The Mercedes-Benz Experimental Safety Vehicle 2009

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ABSTRACT

The way was paved for the first ESV Conference in the early 1970s by the development and discussion of what were called Experimental Safety Vehicles. From the outset, Mercedes-Benz played an active role in this initiative. Up until the mid-1970s, over 20 Mercedes-Benz ESFs (for Experimental Sicherheits Fahrzeug) were built and presented. This short period of time also witnessed the development of basic innovations, some of which represent crucial milestones for vehicle safety:

- Structural safety
- Anti-lock Braking System (ABS)
- Belt pre-tensioner and belt force limiter
- Airbags
- Side impact protection
- Electronic Stability Program (ESP)
- Partner Protection Systems

For the ESV Conference in 2009, Daimler is re-creating this pioneering paradigm shift and developing a new Experimental Safety Vehicle, the ESF 2009. Based on the very latest safety features, such as Advanced Driver Assistance Systems, Adaptive Restraint Systems, and Integrated Safety Systems (PRE-SAFE®) [1], the ESF 2009 will present and demonstrate solutions for the requirements and safety challenges of the future.

This paper presents the safety features that Mercedes-Benz is focusing on to address vehicle and road safety requirements in the future.

In pursuit of our vision of accident-free driving and high-performance occupant safety, the paper looks at the following subjects and solutions, which could provide further sustainable advances in the field of vehicle safety:

- Systems for enhanced perception
- Vehicle communication
- Invisible protection zone
- Driver Assist Systems
- PRE-PULSE and innovative occupant protection systems
- Safety of alternative drive systems

The paper will describe functional models of the different safety features, their potential safety benefits, and feasibility requirements. The main goal of the Mercedes-Benz ESF 2009 is to illustrate mid and long-term safety features and to promote discussion on their relevance for achieving improved traffic safety.

INTRODUCTION AND MOTIVATION

Vehicles from then (Fig. 1) already considered topics relating to both active and passive safety together. This integrated safety approach, based on the technology of the day, offered glimpses of the type of improvements in vehicle safety that were to come. Today, most of the systems that were considered revolutionary at that time can be found in the series production vehicles of virtually every manufacturer. No further experimental safety vehicles have been assembled anywhere in the world, or presented at the ESV conference, since 1974.

In constructing a new experimental safety vehicle (Fig. 2), the intention of Mercedes-Benz is to again promote holistic discussion of the subject of vehicle safety.

Figure 1: ESF 13 from 1972

The hope is to present feasible new solutions based on today's technologies and illustrate the potential they offer. Systems whose production breakpoint is not yet possible from a present-day perspective have been consciously included to elicit discussion of the basic requirements and technological advances that will be required.

Figure 2: The ESF 2009

DESCRIPTION OF THE MAIN TOPICS

The scope of this paper does not permit a comprehensive explanation of the circa 30 topics from six different areas. Selected systems have therefore been presented in more detail as being representative for each of the topic areas. The following areas were included in the ESF 2009, grouped according to the integrated safety approach [2], i.e. ranging from accident prevention and protection for the occupants during an accident to the measures that can be taken after an accident.

Systems for enhanced perception

One area that offers considerable potential for reducing accident statistics is improved perception of the traffic situation by the driver and other road users.

The topic "Adaptive High Beam with Spotlight" offers a solution for extending the visibility of other road users and differentiating between them. The hazard signal used by this technology is provided directly in the traffic situation. The technical solution in the ESF 2009 gives an example of how the inherent visibility of the vehicle can be improved for other road users, particularly from the side. In this case, the inherent visibility was improved using passive reflective measures.

Both topics are described in more detail in the presentation of each later in this paper. The topic of Intelligent Night View for active night vision recognition and for accentuating the visibility of pedestrians and animals is also examined.

Vehicle communication

Vehicle communication systems for accident prevention or rescue will make an important contribution on the way to achieving safer driving. Communication between vehicles offers crucial added value, especially in situations that could be adequately defused with the help of an early warning system, or where a vehicle surrounding sensor system, e.g. in concealed situations, cannot offer any added value. However, at this point, a single-manufacturer solution cannot help us achieve our goal. Instead, what is needed is a successful collaboration between a large number of manufacturers and suppliers with the aim of developing uniform standards and a model for rapid market penetration of the technologies involved. For that reason, this important topic has also been included in the vehicle.

Driver Assistance Systems

Systems to prevent and reduce the severity of accidents represent an important basis for future developments to improve vehicle safety. Building on improved and extended vehicle sensing systems (e.g. radar and stereo cameras), new assistance functions will become possible that will help the driver, e.g. in critical situations at intersections.

The assistance systems in the ESF 2009 address the topics of improving longitudinal and lateral guidance, as well as general perception.

Specifically, these are as follows:

The blind spot assistance system can not only trigger a warning, but also help avoid a potential collision with a vehicle in the blind spot by braking individual wheels.

The extended Lane Assistant also comprises an alarm level, and, if it recognizes the danger of a critical departure from the lane, intervenes by applying independent wheel braking to correct the steering course. At a later stage of development, corrective steering intervention can also occur if collision objects are identified.

Traffic sign assistance system to visualize the currently applicable speed limit.

Virtual crumple zone

Several manufacturers have recently introduced systems to help the driver in situations with a high risk of rear-end collisions. With its introduction of the PRE-SAFE® brake in 2006, and the enhanced version with an emergency braking function in 2009, Mercedes-Benz brought onto the market the final stage of development for the present in a bid to counter the risks posed by escalating parallel traffic. The PRE-SAFE® brake system combines acoustic and visual warnings, adaptive brake assistance, and autonomous partial and emergency braking to offer an all-round package that helps to avoid an accident, or to reduce kinetic energy before a possible collision. Preventive occupant protection functions are also activated. The Brake Bag in the ESF 2009 represents a further development stage. This will be explained in more detail in a later section.

PRE-PULSE and innovative occupant protection systems

To date, the development of occupant protection systems has focused on extending the protective space, and on adaptive restraint systems. Extended fitting of airbags down into the subcompact range, and refinement of the seatbelt with pretensioning and force limiter have greatly reduced the loads to which occupants are subjected in accident situations. Over the last few years, however, we have witnessed an asymptotic trend in the reduction of forces under the specified load conditions. If we consider conventional restraint systems, even experts believe that the possibilities for further development in the future are slim.

Nevertheless, if we consider the pre-accident phase, links can be created between reversible and conventional occupant protection systems that, in combination, open up further possibilities. One example of this is the forward-thrusting PRE-PULSE Side occupant protection system, which will be presented in a later section.

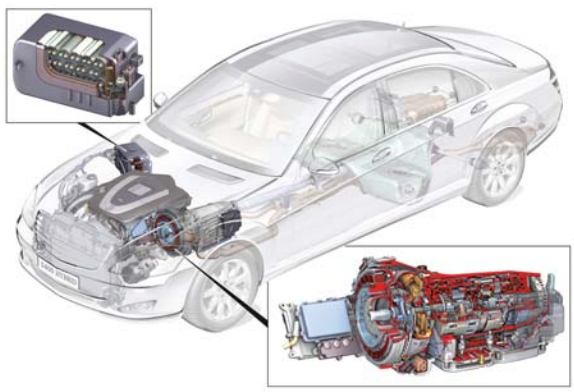
A further area where occupant protection can be improved is in the rear seat row, which has different requirements to the front seat row. On the one hand, children are transported in this area, so that occupant protection systems must meet the requirements for this occupant group. Similarly, the requirements for a chauffeur limousine, as in the present luxury vehicle segment, are quite different as regards occupant protection. The solutions presented for child safety and the belt bag should prove enhancements to the range of protective equipment, and will be described in more detail as part of the vehicle presentation.

On the question of resolving the conflicting objectives of body rigidity and lightweight construction, the topic “inflatable structure” will be addressed and presented separately in a later section.

Safety of alternative drive systems

The ESF 2009 is equipped with a modern hybrid drive system (Fig. 3). The equipment includes a 15 kW magneto-electric motor, a lithium-ion high-voltage battery, and the necessary power and control electronics.

Figure 3: Location of the hybrid components in the ESF 2009



The vehicle is equipped with a comprehensive, seven-part safety concept, designed in particular for the high-voltage electronics system that operates at 120 V. The system includes the following features:

- Color-coded HV cables and contact protection, with generously dimensioned insulation and special plugs
- High-strength steel housing for Li-ion battery
- Cells on bed of gel and discharge ports with bursting disks
- Multiple safety interlock to automatically separate battery terminals
- Short-circuit monitoring
- Active discharging of the high-voltage system in the event of faults or fire
- Pyrotechnic tripping of the HV system in the event of an accident.

TECHNICAL DESCRIPTION OF SELECTED SYSTEMS

LED pixel headlamps for hazard light

Night vision systems are a great help for the driver: with the night vision assistant, even with oncoming traffic, drivers can still see their own lane and the right-hand edge of the roadway without any risk of dazzling other road users. Advances in camera technology and image processing now allow systems to recognize potential dangers on and immediately adjacent to the roadway. These can be specially highlighted on a suitable display to warn drivers. The preferred solution would be for drivers to receive an alert about a potential hazard directly in the traffic area, without wasting time looking at a display. This function will be called a “hazard light” in the following.

There are basically two different approaches to realize this function: (1) a type of search lamp that moves in a similar way to an active curved illumination module, or (2) a fixed headlight with electronically controlled light distribution. The second variant has been implemented in the ESF 2009, since fractions of a second are of vital importance with a “hazard light” (Fig. 4). In principle, there are also two different approaches for the non-mechanical systems: the use of a video projector [3] or similar device, or the use of an electronically addressable LED array [4].

The second approach was the option preferred in the ESF 2009. An array of this kind basically consists of a number of individual LED chips arranged in rows and columns. Approximately 40–100 LED pixels are needed to create a vehicle headlamp (depending on the desired resolution and the maximum area to be illuminated). The ESF 2009 has 96 pixels arranged in four rows, with a different number of pixels per row. Each of the 96 pixels can be dimmed in 256 steps, and can be switched on within a few milliseconds.

Figure 4: Spotlight function

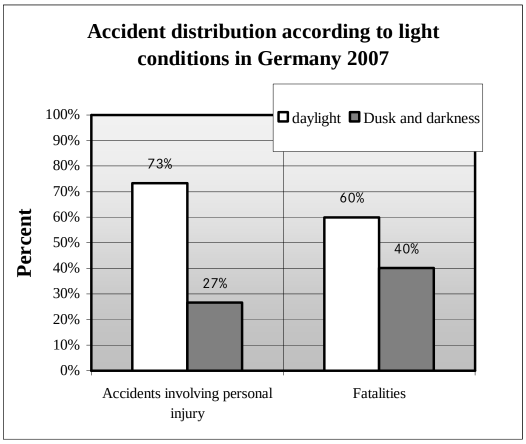
As well as the “hazard light,” it is possible to use this LED array to implement adaptive light functions, such as active curve illumination and partial high beam. In conjunction with the image evaluation, various ways of warning the driver can be tested in the ESF 2009. Simply illuminating any hazard will not be possible, since other road users must not be dazzled. In the case of pedestrians, therefore, two possible solutions would be illumination up to the waistline, or projection of a “light pointer” onto the roadway.

While most of the technical problems have now been solved, further studies are required in this area, and the legal regulation for this new function still needs to be defined.

Side Reflect – improvement in side visibility at night

Dusk and darkness pose an enormous risk potential. Over one quarter of all accidents occur under these lighting conditions. Additionally, the severity of injuries increases during these times. Some 40% of accidents involving fatalities occur at night [5] (Fig. 5).

Figure 5: Accident distribution by light conditions



The (active) lighting techniques have been steadily improved over the last few years. However, there are still many situations presenting an increased risk potential, such as an unlit vehicle that has been left at the side of a country road, or vehicles crossing an intersection without warning.

The objective of Side Reflect is to enhance the side visibility of the vehicle in order to reduce this accident risk at night. The reflective properties under diffused side light conditions are enhanced (Fig. 6). One element consisted of reflective strips on the tires (as has been standard on cycle tires for a number of years).

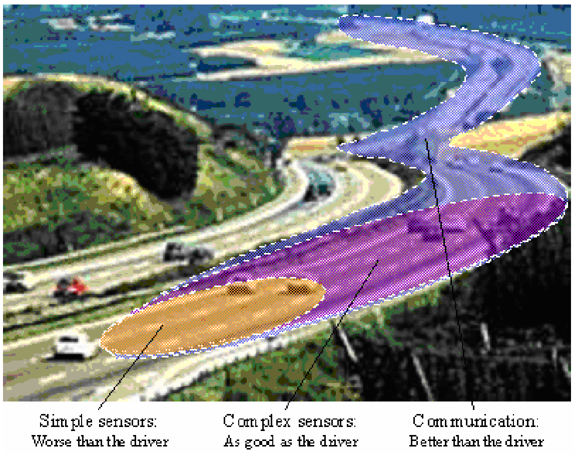
Figure 6: Improvement in side visibility with Side Reflect

An additional component that was presented by way of example in the ESF 2009 was door seals with reflective properties. Here, the external area of the door seal rubber was coated with a special film that integrates seamlessly into the vehicle design. These reflective door seals emphasize the vehicle contour for enhanced night-time visibility.

Vehicle communication

Autonomous sensor systems for hazard detection in the vicinity of the vehicle form the basis for today's driver assistance systems, which can significantly improve active safety. However, the drawback with all the standard solutions at present is that detection of the immediate environment is restricted to the field of vision. With this kind of sensor system, it is not possible to detect or locate hidden objects (vehicles), whether these are behind hilltops, curves, or buildings at inner-city intersections. In this context, vehicle communication offers the option of extending the driver's field of vision and that of the vehicle far beyond the physical range of visual detection through spontaneous (ad-hoc) networking between vehicles (Car-2-Car, C2C), and/or to the infrastructure (Car-2-I) (Fig. 7).

Figure 7: Telematic horizon



The C2C and C2I (= C2X) communication defines a cooperative system that requires the vehicle hardware configuration to be extended to include a radio communications unit (on-board unit) with GPS capability. Vehicles with the appropriate equipment then transmit information such as GPS position, speed, and direction on a cyclical basis. This information allows every receiver to put together a continuous image of the environment and monitor any changes in it.

By passing on data from one vehicle to another ("multihop communication"), the range of radio communication can be extended to areas that are not accessible for direct transmission ("single-hop communication").

The potential of C2X communications for active safety stems in part from the possibilities offered by sensor data fusion. The additional data obtained from C2X communication can improve the quality of conventional environment sensors. New assistance functions can also be realized, thanks to the continuous recording, aggregation, and evaluation of the sensor data available in the vehicle. For example, an ESP intervention might occur without the driver being aware of it when driving round a curve with a partial section that is slippery. The relevant C2X application recognizes this ESP activity and links the information with additional sensor information, such as speed, steering angle, slip/traction, outside temperature, rain sensor, etc. Based on these parameters, a suitable algorithm can detect "risk of ice" or "risk of skidding," and transmit a warning message by multihop communication (Fig. 8). When another vehicle approaches this hazard spot, the driver will receive an acoustic and/or visual warning in good time, and can adapt accordingly to the approaching hazard situation.

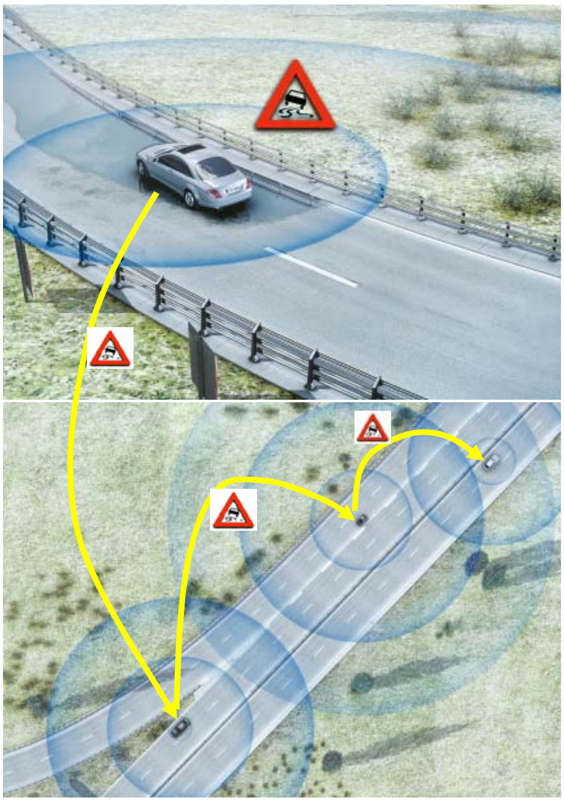
Particularly in the introductory phase of C2X systems, situations may arise where there are no communication partners within radio range. Warnings are then stored, carried further, and passed on as soon as a communication partner (vehicle or communication unit in the infrastructure) is within range (store and forward system). Traffic traveling in the opposite direction can be usefully employed in this context to transport warnings back into the target area in question. Intelligent, position-based routing algorithms ensure that, even in scenarios where there is low traffic density in the danger zone, valid warnings are not wasted, but are safely stored.

Since C2X communication is a cooperative system, its benefits and quality will increase as use of the communication systems spreads.

Rapid penetration will therefore be possible only if there is a uniform communication standard that all automakers adhere to and that is jointly defined by as many manufacturers and suppliers as possible. This will be ensured by the Car-2-Car Communication Consortium (C2CCC), and by the ETSI Technical Committee Intelligent Transportation Systems.

C2X communication, therefore, can potentially play a key role in helping to avoid accidents through automatically generated warning messages before hazards such as accident sites, vehicles left at the roadside, obstacles on the roadway, abrupt breaking vehicles, the end of a traffic jam, construction sites/vehicles, approaching emergency vehicles, etc., and in controlling the flow of traffic, all without generating any additional communication costs. However, it is less suitable for on-board autonomous system intervention (e.g. automatic braking) owing to the latency times involved, and also to system-related inaccuracies in determining position with GPS.

Figure 8: Ad-hoc communications and multihop message passing



Invisible Protection Zone, Brake Bag

The current E-Class model year 2009 features the last development stage for the time being of an automatic emergency brake system. The emergency braking function before an unavoidable collision in escalating parallel traffic reduces the speed of the resulting vehicle collision by approx. 6–8 km/h. Approximately 0.6 s before the collision, the vehicle, which is already performing partial braking, is guided into an emergency braking maneuver. A further escalation level appears impossible at present, since the vehicle has already been fully decelerated up to the slip limit. Increasing the deceleration energy through that of the wheel brake must therefore be seen as a further escalation module.

In this context, Mercedes-Benz has developed the concept of the Brake Bag. An airbag with standard driver inflator was added to the front underbody paneling of a standard S-Class vehicle. This paneling has a double-wall design, so that the airbag can be installed spread out between both body panels. Once activated, the airbag expands, supporting itself on the top side of the front integral carrier (Fig. 9). The underside is fitted with a friction lining designed to achieve optimum deceleration. It is mounted in front on the vehicle crossbar, so as to transfer the fictional forces generated by braking the vehicle on the roadway.

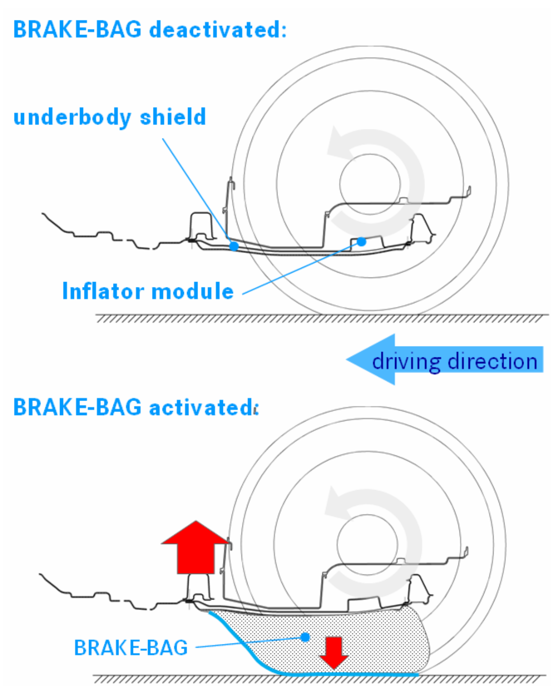
If the Brake Bag is activated in escalating oncoming traffic, i.e. after the warning that is triggered approximately 2.6 s before the time of collision, after initiating partial braking at approx. 1.6 s, and after initiation of emergency braking at approx. 0.6 s before the start of the collision, the result is a rapid and temporary increase in deceleration lasting approximately 75–100ms, with a deceleration rate of 20 m/s^2 (Fig. 10).

The increase in deceleration is primarily influenced by an elevation in the center of gravity of the vehicle as it performs the emergency braking maneuver. When the airbag expands, it momentarily raises the vehicle by approx. 80 mm. During this brief period, the thrust exerted on the friction lining of the Brake-Bag is increased by the factor of the mass acceleration times the overall vehicle mass.

This increased thrust leads to a greater rate of deceleration (Fig. 11) that can be generated with a normal wheel brake. In this context, it is important that the precise collision point is predicted as exactly as possible, since the process is reversed after a certain period, leading to a load reduction that has a negative impact on the deceleration value.

As a result of the vehicle's upward movement, the brake dive movement is also compensated for, thus improving the geometric compatibility of the braking vehicle. The deformation structures adjust to the original design level.

Figure 9: Cross-section of brake bag



The following effects can also be observed:

An influence from the seat structure on the inert mass of the occupants can also be observed, owing to the elevation of the vehicle. The value measured in tests is approx. 20 mm, which means that compression of the elastic seat foam and the convergence of the seat ramp and the bodies of the occupants result in improved coupling in the subsequent crash.

This applies in equal measure to coupling with the already tensioned seatbelt in the PRE-SAFE® phase. In the escalation to the accident, the occupant is held in position by a reversible tensioning, in preparation for the subsequent emergency braking.

Figure 10: Deceleration with brake bag

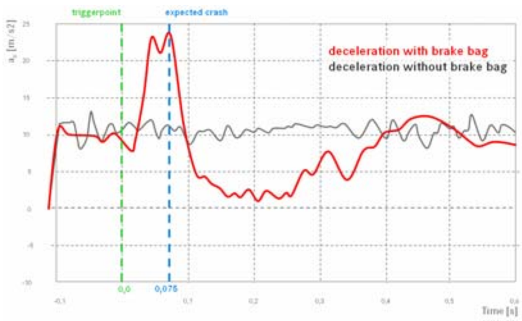
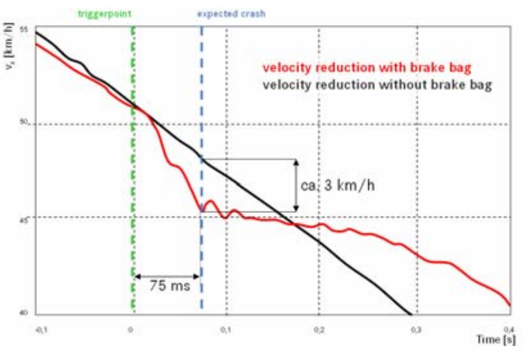


Figure 11: Reduction in speed with brake bag



The emergency braking then generates an increase to approx. 400–600 N on the belt through the inertia force imparted. The deceleration from the Brake Bag of approx. 20 m/s^2 further enhances this seatbelt pre-tensioning to approx. 800–1,200 N, thus contributing to optimize deceleration coupling even before the pyrotechnic belt tensioner is triggered.

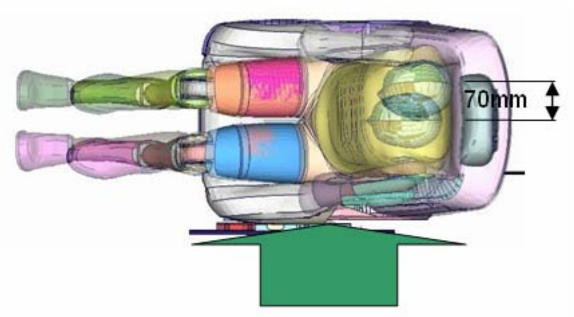
PRE-PULSE occupant safety system

Standard restraint systems can be described as only reactive occupant safety systems. For example, a generation of force and the associated energy conversion within the belt system occurs only after the occupant has traveled the necessary distance after a specific period by being thrust forward in a frontal impact. However, at this point, valuable deformation space has been used only for the vehicle deceleration, but not to decelerate the occupants. The way the airbag operates is similar to the functioning of the belt described above. Only after sufficient internal pressure has developed from precompression of the bag does deceleration (or acceleration in the case of a side impact) occur, followed by a conversion of energy to the occupant.

The crucial lever for reducing the load values in a side impact is the distance between the occupant and the door. The greater this distance, the lower the speed at which the door accelerates the occupant through the occupant protection system. At the same time, this distance is limited by the possible vehicle size and the comfort dimensions. The contact speed of the intruding door is primarily influenced by measures adopted for the body shell and the door. Here, too, there are restrictions imposed by limits on vehicle weight and the vehicle package.

Measures undertaken to date to increase side-impact protection have mainly been implemented in the vehicle itself, i.e. influencing the occupants has not been considered so far. A PRE-PULSE occupant safety system, as presented in the ESF 2009, taking the example of a side impact, uses the early information on the unavoidable collision for a preparatory energy conversion that affects the occupant. Such PRE-PULSE systems accelerate the occupant shortly after the accident event in the direction created by the collision energy (Fig. 12), and thus reduce in good time the energy delta between vehicle and occupant. The energy is not converted exclusively when an impact occurs, but instead the full energy is distributed between a light advance impact, and a reduced main impact.

Figure 12: Deflection of the occupant through forward thrusting



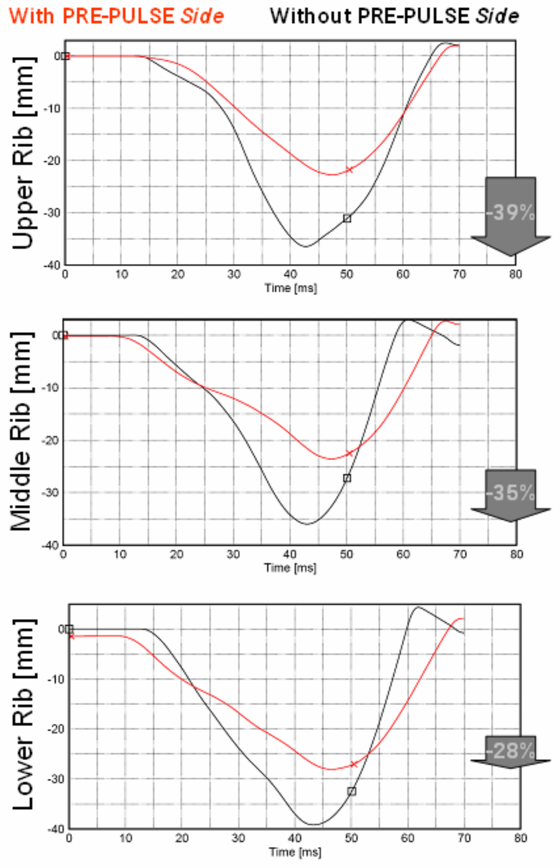
This can be simply explained using the example of a side impact.

The seat was equipped with the dynamic seat component of the multi-contour seat in order to create the PRE-PULSE effect on the occupant. This features air cushions in the “cheeks” of the driver and front seat passenger backrests, to improve lateral support on curves through inflation.

The size and inflation characteristics of these cushions were modified so that they can propel the occupant towards the center of the vehicle after a sudden pulse-type inflation. This process is reversible and can be repeated.

The movement towards the center of the vehicle increases the distance between the occupant and the door.

Figure 13: Rib deflection in load case FMVSS 214new



The side bag can now be safely deployed. The contact point between the door and the occupant occurs later with the restraint system, i.e. at a lower intrusion speed. Additionally, the occupant is already moving at a certain velocity in the direction of impact, and this velocity no longer needs to be converted through contact with the side bag and the door. Simulation tests showed a reduction in rib intrusion of 30% on average (Fig. 13).

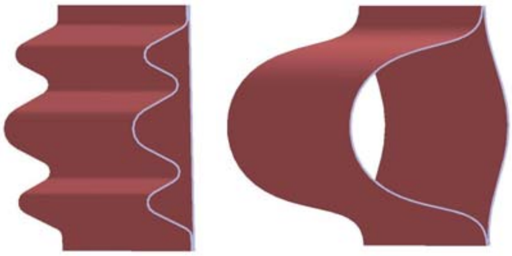
Pressurized Vehicle Components

In general, two principals of pressurized components have been investigated for front and side member applications, involving various departments at Mercedes-Benz:

- The first principle states that the components must retain the original structural characteristics they had before being pressurized. Pressure therefore needs to be carefully adjusted.

- The second principle is that the structure should expand when pressure is applied from a small cross-section to a larger one. This can offer considerable advantages, such as packaging benefits (Fig. 14), an increased moment of inertia, and an extension of the overall crash length. In addition, there are two opportunities to apply pressure and enforce the structure in general:

Figure 14: Pressure-loaded side impact protection beam. Significant increase in geometry.



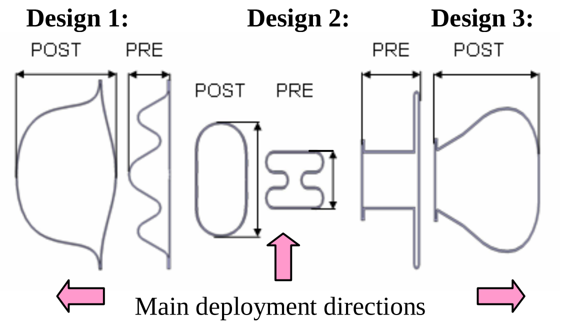
- Adding a gas generator that maintains a defined, virtually constant level of pressure over a period of time. The firing time should match the ongoing deformation of the structures involved and last between 10 ms and 20 ms for the various applications.

For an almost sealed component, high-level pressure will be available for up to 100 ms of deformation.

- Installation of a gas generator that is able to deform a component from an initial structural shape to a final one, without providing pressure for longer than is needed for deployment.

Various dynamic sub-component tests have been conducted for validation. The mean crash load was increased by 20 to 40 kN, and deformation was reduced to between 10 mm and 100 mm. With an increased mean crash load, pressurized front member components could be introduced to cover small and large-sized engines without body-in-white modifications. In addition, it seems possible to introduce new propulsion concepts that can incorporate higher component weights (batteries, hydrogen storage), without major structural modifications being necessary. A door component, the side impact intrusion bar, was investigated for a pressurized side member application. Fig. 15 shows three different designs.

Figure 15: Design studies for side impact intrusion beams.



The extension rate, which describes the rate between the deformed and undeformed cross-section shapes, came to approximately 250%, 100%, and 300%. The weight was reduced by 25%.

Figure 16: Door beam deformed/undeformed

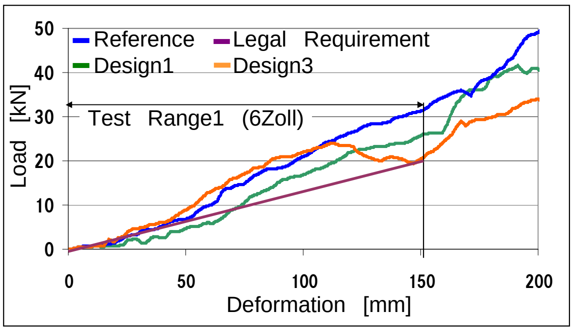
As regards safety aspects, there was an urgent need to have the main direction of deployment directed outward from the car, e.g. Design 1 (Fig. 15).

In the first development stage, the door beam was designed to fulfill FMVSS214 requirements without pressurizing. Using the tube of the gas generator as a load-carrying component, the load level increased by about 7.5 kN to 12 kN.

All undeployed designs fulfilled the FMVSS214 static requirements (Fig. 17).

If, in addition, there was pre-crash activation of the intrusion bar, which the static standard test procedure does not seem to exclude, the mean load level would rise by 6 kN.

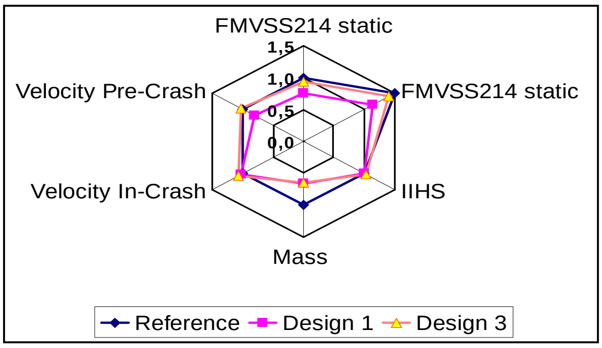
Figure 17: FMVSS214 static pole test



IIHS has been assessed in tests and simulations. It was becoming obvious that FMVSS and IIHS requirements can be achieved with reduced weight. Having lateral pre-crash sensing available, the intrusion velocity of the inner door trim was reduced by over 20%.

It has been demonstrated that the technology provides safety and weight benefits. To transfer the technology to a commercial application, however, a number of challenges first need to be met (Fig. 18). Knowing that the maximum benefits will be achieved for pre-crash applications, lateral sensing has to be established. In addition, optimized jointing, handling, and assembly concepts have to be developed. On the supplier side, there is an urgent need to come up with additional cost and weight reductions for gas generators.

Figure 18: Assessment of pressurized door components



SUMMARY

The purpose of the Experimental Safety Vehicle ESF 2009 is to illustrate new approaches aimed at improving vehicle safety. Some new, as yet unpublished approaches were selected for this. A solid foundation comes from using information on the traffic environment that is as precise and reliable as possible. Recording information using sensor beams and the networking of vehicles with the help of new communication technologies should yield further support measures in the future that will help avoid or reduce the severity of accidents.

Further milestones on the way to our vision of accident-free driving will be achieved by using innovative light technologies to improve the perception reliability of other road users, and also by improving the discernibility of the vehicle itself, particularly from the side.

Along the way, exploiting information about an imminent, unavoidable collision offers further potential for occupant and partner safety. An important component in this area is the use of the PRE-PULSE mechanism to distribute the collision energy over several impulses.

The extended coverage of the area between the occupants to protect against occupant interactions and the adaptability of the size and absorption capacity of the airbag have not been discussed in this paper, but both play an important role in accident protection in the ESF 2009.

The ESF 2009 offers an in-depth look at current development projects relating to vehicle safety at Mercedes-Benz. To an extent, it therefore also represents a risk for the company. However, it is important that experts should have the chance to discuss important new, and, in certain cases, unconventional ways of improving safety, and then develop them systematically.

The features of the ESF 2009 are intended to provide just such an opportunity.

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