CRASH TESTS USING PASSENGER CARS FITTED WITH AIRBAGS AND A SIMULATED OUT-OF-POSITION PASSENGER

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ABSTRACT

Airbags considerably enhance the internal safety of passenger cars. As the number of vehicles being fitted with airbags rapidly increases, so will more answers be sought to the questions relating to injuries which may be caused by the airbag in specific road accidents.

In order to provide protection, the airbag first needs to be inflated. During the inflation process, a corresponding amount of energy needs to be activated. If the vehicle occupants are impacted by the airbag during the inflation phase, additional loadings may result. This can occur if the person concerned is seated out of position at the beginning of an accident, such that their head is positioned close to the airbag cover.

Four tests were carried out at the DEKRA Crash Centre, based on this theme. For the purposes of the study, complete vehicles were driven at 55 km/h with a 40 % frontal overlap into a rigid barrier. In each test a belted Hybrid III dummy was located in the driver´s seat in a normal seating position. In the passenger seat an unbelted Hybrid III dummy was seated bent forward, out of position. Three different passenger cars were used: a Ford Fiesta with Euro bags, an Opel Corsa and an Opel Vectra, both with full size bags. Each of these cars was fitted with driver and passenger airbags. In order to make a comparison for the passenger without an airbag, one more test was conducted with a second Opel Vectra.

The test results are presented in this article and discussed on an inter-disciplinary basis. The problems posed by the out-of-position aspect form the focal point of the text. The article also goes into the medical biomechanical relevance of the recorded impact stresses on the dummies and possibilities for reducing the injury risks caused by airbag deployments.

METHODOLOGY OF EXPERIMENTS

TEST BASE

All experiments were carried out as a 40 % frontal overlap crash of the complete vehicle into a rigid barrier, at a speed of 55 km/h. Figure 1 shows, for example, the test with the Opel Corsa. In each test vehicle a belted Hybrid III dummy (50 % male) was located in the driver´s seat, in a normal seating position. In the passenger seat an unbelted Hybrid III dummy was seated bent forward, out of position. Figure 2 shows, for instance, the dummies in the Ford Fiesta, in a condition ready to test.

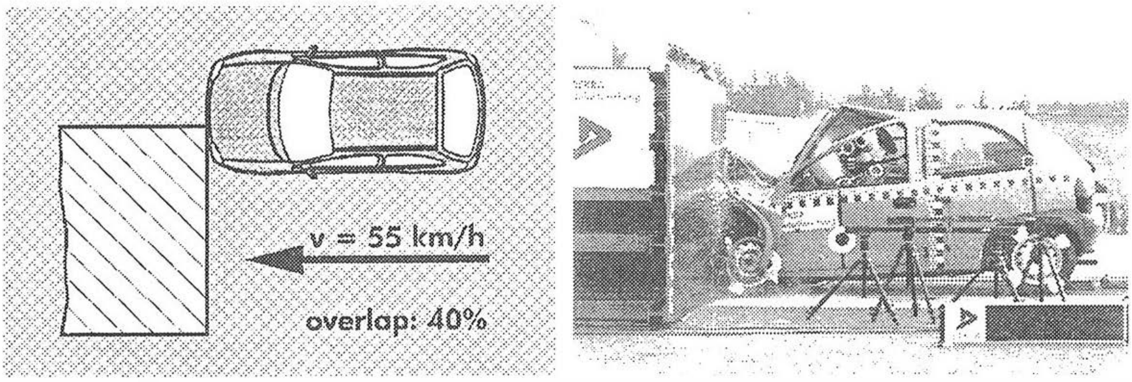

Fig. 1: Crash Test

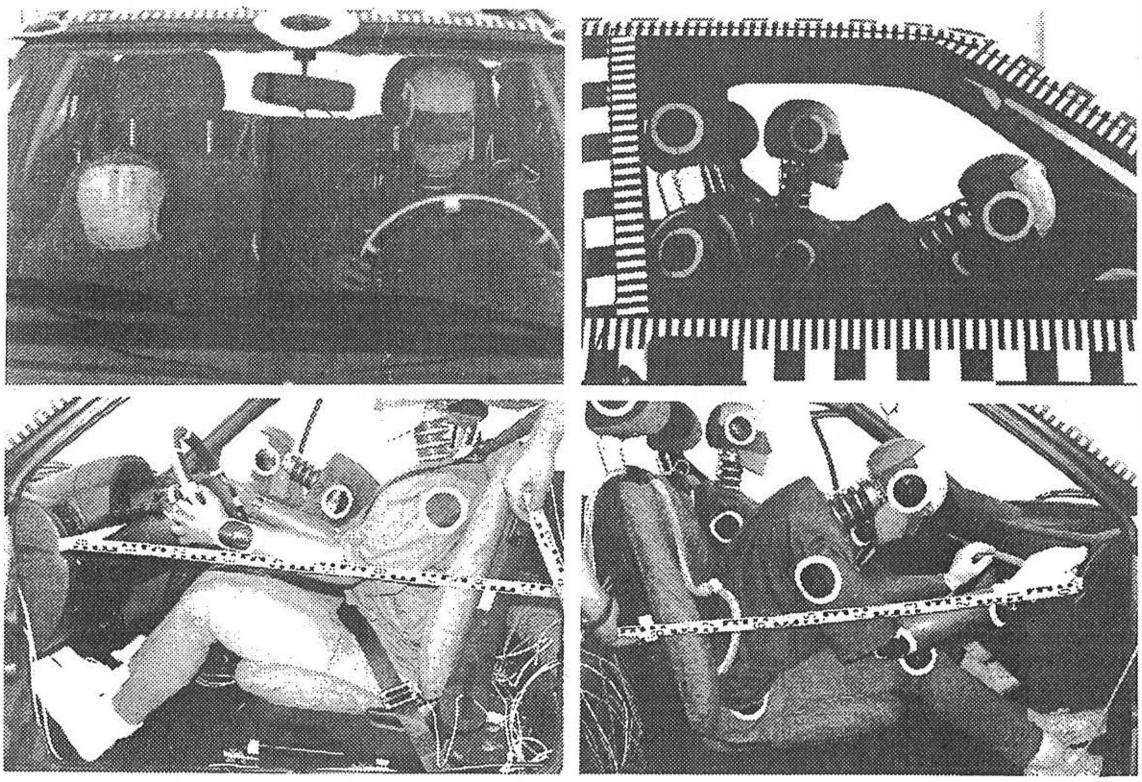

Fig. 2: Seating Positions of the Dummies

The test condition with the passenger dummy bent forward was selected to represent a seating position which is not normal, but none the less realistic. Such a posture can for example occur when the person in the passenger seat is looking for something in the glove box. Other, in some cases more extreme, dummy seating positions were proposed by the german vehicle industry and included in the consultations for the "Test Procedure for Evaluating Out-of-Position Vehicle Occupants´ Interaction with Deploying Airbags" by the ISO/TC22/SC19/WG3 (Wezel, 1992).

The theme of this article is restricted to the passenger. A detailed publication relating to the Ford Fiesta also exists (Berg et. al., 1995).

Test Vehicles

Table 1 gives an overview of the test vehicles, with features of the passenger airbags. The vehicle test weights given include both dummies and the installed data acquisition equipment (sensors, transient recorder and connecting cables). In the Ford Fiesta smaller Euro bags are installed, in the Opel vehicles are Full Size bags. The gas generators in the Ford Fiesta and the Opel Corsa employ the conventional technology. Hybrid gas generators are installed in the Opel Vectra. Test number SH 96.01 serves to compare the loads acting on an unbelted passenger who is sitting bent forward, without an airbag. Another Opel Vectra was used for this test.

Table 1: Test Vehicles

Test No.	**Test Vehicle** **Test Weight**	**Passenger Airbag**
SH 94.35	Ford Fiesta 1 093 kg	Euro bag (60 litres) Coated fabric with vent holes Conventional gas generator Propellant: Nitrocellulose
SH 95. 31	Opel Corsa 1.2 i 1 136 kg	Full-Size bag (100 litres) Uncoated fabric with vent holes Conventional gas generator Propellant: Sodium azide
SH 96.01	Opel Vectra 1.6 16 V 1 434 kg	Not activated
SH 96.02	Opel Vectra 1.6 16 V 1 450 kg	Full Size bag (120 litres) Uncoated permeable fabric Hybrid gas generator Gas: Argon (98 %), Helium (2 %)

The longitudinal velocities and yaw velocities of the four vehicles were determined by analysis of the overhead film views, and are shown in Fig. 3. The rotational velocities rise to maximum values of between 2/s and 3/s within approx. $\Delta t = 0.15$ s. The reason for this is the excentrically acting impact force. The point of maximum rotational velocity gives an indication of the end of the bodyshell compression resulting from the (semi-elastic) impact. In this phase, the values of the resulting longitudinal velocities decrease from the original value of 55 km/h to 10 km/h. Neglecting the here minimal lateral motion, this gives an average velocity change of $\Delta v = (55 - 10)$ km/h = 45 km/h (12.5 m/s) and an average longitudinal deceleration of $a = \Delta v / \Delta t = 8.5$ g (g = gravitational acceleration). Subsequently, the lateral motion of the centre of gravity superimposes its longitudinal motion increasingly noticeably. The determined values of the longitudinal velocity therefore do not pass through zero, but rather slightly increase at the first and then die down, until the vehicles come to a standstill in its final position.

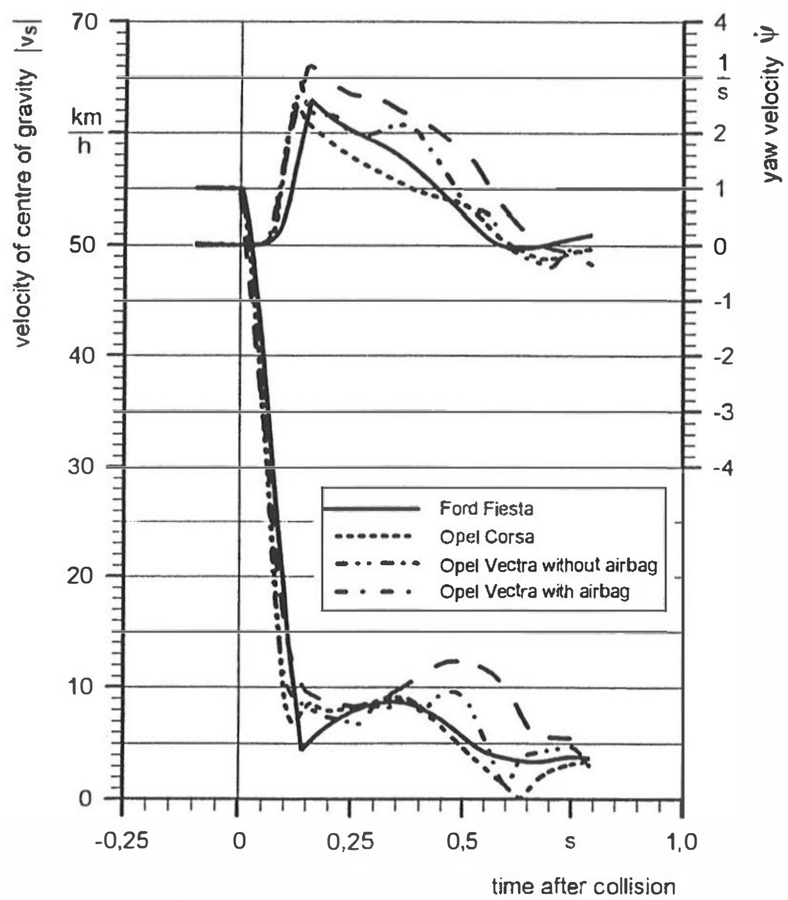

Fig. 3: Longitudinal Velocities and Yaw Velocities of the Four Vehicles, as Determined by Analysis of the Overhead Film Views

An example of a curve of the longitudinal deceleration (x-direction), measured directly on the vehicle, with respect to time, is shown in Fig. 4. The point of measurement is the right sill of the Ford Fiesta, in the region of the base of the B-Pillar. The maximum of the CFC 60 (SAE-J 211 a) filtered deceleration signal is 35 g. The velocity curve is determined by integration of a CFC 1000 filtered deceleration signal.

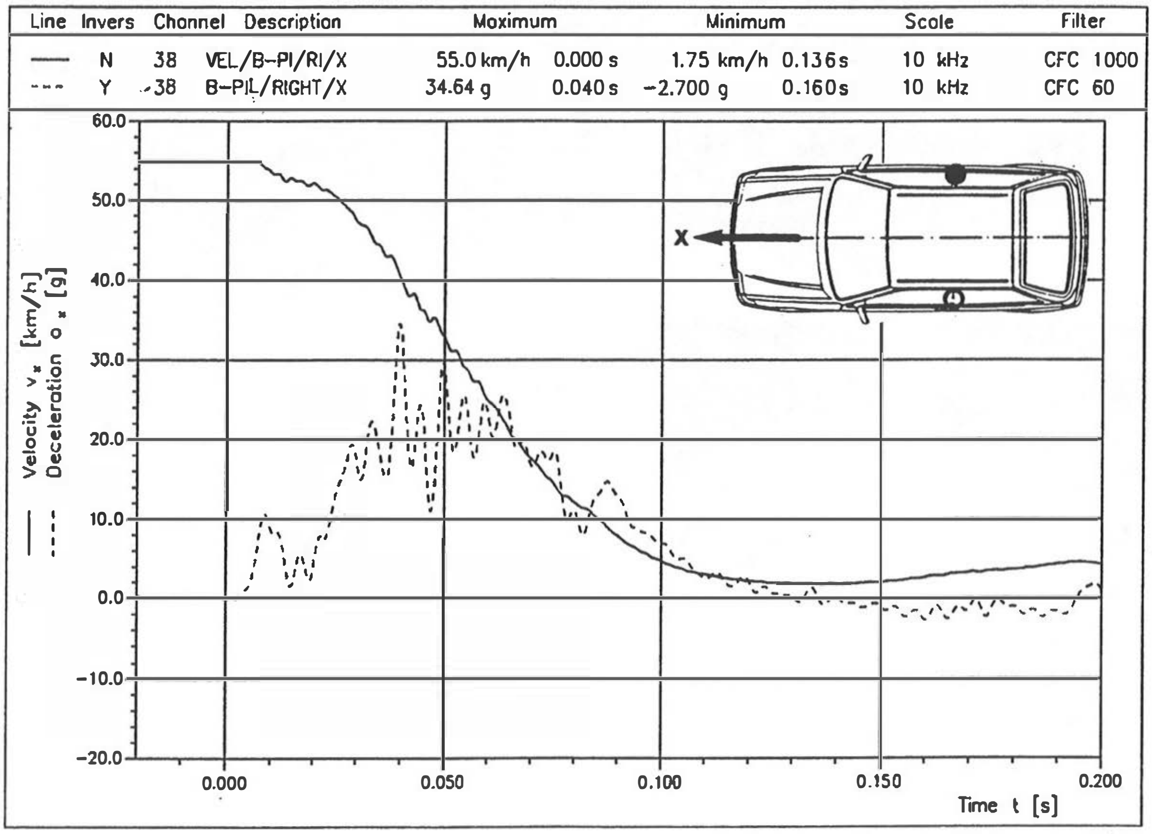

Fig 4: Longitudinal Deceleration Measured at the Base of the right B-Pillar of the Ford Fiesta and the Corresponding Velocity Curve

The maximum values of deceleration for the four vehicles, at the respective measurement positions, is summarized in Table 2.

Table 2: Maximum Values of Deceleration of the Test Vehicles

Test No.	**Test Vehicle**	**Maximum Deceleration (x-direction, CFC 60)**			
		Sill left	**Sill right**	**Tunnel**	**Engine Block**
SH 94.35	Ford Fiesta	33,6 g	35,0 g	42,7 g	31,3 g
SH 95.31	Opel Corsa	29,2 g	42,5 g	66,8 g	47,8 g
SH 96.01	Opel Vectra	39,7 g	39,6 g	44,7 g	104,5 g
SH 96.02	Opel Vectra	39,5 g	39,8 g	48,4 g	-

Fig. 5 gives an overview of the vehicle damage in the region of the front and the passenger side.

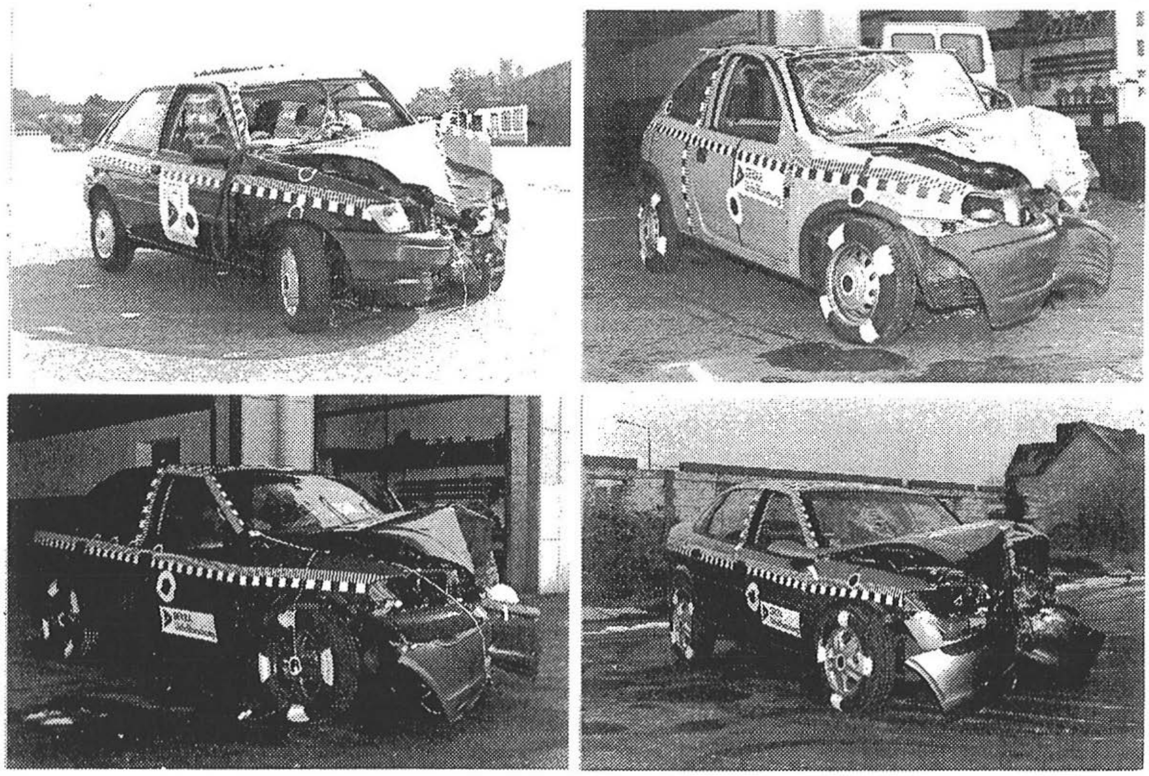

Fig. 5: Vehicle Damage, After Test, at the Front and on the Passenger Side

RESULTS

Dummy Loadings

The loadings on the passenger dummy and the corresponding biomechanical limits are shown for the four vehicles in Table 3. The dummy in test SH 96.01, in the Opel Vectra without an airbag, has no loadings on head and pelvis in the region of, or above the limits. The neck (M_y = -136 Nm) and the chest (a_{3ms} = 75 g) were loaded obove its limits. The dummy loadings in test SH 96.02, in the Opel Vectra with an airbag, were mostly significant lower than in test SH 96.01. All of the measured loadings of the out of position passenger dummy in test SH 96.02 lies clearly under their respective limits. However, here the neck ($F_{z, 45 ms}$ = 992 N, M_y = 68 Nm) were loaded higher and the chest deflection was greater than in test SH 96.01.

In the Opel Corsa all of the measured dummy loadings were also considerably below their biomechanical limits. This applies at the same to the dummy in the Ford Fiesta, with the exception of the head loading. Here the Head Injury Ciriterion (HIC = 1088) lies slightly above the limit of 1 000, whilst the 3 ms deceleration value of 71 g lies below the 80 g limit.

Table 3: Passenger Dummy Loadings and Biomechanical Limits

Part of the Body	Test Vehicle (Test No.) Ford Fiesta (SH 94.35)	Opel Corsa (SH 95.31)	Opel Vectra* (SH 96.01)	Opel Vectra (SH 96.02)	Biomech. Limit
Head					
HIC	1 088	465	556	206	1 000
a_{3ms}	71 g	62 g	64 g	38 g	80 g
Neck					
$F_{x,45\,ms}$	528 N	45 N	724 N	20 N	1 100 N
$F_{z,45\,ms}$	270 N	552 N	562 N	992 N	1 100 N
M_y (+)	133 Nm	26 Nm	0 Nm	68 Nm	190 Nm
M_y (-)	-48 Nm	-55 Nm	-136 Nm	-29 Nm	-57 Nm
Chest					
SI	308	211	704	235	1 000
a_{3ms}	38 g	34 g	75 g	37 g	60 g
deflection	13 mm	28 mm	11 mm	20 mm	76 mm
Pelvis					
a_{3ms}	35 g	37 g	38 g	35 g	60 g
Femur					
F_{left}	6,3 kN	5,2 kN	6,0 kN	6,2 kN	10 kN
F_{right}	3,6 kN	2,5 kN	9,6 kN	4,1 kN	10 kN
			*** without airbag**		

Dummy Kinematics

Due to the differing geometric conditions and influences on the motion of the unbelted dummy, the situation when the head first contacts the still inflating airbag is not identical for tests SH 94.35, SH 95.31 and SH 96.02. This is illustrated by Fig. 6. The situation of the dummy head contact with the windscreen in test SH 96.01, without airbag, is also portrayed.

Fig. 7 showes the head trajectories of the dummy head, with several characteristic positions, as determined by film analysis. In the Ford Fiesta, the complete motion of the passenger dummy head is visible on the high speed film used for the analysis, up to time t = 260 ms after the start of the collision. In the Opel vehicles, the larger airbag completely hid the dummy head over the course of its movement. Here the determination of the head trajectories could therefore only be made over short distances. In the test with the Opel Vectra without airbag, a complete study of the relevant head motion of interest was possible.

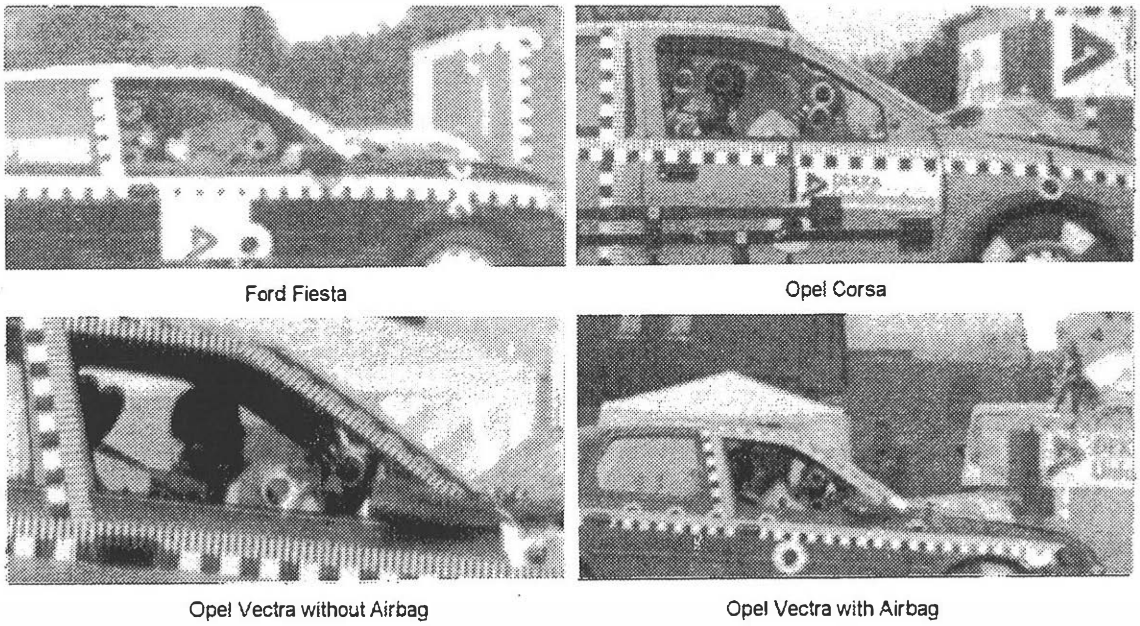

Fig. 6: Situations at First Head Contact with Airbag or Windscreen

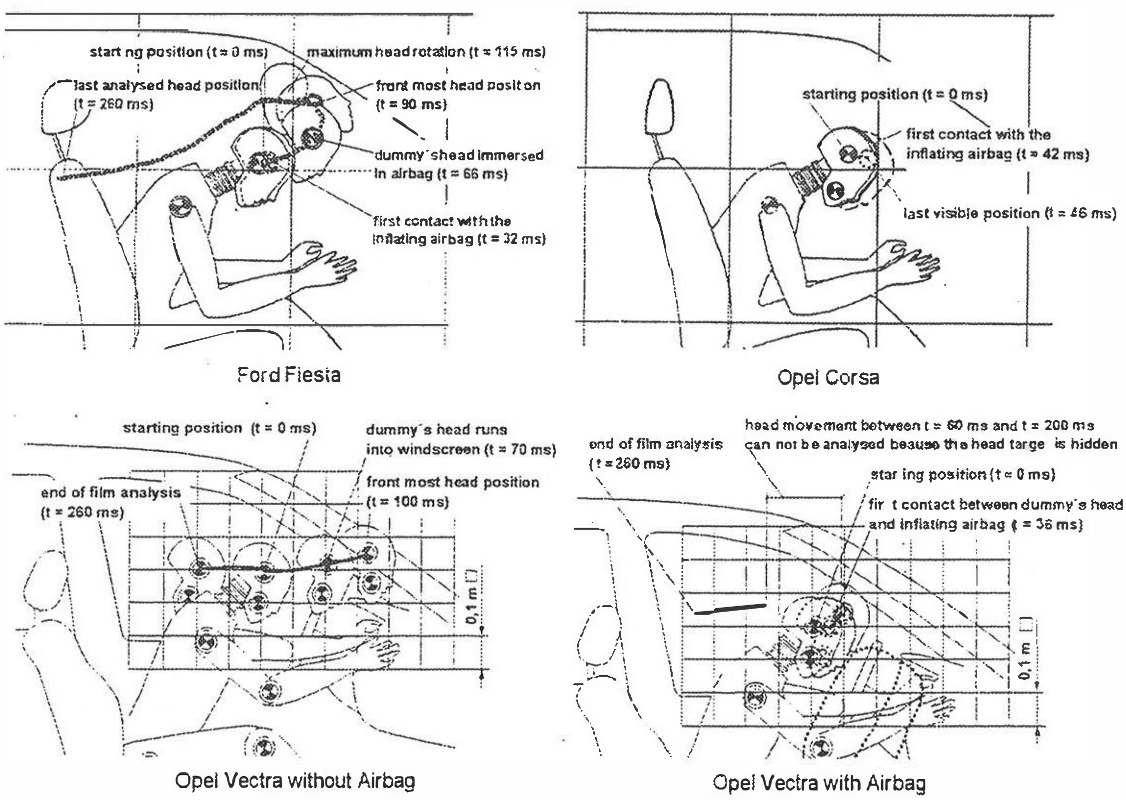

Fig. 7: Trajectories and Typical Positions of the Passenger´s Head

In all four test vehicles, the head of the unbelted dummy pursues a horizontal, straight line forward motion immediately following the start of the impact, due to its inertia. Further analysis of the high speed films produces the following described characteristics, whereby all times are relative to t = 0, at the start of impact.

Ford Fiesta with Euro Bag (Test No. SH 94.35): At t = 32 ms the head meets the still unfolding airbag (Fig. 6 & 7). Between t = 36 ms and t = 67 ms the upper torso of the dummy with neck and head shifts marginally to the middle of the car. Meanwhile, no rotation, flexion or extension of the neck occurs. Up to t = 67 ms the dummy head turns to the right (face turns away from the driver). At time t = 66 ms the dummy head and neck are completely immersed in the airbag (Fig. 7). At this moment the shoulders are also in contact with the bag.

Subsequently the airbag forces the dummy into an upward motion. At t = 80 ms the windscreen, which is already partly separated from the frame due to deformation of the surround and the effect of its inertia, is totally pushed out by the airbag. The forward displacement of the dummy head reaches its maximum at time t = 90 ms (Fig. 7). At this point it partly protrudes from the frame of the windscreen. The rebound phase of the dummy then commences.

The angle of the rotation of the head to the side increases to about 120° in the time from t = 67 ms to 115 ms (Fig. 7). This is superimposed by a nodding motion of the head to the rear (extension), of up to 40°. The head starts to rotate back to the normal position at approx. t = 120 ms. In so doing it retains its reclined position. At the same time the upper torso also falls back into the seat. Overall the spinal column in the neck is subjected to an extreme catapult loading, superimposed by sideward rotation.

Opel Corsa with Full-Size Bag (Test No. SH 95.31): The head contacts the still unfolding airbag at t = 42 ms (Fig. 6 & 7). It is thereby completely restrained by the large airbag. At time t = 52 ms the dummy head and neck are completely immersed in the airbag. At this time the shoulders also come into contact with the bag.

The further forward movement of the dummy takes place with the upper torso inclined to the left. At time t = 60 ms the windscreen splits due to the deformation of the bodyshell and the superimposed surface pressure from the airbags supporting the dummy. The shattering glass is pushed forward to form a bulge, but remains intact. The windscreen does not seperate from the frame.

The head rebound begins at t = 80 ms, without any prior direct contact with the windscreen having taken place. This motion is superimposed by a heavy swinging of the head, with significant neck extension at the beginning, followed by just as significant neck flexion. During the remaining motion, from about t = 350 ms, the head gradually ceases to swing.

Opel Vectra with not Activated Airbag and Belt Buckle Tensioner (Test No. SH 96.01):

The passenger dummy, which is sitting out of position, impacts the front windscreen with the top of its head at t = 70 ms (Fig. 6 &7). As a result of this impact and the superimposed forward motion of the dummy, the dummy neck becomes extended to the rear. At t = 84 ms the dummy head penetrates the glass of the windscreen, which is thereby destroyed.

Furthermore, at t = 88 ms the dummy`s left shoulder impacts the instrument panel, followed by the right shoulder at t = 96 ms. The dummy reaches his maximum head forward displacement at t = 100 ms (Fig. 7).

Subsequently the dummy moves back. During the rearward motion the dummy head has chin contact with the instrument panel between t = 120 ms and t = 130 ms. Afterwards the head nods back near to his starting position.

Opel Vectra with Full-Size Airbag (Test No. SH 96.02):

The passenger airbag unfolds at t = 32 ms. At t = 36 ms the passenger dummy touches the unfolding airbag, first with the lower half of the face and shortly afterwards with the upper torso (Fig. 6 & 7).

The mean contact area between the unfolding airbag and the dummy is in the area of the dummy`s upper torso. Caused by this, the airbag displaces the foreward movement of the dummy in an upward direction. The airbag forces the dummy, which is moving forewards, into an upward motion. The airbag is thereby compressed. The left half of the airbag is compressed more than the right half. Due to this the dummy experiences a rotation to the right (the dummy turns away from the driver). The airbag seam tears open at t = 68 ms.

During the upward motion, the dummy impacts the front windscreen with the top of its head at t = 70 ms, then penetrates the screen. The front windscreen bows severely as a result of, but remains securely anchored in the frame. Due to the intrusion into the front screen, the dummy neck is compressed. The head foreward displacement reaches its maximum at approx. 90 ms. At this point in time the dummy has turned through approx. 17° to the right. Subsequently, the rearward motion of the dummy commences.

Discussion and Conclusion

Out of position situations of vehicle occupants are - on the contrary to situations with a normal belted seating position - fundamentally undefined and numerous. The effect of the airbag on the occupant concerned in an abnormal position is therefore very dependent on the individual circumstances. For less extreme out of position situations of passengers, as can really occur in road traffic - for example with the upper body bent forward - the described tests produce the following observations:

A too early contact with the airbag, in the inflation phase, does lead to increased loadings, but these are not necessarily injury critical or associated with fatality risks, either with an Euro bag or a Full Size bag. Nevertheless, the real accident scene shows, that heavy or fatality injuries are not totally impossible in individual single cases. An investigation in the USA describes seven cases with airbag related fatalities of front seat passengers (Huelke, 1996/1). One case occured with a 57 jear-old female (155 cm height), the remaining six cases with four to nine year-old children. Five children were not belted, one child was belted, but not correctly. The injury mechanism was described as a distraction of the cervical spine, caused by an upward force vector applied to the head (especially chin) and a rearward force vector to the torso. A similar mechanism was described for airbag-induced injuries of drivers (Huelke, 1996/2). Accident analyses in Canada and USA indicate, that in cases with minor and moderate collision severity bag-related injuries (AIS 3+) can quite occur, if the occupant is close to the deploying airbag (Dalmatos et. al., 1996). The data agreed, that female drivers are at higher risk of sustaining bag-induced injuries than male. By this, tests with smaller and lighter dummies ar of special interest in the future.

In out of position situations, as simulated with the described tests, the airbag also can provide protection, although this can be considerably reduced in comparison to normal situations with belted occupants. Results from sled tests produced similar observations (Schmitz, 1995).

Further development of airbag technology, such as reduction of the fabric weight by the use of lighter uncoated materials for the bags, improved folding techniques (at present only available for driver airbags) and the use of hybrid generators can lead to further decreases in the occupant loadings. This applies primarily to the case of the normal seating position of a belted occupant. In association with out of position situations, these types of improvements tend also to be effective, however in view of the fundamentally unfavourable conditions for implementation of the protective effect of the airbag, they are of lesser significance. The available measurement data therefore supplies no new information in this context.

Injury critical loadings generally first occur when the occupant head has direct contact with hard objects, despite the presence of the airbag. Sled tests of the Heidelberg Institute for Legal Medicine have shown, that even in a normal seating position an unbelted large driver passenger could be forced into an upward motion by an Euro bag with subsequent hard contacts of his head with the windscreen or upper parts of it´s frame (Kallieris et. al., 1994).

For clarification of corresponding real accidents, the associated contact features must be paid special attention. Detailed knowledge about the contact events, which can be deduced from this information, is a prerequisite for the assessment of injuries and their causes. One of the central questions is whether the injuries occured despite the presence of the airbag (with an injury reduction effect from the airbag), or because of the airbag. As confirmed by the full scale tests performed at the DEKRA Crash Centre, the influence of the airbag on the occupant trajectory has greater significance than the occupant loading due to contact with the still inflating airbag.

A conclusive evaluation of the neck loads is not possible at this point in time. Although biomechanical limits exist for these, they did not enable any over-critical airbag induced neck loads to be identified in the tests carried out. However, the mechanical model of the spinal column in the neck of the Hybrid III dummy appears to be too imprecise. Furthermore, there is no adequate information about the pattern of airbag related neck injuries from real accidents. Particularly in the test with the Euro bag, a neck motion in which flexion and extension were superimposed by a rotation of the head to the side was observed. This type of multiple loading supports the supposition that the risk of injury is greater than that indicated by the available measurement data.

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