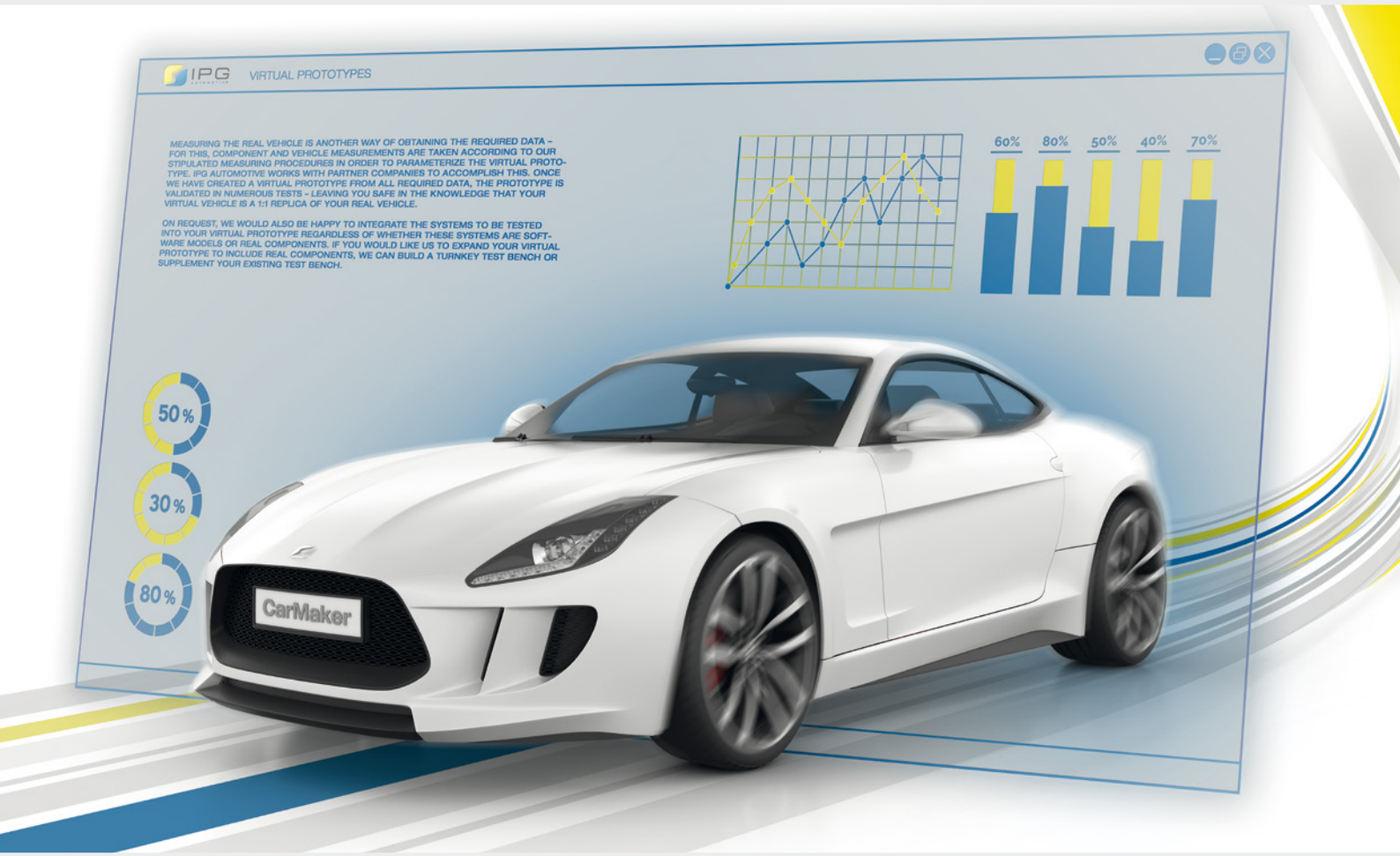
IPG AUTOMOTIVE



BUILDING VIRTUAL PROTOTYPES – WITH OUR ENGINEERING SERVICES

For virtual test driving with CarMaker

SOLUTIONS FOR VIRTUAL TEST DRIVING

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Our Goal: Facilitating Your Development Process

The increasing number of complex electronic control units and their interplay within the vehicle requires a considerable effort with regard to the validation of systems. Test driving is costly and, in addition, the responsible engineer does not generally have access to a suitable prototype. At the same time, however, development cycles are supposed to be shortened and errors to be avoided in the diversity of variants. Virtual test driving allows for reproducible and risk-free testing while also shortening the development time and thus development costs.

In accordance with the automotive systems engineering approach, the vehicle itself plays the essential role in vehicle and system development: Complex systems and their interplay can only be recognized, analyzed and optimized in the context of the whole vehicle. In the development of advanced driver assistance systems, for instance, vehicle dynamics (pitch, roll) also play a key part. Therefore, it is all the more important for engineers involved in vehicle development to have access to a prototype of the whole vehicle.

As real prototypes are rare and expensive, virtual prototypes are an ideal alternative. A whole virtual vehicle enables every engineer to develop, test and in some cases even release systems during the entire development process. With our Engineering Services, we help you optimize your process accordingly.

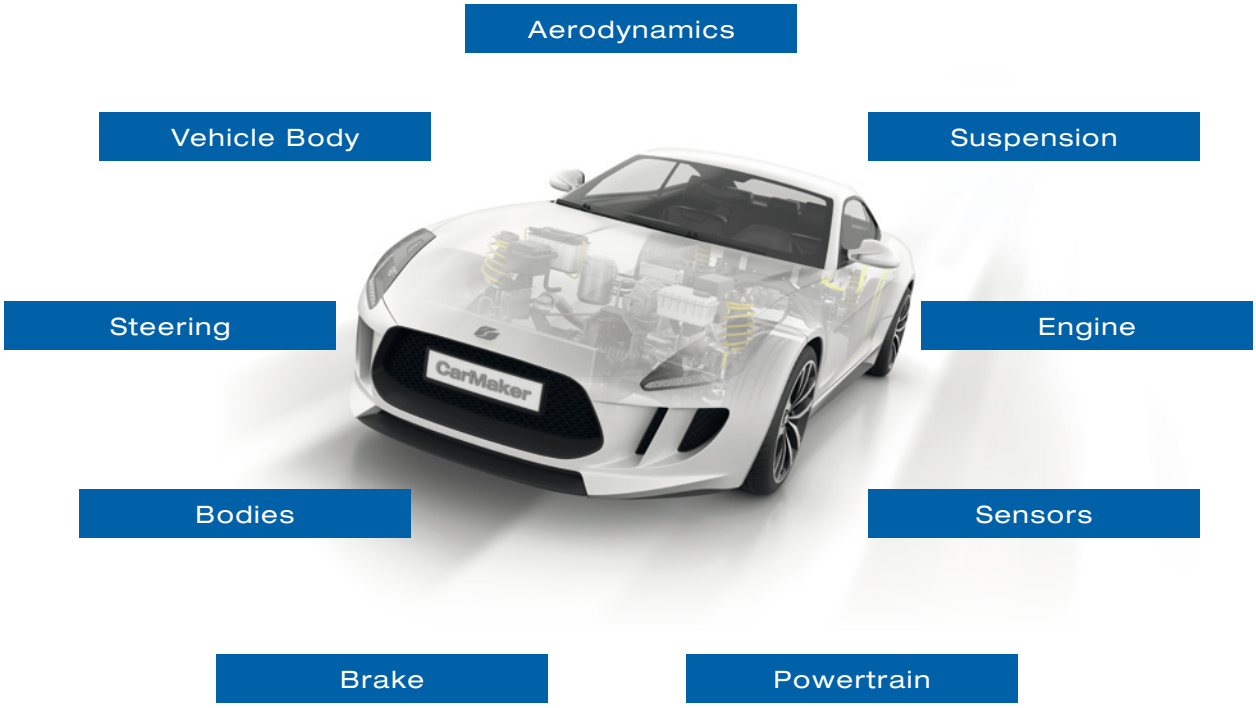
Realistic vehicle model

- Pitching of vehicle
- Influence on sensor and camera coverage

Influence of vehicle dynamics on the testing of driver assistance systems

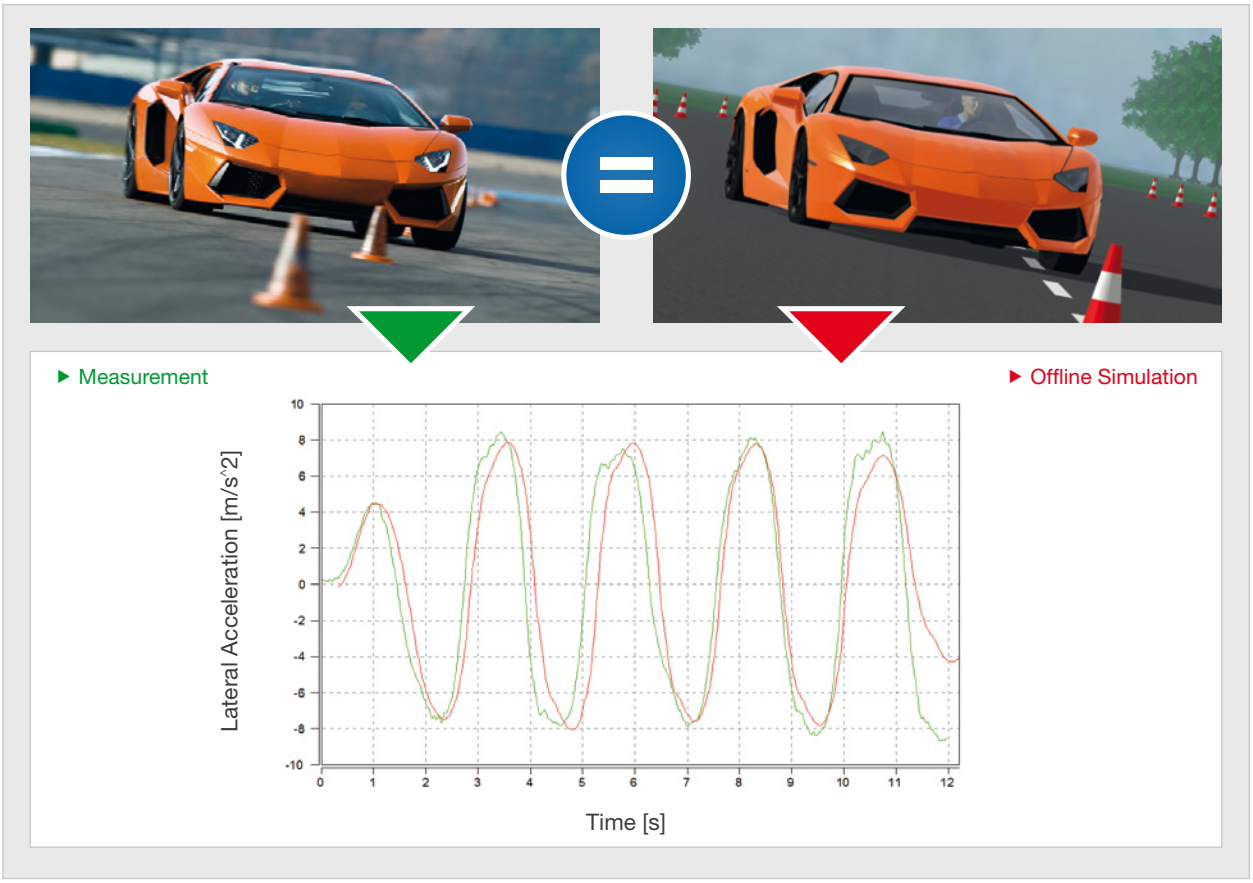
The Virtual Prototype

The virtual prototype is a specific adaptation of the parameters in the CarMaker, TruckMaker or MotorcycleMaker vehicle model in order for them to correspond to the properties and functions of the reference vehicle: The virtual prototype features the same (exchangeable) components and systems as its real basis. This allows for the virtual prototype to exhibit the same dynamic behavior as well once the parameterization is complete.



Vehicle model components

In the course of the development process of the real vehicle, the virtual prototype is continuously complemented and updated – exactly like a real prototype. In contrast, however, the virtual prototype is available earlier and can therefore be used throughout all stages of the development process: from the early testing of the control algorithm (Proof of Principle) with the model-in-the-loop method up to function and release tests of the system on a hardware-in-the-loop test bench (functional prototype).



Vehicle dynamics validation

Additionally, the virtual prototype allows for a cross-domain use in different areas of application, such as the testing of the hybrid strategy when using dynamic powertrain test benches or in the development of functions for autonomous driving. Even the homologation of an ESC can be carried out by means of a virtual prototype.

After the complete parameterization and validation of your virtual prototype, you can encrypt it and share it with colleagues or suppliers in order to continue the component and system development in the whole virtual vehicle.

The CarMaker product family allows for the configuration and simulation of virtual prototypes of all vehicle types: passenger cars, vans, trucks, off-highway and special vehicles, trailers as well as motorcycles.

There are two ways of building virtual prototypes: by means of design data or based on vehicle and component measurements. In addition, the virtual prototype can be adapted by enhancing the software basis, or systems to be tested can be integrated. With our Engineering Services, we support you in every step in a variety of ways. A selection of our services is described in more detail below – enabling you to build and continuously develop your virtual prototypes further.

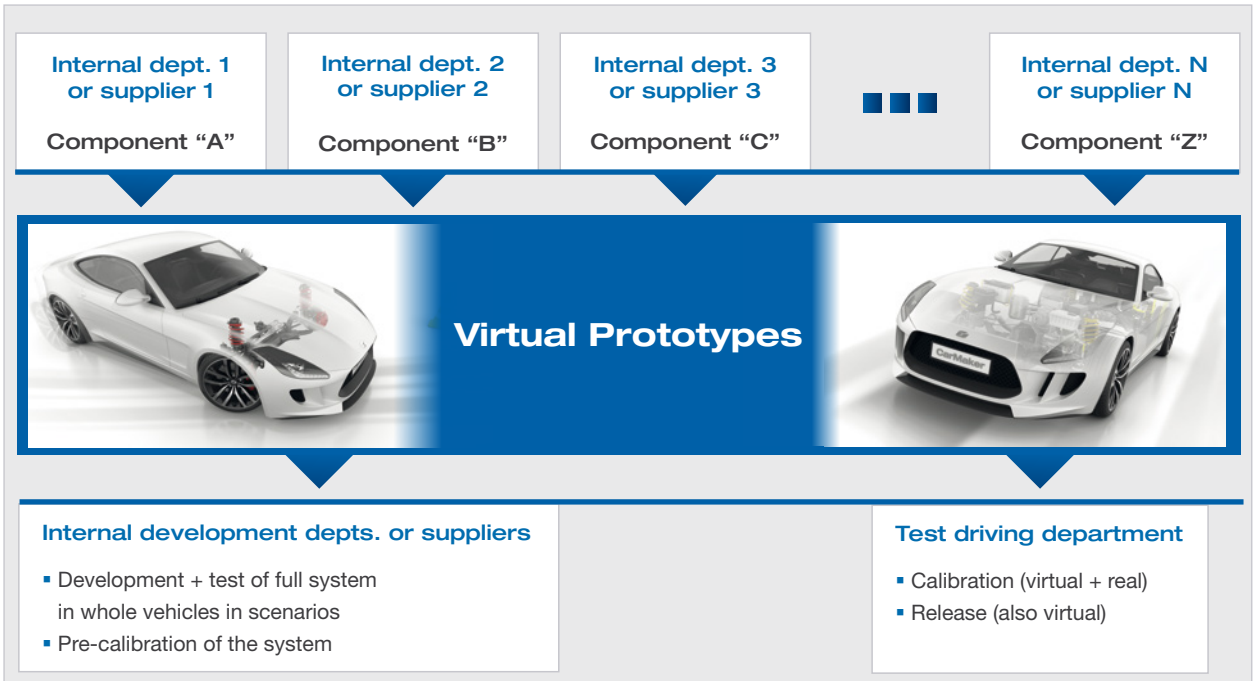
Our Service: Building a Virtual Prototype

The data fusion process

Building a virtual prototype based on the OEM's design data yields a detailed and realistic model. The availability of these data from the vehicle development process allows for a cost-effective generation and use of the virtual prototype already in early stages of development.

We help you identify the data that are required for your specific case of application and use the available data to parameterize the vehicle model. This process involves the compilation of data from different departments, such as chassis development or aerodynamics, or data from already existing databases, and their gradual integration into the virtual prototype. We offer you several ways to facilitate the integration of data by using one of our tools (e.g. the KnC Data Converter), for instance, to adapt the data to the required format. It is our goal to implement the process of building virtual prototypes successfully in your business.

Automotive systems engineering in the development process
Providing internal departments + suppliers with virtual prototypes



Engineers can test and release their systems in a whole vehicle: automotive systems engineering

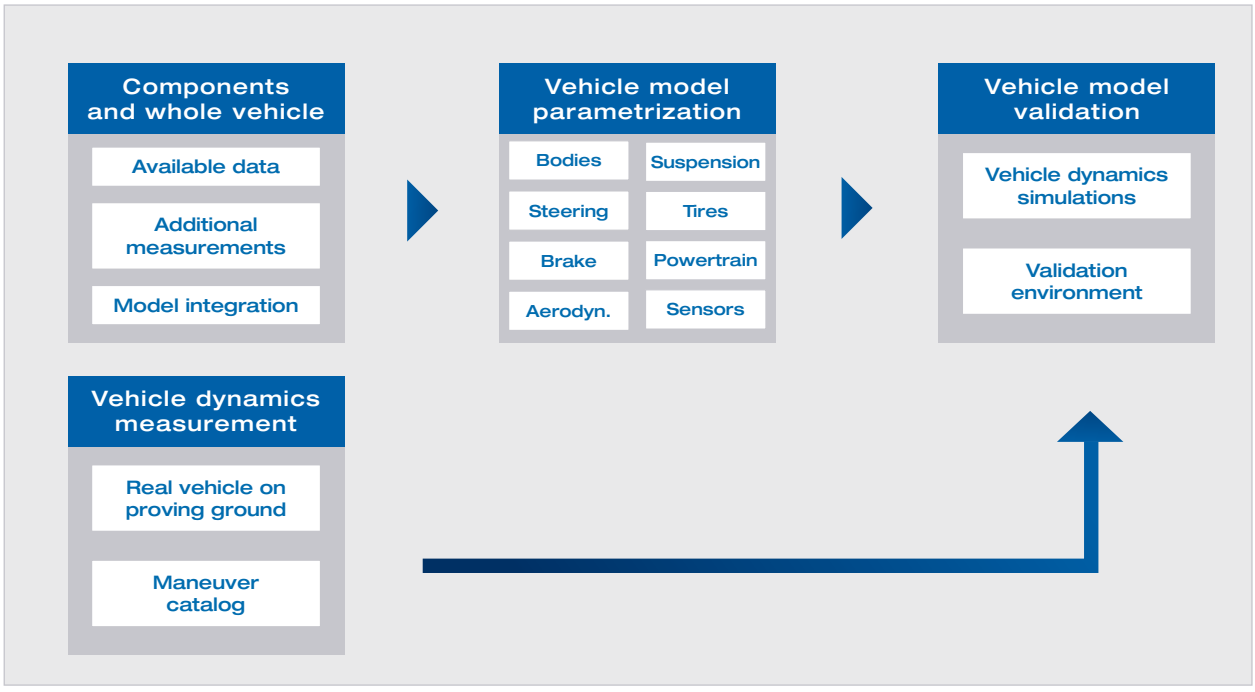
Parameterization and validation based on component and vehicle measurements

Should you only have incomplete design data but access to the vehicle or individual components, you can also build a virtual prototype based on measurements carried out with the real vehicle. We have developed a process to identify unavailable data from the three pillars of

- Whole vehicle measurements, static
- Vehicle dynamics measurements
- Component measurements

We support you in conducting the required measurements at your site or carry out the measurements for you in cooperation with our partners.

Vehicle model parameterization and validation process
Obtaining the required data



We support you during the entire project – from your concept to your validated vehicle

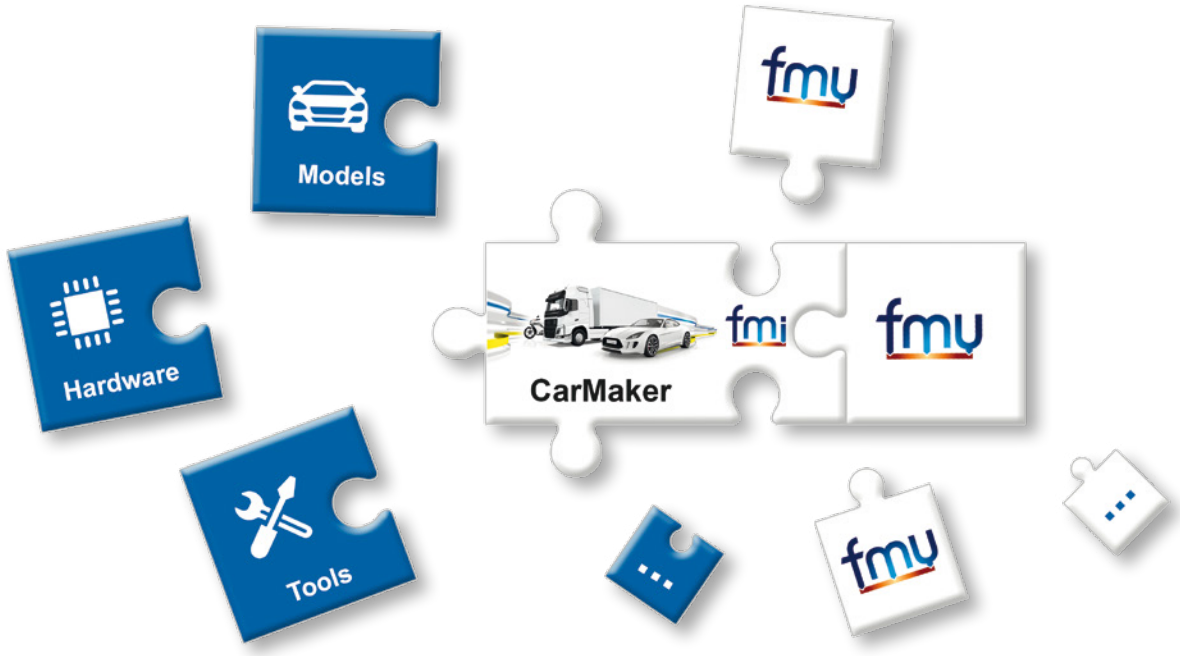
In order to obtain basic vehicle specifications, the stationary vehicle is measured. For the vehicle dynamics measurements, the reference vehicle is equipped with measurement technology and a predefined maneuver catalog of standardized driving maneuvers is performed. The support of one of our engineers and the immediate evaluation of the measured data allow for an instantaneous analysis and release of the results for later use as a reference for the simulation. The component measurements include measurements for obtaining the characteristic values or the characteristic curves of the components that are central to vehicle dynamics, i.e. spring, shock absorber, buffer and anti-roll bars. In addition to the individual components, kinematics and compliance of the axles play an important role for the whole vehicle:

We support you with an elaborate measurement plan for the measurement of the suspension geometry and the subsequent transformation of the data in CarMaker. We also enable you to measure the tire – the only contact surface between vehicle and road – and integrate it into your simulation environment as a tire model that is suitable for your application.

Once all data is compiled, the vehicle model can be parameterized. The behavior of the virtual prototype is subsequently validated based on comparative measurements obtained in real-world test driving: tests and the respective characteristic values and evaluation criteria are determined to this end and analyzed both in the simulation and reality.

Our Service: Developing Your Virtual Prototype

The open integration and test platforms of the CarMaker product family offer a variety of solutions in order to complement the virtual prototype with the devices under test.



CarMaker – the central integration and test platform

Model-in-the-loop: model development and integration

Models can be integrated easily already in early stages of development – independent of the model source or model interfaces since several integration options via FMI, C code, Simulink or co-simulation with third-party tools are available. The virtual prototype can be complemented by special component and system models (e.g. active anti-roll bar, rear wheel steering) or controller models for electronic stability control, lane keeping assist or hybrid control strategy, for instance. The exchangeability of models from all model classifications allows for the safe testing of algorithms by means of model-in-the-loop. In addition, the integration of models is not only available for CarMaker office but also for CarMaker/HIL.

We support you in the development and integration of your models into the CarMaker simulation environment: Together we transform your ideas into models or enhance existing models according to your needs. With our expertise on our open integration and test platform, we find the ideal interface for you to be able to use your models promptly in the whole vehicle. We would be happy to integrate several models for you and link these if necessary. We also take over the model parameterization and validation based on measurement data.

From model development to integration in CarMaker

Hardware-in-the-loop: system integration and turnkey solutions

Potential integration of various systems

Test your electronic control unit reproducibly under real conditions by integrating entire real vehicle systems and ECUs into the virtual prototype. Our services include building customer-specific turnkey hardware-in-the-loop test systems or expanding your existing test benches.

Building test systems is part of our day-to-day activities: you require an ESC HIL test system or a steering-in-the-loop test bench (e.g. for optimizing the steering feel of your steering system)? We develop a concept and plan, build and put your test bench into operation on your premises, enabling you to test just one or several ECUs or even entire vehicle systems. Once the mechanical and electrical integration is complete, we also conduct the restbus simulation and implement the ECUs in our software environment. As a last step, we test the ECU for errors in both static and dynamic operation to ensure that we hand over a functional turnkey test bench to you.

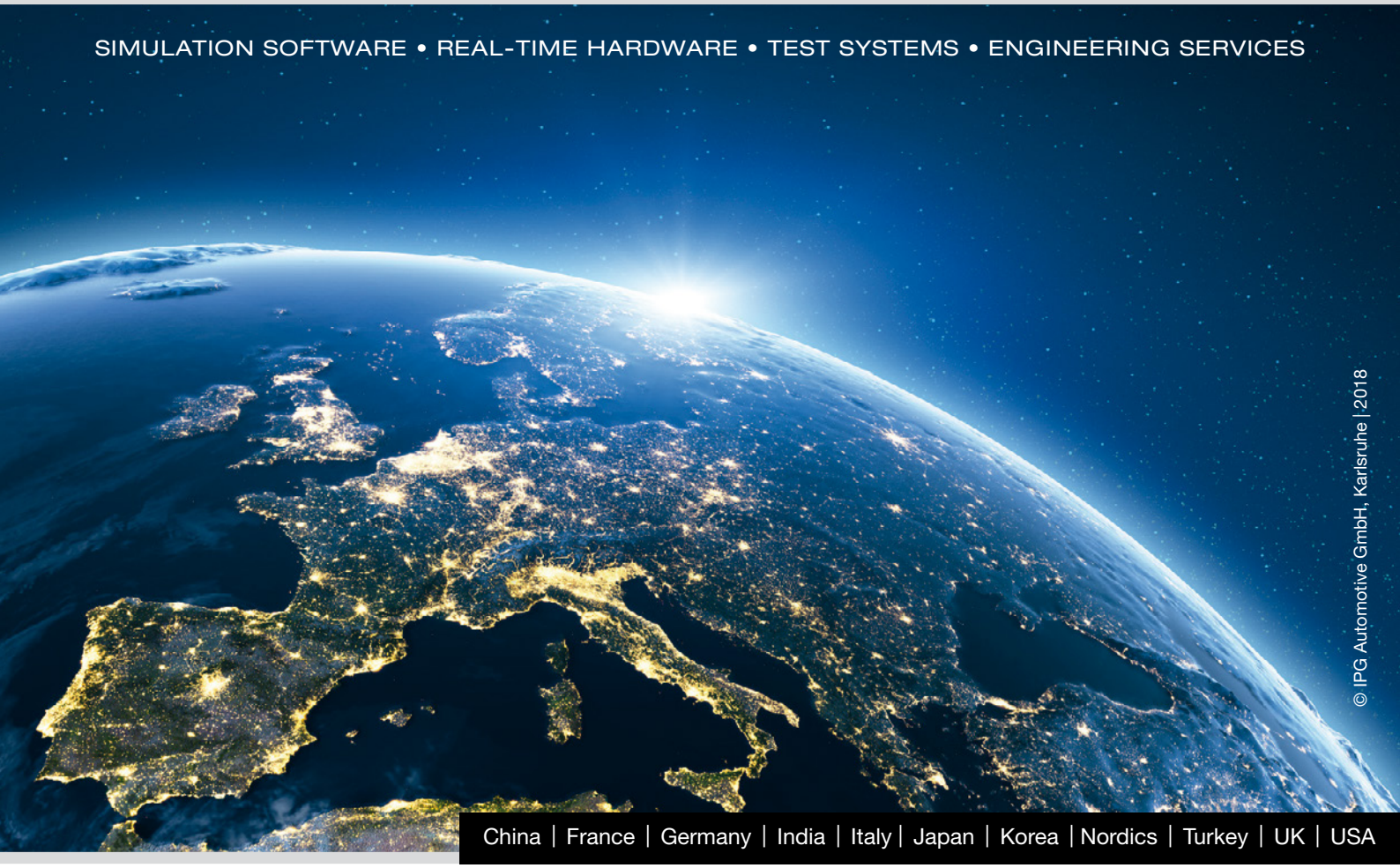
Should you already have test benches for ECU or component testing, we offer several options to combine them with your virtual prototypes in CarMaker: One possibility is the connection of our Xpack4 real-time hardware and CarMaker/HIL to your existing test bench. Another option is the integration of CarMaker/HIL in your already existing complete systems built with National Instruments, dSPACE or ETAS hardware. Lastly, co-simulation with an existing test bench and CarMaker/HIL running on Xpack4 allows you to use the CarMaker product family easily with dynamic engine test benches or powertrain test benches. The key is our Dyno Interface, which enables the analysis of real-world consumption or the adaptation of your hybrid vehicle control strategy.

Key features of the virtual prototype:

- Virtual image of the real prototype
- Suitable for cross-domain use
- Available for all vehicle classes of the CarMaker product family
- Realistic behavior to the limits of vehicle dynamics
- Clear setup according to vehicle subsystems:
  - Efficient implementation of a multibody system – non-linear, expandable and real-time capable
  - Detailed Pfeffer steering model with EPS, HPS and EHPS steering support
  - Support for different tire models
- Flexible, configurable sensor models for advanced driver assistance and vehicle dynamics applications
- Easy verification via the model check function
- Reusable for device under test integration

Overview of our services:

- Survey of required and available customer vehicle data
- Determination and coordination of required component and vehicle measurements; commissioning of partners of IPG Automotive if necessary
- Parameterization of the vehicle model to build a virtual prototype
- Validation of the vehicle model based on reference measurements obtained in real test driving
- Model development and integration to enhance the existing vehicle model
- Planning and building of turnkey test systems
- Integration of ECUs and systems on HIL test benches
- Connecting and putting CarMaker into operation on engine and powertrain test benches



SOLUTIONS FOR VIRTUAL TEST DRIVING

As a global leader in virtual test driving technology, IPG Automotive develops innovative simulation solutions for vehicle development. Designed for seamless use, the software and hardware products can be applied throughout the entire development process, from proof-of-concept to validation and release. The company's virtual prototyping technology facilitates the automotive systems engineering approach, allowing users to develop and test new systems in a virtual whole vehicle.

IPG Automotive is an expert in the field of virtual development methods for the application areas of ADAS & Automated Driving, Powertrain, and Vehicle Dynamics, committed to providing support to master the growing complexity in these domains. Together with its international clients and partners, the company is pioneering simulation technology that is increasing the efficiency of development processes.

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