VALIDATION METHODOLOGY ON AIRBAG DEPLOYMENT PROCESS OF DRIVER SIDE AIRBAG

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ABSTRACT

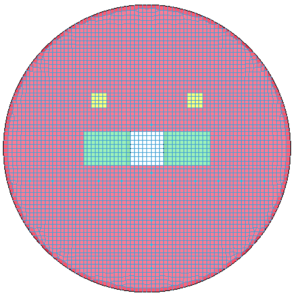
Recent years the numerical method of the simulation for the airbag deployment process has been improved with new material model and thermodynamic model, and has become a standard application of finite element codes. With such simulation tools, it is possible to attempt supporting the airbag module design and evaluating the injuries of dummy in airbag hazard area or out-of-position. Although the simulation model for the airbag's deployment process is usually correlated with the static airbag deployments and reaction force results, up-to-date the numerical approach to represent the fluid flow within the airbag is both costly and time consuming. This paper will provide an overview of the correlation process for reducing the resource to be invested. The following two tests are conducted for acquiring the reference data.
1. Static deployment test for acquiring the airbag internal pressure during the deployment process and
2. Drop tower test for acquiring the fully deployed airbag's reaction force.
The drop tower test is simulated to determine the parameter related to the leakage of fabric and vent holes with the airbag model using the uniform pressure method offering the relatively short solving time. And then Static deployment test is simulated for determining the parameter related to the unfolding phase with the airbag model using the corpuscular (particle) method. These two simulations are compared to the test results and satisfactory correlation is found in both the cases.
The drop tower simulation using the uniform pressure method leads to reduce the total correlation time and to easily extend the application for protection of the driver occupant while in-position. This airbag model can be used in parametric studies to investigate the effects of airbag module design changes and to study the out-of-position (OOP) load case.

INTRODUCTION

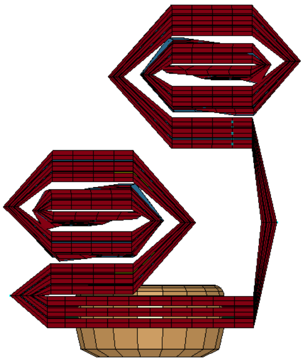
The safety system integration for in-position situation has held a main portion of the safety related simulation which usually uses the uniform pressure method for inflating the airbag. The airbag model adopted the uniform pressure distribution within the airbag volume provides adequate results for the in-position situation because the occupant and the airbag does not have a reciprocal action until the airbag is fully deployed. It is the basic assumption for the uniform pressure method that the gas inside the airbag is an ideal gas and assuming that the pressure and temperature are uniform everywhere inside the airbag. These assumptions are acceptable in the occupant analysis for the in-position situation.
Recent years the need of simulation beyond the uniform pressure method is increased in airbag module design and the OOP situation. In terms of the OOP situation or the airbag module design, the effect of gas flow plays a very important role at the early stage of airbag deployment. In order to simulate the deployment process of folded airbag with various folding pattern and the vent hole design, the meaningful safety simulation tools that allow the integration of the computational fluid dynamics analysis into the finite element airbag model are developed. These sophisticated simulation tools allow to handle the interaction between the gas and the airbag fabric, but the calculation is very expensive in CPU time [1], [2], [3].
Several validation tests and corresponding simulations are usually conducted to get the reliable airbag model on the deployment kinematics and these successive correlating processes are very time consuming job that have to be reduced.
In this study, the effective validation methodology that alternately adopts the uniform pressure method and the recently developed corpuscular method in the LS-DYNA 971 is described. And the model setup for the driver side airbag module is described.

Driver Side Airbag Model Setup

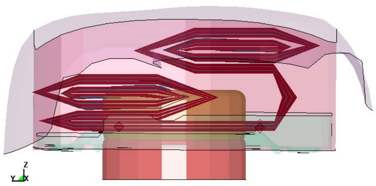
A typical 60 liter driver side airbag used in a mid-size car is selected in this study. Flat airbag cushion is folded with ∑-Roll folding and then the finite element model of the folded airbag cushion is placed in the canister with Y-tear pattern cover is built. The dynamic relaxation is performed until the internal energy of the folded airbag cushion in the canister become stable. The steering wheel is modeled, as it is an important part for the airbag support. The inflator characteristics and the mechanical properties of airbag cushion fabric are considered to achieve the accurate airbag model.
Figure 1 shows the modeling process for the finite element airbag module.



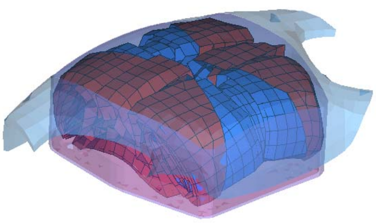
a. Flat airbag cushion modeling



b. Folding



c. packing



d. Relaxation

Figure 1. The modeling process for the finite element airbag module

<u>Fabric Material Property</u> - Both 'tightly' and 'loosely' woven fabrics can show differences on mechanical properties, because woven fabrics can resist in-plane shear loads once the yarn lock-up angle has been reached and the lock-up angle is much lower for tightly woven than loosely woven fabrics [4]. The differences of material property on material direction can affect the shape of fully deployed bag.
Recently developed tools for safety analysis provide a material model that incorporates an in-plane shear stiffness property into warp and weft properties. This shear material model is appropriate for a typical airbag fabric in opposition to the ISOLINEAR and OTHOLINEAR material model which are both linear and cannot rotate relative to each yarn. To gain the in-plane shear stiffness of tightly woven airbag fabrics, the picture frame test can be conducted. The picture frame test device that is made for this study is shown in Figure 2. The corners of the test frame have revolute joint to transform an applied axial loading into the shear deformation of specimen.

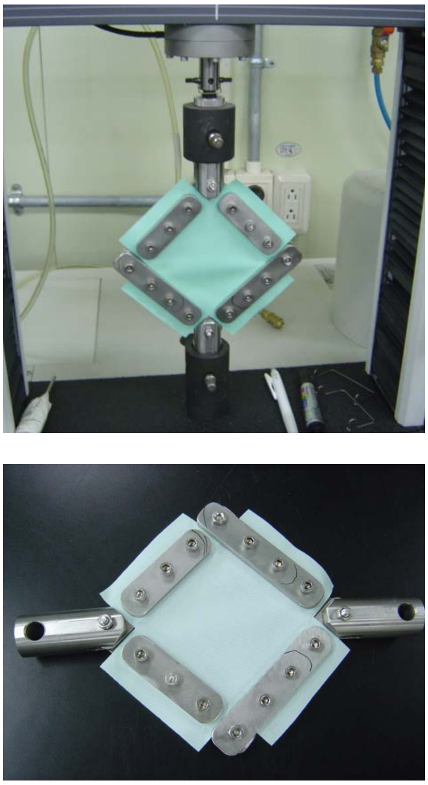
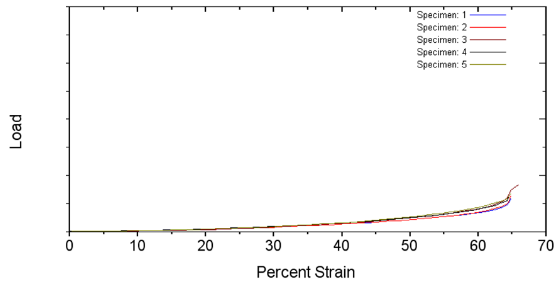
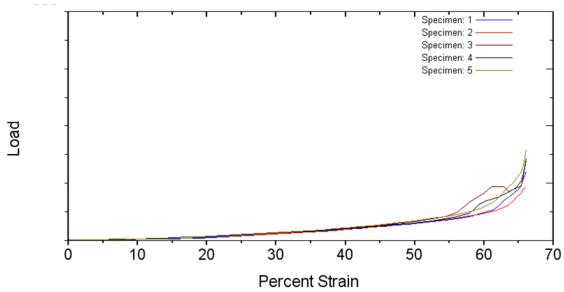


Figure 2. The picture frame test device and fabric specimen

The axial force and axial displacement acquired during a test are converted the true shear stress and the true shear strain in order to be used for the fabric material model. The converted non-linear stress-strain curve is used for representing the initial soft response of the fabric due to the crimp effect [5]. The picture frame tests are conducted with the various loading velocity, and Figure 3 shows the force-strain curve with 1.0x and 1.6x loading velocity. The result shows the inclination of the force-strain curve increases in proportion to the loading velocity. The picture frame simulation is conducted with the fabric test result and the validation procedure that is based on the test setup. The use of LS-DYNA's MAT_FABRIC material and recent parameter helps enhancement of prediction of the picture frame test data.

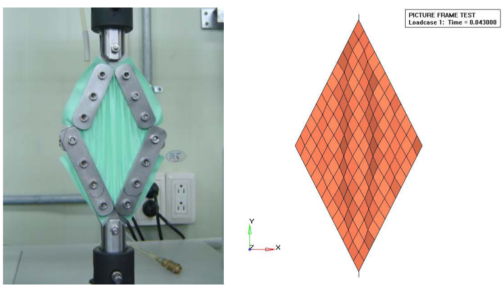


a. 1x

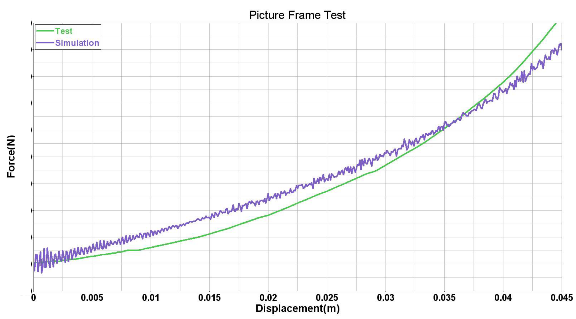


b. 1.6x

Figure 3. The picture frame test result with different loading velocity



a. Deformed shape



b. Force-displacement

Figure 4. Comparison between the picture frame test result and simulation result

In Figure 4 the deformed shape with wrinkle on fabric and the force-displacement results are depicted. The figure shows the simulation result is coincident with the test result. The validated material model based on the sufficient tests is the basis for the reliable airbag model.

<u>Inflator Definition</u> – Two types of inflator are modeled according to the validation phase: AIRBAG_HYBRID_JETTING and AIRBAG_PARTICLE.
AIRBAG_HYBRID_JETTING is used for the conventional uniform pressure method that gives relatively short CPU elapsed time.
AIRBAG_PARTICLE corresponding to the corpuscular method is newly developed for airbag deployment simulation in LS-DYNA. In this method, the gas is modeled as a set of individual particles. The corpuscular method shows the accuracy and agreement with experimental results in [1].
The multiple radial jets at gas discharge orifice are modeled in AIRBAG_PARTICLE option, the vertical jetting vector is employed for comparable result in AIRBAG_HYBRID_JETTING option. Due to these two options have similar parameters, they can be easily switched each other for airbag deployment simulation.

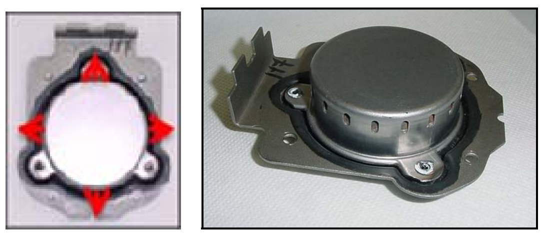


Figure 5. Radial jets and gas discharge orifices

Experimental pressure data of tank test is converted to mass flow rate and temperature input using the MADYMO Tank test Analysis (MTA) program. The inflator gas exit temperature and mass flow rate that are validated through a tank test simulation in LS-DYNA are used for defining inflator.

Drop Tower Test and validation

The two phase validation process for reducing the resources is employed in this study. The following two tests are conducted for acquiring the reference data; a) Drop tower test for acquiring the fully deployed airbag's reaction force, b) Static deployment test for acquiring the airbag internal pressure during the deployment process. The drop tower test is simulated to determine parameters related to the leakage of fabric and vent holes with the airbag model using the uniform pressure method offering the relatively short solving time. And then Static deployment test is simulated for determining the parameter related to the unfolding phase with the airbag model using the corpuscular (particle) method.

Flat Driver Side Airbag – Drop tower test and simulation with flat driver side airbag are conducted to determine parameters related to the leakage of fabric and vent holes. The main events during drop tower test are depicted in Figure 6.

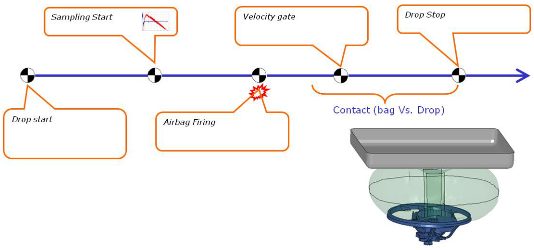


Figure 6. Scheme of Drop Tower Test

To represent the flat airbag cushion on the steering wheel, the pre-position simulation is conducted as a type of pre-simulation as shown in Figure 7.

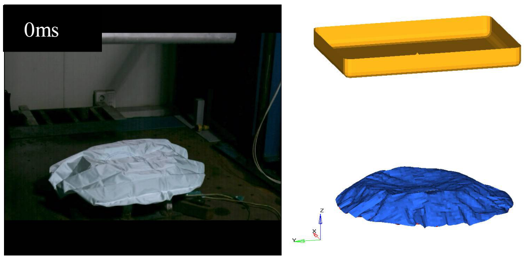
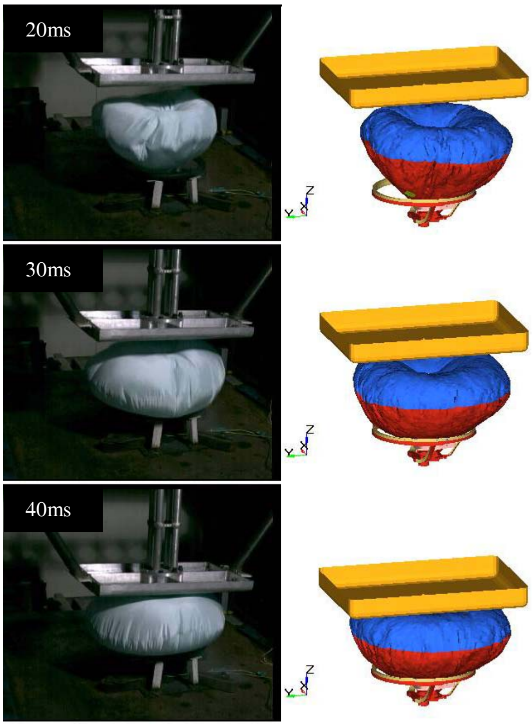
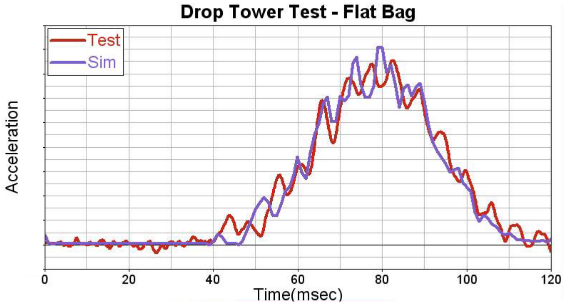


Figure 7. Initial stage of Drop Tower Test with flat bag



a. Comparison of kinematics



b. Comparison of acceleration of drop mass

Figure 8. Comparison between the drop tower test result and simulation result with flat bag

Drop tower test and simulation results for the flat airbag are depicted in Figure 7 and the simulation time history of acceleration data is closely correlated to the test result. Several parameters related to the leakage need to be tuned, because typical leakage model may not be able to cover the leakage characteristics of the specific airbag module.

Folded Driver Side Airbag – Drop tower test with folded airbag is conducted to validate the folded DAB model. In this phase parameters related to the contact definition of airbag fabric itself and the control of the strain that is caused element distortion during folding process are tuned. Increasing the scale factor on slave penalty stiffness, the contact parameter, leads to higher contact forces. The higher contact forces accelerates the airbag deployment and leads to lower pressure peak during unfolding due to faster volume increase. LS-DYNA provides a numerical option to assure that airbags that have reference geometry is able to open to the correct geometry [6, 7]. During airbag folding, some elements are stretched and distorted compare to the reference geometry and these elements result in tensile strains. The airbag that is initially stretched result in the incorrect geometry. So this numerical option can be used to control the transition from initial mesh to reference mesh. But inadequate value for this factor can cause a lower pressure that result from larger element size in vent orifice area or a pressure peak change that result from different contact forces of airbag self contact.

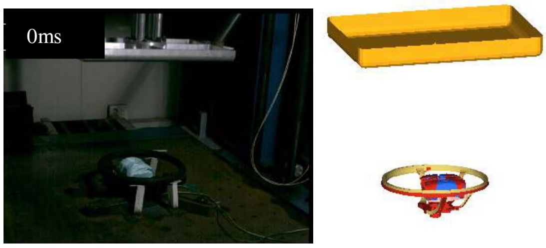
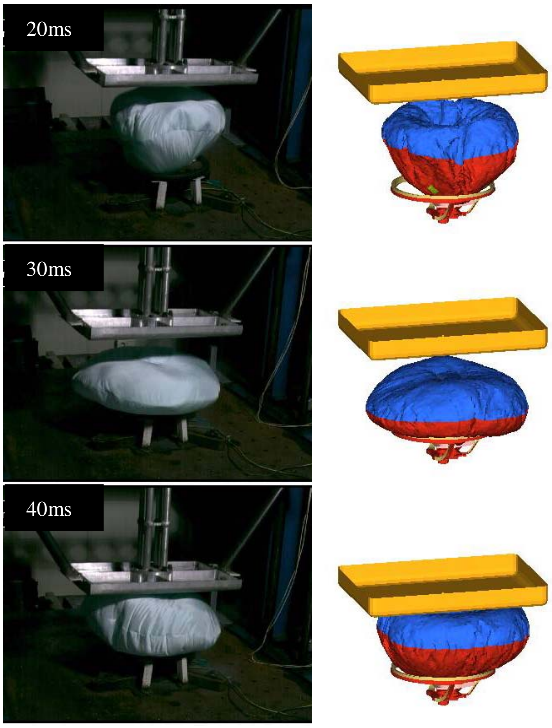
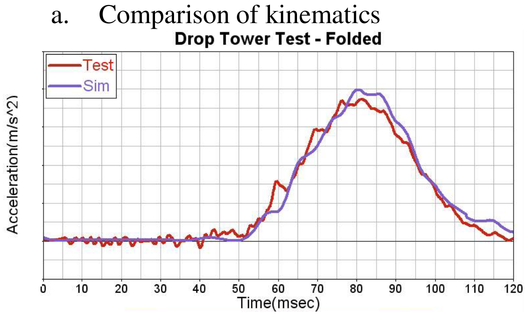


Figure 9. Initial stage of Drop Tower Test with folded bag



a. Comparison of kinematics



b. Comparison of acceleration of drop mass

Figure 10. Comparison between the drop tower test result and simulation result with folded bag

Driver Side Airbag Module – The folded airbag cushion is placed in the canister with Y-tear pattern cover. Tear seam mechanism that uses material failure of element requires smaller time step than the constraint failure mechanism and it can help to reduce the elapsed CPU time. The tear seams are defined as taking advantage of the constraint with failure.

The dynamic relaxation is conducted as a type of pre-simulation until the internal energy of the folded airbag cushion in the canister reaches sufficiently stable state as shown in Figure 12.

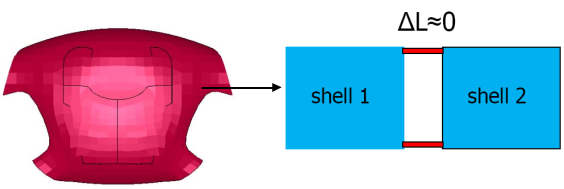


Figure 11. Tear Seam Mechanism

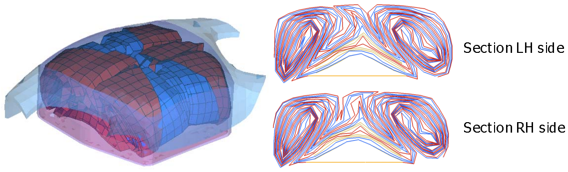
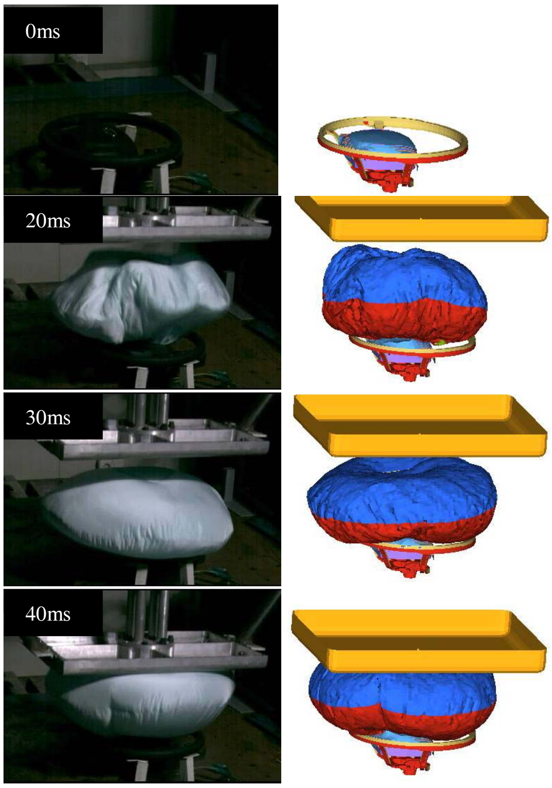
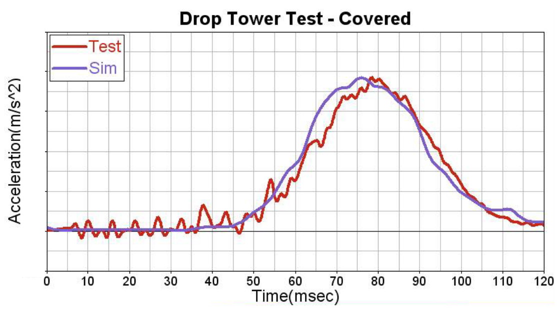


Figure 12. Dynamic relaxation of folded airbag within canister

Drop tower test with airbag module is conducted to validate the DAB module model. In this phase parameters related to the contact definition between the DAB cover and the airbag fabric is tuned. These three drop tower tests and simulations with the uniform pressure method contribute to fast confirmation of the parameters related the gas leakage, contact, stress and strain.



a. Comparison of kinematics



b. Comparison of acceleration of drop mass

Figure 13. Comparison between the drop tower test result and simulation result with airbag module

Static Deployment Test and validation

The drop tower test is a widely used tool for the validation of the airbag characteristic. Good correlation between the tests and simulation models in of the measured acceleration has been achieved with the conventional FE airbag models based on uniform pressure method. Although the reliable and predictable airbag model for fully deployed status provides a confidential result in interaction between the airbag and the in-position occupant, in case of evaluating the injuries of occupant in airbag hazard area or out-of-position and the airbag module design such as the effect of different airbag folding patterns on the OOP occupant or the DAB cover, the drop tower test is not a suitable validation tool.
In OOP situation, the airbag shape and reaction force on each region in time history are important factors for the occupant injuries. Various dynamic test methods with the head form, pendulum or the matrix of load cells have been developed to provide a better evaluation data for airbag deployment simulation model. The distribution of the pressure inside airbag provides an insight into the airbag module and a direct comparison between a test and a flowing gas integrated simulation, whereas the simulation that uses impactor has additional interaction between airbag and impactor. To this purpose, airbag static deployment tests were conducted to acquire the pressure distribution inside a folded airbag and covered airbag.
The folded and covered airbag are modeled with a corpuscular method using 200,000 particles in LS-DYNA for the gas flow, based on the previously validated model with the uniform pressure method and the drop tower tests.

<u>**Folded Driver Side Airbag**</u> **–** Airbag static deployment test and simulation with folded driver side airbag is conducted. The transmission hose is fixed onto the retainer ring of airbag and the pressure transducer is connected with the transmission hose. Even though the transmission hose is fixed onto the airbag fabric for flat airbag, the mounting of transmission hors for folded or covered airbag is subjected to restriction on position. The folded airbag is mounted on the steering wheel and inflated with primary output because the primary output of advanced airbag is adopted for static OOP tests scenario of FMVSS 208 issued by NHTSA.
The pressure peak level at the early moment of the deployment, punch-out phase, of the simulation is substantially coincident with the test data. The decrease in pressure during opening the airbag is also observed, and similar pressure level can be seen in the fully deploying stage. The kinematics during airbag opening of the simulation is coincident with the test data before 15ms. The central area of simulation result expands more toward the perimeter of the bag. But a subjective evaluation provides little information such as the above mentioned, so quantitative assessment method is adopted to evaluate the accuracy of the simulation model in kinematics.

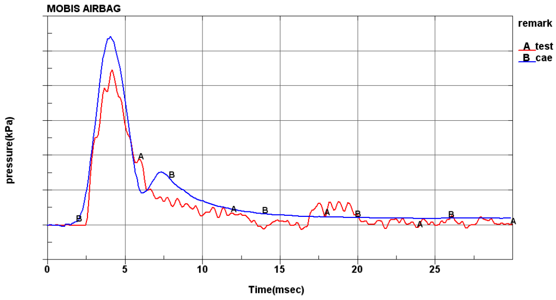


Figure 14. Comparison between the test pressure result and simulation result with folded bag and primary inflator output

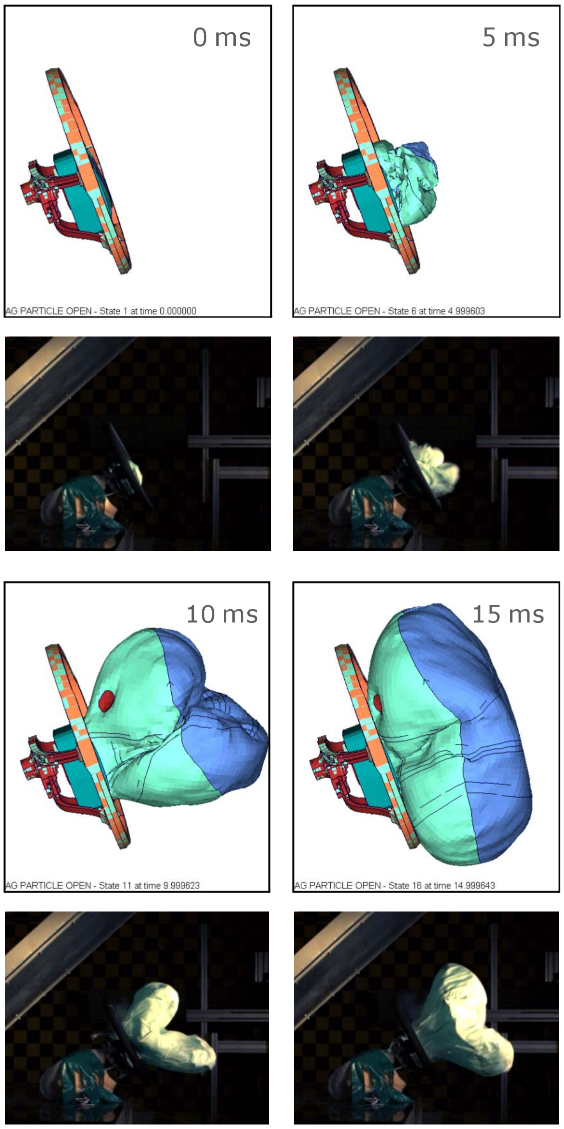


Figure 15. Airbag deployment kinematics with folded bag and primary inflator output

Radial lines with origin in steering wheel are used for estimation of the deployment shape error between test and simulation. 19 lines are used for side view and 36 lines are used for front view as depicted in figure 16. The test and simulation result are scaled in the same size and then positioned at same origin. The distance between the origin of radiated line and intersection on airbag outline is measured. Total error is calculated with equation below.

$$error = \frac{L_{test} - L_{cae}}{L_{test}} \times 100$$

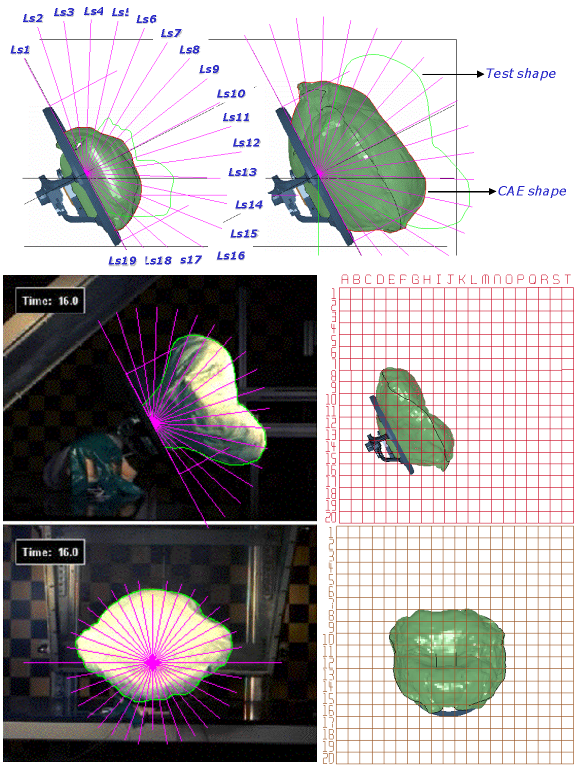
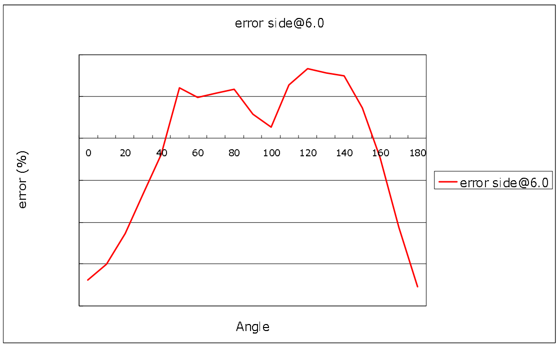


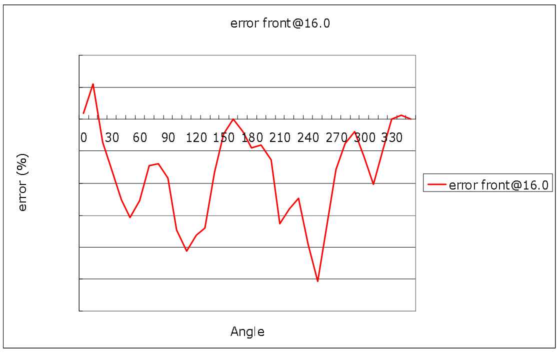
Figure 16. Radiated lines for quantitative error assessment

	side t=6.0				side t=16.0			
	L_test	L_cae	error	error sum	L_test	L_cae	error	error sum
1	72.16	120.89	-67.5	67.53	72.20	123.76	-71.4	71.41
2	75.23	120.48	-60.1	60.15	77.20	163.44	-111.7	111.71
3	82.16	119.51	-45.5	45.46	85.67	217.46	-153.8	153.83
4	90.92	115.22	-26.7	26.73	100.88	147.90	-46.6	46.61
5	104.17	112.08	-7.6	7.59	145.42	250.88	-72.5	72.52
6	147.24	111.97	24.0	23.95	314.62	269.36	14.4	14.39
7	140.77	113.29	19.5	19.52	335.00	264.95	20.9	20.91
8	144.89	113.33	21.8	21.78	344.19	244.00	29.1	29.11
9	144.65	111.00	23.3	23.26	331.86	231.96	30.1	30.10
10	135.38	119.70	11.6	11.58	307.92	236.50	23.2	23.19
11	131.03	124.11	5.3	5.28	292.62	251.53	14.0	14.04
12	184.04	137.02	25.5	25.55	317.04	274.15	13.5	13.53
13	214.64	143.13	33.3	33.32	363.40	292.38	19.5	19.54
14	214.04	147.63	31.0	31.03	377.48	281.13	25.5	25.52
15	222.87	156.41	29.8	29.82	341.34	272.81	20.1	20.08
16	195.26	166.82	14.6	14.57	173.22	220.24	-27.1	27.14
17	158.87	173.95	-9.5	9.49	114.60	181.79	-58.6	58.63
18	125.90	179.40	-42.5	42.49	98.67	153.15	-55.2	55.21
19	101.55	173.31	-70.7	70.66	85.27	135.99	-59.5	59.48
	error ave(%)			**30**	error ave(%)			**46**

Table 1.
Results of quantitative error assessment in side view for folded airbag



a. Side view@6ms



b. Front view@16ms

Figure 17. Deployment shape error for folded airbag

The measured distances and errors in side view at 6ms and 16ms are summarized in Table 1. The diagram of error in terms of angle provides insight into the tendency of shape difference. The average error for folded airbag's kinematics is 29% and a point of reference has to be determined through statistical research.

Driver Side Airbag Module – Airbag static deployment test and simulation with covered driver side airbag (DAB Module) is conducted. The covered airbag are modeled with a corpuscular method in LS-DYNA for the gas flow, and the model is based on the previously validated model with the uniform pressure method and the drop tower tests. The distances and errors are also measured for covered airbag in side view and front view.

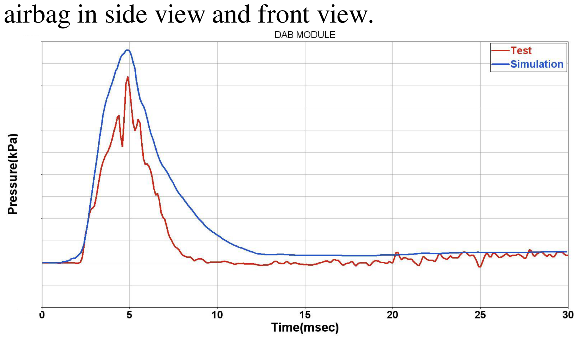


Figure 18. Comparison between the test pressure result and simulation result with covered airbag and primary inflator output

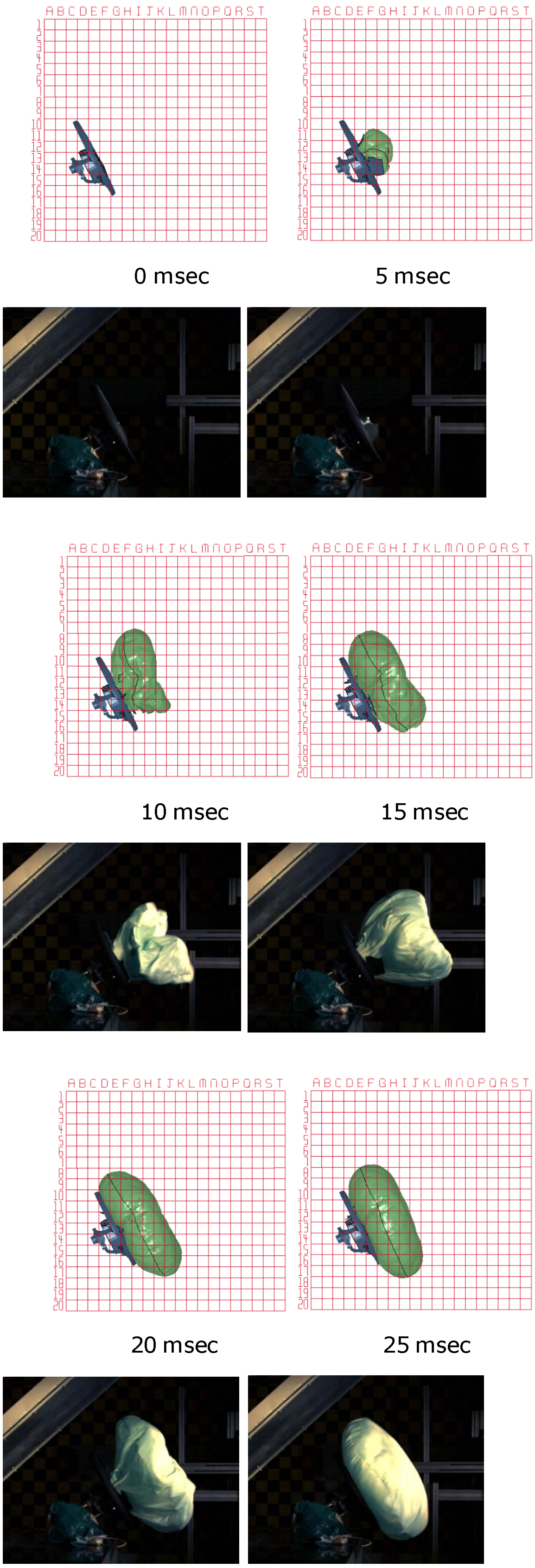


Figure 19. Airbag deployment kinematics with covered bag and primary inflator output

Good correlation of the pressure peak level was observed at the early stage of deployment (about 5ms) and the pressure level at the fully deployed stage (about 25~30ms) of the simulation is coincident with the test data on the whole. The kinematics during airbag opening of the simulation is coincident with the test data before 15ms similar to the folded airbag simulation result.

CONCLUSIONS

The validation process to reduce the total simulation time has been developed. This validation process using the uniform pressure method and the corpuscular method alternatively can decouple the parameters into several problems; gas leakage, contact and cover tearing, the target parameter of validation can be easily determined through correlation to corresponding test data. The uniform pressure method (AIRBAG_HYBRID_JETTING) and the drop tower tests are employed to decide the gas leakage and the contacts. The corpuscular method (AIRBAG_PARTICLE) and small modifications for the contacts and cover tearing are appended to the model based on the validated uniform pressure method. Each validation stage corresponding to the drop tower tests and the static deployment tests shows the good agreement with experimental results in time history.

Switching the simulation method, from the uniform pressure method to the corpuscular method, is quite easy and has no discontinuity because the AIRBAG_HYBRID and AIRBAG_PARTICLE in LS_DYNA have similar parameters for airbag definition. As shown in Figure 20, proposed validation process, switching the simulation method alternatively, can shorten the total simulation time against the case using the corpuscular method only. Therefore the predictable and reliable simulation model is able to get easily, more accurate investigation into the airbag cushion and module design can be made to improve the occupant injuries.

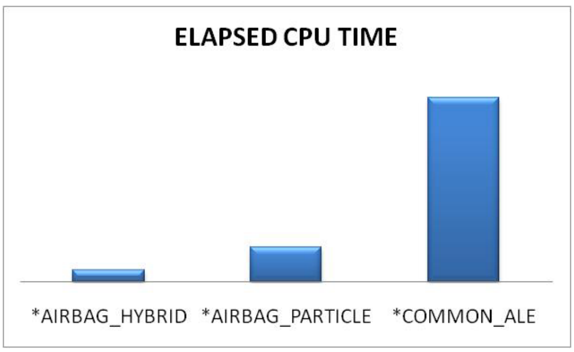


Figure 20. Comparison of computing time between the different simulation model on 4 CPU

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