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Airbags Simulation Using ABAQUS software

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ABSTRACT
The airbag is one of the most significant and vital safety devices needed for a car. After the invention of the airbag and its every increasing significance, this tool is widely used in passenger cars nowadays. As problems with airbag malfunctioning started to happen, the efforts to test and model the airbags took shape. Different tests have been conducted to optimize airbags and ensure their functioning. The project examined the production and the basics of airbags. Then the structure of the airbag was examined in detail. Testing the airbag was another issue stated in the project, and finally the airbag was simulated in ABAQUS.
Keywords: Safety, Airbag, ABAQUS

Introduction

For years, the safety belt was the only means of protection inside automobiles. At first, there were discrepancies about their safety, especially for the children but, with the pass of time, some regulations were enacted in various countries for the compulsory use of the safety belt. Statistics show that the use of safety belts has saved the lives of thousands of individuals who might have otherwise lost them in the accidents. It is now for several years that the airbags are being developed more [1].

The goal of air-bags' use is slowly reducing the forward movement of the passengers to the maximum possible extent so that the lowest damage can be imposed on them and the airbags should open in a fraction of a second. Early efforts were accompanied by many problems, including high price and technical difficulties. The quality of the opening as well as the refolding of the airbags is amongst these problems [2].

In fact, the whole process of the air-bags' functioning takes 1.25 seconds but this short time prevents or reduces the injuries to a considerable degree [3].

Since the beginning of the airbag industry's creation, the experts had predicted that the airbag and the safety belt should function one after the other. The existence of the safety belt was still viewed as being necessary because the airbag only acts at special speeds and, secondly, the passengers were just saved only by the safety belt in the accidents from the sides. Due to the same reason, the installation of the lateral airbags was placed atop of the agenda. Moreover, in accidents from behind, the safety belt plays an important role. Thus, although the airbag technology has undergone a lot of progress, this tool is still useful when it is applied along with the safety belt [4].

It did not take a long time before the researchers figured out that the airbag can cause severe injuries to the individuals that are in a close distance from them. They concluded that the risk zone is within a 5 to 8-inch limit from the air-bags' opening locus. Thus, if the driver is within a 10-inch (25-centimeter) distance from the steering wheel, s/he is in a safe zone. This distance is calculated from the steering wheel's center to the driver's forehead [5].

The engineers of Volvo Company[1] have tested various ways for installing the side airbags and, eventually, chose the installation of the side airbags in the section behind the front seat because this kind of installation enables the protection of the passengers in every dimension. In this method, the mechanical sensors are placed inside a pillow underneath the driver and the side passenger. This causes the non-opening of the airbag on the undamaged side. Furthermore, the air-bags' opening in trivial accidents like collision with a bicycle is prevented. These sensors work in accidents with speeds above 19 kilometers per hour [6].

The engineers of the credible BMW Company have embedded the side airbags in the doors of the vehicles. Since this section has more space, they are allowed to use larger airbags and protect more space.

Considering all these explanations, the airbag industry is rather new and it is rapidly progressing and there are many experts and specialists working and doing research on this technology.

It seems that the safety progresses made in the vehicles would reach favorable and capable results in future and, since an airbag is opened in every section of the vehicle and protects the passengers from hitting the hard objects, newer systems should be accordingly added. Amongst the future goals is rendering the safety systems and their equipment smarter. One of the recent advances in the safety equipment is the smart airbag. This airbag can open with various speeds and air pressures depending on the weight and place of the passengers as well as the intensity of the accident. Unfortunately, the opening of an airbag can sometimes cause serious injuries and even the death of the driver and the passengers. The new technology in the advanced front airbag has been designed for reducing the dangers and heightening the quality of the airbag. This technology's function has been taken into serious account [7].

It appears that airbags would be developed for all the spots of a car for the reason that there are currently vehicles being manufactured and commercialized with a large number of airbags. These bags prevent the various body parts from hitting hard objects. This tool is presently well performing its duty. The recent progress in this industry is recognized under the title of the smart airbags. These bags can be opened under various conditions and with various pressures and speeds. These variables depend on the weight and position of the passenger as well as the intensity of the accident. Unfortunately, in some of the cases, the opening of the airbag causes serious damages and, in some other cases, even the death of the passenger. The new airbag technology has been designed for such a purpose as reducing these dangers. The application of this technology is very important to the extent that the American association of vehicle safety has required all its manufacturing factories based on standard no.208 to use this kind of airbag in their productions within the next few years. You can see a list of the advanced front airbags in various vehicles. Since only a few of the scientific and applied issues enjoy theoretical solutions, the numerical modeling can be utilized as an inevitable instrument in the analyses. To do so, finite element software packages have been widely applied due to flexibility in application in a vast set of the geometrical forms, materials and loading conditions. In today's industrial world, this software type has been recognized amongst one of the most widely applied and most professional finite element applications which work a lot more strongly in contrast to the other software packages in terms of analysis. The use of the numerical methods for analyzing the research and manufacturing issues provides a strong tool for feasibility analysis and prediction of the conditions in the course of the process. Nowadays, the numerical methods are proper solutions in a vast spectrum of the issues in such a way that they have infiltrated in nearly all the science branches [8].

Amongst the software packages used for mechanical engineering's analyses such as ANSYS, LS-DYANA and others that work based on finite element method, ABAQUS is one of the strongest and most authentic finite element software packages having a particular position and popularity amidst the researchers. This software has the ability of analyzing very diverse issues, including expanded forming.

Considering the importance of airbags in the creation of safety for the vehicles' passengers, the present study has dealt with the modeling of airbags and investigation of the forces imposed on the passengers during the opening of the airbag. The above modeling has been carried out in ABAQUS because this software offers acceptable results in modeling and investigating the accidents' investigations.

Investigating the Structure of the Airbags

The work method and function of the airbag systems is similar to the military weapons in such a way that the exact and sensitive sensors sense the impact of the accident in a severe accident and, after analyzing by a controller, the required command is sent to the detonator which is inside an inflator. With the activation of the detonator, the chemicals existent in the inflator react and produce nitrogen and the gas stemming from it expands the bag within a short time. The airbag is expanded within a very short time (usually 0.04 to 0.06 seconds) based on the vehicle type and the airbag system and it is swiftly emptied after absorbing the bump [9].

Sensors are amongst the most important, most exact and most sensitive sections of the airbag system and they are employed for measuring the negative acceleration stemming from the accident and activation of the inflator. The regulation of the speed of action for the airbags is very important in regard to saving the passengers' life in head bumps. An airbag should be capable of expansion (inflation) within several milliseconds after the first severe collision. In addition, the airbag should not be expanded when the car has not collided with anything. Therefore, the first part of the airbag is a sensor capable of sensing the severe collisions and launching the airbag without any hesitation.

Automobile manufacturing companies have each adopted a special method for the use of the airbag sensors. Toyota divides the used sensors into three sets that are placed in various parts of the vehicle:

1) Front sensors
2) Floor sensors
3) Safety sensors

Inflator

One of the important and expensive parts of the airbags is the inflator which is actually the last activated section of the airbag system and, by inflating the airbag before the passenger, it prevents the imposition of serious injuries to the head or chest of the passengers. Disregarding the mechanicalness or electricity of the air-bags' sensors, it is necessary for the command sent to the inflator section to cause a fire order to the detonator followed by the explosion of the chemicals therein. The product of this explosion is the riskless gases that expand the airbag with a high speed and pressure. The chemical placed inside the inflator is sodium azide. The property of these materials is that they are decomposed as a result of high temperature with a high speed and produce a riskless gas that fills the airbag [10].

The inflating bag, as well, is applied for protecting the head and face of the passenger against the impact and absorption of it following which the internal gas is discharged immediately. Polyester and nylon form the materials of the airbags. Due to the following reasons, nylon is more appropriate for use in the airbag. Based on the performed studies, polyester is not suitable for airbags: its longitudinal strain and its moisture absorption is very low. Therefore, it is more appropriate for the safety belts. Since the material used for the airbag should have enough softness and can better absorb the shock, nylon 6 and nylon 66 are suggested for airbags.

Airbag's Cover[2]:

The material used for the airbag system's cover is PVC which is used for keeping the airbag inside its chamber. At the time of the system's functioning, the cover is torn apart from a specific place from which the bag exits. Therefore, since this section of the airbag system is used just for one time, this type of material has been used. The other important issue is that this material should have the sufficient elasticity and use is made of the strengthening vanes for keeping it from fragmentation as a result of tearing and it should also have the required safety for not colliding with and being thrown out to the passenger's side [11].

Gases Filling the Airbag and the Chemical Reactions

There is a generator inside the airbag consisted of a mixture of sodium azide, potassium nitrate[3] and silicon dioxide. Upon colliding with a thing from the front part, a series of reaction, including three chemical reactions, produce nitrogen gas that fills the airbag and the sodium azide which is very toxic (the highest permitted concentration of it is two milligrams per one cubic meter of air) is transformed into a neutral glass (an alkalic crystalline structure).

At first, sodium enters a reaction with potassium nitrate so as to create potassium oxide and sodium oxide plus nitrogen with the latter filling the airbag in a second reaction and creating metal oxides that cause the creation of a silicate glass made of silicon dioxide in a final reaction and it is harmless and stable. The metal oxides of the first period such as potassium oxide[4] and sodium oxide are active. Therefore, it would be dangerous if they were the final production of the air-bags' blast [12].

Calculation of the Amount of the Required Gas

Nitrogen is a neutral gas that inflates in the air-bags' temperature and pressure and its behavior is close to the ideal gases. Therefore, the ideal gas law is a good estimation for the relationship between the pressure and volume in the airbags with the nitrogen amount.

A specific amount of pressure is required for filling the air bag within several milliseconds. When this pressure was determined based on the law of the ideal gas, an amount of nitrogen should be produced for filling the airbag in this pressure. In the gas generator, the amount of sodium azide is carefully selected and calculated so that the exact amount of nitrogen gas could be produced [13].

Collision Test

Collision test is a scale for assessing the quality of an automobile's performance as well as its safety factors (including the power of shock absorbance by the chassis and body, airbag as well as absence of the dangerous regions for the passengers inside the room and so forth) during the accident. The standard of "the new automobile measurement and estimation program" is a credible standard in this regard and it was formed by the joining of several European standards in 1996 with its duty being specification of the amount of the damages imposed onto the passengers through automobile tests in real accidents. Two collision tests are usually carried out on every vehicle [14]:

1) The test of accidents from the front part: this kind of accident is statistically the most common kind of accident. Its simulation is done in the following way: the automobile is allowed to hit a rigid barrier covered with aluminum at a speed of 64kmph. This collision is equivalent to the accident between two cars each of which moving with a speed of 55kmph. One of the important cases in the accidents from the front part is the driver's hit against the steering wheel which causes the breaking of the ribs hence rupture of the interior parts of the chest and the eventual death of the passenger. The ability of the airbag installed on the steering wheel is amongst the points influencing the test results to a large extent.
2) The test of accidents from the sides: the side accidents are in the second degree of importance. Such accidents are simulated by a jack hitting the door on the driver's side in a motionless car with a speed of 50 kilometers per hour. In this kind of accident, the head and the neck undergo the highest injury. The vital role of the side airbags is not negligible in this kind of accident.

   In order to analyze the results, certain crash test dummies shoulder the simulation of the human body's reactions in the accidents. These dummies' standard is 1.78 meters for height and 77kg for weight. In order to determine the forces imposed on these dummies during the accidents, they are equipped with measurement instruments like accelerometer, pressure sensor and motion sensor.

To estimate the damages imposed on the passengers and rate the automobiles in accidents from the front side, stars are marked based on the lowest ranks obtained for head injuries, negative acceleration imposed on the chest and the pressure imposed on the thighs. In order to achieve all the five stars, the injuries imposed on the three above mentioned regions should be below 10%.

In the accidents from the sides and in order to acquire all the five stars, the specified regions should undergo damages below 5%.

Amongst the other experiments is the test investigating the strength of various types of automobiles in the accidents from the side and the front. In this experiment, a metal object, i.e. another vehicle, hits the car from the side. The numbers that are inserted into the equation for obtaining the safety score are obtained from the acceleration imposed on various body parts, including head and chest, at the time of the collision and accident. The vehicle manufacturers have taken measures in line with designing and producing side airbags for acquiring a high safety score in the tests.

Explication of the Test

The accident test is investigated from the following perspectives:

A) Crash test dummies
B) Real accident test
C) The best accident states
D) Safety progresses of the automobiles in figure
E) Background and scoring system

Crash Test Dummies

The duty of the crash test dummies is the simulation of the conditions of the real human beings in the course of a driving accident.

The crash test dummy usually includes three kinds of assessment:

1) Accelerometer
2) Load sensors
3) Motion sensors

Accelerometer:

These devices determine the acceleration amount in a given direction. These amounts can be applied for the determination of the likelihood of injury during the accident. In fact, the acceleration is the rate of the speed change. There are accelerometers in the head part of the dummy and it measures the head acceleration in three directions, namely forward-backward, leftward-rightward and also upward and downward. Additionally, some accelerometers are placed in the chest, pelvis, legs and other parts. Diagram (1) shows the driver's head acceleration in an accident from the front with a speed of 56.3kmph. note that the acceleration's amount is not constant rather it fluctuates [15].

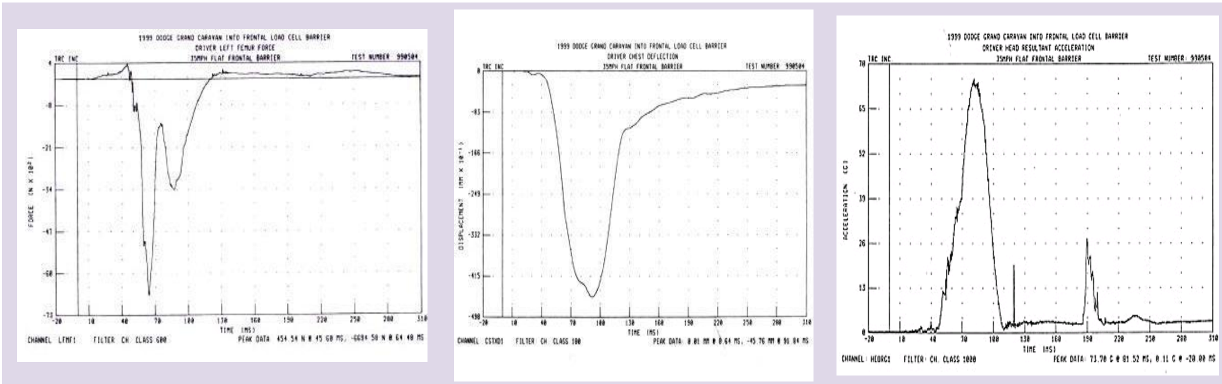
Load sensors

There are load sensors placed inside the dummies and they show the amount of the force imposed on various body parts of the dummy. Diagram (1b) illustrates the amount of the force imposed on the thigh at the time of the accident in newton.

Motion sensors

These sensors are installed on the dummy's chest and investigate the chest's diversion from the normal state. Figures (3-4) display the driver chest's deformations in the course of an accident.

In this special accident, the chest is compressed for about 2 inches equivalent to 46 millimeters. This amount of pressure can be painful but not deadly.



(a) **(b)** **(c)**

Diagram 1. a) driver's acceleration; b) force imposed on the thigh and c) diversion of the driver's chest

Real Accident Test

The US's national organization of the highways' safety has applied two kinds of accident tests:

1) Collision from the front with a speed equivalent to 56kmph in which the automobile directly hits a concrete barrier from the front;
2) Collision from the side in a speed of 56kmph

In this test, a 1368-kilogram barbell is moved with a deformable shield towards the side of the test car. This test actually simulates an automobile which is crossing through a juncture and another automobile hits it on its side.

Application of Color in Accident Test

Before putting the dummies into the test instrument, the researchers use color in them. Various colors and paints are applied for various body parts of the dummies. The knees, the face and different parts of the skull are each painted with a specific color. In the following figure, you can see the blue color of the face on the airbag installed in the steering wheel. You can also see the part that has contacted the red knee of the dummy.

If the researchers note the high acceleration in a part of the dummy's head by the barometers, the paints remaining in the car can well indicate which part of the head has bumped which part of the car.

Materials and Methods

Estimation of the Pressure Required for Filling the Airbag

The estimation of the pressure required for filling the airbag within several milliseconds can be obtained with a simple mechanical analysis. Assume that the air is resting in the front part (i.e. the speed is zero). Then, it starts being filled till the end of inflation in a speed of 200mph (i.e. the final speed is 89.4m/s) and it is found moved for 30cm (the approximate thickness of the completely filled airbag).

The acceleration of the airbag can be computed by the use of the following formula:

$V_f^2 - V_i^2 = 2\times a\times d$ (1)

$(89.5)^2 - (0.00)^2 = 2(a)(0.300) \rightarrow a = 1.33\times10^5 \text{ m/s}^2$

The force exerted on the object is equal to the mass multiplied by the acceleration of the object. Therefore, we can find the force exerted by the gas molecules for filling a 2.5-kilogram airbag. In case of being fair, a 2.5-kilogram airbag is heavy but if we knew how much pressure it has to tolerate, you would note that the light fabric-made bag does not feature the sufficient strength.

Note: in the calculations below, we have assumed that the airbag is protected from behind (i.e. the expansion is frontward and that the mass of the airbag has been considered to fall totally in its front side).

$F = m \times a$ (2)

$F = (2.50\text{kg} \times 1.33\times10^4 \text{m/s}^2) = 3.33\times10^4\ \text{kg}\cdot\text{m/s}^2 = 3.33\times10^4\text{N}$

The pressure of the gas's force is exerted on the surface area of the container (bag)'s walls. Therefore, the pressure (in pascal) in the airbag is determined immediately after inflation easily by the use of the above-calculated force for the front surface of the airbag (the section that moves forward with the exertion of force).

Note: the calculated pressure is manometric. The amount of gas required for filling the airbag in this pressure is obtained by the law of ideal gases. The pressure used in the ideal gas equation is an absolute pressure:

Absolute pressure= atmospheric pressure + manometric pressure (3)

Finite Element Modeling in ABAQUS

The simulation stages and the model creation in ABAQUS are as outlined beneath:

- Part creation environment
- Materials' properties definition environment
- Part assembly environment
- The environment for defining the number of the stages (steps) and the type of the problem solving
- The environment for the definition of the segment interaction type
- The environment for the exertion of the load and boundary conditions
- The environment for the part meshing
- The environment for problem (job) solving
- The environment for displaying and visualizing the results

Methods of Airbag Simulation

The two commonly applied methods for airbag simulation are:

A) **Uniform pressure method (UPM): this** method is extensively applied in the automobile industry. In this method, the pressure inside the airbag is considered during the inflation and it is mostly applied in the analyses performed with the completely in-position (IP) airbag. The pressure can be temporarily variable but the pressure distribution is uniform at a single moment. This assumption is more credible when the airbag is completely inflated. Thus, it is commercially suitable when the impact is imposed after the complete inflation of the airbag. In this dissertation, this method has been utilized.

B) Coupled Eulerian-Lagrangian Solution:

This type of analysis has the ability of modeling the gas flow inside the airbag as well as the effect of air surrounding during the expansion. It can also establish a relationship between the mutual effects of the Lagrangian objects and the materials inside the Eulerian mesh through strong algorithms.

Modeling

The dimensions of the problem have been selected in the form of s, mm and tone. The model includes three airbag parts, pellet and plate. The airbag is 60 liters in volume and in 3D form and it has been delineated by the aid of the command "Shell> Revolution" and in a deformable type.

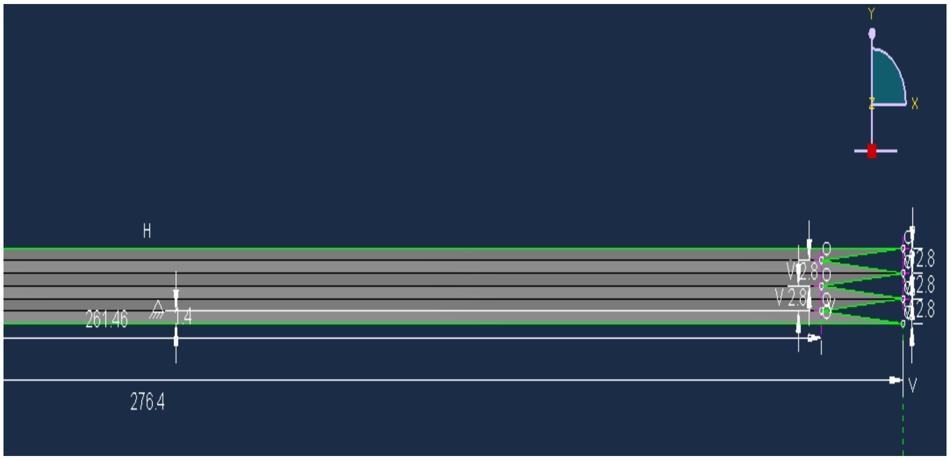


Figure 1. The airbag part in the environment

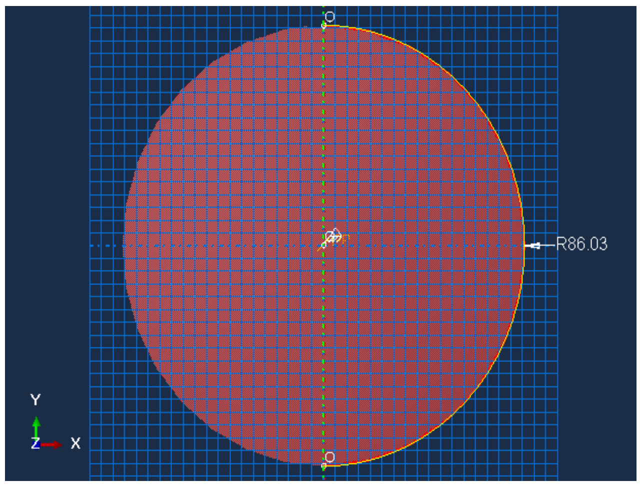


Figure 2. The pellet part in environment

A plate has been delineated for being placed behind the airbag based on Shell Command according to the following dimensions and it is of the deformable type

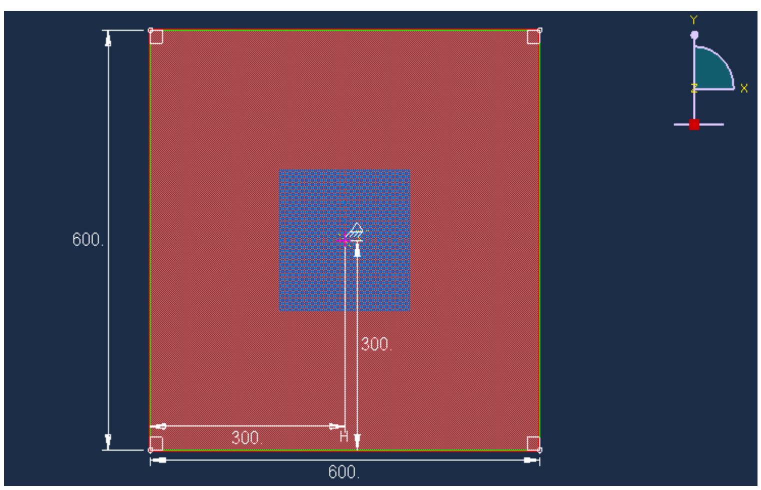


Figure 3. The plate holding the airbag in part environment

The model of the fabric material is nonlinear and anisotropic. Moreover, the mechanical response of the woven fabric is also considered and it can model a large tensile or shear change in an elastic form. It has to be noted that symmetry cannot be used due to the anisotropic nature of the fabric material's model so as to analyze the model in 2D. Due to the impossibility of the material's definition in the graphic environment, the fabric's attributes are inserted through the model menu and the option "edit keyword" in the sent input file for future analysis. The commands "Uniaxial Component=1" and "Uniaxial Component=2" are used for defining the fabric's response respectively along the warp and weft. The command "Uniaxial component=Shear" is also utilized for assessing its shear response.

The insertion of the pellet's features: the pellet is made of aluminum and its density and elastic properties have been given to the software.

The insertion of the thickness of the fabric section: the fabric section is of membrane type as shown in the following figure and a thickness equal to 0.35mm has been considered for it.

The distance of the projectible pellet from the airbag has been set at 400mm.

The insertion of the analysis information: "the type of the solution's analysis is explicit due to the high speed of the collision as well as the large deformation of the elements and the solution time is set at 100 milliseconds. Due to the large rotation of the fabric elements and the solution's cessation, use was made of time scaling factor with an amount of 0.5.

The insertion of the information related to the fabric surface: the contact between the surfaces is of general type.

The insertion of the information on the pellet and surface deformation: due to the trivial deformations of the pellet and the plate during the experiment by the help of the constraint "rigid", these two segments were ignored during the calculation of the deformations.

The insertion of the motion information of the system: the central point of the fabric's lower surface is tied in all directions. Furthermore, part of the fabric is prevented from movement along the y-axis.

The method of exerting pressure on the fabric: the pressure is exerted for 2PSI with changes shown in the figure on the interior surfaces.

The method of forcing the fabric's movement: the plate is also prevented from movement in all directions.

The method of forcing the pellet to move: in order to regulate the initial speed of the pellet, the speed was set at 4500 mm/s.

Membrane is a sort of surficial element that only allows the on-plate forces (and not the torques) to move. This kind of element is more frequently applicable to the thin surfaces' expression in 3D space (membrane) with the plate passing through the element having hardness but not of the flexural type. For example, reference can be made to the rubber sheet of the balloons and fabrics.

The mesh sizes of the airbag, pellet and plate are respectively 11, 20 and 30. The kind of the elements used for the airbag, pellet and plate correspondingly are M3D3 (a 3-node triangular membrane), C3D10M (a 10-node modified quadratic tetrahedron) and S4R (a 4 node doubly curved thin or thick shell, reduced integration, hourglass control and finite membrane strains). The numbers of the elements for each segment respectively are 10092, 3029 and 400. All the segments have been meshed using a free algorithm.

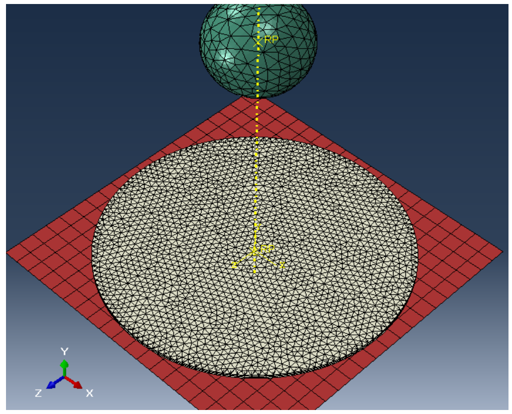
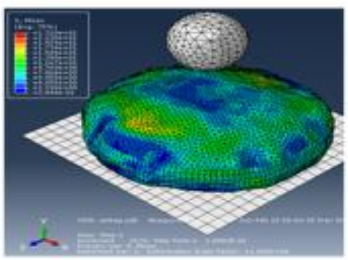


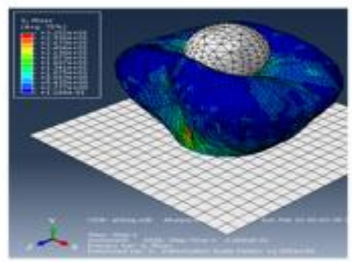
Figure 4. Meshing algorithm

Simulation Results:

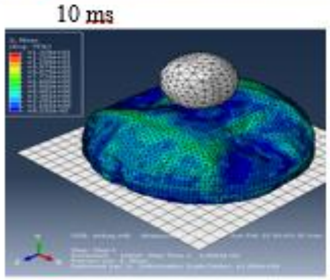
The final results of the airbag simulation in ABAQUS are as shown in the following figures:



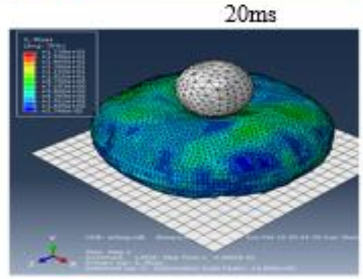
10 ms



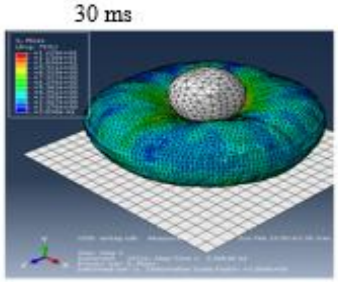
20ms



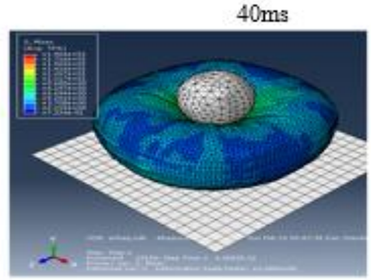
30 ms



40ms



50 ms



60ms

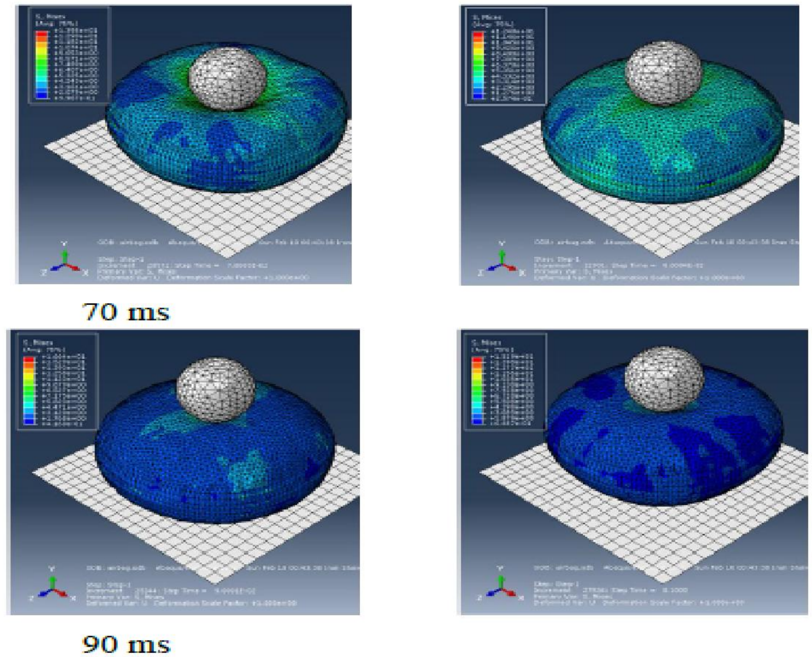
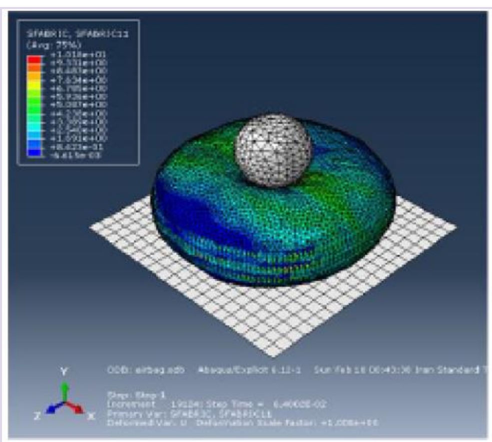
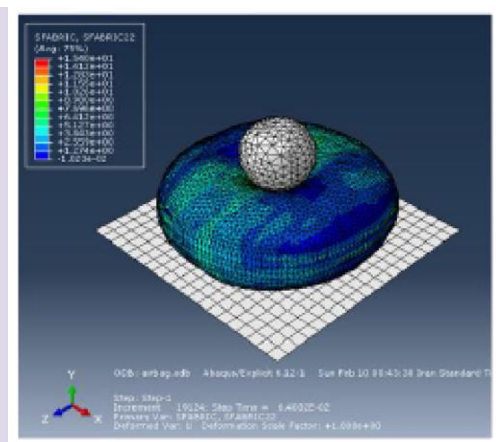


Figure 5. Final simulation results

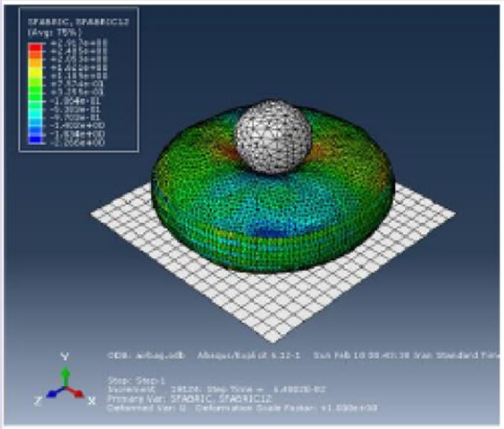
The fabric's stress and strain distributions at the instant of 64 milliseconds are as portrayed in images in figure (6).



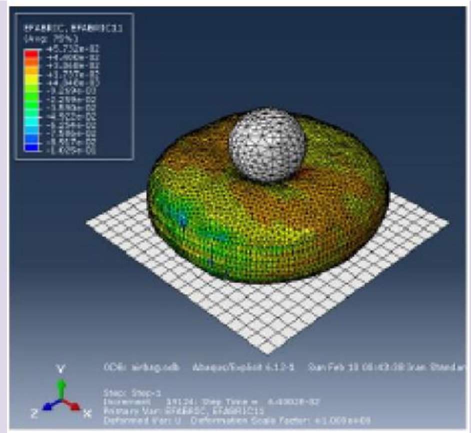
Fabric's stress distribution, vertical component along the x-axis



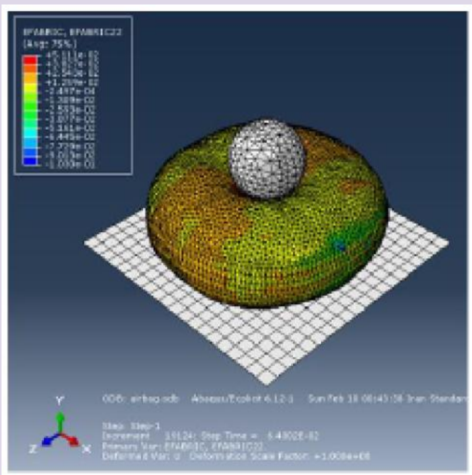
Fabric's stress distribution, vertical component along the y-axis



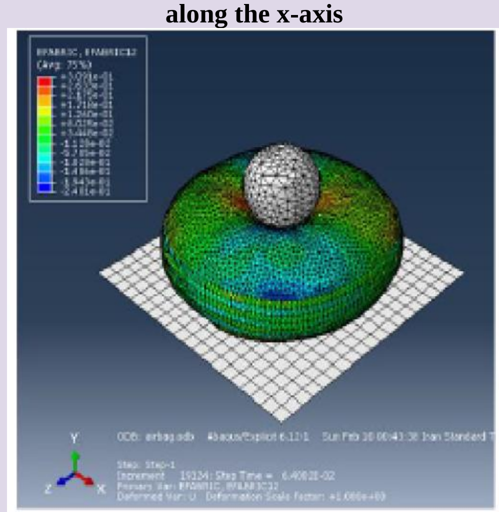
Fabric's stress distribution, XY shear component



Fabric's strain distribution, vertical component along the x-axis



Fabric's strain distribution, vertical component along the y-axis



Fabric's strain distribution, XY shear component

Figure 6. Stress-strain distributions in various directions

Conclusion

In the present study, reference was made seminally to the introducing and importance of the air-bags' existence in the vehicles. Next, some explanations were given about the functioning of the airbag and the quality assessment experiments thereon. In the end, as well, the airbag was simulated in ABAQUS software and the results were presented. Nowadays, airbags are recounted in the automobile-manufacturing industry as one of the primary components of the vehicles' safety in such a way that their use has been able to save the lives of thousands of individuals every year since their invention. Considering the importance of this subject, various kinds of airbag quality assessment methods are employed in different countries for saving the lives of the vehicles' passengers. In these methods, the forces imposed on the pattern as well as its speed and dislocation are investigated and analyzed. In order to assess the quality of the airbag in a theoretical manner and solve it in numerical state under various conditions, the use of software packages like ABAQUS can be promising. Efforts were made in the present study to model the driver's collision with the airbag and the results were presented in the form of the time-displacement and time-speed as well as time-acceleration diagrams. In the end and in line with further future research, the researchers are suggested to perform analyses using the coupled Lagrangian-Eulerian method so that the precision can be considerably increased, especially during the inflation of the airbag. Furthermore, using the practical and laboratory case studies and measuring the speed and acceleration as well as by photographing the various states of the bag, the simulation accuracy can be tested.

References

[1] Jörg Hoffmann, Michael Freisinger, Mike Blundell, Peter Ritmeijer, 2007, "Investigation into The Effectiveness of Advanced Driver Airbag Modules

[2] Zhang H., Raman S., Gopal M. Han T., 2004, "Evaluation and Comparison of CFD IntegratedAirbag Models in LS-DYNA, MADYMO and PAMCRASH", SAE Paper 2004-01-1627.

[3] T. Gholami, J. Lescheticky, R. Paßmann Crashworthiness Simulation of Automobiles with ABAQUS/Explicit ABAQUS Users' Conference, Munich, Germany, 2003.

[4] R. Paßmann, A. Theobald, W. Jansohn Simulation des Kopfaufprall nach FMVSS 201 mit ABAQUS/Explicit VDI Tagung Berechnung und Simulation im Fahrzeugbau, VDI Berichte, Würzburg 2002.

[5] LS-DYNA Keyword User's Manual, version 971, LSTC, 2007.

[6] A. Hirth, A. Houfe and L. Olovsson, "Airbag Simulation with LS-DYNA Past-Present-Future", 6th European LS-DYNA Conference, 2007.

[7] http://meinformation.blogfa.com/post-194

[8] http://www.howstuffworks.com/airbag.htm

[9] http://www.airbagcrash.com

[10] http://www.lemurzone.com/airbag

[11] http://www.Chemistry.wustl.edu

[12] http://www.airbag.net

[13] http://www.airbagsystems.com

[14] http://www.nhtsa.dot.gov/airbags

[15] http://www.mscsoftware.com.