BUMPER BAG FOR SUV TO PASSENGER VEHICLE COMPATIBILITY AND PEDESTRIAN PROTECTION

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ABSTRACT

An external airbag (bumper bag) for improved sport utility vehicle (SUV) to passenger vehicle compatibility in side impact and improved pedestrian protection was developed. The bag was developed and evaluated by means of mathematical simulations and mechanical crash tests.

The mounting location of the bumper bag was below the bumper structure of an SUV. The volume of the bag was 134 liters and the peak pressure of the bag when loaded was approximately 7 bars.

In the mechanical crash tests a Ford Explorer with and without a bumper bag was run into the side of a Toyota Corolla. The impact angle was 90 degrees and the impact velocity was 48 kph (30 mph). It was found that the bumper airbag significantly reduced the b-pillar peak intrusion velocities and maximum deformation of the impacted vehicle.

The potential injury reducing benefits for a pedestrian impacted by an SUV equipped with a bumper bag was also evaluated. Using a pedestrian leg form both impact and inadvertent firing tests were carried out. In the impact test the leg form was impacting the front of the Ford Explorer at 40 kph (25 mph) with and without bumper airbag. In the inadvertent firing tests the leg form was positioned in contact with the bumper of the SUV when inflation of the bumper bag was initiated. It was found that the bumper bag reduced the knee bending angle, shear displacement and tibia acceleration significantly. All injury measures but one was below the EuroNCAP injury assessment values for the lower extremity.

The potential reduction in injury measures for an occupant on the impacted side of the passenger car impacted by an SUV with a bumper airbag was evaluated. The evaluation was carried out by means of sled tests. The intrusion velocities at the chest level of the impacted vehicle in the crash tests were used to drive the sled in sled tests. In the sled tests a state of the art occupant protection system was used. The system comprised a seat belt system and a side airbag. It was found that chest injury measures were significantly reduced when a bumper bag was used in a SUV to passenger vehicle side impact.

Future development of the bumper airbag system will include improved frontal impact compatibility and self protection.

INTRODUCTION

The crashworthiness of passenger cars have been considerably improved during the last decades. From the early 1980's until 2000, the driver death rate per million cars registered decreased 47 percent according to IIHS [1]. However, this improvement was mainly made in frontal crashes for which driver death rate decreased 52 percent, compared to only 24 percent in side impact.

In side impact crashes, on the other hand, IIHS found that side impact crashes accounted for 51 percent of driver deaths during 2000 and 2001 compared to 31 percent during 1980 and 1981. According to information in the FARS database the driver of a struck vehicle involved in a side impact crash is more likely to be killed when the striking vehicle is a large pickup than when it is a passenger car [1] (Figure 1). Out of 40 fatal side impact of pickups into passenger cars, 39 occupants will die in the passenger car while one will die in the LTV (Light Trucks and Vans). Large SUVs such as Ford Explorer are included in the definition of LTV.

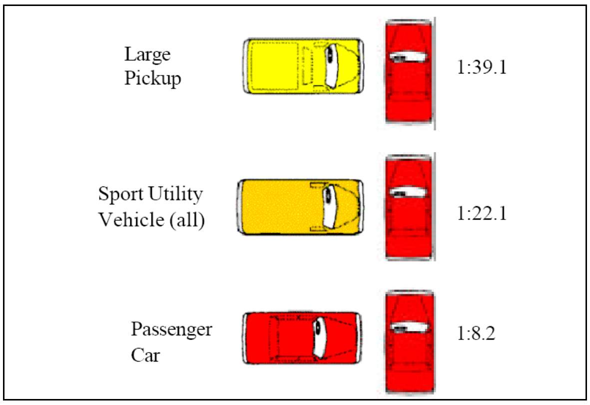

Figure 1
Driver Fatality Ratio of Side Impact Crashes Into Passenger Cars [1]

A study by IIHS confirms the increased risk for an occupant in a passenger vehicle impacted in the side by a SUV. The relative risk of death can be 27-48 times greater for the occupant of a passenger car (Figure 2) [2].

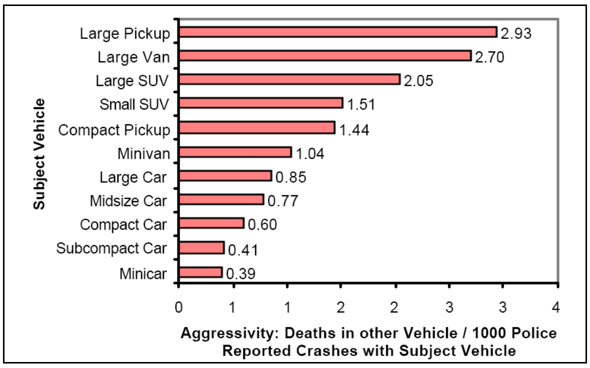

Figure 2
Death in Other Vehicle /1000 Police Reported Crashes with Subject Vehicle [2]

The sales and registration of LTV's in the US have steadily increased as the percentage of the fleet, since 1981 (Figure 3) [1]. In 2004 LTVs represented 45% of the vehicles sold in the US [3]. As the number of LTVs on the roads increases the number of accidents in which a LTV is a part increases.

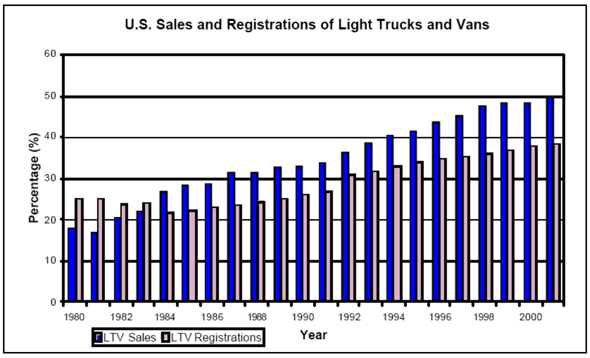

Figure 3
LTV US sales and registrations [1]

The increased number of LTVs relative to the number of passenger cars has lead to an increasing number of fatalities for car occupants that are struck by LTV's, while the fatalities have decreased in car to car crashes (Figure 4) [4].

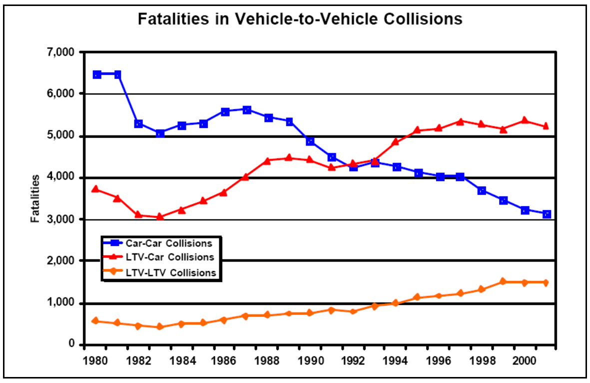

Figure 4
Occupant Fatalities in Vehicle-to-Vehicle Crashes [4]

A reason for the increased risk for an occupant at the impacted side of a passenger car in a SUV to passenger car side impact is that the SUVs are stiffer, heavier than passenger cars. In addition the frame structures of the SUVs are also located higher above the ground. There is a significant height mismatch between a Sport Utility Vehicle (SUV), such as a Ford Explorer, and a passenger car, such as a Honda Accord (Figure 5) [5]. When an SUV impacts a passenger vehicle in the side, the SUV bumper completely mismatches the sill floor of the passenger vehicle. Since the sill and floor is one of the stiffer structures of the car side, there will be a great risk for the SUV to deform the passenger vehicle heavily, thereby increasing the intrusion velocity of the b-pillar and the door. It will result in reduced survival space for the passenger.

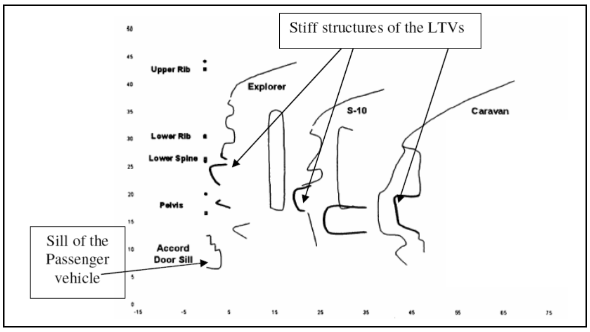

Figure 5
Front Profile of Various Vehicles [5]

Side impacts are the second most frequent type of crashes causing serious injury and death. More than half occur at intersection collisions, and the most serious impacts are those in which the vehicle is struck centrally.

The most common areas for injury include the chest (73%) and the head (53%) (Figure 6) [6].

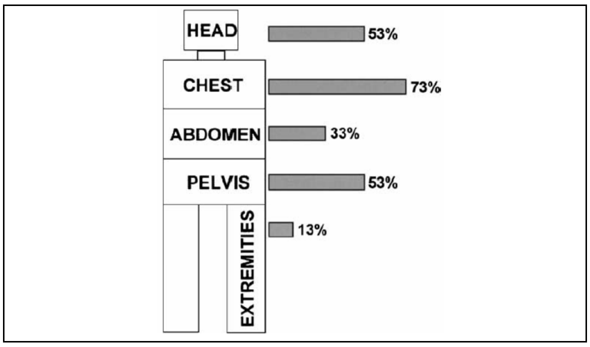

Figure 6
Percent of Patients with Injury AIS $\geq$ 2 designated body regions [6]

These injuries are related to the intrusion of the door panels and B-pillar, and in some cases direct contact with the impacting vehicle.

The intrusion is related to many factors for example the vehicles weight, stiffness, design and speed. Data used by Acierno [6] shows that the intrusion of a pickup into the driver compartment of a passenger car was in the range of 20 cm to 50 cm. The maximum intrusion often appeared above the mid to lower door reinforcement of the passenger vehicle due to the height of the SUV bumpers. In some cases, the occupant's head had a direct contact with the hood of the SUV. The SUV frame contacted the side of the passenger car in weaker, non-reinforced areas, leading to maximal intrusions into the head and upper thorax of the occupants.

The current regulation does not include the SUV to passenger car load case. The lower edge of the ECE R95 side impact barrier is 300 mm above the ground [7]. The FMVSS 214 side impact barrier lower edge is 280 mm above the ground and the bumper part of the barrier is 330 mm above the ground [8]. That means that the FMVSS 214 barrier begins 127 mm (5 inches) above the bottom of the door and ends no more than 13 mm above the window sill (Figure 7). The average LTV front end is considerably higher, striking above the reinforcement added to the vehicles to pass both the ECE R95 and FMVSS 214 regulation.

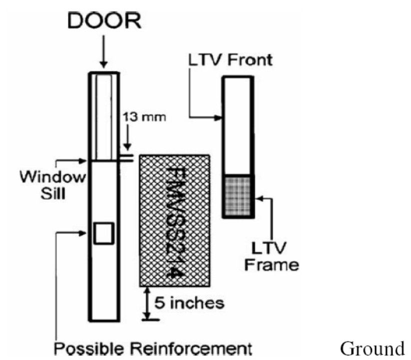

Figure 7
FMVSS 214 Crash Test Barrier Compared to Average LTV Front End [8]

A consumer test procedure that takes the height of the LTV front end above ground into account is a test method developed by IIHS [9]. The moving deformable barrier used in this test was designed to match the front end geometry and ride height of LTVs and SUVs. The bottom of the barrier is 379 mm above ground and the bumper part of the barrier is 430 mm above ground. This is considerably higher than what it is for the ECE R95 and FMVSS 214 barrier.

After analyzing the injury consequences of a side impact an LTV impacting a passenger vehicle, physical criteria had to be found to analyze the severity of simulated side impact since no dummy model was implemented into the passenger car model used in a mathematical analysis. As Ludo [10] demonstrated, it is appropriate to use the velocity change along the y-axis (perpendicular to the side doors) as a representative parameter for dummy impact severity.

To conclude, the following statements by Ludo [10] were useful for the study:

- The door structure velocity in the same time frame of occupant impact is controlled much more by stiffness ratio of the two vehicles than by the mass ratio.
- The door skin peak velocity is that of the bullet car.
- The mass ratio controls the final velocity of the two vehicles.
- A stiffer door reinforcement structure decreases the velocity with which the occupant is struck.
- The velocity change in y-direction of the b-pillar is appropriate to evaluate occupant injuries.

Many concepts and designs of bumper airbag systems have been proposed and patented [11, 12 and 13]. In one external airbag study, two crash tests were carried out using a Cutlass Sierra four door sedans equipped with bumper airbags. The first test was a frontal crash into a rigid barrier at 48.5 kph using two unventilated bags, one set at a high pressure (2.21 bars) and the other set at a low pressure (0.35 bars). With this test setup, 19% of the crash energy was absorbed by the bags. The second test was a side impact crash in which a rigid barrier impacted the passenger car at 48.5 kph. A pressurized bag (0.6 bars) was placed on the side of the passenger car above the sill, overlapping the side door and centered on the B-pillar. The result of this test was not successful. The bag deformed the weak structures of the panel of the side doors providing little additional protection. Two important conclusions were drawn from this study:

- The bumper airbag must deform with a stopping force up to 300 kN for a frontal airbag and 200 kN for a side airbag.
- The deformation of the bumper airbag will deform weak structures of the panel of the side doors.

An additional application of a bumper airbag system can be to reduce injuries to the lower leg of pedestrians in SUV to pedestrian accidents. In pedestrian accidents with passenger vehicles, knee and lower leg are the most frequently injured area. The most frequent injury producing part of the car is the bumper. Therefore EEVC working group 17 proposed in 1998 a test method for the leg to bumper impact which was later introduced in the EuroNCAP rating testing [14]. In the EEVC test method bending and shearing requirements were proposed to mitigate knee injuries as well as an acceleration requirement for the upper tibia mitigating the risk for tibia fractures. A bending of 15 degrees and a shearing of 6 mm was proposed as a threshold values for the knee and 150 g for the upper tibia acceleration. To design a passenger car in order to meet these requirements there are basically two features that can be added. First thick and soft foam in the bumper can be introduced and secondly a support for the tibia below the bumper can be added. All EU regulations and proposals are limited to cars with a gross weight of less than 2.5 tons. This means that many LTVs and SUVs will be excluded. Recently there was a proposal by the US to increase the gross weight to 3.5 tons or even 4.5 tons. This would include more or less all SUVs.

For SUVs the occurrence of leg and knee injuries are slightly lower than for passenger cars, when calculating as a percentage of all injuries, not actual risk. Longhitano et al (2005) reported that for SUVs in the US leg and knee injuries place 3rd after head and chest for both AIS 2+ and AIS3+ injuries [15]. However, for AIS2+ injuries the occurrence was very similar to chest injuries. Lefler and Gabler reported that the overall fatality and injury risk increases with SUVs compared to passenger cars [16]. This involved accidents 1995-2000 in the US. Per 1000 reported single vehicle/pedestrian impacts 115 were killed when an SUV was involved compared to 45 when a passenger car was involved. The fatality risk was thereby increased with more than 2.5 times for SUVs compared to passenger cars. Also it was likely that the risk of so called "run-over" accident increases with SUVs compared to passenger cars due to the higher bumper and ground clearance.

There is a need for a system that will improve the LTV and SUV to passenger car side impact compatibility and pedestrian protection.

AIM

The aim of the study was to by means of mathematical simulations and mechanical crash tests evaluate possible side impact compatibility and pedestrian protection benefits from mounting an external airbag (bumper bag) in the front end of an SUV.

MATHEMATICAL MODEL

The initial development of the bumper airbag was carried out by means of mathematical simulations. The vehicle models used were Chevrolet C250 Pickup Truck model and a Ford Taurus model (Figure 8). The number of elements of the Chevrolet Pickup was 53856 and for the Ford Taurus 65921. The models were developed and initially validated by NCAC [17]. The Ford Taurus model was additionally validated by means of in house crash tests.

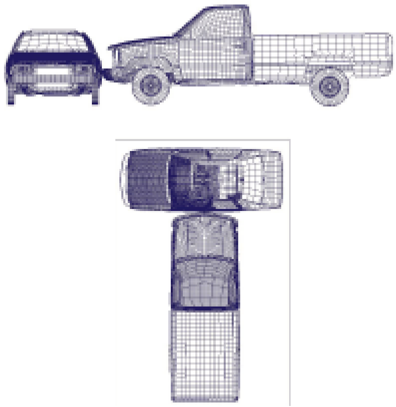

Figure 8
Vehicle Models Used

For evaluation of the potential benefits of using a bumper bag the intrusion velocity and intrusion depth were analyzed for four sensor locations on the b-pillar in the Ford Taurus model (Figure 9). The four locations were sill, pelvis, chest and head level on the b-pillar of the impacted vehicle.

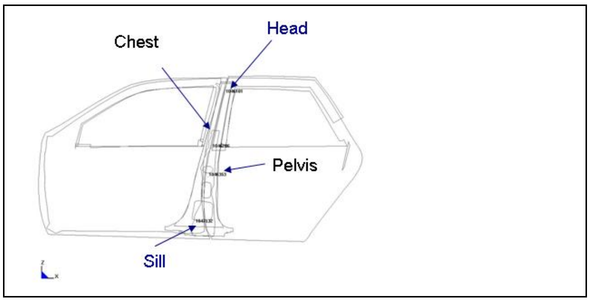

Figure 9
Sensor Locations Used to Record B-Pillar Intrusion Velocity and Intrusion Distance

In the development of the bumper bag the influence of a great number of parameters were evaluated by means of mathematical simulations. The parameters were shape, location, pressure, volume and ventilation of proposed bumper bag. In the shape, ventilation, location and volume evaluation of the bumper bag a pressure of 7 bars was used.

Two different locations for the bumper bag were evaluated. The locations were in front of the bumper and below the bumper (Figure 10).

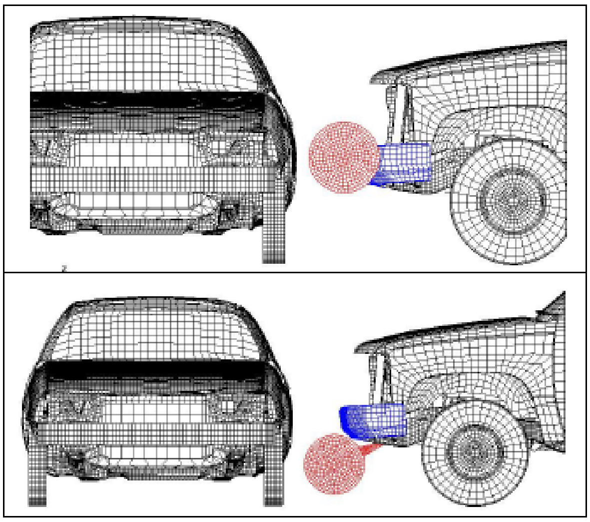

Figure 10
Location of the Bumper Bag

The initial over pressures evaluated were 1, 3, 7 and 10 bars and the volume of the bag evaluated was 47, 102, 147 and 189 liters.

RESULTS MATHEMATICAL MODEL

Some of the most important simulation results from the parameter study are summarized below. The results shown are peak intrusion velocity and peak intrusion distance. The intrusion velocity was the velocity of a point on the b-pillar on the impacted side of the vehicle relative a point on an undeformed location, such as the tunnel, of the impacted vehicle. The intrusion distance was the displacement of a point on the b-pillar on the impacted side of the vehicle relative a point on an undeformed location, such as the tunnel, of the impacted vehicle.

For the evaluation of the location of the bumper bag the lowest intrusion velocity and intrusion distance was obtained for a bumper bag mounted below the bumper (Figure 12). For head, chest and pelvis sensor locations the intrusion velocity was significantly reduced with a bag mounted below the bumper. For the sill sensor location only minor reductions in peak intrusion velocity was obtained. For a bag mounted in front of the bumper only minor reductions were obtained for the head and sill sensor locations. For the chest and pelvis sensor locations no reductions were obtained.

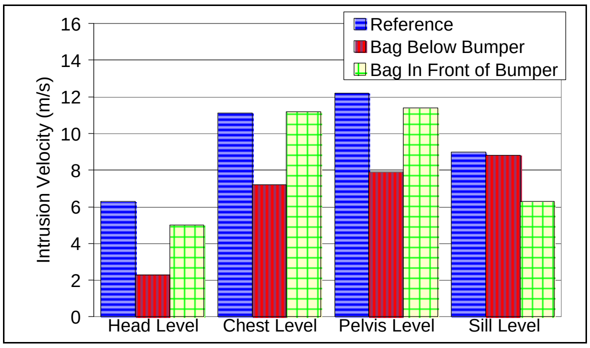

Figure 12
Intrusion Velocity, Peak Values (m/s), Location of Bumper Bag

For the peak intrusion distance significant reductions were also obtained for a bag mounted below the bumper for all sensor locations but the sill location (Figure 13). For the sill sensor location no reductions in intrusion distance was obtained for a bag mounted below the bumper relative to when no bag was used.

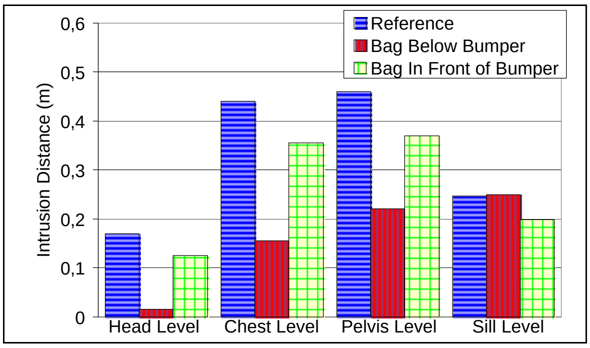

Figure 13
Intrusion Distance, Peak Values (m), Location of Bumper Bag

For the bag pressure evaluation it was found that for the chest and pelvis sensor location the higher the pressure the lower the intrusion velocity (Figure 14). For the sill sensor location the intrusion velocity increased significantly for all bag pressures but 10 bars. For 10 bar pressure intrusion velocity was reduced also for the sill sensor location. For the head sensor location significant reductions were obtained by adding a bag. However only minor variations in intrusion velocity was obtained for the various bag pressures.

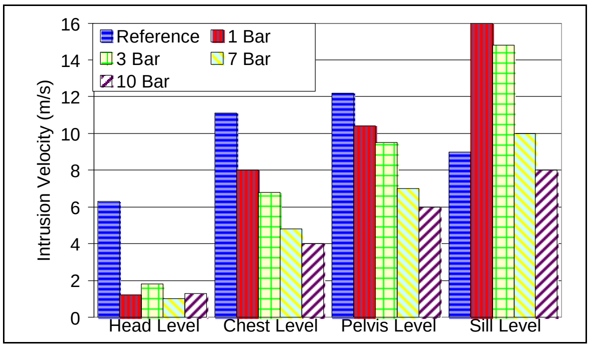

Figure 14
Intrusion Velocity, Peak Values (m), Bag Pressure

In the bag pressure evaluation it was found that for the chest and pelvis sensor locations the higher the pressures the lower the intrusion distance (Figure 15). For the head and sill sensor locations only small differences in intrusion distance for the various bag pressures was observed. However, significant reductions in intrusion distance relative to when no bag was used was obtained.

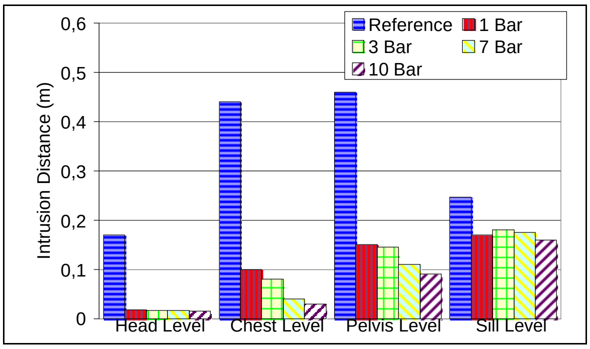

Figure 15
Intrusion Distance, Peak Values (m), Bag Pressure

For the bag volume evaluation greatest reductions in intrusion velocity was obtained for the large volume airbag. The volume of that airbag was 189 liters (Figure 16). For the smallest bag, 47 liters, an increase in intrusion velocity for the sill sensor location was obtained and for the pelvis sensor location no reduction in intrusion velocity was obtained. For the bag with 102 and 147 liter volume reductions in intrusion velocity was obtained for the pelvis sensor location. For the sill sensor location there was an increase in intrusion velocity for 102 and 147 liter bag volume.

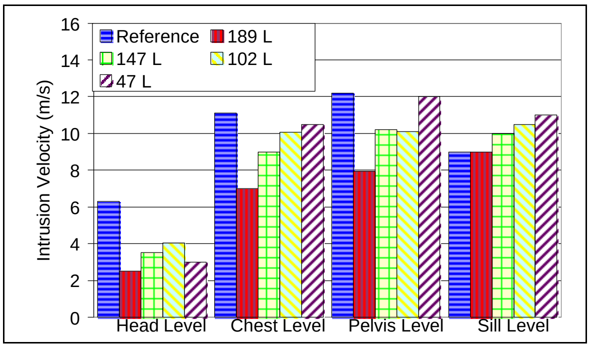

Figure 16
Intrusion Velocity, Peak Values (m), Bag Volume

For the intrusion distance greatest reductions was obtained for the bag with greatest volume 189 liter (Figure 17). For all bag volumes but one peak intrusion distance was reduced significantly. For the sill sensor location there was no reduction in intrusion distance for the various bag pressures.

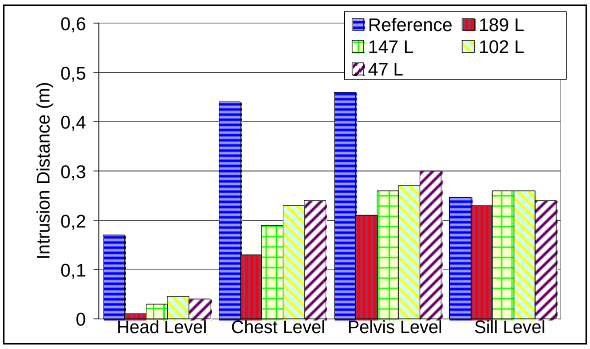

Figure 17
Intrusion Distance, Peak Values (m), Bag Volume

From the mathematical simulation results a bumper bag system was proposed. The preferred location of the bumper bag was below the bumper, the volume was 189 liters and the pressure was 10 bars.

MECHANICAL BUMPER BAG

Based on the results from the mathematical model a mechanical bumper bag was designed and a prototype made (Figure 18). The bag was of tubular shape. The length of the bag was 2.4 m, the width was 0.3 m and the volume was 134 liters. The bag was covered with 53 circular seat belt elements. Half of the bag diameter (0.15 m) was extending in front of the bumper when the bag was inflated. The bag was inflated using 3 passenger side airbag gasgenerators. The peak pressure obtained was 7 bars.

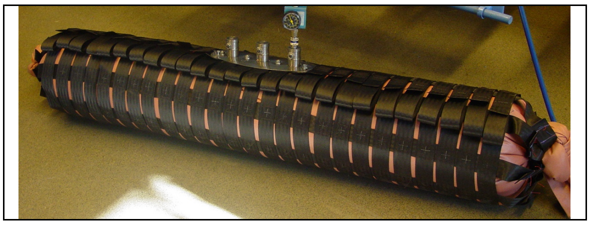

Figure 18
Mechanical Bumper Bag

For the bumper bag to transfer load from the SUV to the passenger car, in a side impact, a load carrying support structure was needed. The support structure was mounted with a hinge joint to the SUV. The bumper bag was mounted on the support structure (Figure 19). When not used the bumper bag was folded and the support structure with the bag was located behind the bumper. In the crash the bumper bag was expanded and pushed the support structure downwards. When in position, the bumper bag support structure was locked providing the bumper bag with a load carrying support structure.

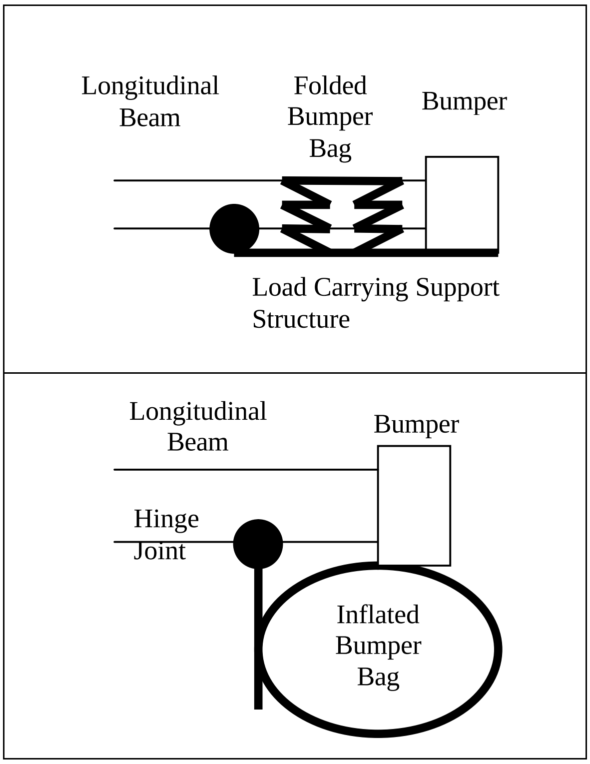

Figure 19
Bumper Bag Schematic

MECHANICAL SUV TO CAR CRASH TEST

The potential compatibility benefits of the mechanical prototype bumper bag were evaluated by means of Ford Explorer to Toyota Corolla crash tests (Figure 20). In the tests the Ford Explorer was impacting the side of the Toyota Corolla at an impact angle of 90 degrees and an impact velocity of 48 kph (30 mph). The mid point of the Ford Explorer bumper was impacting at the H-point of the Toyota Corolla. The Toyota Corolla was MY 1992 and the Ford Explorer was MY 1993. The mass of the Ford Explorer was 2043 kg and the mass of the Toyota Corolla was 1100 kg. Two crash tests were carried out. One reference test without bumper bag and one test with bumper bag. Accelerations and Intrusion distances at 4 sensor locations on the b-pillar were recorded. The intrusion distances were recorded by means of string potentiometers. The same locations as were used in the mathematical model were used in the mechanical tests. In addition, accelerations were recorded at numerous locations on the impacted and non-impacted side of the Toyota Corolla and acceleration was recorded at the tunnel of the Ford Explorer. No crash test dummies were used in the crash tests

Figure 20
SUV to Car Side Impact

RESULTS FORD EXPLORER TO TOYOTA COROLLA CRASH TESTS

For the impacting vehicle, the Ford Explorer, The acceleration, at an undeformed location (tunnel) of the vehicle, was altered somewhat by the addition of a bumper bag (Figure 21). The first local peak acceleration was increased, when a bumper bag was added, from 75 m/s^2 to 100 m/s^2. Peak global acceleration was increased from 136 m/s^2 to 146 m/s^2.

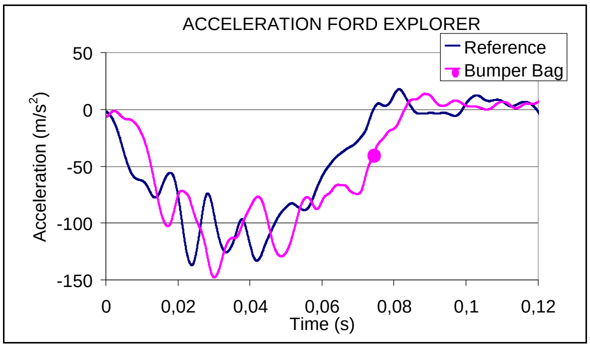

Figure 21
Tunnel Acceleration Ford Explorer

The final velocity at an undeformed location (tunnel) of the Toyota Corolla was 10 m/s for the reference test (Figure 22). For the test with a bumper bag the final tunnel velocity was 11 m/s.

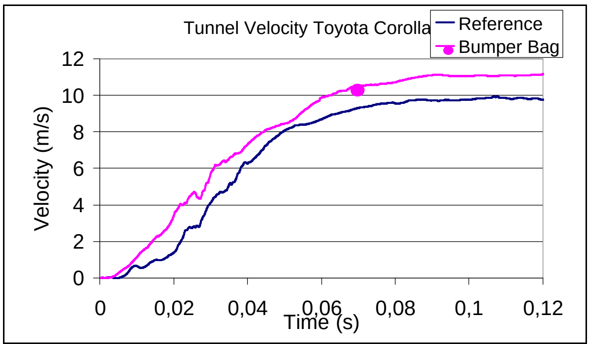

Figure 22
Tunnel Velocity Toyota Corolla

Peak intrusion velocity was very small at the head sensor location for both the reference test and the test with the bumper bag (Figure 23). For the chest and pelvis sensor location peak intrusion velocity was reduced when a bumper bag was added. At the chest sensor location peak intrusion velocity was reduced from 12.5 m/s to 10.0 m/s and at the pelvis sensor location peak intrusion velocity was reduced from 12.0 m/s to 11.0 m/s. At the sill sensor location, however, peak intrusion velocity was increased from 5.0 to 8.5 m/s when a bumper bag was added.

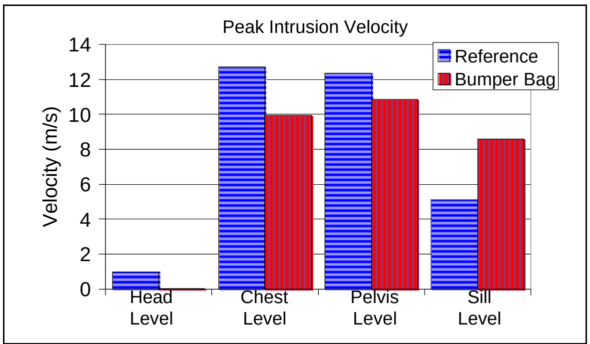

Figure 23
Peak Intrusion Velocity

Peak intrusion distance at the head, chest and pelvis sensor location was reduced with the bumper bag (Figure 24). At the head sensor location peak intrusion distance was reduced from 0.12 m to 0.07 m. At the chest location it was reduced from 0.32 m to 0.28 m and at the pelvis location it was reduced from 0.32 m to 0.24 m. At the sill location it was increased from 0.14 m to 0.24 m.

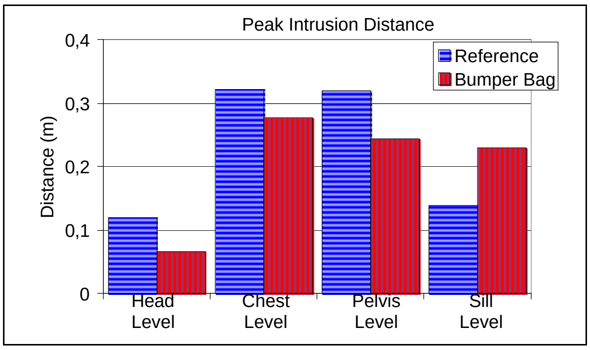

Figure 24
Peak Intrusion Distance

PEDESTRIAN TESTS

A pedestrian evaluation of the bumper bag was also carried out. In the evaluation a pedestrian leg form was used [12]. The tests were a reference without bumper bag, an impact test with an inflated bumper bag and an inadvertent firing test. In the impact test the leg form was impacting the front of the Ford Explorer at 40 kph (25 mph) with and without bumper bag. In the inadvertent firing tests a leg form was positioned in front of the bumper bag when inflation of the bag was initiated.

RESULTS PEDESTRIAN TESTS

In the results from the leg form tests it can be observed that the bending angle was significantly reduced with the bumper bag (Figure 25). There was a significant difference in the bending angle between the two reference tests and the two tests with bumper bag. However, in both reference tests the bending angle was greater than the EuroNCAP injury criteria level. In one of the tests, with the bumper bag, peak bending angle was greater than the injury criteria level. For the inadvertent firing test the bending angle was significantly lower than the injury criteria level.

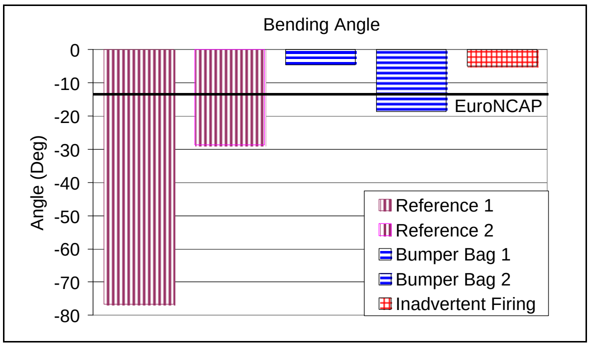

Figure 25
Peak Bending Angle

The shearing displacement in the reference test was 5 mm (Figure 26). In the tests with the bumper bag peak shearing displacement was less than 1 mm.

The shearing displacement was significantly reduced with the bumper bag. However, all test results were below the EuroNCAP injury criteria level of 6 mm. The shearing displacement in the inadvertent firing test was very low.

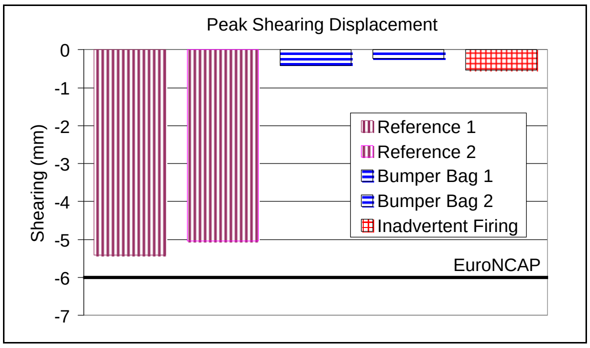

Figure 26
Peak Shearing Displacement

The tibia acceleration in the reference tests were 250 g's (Figure 27). For the bumper bag the tibia accelerations were 120 g's. Therefore great reductions in tibia accelerations were obtained with the bumper bag. The tibia accelerations in the reference tests were significantly greater than the EuroNCAP injury criteria level. The tibia acceleration in the inadvertent firing test was 100 g's which was significantly lower than the EuroNCAP injury criteria level.

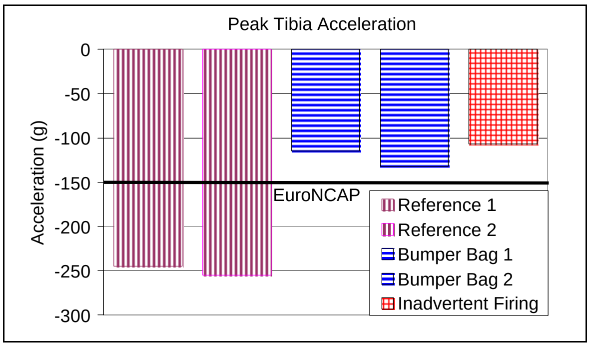

Figure 27
Peak Tibia Acceleration

DISCUSSION

The potential compatibility and pedestrian protection benefit of mounting a bumper airbag on an SUV was evaluated. It was found that the intrusion velocity and displacement was significantly reduced by adding a bumper bag. An added benefit with a bumper bag was that the time available to inflate a side airbag was also increased.

In the modelling results in which the pressure of the bumper bag was evaluated it was observed that the sill sensor location velocity was increased for all pressures but for the bag with 10 bar pressure. The reason was that for all other evaluated pressures the bumper bag was bottoming out and the support surface was impacting the sill of the passenger vehicle resulting in high peak intrusion velocities.

The mechanical prototype bumper bag that was made was not exactly the same as the bumper bag that was proposed based on the mathematical simulations. This was due to the fact that in the mathematical simulations a model of a pickup truck was used and in the mechanical test a Ford Explorer was used. The bag was modified to fit the Ford Explorer geometry. In addition, in the prototype bumper bag the pressure was 7 bar resulting in improved bag integrity. Also less powerful gasgenerators were used in the mechanical test relative to the gasgenerator used in the mathematical model.

In the crash tests no dummies were used. For geometrical reasons it was not possible to both measure intrusion and include dummies. The intrusion measurements using string potentiometers were considered to be more important than dummy measurements.

The acceleration of the Ford Explorer was not altered by adding a bumper bag. However, in both crash tests, the acceleration was at a very low level exposing an occupant to a minor risk of sustaining an injury.

Generally small improvements in intrusion velocity and intrusion distance were observed for the sill sensor location. The aim of the bumper bag was to load the lower stiff structures of a passenger car in a side impact. Therefore the sill sensor location velocity and intrusion distance was not reduced to a great extent. In addition the velocity of an undeformed location of the Toyota Corolla increased when a bumper bag was used due to the fact that the bumper bag loaded the lower stiff structures.

For the bumper bag generally smaller reductions in intrusion velocity and intrusion distance of the b-pillar of the impacted passenger car was obtained in the mechanical tests compared to the mathematical model predictions. One explanation can be that the support structure was also used in the crash test without the bumper bag. Another explanation can be that the impacted vehicle in the mechanical test was a Toyota Corolla which seems to have stiffer side structures than the Ford Taurus.

The reason for using the support structure in the crash test without the bumper bag was to investigate the influence of only the support structure. Therefore, the reductions in intrusion velocity and displacement can be even greater if the result from a test with a bumper bag is compared to the result with a standard Ford Explorer without support structure for the bumper bag.

In the crash tests carried out the bumper bag was unventilated. The energy absorption of the bumper bag can be increased if ventilation is used. In future analysis the potential improvement of a bumper bag system with ventilation will be evaluated.

The potential injury reducing benefits for an occupant by adding a bumper airbag was evaluated by means of mechanical sled tests. The intrusion velocity from both crash tests, without and with bumper bag, was used to drive the sled in the sled tests (Figure 28).

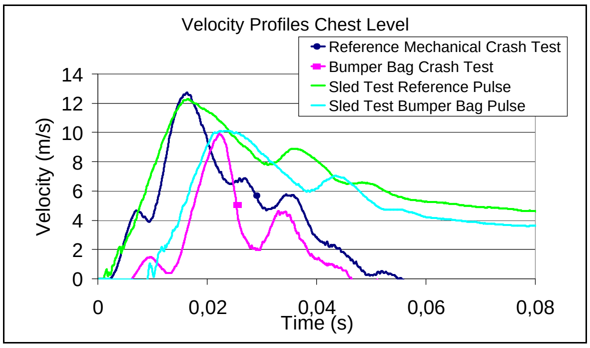

Figure 28
Intrusion Velocity in Crash Tests and Sled Tests

In the sled test a belted ES-2 dummy was positioned in a seat. A rigid wall with 50 mm foam material (Ethafoam 220) with a state of the art side airbag was impacting the dummy (Figure 29).

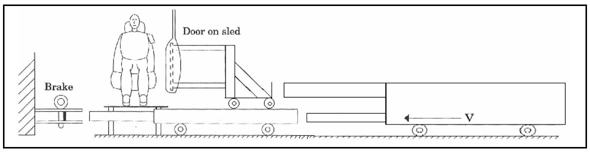

Figure 29
Mechanical Sled Test Set Up

The chest deflection for all ribs was reduced with the bumper bag (Figure 30). For the upper rib the deflection was reduced from 49 to 42 mm. For the middle rib it was reduced from 47 to 37 mm and for the lower rib it was reduced from 42 to 33 mm.

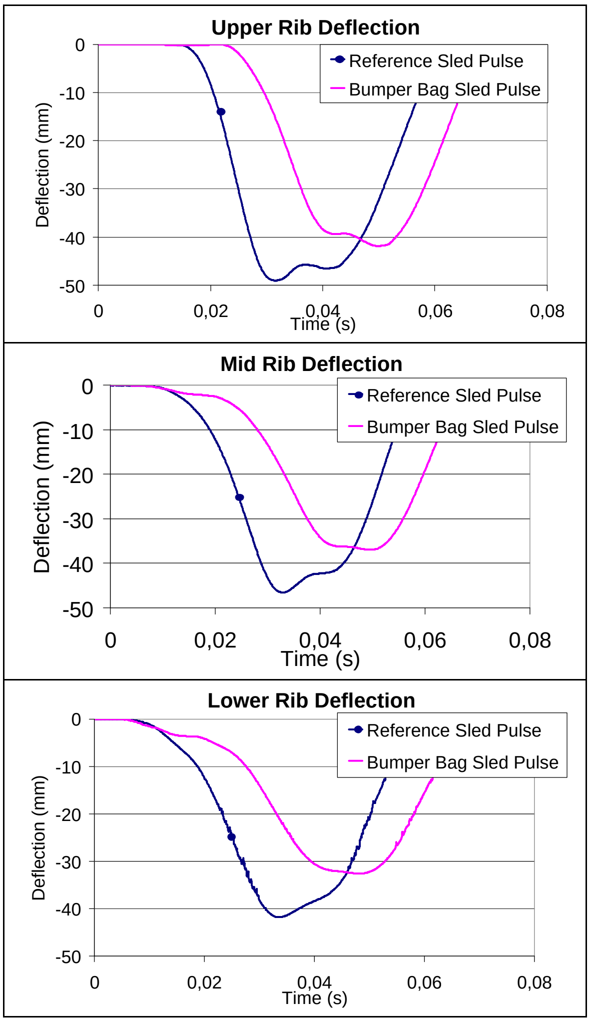

Figure 30
Upper, Mid and Lower Chest Deflection

The sled method used to evaluate the potential occupant injury reductions by using a bumper bag was a simplification of a side impact. The crash pulses used to drive the sled in the sled tests mimicked the corresponding crash pulse up until peak velocity was reached (Figure 28). After peak velocity the curves diverged. The sled velocities remained at a higher level than the velocities from the crash tests. However, the method will serve as an indication of the potential benefits that can be obtained with a bumper bag.

In the pedestrian legform test results there were significant variations in peak bending angle. The reason for the variations was not clear. In the high speed movie a bending angle of 75 degrees, as was measured in the first reference test, was not observed. Therefore the variations are likely to be due to unreliable measurements.

When the bumper bag is used in a pedestrian impact the kinematics of the occupant is altered compared to when the occupant is impacted by the bumper without bumper bag. In future evaluations of the bumper bag system the kinematics of a pedestrian impacted by a bumper bag will be evaluated.

The injury reducing benefits for the lower extremity of pedestrian with a bumper bag is not limited to SUVs. The benefits can also be obtained for a passenger car with a bumper bag.

There are legal requirements (approach angle) for the angle between the bumper structure and the front wheel of an SUV [18]. Mounting a load carrying beam below and in front of the bumper structure, at the same location as an inflated bumper bag, infringes the legal requirements. Therefore, an advantage with the bumper bag is that it fulfills these requirements due to the fact that the bag is located behind the bumper when not inflated. A bumper bag increases the design freedom for the bumper structure of an SUV and also improves the compatibility between an SUV and a passenger car.

For the bumper bag to work properly in a crash it has to be triggered prior to impact. Such triggering systems are now being developed [19 and 20]. They have to be able to reliably trigger irreversible systems such as the bumper bag.

CONCLUSIONS

- A bumper bag reduces the intrusion velocity of the door structure of a impacted passenger car significantly in a SUV to passenger car side impact
- A bumper bag reduces the injury measures for the lower extremity of a pedestrian impacted by a SUV equipped with a bumper bag.

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