SMALL OVERLAP FRONTAL IMPACT – EXPERIENCE AND PROPOSAL FOR A FUTURE APPROACH

Bengt Larsson
Joerg Bakker
Daimler AG
Germany

Paper Number 15-0244

ABSTRACT

This paper examines the field relevance regarding frequency and severity of small overlap accidents by comparing accident data from GIDAS, NASS and Mercedes-Benz accident research and from this perspective shows a proposal of a more realistic small overlap test configuration. The result shows a field relevance of approx. 7% in relation to all frontal impact accidents. With respect to an occupant injury severity of MAIS3+ the field relevance is reduced to approx. 3%. Detailed investigations regarding vehicle deformations and occupant loadings on a Mercedes Benz C-Class (MJ 2013 and earlier) show significantly higher severity in the IIHS load case compared to a typically small overlap field accident. Furthermore, a better severity correlation between field accidents and a car-to-car small overlap or the NHTSA small overlap research load case has been observed. In case of the IIHS small overlap test mode some preferential vehicle concepts related to the results has been observed. Investigations show that front wheel drive vehicles with a “east-west” (lateral) engine mount design seem to have some advantage compared to rear wheel drive vehicles with a “north-south” (longitudinal) engine mount design. Accident data analysis confirms that small overlap accidents have field relevance, although the severity of the accidents is lower compared to the IIHS small overlap test mode. In order to obtain a more realistic test configuration the proposal is to use a deformable barrier in order to simulate this kind of accidents.

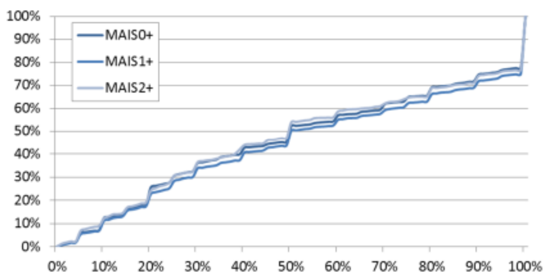
INTRODUCTION

The IIHS Small Overlap test program is one of the latest challenges for the automotive development. This load case was implemented in order to simulate the severity of small overlap field accidents, and since the introduction there is a discussion if this load case accurately enough reflects real world accidents. In the first step a review of accident data from GIDAS(Germany), NASS (US) and Mercedes-Benz accident research and published studies was conducted in order to give an overview of the relevance of frontal impact collisions where a small overlap without engagement of the front longitudinal members and an injury severity of MAIS3+ occured. In the second step a case-by-case study of the relevant small overlap accidents with involvment of Merdedes-Benz vehicles was done to compare with the results obtained in IIHS small overlap crashtests. The objects for the comparison were vehicle deformation paths and vehicle collision kinematics. In the third step a closer investigation of the specific IIHS load case was done in order to better understand and classify the test and to answer regarding questions robustness, what kind of field collisions are adressed and if certain vehihle concepts like front wheel drive or rear wheel drive are preferential. In the fourth step a closer look on the repeatability of the IIHS load case was taken: result comparison of two identical vehicle crash tests and simulations test setup variations. Finally in the fifth step different test configurations were investigated that first better reflect real world accidents and second show more robustness and repeatabillity regarding vehicle kinematics and deformations, because it is important that a test configuration is driven by the most typical types of crashes occurring in the field so that potential design changes will lead to benefits in real-world crashes.

1. Field relevance regarding frequency, severity and opponents of small overlap accidents

1.1 Frequency

There have been many publications about the relevance of the IIHS small overlap test in real world accident scenarios, for example [1],[2],[3], and [4]. Especially, when the test was introduced in 2012, many numbers were quickly published in the press that assessed the relevance in the range 20 – 25% of all frontal collisions. However, there is a simple relation between overlap degree and the frequency of its occurrence in crashes. This relation is valid for the whole range of overlap degrees in frontal offset collisions and basically reflects the frequency distribution of overlap degree in a random impact into the car front. Accident data shows this relation, which can be seen in figure 1-1 (left) where the cumulative frequency of frontal collisions up to a certain overlap degree with different injury severity levels (from uninjured MAIS 0+ to MAIS 2+) is shown. We can see a linear increase with the level of overlap, independent of the injury severity. According to this distribution, the relevance of a small offset crash with 25% overlap degree could be determined as 25%. The question is, can we derive a relevance of an offset crash from this relation? It seems like no particular overlap degree has a special relevance and one could argue that the bigger the overlap, the bigger the relevance. However, technical considerations come into play when considering the range of accidents one specific offset crash test should represent. In case of the small overlap crash, the crash structure, i.e. the longitudinal members should not be impacted so that they would have the ability to absorb energy. This is the specific characteristic of this crash, separating it from other possible offset configurations, and should be reflected in a corresponding accident analysis. Obviously, having 25% overlap as the only selection criterion for accident data is not enough, as many of these cases also overlap with the structure of the car, due to a bigger variance of impact situations and vehicles in real world accident data than in the crash test. Also, within the group of small overlaps that do not impact the longitudinal members, there are types of accidents with very different characteristics, such as super small overlaps (sideswipes) or impacts with a small oblique component resulting in deformations mostly more on the side than at the front of the vehicle.



Source	Country	Data	Year	All Frontal Collisions	Severe Injuries	Fatalities
Prasad et. al, [1]	USA	NASS	2014	7.5 %	4.6 % to 9 % (MAIS 3+)	3 % to 8 %
George Washington University, [4]	USA	NASS	2014	6 %	3 % (MAIS 2+)	
Mercedes Accident Research	Germany	GIDAS	2014	7 %	3 % (MAIS 3+)	

Figure 1-1. Cumulative frequency of overlap degree in car frontal collisions at different injury levels (left) and different studies with in-depth analysis of small overlap crashes and their relevance (right)).

In order to filter out the cases with a small overlap and no impact on the longitudinal members, a detailled and manually conducted study of single accident cases is a reliable but costly method. Automatic selection is usually not very accurate with current accident databases in this situation as they lack the exact detail of deformation of the longitudinal members. Figure 1-1 (right) shows the results of several different and recent efforts to conduct such a manual analysis and it turns out that they are comparable, even when based on different datasets. With respect to all frontal collisions and independent of the injury severity, the small overlap represents about 7 %. These numbers also show that the overall relevance of small overlap impacts is comparable in the US and Germany.

In an analysis of GIDAS data (German In-Depth Accident Study as of 07.2013) from Germany, 2524 frontal car crashes were classified into different overlap characteristics shown in figure 1-2. Full overlap takes up to 41% of all impacts. Partial overlaps can roughly be devided into three big groups: large (50 – 75% overlap), moderate (30 – 50% overlap), and different types of small overlap (up to 30%). The rest is made up of central impacts and others. The variaty of small overlap crashes ranges from super small overlaps, which are basically sideswipes, to impacts more into the side structure of the vehicle. Due to the nature of impacting the corner of the vehicle, there is a greater variaty of different types of crashes in the group of small overlaps, than in the other partial overlaps. Some of these differences are shown in the following sections, when injuries and collision opponents are examined for each group.

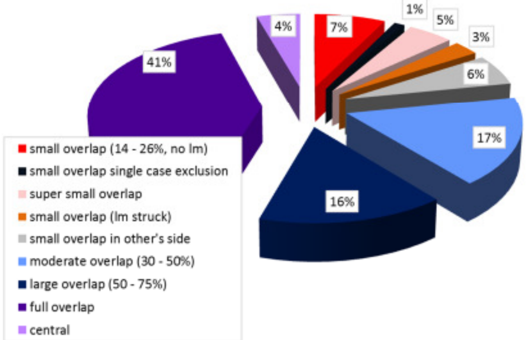


Figure 1-2. Distribution of severe frontal collisions with different overlap characteristics.

1.2 Injury severity

In the previous section, the relevance of small overlap has been discussed on the accident level. When it comes to injuries, the type of injuries sustained in small overlap crashes is different than in other frontal crashes which has an influence on the injury severity. Serious injuries (AIS 2+) in small overlap crashes are mostly located in lower and upper extremities (figure 1-3) opposed to head/neck and chest in other frontal crashes with the latter injury types are generally more serious than the former ones. Thus, the overal relevance is different and decreases at different injury levels to about 3% for MAIS 3+ injuries (and fatalities) in small overlap crashes (figure 1-3). This pattern is not only observed in accident data, but also in the crash test dummy loads of small overlap crashes vs. other frontal crashes, that have been conducted so far. Also, other studies on US accident data show similar results [4].

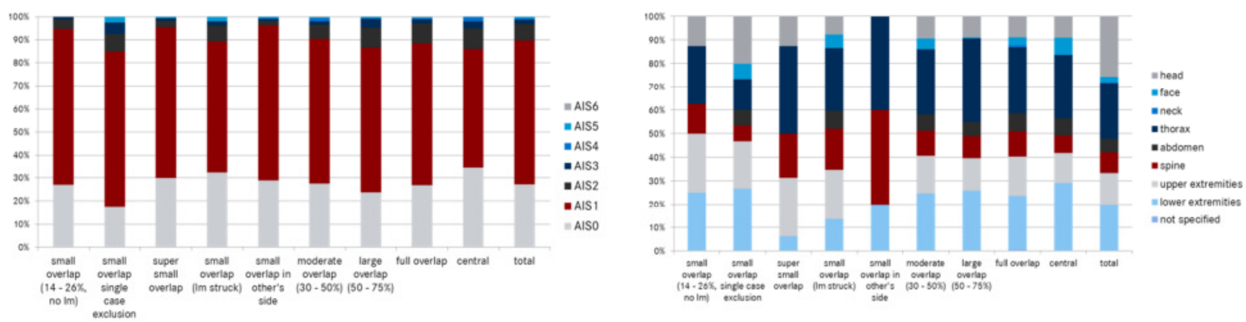


Figure 1-3. Injury severity and body regions of AIS2+ injuries in crashes with different overlap characteristics.

1.3 Collision opponent

The most striking difference between real world accidents and the small overlap crash test configuration gets obvious when looking closer to the impact opponent. In general, when looking at all types of frontal collisions, object collisions are not as frequent as vehicle collsions. This holds also true for small overlap crashes and is in the same order of magnitude as in all severe frontal impacts. Vehicle opponents occure four times as often as object collisions (figure 1-4). Looking at the small overlap object collisions only, it is not surprising that nearly all of them are collisions against a tree or pole. Out of the 49 object collisions, 28 hit a tree and another 9 a pole. In sum these are 76% tree/pole collisions of all small overlap object collions, which is 20% of all small overlap impacts. To summarize, the collision opponent in a small overlap accident is in most cases (94%) either a vehicle or a tree/pole where vehicles are clearly dominant with 74%. Similar results were found by [1], [2] where in 22 small overlap crashes, 19 were impacts with the front or side of another vehicle (86%) and 3 were impacts with a pole, post, or tree (14%).

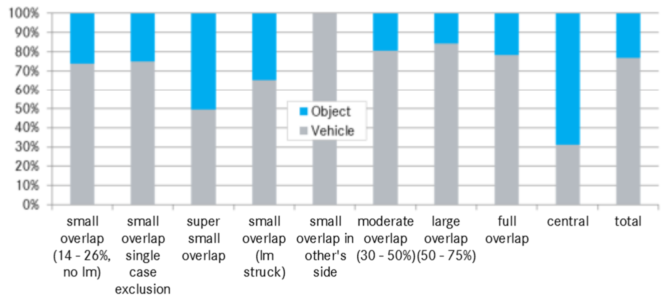


Figure 1-4. Collision opponent in crashes with different overlap characteristics.

2. Small overlap field accidents versus IIHS small overlap crashtest results

To get a picture how IIHS small overlap test results match to known field accidents a comparison of the deformation patterns and kinematics between tested vehicles and real world collisions was investigated. In this case field accidents analyzed from the Mercedes–Benz accident research were compared to the same Mercedes-Benz carline tested in the IIHS crash test setup. As a representative example for this research a Mercedes-Benz C-Class (MJ 2013 and earlier) involved in a vehicle-to-vehicle accident to a mid-size car with an overlap of 23% for the C-Class is shown below (fig. 2-1 above). The C-Class had a calculated Energy Equivalent Speed (EES) of approx. 60 km/h at collision, which is comparable to the EES severeness of the IIHS small overlap test (58- 60 km/h). The occupant in the C-Class suffered no injuries.

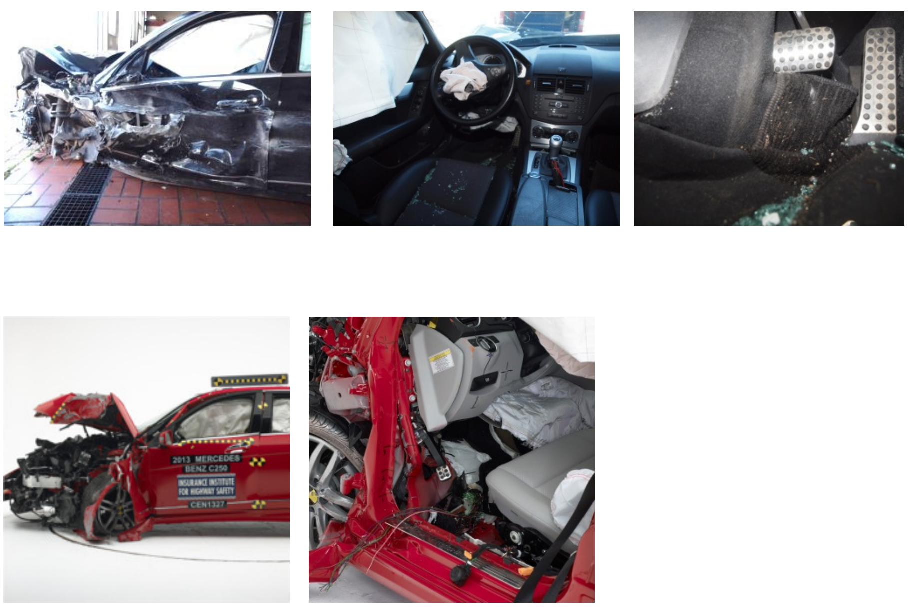


Figure 2-1. Small overlap field accident, C-Class (MJ 2013 and earlier) vs. IIHS small overlap test result C-Class (MJ 2013 and earlier) [IIHS data]

The occupants head, neck and chest was well protected by the seatbelt, driver airbag and side- and curtain airbag. Further the intrusion in the foot area was on a low and therefore acceptable level: no structural rupture and no trapping of the lower extremities. The C- Class (MJ 2013) was official tested in the IIHS small overlap and some test results, especially regarding the intrusion at the lower occupant compartment, were unfavorable (fig. 2-1 below).

Although the collision severeness between the field accident and the IIHS test is comparable, significant differences particularly at the lower compartment intrusions are observed. The explanation for these discrepancies is assumed to be the different collision partners: the rigid barrier in the IIHS test setup induces higher and compared to field accidents not representative intrusions.

3. IIHS small overlap crashtest - working range and limits

To better understand the IIHS small overlap crash configuration the published data from IIHS crash test during the development of the load case was investigated. Additional car-to-car tests with same and different vehicle test partners were conducted in order to examine the vehicle kinematics and how these fits to the IIHS test configuration. Furthermore vehicle tests in the IIHS setup with different vehicle design concepts, longitudinal (“north-south”) and lateral (“east-west”) engine mount were reflected, to find out possible differences in output and behavior.
For development of the IIHS small overlap crash configuration a Volvo S60 was often used as a test vehicle. The data from these tests is available on the home page of IIHS and tests were conducted both against barriers (rigid and deformable) and vehicle-to-vehicle configuration. At first car-to-car tests were studied in order to investigate the vehicle kinematics. As an example two car-to-car configurations are shown below (figure 3-1 above):

- Volvo S60 vs. Volvo S60 with 28% overlap, v= 64 km/h [data from IIHS home-page]
- Volvo S60 vs. Volvo S60 with 22% overlap, v= 64 km/h [data from IIHS home-page]

In both cases both vehicles more (28% overlap) or less (22% overlap) stuck to each other and rotated around the vertical axis. A fully glancing off behavior, which has been observed in the IIHS small overlap crash setup of the Volvo S60 (figure 3-1 below), did not occur

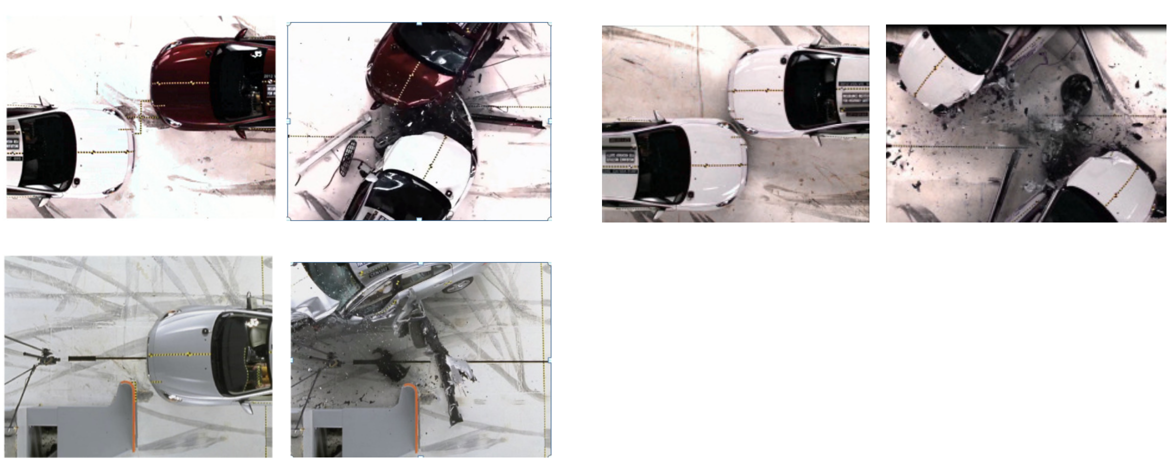


Figure 3-1. Volvo S60 vs. Volvo S60, 28% overlap (above left), Volvo S60 vs. Volvo S60, 28% overlap (above right) and Volvo S60 tested in the IIHS small overlap test configuration (below) [IIHS data]

The first conclusion is that the IIHS test setup more simulates a collision against a rigid object like a pole, post or tree prior to a deformable vehicle-to-vehicle collision. The second conclusion concerns the question of the repeatability (see also step 4 below): a minor variation of the overlap 25% +/-3%, seen in the vehicle-to-vehicle tests, causes a major change of the vehicle kinematics regarding the degree of glancing off.

During the development of the load case the IIHS tested different barrier types. The examples in figure 3-1 and figure 3-2 are showing the rigid barrier with two different radius of the barrier edge: 50 mm vs 150 mm. The test with the Volvo S60 shows a different kinematics between these two barriers: a glancing off with the 150 mm radius and a stuck behavior against the 50 mm radius barrier. Thus, a smaller change of the barrier geometry leads to major change of the vehicle kinematics. In fact, the kinematic result at the barrier with the smaller radius is fitting better to the vehicle-to-vehicle tests.

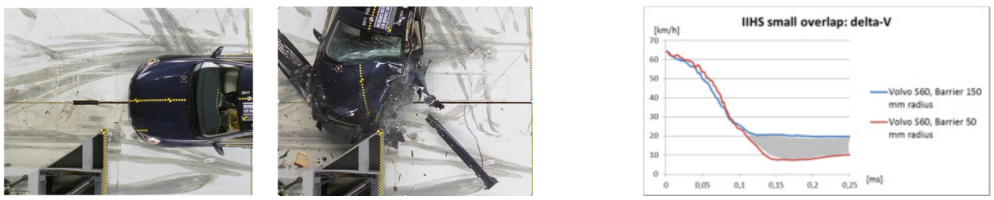


Figure 3-2. Volvo S60 tested in the IIHS small overlap test configuration overlap 20% with a 50 mm radius edge (left) and delta-V characteristic of the Volvo S60 tested in the IIHS small overlap test configuration 25% overlap with a 150 mm barrier radius edge vs. 20% overlap with a 50 mm barrier radius edge (right) [IIHS data]

A glancing off kinematic also leads to less reduction of the kinetic energy at the barrier, what firstly means that the vehicle moves uncontrolled forward with a residual amount of velocity, and secondly to less vehicle structural stress (figure 3-2 right: e.g. Volvo S60 approx. 20 km/h residual velocity after impact). Certainly a glancing off behavior obtains a higher amount of lateral velocity than a sticking behavior that could lead to higher injury risk for the occupants at head and chest, but on the other hand the intrusions and structural stress at the upper compartment area normally are lower compared to a sticking behavior.

The cars that up to now have been rated in IIHS small overlap impact have a vehicle architecture either with a longitudinal engine mount (normally rear wheel drive) or a lateral engine mount (normally front wheel drive).

Two characteristics are observed

- None of the vehichle concepts with a longitudinal engine mount ("north-south") have a glancing off tendence at impact.
- For vehichle concepts with a lateral engine mount ("east-west") every degree of glancing off seems to be possible, but a major part (81%) of the invesigated vehichles have a clear glancing off tendence at impact

To get one explanation for the reason of these differences the two concepts below are compared with regard to the barrier impact.

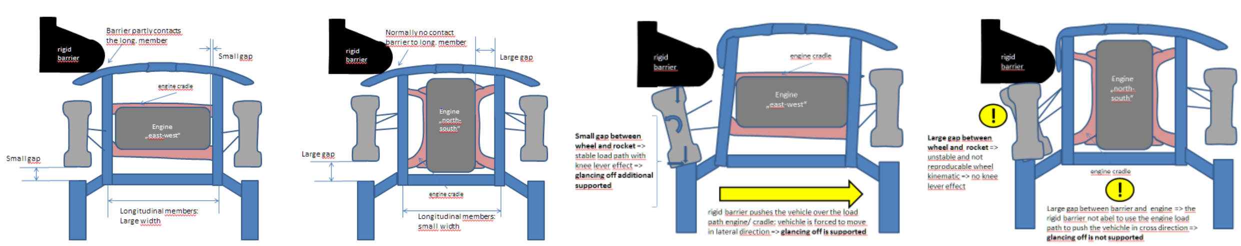


Figure 3-3. Vehicle concept engine mount "east-west" (left) and "north-south" (right)
Schematic results: vehicle concept engine mount "east-west" (left) and "north-south" (right)

Viewed in figure 3-3 are two structures with the same vehicle width. The main differences between the two concepts that have an important impact on the degree of glancing off at the rigid barrier are:

- The width of the longitudinal members: a large width can allow a partly barrier impact to the longitudinal member
- The gap between the longitudinal member and engine: a small gap allows a lateral engine load path, that pushes the vehicle in lateral direction away from the rigid barrier during the impact
- The gap between wheel and rocket (side member): at the barrier wheel impact a small gap allows a stable and reproducable contact to the rocket and during the impact phase the wheel works like a knee lever to support a vehicle glancing off kinematic. A large gap results in an instable an non-reproducable wheel contact to the rocket.

Conclusion:
For this reasons vehicles with a lateral engine mount concept have benefits in the IIHS small overlap crash mode: the geometry of the rigid barrier allows a pushing effect away from the barrier and increase the degree of glancing off possibility.

In the same way vehicles with a longitudinal engine mount do not benefit from the glancing off effect: almost the whole input kinetic energy has to be managed by the vehicle structure.

4. IIHS small overlap – repeatability

During the development of countermeasures and vehicle improvements it was observed that the results of identical vehicle tests didn't give a reasonable repeatability: abnormal large result deviation compared to deviations occurring in for example moderate frontal offset crash configurations. To investigate this, simulations of a large luxury vehicle with a) slightly different overlaps (30%, 20%) and b) different positions of the wheel rim at impact to the barrier were done. Another factor that in a major way influences the test result deviations is the wheel rim styling. In two IIHS small overlap configuration tests of a Mercedes-Benz vehicle with identical body structures and configurations except for the 5 spoke wheel rim styling (fig 4-1) indicate this. In these two cases the rim impact to the barrier for the both vehicles was similar: impact between two rim spokes. However, during the ongoing crash phase the deformation and kinematic of the wheels differs successively, which at the end leads to a complete different structural result especially with respect to the toepan intrusion. These results were also confirmed in numerical simulations with different rim designs and stylings.

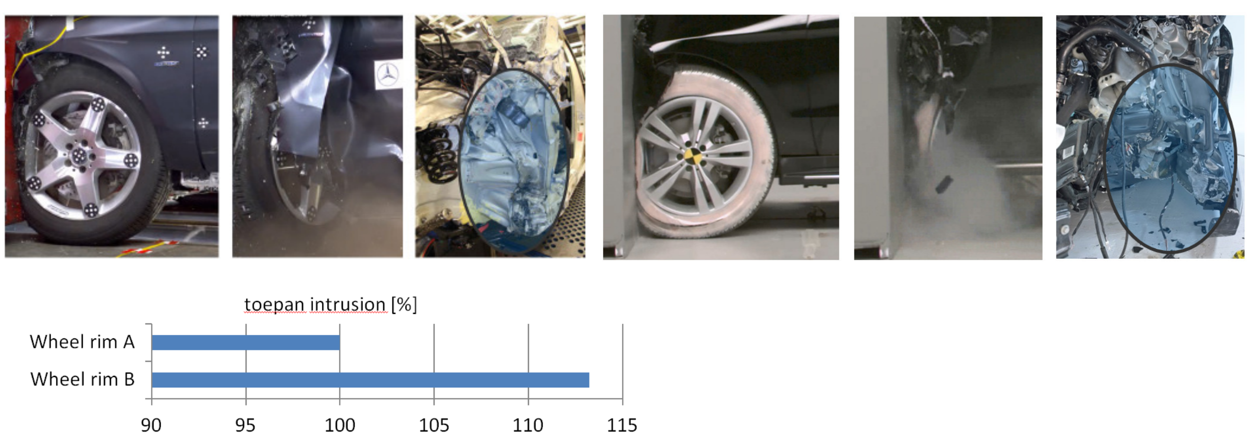


Figure 4-1. Vehicle with wheel rim A (left) and rim B (right, [IIHS data]): rim impact at the rigid barrier, wheel kinematic during crash and structure response at the rocket (vehicle side member, front view)

Numerical simulations of an identical wheel rim but with different rim positions at the rigid barrier impact shows large differences of the rim deformations and wheel kinematic, which causes a variation of body structure intrusions (fig 4-2 above). Depending on the rim deformation and rim impact to the body structure the vehicle intrusions differs up to 30 - 40%. In this case especially a wheel rim styling with fewer spokes seems to be more critical (rim strength distribution more inhomogeneous). Further, other parts like the size and thickness of the brake disc and its rupture behavior and the position of the brake caliper have an additional impact on variation of the wheel kinematic and crash results.

Next, a simulation reflects the influence of a smaller variation of the degree of overlap in the IIHS small overlap setup. The overlap was varied between 20% and 30% and compared to the basis setup 25% in all cases the longitudinal member was not struck (fig. 4-2 below). A slightly smaller overlap (20%) shows results with intrusion deviations up to >20% and a slightly higher overlap (30%) induce intrusion deviations even up to >30%. Thus, a smaller change of the vehicle overlap against the IIHS rigid barrier would significant change the vehicle intrusion values.

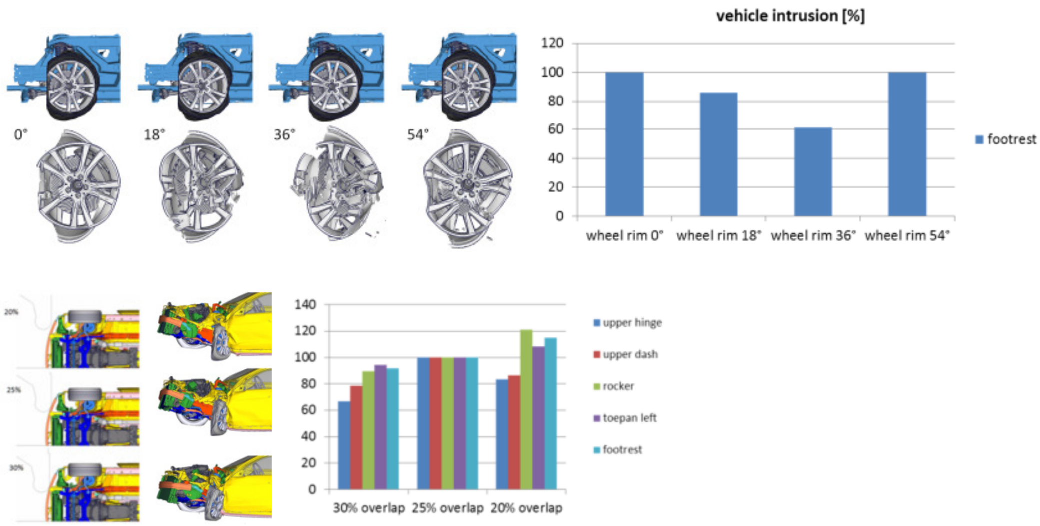


Figure 4-2. above: Wheel rim deformations at different wheel positions at impact to the rigid barrier (0° = 54°)
below: overlap variation at impact and influence on the vehicle intrusions (large luxury vehicle)

Conclusions:

In the shown examples minor variations to the vehicle setup or test setup causes significant deviations to the test result output. Claiming the same high safety requirement for all vehicle configurations and options, for example wheel rim styling, this lack of repeatability and high deviations makes it hardly feasible to reach that claiming goal. On the other hand this means that the IIHS small overlap configuration with the chosen rigid barrier geometry and shape could lead to a point optimization of a certain vehicle setup.

5. Investigations of further small overlap crash test configurations

At the introduction of the IIHS small overlap one main intention was to address severe injuries (MAIS3+) at head and chest areas [Zuby paper 09-0257]. However, almost every tested vehicle since the introduction in 2012 has shown only minor occupants loadings of the 50% HIII in these areas. The major occupant loadings are located to the dummy extremities (femur, tibia and foot) often due to high vehicle body intrusion values in the foot / floor area. For this reason Mercedes-Benz has made further considerations and investigations towards a small overlap load case that could better cover both field accidents severity and also be a robust test configuration with an acceptable repeatability for the vehicle development. The starting point for finding such a load case the objects were:

- no involvement of primary crash structure like longitudal frame members
- test velocity that covers 90% of the relevant field accidents
- barriere configuration that covers the most common field accidents impact objects
- get a stable and reproducable behavior of the suspension and wheel kinematics with a insignisficant impact of for example wheel rim stylings and wheel rim position at barrier contact
- better balancing of the occupant loadings: vehicle kinamatic that for both glancing off and/or sticking behavieur stronger adresses the head/ neck / chest loadings prior to leg and lower extremities loadings

Relevant conclusions and evaluations that have been shown in the previous steps and could be considered for an optimization of a small overlap test configurations are:

- in the examined field accidents a 40 km/h Delta-V covers more than 90% of the real cases, or in other words
- an Energy Equivalent Speed (EES) of 46 km/h covers 90 % of the reviewed relevant accidents
  - ⇒ This gives a representative velocity of 56- 58 km/h against a rigid barrier or 64km/h against a deformable (ODB) barrier.
    (In comparison: EES for IIHS Small Overlap is approximately 55-60 km/h. In GIDAS, this value represents a cumulative frequency of approx. 98%)
- As shown in the first step obove the most small overlap accidents two vehicles are involved. In GIDAS this represent approx. 75% of the cases. Only 25% are vehicle-to-object accidents. This means, that the most common real collision objects are prevalent deformable and not rigid.
- a rigid barrier causes issues regarding repeatabillity especially with respect to wheel kinematics for longitudinal engine mount vehicle concepts.
- the geometry of the rigid IIHS barrier seems to benefit lateral engine mount vehicle concepts where a glacing off effect reduces the needed energy absorbing capacity for the vehicle.

In order to match the requirements to the above conclusions Mercedes-Benz started a simulation and test evaluation program to find an adequate small overlap test configuration. The main result of that work was the recommendation to use a deformable element in front of a rigid barrier. In the investigation the common ODB deformable barrier (Euro-NCAP / IIHS) and the discussed NHTSA oblique/ small overlap deformable barrier were used. The tested configuration with the deformable ODB barrier is as follow

- ODB barrier in front of a rigid block
- Rigid block w/o edge rounding
- 25% overlap, 0° obliqueness
- Vehicle velocity v= 64 km/h
- Vehichle weight and equipment in accordance to the IIHS test protocol

The first observation of the test result is that the use of the deformable barrier makes the reproducibility of the wheel kinematics much higher: due to the deformation of the barrier the wheel displacement is more defined guided towards the side member (rocket). Also the influence of different wheel rim designs and/or wheel rim positions at impact to the barrier is much lower and makes the evaluation of developed vehicle changes much more accurately and predictably (fig 5-1 above).

With this test vehicle (longitudinal engine mount) a sticking kinematic behavior at the barrier impact occurs. The wheel kinematic with a stable contact to the side member leads to a robustly load path on the axis barrier-wheel- side member. This load path increases the rotating velocity of the vehicle and induces a stronger occupant lateral movement towards the vehicle side structure (fig 5-1 mid, below).

The higher lateral excursion of the occupant in the test mode with the deformable barrier increases the injury risks for head and neck. On the other hand the floor intrusions and injury risks for the lower extremities are reduced. In the overall evaluation and comparison of the two test setups the use of the deformable barrier results in a more balanced injury risk distribution: higher injury risks for head/neck/chest and lower injury risks for feet and legs, which also shows a good alignment to the results from the real life accident analysis.

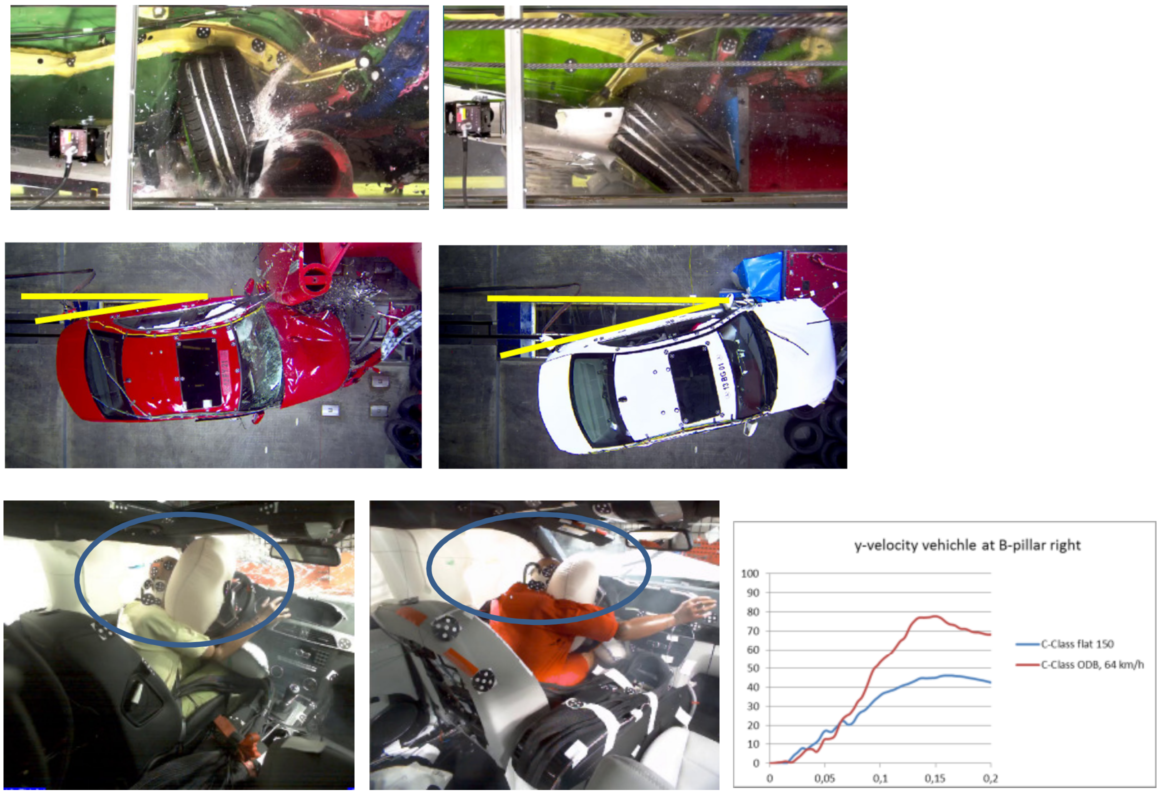


Figure 5-1. above and mid: IIHS small overlap test mode (left), small overlap w. deformable barrier (right)
below: Occupant at maximum excursion; IIHS small overlap test mode (left), small overlap w. deformable barrier (mid), vehicle lateral velocity (right), C-Class (MJ 2013 and earlier)

To review the results above an additional study was done with the discussed crash mode NHTSA small overlap:

- Movable deformable barrier, mass 2500 kg, barrier velocity 90 km/h, vehicle velocity 0 km/h
- 20% overlap, 7° obliqueness

The result is similar to the outcome of the deformable ODB test: the deformable barrier guides the wheel to stable contact with the side member and a high lateral vehicle movement. The intrusions at upper and lower area are good balanced: compared to the IIHS small overlap configuration the upper area is more and the lower area less loaded. Thus, this configuration reflects the original target requirements in a good way (fig 5-2 above and mid).

The occupant kinematic in NHTSA small overlap setup also differs compared to the IIHS small overlap: the upper torso rotates more around the vertical axis, which could increase the injury risk to head/ neck and chest if the coverage of the driver- and curtain airbag is insufficient (fig 5-2 below)

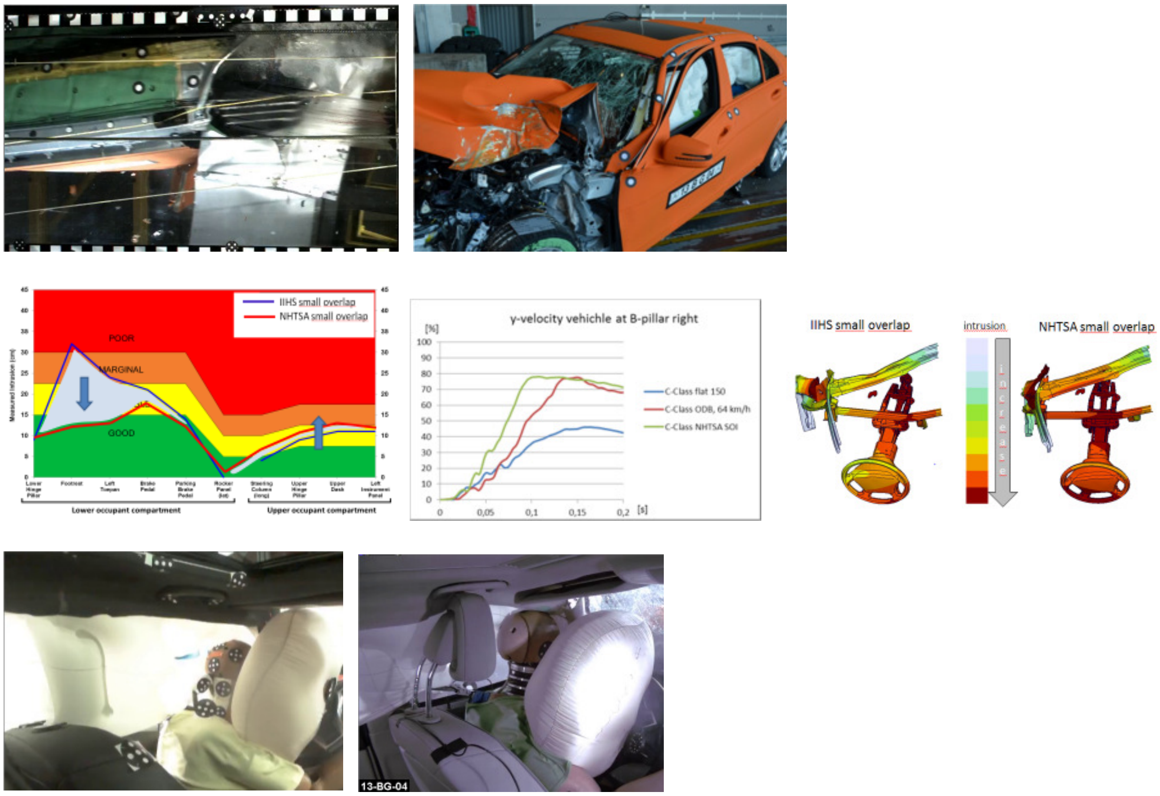


Figure 5-2. above: NHTSA small overlap - wheel kinematic (left) and A-pillar deformation (right)
mid: NHTSA small overlap vs. IIHS small overlap - intrusions and lateral vehicle velocity
below: Dummy kinematic / torso rotation: IIHS small overlap (left) and NHTSA small overlap (right), C-Class (MJ 2013 and earlier), HIII- dummy.

The two examples small overlap with the ODB barrier and the NHTSA small overlap configuration shows that it is reasonable to use a deformable barrier in front of a rigid or movable block. This configuration is able to address the most of previously formulated objects and would make the development more precise and robust. In the investigated setups with the deformable barrier reflects a sticking vehicle kinematic at the barrier impact. In order to also address lateral engine mount vehicle concepts, which have a higher tendency to glancing off, it could be discussed to combine a deformable barrier in front of a rigid block with rounded edge (similar to the IIHS rigid barrier). Such a combination could have the potential to fulfill the previously formulated objects even better.

CONCLUSIONS

Field accident data shows that severe small overlap frontal impacts occurs but have comparatively a low relevance. Most of the cases are vehicle-to-vehicle impacts, so this should be the focus for a realistic near-to-real-world crash test setup. The experience and investigations of the IIHS small overlap test configuration shows that the load case only partly covers the real world accidents, emphasizing injury risks occurring at the lower extremities of the occupants. The chosen rigid barrier with a large rounded edge also gives a benefit for lateral engine mount vehicle concepts, where the barrier can be used to push the vehicle laterally away from the barrier. Further the rigid barrier has an influence on occurring test result deviation, inter alia, depending on wheel rim positions. To get a more general small overlap crash test configuration, which can cover a larger part of the field accidents and shows more robustness in vehicle development process, the use of a deformable barrier layer in front of the rigid block should be considered.

REFERENCES

[1] P. Prasad, D. Dalmotas and A. German, "An Examination of Crash and NASS Data to Evaluate the Field Relevance of IIHS Small Offset Tests.", 2014 SAE International
[2] M. L. Brumbelow and D. S. Zuby, "Impact and Injury Patterns in Frontal Crashes of Vehicles with Good Ratings for Frontal Crash Protection.", 21st International Technical Conference on the Enhanced Safety of Vehicles, Stuttgart, Germany – June 2009
[3] B. C. Mueller, A. S. Brethwaite, D. S. Zuby and J. M. Nolan "Structural Design Strategies for Improved Small Overlap Crashworthiness Performance.", Stapp Car Crash Journal, Vol. 58 (November 2014)
[4] P. Scullion, R. M. Morgan, P. Mohan, C.-D. Kan, K. Shanks, W. Jin, and R. Tangirala "A Reexamination of the Small Overlap Frontal Crash.", 2010