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Next Generation Car – Technologies for future EVs

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The German Aerospace Center has merged a wide range of technological research and development for future cars in a meta-project called “Next Generation Car”. Within this large research project technologies for three vehicle concepts for different applications (urban, regional and interurban), and with different powertrains (fuel-cell, battery and hybrid) are developed. Research questions on different levels from conceptual question about vehicle modularity down to detailed technological aspects like combining hydrogen storage with cabin climatisation are covered by this project. This paper shows the holistic research approach and presents a selection of vehicle concepts and technology topics.

Keywords: car, van, hydrogen, EV (electric vehicle), ZEV (zero emission vehicle), multidisciplinary

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1 Introduction

Within the project Next Generation Car, DLR scientists research on vehicle technologies for the road traffic of the future. The key challenges for future mobility all over the world are:

- Reduction of the absolute energy consumption of vehicles,
- the use of fuels from renewable energy sources,
- avoidance of harmful emissions, particularly CO_2, particles and noise,
- increasing the safety of vehicle passengers and other road users and
- intelligent connection of vehicles with the urban and interurban transport system,
- interoperability in future mobility concepts.

The Next Generation Car research is focused on the development of holistic vehicle concepts for the vehicle market as from 2036. Cars will be lighter, quieter, connected, more comfortable and safer than be today and further they drive autonomously when required. Future cars should have a lower energy consumption, use of fuels from renewable energy sources and produce fewer emissions.

In the six research fields - vehicle concept, vehicle structure, powertrain, energy management, connected vehicle and mechatronic chassis, the DLR develops a variety of technologies demonstrated in three vehicle concepts which are suitable for meeting future mobility needs in urban regions and for the long haul - for individual traffic as well as for the transport of goods. The project Next Generation Car (NGC) is not a single vehicle project; the meta-project has a holistic approach focusing on integrated development of technologies, methods and tools for future cars.

This paper should open a series of presentations. Further detailed results will be presented at the EVS 30 in Stuttgart 2017.

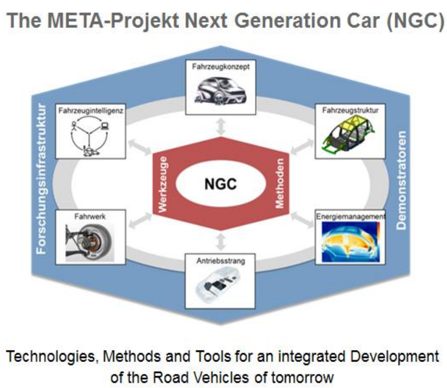
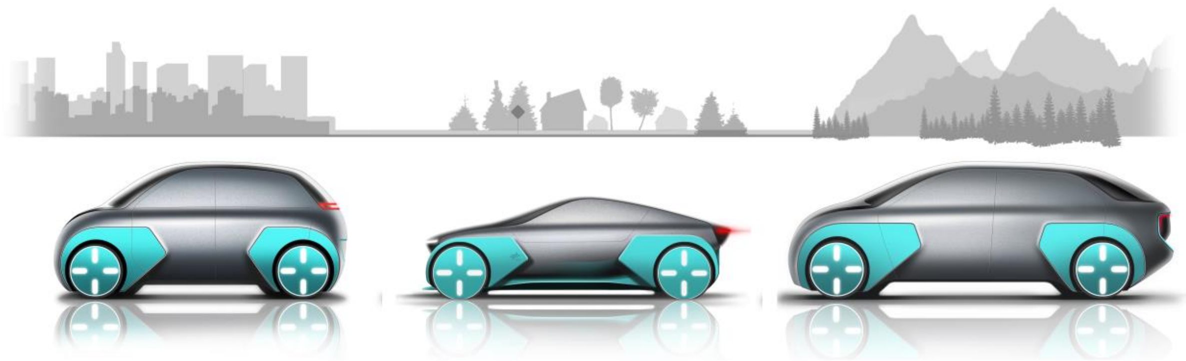


Figure 1 NGC

2 NGC - Vehicle concepts

The pressure on the transport system to change is dramatically increasing. Besides assuring individual and commercial mobility climate change, air quality issues, safety or time losses in transport pose urgent questions to the transport system and its vehicles. On the other hand, rapid development in renewable energy, communication and material technologies offer new opportunities and challenges for solutions.

NGC - Vehicle Concepts develops new ideas for safe, light, connected and automated, zero-emission and renewable-powered efficient and/or electrified mobility on the road. NGC uses three different vehicles for the methodological development of concepts [1], [2], [3], [4], [5], [6]:



a) Urban Mobility Vehicle   b) Save Light Regional Vehicle   c) Inter Urban Vehicle

Figure 2: Next Generation Car - Vehicle Concepts

Integration of DLR Technologies

Within its 33 institutes, DLR has tremendous expertise in transport research and relevant basic technologies in energy storage and conversion, robotics and mechatronics, communication and navigation, lightweight design and structural technologies. A selection of new technologies will be developed for the NGC Vehicle Concepts and will be integrated for test and demonstration.

Transdisciplinary approach

Deeply integrated in engineering research on lightweight structures, energy management, powertrain, chassis and vehicle intelligence, NGC Vehicle Concepts aims for virtual technical vehicles with a dedicated focus on feasibility. Nevertheless NGC Vehicle Concepts has strong links to DLR's transport, mobility and energy systems research, thus aims to follow a transdisciplinary approach in its conceptual work. User needs in a transformed future world, society's trends and expectations are a key starting point for NGC Vehicle Concepts.

The DLR develops vehicle concepts to show trends and technologies for future road vehicles. Based on main goals of NGC,

- improve safety and comfort,
- reduce environmental impact,
- use renewable energy,

each of the three vehicle concepts has a clear application and technology focus as described in the following chapters.

2.1 NGC Safe Light Regional Vehicle – Maximum Safety in the L-category

In the NGC-family of new road vehicle concepts, the SLRV – the "safe light regional vehicle" – is the smallest vehicle of the family addressing the micro electric vehicle segment in the L7e category. Apart from public transport, small electric vehicles could be beneficial compared to conventional internal combustion engine (ICE) driven vehicles in terms of social, economic and environmental benefits [3] [5] [6].

NGC-SLRV addresses the safety concern of typical L7e vehicles. Targeted for type approval in the EU, the curb weight for passenger transport is limited to 450 kg and the maximum continuous power rating is restricted to 15 kW. The reduced size and weight is a well-known potential danger to occupants in case of a collision with larger vehicles.

NGC-SLRV aims to reach highest safety standards common for passenger cars. An innovative metal foam sandwich structure is developed to minimize the weight of the structure and at the same time optimize crash characteristics to protect the occupants. NGC-SLRV is designed for an electric drivetrain powered by a hydrogen fuel cell system. The challenges are to balance good driveability with the overall weight. A low aerodynamic drag is essential to reach ranges of 400 km with one refill of H_2.

NGC SLRV particularly fits commuter's needs for regular point-to-point journeys, as station car at transit stops, or as a car-sharing vehicle in an extra-urban context. It can therefore supplement fixed route public transport in a suburban or rural environment and can be owned as a second car or is well suited for sharing due to the possibility of a fast refill.

Figure 3: SLRV – Front View

2.2 NGC Urban Modular Vehicle

In the NGC-family of new road vehicle concepts, the Urban Modular Vehicle (UMV) is primary designed for a growing urbanization as a modular vehicle concept for different use cases and integration into an intermodal transportation infrastructure [2] [5]. The flexibility of the concept also supports the introduction of autonomous vehicles.

Modularity in concept

NGC-UMV addresses in a unique way the transition period from conventional road vehicles to autonomous vehicles. NGC-UMV tackles this by a modular platform concept in structure, powertrain and levels of automatization. Variants of the concept are 2+2 seater, a shorter compact version, a cargo version for deliveries, a highly automated people mover concept and an autonomous cargo mover concept. All variants are full electric vehicles (FEVs).

Flexibility in production

Flexibility in production at optimized costs is needed because manufacturing of a bigger portfolio of vehicle concepts reduces the production quantity of the single vehicle variants. The modularity in the vehicle concept allows a new way of thinking the established platform strategy for today's carmakers. A wide range of common components from drive, battery, body substructure, electronic and things from interieur and exteriors for all the concept variants support the cost reduction approach.

Automated and autonomous variants

The different levels of automation, from assistance functions like park assistant, over partly autonomous with the driver, up to fully autonomous in the city for the driverless cargo-mover are reflected by the conceptual modularization of the vehicle. This vehicle concept is the new platform for the vehicle intelligence research (Chapter 7) and it will be fully integrated in the C2X infrastructure for new urban mobility solutions.

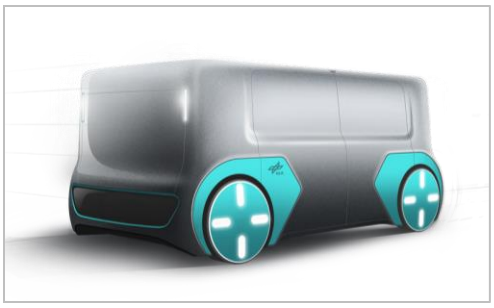


Figure 4 UMV – Autonomous Cargo Variant

Modularity in drives and battery

The powertrain of the UMV is very flexible with a modular design. The driving performance is defined by the selection of 2 x 25 kW drives possible for each axle. The electric motor and the power electronics allow the integration of feature modules like a climate compressor. The drive is combined with the mechatronic chassis with necessary functions for a full automation like drive-by-wire and steer-by-wire. The flexibility in the length of the vehicle in combination with the underfloor design of the battery system enables the necessary flexibility in battery size fitting to the different applications.

2.3 NGC Interurban Vehicle

In the NGC-family, the IUV – the “inter urban vehicle”- is designed for the long range with improved comfort, energy efficiency and safety due to new air flow and energy management concepts, vehicle automatization and a fuel cell powered zero-emission powertrain [4] [5].

A vision for comfort on the long-range

Designed as an upper-class vehicle for 5 persons, the objective is to develop a concept for increased comfort and at the same time reduced energy consumption for maximum range. Optimized combination of automatization, comfort and interior at lightweight and energy conversion is at the core of the concept.

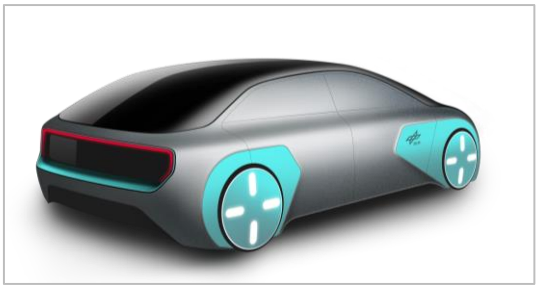


Figure 5 – IUV Rear View

Novel concepts for HVAC

Heating, ventilation and air conditioning are important energy consumers for electric vehicles with significant influence on range and safety. IUV integrates an optimized cabin ventilation and air conditioning concept, validated by numerical simulations and experiment. Cooling and heating is highly integrated with the on-board hydrogen storage system (metal hydrid reactors) to maximize energy efficiency. A dedicated cabin model is developed for the vehicle energy simulation to evaluate and optimize the overall benefit of the system

Interior concepts and automatization

The integration of vehicle automatization with flexible interior design and the structural body to the vehicle is the second pillar in research in IUV for increased comfort. Conceptual designs for the interior are developed and evaluated with regard to functional and technical feasibility. This pillar is tied to basic research in body structures design and research addressing the appropriate design of the human machine interface for different levels of automatization in vehicles.

Lightweight and safe body structures with functional integration

Weight reduction in body concepts is essential to limit energy consumption and therefore enable range in EVs. In IUV a carbon-fibre-reinforce-polymer (CFRP) intensive, multi-material body structure is developed. The objective is to use high performance materials where necessary but to combine metal parts where possible in order to reach increased bending and torsion stiffness goals and limit costs at the same time. One focus is here to exploit additive manufacturing techniques for metallic parts in combination with the multi-material approach. The second objective is to optimize functional integration. One example followed is electric/electronics integration in the body structure; another is the structural integration of other vehicle parts, in order to enable for secondary weight reductions [2] [5].

Zero-emission on the long-range

The fuel cell electric powertrain provides locally emission free driving even on the long distance with a comfortable high range. The objective is to explore the limits and trade-off in packaging taking into account weight and driving dynamics, hydrogen storage with high energy density and range and comfortable, flexible space for the passengers, safety issues, operational strategies and costs.

3 NGC - Body development and technologies

The focus of the working group “vehicle structure” lies on the reduction of the vehicle mass while improving the safety. The application of intelligent requirement, material, concept and manufacturing lightweight design allows prevention and even reversal of continuous weight increase, which has been the case over the past years. Hence, this leads to a reduction in specific energy consumption.

Multi-material structures, adaptable vehicle structure technologies, functional integrated structures (for safety, thermal, comfort, communication (wires and sensors integrated system) and fire protection (battery box)) and the relevant joining technologies play a key role here. However, inherent potentials need to be exploited to an even greater degree. Significant mass reduction is being also achieved through purpose-design in an innovative design. Furthermore, modularization strategies and variable vehicle structures, which can be adapted to different vehicle sizes through scaling, are being used within the NGC. All these aspects are shown in the following figure and will be demonstrated in the car body structures of the three new vehicle concepts.

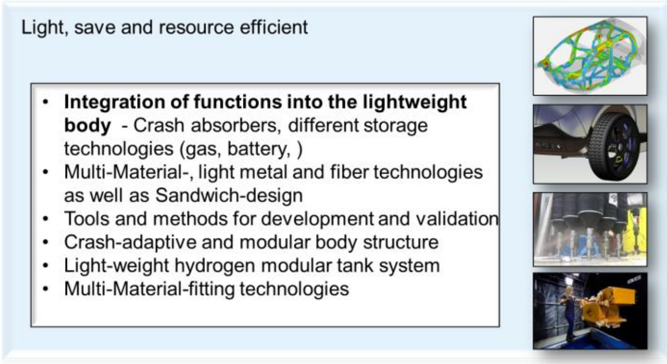


Figure 6 - Objectives of the working group “vehicle structures”

The focus of the NGC Urban Modular body concept lies on a multi-material, function integrated car structure and a modularization strategies for different vehicle variants. The structure is optimized for a battery-electric vehicle in the sense of purpose design and intelligent adaptable security structures. The goal for the car body is a 25% weight reduction compared to current electric vehicles (see also [1], [2]).

For the structure of the NGC Safe Light Regional Vehicle, an innovative metal-foam sandwich structure is used in order to achieve the weight of the body-in-white up to <90 kg while meeting the relevant crash safety state of the art for a passenger cars of the M1 class (see also [1], [3]).

For the NGC Interurban Vehicle a fibre reinforced plastic (FRP) intensively structure is designed, what in particular provide an opportunity to achieve significant weight savings and to integrate different functions (e.g. structural health monitoring systems) [1], [4].

a) NGC Urban Modular Vehicle (UMV) [1], [2]

b) NGC Safe Light Regional Vehicle (SLRV) [1], [3]

c) NGC Interurban Vehicle (IUV) [1], [4]

Figure 7 - Body in white concepts and structures for the three vehicle variants

4 NGC - Energy Management Technologies

As part of the DLR project Next Generation Car new methods and technologies related to the vehicle power architecture are investigated and displayed by the working group of Energy Management:

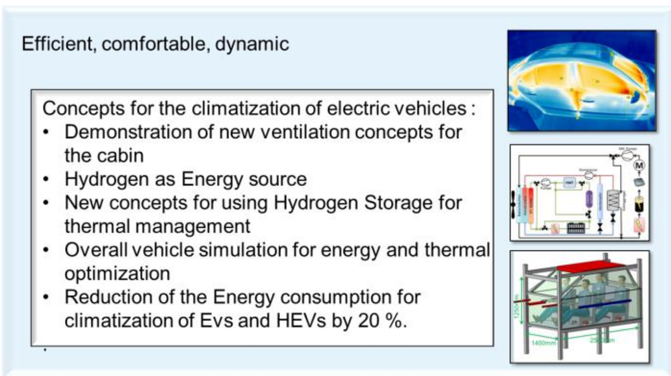


Figure 8 - Objectives of the working group “energy management”

The energy demand for heating and cooling reduce the driving range in electrically driven vehicles dramatically. Real measures for a typical real commuter cycle show an increase by 46% for heating and 27% for cooling [5]. New holistic concepts of energy storage, controlling of the energy flows, air conditioning and temperature control are necessary. A new technical solution for electric and fuel-cell vehicles as NGC-UMV or NGC-IUV is shown in the following figure:

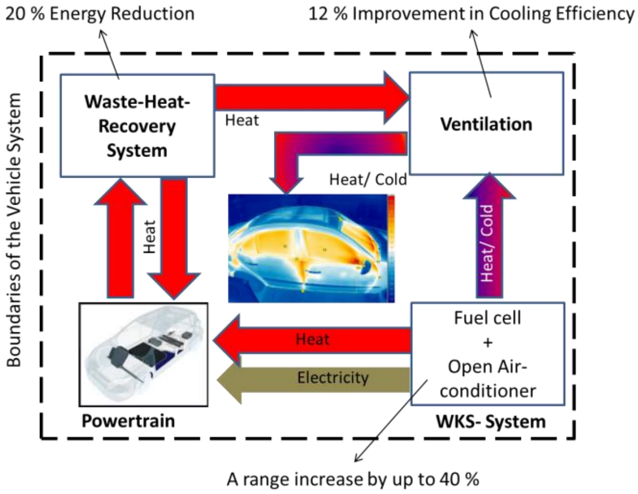


Figure 9 - New leading principle for thermal management

The principle combines different aspects from waste-heat recovery, new climate box principle up to a new ventilation of the cabin:

Waste Heat Recovery: Instead of using a common electrical PTC heater to heat up the cabin the recovery of waste heat has a relevant share for energy efficiency. Reducing the energy consumption of heating and cooling systems of electric and fuel cell vehicles in a middle class vehicle by 20% by using a thermal storage system that stores the waste heat of the drive train components and that is preheating the components to the optimum operating temperatures [6].

New climate box principle: Using a hydrogen-based energy conversion system for cabin air conditioning increases the electric range of electric vehicles by 50% in winter and 20% in summer [7]. The addition of a hydrogen-powered system mainly consists of a fuel cell system and a so called open circuit conditioning using storages based on metal hydrides. By utilizing the heat from the fuel cell system (otherwise emitted to the ambient), the cabin is heated. For the cabin cooling the air conditioner produces coldness by use of the potential energy in the pressure tank. The H_2 system is perfect for fuel cell vehicles but also a zero emission opportunity for pure EVs using this new climate box with a cartridge tank similar to established independent vehicle heaters.

A new flexible vertical ventilation system addressing variable cabin configurations and heat load distribution in electrified vehicles of the future has been developed. Simulation as well as tests with a cabin mock-up show an increase of the heat removal efficiency by 12% by using optimized vertical ventilation instead of mixing ventilation used in common vehicles [8].

Holistic vehicle simulation is needed to estimate the effect of integrating new technologies into the vehicle energy architecture. Furthermore the calculation of all energy fluxes in the vehicle, electrically, mechanically, also of the thermal energy fluxes is essential to pre-calculate the energy demand of the three vehicle concepts. A main simulation tool is Dymola/Modelica where a lot of model libraries for automotive usage were developed in the past. A new method will take the view to the specific application area like drive cycles, climatic environmental conditions, rough and fine calculation and operating strategies into consideration.

5 NGC – Future powertrain technologies

For the different vehicle concepts a set of different powertrain technologies are suitable. Capabilities of very advanced technologies should be discussed. A selection of the energy conversion technologies considered is shown in figure 11.

Electric motors: In the field of electric drive systems this NGC research is focused on systematic concepts, the demonstration of a modularization of motor components and singular novel technologies at assembly level. Electrical and hybrid-excited motor concepts, brushless electronic rotor supplies and wear-free brakes are a selection of the topics. Novel drive designs and modules are developed as part of a modular motor kit. The goal of the development is to generate diverse electric motors that are adapted to the different NGC vehicle concepts. The focus of the work is on the modelling of the electromagnetic components, the control and the integration of additional functions as well as the mechanical integration into the existing installation space for the drive. Furthermore demonstrators will be built as prototypes and examined on test stands.

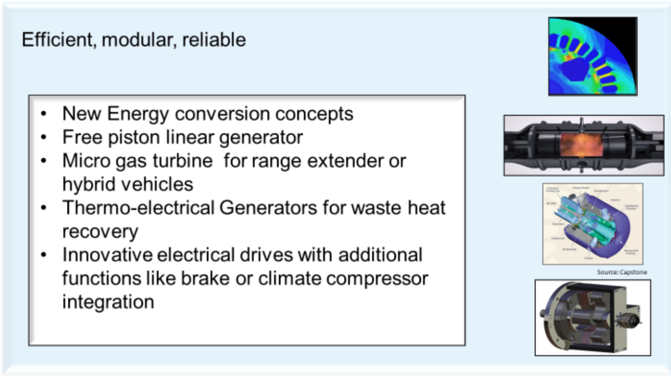


Figure 10 - Energy conversion technologies

Primary energy converter: The micro gas turbine (MGT) is a promising technology for extending the range of the NGC electric vehicles. It can provide electrical energy from liquid fuel. As part of the project a preselected MGT system is adapted to the requirements of the NGC. Thereby developing and optimizing a new recuperator, combustion chamber and air duct to increase the electrical efficiency while optimizing the necessary volume and the possible installation space in the vehicle. The goal is an optimal compromise between efficiency and size and weight regarding the NGC-specific constraints. To demonstrate this primary energy converter, a MGT testbed is built, in which the developed components can be integrated. The innovative FLOX® combustion technology will be pursued, leading to a reduction of emissions in comparison to the available commercial MGT combustion chamber systems.

Waste-heat recovery with thermoelectric generators (TEG): On the path towards electric vehicles, hybrid powertrain with IC engines will be a bridging technology. However the primary energy converters used in the hybrid powertrains rarely achieve an efficiency of over 35%. Thus a large part of the energy stored in the fuel is discharged as waste heat. One solution to convert this thermal energy loss into a gain of electrical energy is the use of thermoelectric generators. Pioneering technologies are used in the manufacture of thermoelectric converter materials, for the construction of the individual components and in planning the operation of the generators. This ensures future TEG is able to present a maximum of economic viability and thus an utmost of efficiency. Through the close cooperation of the Institutes Vehicle Concepts, Materials Research and Engineering Thermodynamics their special skillsets are focused on enabling the vision of a highly efficient thermoelectric generator. Maximum functional integration is the guiding principle from material to system level.

Free piston linear generator: This ‘FPLG’-Technology has been developed for our IUV-Concept. It is an internal combustion engine without a rotating crankshaft. The piston of the combustion chamber, the mover of the linear generator and the piston of the gas spring build one rigid piston unit. In the combustion chamber the energy stored in a fuel is released by a two-stroke internal combustion cycle. The pressure raise due to the heat release moves the piston unit towards the top dead centre of the gas spring, compressing it. The gas spring serves as temporary energy storage and the compressed air reverses the piston movement and accelerates the piston towards its initial position. The linear generator extracts the energy released by the combustion during both the expansion and compression phases and works as actuator for the control.

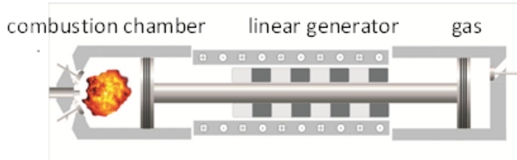


Figure 11 Free Piston Linear Generator

The figure below shows the efficiency map of the measured indicated efficiency of the free piston linear generator system, run at the German Aerospace Center in Stuttgart [9]. Due to the systems inherent freedoms a multitude of variations are tested and the results are scattered. However three areas can be recognized in which experiments took place regarding higher efficiency. Area 1 and 2 represent the result of an optimization for 70 and 80 mm stroke spark ignited operation points. Area 3 is the result of HCCI combustion tests. Keeping in mind that these are measurement results of a system developed for the demonstration of system control the potential of a high efficiency in all load points can be assessed.

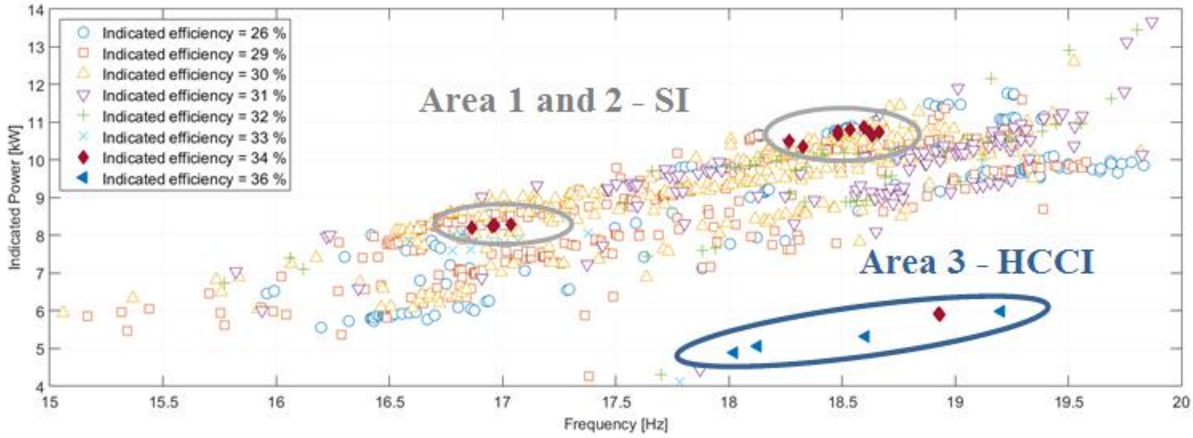


Figure 12 - Efficiency map of the measured indicated efficiency of the free piston linear generator

6 NGC – Mechatronic chassis technologies

For the whole NGC vehicle the chassis plays a key role for its safety, efficiency, and comfort as well as for the realisation of advanced driver assistance systems from active accident prevention to automatic driving.

Our objective is a modular mechatronic highly integrated x-by-wire chassis. Driving motors, brakes, steering, and further actuators which are effective on vehicle dynamics, plus a number of sensors are integrated into the chassis. Advanced control algorithms upgrade it to a flexibly programmable unit. Consequent lightweight design and innovative material systems are employed to counteract the expected increase of unsprung mass and to enhance energy efficiency. The following figure shows a selection of aspects:

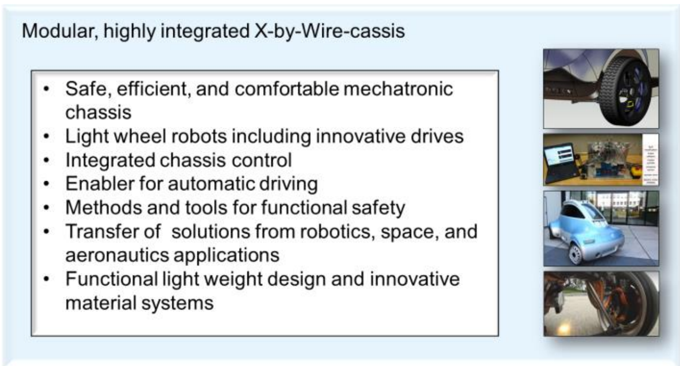


Figure 13: Intelligent Chassis

State-of-the-art rigid links (esp. for steering) are eliminated which arises significance to the development of methods and tools for ensuring functional safety, high availability, and finally homologation. Here, model based development processes and tool chains play an important role. Also for this reason, the technologies for multidisciplinary modelling and simulation are an essential basis to be promoted. They address the complex interactions of the chassis with the road and the total vehicle on the levels of elastic multi-body-dynamics as well as thermal and electric flows.

Moreover, we contribute to improve the exchangeability and mutual usability of models between CAD construction and dynamic simulation. Under the fundamentally changed technical constraints, the realisation of chassis functions like guidance and bearing of wheels, suspension, steering and braking need to be newly designed. Based on our already attained tools for the assessment of vehicle dynamics and comfort we enhance our equipment, in particular for safe testing in terms of real time driving simulation and motion simulation technologies.

One of the highlights of the mechatronic chassis working group is the application of our Robotic Motion Simulator (an industrial robot based motion simulator - left) for interactive driving simulation of the highly manoeuvrable ROboMObil (right) using a three degree-of-freedom stick with force feedback (middle).

Figure 14 - Components for mechatronic chassis development

Closely coordinated with research on vehicle intelligence we develop a central vehicle control for implementation in hierarchic vehicle computer architecture. It will combine the three layers i) human machine interface (freely configurable cockpit), ii) assistance and automation, and iii) stabilisation (integrated chassis control). Contributions in the field of vehicle state estimation are to provide an essential requirement for the feasibility of vehicle stabilisation. Moreover, to exploit the potential for energy resources protection, efficiency optimized operating strategies are developed on the level of the total vehicle system, later also across multiple vehicles. This is performed together with research in the fields of drive train, energy management, and vehicle intelligence.

The concrete elaboration of all topics is mainly concentrated on the Urban Modular Vehicle concept.

7 NGC – Vehicle Intelligence

The working group Vehicle Intelligence of the Next Generation Car (NGC) strives for an improvement of the state-of-the-art in the field of advanced driver assistance systems for road vehicles as well as the field of networked and automated road vehicles – the group addresses the entire spectrum from assisted to fully automated driving. All of the research and development activities with a high relevance for the human/machine interaction are embedded in human-centred design processes and are supported by interdisciplinary teams (e.g. from computer science, different engineering disciplines, and psychology).

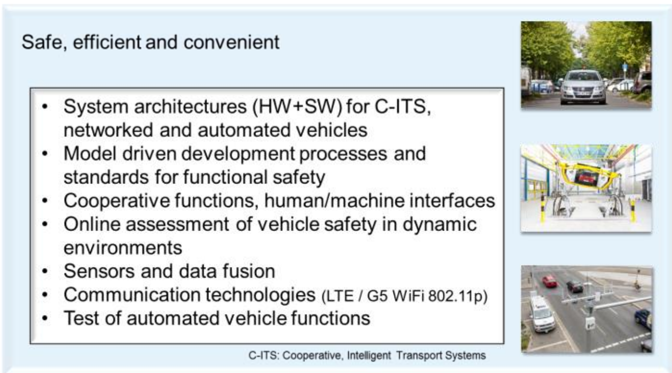


Figure 15: Research aspects for intelligent vehicles

Precisely defined use cases which are relevant for practical applications and very clear research and development roadmaps (e.g. for networked and automated vehicles in urban areas) are formulated and applied to prioritize research activities of the working group. Furthermore, these use cases ad roadmaps are used to select scenarios for the demonstration of concepts and technologies which are also relevant for partners from the industry. The various research and development activities of the group are supported by a wide range of modelling and simulation environments, laboratories, driving simulators, testbeds and a living lab within the city of Braunschweig (Lower Saxonary / Germany) – the Application Platform for Intelligent Mobility (AIM). AIM helps to gain deep scientific results but also provides the infrastructure for a wide range of research activities in the mobility domain [10].

Application Platform for Intelligent Mobility (AIM)

With the Application Platform for Intelligent Mobility (AIM) the DLR-Institute of Transportation Systems operates since 2014 a national as well as international outstanding infrastructure for research, development, practical assessment, demonstration, and testing of intelligent mobility services in urban areas and selected surrounding areas (cf. Köster et al., 2011). Partners involved in AIM are e.g. the Lower Saxony (Germany), the City of Braunschweig, and other stakeholders from science, industry, and the public sector. The operating time is currently planned until 2024 – a continuation is possible.

The following brief description characterizes the large scale research facility AIM: AIM is a large scale research facility for research and development in the field of intelligent mobility services. AIM has significant branches in the public area of the city Braunschweig and selected surrounding regions. The platform provides special test tracks and a powerful tools for simulation and manipulation of large-scale (e.g. traffic flow) and microscopic (e.g. driving or driver behaviour) aspects of transport/mobility.

Figure 16: Infrastructure AIM

The development and improvement of AIM over time as well as the reuse of components of the platform in very different research and development activities are supported by an open and flexible architecture concept. The architecture of AIM is open both in terms of the integration of new technology components and innovative applications in the field of mobility or the mobility-related services. One important building block of the architecture is the information- and communication-infrastructure implemented in AIM.

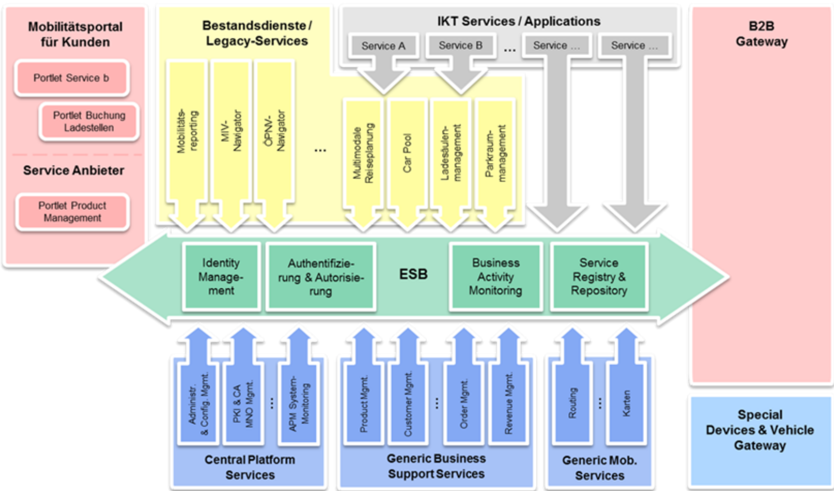


Figure 17: Architecture AIM

Based on AIM the DLR demonstrates continuously results derived from different research and development projects like e.g. UR:BAN (funded by BMWI), InteractiVe (EU), AdaptiVe (EU), D3CoS (EU), HoliDes (EU), ConInCIDE (DFG), and unCoVerCPS (EU). For instance, DLR demonstrates in 2013 the automated valet parking on a public parking lot at the main railway station in Braunschweig. Currently the cooperative function Green Light Optimal Speed Advisory (GLOSA – vehicle and traffic infrastructure are networked and exchange information about the traffic light status and status changes to support a "green wave") is integrated in automated vehicles – a first demonstration is scheduled for the first half of 2016.

8 Conclusion

For the development of the next generation of electrical or hydrogen vehicles many different domains have to be considered. An optimized vehicle is only possible if all the different disciplines contribute with an innovative technology: The vehicle concept strategy deduced on future mobility demand, a lightweight and save body, an efficient and cost effective powertrain, an optimized and comfort spending thermal management as well as mechatronic chassis and vehicle intelligence for different levels of automation are all important factors for a future vehicle design. We presented this unique interdisciplinary research approach with the development of methods, tools and technologies for future cars. The DLR with its 8000 employees is using cross-synergies from aerospace in fields like lightweight design, cabin comfort, control or overall safety. The presented vehicle concepts and technologies will be demonstrated at the next EVS in Stuttgart.

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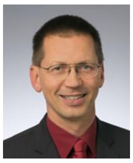	**Tilman Bünte** was born in Heidelberg in 1965. In 1993 he completed his Master (Dipl.-Ing.) in mechanical engineering at RWTH Aachen University. Since 1994 he has been researcher at the German Aerospace Center (DLR) focusing on modeling, simulation, and control of vehicle dynamics. In 1998 he received a PhD from RWTH. He is working with the DLR Institute of System Dynamics and Control and leads the NGC working group „Mechatronic Chassis".