

IMPROVEMENT OF GAS FLOW IN AIRBAG SIMULATION FOR OOP TEST

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ABSTRACT

In the development of driver airbags (DABs), the out-of-position (OOP) test is important in reducing the risk of injury to occupants close to airbag modules. Airbag deployment simulations are valuable in predicting occupant protection in the development and design stages. One of the key elements of airbag deployment behavior is the behavior of gas jets from the inflator. Here, we conducted visualization experiments using the Schlieren method to understand the gas flow behavior of disk-type inflators. Gas flow from an inflator with a retainer showed strong directivity. Gas flow simulations were conducted with a general-purpose finite element program, LS-DYNA. Using the corpuscular particle method (CPM), in which jet direction and cone angle of gas diffusion were essential elements, gave good reproducibility. We compared simulations with experiments of DAB deployment behavior and analyzed the effect of gas flow on deployment behavior. By implementing actual gas flow in the CPM, we improved the accuracy of airbag simulation using DAB OOP positions 1 and 2 as demonstrators. The reproduction of gas flow was a major factor in the reproduction of DAB deployment behavior.

INTRODUCTION

The simulation of airbag deployment is an important and efficient approach to evaluating the occupant protection performance of driver airbags (DABs). The first approach developed, in 1988, was the uniform pressure method, which calculates pressure from the mixed-jet gas properties of the inflator and applies an equation of state inside the airbag. This method can evaluate the energy absorption by an airbag and was used for the analysis of occupant protection in combination with kinematic analysis.[1] However, since the uniform pressure method does not consider gas flow, it cannot accurately determine some aspects of airbag behavior and energy absorption in deployment. To overcome these deficiencies, the Arbitrary Lagrangian–Eulerian (ALE) fluid and structure coupling method was introduced in 2002.[2] But in the analysis of airbag deployment, the ALE method requires enormous computational resources and cost to represent the deployment of the folded airbag.[3]

So a new method—the corpuscular particle method (CPM)—was implemented in 2007 in LS-DYNA, a general-purpose finite element analysis program, to replace gas flow with particle movement. CPM does not treat gas as a continuum but instead calculates gas molecular dynamics, replacing the overall trans-

lational kinetic energy with the equivalent number of particles rather than modeling gas molecules.[4, 5] In CPM, it is not necessary to discretize the entire space as in the ALE method, so deployment can be simulated with mid-range computers. CPM was able to predict deployment behavior and impact force for gas flow in a narrow tube, such as in a curtain airbag.[6] It is now used in product development. However, in our tests comparing actual DAB out-of-position (OOP) tests with simulations shows differences in injuries to dummies. We suspected that a major factor in these differences was the DAB deployment force caused by deployment behavior, which we ascribed to gas flow behavior in the airbag. So to understand gas flow, we visualized gas flow from the inflator using the Schlieren method.[7, 8, 9] Although a previous study observed gas flow inside the inflator,[10] to our knowledge, no attempts have been made at observing the gas flow outside the inflator.

Here, we conducted gas flow visualization experiments and reproduced gas flow by CPM. We used the results to simulate DAB deployment and OOP, and show that the deployment behavior was improved and reproduced well.

METHODS

Visualization by Schlieren Method

To understand the gas jet flow from the inflator, we conducted visualization experiments using the Schlieren method in open air.[11] Inflator gas comprises carbon dioxide, nitrogen and water vapor, which are clear and colorless, so gas flow cannot be seen directly. Therefore, we used a method that captures density change as refractive index change. In the experimental apparatus (Fig. 1), light from a point source is made parallel by a parabolic mirror. The inflator gas is ejected into the light beam, which is condensed again by another parabolic mirror. Light defocused by differences in refractive index is removed by an iris at the focal point, and images of the difference in light contrast are recorded on a high-speed camera. Although the Schlieren method generally uses a knife edge to remove the defocused light, we used an iris, as the gas diffuses radially. Our apparatus used the world's largest class of parabolic mirrors, with a diameter of 1 m and a focal length of 8 m.

We recorded the gas flow from DAB inflators with and without a retainer to redirect gas flow for quick deployment and to avoid heat damage to the airbag fabric, and compared the results.

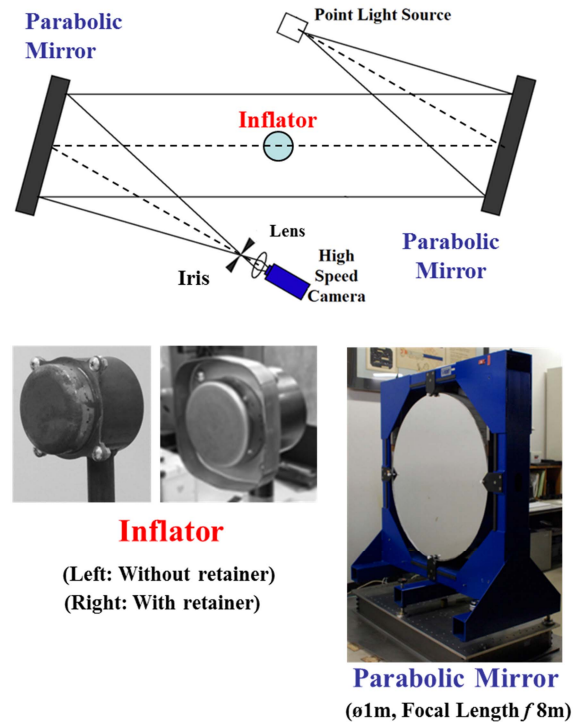


Figure 1. Gas flow visualization apparatus for Schlieren method at Tohoku University.

Simulation of Inflator Gas Flow

We simulated gas flow with and without a retainer using CPM in LS-DYNA to reproduce the observed flow. We optimized seven CPM parameters to best reproduce the gas flow (Table 1).

Table 1.
Parameters for gas flow simulation

Parameter	Without retainer	With retainer
Initial direction of gas inflow	Radial	Axial
Cone angle from orifices	16°	16°
Friction factor	0	0
Dynamic scaling of particle	Inactive	Inactive
Initial gas inside bag	CPM	CPM
Number of orifices	16	16
Number of gas components	Mixed	Mixed

Observation of Airbag Deployment

We observed the static deployment behavior of DABs (Fig. 2) in experiments using an unfolded, untethered airbag with a flow control cloth to redirect the gas flow from the inflator (Fig. 3).

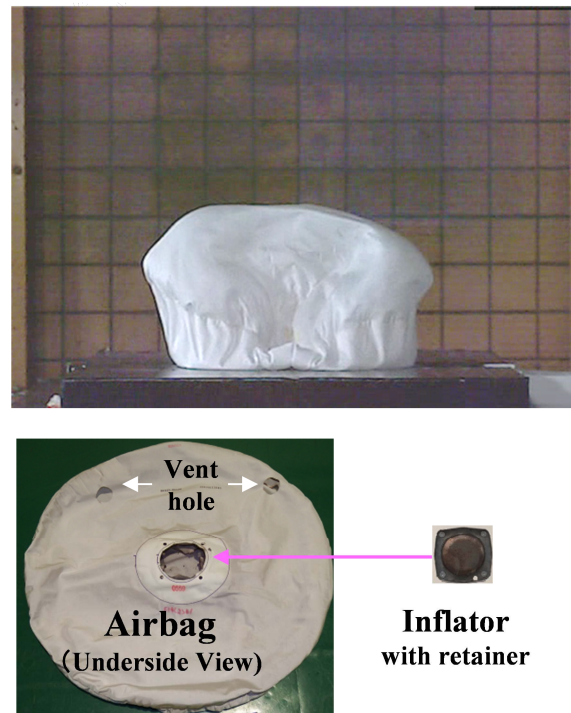


Figure 2. Experimental apparatus and setting of airbag deployment.

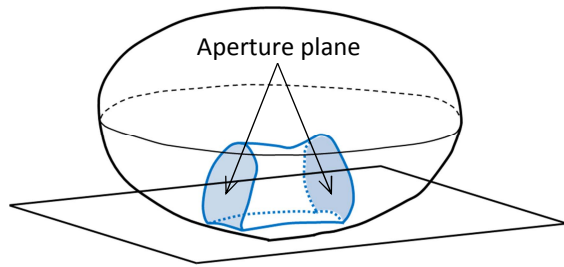


Figure 3. Flow control cloth (blue line) in DAB and its aperture planes.

Simulation of Airbag Deployment

The airbag deployment shown in Figure 2 was simulated by CPM with and without flow direction set at the aperture plane of the flow control cloth and the optimized conditions in Table 1. The reproduction of gas flow was compared with actual airbag deployment.

With the retainer, the jet direction was set in the axial direction along the wall of the retainer, and cone angle was set at an appropriate value (16°).

OOP Test of Driver Airbag

We conducted an OOP test based on Federal Motor Vehicle Safety Standard No. 208 with a 5th female dummy, with three replicates (Fig. 4).

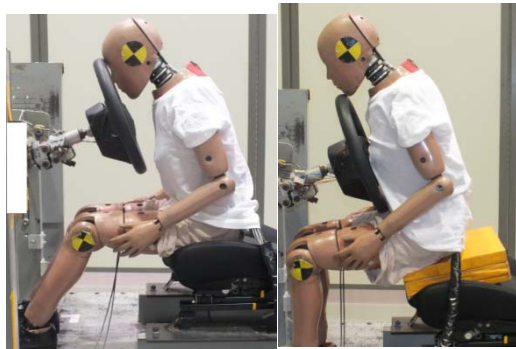


Figure 4. Dummy position (left: position 1, chin on module; right: position 2, chin on rim).

OOP Simulation of Driver Airbag

We conducted OOP simulations for the same dummy positions as in the OOP test. To verify the improvement of gas flow by setting the gas flow direction at the aperture plane of the flow control cloth, we compared injury values between default settings (no flow direction) and improved settings (flow direction set). The positions of the dummy were reproduced from the joint coordinates measured in 3D in the OOP test.

RESULTS

Visualization Experiments and Flow Simulations

The gas flow from the inflator was clearly visualized as dark regions by the Schlieren method (Fig. 5). Differences in flow between tests with and without a retainer were clear. Without a retainer, the gas tended to be released radially and vertically from the inflator orifices. With a retainer, the gas flowed along the wall of the retainer, and did not diffuse immediately after release.

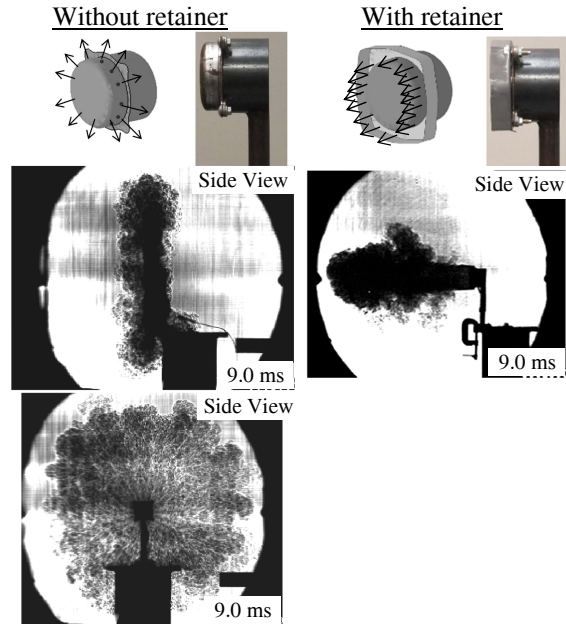


Figure 5. Visualization of gas flow by Schlieren method without and with retainer.

Figure 6 shows simulation results of gas flow with and without a retainer. The retainer redirected the gas flow from the inflator along the retainer wall, and the gas flow direction became axial.

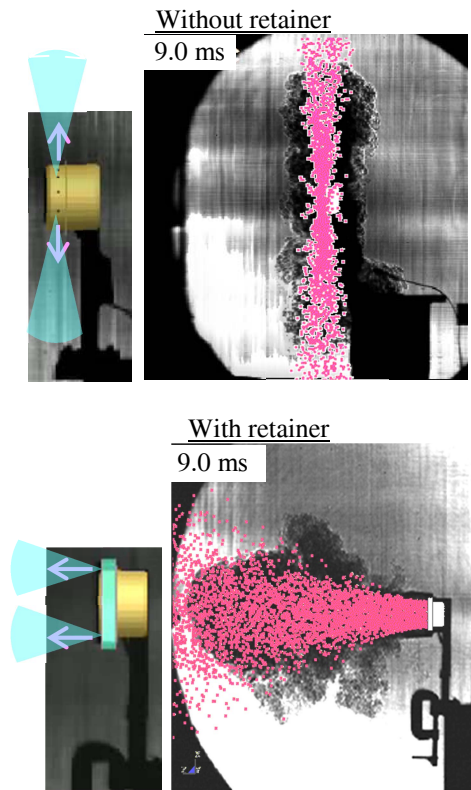


Figure 6. Gas particle distribution of simulation results without and with retainer. Dots are modeled gas particles.

Deployment Experiments and Simulation of Driver Airbag

The results of the deployment experiment and the simulations with and without the flow control cloth setting (gas flow direction set normal to aperture plane of flow control cloth) were compared. The simulation result with flow direction setting is closer to the experimental deployment shape (Fig. 7).

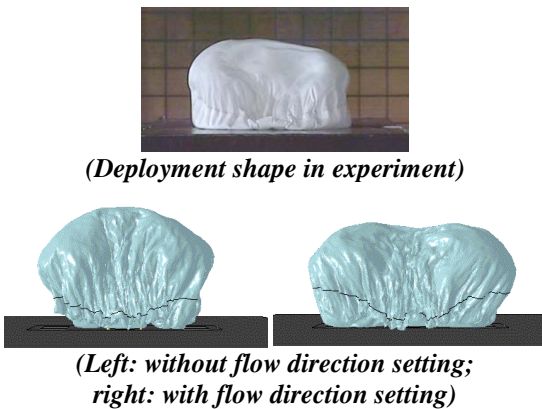


Figure 7. Comparison of deployment shape between experiment and simulation.

OOP Test and Simulation of Driver Airbag

Figure 8 shows injury assessment reference values (IARV) of OOP tests and simulations of dummies in the two positions shown in Fig. 4. The results of chest deflection and neck compression are similar to the test results. The original CPM gave differences in neck tension and neck injury (Nij) in both positions between test and simulation. The improved CPM reduced these differences.

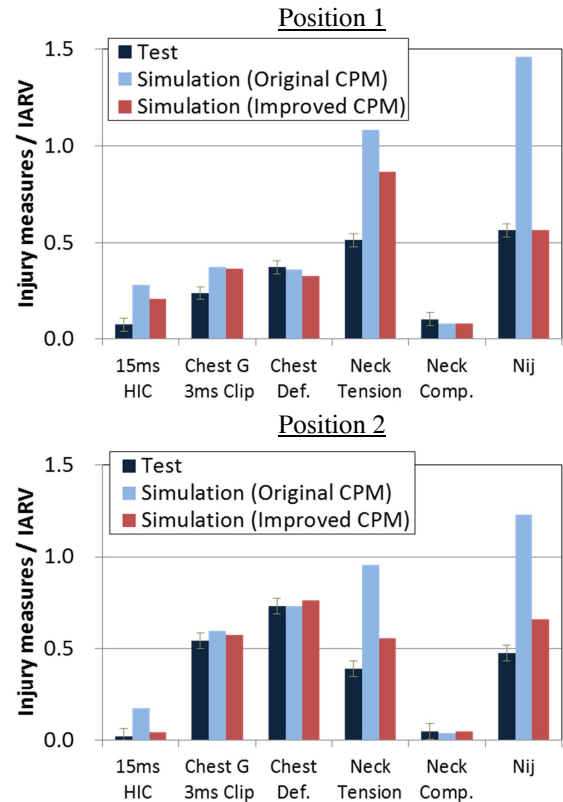


Figure 8. Normalized injury assessment reference values (IARV) of OOP tests and simulations (based on Table 2 criteria).

Table 2. Injury assessment reference values for 5th female dummy

	Injury Criteria	Injury Assessment Reference Values
Head	15 ms HIC	700
Chest	3 ms Clip Acceleration (G)	60
	Chest Deflection (mm)	52
Neck	Neck Tension (N)	2070
	Neck Compression (N)	2520
	Nij	1.0
	Critical Values to Calculate Nij	
	Tension (N)	3880
	Compression (N)	3880
	Flexion (Nm)	155
	Extension (Nm)	61

DISCUSSION

As random movement of particles in open air is dominant, CPM was unable to accurately reproduce gas flow in the original setting. This random movement is explained by kinetic molecular theory, which is based on thermodynamic equilibrium, Newton's laws of motion, and perfectly elastic collision of molecule–molecule and molecule–structure interactions. Therefore, to improve the reproducibility of gas flow behavior, it will be necessary to take these factors into account.

The actual gas flow from the orifices on the inflator is vertical. When a retainer is fitted, if the outlet faces the open side of the retainer, the gas is released perpendicular to that open side. So to reproduce the gas flow from the inflator in CPM, it will be necessary to combine the gas flow direction and a cone angle that suppresses random diffusion. To reproduce the gas flow from the inner vent of the flow control cloth, the gas flow direction should be set normal to the direction of the aperture plane.

The New CPM setting of gas flow direction led to improved deployment shape and force on the dummy, improving the OOP simulation results. To improve the reproducibility of the OOP simulation, the direction of gas flow from the inflator and the control cloth aperture plane is key.

CONCLUSIONS

- Attaching the retainer to the inflator redirects the gas exiting the inflator along the retainer wall in what becomes the axial direction.
- To reproduce the flow of the attached retainer by CPM, the gas flow direction should be set in an axial direction along with retainer wall.
- To reproduce the directional flow from the aperture plane of the control cloth by CPM, the gas flow direction through the aperture plane should be set normal to the direction of the plane.
- Applying the setting of the flow direction at the aperture plane of the flow control cloth so as to improve the reproducibility of DAB deployment shape to the OOP simulation improves the reproducibility of injury values.

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