Vehicle Systems Modelling and Analysis (VeSyMA) Platform

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Abstract

The Vehicle Systems Modelling and Analysis (VeSyMA) platform is a suite of compatible Modelica libraries for modelling automotive vehicles and their subsystems, where the complexity can be tailored to the user's requirements.

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1 Introduction

In this industrial paper we will look at the Vehicle Systems Modelling and Analysis (VeSyMA) platform developed by Claytex. This suite of Modelica libraries was created to provide a modular approach to vehicle modelling, where the user can tailor the complexity of the model to meet their specific needs.

The foundation of this capability is the VeSyMA library which provides the architecture of the vehicle, and the base classes for the vehicle subsystems. It builds upon the open-source Vehicle Interfaces Library (Modelica Association 2018).

The VeSyMA extension libraries then provide more detailed modelling capabilities in specific subsystem and domain areas; such as engines, powertrain and suspensions. Because the VeSyMA extension libraries use the base classes from the VeSyMA library, all the models created are compatible.

Currently the VeSyMA platform[1] consists of the:

- VeSyMA library
- VeSyMA – Engines
- VeSyMA – Powertrain
- VeSyMA - Suspensions
- VeSyMA – Motorsports
- VeSyMA – Drive-in-the-Loop
- VeSyMA – Terrain Server

In the following sections we examine the capability that each of these libraries give the user.

Users can see the Modelica code behind the models in the VeSyMA platform, so they can fully understand how a component is modelled. Users can therefore adapt models to suit their purpose as necessary.

The VeSyMA platform was built on the concept of subsystem models being parameterized individually and then used as 'off the shelf' models to build the complete vehicle model.

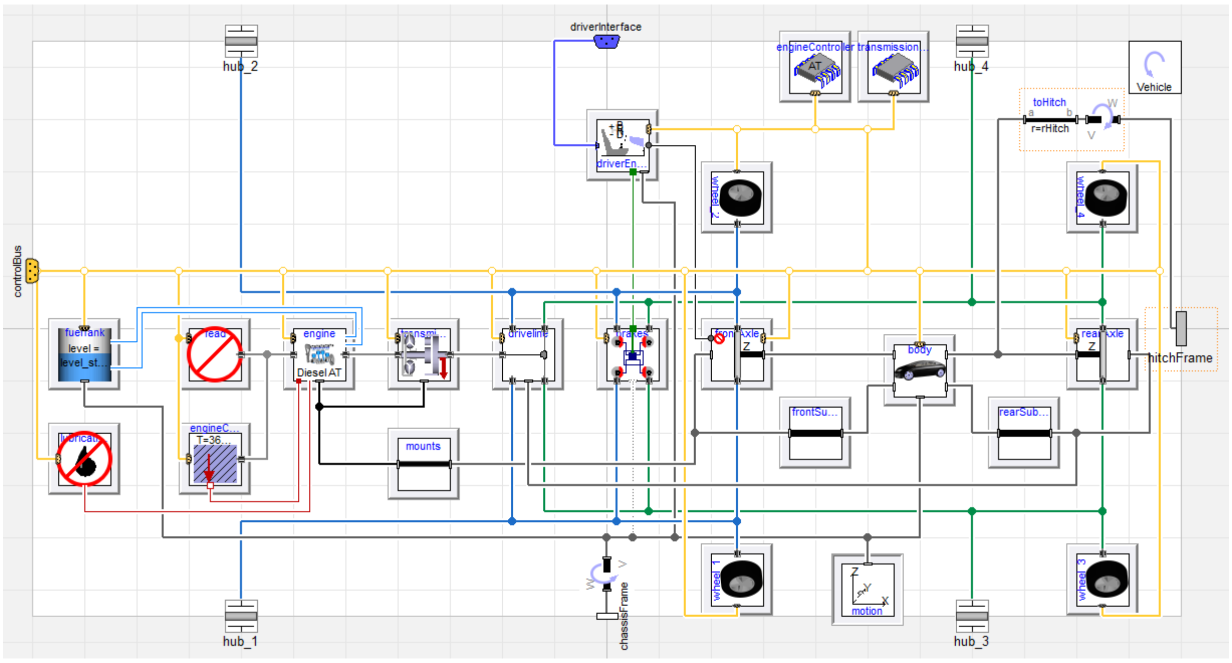

Figure 1. Large, diesel, automatic car model from the VeSyMA library

[1] At the time of publication, the VeSyMA platform is at version 2018.1

2 VeSyMA

The VeSyMA library is the cornerstone of this vehicle modelling platform. It contains vehicle templates for most common vehicle configurations, including internal combustion engine, hybrid and electrically powered vehicles. The subsystems in these vehicle templates are replaceable. As all the VeSyMA platform libraries use common bases classes, the user can easily populate the vehicle model with subsystems derived from any of the VeSyMA platform libraries.

In addition to defining the model architecture, the VeSyMA library includes a collection of idealized subsystem models. This means that vehicles suitable for performing longitudinal studies and drive cycle analysis can be built purely from components from this library. The library includes a set of vehicle examples of various configurations. Figure 1 shows the rear wheel drive, automatic, diesel, large family car example from the library.

The idealized subsystem models can be combined with detailed subsystem models built from the VeSyMA extension libraries to build a complete vehicle model (Ensbury *et al.* 2018). This allows the detailed subsystem to be tested in a vehicle with minimal effort.

The vehicle experiment templates allow the vehicle to be integrated with an open or closed loop driver. Figure 2 shows a New European Drive Cycle (NEDC) test of the vehicle model from Figure 1. There is also the option for the vehicle to tow a trailer if required.

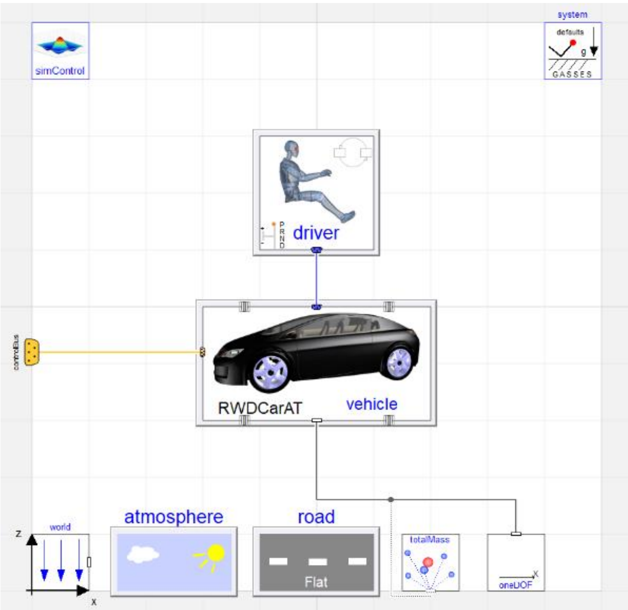

Figure 2. Drive cycle test using the closed loop driver

3 VeSyMA – Engines

The VeSyMA – Engines library is focused on internal combustion engine modelling, providing 2 levels of detail:

- Mean Value Engine Model (MVEM)
- Crank Angle Resolved Engine Model (CAREM)

The MVEMs are used to predict the cycle averaged performance of the engine, permitting fast simulation. The combustion and emissions models are map based using manifold pressure and engine speed as the primary inputs, with further corrections for spark timing and air-fuel ratio. The air mass flow rate through the engine is calculated based on a function which permits reasonable scaling of the engine displacement.

The CAREMs predict the instantaneous torque and air flow through the engine. The combustion heat release is based on the Wiebe model, where tables define the Wiebe coefficients at different engine speeds, loads and air-fuel ratios. Where a predictive functionality is required, the user can select a two-zone predictive combustion model in place of the Wiebe model. Both heat release models include knock prediction. Flow through the engine block is dictated by the valve geometry and opening characteristics as well as the piston-cylinder assembly model. Valve and spark timing effect the fluid dynamics and combustion model. Figure 3 shows the diagram of one of the CAREM examples.

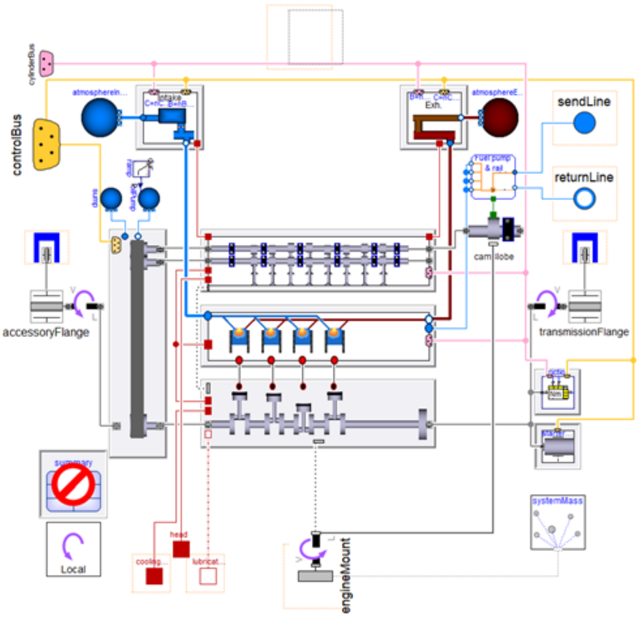

Figure 3. I4, 1800cc, spark ignition, naturally aspirated CAREM with hydraulics based variable cam timing and high-pressure fuel pump

Engine model simulation performance can be improved using surrogate models, where a multi-cylinder engine is represented by a single cylinder with flow and torque replication for the other cylinders.

Both MVEM and CAREM variants use the same engine templates with common intake, exhaust and mechanical components.

The VeSyMA – Engines library supports both naturally aspirated and forced induction engines. With turbocharger, supercharger and intercooler components in the library.

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Emissions are modelled using a map based approach. The exhaust model can include emission treatment devices such as catalytic converters, selective catalytic reduction, ammonia slip catalyst and diesel oxidation catalyst.

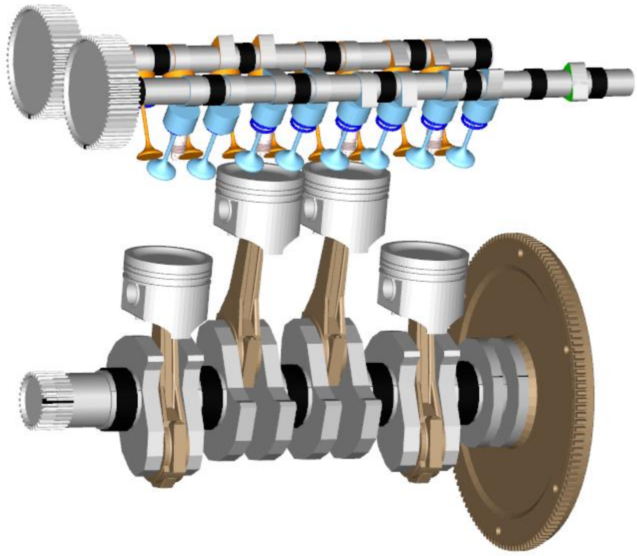

Figure 4. Dyno test animation of a CAREM with hydraulic inlet variable cam timing

This library contains a collection of parameterized MVEM and CAREM examples for a variety of engine configurations. The library provides a dynamometer experiment, allowing both steady-state and transient testing. The dynamometer can also be used to represent a chassis dyno. Figure 4 illustrates the animation from a dynamometer test of a CAREM example.

4 VeSyMA – Powertrain

The VeSyMA – Powertrain library focuses on the modelling of transmissions, gearboxes and drivelines using the same efficient, multibody systems used in VeSyMA – Engines. The library contains advanced models for:

- Shafts
- Bearings
- Gear meshes ranging from ideal to ones with backlash and mesh stiffness
- Flexible joint components

There are complex assemblies, such as epicyclic gearsets and differentials, as well as mounting systems. Figure 5 shows the dual-clutch example from the library.

VeSyMA – Powertrain models capture the full motion of the powertrain on its mounts to allow the vehicle response to be examined for drivability studies (Gillot *et al.* 2017). The library includes examples of idiot start, standing start and tip-in vehicle experiments.

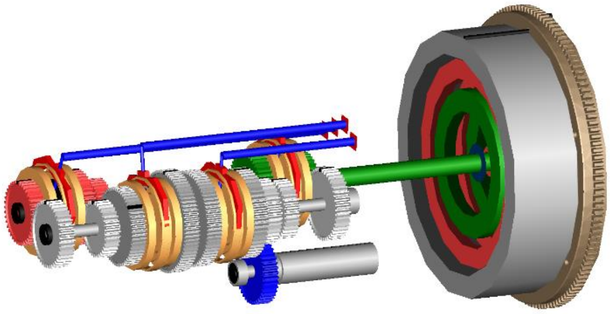

Figure 5. Dual-clutch transmission

5 VeSyMA – Suspensions

The VeSyMA – Suspensions library focuses on modelling the suspensions subsystems to perform vehicle dynamics analysis.

There are multibody suspension models of common road car suspension configurations; MacPherson, double wishbone, multilink, multilink hybrid, trailing arm and trapezoidal. These models can use ideal joints, or bushes and flexible bodies; Figure 6 show a front double wishbone linkage with ideal joints. There are double wishbone examples using aggregate joints, which have been optimized for real-time simulation.

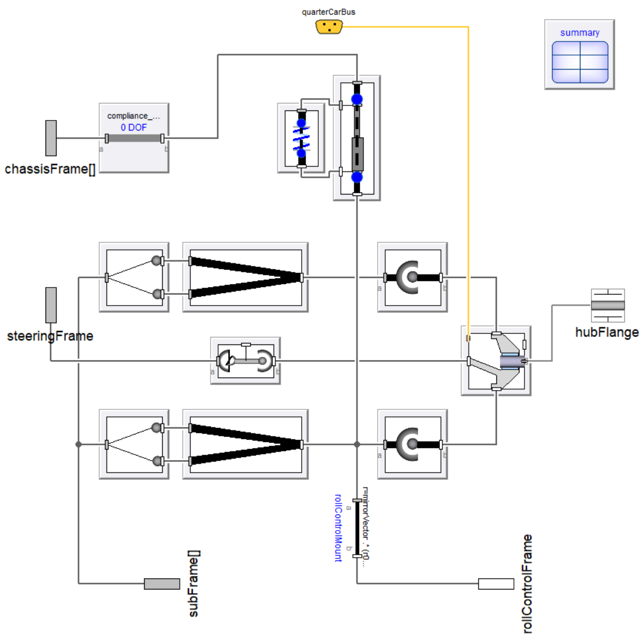

Figure 6. Front double wishbone linkage with ideal joints

There are also table-based examples of the double wishbone and multilink models, where kinematic data is used to define the hub position. These models are less complex than their multibody equivalents, which can improve simulation performance.

The VeSyMA – Suspensions library includes Pacejka MF6.1 and MF6.2 tire models (Besselink *et al.* 2010; Pacejka 2012), as well as an interface to the FTire tool (Cosin 2018). There is the option for both single and multiple contact points.

There are road building functions for creating custom road and circuit models. The VeSyMA - Suspensions road models permit friction, road roughness and curbs to be added. It is also possible to define a driving line and stopping events for the driver model to follow. There is also support for using the OpenCRG road definitions (VIRES 2017).

To perform dynamic vehicle maneuvers, the VeSyMA driver capability is extended to include closed loop drivers with lateral control. A test driver model is also available, where the closed loop control can be overridden.

The road, driver and vehicle models from VeSyMA – Suspensions have been combined to create vehicle maneuver examples, including:

- Acceleration
- Coastdown
- Constant radius
- Braking
- Double lane change
- Slalom
- J-turn
- Fishhook
- Figure of eight

There are several rig experiments provided. Kinematic rigs for testing at the quarter car and half car levels. At the vehicle level, there are KnC (Kinematics and Compliance), four post and seven post rigs, as shown in Figure 7.

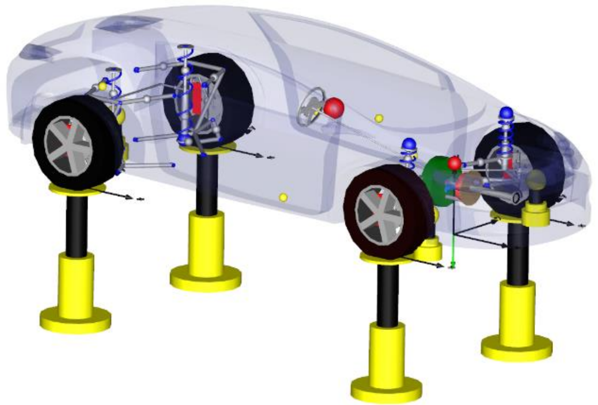

Figure 7. Seven post rig test

The VeSyMA – Suspensions library was designed with real-time simulation capability in mind. The model architecture includes support for the multi-threading features available in Dymola.

6 VeSyMA – Motorsports

VeSyMA – Motorsports is a motorsports focused extension of the VeSyMA – Suspensions library. It includes suspension configurations specific to open wheel race cars, sports cars and NASCAR style vehicles. These suspensions are optimized to minimize the nonlinear systems of equations to improve real-time simulation performance.

The suspensions are parameterized using geometry records, this allows alternative geometries to be easily applied to the same suspension models.

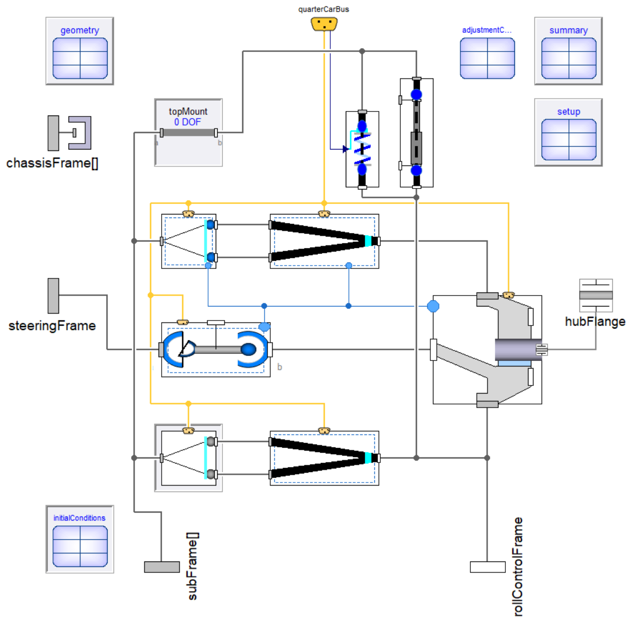

Figure 8. Front NASCAR linkage

There are adjustment shims incorporated into these suspension models, to permit realistic setups to be applied to the vehicle. Figure 8 shows the adjustments, in light blue, in a linkage component. There are two setup test variants, the adjustments can be made in sequential order or simultaneously to achieve the desired targets. Following a setup experiment, the shim values can be extracted from the results for reuse in the suspension models via the geometry records.

Additional aerodynamics models are included for race car bodies and wings. There is also the provision for adding aerodynamics to the wheel models.

7 VeSyMA – Drive-in-the-Loop and VeSyMA – Terrain Server

The VeSyMA – Driver-in-the-Loop (DiL) and VeSyMA – Terrain Server libraries allow the VeSyMA libraries and Dymola to be integrated with rFpro.

VeSyMA – DiL permits vehicles created using VeSyMA – Suspensions and VeSyMA – Motorsports to be integrated with rFpro driving simulators. It includes the templates and tools to run the vehicle model on a wide range of systems connected to the simulator.

VeSyMA – Terrain Server enables the rFpro Terrain Server to be integrated into Dymola simulations. This allows the high-fidelity LiDAR track data available from rFpro (Kangaloosh 2018) to be used in Dymola simulations, promoting consistency between the driver-in-the-loop and Dymola environments.

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8 Summary

The VeSyMA platform provides a family of Modelica libraries to enable the modelling and analysis of automotive vehicles.

At its core is the VeSyMA library, which provides the architecture of the vehicle models and experiments. From the idealized vehicle subsystem models in this library, vehicle models for performing longitudinal and drive cycle studies have been built.

The VeSyMA extension libraries build upon this capability to allow users to develop detailed engine, powertrain and suspension subsystem models. As all the VeSyMA platform libraries are compatible with each other, the user can tailor the vehicle model's fidelity to allow them to perform the analysis they require. For example, the idealized rigid suspension from the VeSyMA library can be replaced in a VeSyMA vehicle by a detailed multibody suspension models from VeSyMA – Suspensions to permit vehicle dynamics investigations to be conducted.

The VeSyMA platform libraries were designed with real-time simulation in mind from the beginning to support software, hardware and driver-in-the-loop testing. Models have been optimized to improve simulation performance, and model structure supports the use of the multi-threading features available in Dymola. VeSyMA – Driver-in-the-Loop and VeSyMA – Terrain Server further support the use of VeSyMA platform vehicle models in the driver-in-the-loop simulator environment using rFpro.

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