Modeling and Simulation of Heavy Truck with MWorks

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Abstract

This paper shows the modeling and simulation of fuel economy and vehicle dynamics of a heavy truck with Modelica. The work was carried out on MWorks, which is developed by Huazhong University of Science & Technology. Comparisons between measured data and simulation results validate the correctness of the model, and demonstrate that Modelica can be used in the modeling and simulation of vehicle performance, and also shows the effectiveness MWorks software.

Keywords: Fuel Economy; Vehicle Dynamics; Modeling; Simulation; Modelica; MWorks

1 Introduction

The modeling and simulation of vehicle performance such as fuel economy, acceleration capability, handling, etc., are always carried out by some different software. For example, the fuel my, acceleration capability and gradeablity are always analysis by AVL-Cruise, ADVISOR or some other software [1].Vehicle dynamics is the science that studies the kinetics and dynamics of wheeled land vehicles. The modeling and simulation of vehicle dynamics are always carried out by some multibody system software such as MSC.ADAMS, Simpack, Carsim, etc [2]. However, these simulation software are only strong in one domain and are not capable to model components from other domains in a reasonable way. This is a major disadvantage since technical systems are becoming more and more heterogeneous with components from many engineering domains [3].

Modelica has been used widely in various domains, and shows the ability in the modeling of complex physical systems. Modelica is a modern language used to model physical systems. The language is object-oriented, non-causal1 and the models are mathematically described by differential algebraic equations. The characteristic of modelica language make it very suited to define model libraries with reusable components, model complex applications involving parts from several application domains, and many more useful facilities [4].

This paper shows the modeling and simulation a heavy truck with MWorks based on unified modeling language Modelica. Comparisons between measured data and simulation results validate the correctness of the model, and demonstrate that Modelica can be used in the modeling and simulation of vehicle performance, and also shows the effectiveness MWorks software.

MWorks is under developed by Huazhong University of Science and Technology. It is a general modeling and simulation platform for complex engineering systems which supports visual modeling, automatically translating and solving, as well as convenient postprocessing. The current version is based on Modelica 2.2 and implements almost all the syntax and semantics of Modelica. More details about MWorks can be referred to [5].

2 Power Transmission Library

The power transmission library is designed to simulation of the automotive driving performance, such as fuel economy, acceleration capability, gradeablity, etc. The library includes the main power transmission components of a heavy truck, such as engine, clutch, gears, final drive, wheel, vehicle, brake, driver, etc., and can be seen in Fig. 1.
The components of the power transmission library are shortly described below:

- Engine

  The component engine contains a model for a combustion engine. As the characteristic curves for the full load, the fuel consumption and others can be freely defined by the user. It is possible to define a gasoline engine as well as a diesel engine. The engine will be modeled by a structure of characteristic curves and maps.

- Clutch

The clutch contains the model of a friction clutch as used in cars with manual gear boxes. It is controlled by the driver via the clutch pedal position.

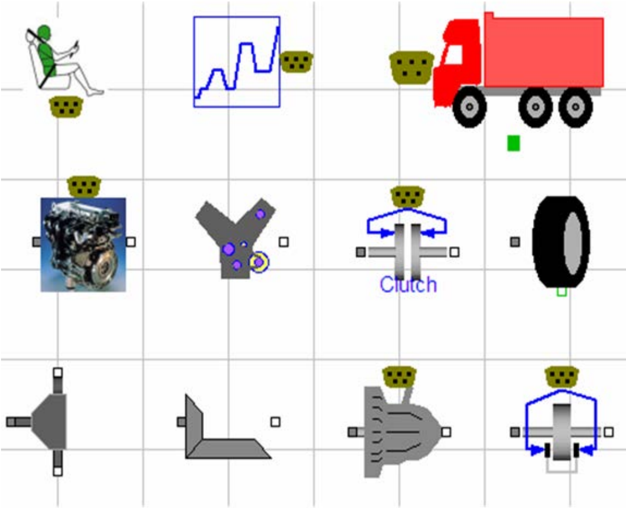

Fig.1 Components of Power Transmission Library

➢ Gears

The gear package includes gears in the vehicle, such as gearbox, differential gear, final drive, etc. The gears are modeled as gear ratios, and the inertial of the gear and moment loss are considered.

➢ Wheel

The wheels and tires link the vehicle to the road. This component allows to consider many influencing variables and their effect on the rolling state.

➢ Vehicle

The vehicle is one of the main objects in a model. This component contains general data of the vehicle, such as nominal dimensions and weights. The library presents only dynamic models for the longitudinal motion of the vehicle. So a sliding mass may represent as vehicle body.

➢ Driver

The driver includes gearbox control, clutch control brake control, throttle control and so on.

➢ DriveCycle

The drive cycle model includes some drive cycles, such as EDC, UDDC, NYCC driving cycles, etc.. Some other cycles can be added if desired.

➢ Brake

This is described by braking data and dimensions. By the implementation of a specific braking factor it is possible to model disc brakes as well as different forms of drum brakes.

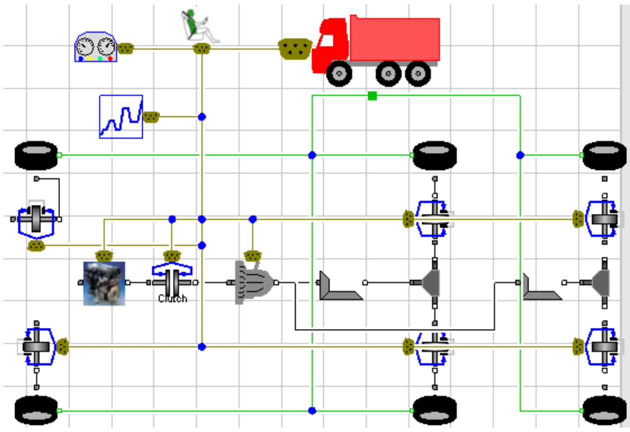

Fig.2 Model of the Heavy Truck

The user can build a heavy truck model very easily, seen in Fig. 2. The user drags the components together and connects lines in the graphic user interface. The vehicle was modeled by a forward-facing approach include the driver model, which controls the throttle, brake, clutch, gearbox to make the vehicle speed follow a given driving cycle.

3 Vehicle Dynamic Library

The vehicle dynamic library is designed to simulation of the dynamic performance such as handling, K&C of the heavy truck. The library was built based on standard library. The wheel model and bushing model used in this paper are from VehicleDynamics Libraray 0.8 which is designed by Modelon [6] and made some modification. As can be seen in Fig.3, the subsystem is build by basic components, and the heavy truck was assembled by the subsystems.

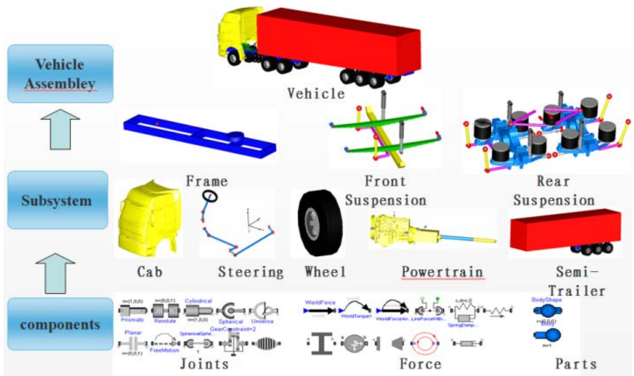

Fig.3 Vehicle Dynamic Library

The standard library MultiBody is a free Modelica package providing 3-dimensional mechanical components such as joints, functions, forces, parts, sensors, etc., to model mechanical systems. However, it's not enough to carry out vehicle dynamic modeling and simulation. Many important components such as nonlinear spring, nonlinear damper, bushing, beam, airspring, tires, etc., don't exist in the standard modelica library. So we must extend the mutibody library to carry out vehicle dynamic modeling and simulation.

The heavy truck with ten-wheel three-axle was designed and manufactured by China National Heavy Duty Truck Group Corp., Ltd. The truck has conventional steering system, leafspring front suspension and airspring rearsuspension, and will be described in the following.

3.1 Leaf Spring Modeling

Leaf springs are commonly used in the suspension systems of heavy truck. Accurate modeling of the leaf springs is necessary in evaluating ride comfort, braking performance, vibration characteristics, and stability [7]. There several ways to model the leaf spring. In this paper, simple beam theories are used to model the dynamics of the leaf spring. The beam elements have the constant cross section. A total of 17 elements were used to create the single leaf spring model, seen in Fig.4.The shackle and the leaf seat are modeled as rigid parts. The pin joints are represented by revolute joints with one degree of freedom along the global y-axis. The forces and moments are applied at the axle seat. To decrease the amount of the equations and increase the calculation efficiency, the frictions between the leaves and the contact force are neglected.

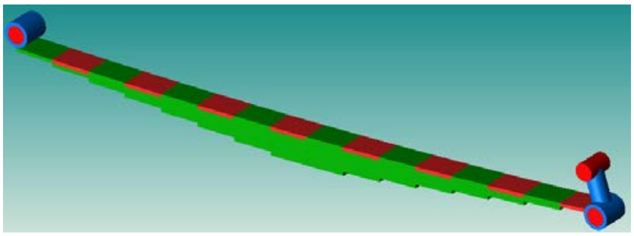

Fig.4 Leaf Spring Model

3.2 Front Suspension Modeling

The front suspension includes leaf spring, antiroll bar, axle and the shock absorber. According to the topology, the front suspension was build very easily, seen in Fig.5. The port F is connected to frame, the port LS is connected to the left part of the steering system, and the port RS is connected to the right part of the steering system.

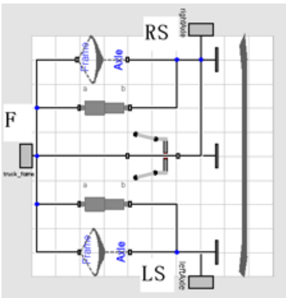

Fig. 5 Front Suspension

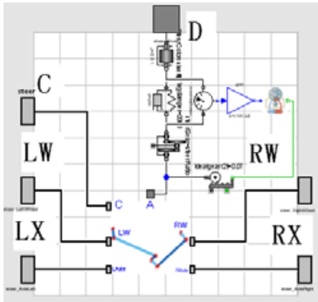

Fig. 6 Steering System

3.3 Steering Modeling

The steering system includes a steering column and steering trap. In this paper, the steering column is modeled as a inertial for simplification, and the steering trap is modeled according to the topology. The steering column and the steering trap is connected by ball screw, which is modeled by IdealGearR2T in the Modelica library. The hydraulic power steering is essential to the heavy truck to assist the driver, and also modeled by hydraulic components. As can be seen in Fig.6, the port D is connected to the driver model, the port LX and RX is connected to the left and right axle, and the port LW and RW is connected to the left and right wheel.

3.4 Rear Suspension Modeling

The rear suspension includes v-rods, push-rods, air springs, antiroll and shock absorber. According to the topology, the rear suspension was build, seen in Fig.7. The port F is connected to frame, the port LW is connected to the left wheel, and the port RW is connected to the right wheel.

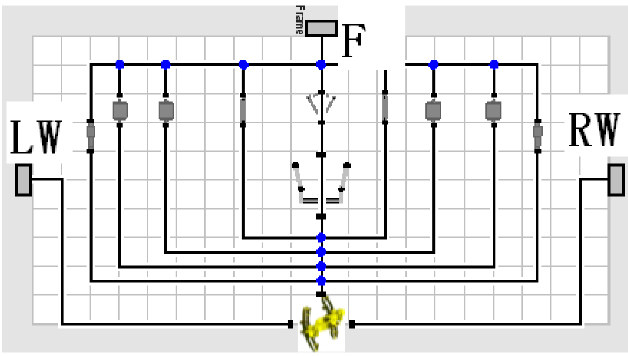

Fig. 7 Rear Suspension System

3.5 Vehicle Assembly

Based on the subsystem model, the user can build subsystem assembly and vehicle assembly very easily, seen in Fig.8 and Fig.9. The user drags the components together and connects lines in the graphic user interface. The Model includes the front suspension, steering system, the middle and rear bride, the frame, the cab, powertrain, the driver, wheels and the semitrailer. Based on the model, the K&C and the handling can be carried out to analysis the performance of the heavy truck.

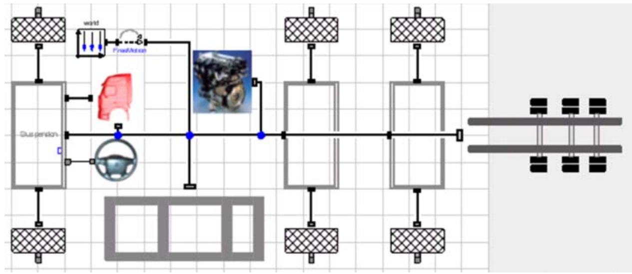

Fig. 8 Heavy Truck Assembly

Fig. 9 3D View of Heavy Truck model

4 Simulation and Results

To analysis the performance the heavy truck, the simulation about the fuel economy, the K&C of the subsystem and the handling performance were carried out in the following.

4.1 Fuel Economy Simulation

Fuel consumption is the amount of fuel used per unit distance. Lower values mean better fuel consumption. The key parameters of the vehicle can be seen in Table 1. The simulation was carried out to caculated the fuel consumption with constant speed in 15th and 16th gear. The simulation results can be seen in Fig.10 and Fig.11.

Table 1 Key parameters of the vehicle

Components	Key Parameters
Engine	Maximum power: 1802kW@1500rpm Maximum torque: 309Nm@2000r/min
Final Drive	3.93
Transmission	15.59/13.12/10.89/9.17/7.48/6.30/5.20/4.38/3.56/3.00/2.49/2.10/1.71/1.44/1.19/1.00
Vehicle Mass	49000Kg
Wheel Radius	0.548
Rolling Resistance	0.0091
Frontal Area	8.5m^2
Coefficient of Aerynamic Drag	0.585

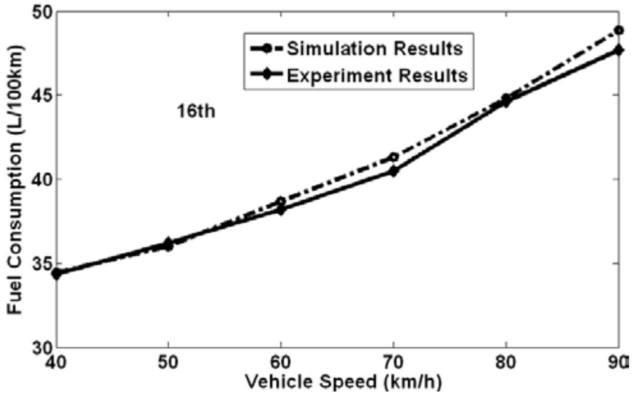

Fig 10 Fuel Consumption with Constant Speed in 16th Gear

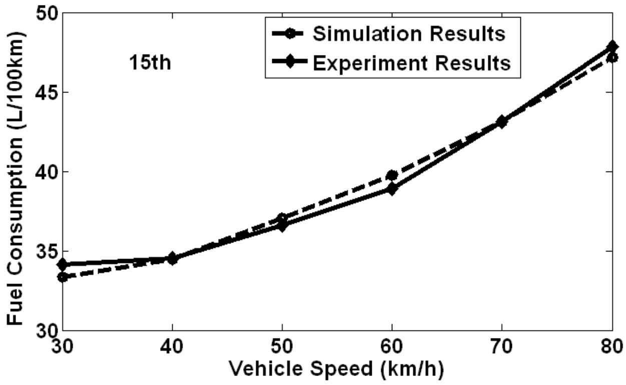

Fig.11 Fuel Consumption with Constant Speed in 15th gear

The dashed line is the experiment data, and the solid line is the simulation data. The figures showed that the simulation results were very close to the experiment data.

4.2 Vehicle Dynamic Simulation

With the vehicle dynamic library, the vehicle be built very easily, and some open loop test can be simulated, such as step steer, impulse steer, brake, etc.

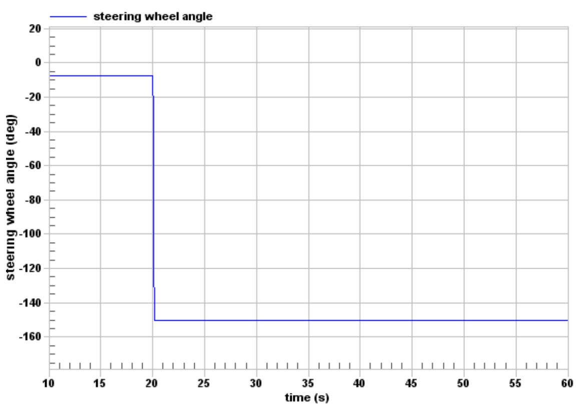

Fig.12 Steering Wheel Angle

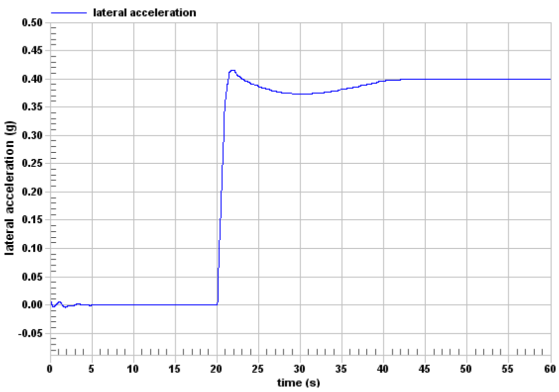

Fig.13 lateral acceleration

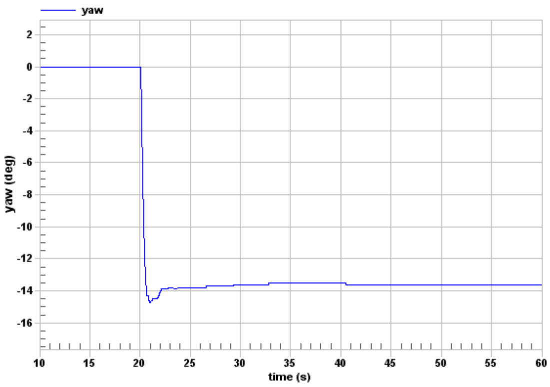

Fig.14 Yaw speed

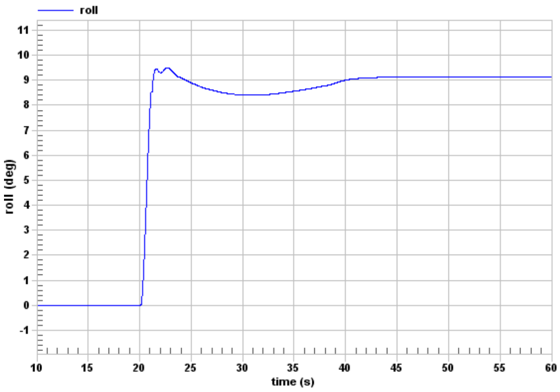

Fig.15 Roll Angle

The step steering simulation was carried out. The steering angle and vehicle speed were considered as input, seen in Fig.12. Fig.13-Fig. 15 showed the dynamic performance of the vehicle.

5 Conclusions

This paper shows the modeling and simulation of fuel economy and vehicle dynamics of a heavy truck with Modelica. The work was carried out on MWorks. Comparisons between measured data and simulation results validate the correctness of the model, and demonstrate that Modelica can be used in the modeling and simulation of vehicle performance, and also shows the effectiveness MWorks software.

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