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Numerical Simulation of Airbag and Study on the Effect of Airbag Parameters on Head Injury Criteria

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Abstract: In the case of an accident, inflatable restraints system plays a critical role in ensuring the safety of vehicle occupants. Frontal airbags have saved 44,869 lives, according to research conducted by the National Highway Traffic Safety Administration (NHTSA).Finite element analysis is extremely important in the research and development of airbags in order to ensure optimum protection for occupant. In this work, we simulate a head impact test with a deploying airbag and investigate the airbag's parameters. The airbag's performance is directly influenced by the parameters of the cushion such as vent area and fabric elasticity. The FEM model is analysed to investigate the influence of airbag parameter, and the findings are utilised to determine an optimal value that may be employed in the construction of better occupant safety systems.
Keywords: airbag, finite element method, occupant safety, frontal airbag, vent size, fabric elasticity, head injury criteria

I. INTRODUCTION

One of the most important goals in vehicle design is occupant safety and restrained systems play an essential part in preventing harm. During the collision vehicle begins to slow down but the occupant continues to travel at the same rate of velocity toward the point of impact So, Restraint systems are designed to slow the person for as long as feasible and absorb impact energy between the occupant and the vehicle interior. The most well-known passive restraint system for occupant safety in frontal crashes is the supplemental airbag restraint system. When a particular level of crash severity is reached, the airbag is automatically deployed and inflated airbag withstand some of the occupants' initial kinetic energy, then compressed to absorb them. These safety features can help minimise road fatalities, and their protective benefits have been widely recognized. An airbag's purpose is to slow the forward motion of the passenger as evenly as possible and absorb impact energy in a fraction of a second. An airbag is made up of three important components (Bag, Crash Sensor and inflation's system) that work together to achieve the goal. The airbag is composed of a thin, nylon fabric. It has a low coefficient of friction, which allows it to smoothly unfold and make soft touch with the skin. The airbag crash sensor differs depending on the manufacture, while all of their designs are based on the same principle, during the normal driving condition the circuit is opened and when the vehicle is subjected to deceleration around 15g due to collision then the circuit is closed that when the sensor sends information to airbag to inflate.

Fig. 1: Airbag deployment during crash

The airbag's inflating mechanism interacts with sodium azide (NaN_3) with potassium nitrate (KNO_3) .It produces a large volume of nitrogen gas, which rushes into a nylon bag stored below the steering wheel. As the bag grows, it blows the steering wheel's plastic cover off and inflates in front of the driver.

The time it takes for an airbag to fully inflate after the first impact of a collision is roughly 40 milliseconds, and within that time, the airbag transforms from a folded condition to a completely inflated condition with a high internal pressure. Meanwhile, after the airbag is fully inflated, the deflating process begins. Due to the high pressure of the airbag chamber relative to ambient pressure, the gas in airbags discharges out from vents, providing a comfortable cushion for the body contacting it. At this point, the victim in the accident should ideally come into touch with the airbag.

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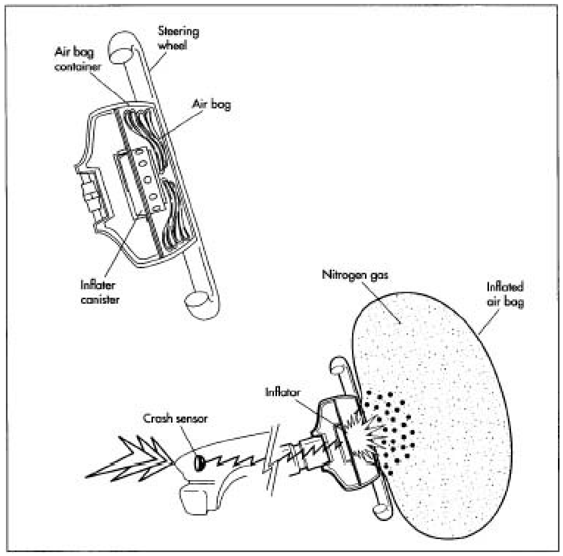

Fig. 2: Airbag deployment mechanism

The initial development was to capture the effect of dummy hit on fully inflated airbags and improve the result. Later on, deployment of kinematics of folded airbags, variable folding methods, and vent-hole design became progressively crucial.

The finite element method has been widely employed in industry for modelling and simulation of airbag inflation and its interaction with occupants. The gas dynamic during inflations is very crucial to represent the airbag accurately in finite element method. The control volume (CV) method has traditionally been used to imitate airbags. Using mass flow and temperature curves acquired from a tank test, the pressure within the airbag is calculated. Using simulation technologies, it is possible to optimise the parameters of airbag deployment. The main aim of study is to the evaluate the performance of airbag deployment and investigate the influence of airbag parameter using finite element methods.

II. METHODOLOGY

In this Study Using Finite element analysis the child headform were impacted on the fully deployed airbag and the head injury criteria were investigated with the influence of airbag parameters such as vent size, input gas temperature.

Modelling the airbag in finite element methods involves two important aspects, modelling the inflator gas flow inside airbag, Airbag material characterization.

A. Gas Modelling Technique

Finite element modelling of airbags utilizes pretty complex techniques such as Arbitrary-Lagrangian- Eulerian method, corpuscular (particle) method and Control volume method to describe the inflator gas flow inside the airbag. Because of the lower computational, the interior of the airbag is represented using the control volume technique. A control volume is defined as the volume contained by an airbag fabric control surface and a gaseous interior in the control volume.

An inflator pumps high velocity gas into an airbag during deployment, causing it to inflate fast. Wang and Nefske developed uniform pressure methods to approximate the time-dependent behaviour of the interior pressure of the bag. [4]

Using the Gamma law equation of state we can determine the pressure in the airbag with relation to gas density and specific internal energy. Furthermore, the gas inside the airbag is considered to be ideal and also have constant entropy.

$$p = (\gamma - 1).\rho.e \tag{1}$$

Here p, ρ, and e are respectively the pressure, density, and specific internal energy, and γ is the ratio of the heat capacities of the gas. There are two distinct states of specific internal energy e1 and e2 , each with distinct specific volumes v_1 and v_2 at two different state is given by

$$e1 = e2[v2 / v1]^{1-\gamma} \tag{2}$$

Control volume, gamma law of equation, and specific internal energy equation, all of these equations were combined to create a pressure-volume relationship for airbag inflation.

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B. Material Modelling

To determine the mechanical characteristics during airbag inflation, an orthotropic material model must be defined. For the Airbag Fabric a composite orthotropic elastic material model presented in the LS-DYNA manual is utilized. Three material constants must be specified to represent the airbag as an orthotropic model.

The fabric has a high level of material nonlinearity and is unable to withstand compressive and bending forces. Assuming a plane stress condition, Material model is implemented by transformation of the Cauchy stress tensor and strain tensor with a material local coordinate system. Stress state is incrementally updated by the material coordinates are given by

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{Bmatrix} = \begin{pmatrix} Q_{11} & Q_{21} & 0 \\ Q_{12} & Q_{22} & 0 \\ 0 & 0 & Q_{66} \end{pmatrix} . \begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{Bmatrix}$$

Fig. 3: Stress State Matrix

Where the normal stress is denoted by σ and the shear stress is denoted by τ the principal material direction is referred by the subscripts and ε is normal strain and γ is shear strain in strain tensor .The material elastic constants Qij are defined as follows

$$Q_{11} = \frac{E_1}{1\text{-}\nu_{12}.\nu_{21}} \text{ , } Q_{12} = \frac{\nu_{12}.E_2}{1\text{-}\nu_{12}.\nu_{21}} = \frac{\nu_{21}.E_2}{1\text{-}\nu_{12}.\nu_{21}}$$

$$Q_{22} = \frac{E_2}{1\text{-}\nu_{12}.\nu_{21}} \text{ , } Q_{66} = G_{12}$$

Fig. 4: Material Elastic constants

The Poisson ratio of the material is denoted by νij the subscripts j represents the direction of transverse strain for a material which undergoes the stress in the ith direction and Gij and Eij are the shear modulus and Young's modulus of the material respectively Material Table I.

TABLE I
Material properties for the airbag fabric

Parameter	Value
Density (kg/mm^3)	8.76e-07
EA-Young's modulus - longitudinal direction	0.3
EB-Young's modulus - transverse direction	0.2
Poisson ratio	0.2

C. FEM Modelling

The airbag modelling was carried out in Hypermesh and the airbag simulation was carried out in LS-DYNA. To examine and optimize the airbag using Finite element analysis, we required the FE model of the airbag which consists of three parts: Airbag itself, Inflator Can, and Tether.

The airbag's starting condition is a closed rectangle with sides to be 620x 620 mm2 with 2 vent holes, as illustrated in Figure 4. It's modelled with 2D element Belytschko-Tsay membrane formulation (ELFORM 5) which is a fully integrated membrane that is recommended for fabrics materials where bending stiffness is negligible.

The airbag material is simulated using the material model FABRIC (MAT 34).The membrane element was discovered to be particularly well suited to orthotropic fabric behaviour, Though wrinkling normally occurs in airbags under larger deformation.

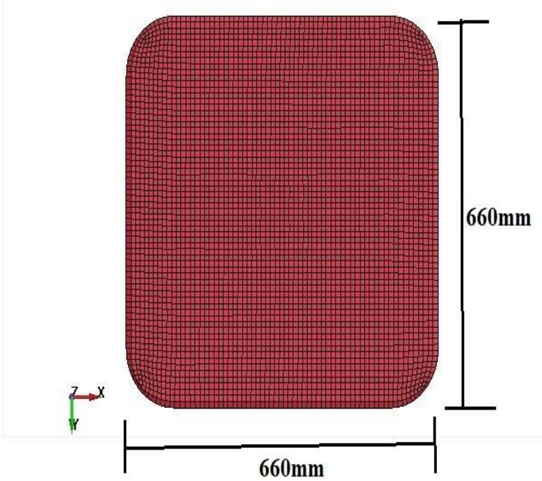

Fig. 4: Airbag dimension

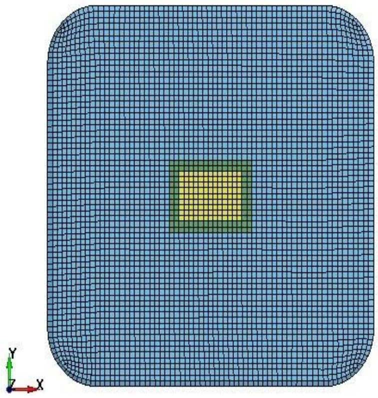

Fig. 5: Airbag Bottom View

The Compressive Stress Elimination Option for Airbag Wrinkling is set to be CSE= 1 (the "no compressive stress") which switches off compressive stress in the fabric, thereby eliminating wrinkles. Table 1 shows the numerical values for the fabric material and geometric properties of the airbag. For a given airbag, Atmospheric temperature, Atmospheric pressure, Atmospheric density temperature of the gas , coefficient for molar heat capacity of inflator gas at constant pressure and molar weight and load curve for the mass flow rate were defined .The numerical values for the above are presented in Table II.

TABLE III
Thermodynamic properties of the gas and ambient AIR

Parameter	Value
Atmospheric Pressure[GPa]	1.013e-04
Atmospheric Temperature [K]	294.4
Atmospheric Density [Kg/mm^3]	1.20e-9
Universal molar gas constant.	8.3140001
Molecular weight [kg/mol]	0.02897

The gas outflow (vent) was characterised by an exit hole discharge coefficient (C23) and exit area (A23).For the mass flow rate, a load curve was created.

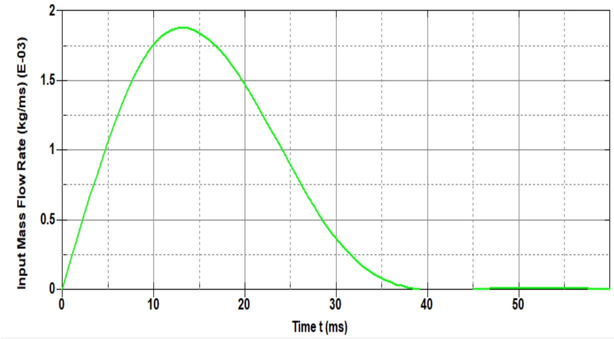

Fig. 6: Mass Flow rate for airbag

There is Possibility during the inflation of airbag that nodes might penetrate into its surface due to large deformation, so to eliminate the penetration between nodes and surface, we have defined an Airbag Self-Contact using AIRBAG_SINGLE_SURFACE with segment based (SOFT=2) formulation.

These Bags need to be packed in small spaces and should be deployed within milliseconds to provide appropriate protection to the occupant. It is important to acquire the ability to simulate the intricacies of the folding pattern in a finite element model of an airbag, to able to achieve accurate deployment.

LS-PrePost offers various tools to model airbag folding patterns. The airbag folding in our setup was executed through the airbag folding toolbox option. Where the folding lines and direction of fold can be setup, the spiral folding pattern was executed in our model as shown Figure 7.

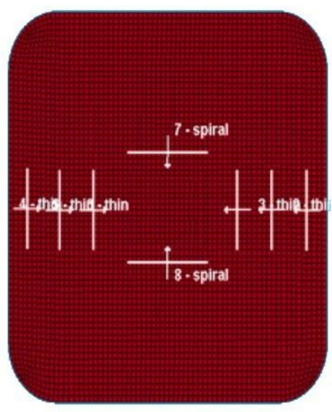

Fig.7: Folding lines

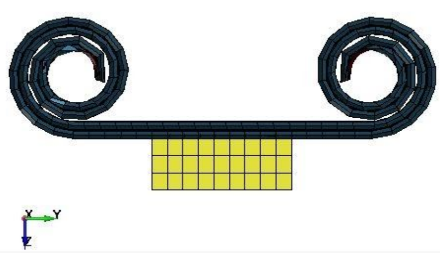

Fig. 8: Spiral Fold – Side View

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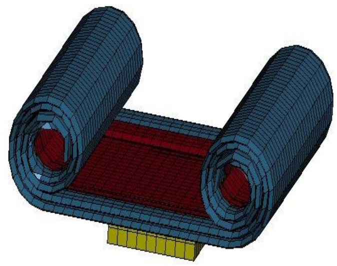

Fig. 9: Spiral Fold – Iso-view

To study the Head injury criteria of the child head impacting on deploying airbag, the FE Model of Child Headform impactor was utilized. The head is made of a spherical shape of 165 mm overall diameter. This sphere is covered with a 14 mm thick synthetic rubber skin, covering more than half of the front face, while having provision for instrumentation at the flat rear face. The total mass of the Child Head is 3.5 kg, with the centre of gravity (CG) located at the geometric centre of the sphere.
A triaxial accelerometer is mounted in the sphere recess, used for measuring the total acceleration of the impactor during impact and subsequently the Head Injury Criterion (HIC) value. [2]

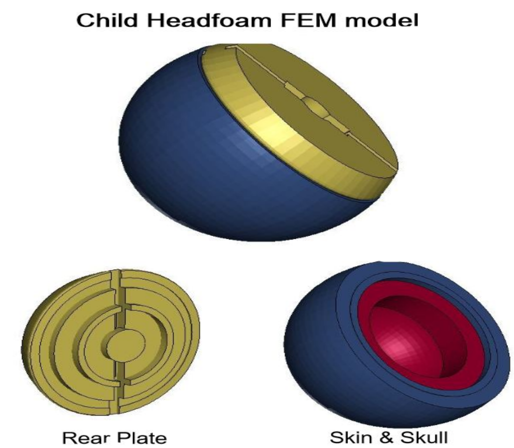

Fig.10: Child head FE Model

The head's initial velocity is defined as 35km/hrs.*CONATCT_AUTOMATIC_SURFACE_TO_SURFACE with segment-based contact algorithm formulation (SOFT=2) was defined between the airbag and child head.

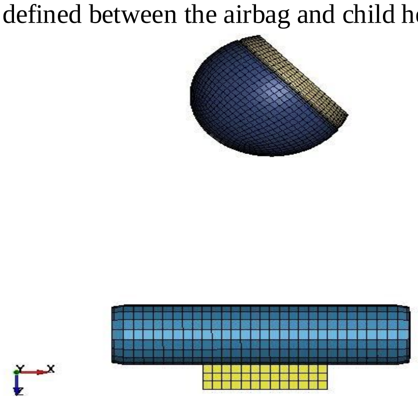

Fig. 11: Airbag and Head Setup

The evolution of head injury criterion and volume, pressure of the airbag was studied by modifying different airbag parameters such as Vent size and Fabric elasticity.

III. SIMULATION RESULTS

As a first step, the airbag deployment was performed in order to understand the airbag characteristics and behaviour. Next, a child head impact analysis was performed in order to examine how the interaction of head affects the airbag behaviour. Finally, a parametric study is conducted for airbag variables such as vent size and fabric elasticity.

A. Airbag Inflation

In this section the result of airbag inflation from the initial position is discussed where no vent is assumed in the first model. The total simulation time is 40 millisecond. Figure 12 Displays airbag at various inflation phases. Figure 13 interpret the airbag volume during the inflation process within half of the termination time (i.e. 20 millisecond) 90% of the whole volume is filled. In the present simulation the maximum volume of 87 litres reached at 40 milliseconds, which validates with actual volume of driver airbag. Figure 14 shows the pressure inside the airbag during the inflation, the peak pressure is observed at the first stage of deployment because the spiral fold is packed tight so the pressure required to unfold and deploy freely is more in the first stage.

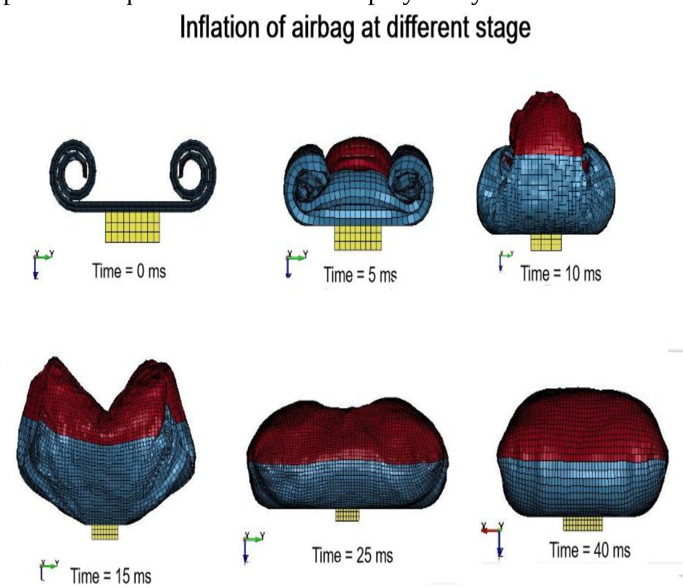

Fig. 12: Inflation of airbag at different stage

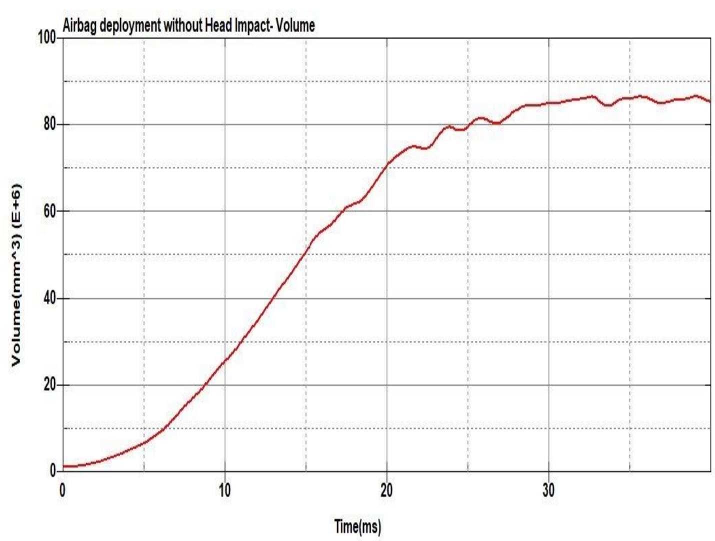

Fig. 13: Airbag Volume

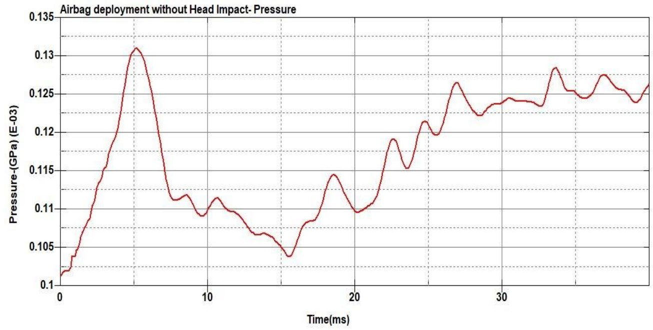

Fig.14: Airbag Pressure

B. Interacting of Airbag with Child Headfoam

The Child Head was initially 280mm away from the airbag and travelled at a speed of 7 metres per second. Figure 11 depicts the airbag and child head form finite element model setup. The airbag's material and physical qualities are the same as those detailed discussed previously. The airbag was inflated until 14 milliseconds, and the head continued to move at a steady speed without colliding with the airbag. Between 14 and 15 milliseconds, the head made contact with the airbag, and by 22 milliseconds, the head had entered the airbag and reduced its volume. The head bounces back from the airbag after 22 milliseconds Figure 15 compares the volume inside the airbag with head impacting and without head impacting on airbag. The volume of both cases remains same till 15millisecond, once the head comes into contact with airbag (i.e. after 15ms) the volume of the airbag reduces.

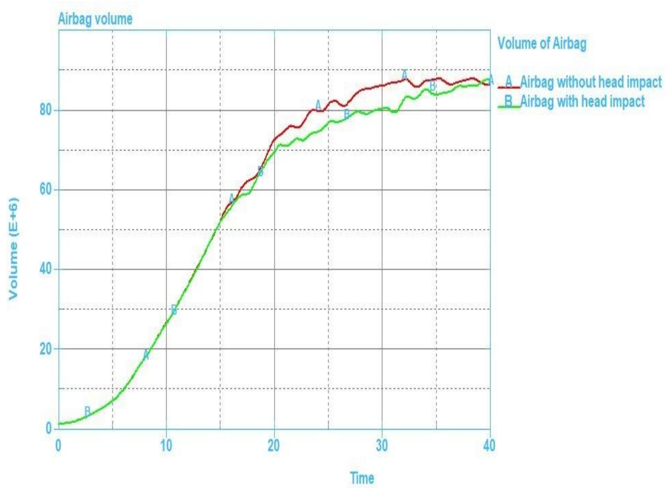

Fig. 15: Airbag Volume with and without head impact

Figure 16 depicts the pressure inside the airbag with a head impact versus without a head impact. As shown in the figure the maximum pressure is attained with head impacting on the airbag cases because when the head impact with the airbag the volume of the airbag reduces which eventually increases the pressure inside the airbag

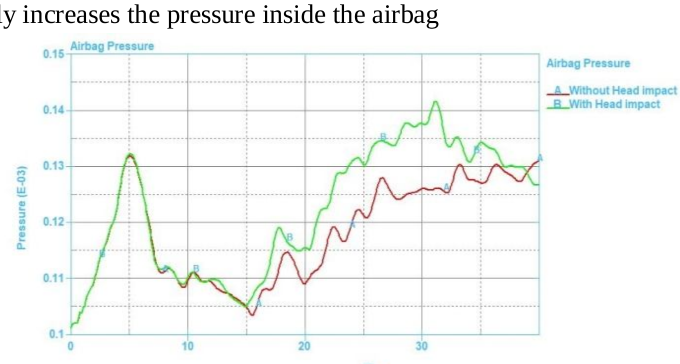

Fig. 16: Airbag Pressure with and without head impact

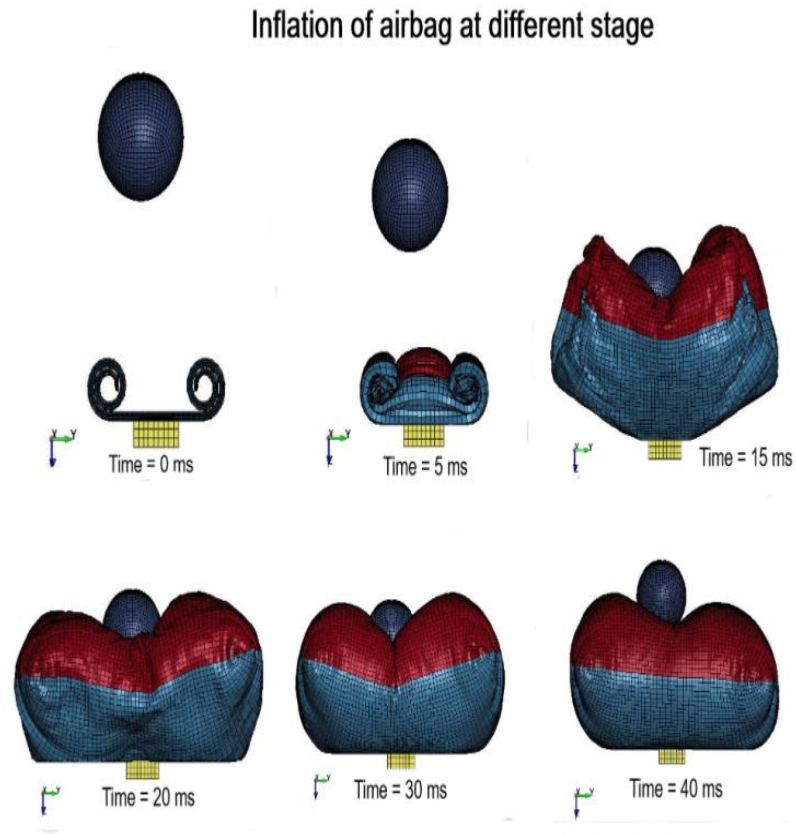

Fig. 17: Inflation of airbag with head impacting at different stage

The accelerometer inside the child head measures the head injury criteria Figure18 shows the HIC value of airbag impacting the airbag where no vent is considered.

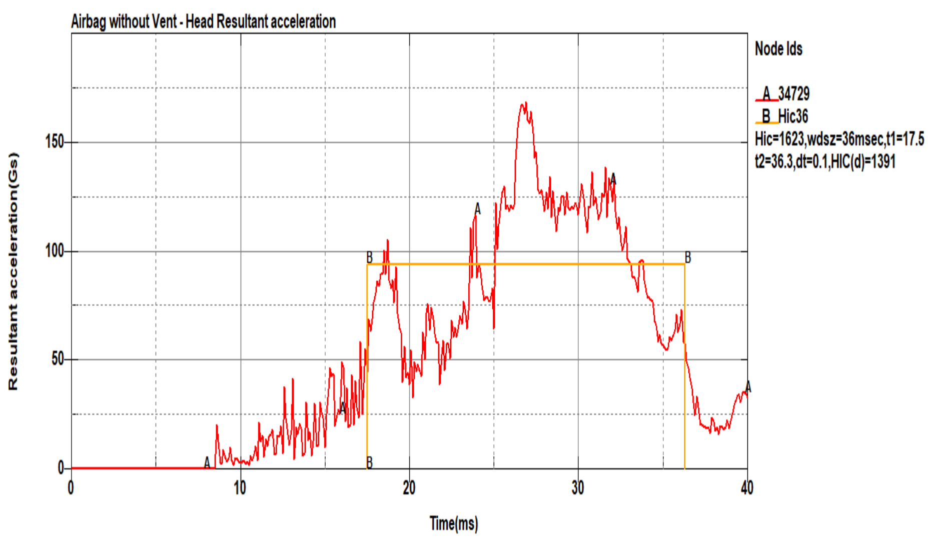

Fig. 18: HIC Value for the Child Head impacting on airbag without vent

However in the other cases the vent size and elasticity of the fabric are modified to better understand how these parameters affect Pressure, volume of airbag and HIC of the child head.

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C. Effect of Vent Size

The influence of vent size parametric variation on the development of pressure volume and HIC is investigated. Three different vent sizes were studied varying from zero, 5.00cm2, 10.0cm2.The vent hole's discharge coefficient is considered to be 0.7 in all circumstances. The initial contact time is at 15 milliseconds which is same for all three cases.

The volume of the airbag in all three cases was studied. In Figure 19, the airbag with no vent had the highest volume, while the airbag with a 10cm2 vent size had the lowest volume. As the vent size increases the mass outflow of the airbag also increases as result in decrease in the volume as the vent size increases.

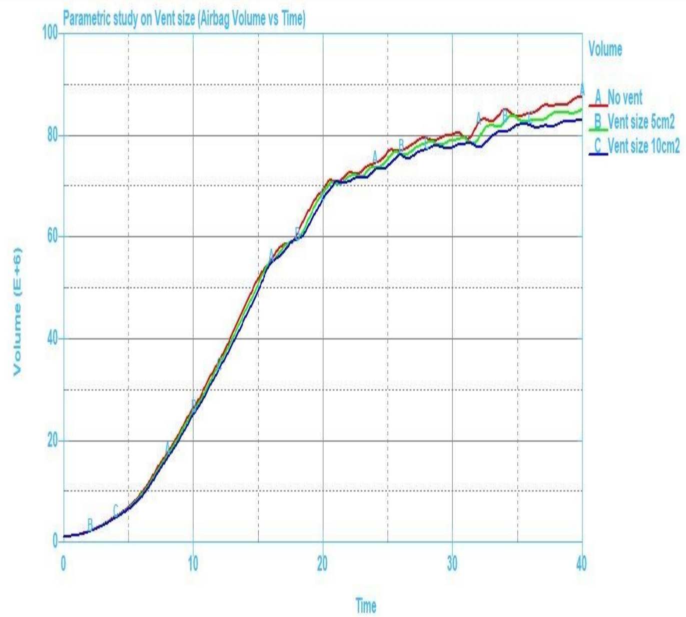

Fig. 19: Airbag Volume for different vent size

The pressure behaviour in all three cases were also studied, As the Figure 20 interprets the airbag with no vent had the highest Pressure, while the airbag with a 10cm2 vent size had the lowest Pressure. Because of the airbag's vent, which allows some of the pressure to dissipate as the head collides with it, as the size of the vent increases the pressure dissipation also increases which results in reduction in total pressure of the airbag.

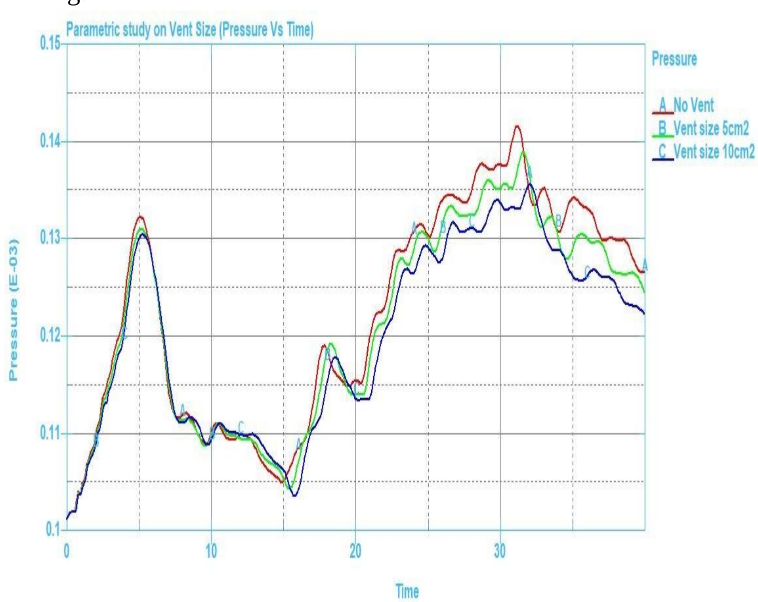

Fig. 20: Airbag Pressure for different vent size

The HIC value for the no vent airbag is recorded as 1623 and 1471 and 1326 for 5cm2 and 10cm2 respectively as show in Table III.

TABLE IIIII
Head Injury Criteria for different vent size

Vent Size	Head Injury Criteria
No Vent	1623
$5cm^2$	1471
$10cm^2$	1326

Reason of the HIC changes with respect to the vent size can be observed by resultant velocity of the head as Figure 21 shown below.

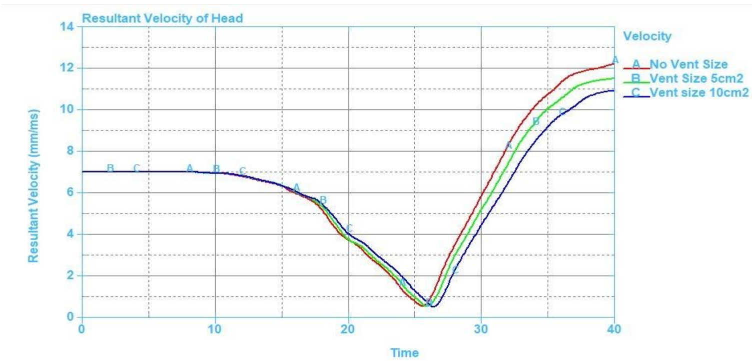

Fig.21: Resultant velocity of head for Different vents size

The resultant velocity of the head for all three cases is Shown in Figure 21, as the Figure interprets the time when the head rebounds backs and the rebound velocity of the head are different in all three cases, Airbag with no vent has the highest rebound velocity thus results in Higher deceleration of the head and the airbag with 10cm2 vent size has the least rebound velocity which results is lower deceleration. Since the head injury criteria is calculated based on the deceleration of head, Highest HIC value is experienced on the airbag without vent and Lower Value on the airbag with largest vent hole (10cm2).

D. Effect of Fabric Elasticity

To study the effect of Fabric Elasticity on airbag deployment and influence on head impact. Parametric study was carried with three different young's modulus for the Airbag fabric material 0.25kg/mm2, 0.30kg/mm2 and 0.35kg/mm2 .Material properties of the airbag are same for all three cases expect the young's modulus and The vent size and vent hole's discharge coefficient are considered to be 10cm2 and 0.7 respectively in all cases. According to the pressure curve in Figure 22, airbags with a higher Young's modulus have a marginally greater pressure than others. According to the Volume graph in Figure 23 the airbag with the lowest Young modulus has the largest volume.

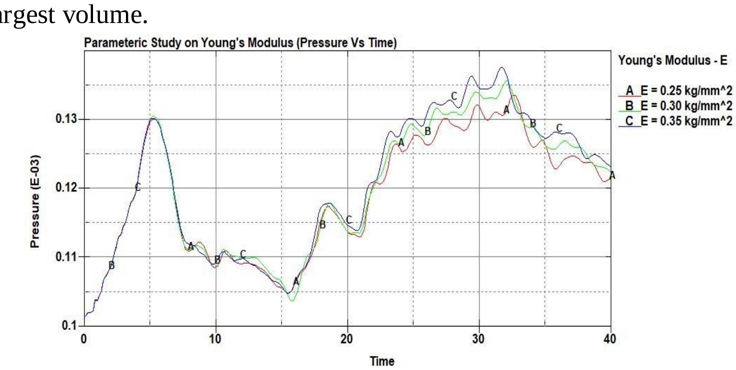

Fig 22: Airbag Pressure for different Young's Modulus

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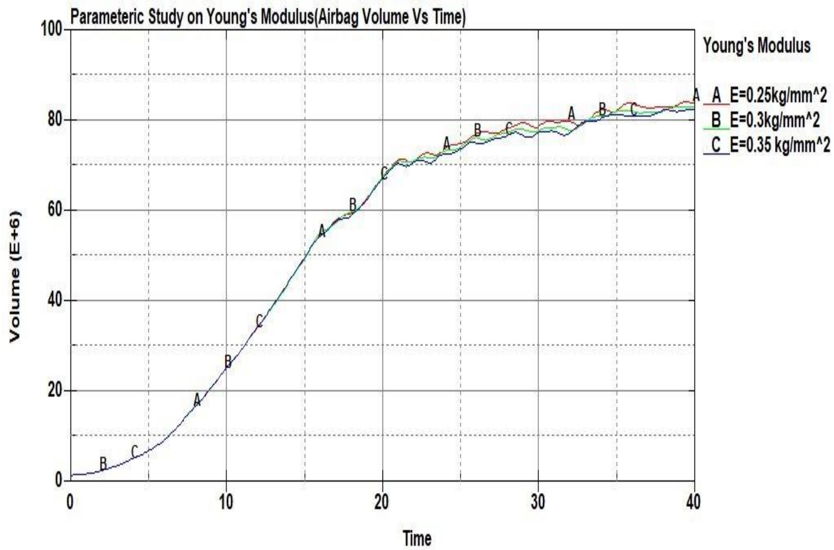

Fig. 23: Airbag Volume for different Young's Modulus

As indicated in the Table IV, the airbag with the lowest Young modulus had the lowest HIC value, whereas the airbag with the maximum Young modulus had the highest HIC.

TABLE IVV
Head Injury Criteria for Young's Modulus

Young's Modulus	Head Injury Criteria
0.25kg/mm^2	1189
0.30kg/mm^2	1326
0.35kg/mm^2	1409

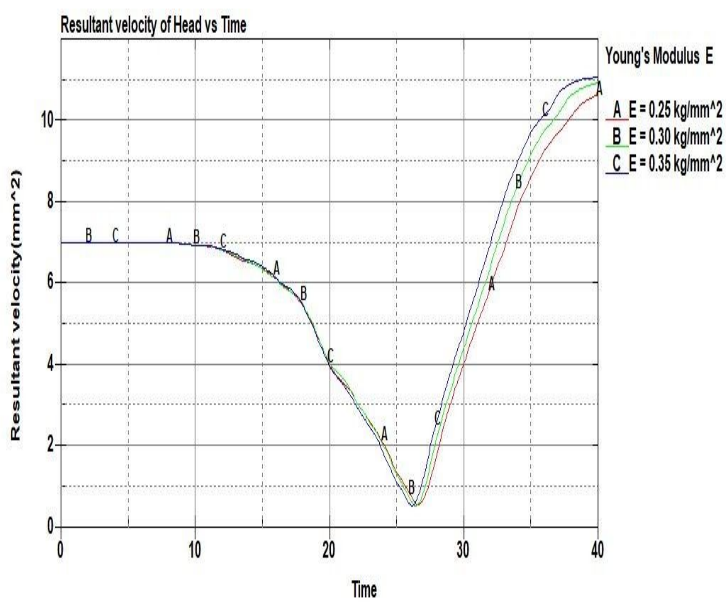

Fig. 24: Resultant velocity of head for different Young's Modulus

The resultant velocity of the head for all three cases was shown in Figure 24. From the figure the Initial contact time of the head is same in all three cases but the contact duration is larger for the airbag with lower young modulus and least in the airbag with higher young modulus because the young's modulus determines the stiffness of a material. As a result, the lower the young modulus is the more flexible the fabric is allowed to stretch and deform which in turn absorbs more force from the head and slows the rebound velocity which is why the least rebound velocity is record in the airbag with lower young's modulus and highest young's modulus is recorded in the airbag with larger young's modulus.

IV. CONCLUSION

A Finite element analysis of airbag folding and deployment was carried out in LS-DYNA. Airbag modelling and spiral fold were modelled in the initial step to investigate airbag behaviour, second the initial stage airbag model was impacted against the child head foam to examine head injury criteria and study airbag response characteristics during and after impact.

In the Last phase, a parametric study was performed to improve the injury criteria and to investigate the significance of the airbag parameters during collision with the child head. The airbag parameters that were taken into account were vent size and Young's Modulus of the airbag fabric.

Based on the simulation, it was determined that vent size has a significant impact on occupant safety. As the vent size increases the head's acceleration decreases, resulting in less head injury. In addition, the vent size is directly proportional to the amount of gas dissipated, so when the vent size is increased, the airbag pressure and volume are also reduced.

The change in fabric Young's modulus had no significant influence on airbag parameters like pressure or volume, but it did have a substantial impact on the head injury criterion. The least head injury criterion were those with a lower young's modulus, which caused the fabric to deform and stretch more which absorbed more force from the head during the collision.

With the aid of the finite element analysis tool, we were not only able to simulate airbag deployment, but also investigate the factors that influence airbag deployment and occupant safety, which allowed us to create a safer design. It is necessary to conduct testing using real-world airbags and compare the experiment results and verify the findings. This will be done in the near future.

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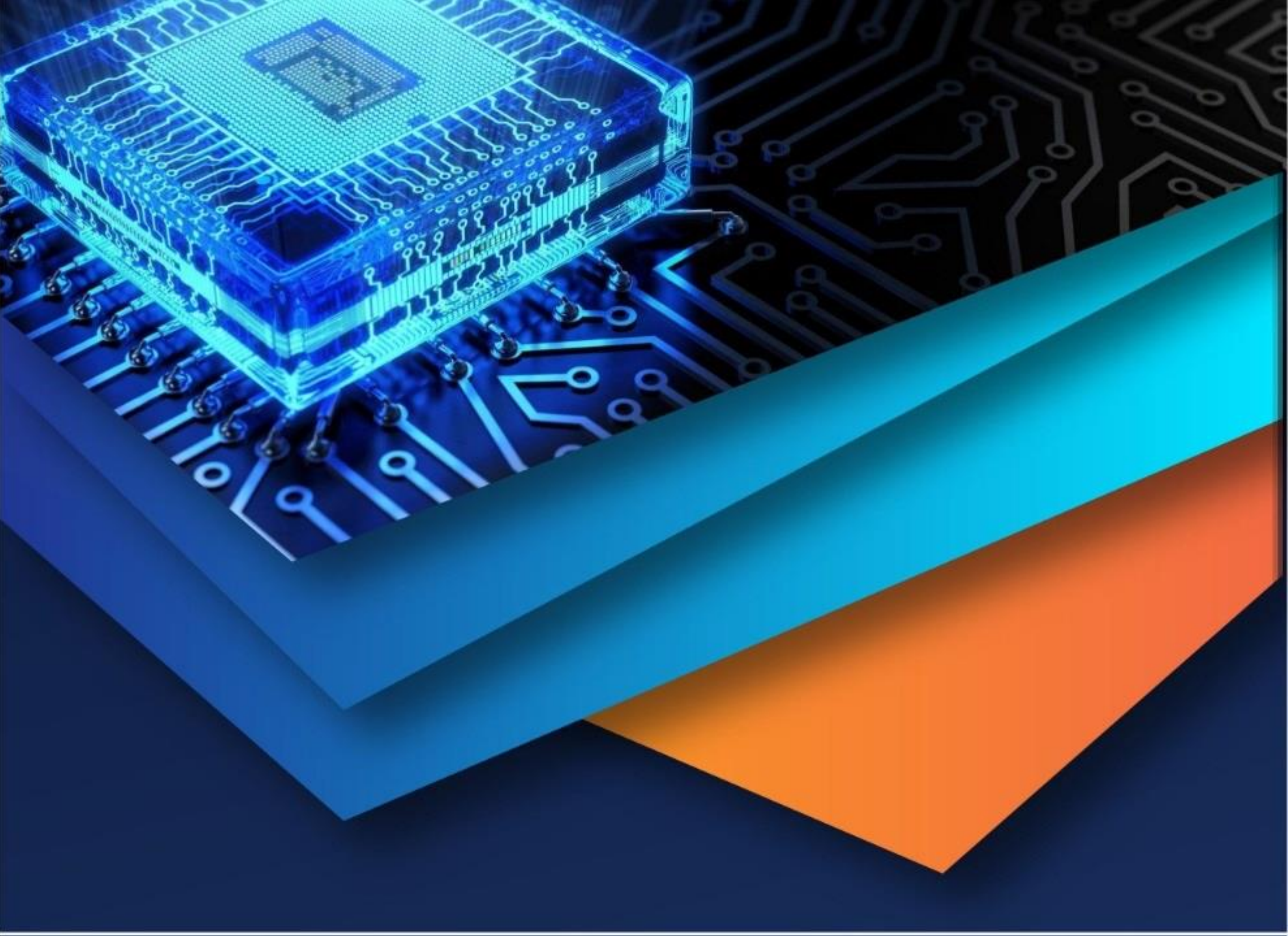

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