BUMPER AND GRILLE AIRBAGS CONCEPT FOR IMPROVED VEHICLE COMPATIBILITY IN SIDE IMPACT: PHASE I

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ABSTRACT

Fundamental physics and numerous field studies have clearly shown a higher injury and fatality risk for occupants in smaller and lighter vehicles when colliding with a heavier, taller and a higher one. The consensus is that the significant parameters influencing compatibility in front-to-side crashes are geometric interaction, vehicle stiffness, and vehicle mass. The objective of this research is developing a concept of deployable bumper and grille airbags for improved vehicle compatibility in side impact. The external airbags, activated by signals from pre-crash sensors, may help mitigate the effect of weight, geometry and stiffness differences and reduce side intrusions. However, a highly reliable pre-crash sensing system is required to enable the reliable deployment, which is currently not technologically feasible.

Analytical and numerical methods and hardware tests were used to help develop the deployable external airbags concept. A simplified spring-mass model was initially developed to set the target for bumper and grille airbags parameters. Finite Element (FE) models of the inflatable structure (bumper airbag) were developed and exercised. Several iterations were executed to help develop the airbags and guide efficient test plans. The concept development was executed and validated in two phases. This paper covers “Phase I” only, which consists of extensive analytical, simulation and test iterations to achieve the inflatable structural system design for integrity and performance on component, subsystem and VIA sled testing levels. Examples of Phase I tasks were: Fabric Material testing and evaluation for ultimate strength and module of elasticity properties; Sewn versus bonded airbag construction technique; Airbag vent types; Overall bumper and grille inflatables and canister design and fabrication; and VIA sled testing to evaluate inflatable design, integrity and performance.

For the initial assessment of the inflatable system, a 48 kph perpendicular side impact of an SUV-type impactor against a stationary passenger car equipped with a US-SID-H3 crash dummy mounted on the sled was executed. Test results in terms of the airbags initial parameters, Head Injury Criteria (HIC), Thoracic Trauma Index (TTI), and Pelvic acceleration for the SID-H3 dummy, with bumper and grille airbags, were compared to those of baseline test results with no external airbags. This Phase 1 of the study was deemed successful in achieving the initial design parameters of the airbags, their integrity and their deployment and successfully staged the research for Phase II. The Phase II research investigated the concept of the inflatables and pre-crash sensing development, and was beyond the scope of this paper.

INTRODUCTION

Vehicle compatibility has been investigated in many studies using different approaches such as real-world crash statistics, crash testing and computer modeling [1-6]. Field data analysis shows that side impacts can be severe, harm-producing crashes, even though they occur less frequently than frontal impacts [7]. In vehicle designs, in general, front-end and side stiffness of vehicles are often inherently incompatible. Therefore, occupants in vehicles, particularly passenger cars, are at more risk when their vehicle (the "Target" vehicle) is struck from the side by another vehicle (the "Bullet" vehicle). The increased risk for the occupant of the Target vehicle results from at least two factors: there is less "crush" space in a side impact, and the "side-impact" stiffness of the Target vehicle, particularly when struck by a high-mounted bumper, is relatively low. This difference is particularly acute when the Target vehicle is a passenger car and the Bullet vehicle is a truck or SUV, since the latter types of vehicle are generally stiffer in the frontal direction, are higher mass, and have high bumpers.

Barbat et. al. [6] investigated the effect of mass, geometry and stiffness on occupant responses in front-to-side impacts using computer simulations. A FE model-based DOE methodology focused on discerning the effects of a few design variables on dummy responses in front-to-side vehicle crash was developed in their study. The striking vehicle was selected to be an SUV while the struck vehicle was a mid-sized passenger car. It was concluded that the geometrical compatibility and interaction were the dominating factors in increasing dummy responses and side intrusions. Dummy responses in side impact are related to the side and B-pillar intrusions and door's inner velocities at the instant when contact with the side impact dummy occurs. The structural stiffness and the energy absorbing capacity at the vertical mid point of the door and above, in which the front-end of the striking SUV interact, are significantly less compared to the stiffness and energy absorbing capacity of the side structure below the vertical mid point of the door and close to the rocker.

In this research, the authors investigated the concept of external airbags on SUVs to mitigate the effect of mass, stiffness and geometrical interaction differences in SUV-to-passenger car side impacts. Some authors of this paper conducted the bumper airbag research in late 1999 and are co-inventors on US granted patents associated with this concept [8-11]. An early investigation of bumper airbag concept for improved compatibility in front and side impacts was conducted by Clark, C. and Young, W. [12-14]. Their work involved two commercial airbags, low pressure and high pressure airbags, built for other purposes. The low pressure airbag was a modified 'pillow bag" bladder bag, made of coated nylon and used commercially for storage of liquids or gases at less than 69 kpa pressure. The high pressure airbag was a Maxiforce KPI 35L Air Lifting bag made of coated Kevlar. Clark and Young [14] carried out two crashes with a 1989 Cutlass Ciera four door sedan equipped with bumper airbags. The first test was a frontal crash into a rigid barrier at 48.5 kph with high pressure (221 kpa, 2.21 bars outboard) and low pressure (20 kpa, 0.35 bars inboard) airbags totaling 84 cm thickness. The airbags were roped together, in a Kevlar sheet attached below the bumper and above the luggage rack on the roof. The low pressure airbag ruptured as expected in the frontal impact and the external airbags system absorbed approximately 19% of the crash energy. The second test was a side impact crash in which a 48.5 kph moving rigid barrier impacted just the 20 cm thick high pressure airbag (76 kpa, 0.6 bars) mounted on the side of the passenger door above the sill, overlapping the side door and centered on the B-pillar. The result of this test was unsatisfactory due to excessive penetration of the airbag into the yielding side structure of the struck vehicle.

The study is focused on concept development of the external bumper and grille airbags for improved vehicle compatibility in side impact, and it consists of two Phases. This paper covers Phase I ONLY, associated with the feasibility study of the external airbags concept. In this Phase, extensive component, subsystem and VIA sled testing were used to help establish the initial airbag design parameters (volume, initial pressure, burst pressure, venting mechanism, chambering, tethering), fabric selection, and construction method. The initial airbag design parameters were optimized through extensive FE simulations and helped develop test methods for preliminary performance evaluation of the concept. A simplified 1-D spring-mass model was developed and used to set up the initial airbag parameters. Results associated with structural intrusion, dummy responses and external airbag parameters, obtained from the VIA sled tests and simulations, are presented and discussed in this paper.

This futuristic external airbags concept requires highly reliable pre-crash sensors for target vehicle recognition and timely deployment of the airbags to minimized false positive triggering. The development of the required sensors has not been addressed in this paper and was beyond the scope of this research. Recently introduced safety features such as curtain airbags in passenger cars offer additional opportunities for improved front-to-side compatibility and traffic safety, but the concept of external airbags may also have potential in mitigating pedestrian injuries.

VEHICLE-TO-VEHICLE SIDE IMPACT PHYSICAL EVENT AND MODEL

Physical event

Stiffness incompatibility between the front-end and the side structures of a vehicle is an outcome of the nature of vehicle designs. Stiffness is only one parameter, in addition to mass and geometry, influencing vehicle compatibility in front-to-side crashes. Generally, higher Bullet vehicle front-end stiffness may cause higher side intrusions in the side of the struck Target vehicle, in a vehicle-to-vehicle side impact. The side structural intrusions in the Target vehicle can be higher when the Bullet vehicle is an SUV/LTV, due to higher front-end stiffness of these types of vehicles as compared to passenger cars. In side impact crash tests, higher dummy responses‘ are related to higher door and B-pillar intrusions and velocities, and in some cases with direct contact of the Target vehicle dummy's head with the intruding structures of the Bullet vehicle. In an SUV/LTV-to-car side impact, the intruding structure of the Bullet vehicle may potentially cause higher dummy responses in the head and thorax area, due to geometrical and mass incompatibility in addition to the stiffness incompatibility.

Therefore, the concept of providing adaptively to the front-end structure of the Bullet vehicle, enabled by reliable pre-crash sensing, has the potential to help mitigate the effect of stiffness, mass and geometrical incompatibility between SUV/LTV and passenger cars in side impacts. Introducing the futuristic bumper and grille external airbags concept on an SUV/LTV may have the potential to help in two ways: first, the bumper airbag may absorb part of the crash energy before the vehicle structures come in contact during a crash tests and second, the grille airbag may have the potential to prevent dummy head contact with the leading edge of the intruding hood of the bullet vehicle.

Spring-mass model

To develop a simplified spring-mass model for setting the initial parameters of the bumper airbag, information about the average stiffness of the vehicle cab in standard front and side impact crash tests is needed. Average longitudinal and lateral vehicle crash pulses with their corresponding step function approximations studied by Barbat et.al., were used [18]. Figure 1 show an average passenger car's lateral acceleration crash pulse measured at the vehicle center of gravity (C.G) obtained from standard tests such as IIHS and FMVSS214 MDB crash tests. The average acceleration of this crash pulse is approximated by an idealized one-step function shown on the same figure [18]. The impact force can be estimated by multiplying the average acceleration by the mass of the vehicle. Similarly, Figure 2 shows a typical average longitudinal crash pulse obtained from the standard frontal impact NCAP crash tests at 56 kph against a rigid barrier. On the same figure, its corresponding idealized two-step function approximation is also shown [18]. The accelerometers location for this average crash pulse was either at the B-pillar at Rocker or at the vehicle C.G. location. The approximated impact force in frontal impact can be calculated by multiplying the average longitudinal acceleration by the vehicle mass.

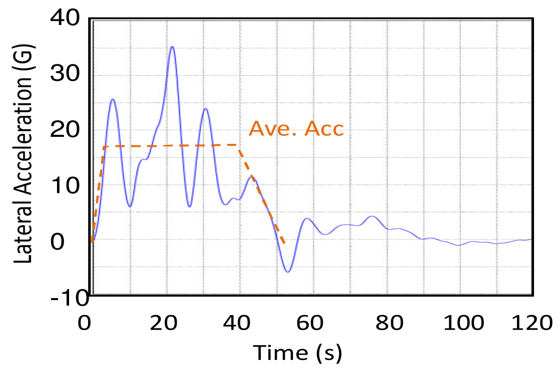


Figure 1. An average lateral acceleration crash pulse of a mid-size passenger car.

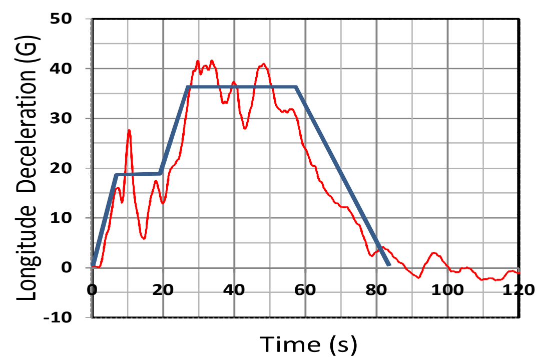


Figure 2. An average of a longitudinal deceleration crash pulse from NCAP test.

For this study, the front-end stiffness of the Bullet vehicle and the side structure stiffness of the Target vehicle were represented by the initial slopes of their idealized pulses. Stiffness differences in vehicle-to-vehicle side impact are shown in Figure 3, in which the stiffness of the striking vehicle is higher than that of the struck vehicle.

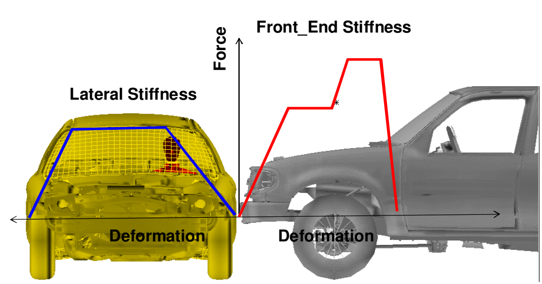


Figure 3. Stiffness incompatibility between the front and side structures.

The initial front-end stiffness of the striking Bullet vehicle can be conceptually adapted by adding an inflatable structure such as external bumper airbag, see Figure 4. The external bumper airbag stiffness can be adjusted through internal pressure and venting to adapt to the level of impact force. The external bumper airbag can decelerate the Bullet vehicle while managing a portion of the impact energy during impact. This will soften the initial structural front-end stiffness resulting in a reduced impact velocity when the structures of both struck and striking vehicles get in contact. In addition, the bumper airbag can help distribute the impact force across a larger contact area of the struck side of the Target vehicle. This can result in reduced local intrusion and reduced potential contact of the dummy with hard points of the intruded metal and trim.

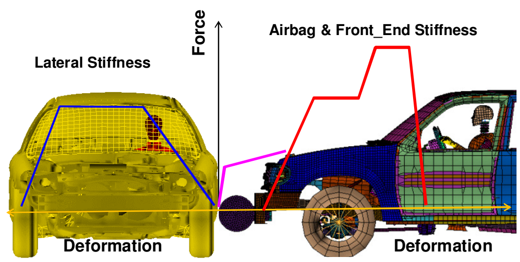


Figure 4. Added bumper airbag stiffness.

Figure 5 provides an illustration of a simplified 1-D vehicle-to-vehicle side impact spring-mass model, in which the striking vehicle is equipped with an external airbag. K1, represents the lateral stiffness of the struck vehicle; K2 represents the longitudinal front-end stiffness of the striking vehicle, and Ka1 and Ka2 represent the stiffness function of the bumper airbag. The C represents the damping coefficient of bumper the airbag.

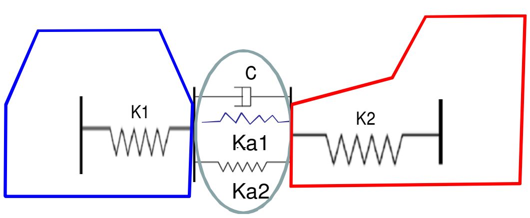


Figure 5. Simplified spring – mass model with bumper airbag.

<u>Spring's coefficient of the bumper airbag</u> The contact force generated by the bumper airbag (F) is defined by airbag pressure (P) multiplied by the effective contact area (A).

$$F = P \cdot A \quad (1).$$

Where, P, is the internal pressure in the airbag, which can be controlled by vent opening; and, A, is the effective contact area in Y_Z plane of the airbag, which varies with airbag deformation. In Eq. 2, the total stiffness of the airbag (K_x) is determined by differentiating the force, F, with respect to x, (dF/dx). Both the pressure, P, and the contact area, A, varies with compression or deformation during impact. Therefore, Eq. 2 can be expressed as:

$$K_x = \frac{dF}{dx} = \frac{d(P.A)}{dx} = A\frac{dP}{dx} + P\frac{dA}{dx} \quad (2).$$

The spring coefficient can be represented in time domain by introducing dx =V dt into Eq. (2).

$$K_x = \frac{A}{V}\frac{dP}{dt} + \frac{P}{V}\frac{dA}{dt} = K_{a1} + K_{a2} \quad (3).$$

Where, V= dx/dt is the impact velocity. The first term in Eq. 3 represents the pressure change with time, while the second term represents the bag contact area change with time.

Determine bumper airbag characteristics

<u>Side structure contact force</u> The initial pressure of the bumper airbag can be calculated from Eq. 1, if the bumper airbag size and the estimated contact force, sustained by the side structure of a passenger vehicle in an FMVSS 214 MDB crash test are given. In the FMVSS214 MDB crash test, the barrier may engage a few major structural components such as the rocker, lower B-pillar, front door and rear door. Jayasuriya and Saha [17] used computer simulations to evaluate the force distributions on the contact area in an FMVSS214 MDB side impact, see Figure 6. The total contact force ranged between 155 ~ 200 KN. This force magnitude was used for the calculations of the bumper airbag pressure.

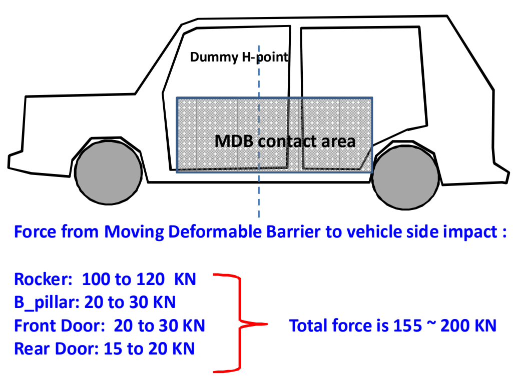


Figure 6. Contact force distribution on the side structure in an FMVSS214 with MDB.

Bumper airbag's initial pressure As shown in Figure 7, during the initial contact of the airbag to the side structure, the airbag only makes contact with the doors and B_pillar, no contact with rocker. The estimated contact force for the doors and B_pillar is between 55 KN and 80 KN, see Figure 6. The doors and B_pillar will only start to deform when the initial force exceeds 55 KN. If the diameter and length of the circular cylindrical airbag are 0.37 m and 1.22 m, respectively, then the airbag's effective contact area is 0.50 m^2. The initial pressure, P, of the bumper airbag is calculated by Eq 1 to be 110 KPa.

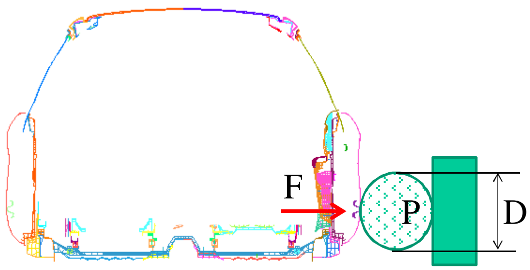


Figure 7. Initial contact of the bumper airbag to the side structure.

Maximum airbag pressure The bumper airbag contact area increases, and may engage the rocker, as the deformation of the airbag increases. As the contact area increase the load distribution will be more uniform and the contact force increases by engaging the rocker, which can sustain a higher impact load compared to other side structural components. The total side impact force, calculated from the major contact structures was ranging between 155 KN to 200 KN (see Figure 6). These calculations were made based on the contact area of the FMVSS214 MDB face. Since the contact area of the bumper airbag, suggested for this study, is smaller than that of the deformable barrier face, a contact force ranging between 80 KN and 100 KN, was chosen in this study.

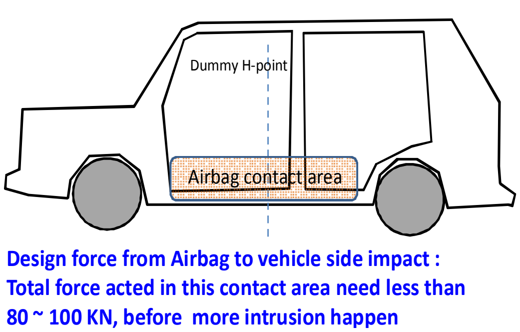


Figure 8. Bumper airbag design force and pressure.

It is assumed that the cross section of the airbag across the length does not change and the vent pressure can be controlled between 160 KPa and 200 KPa.

Stiffness change with airbag deformation

Eq. 2 states that the total airbag stiffness (Kx) changes as the cross sectional area of the airbag changes with deformation (dA/dx). A simple model was constructed to calculate the section change as a function of deformation x (see Figure 9). It was assumed that the circular cross sectional airbag will progressively deform into elliptical cross sectional airbag.

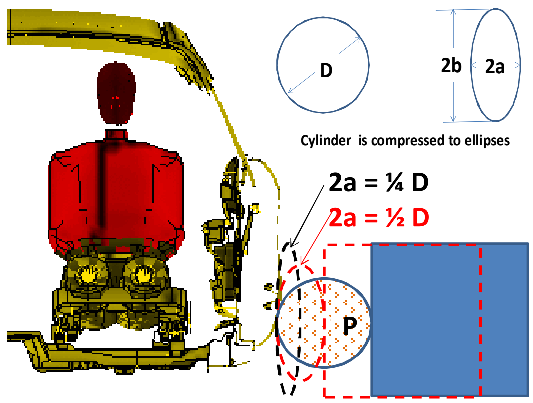


Figure 9. Circular section airbag deformed into elliptical section airbag.

In Figure 9, "D" represents the initial diameter of the circular cross section of the airbag. If the stretch of the fabric is ignored during bags pressurization, then the original perimeter of the airbag cross section (π D) remains constant during the progressive deformation and compression of the airbag.

The circle perimeter is (πD) ;

The elliptical perimeter is $2\pi\sqrt{\frac{a^2+b^2}{2}}$;

where, "a" and "b" represent the minor and major radii of the ellipse, respectively.

$$\pi D = 2\pi\sqrt{\frac{a^2+b^2}{2}} \qquad (4).$$

If the minor radius of the elliptical section "a" is expressed as a function of "D" then the major radius "b" of the elliptical section can be solved as a function of "D", using Eq. 4. The progressive contact area (2 b * L) and the total contact force can be calculated, see the relationship of the bag deformation with the force in Figure 10. Example, if the airbag is compressed to ½ D (2a = ½ D) the major diameter of the ellipse 2b=1.33 D. If the pressure and L (length of the airbag across the width of the vehicle front end) are kept constant, the contact force becomes 1.33 times the initial contact force.

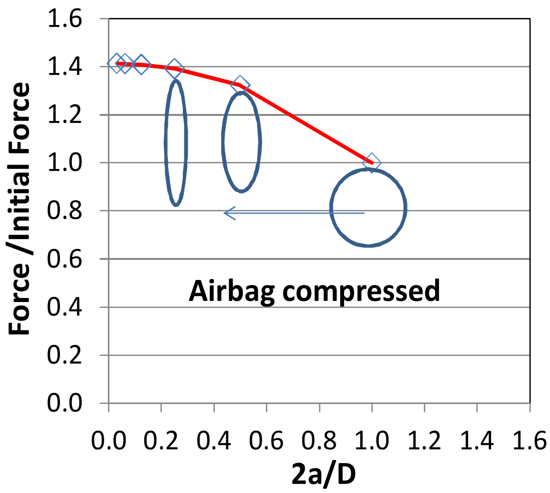


Figure 11. Variation of total contact force with airbag deformation.

EXTERNAL AIRBAG DESIGN

Analytical models, finite element models, and hardware testing were used during all stages of the external airbag development. Significant number of iterations was executed, starting with fabric material selection and ending with the concept readiness demonstration. Examples of Phase I hardware testing conducted to guide the structural integrity of the bags and the pyrotechnic inflation system to meet the targeted collision severity reduction and deployment requirements are listed below:

- Fabric material testing and evaluation (ultimate strength, modulus of elasticity, ability to package)
- Construction technique (sewn versus bonded bags)
- Seam Type evaluation (a solid baseline of double needle chain stitch with spectra 138 thread)
- Overall inflatable structure and canister design and fabrication
- Energy management features (burst type vent ports)
- Component Testing (fabric, fabric with seams, burst type vent, performance under approximate loading and boundary conditions with parallel rigid plates)
- Sled testing (evaluate inflatable design with a moving impactor approximation)
- VIA sled testing (evaluate inflatable design, integrity and performance on pre-inflated bags mounted on an SUV-type sled impacting a stationary passenger car in perpendicular side impact at approximately 48kph)

SLED TEST TO EVALUATE INFLATABLE SYSTEM PERFORMANCE

In an attempt to evaluate fabric integrity, vent performance, and prove out the inflatable system, sled tests were designed and executed. The sled test setup, shown in Figure 12, consisted of a moving Bullet sled of 1994 Kg with two aluminum honeycomb blocks, mounted on its front face, and a stationary Target sled that has a sliding carriage to simulate door crush with honeycomb. On the Bullet sled, the honeycomb block at the top is to interact with the grille airbag while the bottom one is to interact with bumper airbag. Both folded airbags are mounted on the stationary target sled. The Bullet sled impacted the stationary one at an impact speed of 48 kph.

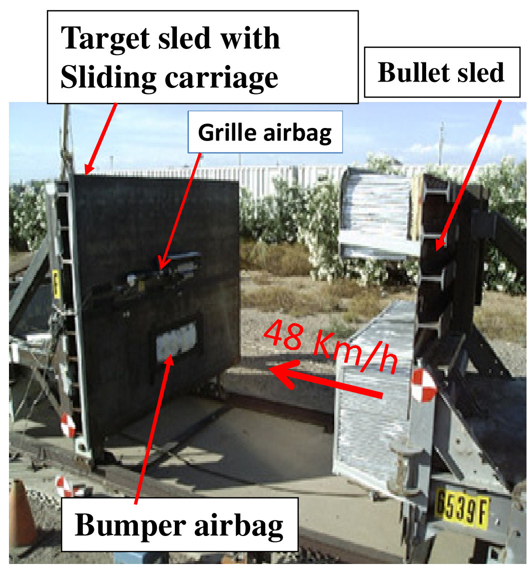


Figure 12. The sled setup.

The lower honeycomb block has a crush strength of 321 KPa and is the same as that of the standard NHTSA FMVSS-214 side impact MDB, without bumper structure. The dimensions of the lower honeycomb block were 127 cm width, 56 cm height and 38 cm depth. The upper honeycomb block had a crush strength of 178 KPa and dimensions of 127 cm width, 30 cm height and 38 cm depth.

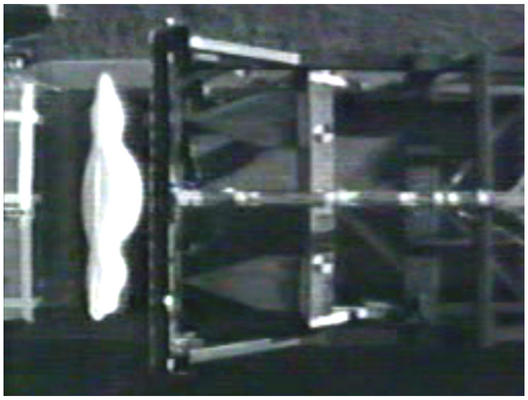


Figure 13. Top view of the real time grille airbag deployment.

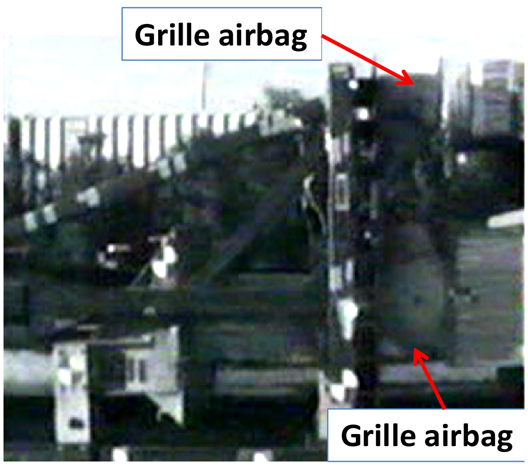


Figure 14. Side view of the real time airbag deployment.

Three tests were conducted, one baseline test with no airbags and two tests with airbags of different venting mechanisms, a discrete open vent design and a rupture disk vent design (disk ruptures at a pre-set pressure range).

Sled test results

Baseline test This test did not have any airbags mounted on the sliding carriage of the Target sled. Although this test did not have any inflators, the Trip-Stick mechanism was included to check for accuracy of ability to fire inflators at a certain time (flash bulbs were utilized to measure this data). The Trip-Stick was located such that the distance between the front face of the honeycomb blocks and the flat surface of the sliding carriage was 175 cm.

Inflatables test with bumper and grille airbags The circular cylindrical bumper airbag and the grille airbag canister assemblies were mounted on the sliding carriage. The discrete open vent and rupture disk vent airbags were used in the tests. The same grille airbag was used in both tests. The circular cylinder bumper airbag was compressed 100%. The peak pressure in the discrete open vent reached 350 KPa and the peak pressure in the rupture disk vent case was 286 KPa. The airbag integrity was maintained. The sliding carriage relative velocity curves of the test with an airbag with discrete open vent and the baseline test are shown in the Figure 15. The sliding carriage relative velocity curves of the test with an airbag with rupture open vent and the baseline test are shown in the Figure 16. Comparing the relative velocity of the three tests, the bumper airbag with rupture disk vent yielded the lowest relative speed for the sliding carriage. The test with rupture disc vented airbag absorbed more energy during the impact. Figures 17 and 18 show the variation of the airbag pressure versus the airbag compressing time for both venting mechanisms.

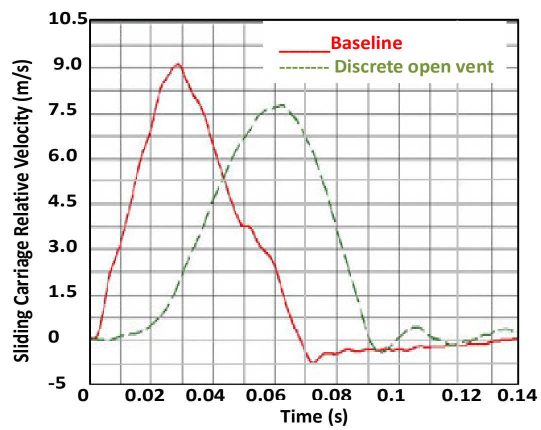


Figure 15. Sliding carriage relative velocity of baseline vs. discrete vent airbag.

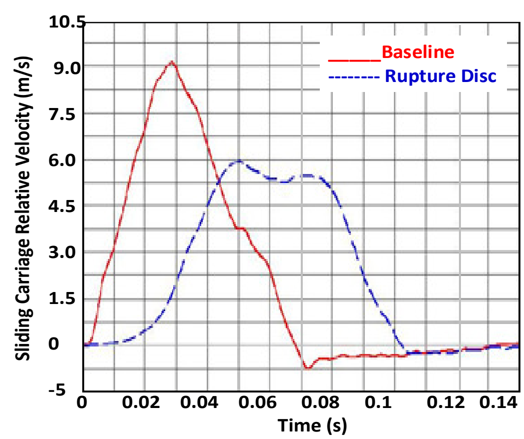


Figure 16. Sliding carriage relative velocity of the baseline vs. rupture disc airbag.

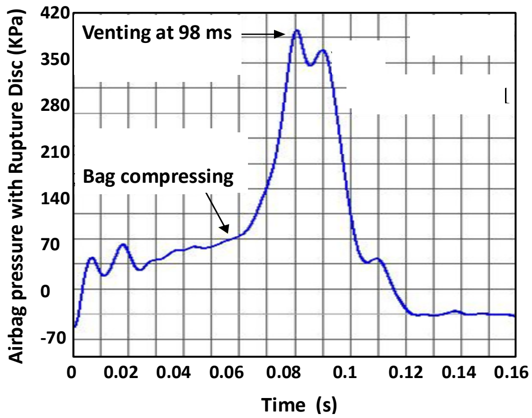


Figure 17. Pressure curve of the rupture disk vent airbag test.

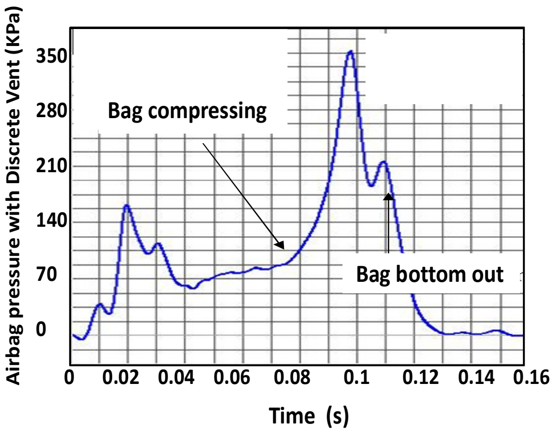


Figure 18. Pressure curve of the discrete disk open vent airbag test.

SIDE IMPACT VIA SLED TEST AND CAE MODEL DEVELOPMENT

In order to develop a successful and efficient test plan, FE models of the inflatable structure (bumper airbag) mounted on a test buck impactor were used. The models were validated with tests and used to set up the initial parameters of the inflatable system and to help optimize airbag and inflator parameters to achieve the intended targets. The airbag shape and design parameters were determined in Phase I and carried over to Phase II (subject of another paper) for further refinements. As a result, the initial bumper airbag system's specification developed in Phase I and to be used in Phase II for further refinement are as follows: 122 cm long untethered circular cylinder shape bumper airbag with initial pressure of 105 KPa, peak pressure of 186 KPa, and vent pressure of 106 KPa; bumper face in which the airbag canister was mounted at its center was a 40 cm high and acted as a reaction surface to prevent the airbag rolling back.

SUV-Type impact buck

Figures 19 shows the developed SUV-type impactor mounted on the VIA sled with the bumper and the airbag module. The bumper face was extended to provide a reaction surface for the deployed airbag. The Bullet vehicle had a mass of 1825 kg and was a rigid construction so it could be used for multiple tests but with the capability to replace the hood for each test. Figure 20 shows the bumper and grille airbag module housed in the extended bumper. A finite element model for this impactor, including the airbags and module, was also generated for the FE analyses, see Figure 21.

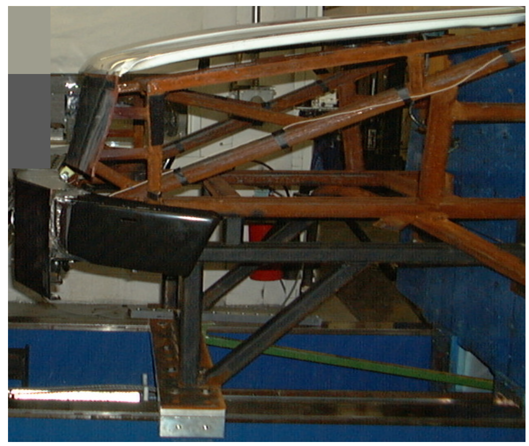


Figure 19. SUV-type buck on the VIA sled.

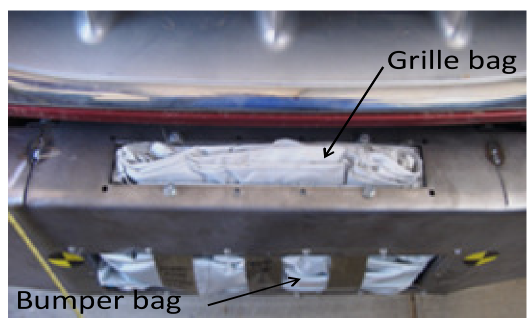


Figure 20. Housed airbags module.

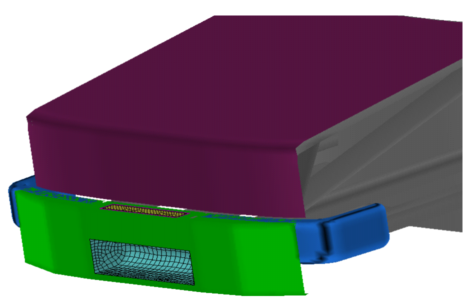


Figure 21. CAE model of the bullet buck.

VIA sled test-setup

Figure 22 shows the VIA sled experimental set-up for evaluating the external airbags concept in side impact. It can also be used for baseline testing in which the striking buck has no external airbags. The stationary Target vehicle used in this VIA sled series was a mid-size sedan. The bullet vehicle was simulated by an SUV-type rigid buck mounted on the sled that can be given an initial velocity to impact the Target vehicle. The buck had a rigid vertical plate attached to the front bumper beam. The inflatable structure (airbags) and the inflator(s) were integrated into a mechanical module or canister packaged through an opening at the center of this rigid plate. This plate is also used to act as a reaction surface for the bumper airbag to enhance stability and performance and to prevent the airbag from rolling under and behind the bumper beam.

Figure 22. VIA sled side impact test set-up .

The Target vehicle contained a belted, instrumented SID-H3 dummy for the driver. The driver seat was at the mid-position and the driver airbag was not activated. The Target vehicle and the Bullet Buck weights are listed in Table 1. Accelerometers were mounted at the armrest to calculate door velocity at discrete locations. Two types of bumper airbag venting mechanisms, rupture disc and discrete, were used in sled tests (see Table 1).

Table 1.
Test set-up characteristics

		BASELINE	RUPTURE DISC	DISCRETE VENT
Buck Speed	Km/h	48	48	48
Target Speed	Km/h	0	0	0
Buck Weight	Kg	1825	1833	1826
Target Weight	Kg	1818	1805	1803

Finite element model of the VIA sled test setup

Reliable finite element models of the passenger vehicle were required to enable reasonable predictions of structural performance. In this study, the passenger vehicle model was the same as that used by Barbat et. al. [6], in their CAE-based methodology analyses of front-to-side vehicle-to-vehicle impact. This FE model was constructed and correlated to physical FMVSS 214 and vehicle-to-vehicle front-to-side crash tests.

FE models were developed and side impact simulations were executed to guide the test plan and provide an initial performance assessment of the inflatables devices. Figure 23 shows the initial set-up of the FE model simulating a 48 kph perpendicular impact of the SUV-type rigid buck, with mounted bumper and grille airbags, against a stationary mid-sized passenger car equipped with the SID-H3 dummy in the driver seat. FE models of the inflatable structure (external airbags) were also developed and an extensive number of iterations was executed to ensure their validity before executing the side-impact VIA sled simulations. In the simulation, the airbags were pre-inflated, deployed and in position prior to contact with the target vehicle. The buck construction was modeled as rigid material, because no deformation in the buck was observed in the baseline (no airbags) impact test against a passenger car at 48 kph. The reaction plate in which the airbags were mounted was modeled with elastic shell elements (Poisson's ratio of 0.3, Young's modulus of 200 GPa).

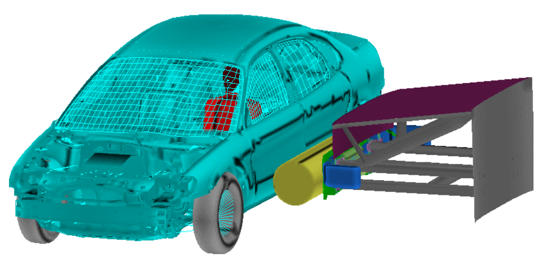


Figure 23. CAE model of VIA sled test simulation.

VIA SLED TEST AND RESULTS

The main purpose of this test series was to evaluate the bumper and grille airbag prototype assemblies for their capability to deploy the inflatable device and absorb energy in a simulated vehicle-to-vehicle collision using VIA sled. The VIA sled results obtained from the buck impacting the side of the 4-door passenger car, both mounted on the sled, verified the bumper and grille' airbags deployment times, venting mechanisms and time, coverage and integrity. The bumper airbag had initial pressure of 105 KPa, peak pressure of 172 KPa, and a 150 mm diameter rupture disc vent. The grille airbag had an initial pressure of 3.44 KPa, and no vents. The airbags were instrumented with pressure transducers and were fully inflated prior to the tests. The dimensions of the circular cylinder airbags were 36.8 cm diameter and 122 cm length. Bumper airbag's deployment characteristics were deemed acceptable and the bumper airbag was compressed 90 - 95%. Bumper airbag integrity was maintained with no tears. Bumper airbag peak pressure reached 243 KPa, lower than expected. Grille airbag peak pressure reached 4.3 N/cm^2, as expected. In the test, the pre-deployed bumper airbag contacted the vehicle side at the right location, (see Figure 24 (a) and (b)).

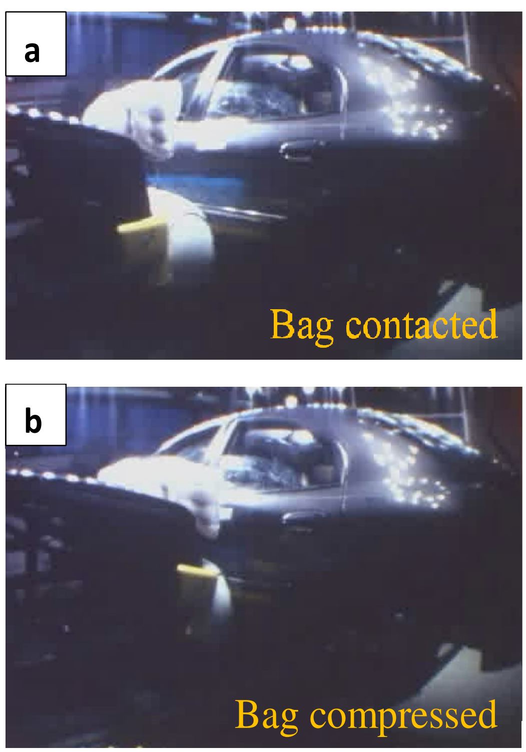


Figure 24 Bumper and grille airbag contact locations.

The grille airbag helped prevent the dummy's head from contacting the leading edge of the buck's hood (see Figure 25). The bumper airbag did not achieve the desired performance in terms of dummy responses, intrusions, and door velocity reductions. It was believed that further refinements for the bumper airbag design parameters and reaction surface design is required to achieve the desired outcome. However, the intent of the test and the current results met the objective of Phase I. Further refinements in the design of the airbags, reaction surface, and packaging are the subject of Phase II research.

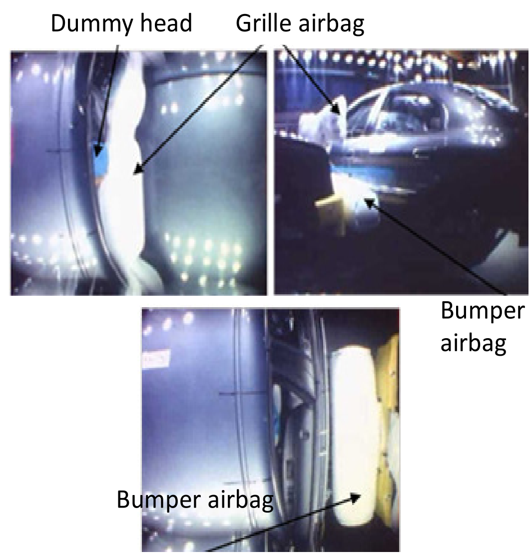


Figure 25. External airbags' interaction with vehicle structure and dummy head.

Model validation

Figure 26 shows the FE model that was exercised in a 48 kph side impact against a four door sedan simulating the VIA sled testing condition. Figure 27 shows an example of section taken through the dummy H-point, pointing out the importance of such models to better understand the external airbags' interactions with the dummy head and vehicle structure. For instance, Figure 27 shows how the bumper airbag provides a larger contact area with the vehicle side structure when it compressed.

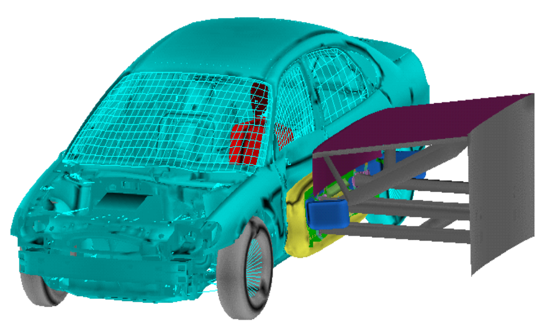


Figure 26. The CAE simulation of VIA sled test.

FE models allow for intrusions measurements and to a better understanding of the impact force distribution over a bigger contact area during the impact. The VIA sled test data and results were used to further validate the model to be used in Phase II to optimize the performance of the inflatable devices and help guide the conceptual design.

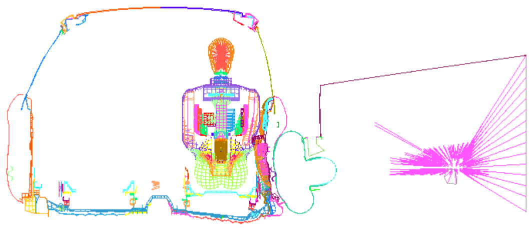
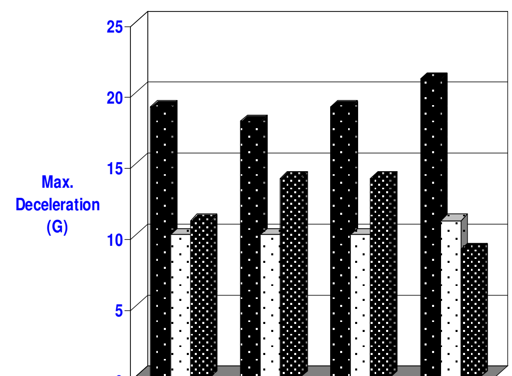


Figure 27. Section of the VIA sled simulation during impact through dummy H-Point.

Discussion of results

Bumper airbag effect on bullet and target decelerations Figure 28 shows the maximum deceleration measured at various locations of the bullet buck's bumper, buck's C.G. and the carrier. Data collected represented those of the three tests: baseline test with no external airbags, test with discrete vented bumper airbag and test with rupture disc vented bumper airbag.



	Max. Decl @Buck	Max. Decl @Right Bumper	Max. Decl @Left Bumper	Max. Decl @Carrier
BASELINE	19	18	19	21
RUPTURE DISC	10	10	10	11
DISCRETE VENT	11	14	14	9

Figure 28. Maximum deceleration at various striking buck locations.

When the striking buck contacted the Target passenger car, the B-Pillar and the body side of the Target vehicle quickly accelerated to match the velocity of the striking bullet. The test with the rupture disc bumper airbag reduced the maximum deceleration of the striking buck by approximately 50%, compared to baseline results. The Target vehicle's accelerations were also reduced with the use of bumper airbag compared to those of the baseline (Figures 29 and 30). In these tests, the conceptual bumper airbag managed to absorb part of the impact energy and reduced the impact forces.

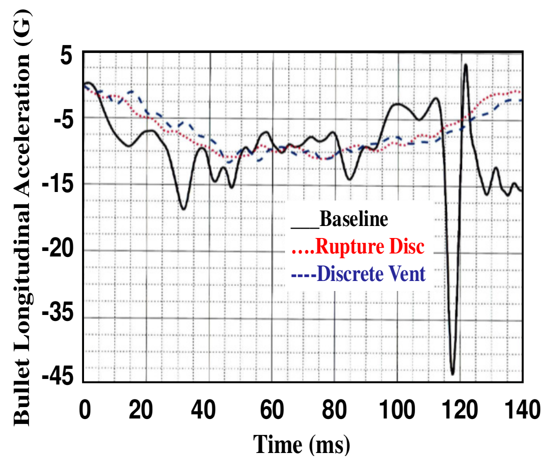


Figure 29. Deceleration time-history curves of the striking buck.

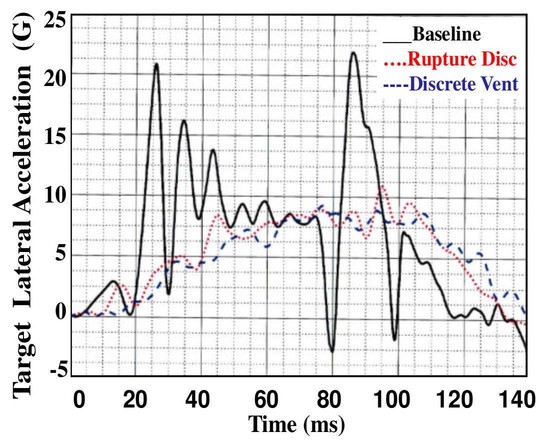


Figure 30. Deceleration time-history curves of the Target vehicle.

Bumper airbag effect on armrest lateral velocity The acceleration pulses at the armrest location, collected during the VIA sled test, were integrated to obtain the lateral velocity at that location. The results of the armrest lateral velocities obtained from impacts by the bullet buck with and without external airbags are presented in Figures 31 to 33. The test with the rupture disc bumper airbag provided lower lateral velocity on the armrest compared to the other tests.

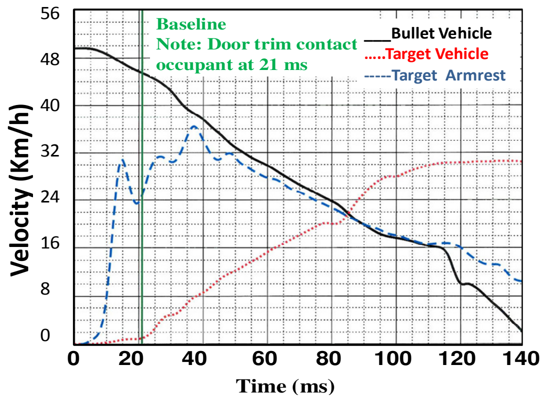


Figure 31. Armrest lateral velocity in the baseline test with no bumper airbag.

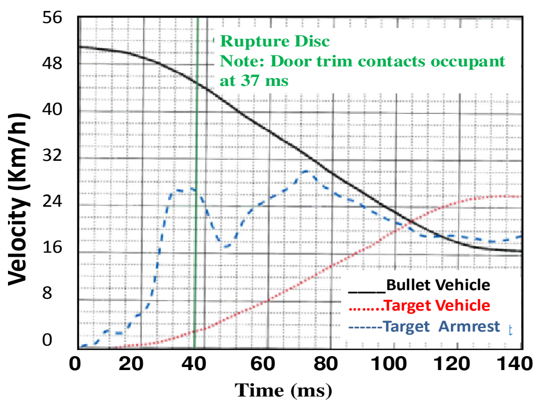


Figure 32. Armrest lateral velocity in the test with rupture disc vent bumper airbag.

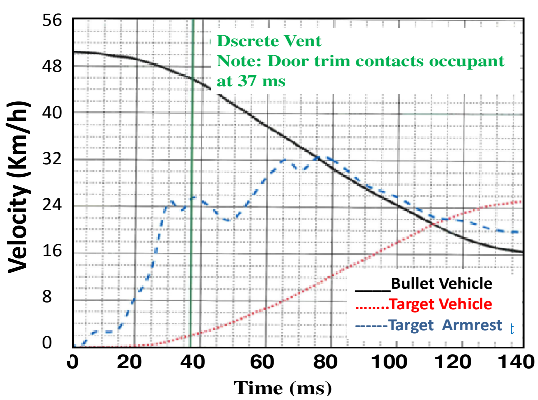
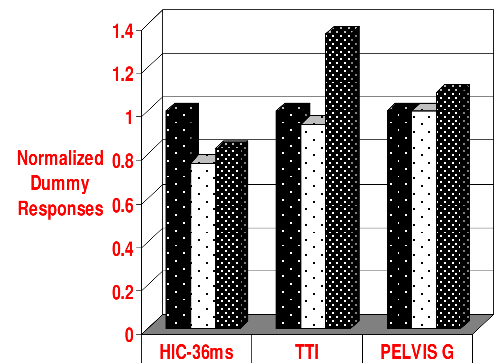


Figure 33. Armrest lateral velocity in the test with discrete vent bumper airbag.

__Bumper airbag effect on selected dummy responses__ The effect of the bumper and grille airbags concept on SID-H3 responses is shown in Figure 34. The selected Head Injury Criteria (HIC), Thoracic Trauma Index (TTI), and Pelvic acceleration (G) were normalized by their corresponding values obtained from the baseline test with no external airbags. The rupture disc vent type of bumper airbag and the grille airbag reduced the HIC by 24% and the TTI by 6%, but did not improve the Pelvis response. In the case of the discrete vent type of bumper airbag, a negative impact was observed on the TTI and Pelvis responses while it provided a 17% reduction in the HIC value. This consistent trend shows that for the design considerations in the next Phase II of the study the venting mechanism of the bumper airbag will be that of the rupture disc type. However, at the same time results pointed out that there are other important considerations that need to be taken into account in addition to the airbag design.



	HIC-36ms	TTI	PELVIS G
BASELINE	1	1	1
RUPTURE DISC	0.76	0.94	1.00
DISCRETE VENT	0.83	1.35	1.08

Figure 34. SID-H3 dummy responses in the target vehicle.

Altering the bumper airbag height was not considered in this test series. FE simulations indicated that aligning the bumper airbag more with the rocker, which is a major load path in side impact, may have the potential to provide further enhancement in the reduction of dummy responses and structural side intrusions. This task was deferred to Phase II in which a new design of the airbags, reaction surface and heights for rocker alignment were considered and are presented in a different paper.

CONCLUSION

- Analytical, numerical, and hardware testing methods were successfully developed and used to help set the initial design parameters for the external airbags concept
- Simplified spring-mass models were developed to set the bumper and grille airbag stiffness targets
- Computer simulations and physical testing were conducted on component, subsystem and sled testing levels to evaluate the performance of inflatable bumper system concept

- The following tasks were successfully achieved:
  - Fabric material testing, evaluation and selection
  - Inflator selection for bumper and grille airbag inflation
  - Airbag sewn construction technique and seam type evaluations
  - Design and fabrication of overall inflatable structure and canister
  - Component testing and simulations under approximate loading and boundary conditions with parallel rigid plates
  - Sled test with 48 kph striking Bullet sled against a Target sliding sled to evaluate the conceptual inflatable bumper design, integrity and vent type performance
- VIA sled test performance evaluation indicated that the rupture disc provided better performance related to energy management and reduced dummy responses
- The concept design of the initial prototype bumper and grille airbags was successfully demonstrated through a remote deployment in a VIA sled of an SUV-type buck-to-Passenger car perpendicular side crash tests at 48kph
- Head Injury Criteria (HIC), Thoracic Trauma Index (TTI), and Pelvic acceleration of the SID-H3 dummy were used as performance metrics for the bumper and grille airbags
- Bumper and grille external airbag FE models and a sled test to evaluate performance were developed
- The Phase I VIA sled test identified the areas of research for Phase II: designing a more efficient reaction surface, considering airbag chambering for stability, engaging the bumper airbag with the rocker, and further tuning of airbag parameters
- This research provided lessons learned and help set direction for future research and development of external airbags
- However, there are major limitations which may hinder making this concept production feasible such as packaging of the airbags, inflators, reaction surface. Most importantly, the airbag deployment is irreversible and requires very reliable and robust pre-crash sensors in all weather conditions and day or night. Currently, these types of pre-crash sensing systems are not available for the automotive environment
- An additional requirement is that the bumper airbag system functions in a frontal barrier impact and does not compromise any other FMVSS 208 test results

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REFERENCES

[1] Hollowell, W.T. and Gabler, H.C.; "NHTSA's Vehicle Aggressivity and Compatibility Research Program", 15th ESV Conference, Paper No 96-S4-O-01, Melbourne, Australia, 1997.

[2] Summers, S., Hollowell, T., Prasad, A.; "NHTSA's Research Program for Vehicle Compatibility", 18th ESV Conference, Nagoya, Japan, 2003.

[3] Arbelaez, R. B., Baker, B. C., Nolan, J. M.; "Delta VS for IIHS Side Impact Crash Tests and Their Relationship to Real World Crash Severity", 19th ESV Conference, Paper 05-0049, 2005.

[4] Nolan, J., Powell, M., Preuss, A., and Lund, A.; " Factors Contributing to Front-Side Compatibility: A Comparison of Crash Test Results", Stapp Conference, 99SC02, 1999.

[5] Lugt, D.V., Connoly, T., and Bhalsod, D.; "Vehicle Compatibility – Analysis of the Factors Influencing Side Impact Occupant Injury", SAE 1999-01-0067, 1999.

[6] Barbat, S., Li, X., Prasad, P.; " Front-To-Side Crash Compatibility Analysis Using A CAE Based Methodology", 20th ESV Conference, Lyon, France, Paper 07-0347, 2007.

[7] Gabler, H.C.; "The Evolution of Side Crash Compatibility Between Cars, Light Trucks and Vans", SAE Paper 2003-01-0899, 2003.

[8] US Patent No. 7, 036, 844, "Bumper Airbag with Multiple Chambers".

[9] US Patent No. 6, 923, 483, "Bumper Airbag and System".

[10] US Patent No. 6, 950, 014, "Method for Operating a Pre-Crash Sensing System in a Vehicle Having External Airbags".

[11] US Patent No. 6, 757, 611, "Adaptive Safety System for a Bumper-Bag Equipped Vehicle".

[12] Clarke, C.; "The Crash Anticipating Extended Airbag Bumper"., 14th ESV Conference, 1994.

[13] Clarke,, C., William, Y. A.; "Airbag Bumper just Inflated Before the Crash", SAE Conference, Paper 941051, 1994.

[14] Clarke, C., William, Y. A.; "Car Crash Theory and Tests of Airbag Bumper Systems", SAE Conference, Paper 951056, 1995.

[15] Barbat,S., Li, X., and Prasad, P.; "Bumper and Grille Airbags Concept for Improved Vehicle Compatibility in Side Impact: Phas II", 23th ESV Conference, Paper 0140. 2013.

[16] RADIOSS Crash Code, Altair.

[17] M. M. Jayasuriya & N. K. Saha, "Local structural force evaluation of a vehicle in side barrier impact", International Journal of Crashworthiness, 2005 Vol. 10, No 5 page 451.

[18] Barbat, S., Mehall, M., Nayak, R., Nusholtz, G., S., Olds, N., Shi, Y, Stanko, B., Wang, J., T., Weerappuli, P., Xu, L., Yalamanchili, K.; "Idealized Vehicle Crash Test Pulses for Advanced Batteries"; SAE conference, paper 2013-01-0764, 2013.