SIPSBAG - A New, Seat-Mounted Side Impact Airbag System

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ABSTRACT

Injuries in side impact collisions constitute one fourth of the serious-to-fatal injuries sustained by occupants in ordinary passenger cars. The Side Impact Protection System (SIPS), introduced in the latest Volvo models, provides a substantially enhanced protection for car occupants in side collisions.

Further protection can be achieved by adding a quick-deploying side airbag which will help reduce and mitigate injuries in car-to-car side impacts as well as in collisions with trucks and poles. Sensing time and bag inflation time must be extremely short due to the short deformation distance available.

Several locations and sensing possibilities have been evaluated. The system described has the sensor, the gas-generator, and the bag in one closed unit, making the function simple and reliable. The system is completely non-electric – the function is a mechanically triggered pyrotechnic device, safe against unwanted trigging from minor exterior violence.

INTRODUCTION

The evolution of car design to date has produced car crashworthiness characteristics that are primarily focused upon occupant protection in frontal impacts. Although frontal impacts still account for the largest number of injuries in accident statistics, approximately 25% of all serious-to-fatal injuries are caused in side impact accidents, see Fig. 1*).

Today, frontal crash safety has been refined to such a degree that the safety benefits of a given design effort aimed at improving side impact protection are probably higher than the benefits of an increased design effort on enhanced frontal crash safety. One reason for this is that severe injuries sustained in side impacts occur over a fairly wide range of crash severities, with a relatively high frequency of injuries occurring even at low severities, see Fig. 2. Consequently, there is much to gain in terms of injury reduction by improving the side impact protection characteristics not only at high crash severities, but also in the low-medium range of the crash severity distribution.

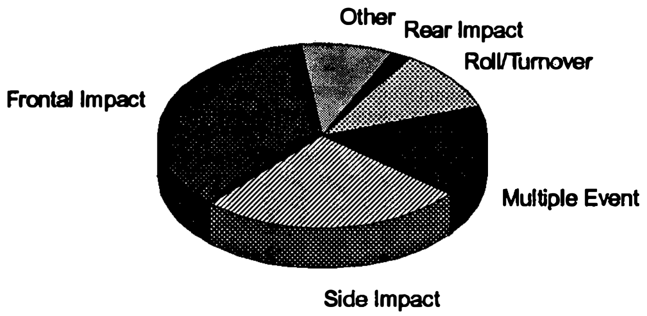

Figure 1. Distribution of serious-to-fatal car accidents (AIS 3+) by crash type.

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*) The statistics in Fig.1 - Fig.5 are derived from Volvo's accident data base, containing approx. 25.000 tow-away accidents involving Volvo cars in Sweden with data on more than 35.000 occupants. In case of an injury accident where someone has received medical attention, occupant injury data is acquired from the medical case records.

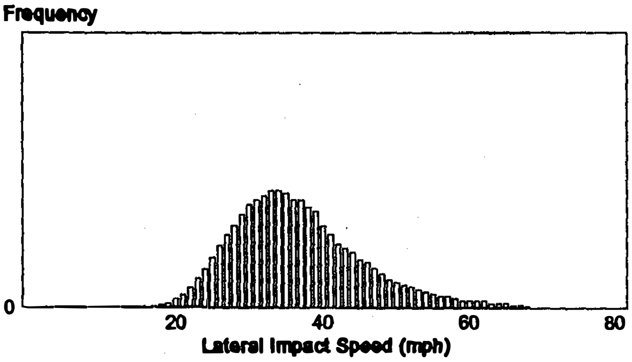


Figure 2. Distribution of injured occupants (MAIS 3+) by crash severity in car-to-car side impacts.

Structural reinforcements are needed to lower the velocity of the intruding side structure in car-to-car impacts and to provide a base on which interior padding will work satisfactorily. With the SIPS system [1], Volvo has taken a first step towards an increased occupant protection against side impacts by reinforcing many systems of the car including the doors, the B-pillars, the floor, the floor tunnel, the roof, and the seats. Energy-absorbing elements have been added to the car interior inside the door panels.

The scope for further improvements to side impact protection through thicker doors is limited by space considerations as the driver must have sufficient room to drive the car in a safe and comfortable manner. However, providing further interior energy absorption elements in one form or another (foam, bags, etc.) offers the greatest potential for injury reduction since this method is effective both in car-to-car impacts and in side collisions with trucks (mainly at lower speeds) and other undeformable objects (e.g. poles, trees). These collision objects account for a considerable proportion of the severe occupant injuries in side impacts, Fig. 3.

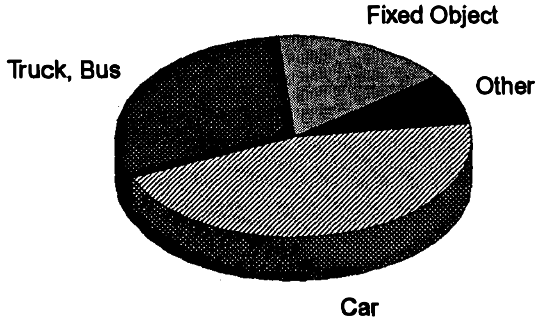


Figure 3. Distribution of collision objects in serious-to-fatal side impacts (AIS 3+).

In collisions with trucks and fixed objects, body stiffness and strength are of lesser importance, since the collision object is undeformable. Interior energy-absorbing components, however, can considerably improve occupant protection by smoothing out the contact phase between the occupant and the interior side structure of the car.

Injuries to the head, chest, abdomen, and pelvis are more common in side impacts than in other accident types, see Fig. 4. Head protection in frontal collisions has been continually improved (through the development of deformable steering wheels, collapsible steering columns, increased belt use, and the introduction of frontal airbags) such that today there is also a higher incidence of head injuries as a result of side collisions than in other accident types, especially in impacts with trucks and fixed objects.

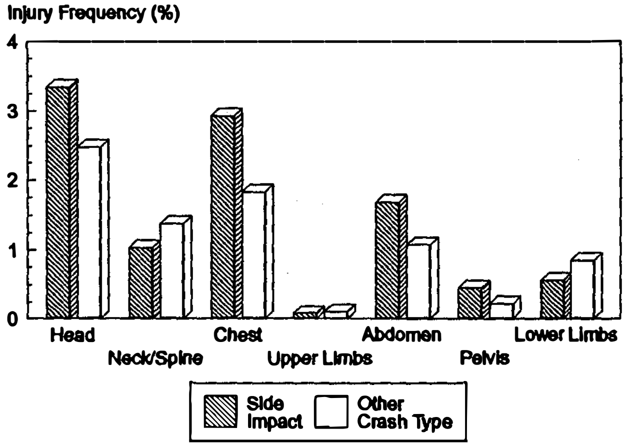


Figure 4. Injury frequency (AIS 3+) by body area (all collision objects).

The side airbag described in this paper provides a solution to space constraints. It is intended to be a supplement to the SIPS (Side Impact Protection System) used in Volvo cars. It is therefore called **Sipsbag**.

This first design step focused on further improvement of chest and abdominal protection, mainly in car-to-car side impacts, since this is the most common injury producing side impact crash configuration. The chest, head, abdomen, and pelvis are the areas of the body most commonly injured in car-to-car side impacts, Fig. 5.

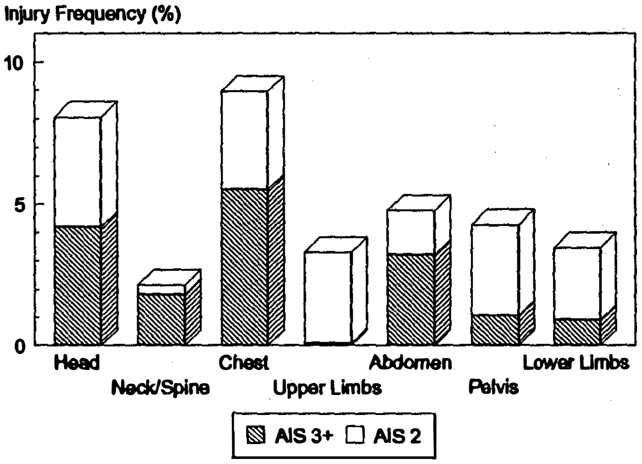


Figure 5. Injury frequency by body area in car-to-car side impacts.

Although the Sipsbag is designed primarily to reduce chest and abdominal injuries, there is also a potential for reduction of head and pelvic injuries as described below.

In the longer term it is highly desirable to examine the possibilities for further increases in head protection in side impacts. Whether this is best achieved by addition of another airbag or by some other form of head protection device remains to be investigated.

REQUIREMENTS AND CRITERIA

Volvo cars equipped with the Sipsbag bag will meet internal Volvo requirements as well as the requirements of both the American FMVSS 214 and the proposed European regulations.

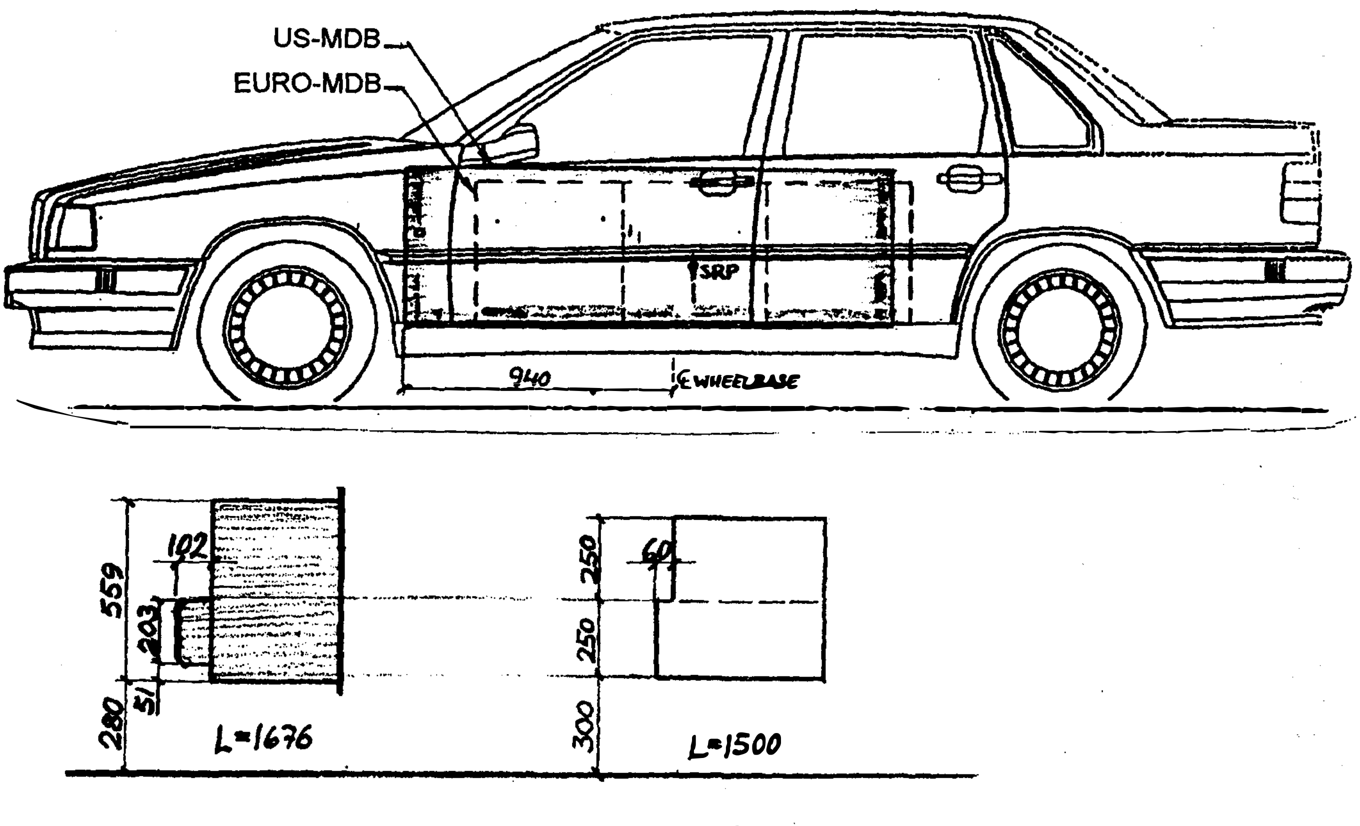
The American standard test involves a side collision with the US-MDB (Moving Deformable Barrier), at an angle of 27° ("crabbed") and a test speed of 33,5 mph. The equivalent test for Europe is the EURO-MDB at an angle of 90° and a test speed of 50 km/h, see Fig. 6.

Criteria for USA-test (FMVSS 214):

- Thorax	TTI	< 85g
- Pelvis	amax	< 130g

Criteria for Europe-test (proposed):

- Head	HPC	< 1000
- Thorax	Defl VC_{max}	< 42 mm < 1 m/s
- Pelvis	PSFP	< 6,0 kN
- Abdomen	APF	< 2,5 kN



US-MDB

EURO-MDB

Figure 6. Impacts areas with the US and the EURO moving deformable barriers, respectively.

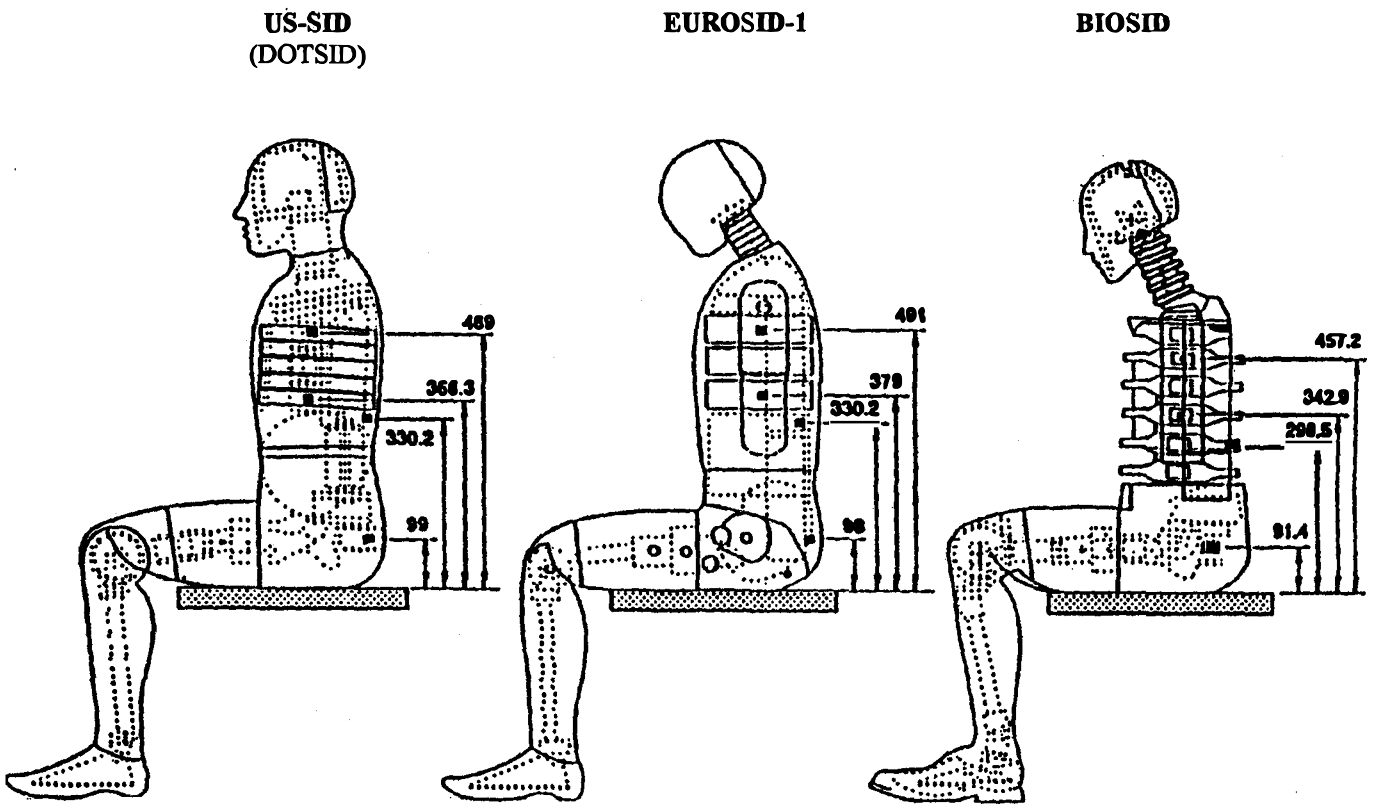


Figure 7. Dummies used in side impact testing.

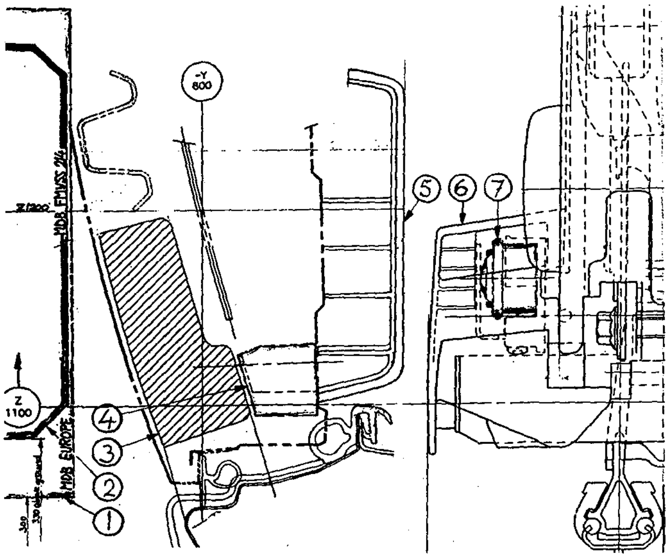


Figure 8. Cross section through lower door and seat at sensor location. Euro-bumper (1), US-bumper (2), SIPS-blocks (3 and 4), doorpanel (5), sidepanel of seat (6), sensor (7).

In these tests, different test dummies are used (see Fig.7 which illustrates the DOTSID, EUROSID, and BIOSID dummies). The DOTSID and EUROSID dummies are used for the American and European tests respectively. The BIOSID is a proposed alternative to the US-SID.

However, since experience shows that car occupants sustain serious injuries over a wide range of crash severities (see Fig. 2), it is also an Volvo design requirement to increase occupant protection in both the frequent low severity impacts (e.g. 35-40 km/h lateral test speed) and at higher test speeds than those used in the American and European test procedures (up to 40 mph, "crabbed" at an angle of 27°, which corresponds to 57 km/h lateral speed at an angle of 90°).

The trigger function is based on force-transmitting elements in the door, the door panel, and the side panel of the seat. An impacting bumper transfers part of its inertia to the sensor which triggers more quickly the smaller the clearances are. The standardized MDB-bumpers used in the US- and Euro-tests are shown in Fig. 8 (and Fig. 6).

The trigger criteria are based on findings from actual accidents and are selected to ensure that the Sipsbag will deploy only when the violence of the side impact is such that a bag can be expected to have positive effects in reducing injury. In most cases, this involves a direct impact against the front door.

According to Volvo's accident data, about 90% of the serious-to-fatal injuries (AIS 3+) caused by side impacts occur when the front door is impacted. Ongoing investigations by Hassan et al [2] at the Birmingham University indicate that most of the AIS 3+ injuries (almost 90%) to the front seat occupants occur when the rear lower quadrant of the front door is impacted.

An impact behind or in front of the front door will rotate the car but will not deform the door, and the bag will not deploy. However, there is little need to deploy the bag in these cases since the energy of the impact between the occupant and the door is considerably reduced.

SYSTEM DESCRIPTION

In this side airbag system both the airbag module and the sensor are fitted into the seat. These units are connected by non-electrical means, see Fig. 9.

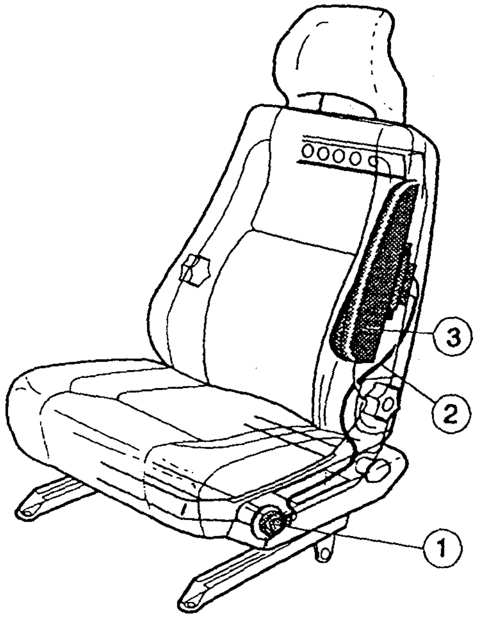


Figure 9. The Sipsbag system has sensor (1), non-el connection (2), and bag module (3) in the seat.

Advantages with a seat-mounted airbag are:

1. The airbag is always correctly positioned relative to the occupant, regardless of the seat position.
2. The energy absorption capacity and deformation stroke available in upper part of door remains (i.e., no hard gas generator, brackets, etc in the door will interfere).
3. The system is immune to sabotage/vandalism, i.e., it cannot be triggered by kicks to the side of the door, etc.
4. The system is comprised of a single, enclosed unit totally contained in the seat with no movable connections, and sealed by the manufacturer.
5. The environment is more "friendly" for an airbag mounted in the seat as opposed to inside the door.

Airbag module

The airbag module consists of

- a sewn bag with vent holes
- a diffuser for cooling and spreading the gas
- two gas generators, each with approximately 2g of nitro-cellulose explosive
- housing for packing and protection of bag and for support of the seat upholstery
- bracket for attachment to the seatback structure.

The bag has a volume of 12 litres. It is made of polyamide with an internal coating of silicone rubber. The function of the coating is to make the bag more resistant to hot gas during deployment. Silicone is advantageous relative to other rubber types due to its high temperature resistance and its ability to be applied in a thinner (and lighter) layer.

The bag is ventilated, which is advantageous for reducing dummy criteria based on deflection [3].

Two gas generators are mounted at the centre of the diffuser surrounded by the bag. The gas generators are of a similar type as those used today in our pyrotechnic belt pretensioners. They are designed such that the bag will be fully deployed approximately 7 ms after triggering. One of the gas generators is retarded slightly to reduce peak pressure during inflation and improve protective performance.

Sensor

The sensor is a speed sensitive, mechanically triggered, pyrotechnic device. It has an firing pin which penetrates a small percussion cap. The device is enclosed in a metal housing.

The conditions required to trigger the device are:

- Speed > 2 m/s
- Force > 500 N
- Stroke > 2 mm

The sensor is attached to the outboard side of the seat frame, see Fig. 9.

The position of the sensor varies according to the car model, taking into account the strength of the supporting structure, space required for seat adjustment devices, design of door pockets, force transmission in door and door panel, etc.

The positioning of the sensor and force transmitting elements and the clearances between them are adjusted such that triggering occurs no later than 5 ms after the first contact in a typical side impact.

Accordingly, the bag is fully deployed after approximately 12 ms (for an impact speed of 50 km/h). This speed of deployment is essential, since the impacting object travels at 14 mm/ms and the total available distance from impactor to occupant is about 300 mm.

Non-electrical connection

The sensor is connected to the gas generators through two plastic tubes containing pyrotechnic powder dusted and bound on the inside. This explosive propagates a flame at a speed of 2000 m/s (2 metres/ms).

The use of such deflagrating explosives is well proven for military applications. It is a very safe and reliable method which can only be ignited by a high-temperature detonator (for example a percussion cap).

Seat

When the bag deploys, it breaks open the normal seam in the upholstery on the outboard side of the seatback (no special design changes were required). The bag moves forward and outward along the door panel as it inflates.

The seat structure must be rigid and firmly anchored to the floor. A good example is the Volvo 850 seat, which is an ideal platform and an integral part of the SIPS system.

Since the sensor operates based upon the relative movement between its outer and inner sides, it is essential that the sensor is firmly anchored in position.

Door/doorpanel

In order to get a quick triggering, the force of the side impact must be transmitted as rapidly as possible to the sensor. This necessitates minimal clearances and the use of strong elements at sensor height in the lower part of the door and between the door and the doorpanel.

At chest height, the door and the door panel are the same as in a car with a standard SIPS system without Sipsbag.

STATIC DEPLOYMENT TESTS

Initial tests were conducted to investigate static deployment. The seat was placed closer than normal to the door, simulating the anticipated door deformation 12 ms after impact (the time taken for the airbag to fully deploy).

The dummies used were Hybrid III, 50-percentile, Hybrid II, 95-percentile, and BIOSID. The Hybrid dummies were chosen to get a more realistic representation of the arm than is the case for the side impact dummies. The dummy's outboard arm was placed in different positions. In some test the dummy was in placed inclined against the door. Fig. 10 shows one of the test arrangements.

Conclusions from these initial tests, conducted in January 1992, were as follows:

- The airbag deployed fully forward even when the dummy was inclined against the door.
- Arm in high position on the steering wheel: deployment unaffected.
- Arm in low position on armrest: the arm was displaced forwards by the inflating bag, but not with such force as to give rise to concern.
- Dummy response values were moderate.

Since then, many other deployment tests have been performed, using the EUROSID-1 dummy as well.

Figure 10. Static deployment test.

LOW SPEED TRIGGER TESTS

The next challenge was to ensure that the airbag triggers in all situations where its deployment could be expected to reduce the risk of injury, i.e., high and low points of impact, both perpendicular and angled collisions with different angles, sensor positions, impact speeds, and impactors (MDBs, cars). Fig. 11 shows one of the first low speed crashes using the US-MDB.

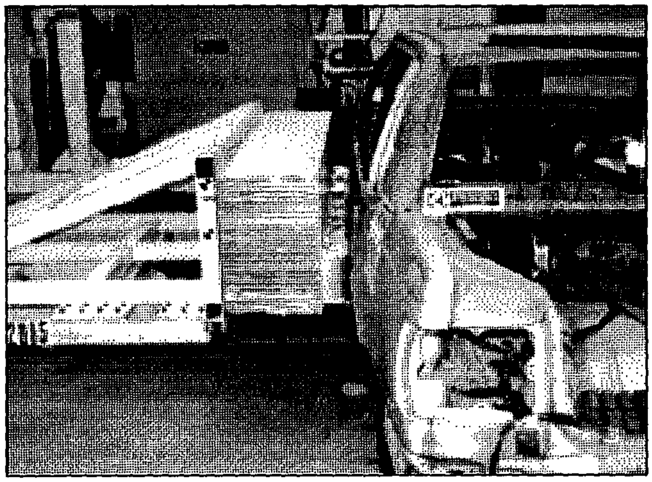


Figure 11. Low speed trigger test.

An initial problem encountered was the difficulty to achieve sufficient rate of deformation at the sensor to trigger the airbag, since in low velocity collisions a large proportion of the energy of impact is dissipated by metal deformation distant from the sensor. However, a speed-sensitive sensor is advantageous in avoiding unwanted deployments during handling, assembly, etc.

To fire the percussion cap, the igniting pin requires a speed of at least 2 m/s. To achieve this speed even during low speed collisions, adjustments were made to the sensor position, its mounting, and the load-transmitting elements. Sufficient deformation speed remains for triggering in reasonable impact configurations.

FULL-SPEED CRASH TEST

A number of full-scale tests have been performed, according to American as well as European standards, not only at the required/proposed test speeds, but also at lower and higher speeds.

Results - European test procedure

Typical results from the proposed European test procedure are illustrated in Fig. 12-15. At a test speed of 50 km/h with no airbag fitted, deflection of the dummy (see Fig. 12) starts late, 25 ms after the beginning of the crash, and reaches a relatively high value in the three ribs.

The Viscous Criterion (VC), Fig. 14-15, is defined as the relative chest deflection multiplied by the velocity of this chest deflection, i.e.,

$$VC(t) = d(t)/D \cdot v(t)$$

where $d(t)$ = chest deflection
D = distance to CL dummy (half chest width)
$v(t)$ = velocity of chest deflection = $d'(t)$

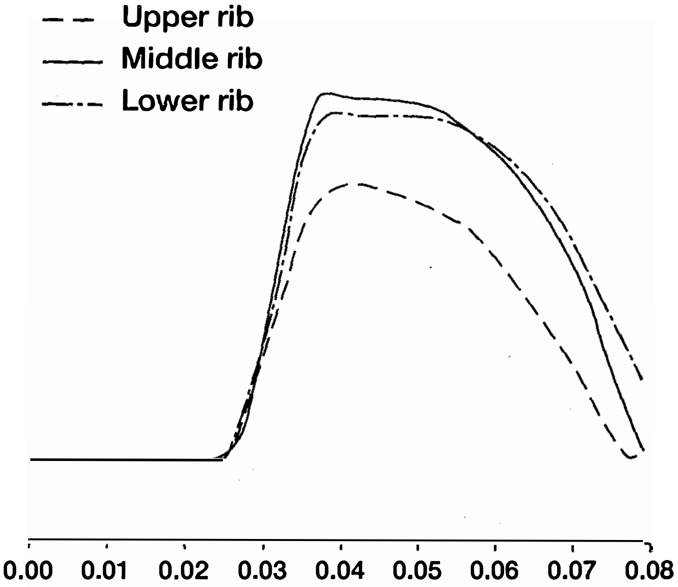


Figure 12. Deflection vs time (sec), without Sipsbag.

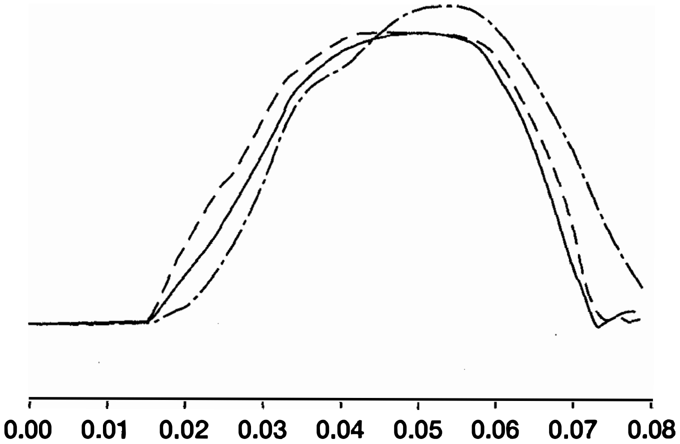


Figure 13. Deflection vs time (sec), with Sipsbag.

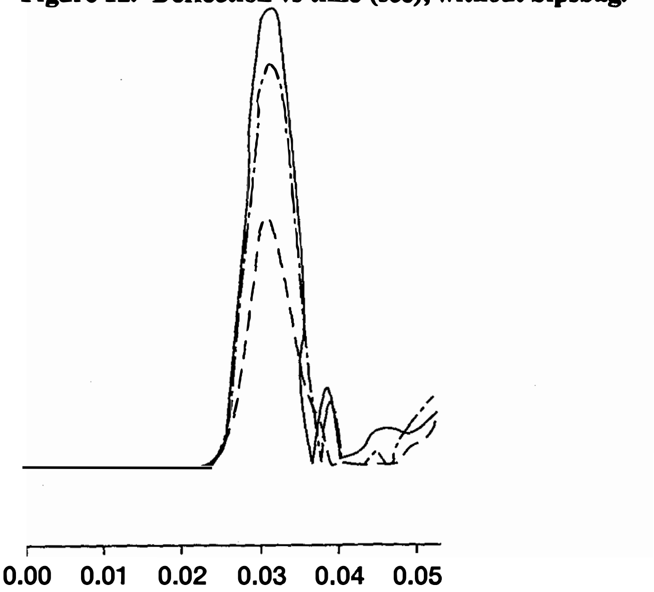


Figure 14. VC vs time (sec), without Sipsbag.

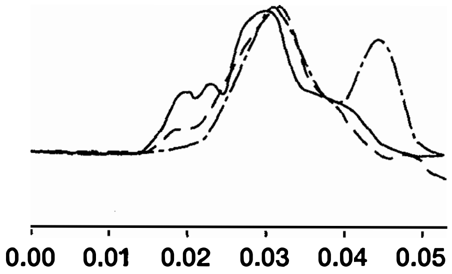


Figure 15. VC vs time (sec), with Sipsbag.

Since deflection does not start until after 25 ms, it rises steeply and the contact velocity rapidly increases to a high value. Accordingly, VC also becomes rather high.

Figures 13 and 15 show the corresponding values for a test at the same speed with Sipsbag. Deflection starts earlier (12 to 15 ms after impact), giving a flatter curve with a lower peak value. Accordingly, VC_{max} is much lower, in this case less than 50 % of VC_{max} for the same test conditions without Sipsbag, above.

A reduction of the dummy's head displacement relative to the car outer profile was observed as well.

Results - American test procedure

Acceleration results from two typical tests according to the American test procedure are shown in Figures 16-17, without and with Sipsbag, respectively. In both cases, the test speed was 33,5 mph (27° "crabbed" configuration).

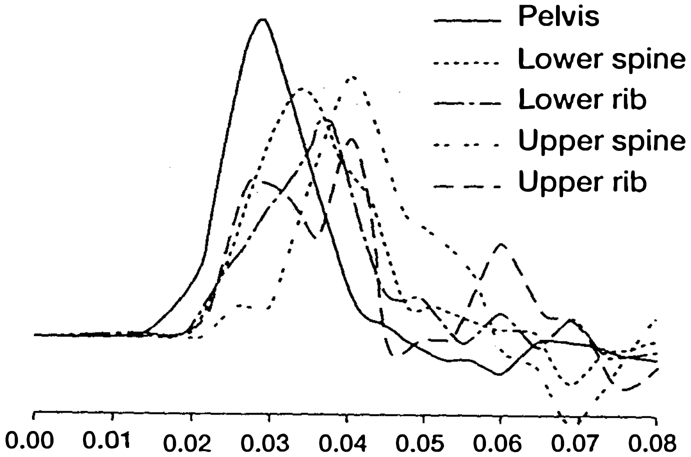


Figure 16. Accelerations vs time (sec), without Sipsbag.

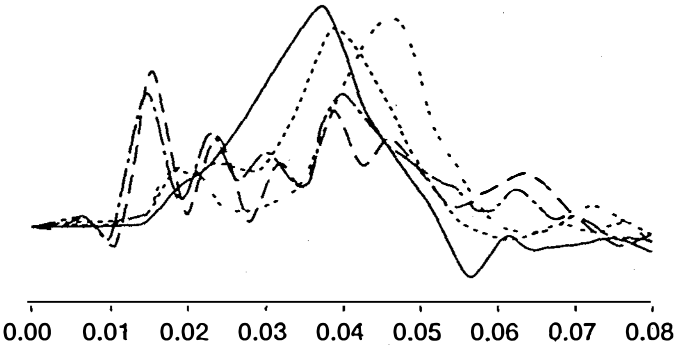


Figure 17. Accelerations vs time (sec), with Sipsbag.

Figure 16, illustrating the results for the test without airbag, shows that dummy accelerations start late and increase to relatively high peak acceleration values for ribs, spine, and pelvis.

TTI (Thoracic Trauma Index) is defined as the average of the maximum rib and lower spine accelerations, i.e.,

$TTI = (g_r + g_{ls}) / 2$, where

g_r = maximum acceleration, ribs

g_{ls} = maximum acceleration, lower spine.

Figure 17 shows the results for the test with Sipsbag fitted. Rib acceleration increased rapidly but the peak value was lower. Acceleration of the lower spine started later and reached a lower peak value. These factors combined gave a 25% reduction in the TTI obtained. The rate of change of pelvic acceleration was also more gradual, giving a peak value reduction of the same magnitude.

It must be noted that these are just two single tests and that there is a spread in results from several tests.

Tests were also conducted at 24, 28, and 39 mph ("crabbed" impact configuration), showing dummy response reductions of the same magnitude.

COMPUTER SIMULATIONS

In addition to the different trigger tests and full-scale tests, computer simulations were used for studying bag and trigger behaviour.

Parameters like bag pressure, bag position, and velocity of the inner sheet were varied. The goal was to find optimal solutions for bag position and bag pressure in order to lower the dummy injury criteria values.

The calculations were carried out with a model of a full side impact test, using a finite element program, see Fig. 18. The airbag is placed in the seat and the bag behaviour during expansion is simulated.

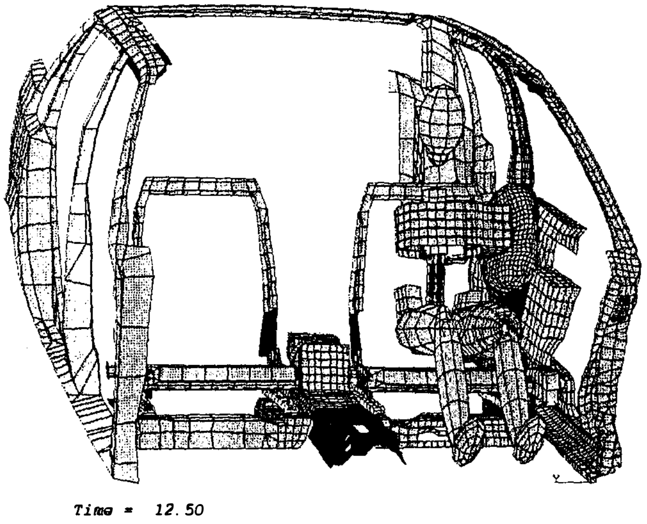


Figure 18. Finite element model of a full side impact.

This type of simulation consumes a lot of computer time, and to make parameter studies, it was necessary to use a smaller mathematical model. This so called part model needs much less computer time and makes a large number of simulations possible. The part model consists of the upper part of a DOTSID dummy (chest and head), the door panel, and the door inner sheet, see Fig. 19. The inner sheet was controlled by using a velocity function as input data.

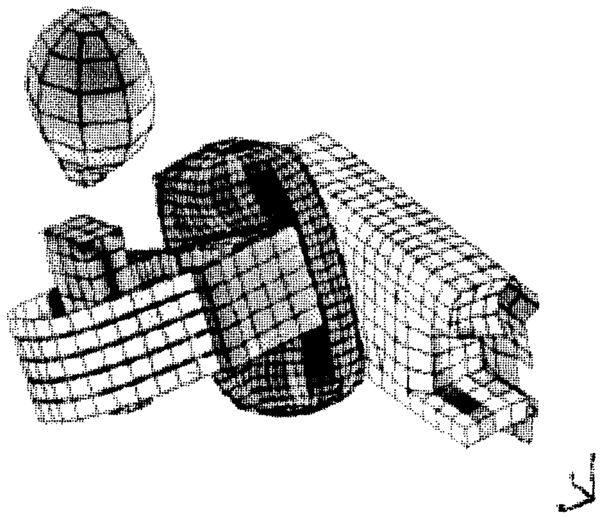


Figure 19. Part model used for parameter studies.

Computer simulations were also used for studying the trigger behaviour of the Sipsbag sensor. A model consisting of a bumper that hits the door structure was developed. In the model, the bumper height was varied and different ways to transfer forces through the door to the sensor were studied.

CONCLUSIONS

The aim of this first generation side airbag (the Sipsbag) is to further reduce mainly chest injuries in side impacts and also, as a secondary benefit, to reduce head injury by maintaining a distance between the door and the occupant.

Mounting the Sipsbag in the seatback instead of in the door, B-pillar, etc., means that it is always in the correct position relative to the occupant, no matter how the seat is adjusted.

A mechanically triggered, pyrotechnic sensor eliminates the need of electrical connections and electronic diagnostic circuits. It also makes possible a completely sealed module, reducing the risk of contact malfunction. The environment is friendlier when the airbag and sensor are mounted in the seat as opposed to inside the door.

Tests have shown that the Sipsbag substantially reduces dummy response values over a wide range of crash severities and thereby has a good injury reduction potential in real-life side impacts.

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