

Effectiveness Potential of PRE-SAFE® Impulse Using the Scenario of a Major Accident at an Intersection as an Example.

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ABSTRACT

Research Question/Objective

As automatic emergency braking systems are increasingly penetrating the market and their rates of efficiency are improving, initial trends show that there will be a reduction in the number and severity of accidents in longitudinal traffic scenarios.

The focus in the future will therefore increasingly be on side impacts in particular and the accompanying high risks of injury observed. Modern driver assistance systems address driver assistance and measures for avoiding accidents and reducing the severity for the driver's vehicle if it is involved in an accident with another party. However, the one area where assistance systems have hardly had any influence so far is side impacts. Improving this area can only be achieved by extending the protection available in the event of an accident.

Methods and Data Sources

The launch of the new E-Class in 2016 marks the first time that Mercedes-Benz has implemented an additional side protection system that uses modern systems that monitor the surroundings to initiate measures for enhanced protection in an accident even before a possible collision occurs. PRE-SAFE® Impulse Side detects the danger of an accident via radar sensors fitted on both sides of the car and moves the occupant moderately toward the center of the vehicle just before the imminent collision by inflating an airbag in the

side seat cushion. The effect of the additional distance and the reduced contact speed at the time of the actual impact can be observed in all side impact configurations.

In this study, a particularly severe impact configuration was tested and analyzed in full-scale crash tests. For this purpose, crash tests were performed with two vehicles in each case. In the tests, the bullet vehicle had an impact speed of 65 km/h, while the target vehicle had a vehicle speed of 50 km/h. The target vehicle was equipped with PRE-SAFE® Impulse in one test and did not have the preventative protection system in the other test. The collision angle of the two vehicles was 105°. The point of impact of the bullet vehicle in the side of the target vehicle was the center of the passenger compartment.

INTRODUCTION

Due to improved structure, seat belts and airbags the safety level of modern vehicles has reached a very high standard. Even small cars offer an impressive degree of protection. Further improvement of occupant protection, even implementing modern restraint systems such as adaptive airbags and switchable belt force, is only possible to a certain extent.

To date, occupant protection systems have only been actively deployed after the accident has started to transpire.

The enhancement of sensor technology offers a better reliably detect accidents in advance, the time window in which restraint systems can offer protection increases dramatically. This, in turn, leads to great potential for further improvement of occupant protection in a passenger car.

In the future Advanced Driver Assistance Systems will largely contribute to reduce the number of injured occupants by avoiding crashes or mitigating their consequences. Growing market penetration of ADAS will also lead to an increase of the importance of crossroads collisions [3]. Indeed potential collision partners are often hidden and cannot be properly seen i.e. tracked by the car sensors until the collision is unavoidable. At least when our own car is standing on-board driver assistance systems are incapable of minimizing the intensity of the accident or avoiding the accident. In that case, the

severity of the impact at the side of the vehicle is directly linked to the proactive measures undertaken by the colliding vehicle partner. Nevertheless if restraint systems (passive safety) and driver assistance systems (active safety) taken individually cannot offer great improvement for side crash scenarios, the integral safety approach, combining both active and passive safety components in one system appears extremely promising.

In this paper a solution will be proposed that shows to what extent the pre-accident phase can be taken into account to prepare the occupant for a side impact.

OPERATIVE MECHANISM

Mechanisms of action in a side impact depend on the distance between occupant and vehicle structure as well as on the intrusion or contact speed of the vehicle structure to the occupant. Compared to frontal impact there is less absorption way and time to protect the occupant in side impacts. There are only limited distance between the occupant and the struck side of the vehicle as well as short time between the beginning of the collision and the moment when the occupant is loaded by the impact of the door/B-pillar.

The vehicle's dimensional design usually limits the distance between the occupant and the vehicle structure. Potentials to reduce the intrusion velocity have been primarily achieved through structural measures. Present airbags for side protection are designed and dimensioned to be activated shortly after the beginning of the impact. Involving the occupant in the sequence of an accident event earlier or even prior to a collision has not been considered till now.

PRE-SAFE® IMPULSE

Today, occupant restraint systems are classified as reactive systems. The downside of these occupant protection systems is that they only take effect once the accident has already started. Occupants are then decelerated with a considerable time delay with respect to the initial collision sequence. Energy only begins to be dissipated once the occupant has traveled a required distance within a specific time as a result of his or her forward excursion. In this time window, valuable

deformation space has already been used to decelerate the vehicle but not the occupant. The aim of PRE-SAFE® Impulse restraint systems is to couple the occupant as early as possible to the vehicle deceleration by distributing the total impact energy over a minor initial impact and a major impact whose intensity is reduced accordingly.

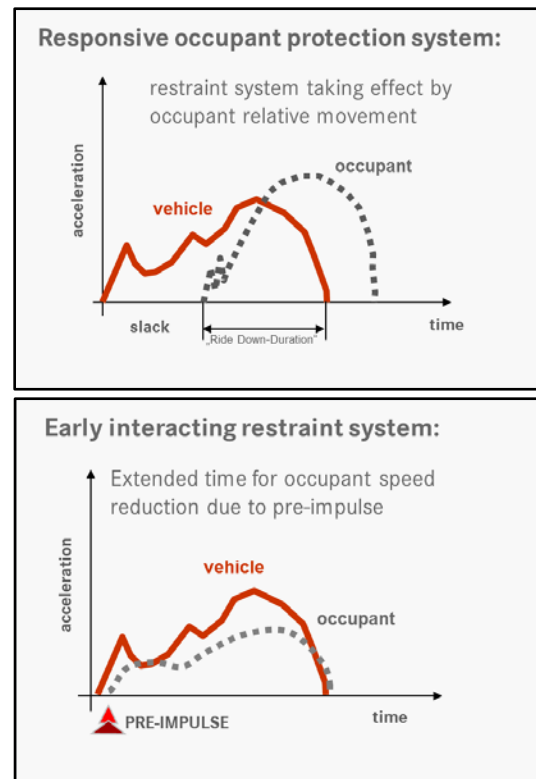


Figure 1: Comparison of responsive and early interacting occupant restraint system [4]

Figure 1 shows a reactive and an early interacting restraint system [4]. With an early interacting restraint system, the occupant is jolted in a very early phase of the accident, when the vehicle deceleration has not yet acted on him. The occupant perceives this as an acceleration impulse. This results in occupant deceleration, the occupant is briefly slower than the vehicle in which he is seated. The occupant is moved in impact direction. The displacement path gained by the relative speed can be released again over the course of the accident via energy dissipation.

Such a restraint system influences the ride-down effect and occupant kinematics and can reduce

the occupant load values via the longer deceleration period. Assuming that the impact is known properly, the principle of reactivity can be augmented by actively moving the occupant in a defined direction. Prior to the impact occupants are not yet subjected to impact-specific inertial forces and can therefore be moved using little energy reaching comparable improvement with a lower pre-loading of the occupants (Figure 2)[2].

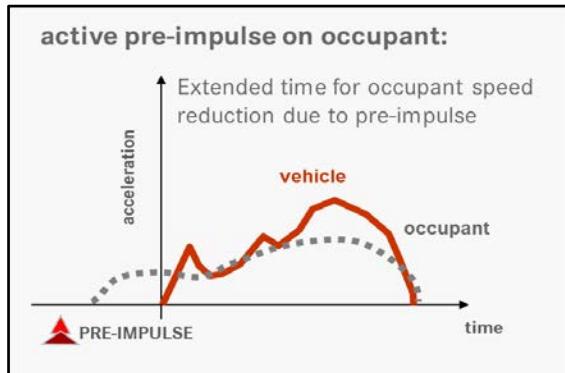


Figure 2: Active pre-impulse on occupant enable the change of velocity over the maximum of time

PRE-SAFE® IMPULSE SIDE

The PRE-SAFE® Impulse Side protection system demonstrates how a pre-impacting system could work. PRE-SAFE® Impulse Side is the very first of a new generation of pre-impacting restraint systems whose field of action will be extended prior to the collision due to the integration of active and passive safety.

Occupant Impact as Operative Mechanism

At a precisely calculated time prior to the side impact, the occupant of a vehicle is laterally displaced by a movement of the backrest side bolster. This small impulse moves the occupant toward the center of the vehicle before the impact occurs.

Actively moving the occupant toward the center of the vehicle increases the distance between the upper body of the occupant and the door panel so that the side airbag can be safely and efficiently deployed.

The contact time between intruding structure and occupant also occurs later and therefore with

reduced intrusion speed. In addition, the occupant is already moving at a certain speed in the direction of the impact. His/her relative velocity regarding to the intruding structure is smaller thus less kinetic energy has to be dissipated by the contact with the restraint system and/or the car structure. PRE-SAFE® Impulse Side, like all other PRE-SAFE® systems, acts as an additional measure that does not replace the conventional restraint system, but enhance it.

PRE-SAFE® Impulse Side Actuator

The seat was equipped with a dynamic multi contour seat component. There, in the side bolster of the driver and passenger seat backrests, an air bladder is inserted that can be filled to improve lateral support during cornering. To generate the impulse on the occupant, this air bladder was modified in terms of their size and filling characteristics so that they are strong enough to initiate the movement of the occupants toward the center of the vehicle. This process takes place within the seat without any damage and can therefore be repeated. The challenge with this setup is to create an upholstery concept, which on the one hand must allow sufficient movement, but on the other hand has to meet customer requirements in terms of design and comfort.



Figure 3: Occupant interaction due to PRE-SAFE Impulse activation

Sensor Systems

The monitoring of car surroundings using primarily radar sensors, but also cameras and ultrasonic sensors, has established itself as an enabler for assistance systems in modern vehicles.

Figure 4 depicts the equipment fitted to a Mercedes-Benz E-Class that features a 2016 driving assistance package plus .

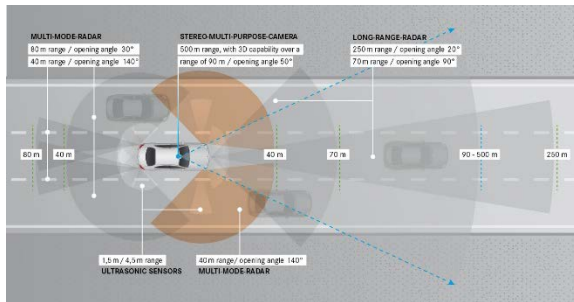


Figure 4: Sensor equipment of 2016 Mercedes-Benz driving assistance package plus

These sensors as used for driver assistance systems could also be used to develop spin-off applications that offer protection in an accident. Current Mercedes-Benz carlines equipped with a driving assistance package utilize targeted algorithms to detect an upcoming collision using forward-facing sensors and the sensor in the rear bumper. For this purpose, special algorithms were created that analyze the sensor data to detect directly "collision objects". Such detection can be realized independently of the assistance functions and operating status of the vehicle. The overarching objective is to detect "objects on a collision course", whereby this detection refers to the vantage point of the respective sensor. From this perspective, a passing vehicle in oncoming traffic is just as much an "object on a collision course" as a bridge pillar that the appropriate vehicle is approaching. Potential collision objects can also be detected when the vehicle is stationary. In the event of an impending frontal or rear-end collision, graduated preventive safety measures are activated. These measures are up to now always reversible in line with the underlying idea of the PRE-SAFE® concept.

Areas of coverage

The relevant space of time for detecting collision objects begins nearly half a second before the impact. From this time onwards it is possible to accurately predict whether the collision is unavoidable or not. As a consequence the short distance area to the vehicle (typically under 15 meters) must be covered by the sensor system for such functions. To realize the PRE-SAFE® Impulse Side function sensors that monitor the side area near to the car are needed in order to detect

objects on a collision course in the car environment. Therefore, it is mandatory to define areas of coverage that the sensor system has to monitor, in order to be able to address relevant use cases. In [5] and [6], an analysis of the pre-crash phase using the "Pre-Crash Matrix" of the GIDAS Database had been done, showing the rapprochement of collision objects between 400 and 200 ms prior to side collision. The result of this analysis can be seen on figure 5. The area of coverage of the radar sensor implemented (blue lines) has been overlaid to the rapprochement vectors showing that a very large majority of side collisions can be detected through the system.

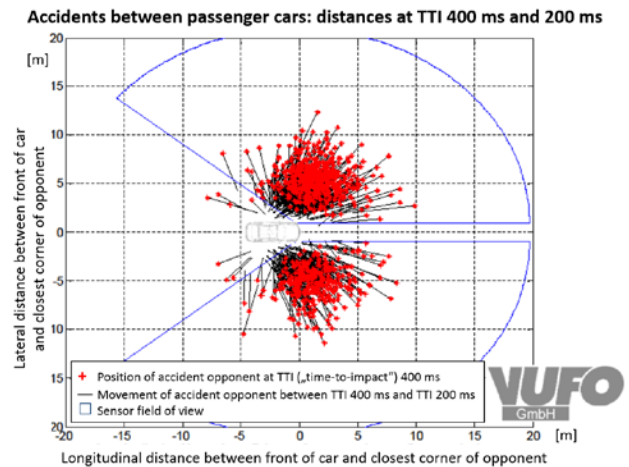


Figure 5: Rapprochement of collision objects between 400 and 200 ms prior to side collision

Sensor Systems

The relevant areas of coverage for the PRE-SAFE® Impulse Side function were not monitored from already implemented sensors as one can see on Fig.4 (grey areas). As a consequence, 2 new radar sensors have been implemented (orange areas on fig.4). These sensors filled this gap in the sensor coverage achieving a 360° monitoring of the car surroundings.

CRASH SET-UP

In order to assess the potential of the PRE-SAFE Impulse Side function, full scale crash tests were performed.

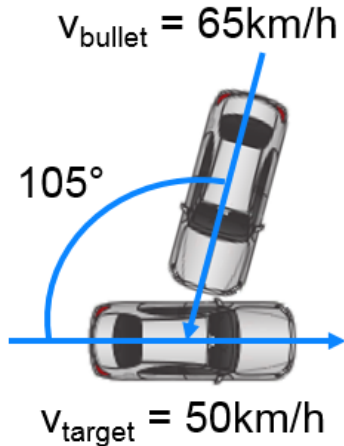


Figure 6: Side collision set-up

The test set-up is shown on Fig. 6. The bullet vehicle (Mercedes-Benz C-Class) had an impact speed of 65 km/h, while the target vehicle (Mercedes-Benz E-Class) had a vehicle speed of 50 km/h. The target vehicle was equipped with PRE-SAFE® Impulse in one test and did not have the preventative protection system in the other test. The collision angle of the two vehicles was 105° . The point of impact of the bullet vehicle in the side of the target vehicle was the center of the passenger compartment. The E-Class is equipped with a 50th percentile World-SID ATD in order to assess the loading on the driver. The purpose of the tests is to determine the potential of PRE-SAFE® Impulse in a real accident situation. The chosen situation was a severe side impact configuration of the kind that can easily occur at a road junction.



Figure 7: collision position at time frame $t=0 \text{ ms}$



Figure 8: collision position at time frame $t=90 \text{ ms}$

Fig. 7 shows the impact configuration at time $t=0 \text{ ms}$, while Fig. 8 shows the same at time $t=90 \text{ ms}$ at the start of the phase of separation of the bullet vehicle. The two vehicles impact each other approximately at right angles, the bullet vehicle directly in the A- to C-pillar region during the energy transfer process.

KINEMATIC ANALYSIS

To begin with, the analysis of the measured data is to be preceded by an analysis of the occupant kinematics. Fig. 9 and 10 both present the occupant situation of the driver at the start of the impact situation at time $t=0 \text{ ms}$. It can be clearly seen that, in Fig. 9, the dummy was pushed around 30-35 mm toward the center of the vehicle. Especially in the upper thoracic region, the distance between the dummy and the door panel has increased by this amount. This effect has the greatest impact on the upper region of the dummy, because this region is propelled about the fulcrum of the hips. Moreover, at the time of the start of the collision, the dummy is still moving inward, with the result that the change of velocity through the collision impact is lower than in the test without the PRE-SAFE® Impulse system.



Figure 9: Dummyposition @ 0ms with PRE-SAFE® Impuls

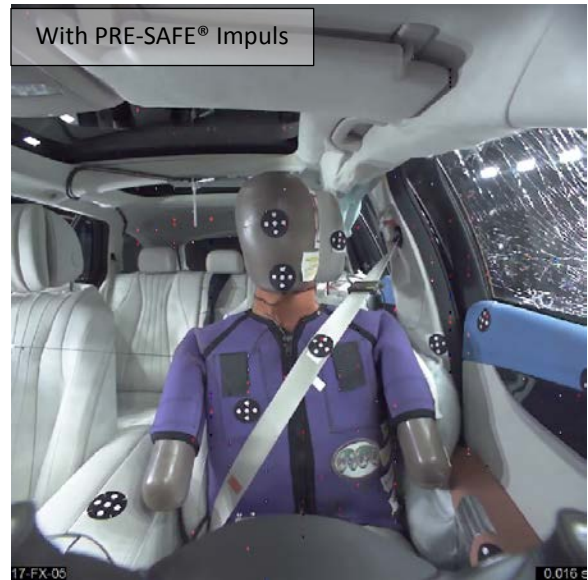


Figure 11: Dummyposition @ 16ms with PRE-SAFE® Impuls

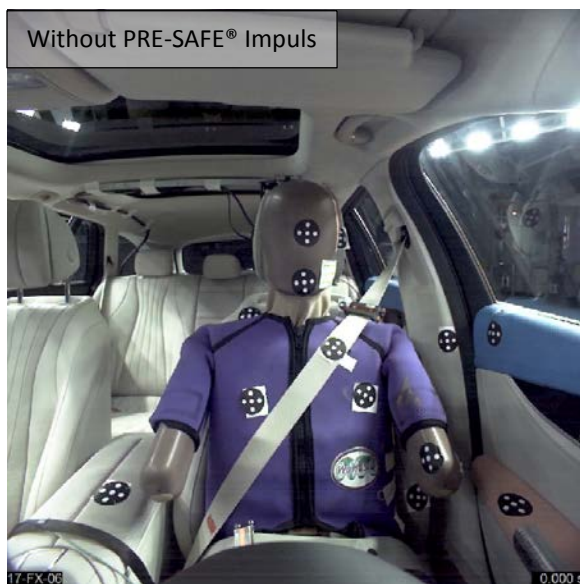


Figure 10: Dummyposition @ 0ms without PRE-SAFE® Impuls

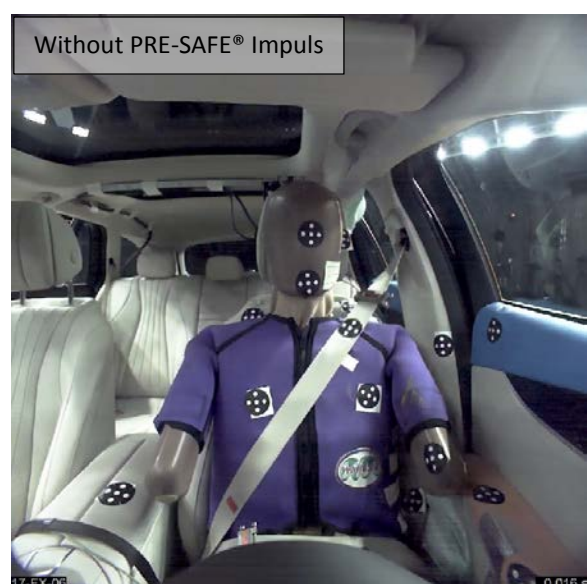


Figure 12: Dummyposition @ 16ms without PRE-SAFE® Impuls

Fig. 11 and 12 show the dummy position and airbag deployment at $t=16\text{ms}$. Despite an identical ignition time, a more favorable side airbag deployment can be seen in the test with PRE-SAFE® Impulse on account of the improved spatial conditions. This effect is all the more pronounced, the more the situation immediately before the collision leads to a dynamic displacement of the occupants due to a corresponding change of direction or evasive maneuver.

Fig. 13 and 14 both show the dummy position at $t=30\text{ms}$. At the start of the absorption phase, there is likewise a discernible kinematic advantage in the test with PRE-SAFE® Impulse. Both upper torso and head are at a greater distance from the intruding door. In Fig. 13, especially the center axis of the body is less inclined at the same time in the test with PRE-SAFE® Impulse.

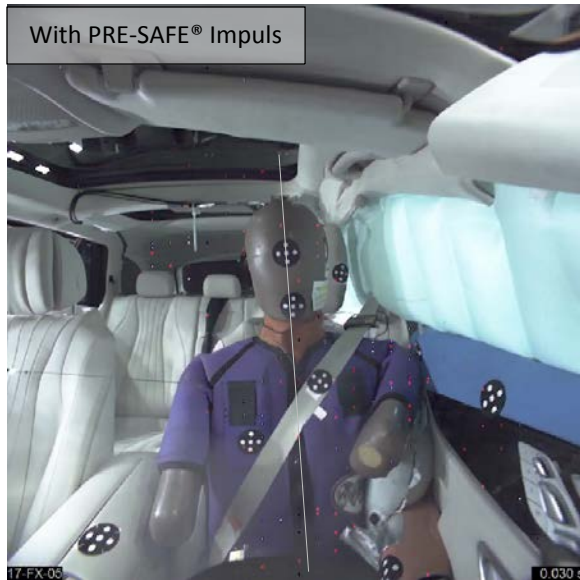


Figure 13: Dummyposition @ 30ms with PRE-SAFE® Impuls



Figure 14: Dummyposition @ 30ms without PRE-SAFE® Impuls

Fig. 15 and 16 show the occupant positions at $t=67$ ms at the end of the energy conversion phase. It can be seen that, in the test with PRE-SAFE® Impulse in Fig. 15, the impact on the shoulder rib is less pronounced than in Fig. 16, the test without PRE-SAFE® Impulse, as will be later apparent also in the measured data.

Overall, there is evidence of a more favorable kinematic configuration on the side away from the impact. Especially in driving situations that precede the crash, e.g. due to evasive driving maneuvers, driver and/or front passenger are exposed to these driving dynamics. This can lead to situations in which the body of the driver or front passenger is in contact with the side door panel and the thorax airbag has a constrained deployment space. In such a situation, PRE-SAFE® Impulse can increase the distance between thorax and side door panel, thereby opening the deployment space of the thorax airbag.



Figure 15: Dummyposition @ 67ms with PRE-SAFE® Impuls



Figure 16: Dummyposition @ 67ms without PRE-SAFE® Impuls

ASSESSMENT SYSTEM PERFORMANCE

As already discussed in the kinematic analysis, the potential of PRE-SAFE® Impulse is discernible especially in the upper thoracic region. In this impact configuration, the shoulder region is especially at risk and can be better protected by a precisely timed Impulse.

Fig. 17 to 21 show the relevant loading measurements from the crash test dummy in a comparison of the two tests. The scaling of the measured data was normalized to 100% in the baseline test, i.e. without the PRE-SAFE® Impulse system (red dotted curves). In contrast, the measured value from the test with PRE-SAFE® Impulse was plotted as a percentage (black curves).

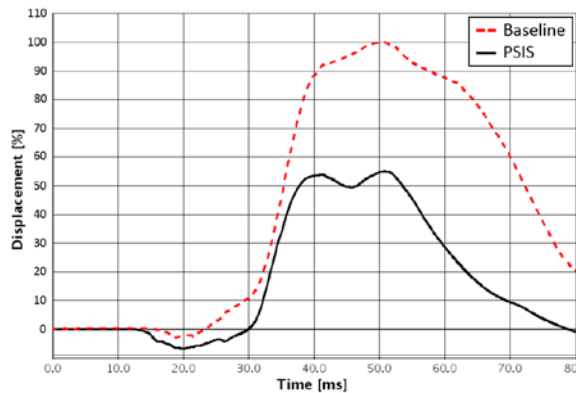


Figure 17: Measurement of the shoulder deflection

Fig. 17 shows that the deflection of the shoulder rib is only 55% in relation to the measured value from the baseline test. Moreover, a significantly earlier unloading of the shoulder rib is discernible.

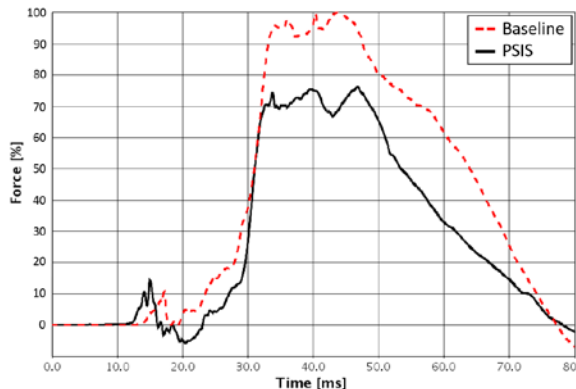


Figure 18: Measurement of the shoulder force

The same potential is visible in the measured value of the shoulder force in Fig. 18. The measured value in this case is only 77% in relation to the baseline test. In current ratings and legal regulations, the shoulder force in particular represents a key hurdle for meeting the targets. This is where PRE-SAFE® Impulse can bring about an improvement in tests and in real accidents.

Fig. 19 shows the improvement of the upper thoracic rib in relation to the baseline test. A 20% improvement is identifiable.

As already mentioned, the improvement reduces, the nearer the measurement is to the hips, the fulcrum of the PRE-CRASH displacement.

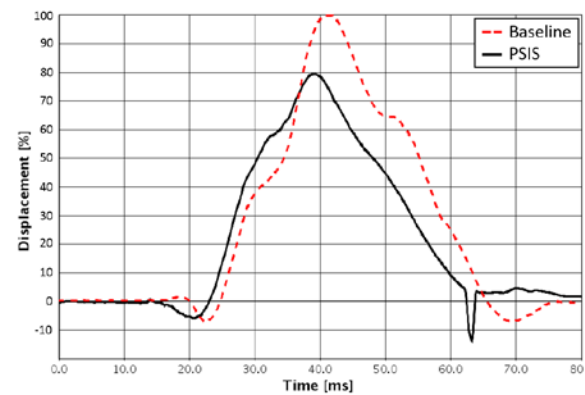


Figure 19: Measurement of the upper rib deflection

In the region of the middle thoracic rib in Fig. 20, an improvement is no longer discernible. However, the test with PRE-SAFE® Impulse shows an earlier start of absorption than the baseline test. This is due to the inflated seat side bolster, which interacts with the side airbag in the absorption phase.

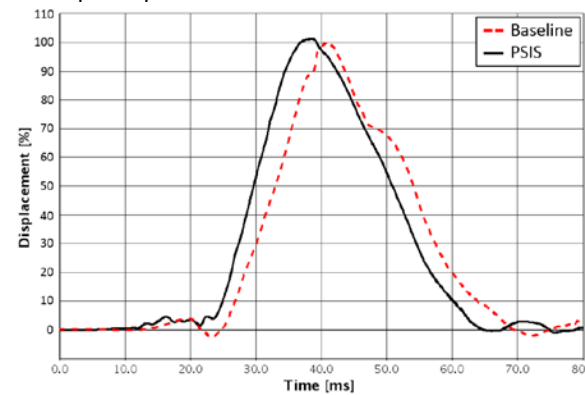


Figure 20: Measurement of the middle rib deflection

Fig. 21 shows the lower value of the thoracic rib. There is no identifiable improvement in this case. The proximity to the fulcrum of the PRE-CRASH displacement did not lead to a change of location or velocity of the lower thoracic region.

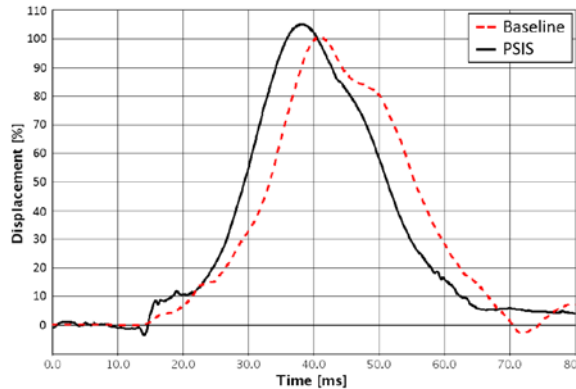


Figure 21: Measurement of the lower rib deflection

CONCLUSIONS

In medium to severe side impact configurations, PRE-SAFE® Impulse can, through preventive displacement of the occupant toward the center of the vehicle, significantly reduce the forces to which the occupant is subjected. The maximum measured potential is 45% deflection and 23% of the force. The additional absorption space as well as the relative displacement toward the vehicle center represent the physical basis for improving the kinematics and the therefrom resulting measured data.

Mainly the upper thoracic regions are affected. The initiated kinematics causes the occupant to be tilted about the fulcrum of the hips toward the center of the vehicle. This guarantees the safe and timely deployment of the airbag.

In situations with prior driving dynamics, the occupant can constrain the airbag, in which case PRE-SAFE® Impulse, by displacing the occupant prior to airbag ignition, can contribute to improving the situation.

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