U.S. Department
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**National Highway
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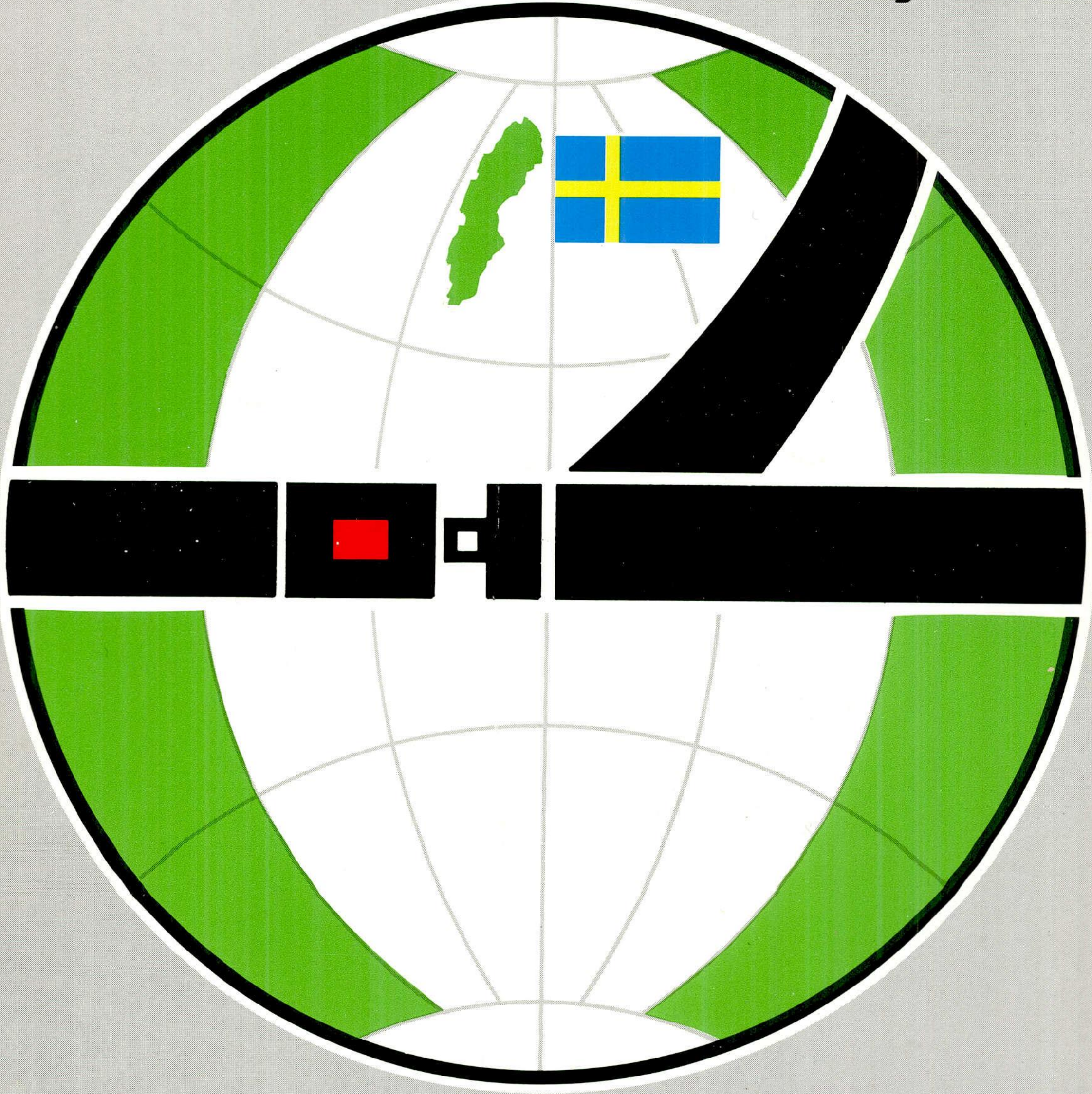
Twelfth International Technical Conference on Experimental Safety Vehicles



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cause large variations in dummy readings, other parameters being held constant.

The conflict between roominess and the desire to use a deeper door padding became very obvious in this project. Unless future consumers are willing to sacrifice some of the interior space, the only solution seems to be to make the padding expand when an impact occurs. This could be made, for instance, with a side airbag (12, 13).

It is also possible that the introduction of a new side impact dummy with better biofidelity will make it necessary to re-tune the padding force deflection characteristics of the door panel.

Conclusions

In this project, it has been shown that a significant reduction of chest response [TTI(d)] can be achieved by careful engineering and reinforcement of a conventional uni-bodied car. Studies of the production feasibility of the changes are underway.

The prototype where structural and interior improvements are combined in an integrated, expanded solution improved the results even further and this suggests that a reduction of up to 50% for the chest and 25% for the pelvis of severe to fatal injuries in car-to-car impacts is a realistic goal. Further testing with an MDB at different impact velocities and with bullet cars with bumpers must be done before final conclusions can be made.

The conflict between compartment roominess and keeping the vehicle cross area small, and still being able to add sufficient depth of energy absorbing door padding, is obvious.

Ongoing research and innovations in this area, however, seem promising.

Redesign of the car door as a concept or the fitting of a side airbag could perhaps be solutions to this problem.

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Air Bag System for Side Impact Protection

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Abstract

It is difficult to install side impact padding of sufficient depth, due to the limited space inside conventional automobiles. A different approach is to use the air bag technique to provide sufficient energy absorption and softening of the occupant door impact.

Presented is an air bag system for side impact protection jointly developed by Volvo Car Corporation and Electrolux Autoliv AB.

The system uses pyrotechnical gasgenerators to deploy a side air bag hidden within the door structure.

A description of the function of the system is given to-

gether with a detailed description of the system components including the sensor and diagnostic unit, the gasgenerators and the side air bag.

Results from crash testing and computer simulation of the system will also be presented.

Introduction

Accident and legislative situation

Side impact is a severe type of traffic accident with a larger injury risk than other types of accidents.

The car accident situation is presented in the ESV paper "Volvo Traffic Accident Research Systems as a tool for side impact protection and development" by Hans Norin et al.

According to Norin approximately one-third of the accidents, resulting in injuries with an Abbreviated Injury Scale reading (AIS) ≥ 2 are side impact accidents. Injuries to the chest represent 34% and head 22% of the injuries to the various parts of the body. The proportion of injuries to the chest and head also increase when the crash severity increases.

This situation has also been observed by the legislative authorities in different countries.

One example of this is the notice of proposed rulemaking for side impact protection, NPRM, presented by DOT/NHTSA Docket 88–06 Notice 1. This NPRM is primarily focused on thoraxic protection since the data indicates that contact between the thorax and the side interior is a major source of serious injuries and fatalities. A test method and the means to determine the injury criterion is also included.

DOT/NHTSA have also presented an advanced notice of proposed rulemaking, ANPRM, Docket 88–06, Notice 3, which specifically asks for information and discussion around the problem of head and neck injuries and ejections in side impacts. The ANPRM states that "several studies have shown that ejection increases the probability of an occupant fatality or serious injury by several times over that for non-ejection".

The conclusion of all this information is that an improved side impact protection level must be focused on injuries to the chest and head. The improvement for the head must be to reduce the ejection level.

Technical alternatives

The ways to improve the protection level up to now have mainly been reinforcements of the side structure and/or the implementation of padding on doors, pillars and headers.

These modifications on the other hand have major drawbacks with increased weight, increased fuel consumption, reduced interior room, obstructed visibility etc. These properties are also important in a modern car and are therefore difficult to combine with improved side impact protection.

An alternative way to improve the side impact protection level could be the use of air bag technology. Air bags are widely used today and the technique has matured especially after the enforcement of FMVSS 208. However all air bag systems presently used are intended for occupant protection in frontal crashes; could air bags be used in side crashes too?

A study to evaluate the feasibility of a side air bag system was therefore started between Volvo Car Corporation and Electrolux Autoliv AB.

The study included a preliminary design and evaluation of a complete system, including sensor, diagnostics, bag and gasgenerator.

System Design

System analysis

In the ESV report "Side impact protection system—a description of the technical solution and the statistical and experimental tools" by H. Mellander et al. the behavior of the side structure in a side impact was described. These results are used as input for this program. The tests performed show that the deformation zone is limited and there is contact between the dummy and the side structure after 18–20 ms.

An air bag system working under these conditions must therefore detect the crash and fill the bag considerably faster than a regular air bag system used for FMVSS 208 protection.

Another important difference compared to a regular air bag system is the distance between the occupant and the car structure. While the occupant in a normal passenger car compartment has a distance of 400–600 mm to the steering wheel or the instrument panel, he only has 150–200 mm to the side structure. A side air bag system must therefore be designed according to these conditions.

The height of the bag is dependant upon what parts of the occupant body the system is intended to protect. In our case, where the chest is considered most important, the height must be approximately 200–350 mm above the H-point.

In figures 1 and 2 it can be seen that the bag, in its deployed mode, is located close to the upper part of the door structure.

The bag must give protection over the whole chest width and the full seat track travel and it is therefore made in an ellipsoid tube shape. The main chest impact area in the vehicle is the upper rearward part of the door structure and the bag system was therefore located at this position.

With the seat track in the rearmost position the chest will impact against the B-pillar and the bag must therefore be designed in the asymmetric way shown in figure 2.

Mathematical simulation

Mathematical models are useful especially in the early phases of projects because it is possible to study and sort out important parameters in a short time without extensive tests, even when no hardware is available. In this project a model was used to study the effect of using an air bag as protection in side impact.

The mathematical model used in this study is specially developed for simulations of side impacts and is designed as a one dimensional lumped mass model, shown in figure 3.

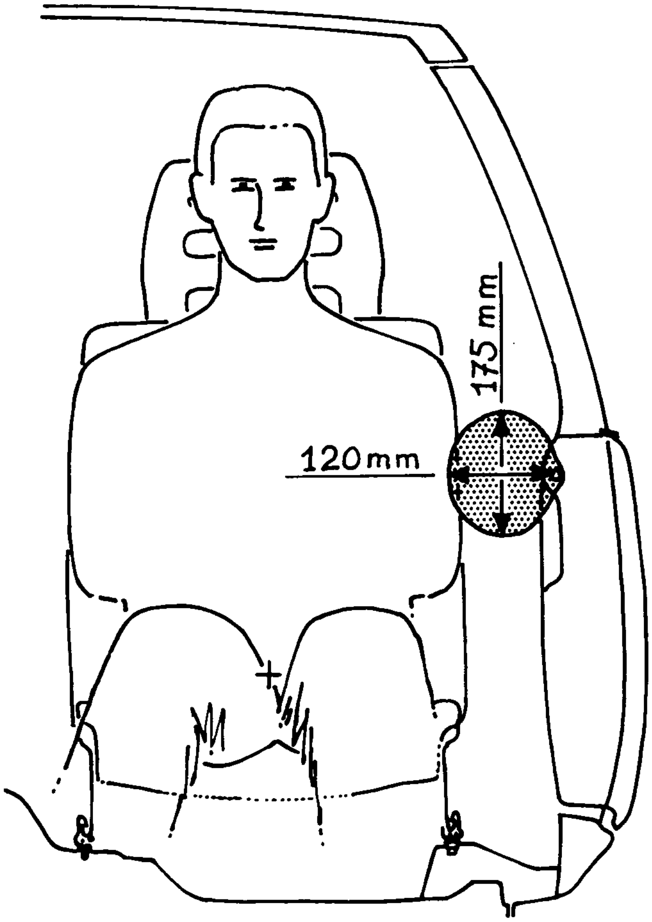

Figure 1. Frontal view of deployed side air bag.

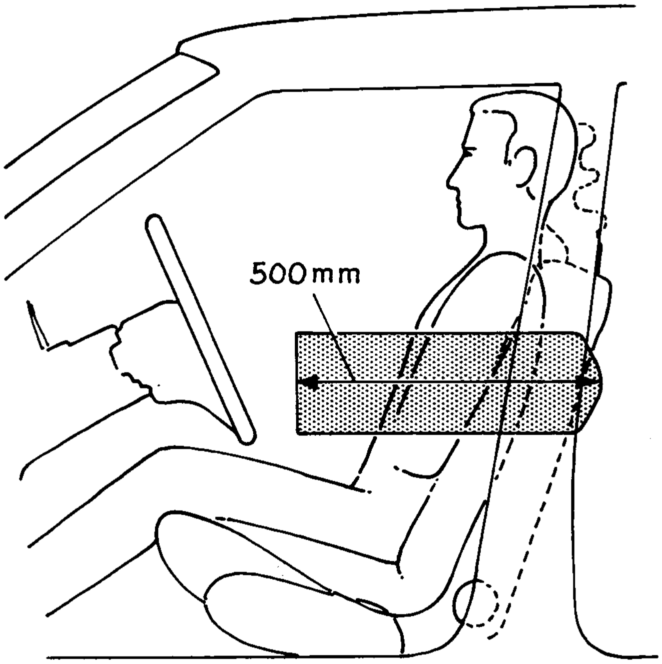

Figure 2. Side view of deployed side air bag.

The characteristics of springs and dampers are strongly nonlinear, and have been validated against dynamic experiments.

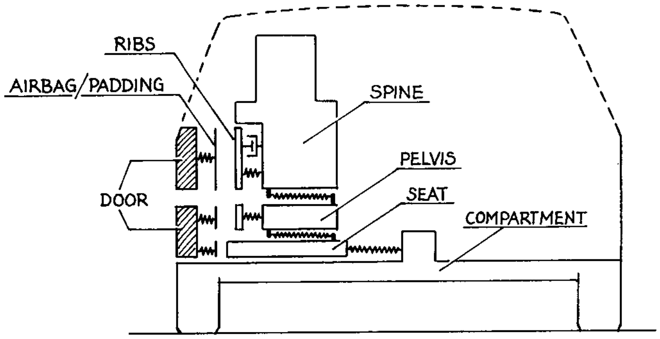

Figure 3. Mathematical model for side impact simulations.

The basic model has been used in several studies and is validated against sledtests as well as fullscale tests. An air bag system was implemented in the model as a separate unlinear spring characteristic.

Simulation results.—Simulations were made with different system configurations to define the bag system which gives an optimal system performance. The chosen system in this study was to use an 8 Litre bag filled to an over pressure of 1 Bar within 10 ms. With this system the improvement of occupant injury criteria was investigated at different door impact velocities.

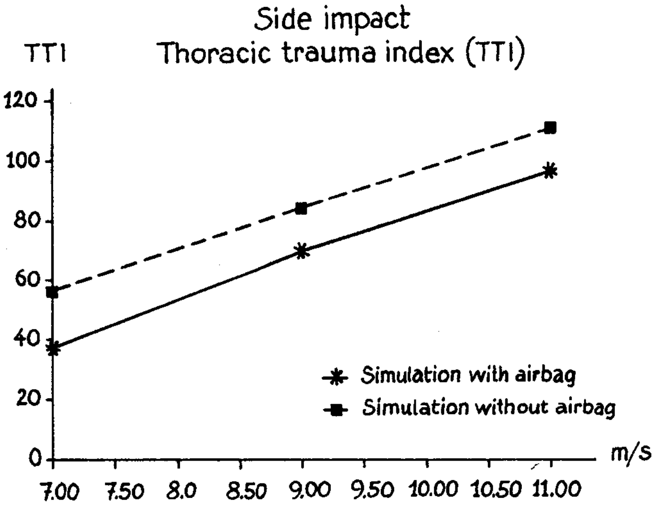

Figure 4. Simulation results with and without side air bag system at different door velocities.

In the initial simulations a constant door velocity was used corresponding to the sled test conditions. Simulations were also made with a realistic door velocity from a side impact test with complete vehicle. Door velocity according to figure 5 was used.

An improvement of the same magnitude can be seen also for the realistic door velocity.

Figure 6 also shows that the bottoming stiffness of the door structure has a great influence on the TTI value. TTI increases when stiffness increases. The reduction in injury index that is caused by the air bag system, does not decrease significantly if the bottoming stiffness decreases, which means that sledtests (with constant velocity and simulated door structure) could be used to reproduce a real side impact crash.

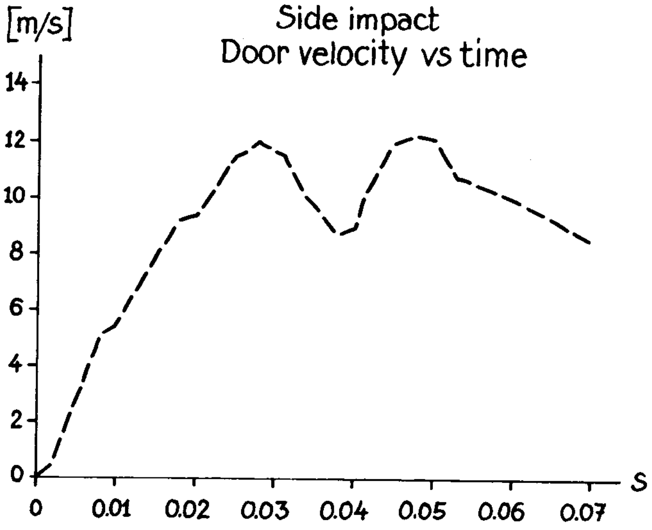

Figure 5. Side impact, door velocity versus time.

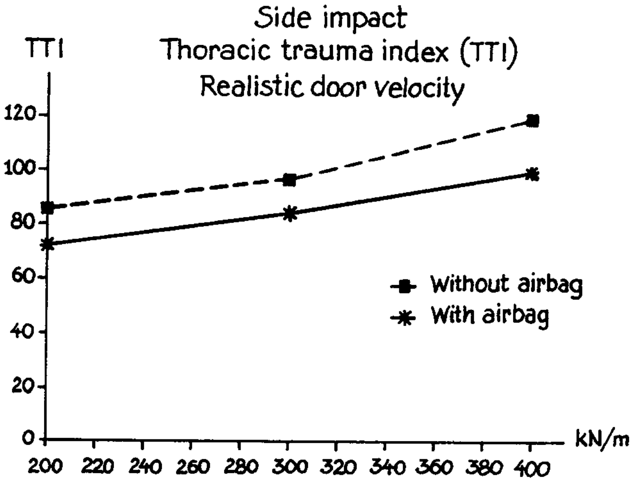

Figure 6. Thoracic trauma index (TTI) with realistic door velocity versus bottoming stiffness.

Component design

To achieve the required system performance several alternatives were analysed. The best solution found was to use gasgenerators of a similar type to that used for pyrotechnical pretensioner retractors. For the side air bag application the generators must be loaded with 3–4 grams of propellant to meet the bag fill criteria.

The system is triggered by a deflection and force sensitive membrane switch located in the lower part of the door. The switch consists of eight segments. Segments one, three, five and seven close the circuit between the battery and the squib and segments two, four, six and eight close the circuit between the squib and the ground.

The intention is that two independent closures are required before the whole firing circuit is closed and the bagsystem is triggered. The project goal has been to have a closure of the complete firing circuit within 3 ms.

To meet this goal the sensor switch must be fixed to a rigid structure which gives a good reaction force. The switch was therefore fixed to the side impact bar in the lower part of the door, see figure 7.

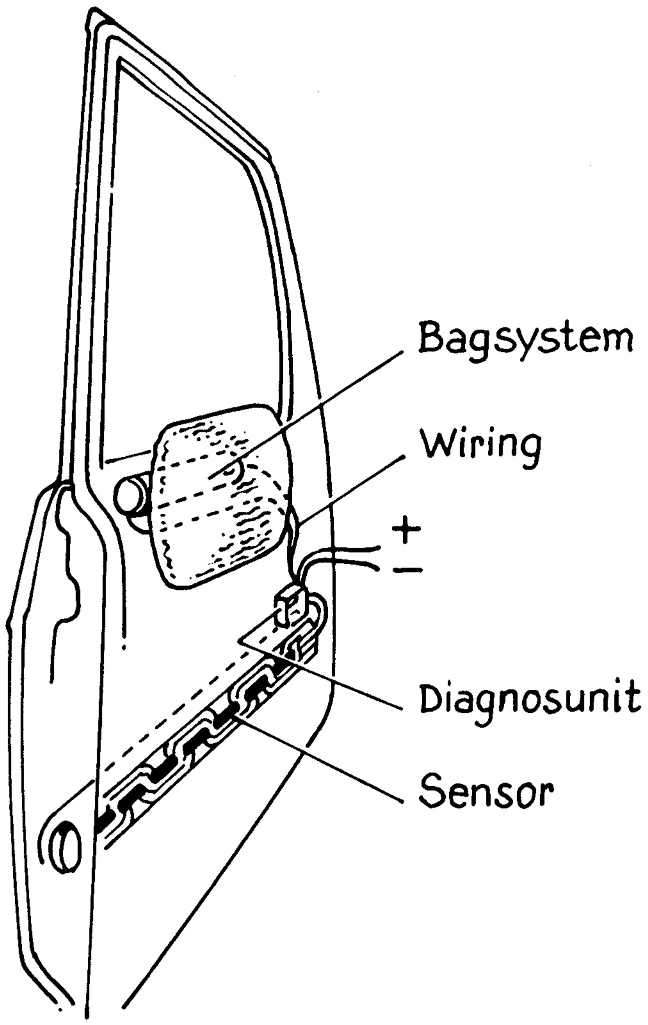

Figure 7. Complete side air bag system.

A diagnostic unit will also be fixed to the bar, controlling the system function.

The complete system including the bag system, the sensor and the diagnostic system will then be independent and selfcontained within the door with the only wiring connections being the battery voltage, ground and readiness indicator.

Tests Performed

The bag system and the sensor system were tested separately to evaluate if an acceptable system performance could be reached.

Bag system

Dynamic tests were made with a crash sled where the proposed type of side impact was simulated.

Test conditions.—A rigid door with a B-pillar was built from undeformable steel tubing and was fixed to the crash sled. A layer of padding, 25 mm thick, covered the rigid door with the intention of simulating the stiffness of a regular door. The alternative of using a regular door instead of the rigid one was found to give a softer impact structure than in a car crash test—because it is already deformed by the barrier when the dummy is hit. It would also introduce an uncontrolled variation in the stiffness which could influence the results. It was therefore not chosen for the tests in this study.

A regular door panel and a B-pillar panel were fixed to the rigid door on the outside of the padding.

When an air bag system was used, a hole was cut in the upper rear part of the door panel. The airbag system was then fixed to the door with metal bands.

In the NPRM it is stated that the DOT–SID will be used for the determination of the side impact protection level. The acceleration in the chest rib, both upper and lower, the chest spine and the pelvis were measured and used for injury criteria calculation.

There was a difference compared with the proposed test procedure, in that the signals were not filtered in the required manner. Filtering according SAE CFC 180 was only used. This difference has an influence on the absolute values of the injury criteria and a direct comparison can not be made with other data. On the other hand a relative comparison can be made within this test series.

The dummy was placed on a styrofoam seat across the crash sled path. The position was aligned to give a chest impact in the centre of the deployed bag.

Figure 8. Rigid door with dummy before test.

The sled with the door and a B-pillar was then accelerated, and when a constant speed was reached at the end of the path, the side of the dummy was hit, as in a side impact.

The speed of the door at impact was lowered slightly to compensate for the stiffness of the rigid structure used in the door. Crash test results described in the ESV report "Side impact protection systems" by H. Mellander specify the impact speed to 11 m/s. In these tests the impact speed was reduced to 9 m/s.

During the sled tests with the air bag system, the deployment was initiated by an external timer. The triggering time was chosen by taking a sensor closure time of 3 ms into account. The triggering that initiated the bag deployment was therefore started 15 ms before the nominal contact between the door and the dummy chest.

While having contact door-chest the door and sled were not decelerated by any other means than the mass of the dummy. The intention was to have a constant door speed during the contact time. When the dummy started to separate from the door, at 350 mm after nominal contact between the door and the dummy, the sled was stopped mechanically.

Test results.—Several test series were performed and from the final series, the results with and without the side air bag system are presented.

Figure 9. Bag deployment and influence on a dummy kinematics.

Chest acceleration traces both with and without a side air bag can be seen in figures 10, 11 and 12 below.

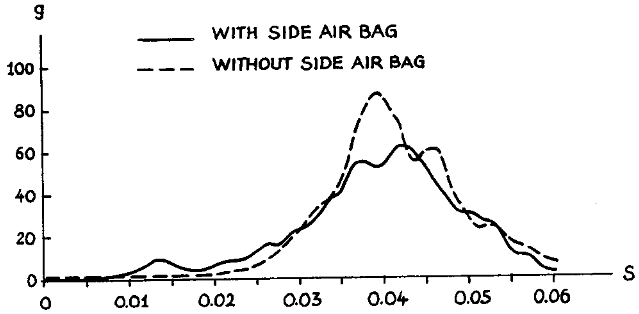

Figure 10. Lower spine acceleration.

Zero in the diagram time scales is at gasgenerator triggering, 15 ms before the nominal contact between the door and the dummy.

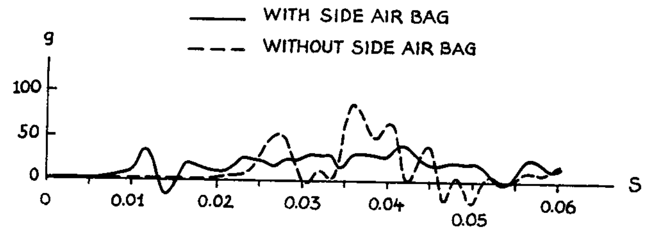

Figure 11. Upper rib acceleration.

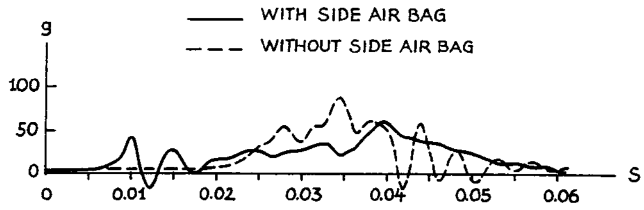

Figure 12. Lower rib acceleration.

In the lower spine diagram the influence of the air bag system can be seen as the bag accelerates the chest with approximately 5–10 G before there is contact between the door and the dummy. The severity of the impact when the door hits the chest is then reduced significantly.

In figure 11 and 12 the influence of the air bag system is seen on the rib accelerations. As for the lower spine the ribs are accelerated earlier and the maximum level is lowered when an air bag is used.

From high speed film analysis the head ejection can be studied. With the deployed bag the body movement is better controlled and retained in the compartment. The head ejection is also reduced which is shown in figure 13.

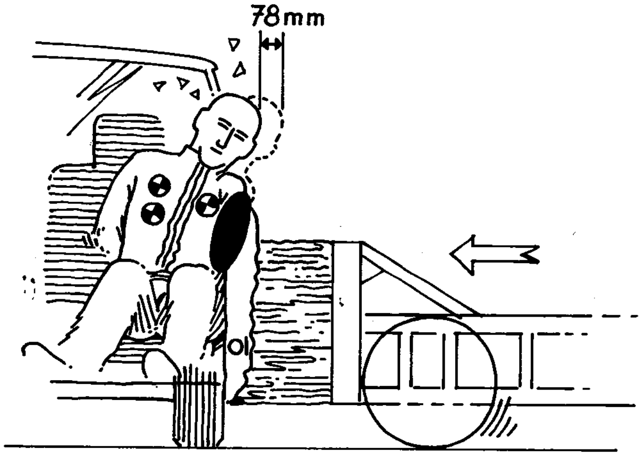

Figure 13. Head ejection.

In this final series of two tests, each test was done both with and without an air bag system. The injury criteria with equivalent systems shows good correlation and an average value is therefore calculated.

An improvement is also seen in the pelvis acceleration despite the fact that the bag is small and is not intended for a direct protection of the pelvis. An explanation is probably that when the bag starts to accelerate the chest, the pelvis also starts to move and the severity of the impact between the door and the pelvis is reduced.

Mathematical simulation validation.—The good correlation between sled test and simulations is shown in figure 15.

TEST No	SET UP	CHEST ACCELERATION				PELVIS ACC (g)	HEAD EJECTION (mm)
		LOWER SPINE (g)	UPPER RIB (g)	LOWER RIB (g)	TTI (g)		
9166	WITH SIDE AIR BAG	62.6	43.2	61.4	62.0	87.0	143
9172	–"–	65.8	40.9	68.6	67.1	102.0	127
AVERAGE	WITH SIDE AIR BAG	64.2	42.0	65.0	64.5	94.5	135
9170	WITHOUT SIDE AIR BAG	87.7	79.5	92.4	90.0	114.2	221
9171	–"–	86.2	91.5	88.5	87.4	123.6	208
AVERAGE	WITHOUT SIDE AIR BAG	87.0	85.5	90.4	88.7	118.9	214
IMPROVEMENT OF RESULTS		26%	51%	28%	27%	21%	79 mm

Figure 14. Summary of crash test results.

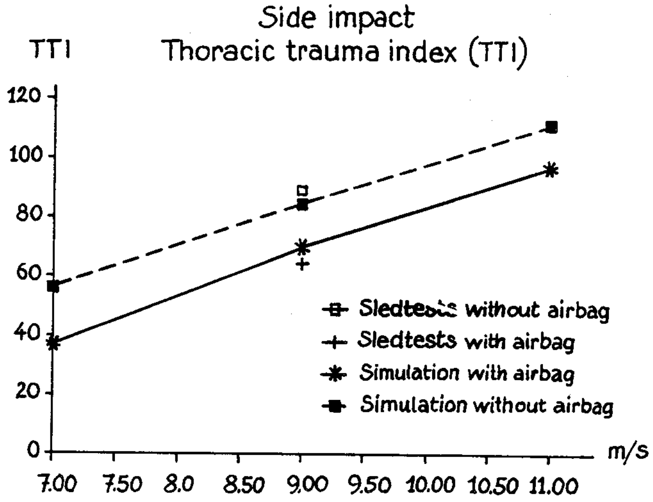

Figure 15. Simulation model validation.

The theoretical model of the air bag system shows a slightly less improvement than what has been measured in the sled tests. This could be explained by the fact that the model does not take any 3D effects into account.

Sensor systems

Tests with the sensor system were made to evaluate the triggering performance and to analyse the "No fire" and "All fire" level.

Test conditions.—The tests with the sensor system were conducted in two basic situations:

- Pole impact against a fixed door.
- Side impact test in complete vehicle with moving barrier.

The pole impact tests were made with the door fixed to the ground, which was impacted by a rigid tube attached to a pendulum.

The simulated pole was designed to have approximately the same weight as a door (≈35 kg). The impact velocity was decided after analysis of how fast a door could be opened. The impact velocity was then set at the maximum level 3 m/s.

This test was performed to study the resistance to unwanted sensor triggering in minor impact situations such as parking area accidents, door opening damages, etc. In these types of accident the door might be deformed but the sensor is not allowed to trigger.

Impacts were made at different places along the door and each impact place was tested once.

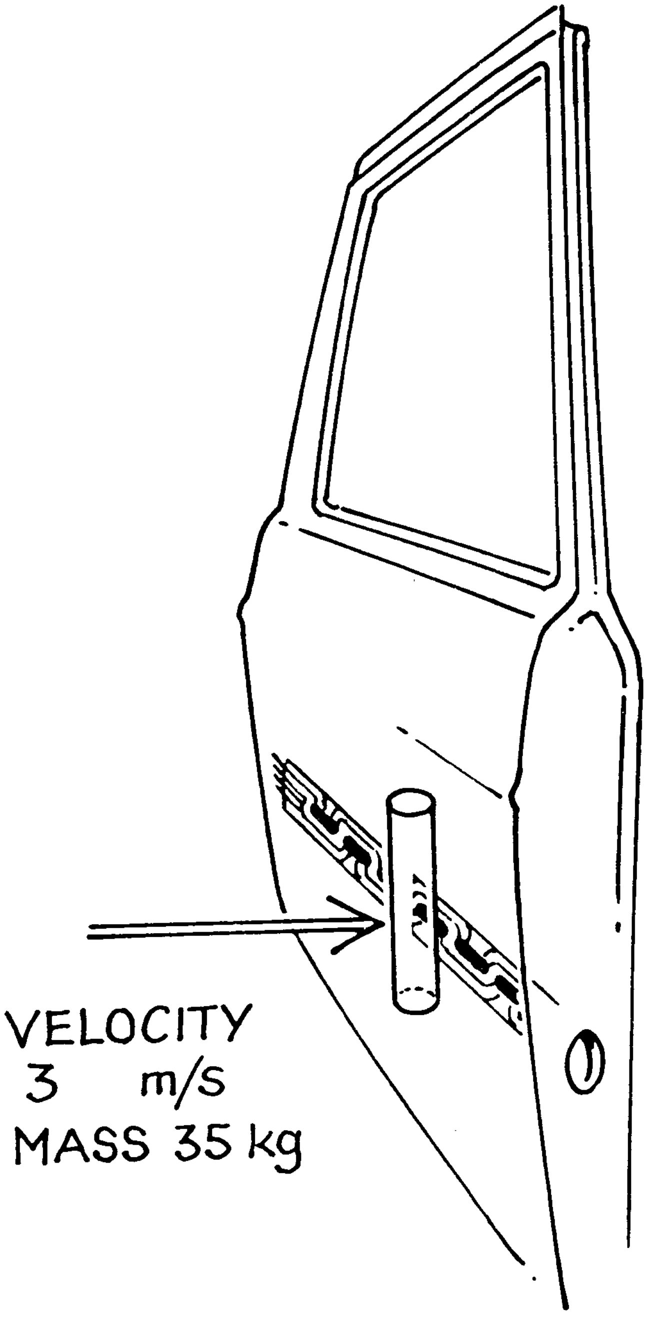

Figure 16. Pole impact.

The sensor system was also installed in a complete vehicle which was crashed in side impact with a moving barrier. Due to convenience and availability the crash was made according to the proposed European test standard with CCMC barrier and perpendicular impact configuration. This test was made to verify the triggering time in a crash where the side air bag must deploy.

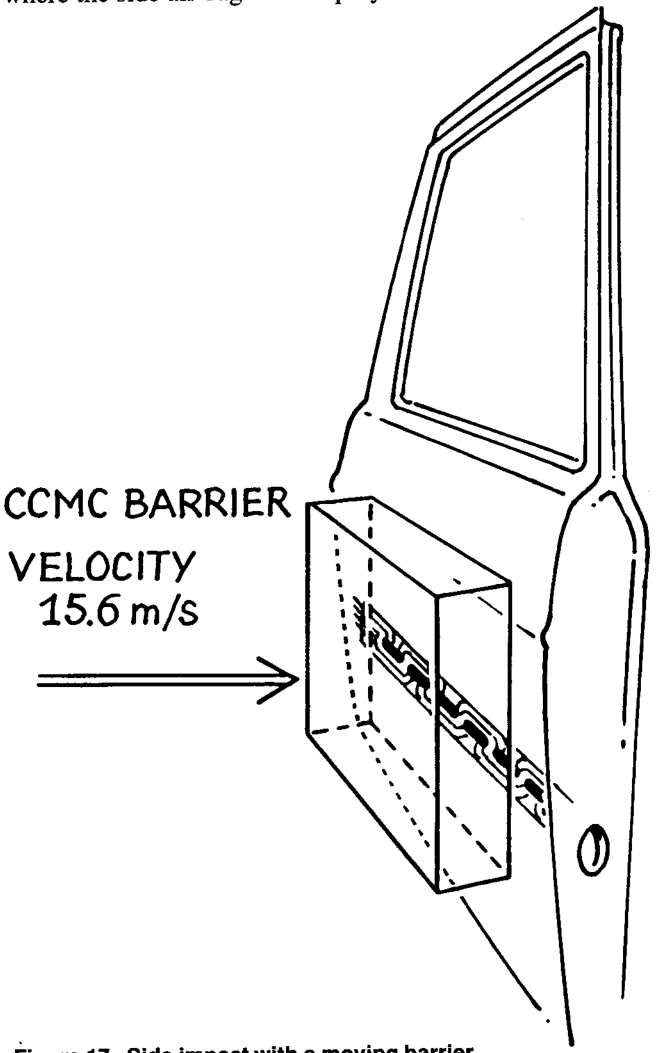

Figure 17. Side impact with a moving barrier.

Test results.—The sensor system has fulfilled the requirements in all crash situations. There was no triggering during pole impact. In the worst condition only one segment closed, which is insufficient for system triggering. The system will only trigger with two separate segment closures.

In the complete vehicle side impact crash the sensor triggered according to the requirement at 2–4 ms.

Conclusion

It is possible to use air bag technology for side impact protection:

- With a deflection and force sensitive membrane switch the situations, where an air bag is needed, can be detected.

- A bag with a volume of 8 Litre can be filled quickly enough to cushion the occupant in a side impact.

A side air bag system can reduce the injury criteria by 20–30%:

- The chest acceleration levels are lowered for both ribs and spine, giving a reduction of TTI of approximately 27%.
- The head ejection is reduced by approximately 80 mm.
- The TTI value reduction is independent of door impact velocity between 7 and 11 m/s.

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Study on Side Impact Test Methods

Analysis by Component Tests and Simulation

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Abstract

In order to contribute to the worldwide discussions aimed at an improvement of the existing side impact test method, JARI and JAMA are engaged in a research project designed to provide a more realistic and effective test method in view of international harmonization.

The results of the full-scale tests by various research groups have shown that at least three problems exist: One, only a small amount of information on the vehicle characteristics can be obtained from full-scale tests. Two, it is difficult to relate the results of full-scale tests to the modification of vehicle designs. Three, it is even more difficult to apply the results of full-scale tests to vehicle design in progress.

To deal with these problems, JARI and JAMA have attempted to determine factors influencing the impact forces on vehicle occupants in a lateral collision, and have investigated the possibilities of a method combining component test procedures with a mass-spring simulation model. In this paper, factors influencing the severity of impact on the occupant were investigated by combining a component test with a simulation technique, and the results obtained were compared with those of a full-scale test, using structurally modified and padding-added vehicles.

It was found possible, by combining the component test and the simulation technique, to make a consistent prediction of the influences of vehicle specification differences, to determine in detail the side impact behavior occurring in a full-scale test, and to use the calculated results for an improvement of vehicle design.

In addition, an attempt was made to evaluate the feasibility of the CCMC-proposed composite test procedure (CTP) as an alternative to the full-scale test. The results indicated that there is a more or less satisfactory correlation between the CTP and a full-scale test, and suggested that the CTP could be substituted for the full-scale test if the remaining problems found are to be solved.

Introduction

The study on occupant protection in lateral collisions is a matter of worldwide importance nowadays. So far, full-scale tests (1, 2, 3, 4)* and component tests (5, 6, 7, 8, 9, 10) have been proposed and studied in the United States and Europe.

Accordingly, in the interest of international harmonization, JARI and JAMA are carrying out a joint investigation of side impact procedures, to participate in the worldwide discussion for the development of a realistic and effective side impact test. As part of this investigation, we have already reported on the development of a new MDB (Moving Deformable Barrier) (11), a dummy evaluation test (12, 13, 14), and a full-scale test (15, 16, 17) at various international conferences.

Full-scale tests can provide only a small amount of information on vehicle characteristics, and that it is difficult to reflect the results directly on vehicle designs and to apply the results for modification of vehicle design underway.

We therefore studied a simulation technique combining a

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*Numbers in parentheses designate references at end of paper.