MATHEMATICAL METHODS IN DYNAMICS AND DURABILITY

Interactive simulator RODOS® with attached passenger car cabin: The simulation scenario in use is based on 3D laser scanner data, recorded with REDAR. The attachment is used for the development and testing of assistance and automated solutions for passenger vehicles. Test drivers experience a highly immersive virtual environment where they can also perform high risk maneuvers. Compared with field testing, reproducibility in the simulator is excellent.

DR. KLAUS DRESSLER
HEAD OF DEPARTMENT

In our department, we are dealing with modelling and simulation of usage variability, durability, energy efficiency and real-driving-emission of vehicles. For such ‘transient’ attributes a good model of the vehicle is not sufficient, however, the simulation of the boundary conditions i.e. “the interaction with the rest of the world” is needed as well - in particular, good models for the road network, topography, road conditions, traffic, tires and driver’s behavior. Most important, validation processes for such vehicle properties require statistically qualified test and simulation scenarios, which capture the real usage variability of loads, consumption and emission. Fraunhofer ITWM is working on these topics systematically in the framework of the Fraunhofer Innovation Cluster Vehicle-Environment-Driver Interaction.

Furthermore, we are developing simulation methods and software for the optimization and validation of engineering and production. In cooperation with Fraunhofer-Chalmers Center (FCC), we are working on IPS Cable Simulation, the leading software for the engineering of wiring harness, cables and hoses, and on solutions for the ergonomic analysis of human workers in the production process.

MAIN TOPICS

- Modelling and simulation of usage variability in vehicle engineering (VMC®/U·Sim)

- Simulation of the vehicle-environment-human interaction
  - Tire and full vehicle simulation (CDTire)
  - Interactive simulation/simulator RODOS®

- Simulation of cables and hoses (IPS Cable Simulation)

- Dynamic simulation of human motion: MAVO project “Ergo-dynamic Moving Manikin with Cognitive Control”

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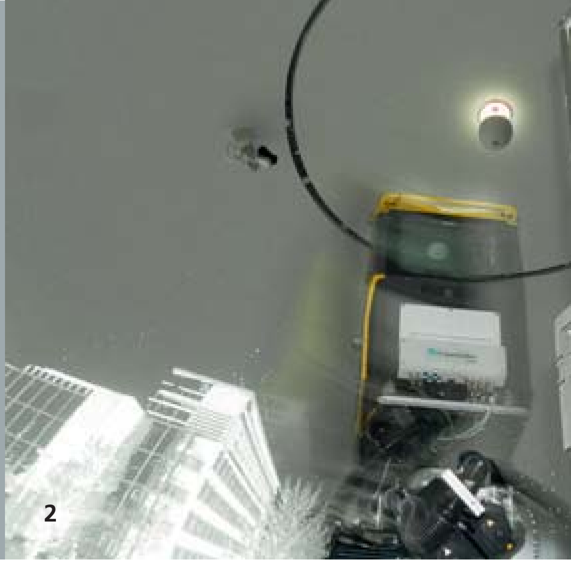
USAGE MODELING OF VEHICLES USING VMC®

1 *Automatically generated route for a commuter. Direct connection lines between origin, destination and one stopover are colored in red. Real route on road network calculated by VMC® is colored in blue.*

One of the main research topics in the department "Mathematical Methods in Dynamics and Durability" (MDF) at Fraunhofer ITWM in Kaiserslautern is about usage modeling of vehicles taking geo-referenced data into account. In cooperation with five big truck companies the software package "Virtual Measurement Campaign" (VMC®) has been developed. For vehicle manufacturers not only the acquisition and evaluation of real measurement data is important, furthermore a deeper knowledge and understanding of the vehicle's usage becomes more and more a major topic. Those aspects have to be taken into account to extrapolate data for different customer groups to the whole lifetime of a vehicle. Besides other applications, VMC® offers important contributions in designing and evaluating measurement campaigns. The following example gives a brief overview about the mathematical methods and software tools, which have been applied during a project conducted together with Volkswagen Nutzfahrzeuge.

Using the software module "VMC® GeoStatistics", a measurement campaign was planned in detail for a desired target region. In this process, relevant topographical factors like road type, slope or curviness were taken into consideration. Our aim was the determination of a route for the campaign reflecting well all characteristics of the targeted region. All important topographical factors and relevant driving conditions have been sufficiently included, allowing statistical evaluations of the data collected during the measurement campaign. In parallel, the vehicle usage was also considered. Depending on the vehicle type, different industrial sectors and fields of application with their differing operational profiles are of importance. These include, amongst others, parcel service distributors or craftsmen. The latter for instance mostly travels from his premises to his diverse customers, but in addition, he also has to buy consumables as needed. Visualizing his daily travelled routes inside his area of operation shows some star-shaped pattern. In contrast to that, a typical tour of parcel services and distributors looks more like a circuit. Typical tours include more stopovers than the trips of craftsmen. In order to generate representative routes for different customer groups, spatial information and potential single targets are needed. Those have been extracted from the VMC® database. For each customer group several thousand routes have been generated. The obtained results are verified with generally accessible statistics including for example typical driven distances of commuters as well as specific measurement data. Digital map data allows the determination of the topographical conditions on the roads travelled and the composition of trip types. Finally, these parameters were used during extrapolation of measured data to expected load distributions. In particular, sensitivity studies and comparisons between different customer groups have been conducted. These allow customized configurations of vehicles and an overall customer oriented design and development.



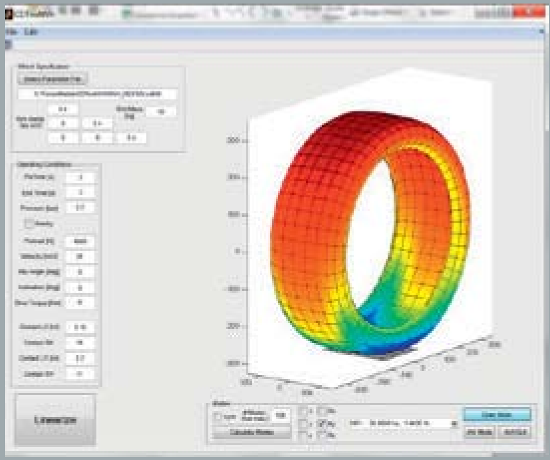
INTERACTIVE DRIVING AND OPERATING SIMULATION WITH RODOS®

In the simulation-based testing of new vehicle concepts, all relevant influences on the vehicle model have to be correctly displayed in very early project phases. The environment as well as the human-vehicle interaction is particularly challenging. With the rapidly increasing complexity of vehicles, which not only support the driver in a multitude of decisions, but also increasingly take over the actual driving partly or completely, new requirements arise for the simulation chain in the development process. The number and nature of the interactions between the vehicle, the environment and the human (driver), which have to be taken into account in vehicle development, has increased considerably in the recent past.

Traditionally, the focus of a simulation has been to compute the physical characteristics of the vehicle, taking into account a few partial aspects of the environment (e. g., the road surface) and the driver (e. g., as a controller). Also for the coupling of these input variables less complex approaches have so far generally led to meaningful results. Aspects such as automated and autonomous driving have to be approached with new global methods and developed iteratively during the simulation. With increasing intelligence of the vehicle and the resulting more active role of the vehicle, a relatively simple modeling of the driver's behavior is no longer sufficient. The reactions and feelings of the driver are now very strongly dependent on the 'decisions' of the vehicle itself. The subjective feeling of driving no longer results solely from the physical characteristics of the vehicle but also from its 'intelligent' behavior (active intervention in the process of driving) as well as the (partially autonomous) behavior of other vehicles. Furthermore, the necessary degree of detail of the environment increases as the built-in sensors detect with a high degree of accuracy and, for example, a description of the road surface as an input variable in the model is by no means sufficient. In particular, the human being, whose immersion experience is strongly influenced by visual and vestibular impressions, reacts significantly to different degrees of complexity and realism in the simulated environment. To this end, the ITWM developed a new tool chain that starts with a highly accurate laser-based 3D (REDAR) recording of the environment and ultimately integrates the driver into the simulation environment using a robot-based driving simulator (RODOS®) with an extraordinarily high degree of immersion. The vehicle simulation itself, in addition to the driver interaction, also uses the environmental data – e. g. via a specially developed terrain server for the tire models – as input. Despite the immense amounts of data, the environmental representation based on point clouds is realizable on the basis of new 'out-of-core' approaches.

1 *Simulation scenario based on measured 3D point clouds (Trippstadter Straße in Kaiserslautern)*

2 *Excavator simulation in a point cloud-based scenario*



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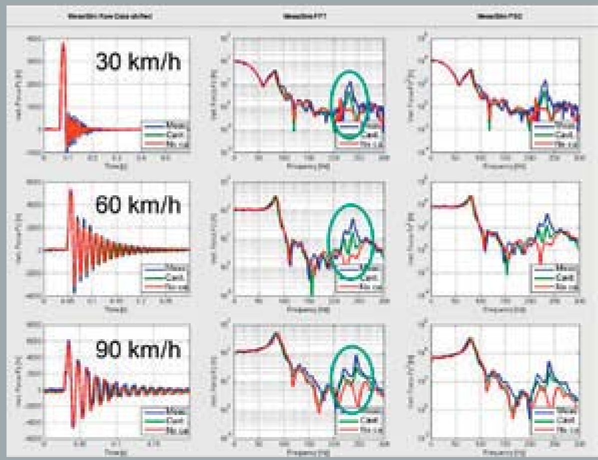

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INFLUENCE OF THE DYNAMICS OF THE INFLATION GAS ON THE OPERATING CONDITIONS OF A TIRE

1 *CDTire/NVH: Linearization of the rotating tire*

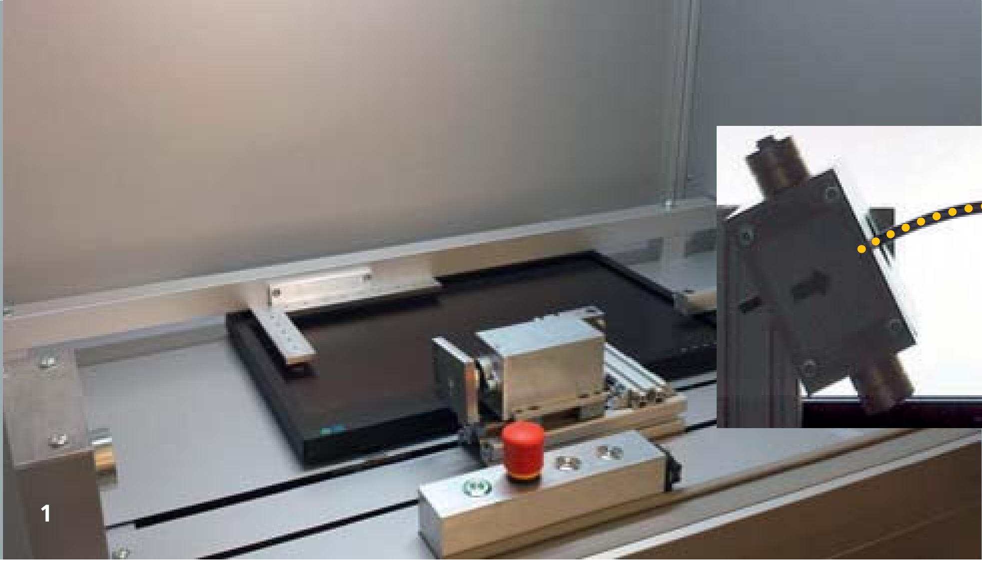
2 *Vertical spindle force comparison for cleat runs: measurement (blue) vs. simulation with (green) and without (red) dynamics of the inflation gas*

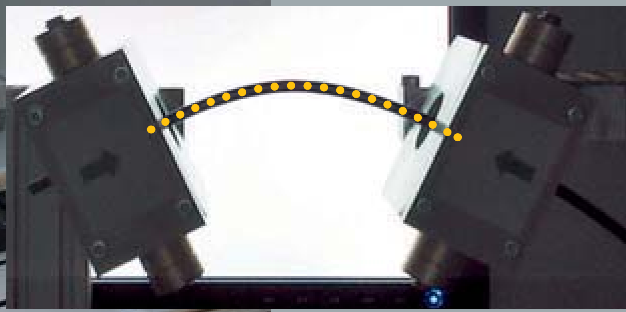
The ITWM developed the tire model CDTire/3D, a shell-based bead-to-bead model with materialized modeling of sidewalls and belt. All functional layers of a tire (inner liner, carcass, belt and cap plies and the tread) are modeled as separate entities accessible in pre-processing and condensed into one geometric shell representation. The structural properties of each layer can be parameterized separately and may vary with local cross section position. This modeling yields an optimal compromise between computational effort and solution accuracy, allowing for full vehicle simulation scenarios for all typical application attributes to assess and optimize vehicle suspension, structure and dynamics with more than reasonable simulation times.

CDTire/3D models the tire from bead to bead, including the sidewalls. As such, the inflation pressure can applied correctly onto the innermost layer (innerliner) of the tire. For many applications, it is feasible to model the inflation pressure as a prescribed value, provided as a function of time. This modelling already allows for complex application scenarios such as sudden total pressure loss simulations in safety-critical virtual developments of vehicle control systems.

However, there are applications where it is needed to model the inflation gas dynamically and the tire’s dynamic interaction with it. Such an example is the extension of the frequency range of NVH (noise, vibration, harshness) applications up to and beyond 250 Hz. For typical passenger car tires, the first resonance of the inflation gas (air) – the so-called cavity mode – lies at around 220 Hz. In this frequency range, the dynamics of the inflation gas (air) couples with the tire structure, generating significant peaks in the spindle forces acting on the rim.

In order to feature these applications, CDTire/3D now has the capability to model the inflation gas as an isotropic compressible Euler equation with time-varying cross section area. With this modeling, sudden changes in cross section area (as experienced e. g. in cleat runs) yield local changes in the pressure that propagate with the velocity of sound in both circumferential directions of the tire’s cavity. This modeling also takes into account that the inflation gas within the tire is rotating with the tire. Within the rotating inflation gas, the pressure variations still propagate with the speed of sound in both directions, but a non-rotating observer will register two different frequencies relative to a non-rotating frame. This velocity-dependent split in the frequency of the cavity mode is also visible in measurements.





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IDENTIFICATION OF MODEL PARAMETERS FOR IPS CABLE SIMULATION WITH MESOMICS

The numerical simulation of highly flexible components like cables and hoses is an important aspect of modern virtual product development. The software IPS Cable Simulation, developed from FCC and ITWM, allows an interactive and at the same time accurate simulation for design and assembly situations.

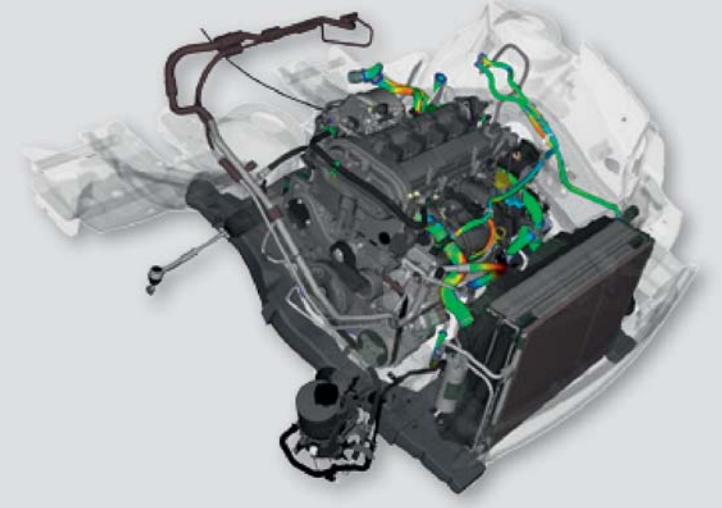
For a physical correct prediction in the digital mock-up of cables and hoses, their mechanical properties are an essential model input. Therefore, recently a highly automated measurement system (MeSOMICS) was developed, constructed and registered for patent. MeSOMICS stands for "Measurement System for the Optically Monitored Identification of Cable Stiffnesses." Besides classical measurement quantities like forces and moments, it provides an optical detection of the cable bending line. This optical detection is used to monitor the measurement process.

The measurement system is especially tailored for a comfortable handling and automated evaluation of parameters. For instance, the assembling of specimens is very easy, the subsequent measurement performs automatically and the relevant model parameters for IPS Cable Simulation are derived immediately after the measurement. Moreover, the innovative concept for the bending test allows practically relevant radii of curvature, which is not the case for the standard 3-point bending test. Thus, the scope of validity is significantly increased.

Based on nonlinear beam theory, an elaborate evaluation algorithm identifies the stiffness parameters from the measured data. By using all recorded quantities – forces, moments, displacements und the mentioned camera images – the algorithm is very robust. In particular, the identified bending stiffness is directly verified by a theoretical solution of the corresponding bending line. Finally, MeSOMICS provides a complete set of cable stiffnesses for the numerical simulation with IPS Cable Simulation.

1 *MeSOMICS sample chamber*

2 *Optical monitoring of the bending test with theoretically identified bending centerline*



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DYNAMIC SIMULATION OF CABLES AND HOSES

1 *Complex cable harness in an engine compartment*

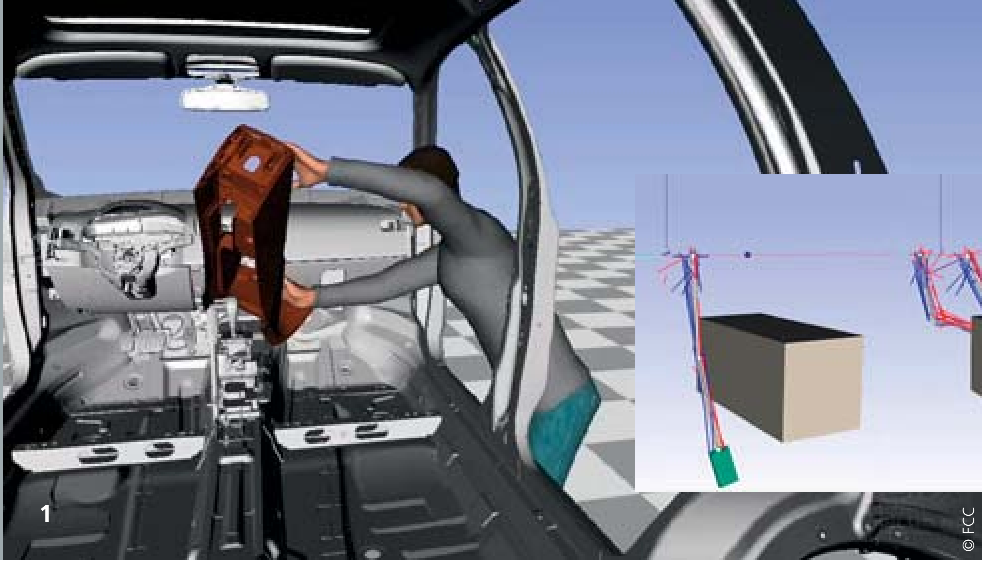
Numerical simulation has become an important aspect of modern production processes in vehicle industry. Very early in the process chain – even before the first prototypes are built – simulation is used for digital mock-up in order to discover possible problems and to improve certain components and their assembling.

Especially challenging is the simulation of highly flexible components like cables and hoses, for which high loads and contacts with high friction should be avoided. Considering slow or quasi-static motions, our software IPS Cable Simulation already enables an interactive, but at the same time highly accurate, simulation of assembly processes of flexible components. It was developed by the FCC in Gothenburg together with the ITWM and is widely used by leading car manufacturers. The software is distributed by the spin-off fleXstructures GmbH.

Nevertheless, when it comes to fast excitations with high frequencies, inertia effects cannot be neglected and dynamic simulation of cables is indispensable. To achieve fast and accurate results with the computational more expensive dynamic simulation, the cable is formulated as geometrically exact Cosserat rod. In combination with modern approaches from discrete differential geometry, this model allows for rather rough discretization, thus short computational time, and still leads to robust and realistic results.

Currently, we integrate the dynamic cable simulation in IPS Cable Simulation. Thus, experienced users can generate flexible cables as before, assemble them digitally and easily compare variations. In contrast to quasi-static simulation, they only need to add some further information: dynamic excitations and damping characteristics of the cable.

An essential tool for the assessment of assembly configurations are accumulated damage values, which are computed in the fatigue analysis after the simulation. In this context, we distinguish two approaches. On the one hand, we already provide a so-called comparative load data analysis (LDA). This method computes pseudo-damage values on the cable surface, which do not predict the absolute lifetime of a component, but allow to compare several configurations to find the best one in the sense of damage. On the other hand, there is a strong interest in absolute lifetime predictions. Algorithmically, we can proceed similar to the comparative LDA but have to use component specific Wöhler curves, which provide the number of acceptable load cycles at certain amplitudes. The assessment of this process is part of our ongoing research.



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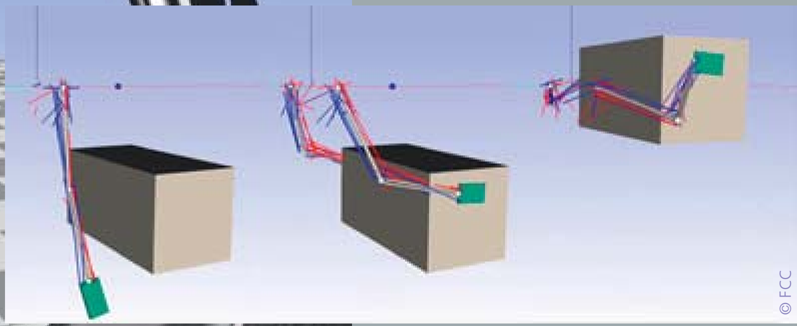

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DIGITAL HUMAN MODELING FOR VIRTUAL ASSEMBLY PLANNING AND ERGONOMIC WORKPLACE DESIGN

The modeling and efficient simulation of human motions for applications in the fields of ergonomics, medicine and computer graphics is a big challenge. The objective of the project "Ergodynamic Moving Manikin with Cognitive Control" (abbrev. EMMA-CC) is the development of an enhanced digital human model for ergonomic assessment of dynamic motions by validated simulation to support the design of healthier and safer workplaces in future product development and product planning processes. Six Fraunhofer Institutes are collaborating in this project: FCC, IAO, IGD, IPA, IPK, and ITWM.

The digital human model IPS IMMA – developed by FCC department "Geometry and motion planning" – therefore provides a basic tool, which we want to enhance by combining it with our research fields in biomechanics and optimal control (ITWM), biomechanical 3D muscle modeling and validation (IPA), hybrid parallelization of biomechanical simulations (IGD), ergonomy methods (IAO), and cognitive control modeling (IPK) in order to achieve our ambitious objectives.

ITWM and FCC are collaborating closely on biomechanics and optimal control, with the goal to generate realistic human-like motions of the DHM from generic working instructions like for example "move a box from A to B." Such a model would enable the engineers to take into account physical workloads and reachability issues in virtual assembly planning. The digital human is modeled as a biomechanical multibody system with muscles as actuators. The motions of the DHM for specific working instructions are predicted with the help of optimal control, where an objective function accounting for physiological quantities that are relevant for humans is minimized. This new approach enables the user to make quantitative statements about muscle forces and joint loads during assembly, which are important indicators for ergonomic assessment.

With the model developed in the project EMMA-CC it will be possible to develop new ergonomic guidelines for dynamic motions. These provides the basis for an ergonomically favorable assembly planning accounting for dynamical effects, as well as a personalized ergonomic workplace design. Due to fast and robust numerical algorithms the model is running nearly in real time on a modern personal computer, which allows for the productive use in optimizing virtual assembly. The practical relevance of the simulation tool is validated by numerous ongoing experiments conducted by Fraunhofer IPA, and its practical utility for application engineers is demonstrated in a virtual reality environment developed by Fraunhofer IPK.

1 *Simulation of the assembly of the center console of a passenger car in IPS IMMA*

2 *Lifting of a box, simulated with a biomechanical digital human model actuated by muscles*