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NEW MODEL OF THE SIMULATION OF THE AIRBAG OPERATION IN THE CASE OF THE OUT-OF-POSITION OCCUPANT – THE COMPARISON WITH EXISTING MODELS

New model of the simulation of the airbag inflation process, taking into account the influence of the airbag environment on the folding process, have been proposed. Equations describing a new model and the used numerical schemes were presented. The differences of the airbag fabric skin motion during the folding process, obtained by the use of different process models (existing and proposed), have been presented on the simple geometry examples. From the analysis of obtained results one acknowledged that the proposed model should be used in all calculations of the airbag operation in non-typical situations, out-of position occupants, side airbags, particularly in the case of small distances between the closed airbag and the elements of the body of the protected person.

1. Introduction

For years, the trusty seat belt provided the sole form of passive restraint in commonly used cars. Statistics have shown that the use of seat belts have saved thousands of lives that might have been lost in collisions. Actually, the seat belts are accompanied by airbags. Airbags have been under development for many years. The first patent on an inflatable crash-landing device for airplanes was filed during World War II. In the 1980s, the first commercial air bags appeared in automobiles. All new cars have been required to have air bags on both driver and passenger sides. To date, statistics show that air bags reduce the risk of dying in a direct frontal crash by about 30 percent. Except commonly used steering-wheel-mounted or dashboard-mounted bags, not so widely used, are seat-mounted and door-mounted side air bags. There are opinions that within the next few years,

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passenger cars will go from having dual air bags to having six or even eight air bags. Having evoked some of the same controversy that surrounded seat-belt use in its early years, air bags are the subject of serious industry research and tests [2], [4], [8], [13]. Actually, airbags, safety belts and proper car frame structure determine a basic car feature called the passive safety of the vehicle. During the road collision, large inertial reactions can act on car occupants. This may cause offences of the body as result of the body motion and elements of the equipment (the wheel, the distributive board) impact. The main task of the airbag is the quick fulfilment of the space among locomotive and structural members of the vehicle, and reduction of the impetus and redeeming of the percussive force. This results in less working surcharges on the body of the passenger. The airbag opening time must be properly short (usually this is 25 to 30 of milliseconds from the event signal). Taking into account the necessary time for detection of the conflict by sensors, it could get down to work efficiently. These require, regarding the quality of the realisation, qualities of used constructional solutions, used materials and airbag performance. That means also that the velocity of the airbag fabric during early stages of the inflation process has to be relatively high and because of that dangerous. An out-of-position occupant (OOPO) is defined as the one who is not in his normally assumed seating position. The risk of injury to an out-of-position occupant increases when the occupant is very close to the air bag when it deploys [9], [10]. Prior to deployment, the occupant may move out-of-position due to voluntary movement, pre impact vehicle dynamics and crash dynamics.

The limited space (the central part of the wheel) in which the airbag ought to be placed in the case of the driver protection is the additional difficulty and the dimensions limitation. It must be small enough, to be located in this limited space, and additionally do not obstruct the observation of the instrument board by the driver.

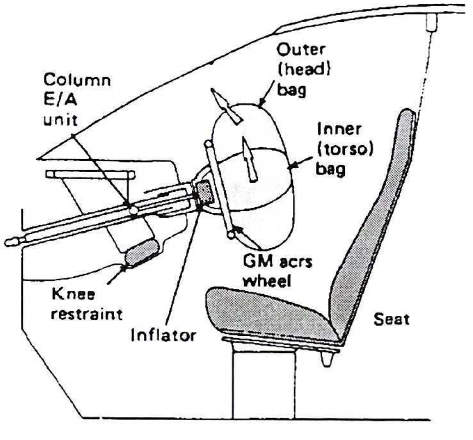


Fig. 1. The schema of the interior of the vehicle along with the airbag situated in the wheel [12]

The air bag has a fraction of a second to fill the space between the passenger and the steering wheel or dashboard. Every tiny amount of space and time is valuable, however, if the system can slow the passenger evenly rather than forcing an abrupt halt to his motion.

Fundamentally in the airbag construction we can define three basic elements:

- The master device, the set of sensors detecting the collision and then initiating the activity of the airbag. Inflation happens when there is a collision force equal to running into a brick wall at 10 to 15 miles per hour (16 to 24 km per hour). The sensors receive information from an accelerometer built into a microchip.
- The air bag's inflation system (the source of the airbag pursuant gas). Typically reacts sodium azide (NaN3) with potassium nitrate (KNO3) to produce nitrogen gas. Hot blasts of the nitrogen inflate the air bag.
- The bag itself is made of a thin, nylon fabric, folded into the steering wheel or dashboard or, more recently, the seat or door.

Self-evident solution of source of the gas for the airbag seemed the container with a compressed air. In the case of the passenger protection, such solution did not cause troubles. In the case of the driver protection, mainly due to the limited space, this solution was not practically used. The container cannot be placed in the wheel or else in the steering column. It had to be situated in another part of the car, and the compressed air should be delivered to the airbag by a special line. The solution was tested by the Volkswagen engineers, but they did not reach satisfactory results. This induced constructors to research of other, more compact sources of the gas. The research was managed in United States. Investigation carried out by Chrysler with gas generants on the basis of the black powder did not succeed. Instead, the General Motors reached the success by using its own generator based on the nitrate of the sodium. As the result of combustion, one obtained the harmless nitrogen to the infusion of the airbag. The solution is practically used to date. The air bag system ignites a solid propellant, which burns extremely rapidly to create a large volume of gas to inflate the bag. The bag then bursts from its storage site at up to 200 mph (300 kph). A second later, the gas quickly dissipates through tiny holes in the bag, thus deflating the bag to unshackle seat occupant. The source of the gas adopted now has the form of small device reminding the solid fuel rocket and could be situated in the wheel of the vehicle along with the airbag fabric. In the case of the airbag for the passenger, the range of possible solutions is greater. One used the compressed air, or the compressed air and the gasifier. Pyrotechnical devices have been mostly used for the rise of the temperature to increase the air energy forced to the airbag.

The powdery substance released from the air bag, seen on some photographs, is talcum powder, which is used by the air bag manufacturers to keep the bags pliable and lubricated while in storage.

Inflator constructions using liquid gases under very high pressures have also been known. Small capsule containing highly compressed gas is closed by a metal diaphgram pyrotechnically broken on the beginning phase of airbag inflation.

The devices realising hydrogen burning process have also been considered.

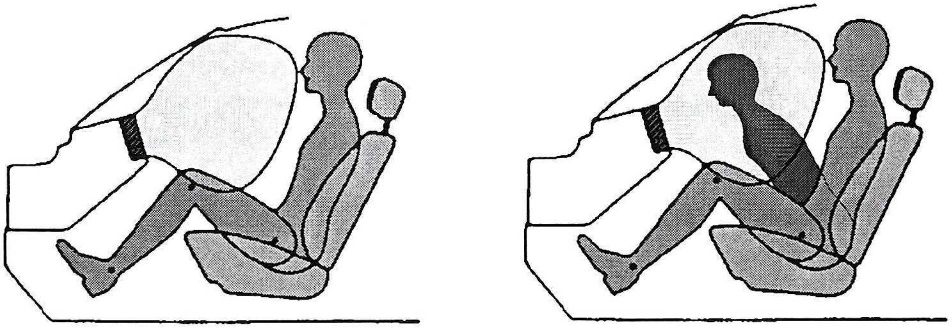


Fig. 2. The schema of the activity of the airbag for the passenger in and out of position [12]

In the early days of auto air bags, experts cautioned that the new device was to be used in tandem with the seat belt. Seat belts were still completely necessary because air bags worked only in front-end collisions occurring at more than 10 mph. Only seat belts could help in side swipes and crashes (although side-mounted air bags are becoming more common now), rear-end collisions and secondary impacts. As the technology advances, air bags still are only effective when used with a lap/shoulder seat belt.

Collected experiences from the usage of airbag brought back the greater attention on the activity of master parts of airbag.

One noticed certain defects of airbags. In the initial phase the inflation, after the perforation of protection covers, the airbag fabric is thrown out with high speed. When occupants are in the unsuitable position in the vehicle (too near the airbag) the airbag can act traumatically. It didn't take long to learn that the force of an air bag can hurt those who are too close to it. It has been determined that the risk zone for driver air bags is the first 2 to 3 inches (5 to 8 cm) of inflation. An air bag can seriously injure or even kill an unbuckled child who is sitting too close to it or is thrown toward the dashboard during emergency braking. Because of that, the essential meaning gathered the different kind sensors used for the assignment the qualification of the height and of occupant position. One began to use airbags of double-activity, equipped by two sources of the gas of different power [7]. Inflators are activated in the dependence from the occupant's position and also from the energy of the collision. High requirements have been imposed on materials from which one executes the airbags. They must be light, resistant and occupy not much room to swing. Besides, they should not have resilient proprieties, absorb the energy, and not accumulate it.

The range of airbag applications constantly increases. Except of the mentioned previously front airbags for the driver and the passenger, there appeared side airbags and aerial curtains. Their assignment is the protection of occupant heads during strikes into the side of the vehicle. This is insomuch essential, because this event type determines the large percentage of all road – collisions. Activities aimed at maintaining and improving the lifesaving benefits of air bags are in full development. Until recently, most of the strides made in auto safety were in front and rear impacts, even though 40 percent of all serious injuries from accidents are the result of side impacts, and 30 percent of all accidents are side-impact collisions. Many carmakers have responded to these statistics by reinforced doors, door frames, floor and roof sections. Cars that currently offer side air bags represent the new solution of occupant protection. Designing effective side air bags is much more difficult than designing front air bags. This is because much of the energy from a front-impact collision is absorbed by the bumper, hood and engine, and it takes almost 30 to 40 milliseconds before it reaches the car's occupant. In a side impact, only a relatively thin door and a few inches separate the occupant from another vehicle. This means that door-mounted side air bags must begin deploying in a mere five or six milliseconds.

Volvo engineers experimented with different ways of mounting side air bags, chose seat-back installation because that protects passengers of all sizes regardless of how the seat is positioned. This arrangement allows them to place a triggering mechanical sensor on the sides of the seat, airbags under the driver and front passenger. This prevents the air bag on the undamaged side of the car from inflating. It takes a collision of about 12 mph (19 kph) to trigger side air bags. BMW engineers have chosen door-mounted air bags. The door has more space, allowing for a bigger bag that provides more coverage.

The head air bag, or Inflatable Tubular Structure (ITS), was featured in all of BMW's 1999 models. The head bags look a little like big sausages and, unlike other air bags, are designed to stay inflated for about five seconds to offer protection against second or third impacts. Working with the side air bag, the ITS is supposed to offer better protection in some side collisions.

All of this makes it clear that the science of air bags is still new and under rapid development. We can expect many advances in this field as designers come up with new ideas and learn from real-world crash data.

2. Models of the airbags

2. 1. Existing models

To the simulation of the airbags inflation and then its operation, a three-dimensional model have been commonly used, basing themselves on the method of finite elements. The model of the airbag fabric is created from tegumentary elements [1]. A direct approach for modelling the airbag inner volume would be to discretize the interior of the airbag using volume elements. But it seems to be very difficult to implement during the inflation phase of the airbag deployment. Because of that, some simplified solutions have been used commonly.

The entire mass of the gas in the airbag is equal to the mass delivered by the gas generator minus the mass of the gas getting to the external environment by micro-crevices and special openings in the fabric.

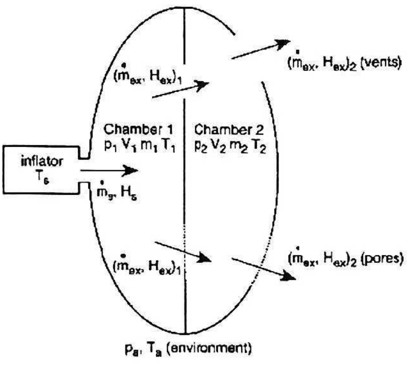


Fig. 3. The schema of gas flow from the generator to the air-bag and then to the external environment.[5]

There exist three basic models of the simulation of the airbags gas infusion process.

In all of them, the movement of the fabric skin of the airbag is an effect of the gas forces acting on fabric internal surfaces. These forces originate from the internal pressure in the airbag being the result of a new portion of the gas provided by the generator. The differences are included in formulas for the surface pressure distribution calculation.

The first and also most simple model of the airbag inflation states the uniform increase of the pressure in all parts of it volume as the gas is forced to the interior. A serious drawback of this model is the lack of dynamic effects resulting from the influence of the inflating gas stream on the airbag. It should be remembered that the gas is provided from the generator at a very high speed. This can bear on results of the simulation especially in first phase of the airbag inflation. The model is commonly used due to its simplicity and is correct in simulation of a typical airbag operation processes but can be inefficient in the out of position of the occupants case.
Some improvements to this model can be added.

Modern, professional computer programs [5],[6] give the possibility of taking into account the effects of the gas stream activity on the airbag components. The working forces on the airbag inner surfaces are the result of summation of the static pressures and dynamic action of the gas streams. This model is the second one among considered models of the airbag inflation.

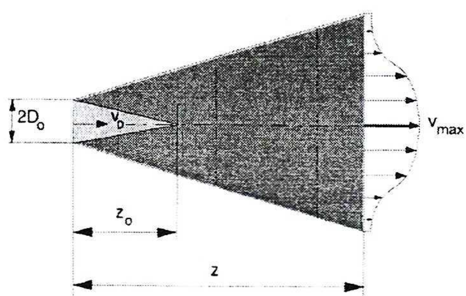


Fig. 4. Schematic presentation of the shape and the decay of the speed of the stream of the influent gas to the airbag.

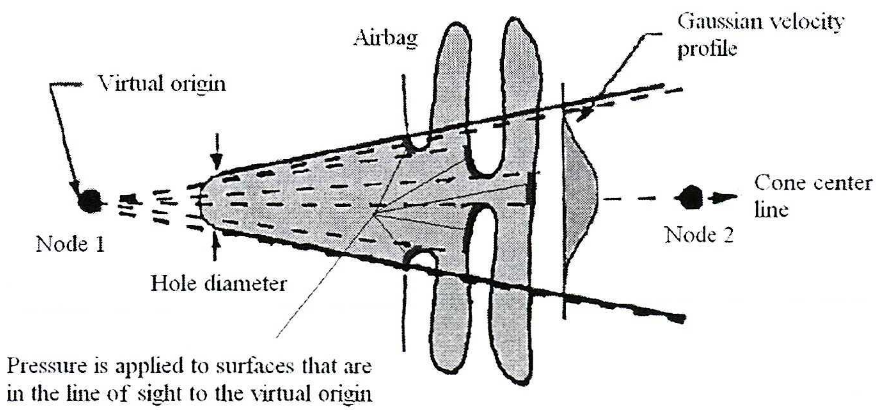


Fig. 5. Schematic model of the influence of the stream of the gas on the airbag fabric skin [3]

The third model takes into account the variation of inner pressure in space and time inside the airbag. Set of the Euler equations describing the unsteady flow of compressible fluid inside the airbags is solved to describe local pressure values on the surface of airbag fabric skin [11]. The space inside the airbag is discretisied by small volumes. In each elemental volume, the variation of the density, pressure and velocity components are considered and calculated. In the connection with the model of the airbag fabric skin formed by surface elements, one can receive the model representing dynamic interaction between the gas and structure. In that way, the influence of the gas on the airbag fabric and airbag fabric on the gas can be traced.

The described model is used to research of early phases the airbag inflation (important when passengers of the vehicle are in out of position) and to the simulation of the activity of more complicated arrangements, such as many airbags supplied from one source by means of lines or aerial curtains.

2.2. Proposed model

All, introduced till now, manners of the simulation of the activity of the airbag took into account only these physical processes which happen in it interior (interior space in Fig. 6). No one takes into account influence of the external environment (outer space in Fig. 6). Airbag inflation happens in area filled by the air. In first stages of airbag inflation the airbag fabric is thrown out from the container with a speed reaching several hundred meters per second. Accelerating fabric will generate pressure wave that, except the evocation of acoustic effects, can influence manner of airbag fabric skin motion. As it was mentioned earlier, that side airbags have the necessary inflation time less than 6 milliseconds. In such conditions the influence of unsteady effects seems to be rather crucial.

In the model proposed calculation of the gas dynamic processes covers both an inner and outer space simultaneously. The reason of the creation of the new model of the simulation of the airbag inflation was the wish of finding the possible reasons of discrepancies between results obtained by the use of commonly approved models and results of experimental investigations. To show the main idea of the proposed model and investigate the range of influence of the considered physical phenomena, the airbag model has been limited to the two-dimensional case.

To test the proposed idea a numerical code in Fortran have been built and used for comparative calculations. Some particulars of used model and algorithms are presented below.

In the built model the considered computational area is restricted to the inner airbag space and some space around it (outer space in Fig. 6). Two flow areas separated by the representation of the fabric skin surface have been used. Practically two rectangular overlapping grids are applied. One grid, called high pressure grid, was used for calculation of the gas parameters inside the airbag. The second grid, called the low pressure grid, was the base for calculation of the gas parameter variation outside the airbag. The fabric skin of the airbag determines the border dividing the area of the high pressure (inside airbag) from the area of the low pressure (outside airbag).

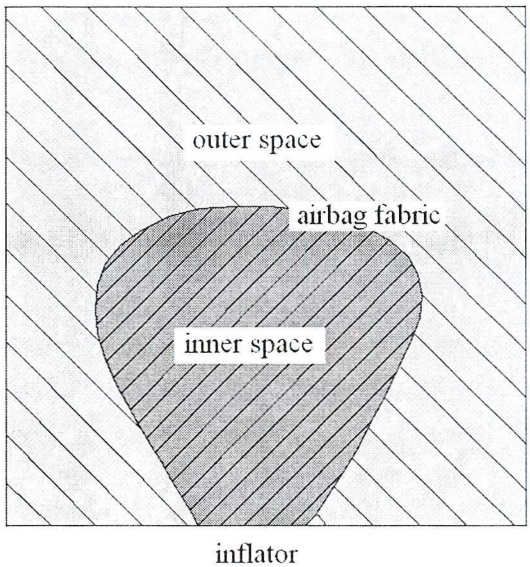


Fig. 6. Scheme of a new model

2.2.1. Airbag fabric skin lumped parameter model

The lumped parameter model comprising the set of masses and springs representing the inertia and stiffness of the airbag coat material have been used for modelling of the airbag fabric.

Airbag fabric has been divided into small elements to which one credited the elementary mass and the surface. It is assumed that material points model airbag fabric skin, collecting all mass of the element forming the coat of the airbag elements, and that they are joined by the set of springs connecting neighbour nodes.

For every element, one can give two co-ordinates describing its position on the fabric surface, two velocity components of motion and the angle created by the elementary surface with the chosen direction of the reference. This angle qualifies the orientation of the element on the surface.

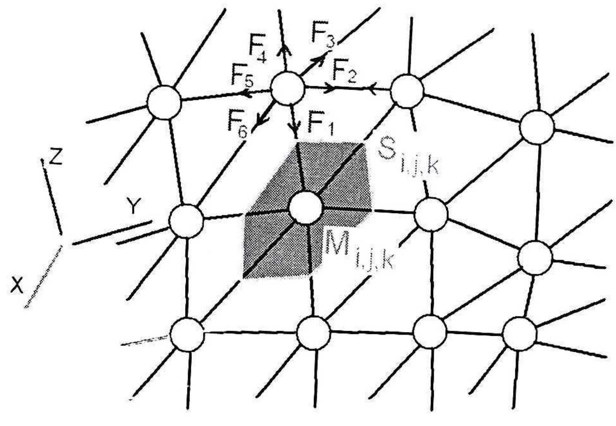


Fig. 7. Scheme of the lumped model of the airbag fabric skin

Every airbag fabric skin element moves due to the pressure forces and fabric elastic forces acting on it. The elastic force appears when the distance among two neighbouring elements will increase beyond the settled value. It is considered also the elastic force what pushes back the elements being in close neighbourhood when the distance among them is smaller than the settled value. This is the condition of non penetrability of two separate layers of the folded airbag.

The movement of each airbag fabric elements one can describe by means of the equation of motion.

2.2.2. Gas dynamics model

Gas from inflator spreads out freely inside the airbag, accelerating the airbag fabric. The mowing fabric surface compresses the gas in front of it forming a compression wave expanding in the airbag surroundings.

It was assumed that the physical phenomena accompanying the airbag folding process can be described by the set of Euler equations in conservative form of continuity, momentum and energy equations

$$\frac{\partial \mathbf{U}}{\partial t} + \frac{\partial \mathbf{F}}{\partial x} + \frac{\partial \mathbf{G}}{\partial y} = 0 \text{ where } \mathbf{U} = \begin{Bmatrix} \rho \\ \rho u \\ \rho v \\ \rho e \end{Bmatrix} \mathbf{F} = \begin{Bmatrix} \rho u \\ \rho u^2 + p \\ \rho uv \\ u(\rho e + p) \end{Bmatrix} \mathbf{G} = \begin{Bmatrix} \rho v \\ \rho uv \\ \rho v^2 + p \\ v(\rho e + p) \end{Bmatrix}$$

which state the unsteady two-dimensional flow of the perfect gas.

$$e = \frac{p}{(k-1)\rho} + \frac{1}{2}(u^2 + v^2)$$

Where e expresses the entire energy.

On the borders of the computational area one accepted two kinds of boundary conditions. The first of them describes the condition of the impermeability for the gas, the second one simulates reflectionless termination.

2.2.3. The numerical algorithm.

The movement of each airbag fabric element result from the forces being the sum of elastic forces and forces originating from the difference of pressures among areas of high and of the low pressure on the elementary surface assigned to the element.

One can obtain the data defining position and speeds of elements of the airbag shell integrating the equation of motion. Such equations for each element of the airbag fabric can have the following form:

$$m_i \frac{d^2 x_i}{dt^2} = S_y^i (p_{high}^i - p_{low}^i) + \sum_{k=1}^{k=nneighbour} F_x^k$$

$$m_i \frac{d^2 y_i}{dt^2} = S_x^i (p_{high}^i - p_{low}^i) + \sum_{k=1}^{k=nneighbour} F_y^k$$

With initial conditions:

$$x^i(t) = x_p^i \qquad \left.\frac{dx^i}{dt}\right|_{(t=0)} = 0$$

$$y^i(t) = y_p^i \qquad \left.\frac{dy^i}{dt}\right|_{(t=0)} = 0$$

The system of differential equations of the second order can be transformed to the system of first-order equations and numerically integrated by the Runge-Kutta method.

Parameters of the gas (density, velocity and pressure) in each nodes of high and of the low pressure grid have been calculated based on the Lax-Wendroff-Richtmyer algorithm. It consists of two steps. During the first step, the auxiliary values of streams in each nodes of the net for the half time level $(t + \frac{1}{2\,\Delta t})$ are calculated:

$$\mathbf{u}^{n+1/2}_{i+1/2,j} = \frac{1}{4}(\mathbf{u}^{n}_{i+1,j} + \mathbf{u}^{n}_{i,j} + \mathbf{u}^{n}_{i+1/2,j+1/2} + \mathbf{u}^{n}_{i+1/2,j-1/2}) -$$
$$-\frac{1}{2}\frac{\Delta t}{\Delta x}(\mathbf{F}^{n}_{i+1,j} - \mathbf{F}^{n}_{i,j}) - \frac{1}{2}\frac{\Delta t}{\Delta y}(\mathbf{G}^{n}_{i+1/2,j+1/2} - \mathbf{G}^{n}_{i+1/2,j-1/2})$$

The final result we receive in the second step using previously calculated auxiliary values:

$$\mathbf{u}^{n+1}_{i,j} = \mathbf{u}^{n}_{i,j} - \frac{\Delta t}{\Delta x}(\mathbf{F}^{n+1/2}_{i+1/2,j} - \mathbf{F}^{n+1/2}_{i-1/2,j}) - \frac{\Delta t}{\Delta y}(\mathbf{G}^{n+1/2}_{i,j+1/2} - \mathbf{G}^{n+1/2}_{i,j-1/2})$$

The time step used in integration formula is calculated from the CFL stability criterion:

$$\Delta t = \frac{1}{2}\min\left\{\frac{\Delta x}{|u + c|}, \frac{\Delta y}{|v + c|}\right\}$$

For symmetry of the used numerical scheme, some additional nodes have been added with flow parameters obtained from interpolation based on occurrent values in neighbouring nodes.

As we have already written, the fabric skin of the airbag determines the border among areas of high and of the low pressure. The gas expanding in the airbag interacts and is reflected by the airbag fabric.

On the moving boundary, two types of boundary condition have been used. Virtual nodes (duplicated inner boundary nodes) located on the outer side of the airbag fabric skin have been applied.

$$w_{iout} = - w_{iin} + 2w_{fab}$$

Where w_{iout} is the speed of the gas in the virtual node outside of the airbag but belonging to the inner space net, w_{iin} the speed in the internal node, w_{fab} is the speed of the fabric skin. The remaining parameters (density and pressure) are equal to parameters of the internal boundary node. In a similar manner the speed of the fabric skin in the low pressure net (in outer space) is taken into account.

$$w_{oout} = - w_{oin} + 2w_{fab}$$

In the case when the created model founds the partial permeability of the airbag fabric skin the coefficient of permeability (accepting value from the range from 0 to 1) have been included in equation of boundary condition.

In the steady uniform grid used for gas dynamics there, still exists the matter of distinction which nodes are internal, and which already external. In present work, one accepted the rule that the terminal internal node are those nearest to fabric skin of the airbag. The external node is one of its four neighbours, according to the orientation of the element of the airbag fabric skin on the surface (see Fig. 8).

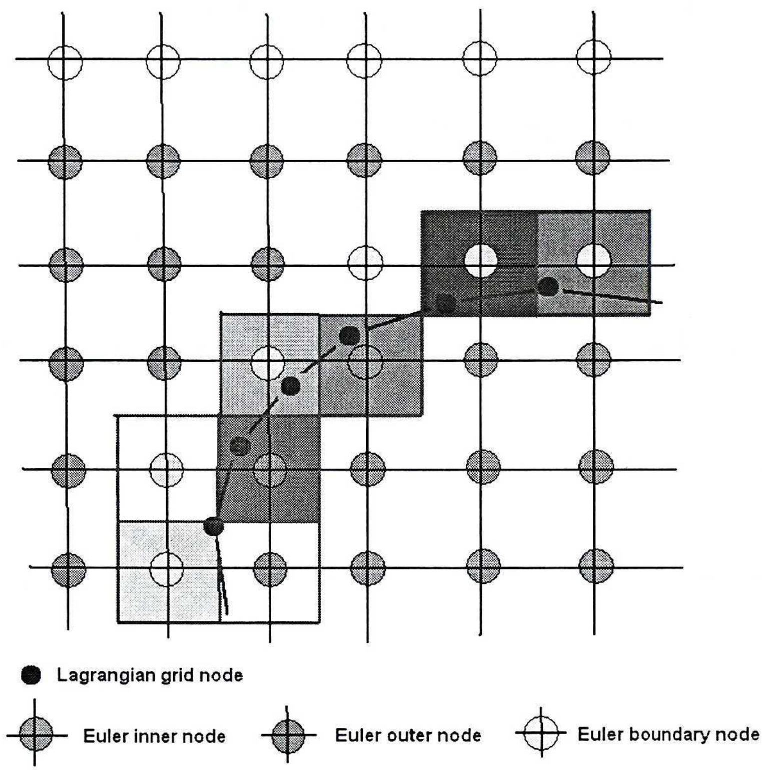


Fig. 8. Scheme of distinction between boundary and virtual nodes.

3. Results of calculations

In the present work, one made comparisons between different manners of the airbag activity simulation. To this aim, one built several numeric models and performed calculations. To clear explanation of the proposed model, the set of cases having very simple geometry have been chosen. In all calculations the same geometry, material and gas parameters have been used to make sure that the obtained differences are results of only the used different model assumption.

First of the analysed examples is the simple case of the container whose one wall creates the deformable, elastic diaphragm. The container is filled

through the orifice located in symmetry plane from volume filled with the gas under high pressure. Four numeric simulations using four different calculation methods have been executed and their results compared.
The first considered airbag model assuming the uniform pressure distribution inside the volume of the container.
The second model is a modification of the first model with simulation of the dynamic influence of the gas jet from the inflator on the elastic diaphragm. The third model treats the process of the container infusion as unsteady two-dimensional flow of perfect gas described by the set of Euler equations.

The fourth model, also fully gas dynamic, includes the proposed modification of the third method taking into account the influence of the external environment of examined container. The processes happening outside of the container (generating of pressure wave by the moving diaphragm) are also described by the Euler equations.
Due to symmetry, only half of the diaphragm was considered.

The obtained results were presented in two manners. First from them (drawings the exhibitory deformation of the diaphragm in following temporary time moments) makes possible the visual estimation of the influence of used method on the change of the diaphragm shape. On the presented illustrations one can also see the fields of the speed of the gas (for dynamic methods and of the static method with the regard of the influence of the stream of the gas) in the form of pointers (vectors). Pressure magnitudes are presented by color code.

The second manner of presentation of the results has the form of graphs depicting the differences in the speed of the diaphragm displacement calculated using different inflation process models. The speeds were recorded in three different points of the diaphragm, with the first one located in the axis of the symmetry, the second in 1/3 from the axis of the symmetry and in the third lying in the distance of 2/3 from the axis of the symmetry of the diaphragm.

Analysing changes of the diaphragm shape during the investigated inflation process one can notice that from among four described earlier inflation simulation methods the one that differs most from others is the leaning method based on the assumption of uniform pressure distribution inside container without the regard of the influence of the gas jet. As opposed to the remaining methods all parts of the diaphragm begin the movement at the same time and with the similar speed, and first of it deformation appear at banks where it is fastened to sides of the container. In the remaining cases, the diaphragm deformation in the first instance appears in the axis of the symmetry as the result of the influence of the gas stream and then disperses on the rest of its part. Besides, one can notice that along with the progress of the inflation process, differences in the shape gradually disappear, what would suggest that the choice of the suitable method of the simulation is especially important in the analysis of first phases of the activity of the airbag. In practice such condition exists in the out-of-position case.

Analysing graphs of the dependence of the diaphragm speed in the function of the time, one can see that (in every from three measuring points) lowest speeds and least their amplitude was reached for the most simple model (with the uniform pressure). Highest diaphragm speeds were reached for the gas dynamic model without the regard of the influence of the external environment.

The model being the basic object of the analysis of the present work (gas dynamic with the influence of the external environment) is characterised by a little lower speeds of dislocations of the diaphragm. Also, the changes of the speed are more spread out in time, have the less impetuous in comparison with these of the remaining models. One can venture the ascertainment that the external environment affects the diaphragm stabilizingly, extinguishes it twitch.

In the case of control points located at some distance from the axis of the symmetry, one can also see differences among both groups of numeric methods. In the first group (uniform pressure models) the movement of the fragment of the diaphragm located away from axis sets up earlier. More exactly, all diaphragm elements sets up simultaneously to translocate under the pressure. This is not in agreement with experimental observations. In the second case (gas dynamics models) each of diaphragm part set up to move in the different time. As the first ones begin the movement elements located in the axis of the symmetry and to it vicinity. There also appear first deformations as a result of local pressure increase due to the velocity of the gas stream. Then, the resultant disturbance disperses on further parts of the diaphragm. The movement process of each fabric elements is a result of the difference of non-uniform pressures among areas of high and of low pressure and the stiffness force working among them.

The next tested case is the model of the symmetrical, uncomplicated airbag. Also at this time, four numerical simulations have been performed using methods described previously. The results of the simulation are presented in the graphical form. Fig. 13 includes the set of temporary fabric skin shapes obtained for each considered model of an airbag. In Fig. 14 the comparison between the fabric velocity variations in time is shown. The sketch presents velocity variation of the point located in the center of airbag fabric and of points located in 1/3 of initial airbag dimension from the center.

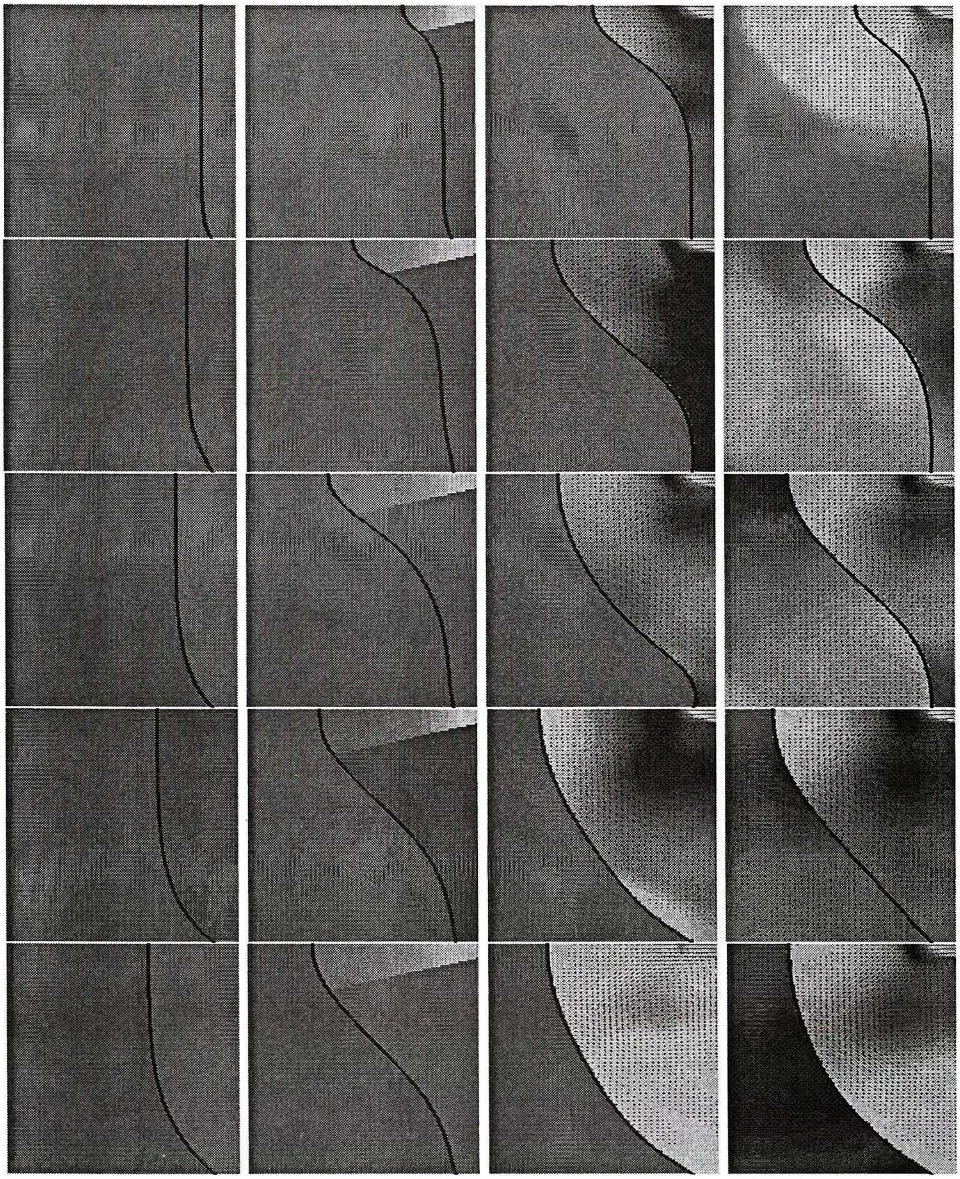


Fig. 9. Comparison of temporary diaphragm shapes obtained by the a) uniform pressure model, b) uniform pressure model with stream correction, c) inner gas dynamics model, d) inner and outer gas dynamics model.

The performed simulations confirm conclusions developed during the investigation of the preceding case. The differences in the process of the airbag infusion, which is reflected by the different shapes of fabric skin, most strongly appear in first phases of the inflation process and later have tendency to disappear.

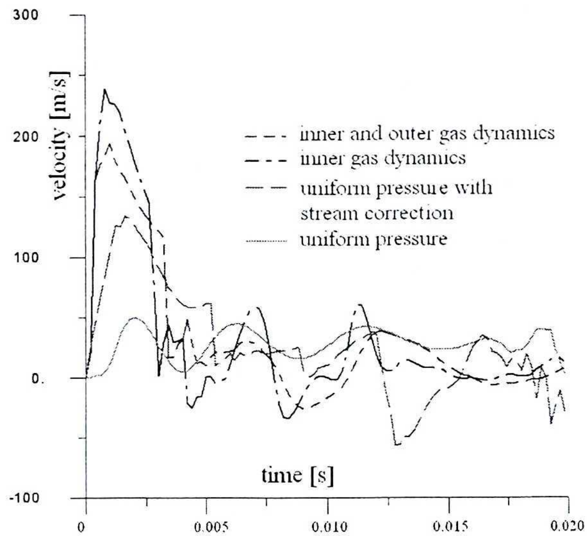


Fig. 10. Variation of the diaphragm speed in the symmetry plane for compared inflation models

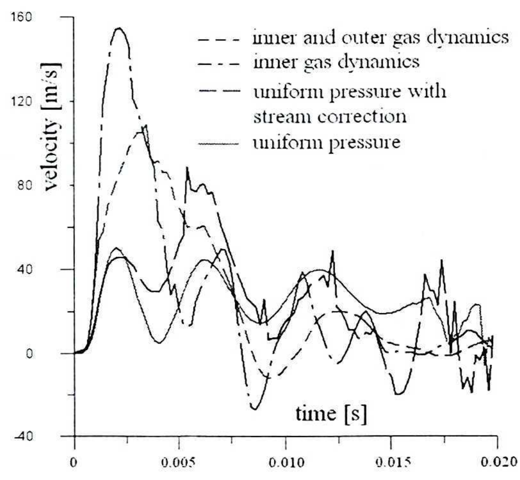


Fig. 11. Variation of the diaphragm speed in the plane located 1/3 from the symmetry plane for compared inflation models

Much more important is the difference visible between the fabric skin speed calculated using different models.

Clearly visible is the tendency to the oscillation in cases where the external environment is not taken into account, and the significantly lower speed of the fabric for the model with uniform pressure and without simulation of the dynamic effects of the inflator gas streams.

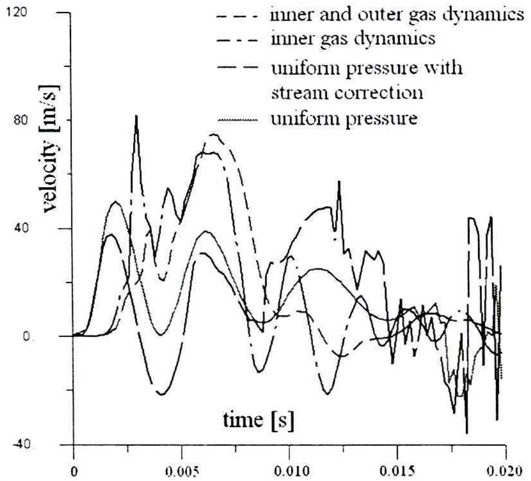
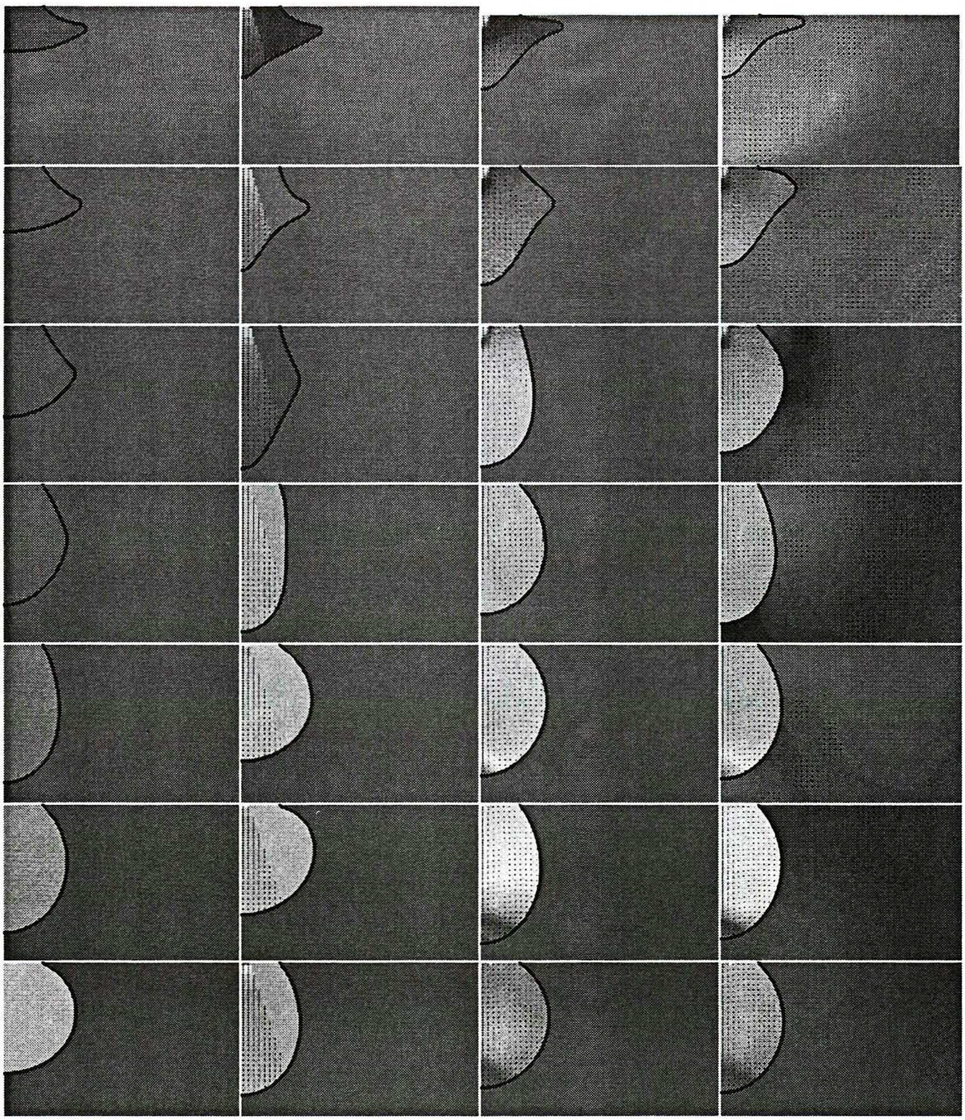


Fig. 12. Variation of the diaphragm speed in the plane located 2/3 from the symmetry plane for compared inflation models

The third analysed case is the airbag supplied from one source by means of the line which has two outlets delivering the gas. This is the equivalent of the simplified model of the aerial curtain. Basing on the earlier presented models, two numeric simulations using full unsteady gas dynamic two-dimensional flow of the perfect gas have been performed and the results compared. The first method takes into account only changes of pressure inside airbag, second takes into account also pressures variation outside the airbag fabric.

Fig. 15 presents the following phases of inflation of the aerial curtain and Fig. 16 the corresponding graphs of the speed of the airbag fabric skin in the function of the time. Aerial curtain more quickly attains the extreme position in the case of the use of the method neglecting the influence of the external environment. Of course, the speed of curtain fabric is also greater than in the case of the method taking into account airbag environments.

The proposed method of airbag inflation process has been implemented for the 3D models of an airbag. Fig. 17 presents the comparison of the airbag fabric skin shape of a simple circular airbag in the same time instances for model with and without the environment influence. The differences are clearly visible.



a b c d

Fig. 13. Comparison of temporary airbag shapes obtained by a) uniform pressure model, b) uniform pressure model with stream correction, c) inner gas dynamics model, d) inner and outer gas dynamics model

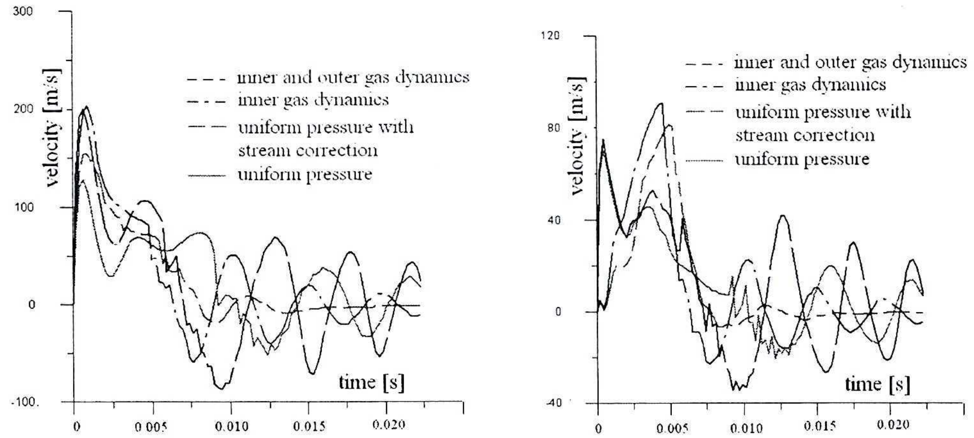


Fig. 14. Variation of the airbag fabric velocity of points located in axis of symmetry (left diagram) and 1/3 of airbag dimension above (right diagram).

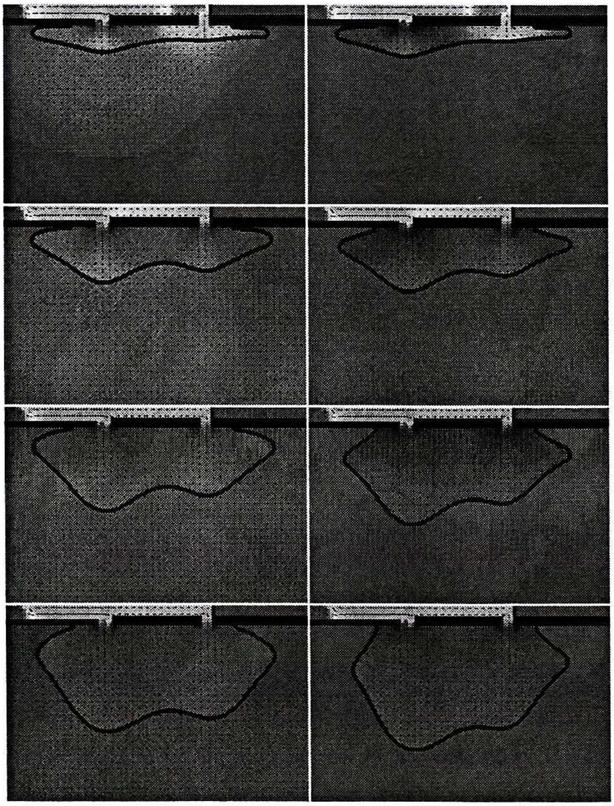


Fig. 15. Temporary shapes of an air bag – left row model with environment influence (inner and outer gas dynamics), right row model without environment influence (inner gas dynamics).

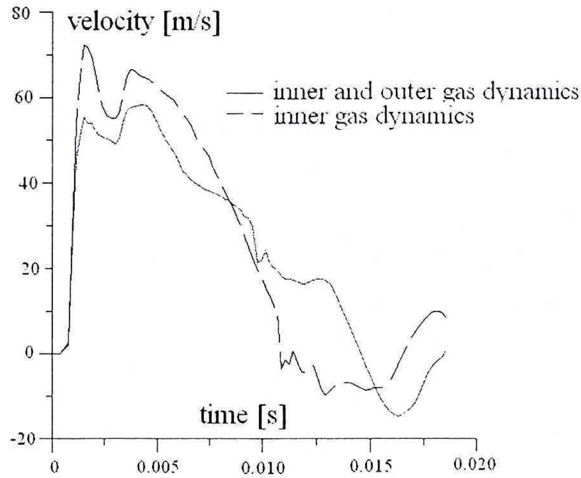


Fig. 16. Central point of air bag fabric skin velocity variations (model with and without environment influence)

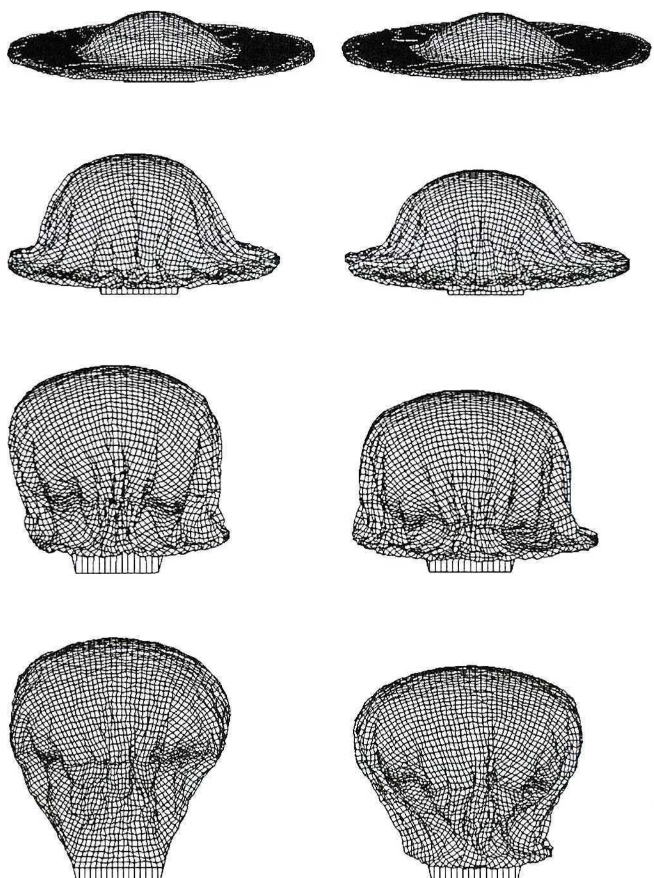


Fig. 17. 3D case – left row model omitting environment influence, right row model including environment.

4. Conclusions

A simple set of analysed geometries has been chosen to clarify the basis of proposed new model. The comparison between the results of simulations obtained with known and commonly used methods and the method proposed in the present work suggest that the influence of the airbag environment in initial phases on the airbag inflation process might be essential. One can suggest that all calculations, in which the first phase of the airbag opening is important, should be performed using the proposed model. It is particularly crucial in the cases in which the driver or passenger is located too close to the ignited airbag. In contrary to airbags commonly used for many years, the airbags of driver and passenger having a folding time about 25–30 milliseconds, the new generation of side bags had to fold in 5–6 milliseconds. Such short time of folding process suggests the importance of all kinds of unsteady processes. It seems that in investigation of the side airbags opening the influence of environment can not be neglected. Omitting the effect of environment results in incorrect estimation of forces acting on protected persons. In the cases in which only the shape of the fully opened airbag is important, all models give almost identical results.

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Nowy model symulacji napełniania poduszki powietrznej w przypadku nietypowej pozycji kierowcy – porównanie z modelami istniejącymi

Streszczenie

W pracy obszernie omówiono problemy związane z obliczeniami rozwijania poduszek powietrznych w przypadku gdy istotny jest początkowy okres tego procesu. Przedstawiono istniejące do tej pory modele procesu napełniania poduszki. Zaproponowano nowy model procesu napełniania. Na kilku prostych geometrycznie przykładach wykazano występowanie wyraźnych różnic w rozwiązaniach uzyskanych omawianymi modelami. Wykazano zalety proponowanego modelu w stosunku do modeli istniejących i podano zakres jego efektywnego stosowania.