Scaled Vehicle Dynamics

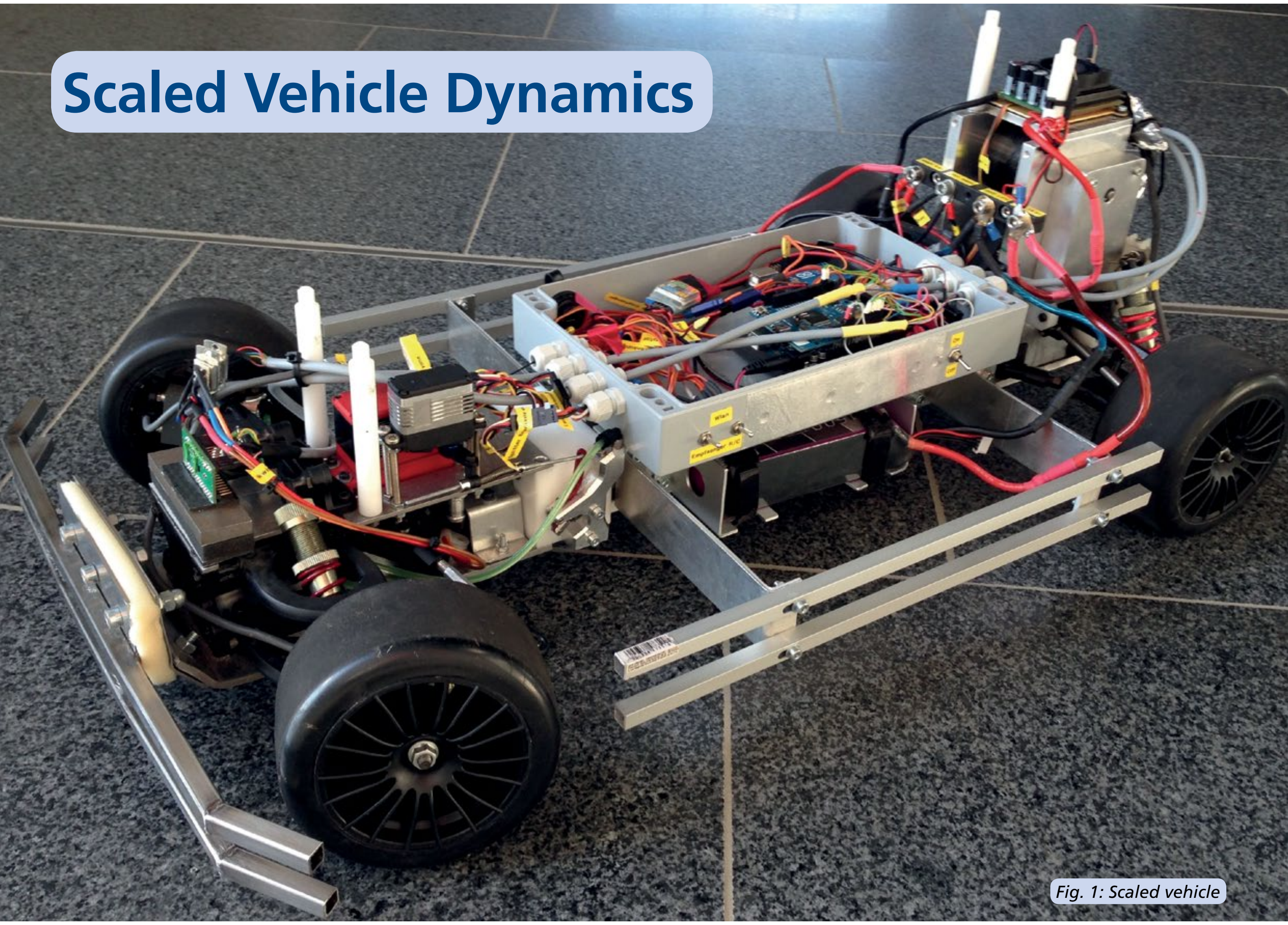

Fig. 1: Scaled vehicle

Vehicle dynamics is a fascinating subject in industry, in research, and in education. Commercial packages, like SIMPACK, make it easier to build up virtual vehicle models and to perform simulations. However, in order to gain confidence in the model quality, a comparison to field test is desirable or may even be necessary. Field tests are very expensive and can hardly be performed as a student's project. Motivated by a project on the investigation of vehicle rollover in off-road conditions [1], the Laboratory of Multibody and Vehicle Dynamics initiated a student's project on a scaled vehicle.

SCALED VEHICLE

The vehicle shown in Fig. 1 is based on a 1:5 scaled commercial car model. A trapezoidal-link suspension at the rear, a double wishbone suspension at the front axle combined with a lever-arm steering system, coil springs, and dampers, as well as rubber tires match perfectly with full scale vehicles.

The scaled vehicle is driven by an electric motor that distributes the drive torque via a differential equally to both rear wheels. The front wheels are equipped with hydraulic disk brakes.

The scaled vehicle is operated by a remote control acting on the steering system, the brakes, and the electric motor. At present, it is equipped with sensors measuring the wheel speeds, the steering angle, as well as the accelerations at the front and the rear part of the chassis.

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MULTI-BODY MODEL

The multi-body system approach is most appropriate to investigate the handling properties of vehicles by computer simulations [2]. As the topology of the scaled vehicle corresponds with the standard layout of a real passenger car, the multi-body model of the scaled vehicle will also be valid for real vehicles.

The multi-body software package SIMPACK was used to generate the simulation model. The model consists of 24 bodies and has 14 degrees of freedom (DOF). The chassis is represented by one rigid body. The double wishbone suspension systems at the front axle consist of two control arms, the toe bar, the knuckle, and the wheel. The double wishbone suspension and McPherson suspension, which are described and modeled [4] by a multi-body system, are standard passenger car suspension systems. The wheels at the rear axle are guided by trapezoidal-link suspension systems, each modeled by a control arm, a lateral link, the knuckle, and the wheel. The correspond-

ing SIMPACK model, shown in Fig. 2, also provides the anti-roll bar which was deactivated in the test in order to avoid a strong oversteer tendency.
The scaled vehicle is also equipped with coil springs and pneumatic dampers which are modeled by non-linear Force Elements. The steering system consists of servo-driven lever arms which transmit the steering motion via the toe bar to knuckle and wheels. The wheel was supplemented with the TMeasy tire model [5], which provides an interface to SIMPACK. All these structures are fully parameterized, so the simulation model can easily be adopted to different vehicles.
Predefined Input Functions control the steering angle and the drive torque that is applied directly to the rear wheels in this first model approach.

VEHICLE DATA

The geometry and the mass and inertia properties of the scaled test vehicle with respect to the center of gravity (CG) were carefully measured. The characteristics of the small coil springs and the pneumatic damper elements were recorded separately on a small test rig. The main data of the scaled test vehicle are compared in Table 1 with a downsized data set of a typical midsize passenger car. According to the geometric scaling factor of 1:5 the factors 5^3 and 5^5 must be used to scale the mass and the inertias, respectively.
Nearly all data of the scaled test vehicle match quite well with the corresponding downsized values of a typical midsize passenger car. Only the inertias differ somewhat. This is caused by a more compact mass distribution in the scaled vehicle.

"The TMeasy tire model has been successfully applied to many different tires ranging from large agricultural tires over heavy truck tires to passenger car tires."

TIRE MODEL

The TMeasy tire model has been successfully applied to many different tires ranging from large agricultural tires to heavy truck tires to passenger car tires. TMeasy is a typical handling tire model [3]. It provides all forces and torques generated in the contact patch of the tire. It operates with data that has a physical meaning and may be set appropriately by an engineer's guess in the absence of tire measurements. The scaled vehicle is equipped with small pneumatic tires that, although not inflated and not reinforced by steel, rayon or nylon, should exhibit a typical tire performance. So, we were confident that these tires could be described by the TMeasy tire model.

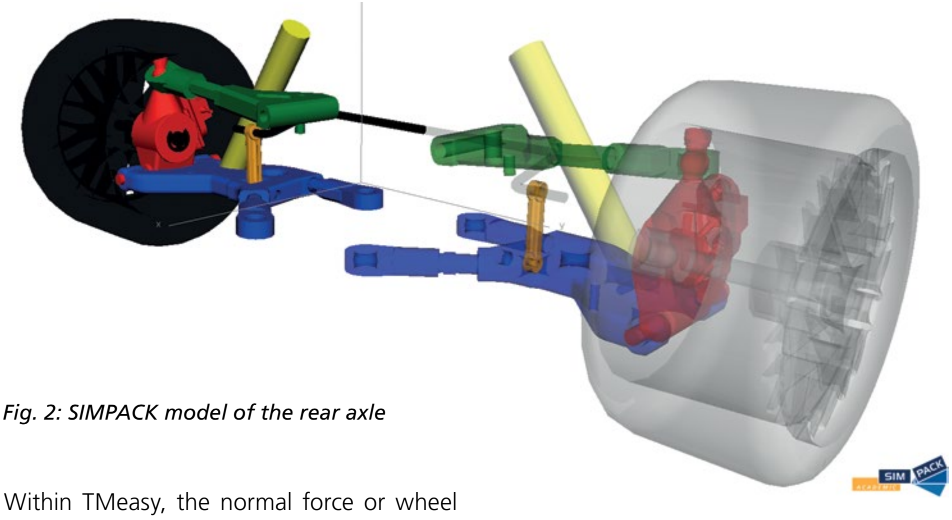

Fig. 2: SIMPACK model of the rear axle

Within TMeasy, the normal force or wheel load F_z is approximated by a spring damper element. The longitudinal force as a function of the longitudinal slip $F_x = F_x(s_x)$ and the lateral force depending on the lateral slip $F_y = F_y(s_y)$ are defined by characteristic parameters, Fig. 3. These are the initial inclinations dF_x^0, dF_y^0, the locations s_x^M, s_y^M and the magnitude of the maximum forces F_x^M, F_y^M as well as the sliding limits s_x^S, s_y^S and the sliding forces F_x^S, F_y^S.
The lateral force characteristics of the tires of the scaled vehicle are defined by the two sets of data shown in Table 2. Thus, the influence of the wheel load F_z to the tire forces and torques is taken into account. The measurements with the scaled vehicle have been performed on a hard sports area. The traction coefficient in lateral direction was estimated by a value slightly larger than one on this particular surface. Setting the traction coefficient to $\mu = 1.08$ will then result in a payload of $F_z^N = 25\,\text{N}$ in a maximum lateral force of $F_y^M = 1.08 \cdot 25\,\text{N} = 27\,\text{N}$. Furthermore, a degressive influence of the wheel load to the lateral force characteristic was assumed, which reduces the traction coefficient in the lateral direction from $\mu = 1.08$ to $\mu = 45/(2 \cdot 25) = 0.90$ at double the payload. As is common with many tires, the lateral sliding force equals the maximum force $F_y^S = F_y^M$. Then, the slip value s_y^M where the lateral force F_y amounts to the sliding force F_y^S is of no importance here; it just has to satisfy the condition $s_y^S > s_y^M$.
The TMeasy model approach requires an initial inclination (cornering stiffness) of the lateral tire characteristics that is limited to values of $dF_y^0 \geq 2 \cdot F_y^M / s_y^M$. As the slip value

		Scaled vehicle	Downsized values of a real vehicle
Tire radius	[m]	0.0618	0.3170/5 = 0.0634
Wheel base	[m]	0.5080	2.6000/5 = 0.5200
Track width	[m]	0.3210	1.5500/5 = 0.3100
Height CG	[m]	0.1397	0.6500/5 = 0.1300
Mass	[kg]	12.215	$1600/5^3$ = 12.800
Inertia (long.)	[kgm²]	0.1038	$600/5^5$ = 0.1920
(lat.)	[kgm²]	0.5730	$2000.0/5^5$ = 0.6400
(vert.)	[kgm²]	0.6291	$2200.0/5^5$ = 0.7040

Table 1: Main data of the scaled vehicle compared to downsized values of a real vehicle

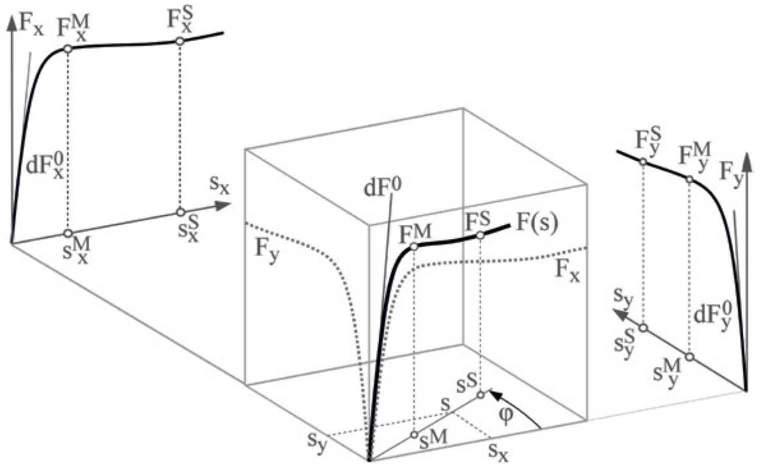

Fig. 3: Longitudinal, lateral and generalized TMeasy tire characteristics

Characteristics at loads	$F_z = F_z^N = 25\,\text{N}$	$F_z = 2\,F_z^N = 50\,\text{N}$
initial slope dF_y^0	400 N	730 N
maximum force F_y^M	27 N	45 N
slip s_y where $F_y = F_y^M$	0.20	0.22
sliding force F_y^S	27 N	45 N
slip s_y where $F_y = F_y^S$	1.00	1.00

Table 2: Lateral tire force characteristics

where the lateral force reaches its maximum was set to $s_y^M = 0.20$, the limit will be defined by $dF_y^0 \geq 2 \cdot 25\,\text{N} / 0.20 = 250\,\text{N}$. The chosen value of $dF_y^0 = 400\,\text{N}$ is moderately larger, and hence, will represent a rather soft tire performance. Similar data sets are provided for the longitudinal tire force characteristics. By combining the longitudinal and lateral slip to a generalized slip s, the combined force characteristic $F = F(s)$ can be automatically generated by the characteristic tire parameter in the longitudinal and lateral directions, Fig. 3. In addition, a three-dimensional slip is introduced that combines the turn slip and the generalized slip [5].
The self-aligning torque is approximated via the pneumatic trail, which again is described by a characteristic parameter. The influence of the camber angle to the lateral tire force and the self-aligning torque is modeled by an equivalent lateral slip and by a bore torque, which is generated by the component of the wheel rotation around an axis perpendicular to the local track plane. The TMeasy model data are completed by geometric data as well as stiffness and damping properties of the tire.
By taking the tire deformation into account, the TMeasy approach to steady state tire forces is automatically extended to dynamic tire forces and torques.

FIRST RESULTS

For a first test, a simple step steer input was chosen where the focus was placed on steady state performance. The step steer input was set at a vehicle velocity of v = 15 km/h. The steering angle applied to the scaled vehicle and the SIMPACK model was chosen such that the vehicle is close to the limit range when reaching steady state, Fig. 4. Due to the roughness of the hard sports area, the measurements are quite noisy although the computed lateral vehicle acceleration conforms well with measurements.

CONCLUSION

The project 'Scaled Vehicle Dynamics' combines theory and experiment or simulation and measurement perfectly. Not only students but, also supervisors were able to gain or deepen their knowledge in multi-body systems, data supply, simulation techniques, planning and performing measurements, and model verification.
At present, only a first loop was carried out. Future project groups plan to perform more enhanced field tests, improve the quality of the multi-body model, develop sophisticated model verification tests, and hopefully find a way to apply at least some of the model results back to real vehicles.

"The project 'Scaled Vehicle Dynamics' combines theory and experiment or simulation and measurement perfectly."

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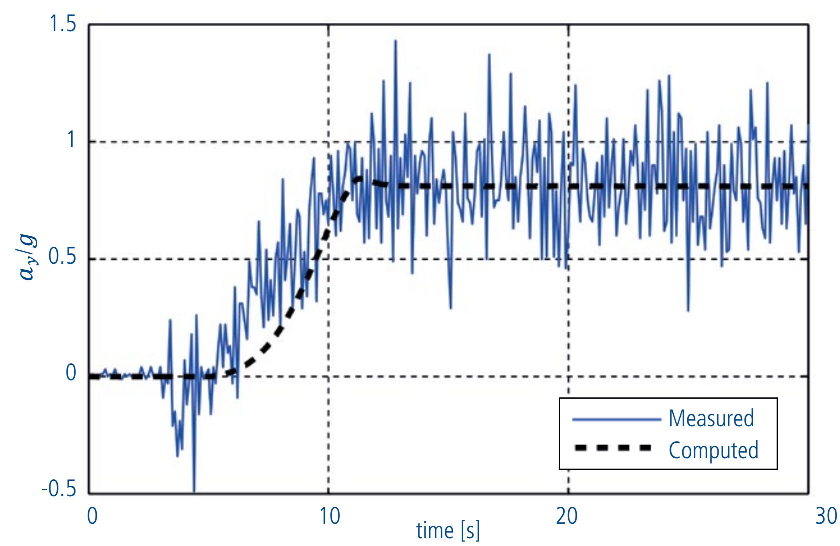

Fig. 4: Measured and computed lateral vehicle acceleration a_y versus time normalized to gravity g