Passive Safety
A Comprehensive Concept for Protecting Occupants and Partners

The Mercedes-Benz brand stands for premium safety. The new E-Class embodies this claim by integrating an ever more advanced concept of Passive Safety based on the three Mercedes-Benz safety pillars of accident research, numeric simulation, and testing.

1 Introduction

The many years of experience gained by development engineers, coupled with the findings of Mercedes-Benz accident research, form the basis for development of Passive Safety. Here, direct interfacing between testing, computation, and design engineers allows detailed development work to be carried out. The goal of all innovations and developments is to provide optimal protection for occupants. After all, every component of the safety concept must work properly in the event that a real accident occurs.

2 Integral Safety Concept

Mercedes-Benz has adopted an integral safety concept as part of an overall strategy to combine Active and Passive Safety. Safe driving means helping the driver avoid dangers, warning the driver in good time, and offering him or her with the necessary assistance. PRE-SAFE, a safety system offered in the E-Class as standard equipment, responds in a preventive manner by avoiding accidents or reducing their impact and setting up the vehicle to best cope with an impending accident. If an accident cannot be avoided, each occupant and road user is provided with the amount of protection they need to minimise injury. After the accident, steps must be taken to prevent further accidents from occurring and to promote recovery.

3 Development of Passive Vehicle Safety

Early in the development phase (long before the initial prototype is built), a digital prototype (DPT) is created to optimise each part of the bodyshell based on how it responds to over 5000 “virtual crashes” that test geometry, material thickness, joints, and material quality. An additional 12,500 calculations were performed to design and optimise the pedestrian protection characteristics of the new E-Class. Computation engineers at Mercedes-Benz used one of the world’s largest clusters of multi-processor computers for crash simulation to analyse the complex models. Integrated occupant simulation made it possible to determine at an early stage how occupants would interact with the vehicle structure and restraint systems. This knowledge was then applied to the design of the overall vehicle. Taking occupant kinematics and loads into account meant considering every aspect of safety and ensuring the right approach to designing each component. To this end, the impact-absorbing steering column, driver’s airbag, kneebag, and favourable seat structure were integrated with

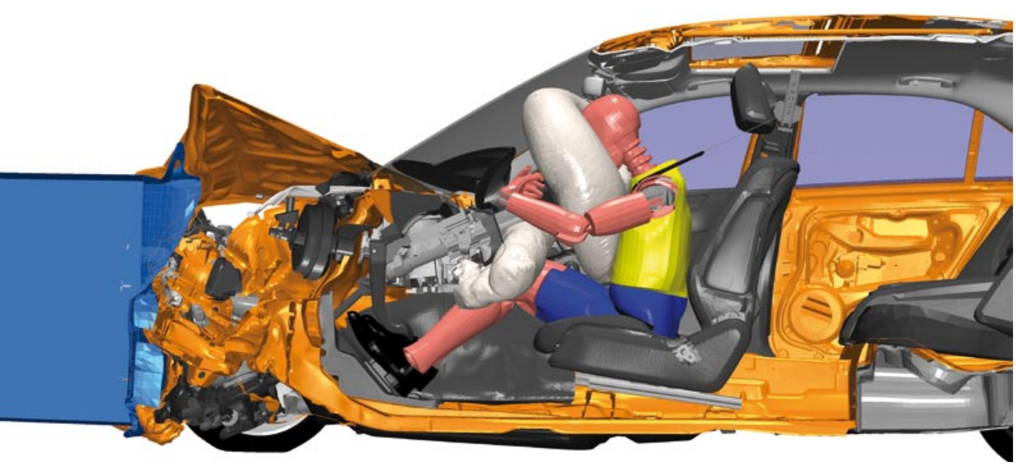

Figure 1: New E-Class numerical simulation of frontal collision

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Figure 2: New E-Class numerical simulation of side collision

each other very early in the design stage for the frontal-impact restraint system. The entire interior and dummies were simulated using the Finite Element Method (FEM) for the frontal- and side-impact restraint system. The finite element method, which has been used to analyse vehicle structure models for many years, again proved to be beneficial in visualising occupant motion, Figure 1. Bodyshell and door panel deformation characteristics and the deployment of the window curtain airbag and thorax bags were adapted for side-impact protection by running through extensive integrated scenarios, Figure 2. These simulations were supplemented with a large number of component tests. As a result, the size, volume, and shape of the airbag systems could be determined with a fair degree of accuracy in advance. All of these component designs, which were drafted and refined on the computer, were also physically tested prior to initial overall vehicle trials. This led to a very high degree of maturity among the test vehicles.

4 Frontal Collision

The impact-absorbing front-end structure, together with the very rigid passenger compartment, are primary passive safety features of the new E-Class, Figure 3, that can minimise the deceleration forces that act on the vehicle occupants during an accident (even a serious one), while providing them with ample protection room. Especially noteworthy safety features of the new E-Class bodyshell:

– The high degree with which an impact is absorbed at the front end is safeguarded by including homogeneous load application and transfer points across multiple parallel load paths, Figure 4. This also ensures good distribution in offset frontal collisions.
– Major assemblies at the front end are positioned in a way that maximises the protection offered by the crumple zone. The engine, for example, is mounted to a bolted integral support frame made from an ultra high-strength steel alloy specially designed to deform upon impact.
– The front-end structure is designed to work with the crash impact systems of other passenger cars in a frontal collision.
– The front wheels are braced by longitudinal support beams that have been moved forward to introduce an additional load path. This greatly contributes to the crash protection offered by the front end during a severe frontal collision.
– The widespread use of high-strength and ultra high-strength steel alloys, in conjunction with the increased use of high-strength adhesive joints, has resulted in an extremely rigid passenger compartment, Figure 5.
– Both front doors feature a crash barrier that prevents the fender from being pushed into the door gap to make it easier to open the door even after a severe frontal collision has occurred.

Optimal occupant protection during a frontal collision is ensured not only by the efficient deceleration curve and very rigid passenger compartment, but also by restraint systems that tighten seat belt slack via reverse tensioning before an accident occurs (PRE-SAFE) and work together with the pyrotechnical belt tensioner to provide maximum restraint for occupants. The goal of these systems is to involve occupants in the deceleration process as soon as possible in the event of an accident so that interior space can be optimally used as an additional buffer. Like the predecessor model, the driver and front-passenger airbags have two-stage gas generators, which can be activated if the situation requires it. Adapting the level of restraint applied to the severity of the accident further reduces the load placed on the occupants. The front seat belts integrate high-performance tensioners and belt force limiters. The belt height adjuster and accompanying belt buckles allow occupants to individually fit their seat belt. The kneebag provides the driver with additional protection primarily in the knee and lower leg area. Pelvic restraint, which is applied early on by the driver's kneebag, improves the way in which the driver becomes involved in the deceleration process, allowing the forward displacement path to be utilised as efficiently as possible. This further reduces occupant loads,

Figure 3: 40 % offset front crash

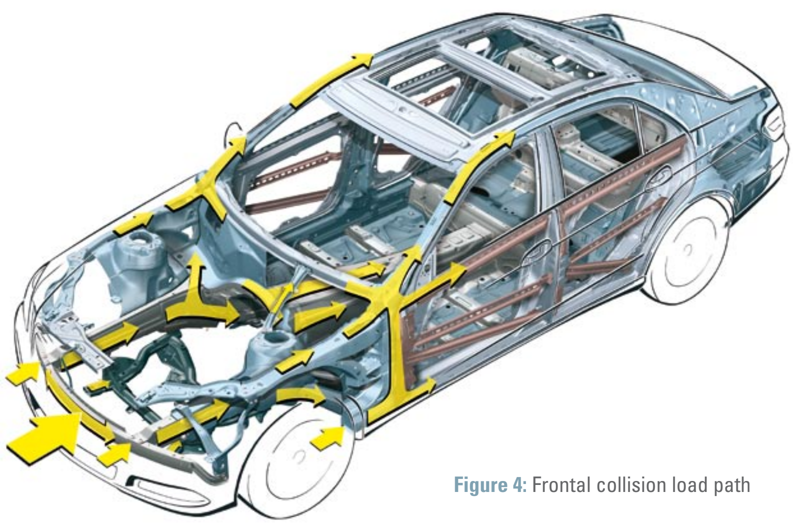
Figure 4: Frontal collision load path

especially in the upper torso area. The kneebag is located behind the cockpit trim panel under the steering column and deploys here together with the driver's airbag. The impact-absorbing steering column extends the displacement path available to the driver, thus further reducing loads placed on the chest and head during a frontal collision. An automatic child seat recognition system can be ordered for the front-passenger seat. This system deactivates the front-passenger airbag via a transponder when a child's seat recommended by Mercedes-Benz is used. The rear seats are also equipped with three-point seat belts as well as high-performance tensioners and belt force limiters (outer seats only). Adaptive control of the front restraint systems is ensured by an optimised network of crash sensors. The new E-Class uses two exposed up-front sensors at the front in addition to acceleration sensors in the central control unit to detect a frontal collision, Figure 6. The effect of these protection systems, however, can only be maximised when the occupants are wearing their seat belts. This is why the new E-Class comes equipped with belt status sensors at all seats. Visual and audible alerts are triggered whenever the driver and front passenger do not fasten their seat belts. The number of fastened seat belts in the rear is also displayed in the central display area of the instrument cluster for the driver.

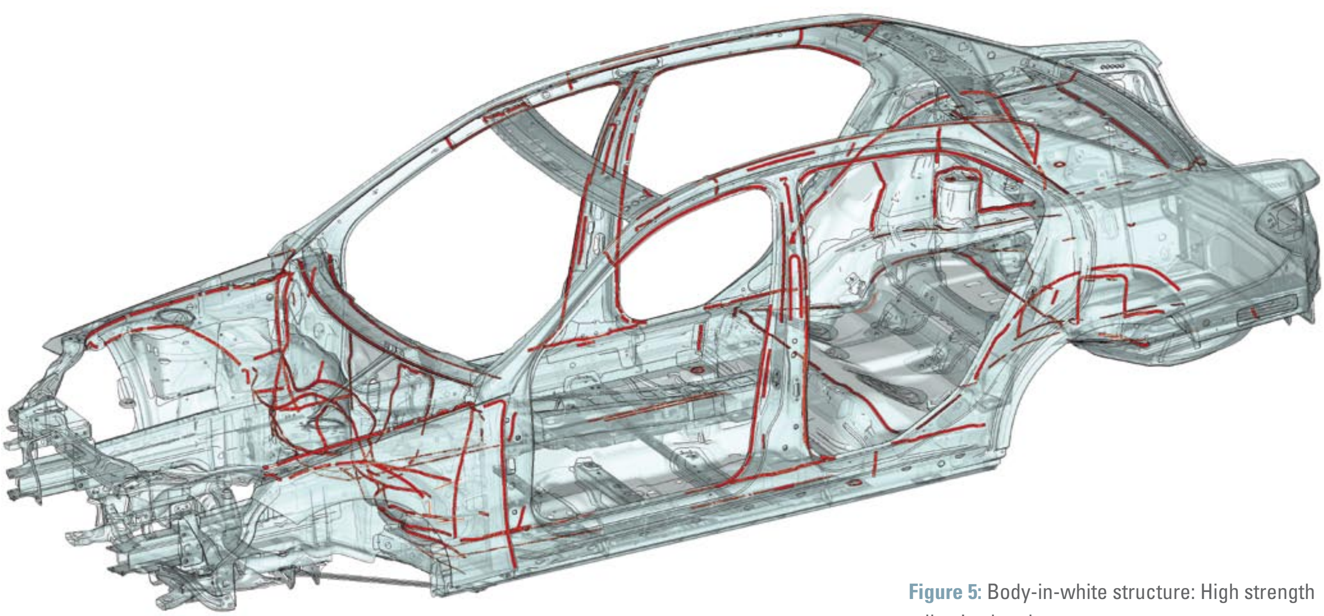
Figure 5: Body-in-white structure: High strength adhesive bonds

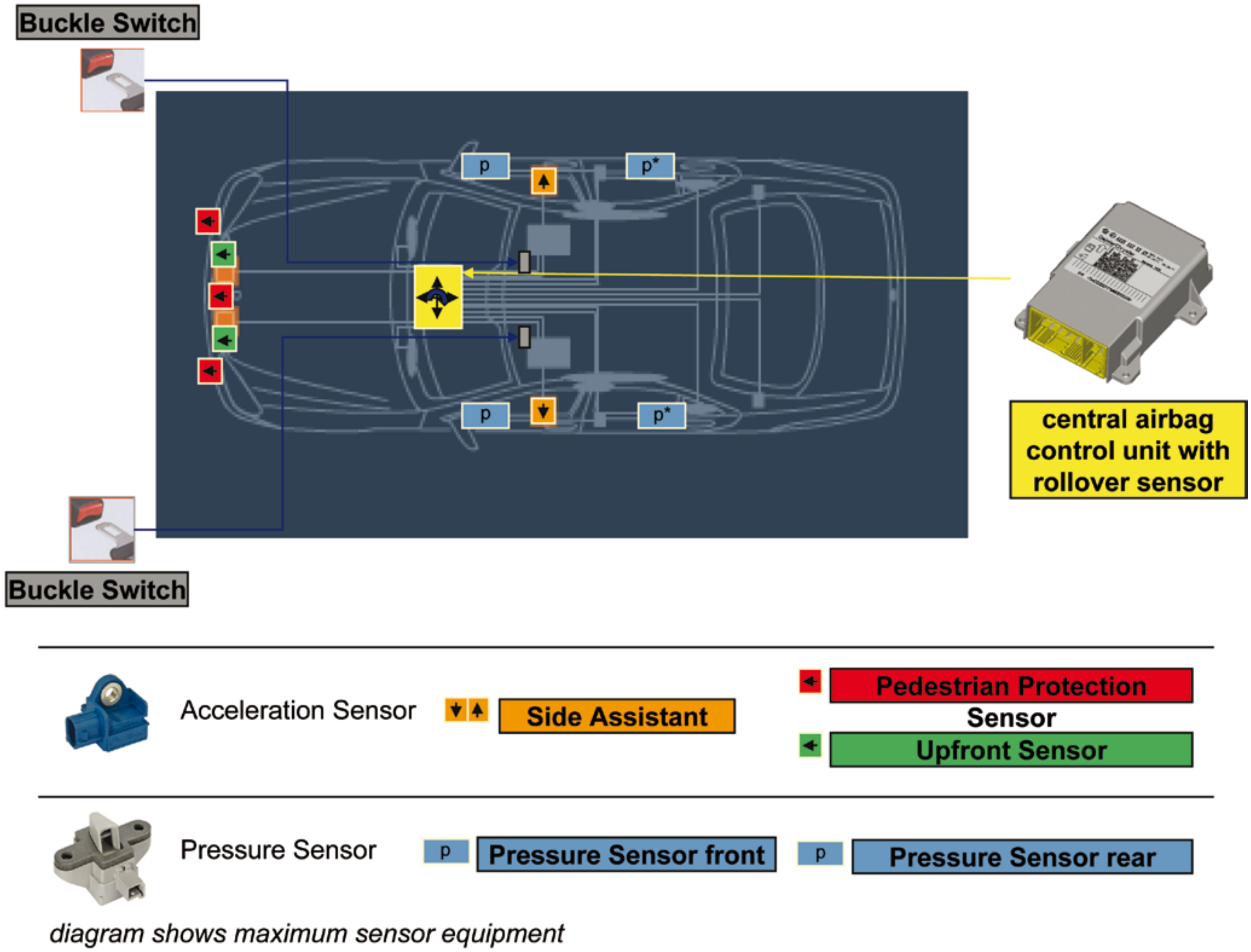

Figure 6: New E-Class Passive Safety sensors

5 Side Collision

A rigid passenger compartment is also essential if effective occupant protection is to be provided during a side collision. The side of a vehicle, unlike its front end, offers very little room that can be used to protect occupants. The biggest challenge was, therefore, to integrate a concept that would provide occupants with optimal protection here as well. This goal could only be reached by using an extremely robust sidewall structure in conjunction with effective restraint systems. The passenger compartment of the new E-Class, which is also extremely rigid at the sides, uses ultra high-strength steels in the B-pillars, the rocker panels, and in the lateral roof frame. These areas are reinforced by additional reinforcement structures including a crossmember under the windshield, seat crossmembers under the front and rear seats, a pedal floor panel crossmember, front roof crossmembers, a gearbox crossmember, and support brackets on the tunnel, which effectively enhance sidewall strength and channel the force of the impact to the other side of the vehicle. The E-Class is already in line with the future side-impact requirements defined in revised US Federal Motor Vehicle Safety Standard 214. For example, it already passes the angled pole test with additional reinforcements in the floor and rocker panels to protect occupants in such an accident. The load paths characteristic of a side collision are shown in Figure 7. The doors are key to ensuring the rigidity of the side structure and integrate additional side collision profiles. They are also mounted on the pillars via robust hinges and latches to prevent forced entry into the safety zone of the occupants. The door panelling is designed to brace the thorax bag when it deploys and does not have any overly protruding areas. These measures safeguard protection room while providing the space required for the window curtain airbag and thorax bag protection systems to deploy. The driver and passenger-side thorax bags are located in the backrests; thorax bags for rear occupants (optional extra) are fitted behind the wheel well liners. Standard window curtain airbags cover the side of the vehicle between the A- and C-pillars and are deployed via a gas generator mounted in the lateral roof frame behind the B-pillar. In the event of a side collision, the window curtain airbag can support the occupant's head in the early stages of an accident. This minimises lateral pendulum motion and cushions potential impact with a side window, B-pillar, C-pillar, or roof frame. Broad coverage of side windows can also provide protection from penetrating objects, reduce the risk of occupants being thrown out of the vehicle, and protect their arms. The pelvis airbag, fitted in the outer side of the seat protects the pelvic area from sustaining injury caused by skidding into a tree or lamppost, for example. Early ignition of the airbag systems, which is especially critical during a side collision, is ensured by a central control unit in conjunction with acceleration sensors in the B-pillar and pressure sensors in the front doors, Figure 6. The enhanced interaction of the vehicle body, seats, interior panelling, restraint system, and sensor system achieved through rigorous simulation and testing can provide state-of-the-art, comprehensive protection for E-Class occupants in side collisions, **Figure 8**. The E-Class is equipped with a rollover sensor that works together with the belt tensioners and window curtain airbags to more effectively protect occupants from injury in the event that the vehicle rolls over.

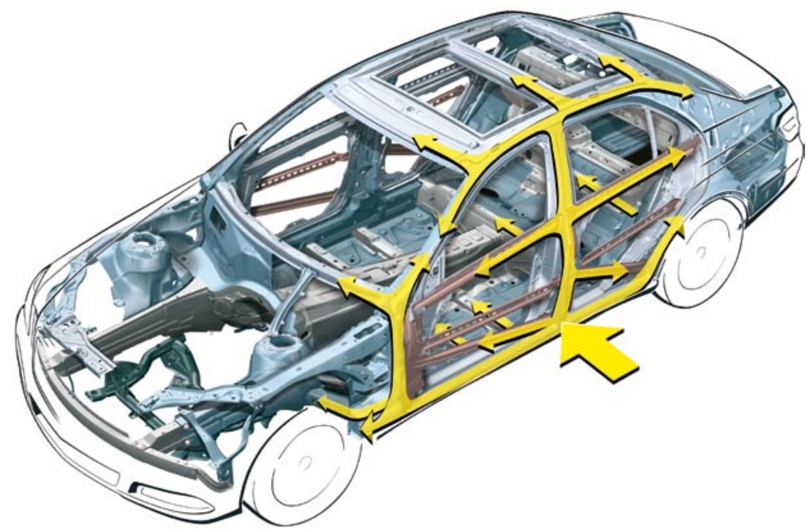

Figure 7: Side collision load paths

6 Rear-End Collision

In a rear-end collision, impact energy is channelled via a rigid bumper bracket and crashboxes to both rear longitudinal support beams, which are made from high-strength steel. The fuel tank is mounted outside the crumple zone under the rear seats in front of the rear axle. This allows the entire rear section of the vehicle and its impact-optimised structures to be used as a crumple zone to effectively protect occupants in a rear-end collision as well. The highly rigid passenger compartment protects the interior from critical deformations in frontal and side collisions up to very high impact speeds. The belt tensioners are activated in the event of a severe rear-end collision to keep occupants in their seats. Active front head restraints (NECK-PRO) are integrated into both front seats and work in conjunction with the rigid backrest to provide immediate support for the head (even in minor rear-end collisions). When the vehicle is struck from the rear, the sensor-controlled head restraints move toward the occupants via pretensioned springs to reduce the load placed on the head and neck. Activated head restraints can be reset by simply pushing them back. This lowers repair costs (especially when the vehicle was involved in a minor accident) and the head restraints are fully functional again. In addition to staged frontal, side, and rear-end collisions, roof-drop and dynamic rollover tests were carried out to ensure that the protection room provided by the passenger compartment remains intact in all accident scenarios, **Figure 9**.

7 Compatibility

For many years, ensuring compatibility has been a critical aspect of achieving vehicle safety at Mercedes-Benz. Compatibility in an accident refers to the ability of a vehicle to interact with the other road user to the benefit of both parties. When a compatible vehicle collides with another car, the forces involved are balanced out early on so that the crumple zones and protection systems relevant to the accident can be activated at both ends. Critical requirements that had to be met when the structure of the E-Class was being redesigned were rigidity and compatibility of shape. Accident prevention and impact-reducing active safety

Figure 8: New E-Class airbag systems

systems make a considerable contribution to this end. The electronic stability programme and improved electronic Brake Assist System BAS PLUS (activated in emergency braking situations), for example, have proven to be effective at avoiding accidents. The PRE-SAFE brake also helps the driver avoid critical situations. The interaction of these systems reduces stopping distance substantially and increases the vehicle's potential to completely avoid a collision or reduce its severity, thus greatly enhancing the level of protection available.

8 Pedestrian Protection

Reducing accident severity is especially critical for more vulnerable road users such as pedestrians or bike riders, since they do not have a crumple zone. Here, passive measures for protecting pedestrians were further improved to enhance active measures such as BAS PLUS, which help to avoid an accident or reduce its severity. In order to reduce impact of the engine hood, for example, the deformation depth between the hood and the components beneath it was increased. This was achieved by raising the exterior contour of the vehicle at the front end and lowering the installation position of the engine as well as rearranging other components in the engine compartment such as control units and fluid reservoirs. The E-Class also features an active engine hood for the first time. When a pedestrian strikes the engine hood, a sophisticated sensor system (three sensors in the bumper) and intelligent algorithms process the crash data and trigger actuators near the hood's hinges to lift the hood by 50 mm. The additional space between the engine hood and the underlying components serves to gently, yet efficiently reduce head impact, **Figure 10**. The engine hood was specially designed to meet these deformation requirements. The use of aluminium and a unified reinforcement assembly on the underside of the hood further reduce the load placed on pedestrians. The impact area of the bumper was enlarged, which is especially noticeable in the flush design of the spoiler lip. The engine compartment panelling used here, which has been reinforced, also acts as a sturdy brace. This,

Figure 9: High and super high-strength steel used in the new E-Class body-in-white structure for more safety and fatigue strength

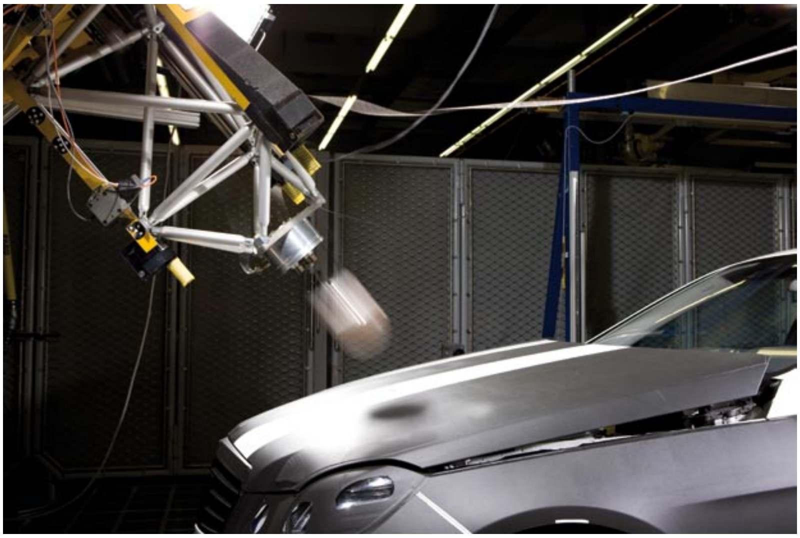

Figure 10: Excellent results in head impact testing for child and adult heads

Figure 11: Child safety seat in front passengers position: Safety by the Automatic Child Seat Recognition System

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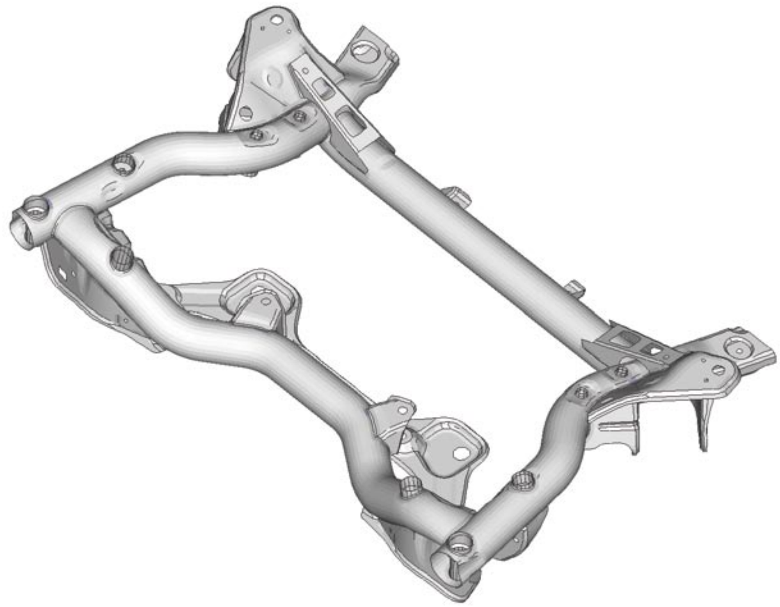

Figure 12: Front cradle: High-tensile but ductile steel

together with the lower foam density in the bumper impact absorber, reduces leg impact. Other design details such as folding outside mirrors and recessed windshield wipers also increase pedestrian protection.

9 PRE-SAFE

This preventive protection system made its debut in the redesigned S-Class in 2002 and is included in the E-Class as standard equipment. When PRE-SAFE detects critical driving situations that can lead to an accident, additional safety measures are activated to provide better protection for occupants. One of these measures involves immediately tightening belt slack via the seat belt tensioner to keep occupants firmly seated so that they can be incorporated into the deceleration process as soon as possible and undesirable movements can be avoided. This allows the loads placed on occupants to be further reduced.

10 Child Safety

A great deal of attention was focused on ensuring child safety in the new E-Class, Figure 11. Comprehensive tests were carried out to achieve a perfect seating system and optimal protection for small occupants, regardless of whether they are sitting in a rearward or forward facing child's seat. Installation and removal of child's seats is now easier thanks to improved guides and markings for Isofix seats with a top-tether anchor or support leg. The Automatic Child Seat Recognition System (Baby Smart) for the front passenger's seat also greatly increases safety by reliably activating or deactivating the airbag automatically.

11 Durability

Another safety aspect of Mercedes-Benz vehicles is durability, or reliability. By using calculation-based design programmes, running through simulations, and carrying out real-world tests, the durability of the body could be optimised to attain ambitious performance goals and minimise vehicle weight. The support frame of the new E-Class plays an especially important role here. High in strength yet ductile, it is very good at absorbing the impact of a crash while remaining unsusceptible to high operating loads, Figure 12. ■

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