

Validation of Longer and Heavier Vehicle Combination Simulation Models

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ABSTRACT

This paper discusses the development and subsequent validation process of generic multi-body models for commercial vehicle combinations. The model is intended for performance assessment and improving of current and future combinations for the European road network. A second goal is to employ the model for the development of driver support systems and active steering strategies for both low speed manoeuvrability and high speed stability. The model is developed in SimMechanics, which is part of the MATLAB/Simulink software. Due to its modularity, one can quickly modify the model to the desired configuration and dimensions; therefore various multi articulation vehicle models can be created. The paper further illustrates the simplified and generic modelling methods used to build particular components such as chassis, tyres or suspension in the multibody domain. A stepwise approach of the model validation is presented, followed by a sensitivity analysis illustrating the effect of the selected vehicle parameters on particular vehicle states. To conclude, the approach is applied to the validation of the simulation model using measurement data obtained from experimental testing of two different vehicle combinations.

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INTRODUCTION

Increasing freight transport in the EU with the available infrastructure represents a challenging issue that cannot be underestimated. According to [2], it is predicted that freight transport in Europe will grow between 2000 and 2020 by 50%. Actual numbers are in accordance with this forecast, which underlines the link between transport and economic growth [1]. More in particular, the GDP of a country can be considered to be directly proportional to the amount of transported goods. Considering the fact that in Europe almost 75% of the inland transport is being realized through the motorways and highways, one can see a potential problem, which can arise if the current freight transport system will not

be modified. The biggest restriction is coming nowadays from the EU legislation 96/53EC that prescribes the maximal length and weight of the vehicle to be 18.5 meters and 44 tonnes respectively. The directive, however, does not allow cross border operation of performance oriented vehicle combinations in EU, which can be longer and heavier, but if appropriately designed can also be safer, more efficient, ecological and road friendlier. This fact has been already shown by practice and by several benchmarking studies from Australia, Canada and South Africa, where these vehicles are allowed to operate [3]. In the Netherlands longer and heavier vehicles (LHV) are well accepted and can be legally used (see [Figure 1.](#)), however, as written previously, an

international cross-border operation is not allowed, which limits their potential.

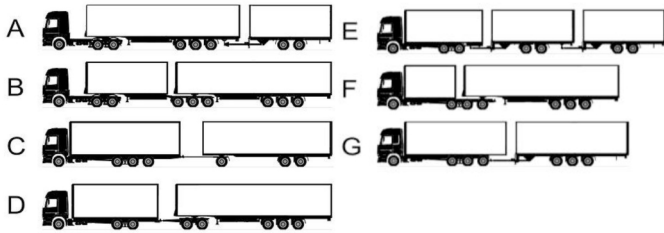


Figure 1. LHV combination types allowed in Netherlands

Based on this point of view, a research project has started involving co-operation of academia and major commercial vehicle industry players. The project is aiming at the identification of design of future commercial vehicle concepts for the years 2020+. They will reduce CO₂ emissions, meet the future needs of logistics companies, be compatible with existing infrastructure and facilitate inter-modal cross border transport within Europe. The concepts will be based on existing modules used in road-rail-water-air. Furthermore, active wheel steering and driver support systems for maneuvering are anticipated. The development of both systems requires a fundamental understanding of the vehicle behavior, for which an appropriate vehicle model is necessary.

In general there are two ways of building a vehicle model. One can either assemble equations of motion (EOM) of the vehicle combination by hand and create a mathematical model [9] or employ software that will assemble EOM using symbolical mathematics. The second way to build the model is by a multi-body formalism that uses bodies connected by means of joints allowing/restricting particular degrees of freedom. In a second approach, the equations of motion and the constraint equations are generated automatically by the software package. In this paper we restrict ourselves to multi-body modeling only.

The multi-body modeling approach is already employed successfully in virtual prototype development for more than 20 years. One can choose nowadays between several generally applicable packages such as ADAMS, LMS Virtual.LAB, Dymola, or decide for dedicated vehicle simulation software like CarSim, TruckSim or veDYNA. These are rather easy to operate due to built-in GUI and user-friendly visualization tools [7]; however the flexibility and modularity for applied research of control systems, may sometimes prove to be a limitation. Furthermore as pointed out in [5], the papers describing the models created in some of the programmes listed above and subsequently validated against the experimental results are very rare. In this paper a generic and modular vehicle model library for multi-articulated vehicles is described, which is used to build two different vehicle combinations. The models are subsequently validated against the experimental results. The model can be

directly utilized for performance assessment of various vehicle combinations as well as for the development of the controllers enhancing vehicle handling stability and low speed manoeuvrability.

The paper is structured as follows. First, the simulation environment used for model development is described. Section 2 outlines the detailed topology of the vehicle model and sub-modules, followed by a description of the instrumentation of two vehicles and test program. Section 4 proposes a stepwise methodology process for model validation, together with an optimization and a sensitivity analysis illustrating the effect of several parameters on vehicle behavior. To conclude, the approach is illustrated by validating the models against experimental data, which is being discussed further and summarized at the end of the paper.

SIMULATION ENVIRONMENT

The simulation environment should be able to interact with other software, necessary for future research of controllers. Besides that, the model should be sufficiently flexible and generic, thus modification of model parameters should be possible with minimal effort. Because of these reasons, and positive experience from previous projects [5], SimMechanics, which is the multi-body toolbox of MATLAB/Simulink, has been selected.

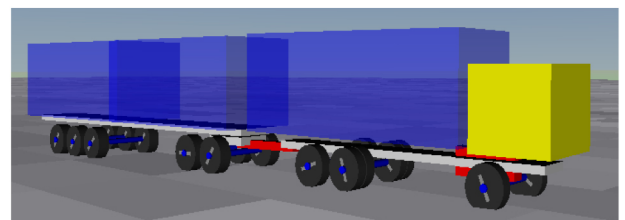


Figure 2. Model visualization by Virtual Reality Toolbox

Although SimMechanics is not especially designed for simulating vehicle dynamics, one can customize it for vehicle dynamics modelling, due to its good interfacing with other MATLAB Toolboxes. An essential Toolbox for vehicle dynamics is undoubtedly the tyre model. It is represented by TNO-Delft Tyre model, which is also used by many of the listed multi-body packages. A suitable option for visualization and animation of simulated results in MATLAB is the Virtual Reality Toolbox as depicted in Figure 2., and demonstrated by [6].

MODEL TOPOLOGY

Models of the two vehicle combinations, LHV-B and LHV-D (see Figure 1.), have been built up by means of the Commercial Vehicle Library (CVL), which is a generic library consisting of truck, trailers and components, developed in SimMechanics by the Eindhoven University of Technology.

This library is divided in five sections:

- Vehicles (Towing vehicles)
- Trailers (Towed vehicles)
- Assemblies (Cabins, Loading Units, Axles...)
- Components (Tyre, Brake system)
- Utilities (filters, sensors...)

The structure of these models is modular in order to give the user freedom to create and develop many different combinations. At the same time, the user has the flexibility to easily customize all the components of each sub-model without operating on the entire multi-body model. The purpose of the library is to represent an average vehicles and avoid all the details that can be different for every particular vehicle as for example nonlinearities in chassis suspension, roll steer or cabin-chassis suspension layout. These can be further customized by user if necessarily needed.

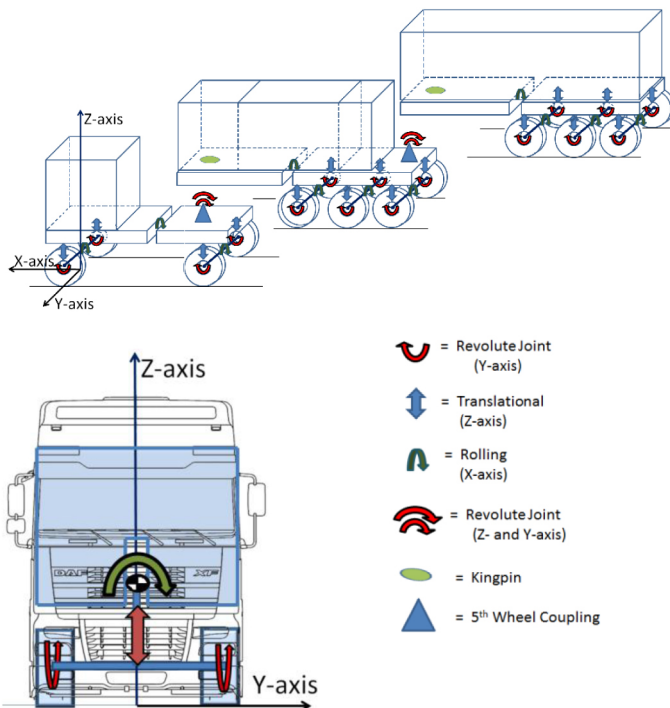


Figure 3. Visualization of the multi-body model degrees of freedom.

Every sub-model has its own local coordinate system, with respect to which the position and the dimension of all the components within the model are specified. For the towing vehicles, the origin of its own coordinate system is placed at the contact point between a vertical line going through the center of the front wheels and the ground. For towed units, the origin is instead the point where a vertical line passing through the kingpin is crossing the ground. For creating a combination, the local coordinate system of the

towing vehicle is considered the global coordinate system respect to which the own local systems of all the units are positioned. All the coordinate systems use a right handed system; the positive X-axis points forward, the positive Y is toward left and Z-positive is directed upward (see the [Figure 3](#)).

The TNO Delft Tyre Model describes the vertical, lateral and longitudinal forces of the tyres, employing the Magic Formula of Pacejka [8]. The CVL includes three types of tyre files, one for steered axle, one for the driven axle and another one for the trailer axle; they report the main characteristic of the tyre (masses, inertia) and their properties, such as cornering stiffness, vertical and lateral stiffness, longitudinal slip scaling factor and many other coefficients [8, 11]. In the validation process, also the tyre files have been adapted for finding a realistic cornering stiffness.

We will demonstrate the topology of the library on building the B-Double model composed from a 2-axle Tractor, a B-dolly carriage unit and a semitrailer module; both of them equipped with 3 axles (see the [Figure 3](#)).

The tractor module is composed by a chassis divided into two parts, front and rear, connected to each other with a revolute joint and a torsional spring to reproduce the torsional stiffness of the vehicle. Cabin and engine are rigidly connected to the chassis and the steer and drive axle are linked to the chassis by means of the suspension system. The suspension model simplifies the vertical and rolling movement of the axle with respect to the chassis, placing a custom joint in the roll center of the axle. Basically, the axle module has only two degrees of freedom with respect to the chassis module: the z-axis translation and the x-axis rotation (see [Figure 3](#)). Two linear springs and two linear dampers have been implemented, one on the left and one on the right side of the axle. A torsional spring has been located in the roll center, representing the antiroll bar. On both ends of the steering axle, a body with a negligible mass is connected through a revolute joint with rotational freedom around z axis, which equals the steering angle; the angle at these joints is determined by the steering system using a prescribed steering ratio; for validation purposes, this angle has been directly measured on the wheel hubs. These bodies are then connected to the tyre module, described above, using a revolute joint. On both ends of the driven axle, these latter joints receive also the moment generated by the driveline model, which uses a continuous variable gear ratio for determining the torque at the driven wheels.

The B-Dolly unit is composed in a similar way: the chassis is divided in a front and rear part, on which the loads are applied rigidly, a torsional spring in between, suspension systems on all of the three axles. Six wheels, the kingpin and the 5th wheel are rigidly connected to the chassis, for the coupling with other towing units. The allowable degrees of freedom of this coupling are the yaw rotation and, only when the towing and the towed vehicles are aligned, also the pitch rotation. The center of gravity of the trailers depends on the

masses of the components and on the loading condition. Finally, the axles of the last semitrailer have been modeled as an independent suspension, in order to correctly represent the suspension of double deck trailer of the test. The roll center is placed automatically at ground level by modeling this suspension. Two transitional joints have been placed on the right and left side of the chassis, each one connected with a “suspension” body. For each side, a damper and a spring have been linked in between. [Figure 3](#) shows a schematic overview of the degrees of freedom of the full B-Double model.

Thanks to the flexibility, offered by the CVL, also the LHV-D Combination was created with minimal modeling effort.

EXPERIMENTS

Full scale tests were executed to validate the simulation models. The measurements were done with two different vehicle combinations with two articulation points and length and weight exceeding the current European Union regulations (see [Figure 4](#)).



a). LHV-D



b). LHV-B

Figure 4. Test Vehicles a) LHV- D b) LHV - B

The LHV-D is composed of a rigid truck with a 20 foot container and a conventional 40 foot container semitrailer connected to the truck by means of a two axle dolly. The second configuration is a LHV-B involving a tractor linked to a B-module carrying a 20 foot container and further connected to the double-decker semitrailer with a special

independent wheel suspension implying also lower roll centre than conventional. Both configurations are 25.25 meters long and are equipped with air suspension. The configuration of the vehicle combinations are selected differently on purpose, in order to validate different vehicle configurations.

Each vehicle combination is tested in two different loading conditions to cover different axle load and moments of inertia. The layout of two load distributions for LHV-D is shown in [Figure 5](#).

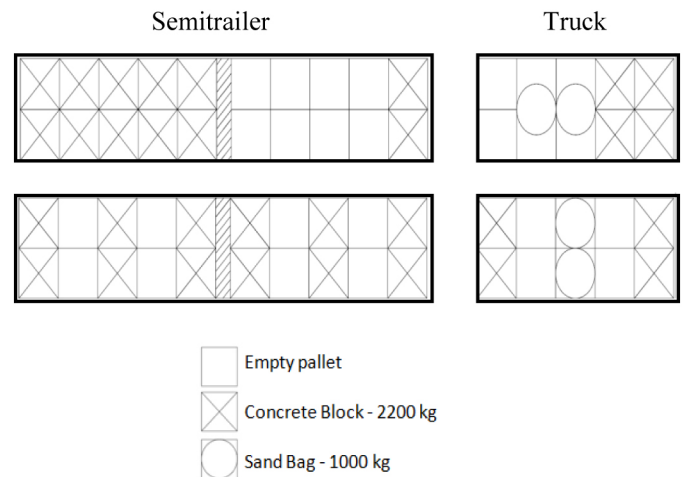


Figure 5. Top view load configurations of LHV-D

The overall vehicle weight for both combinations is 60 tonnes, which is also the maximum allowed for LHV's in The Netherlands. Both vehicle combinations are instrumented in a similar way. The instrumentation involves more than one hundred measurement channels with emphasis on collecting sufficient data that enables the validation of dynamic model behaviour in longitudinal, lateral, and vertical direction. In this paper we however restrict ourselves on presenting the signals related to handling and low speed manoeuvring only. A schematic picture of the externally placed sensors on LHV-B is given in [Figure 6](#). As can be seen, position, velocity and acceleration were measured for each vehicle body in translational and rotational direction. Additional potentiometer sensors measuring the position between chassis and axles as well as vehicle bodies with respect to each other are incorporated. The sensors are necessary due to limited accuracy of the translational and angular position measurements when evaluated from accelerometers. Such a signal might be inaccurate, because of integration error and drift [12]. Potentiometers are also used for measurement of the steering angle of towing vehicle axle for left and right wheel, as the left and the right steer angle differs when reaching bigger values. Furthermore selected signals from the CAN-bus of the towed vehicle are recorded such as the angular velocity of wheels, the engine torque, and the brake pressure. The sampling frequency is in most of cases 100 Hz only the signals coming from CAN-bus were limited to 10 Hz.