Using SIMPACK for the Numeric Demand during

In this article, a new simulation platform is presented which was designed at the Institute for Internal Combustion Engines and Automotive Engineering (IVK) of the University of Stuttgart and at the Research Institute of Automotive Engineering and Vehicle Engines Stuttgart (FKFS). The MATLAB®-based development tool rates vehicles energy demand while driving. It can be applied during all stages of development. The simulation platform uses SIMPACK to represent mechanical vehicle components. Due to SIMPACK's extra ordinary modeling and simulation opportunities, a wide range of different vehicle energy demand analyses can be performed. The integrated driving cycle database provides time-variable loads for many legal test cycles and selected customer driving cycles. The focus of this paper is on the energy and power demand of conventional hydraulic dampers while driving on different road surfaces and with various damping rates.

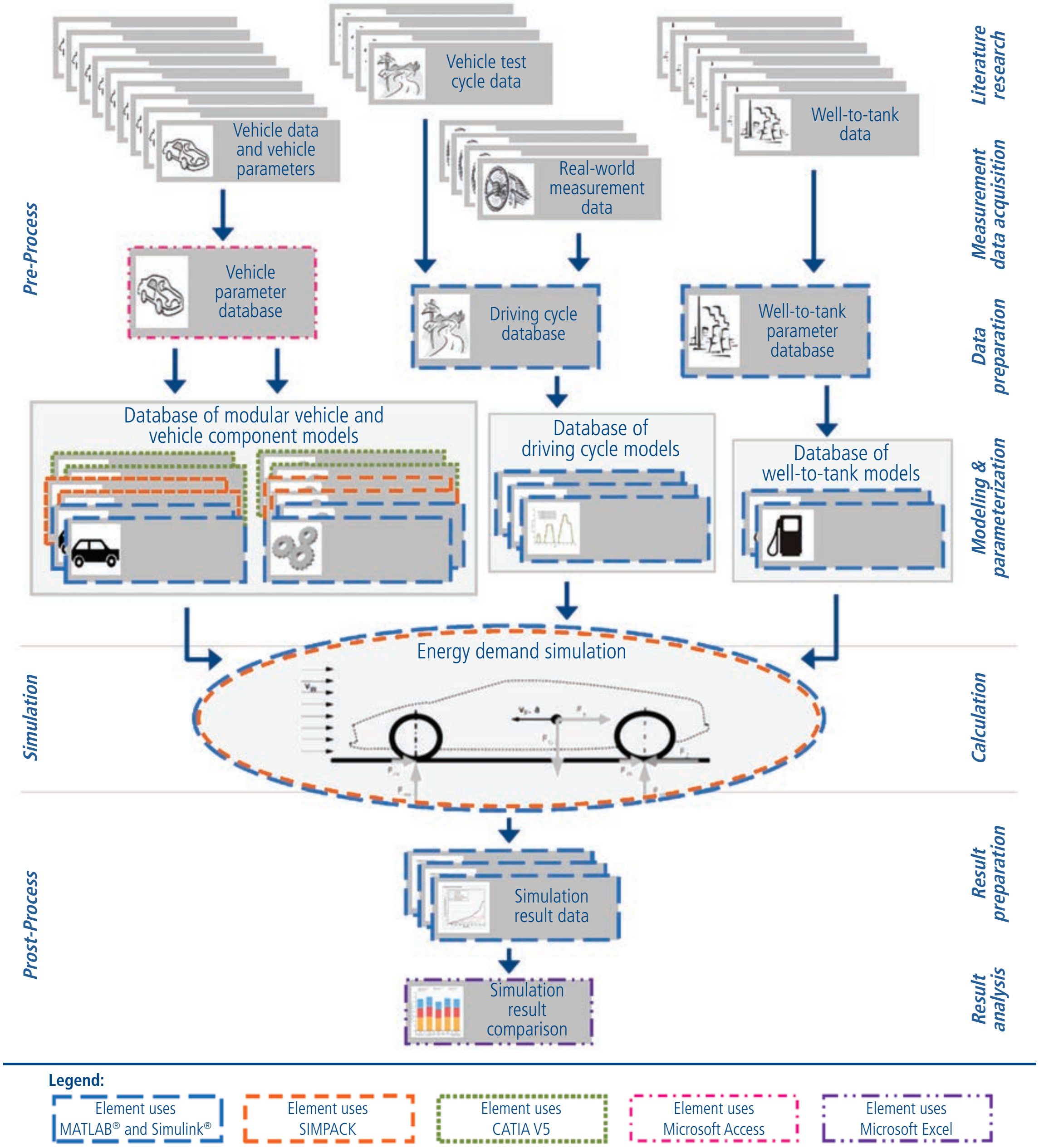


Fig. 1: Components and functionality of the new IVK/FKFS-simulation platform for rating vehicle energy demand

Simulation of Vehicles Energy Customer Driving

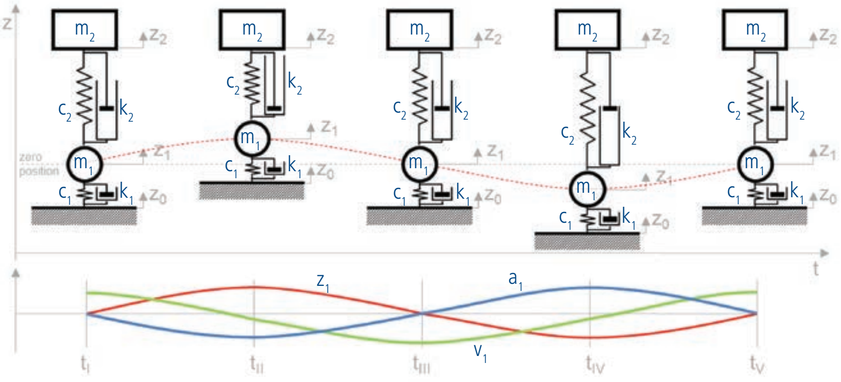
PRESENT & FUTURE REQUIREMENTS ON THE NUMERIC SIMULATION OF VEHICLES ENERGY DEMAND FOR DRIVING

Energy demand reduction is one of the main topics in modern vehicle development. In the last decades many improvements have been achieved. Most new innovations deal with increasing energy conversion efficiency in the powertrain and decreasing driving resistances. In order to find unconsidered potentials, all vehicle components must systematically be analyzed. The growing cross-linking of powertrain, chassis and body helps in reducing a vehicle's energy demand for driving, while making rating of energetic potentials more complicated. The amount of saved energy is highly dependant upon the driving situation and vehicle components operation strategy. Therefore, new development methods and tools must be offered in order to answer interactive questions of driving dynamics and vehicle energy efficiency. The new IVK/FKFS-simulation platform for rating a vehicle's energy demand was created to meet these simulation requirements. It allows the simulation of vehicle behavior in legal test cycles as well as real-world driving cycles at all stages of vehicle development — starting with rough concepts and ending with high-end design issues.

FUNCTIONALITY OF THE NEW IVK/ FKFS-SIMULATION PLATFORM

The new database-supported simulation platform combines the mathematic and control abilities of MATLAB and Simulink® with the advantages of the multi-body simulation tool SIMPACK (Fig. 1). The simulation approach uses free in scale vehicle and vehicle component models. All models are parameterized via a user friendly interface. The required parameters can be provided by a vehicle parameter database or can be entered manually. The modular simulation models allow a holistic rating of vehicles with different powertrain concepts. The simulation platform offers advantages during the discussion of driving dynamic parameters and their energetic relevance. It can be used for a closely linked optimization of driving dynamics and energy efficiency.

Depending on the simulation target, the applied simulation models are based either on Simulink or on SIMPACK. A co-simulation of



Legend:

m_1:	Mass (wheel)	c_1:	Spring rate (tire)	k_1:	Damping rate (tire)
m_2:	Mass (vehicle body)	c_2:	Spring rate (coil spring)	k_2:	Damping rate (hydraulic damper)
z_0:	Elevation (road)	z_1:	Elevation (wheel)	z_2:	Elevation (vehicle body)
t_i:	(Point in) time	v_1:	Vertical velocity (wheel)	a_1:	Vertical acceleration (wheel)

Fig. 2: Kinematic dependencies while driving on a bumpy road (simplified quarter-vehicle without vertical vehicle body motion)

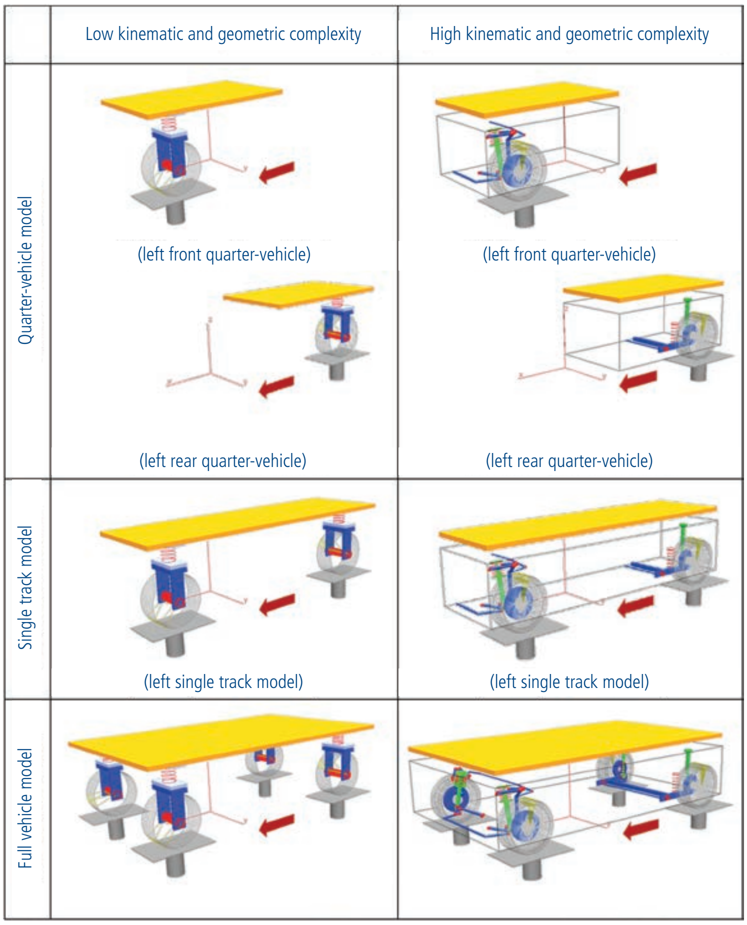


Fig. 3: Database of chassis models with varying levels of complexity and varying represented vehicle range

Simulink and SIMPACK is possible, too. In order to analyze concepts at an early stage of development, the database of modular vehicles and vehicle component models was set up. It allows a fast comparison of different vehicles in order to identify energetic potentials.

The integrated large driving cycle database contains legal test cycles, real-world driving cycles and measured driving cycles. The additionally integrated well-to-tank database supplies parameters for well-to-tank and well-to-wheel ratings.

DRIVING RESISTANCE CAUSED BY HYDRAULIC VEHICLE DAMPERS

Compared to current certification test cycles (e.g., NEDC or FTP75) — which do not consider elevation profiles or bumpy roads — vehicles are exposed to different types of vertical excitations during specific non-standard driving tests. Most well-known studies on vertical wheel excitation deal with comfort or driving safety. A way of analyzing, the influence of bumpy roads on vehicles energy demand is described in [1].

The relative motion between wheel unit and vehicle body depends on road surface conditions and on many vehicle parameters. These vehicle parameters include body mass, unsprung mass, spring characteristics, damper characteristics, and vehicle geometrical proportions. The kinematic dependencies while driving on a street with buckles and bumps are shown in Fig. 2 with a simplified quarter-vehicle model. In order to illustrate the conditions more clearly, vertical motion of the vehicle body is assumed to be zero and tire suspension, as well as tire damping, is neglected.

During vertical vehicle and vertical wheel unit excitation, a continuous conversion of different kinds of energy takes place. Looking at a conventional chassis with coil springs and hydraulic dampers, the following types of energy are involved:

- potential energy of vehicle body and unsprung wheel components (proportional to elevation of component center of mass),
- motion energy of vehicle body and unsprung wheel components vertical to the road (proportional to vertical component velocity),
- energy stored in the spring (anti-proportional to spring length) and
- energy demand of the hydraulic damper (proportional to relative damper velocity).

In the case of pneumatic tires, the suspension and damping energy of the tires must be considered as well.

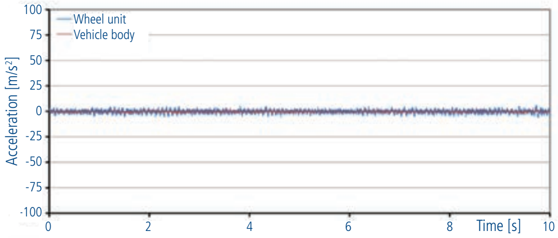
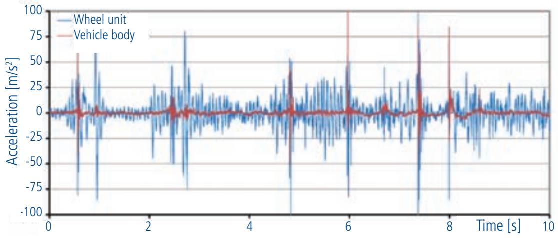
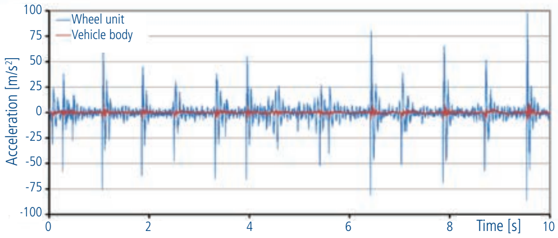
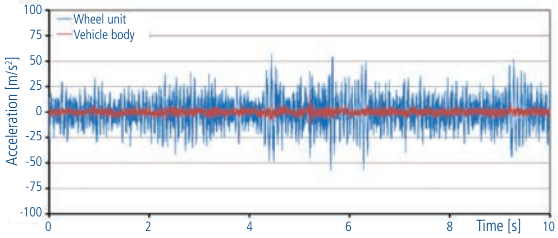
Road type	Picture road surface	Exemplary measured acceleration of vehicle body and wheel unit in vertical direction
Asphalt without road damage		
Asphalt with road damage		
Concrete slabs with transverse joints		
Natural cobblestone		

Fig. 4: Analyzed road surfaces and exemplary vertical acceleration of vehicle body and wheel unit driving at 70 km/h

Balancing the different vertically acting energies for a horizontal driving cycle on a flat bumpy road leads to the following conclusions: If the vehicle is not moving at the beginning and at the end of a test ride, only the damping energy of the hydraulic dampers and the damping energy of the tires raise the vehicles energy demand. All other types of energy do not dissipate. Thus, they must be the same amount at the beginning and the end of the horizontal test ride. Neither does the potential energy of the vehicle body change nor does the potential energy of the unsprung wheel unit increase or decrease. The energy stored in the coil springs does not change in the case of an identical spring length at the start and the end of the test ride.

A comparison between the energy demand of the hydraulic dampers and the tires shows that most damping energy dissipates in the hydraulic dampers. The energy demand of the tires due to vertical damping can be neglected.

> ***"During vertical vehicle and vertical wheel unit excitation, a continuous conversion of different kinds of energy takes place."***

NUMERIC SIMULATION OF DRIVING RESISTANCE CAUSED BY HYDRAULIC VEHICLE DAMPERS

The presented study is based on a mid-size vehicle with McPherson front axle and twist beam rear axle. In Fig. 3, the geometric representation of the used and compared chas-

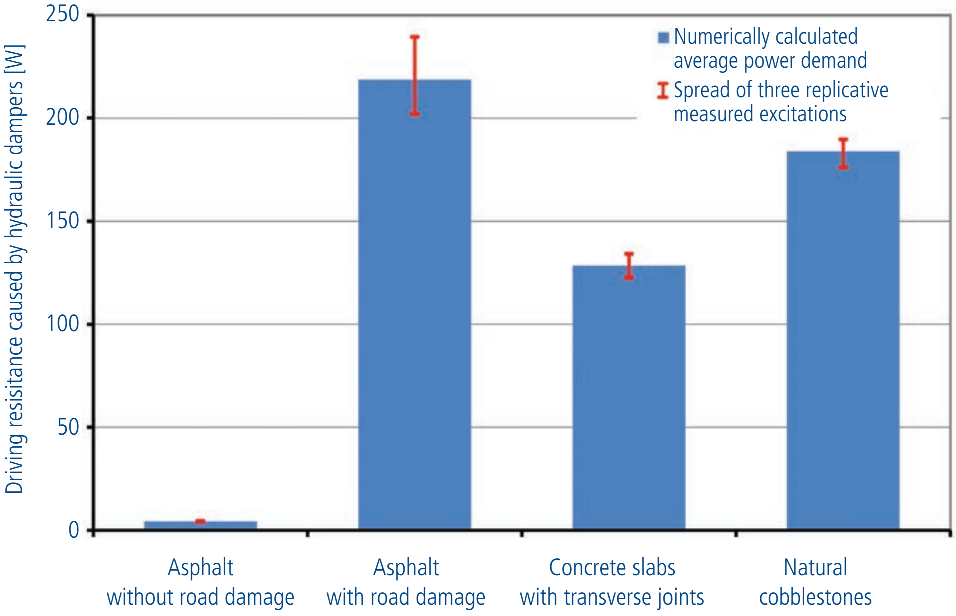


Fig. 5: Power demand caused by four hydraulic dampers of a mid-size vehicle on different road surfaces

sis models is shown. The simulation models differ in geometric complexity and represented vehicle range (quarter-vehicle model, single track model, full vehicle model). Two types of each model were set up. One version considers elastic top-mounts. In the other version, the coil springs and dampers are connected to the vehicle body without an elastic bearing.

The kinematic excitations (accelerations of the wheel carrier) were measured with a test vehicle on the street. In the simulation, the measured signals were applied to the wheel carriers of the SIMPACK models. Thus, the representation of the vertical tire behavior could be avoided. This simplification is acceptable as the presented study focuses on the hydraulic dampers.

In Fig. 4, the analyzed road surfaces are shown. Next to the pictures exemplary measured accelerations of the vehicle body and the unsprung wheel unit are displayed. They were measured at a vehicle velocity of approx. 70 kilometers per hour.

DEPENDENCIES AND REDUCTION OF DRIVING RESISTANCE CAUSED BY HYDRAULIC VEHICLE DAMPERS

a) Dependencies

Fig. 5 shows the driving resistance related energy demand caused by hydraulic dampers of the test vehicle for the above introduced road types. The displayed power demand represents mean values for three test drives on the same road. The red bars show the spread of the three single test drives. All values were calculated using the full vehicle model with high complexity and elastic top-mounts. For this simulation model, the measured and calculated vehicle reactions correspond best.

The relative influence of the vehicle velocity on the power demand is shown in Fig. 6. All values refer to the asphalt road with road damage. The consequences of a change of the damping rate are also displayed. The relative damping rates can be found in the box in Fig. 6.

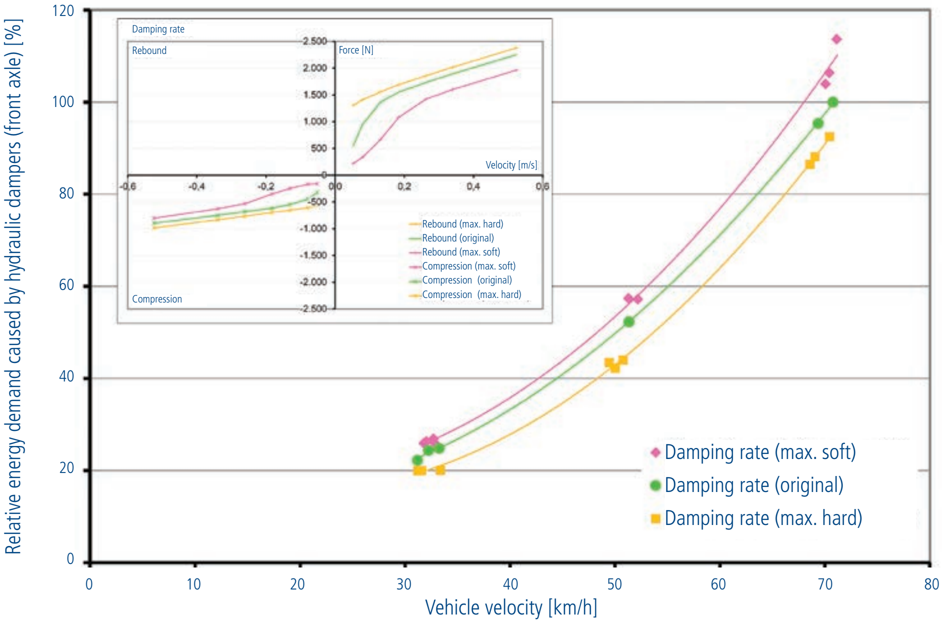


Fig. 6: Relative power demand caused by hydraulic dampers (front axle) depending on vehicle velocity and damping rate

b) Reduction

Due to the frequency-dependent correlation of damping rate and power demand, a change of the damping rate can favorably influence the amount of dissipated energy in the hydraulic damper. Furthermore, a recuperation of the dissipated damping energy is possible, too. However, the installation of an additional system for the recuperation of this amount of energy must be rated with regard to effort. An increase of vehicle mass caused by a damping energy reducing or recuperating system lowers the energetic benefit. The attempt to recuperate additional energy out of the vertical wheel unit motion must be analyzed critically. The recuperation of additional energy must not cause an increase in driving resistance or have an adverse effect on driving behavior.

ACKNOWLEDGMENTS

Special thanks goes to the Friedrich-und-Elisabeth-BOYSEN-Stiftung, which funded the research project within which the platform for rating vehicle energy demand was created.

REFERENCES

[1] Horn, M.; Neubeck, J.; Wiedemann, J.: Anwendung und Erweiterung einer Simulationsumgebung zur Bewertung von Maßnahmen für die Reduktion des Energiebedarfs von Kraftfahrzeugen während unterschiedlicher Entwicklungsphasen. Final Report, Project funded by Friedrich-und-Elisabeth-BOYSEN-Stiftung, 2011