Validation of Unfolded and Folded Simple Curtain Side Airbag by Continuum-based Particle Gas (CPG)

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Abstract

Since 2023, we have been conducting continuous verification using a CPG implemented in Ansys LS-DYNA [1], which aims to achieve a more highly predictable level of simulation for the deployment behavior of airbags, which is important for predicting the injury level of occupants in automotives. We have obtained results in which the gas front velocity and deployment behavior generally matched the test results using S-shaped airbags and simple curtain side airbags (CSABs) that have no vents or porosity [2]. In this paper, we continue to verify the prediction of the airbag internal pressure, which is necessary for predicting the injury value of the occupant, using the simple CSAB.

The results were qualitatively similar to those of the test, but there was a quantitative discrepancy, and the cause was discussed. In addition, the application of a newly developed turbulent viscosity model showed partial improvement in pressure history. Furthermore, the simplified CSAB was deployed from a folded state, and the deployment behavior was compared with the test, showing good agreement.

1 Introduction

Toyoda Gosei Co., Ltd. and Toyota Motor Corporation had pointed out that the challenges in airbag simulation by CPM were gas flow into narrow gaps and gas distribution when the flow was diverted.

In both cases, CPM was able to reproduce deployment behavior that matched the test results using some tuning parameters, but it had not yet reached a level where it could be predicted.

We have confirmed that the CPG method implemented in Ansys LS-DYNA can reproduce the deployment behavior of several simple airbags without using tuning parameters.

The ultimate goal of airbag simulation is to accurately predict occupant injury levels. This paper examines whether it is possible to predict the history of pressure inside an airbag, which affects occupant injury, for simple curtain side airbags without vents or leaks.

The deployment behavior from a folded state was also compared with tests to confirm whether a situation closer to practical use could be reproduced.

Furthermore, there have been said that there are cases where considering turbulent viscosity inside a long, thin flow channel changes the behavior of the internal structure, including this channel, and affects deployment behavior. To take this into account, a turbulent viscosity has also been implemented in Ansys LS-DYNA. In this study, an attempt was made to apply this to a folded, simple curtain side airbag to confirm whether or not there was any effect.

2 Validation Outlines

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.
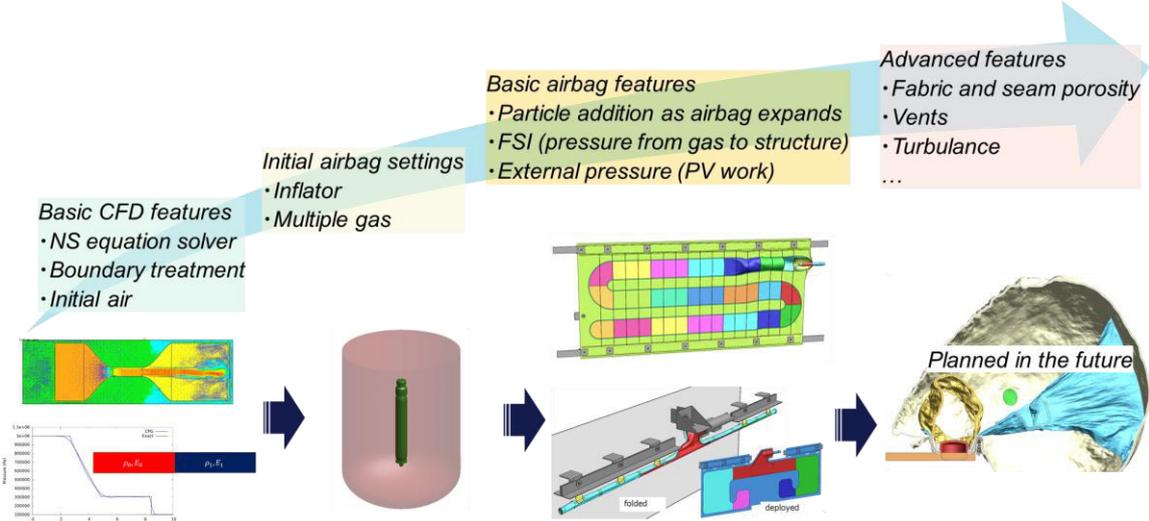

Fig.1: Requirements for airbag and validation procedure

3 Validation of Pressure Inside CSAB

3.1 Outline

To evaluate the pressure inside the airbag, a relatively simple CSAB was used, in which gas was injected without being folded, and the internal pressure was measured. A simulation model equivalent to this airbag was created, and the gas behavior and pressure history were compared.

3.2 Test and Model

Figure 2 shows the state of the CSAB before testing, and Figure 3 shows the simulation model. During the test, the upper part of the airbag was suspended from a jig at five points using tape, and the lower part was fixed to the jig at four points. The pressure during gas injection was measured at the four points indicated by squares in the center of each air chamber. The inflator is the same as that used in the previous report. This airbag does not have a vent, and the fabric is sealed to prevent gas leakage. In addition, a line is drawn on the airbag base fabric to make it easier to see where the gas tip is located. 3 test cases were conducted (N=3). The simulation model was the same as previously reported (mesh size of the base fabric was 2.5 mm, Global H (HLEN) = 5 mm, radius around the inflator was 20 mm to 120 mm, Local H changed from 2.5 mm to 5 mm). No vent or leak was set, and a part of the fabric was divided at each location where there was a pressure sensor, and the sensor pressure was evaluated.
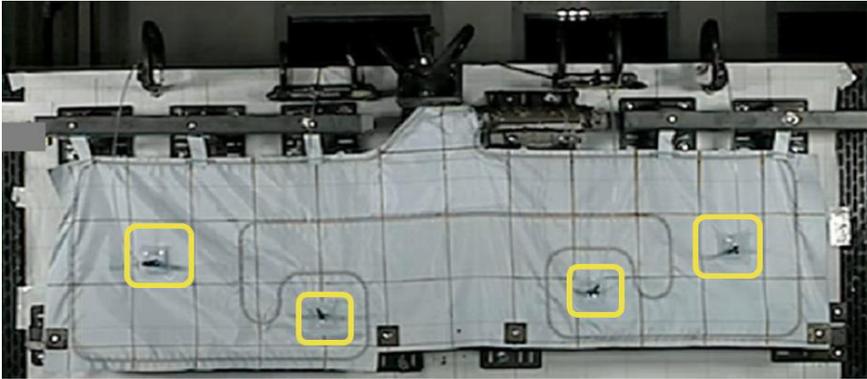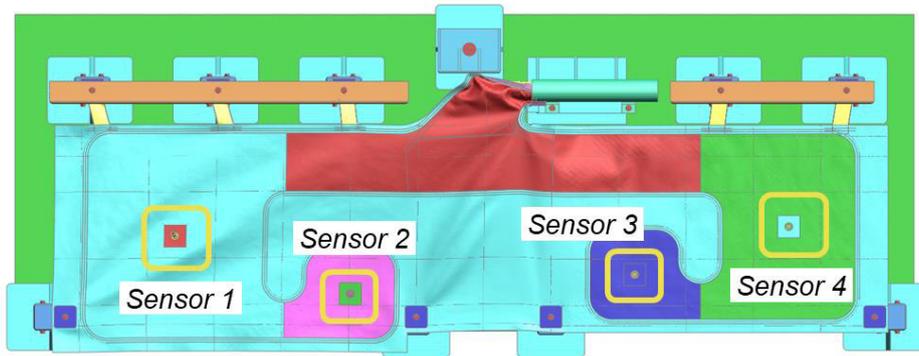

Fig.2: CSAB Test Setup

Fig.1:   CSAB Simulation Model

3.3   Result

Figure 4 shows a comparison of gas behavior (red and blue line indicates the approximate gas front). In the initial stage up to 1.6 ms, the gas advances more slowly with the CPG than with the test. After that, at around 4.0 ms, the positions of the gas leading edge advancing to the main chamber on the left are almost the same, and the gas enters the sub-chamber slightly faster with the CPG. The reason the gas advances faster with the CPG as time progresses is because the boundary conditions with the fabric are nearly free slip. (The gas viscosity and a friction coefficient between the fabric, PFRIC = 1.0, are defined but this is thought to have almost no effect on gas behavior.) The difference in the initial gas behavior up to 1.6 ms suggests that the accuracy of the inflator mass flow rate needs to be re-examined in the future.

Figure 5 shows a comparison of the pressure history of each air chamber. The test results are shown in gray lines (N=3). The simulation results, shown in orange solid lines, show the history of pressure in the central patch of each air chamber. The simulation results showed higher pressure than the test in all locations except for sensor 1. The timing of the pressure rise for the left and right main air chambers was almost the same in both the test and simulation, but the simulation result for the sub-air chamber was faster, which is consistent with the analysis using animation of gas behavior.

There are various possible reasons for the high pressure, but since it has been confirmed that the weight difference before and after use of the actual inflator used in the experiment is the same as the gas mass of the mass flow rate in the simulation, there is no problem with the total energy of the mass flow rate. Another possibility is a gas leak during testing, but since it was confirmed that the gas remained fully inflated after the airbag was deployed, it is unlikely that gas leaked during the latter stages of deployment. Finally, it is possible that gas leaked from around the inflator during the early stages of deployment, and we plan to conduct tests with countermeasures in place in the future.
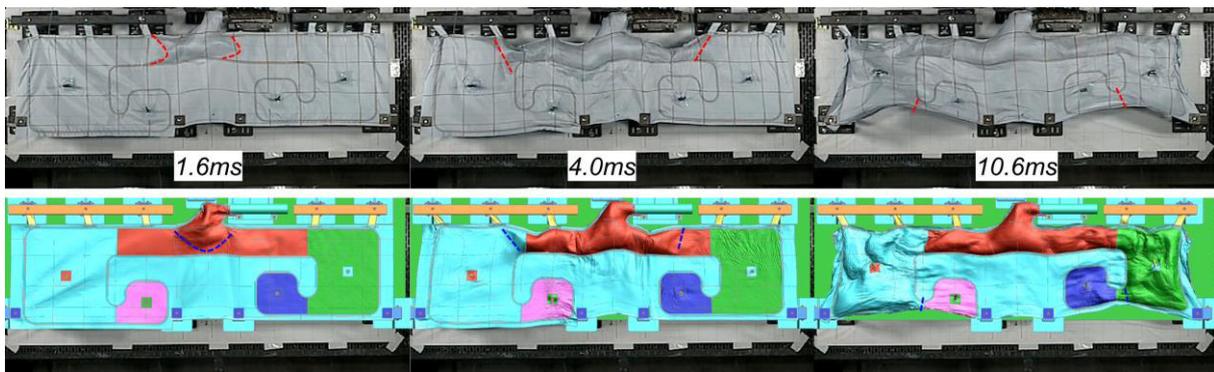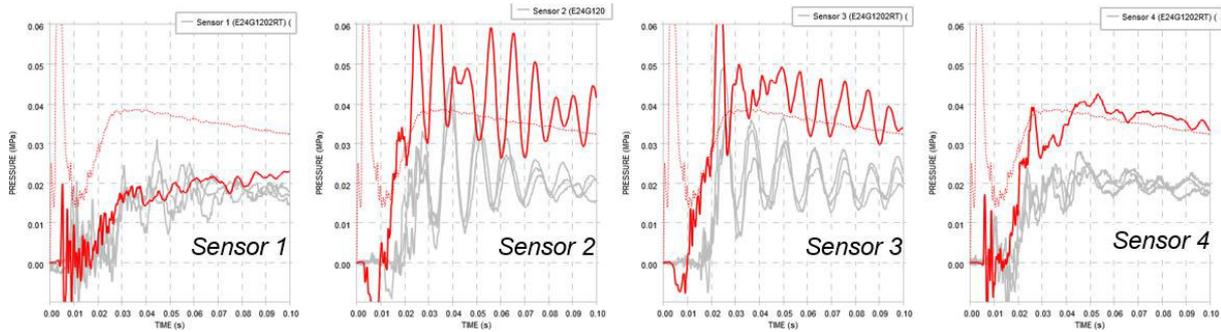

Fig.2:   Gas Behavior of CSAB

Fig.3:   Gas Pressure History of CSAB

3.4   Additional survey

In Section 3.3, we considered the possibility that the discrepancy in pressure between the test and simulation was due to temporary gas leakage around the inflator in the early stages. Therefore, we performed a simulation in which the inflator output was set to approximately 82% in order to virtually represent the initial gas leakage. Figure 6 shows the history of pressure. As a result, the pressure levels in the test and simulation were almost the same except for the left main air chamber. Furthermore, when observing the gas flow velocity vectors for the left main air chamber, it was confirmed that the gas continued to circulate around the air chamber like a vortex, as shown in Figure 7. In other words, in the simulation, the gas behavior was less likely to damp, resulting in local pressure differences between the center and other areas (blue and red lines in Figure 6), whereas in the test, the flow was more averaged, which may have resulted in higher pressure.

Since turbulent viscosity had been added to CPG in response to another request, we also investigated the extent to which turbulent viscosity affects the behavior and pressure difference of the gas inside the airbag in this case. The turbulent viscosity implemented in LS-DYNA is a general model based on the k-ε model.

Figure 8 shows a comparison of the gas flow velocity vector distribution at 60 ms with and without turbulent viscosity, and the pressure history in the left main chamber. An attenuation of the flow velocity itself and a decrease in pressure were observed.
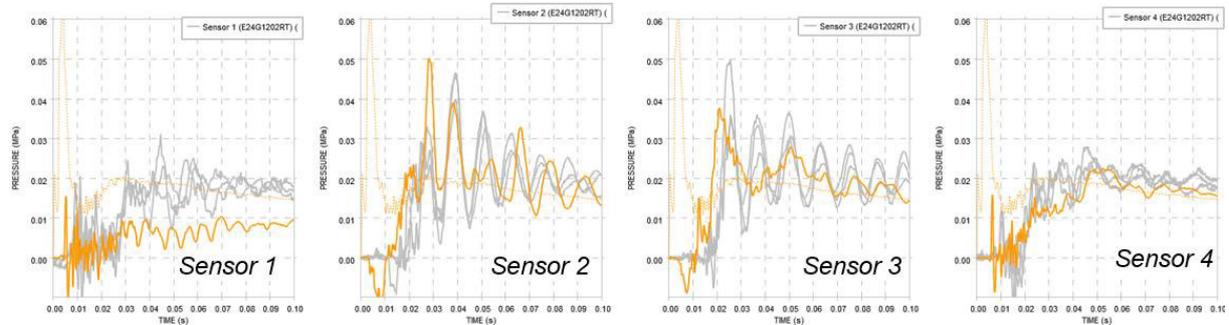

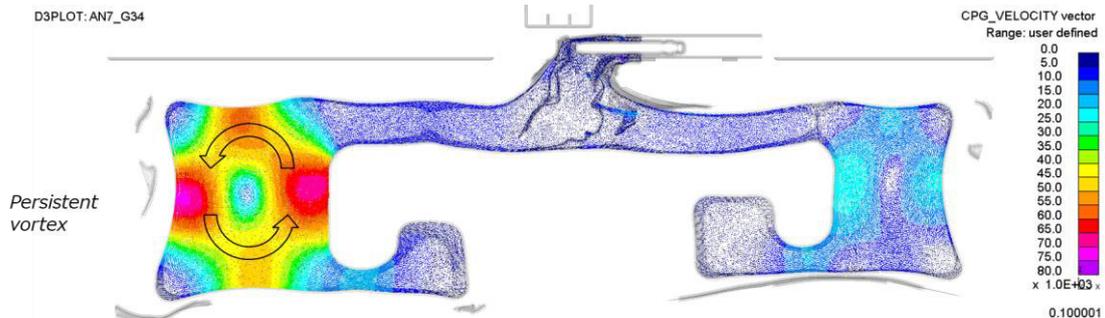Fig.4:   Gas Pressure History of CSAB (inflator 82%)
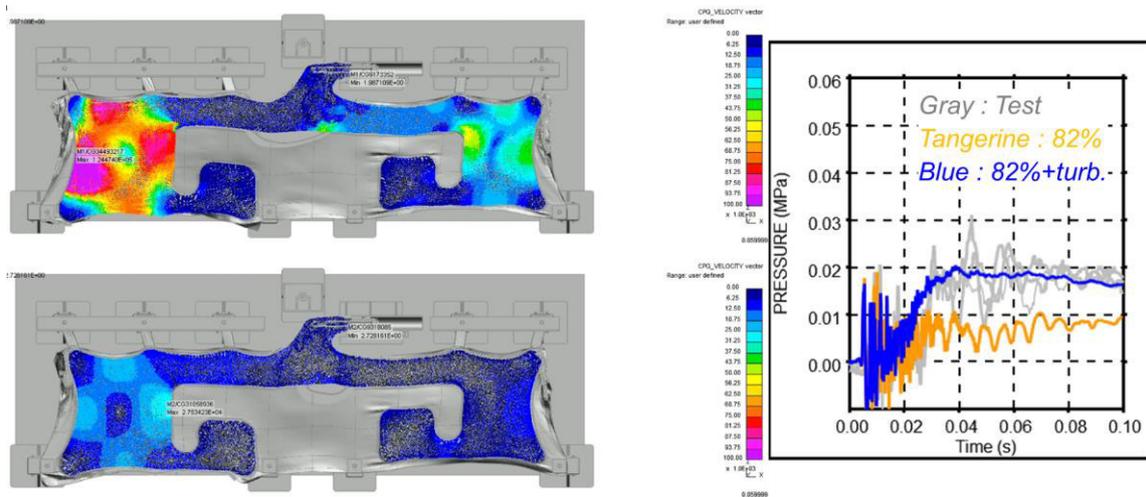

Fig.5:   Gas Vortex Inside Left Main Chamber

Fig.6:   Gas velocity vector and pressure history at left main chamber

(upr : without turbulent viscosity, lwr : with turbulent viscosity)

4 Validation of Folded CSAB

4.1   Outline

Various airbags, including curtain side airbags, are basically deployed from a folded state to protect occupants. All previous verifications have been carried out on airbags that do not involve folding, but this time we will apply CPG to verify the deployment behavior of curtain side airbags from a folded state, which is closer to reality. The same airbags and inflators as in Section 3 were used.

4.2   Folding

The folding procedures for this CSAB using JFOLD are shown in Figure 9. JFOLD is a pre-tool that uses Ansys LS-DYNA simulation to reproduce the actual folding process of an airbag. This time, input data was prepared for four separate processes: Z-folding, roll-folding, wrapping, and inflator insertion. JFOLD provides tools and recommended settings for recreating a folding process close to the actual process, making it possible to reproduce stable folding with minimal penetration between the base fabrics. This is an important factor in CPG, where the creation of a closed space is crucial.
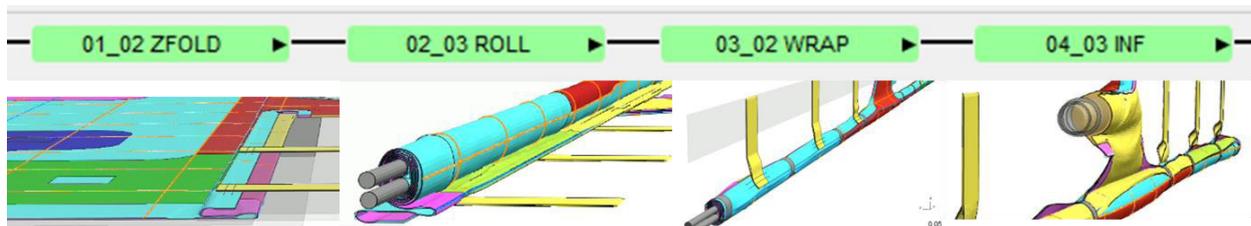

Fig.7:   S-shaped Airbag Airbag

4.3   Folded CSAB Simulation Result

Figure 10 shows a comparison of the deployment behavior in the test and the simulation (inflator output was set to 85%, which was employed at some point of our study). As with the non-folding case, gas tends to enter faster in the test than in the simulation in the initial stage up to 3 ms. After that, at 10 ms, the test still deployed slightly faster, but at 20 ms the deployment behavior was almost the same. Even for airbags with folded sections, the deployment behavior tended to match the test results, demonstrating the possibility that CPG can predict deployment behavior.

Furthermore, a notable trend that emerged when comparing the CPM and CPG simulations was the bouncing behavior of the airbag after deployment. Figure 11 shows the state of the airbag at 100 ms,

with CPM showing a noticeable bouncing behavior after deployment, causing the bag to rise upward, whereas CPG did not show this phenomenon and behaved in the same way as the test. It is speculated that the unexpected behavior of the CPM was likely the result of random collisions between the particles and the base fabric, which could pose a problem for accuracy in cases where the occupant is hit shortly after deployment, demonstrating the advantages of the CPG.
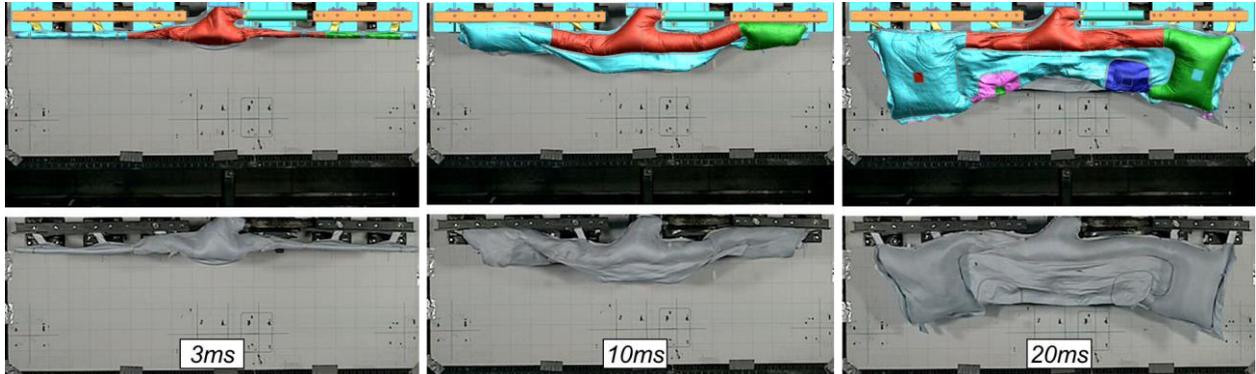

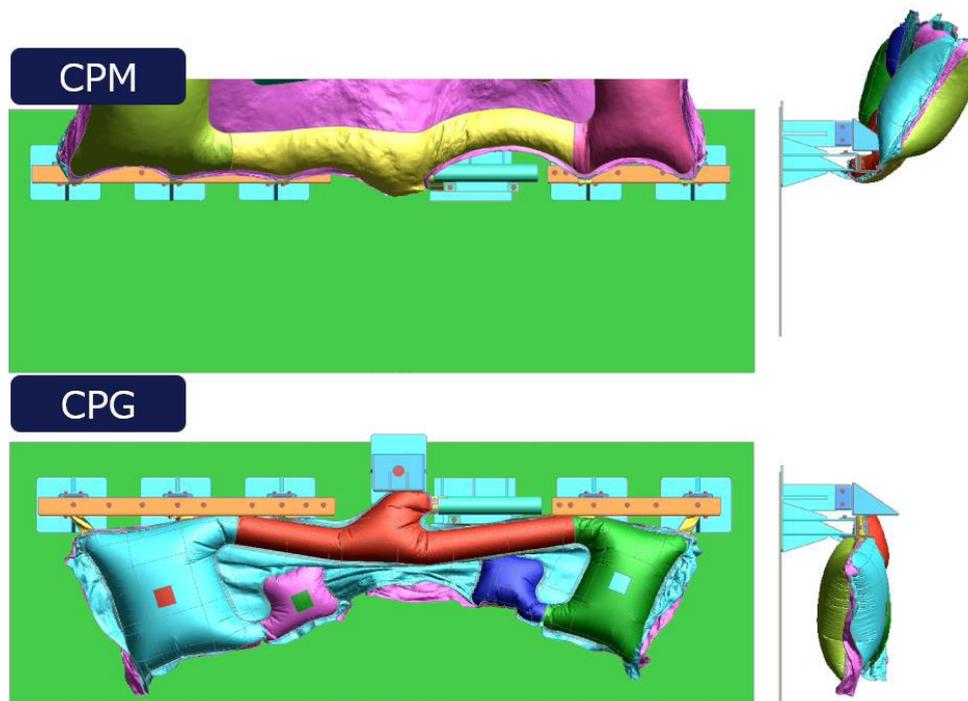*Fig.8: Deployment of folded CSAB (3ms, 10ms, 20ms)*

Fig.9: Deployment of folded CSAB (3ms, 10ms, 20ms)

5 Conclusion

CPG showed good agreement in deployment behavior and pressure history using unfolded CSAB.

・CPG showed a bit faster inflation in early phase, which is expected to be improved by obtaining further accurate mass flow rate history by better experiment than conventional tank test

・CPG showed higher pressure level in each chamber, which is considered due to the leak around inflator in early phase, we may try additional test with less leak around inflator

・The effect of turbulent viscosity is to migrate and average the pressure and gas velocity distribution

CPG showed good agreement in deployment behavior using folded CSAB

・Folding by JFOLD helps less initial penetration, which is important for CPG simulation

・Deployment width at 20ms is roughly measured and matched to the test

・CPG showed better behavior than CPM in later phase (without unexpected bounce)

6 Literature

[1] Edouard Yreux, Jason Wang, Inaki Caldichoury, Mohammed Mujtaba Atif, "Continuum-based Particle Gas (CPG): A New Approach for Airbag Deployment Simulations" 17th International LS-DYNA Conference 2024

[2] Hiromichi Ohira, Richard Taylor, Shinichi Arimoto, Kosho Kawahara, Hiroyuki Umetani, Edouard Yreux, Inaki Caldichoury, Shinya Hayashi, Masato Nishi, "Preliminary Validation of New Continuum Particle Gas (CPG) Method for Airbag Deployment Simulations" 17th International LS-DYNA Conference 2024