When Cars Become Networks on Wheels
Control your complexity with virtual test driving tools and methods.

Modern automobiles have become multi-system landscapes on wheels. Innovative electronic driver assistance and control systems enhance safety, energy efficiency, comfort and, last but not least, agility. To this end, a large number of highly complex single components with sophisticated functions have to be successfully integrated in the whole vehicle as early as possible. Global development projects, a significant increase in variants and validation requirements, contrasted by massive reductions of prototypes plus shorter time to market, are some of the key aspects that shape today’s developments. At the same time, it is crucial to ensure that fundamental issues, such as the effects of detailed modifications on the characteristics of the whole vehicle, are detected before physical testing begins.

Vehicle development is faced with the global challenge of working in concert and taking the right actions at the right time in any phase of a project. The transition from an isolated modular to an integrated full-vehicle view is an indispensable prerequisite for reliable evaluation of the mutual effects and interactions between modules and systems. This can be achieved at any time through virtual test driving with its vast array of driving maneuvers and driving modes.

The powerful tools and reliable methods offered by IPG Automotive allow you to import existing models, tools and processes into an open, cross-functional integration and test platform. This makes virtual test driving available to you for a wide range of applications across all development phases. System defects can thus be corrected long before the first physical test drive and prototypes achieve a much higher degree of maturity. Plus, your test drivers can pay higher attention again to optimizing handling and controller characteristics.

“We want to enable every engineer in the process to evaluate vehicle characteristics and performance in the whole vehicle.”

Dr. Alexander Schmidt & Steffen Schmidt, IPG Automotive

SOLUTIONS FOR VIRTUAL TEST DRIVING
More safety, efficiency and comfort for future mobility with IPG Automotive.

Facing the challenges of tomorrow our simulation solutions promise high user friendliness, precision and top-quality results. The reliability and efficiency achieved throughout the development process leads to major cost savings and faster time to market for the products of our customers, assisted by highly responsive delivery of our reliable expert support.

Drawing on unique methods and process expertise, integration in an international academic research network and a keen sense of recognizing trends we develop forward-thinking, platform-independent software and hardware solutions for virtual test driving. They are used in general vehicle dynamics as well as for developing and testing networked control systems, driver assistance systems, fuel efficiency and e-mobility, among others.

Our claim and aim: Together with our customers, we contribute to tomorrow’s personal mobility in the course of technical progress – with respect to safety, economy and environmental compatibility. As an innovation leader in the field of virtual test driving, IPG Automotive provides vehicle engineers with access to the vehicle on a broad base – in the virtual world!
Perfect Fusion of Methods and Tools
Combining software, hardware and driving experience for leading-edge virtual test driving.

### Simulation Software

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4  Simulation Software
5
IPGDriver is extremely adaptable. It simulates a vast array of driving styles with consummate
precision. All parameters – from sporty driving through to slow cruising – can be configured easily and quickly.
IPGDriver responds to control and driver assistance systems just like a human driver would. It competently executes
challenging tasks, from tricky parking maneuvers and stop-and-go traffic through to driving at the dynamic limits.

Using the Maneuver Control, open- and closed-loop maneuvers of lateral and longitudinal dynamics can be combined
to a test sequence. For every mini-maneuver you can define an action which IPGDriver
will execute.

IPGTraffic and scenario based testing

Any real-world road test is unique, even when based on identical test standards. By contrast, the traffic model
IPGTraffic allows you to easily generate challenging traffic situations with a large number of participants and to repeat
them as often as you like, with no risk involved. Thanks to powerful test automation, the scenarios can simply be
modified step by step or run on different test rigs in an automated process - even overnight, if necessary.

IPGCar

The CarMaker product family including CarMaker®, TruckMaker® and MotorcycleMaker® allows you to simulate
different types of vehicles with exceptionally realistic and precise handling characteristics – visualized through highly
realistic 3D graphics. Whether you wish to test models, software or physical vehicle components, either discretely or
in the form of networked systems, CarMaker® integrates them all into digital prototypes for virtual test driving.

IPGRoad

The 3D road model, with its exchange format ROAD5, serves to generate roads or customer-specific test tracks in
a very short period of time. Even real-world roads based on digitized map data and digital grids – including corners,
slopes, obstacles, road bumps, traffic lights, signage and peripheral buildings – are imported into the simulation en-
vironment by just a few mouse clicks. You can drive your test vehicle wherever you like – for example in the middle of
the urban traffic within a big city or on an alpine mountain pass full of serpentes.
From the V-Model to X-in-the-Loop

Working Together
Obtain early proof that your whole vehicle meets market requirements.

The traditional V-model continues to form the “skeleton” in vehicle engineering. However, in view of the complexity of current and future integration and testing tasks, all components have to be included and validated in the entire evaluation process as early as possible. Virtual test driving makes it possible to interlink the individual domains such as the chassis, powertrain, electrical/electronic or driver assistance systems at a very early stage of the V-process. It thus enables virtual integration and analyses.

This is the starting point for the “X-in-the-Loop” approach developed by the Karlsruhe Institute of Technology (KIT).

IPG Automotive has purposefully implemented this approach in its products in multiple ways. X-in-the-Loop means that all relevant components – whether software, models or hardware – are included in the development, integration and testing tasks. This virtual integration – along the V-model – allows you to know the effects of the tested component on the whole vehicle at any time during the development cycle. With that, you can take appropriate actions to save costs and time and ensure quality: for control system, general vehicle dynamics, advanced driver assistance system plus fuel efficiency & e-mobility applications.

CarMaker is an optimally suited simulation platform for X-in-the-Loop applications

Thanks to our certified models, the correspondence between simulation and reality is very accurate and reliable. The test cases range from concept evaluation through providing reliable software releases to the approval of car components like real engines or their ECUs on dynamic and powertrain test rigs in the virtual test drive. Every component of a car can be validated to meet market requirements and targets. From single components like the gearbox through subsystems like the powertrain up to the whole vehicle – in each case either as real or virtual components. As an application example, let us take a closer look at the ECU-in-the-Loop: In this case, every component of the car, the whole environment as well as the driving maneuver itself is simulated – except the real existing ECU, which is supplied with signals out of the simulation environment. The ECU is integrated into the virtual vehicle model of CarMaker® and tested in virtual test drives. Regardless of the particular development phase of a component, you can work with the same tools, models, parameters and test scenarios at each stage, using a fast, robust and productive simulation environment.
Key Application Areas

Vehicle Dynamics
Shift the driving test from the test track into your office or laboratory! The advantages: Early concept optimization and validation with regard to your target values – cost-effective, reproducible and secure. The virtual TestRuns are valid up to the dynamic limits.

Driver Assistance
Adaptive Cruise Control, autonomous driving, Car2X, Lane Keeping Assistant, Lane Departure Warning, Parking or Emergency Braking Assistants as well as Pre-Crash Systems; the complexity of networked assistance systems requires innovative methods. With our simulation solutions you can seamlessly test advanced driver assistance systems in virtual traffic situations at your desk through to the laboratory.

Powertrain
Optimizing real driving emissions, hybrid and electrical powertrain models, real world energy consumption and thermal management with CarMaker®, TruckMaker® and MotorcycleMaker®.
A Driving Experience Customers Will Love

Design vehicle dynamics that assure safety and evoke emotions.

Safety is a given and emotion the icing on the cake. Your customers want to feel confident at the steering wheel of the current – or future – vehicle you are developing for them. They also expect the pleasure of a dynamic yet comfortable driving experience. The successful interaction of all systems and components in the whole vehicle is crucial to achieving both.

From on-center steering feel, stability, agility and comfort studies to optimizing performance or lap times, IPG’s simulation solutions cover all the bases of vehicle dynamics in virtual test driving with high precision. Detailed model assemblies put your development on a fast and sure track. They give you a quicker picture of the interactions within the whole vehicle and help you to design desirable driving characteristics more efficiently. IPGDriver fully brings its strengths to bear with its wide range of driving strategies: from rest to full drift. Our virtual driver will put your vehicle through a tough test with consummate ease and intuition!

The Future at Work in the Here and Now

The basis for the vision of autonomous driving.

Networked systems account for about 70% of today’s automotive innovations, with a lot more on the horizon. Advanced Driver Assistance Systems (ADAS), for instance, are increasingly using ambient information from cameras, radar, lidar ultrasonics and GPS. Sensor data fusion is critical for faultless operation around the globe at any time with any conceivable driving style. This requires testing of mammoth proportions. The real world has “virtually” become too small for these dimensions.

IPG Automotive provides you with simulation solutions to reliably, repeatably and efficiently explore and optimize safety and comfort systems in virtual test driving. Combinations of active and passive safety are possible, too. The IPGDriver realistically models human responses to electronic instructions and interventions. It only takes a few mouse clicks to create complex traffic scenarios in which the “players” accomplish defined tasks. Freely configurable sensors for radar, LIDAR, ultrasonic and cameras, even with fisheye lenses are available to you as needed, synchronously and in real time. Based on digital maps from navigation systems you can generate your routes. With no limitations and according to the ADASIS standard!

“CAE with CarMaker can provide a serious prediction of vehicle dynamics press ratings long before SOP.” Dr. Henning Holzmann, Opel

“CarMaker supports us in speeding up our development process for innovative driver assistance functions and in quickly evaluating new product concepts.”

Dr. Stefan Lüke, Continental

Simulation Software
Real driving simulation – for development and testing.

Realistic load duty cycles are the basis for the development, analysis and testing of powertrain systems. In many cases, speed and torque profiles from vehicle measurements or simplified longitudinal dynamics vehicle models are used in simulation and on test benches to evaluate the energy consumption, thermal behavior, durability and emissions of new powertrain concepts, components and systems. However, this approach offers very limited options to investigate system variations and calibration within a full vehicle under real driving conditions and has low flexibility concerning changes in vehicle configuration, driver behavior and operating strategy.

The CarMaker product family consisting of CarMaker, TruckMaker and MotorcycleMaker is a comprehensive and easy to use open integration and test platform with representative models of the vehicle, driver, road, traffic and environment. The provided model environment is used for closed-loop applications to generate realistic load duty cycles for powertrain system development and analysis in office simulation, HIL simulation and for testing on test benches. The closed-loop approach offers a high degree of flexibility, because realistic load duty cycles are not needed as an input for this type of maneuver-based closed-loop simulation and testing on test benches. Driving cycles defined by vehicle speed and real driving scenarios can easily be performed with virtual prototypes driven by a representative driver model. IPGDriver is capable to follow a predefined target speed as well as to choose the driving speed according to the course and the vehicle behavior. With the road data import functionality, open interfaces to third-party tools, its model integration capability and real time performance CarMaker offers an outstanding open integration and test platform for powertrain applications.

Virtual test driving with CarMaker allows for a seamless development, analysis and testing of powertrain systems taking into account all relevant interdependencies between the powertrain, chassis/suspension and brake system. Especially for the development and testing of hybrid electric vehicles, but also for all other current and future powertrain concepts, this approach is essential to evaluate real driving energy consumption, performance and emissions.
Virtual Reality & Driving Simulators
More information on page 18-19

Virtual Reality
By combining simulation solutions with photo-realistic virtual reality design tools and 3D projections in virtual rooms (CAVES), you can gather relevant and highly realistic impressions at an early stage of development to evaluate ergonomics, comfort as well as the interactions of form and function.

Off-Highway Applications
More information on page 20-21

Off-Highway Applications
Due to the complex design of trucks, off-highway vehicles and mobile machines as well as the diversity of their control functions, a broad spectrum of test maneuvers is required. Variations of terrain and soil conditions like asphalt, gravel or sand as well as loading conditions onto the vehicle, its auxiliary system and trailer must be considered.
Moving Forward into a New Dimension
Gain early knowledge of your customer’s view.

Different driving situations affect the driver's view. As a body designer, how can you be sure, for instance, that your customer can see a child behind the car when backing out of a parking space? Or maybe you have designed an advanced head-up display. It is not uncommon for consumers to respond differently to new cockpit instruments when the vehicle is parked or moving. The question is: How can you evaluate the interactions of form and function?

The answer lies "in motion". By combining the physics of IPG’s Simulation Software with photo-realistic virtual reality design tools from 3DEXCITE and 3D projection in virtual rooms (CAVES), you can gather relevant impressions at an early stage in highly realistic conditions. Just get behind the wheel of your virtual car and start your virtual test drive. Experience your vehicle concepts as photo-realistic 3D real-time models with authentic dynamics and functionalities. The fusion of virtual and real-world components allows you to evaluate ergonomics, vision and comfort. Comprehensively and in a realistic environment!

“The combination of virtual reality (digital mock-up) with a functional mock-up is a major step forward in the realization of customer experience early in the development process.”
Robert Bauer, BMW

At a Glance
• Interface between the high-end visualization software 3DEXCITE DELTAGEN and CarMaker®
• Enables to drive in an immersive setting like a CAVE (Cave Automatic Virtual Environment)
• Highly realistic 3D environments and a test environment that simulates haptic feedback from the car

Key Applications
• Various ranges of models can be tested within a short time frame, which will save a lot of time and costs
• Ensures an extremely realistic driving experience

Key Functions
• True life scale
• Exterior review
• Interior review
• View analysis (in motion)
• Ergonomic studies (in motion)
• HMI design
• Visual simulation

Virtual Reality & Driving Simulators
The System Experience Platform from IPG Automotive... in combination with DeltaGen from 3DEXCITE... leads to an extremely realistic driving experience.
Virtual Integration and Test Driving for all Types of Vehicles

At a Glance

- Integration and maneuver-based testing of special purpose vehicles like construction machines, municipal vehicles, agricultural and forest machinery as well as forklifts in office and HIL environments
- Flexible integration of component and subsystem models from Simulink, Dymola, CRUISE Interface, C-Code and via Functional Mock-up Interface (FMI)
- Comprehensive environmental models for terrain and traffic

Key Applications

- Analysis of off-highway and off-road driving conditions
- Validation of vehicle stability and performance
- Investigation of energy consumption
- Evaluation of all-wheel steering and special suspension concepts
- Optimization of vehicle stability control, auxiliary devices and energy management of mobile machines

Key Functions

- Easy setup of special chassis, suspension and steering design models
- Driving off-road on variable soil conditions
- Integration of special tire models like earthmoving tires or chain drives
- Model for variable rolling resistance
- Flexible terrain models based on predefined obstacles or integration of OpenCRG data
- Models for chassis attachments and auxiliary systems like cranes, lifts, ploughs or gensets
- Open interfaces to customer specific data management and post-processing tools

Shorten the Development Cycle

Virtual test driving applied from concept phase to production support.

The complex design of off-highway vehicles and mobile machines as well as the diversity of their control functions requires a broad spectrum of test maneuvers with variations of terrain and soil conditions like asphalt, gravel or sand. In addition, a multitude of loading conditions onto the vehicle, its auxiliary system and trailer has to be taken into account. The resulting virtual driving maneuvers can be merged into a comprehensive test catalog and made available in all development phases.

The powerful Model Manager enables the seamless integration of models from different model sources like Simulink, Dymola or AMESim into the test platform CarMaker®/TruckMaker®. It supports the test engineer with precise predictions about fulfillment of the given targets regarding the specifications at vehicle level already in the early phases of the development. The consistent re-use of the detailed models in later phases at test rigs and the combination of interactive maneuver control, an intelligent driver model and environment models enable a realistic and reproducible reconstruction even of the most demanding use cases.

“TruckMaker enables us to simulate agricultural, forestry and construction machinery in defined conditions and surroundings for our research.”
Prof. Dr.-Ing. Marcus Geimer, Karlsruhe Institute of Technology (KIT)

Virtual Integration and Test Driving for all Types of Vehicles

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Simulation Software
Simulation Software

“Our Simulation Software product portfolio supports you in every single step of the whole vehicle development.” Kai Hammam, IPG Automotive

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More information: https://ipg-automotive.com/de/produkte-services/simulation-software/
Challenges in Vehicle Engineering

Why virtual integration builds the future of vehicle engineering

There are many reasons, why more and more resources are required for successful system validation and verification.

In the following, you will find the main causes for this trend:

- The number of connected systems within one vehicle
- The system complexity
- Shorter development cycles
- Much more derivatives and variants of vehicles
- A huge variety of vehicle prototypes is required during the development phase
- A big amount of models from different MATLAB-releases

In the years ahead, these challenges will get bigger and bigger, as there are not enough resources for constant quality in vehicle development.

Our approach for improvement: Virtual Integration

- The CarMaker product family including CarMaker®, TruckMaker® and MotorcycleMaker® offers the optimally suited solution for the approach of virtual integration
- It allows the initial operation of a system in a virtual prototype vehicle long before an expensive and real prototype is available
- More reliable systems for initial operation in the real prototype
- Much more time available for development of new functions and calibration in the real vehicle

The resource challenge:
The gap between available and required resources in vehicle development

Without virtual integration:
Vehicle development without virtual integration

Using virtual integration:
Vehicle development using virtual integration
Open Integration and Test Platform
The fast track to the next level

In light of the current challenges, seamless control of vehicle development requires holistic concepts. To this end, IPG Automotive has enhanced the CarMaker® product family including CarMaker®, TruckMaker® and MotorcycleMaker® that has been successfully used for years as an open integration and test platform for virtual test driving. The integration platform allows users to integrate optional systems and components such as engines, powertrains, chassis, controls, assistance systems or onboard networks from different development environments such as MATLAB/Simulink, Dymola or pure C-Code into your virtual prototype by mouse click.

Enabled through a comprehensive and outstanding interface management, the provided models can be modified easily, for example by replacing specific existing vehicle components or even the whole car by your own models. Additionally, control systems can be integrated very easily. All systems and components are exchangeable as needed, as models, software, ECUs or hardware on mechatronic test rigs and prototypes in different stages of the development process – from MIL up to HIL. The multi-domain models may be generated as third-party units or according to the Functional Mock-up Interface (FMI) standard. Beside the integration of models, CarMaker® also offers a quick and easy integration of real physical vehicle parts like the engine, the powertrain, the battery or the steering system into your simulation environment.

The CarMaker® product family is a platform-independent IT solution for the integration of models from different authoring tools, test rigs, calibration systems, diagnostic, DoE and post-processing tools. The test platform assures effective maneuver execution based on real-world principles and allows fully automated running of the comprehensive test catalogs. Furthermore, CarMaker® is capable to drive other tools, for example calibration tools like Inca® from ETAS. Of course, CarMaker® by itself can be driven from other tools, too. You can use test automation tools like ProveTech® or DoE (Design of Experiment) tools like Cameo® or modeFRONTIER® in collaboration with CarMaker®, which enables you to integrate CarMaker® in your own environment chain.

With virtual test driving, IPG Automotive closes the gap between conventional computer simulation, rig testing and real-world road tests. Physical test driving thus becomes significantly more effective.

“With our open integration and test platform we fuse the virtual and the real world.”
Steffen Schmidt, IPG Automotive
Maneuvers According to the Modular Design Principle

Maneuver- and scenario-based testing

By using the approach of maneuver- and scenario-based testing, target functions will be evaluated. IPGDriver™ as well as the traffic receive driving maneuver action and monitoring instructions. The instructions which IPGDriver™ will execute can be conditions like driving exactly 50 kph, reaching a steering wheel angle of 180 degrees or building up a specific brake pressure.

CarMaker® makes it very easy to reconstruct real and complex test scenarios and to shift them into simulation. Every operation a real test driver could accomplish can be defined in a very intuitive way with the help of the so called mini-maneuvers.

Complex driving maneuvers like μ-split braking, NEDC drive cycles or ACC supported driving are split into single mini-maneuvers which are exactly reconstructed in the simulation. You can combine open- and closed-loop maneuvers of lateral and longitudinal dynamics to a test sequence in any way you require.

For every single mini-maneuver you can define an action which IPGDriver™ will execute. This might be the acceleration of the car or the approaching of a specific steering wheel angle. Furthermore, an end condition like reaching a velocity of 100 kph can be defined. When a preassigned end condition occurs, the successive mini-maneuver will be executed.

The maneuver- and scenario-based testing approach can be applied for all applications areas: Advanced Driver Assistance Systems, Control Systems, General Vehicle Dynamics as well as Fuel Efficiency and E-Mobility. This approach is also valid for all traffic objects to reconstruct every imaginable traffic situation.
Integral Vehicle Evaluation

Route-based testing

The approach of route-based testing is unobstructed, therefore it clearly differs from the maneuver- and event-based testing. The global vehicle performance can be evaluated on different types of routes like city, country, highways and mountains which can be driven by different types of drivers (sporty, normal, defensive and eco). This allows the integral evaluation of the complete vehicle characteristic. As an example, it is possible to set up a fuel consumption Test Run with predefined sections of city and country roads as well as highways. Furthermore, with a few mouse clicks you can integrate real-world tracks which were digitally measured – for more information have a look at the section IPGRoadData™, where you will find famous roads for every imaginable kind of measurement.

Methods for Virtual Test Driving

Testing Methods

Maneuver Example: µ-Split Braking

Mini Maneuver 0
IPGDriver™ accelerates the car to 100 kph and approaches a µ-Split area.

Mini Maneuver 1
When the marker “Roll” is reached, IPGDriver™ releases the gas pedal and pushes the clutch. If necessary, IPGDriver™ will countersteer to stay straight on.

Mini Maneuver 2
When the marker “Brake” is reached, IPGDriver™ pushes the brake pedal. Due to its reaction time, IPGDriver™ will hold the steering wheel in its position for one second, even if the car will side-slip.

Mini Maneuver 3
After executing Mini Maneuver 2, IPGDriver™ will correct the direction of the car until there is no more lateral acceleration.

Mini Maneuver 4
When a velocity of 50 kph is reached, a failure will be applied to the car. In this case a wheel sensor fails, which will - among other effects - influence the control strategy of the ESP system.

Mini Maneuver 5
In the last Mini Maneuver, IPGDriver™ will brake the car down to standstill. After reaching standstill, the diagnosis of the ECU will be executed automatically.

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<th>Driver Command/Action Command</th>
<th>Longitudinal</th>
<th>Lateral</th>
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<tr>
<td>0</td>
<td>Accelerate up to 100 kph, approach µ-Split area</td>
<td>ClosedLoop IPGDriver™</td>
<td>ClosedLoop IPGDriver™</td>
</tr>
<tr>
<td>1</td>
<td>Marker „Roll“ - Free Rolling</td>
<td>OpenLoop IPGDriver™</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Marker „Brake“ - Braking, hold steering</td>
<td>OpenLoop</td>
<td>OpenLoop</td>
</tr>
<tr>
<td>3</td>
<td>After 1 sec steer correction</td>
<td>OpenLoop IPGDriver™</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>At 50 kph - Failure Impact e.g. a defective wheel sensor</td>
<td>OpenLoop IPGDriver™</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Braking up to standstill - Diagnostic of the ECU</td>
<td>OpenLoop IPGDriver™</td>
<td></td>
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</tbody>
</table>

Using an exported route of ADAS RP to realize an electronic horizon in CarMaker®

Triggering Real and Complex Testing Situations

Combination of maneuver-, event- and route-based testing

Using the route-based testing approach in combination with the maneuver- and event-based testing, freely definable traffic events can be triggered along the predefined route. IPGDriver™ can receive maneuver instructions at specific milestones as well as driving recommendations from the HMI. As an example, the driving recommendation might be to activate the ACC when the car is driving below 20 kph and to observe the effect on the fuel consumption afterwards. Another possible application would be to drive too fast in every curve which is smaller than a specific radius and to observe in order to at which point the ESP starts to work.
The Sophisticated Driver for Every Driving Task

IPGDriver™ is the most sophisticated driver model for open and closed loop driving tasks with a close-to-reality artificial intelligence, an extraordinary performance as well as several special driving strategies. From parking maneuvers up to the dynamic driving limits - every task a real test driver could accomplish, will be executed precisely and reliably by IPGDriver™:

- Controlling the whole car
- Operating all vehicle systems
- Observing the state of the car
- Operating complex test devices like calibration, diagnostic and failure insertion tools

IPGDriver™ is suitable for all passenger and racing cars, light utility vehicles as well as heavy trucks and motorcycles. Supported by the powerful maneuver control of CarMaker®, IPGDriver™ follows every predefined driving instruction with an undisputed precision like a real test driver.

By executing the included driver adaption, IPGDriver™ will acquire comprehensive knowledge specific to the car and its current configuration. Among other things, it will learn the handling of control systems or the best possible engine speeds for shifting up and down. Running the fully automated and complex race driver adaption, IPGDriver™ will test any conceivable maneuver regarding the physical limits of the car to optimize the lap times on the circuit.

As if that were not enough, you can determine its dynamic limits by yourself. Decide on the maximum longitudinal acceleration and deceleration as well as the maximum lateral acceleration via an easy to use g-g diagram and tell IPGDriver™ to drive relaxed or like a race driver. Three inconspicuous values which can change the whole driving behavior within your simulation.

The capability to apply additional control strategies allows IPGDriver™ to drive through narrow curves, to compensate swinging caravans or trailers and to start at hills by using the parking brake.

No matter what you want to simulate - IPGDriver perfectly reproduces the actions and reactions of a real driver.
Vehicle Dynamics

Using the integrated, powerful maneuver control for any combination of open- and closed-loop maneuvers, the CarMaker® product family enables a consumer test rating prediction. The integrated, highly sophisticated driver model IPGDriver™, including a racing and rally driver function, will execute every imaginable laptime and handling performance investigation - supported by the detailed Pfeffer steering model with EPS, HPS or EHPS steering. The segment-based or digitized 3D road models with freely configurable obstacles like bumps, as well as Curved Regular Grid (CRG) provide the basis for comprehensive ride & comfort analysis.

Driver Assistance

Thanks to a freely configurable traffic object behavior for cars, trucks, pedestrians and stationary objects, it is possible to test collision avoidance systems without any risk for human or machinery. Extendable with user defined models (Simulink, C-Code, etc.), the CarMaker product family enables the user to integrate controller models. Using the environment, road and sensors, driver assistance systems like ACC, autopilots or traffic sign recognition can be tested with ease.

Powertrain

IPGCar offers a modular powertrain model, which allows the exchange of the whole powertrain or single parts of it with user defined models. These are best conditions for the testing and evaluation of predictive powertrain and auxiliary control systems. There are a number of open interfaces to navigation and map-based systems, e.g. to receive an electronic horizon for predictive driver assistance systems like energy efficient route planning and driver guidance systems. IPGDriver™ offers different driver behaviour such as predictive or aggressive driving, which is essential for fuel consumption analysis and fuel consumption investigation.
Vehicle Dynamics

The CarMaker® product family including CarMaker®, TruckMaker® and MotorcycleMaker® enables you to perform maneuver- and event-based as well as route-based tests on virtual proving grounds, cross-country and mountain roads, urban streets and highways including realistic traffic scenarios. It is possible to flexibly integrate your own models via a Functional Mock-up Interface (FMI) as well as various interfaces for CRUISE Interface, C-Code, GT-Suite and Matlab Simulink. Furthermore, real existing parts like engine-, e-motor-, battery-, chassis- or powertrain can be tested in-the-loop.

Additionally CarMaker® also offers digital map interfaces to ADAS RP, Google Earth, Google Maps as well as Bing Maps. The driving style of IPGDriver™ is fully adaptable from economy to racing modes.
**Driver Assistance**

The CarMaker® product family with CarMaker®, TruckMaker® and MotorcycleMaker® enables an easy reconstruction of complex real-world test scenarios, which can be built using comprehensive traffic, a complex road infrastructure and multiple environment sensors.

The sophisticated driver model IPGDriver™ is specifically geared to Advanced Driver Assistance System interactions. CarMaker® supports multiple virtual cameras with numerous lens effects (e.g., fisheye), which, for example, can be fused for top view parking assistance systems. Another major advantage of the CarMaker® simulation environment is the variety of digital map interfaces to ADAS RP, Google Earth, Google Maps as well as Bing Maps. CarMaker® also offers many functions and interfaces for integrated active and passive safety systems.
Powertrain

The CarMaker® product family with CarMaker®, TruckMaker® and MotorcycleMaker® enables you to perform maneuver- and route-based tests on cross-country and mountain roads, urban streets and highways including realistic traffic scenarios. It is possible to flexibly integrate your own models via various interfaces for Matlab Simulink, CRUISE Interface, C-Code and a Functional Mock-up Interface (FMI) as well as to test real existing parts like engine-, e-motor-, battery- or powertrain-in-the-loop.

Additionally CarMaker® offers digital map interfaces to HERE ADAS RP, Google Earth, Google Maps as well as Bing Maps. The driving style of IPGDriver™ is fully adaptable from economy to racing modes.

Functions & Typical Use Cases

Powertrain

- Modular powertrain model of IPGCar, which also allows exchange of the whole powertrain or single parts of it with user defined models
- Integration of detailed environmental models like traffic along a planned route, sun radiation and weather conditions
- Hybrid (Parallel, Axle Split, Power Split, Serial) and electric powertrains
- Open interfaces to navigation and map-based systems, e.g. to receive an electronic horizon for predictive driver assistance systems
- Flexible Model Manager to integrate and manage component & controller models from different sources like Simulink, CRUISE Interface, C-Code, Dymola, SimulationX, GT-SUITE, AMESim
- Consistent use of CarMaker MIL/SIL/HIL up to engine-, or powertrain test rigs
- Easy import of digitized routes (GPS-measured) or from tools like HERE ADAS RP, Google Earth/Maps, Bing Maps
- Different driver behavior such as predictive or aggressive driving, which is important for fuel consumption analysis
- Consistent use of CarMaker MIL/SIL/HIL up to engine-, or powertrain test rigs

Powertrain

40 Simulation Software
### Product Lines

#### CarMaker

CarMaker® is the optimal simulation solution for virtual test driving of passenger cars and light utility vehicles. CarMaker® simulates the interaction of vehicle, driver, tires, road, traffic and environmental conditions with detailed, substitutable system and component models. The open integration and test platform enables a wide spectrum of applications regarding Vehicle Dynamics, Powertrain and Advanced Driver Assistance Systems.

#### TruckMaker

Using TruckMaker®, heavy commercial vehicles or mobile machines with or without a trailer as well as multiple axles can be simulated. All specific characteristics of commercial vehicles like trucks, trailers, articulated lorries and busses can be simulated in every detail. Even for complex truck variants, TruckMaker® delivers full real-time capabilities. Due to the variable parameterization and its high numerical stability, even extreme driving maneuvers such as exceeding the rollover limit can be simulated easily.

#### MotorcycleMaker

MotorcycleMaker® is the optimal simulation solution for motorcycles, scooters and e-bikes. It contains a three-dimensional, fully parameterizable motorcycle model with subsystems for suspension, brakes, engine and powertrain. It empowers sophisticated vehicle dynamics investigations on three-dimensional test tracks with arbitrary traffic situations. This allows to analyze dynamic mechanisms as well as to validate and optimize concepts early in the development process. The dangerous driving tests on real test tracks can be shifted into office or laboratory.
The CarMaker Architecture to Integrate Your Models and Tools

**Front End**
- **Tool environment** (P. 66)
- **CarMaker GUI** (P. 46)
- **IPGMovie** (P. 70)
- **IPGControl** (P. 68)
- **Instruments** (P. 66)
- **Digital Maps**
- **ADTF**
  - ADAS RP
  - ETAS Inca
  - ...
- **Custom Panels/GUI**
- **Scenario Editor**
- **APO Interface**

**Back End**
- **Model environment** (P. 94-104)
  - IPGCar (P. 94)
  - IPGRoad (P. 94)
- **Basic Services**
  - XCP
  - Data Dictionary
  - MIO
  - RTexpr
  - DVA
  - APO
  - DStore
- **Interaction**
  - Info files
  - Log

**Virtual File System**

**Ethernet**

**Remote file system (NFS)**

**System under Test (SuT)**
- MIL
- SIL/HIL
- HIL

**Interfaces**
- ESP, ARS, CDC, ACC, AFS, LKA, Engine, Hybrid, ...

**Simulation Software**
Integrate and Manage Your Models and Tools

Easy configuration and handling with the simulation platform

CarMaker® is an open integration and test platform for maneuver- and event-based testing of passenger cars and light utility vehicles. It offers several opportunities to shorten development cycles, enhance product quality and secure market advantages and accordingly saves costs in the development process.

CarMaker® simulates the interaction of every component of the vehicle with all environmental effects like the road, the driver as well as the traffic with detailed, substitutable system and component models. With an impressive performance it guarantees the highest flexibility, productivity and precision for all of your simulation tasks.

In contrast to common vehicle dynamics simulation tools, CarMaker® can be used in the whole development process: From office simulations on a PC such as Model- or Software-in-the-Loop tests, through Hardware-in-the-Loop tests on single and multi ECU test systems up to HIL tests on large system test rigs with physical components like a real engine or a real suspension system.

Advantages

- The reconstruction of real world test scenarios is very easy and intuitive because of a unique maneuver- and event-based testing approach.
- Precise dynamic models realistically simulate the interactions of car, trailer, driver, road and traffic which guarantees high-quality simulation results.
- CarMaker® is an open integration platform. According to specific requirements you can easily extend the software with your own models, controllers and tools.
- Due to its unique software and model architecture, CarMaker® is extremely fast - in SIL/MIL applications it can run up to 40x real-time. The extraordinary performance saves development time and costs.
- The sophisticated driver model IPGDriver™ performs even the toughest driving maneuvers with ease.
- Driving behavior investigations on roads with critical characteristics (e.g. corrugations, bumpiness, unevenness, roughness, longitudinal and lateral grooves, ruts, black ice etc.).
- The versatile test management and -automation functions make your work efficient and time-saving.
- Online devices give you an overview and interactive control over the whole simulation environment. Simulation results can be monitored even during the simulation is running – with a clear picture of the calculated quantities in IPGControl™ or vividly demonstrated in IPGMovie™.
Simulating Complex Truck/Trailer Configurations

Precision and performance up to the finest detail

TruckMaker® is an open integration- and test platform for maneuver- and event-based test driving of heavy commercial vehicles, articulated lorries and busses. It offers several opportunities to shorten development cycles, enhance product quality and secure market advantages.

TruckMaker® simulates the interaction of every component of the vehicle with all environmental effects like the road, the driver as well as the traffic with detailed, substitutable system and component models. With an impressive performance it guarantees the highest flexibility, productivity and precision for all of your simulation tasks.

In contrast to common vehicle dynamics simulation tools, TruckMaker® can be used in the whole development process: From office simulations on a PC, such as model- or software-in-the-loop tests, through hardware-in-the-loop tests on single and multi ECU test systems up to HIL tests on large system test rigs with physical components like a real engine.

Advantages

- TruckMaker® is an open integration and test platform. According to specific requirements you can easily extend the software with your own models, controllers and tools.
- The reconstruction of real world test scenarios is very easy and intuitive because of a unique maneuver- and event-based testing approach.
- Due to its unique software and model architecture TruckMaker® is extremely fast - in SIL/MIL applications it can run up to 40x real-time. The extraordinary performance saves development time and costs.
- The versatile test management and test automation functions make your work efficient and time-saving.
- Precise dynamic models realistically simulate the interactions of truck, trailer, driver, road and traffic.
- Online devices give you an overview and interactive control over the whole simulation environment. Simulation results can be monitored even during the running simulation – with a clear picture of the calculated quantities in IPGControl™ or vividly demonstrated in IPGMovie™.
- TruckMaker® supports special kinematics for construction equipment like a mobile crane.
- The sophisticated driver model IPGDriver™ performs even the most complex driving maneuvers with ease, e.g. it has the capability to detect the rollover limit.
- Driving behavior investigations on roads with critical characteristics (e.g. corrugations, bumpiness, unevenness, roughness, longitudinal and lateral grooves, ruts, black ice etc.)
- An automatic speed planning depending on truck/trailer characteristics is available.
- TruckMaker® can be validated for ECE 13/11 homologation, e.g. of the braking systems.
- All axles can be individually configured, e.g. with single or twin tires
- Different models for hitch systems (ball with damping, friction or trapezoid) are available.
- Hydraulic and pneumatic braking model for vehicle stability control like ABS/ESP
- Many special suspension types for truck and trailer are supported: rigid, steerable, driven and lift axles
- An elastically mounted driver’s cab and platform is supported.
- You can choose between various powertrain versions from 4x2 up to 8x8.
- The load situations are freely configurable with fixed or moving loads.
- External force models, for example used for amphibious vehicles floating in water, are integrated.
- Supports special powertrain configurations such as electric drives or hydrostatic transmissions.
- Retarder interface
Precise Simulation of Two-Wheeled Vehicles

Virtual test driving of motorcycles and scooters – close to reality

MotorcycleMaker® is an open integration and test platform for maneuver- and event-based test driving of motorcycles, scooters and bicycles. It offers several opportunities to shorten development cycles, enhance product quality and secure market advantages.

MotorcycleMaker® simulates the interaction of every component of the vehicle with all environmental effects like the road, the driver as well as the traffic with detailed, substitutable system and component models. With an impressive performance it guarantees the highest flexibility, productivity and precision for all of your simulation tasks.

In contrast to common vehicle dynamics simulation tools, MotorcycleMaker® can be used in the whole development process: From office simulations on a PC, such as Model- or Software-in-the-Loop tests, through Hardware-in-the-Loop tests on single and multi ECU test systems up to HIL tests on large system test rigs with physical components like a real engine.

Advantages

- MotorcycleMaker® is an open integration and test platform. According to specific requirements you can easily extend the software with your own models, controllers and tools.
- The reconstruction of real world test scenarios is very easy and intuitive because of a unique maneuver- and event-based testing approach.
- Due to its unique software and model architecture, MotorcycleMaker® is extremely fast - in SIL/MIL applications it can run up to 40x real-time. The extraordinary performance saves development time and costs.
- The versatile test management and -automation functions make your work efficient and time-saving.
- Online devices give you an overview and interactive control over the whole simulation environment. Simulation results can be monitored even during the running simulation – with a clear picture of the calculated quantities in IPGcontrol™ or vividly demonstrated in IPGMovie™.
- Driving behavior investigations on roads with critical characteristics (e.g. corrugations, bumpiness, unevenness, roughness, longitudinal and lateral grooves, ruts, black ice etc.)
- Precise dynamic models realistically simulate the interactions of motorcycle, driver, road and traffic which guarantees high-quality simulation results.
- The aerodynamic effects influences the driving stability.
- Driving behavior analysis on downhill and uphill slopes and banking on three-dimensional tracks.
- MotorcycleMaker® supports different front and back wheel carriers like telescopic fork, telelever, upside-down swing arm and paralever.
- MotorcycleMaker® contains different drive concepts like based on driveshaft, on chain or on swing arm mounted engine.
- You can benefit from a flexible quantity distribution, e.g. to simulate baggage.
- MotorcycleMaker® takes into account the bending and the torsional stiffness of the body frame and the wheel carriers.
- A complex tire model takes into account the influence of large camber angles and transient tire behavior.
- Reproduction of typical driving mistakes (driving too fast in curves, too much brake force at the wheel, a too rapid increase of brake force, etc.).
- Driving behavior investigations on roads with critical characteristics (e.g. corrugations, bumpiness, unevenness, roughness, longitudinal and lateral grooves, ruts, black ice etc.)
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- Reproduction of typical driving mistakes (driving too fast in curves, too much brake force at the wheel, a too rapid increase of brake force, etc.).
Model Environment

IPGCar
The CarMaker product family including CarMaker®, TruckMaker® and MotorcycleMaker® allows you to simulate different types of vehicles with exceptionally realistic and precise handling characteristics – visualized through highly realistic 3D graphics.

Whether you wish to test models, software or physical vehicle components, either discretely or in the form of networked systems, CarMaker® integrates them all into digital prototypes for virtual test driving.

IPGRoad
The 3D road model, IPGRoad™, serves to generate roads or customer-specific test tracks in a very short period of time. Even real-world roads based on digitized map data and digital grids – including corners, slopes, obstacles, road bumps, traffic lights, signage and peripheral buildings – are imported into the simulation environment by just a few mouse clicks. You can drive your test vehicle wherever you like – whether in the middle of the urban traffic within a big city or on an alpine mountain pass full of serpentine.

IPGDriver
The virtual driver IPGDriver™ is extremely adaptable. It possesses a vast array of driving styles and simulates them with consummate precision. All parameters – from sporty driving through to slow cruising – can be configured easily and quickly. IPGDriver™ responds to control systems and driver assistance systems just like a human driver would and competently executes challenging tasks from tricky parking maneuvers and stop-and-go traffic through to driving at dynamic limits.

IPGTraffic
Due to environmental conditions, any real-world road test is unique, even when based on the maneuver- and event-based testing approach. By contrast, the traffic model IPGTraffic™ allows you to easily generate challenging traffic situations with a large number of participants and to repeat them as often as you like, with no risk involved. Thanks to powerful test automation, the scenarios can simply be modified step by step or run on different test rigs in an automated process, even overnight, if necessary.
## Vehicles That Become Functional Mock-up Prototypes

The focus of vehicle dynamics simulation is on vehicle and trailer models capable of real-time performance, which are valid up to the limits of driving dynamics. Their bodies are modeled as multibody systems which are fully non-linear and extendable. The Multi-Body-System models form the core model and integration platform for all other sub-components such as suspension, steering system, tires, brake system, drivetrain and aerodynamics. The existing models are arranged manageably in terms of the individual sub-assemblies and can be modified or exchanged for models from different authoring tools like Simulink and/or on C-code level. The parameterization can be done easily via a graphical user interface. Afterwards, you can validate the parameters of single subsystems using the Model Check functionality.

### Technical Data IPGCar

#### Vehicle Body
- Flexible or rigid (torsion, bending) with sprung mass, loads, engine, trim loads

#### Engine Mount
- Elastically mounted engine with generalized joint force or explicit force elements

#### Suspension
- Spring (linear, non-linear)
- Secondary Spring (linear, non-linear)
- Damper (linear, non-linear)
- Buffer (linear, non-linear)
- Stabilizer

#### Kinematics
- Selectable kinematics & compliance tables linear and non-linear with up to 3D dependencies
- Compliance
- Wheel bearing / wheel bearing friction
- External Forces

#### Tires
- IPGTire
- Pacejka MF-5.2 and 6.1
- Michelin Tametire
- TASS MF-Tyre/MF-Swift 6.2 and 7
- Configurable with single or twin tires

#### Brake
- Detailed Hydraulic Model valid for ABS/ESP with booster, master and brake cylinder, pump, valves, line volume, accumulator, attenuator
- Pressure distribution via pedal actuation or via pedal force

#### Aerodynamics
- 3D aerodynamics
- Crosswind build-up

#### Powertrain
- Engine
  - Transverse and longitudinal engines
  - Fuel consumption maps
  - Engine mappings (Drag and Full Load / Engine Speed and Gas)
  - Electrical engines
  - Hybrid engines (Parallel, Axle Split, Power Split, Serial)

#### Clutch
- Friction
  - Converter
- Dual-Mass Flywheel
- Gearbox
  - Automatic / Manual / No Gearbox
  - Dual-Clutch Transmission
- Driveline
  - Front drive / Rear drive / All wheel drive
  - Definable differentials

#### Sensors
- Side Slip Angle
- Inertial
- Object
- Free Space
- Traffic Sign
- Line
- Road
- Collision
- Radar
- Global Navigation
- Camera RSI

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![Simulation Software](image-url)
Technical Data IPGTrailer

**Trailer Body**
- One and two axle semi trailer

**Suspension**
- Spring (linear / non-linear)
- Secondary spring (linear / non-linear)
- Damper (linear / non-linear)
- Buffer (linear / non-linear)
- Stabilizer

**Kinematics**
- Selectable kinematics & compliance tables linear, non-linear, and non-linear with up to 3D dampen-
  cies

**Compliance**
- Suspension with linkage equation for all axle types with one model
- Single tunable components (damper, spring, buffer, stabilizer, external forces)
- Wheel bearing
- Wheel bearing friction

**External Forces**
- Brake
- Hydraulic System
- Overrun brake
- Overrun brake with friction

**Hitch**
- Ball
- Ball with damping / friction / trapezoid

**Aerodynamics**
- 3D aerodynamics
- Crosswind build-up

**Sensors**
- Slip Angle
- Inertial
- Object

*The bodies tab within the Vehicle Data Set*
*Definition of the trailer aerodynamics*
*Sensors GUI*
*Powertrain GUI*
Roads That Become Test Centers

The ROAD5 modeling approach enables you to build three-dimensional open and closed tracks as well as complex road networks for CarMaker®. You can arrange the track with simple individual elements by stringing together straight lines, curves, and clothoids, or you can use the Scenario Editor. The Scenario Editor of the CarMaker product family enables the fast and efficient generation of scenarios for virtual test driving. The manual creation and configuration of generic scenarios as well as the processing of real roads imported from map or measurement data from the real-world environment thus become possible.

A multitude of functions for the manual definition of generic test scenarios is included in the Scenario Editor, with an emphasis on the easy creation of road networks and the straightforward configuration of the scenario with static and dynamic objects via drag and drop. Changes to the scenario are supported by graphics and are thus comprehensible and easy to implement.

The ADAS RP interface of the CarMaker product family is one option for the import of real roads into scenarios. It allows for the export of road networks including traffic signs, road markings as well as traffic lights from HERE maps and the subsequent addition of road users and static objects such as buildings or vegetation in the Scenario Editor. If specific cases of application require a more accurate representation of reality, a second option enables detailed and wide real-world road networks to be captured by means of a range of different measurement technologies and the subsequent processing of this data for use with the CarMaker product family.

The different lanes (up to 10 for each side) can be defined as road, pedestrian walk, bicycle way, border, traffic island, etc. The particular track sections can further be defined with obstacles, friction coefficients, side wind and other track conditions. In addition, user-defined trigger points can be assigned to road segments for velocity changes, stopping places, or maneuver commands. Optionally, you can also use measured road data as a three-dimensional track model, for example from test tracks or common tracks like the Nürburgring Nordschleife.
Individual Customers That Become Test Drivers

In combination with the powerful maneuver control of CarMaker®, MotorcycleMaker® and TruckMaker®, the intelligent driver model IPGDriver™ enables the simulation of complex test scenarios.

Key features
- Self-learning capabilities and knowledge memory
- Independent lane & speed choice based on
  - Road & driver characteristics
  - Lane usage with respect to the track borders including corner cutting
  - Vehicle characteristics
- Independent longitudinal & lateral dynamics
- Steering by steering wheel angle or torque
- Driving at the limits with counter steering
- Identification of the optimal brake and acceleration points
- Gear shifting with or without clutching, independent and via external access
- Target braking & stopping at traffic signs
- Stop & go, driving at walking pace and shunting at short distance (< 20 cm)
- Hill-starting using the parking brake
- Driving backwards and parking
- Retrace of driving cycles such as FTP72, FTP75, NEDC, WLTC_3, JC08, etc.
- Independent overtaking
Economic Driving
IPGDriver™ can drive electric and hybrid cars and retrace common driving cycles such as NFEC, NEDC, ECE and FTP. These features enable you to determine the consumption of fuel or electricity on predefined routes with a predefined driving behavior - on real existing test rigs.

Driving at the Dynamic Limits
IPGDriver™ is able to drive at the dynamic limits by adapting itself to the vehicle. In situations beyond the physical limits, it is even able to counter steer. Its competencies involve a speed correction with a road height profile (e.g. for slowing down in vertical curves) as well as maximum slip as function of speed and longitudinal/lateral direction in the race driver mode.

Handling of ADAS
Almost every modern car is equipped with several driver assistance systems. IPGDriver™ empowers you to simulate every current and future assistance system - like adaptive cruise control (ACC), lane keeping (LKA), collision avoidance or parking assistance systems (PAS).

Stop & Go
IPGDriver™ can interact with traffic objects, e.g. in traffic situations in a city. It is able to follow vehicles in a predefined distance, to react on traffic signs and traffic lights and to proceed target braking.

Independent Course & Speed Choice
IPGDriver™ can choose the course & speed independently based on the road, driver and vehicle characteristics. The different lanes are used with respect to the track borders incl. corner cutting.

Independent Overtaking
IPGDriver™ is able to detect oncoming traffic, to recognize if a curve is suitable for overtaking and to overtake fully independently. The overtaking procedure also includes the indicators as well as sheering out and in - even in a line of cars.

Parking
IPGDriver™ perfectly masters the parking discipline. It is able to drive at walking pace and to shunt at short distances (< 20 cm) which enables it to maneuver the car even in the tiniest parking lot. To realize low velocities, IPGDriver™ perfectly controls the clutch.

Controlling the Vehicle in Every Situation
The usage of all kinds of active control systems like ABS, ESP and AFS can be simulated by IPGDriver™ to get an accurate and realistic driving behavior in all kinds of real driving situations. The rally driver functionality is well-suited for the tuning of the ESP sports mode.

Simulation Software
Traffic Situations That Turn into a Repeatable Hazard

The IPGTraffic module is perfectly suited for the development of functionalities for sophisticated driver assistance systems like the adaptive cruise control (ACC), emergency braking system (AEBs), lane keeping assistant (LKA), parking assistance system (PAS), collision avoidance system and traffic jam assistant. Even predictive energy management strategies can be subjected to comprehensive testing tasks. IPGTraffic masters complex scenarios and assists users in quickly and easily configuring individual test scenarios with mobile objects such as cars, cyclists and pedestrians, as well as immobile objects like parked vehicles, traffic signs, traffic lights, buildings and construction sites.

In addition, even complex traffic scenarios such as event tree analyses and corresponding real-world use cases can be easily reconstructed and varied, with or without driver intervention. Every single traffic object can also follow its own route differing from the route of the test vehicle, which can be freely defined. This way, countless traffic scenarios can be freely defined. In addition, IPGTraffic offers a high degree of reusability of previously existing data. Another advantage: no model adaptations are necessary for the configuration.

Convenient test set-up through intuitive and compact user concept

The highly capable user concept is well structured. All relevant parameters can be specified in the course of the maneuver irrespective of the vehicle and varied during the runtime. The number of objects plus the starting position on the single- or multi-lane roads is freely selectable. IPGTraffic masters a practically unlimited number of traffic objects and mini-maneuvers. The maneuvers can be allocated easily to the various traffic objects, subjected to event-based control during the test and executed with millisecond precision.

- Well-arranged structure with a GUI easy to understand
- All objects can be generated easily, reproduced as needed or imported by existing test databases, simply by mouse click
- Easy allocation of individual properties
- Reproducible object groups to generate high traffic volume
- Easy allocation of the maneuver tasks in longitudinal and lateral dynamics
- Manageable selection of condition parameters plus formulation of start and end conditions of maneuvers
- High reusability due to easy importation of entire traffic scenarios from libraries
- 2D contour for traffic objects, e.g. used in parking scenarios
- Autonomous traffic
- Maneuver- and event-based approach for traffic objects
- Freely definable routes for traffic objects
- Maneuver control
- 3D motion models (cars, motorcycles, pedestrians...)
- Stochastic distribution

High capability in real time

Last but not least, the model’s capabilities are compelling. By optimizing the program flow control and the model code, the complete CarMaker® model, including the vehicle, driver and road, calculates nearly 1000 objects within one millisecond. In real time and with maximum accuracy. IPGTraffic can also be extended by the user’s own models. All traffic objects are dynamically set up and allocated to the simulation’s runtime and keep the entire simulation “lean”, manageable and highly capable. In addition, objects that have been set up but are not present in the defined presence area are subject to reduced calculations.

Traffic objects receive event tasks: for repeatable virtual test drives with millisecond-accuracy

Unlike in the case of conventional systems, concrete maneuver tasks, which are performed based on events of optional condition parameters, can be assigned to the various objects. Both longitudinal and lateral dynamics can be freely parameterized and the start and end conditions flexibly defined. The course of the maneuver may be mutually influenced either via the virtual test driver, IPGDriver™, or via traffic. This easily generates repeatable scenarios between the test vehicle and traffic environment. In addition, traffic objects can disappear under predefined conditions, e.g. to test ACC-algorithms. Other specifications can additionally and flexibly be fed in from the outside using an acceleration interface (via a bypass model). This also opens up the model for customized extensions. Furthermore, Input from File also is available for IPGTraffic. Last but not least the various traffic objects can be interlinked, which enables further interesting application options.

Real time criterion as start and stop criterion

This function enables any maneuver or maneuver step to be started and stopped by an incoming event with millisecond-accuracy. The optionally parameterizable access to all condition parameters of the total environment such as vehicle, driver, traffic, road, controller and IO (CAN, analog etc.) of this function enables complete flexibility and incredible possibilities for the reconstruction of complex, repeatable scenarios. The crucial aspect lies in the fact that no model adaptation is required here, which significantly increases the user’s productivity.
**Easy replication of object groups to generate high traffic volume**

**Longitudinal and lateral dynamics as well as the start and end conditions of the traffic objects can be freely defined**

**Various traffic objects can be interlinked, which enables interesting application options**

**Integration of mobile objects such as traffic, pedestrians and vehicles as well as immobile objects like parked vehicles, traffic signs, traffic lights, construction sites and buildings**

**Complex traffic scenarios such as event tree analysis and corresponding real-world use cases can be easily reconstructed and varied**

**All traffic objects are generated using input fields, reproduced as needed or imported by existing test databases, simply by mouse click**

**High reusability due to easy importation of entire traffic scenarios from libraries**

**Easy replication of object groups to generate high traffic volume**

**IPGTraffic can also be extended by the user’s own models**

**Simulation Software**
With the tools IPGControl™, IPGMovie™ and Instruments, you get dynamic access to parameters, data, information and models. It thus establishes direct feedback between user and simulation – even during the running simulation.

**IPGControl™**

IPGControl™ is used to plot and display the results of a simulation (quantities) and especially suited for analyzing a large amount of data. It allows the user to manipulate the plotted quantities, change the scaling, axis, etc. so that the results can be analyzed more efficiently and effectively. IPGControl™ can be used anytime: during the running simulation to display diagrams of the simulation you are performing right now, or when it is finished. Furthermore, IPGControl™ enables you to export your result files into the ASCII or Microsoft Excel format as well as to load external result files which were created before. The data saved in the external result files can be plotted in other diagrams.

**IPGMovie™**

IPGMovie™ enables you to observe the virtual test drives online in a user-definable environment. As an example of its numerous practical functions, an animation can be recorded in multiple, freely definable views. You can even compare different Test Runs by superposition of a reference vehicle.

**Instruments**

The Instruments displays the most important instruments, dials and information about the actions of the driver like pedal position, steering wheel angle, gear selection as well as the vehicle’s driving condition like ignition, speedometer, ESP- and ABS-warning lamps, brake lights and turn indicators. Using the Tcl/Tk programming language, it is possible to easily change the instruments according to your personal requirements. A complete reading- and writing access to every single quantity of your simulation empowers you to trigger events at the touch of a button or to build new instruments to visualize quantities of the simulation.

**Test Manager**

The Test Manager facilitates a smooth, robust and automated test process as well as an organized platform to manage your project data.
Realistic Vision for Online Evaluation

The 3D animation tool IPGMovie™ enables you to observe the virtual test drives online in a user-definable environment – you can define the scenery as well as the time of day including the sun positioning based on a geographic definition. It has numerous practical functions like recording an animation in multiple, freely definable views, colored bars at the contact point of the tire which show the forces in x-, y- and z-direction, different types of sensor beams for every activated sensor as well as the possibility to compare different Test Runs by superposition of a reference vehicle.

Instead of the visualized body of the car, the ABRAXAS view, which shows several important details like the steering wheel angle, can be activated. On-screen instruments like a speedometer and a tachometer enables you to see the most important facts at a glance, including powertrain flow, current state of charge of the battery, current tank capacity, gas activity and brake activity. The RoadView displays an overview of the route, the SensorView visualizes the traffic objects around the ego-vehicle.

The export functionality to numerous video and picture formats is very useful for documentations and presentations. Furthermore, there are numerous light functions like headlights, brakelights and indicators available in IPGMovie™ – even for the traffic vehicles.

The graphics are freely configurable in terms of quality and offer great features like real-time reflections of the environment on the vehicles, light reflections on the road surface and puddles, shadow generation, supersampling, blooming and motion blur.

The view can be splitted in up to four windows with various arrangements. Every single view can obtain separate camera specifications. This features offers almost endless possibilities to personalize your IPGMovie – for example to realize rear- and side mirror views for driving simulators or fish-eye camera settings to display the view of parking assistant cameras.
The Test Manager facilitates a smooth, robust and automated test process as well as an organized platform to manage your project data. Using this powerful interface, *.xls-files containing maneuver catalogs, variant matrices and evaluation criteria exported from DOORS can be easily imported into the Test Manager of CarMaker®, TruckMaker® and MotorcycleMaker®. The specification of test automation can be done without any programming skills. If required, user-defined start, end and simulation script procedures can be inserted as Tcl/Tk or MATLAB scripts.

After the test is finished, the results are automatically stored in test protocols and can be returned to the requirements management tool. The report function will automatically create a predefined customized PDF-file at the touch of a button, which contains detailed results of the whole test series as well as of every single Test Run including criteria results and diagrams (see the images on the right side). Furthermore, it is possible to calculate parameters during the running simulation, which also will be put out via the report function. Within the Test Manager you can access all parameters, which enables the easy varying of parameters to conduct comprehensive parameter studies.

The test configuration item serves as a link to the TestWare functionality. The main difference between the Test Manager and the Test Configurator is the front-end which is adapted to different user groups.

The work of the second user group, usually the end users, is based on these files. The Test Configurator allows the user to configure and parametrize pre-defined tests which are part of different so-called TestWare packages. Typically a TestWare package is a catalog of several tests which share a common aspect. Those tests are presented in the Test Configurator in a more abstract level than the TestManager provides, hiding all implementation specific details and showing only the essential information to the user. They enable the user to execute the test automation in a simplified and clearly arranged way. Different variations of the driving tasks can be easily created and modified.

When this is done, the selected variations will be converted into the the Test Manager.

The vehicle configuration item allows easy modification or replacement of the primary test vehicle, its tires, its trailer and other vehicle parameters. The calculation of characteristic values is possible online during simulation via Real-Time Expressions or as a post processing step utilizing tcl-code. For each simulation several criteria can be defined which will rate the overall outcome. Part of a criterion formula may be user accessible quantities and previously calculated characteristic values. Diagrams defined with this item are automatically generated after the simulation. Several types of diagrams are available, displaying data of the previous simulation and/or content from a specified reference file is possible.
Physical Sensor Models

Due to the heavily growing diversity of variants and the (lacking) availability of physical prototypes, the waiting periods until a hardware prototype can be made available are long in many cases and require extensive coordination work between the various departments involved. However, the functions can already be developed to a high level of maturity without a physical prototype. The various sensors and their technical requirements will be presented as well as the possibilities which the different sensor models offer in the vehicle development process to test advanced driver assistance functions.

MBS Axles

You can use our range of detailed MBS axles with real-time capability for the CarMaker simulation environment to test different axle types effectively and at an early stage in a single tool. Our test automation tool, Test Manager, and the option to connect common design of experiments tools, make axle optimizations extremely efficient. The MBS axles are suitable for detailed tests of vehicle handling in the context of the whole vehicle, taking into account the interaction between the axle and other vehicle subsystems such as steering together with the EPS control unit or tires. With the results obtained in this way, you can make well-founded decisions for the continuing development process.

TameTire Powered by Michelin

The TameTire model developed by Michelin has achieved a new breakthrough in tire modeling to simulate handling. By increasing the accuracy and quality of vehicle dynamics simulation, it creates the prerequisites for realistic reconstruction of a wider range of track tests and test conditions. TameTire uses physical parameters which are easy to understand. This integrates the tire into the parameter space as a tuning and tolerance element in order to investigate the vehicle-tire interaction with respect to a target function.

Pfeffer with Power Steering

Conventional steering models are typically based on a simplified approach that does not consider non-linear friction effects, stiffness, mass, inertia, etc. In addition, a comparison between the simulation results and the physical test drives reveals significant differences. The integration of Pfeffer model with Power Steering, combined with the SensoDrive “SensoWheel” steering simulator, produces a very realistic reflection of the steering and handling feel, as numerous test users have confirmed. The steering model is very simple and, using the CarMaker® GUI, easy to operate.

The user can select, configure and parameterize both the mechanical model and the steering assistance unit plus the steering ratio (linear or non-linear).

IPGRoadData

The IPGRoadData™ package contains digital replications of real existing roads. The RoadData files consist of tabulated data points, which describe the course of the center line of the road including the altitude and the lateral slope of the road surface. The file describes the general layout of the road. During the measurements of the driving dynamics, the vehicle speed, the driven distance, the yaw rate, the longitudinal and lateral accelerations as well as the roll and pitch angles were measured as a function of time.
Simulation Method for Physical Sensor Models

Virtual test driving includes the same components as real-world test driving, in other words a virtual vehicle into which the functions under test are integrated, a virtual driver, a virtual road as well as other virtual road users and pedestrians, in order to depict the wide variety of scenarios. Furthermore, the virtual scenarios include a range of traffic signs, road markings, buildings, etc. in order to represent country-specific characteristics as well which can be used to test the relevant camera-based functions.

The various sensors and their technical requirements are presented below as well as the possibilities which the different sensor models offer in the vehicle development process to test advanced driver assistance functions.

Ideal Sensor
In theory, a perfect simulation solution would have the ability to represent all physical effects, shadows, reflections, environmental conditions, etc. of the real world. However, this goal can only be realized to a limited extent as an exceeding amount of processing power would be required. Therefore, the effects that are relevant for the simulation must be determined. Ideal sensor models are suited for rapid prototyping as well as feasibility studies.

They provide ground truth information which is relevant for the detection of the environment as well as object tracking. In addition, the information may be used to verify the recognition via specially implemented sensors. The use of an ideal sensor model entails the generation of an object list which is independent from the sensor technology utilized. Here, each sensor can be parameterized independently from the others.

Examples for Ideal Sensors: FreeSpace Plus, Object, TrafficSign, Line, Road, Collision

HiFi Sensor
High Fidelity (HiFi) Sensors are suited for the development and validation of functions. The object list generated varies depending on the technology used such as radar, for instance. In this case, the recognition of the environment is effected by a reduced signal propagation based on a phenomenological approach.

Examples for HiFi Sensors: Radar, Ultrasonic, Camera, Lidar, Global Navigation

Raw Signal Interface (RSI)

The Raw Signal Interface (RSI) for component and signal-based testing provides unprocessed raw signals instead of object lists. This information can be used as input for a signal processing and object tracking algorithm. Depending on the selected sensor type, different physical effects need to be considered such as the reflection of electromagnetic waves or optical effects for cameras.

The lack of a processing or tracking component offers the user the opportunity to model their own components of the software and electronics. This allows for the configuration of the antenna properties, radar waves or signal type, for instance, according to the specifications of the real unit under test without the need to disclose confidential information.

Examples for Raw Signal Interface Sensors: Ultrasonic RSI, Camera RSI, Lidar RSI

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Examples for Raw Signal Interface Sensors: Ultrasonic RSI, Camera RSI, Lidar RSI
A Thermomechanical Tire Model

The TameTire model developed by Michelin has achieved a new breakthrough in tire modeling to simulate handling. By increasing the accuracy and quality of vehicle dynamics simulation it creates the prerequisites for realistic reconstruction of a wider range of track tests and test conditions. TameTire scaling parameters allow vehicle-tire interaction analysis, both for achieving targets and for tolerance studies. TameTire has been made available worldwide by IPG Automotive as a fully integrated model in CarMaker and as a stand-alone model.

TameTire considers tire forces and tire moments in a wide range of conditions including thermal effects, speed effects, tire inflation pressure and transient effects. TameTire also uses comprehensible physical properties with scaling parameters which are easy to handle. The TameTire model provides significant advantages over state-of-the-art models such as:

Advantages of TameTire:
- Wider scope of testing maneuvers and testing specification
- Extended parameter space for vehicle/tire optimizations
- Elaboration of tire properties for vehicle dynamics target function
- Real-time performance capabilities
- Considers the deformation of the tire structure while cornering
- TMPS system application

Total force is assumed as the sum of the shear forces of the tread elements in the adhesion and sliding areas of the contact patch

Considers the rubber properties for calculating the friction coefficient (relative slip between the tire and track surface)

Calculates the contact, surface and inside temperatures of the tread, considering the convection to the air, thermal conduction to the track, frictional heat and viscous heat generated in the tread

Add-Ons (Models)

TameTire powered by Michelin

Additional functions and applications with CarMaker

TameTire was integrated into CarMaker® in order to model the interaction of the vehicle/tire system and to realistically simulate the complex control loop of driver, vehicle and road. The integration has expanded the functions and applications of TameTire even further. CarMaker®‘s tire standstill model, for instance, extends the working range. The GUI-based test automation enables extensive test test catalogs to be run and offers tools for parameter studies. Inflation pressure tolerances and tire stiffness values in combination with vehicle parameters automatically can be investigated over night. IPGDriver™ is able to systematically modify and manipulate tire inflation pressures or temperatures during the Test Run.

Practically directly from the cockpit, systematic adjustments of operating parameters or a defined pressure loss to test tire pressure monitoring systems (TPMS) are implemented in the Test Run. A status observer can query all TameTire parameters with millisecond-accuracy to ensure event-based testing. The loss power model of CarMaker® delivers the corresponding performance summary based on rolling resistance, lateral and longitudinal slip, self-alignment and deformation of the tire for the purpose of performing energy analyses.

TameTire database

A TameTire database with several tires in different vehicle classes has been integrated and is regularly updated by adding new tire datasets. Additional tires can be measured upon request. The tires cannot only be used for the different vehicle dynamics tasks, but can also be defined and modified by scaling parameter plots for related target functions.

TameTire as standalone version:
- Is delivered as a library with a C-interface for integration into the vehicle model.
- Models are integrated as block set and available for Matlab 2012a
- Includes the CarMaker standstill model.

<table>
<thead>
<tr>
<th>Input</th>
<th>Additional signals</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slip Ratio</td>
<td>Side Slip Angle</td>
<td>Longitudinal Force (Fx)</td>
</tr>
<tr>
<td>Camber Angle</td>
<td>Wheel Load</td>
<td>Lateral Force (Fy)</td>
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<tr>
<td>Travelling speed</td>
<td>Inflation pressure</td>
<td>Self-Aligning Torque (Mz)</td>
</tr>
<tr>
<td>Ambient air temperature</td>
<td>Track temperature</td>
<td>Camber Torque (Mx)</td>
</tr>
<tr>
<td>Initial tire temperature</td>
<td>Time</td>
<td>Roll Torque (My)</td>
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Eff. Rolling Radius (Reff)
Steering Model for Improved Handling Feel

Conventional steering models typically are based on a simplified approach that does not consider non-linear friction effects, stiffness, mass, inertia, etc. The achievable simulation result is described as an “out-of-true”, non-authentic steering or handling feel. In addition, a comparison between the simulation results and the physical test drives reveals significant differences.

In this context, the integration of the Pfeffer model with Power Steering into the open CarMaker® integration and test platform is truly sensational. Combined with the SensoDrive “SensoWheel” steering simulator, it produces a very realistic reflection of the steering and handling feel, as numerous test users have confirmed. Even small modifications to the vehicle such as suspension kinematics, springing, tires, weight distribution and aerodynamics are equally identifiable and perceptible as active control interventions and changing road conditions. In addition, particular attention was paid to extremely easy parameterization and operation plus a wide range of possible applications.

In combination with the fully non-linear car model, IPGCar, the high-performing driver model for demanding closed-loop driving tasks, IPGDriver™, and the new tire model extensions for the stop-and-park model (turn-slip) almost any driving situation can be modeled precisely.

The new steering model masters even the most demanding tasks:

- Evaluation of steering characteristics and steering effort in the full vehicle, e.g.: On-center performance
- Non-linear stationary performance
- Closed-loop test drives
- Transient transmission performance
- Parking performance
- Development and testing of driver assistance system functions with active steering recommendation such as:
  - Active steering support
  - Lane keeping assistance
  - Parking assistance

Realistic steering feel is primarily the result of the steering torque in the driver-vehicle-tire-road interface. In addition, the perfect interaction between the mechanical model and the steering assistance unit ensures the precise modeling of steering characteristics. Therefore, a strong focus was put on detailing the individual steering components, modeling the mechanical friction mechanisms as well as the implementation of the various steering assistance systems in order to achieve a good and authentic reflection of the steering torque. From the steering assistance unit, the following selections can be made: hydraulic steering assistance (HPS, power steering), electrical assistance at the steering rack (EPSapa = Axially Parallel Drive) plus electrical assistance at the steering column (EPS to Column) in which the support may be defined at the upper steering column (Column) or at the pinion. Both of the two EPS models are available as simplified or as detailed steering assistance models with additional mechanical degrees of freedom. Depending on the selected type of axle, steering is automatically configured in front of or behind the axle in CarMaker®. This interaction produces a highly resolved, detailed image of reality.

High-performing interfaces – extendable and usable as needed

The steering model has been extended by the proven Model Manager, which enables the various model parts to be conveniently selected in the GUI. Due to the modular structure and extensive interface structure, model parts may be replaced or extended as needed by means of the bypass model – for example by the user’s own steering support systems, e-machines or controllers. Furthermore, various bypass interfaces for external torques, angles, positions, electric power etc. were created in order to model an active steering recommendation using torque, desired steering angle specifications or targeted error injections.

The new steering model is very simple and easy to operate using the CarMaker® GUI. The user can select, configure and parameterize both the mechanical model and the steering assistance unit plus the steering ratio (linear or non-linear). The speed-dependent steering assistance is mapped via the boost curve for the EPS motor current. Here, the user benefits from the highly detailed parameterization possibilities of the steering model as well as of the very high overall user friendliness.
Put the Roads of the World into Simulation

A digitized road file is a binary converted ASCII file. These files contain tabulated data points, which were measured on the real existing roads. The points describe the course of the center line of the road in the xy plane (x,y) in 3D including the altitude (z) and the lateral slope of the road surface (q).

During the measurements of the driving dynamics, the vehicle speed, the driven distance, the yaw rate, the longitudinal and lateral accelerations as well as the roll and pitch angles were measured as a function of time.

Based on these values, the route y(x), the height profile z(s) as well as the lateral slope of the lane q(s) were reconstructed. The file describes the general layout of the road. Other important road characteristics like surface friction as well as the left and right lane width are listed in the *.road file and can be defined in the global road attributes of the road dialog.

All parameters of road segments can be used for digitized roads as well. In this case, the segments are used to define special properties of the road on a given distance.

If you wish, you can separately define longitudinal and lateral slope and camber which can be very useful to define bumps and markers. Finally, for selected segments you can also define a special width or friction coefficient by overriding the attributes.

Listing of available data:
- Falzarego
- Le Mans
- Pordoi Joch
- Grödner Joch

Add-Ons (Models)

Simulation Software
Add-Ons

IPGKinematics

IPGKinematics™ supports the effective design and optimization of the kinematics and compliance of wheel suspensions. All actual axle types are mapped with great detail as non-linear multi-body systems in templates and can be easily modified, e.g., at hard point, stiffnesses, dampings, frictions, masses, etc. The results of the freely defined tests at the virtual K&C test bench can be analyzed, exported, or transferred very easily into the CarMaker® or TruckMaker® axle model by a single mouse click.

KnC Data Converter

The KnC Data Converter makes the automated transfer of measurement data on the kinematics and elasto-kinematics of your vehicle into CarMaker axle models quick and easy. A clearly laid out user interface enables you to import measurement data generated on MTS and Anthony Best Dynamics test benches, providing a convenient means of generating the correct parameterization for CarMaker from this data.

ADAMS Data Converter

With the ADAMS Data Converter, the data of the overall vehicle models constructed in Adams/Car can be easily transferred into CarMaker vehicle models. Even if the focus is on extracting the kinematic and elasto-kinematic characteristics of the vehicle’s axles, the converter still aims to create a complete virtual prototype. Once you have successfully converted your data from Adams/Car, you can use the newly created virtual prototype directly in CarMaker for virtual test driving.

CarSim Data Converter

Using the CarSim Converter, it is possible to import a vehicle data set of the CarSim environment into a vehicle data set which is readable by CarMaker®. CarMaker® is able to cover all functional contents and offers additional contents. The vehicle imported from CarSim can be used within the whole CarMaker® environment, including IPGTraffic, maneuver- and event-based testing and any other function of the open integration and test platform.
Testware

The upgrade package Testware contains test cases, test automation and post-processing routines to extensively test ACC, NCAP, ESP by a mouse click. It contains realistic scenarios which have been developed by means of findings from the risk analysis and the functional safety analysis. This basic test catalog was extended by numerous scenarios that are hard to realize on the test track or in public traffic. These are, for example, security-sensitive driving situations or tests that could not be realized under reproducible conditions due to the complex interdependencies between test vehicle and traffic. Using the models and functions described above, the developed maneuver catalog has been fully implemented in CarMaker®.

AVL CONCERTO

AVL CONCERTO is designed to handle different kinds of data from office simulation, HIL test beds or real vehicles. It enables the user to visualize and evaluate the acquired information as well as to manage, calculate and present the data. Due to the uniform access to different data sources and different data formats, no additional data conversion tools are required.

Adletec SoundMaker Professional

SoundMaker Professional is a standalone 3D audio module for the CarMaker product family that provides a realistic sound experience during virtual test driving. It is equipped with a wide range of predefined sound profiles. Additionally, users can also create customized profiles automatically using the SoundMaker Editor. All parameters offered by CarMaker are available and can be used to create mathematical rules for the new profile. The position, direction, velocity, volume and pitch can be defined separately for each source.

SoundMaker Professional is connected to CarMaker via a network protocol. This makes it easy to run the audio module on a different system and connect to the CarMaker instance on Linux or a HIL system.
Accurate Replication of Suspensions

Exact characteristics for the suspension kinematics

IPGKinematics™ is a program designed to simulate a vehicle axle on a virtual axle kinematics test bench and to calculate the kinematics, steering kinematics and compliance of all types of suspension. It assists the designer in developing new suspensions as well as in optimizing existing axle designs. IPGKinematics™ combines the accurate replication of suspensions with short simulation times. A suspension submodel independent of the overall model provides exact characteristics for the respective axle kinematics.

Each kind of suspension has been modeled as multi body system with MESA VERDE and then converted as a library. A customized Graphical User Interface (GUI) suits each library. Furthermore, the open and modular program structure makes it possible to expand functionality to include any number of additional axle designs or special construction types.

IPGKinematics™ calculates all information the chassis engineer needs to optimize the design:

- Wheel travel kinematics
- Steering kinematics
- Compliance effects

Output parameters

The parameters calculated by IPGKinematics™ range from toe-in angle, track-lever radius and steering differential angle to the inherent structural frequency and control-arm and bearing forces. The axle kinematics can also be passed directly to a vehicle dynamics model via an export interface.

Wheel suspensions

The range of standard constructions covers all available axle constructions and is continuously being extended as new requirements arise. All front axles are available with rack and pinion steering, truck front axles additionally are available with a recirculating ball and nut steering gear. The axle spring can be connected to any part of the wheel suspension of all front and rear axles. Axle suspension is also available via a pull/pushrod for use in motor sports.

IPGKinematics™ currently supports the following suspensions:

Front axles:
- McPherson
- Double wishbone
- Multi link

Rear axles:
- Suspension strut/shock absorber strut
- Double wishbone
- Multi link
- Semi trailing arm
- Trailing arm
- Twist beam
- Four link
- Swing arm motorcycle suspension

TruckMaker front axles:
- Steerable rigid axle
- Steerable swing axle

TruckMaker rear axles:
- Four link rigid axle
- Leaf spring rigid axle
- Four point link rigid axle
- Swing axle

TruckMaker trailer axles:
- Twist beam
Test Scenarios Under Control

In order to give the user a quick start in the model based testing of driver assistance systems, the upgrade packages Testware/ACC, NCAP and ESC was integrated in CarMaker®. They contain test cases, test automation and post-processing routines to comprehensively test vehicle control or driver assistance systems by mouse click.

Using the Testware Designer, a test developer can identify atomic test units and set up TestRuns and evaluation functions to create TestWare packages based on real driving tests like sheer-in/sheer-out scenarios or traffic jam assists.

Test Configurator

The Test Configurator allows the user to configure and parametrize the pre-defined tests from the test developer which are part of different so-called TestWare packages. Typically a TestWare package is a catalog of several tests which share a common aspect. Those tests are presented in the Test Configurator showing only the essential information to the user. They enable the user to execute the test automation in a simplified and clearly arranged way. Different variations of the driving tasks can be easily created and modified.

E.g. the user can specify:
- Different velocity and acceleration profiles for the test vehicle and the traffic objects
- Lane changing dynamics of the test vehicle and the traffic
- Setting of the maneuver trigger
- Setting of the control system
- Road configurations

The simulation results are stored in automatically generated test protocols. They show important signal flows, such as distances, velocities and accelerations as a function of time and distance in tables and graphs. Due to the high number of calculated values, the relative vehicle momentums (relative position, relative velocity, relative acceleration) are additionally clustered to qualifiable characteristics with an automated post-processing routine, based on vehicle dynamics experiences. They concisely reflect the system characteristics and make the comparison of the results easier. In addition to maxima and minima, the following provide pertinent characteristics: window evaluations, particularly, reaction and response times, vehicle distances at system reaction and over-/undershooting.

Conclusion

The presented simulation environment enables the development and reproducible testing of advanced driver assistance systems under realistic conditions. Real driving situations are reconstructed easily and quickly with CarMaker®. This enables the testing if driving situations are recognized reliably and if the optimal control strategy is used. The Testware contains important test scenarios for simulation. Using it, tests can be performed by a mouse click without having to worry about the programming of traffic scenarios. The results are provided in an automatically generated test protocol after the simulation. The presented solution can be used continuously for model-, software- and hardware-in-the-loop testing.

At a glance:
- Test automation to test advanced driver assistance systems
- Test and evaluation catalog with close-to-reality driving tests
- Reproducible conditions despite complex interdependencies between vehicle and traffic
- Fully implemented in CarMaker®
- Arbitrary number of common types of sensors
- Results in automatically generated test protocols
CONCERTO is a data evaluation and visualization software package specifically designed to handle all the different kinds of data that can be acquired in office simulation, on HIL test rigs or in real vehicles. CONCERTO contains tools for data browsing, data management, data presentation, calculation, report generation and batch processing. The uniform access to recorder data on files or in an ASAM ODS database makes data conversion tools unnecessary and also allows easy correlation of different kinds of data. Due to its wizard support, CONCERTO is easy-to-use and highly intuitive. Creating sophisticated diagram displays or impressive reports is just a matter of a few mouse clicks.

At a glance:
- Common post-processing platform for measurement and simulation data for validation and evaluation
- Fast and easy data analysis, post-processing and reporting from different sources
- Concerto-Plots can be created automatically with a predefined layout using the Test Manager (see p. 108)
- Powerful data navigation, signal handling, data view and presentation features
- Formula Calculator and Editor with mathematical and analysis functions
- Data explorer and data management
- Numerous data formats such as CarMaker®, AVL InMotion, ASAM ODS Data Base, NI-Odium, MATLAB, NI-TDM, ASCII, EXCEL, Yokogawa, FAMOS and much more
- Scripts for list processing or user defined analysis functions
ADAS RP

The ADAS RP CarMaker® plug-in enables consistent, fully automated and comfortable route generation and enables the consistent development of modern, map-based driver assistance systems and predictive energy management, which requires access to digital map data. Furthermore, it offers information regarding the electronic horizon which can be used as input for e.g. a hybrid control strategy like in real cars.

GT-SUITE

GT-SUITE is an engine and powertrain simulation tool, applicable to design of any machinery powered by internal combustion engines. It offers an extensive library of various multi-physics components, from which users can create any advanced concept. GT-SUITE is used by leading car and truck OEMs worldwide, as well as by their suppliers. It provides features for pre- and post-processing, DoE/optimization and control modeling.

GT-SUITE is designed for steady state and transient simulation and is fully supported by CarMaker®.

CRUISE Interface

IPG Automotive and AVL have tightly interfaced the detailed powertrain simulation AVL CRUISE to the open integration and test platform CarMaker. The solution enables to simulate the multi-dimensional losses of individual vehicle components in realistic driving situations CarMaker/CRUISE is optimally suited to test the driving dynamics characteristics of hybrid vehicles which result from the complex interaction of components and systems. The integrated solution creates an unique continuity across multiple sectors. Engineers in driving dynamics and powertrain now have a common platform at their disposal to exchange their development status or optimization.

Dyno Interface

The Dyno Interface integrates our real-time capable vehicle simulation environments CarMaker, TruckMaker and MotorcycleMaker into your test bench. The interface including a tool box allows for the use of real driving simulation including models of the vehicle, driver, road, traffic and surroundings on test benches of all leading manufacturers and established automation systems.
Add-Ons (Interfaces)

Overview

Integration with MATLAB/Simulink

CarMaker® for Simulink is a complete integration of IPG’s open integration and test platform CarMaker® into The MathWorks’ modelling and simulation environment, MATLAB/Simulink. The highly optimized and robust features of CarMaker® were added to the Simulink environment using an S-function implementation and the API functions that are provided by MATLAB/Simulink. CarMaker for Simulink is not a loosely coupled co-simulation but a closely linked combination of the two best-in-class applications, resulting in a simulation environment that has both good performance and stability.

Functional Mockup Interfaces (FMI)

As a tool independent standard, the Functional Mockup Interface (FMI, Dymola, SimulationX, AmeSim) supports the model exchange as well as the co-simulation of dynamic models by combining compiled C-code and XML-files (tool coupling). The goal of the FMI is to optimize the simulation model exchange, to increase the process quality and to reach a higher efficiency. Invented by the Daimler AG, 16 companies and research institutes take part in the further development today. The FMI-standard is fully supported by CarMaker®.

C-Code Interface

CarMaker® offers the option to integrate user models which are written in plain C-Code to extend or replace CarMaker® models, as well as models, which were exported as C-Code out of other authoring tools. Using the included powerful Model Manager, this procedure is very easy and intuitive. By choosing a proper Model Manager class, all parameters of the selected model are automatically allocated and available on the dynamic interfaces. There are many different model classes ranging from several vehicle subsystems to the driver model. Moreover, using the plain wrapper any kind of model can be integrated independently.

ETAS Inca

ETAS Inca offers comprehensive measuring and calibration functions as well as tools for the administration of application parameters, measurement data evaluation and the flash programming of ECUs directly from the CarMaker® maneuver. Thanks to the integrated database it is possible to reuse already existing configurations and experiments for new ECU-projects. Using the open interfaces of INCA, it can be integrated in the CarMaker® environment.
ADASRP Interface

Navigation-in-the-Loop for Higher Safety and Energy Efficiency

The consistent development of predictive energy management and modern, map-based driver assistance systems requires access to digital map data. CarMaker® provides a plug-in for data transfer from navigation systems, for instance from the ADAS Research Platform (ADAS RP) development environment by here. This plug-in enables consistent, fully automated and comfortable route generation even of very long routes with corresponding information about the road infrastructure.

Prerequisites for the development of map-based systems

Modern energy management or novel driver assistance systems, in addition to the current driving mode and ambient information, also require predictions to be made about the anticipated characteristics of the route. For their control strategy they include, for example, uphill sections in the road, cornering radii, speed limits and traffic lights. The fusion of this information leads to a plus in safety and energy efficiency.

The ADAS RP development environment offers the required data for road characteristics which is displayed by the electronic horizon. The probable route of the vehicle, the Most Probable Path (MPP), is continually determined. The algorithms use static map attributes such as signage as well as dynamic parameters like the vehicle speed. This information is transmitted to the driver assistance systems or to hybrid, engine or transmission control units.

Comfortable route generation – ready for virtual test driving

The data of real-world road characteristics is imported from ADAS RP into the CarMaker® simulation environment and displayed in IPGRoad™. The virtual vehicle automatically establishes a connection to the navigation system and exchanges the required data to start for a test drive immediately. The route is presented in CarMaker® with a high degree of realism. In addition, CarMaker® can read the road, road markings, signage and other attributes. This means it offers a fast applicable substitute for navigation systems and front cameras for testing the aforementioned functions with minimal effort.

Even very long distances are realized faultless. By means of carefully conceived 3D-spline functions, CarMaker® is able to calculate existing artefacts or complement missing parameters such as the altitude information or corner characteristics. Even the modeling of winding routes or the exportation of signage can thus be accomplished automatically and without limitations. If required, route data can be modified, overlapped or supplemented easily using the GUI, for instance to achieve targeted deviations.

Visualize your Test Run on Google Earth

CarMaker® has a plug-in to Google Earth which allows to impressively visualize and track the route online. The position data is continually transmitted to Google Earth and cyclically updated. In addition, CarMaker® has a global navigation sensor module which is integrated in the test vehicle and all traffic objects. This not only serves to transmit the data of the test vehicle to the navigation but also the positions of the involved traffic objects.

Technical background

CarMaker® generates the GPS signals and transfers this data to ADAS RP, which calculates the Most Probable Path and delivers it back to CarMaker®. In the office version, the communication takes place via a TCP/IP interface and the UDP/IP protocol. For Hardware-in-the-Loop simulations via the CAN interface, it takes place via with the standardized ADASIS v2 standard protocol. Since ADAS RP can be accessed via the TCP/IP interface, CarMaker® calculates the simple Flat-Earth-Geo model and the more complex Gauss-Krüger-Geo model. Consequently, the allocation to other navigation devices is easy to implement.
Full Analysis of Power Losses During Realistic Drive Cycles

CarMaker®/CRUISE raises the potential for an efficient use of energy, considering both safety and comfort at the same time. Realistic driving maneuvers instead of driving cycles enable the establishment of a balance sheet of the power loss for all subsystems like suspension, steering, brakes, tires, masses and aerodynamics as well as engine, gearbox, differential, auxiliary equipment and the battery. Thus the interaction of components can be detected, powertrain systems as well as driving dynamics systems can be adjusted relative to one another in the complete vehicle in longitudinal, lateral or vertical dynamics cycles. The engineers can work with their familiar tool environment (CarMaker®, Simulink or CRUISE) and bring the developed models, parameters and test cases together in CarMaker®/CRUISE for integration tasks. CarMaker®/CRUISE is suitable for office applications as well as Hardware-in-the-Loop (HIL) on test benches for ECUs, engines or powertrains.

Thanks to the sophisticated CarMaker® models IPGDriver™, IPGTraffic and IPGRoad, maneuvers on the handling course can be recreated reproducibly just as well as urban drives, interurban drives or highway drives to which any driving situation can be added. The test methodology based on maneuvers and situations outclasses the possibilities offered by longitudinal drive cycles only (i.e. NEDC) as they are usually driven on chassis dynamometer test benches. In accordance with the reality, the multidimensional losses of the individual components can be represented additionally in the longitudinal, lateral or vertical directions. This allows, for example, the precise analysis of how the various subsystems contribute to the increase in fuel consumption in curves, slopes or in a stop & go traffic situation.

Testing of hybrid vehicles based on maneuvers and situations

CarMaker®/CRUISE is also best suited for the analysis of driving dynamics for hybrid vehicles. The hybrid vehicle specific functionalities like recuperation, boosting, automation of start/stop and the driving with solely electric energy create important interactions from the powertrain on the driving dynamics. This interaction can be tested comprehensively with CarMaker®/CRUISE to analyze the functionalities of assistance, security, stability and performance in the whole vehicle.

The full integration of CRUISE enables the integration of hybrid powertrains in the whole vehicle model of CarMaker® at the push of a button. The closed loop of the hybrid vehicle, driver and road can thus be tested comprehensively during virtual tests. The flexible maneuver regulation of CarMaker® enables the user to reconstruct any Open-Loop or Closed-Loop maneuver in order to analyze the behavior of the hybrid vehicle by braking, curves, start and comfort. A further possibility to use CarMaker®/CRUISE is to optimize the operation strategy of driver assistance systems regarding the consumption. It could be possible to adjust the operating strategy of a hybrid vehicle combined with an ACC system to increase the energy efficiency of the vehicle. To analyze such interactions, the user creates driving situations with IPGTraffic. Specific configurations in regard to vehicle, driver, road and traffic can be reproduced exactly. The user meets no limit concerning the number of traffic items or the length of the single-lane or multi-lane tracks. Regarding these use cases, the export of roads out of ADAS RP or the import of kml-files is an excellent method.

Open integration and test platform

CarMaker®’s attribute of being an open integration and test platform shows all its effects in the solution CarMaker®/CRUISE. The models and functionalities of CRUISE are fully integrated into CarMaker®. The parameterization of the CRUISE and CarMaker® models takes place quickly and easily. For first concept studies it is possible to generate parametrization with ease with the parameter generator. Parameters from other systems can also be integrated.

Continuous application through the development process

CarMaker®/CRUISE can be used continuously throughout the concept and software development as Model-in-the-Loop and Software-in-the-Loop simulation. It also supports the Hardware-in-the-Loop testing with the same models, maneuvers and situations on ECU test benches for ECU, components or systems.
Real driving simulation on the test bench

The Dyno Interface integrates our real-time capable vehicle simulation environments CarMaker, TruckMaker and MotorcycleMaker into your test bench. The interface including a tool box allows for the use of real driving simulation including models of the vehicle, driver, road, traffic and surroundings on test benches of all leading manufacturers and established automation systems. The Dyno Interface ensures safe test bench operation in all driving situations. A synchronized real-time coupling of simulation environment and test bench enables a high-performance closed-loop integration of the systems to be tested on the test bench.

Overview
- Real driving simulation on the test bench
- including models of the vehicle, driver, traffic, road and environment for the reproduction of real driving scenarios
- Closed-loop integration of real systems into the virtual environment
- Available for engine/electric motor, drivetrain/powetrain and vehicle/chassis dynamometers

Applications
- Propulsion concept studies
- Powertrain calibration and validation
- System integration tests
- Analysis of advanced driver assistance systems

Evaluation of
- Real Driving Emissions (RDE)
- Real-world consumption/range
- Performance/vehicle dynamics
- Exhaust gas aftertreatment
- On-board diagnostics (OBD)
- Acoustics and drive comfort (NVH)
- Thermal management/HVAC system

Features
- Consideration of all real driving resistances in the vehicle model
- Integration on existing and new test benches of different manufacturers (AVL, FEV/D2T, Horiba, Kratzer Automation, KS Engineers, OPV Engineering, ONG SOKKI and many more)
- Integrated data handling and safety concept with watchdog monitoring and error handling
- Support for different bus systems such as EtherCAT, CAN or UDP
- User-friendly interface tailor-made for test bench operation

Advantages
- System evaluation under realistic driving conditions even without vehicle prototypes
- Continuous use throughout the entire development process due to office PC compatibility of the simulation environment
- High flexibility (vehicle, road, driver) in addition to full reproducibility of real driving scenarios
- Usability of high-fidelity test bench measurement equipment in real driving operating conditions
- Virtual electrification of propulsion systems
- Maximum utilization of test bench operating time thanks to test automation
MATLAB/Simulink

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Because of this integration, it is now possible to use the power and functionality of CarMaker® in the intuitive and full-featured environment of Simulink. Using CarMaker® in the Simulink environment is no different than using standard S-function blocks or built in Simulink blocks. The CarMaker® blocks are connected in the same way other Simulink blocks are connected, and existing Simulink models can now easily be added to the CarMaker® vehicle model with a few mouse clicks.

Integration does not, however, mean a loss of functionality, as all the features that make CarMaker® the premier software in its domain have been included and can now be used in conjunction with Simulink's rich tool set. The CarMaker® GUI can still be used for simulation control and parameter adjustments, as well as defining maneuvers and road configurations. IPGControl™ can still be used for data analysis and graphing and IPGMovie™ offers a realistic animation and rendering of the multi-body vehicle model in 3-dimensional space to bring the vehicle model to life.

Access to CarMaker®'s simulation results is possible using the cmread utility that can be called from MATLAB. This utility loads the data of any CarMaker® simulation results file into the MATLAB workspace. Once available in the workspace, the simulation data can be used and manipulated in every conceivable way for post-processing and plotting. All functions of MATLAB can be used as usual, as an example, the drawing of diagrams or the smoothing of functions.

Key benefits

- Integration of the complete functionality of CarMaker®
- CarMaker® models are integrated as Simulink blocksets
- Sub-segmented to all vehicle sub-systems for an easy customization
- Simple user modification, extension and replacement of blocks
- Use of the respective tool specific model solvers and step size
- Same GUI, models, Test Runs, parameters and mechanisms as in CarMaker® standalone
- Direct access to all variables
- Parallel C-interface for all subsystems for C-code model adaption and performance improvement
- Same performance optimized code using multi-threading, multi-rating and multi-tasking
- The user can access all CarMaker-internal signals like input signals for user specific controllers
- The user can implement own values in DDict, which can be accessed during the maneuver via RTexpressions

Post-Processing using MATLAB/Simulink

CarMaker® / TruckMaker® / MotorcycleMaker® for Simulink is a complete integration of IPG's vehicle dynamics simulation software into The MathWorks' modeling and simulation environment, MATLAB/Simulink. The Matlab support package offers the possibility to export the simulation results into the Matlab workspace. Once available in the workspace, the data can be used and manipulated in every conceivable way for post-processing and plotting. The result is a closely linked combination of the two best-in-class applications, that has both good performance and stability.
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SOLUTIONS FOR VIRTUAL TEST DRIVING

As an innovation driver for virtual test driving, the company is a leading global provider of software and hardware products for the automotive and supplier industry. With the areas Simulation Software, Real-time Hardware, Test Systems and Engineering Services, IPG Automotive supports its customers in creating innovations and improving their development process efficiently. The simulation solutions CarMaker, TruckMaker, and MotorcycleMaker, as open integration and test platforms, facilitate great savings in time and cost for customers, in a continuous development process of Model-, Software- and Hardware-in-the-Loop, all the way to the Vehicle-in-the-Loop method. The application ranges from the general vehicle dynamics simulation, developing and testing of chassis control systems, as well as interconnected systems such as chassis, powertrain, and steering in full electric and hybrid vehicles. Another strength of IPG Automotive is the development of future-oriented solutions for the integration and testing of advanced driver assistance systems.