

Re-Defining Driving Experience - Competences & Concepts Behind the Research Vehicle SpeedE

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Summary

The Institute for Automotive Engineering (ika) of RWTH Aachen University is currently developing, constructing and implementing the research vehicle SpeedE as an open innovation platform for research and industry. Today's automotive development process is characterized by many challenges as well as new trends. The most difficult challenge is the conflict between efficiency, safety and driving experience. Major trend is the topic of highly advanced driver assistance systems up to automated driving. This paper will present the research vehicle SpeedE and illustrate the different competences and concepts in order to meet these challenges and further investigate on upcoming trends.

1 Basis for New Systems

Focus of the SpeedE project is to make the extensive innovation potential of electrically powered vehicles tangible by significantly enhancing the driving experience compared to conventional vehicles. The research vehicle, a sporty three-seater with 160 kW power, has been conceptualized in cooperation with the Transportation Design of Pforzheim University and has been built up at ika of RWTH Aachen University together with partners from research institutes and industry. The project is a basis for the development of new components, systems and functions, their integration within a full vehicle and the subjective and objective evaluation in driving tests. The platform shall be used to cover the major challenges and trends regarding future mobility. The project has been funded mainly by Hans Hermann Voss Foundation and fka Forschungsgesellschaft Kraftfahrwesen mbH Aachen.

In Figure 1 the three main challenges of current automotive development – efficiency, safety and driving experience – are complemented by the solution approaches realised in SpeedE. As major challenges increased efficiency, improvements in the field of safety and the definition of electric driving experience are highlighted [1]. Innovations such as the Steer-by-Wire system with wheel steering angles up to 90°, steering using sidesticks and the novel vehicle architecture of SpeedE represent conceptual cornerstones and lead to the transformation of e-mobility into “e-motion”.

Besides the mentioned challenges, new trends in automotive development and customer expectation can also be addressed. The major trends are improved driver

assistance, automated driving, connectivity and purpose build fully electric vehicles. The SpeedE research platform has been conceptualized specifically in order to meet these challenges.

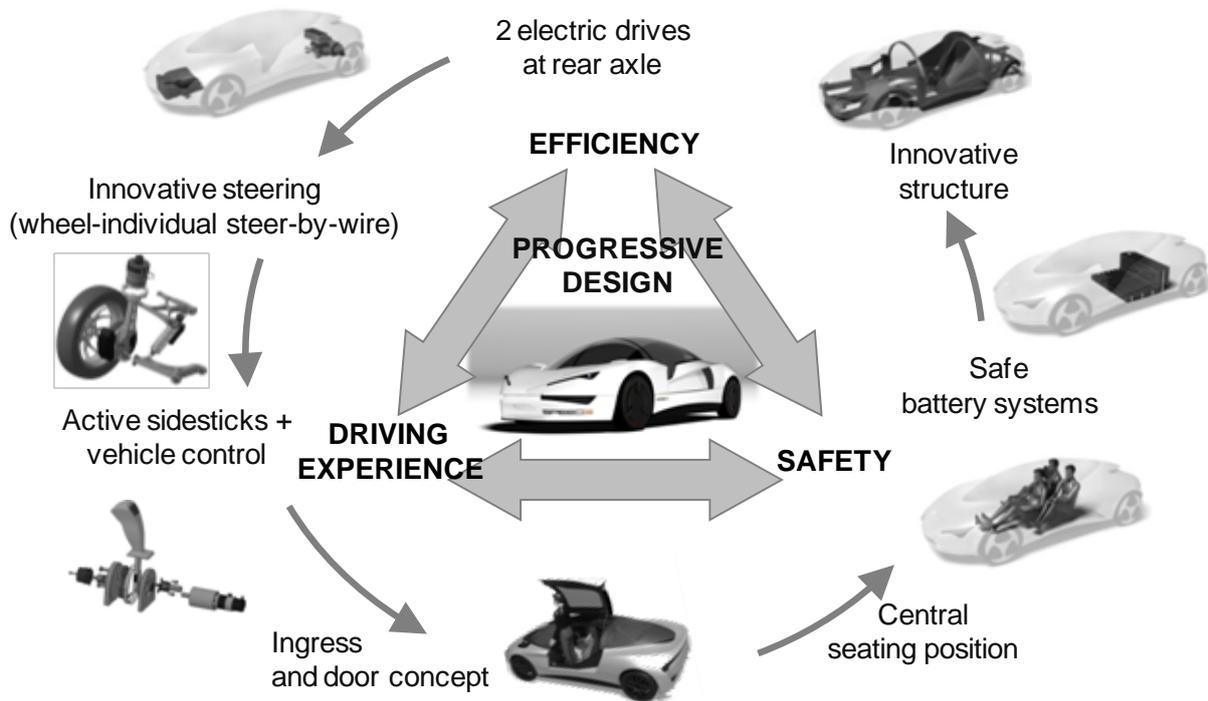


Fig. 1: Challenges in Automotive Development

The solution approach is based on two powerful electric machines mounted on the rear axle that can propel both wheels individually. In case of only one rear wheel being propelled, the vehicle can turn around the other rear wheel using the Steer-by-Wire system with up to 90° wheel steering angle – the vehicle's capability to turn in very small spaces opens a new dimension of driving experience. The steering wheel has been replaced by two active control devices, so-called sidesticks, mounted to either side of the driver. On this basis large steering angles can be commanded with minimum effort while the cockpit can be reorganised in view of increasing automatisisation in driving. Both sidesticks move synchronously, as if they were mechanically coupled, and measure the driver's hand forces in order to calculate the steering angles of the front wheels. The sidesticks allow a good view onto the instruments and lead to a new driving experience and sense of space. This is further supported by the central position of the driver's seat, which is, as are the rear seats, easily accessible due to a new door and ingress concept. Both the motors as well as state variables of the wheel individual braking (Brake-by-Wire) are part of the Drive-by-Wire system. Regenerative braking and steering with minimum slip angle can further increase the vehicle's efficiency.

Regarding safety, a vehicle structure has been designed that incorporates the traction battery in an optimal way and fulfils all demands for a purpose-build electric vehicle. The structure is made up of an extremely stiff aluminium spaceframe and a front structure built up of a steel-CFRP composite with very high energy absorption capability. Also integrated into the front of the vehicle is a crash deformable 48-V

battery developed at ika that delivers energy for all components of the steering system in redundancy with an efficient DC/DC converter based on silicon carbide.

2 Functionally Adapted Physical Vehicle Architecture

In many cases the development of a new vehicle is based on an existing basic concept and the according physical architecture [2]. This is an efficient design approach with low risk regarding investments or feasibility. However, the innovation potential for both technical and creative design is limited and improvements in general are evolutionary. Enhancing competitiveness by filling a niche according to new customer demands or complying with changed legal requirements can result in ambitious or unique targets within a vehicle project. If fulfilling these targets requires new functions and technologies or geometrical boundary conditions that cannot or not efficiently be incorporated into an existing basic vehicle concept a new vehicle architecture has to be developed.

A complete new design of a vehicle is often referred to as purpose design, particularly in the context of electric vehicles [3]. Electrification of the drivetrain results in significant changes of technical and geometrical requirements of many major package components. Hence, this is a good example of a target that can justify purpose design rather than the integration in an existing architecture evolved from decades of optimization dominated by the conventional drivetrain with combustion engine. However, the term purpose design is more general and applies to any changes to a vehicle that cannot be mapped to an existing architecture. Purpose design will play an important role in the future of the automotive industry for example when dealing with the question of individual mobility in megacities [4] or fully exploiting the opportunities of intelligent and autonomous vehicles.

Different reasons or targets may justify purpose design. The bigger the deviation from an existing architecture is the stronger the implications on the design process will be. Existing design standards, templates, best practice experience and functional chains may not apply any longer and even legislative requirements might have to be reconsidered. In return vehicles with unique characteristics can be created tailored to the mobility demand of the future. The implications on the design process as well as the prospects of purpose design are studied, demonstrated and evaluated using the SpeedE vehicle concept as an example. In order to do so the basic concept of SpeedE has been defined in parallel to the development of the F12 electric sports car concept in the research project e performance funded by BMBF [5]. Since F12 has been developed based on an Audi R8 platform in a conversion design approach the different design strategies can be compared. Consequently, the main vehicle properties like vehicle category, outer dimensions etc. of F12 have to be adopted for SpeedE (see Figure 2). However, while the project e performance focused on the development of new components and technologies for electric vehicles the project SpeedE addresses amongst others the development of a new vehicle architecture enabling unique functions of electric vehicles.

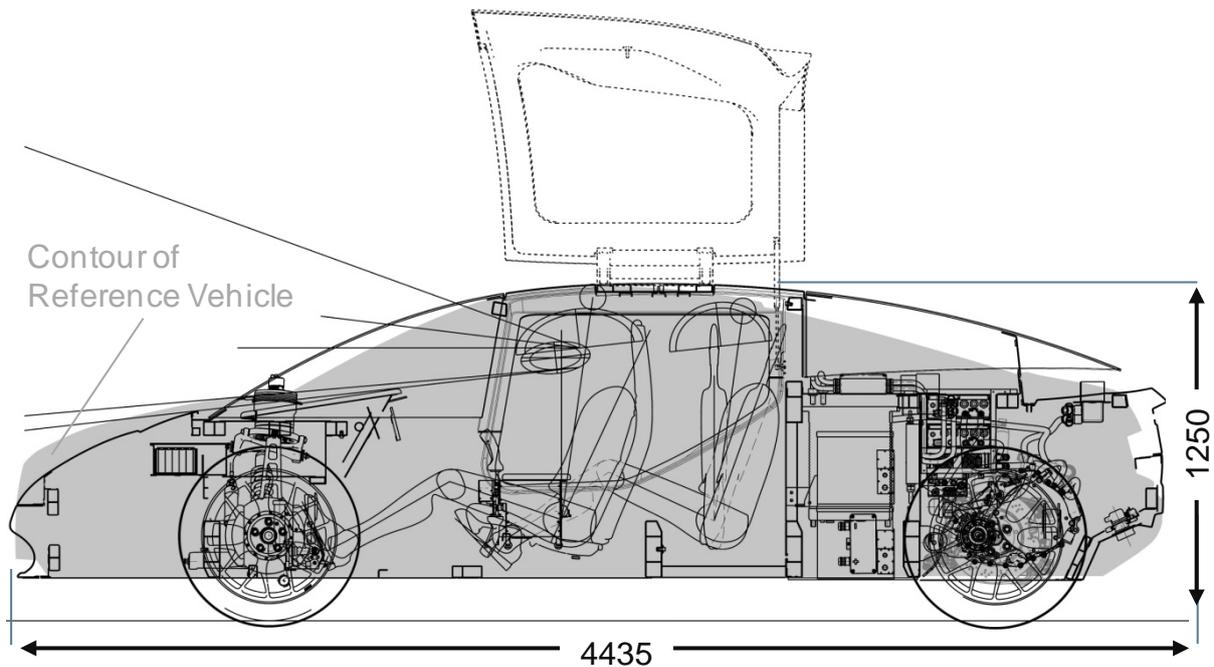


Fig. 2: Package section of SpeedE with silhouette of F12 electric vehicle

The physical architecture layout of SpeedE is functionally driven meaning that the functions to be achieved along with their design space requirement define the topology rather than integrating functions and according components in a best way in an existing arrangement. The most important functional objectives influencing the layout of SpeedE are:

1. Maximization of interior space without a tunnel for roominess feeling and different interior design options
2. Increase of number of passengers from 2 to 3 with central driver position (cockpit feeling)
3. Innovative and comfortable ingress strategy for central driver seat
4. Steer-by-Wire system with wheel steering angles up to 90°
5. Replacement of steering wheel by sidesticks
6. Unconventional exterior design with elliptical greenhouse

The basic idea behind the architecture development for SpeedE is to reduce the problem to a design space optimization in an initial step. The space demands of the major components or geometrical boundary conditions are modeled in a parametric-associative CAD system. This enables efficient plausibility checks, detection of geometrical conflicts, studies of packaging alternatives and provides indication on the weight distribution and inertia. This approach offers a quantitative basis for layout decisions.

An illustrative example of a functional requirement having strong influence on the physical vehicle architecture is the ingress strategy. A challenge when entering wide vehicles with central driver position, e.g. the McLaren F1, is to overcome the lateral distance to the seat. As presented in [6] the fundamental principle of the unique ingress strategy is to first step over the sill in an upright posture. This reduces the

lateral distance to the seat. After that, the occupant is standing on the floor panel next to the driver seat (see Figure 3). The occupant then can either comfortably take place in the driver seat or directly sit down on the rear seat bench in the back. A design space envelope has been derived from human models following the trajectory of the movements described above. This geometry has been considered in the early phase of the physical vehicle architecture development and strongly influences structural body layout. As a result the innovative ingress strategy has successfully been transferred from the seating buck study to the driving prototype (see Figure 3). It shall be mentioned that for this ingress strategy a door concept has to be chosen that clears the design space envelope of the ingress trajectory in particular head- and shoulder room in the open position. A slightly curved wing door, as implemented in the prototype, or a rotatory sliding door, as presented in [6] are options for that.

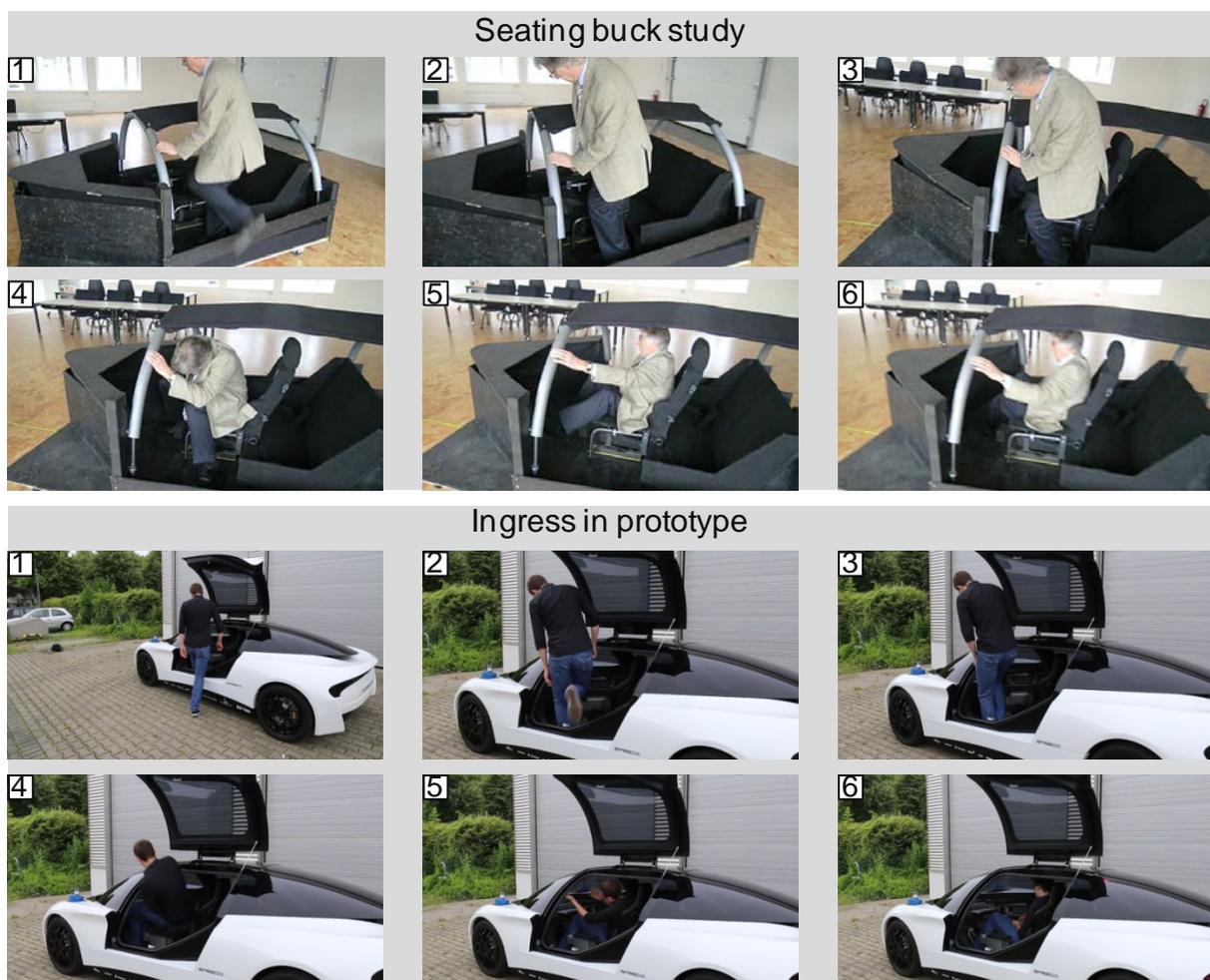


Fig. 3: Transfer of ingress strategy from seating buck study (top half) and prototype (bottom half)

3 Body Structure

The unique features and functions of the SpeedE vehicle concept as well as its exterior design with the ellipsoid greenhouse strongly influence the body layout and topology. Therefore, the body structure is designed from scratch in parallel to the

exterior design. The multi-material body is composed of an aluminium spaceframe with GFRP body panels and a front section made of steel-CFRP composite (sandwich St-CFRP-St). Along with the predominant use of straight profiles this approach enables a realistic yet cost-effective prototypical implementation of a body with structural performance on sports car level.

In body engineering typical body structure topologies have evolved tailored to conventional vehicle architectures and components. A car body can be composed of different of those well proven quasi-standard components that have to be dimensioned and optimized according to the specific vehicle properties and requirements. The challenge of designing a car body for a new physical vehicle architecture is that these quasi-standard components do not necessarily fit and load paths may change due to unconventional design space distributions. This challenge is even enhanced if time is critical and decisions have to be made fast without being able to analyze many different design options. Topology optimization is a mathematical approach to support the designer in identifying an optimized geometrical layout of a mechanical structure within any kind of given design space with respect to prescribed performance targets, loads and boundary conditions. Originally mainly used for the design of components, this tool has been qualified for the concept development of entire car bodies with some restrictions regarding deformation zones. However, the optimization results are sensitive to various optimization preferences, in particular the definition of quasi static pseudo load cases. Even more important interpretation and abstraction are essential to transfer the optimization results to a feasible, fully functional body structure. Consequently, direct deduction of body structures from topology optimization results requires experience mainly available for conventional vehicle architectures.

For this reason topology optimization serves an unconventional purpose in the development of the body structure of SpeedE. Rather than deriving load paths from the optimization results the results are used for systematic reduction of the design space allocated for the body structure. This is done by identifying areas of low structural mechanical relevance and removing those from the permitted design space. These areas represented by low dense elements in a density approach finite element topology optimization are usually less sensitive to optimization preferences and converge faster than dense elements representing potential load paths.

Following this approach the extensive design space resulting from subtracting only major package components and geometrical boundary conditions from rough exterior limits can be reduced efficiently (see Figure 4). The result is a design space with complexity comparable to the typical body design space of conventional physical vehicle architecture. This enhances the design and decision making process by reducing the solution space for potential body structures and at the same time releases design space for the detailed packaging and exterior/interior design. The procedure for applying topology optimization in the proposed way is similar to a conventional topology optimization of body structures. The main difference is that the initial design space is more extensive and rough and the result will be interpreted as a new design space rather than a structural proposal. Based on the reduced design

space and the selected construction and manufacturing method the actual body structure can be developed and dimensioned using traditional structural design guidelines and tools. For inspiration or plausibility checks a subsequent topology optimization can be carried out based on the reduced design space or parts of it.

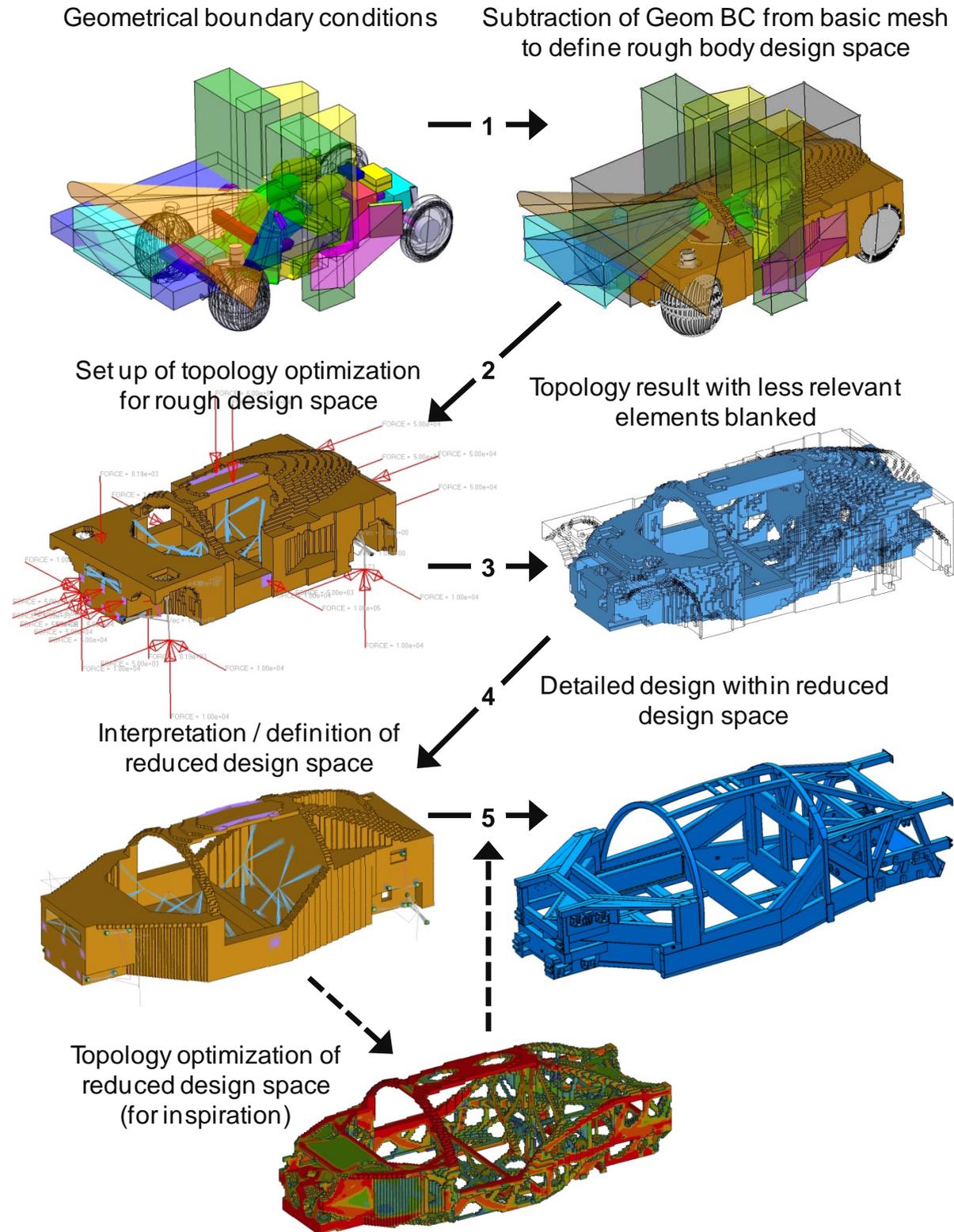


Fig. 4: Reduction of design space using topology optimization

The front and rear crash elements are pre-dimensioned using sub-system crash models and optimized in the detailed design and dimensioning phase of the main body structure. The final total body structure is shown in Figure 5. The front section has to be narrow in order to provide sufficient clearance for the wheels at 90° steering angle. However, it still has to offer crash compatibility in overlap configurations. In order to solve this conflict, the front of the passenger cell is designed in a V-shape following the design principle of a dome. Due to the V-shaped front, the vehicle can slide off sideways in accidents with small overlap (cf. IIHS small overlap crash test). This reduces intrusions as well as accelerations. In front accidents with larger overlap (cf. Euro NCAP front crash test / offset deformable barrier ODB) the impact energy is dissipated in a conventional way by deformation of the front structure (see Figure 6). The front structure is made of steel-CFRP sandwich material composed of a CFRP core and two high-strength steel outer layers. In this way the sandwich material combines the high specific energy absorption capability of CFRP with the ductile failure behavior of steel [7].

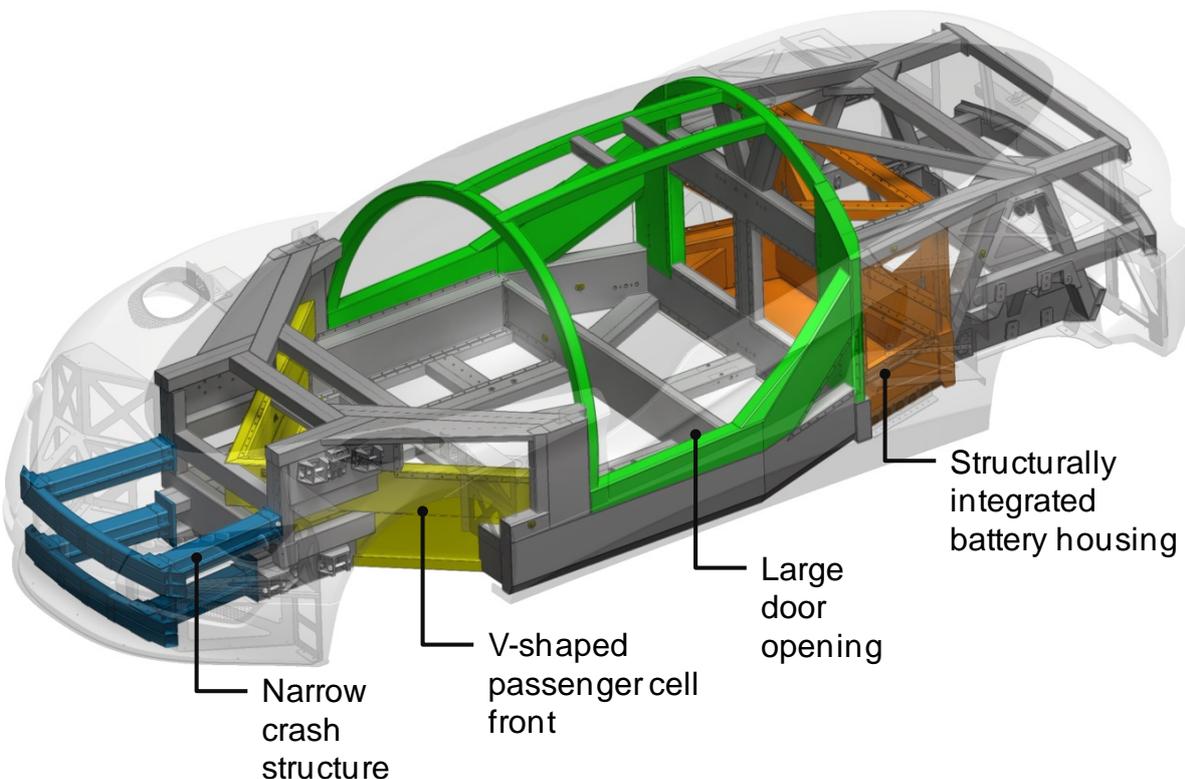


Fig. 5: Special features of the body structure

The high sills rising to the rear provide side impact protection for the passengers but would strongly reduce ingress comfort in a conventional body layout. Accordingly, the body structure of the SpeedE vehicle concept offers a large door opening, which enables the alternative ingress strategy described above, making both overcoming the sill as well as reaching the seat in the centre more comfortable.

The traction battery is located behind the passenger cell. The battery housing can be fully integrated into the body structure thanks to the purpose-design approach. In this way, the high-voltage traction battery, which is in contrast to the 48-V lithium-ion

battery not deformable, is protected by the body structure in the event of a crash. The final body structure is analyzed by means of numerical simulation regarding crash (see Figure 6), strength and stiffness.

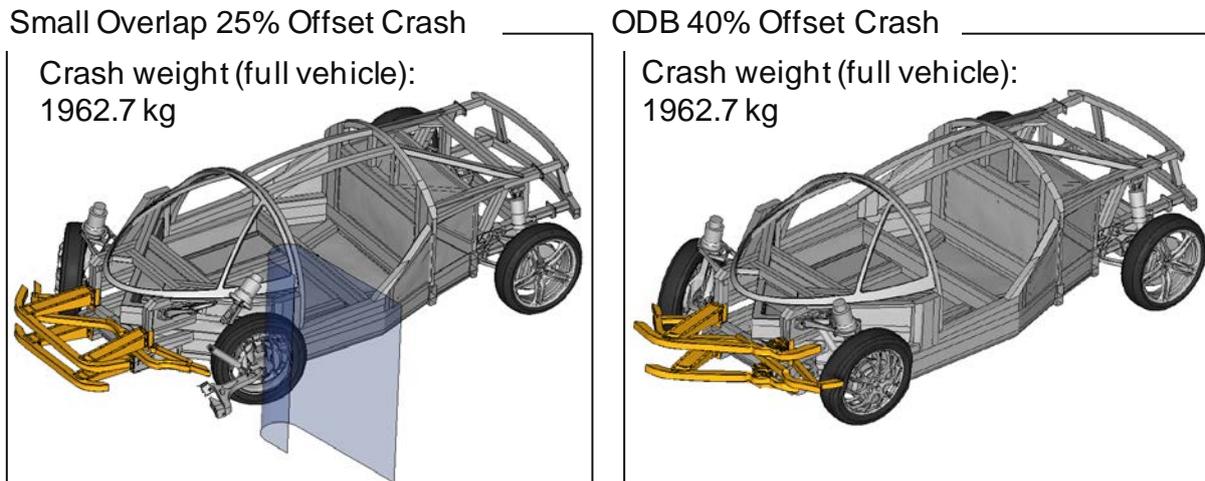


Fig. 6: Numerical crash analyses for frontal crash with different offset [7]

The exterior body panels are the result of cooperation between ika and Transportation Design of Pforzheim University. In a design and technology convergence process, the creative aesthetical ideas of the designers led by Prof. James Kelly and Prof. Lutz Fügner have been harmonized with the space demands of the occupants and the technical components as well as the major legal requirements. In the course of the process, the permitted design space for body structure and body panels is reduced successively from inside and outside. This is supported by a parametric-associative CAD-model of the package and the primary design surfaces as well as auxiliary geometry for representation of legal requirements. The detailed shaping and design is done after the design space has been reduced and adjusted several times. In this phase, the design space limits must be observed. Conflicts, clashes and violation of requirements can be prevented a priori by this approach. However, since exterior panels and body structure are modeled in the same parametric-associative CAD-system A-surfaces can, if necessary, still be modified efficiently in the late design phase (see Figure 7).

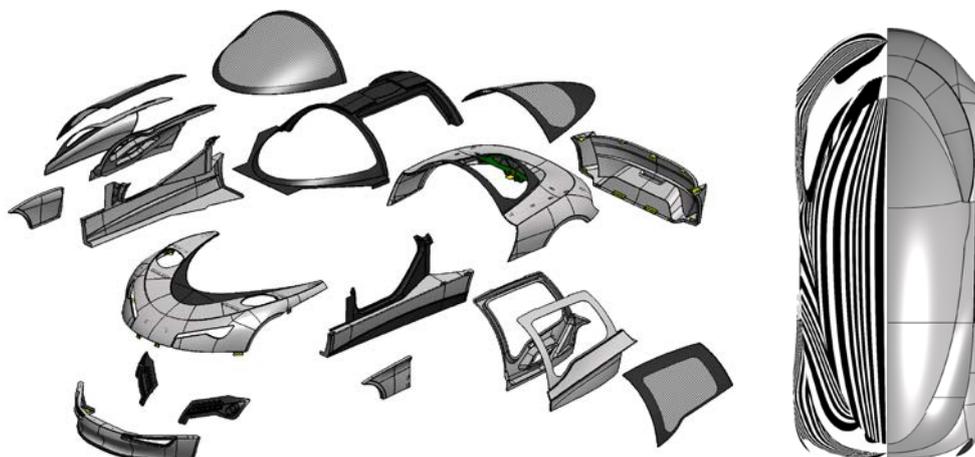


Fig. 7: Parametric-associative A-surface design

4 Electric Powertrain and Vehicle Electrical System

In Figure 8, the powertrain topology as well as the different voltage levels of the vehicle electrical system are depicted. The vehicle has two wheel-individual electric machines installed on the rear axle, each having a peak power of 100 kW and a constant power of 80 kW. Each electric machine is connected to the wheels via a single speed transmission. There is no mechanical coupling between the two machines and they can be controlled independently.

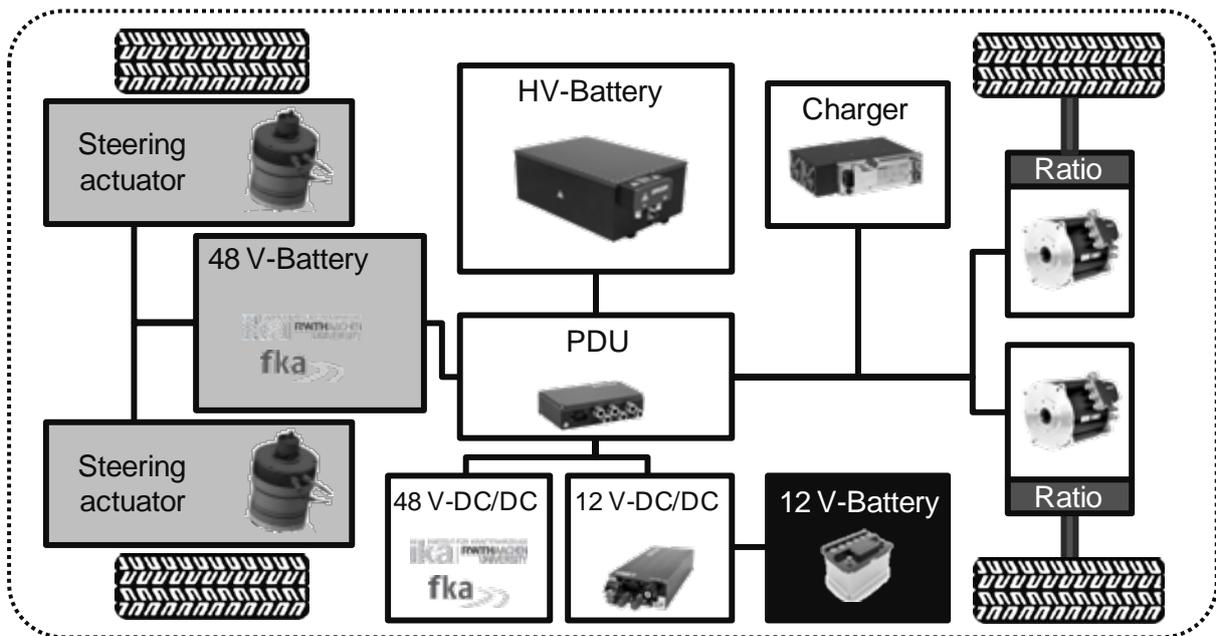


Fig. 8: Powertrain topology and voltage levels of the vehicle electrical system

The nominal voltage of the corresponding traction battery, is 400 Volts, the energy content is 16 kWh. Besides the 400-V high voltage vehicle electrical system, the SpeedE offers two additional voltage levels: firstly, a 12-V vehicle electrical system to supply different auxiliary users as well as the Brake-by-Wire system, which has been realised using wheel-individual electro hydraulic actuators, and secondly, a 48-V vehicle electrical system. Both low voltage vehicle electrical systems are supplied via the high voltage vehicle electrical system using a DC/DC converter and have an individual battery to compensate peak voltages. The extra battery is especially important for the 48-V vehicle electrical system to guarantee a steady energy supply for the Steer-by-Wire system and for the 12-V vehicle electrical system to supply the Brake-by-Wire system with energy. Table 1 shows the technical data of both electric machines and the high-voltage traction battery.

Feature	Value
Two Electric Machines (rear axle)	
max. Power	100 kW
max. Torque	220 Nm
max. Speed	12 000 rpm
Transmission Ratio	5.5
Traction Battery	
Energy Capacity	16 kWh
Nominal Voltage	400 V
max. Discharge Power	160 kW (400 A)

Tab. 1: Technical data of both electric machines and high-voltage traction battery

One major advantage of having two wheel individual electric machines is the resulting torque vectoring capability. On the one hand the torque vectoring functions are used to realise a dynamic driving behaviour and therefore lead to a sporty driving experience. While driving in a straight line the demand torque is split equally to both wheels. When cornering, the lateral dynamics manager calculates a torque split depending mainly on the actual velocity and the curve radius. On the other hand torque vectoring is an essential part of the functional safety concept for the Steer-by-Wire system.

The electric machines are also part of the Brake-by-Wire system. Besides the two machines on the rear axle, the Brake-by-Wire system is made up of four electro-hydraulic brake actuators that can be controlled wheel-individually and realise a fully-variable brake torque distribution. Low decelerations under straight ahead driving are covered fully recuperative by the rear axle's machines. For higher decelerations or under lateral dynamics the front axle is also braked using the electro-hydraulic actuators. As soon as the electric machines have reached their recuperation limit, the system distributes the remaining brake force demand such that an ideal brake force distribution is achieved. To achieve high recuperation efficiency also under lateral acceleration, the rear axle is able to realise asymmetric brake torques (brake torque vectoring). Therefore, driving stability can be guaranteed while maximising efficiency [8].

5 Wheel-Individual Steer-by-Wire

A wheel-individual Steer-by-Wire system decouples the mechanical link between the steerable wheels and the driver input control unit. Therefore, the haptic feedback to the driver can be individually adjusted via the active controls. In case of a wheel-individual Steer-by-Wire system not only the control unit is decoupled from the steerable wheels, but also the steerable wheels do not have a mechanical link

among each other. By using two individual electrical actuators it is possible to adjust each wheel steering angle independently. The Steer-by-Wire system of SpeedE focuses on the fields of research in wheel guidance, vehicle dynamics functionality, driver interface and functional safety.

The mechanical implementation of the front axle's Steer-by-Wire system, which is based on a modified double wishbone suspension, is shown in Figure 9.

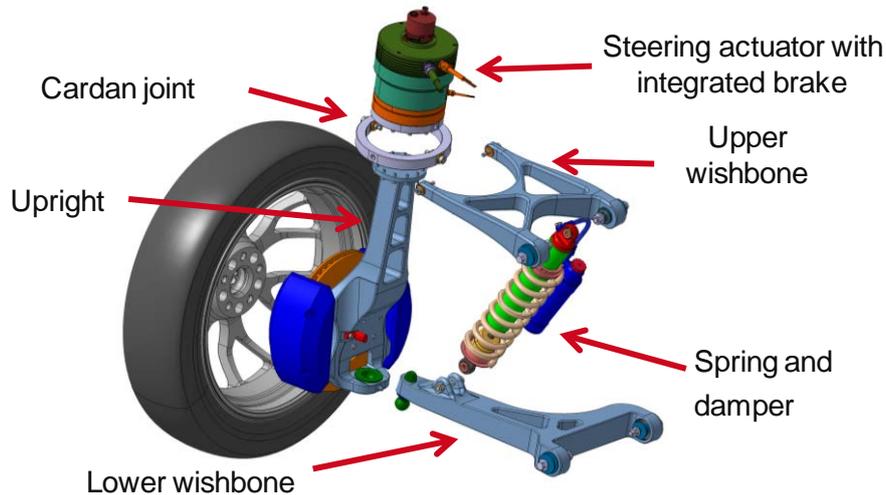


Fig. 9: Exploded view of the suspension of the left front wheel

The electrical actuator is the central core of the suspension, which is integrated in the upper wishbone. The tie rod and the upper ball joint are substituted by a cardan joint. The cardan joint links the housing of the steering actuator with the upper wishbone. The rotor of the actuator is linked to the upright so that an individual steering is possible. Due to the required steering torque that has to be provided by the actuator the electric machine is combined with a strain wave gear. The reduction gear's high transmission ratio of 100:1 allows a torque about the steering axis of up to 450 Nm. The strain wave gear is characterized by high torsional stiffness and free of play within a small installation space. In addition, the actuator is able to measure the torque about the steering axle while driving by means of an additional high precision sensor [9].

Due to the orientation of the electrical steering actuator and the design of the front axle, steering angles up to 90° at the inner wheel and up to 60° at the outer wheel are realized. The large steering angles improve the maneuverability of the vehicle at lower speeds. A parking maneuver using the wheel-individual Steer-by-Wire system at the front axle is depicted in Figure 10. Given the vehicle's geometry, the instantaneous centre of rotation of the vehicle movement is located at the rear inside wheel. For this situation, a variable distribution of drive torque is necessary, such that only the outside rear wheel is driven. In this case the parked vehicle is able to turn around and drive directly in the opposite direction even in narrow streets.

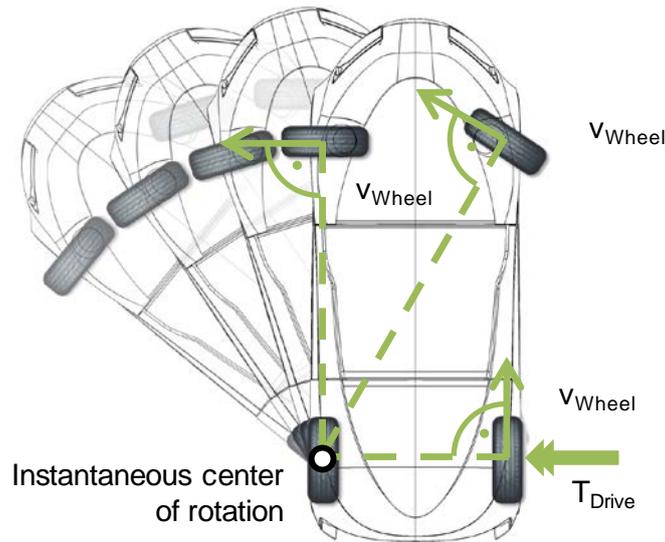


Fig. 10: Schematic representation of a parking maneuver of the SpeedE

In addition to the innovative features of the front axle, the suspension of the SpeedE front axle fulfils all the ambitious requirements concerning kinematics and elasto-kinematics. For example, due to the wheel steering angle being measured between the attachment of the actuator to the upper wishbone and the attachment to the upright, any change of toe angle due to kinematic effects needs to be avoided. Consequently, a low toe angle change during wheel travel is achieved [10].

Compared to conventional suspension concepts, the design of the front axle's Steer-by-Wire System allows a wide range of innovative functionalities. Besides the realization of the mentioned parking maneuver, the steering system facilitates a situational adjustment of the individual wheel steering angles. Therefore the conflict between distortion-free and slip angle free wheel rolling motion at lower speeds and an optimized utilization of the tire friction coefficient at higher lateral acceleration can be solved. The wheel steering angle varies between the Ackermann geometric design for driving speeds up to 15 km/h and the force potential optimized design for speeds above 40 km/h. Therefore the steering system helps to improve the energy efficiency of the vehicle at lower speeds and the driving safety at higher speeds. Furthermore, the measurement of the torque about the steering axis allows detecting an understeering situation. This constitutes an additional significant improvement of the vehicle's driving safety. In general, the lateral force of a tire decreases after exceeding the slip angle of the maximum lateral force due to the non linear tire behavior. The torque about the steering axis due to the lateral force in the tire contact patch and the caster trail decreases before the lateral force reaches the maximum slip angle. This circumstance is depicted in Figure 11 for a constant cornering maneuver. The steering system is able to detect this situation and stay at the maximum obtainable lateral force. In this way the lateral acceleration does not drop off in an understeering situation.

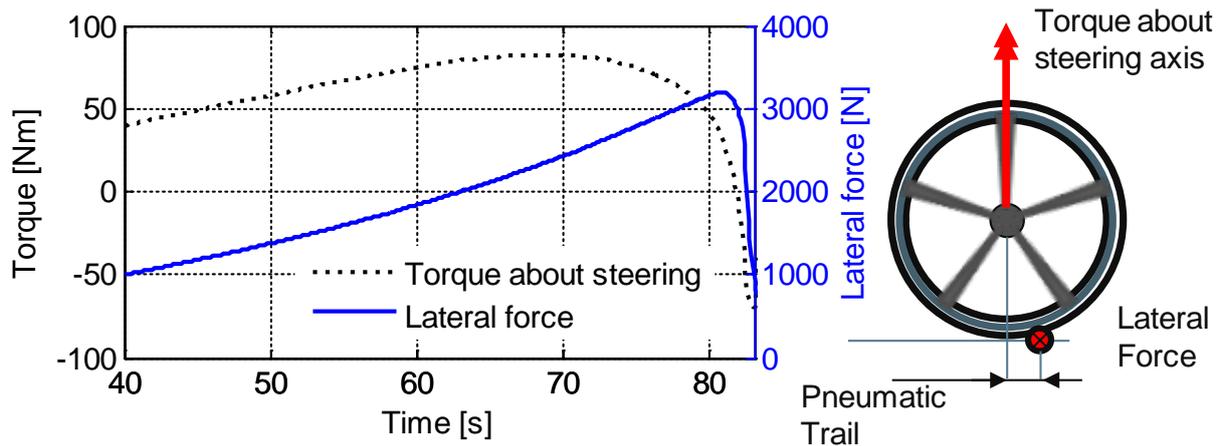


Fig. 11: Lateral force and the corresponding torque about steering axis for an understeering driving situation

Also the mechanical decoupling of the front wheels offers the opportunity to realize a park brake functionality. The front wheels are steered in an opposite way to generate a hold functionality of the vehicle. Consequently the conventional parking brake may be substituted resulting in package and cost savings. Furthermore, the mechanical decoupling of the front wheel improves safety for a braking situation on different friction coefficients (μ -split braking) by an intelligent system reaction. In this situation, the unequal braking forces on both vehicle sides result in a yaw moment that needs to be compensated by the driver by commanding a steering angle in order to drive straight ahead. Returning to a homogenous μ -high surface will consequently lead to another yaw impulse, which is even harder to control by the driver. To prevent this yaw impulse, the wheel on the low coefficient side is steered in the direction of the high coefficient side leading to a large tow-in value. If the car is leaving the μ -split situation in this configuration, the lateral forces on the front axle is balanced and the yaw rate response due to the yaw impulse is almost completely avoided [11] [12].

Besides the opportunities of new functionalities with the wheel individual Steer-by-Wire system, the energy consumption of the steering system compared to a conventional electrical power steering system may be increased. Particular for Battery Electric Vehicles (BEV) the area of conflict between innovative functionalities and energy consumption is an important issue. Because of the omission of the mechanical link between the two front wheels the two steering actuators integrated in the upper wishbone have to permanently apply a torque about the steering axis. Particularly for driving maneuvers where no change at the wheel steering angle is desired, the electric machines have to provide a torque about the steering axis in contrast to a conventional mechanical linked steering system. To reduce the energy consumption of the wheel individual steering system an innovative design and layout of the front axle is achieved. Through this, the torque about the steering axis is significantly reduced. A further reduction of the energy consumption of the Steer-by-Wire system is achieved by using the integrated friction brake of the steering actuator, so that the degree of freedom of the wheel about the steering axis is locked. In this case the torque about the steering axis is not supported by the electric steering actuators. For a situation in which a small correction of the vehicle yaw

moment is necessary to reach the target path, the torque vectoring at the rear axle is used. If the yaw moment generated by the torque vectoring is not sufficient to achieve the target path, one steering actuator can be unlocked and set a wheel steering angle [13].

Besides the system construction and the implementation of innovative functionalities one of the main challenges is to ensure safe operation and high availability of the wheel-individual Steer-by-Wire system. In order to reduce cost, both steering actuators are designed fail-silent. In case of a steering actuator malfunction the actuator is locked by the integrated brake and the yaw moment error is compensated by functional redundancy. This means that the vehicle systems such as torque vectoring on the rear axle, individual steering on the front axle as well as brake application to individual wheels are combined in a useful way [14, 15]. Figure 12 demonstrates the resultant trajectory with and without applied counteractions.

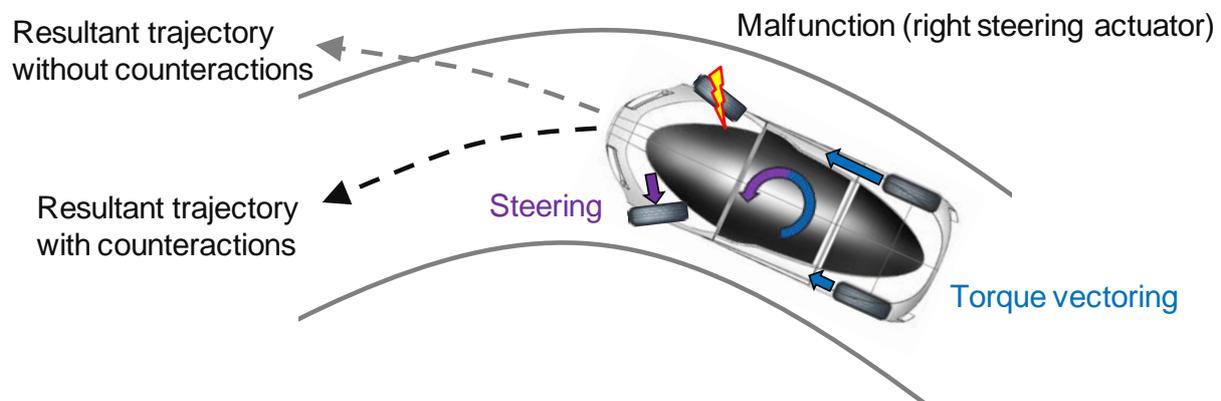


Fig. 12: Resultant trajectory due to applied counteractions

6 Sidesticks for Lateral Vehicle Guidance

In contrast to a conventional car with steering wheel, the vehicle guidance of SpeedE in lateral direction is realized by two active sidesticks. The vehicle guidance in longitudinal direction is realized in a conventional way by an accelerator and brake pedal. The sidesticks are positioned on the left and right side of the driver seat to provide the opportunity for guiding the vehicle with one or with both sidesticks. Due to the mechanical decoupling between the control element and the wheels, the haptic feedback for the driver can be programmed and designed based on the particular situation. Therefore, each sidestick unit contains one actuator with a strain wave gear that provides a rotation angle of $\pm 30^\circ$ under normal driving conditions. For controllability, two electronic control units are integrated which communicate via FlexRay with the remaining vehicle systems. Strain gauges, which are installed below the sidestick handle bar, realize the applied driver force measurement on the sidestick. Figure 13 demonstrates the mechanical assembly of one sidestick unit.

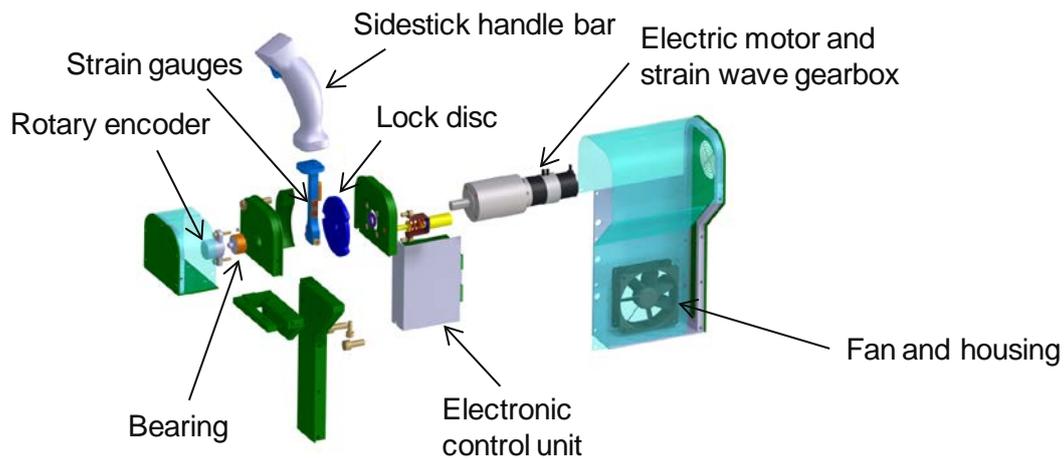


Fig. 13: Mechanical assembly and components of one Sidestick-Unit

Based on the total hand force of the left and right sidestick and selected driving condition parameters, the individual wheel steering angles are calculated. At low speed, the Ackermann condition is complied in order to ensure a slip angle free rolling state. With higher speed, a dynamic part is added or subtracted to the wheel steering angles. To provide a precise feedback of the actual driving state for the driver, an angle-based control concept is used. Therefore, the actual wheel steering angles and the actual driving condition are used to calculate the desired angle of the sidesticks. To suggest a mechanical coupling between the left and right sidestick, the calculated angle is adjusted at both sidestick units [16].

7 Synopsis and Outlook

One major trend in current automotive development is driver assistance up to automated driving. While not being able to move without a driver yet, SpeedE resembles a platform that is ready to drive automatically. One very important feature for automated driving is the absence of mechanical connected control devices in order to navigate the vehicle. Due to the Drive-by-Wire, Steer-by-Wire and Brake-by-Wire systems installed in SpeedE, every function of the vehicle can be controlled by software and with the absence of driver forces.

Due to the seating concept with the driver taking place in the middle of the vehicle, and the absence of a steering wheel the sense of space is significantly better compared to a conventional vehicle. When switching to automated driving, for example on a highway, the driver has now a sufficient amount of space to lean back comfortably, read, work or spent his time in another way.

The next steps regarding SpeedE and automated driving will be the development of a sensor concept for the vehicle. Based on this the first functions are supposed to be automated parking functions before starting with fully automated driving.

The SpeedE project represents an open research and technology platform that combines the advantages of electric mobility with the complex requirements

regarding efficiency and safety, and defines a new driving experience. To reach this goal, the competences of numerous scientific disciplines have been joined. The interdisciplinary network links expertise from design, automotive engineering, electrical engineering and information technology, material sciences as well as economics, ergonomics and psychology. Thanks to this conception, SpeedE resembles an OEM brand-neutral research platform to investigate all aspects regarding future mobility. Possible topics range from innovative HMI and vehicle guidance to new driver assistance and chassis control concepts as well as to functional safety concepts for Drive-by-Wire, Brake-by-Wire and Steer-by-Wire.

Looking at hardware, new components can be easily integrated into the vehicle, for example environmental sensors for research in automated driving. Every possible question cannot only be analysed from a technical point of view but also from the user acceptance when looking at different driver groups. Besides the presented vehicle, a SpeedE mock-up has been built up and is to be used inside ika's new high fidelity driving simulator. New functionalities can be tested reproducibly in a safe environment first, before the findings are transferred to the research platform for validation in real testing on test tracks afterwards.

8 References

- [1] ECKSTEIN, L.
Das Automobil der Zukunft - Forschungsfelder und Innovationen
VDI-Jahrbuch 2012/2013, ATZ Sonderheft für VDI-FVT
- [2] BRAESS, H.; SEIFFERT, U.
Vieweg Handbuch Kraftfahrzeugtechnik
Springer Vieweg
Wiesbaden, 2013
- [3] WALLENTOWITZ, H.; FREIALDENHOVEN, A.
Strategien zur Elektrifizierung des Antriebsstranges
Vieweg+Teubner Verlag
Wiesbaden, 2011
- [4] BURKERT, A.
Smart Mobility und die Frage, wie wir morgen fahren
ATZ Automobiltechnische Zeitschrift 1/2016
Springer Vieweg
Wiesbaden, 2016
- [5] ALLMANN, C.; SCHÜSSLER, M.; LANDGRAF, J.
Forschungsprojekt e performance
Cuvillier Verlag
Göttingen, 2014

- [6] FAßBENDER, S.; ECKSTEIN, L.; HÖREN, B.; STEIN, J.; HESSE, L.; URBAN, P.
Prospects of Holistic Purpose Design by the Example of the Electric Vehicle Concept "SpeedE"
21st Aachen Colloquium Automobile and Engine Technology
Aachen, 2012
- [7] FAßBENDER, S.; HAGEBEUKER, L.; GÖBBELS, R.; ECKSTEIN, L.
Development of a vehicle front structure made of innovatvie steel/CFRP sandwich material
FutureCarBody 2014
Vincentz Network
Hannover, 2014
- [8] STRUTH, M.; ECKSTEIN, L.; SCHULZE-FORSTHÖVEL, G.
Functional Potential by Crosslinking Domains - Optimized Recuperation for the SpeedE Research Vehicle
24th Aachen Colloquium Automobile and Engine Technology
Aachen, 2015
- [9] HESSE, L.; SCHWARZ, B.; KLEIN, M.; ECKSTEIN, L.
The Wheel-Individually Steerable Front Axle of the Research Vehicle SpeedE
22nd Aachen Colloquium Automobile and Engine Technology
Aachen, 2013
- [10] SCHWARZ, B.; ECKSTEIN, L.; HESSE, L.
The wheel-individually steerable front axle of the research vehicle "SpeedE" – virtual design and achieved performance of the first prototype
5th International Munich Chassis Symposium 2014
Wiesbaden, 2014
- [11] KLEIN, M.; MIHAILESCU, A.; HESSE, L.; ECKSTEIN, L.
Einzelradlenkung des Forschungsfahrzeugs SpeedE
Wiesbaden, ATZ Automobiltechnische Zeitschrift 115 (2013), Nr. 10
- [12] SCHWARZ, B.; HESSE, L.; ECKSTEIN, L.
Innovative Vehicle Dynamics Functionality of the Wheel-Individually Steerable Front Axle of the Research Vehicle SpeedE
International Symposium on Advanced Vehicle Control : AVEC '14
Tokio, 2014
- [13] SCHWARZ, B.; ECKSTEIN, L.
Design of an energy-efficient front axle for a wheel-individual steer-by-wire system illustrated by the SpeedE research vehicle
7th International Munich Chassis Symposium 2016
Wiesbaden, 2016

- [14] GILLEN, C.; HESSE, L.; MIHAILESCU, A.; ECKSTEIN, L.
Safety strategy for the Steer-by-Wire system of the research vehicle “SpeedE”.
3rd International Munich Chassis Symposium 2012 : Chassis.tech plus
Munich, 2012, p. 531–549
- [15] GILLEN, C.; HESSE, L.; LAMMERMANN, M.
The Efficient Safety Concept of the SpeedE Steer-by-Wire System.
23rd Aachen Colloquium Automobile and Engine Technology
Aachen, 2014, p. 379–388
- [16] KLEIN, M.; MIHAILESCU, A.; GILLEN, C.; HESSE, L.; ECKSTEIN, L.
Potentials and Challenges for the Application of Active Sidesticks – Case Study
“SpeedE”.
21st Aachen Colloquium Automobile and Engine Technology
Aachen, 2012, p. 663–674

