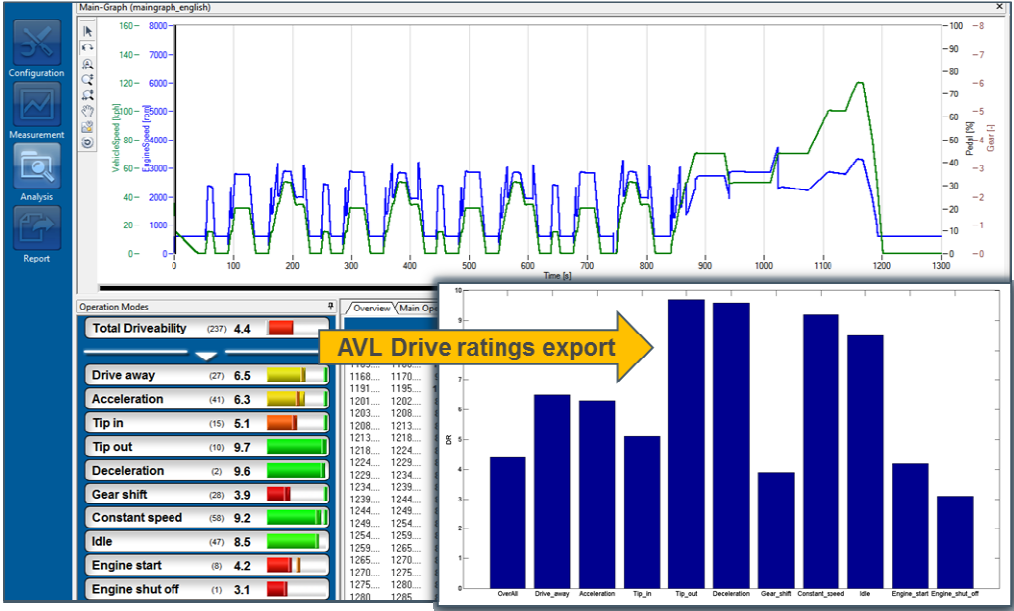


Figure 6: AVL DRIVE assessment on a NEDC simulation

7 VEHICLE MODEL.

The vehicle model is built on the VehicleInterfaces library standard from Modelica Association. All models use Multibody components and are designed for easy assembly and efficient comparison.

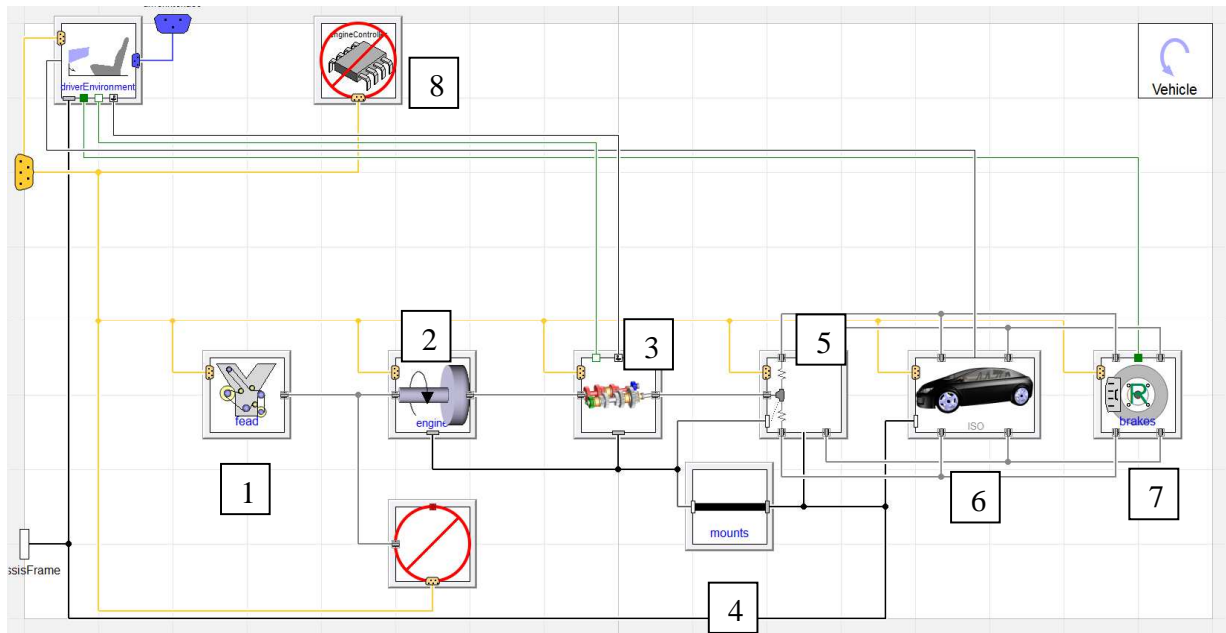


Figure 7. Vehicle model: 1. Accessories, 2. Engine, 3. Transmission, 4. Mounts, 5. Driveline, 6. Chassis, 7. Brakes, 8. ECU

This vehicle model has a manual transmission, a compliant driveline, rigid mounts and a torque source as an engine. A mapped engine in Simulink outputs a torque signal to feed the torque source. The ECU is not included in the Dymola model, a Simulink controller or the Ford controller will be used instead, depending on the application.

8 ENGINE MODEL SPLITTING

The internal combustion engine model developed in Dymola has been revised to be split into separate portions so that any number of portions can be run on a separate core. The benefit of this approach is not only to distribute the CPU loading on several cores but also to be able to run portions of the model at different solver rates. This would allow the combustion model to run at a potentially higher rate on a dedicated core whilst subsystems accepting a larger time step could run separately on additional cores.

The engine model is split into 3 parts: air-paths, combustion and mechanics. Currently the combustion model and mechanics are running at 0.2ms time step. The air-paths currently require robustness improvements to be able to increase the time step with respect to the combustion and mechanics.

9 WORKFLOW UTILITIES

9.1 Automated model reduction.

We need to reduce the vehicle models in order to have them to run in real-time. We take the advantage of the test conditions to make some assumptions that will allow us to make simplifications in the model that will preserve the required detail in the results. Since all the tests we are interested in (Gear Shift, Tip In Tip Out, etc.) are straight-line manoeuvres, we assumed that the results will be the similar for the left and right hand side of the vehicle. A series of tests in Dymola confirmed this.

The main model reduction in this case happen in the chassis and driveline models. The front right and rear right suspensions are removed and replaced by a force source fed with the force calculated respectively in the front left and rear left suspension models. The same is done to the drive shafts: the right one is replaced by a torque actuator which receives as an input the torque calculated the left drive shaft. In the same way, only one brake model is kept in the reduced model.

To reduce the transmission model, we developed a function that runs the detailed transmission over a range of speeds and loads in each gear and then gets the losses and inertia for all working conditions. The parasitic and efficiency losses together with the inertia are then lumped into a component in a simple gear set model that uses a variable ratio to change gear.

In all scenarios the models still retain physical representation of mechanisms and are not reduced to transfer functions. This allows parameter values to be editable even after the model has been compiled to alter or tune system characteristics.

Thanks to conditionally enabled/disabled components, we can switch between normal/reduced models in just one click.

9.2 Parameter tool

Parameter values for model can be difficult to retrieve but more importantly, it is inefficient to manually compile lists of parameters, units and descriptions to send to the relevant departments within an organisation. To aid this a parameter handling tool has been developed where an FMU (Functional Mock-up Unit) of a model is generated and used for the extraction of all parameter names, values and descriptions using XML format. Parameter filtering is also possible in relation to the model use and criticality of having accurate values.

Within the tool user interface, the user has access to all the model parameters which are displayed in a tree that follows the model hierarchy. New parameter values can be saved and reloaded into an automatically extended Modelica model. The model can now be run with revised parameter values.

Criticality of parameter value accuracy is obtained through DoE (Design of experiments) exercise which is performed with Visual DOC prior to the parameters being extracted using the parameter tool. The DoE study allows the parameter list to be focused on the most critical parameters for the models to run with and yield a reduction in efforts which would otherwise be expended to retrieve all parameters within the models whether critical or not.

10 CONCLUSION & FUTURE WORK

Currently we have a physics based vehicle model running in real time which will be coupled to a split engine model as described in the Workflow Utilities section. Issues due to communication between coupled s-functions are being surmounted and we are now in a good position to deliver real time capable models to SiL and HiL testing.

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