What is a Realistic Frontal Offset Test Procedure

Dieter Scheunert, Rainer Justen, Roland Herrmann,
Falk Zeidler, Jürgen Decker, Ingo Kallina

Mercedes-Benz AG, Sindelfingen / Germany

Abstract

With an increasing number of vehicles performing the FMVSS 208-flat barrier impact test and increasing belt usage in European countries, a high reduction of occupant injuries in general and a change of acceleration- versus intrusion- induced injury mechanisms could be observed in Europe.
Therefore, beginning in 1978 Mercedes-Benz has emphasized front structural countermeasures effective in the frequent asymmetrical frontal impacts in order to answer this new challenge. As an internal test, an offset-impact with 40% overlap against a rigid barrier was defined. Since then, one of the high priorities in the design of Mercedes-Benz passenger cars is to fullfil these internal requirements with a test speed of 55 km/h.

1 Introduction

In spite of highly increased belt usage rates and numerous safety actions of legislation and car manufacturers, 22604 car occupants were fatally injured in road accidents within the European community. Frontal car crashes still represent the majority of accidents. Head and thorax injuries lead in the statistic of the severe, life threatening injuries. Especially in frontal crashes, this kind of injury is caused by intruding parts or a disintegrating passenger cell. This is verified by a research study from United Kingdom [Lit. 1]. Since the late 1960's, most countries require different crash tests to evaluate the secondary safety of a car model. The standard tests of US Federal Motor Vehicle Safety Standard (FMVSS) 208 or ECE Regulation 12 against a flat, rigid barrier which is perpendicular or at 30 degrees, do not sufficiently represent the actual accident scene on the road. According to FMVSS 208, the dummy values must not exceed a certain limit, whereas the European R12 limits the maximum horizontal displacement of the steering assembly. A stronger orientation to real world accidents and the derivation of a realistic frontal test is necessary.
Since 1969, Mercedes-Benz investigates severe accidents with Mercedes-Benz passenger cars. Up to now, about 2400 severe accidents with over 3800 injured occupants in Mercedes-Benz passenger cars were analysed. From the results we have derived test configurations which supplement legal requirements to reach the high safety performance of Mercedes-Benz passenger cars. As early as 1973 we started with crash tests where the cars crashed into the wall with a partial overlap of 50 % of the front end. In 1978 different structural modifications were implemented for the most frequent asymmetrical frontal accident and an internal offset test was defined with 40% overlap and 55 km/h impact speed against the rigid barrier. All current car lines must meet this internal requirement in addition to the legal tests.

2 Accident Research

2.1 Description of Collisions

The implementation of effective countermeasures is mainly based on the knowledge of the collision distribution [Fig. 1]. The frontal collision, with 62 % the most frequent type of collision, has to be further classified according to the degree of overlap with the car front end to define significant test procedures.

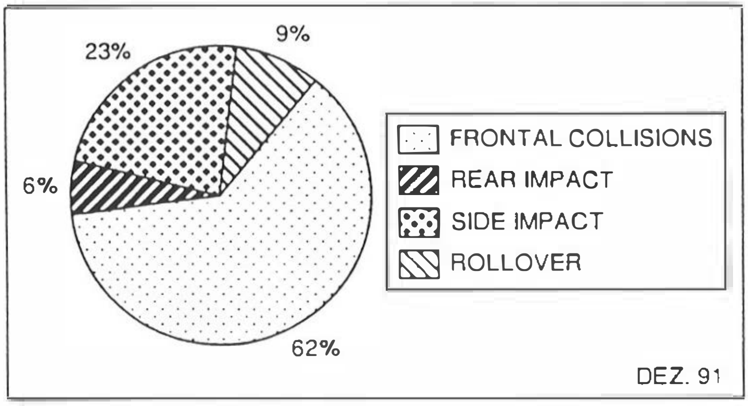

Fig. 1: Distribution of the collision configuration.

The injury severity of the occupants mainly depends on the following parameter:

- the degree of overlap of the car front end
- the engine participation
- the stiffness of the passenger cell
- and the accident severity.

The accident severity is defined by the deformation energy on the basis of comparative crash tests. The result is a speed value for the energy: the Energy Equivalent Speed (EES). Also important is the Equivalent Test (ET). With the same deformation, the ET is the adjacent test to real accidents. Fig. 2 shows the classification of real frontal collisions to different ETs. 28 % of the frontal accidents had a partial overlap close to 100 %, 15 % of the accidents are comparable to a 30°-crash into a rigid barrier and 57% of the cases are well approximated by a test where the cars hit the object / car with some kind of various partial overlap: the offset-test. Only 11 % of the offset-collisions are comparable to a 50 % barrier impact, as it was performed by the German auto magazine "auto motor & sport" [Lit. 4]: 50 % offset into a rigid barrier, 55 km/h crash speed, 15 ° angled barrier. The initial overlap degree in car-to-car collisions must significantly exceed 50 % to involve the engine to the same extent as in this test. As is shown in Fig. 2, the test requires an initial overlap degree of 60 % to 80 %. In these cases, in Mercedes-Benz cars, the passenger cell shows no relevant deformation; the cars do not glance-off.

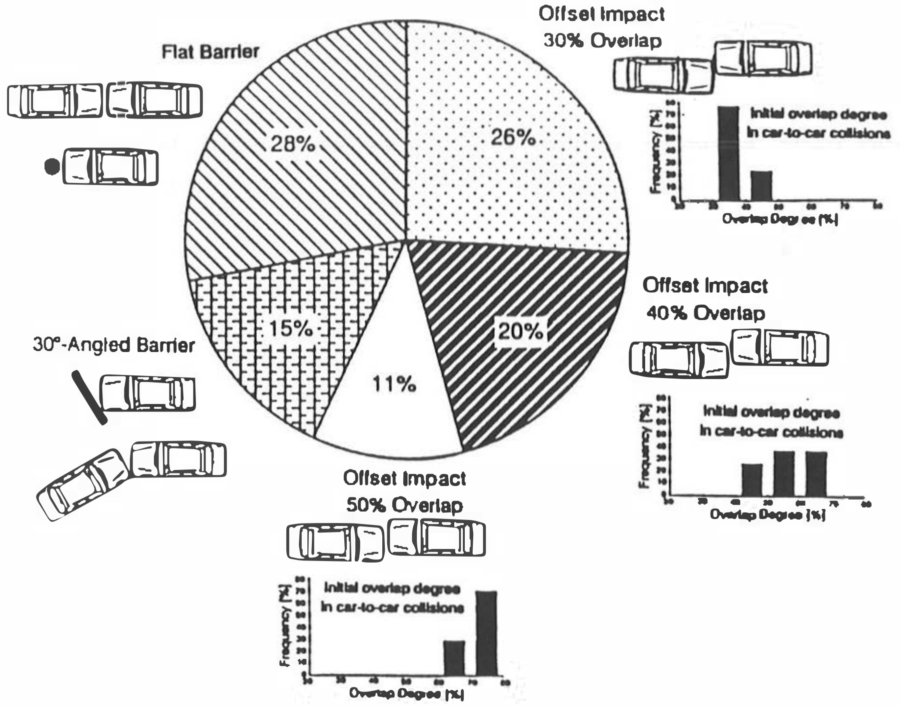

Fig. 2: Frontal impact configuration in real world accidents assigned to equivalent test procedures.

The far more frequent accidents (46 %) with smaller overlap degrees between 30 % and 60 % can be simulated with a barrier test with overlap degrees between 30 % and 40 %. Compared to the 50 % offset test, the resulting deformations are much greater as the car structure is heavily loaded. Therefore, the injuries caused by intrusions increase and injuries caused by accelerations decrease. The engine is not directly hit and there is a tendency for the car to glance-off with a smaller overlap degree, rotating counterclockwise. Deformations adjacent to a 30° barrier crash occur only with 15 % frequency.

Looking at the distribution of the initial overlap in (Fig. 3) shows a peak of 30 %. 2/3 of all cases occur in a range between 30 % and 50 %. With increasing overlap, the frequency clearly decreases.

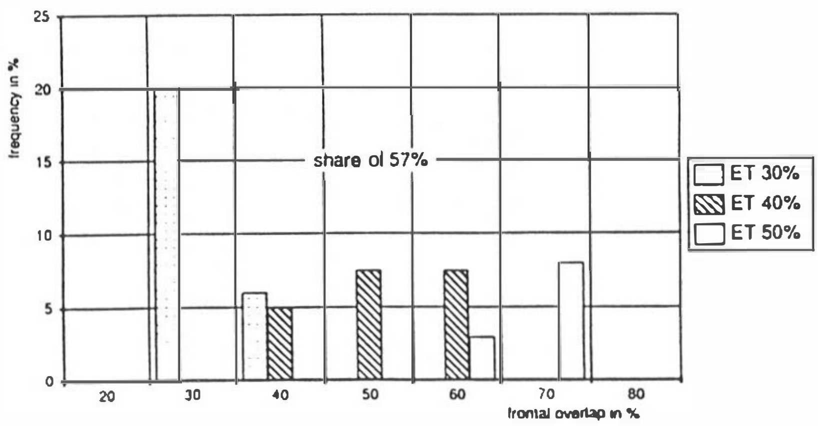

Fig. 3: Frequency of initial overlap degrees in real frontal collisions related to equivalent barrier tests.

Accident research in the United Kingdom produces an even smaller tendency to higher overlap degree [Lit. 1]. Only 17 % of all frontal collisions took place as full frontal, whereas 45 % had an overlap degree up to a third. This fact explains the typical on-coming traffic situation where evasive driving manoeuvers preceed the impact. Another investigation from Germany [Lit. 2] concludes similar results. Only 21 % of all frontal crashes were full frontal and in 50 % of all cases less than half of the front end was impacted. The angle of the impact force is maximum parallel to the car longitudinal axis. Evaluations of Mercedes-Benz accident research had a similar result in the range between ±15°. Left side impacts of the car front end are obviously more frequent than right side (11 %).

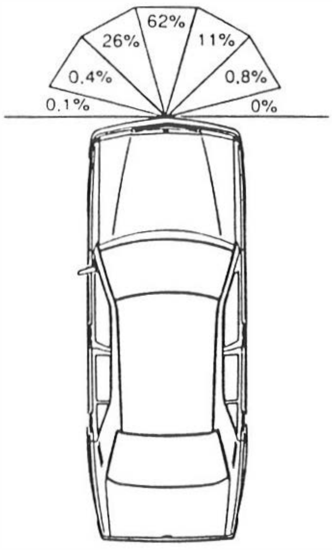

Fig. 4: Frequency of the impact directions referring to the car front.

The legally prescribed crash tests are conducted at 50 km/h. The evaluation of Mercedes-Benz frontal collisions with full overlap shows that 90 % of all cases happen with an EES smaller or equal to 50 km/h. For the same 90 %-value in offset collisions [Fig. 5A], a test speed of 50 - 55 km/h is justified which means that only 10 % of the frontal collisions with partial overlap have a higher accident severity. A test speed of 55km/h covers about 50% of the offset collisions [Fig. 5B] with severe to fatal injuries (MAIS 3+).

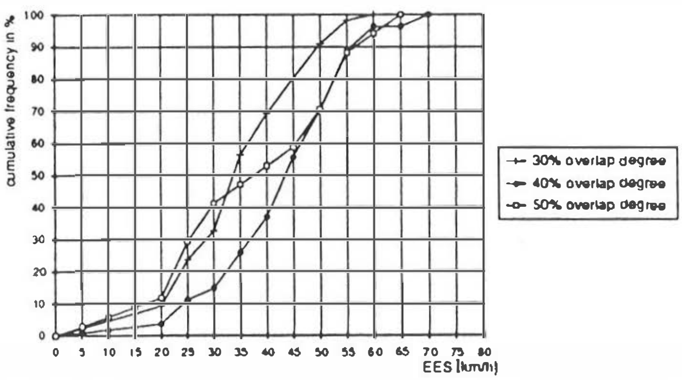

Fig. 5A: Cumulative frequency of EES in frontal collisions (MAIS 1+).

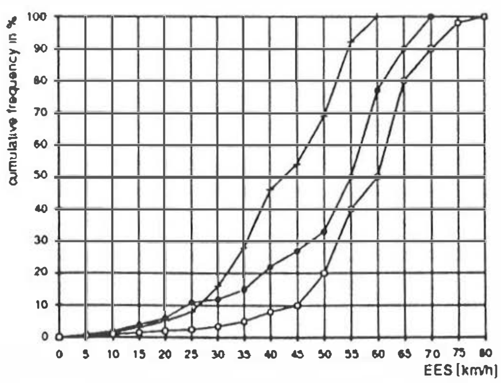

Fig. 5B: Cumulative frequency of EES in frontal collisions (MAIS 3+).

2.2 Occupant Injuries

The injury severity and the causes are strongly dependent on the direction of impact, the overlap degree of the impacted car front end, and the amount of energy. These parameters primarily define the occupant kinematics. Analyses of the Mercedes-Benz accident research show in many cases that the occupants move straight forward or oblique to the left (Fig. 4). The injuries are coded with the AIS (Abbreviated Injury Scale

[Lit. 3]) which ranks in 6 severity levels:

1 minor injuries
2 moderate injuries
3 serious injuries
4 severe injuries
5 critical injuries
6 maximum injuries (currently untreatable)

The MAIS-value is set according to the maximum injury level. In Fig. 6 the frequency of injuries for belted drivers and passengers in frontal collisions is shown for the different Mercedes-Benz car lines. 167 cases with 220 occupants total in the previous mid range model 123 and 259 cases with 349 occupants total in the actual car lines 201, 124, and 126 were evaluated. Cases with airbag deployment were excluded to maintain the data compatibility. Moreover, only cases in the accident severity range of 41 - 60 km/h were considered, as the test speeds of legal crashes or from published test series like "auto motor & sport" and "New Car Assessment Program" are within that range. This limitation reduces the number of front occupants involved to 76 in the series 123 and to 100 in the series 201, 124, and 126. The distribution of the accident severity is similar. Significant changes of the MAIS were achieved in the new car lines, compared to the model 123:

MAIS 4 - 6:	- 70 %
MAIS 3:	- 30 %
MAIS 2:	+ 20 %
MAIS 0 - 1:	+ 57 %

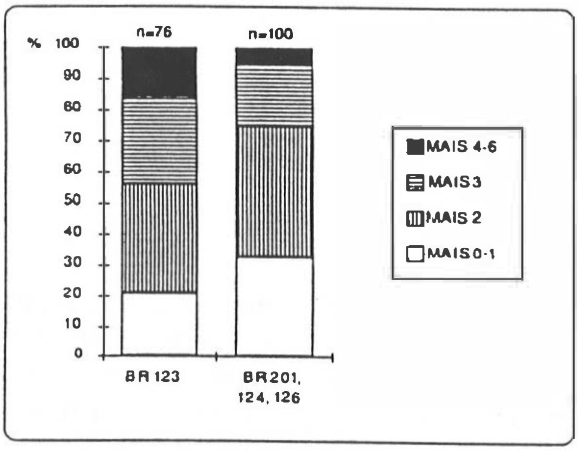

Fig. 6: Frequency of injuries for belted front occupants in different Mercedes-Benz car lines. EES 41 - 60 km/h.

The shift from higher to lower injury levels expresses a significant increase in safety performance. This result is confirmed in Fig. 7 as the risk to be severely injured at different body regions is also clearly reduced in modern Mercedes-Benz car lines. The evaluation included head injuries which are frequently life threatening in frontal collisions and injuries of the lower extremities, often the cause of long term impairment and high cost [Lit. 5].

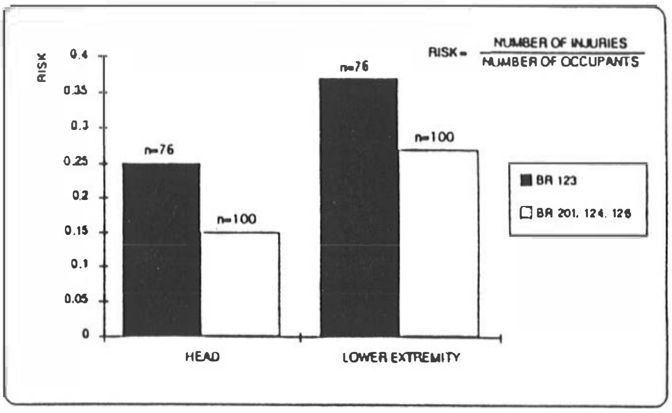

Fig. 7: Injury risk of the head and the lower extremities (AIS2+) for belted front occupants in different Mercedes-Benz car lines. EES 41 - 60 km/h.

The new car lines had 40 % less head injuries and 27 % less extremity injuries. The evident reduction of both injury frequency and severity is based on effective countermeasures which are based on the experience of accident investigation. It follows, that such countermeasures can be implemented in running series production to a certain extent only or in new models. The first priority of the offset design of the car body [Lit. 6] is to resist excessive intrusions from an asymmetrical crash with an overlap degree of 30 % - 50 % where the engine is not directly hit. According to [Lit. 1], large intrusions are mainly responsible for severe to fatal injuries (AIS 3+) in frontal collisions. Further safety features were integrated i.e.

- floor carpet with foam wedge to reduce the foot contact velocity
- fixed safety steering assembly with corrugated tube
- energy absorbing steering wheel and perforated yielding cover in the NON-AIRBAG hub
- height adjustable belt system with pretensioners
- padding measures.

3 Test Procedures

3.1 Car-to-Car Test

A car to car test with an initial overlap degree of 50 % relative to the front end width would correspond to an overlap degree of 57 % relative to the full car width. Again it is important to say that the engines will only hit with an overlap degree greater than 60 % relative to the full car width. A crash of two identical cars with 55 km/h speed each has the following result: During the deformation, no major glance-off is observed. Both cars crumple equally at the point of impact. Late, at the end of the deformation phase, both cars rotate counterclockwise. In final position, both cars have rotated some 40° to the center line with small rebound. The deformation of front end and passenger cell decrease to the center line. The side structure has the greatest difference both in deformation and compartment intrusion compared to the rigid barrier test. The beginning passenger cell deformation is indicated by a sharp A-pillar bend at the height of the belt line and the roof member. The driver's door is also heavily loaded and bends. At this overlap degree, the in-line engine is hit very late by the striking car's wheel and forced back. At this time of engine movement, the remaining energy is dissipated by passenger compartment deformation. Fig. 8A shows a typical deformation characteristic of an asymmetrical crash.

The dummy loads are significantly lower than in a FMVSS 208 test, though the impact speed is 5 km/h higher. The relatively soft deforming front end leads to more deformation and a lower average deceleration. Despite a low deceleration, excessive intrusion can cause severe injuries. These mechanical loads are not monitored with the existing dummy devices. Only femur forces are measured up to now, all other signals are derived from deceleration measurement. In order to understand potential injury associated with intrusion, additional measurement devices with pressure sensitive foils or displacement potentiometers are urgently needed.

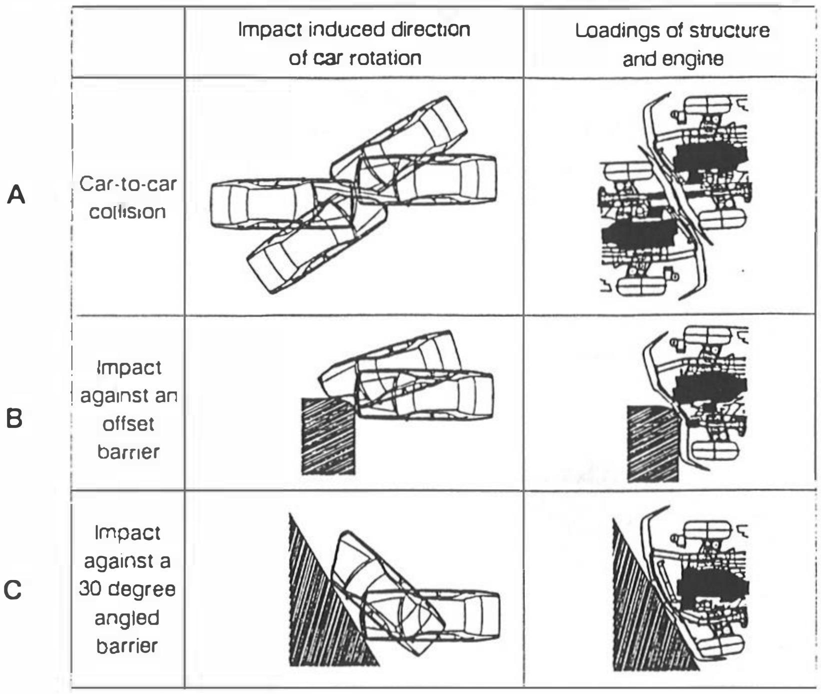

Fig. 8: (A) Car-to-car collision,
(B) Car against an offset barrier,
(C) Car against a 30° angled barrier.

3.2 Barrier Tests

It is important to produce the same deformation pattern of the front end with maximum longitudinal values in the side structure and low resulting deceleration values to simulate the most frequent asymmetric frontal accident loadings

3.2.1 Partial Overlap Frontal Crash Test (Offset)

In a 30 % or 40 % offset crash against a rigid barrier, the structure of front end and the passenger cell are heavily loaded. The engine is not directly hit and the opposite side structure is involved through tensile forces. The car rotates counterclockwise (Fig. 8B) and glances-off depending on the degree of overlap. The compartment intrusion is very high in a 30 % offset test also in the door area. With increasing degree of overlap (up to 40 %), the rearward displacement of the side structure decreases but the fire wall intrusion increases mainly in the area of the lower extremities. In these "true" offset configurations, the occupant deceleration does not reach an injury relevant level. In a 50 % offset test, the engine directly hits the barrier. The front end deformation is concentrated on only one longitudinal member. The remaining energy leads to high deceleration as the passenger cell gives support to the engine. The occupant injuries obviously result from deceleration peaks. The deformation is negligible in this respect.

3.2.2 30° Oblique Crash Test

The deformation pattern of a 30° test shows similarities with an asymmetrical accident at the first glance. A closer look reveals major differences. The lateral component of the impact leads to a glance-off thus reducing the accident severity. The front member yields with broad support from the engine (Fig. 8C). The car rotates clockwise. Even at higher impact speeds, the passenger cell is only lightly loaded compared to the deformations found in road accidents. The glance-off of the car initiates a different occupant kinematics and lower occupant loads as in an offset test with the same accident severity.

3.3 Comparison of the Car-to-Car Test with Barrier Tests

The offset test reproduces the injury risk of real car-to-car accidents much better than a 30° oblique test. The most important degree of overlap of the car front end should not be applied from accidents to the barrier tests. The evaluations in 2.1 have shown that the initial degrees of overlap differ from the final deformation pattern and influence the classification to an equivalent test (ET). The 50 % barrier test and 50 % (57 %) car-to-car test have completely different values for deformation and deceleration, primarily caused by the interaction of the engine. The same tendency could also be expected with transversely mounted engines and front-wheel drive. Fig. 9 illustrates the influence of various overlap degrees.

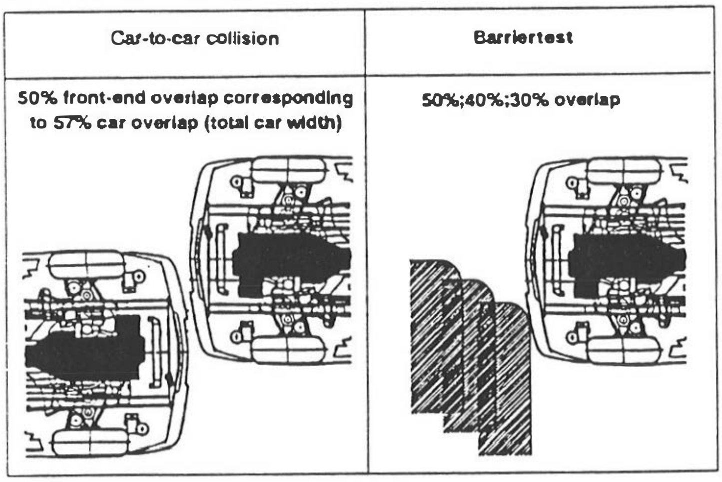

Fig. 9: Comparison of the overlap in car-to-car tests with barrier tests.

A car-to-car crash with an initial overlap of 57% and a 40 % offset test have very similar test characteristics (Fig. 10).

The conclusion is that the overlap degree in a rigid barrier impact must be smaller than in a car-to-car test taking into account the more inhomogeneous stiffness properties of the car's front end structure. This is confirmed by evaluations from NHTSA and C.Ragland [Lit. 7]. This experience allows one to define representative barrier tests for the car-to-car tests (Fig. 11).

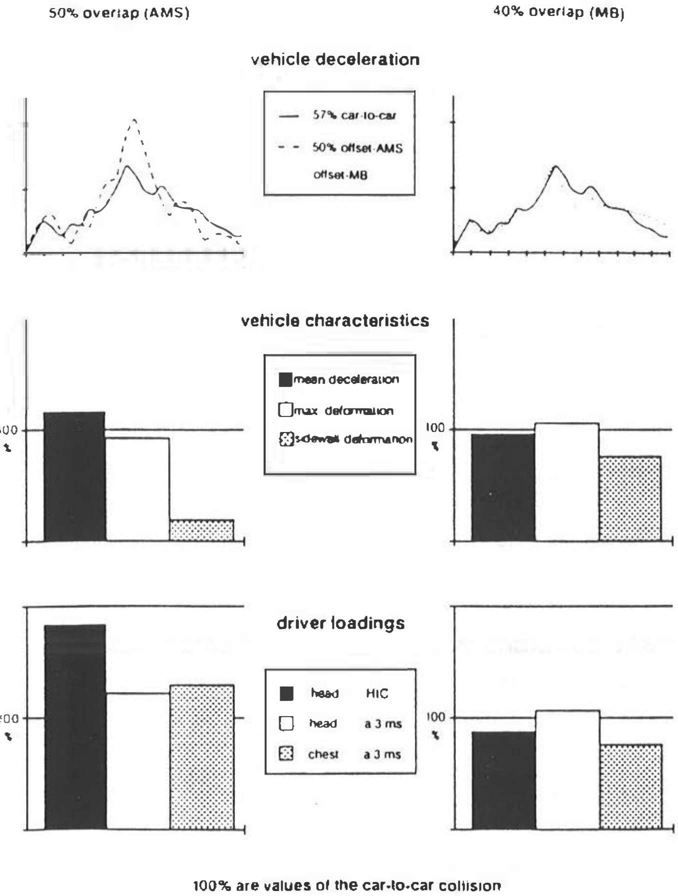

Fig. 10: A Car-to-car collision compared with barrier tests.

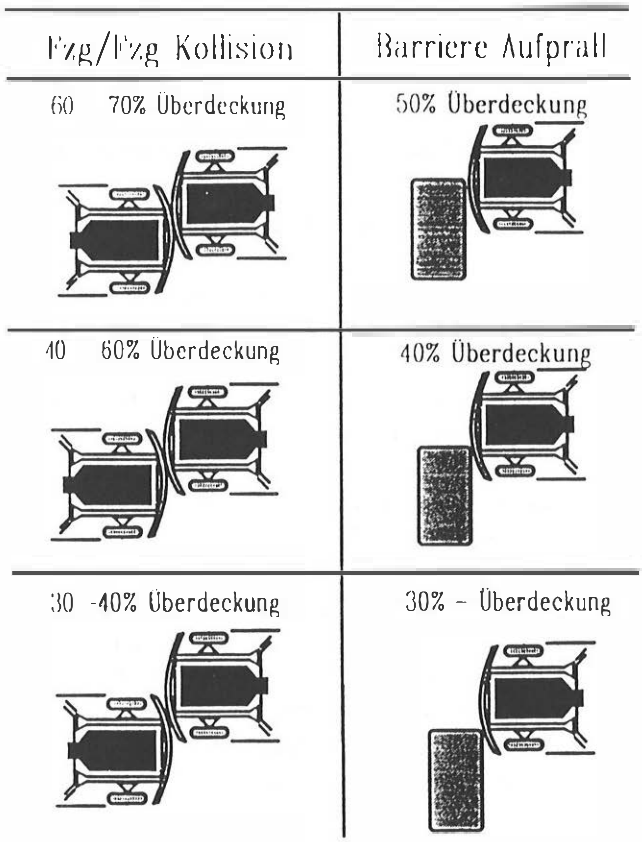

Fig. 11: Frontal impact configurations assigned to offset barrier tests with different overlap degrees.

4 Consequences for a Realistic Frontal Impact

The most frequent type of accident was found to be the driver side offset collision with overlap degrees between 30 % and 70 % of the car front end. The car will glance-off and rotate counterclockwise. Excessive intrusions mainly account for the injuries and not high decelerations. The comparison of the out-of-production model Mercedes-Benz 123 with new offset designed car lines has indicated a reduction of the higher injury severity levels. This is strong proof for the necessity to conduct offset tests. Car-to-car crashes can be simulated with an appropriate degree of overlap with the barrier. The range between 30 % - 50 % reflects extreme loads. The 30 % offset test causes extreme intrusions and low decelerations, whereas the 50 % offset test results in high decelerations and smaller intrusions.

The design of a car should be oriented toward both test procedures. The common 0°-barrier test with 50 km/h according to FMVSS 208 represents a restraint test since high decelerations are produced. Both the 50 % offset test and US consumer test NCAP would unnecessarily intensify the restraint test. They have no statistical relevance in real world accidents in frequency and in injury severity. Mercedes-Benz has defined a "true" offset test against a rigid barrier with an overlap degree of 40 % where one front member is loaded but not the engine. Complementary test series with a deformable barrier are conducted for possible refinement. The optimization of the structure is a consequence of both, 40% offset and 0°-barrier test according to FMVSS 208. The true injury reduction benefit is only partly seen with dummy measurements based on acceleration. Methods to quantify occupant loads from intrusions must be further developed as a common task. Most important however is the close evaluation of real world accidents.

5 Consequences for Future Car Design

5.1 The Influence of Different Exposure

The definition of the above test procedure is based on the findings from accidents with Mercedes-Benz passenger cars at present and their specific exposure, e.g. a high proportion of highway mileage and a lower one for urban and rural roads but higher accident risk for the latter ones.
To further identify the safety requirements for cars with a different pattern of road use, i.e. small or even zero emission cars, the accident data have been analysed for different types of roads.
According to figure 12 showing the findings from highway and non-highway accidents, there is no difference neither in the frequency of accident severity (EES) nor in the percentage of injury severity. Only for city streets the injury risk is significantly lower.
Figure 13 shows that on non-urban roads offset collisions with an overlap degree below 50% have a higher proportion than frontal impacts with an overlap above 50%. Taking into account this result an offset test for cars mainly used in rural areas is even more appropriate. In contrast for urban accidents the overlap degree of the car front increases and most frequently exceeds 50%. Moreover appr. 90% of all severe urban (city streets) accidents occur with an EES lower than 45 km/h (fig. 12B).
Therefore, it may be concluded that for city cars a test procedure similar to the FMVSS 208 seems to be appropriate but the test speed should not exceed 40-45 km/h. However, if these small cars are not restricted to urban roads an additional test (40% offset with an impact speed of 50-55 km/h) is necessary.

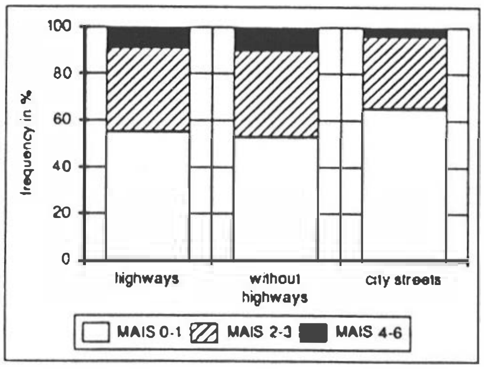

Fig 12A: Frequency of injury severity considering the accident location.

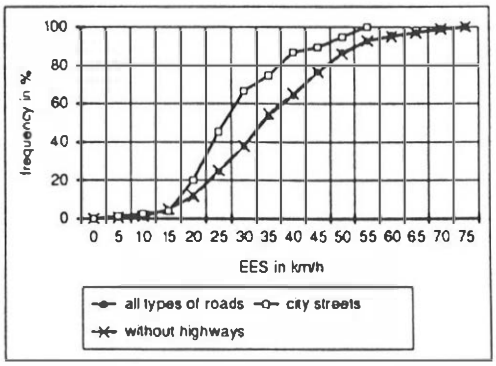

Fig. 12B: Frequency of accident severity.

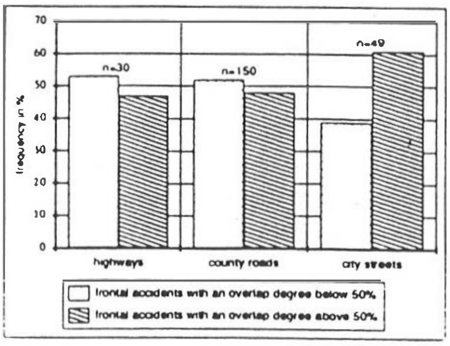

Fig. 13: Frequency of frontal overlap degrees for different types of roads

5.2 The Compatibility of Different Front End Structures

To demonstrate that offset design guarantees the integrity of the passenger compartment without an increase of the maximum forces, some force/deceleration - deflection characteristics for different types of cars are shown for 40% offset crash tests and 0^{o}-barrier tests as well.

To compare different front end structures the results from offset tests with 55 km/h for cars with similar weight are given in figure 14 and 15. The deceleration in figure 14 for an offset designed car reaches the same maximum value as the one for the non-offset designed cars (fig. 15). The passenger compartment of the car in figure 14 withstands the loading and remains intact. In contrast the passenger cells of the non-offset designed cars (fig. 15) did collapse. Despite of different engine concepts in these two non-offset designed cars the accelerations/deformations are nearly the same, independent on the involvement of the engine in this 40% offset test.

Since an offset designed car is obviously compatible with other cars of the same weight in an offset collision it can be assumed, that the same is true for a full frontal crash. Figure 16 and 17 show the force/ deflection characteristics for different types of cars in a 0^{o}-barrier impact with 50 km/h.

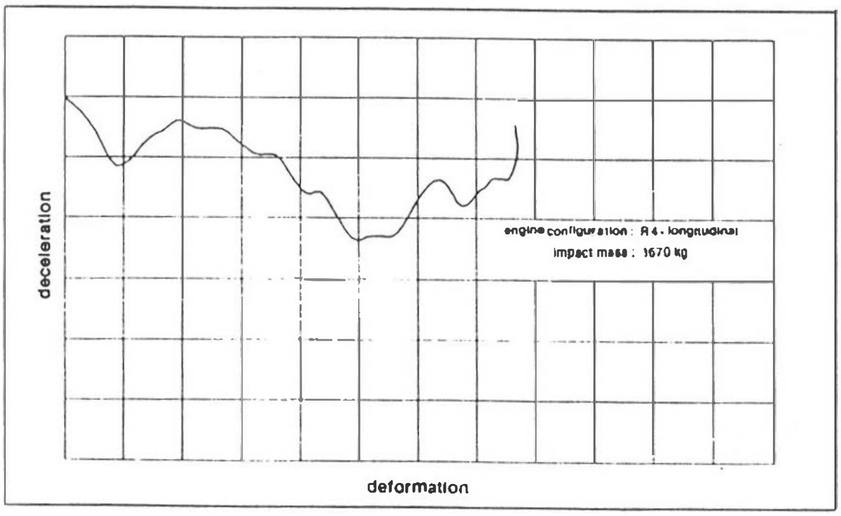

Fig. 14: Offset crash against a fixed barrier, overlap degree 40%, impact speed 55 km/h. Mercedes-Benz car line 124, especially designed for offset configuration.

It seems that some manufacturers have redesigned their cars according to the offset requirements derived from real world accidents.

Figure 18 shows the deceleration/deflection characteristic of a modern car concept.

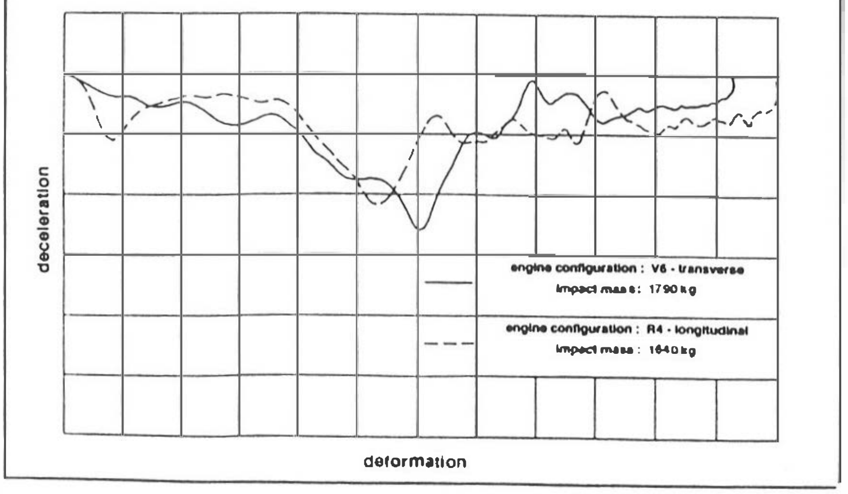

Fig. 15: Competitor cars, not especially designed for offset configuration.

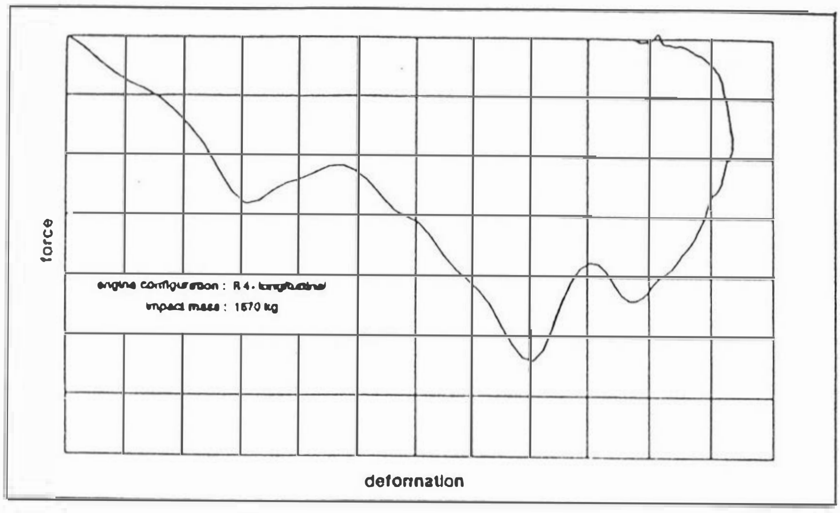

Fig. 16: 0°-Barrier crash, impact speed 50 km/h. Mercedes-Benz car line 124.

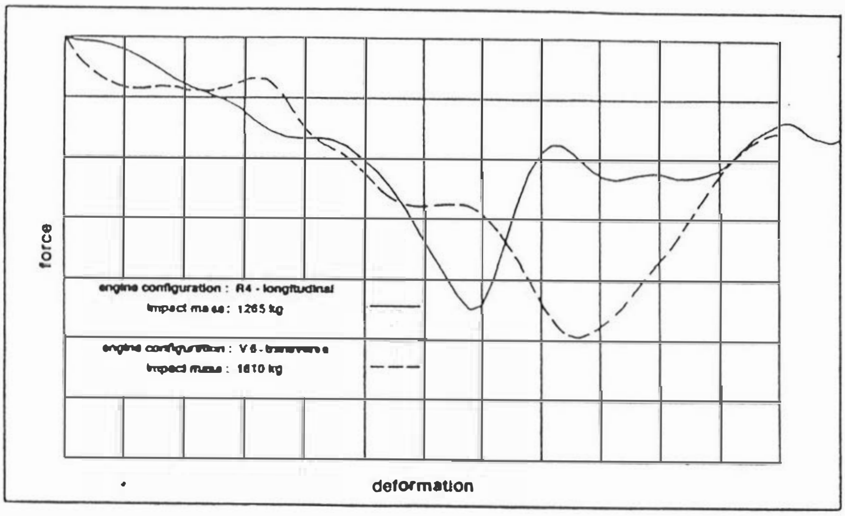

Fig. 17: 0°-Barrier crash, impact speed 50 km/h. Competitor cars.

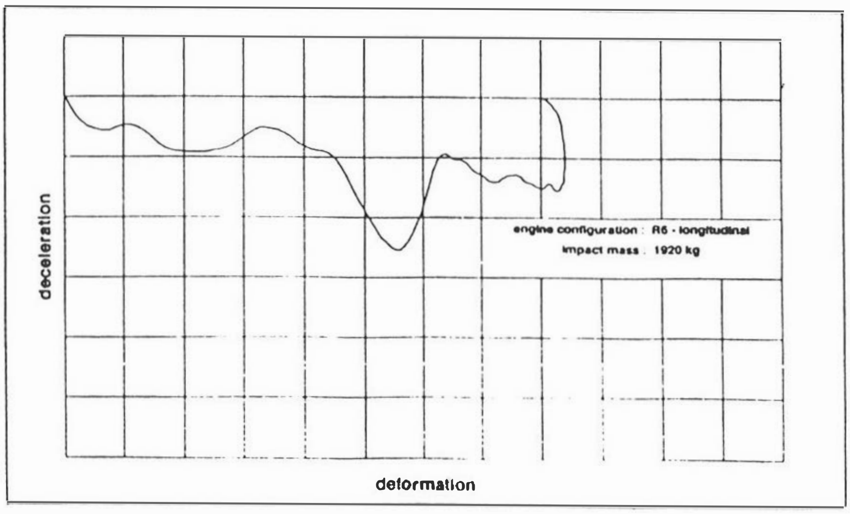

Fig. 18: Offset crash against a fixed barrier, overlap degree 40%, impact speed 55 km/h. Modern car concept.

6 Literature

[1] C.A. Hobbs.: The Need for Improved Structural Integrity in Frontal Car Impacts. Tranport and Road Research Laboratory. 13. ESV-Konferenz, Paris 1991.

[2] D. Otte.: Realitätsbezug von Crashtest-Bedingungen zu den Situationen des realen Unfallgeschehens. Verkehrsunfall und Fahrzeugtechnik, Heft 12, 1991.

[3] Abbreviated Injury Scale 1990 Revision. Association for the Advancement of Automotive Medicine. Des Plaines, IL 60018,USA.

[4] auto motor & sport, Heft 19/90. Motor-Presse-Verlag GmbH & Co. KG, Stuttgart.

[5] F. Zeidler,et al: Development of a New Injury Cost Scale, 33rd Annual Proceedings. Association for the Advancement of Automotive Medicine, 1989.

[6] J. Decker, et al: Realitätsnahe frontale Crash-Versuche und daraus abgeleitete Schutzmaßnahmen in Mercedes-Benz Fahrzeugen. Automobiltechnische Zeitschrift 92, 1990.

[7] C. Ragland.: Overlap car-to-car tests compared to car-to-half barrier and car-to-full barrier tests. National Highway Traffic Safety Administration. 13. ESV-Konferenz, Paris 1991.

[8] L. Grösch: Safety Performance of Passenger Cars Designed to Accomodate Frontal Impacts with Partial Overlap. 1989 SAE Congress, Detroit.