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Development of the Safe Light Regional Vehicle (SLRV) vehicle concept within the DLR Next Generation Car (NGC) project

Michael Kriescher, Sebastian Scheibe, Cedric Rieger, Philipp Straßburger (German Aerospace Center (DLR) Institute of Vehicle Concepts),

Christophe van Herreweghe, (DuPont Transportation & Advanced Polymers)

Michael Kriescher *(corresponding author) DLR Institute of Vehicle Concepts, Pfaffenwaldring 38–40, michael.kriescher@dlr.de*

Summary

The DLR 'Next Generation Car' (NGC) project addresses current and future challenges in automotive development based on three unique vehicle concepts, in order to demonstrate technologies for future road vehicles.

The Safe Light Regional Vehicle (SLRV) is the smallest vehicle in the NGC family of new road vehicle concepts. It addresses the light electric vehicle segment and is powered by a fuel-cell-hybrid drive train. An important innovation of this vehicle concept is the car body, designed as a sandwich construction, in order to achieve a combination of low weight, good crash performance and acceptable cost.

Keywords: light vehicles, passenger car, fuel cell vehicle

Introduction – overview of the Next Generation Car (NGC) project

In the DLR Next Generation Car (NGC) project, DLR researchers are investigating vehicle concepts, technologies and mobility solutions for the road vehicles of the future [SCH2018].

Some of the key challenges are:

- Reduction of the absolute energy demand of vehicles
- Avoidance of harmful emissions, in particular CO_2 and noise
- Resource conservation through the use of fuels from renewable energy sources
- Increased safety of passengers and road users
- New technological possibilities, such as the networking of vehicles with urban and inter-urban transport and the energy infrastructure.

The research approaches and results are summarised and demonstrated in three innovative vehicle concepts (Figure 1): The Urban Modular Vehicle (UMV) for use in urban areas, the Inter-Urban-Vehicle, intended for long range travel between cities and the Safe Light Regional Vehicle (SLRV), for medium range commuting, which is a cost-effective, entry-level, two-seat vehicle in the L7e class.

Figure 1: Next Generation Car concepts

SLRV vehicle concept

One important goal of the NGC-SLRV concept is to offer solutions to some of the main challenges of electric vehicles, providing an adequate range at a reasonable purchase price. In order to address these challenges, a major goal of the concept is to minimise the driving resistance, which leads to a lightweight L7e-type vehicle.

The NGC-SLRV addresses safety concerns relating to typical light vehicles. It is therefore specifically designed to provide a level of passive safety that is comparable to current full-size vehicles.

The SLRV is a two-seater with a low, elongated body, to minimise aerodynamic drag. An innovative metal sandwich structure is used for the car body to keep the vehicle weight low. This allows the use of small and relatively cheap drivetrain components, giving secondary weight saving effects [see also ECK2011].

SLRV drivetrain

NGC-SLRV is designed for an electric drivetrain, powered by a hydrogen fuel cell system (Figure 3) in order to achieve the necessary range of the vehicle concept.

Fuel cells generally have a lower overall well-to-wheel efficiency than batteries. They also require a hydrogen infrastructure that must be developed and established. However, for the targeted range of 400 km, a fuel cell system can achieve a much lower weight than an equivalent battery system (Figure 2).

Due to the low driving resistance of the vehicle, the fuel cell system can be designed with a low power output, which lowers the cost of the system, as well as the consumption of hydrogen.

For the SLRV, preliminary calculations show an estimated fuel consumption of 0.34 kg of H_2 for 100 km in the NEDC-cycle, which is about half of the H_2 consumption of a mid-size fuel cell powered passenger car.

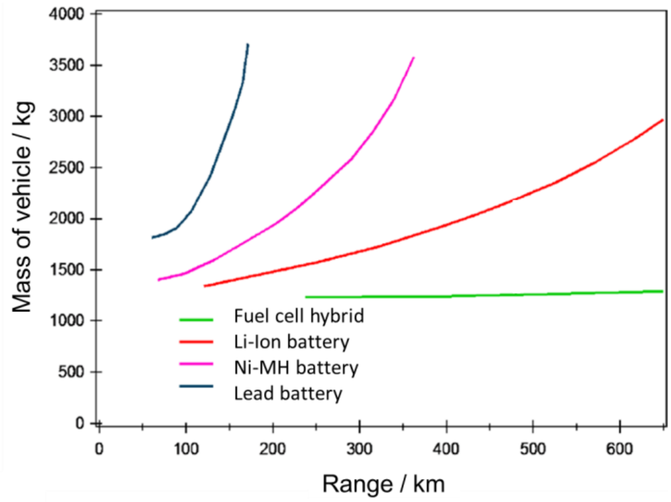

Figure 2: Range vs vehicle weight for different energy storage systems [AFR2014], example of a mid-sized passenger car

The fuel cell, including its systems, such as the radiator, the air compressor and the required piping, are located in the front of the vehicle. This provides optimal airflow through the radiator and also keeps all the lines for air, water and fuel in the front of the vehicle. Therefore only a power cable has to run from the fuel cell system in the front to the battery and electric motors in the back of the SLRV.

A relatively small fuel cell stack with a maximum continuous power output of 8 kW is used to provide continuous power for all vehicle operations. The battery is designed to deliver short-term power levels of up to 25 kW for acceleration, and is also used for energy recovery.

The H_2 for the fuel cell is supplied by a tank with a maximum operating pressure of 700 bar, which is located in the tunnel of the vehicle.

Propulsion is provided by two permanent magnet synchronous motors. This eliminates the need for a differential gear and offers the possibility of easily applying torque vectoring, thus enhancing the vehicle's driving dynamics.

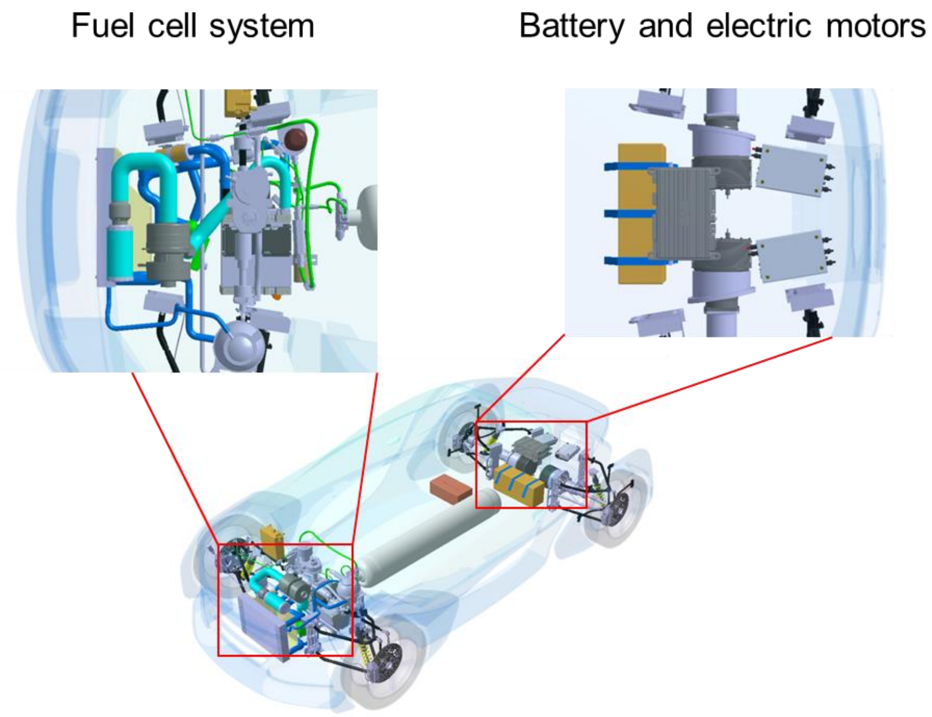

Figure 3: SLRV drivetrain components

SLRV chassis

The chassis of the SLRV uses a double-wishbone suspension system. An innovative crash mechanism has been developed for this suspension, which is designed to avoid an impact of the wheels on the cabin in the event of a frontal crash. This allows the design of a lightweight passenger compartment and improves the safety of the vehicle (Figure 4).

The use of a drive-by-wire system makes mechanical steering devices and their associated support structures unnecessary, thus helping to achieve the goal of a very low vehicle weight. It also allows for the integration of autonomous driving features in the future.

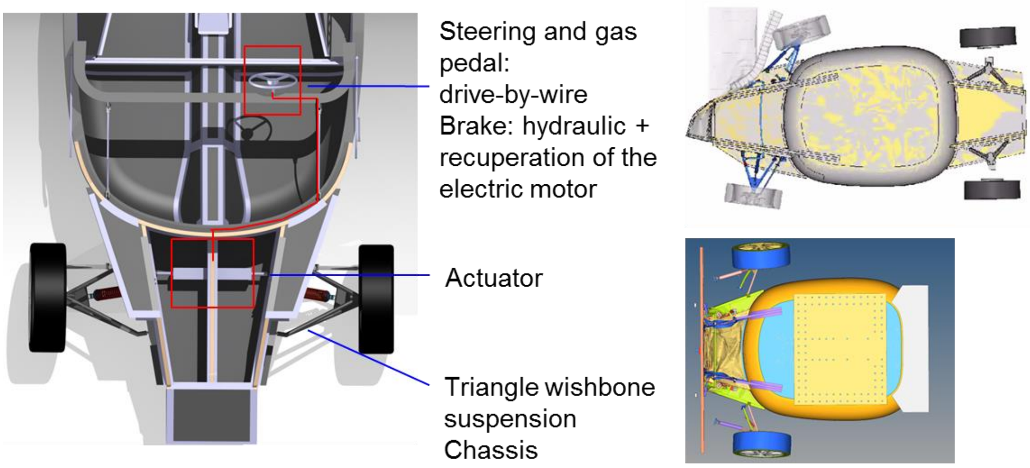

Figure 4: Concept of the Front Chassis and Steering

SLRV car body

An innovative metal sandwich structure is being developed to achieve a very low weight for the body in white – only 90 kg – and at the same time optimise the crash behaviour to protect the occupants. The use of a metal sandwich structure lowers the material and manufacturing costs and also helps to reduce the number of separate parts necessary for the assembly of the vehicle body. Conventional materials such as aluminium, steel and plastic foam are used to keep material costs low.

Innovative deformation mechanisms are used on several parts of the vehicle body structure, in order to achieve a favourable relationship between crash performance and lightweight design.

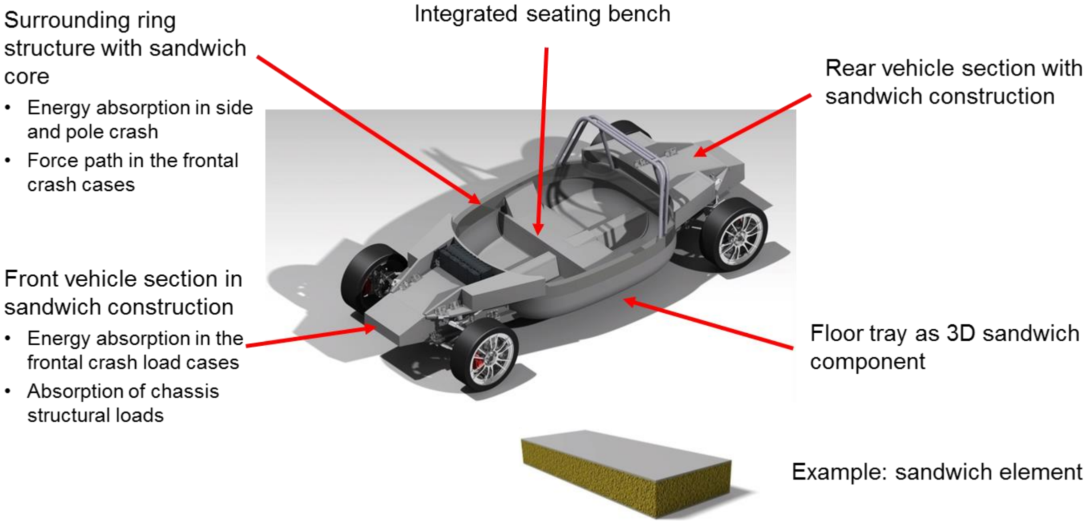

Figure 5: SLRV vehicle body with metal sandwich construction – weight 90 kg

Testing of the car body

The aim of these tests was to investigate the deformation behaviour of the vehicle body structure and to verify the anticipated positive attributes of sandwich design, which have already been studied using FE calculations and in the form of generic components [KRI2015] – this time in interaction with the entire vehicle structure.

Experimental set-up and implementation

Two crash tests were carried out – firstly, a pole crash in line with EURO-NCAP, and secondly a frontal crash in accordance with US-NCAP. Investigations into the degree of injury suffered by the occupants could not be carried out within the context of this project, but the results of the behaviour of the vehicle structure give a first input.

Crash-test facility at the DLR Institute of Vehicle Concepts

The Institute of Vehicle Concepts has a sled system for dynamic tests on larger components and assemblies. The facility consists of two crash sleds guided by a system of rails, so that they can only be moved in a longitudinal direction (Figure 6). Sled one, with a total weight of 1300 kg, can be accelerated using a pneumatic cylinder to a maximum speed of 64 km/h. This allows body assemblies for lightweight vehicles to be tested under realistic conditions.

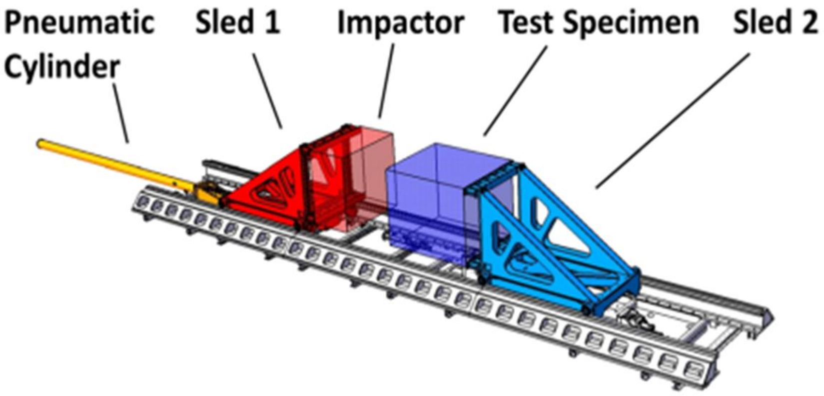

Figure 6 Arrangement of the crash-test facility at the Institute of Vehicle Concepts [DYN2013]

Pole crash experimental set-up

DLR’s crash-test system involves the vehicle colliding with the pole at a 90°-angle to its longitudinal axis. The vehicle weight is at 530 kg which corresponds to a payload of 120 kg.

The vehicle body had to be shortened due to the width of the crash system, which is approximately 3.5 m (Figure 7). This had no effect on the behaviour of the body during the pole crash, as the components removed for the shortening are far away from the areas where deformation occurred.

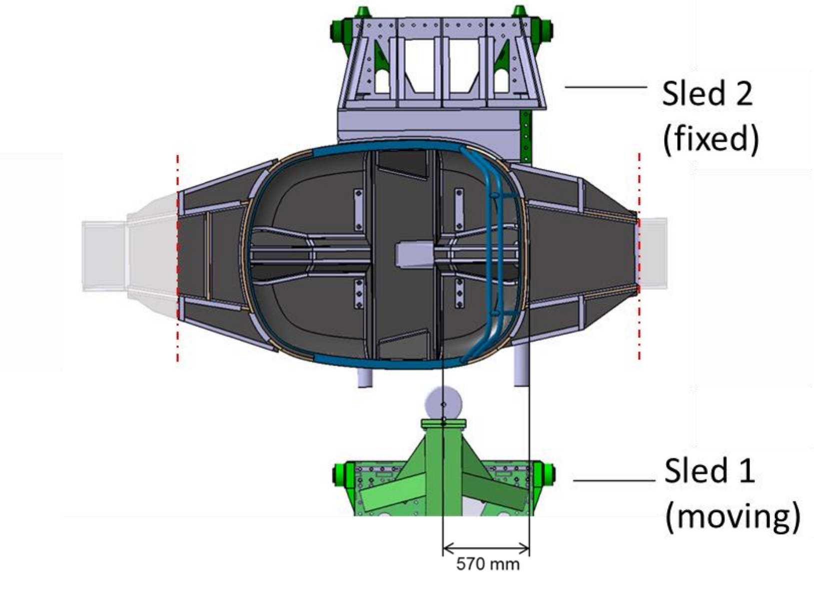

Figure 7: Experimental set-up for Pole crash test

Pole crash test implementation

The kinetic energy of the SLRV during the pole crash, at a vehicle mass of 530 kg and an impact velocity of 29 km/h, was 17.2 kJ. Due to the higher weight of the impactor sled compared to the vehicle weight, a slighter lower velocity of 24.4 km/h had to be applied during the crash test in order to achieve the same impact energy (Table 1). The velocity measured in the test was 24.48 km/h.

Table 1: Comparison of mass and velocity in a pole crash with the same impact energy

	Mass [kg]	Velocity [m/s]	Velocity [km/h]	Energy [kJ]
SLRV complete vehicle crash simulation	530	8,06	29,00	17,20
Impactor sled	748,40	6,78	24,41	17,20
Values in test	748,40	6,8	24,48	17,30

During the pole crash, the body exhibited uniform deformation behaviour, without any major reduction in force (Figure 8 and Figure 9). At the beginning of the deformation process, there was a good deformation pattern. However, a detachment of the adhesive joints between the floor pan and ring structure, as well as the support for the bench on the ring structure occurred as the deformation continued. This separation of the adhesive joints could not be represented in crash simulations of the pole crash (Figure 10), which leads to future investigation.

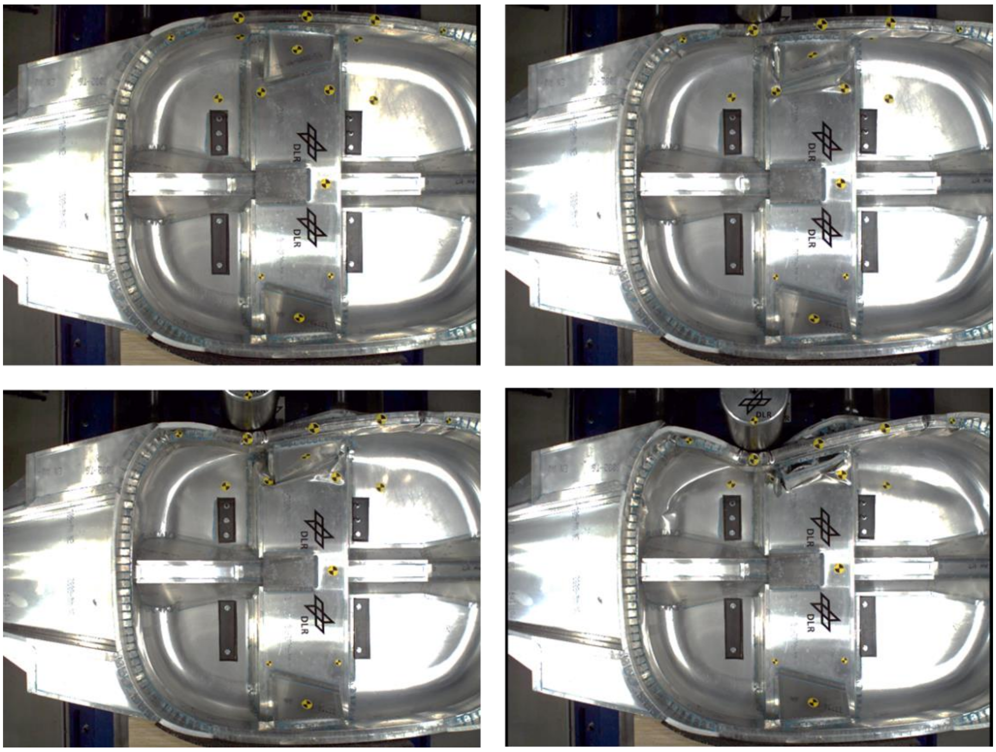

Figure 8: Deformation behaviour of the body during the pole crash, 0–280 mm intrusion; view from above

Figure 9: Force-displacement curve of the pole crash

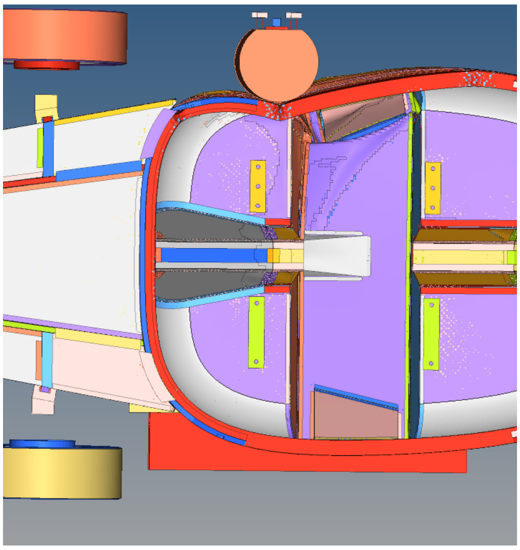

Figure 10: Simulation of the pole crash

Experimental set-up for frontal crash test

In a US-NCAP frontal crash test, the vehicle collides with a fixed, non-deformable barrier at 56 km/h [CAR2018]. The aim of this test is to investigate the deformation behaviour of the front end in conjunction with the chassis, as well as the structural integrity of the passenger cell.

The vehicle body is firmly connected to Sled 2, which remains fixed during the experiment. The barrier, a non-deformable plate, is mounted on Sled 1, which is accelerated in the experiment and collides with the fixed body at the set impact velocity (Figure 11). The body is connected to fixed Sled 2 by a flat support on the rear part, and by plates bolted to the vehicle floor.

Figure 11: Experimental set-up for the frontal crash test, with sled 2 (fixed) on the left and sled 1 (in motion) on the right

The short acceleration distance available for the impactor sled means that high acceleration is necessary to achieve the desired crash energy. In this test, the barrier is accelerated rather than the car to ensure that such acceleration does not lead to a premature deformation the vehicle body.

As in the case of the pole crash, in this test the mass of the sled is greater than that of the SLRV, so the impact velocity had to be reduced from 56 km/h to 44.85 km/h in order to achieve the same impact energy.

Table 2: Comparison of mass and velocity in the frontal crash test, at the same impact energy.

	Mass [kg]	Velocity [m/s]	Velocity [km/h]	Energy [kJ]
SLRV complete vehicle crash simulation	530	15,56	56,00	64,12
Impactor sled	826,40	12,46	44,85	64,12
Values in test	826,40	13,30	47,88	73,09

The actual measured velocity was 47.88 km/h, so the body was impacted with 14% higher energy than that required by the US-NCAP standard.

Behaviour of the front vehicle structure during the frontal crash test

The behaviour of the vehicle structure during the frontal crash test can be roughly divided into four phases, of which the first three correspond to the different sections in the design of the vehicle’s forward structure (Figure 12 and Figure 13).

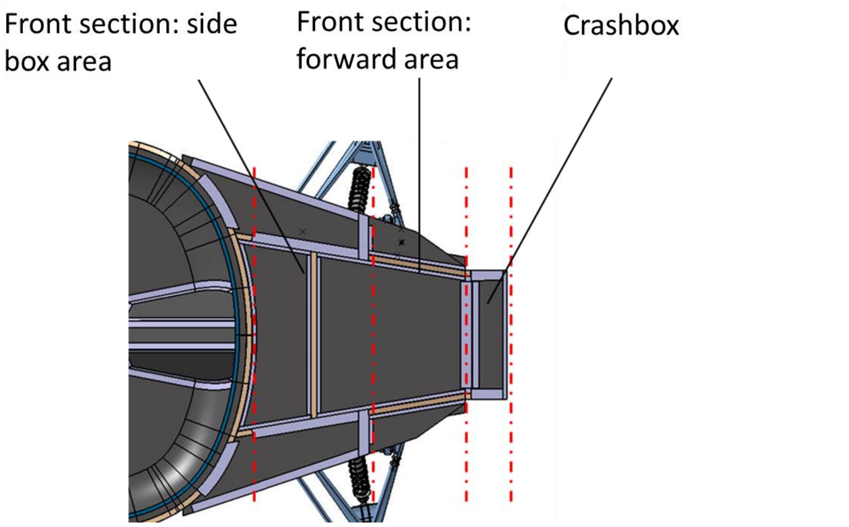

Figure 12: The front of the vehicle divided into different crash zones

In the first phase, the crash box was deformed, while the rest of the vehicle remained free of deformations. An energy of approximately 4.5 kJ was absorbed in this process.

In the second phase, the front part of the forebody was deformed. The wheels and suspension were also hit by the barrier and then became detached. This impact can be seen in the force-displacement-curve (Figure 14) starting at a deformation of 200 mm.

At the beginning of the third phase, the deformation reached the side boxes, which then also deformed. It is also evident that the wheels and suspension were guided past the passenger compartment. Maximum deformation was achieved at the end of the third phase.

Phase 4 consisted of the elastic rebounding of the structure, pushing back the impactor sled. In addition, the wheels were decelerated by the energy absorbers integrated into their retaining ropes.

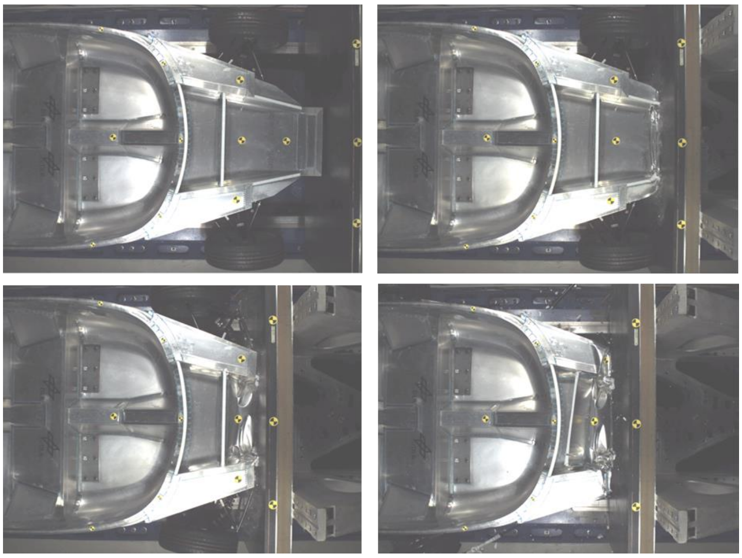

Figure 13: Behaviour of the SLRV body in a frontal crash test

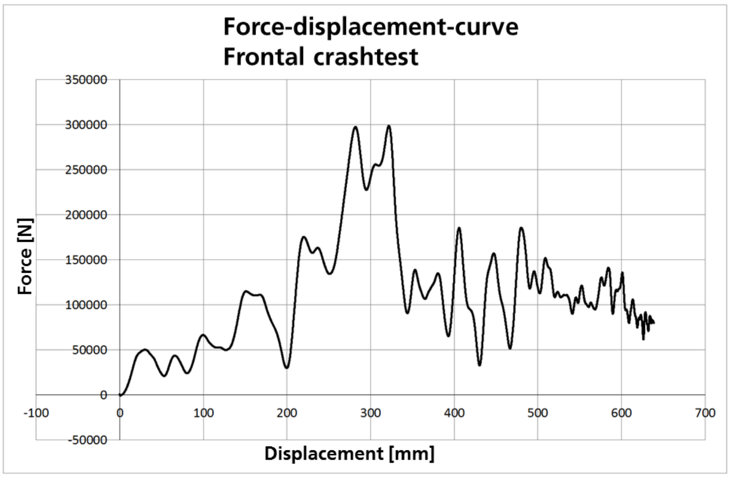

Figure 14: Force-displacement curve of the frontal crash test with the SLRV body in white

Overall, the SLRV front structure displayed an even, continuous deformation behaviour with sufficient energy absorption. The adhesive joints also performed as well as in the simulation. The chassis worked as planned during the crash and successfully prevented an impact of the wheels on the passenger compartment.

Behaviour of the passenger compartment in the frontal crash test

A slight deformation of the tunnel occurred at the point at which the wheels were impacted, at around 200 mm. Otherwise, no plastic deformation of the passenger compartment occurred during the entire crash test, so the survival space for the passengers remained fully intact. Visible elastic deformations occurred in the area of the ring, but they completely disappeared by the end of the test. Disregarding the impact of the wheels, the deformation force of front structure is around 100-120 kN. This equals a deceleration of 20-23 g and is therefore below the maximum deceleration of state of the art passenger cars. Therefore, with a working passenger restraint system, a low risk of injury is to be expected.

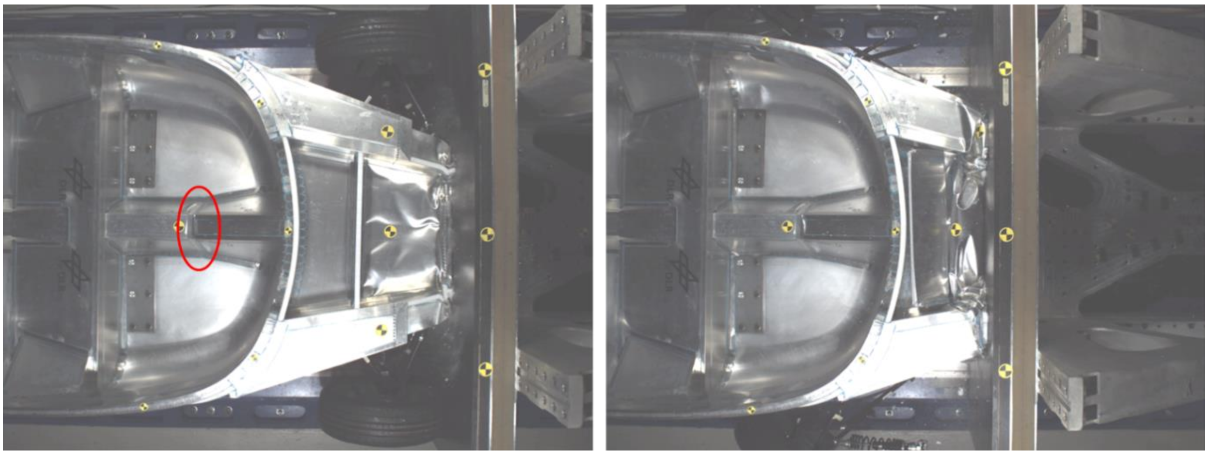

Figure 15: Appearance of a slight deformation in the tunnel area

Outlook – building a research vehicle

The DLR will build three full-size demonstrators for the UMV, IUV and SLRV based on the work performed in the Next Generation Car project.

In the case of the SLRV, a research vehicle version of the SLRV will be built and tested. The goal is to evaluate the concept as well as the performance of all of its systems during test drive campaigns. Additionally research of different aspects of sandwich structures, such as fatigue properties, joining and manufacturing concepts will continue within the DLR Next Generation Car research program.

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Authors

Michael Kriescher has studied mechanical engineering at the technical university of Munich. Since 2005 he works as a scientist at the German Aerospace Center's Institute of Vehicle Concepts, in the field of of Vehicle Architectures and Lightweight Design concepts. He works on structural testing and lightweight vehicle concepts and has the project lead of the Next Generation Car Demonstrators Project.

Sebastian Scheibe was born on December 21, 1989 and comes from Weil am Rhein. After the university entrance qualification, he studied Aerospace Engineering (M.Sc.) at the University of Stuttgart. Since July, 2017, he works as research associate in the field of Vehicle Architectures and Lightweight Design Concepts at the Institute of Vehicle Concepts of the DLR in Stuttgart. There he works on the construction of research demonstrators like the SLRV and tests new vehicle structures.

Philipp Straßburger works as a research associate for the DLR Institute of Vehicle Concepts since 2009. He studied mechanical engineering with a specialization in automotive engineering at the RWTH Aachen. In his research his main topic is to simulate the real deformation behavior from crash loads on vehicle components reproducible on a test rig. He works on designing, simulating and implementing these test setups.

Cedric Rieger joined the DLR Institute of Vehicle Concepts in 2012. He works on static and dynamic tests of vehicle structures.

Christophe van Herreweghe works as a Global Marketing Manager Transportation Assembly at DuPont Transportation & Advanced Polymers. Christophe began his career at Dow in 2001 as technical service engineer for Volvo cars handling the body protection & dampening product portfolio, progressing into application specialist for PVC paint shop sealers and application development for Ford (Europe, Middle East, Africa). In 2013 he added the role of key account manager for Ford and Volvo. Christophe is a passionate marketer of material assembly solutions like BETAMATE™, BETAFORCE™ and BETASEAL™ adhesive solutions that enable multi-material, lightweight body and battery pack designs.