DUMMY-LOADINGS CAUSED by an Airbag In SIMULATED OUT-OF-POSITION SITUATIONS

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ABSTRACT

A series of crash tests which were carried out to examine the stresses on passenger dummies (hybrid III, 50 % male) in a simulated out-of-position situation (BERG et al., 1996a) has been continued to include the lower speed range close to the airbag trigger threshold. In these tests, the passenger dummy was unbelted and bent forward out of position.

Two new full-scale tests were carried out with an Opel Corsa at impact velocities of 29 km/h and 34 km/h. The vehicle impacted a rigid barrier with 40 % frontal overlap. In the test at 29 km/h, the airbag trigger threshold was not reached. In the test at 34 km/h the airbags were triggered. Between the two tests, the car was repaired in a body shop with a complete interchange of the damaged parts. In addition, two tests were performed triggering the passenger airbag whilst the vehicle was stationary and varying the position of the corresponding passenger dummy. This dummy was bent forward in each of the cases. In one case the dummy's head was close to the dashboard, in the other the distance between its nose and the dashboard was 175 mm.

The test findings are presented and discussed on an interdisciplinary basis. The main attention is focused on: the traumato-mechanical relevance of the loadings recorded on the dummies, knowledge of biomechanical limits of the cervical spine, analyses of the worst case of the stresses with respect to traumato-mechanical aspects and the evaluation of the problems against the background of real world accidents.

METHODOLOGY OF THE EXPERIMENTS

The Tests

Two full-scale tests were carried out with a 40 % frontal overlap crash of the test vehicle at a speed of 29 km/h and 34 km/h against a rigid barrier. Figure 1 shows, for example, the test at 29 km/h. In each case, the test vehicle

was an Opel Corsa. Between the two tests, the car was repaired in a body shop with a complete interchange of the damaged parts.

In both full-scale tests, a hybrid-III-dummy (50 % male) was seated belted in the driver´s seat in a normal sitting position. On the passenger´s seat another hybrid-III-dummy was seated bent forward, unbelted and out of position. Figure 2 shows the dummies in position and ready to test.

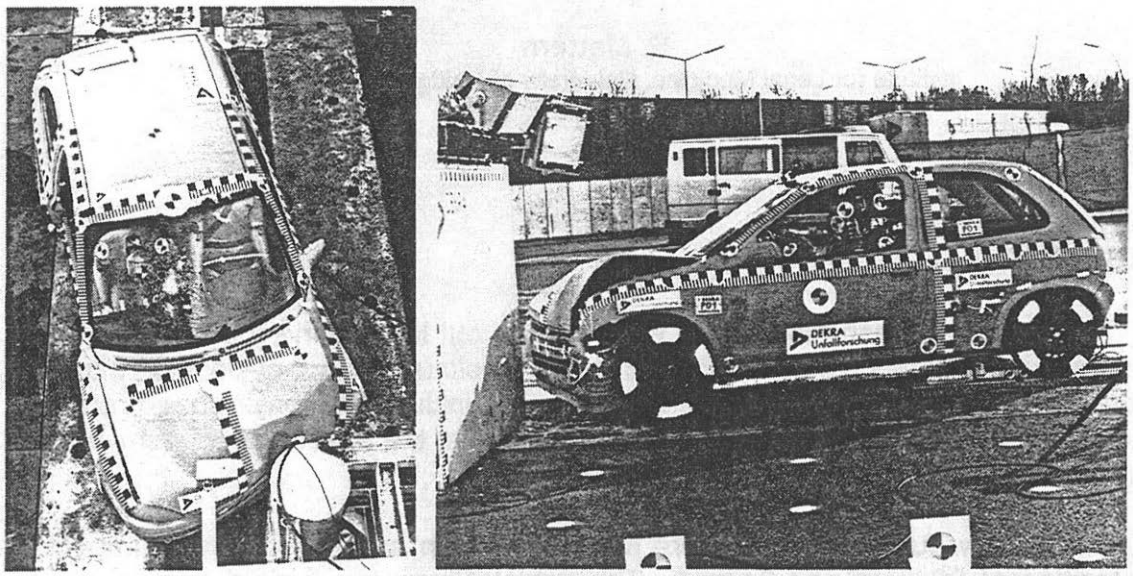


Fig. 1: Full-Scale Crash Test (Overlap 40 %, Velocity 29 km/h)

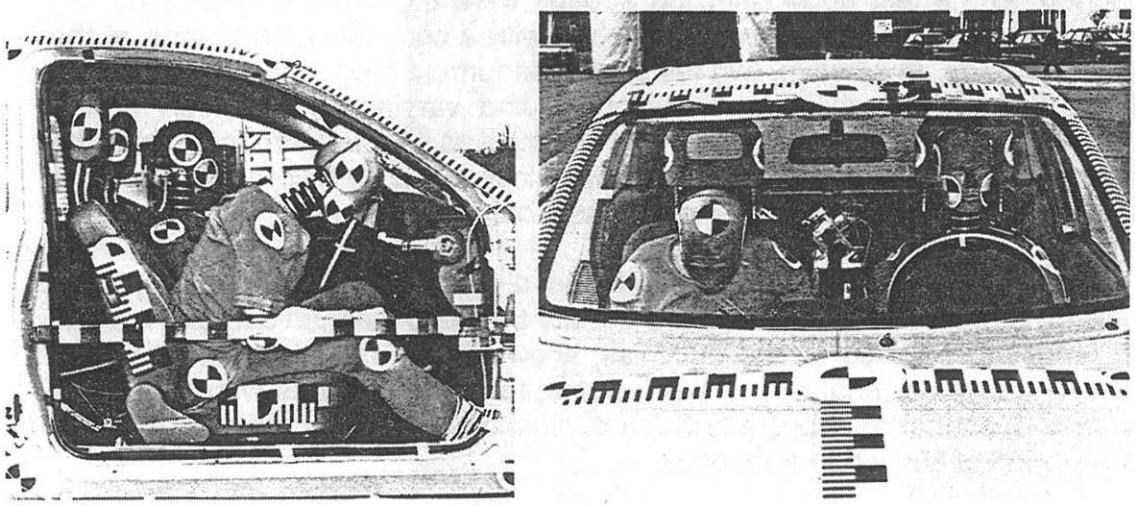


Fig. 2: Seating Positions of the Dummies in the Full-Scale Tests

These two full scale tests continued a series of earlier tests with 40 % overlap impact at 55 km/h on four vehicles (Ford Fiesta, Opel Corsa, 2 Opel Vectra) in which the dummies were seated similarly (BERG et al., 1996, 1996a). These two further tests addressed the lower speed range close to the airbag trigger treshold.

Two additional tests were carried out triggering the passenger airbag in the stationary vehicle. In each test the dummy was seated bent forward, in one case with its head close to the dashboard and, in the other case with a distance of 175 mm between its nose and the dashboard (Fig. 3). The test condition with the passenger dummy bent forward without its head being close to the dashboard represents a seating position which is more realistic in real world accidents. The other position is extreme and represents a worst case, as proposed by the German car industry (WEZEL, 1992).

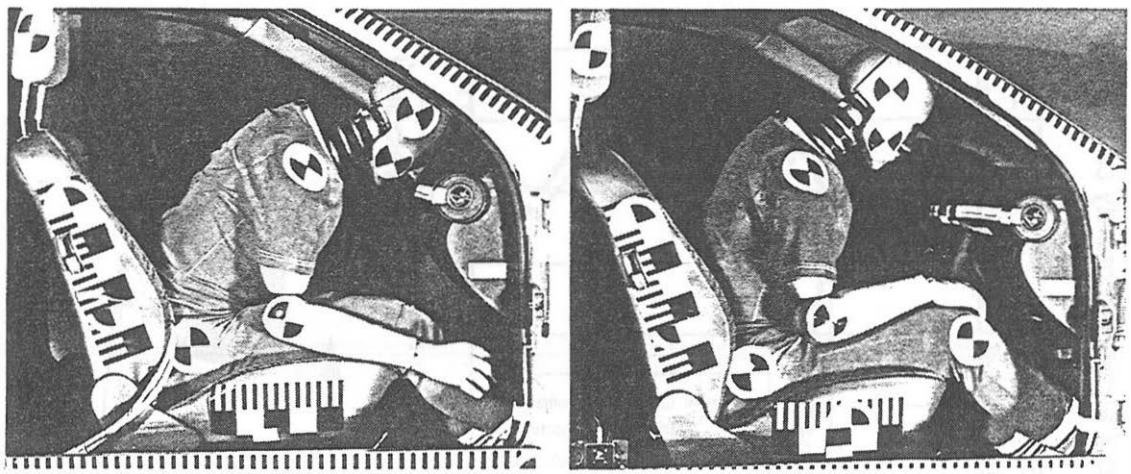


Fig. 3: Seating Positions of the Passenger Dummy in the Stationary Vehicle

Test Vehicle

Table 1 includes some data on the test vehicle including features of the restraint system. Full-size bags were installed on the driver and on the passenger side. The bag material was uncoated fabric with vent holes. The bags were inflated by conventional gas generators and supplement active belt systems with belt buckle tensioners and adjustable upper mountings.

Fig. 4 shows the longitudinal velocities of a target on the roof above the centre of gravity and the yaw velocities of the test vehicle in both full-scale crashes

Table 1: Test Vehicle

Test Vehicle:	Opel Corsa 1.4 i
Test Weight:	1 049 kg
Safety Belts: **(Driver and Passenger)**	3 Point Belt with Belt Buckle Tensioner Adjustable Upper Mountings
Airbags:	Full-Size Bags Driver: 67 Litres, Passenger: 100 Litres Uncoated Fabric with Vent Holes Conventional Gas Generator (Sodium Azide)

derived from analysis of the overhead film. The characteristics of the velocity at the centre of gravity and the yaw velocity indicate that the crush phase ended near t = 0.12 s in both tests. During this time interval, as shown in the diagram, the velocity vector change at the centre of gravity was found to be Δv = 29 km/h in the test without airbag activation and Δv = 34 km/h in the test when the air-bag triggered.

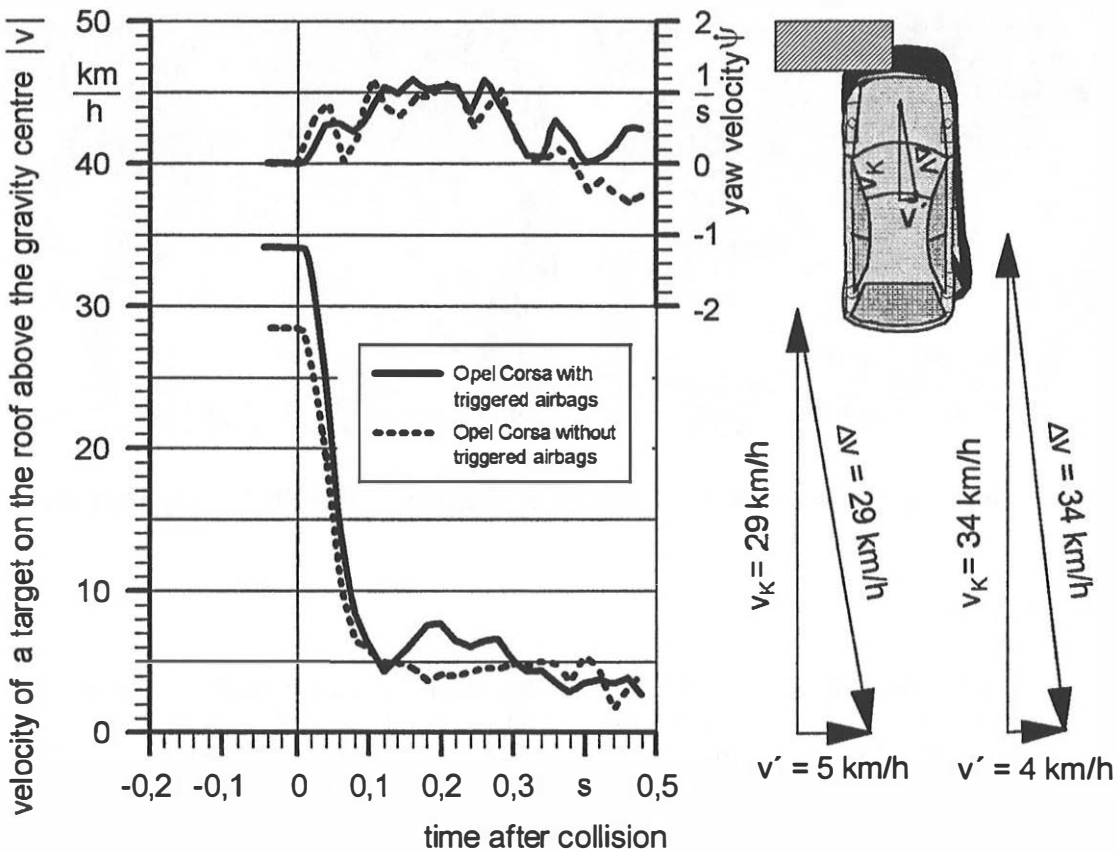


Fig. 4: Longitudinal Velocities and Yaw Velocities of the Test Vehicle during the two Full-Scale Crashes, as Determined from Analysis of the Overhead Film

The longitudinal deceleration (x-direction) of the passenger compartment in the two full-scale crashes is shown in Fig. 5. The measurement point was on the floor of the compartment, in the centre between the B-pillars. The CFC-60-filtered signal (SAE-J 211 a) has a maximum a_x = 27.0 g at t = 59 ms in the case without airbag activation. In the case when the airbag triggered the maximum was a_x = 39.6 g at t = 49 ms.

The velocities were determined by integrating of the CFC-1000-filtered deceleration signals. They indicate a path through zero at approx. t = 80 ms

after the start of the crash. The rebound phase then starts. At approx. t = 100 ms the velocity is close to -5 km/h. In the test without airbag ignition, the longitudinal change in velocity was Δv_x = 33.7 km/h at the measurement point, in the test when the airbag triggered, it was Δv_x = 38.8 km/h.

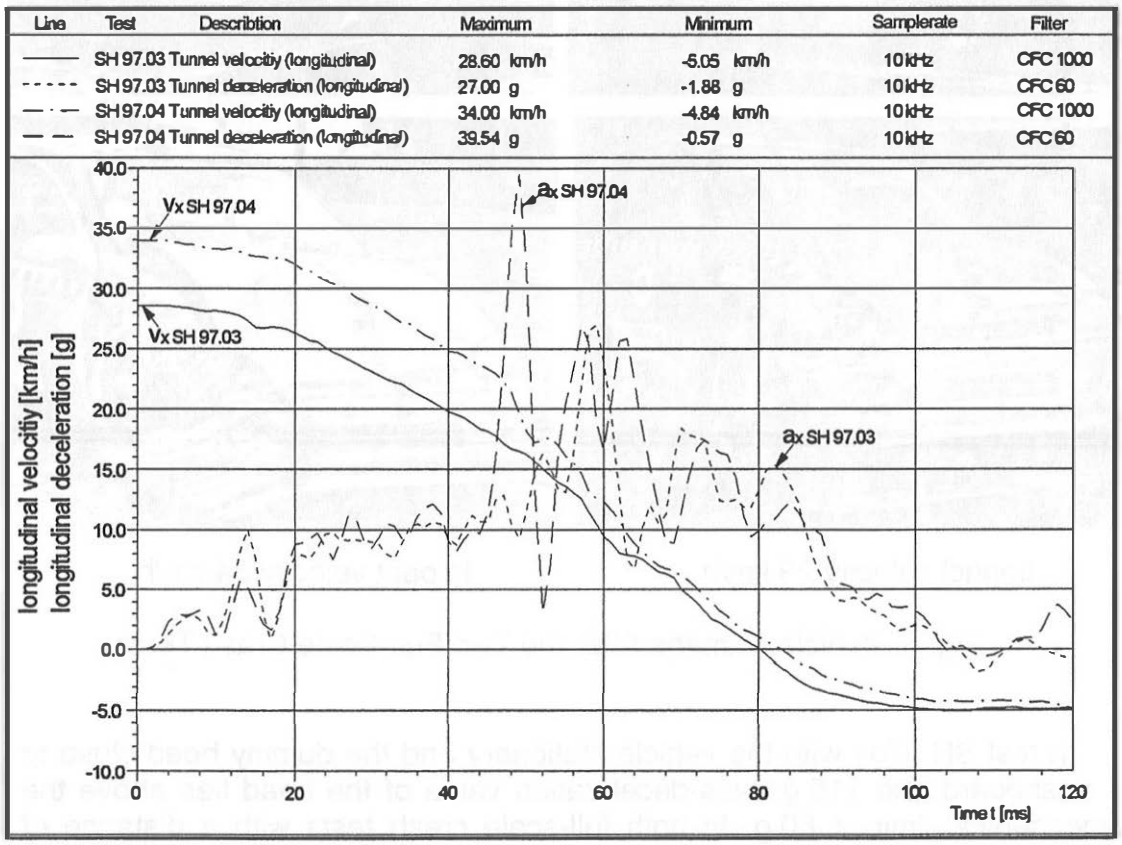


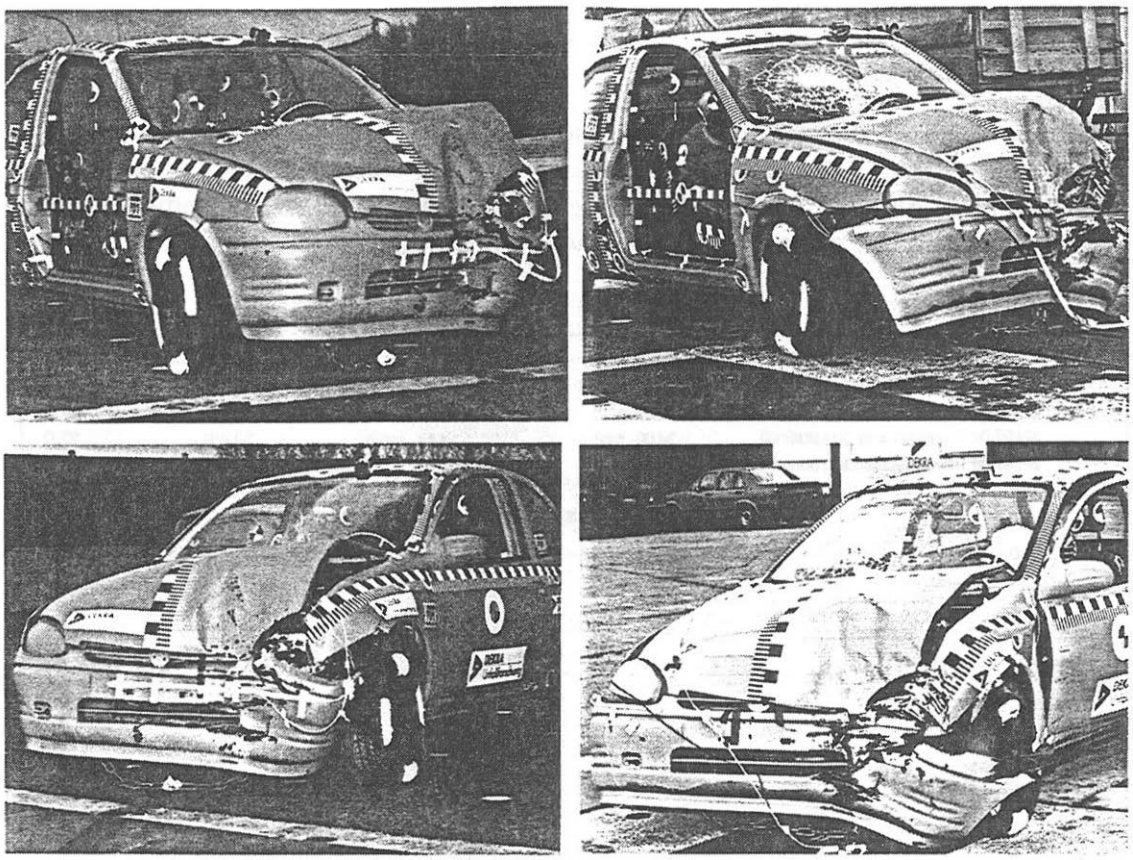
Fig 5: Longitudinal Deceleration Measured on the Floor of the Passenger Compartment and Corresponding Velocity Curves for the Two Full-Scale Crash Tests

Fig. 6 gives an overview of the damage to the front of the vehicle after the two tests. The characteristics are typical for front to front collisions of two cars in opposing traffic with a medium severity near to the actual designed trigger treshold of the airbags.

RESULTS

Loadings on the Dummies

Table 2 shows the loadings acting on the passenger dummy and the corresponding biomechanical limits for the two tests with airbag activation whilst the vehicle was stationary and also for the two full-scale crash tests.



Impact velocity 29 km/h Impact velocity 34 km/h

Fig. 6: Vehicle Damage After the Two Full-Scale Crash Tests

In test SH 9701 with the vehicle stationary and the dummy head close to the dashboard, the 115 g 3-ms-deceleration value of the head lies above the biomechanical limit of 80 g. In both full-scale crash tests with a distance of 175 mm between the dummy nose and the dashboard, the neck loading exceeded the relevant limits. In test SH 9703 when the airbag did not trigger, the neck moment M_y = +243 Nm (flexion) lies above the limit of +190 Nm. In test SH 9704 when the airbag triggered, the neck moment M_y = -86 Nm (extension) was outside the limit of -57 Nm.

The other loadings measured on passenger dummy seated out of position in the four tests clearly lie within their respective biomechanical limits.

Dummy Kinematics

Test with stationary vehicle, dummy's head close to the dashboard (Test SH 9701, Fig. 7): The airbag cover blows open at t = 9 ms after generator ignition. The cover flap then, without contacting the dummy head, strikes the windscreen which partially shatters as a result. The deploying airbag meets the dummy's forehead at t = 10 ms. At t = 17 ms the head, neck and shoulders are in contact with the deploying airbag. Simultaneously the dummy head is pushed backwards, which rapidly results in a pronounced extension (backward bending) of the neck. A slight turning of the head to the right is superimposed

Table 2: Loadings on the passenger dummy and biomechanical limits

Body Region	Test Condition (Test No.)				Biomech. Limit
	Stationary Vehicle		Full-Scale Crash test		
	*) (SH 9701)	**) (SH 9702)	29 km/h **) (SH 9703)	34 km/h **) (SH 9704)	
Head					
HIC	801	49	156	402	1 000
a_{3ms}	115 g	35 g	37 g	60 g	80 g
Neck					
$F_{x,45\ ms}$	200 N	192 N	169 N	161 N	1 100 N
$F_{z,\ 45\ ms}$	27 N	4 N	247 N	143 N	1 100 N
M_y (+)	+ 42 Nm	+ 12 Nm	+ 243 Nm	+ 17 Nm	+ 190 Nm
M_y (-)	- 34 Nm	- 42 Nm	-11 Nm	- 86 Nm	- 57 Nm
Chest					
SI	13	3	128	172	1 000
a_{3ms}	12 g	7 g	34 g	40 g	60 g
deflection	4 mm	2 mm	5 mm	9 mm	76 mm
Pelvis					
a_{3ms}	5 g	2 g	29 g	32 g	60 g
Femur					
F_{left}	1 kN	0 kN	- (not measured)	6 kN	10 kN
F_{right}	1 kN	1 kN	5 kN	5 kN	10 kN

*) Dummy Out of Position, Head Close to the Dashboard

**) Dummy Out of Position, Distance Between Dashboard and Nose 175 mm

on this. At t = 30 ms the upper body of the dummy is pushed backwards by the airbag which is still deploying. At t = 32 ms the head (top of the skull) contacts the windscreen. This results in a crack in the screen at the contact point. Airbag deployment is complete at t = 35 ms. The airbag now has filled the free space between the dummy's torso, its thighs and the dashboard. The airbag is tight against the dummy's head, neck and chest. During the backward movement at t = 78 ms the crown of the dummy's head contacts the roof and sun visor. This causes a slight flexion (forward bending) of the neck which changes once more to an extension as the head swings back (t = 172 ms). At this stage the dummy´s body is already tight against the seat back. Further in the sequence the back of the head lands on the headrest.

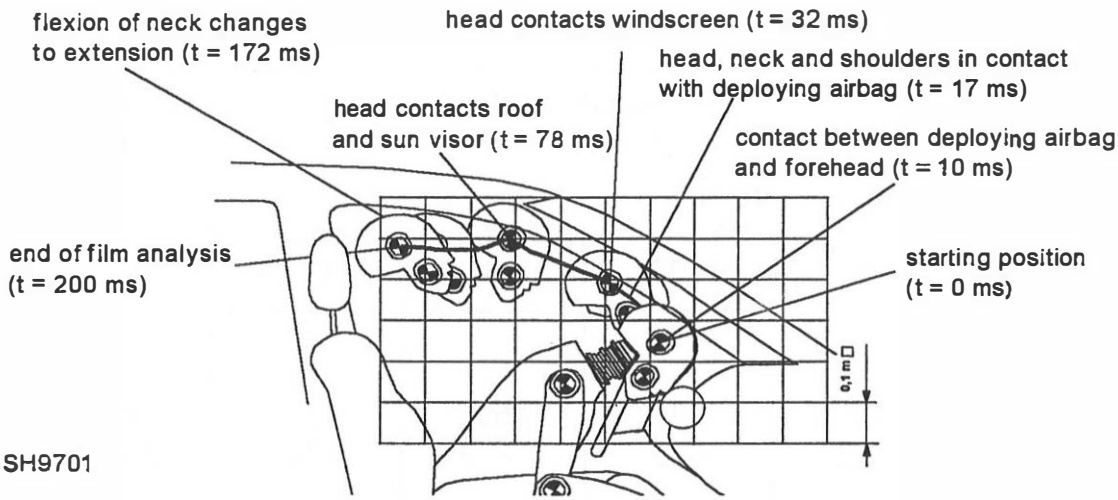


Fig. 7: Movement of the dummy in test SH 9701 (Stationary Vehicle)

Test with stationary vehicle, 175 mm distance between dummy nose and dashboard (Test SH 9702, Fig. 8): The airbag blows the cover flap off at t = 11 ms after the ignition. The dummy head meets the airbag in the region of the upper half of the face at t = 16 ms. At t = 24 ms the airbag has contact with the entire face, the neck and body of the dummy. Immediately after this, at t = 26 ms, the airbag starts to push the dummy head backwards, whereby a pronounced extension (backward bending) of the neck occurs. At t = 42 ms the airbag is fully deployed and the torso of the dummy is also being pushed backwards. The head now maintains its bent back attitude, striking the headrest at t = 132 ms. At t = 144 ms the torso lands heavily on the backrest,

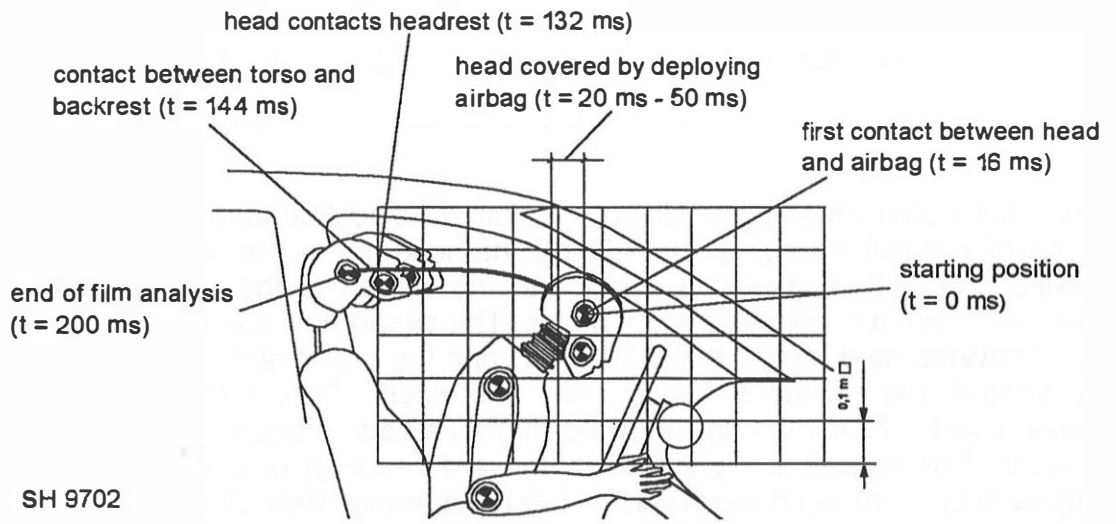


Fig. 8: Movement of the dummy in test SH 9702 (Stationary Vehicle)

bending it backwards. As events proceed a reverse deformation of the backrest occurs and the dummy swings once more forwards.

Full-scale crash test at 29 km/h collision velocity with no triggering of the airbag, 175 mm distance between dummy nose and dashboard (Test SH 9703, Fig. 9): The inertia of the forward leaning passenger dummy causes a pronounced forward movement relative to the vehicle starting at t = 26 ms. At t = 77 ms the dummy strikes the dashboard first with the nose and then with the mouth. This leads to a forward movement of the head with flexion (forward bending) of the neck. The forehead of the dummy then contacts the dashboard at t = 90 ms. This is the point at which the flexion of the neck reaches its maximum. At t = 105 ms the dummy is at its most forward position with respect to the vehicle. As the movement continues the dummy's body falls back into the seat.

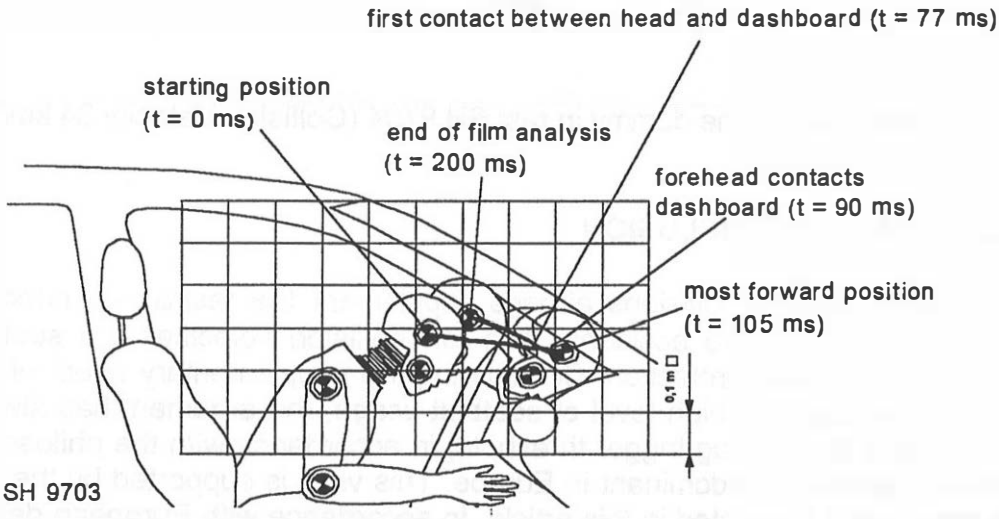


Fig. 9: Movement of the dummy in test SH 9703 (Collision Velocity 29 km/h)

Full-scale crash test at 34 km/h collision velocity with triggering of the airbag, 175 mm distance between dummy nose and the dashboard (Test SH 9704, Fig. 10): The forward movement of the forward leaning dummy relative to the vehicle begins, as a result of its inertia, at t = 29 ms after the start of the collision. At t = 75 ms the emergence of the airbag from the dashboard and its subsequent deployment begin. At t = 79 ms the airbag touches the right hand side of the dummy's face. At this stage the dummy head is above the airbag, which is inflating beneath it. The further deployment of the airbag under the dummy's torso is displaced to the right. As the forward movement proceeds, the crown of the dummy's head strikes at t = 84 ms against the windscreen. This results in some local splintering and deformation of the windscreen. The airbag is fully deployed at t = 104 ms. The forward displacement of the dummy relative to the vehicle is completed by t = 102 ms when the head has its maximum penetration into the windscreen. A maximum deformation

depth of approx. 23 mm was later determined in this region. As the sequence continue the dummy falls back into its seat.

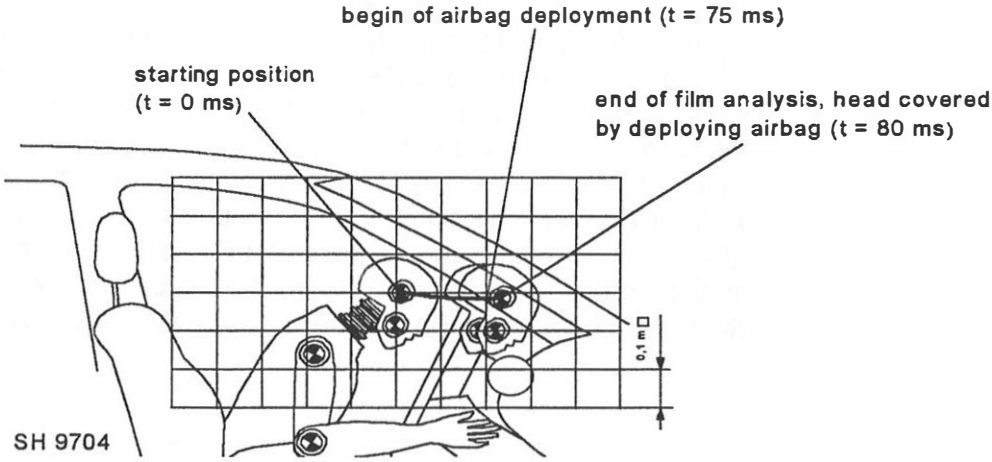


Fig. 10: Movement of the dummy in test SH 9704 (Collision Velocity 34 km/h)

DISCUSSION and CONCLUSION

In severe frontal collisions airbags supplement the restraining effect of seatbelts. In less severe accidents with low collision velocities the seatbelt alone gives adequate protection. Considering the supplementary effect of air-bags and the relatively high level of seatbelt usage, the argument has always been put for a high airbag trigger threshold, in accordance with the philosophy and design practice predominant in Europe. This view is supported by the full-scale crash tests presented in this article. In accordance with European design practice, the literature generally quotes a trigger threshold for airbags Δv of approx. 25 km/h. In comparison to this the triggering threshold of the airbags in the Opel Corsa may at first seem high, being a collision dependent velocity change Δv of over 30 km/h in a frontal impact with 40 % overlap against a rigid barrier. It is however consistent, because the belted occupant is to be adequately protected. It should also be borne in mind in this context that the new algorithms for airbag triggering no longer work with fixed thresholds but variably. Depending on the manner of the deceleration, the velocity change trigger threshold, Δv, is higher in relatively soft collisions such as the offset crash, than in hard collisions with full overlap against a rigid barrier.

Given that triggering occurs, the best possible protection from the airbag is available when it is fully deployed. Achieving this in a timely manner requires the release of appropriate amounts of energy. The way an occupant is stressed by a prenature contact with the airbag is therefore of special interest. As four published tests have already shown, contact with the inflating airbag in corresponding non-extreme out-of-position situations do not necessarily lead to injuries or life threatening stresses (BERG et al., 1996, 1996a). For unbelted,

bent forward passenger dummies at impact velocities of 55 km/h more of a protective effect than a danger was afforded, whether by contact with an Euro bag or with a full size bag.

SCHMITZ (1997) published results from nine sled tests (collision velocity 50 km/h) with a variety of dummies (50 % male, 5 % female) and differing sitting positions, which are in agreement with the previous observations. In this case Euro bags of 65 litre volume were used on the passenger side. Increased stresses were indeed measured both on an unbelted dummy and on a dummy sitting in a forward leaning posture, but these nevertheless lay below the appropriate biomechanical limits. Dummy stresses which would predict serious or fatal injuries were established in a case of extreme sitting posture, a sleeping position with the seatback tilted backwards. However the immediate effect of the airbag was not significant in respect of the high forces but rather the unfavourable sequence of dummy movement.

The residual protective effect of airbags for unbelted occupants in non-extreme out-of-position situations could not be established with equal clarify from the two full-scale tests published in this article. The neck of the dummy in the test without airbag triggering (collision velocity 29 km/h) was stressed with a maximum flexion moment of 243 Nm, well above the appropriate limit of 190 Nm. In the test with airbag activation (34 km/h collision velocity) the permitted limit for the extension moment of -57 Nm was clearly exceeded by the maximum attained value of -86 Nm. However the stress was caused not so much by the airbag as by the contact with the windscreen. The deployment of the airbag, and with it the restraining effect, was hindered by the torso and head of the dummy to such a degree that a severe impact of the head against the windscreen could not be avoided.

The risk of injuries induced by the airbag increases in cases of extreme out-of-position situations. In this article two tests are described where the airbag was activated in the stationary vehicle. When the dummy is bent forward in a non-extreme position, with a distance of 175 mm between its nose and the dashboard, all the measured stresses lay below the appropriate biomechanical limits. In an extreme position with the nose close to the dashboard however, the 3 ms deceleration value of the resulting head movement lay at 115 g well above its limit of 80 g.

Tests with cadavers also indicate an increased risk of injury if there is immediate contact between parts of the body and the airbag cover at the beginning of the airbag release (Schroeder et al. 1997). Thus, for example, with contact of the head, HIC-values lying above 1000 and 3 ms deceleration values above 80 g were measured at the head. In one case an open fracture of the nose occured which was related to the impact of the airbag cover. Serious injuries to the neck vertebrae were also found.

A few cases are known from the history of real world accidents which give reasons to suppose that the effects of an airbag could led to fatal injuries. Amongst these is the case of a belted female passenger (age 57 years, height

157 cm, weight 67 kg) in a taxi which collided head on with a tram at a velocity of approx. 30 km/h at an angle of between 80° and 85° (MAXEINER et al. 1996). Both of the full-size front airbags in the taxi triggered. The driver suffered slight injuries, but the passenger received very severe injuries to the neck vertebrae from which she died 13 days after the accident. Skin abraisons to the face provided evidence of an aggressive airbag contact. It was established that the passenger seat was almost all the way forward. An active forward bending movement of the torso immediately before the collision was suspected. The woman was wearing thick, bulky winter clothing and the belt was correspondingly loose. An extreme out-of-position situation as the airbag released caused by a further increase in the forward movement of the torso resulting from the impact deceleration can therefore be assumed.

These difficulties are being taken into account in the further technical development of airbags (smart bags) through graduated gas generator output, adjusted to the severity of the accident and to the occupant parameters (BIGI et al., 1996). The sensing of occupant position and the recognition of extreme out-of-position situations is also possible.

Evidence for the protective effects of airbags is provided by the events of real world accidents. As an example, a summary from the American National Highway Traffic Safety Administration (NHTSA) shows that in the USA 1500 drivers and 164 passengers have been saved from fatal injuries by airbags. Nevertheless 19 fatalities on the driver side and 32 fatalities with children on the passenger side were registered low speed collisions with triggering of the airbag. (VDA Report No. 2, 18.02.1997). Most of these people (adults/children) did not use safety belts or child restraint systems. Some of the fatalities involved children in rearward facing child restraints in the front passenger seat. This makes the out-of-position problem especially relevant.

Against this background there is a considerable need for objective public clarification of the mutual effect of airbag and belt, as well as of possible dangers in extreme out-of-position situations. The airbag has opened up possibilities for further reducing the number of vehicle occupants killed in traffic accidents. A prerequisite for the realisation of these possibilities is the widespread fitting of airbags to, as far as possible, all cars. Tragic exceptions and the danger of injuries in extreme circumstances or in case of misuse, are reasons for further technical development. However the protective potential and the benefit of airbags has been proven not only through tests, but repeatedly by the history of real world accidents.

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