Development of the Safe Light Regional Vehicle (SLRV): A Lightweight Vehicle Concept with a Fuel Cell Drivetrain

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Abstract The safe light regional vehicle (SLRV) concept was developed within the DLR project next-generation car (NGC). NGC SLRV addresses the safety concern of typical L7e vehicles. The SLRV is therefore specifically designed to demonstrate significant improvements to the passive safety of small vehicles. Another important goal of the NGC SLRV concept is to offer solutions to some of the main challenges of electric vehicles: to provide an adequate range and at the same time a reasonable price of the vehicle. In order to address these challenges a major goal of the concept is to minimize the driving resistance of the vehicle, by use of lightweight sandwich structures. A fuel cell drivetrain also helps to keep the overall size and weight of the vehicle low, while still providing sufficient range.

Keywords L7e vehicle concept • Safe sandwich vehicle structure • Fuel cell drivetrain

1 Safe Light Regional Vehicle Concept (SLRV)

The safe light regional vehicle concept (SLRV) has been developed as one of three different vehicle concepts, within the DLR's research project next-generation car (NGC). One important goal of the NGC SLRV concept is to offer solutions to some of the main challenges of electric vehicles: to provide an adequate range and at the same time a reasonable price of the vehicle. In order to address these challenges, a major goal of the concept is to minimize the driving resistance of the vehicle, which leads to a reduced demand for power, energy and resources. The SLRV concept has been developed for regional distances that extend beyond the urban range. It is intended for example, to be used by commuters who have regular point-to-point journeys, such as a feeder vehicle to the public transport connections or as a car-sharing vehicle in an out-of-town context. It can therefore supplement public

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transport in a suburban or rural environment, be used as a second car and is well suited for sharing due to its fast H₂ refuelling capability.

NGC SLRV also addresses the safety concern of typical L7e vehicles. The SLRV is therefore specifically designed to demonstrate significant improvements to the passive safety of small vehicles.

The SLRV is a two-seater with a low, elongated body, to provide minimal 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 therefore low cost, drivetrain components, due to secondary weight saving effects [1].

A potential advantage of sandwich structures is the fact that large, relatively simple parts can be designed, without the need for additional stiffeners, reducing the overall number of parts of the car body. This reduction in part count and assembly effort is important to make sandwich structures competitive, since a single sandwich component is typically more expensive than parts made from metal sheets.

An example for this is the passenger compartment of the SLRV which consists of a single floor tray, reinforced by a ring structure. This floor tray substitutes several parts of a conventional car body, such as the door sills, the fire wall and the rear wall as well as the floor itself (see Fig. 1).

In order to reduce the part count further, the SLRV was designed with a single canopy instead of conventional doors. It therefore only needs a rollover bar instead of a roof and A- and C-pillars.

The use of a drive-by-wire steering system simplifies the layout of the car body further, since a steering column with the associated attachment structures becomes

Fig. 1 Overview of the SLRV concept

unnecessary. In the SLRV, the steering wheel is located on a cross-beam which swings open, along with the canopy.

The suspension of the SLRV is optimized with respect to its deformation behaviour during a frontal crash. Several predetermined breaking points are used to avoid an intrusion of the wheel into the cars body (see also chapter [Velomobiles and Urban Mobility: Opportunities and Challenges](#)).

2 Concept of the Car Body

An innovative metal sandwich structure is developed to achieve a very low weight for the body in white—only 90 kg—and at the same time optimize the crash behaviour to protect the occupants (see Fig. 2). The use of a metal sandwich structure reduces 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.

The front and rear sections of the vehicle are made from sandwich panels, which are bonded to form the front and rear structures. These structures carry the attachment points for the chassis and most of drivetrain components. They also work as energy absorbers in the case of a frontal or rear impact. The passenger compartment is made of a floor tray with a surrounding ring structure. These components protect the passengers in the case of a side-, or pole impact. They also bear the loads of a front- or rear impact.

Fig. 2 SLRV vehicle body with metal sandwich construction—weight 90 kg

3 Testing of the Car Body

Two prototypes of the SLRV body in white were built for crash testing. The aim of these tests was to investigate the deformation behaviour of the entire vehicle body structure and to verify the anticipated positive attributes of sandwich design, which had previously already been studied using FE calculations and in the form of generic components [2].

3.1 Experimental Set-Up and Implementation

Two relevant 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 are an important first result, in order to assess the passive safety of the vehicle.

3.2 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 (see Fig. 3). 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

Fig. 3 Arrangement of the crash-test facility at the institute of vehicle concepts [3]

Fig. 4 Deformation behaviour of the body during the pole crash, 0–280 mm intrusion; view from above

for lightweight vehicles to be tested under realistic conditions. The forces during the crash tests (see Figs. 4 and 5) were obtained by measuring the deceleration of the sled.

3.3 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. The velocity measured in the test was 24.48 km/h.

During the pole crash, the body exhibited uniform deformation behaviour, without any major reduction in force (see Figs. 4 and 5). 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, which leads to future investigation.

Fig. 5 Force–displacement curve of the pole crash

3.4 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 [4]. 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 (see Fig. 6). The body is connected to fixed sled 2 by a flat support on the rear part, and by plates bolted to the vehicle floor.

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 of 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.

4 Results of the Front Crash Test

Overall, the SLRV front structure displayed an even, continuous deformation behaviour with sufficient energy absorption (see Fig. 7). The adhesive joints also performed as well as in the simulation. The front suspension worked as planned during the crash and successfully prevented an impact of the wheels on the passenger compartment.

Fig. 6 Left: Experimental set-up for the frontal crash test, with sled 2 fixed; Right: sled 1 in motion

Fig. 7 Behaviour of the *SLRV* body in a frontal crash test

4.1 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 (see Fig. 9). 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 (see Fig. 8). 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.

For the future development of small electric vehicles, an investigation of the occupant's safety, by using crash-test dummies, would be beneficial. This could first be done by simulation and could lead to a more complete test program, including crash-test dummies and the appropriate restraint systems.

4.2 Drivetrain of the SLRV

NGC SLRV is designed for an electric drivetrain, powered by a hydrogen fuel cell system (see Fig. 10). For the targeted range of 400 km, a fuel cell system can achieve a much lower weight than an equivalent battery system [5]. Due to the low driving resistance of the vehicle, the fuel cell system is designed with a low power

Fig. 8 Force–displacement curve of the frontal crash test with the SLRV body in white

Fig. 9 Appearance of a slight deformation in the tunnel area

output, which limits the cost of the system, as well as the consumption of hydrogen. The challenges are to balance good drivability with the overall weight.

In order to achieve sufficient acceleration, the drivetrain is designed as a hybrid system. It consists of a fuel cell which provides a maximum power of 8 kW and a battery system, which can deliver up to 25 kW, additionally. This limits the cost and weight for the fuel cell and also enables recuperation.

Hydrogen is stored at up to 700 bar, in a single pressure tank, located in the tunnel of the SLRV. The tank has a capacity of 1.6 kg of H_2 at 700 bar. With an estimated fuel consumption of 0.34 kg H_2 for 100 km in the NEFZ cycle, this should theoretically be enough for 470 km range. Since the SLRV is an L-category vehicle, the WLTP C2 cycle would lead to an even lower fuel consumption and an even greater range.

It is understood that small electric vehicles are very cost sensitive (see also chapter ‘Small electric vehicles—benefits and drawbacks’). Economic efficiency calculations for hydrogen propulsion have to take the future use of regional vehicles into account. The degree of utilization, the mileage per day, as well as hydrogen availability and costs play an important role. This part of the study has not been finished so far and is subject to in future investigations and publications.

4.3 Installation of the Operable Research Vehicle

A research vehicle of the SLRV is being built based on the work described above (Fig. 11). It will be completed and tested until the end of 2020. The goal is to evaluate the concept as well as the performance of all of its systems during test-driving. The tests will evaluate the performance, H_2 -consumption and diving dynamics of the vehicle. Also, the mechanical loads and the strain on structural components will be measured, in order to evaluate the performance of the sandwich structure under driving conditions.

Fig. 10 Drivetrain concept of the SLRV

Fig. 11 SLRV research vehicle, November 2019, the drivetrain is still being developed

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