MATHEMATICAL METHODS IN DYNAMICS AND DURABILITY

Excavators and wheel loaders move many cubic metres of various materials. For many years we have been helping Volvo optimize durability, energy efficiency and human-machine interaction with simulation software and services. Our DEM simulation software GRAPE and the driving simulator RODOS®, which Volvo has been using regularly for years to develop advanced assistance systems, play a special role here.

DR. KLAUS DRESSLER
HEAD OF DEPARTMENT

SIMULATION TECHNOLOGIES FOR VEHICLE ENGINEERING

Usage variability modelling for vehicle design reaches a whole new level with efficient data- and physics-based methods for durability, reliability, and energy efficiency. The VMC® and USim products developed in the "Virtual Measurement Campaign" combine statistical and simulation approaches with geo-referenced databases. Appropriately, we focus our system simulation activities on vehicle-environment-human interaction. We develop tire simulation models, surface-interaction models, and methods of invariant system excitation. Our robot-assisted RODOS® driving simulator enables advanced studies of driver-vehicle-interaction and the development of tools for driver assistance systems (ADAS – advanced driver assistance systems).

The mathematical modelling and simulation of highly deformable structures is the basis of our simulation tools CDTire (for tires) and IPS Cable Simulation (for cable and hoses). CDTire enables the efficient simulation of tires for use in the optimization of driving dynamics, operating loads, and vehicle comfort. IPS Cable Simulation is used for cables and hoses: The virtual design, optimization, and the validation of assembly and operation are supported by interactive simulation.

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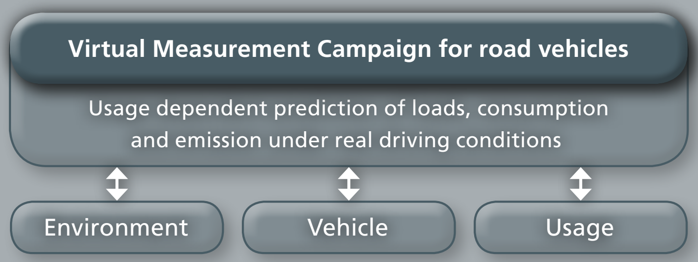
MAIN TOPICS

- Usage Variability and Loading Statistics
- Durability and Reliability
- System Simulation
- Human-in-the-Loop Driving Simulator RODOS®
- Nonlinear Structural Mechanics
- Tire Models – CDTire



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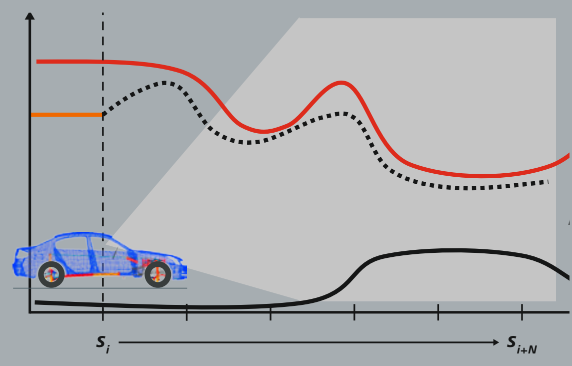

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VMC® SIMULATION – REPRESENTATIVE PREDICTION OF LOADS AND ENERGY CONSUMPTION

1 *Main components of the Software-Suite VMC®*

2 *Route-, vehicle- and driver-specific calculation of speed profiles*

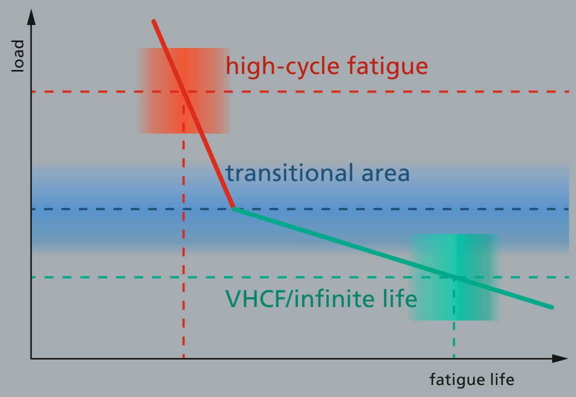
For many years, we have been working on the integration and use of global geo-referenced data in the vehicle development process. This has led to the development of the software suite Virtual Measurement Campaign VMC®. Its fundamental objective is to efficiently analyze the strongly varying usage variability and the resulting variations in the loads and performance requirements. This opens the possibility to take those results into account even at an early stage in the design process.

Most recently, we have designed and implemented several substantial innovations, particularly in the module VMC® Simulation. VMC® Simulation uses a model of the world in which, among others, the worldwide road network, altitude profiles and traffic signs are available. We use simplified vehicle models to predict simulation-based driver- and vehicle-specific loads, energy requirements or vehicle consumption. After defining one or more routes and defining driver and vehicle characteristics, a speed profile is computed by an optimal control approach, from which longitudinal and lateral loads, driving resistances, energy requirements or consumption can be derived.

The results are used, e. g., in the fields of durability and powertrain development, but also in the context of real vehicle consumption and emission determination, to derive customer- and usage-specific reference routes.

New developments with MAN

In projects with MAN Truck & Bus AG, we have implemented improved powertrain models, which allow predictive statements about engine torque, speed and gear distributions on selected routes or in certain regions of the world. Furthermore, we have developed a new algorithm that selects a set of routes and road segments, which are representative for a region with respect to certain criteria (e. g. occuring slopes). In a next step, a route of specified length can be chosen, which is as representative as possible and which can also be actually driven by a real vehicle (campaign planning).



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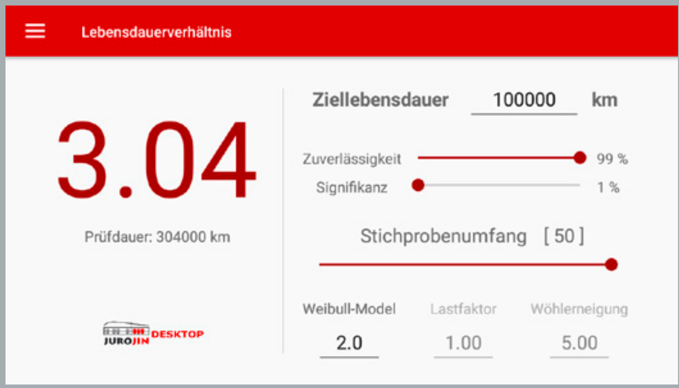

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JUROJIN – STATISTICAL EVALUATION OF FATIGUE TESTS

Our statistics program JUROJIN supports the planning and evaluation of durability tests. Methodology and program structure are based on projects and practical application cases with car and commercial vehicle industry. A number of vehicle manufacturers and suppliers are using JUROJIN to solve typical tasks quickly and efficiently.

1 *Combined Wöhler model*

2 *Screenshot of the test planning in Jurojin Mobile*

Before components enter production only few and expensive prototypes are available for reliability demonstration. Especially for safety relevant components, this demonstration is crucial.

Reliabilty estimation is expensive

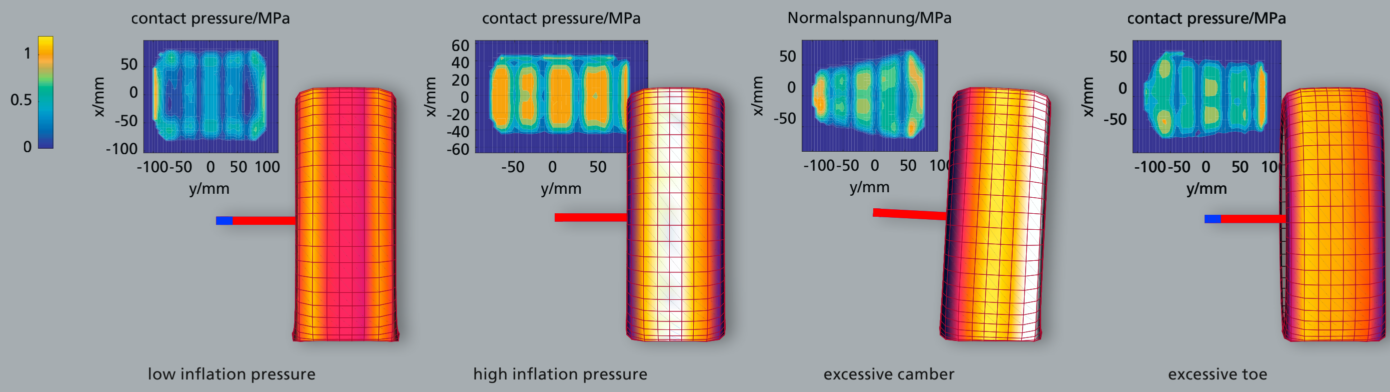
Several typical questions arise: How many prototypes need to be tested? At what test duration? Either many short or few long tests? To evaluate the test results one has to deal with small sample sizes and censored data (i. e. tests without failure).

JUROJIN answers these questions by improving well-tried methods like Maximum Likelihood, depiction in probability papers and Success Runs. Bootstrap algorithms compensate errors from small sizes and utilize all information from censored data. In 2017 we made the module "Design of Test Schedules" available for the Android plattform. Next to the extensive desktop suite there ist now a lean mobile solution answering the questions above.

Efficient Woehler Models

For cyclic loads with medium to high amplitudes, the relationship between load amplitude and fatigue strength (S-N-curve) is often observed to be linear in a double-logarithmic diagram. For lower amplitudes, a nearly horizontal curve is typical. In this range loads may theoretically be applied "infinitely often" (more than one million repetitions). Traditionally, regression in load direction is performed based on the information {component fails/component is durable} to identify the endurance strength.

The fact that fatigue and endurance strength are evaluated separately leads to information loss. Driven by industrial cooperation projects we developed a new stochastic model that allows joint identification of high-cycle fatigue and infinite life or very-high-cycle fatigue behavior.



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TIRE SIMULATION IN THE FIELD OF TENSION BETWEEN DRIVING DYNAMICS AND TIRE ABRASION

1 *Tire abrasion with different chassis configurations*

Tires play an increasingly important role in the development process for a new vehicle. This is particularly true in the area of driving dynamics. In recent years, enormous progress has been made through the development of new axle concepts, but also through the symbiotic integration of tire development in the chassis development process.

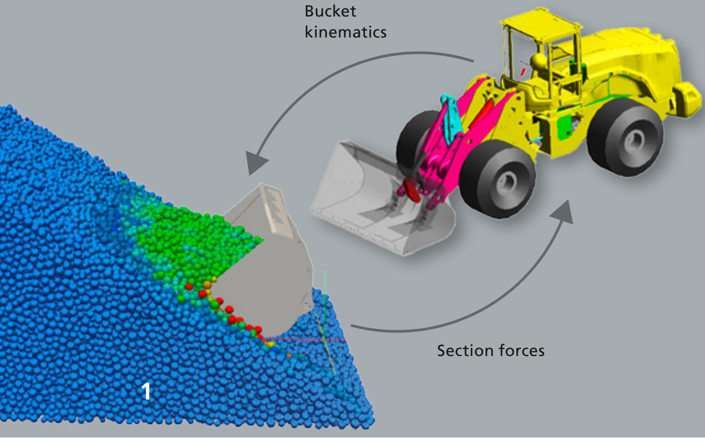
A very good example of the tire/chassis symbiosis is the simultaneous optimization of the vehicle's driving dynamics properties and the resulting tire wear which is caused by the friction of the tire on the road surface. In rolling contact with the tire, this friction can never be completely avoided, even when the tire is rolling freely.

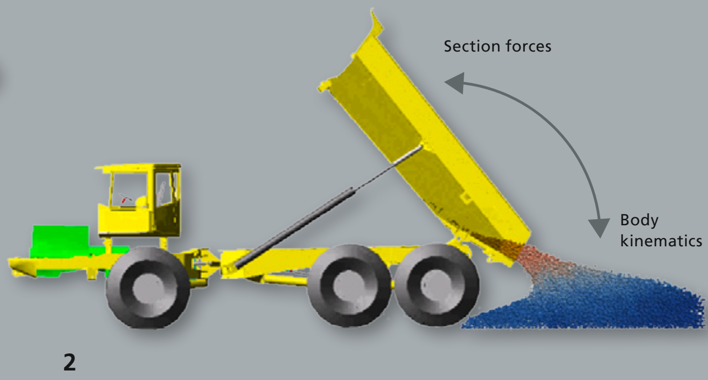
Low abrasion typically has a negative effect on the tire's steering and braking properties. Efforts are therefore being made to optimize both abrasion and steering properties simultaneously and to ensure that the abrasion progresses evenly across the tire width. Toe-in and camber adjustments of the wheel in particular promote uneven tyre wear. But the right choice of tire pressure also has a decisive influence on abrasion. The optimization of the steering properties alone via camber and toe-in can certainly contradict the optimal abrasion behavior.

Structural tire model

In order to find an optimal solution in this area of tension, full vehicle simulations are increasingly used in the early vehicle development phase. Our structural tire model CDTire/3D offers all necessary characteristics to consider the tire in this pocess. It not only calculates the local tire wear, but also analyses the contact area of the tire in all maneuvers relevant to driving dynamics, also depending on tire pressure.

On the one hand, this allows chassis settings to be optimized for both tire abrasion and driving dynamics characteristics, and on the other hand it supports the selection of the optimum tire dimension.





SOIL MODEL GRAPE IN THE VIRTUAL PRODUCT DEVELOPMENT OF VOLVO CONSTRUCTION EQUIPMENT

We have cooperated with Volvo Construction Equipment for more than three years. Within this period, we have integrated our software GRAPE (GRAnular Physics Engine) for particle simulation into Volvo's virtual product development process and continuously promoted the implementation.

GRAPE makes it possible to represent soft soil and gravel with realistic material properties on the computer. GRAPE's core functionality is to represent the interaction with a virtual vehicle or machine and predict the corresponding reaction forces from the soil or pile on the machine adequately.

Implementation of a force-displacement-coupling

In close cooperation, we have implemented a force-displacement-coupling between multibody models of Volvo's construction machines and GRAPE material models by means of a co-simulation scheme. Within this simulation environment, Volvo's wheel loader model, for instance, can approach a virtual gravel pile and we obtain the respective forces acting on bushings and joints in the lifting framework when filling the bucket.

Simulation of typical development cycles

Due to our software's performance, we are able to simulate typical development cycles of such maneuvers like charging and discharging of a wheel loader bucket within an appropriate simulation time. Hence, we can particularly predict durability properties and damage of important components, which are essential for the wheel loader's development process.

Furthermore, Volvo simulates the discharging of granular material from an articulated hauler with the help of GRAPE. While discharging the vehicle when lifting the body, forces are acting on axles and tires because of the material flow. These forces can now be predicted and we can draw important conclusions on the development process.

1 *Simulation of soil and wheel loader model interaction when charging the bucket*

2 *Simulation of gravel and hauler model interaction when discharging the body*

SUCCESS STORY

VEHICLE, ENVIRONMENT, BEHAVIOUR: REAL-TIME SIMULATION

"We see enormous potential in the interactive simulation with RODOS for construction machinery and commercial vehicles, in order to sustainably and profitably expand our development and testing activities in Konz."

Martin Frank
AE Program Leader Machine Intelligence & User Experience

Possibilities and requirements for simulation in vehicle engineering have increased considerably over the last 30 years. From component simulation to system simulation of entire vehicles, additional consideration is now given to the driver and the environment. REDAR and RODOS® support these new challenges in the engineering process, starting with three-dimensional environment acquisition up to test drives in the driving simulator.

Where do we get the environmental data?

The REDAR measuring vehicle (Road & Environmental Data Acquisition Rover) uses two 360-degree laser scanners to record its environment with high accuracy at normal driving speed. As a result of the measurement, a three-dimensional image of the environment in the form of a point cloud is obtained. Data volumes of several terabytes are not unusual. One possible application is, for example, the realistic 3D environment representation in a driving simulator. The greatest challenges are setting up such a complex measuring system and developing suitable algorithms to consistently process the data. The measurement vehicle has been in service, busily collecting data for individual customer projects, since 2015.

What happens to the data?

ITWM's driving simulator RODOS® (RObot based Driving and Operation Simulator) processes the measurement data from REDAR as input for simulation and visualization. Various cabins equipped with control elements like the steering wheel, gas pedal, and brakes can be mounted on the six-axis robot. When navigating interactively through the virtual world, the robot moves the cabin in a way that corresponds to the feelings of acceleration, braking, or taking tight curves normally felt by the driver. The optimization of the perception of reality, currently is the subject of a dissertation in psychology.

The road network as the database

The simulations are supported with information from the Virtual Measurement Campaign VMC® database system. The world's road network with its topography, regulations, weather information and other geo-referenced data is stored there. With the help of special statistical methods, the scenarios that are considered important and representative can be filtered out for more detailed investigations with REDAR and RODOS®. Linking these two worlds is a major step in determining efficient and targeted test scenarios for road vehicle design. The current state of research focuses on the definition of reference routes and the search for the ideal testing environment: for example, is there a real city somewhere that has a representative mix of the major test parameters for various cities or even for all urban scenarios?

On the move with REDAR: 360-degree laser scanners detect the environment with high accuracy.

In addition to virtual testing of driver assistance or autonomous systems, this development environment also allows an efficient and flexible investigation of fuel consumption and emissions: A wide variety of test scenarios can be categorized, weighted and realistically compared. VMC®, REDAR and RODOS® represent a flexible and universally applicable tool chain to describe the interaction between humans, vehicle and environment.

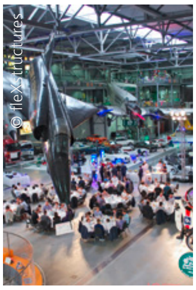
RODOS® technical data

- Design and construction time: 2009 – 2012
- 18 projectors for all-round visibility in the projection dome (diameter: 10 meters)
- Resolution: 11520 × 3600 Pixels
- Six-axis industrial robot enables wide field of maneuver and large tilt angle
- Interchangeable cabins (currently: excavators, cars, tractors)
- Payload: 1000 kg

NEWS

WORLDWIDE INTEREST IN IPS CABLE SIMULATION

Cables and hoses are omnipresent in modern technical products. To optimize the assembly of these highly flexible components in early stages of product development, simulation is used. The Software IPS Cable Simulation, developed in cooperation with the Fraunhofer-Chalmers Centre, is the leading tool for this task and the user group is continually growing. Our spin-off fleXstructures GmbH takes care of the distribution of the software. In the past year alone, 25 new customers could be convinced of our software solution.



3. International IPS Cable Simulation User Conference in Speyer
IPS users from all over the world met in June 2017 at the third IPS Cable Simulation User Conference in the Technik Museum Speyer. Over 90 participants from USA, Asia and Europe stimulated interesting discussions. Contributions from Adam Opel, BMW, Delphi, fleXstructures, Fraunhofer ITWM, Fraunhofer-Chalmers Centre, Komatsu, SCANIA, techViz, Volkswagen and Volvo Cars gave an insight on new applications, requirements and developments from industry and research.

An announcement from BMW illustrates the increasing acceptance of IPS Cable Simulation: at their 100th anniversary, the car manufacturer exhibits 100 IPS Cable Simulation users.

Independent Conferences in China and Japan
The second Chinese IPS Technology Conference took place in Shanghai. About 80 participants from automotive and supply industry, aerospace, rail vehicle industry and research attended the event. Our Chinese distribution partner Pan-i successfully organized this conference.

More than 100 participants from different industries attended the second Japanese IPS Cable Simulation User Conference in Tokyo, organized by our Japanese distribution partner SCSK. With great interest, the participants listened to presentations from SCSK and industrial applications from Japanese customers.

Front, left to right: Vanessa Dörlich, Francesco Calabrese, Christine Biedinger, Dr.-Ing. Michael Roller, Dr. Klaus Dreßler, Caroline Wasser, Dr.-Ing. Joachim Linn, Dr. Michael Burger, Dr. Jochen Fiedler, Eduardo Pena Vina, Tim Rothmann, René Reinhard, Hannes Christiansen, Dr. Andrey Gizatullin, Dr. Fabio Schneider, Dr.-Ing. Michael Kleer, Steffen Polanski, Björn Wagner, Thomas Halfmann, Thomas Stephan, Christoph Mühlbach, Thorsten Weyh, Christine Rauch, Dr. Michael Speckert, Dr. Sascha Feth, Axel Gallrein, Dr. Stefan Steidel, Thomas Jung, Simon Gottschalk