Heavy Vehicles Modeling with the Vehicle Dynamics Library

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Abstract

This paper presents and describes recent extensions to the Vehicle Dynamics Library (VDL) for heavy and commercial road-vehicle modeling and simulation (VDL/Trucks). Until now, the VDL was targeted mainly at passenger cars applications (VDL/Cars). Users in this domain have been particularly enthusiastic about the openness, flexibility, and extensibility compared to many competing solutions. These advantages which are inherent to Modelica technology are even more important for heavy vehicles applications, where a much larger set of vehicle configurations and variations must be supported. It has therefore been natural to extend the scope of the library also into this field with the VDL/Trucks options presented in this paper. New components and templates have been introduced to reflect many standard chassis layouts. A number of new experiment templates are also supplied to make standard analysis tasks easy to perform.

Keywords: heavy vehicles; trucks; vehicle dynamics; Vehicle Dynamics Library

Figure 1: Truck-fulltrailer in a double lane-change

1 Introduction

The Vehicle Dynamics Library (VDL) [1, 2] was originally designed for studies on vehicle handling for passenger cars (VDL/Cars). It was early clear that an extension into the heavy vehicles domain would be natural. The inherent flexibility and extensibility of the Modelica-based solutions offers great benefits in this domain where a vast set of vehicle configurations and variants must be handled, such as combinations of trucks, tractors, full trailers, semi-trailers, tankers, with various axle and powertrain configurations, and also a wide range of payload conditions. This paper introduces the VDL/Trucks option of VDL aimed at modeling and simulation of heavy vehicles.

Vehicle dynamics analysis of heavy vehicles and passenger cars have many common inputs such as a human driver model with similar driver-vehicle interface, road and environment properties, etc, and outputs of interest such as tire forces at the contact patches, chassis and suspension motion. Joints, links, springs, dampers, drivers, roads, and tires all produce similar types of constraints on the model. A large set of model components are therefore common for cars and truck modeling. There are, however, some major differences between heavy commercial vehicles and passenger cars when it comes to chassis layout. The number of axles, tires and trailers are some of the many parameters that are combined to form a heavy vehicle configuration, while cars have a more static setup. This requires an even more flexible interface and template design for heavy vehicles than for cars.

The heavy vehicles option has been developed from the same library base as the car option. This means that the new heavy vehicle models can benefit from an already well tested and mature overall design.

2 Heavy vehicle components

As mentioned above, there are many low level components that are shared between VDL/Cars and VDL/Trucks, but there are of course many examples of new components and components that are used differently in the context of heavy vehicles [3]. Essentially, this is due to the difference in weight and dimensions. The higher over-all weight requires different solutions and very large load variations means that good performance have to be achieved for a wide variety of load cases. The higher center-of-gravity makes rollover rather than road adhesion the handling limit in many situations. This section highlights some of the extensions made to VDL for heavy vehicle simulation to address these differences. Figure 2 shows a screen shot of parts of the library, indicating some important new additions.

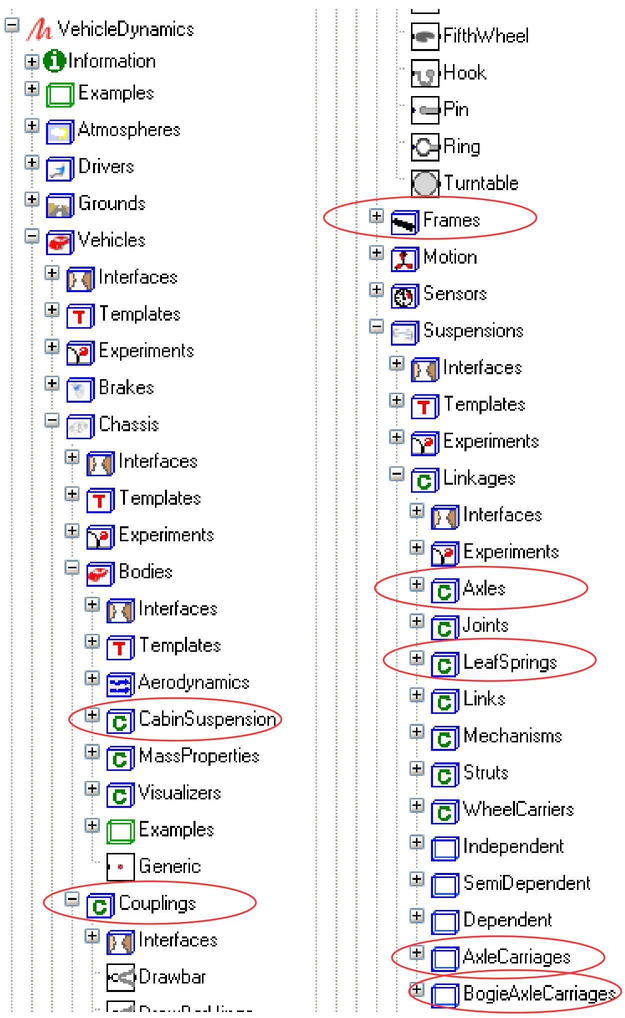

Figure 2: Screen shot of parts of VDL as it appears in Dymola. Some main extensions to VDL for heavy vehicles are indicated.

Suspension The suspension designs in heavy trucks are usually axle-based for the steerable and non-steerable wheels. Leaf springs are commonly used for both axle guidance and load support and are implemented as described in [4]. To meet the requirement of high load variations the leaf springs are often mounted in such a way that the effective length of them decreases when they are subjected to load. There are also leaf spring versions that are equipped with helper springs that becomes active when the vehicle is loaded. Air springs are often used in heavy vehicle suspensions in conjunction with trailing arms to easily adjust for different load cases, see Figure 3. Air springs can be used to change the ride height of the vehicle by increasing the air mass inside the spring, which also results in a stiffer spring that can carry more load.

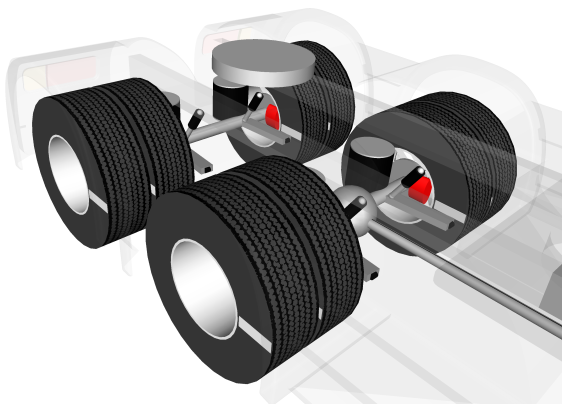

Figure 3: Typical heavy vehicle rear axles.

Frame The frame elasticity influences the load distribution between the axles, and therefore the available grip from the tires. The elastic frame included in VDL trucks has a torsional degree of freedom. It is easy to add or change the degrees of freedom in the frame by extending the interface so the common template connectors are used.

Payloads The payloads can be static (e.g. a crane), dynamic (e.g. a tank for liquid load) or have varying masses or mass distributions (e.g. cargo containers). These different cases are supported with user-friendly configuration setup. The existing liquid payload model considers the dimensions of the tank and a rotational damped degree of freedom for slosh.

Cabin The truck cabin is usually suspended for driver comfort since the chassis suspension must be

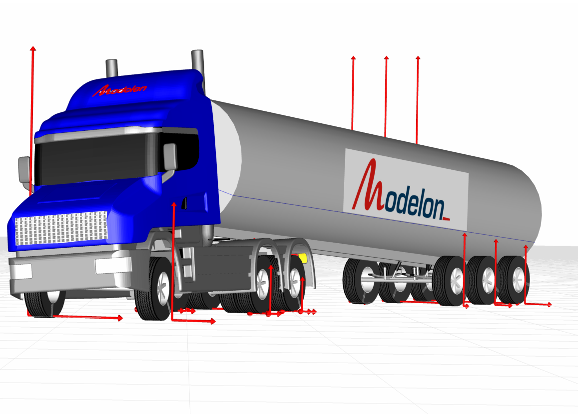

Figure 4: Sine-excitation of a tractor-trailer combination with the liquid load in the tank modelled with with a one degree of freedom to capture dynamic load distributions.

stiff to accommodate the high loads. The cabin suspension is a linkage mechanism equipped with springs, dampers and antiroll bars. The suspension also causes a relative motion between the steering wheel and the steering gear since the steering wheel moves with the suspended cabin. This is incorporated in the vehicle templates and ensures that it is easy to change the different subsystems such as the cabin suspension or the steerable axle linkage in an flexible way.

Couplings Heavy vehicle combinations often have tractor (driven) and trailer vehicle units. The attachment to guide and constrain the trailer can vary, but has a significant effect on the handling and vehicle behavior. One of the most common couplings is a fifth wheel for the tractor/semi-trailer combination. Full trailers and dollies usually have a draw bar and hook to attach to the tractor, driven truck, or preceding trailer (in the case of road trains). The coupling must have a mass on both sides of the joint or be locked to avoid a singular setup when no unit is attached on one side. This is conveniently handled without much user intervention by the available components and templates.

3 Heavy vehicle templates

The variation and configuration space of heavy vehicle combinations are much larger then for normal passenger cars. Also, the components can be of varying fidelity depending on the design and purpose of the model. A new set of templates for heavy vehicle components has therefore been developed to sustain the user-friendliness offered in VDL/Cars. These new templates are based on the same usage principles as the car templates, where templates for aggregate models are built by connecting replaceable components that can be parameterized depending on application. An example of a tractor template is given in Figure 5.

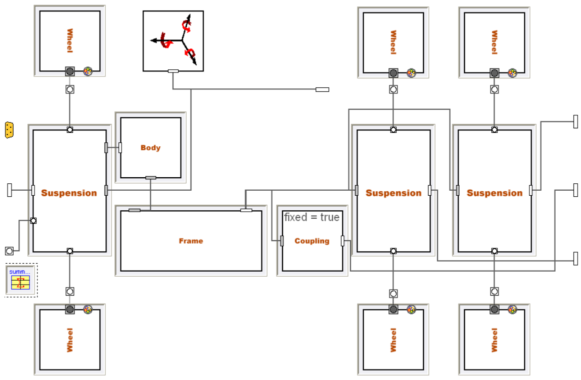

Figure 5: Tractor template with two rear axles.

The heavy vehicle interfaces for basic components are largely the same as those for cars. Some changes include extra connections to incorporate the frame and suspended cabin. The axle-based suspension models typically have connectors for the axle and chassis, instead of using separate connectors for the left and right suspension linkage models. The templates still have all connections and parameters predefined and propagated between models so they only require the replaceable components to be redeclared from the graphical Dymola user interface.

The main chassis components include a number of suspension models that contain one or more axles, frame, coupling, wheels, and a body or payload. Trailers can also include components for a dolly.

The suspension templates are based on axle constraints. The axle can be a steerable or non-steerable version. The axle connects through the linkage to the chassis. The linkage has external or internal force elements such as coil/air springs or leaf springs, respectively, to support the chassis. An anti-roll bar is attached to the axle and chassis. The suspension components vary from the most basic bounce and roll degrees of freedom to detailed elasto-kinematic setups.

4 Experiments

Simulation experiments for passenger cars and heavy vehicles have many similarities and correspondingly share setup of e.g., drivers, roads and grounds, and environments. Just as for cars, both the open and closed loop driver models are available. The double lane-

change road maneuver as seen in Figure 1 is useful for emergency handling evaluation since it excites the roll motion which may cause roll-over [5]. The experiment is set up using a driver model that follows the road path defined by RoadBuilder [2]. The sine steering excitation experiment shown in Figure 4 is instead realized using an open loop steering robot while a drive robot is keeping the speed constant.
For out-of-plane frequency response, the shaker table can be used [2]. It is implemented as a ground model containing patches with time dependent altitudes, defined by inputs. Since a heavy vehicle can have more than two axles, the shaker table has a configurable number of patches to suite any number of axles and wheel locations. Correspondingly, several suspension rigs can be used together for detailed analysis of bogie axles, see Figure 6.

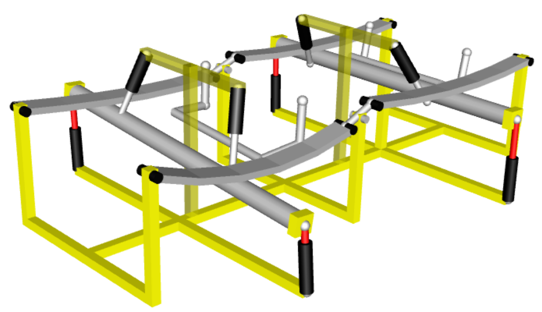

Figure 6: Twin axle with load distribution linkage in a suspension rig.

monly used in e.g. Australia. These vehicle combinations allow for one driver to freight a larger amount of cargo compared to a tractor pulling a single trailer. Unlike rail-carried trains that are self steered by the rail-wheel interaction, road trains are more sensible to disturbances and may even exhibit instability if care is not taken. Additionally, road trains are heavy and thereby hard to stop which requires them to be able to steer to avoid accidents. This puts high demands on the design of trucks and trailers so that they safely can be combined into road trains under a variety of load conditions. In VDL, these configurations can be defined and tested conveniently. Figure 7 shows a set-up with tree trailers pulled by a tractor.

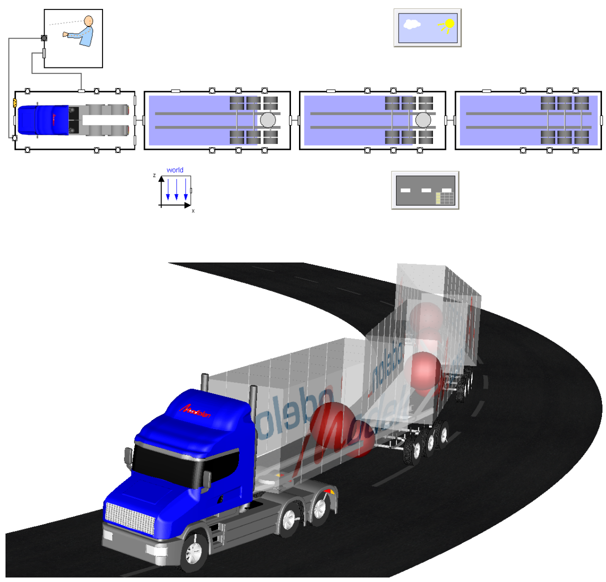

Figure 7: Road train with three trailers, diagram view (top) and animation screen shot (bottom).

5 Customization

Just as for passenger cars and light vehicles, VDL/Trucks is extended with a set of examples for heavy vehicles. This includes both truck with full trailer and tractor with semitrailer as seen in Figures 1 and 4, respectively. Thanks to the flexibility inherent in the library, it is straightforward to re-configure these and even build completely different equipages, as illustrated by the examples in this section.

5.1 Road Train

Equipages with combinations of a truck or tractor with two or more trailers forms a road train of the type commonly used in e.g. Australia.

5.2 Moving tire test rig

Tire test rigs are can be subdivided into two main categories depending on if the tested wheel or the ground surface is moving. For the latter case, the ground is typically implemented as drum or a belt. The drawback with these two concepts are on one hand that the belt only makes it possible to use elastic surface material such as steel and on the other hand that a drum has to have a curvature which impacts the tire-surface contact. To avoid this and to enable testing on real road surfaces such as gravel, asphalt, and ice under different conditions with respect to moisture, temperature, and so on, the tested wheel can be mounted on a moving rig, typically attached to a heavy truck. However, a moving rig is harder to control, especially since the forces generated from the tested wheel will affect the course of the truck. To investigate both the static and dynamic effects of the total system of truck, rig, and tire on resulting measurements, a moving tire test rig was implemented by mounting a test rig with wheel onto a truck model as illustrated in Figure 8. The results were then compared to standard test rig simulations and real mobile-rig mesurement results and provided insight into the interpretation of sensor signals.

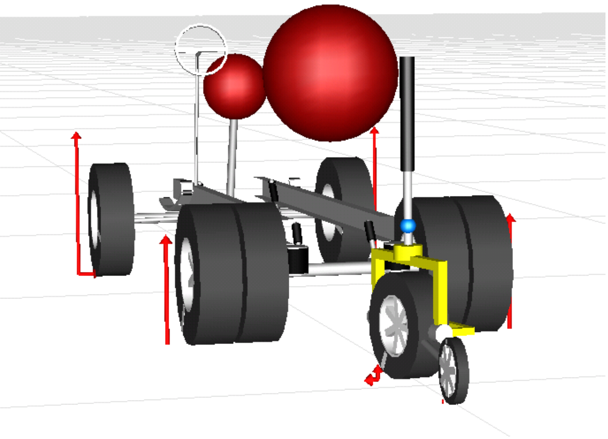

Figure 8: Mobile tire test rig mounted on a truck.

6 Simulink

Just as for passenger cars, heavy vehicles modeled with VDL can be imported into the Simulink [7] environment. Figure 9 shows an experiment layout in Dymola [6] used for the yaw control application in Simulink shown in Figure 10. In applications like this VDL/Trucks can provide models that are of great use in the design and validation of various chassis control functions.

7 Future

Currently the VDL/Trucks option is focused on the chassis and covers well the most commonly used vehicle types. VDL/Cars have more complete support for full vehicle modeling with templates for powertrains, drivelines, brakes, engines, etc. Future development will move in the direction of complete vehicle modeling also for heavy vehicles. Until then, many components are still available to build those subsystems from base classes, but without extensive templates.

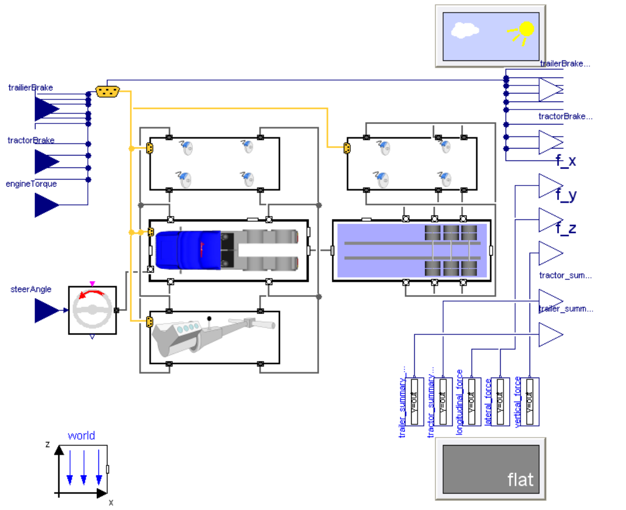

Figure 9: Experiment with in- and outputs for Simulink. Inputs: Steering wheel angle, engine torque, gear, wheel brake clamp forces. Outputs: Vehicle states, tire forces and wheel spin velocities.

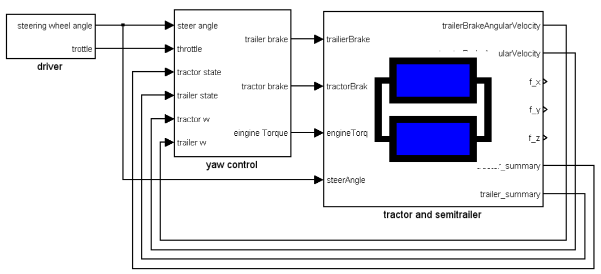

Figure 10: Yaw control application for the tractor-semitrailer combination shown in Figure 9.

8 Summary

This paper shows how the Vehicle Dynamics Library is extended with the VDL/Trucks option for heavy and commercial road-vehicle modeling and simulation. An overview of the recent additions is given and it is shown with several examples how the openness, flexibility, and extensibility from VDL/Cars is maintained and extended.

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