Preliminary Validation of New Continuum-based Particle Gas (CPG) Method for Airbag Deployment Simulations

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Abstract

CPM (Corpuscular Particle Method) is widely used as a standard simulation technique for airbag deployment simulation among users for a long time. It is very fast and robust for most of the cases. On the other hand, we may need additional effort to reproducing the realistic gas flow around narrow area such as curtain airbag, vents, and so on. A new fluid solver (CPG ; Continuum-based Particle Gas) has been developing to reproduce it by directly solving the Navier-Stokes equation. 3 types of simple airbag tests are suggested and conducted to validate the CPG solver. Due to inviscid and free slip assumption for now, the gas frontal speed is faster than tests, but CPG showed a good result in terms of gas flow around narrow area.

1 Introduction

The control volume method (CV method) was first applied to airbag deployment analysis using Ansys LS-DYNA around the 1980s. The gas itself discharged from the inflator is not modeled, but the pressure is calculated from the volume and energy of the gas inside the airbag, which is a defined closed space, and that pressure is applied evenly to the fabric of the airbag. As this allows the deployment of an inflated airbag before the occupant comes into contact to it to be expressed very quickly and easily, it has become widely used in airbag deployment analysis, and functions specific to airbags (vents and leaks) have also been developed. This technique is sometimes used today, especially in cases where dummies and airbags are used in full car crash simulations. However, since the logic is to apply a constant pressure to the fabric, there is a limitation to express a situation where the pressure is uneven, such as in the early stage of development. For example, jetting that increases pressure in some areas artificially is used and it requires some parameter study after the test.

Later, in the 2000s, fluid-structure interaction using ALE began to be applied to airbags. This method allows us to accurately solve the compressibility of gas and its behavior as a fluid, making it possible to improve accuracy in situations where pressure is uneven. However, due to the problem of fluid leakage in the coupling between structures and fluids, and the problem of calculation speed due to the need for fine mesh in narrow spaces, ALE is used in limited specific situations.

In 2003, the now widely used airbag particle method (CPM) was developed [1]. This method differs from previous methods in that the gas flow is expressed by particles based on gas molecular kinetic theory, and the particles themselves move in rigid body motion, which is extremely fast and robust, and expresses local pressure differences. This method has been accepted by many users. Although CPM is widely used for airbag deployment and injury prediction simulations, it can be said that issues remain in some specific cases. It is sometimes difficult to accurately represent the gas flow in narrow space by statistic collisions between particles[2].

We have been discussing ways to achieve such a “tuning-less” prediction in collaboration with Toyoda Gosei Co., Ltd., Toyota Motor Corporation, and Toyota Systems. Ansys solves this problem by CPG which solves the Navier-Stokes equations to directly derive the pressure, temperature, and flow velocity. The inside of airbag is discretized by particles [3]. For the basic performance and verification of CPG fluid, please refer to the developer's paper. In this paper, we describe some preliminary validations we have obtained so far including tests using simpler airbags and simulation results using CPG, which we have conducted with co-authors.

2 Development and Validation

As shown in Figure 1, when developing a CPG, we organized the functions necessary for airbag deployment analysis and then divide the process into four major stages. At each stage, we determined the necessary verification and evaluation methods. The first stage is the basic functions of a compressible fluid solver, and we mainly verified basic examples that can yield theoretical solutions. This part is not included in this paper. The second stage is to develop functions to model the inflator, which is the condition for gas inlet condition of the airbag. We evaluated and investigated the characteristics of inflator gas containing multiple gases using a tank test as a benchmark model. The third stage involves the development of key functions that are essential for airbag deployment, such as interaction with fabric, expansion/reduction of the fluid region, and expression of atmospheric pressure outside the airbag. In response, we conducted tests and simulations of S-shaped airbag that is not folded. Then we also conducted tests and simulations of a simple curtain airbag, which is closer to practical airbags. The gas flow into the narrow space will be tried to assess with these types of airbags. In the fourth stage, we are considering testing DAB (Driver Airbag) and PAB (Passenger Airbag) in order to evaluate venting and leakage functions so that they can be used in more kinds of practical airbags. Furthermore, we plan to continue our activities with an eye toward analyzing the system while it is installed in a vehicle.

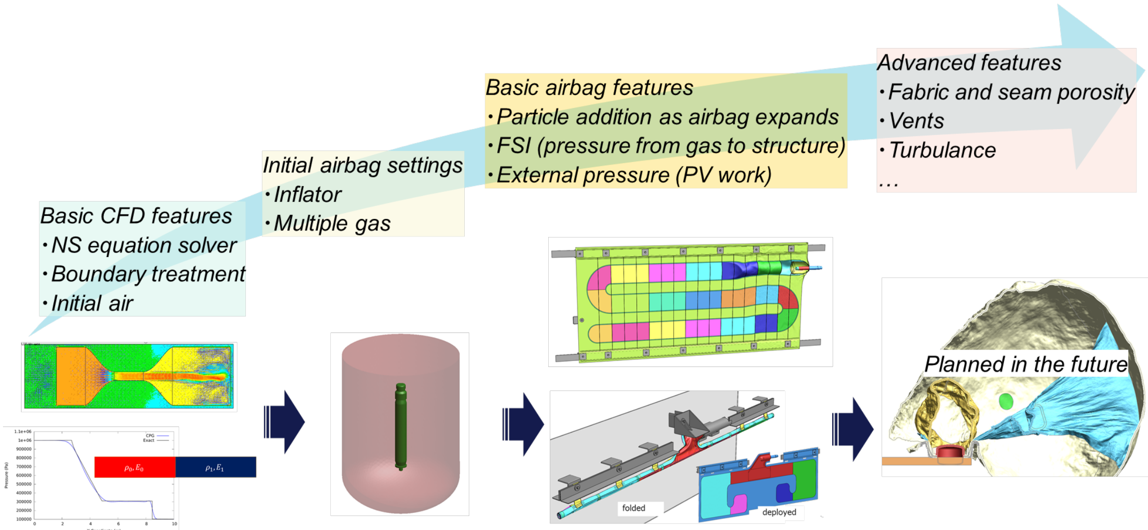

Fig.1: Requirements for airbag and validation procedure

3 Validation of Inflators

3.1 Outline

It is one of the important elements for reproducing airbag deployment behavior to accurately represent the flow of gas from the inflator. Some features related to inflators are validated in this chapter. For example, the definitions of multiple gases, orifice areas, and adjustment of particle deisity around the orifice are included here. A tank test was conducted and the pressure history inside the tank was compared.

3.2 Tank Test Model

The inflator is a hybrid type, and the same inflator is used for all airbag tests conducted in Chapter 4. The orifice of an actual inflator has several small holes of several millimeters in diameter at its tip. In order to reproduce these holes as they are and solve the gas flow around them with high precision, discretization using fairly fine particles is required. Therefore, as shown in Figure 2, the orifice region was made to be the tip of the inflator (the red part in the figure), and the particle density was gradually changed from 2 mm to 5 mm. Specifically, the inside of a sphere with a radius of 20 mm was uniformly 2 mm, the volume between 20 mm and 60 mm was set from 2 mm to 5 mm, and the outside was set to 5 mm. In addition, the input of inflator conditions for CPG in Ansys LS-DYNA follows the CPM method considering the availability up to now. There are five types of gases, and the molar mass and constant pressure heat capacity of each were defined from the received data. The inflator itself was made of 2.5mm mesh.

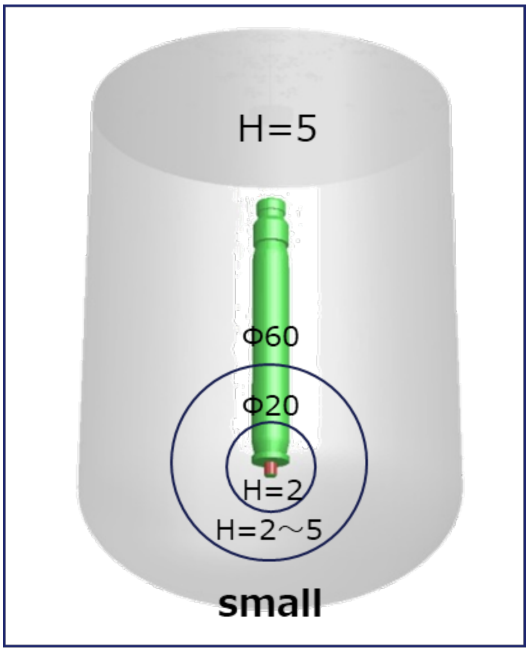

Fig.2: Inflator and Tank model

3.3 Tank Test Result

Figure 3 shows a comparison of the tank pressure history between test and simulation, as well as the gas velocity distribution results at 10 ms of CPG. Although the final pressure value was slightly higher than the CPM result, good results were obtained. The test results show that the pressure decreases over time, which is due to heat loss from the tank. Both CPM and CPG have developed functions that take this into consideration, but they are not applied here.

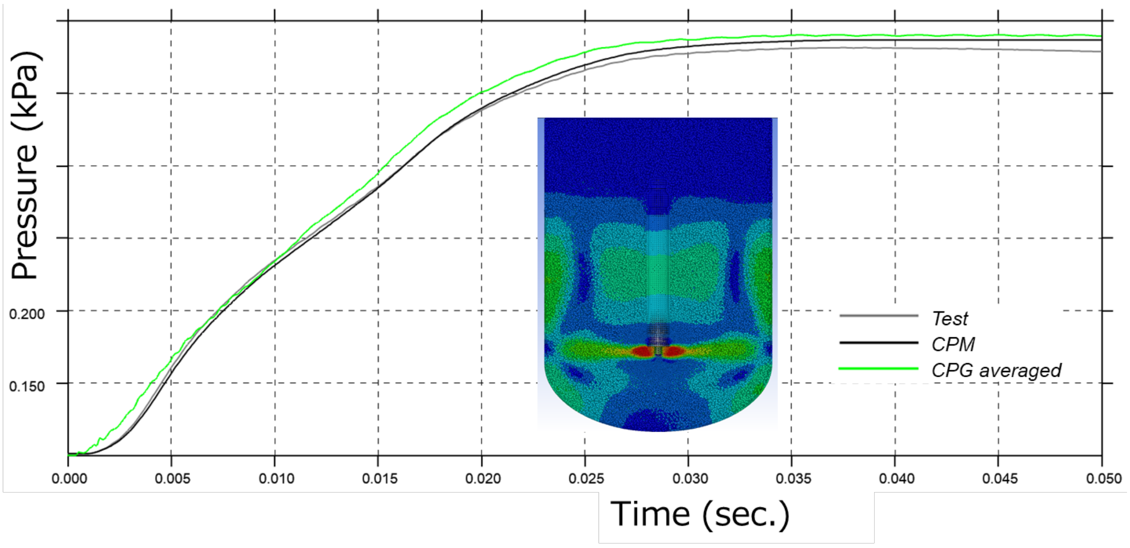

Fig.3: Pressure History and Gas Velocity Distribution(10ms) of Tank Test

4 Validation of S-Shaped Airbag

4.1 Outline

We conducted a S-shaped airbag deployment tests and simulations in Figure 4 to verify if the gas velocity in the airbag is well represented and the airbag behavior is reasonable or not. The objective is to confirm the function of the particle addition and removal as the volume of the airbag changes and FSI between fabric and gas. CPM simulation is also conducted to compare if CPG improves gas entry into narrow areas, which could become an issue with CPM. We evaluated the gas velocity at each position. This airbag has no vent, and a sealant is applied to the base fabric to prevent leakage from the base fabric. The test was conducted with N=3. We used 2 types of inflators shown in Figure 4, one is the same as chapter 3 and the other one has relatively larger orifice areas.

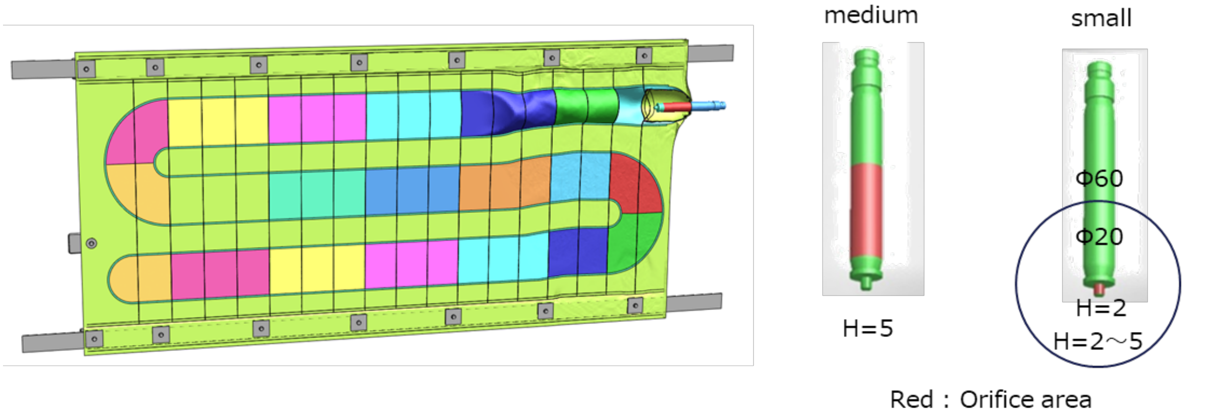

Fig.4: S-shaped Airbag Airbag

4.2 S-Shaped Airbag Test Result

Figure 5 shows all test results for the S-shaped airbag. Similar results were obtained in the three cases. Markers are placed on the airbag every 100mm, and the velocity of the gas tip position can be roughly estimated from the animation results. The speed at which gas passes through the S-shaped airbags is approximately 240 m/s, 200 m/s, and 210 m/s for the upper, middle, and lower stages, respectively.

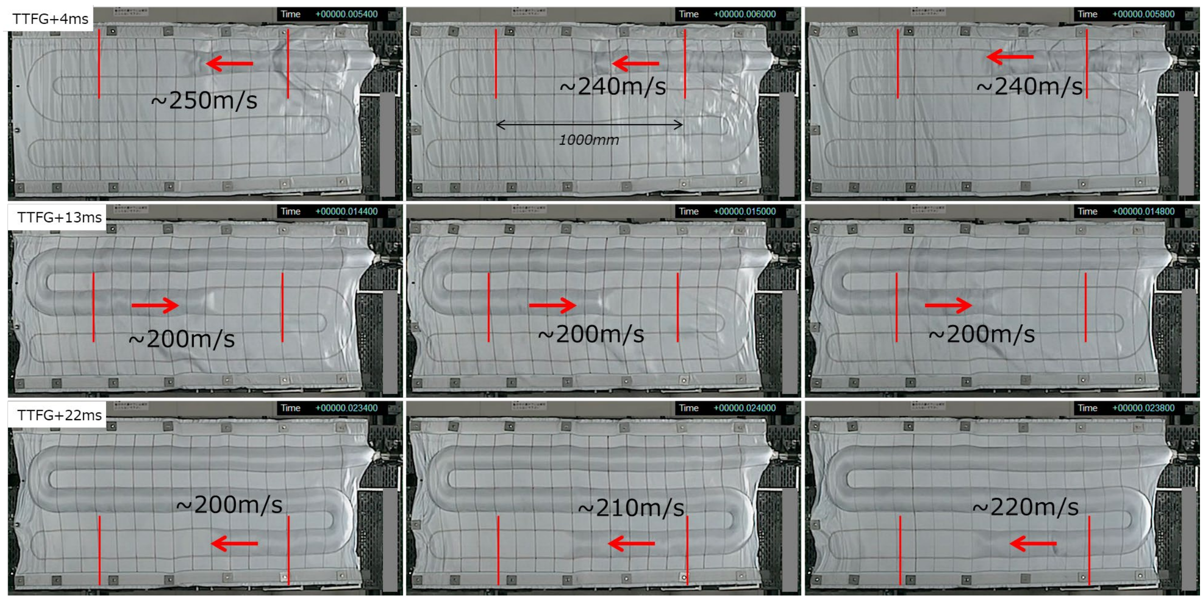

Fig.5: S-shaped Airbag Test (all cases, upper=4ms, middle=13ms, bottom=22ms)

4.3 S-Shaped Airbag Simulation Result

Figure 6 shows a comparison of the positions of the airbag gas tips at 26ms. Firstly, it is observed that gas was flowing into the S-shaped airbag starting from near the inflator to the end of S-shape. As a result, it can be said that the interaction between the gas and the fabric and the function of addition and removal of particles as the volume of the airbag changes works fine. CPM and CPG (Infrator: small) tended to have faster gas arrival than the test, and CPG (Infrator : medium) tended to be slightly faster than the test. Since the boundary condition between the fabric and gas for CPG is Free Slip, this result can be expected. Although the pressure difference between the two inflators in the tank test was not large, installing them in the S-shaped airbag had a certain influence on the results.

In addition, we considered the gas velocity divided into upper through lower stages. Table 1 shows the results of measuring the gas velocity at each part based on the animation. When looking at the upper location, it is confirmed that both CPM and CPG could reproduce the gas flow to the narrow space in this airbag, and CPG is a little bit faster than CPM. In the test, the velocity was the fastest in the upper stage and tended to slow down from the middle to the lower stage. The CPG's fluid velocity after the middle stage was closer to the test result. This is thought to be because CPG captures the effect of deceleration due to gas rebound pressure at the corner better than CPM. The animation also showed the gas bouncing around the corners.

Location/Case	Test	CPM	CPG medium	CPG small
Upper	240	217	238	238
Middle	200	227	208	208
Bottom	210	227	185	200

Table 1: Gas Edge Velocity (m/s)

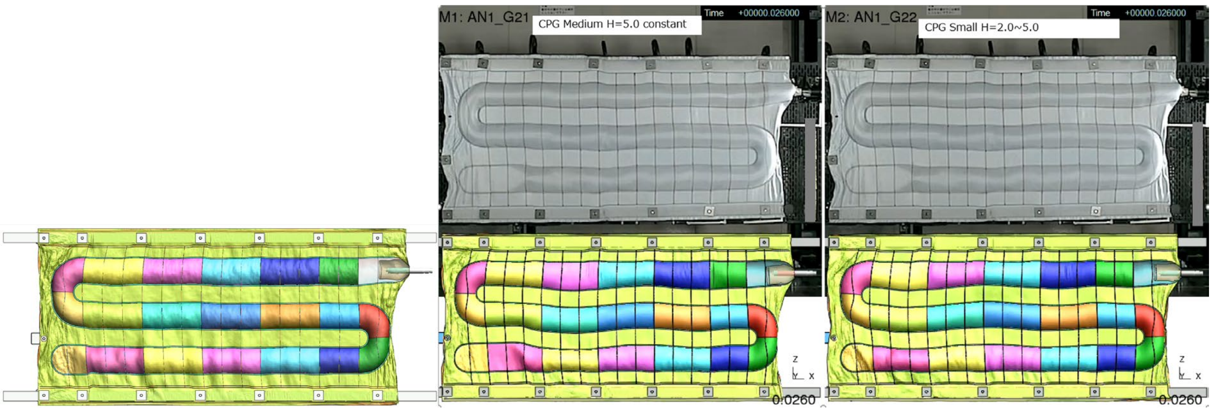

Fig.6: S-Shaped Airbag Deployment @26ms (Left : CPM, Center : CPG/Medium, Right : CPG/Small)

5 Validation of Simple Side Curtain Airbag

5.1 Outline

In a simple airbag shape in Chapter 4 where gas release direction is limited to the “front” of the inflator, CPM and CPG had relatively similar behavior in terms of gas entering the airbag. In this chapter, CPG is applied to the deployment of a curtain airbag in which the gas flow diverges in the immediate vicinity of the inflator. The gas flow around the inflator, into the main chambers and sub chambers, and airbag deployment behavior, will be evaluated. More evaluation such as folding, inner pressure will be evaluated in the future.

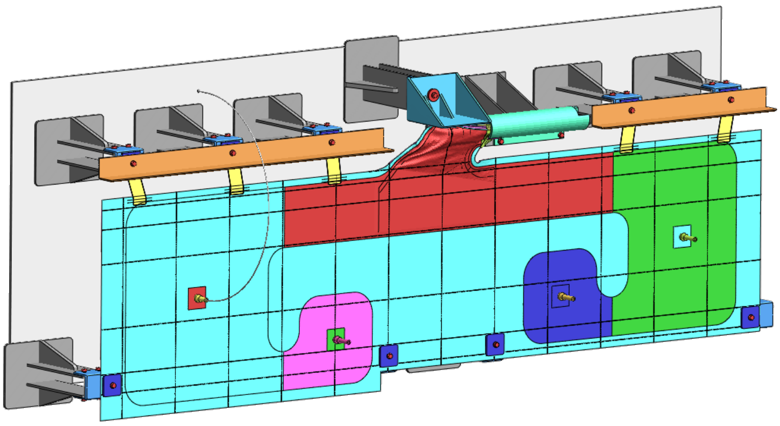

Fig.7: Simple Curtain Side Airbag Test

5.2 Simulation and Test Result

Figure 8 shows an animation between simulation and test for a simple curtain airbag. First, when compared at 1.6ms, gas seems to enter the area around the inflator a little faster in the test. This may depend on the matching of the inflator TTF between simulation and test, but if the timing of gas entering around the inflator matches, then the timing of gas entering main chamber does not match. A possible reason for this may be that the mass flow rate of the inflator was slightly different from the test. At 4.0ms, it can be said that the deformation of the airbag around the inflator and the timing of gas entering the main chamber are close between the simulation and the test. After that, the gas flow from the main chamber (large chamber) to the sub chamber (small chamber at the tip) is faster in the simulation. This is thought to be due to the free slip condition between the gas and the airbag, like the case with the S-shaped airbag. The overall behavior of the airbag was generally consistent with simulation and test, and we found that CPG could be applied even in cases where there is a branch immediately after gas is discharged from the inflator, such as in curtain airbags.

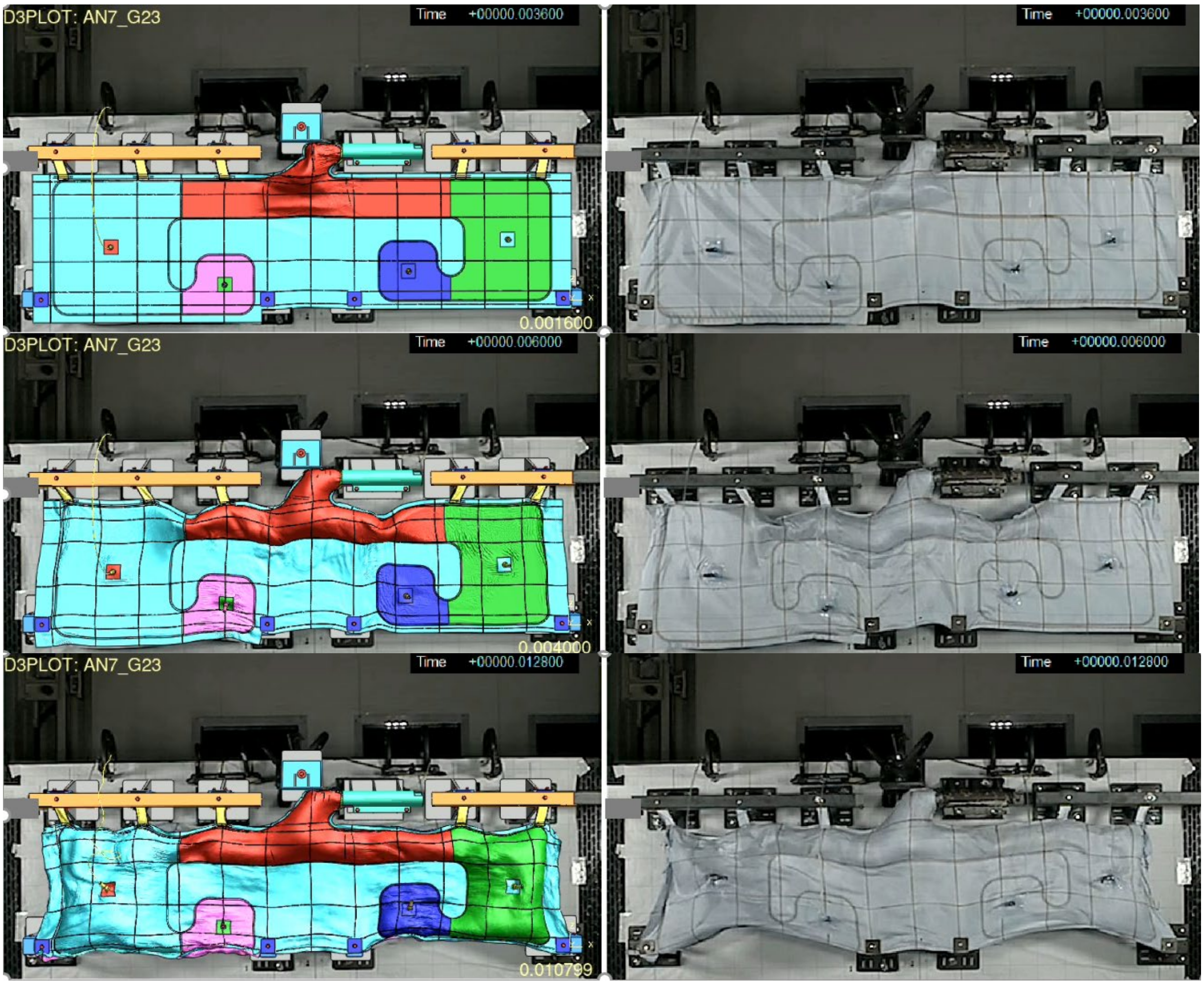

Fig.8: Simple Curtain Side Airbag Deployment (upper : 1.6ms, middle : 4.0ms, bottom : 10.8ms)

6 Conclusion

In order to apply the newly implemented CPG in Ansys LS-DYNA into use for practical airbag deployment simulation, we conducted preliminary verification using airbags with relatively simple shapes. Tank test is validated and the result is generally in accordance with theory. Since the modeling of inflator had a significant impact on airbag deployment analysis. It is necessary to continue studying the modeling of inflators. In the verification of the S-shaped airbag, in addition to the fact that the CPG allowed gas to enter the vehicle a little faster than in the test, it was also possible to reproduce the deceleration behavior due to the rebound pressure of the gas, which was not observed in the CPM. In the verification of the simple curtain airbag, although there was a slight difference in the timing of gas entering each air chamber compared to the test, the overall behavior was reasonable. In the future, we plan to investigate the internal pressure and reaction force of airbags, which are important for the occupant protection performance. Both airbag results by CPG showed a good behavior in terms of the gas flow in narrow space, but we're also planning to evaluate it by folded airbags where it is more important for gas to enter a narrow space. In order to achieve "tuning-less" airbag simulations, we still have a lot to be validated and evaluated, we'll continue our efforts on this theme.

7 Literature

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