Reduction of Acceleration Induced Injuries from Mine Blasts under Infantry Vehicles

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Abstract

Anti tank (AT) mines and improvised explosive devices (IED) pose a serious threat to the occupants of infantry vehicles. The use of an energy absorbing seat in conjunction with vehicle armor plating greatly improves occupant survivability during such an explosion. The dynamic axial crushing of aluminum tubes constitutes the principal energy absorption mechanism to reduce the blast pulse transmitted to the occupant in this investigation. The explicit non-linear finite element software LSDYNA is used to simulate the effect of an explosion under a vehicle seat in which an occupant is seated. The injury mechanisms of the vehicle-occupant contact interface corresponding to the vehicle seat structure upon the occupant's torso are simulated. Data such as compressive lumbar loads, head and torso accelerations, and neck moments are collected from the numerical dummy which is used to simulate the occupant's response. This data is then compared to injury threshold values from various references to assess survivability.

Keywords: Energy Absorbing Seat, Mine Blast, LSDYNA, Occupant Protection, Survivability, Energy Balance Formulation, Axial Crushing

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1. Introduction

During the explosion of an AT (anti tank) mine or IED (improvised explosive device) under an infantry vehicle, significant impulse loads are transmitted to the occupant through the vehicle-occupant interfaces such as the floor and seat. If these loads are not attenuated to survivable levels, it normally leads to fatality of the occupant. Armor plating a vehicle is not sufficient to protect the occupant against land mine explosions and thus further protective techniques need to be investigated.

One such concept is an Energy Absorbing Seat Mechanism (EASM) that cushions the occupant against these shock pulses by absorbing the kinetic energy of a mine blast through the elastic and/or plastic deformation of various energy absorbing elements thereby attenuating acceleration pulses transmitted from the vehicle structure to the occupant to survivable levels. There is currently no effective energy absorbing seat mechanism in use in US Army ground combat vehicles.

In 1996, Alem et al. [1] evaluated an energy absorbing truck seat to evaluate its effectiveness in protection against landmine blasts. In 1998, the Night Vision and Electronic Sensors Directorate published a report on Tactical Wheeled Vehicles and Crew Survivability in Landmine Explosions [2]. Concepts that are used in the crashworthiness analysis of aircraft seats are some what similar to those used in crew protection against mine blasts. This is because both events predominantly deal with the attenuation of very large vertical acceleration pulses. In 2002, Kellas [3] designed an energy absorbing seat for an agricultural aircraft using the axial crushing of aluminum tubes as the primary energy absorber, which forms the basis of our simulation.

This study focuses on the numerical simulation of an EASM subjected to a mine blast. The mine blast is realistically simulated by prescribing acceleration pulses to the structure that imparts the same response to the structure as would an actual land mine explosion directly underneath an infantry vehicle. The human occupant is simulated by a numerical 5th percentile HYBRID III dummy. Data

such as head and torso acceleration, neck moments, and dummy-structure contact forces are collected during the simulation and analyzed for injury assessment. Only the contact interface of the occupant and seat is focused upon in the first part. New concepts to further minimize transmitted pulses are introduced, such as a foam and airbag cushion. The EASM design is then finalized.

In order to determine the effectiveness of a design that protects occupants against injury caused by crash and mine blasts, certain injury criteria need to be defined. Occupant crash data such as forces, moments and accelerations are collected from experiments or simulations and then compared to these injury criteria to assess occupant survivability and human injury. It is important to note that these injury criteria cannot predict the extent of an injury; rather they indicate whether the injury will occur and if so, the probability of survival. According to [4], the approximate tolerance level for -Gz accelerative force is 15 G, while for +Gz it is 25 G. The lumber load criteria states that the maximum compressive load shall not exceed 1500 pounds (6672 N) measured between the pelvis and lumbar spine of a 50th-percentile test dummy for a crash pulse in which the predominant impact vector is parallel to the vertical axis of the spinal column. Also, the compressive load must not exceed 3800 N in a 30 ms interval. This is one of the most widely used criterions in vertical crash and impact testing [3-8]. If the spinal cord is severely compressed or severed, it can lead to either instant paralysis or fatality.

The U.S. Army's Aberdeen Test Center [4] has established injury criteria for mine blast testing of high mobility multipurpose wheeled vehicles (HMMWV). These criteria are comprehensive, provide a good assessment of injury, and take into account the entire occupant's body subject to any combination of external stimuli associated with a mine blast. A few criteria are listed in Table 1.

2. Review of Human Injury Tolerance Criteria

In order to determine the effectiveness of a design that protects occupants against injury caused by crash and mine blasts, certain injury criteria need to be defined. Occupant crash data such as forces, moments and accelerations are collected from simulations and then compared to these injury criteria to assess Occupant Survivability and Human Injury. Summary of the injury criteria available in the literature are listed in the following section.

2.1 Generalized Human Tolerance Limits to Acceleration

Table 1 [4] displays the human tolerance limits for typical crash pulses along three mutually orthogonal axes, for a well restrained young male. These values provide a general outline of the safe acceleration limit for a human during a typical crash. However, the time duration of the applied acceleration pulse has not been specified. Higher acceleration pulses can be sustained for shorter durations compare to lower acceleration pulses for longer durations, thus the time duration in question is important [4].

2.2 Injury Scaling

Injury scaling is a technique for assigning a numerical assessment or severity score to traumatic injuries in order to quantify the severity of a particular injury. The most extensively used injury scale is the Abbreviated Injury Scale (AIS) developed by the American Association for Automotive Medicine and originally published in 1971. The AIS assigns an injury severity of “one” to “six” to each injury according to the severity of each separate anatomical injury. The primary limitation of the AIS is that it looks at each injury in isolation and does not provide an indication of outcome for the individual as a whole. Consequently, the Injury Severity Score (ISS) was developed in 1974 to predict probability of survival. The ISS is a numerical scale that is derived by summing the squares of the three highest body region AIS values. This gives a score ranging from 1 to 75. The

maximal value of 75 results from three AIS 5 injuries, or one or more AIS 6 injuries. Probabilities of death have been assigned to each possible score.

2.3 Dynamic Response Index (DRI)

The DRI is representative of the maximum dynamic compression of the vertebral column and is calculated by describing the human body in terms of an analogous, lumped-mass parameter, mechanical model consisting of a mass, spring and damper. The DRI model assesses the response of the human body to transient acceleration-time profiles. DRI has been effective in predicting spinal injury potential for + Gz acceleration environments in ejection seats. DRI is acceptable for evaluation of crash resistant seat performance relative to spinal injury, if used in conjunction with other injury criteria including Eiband and Lumbar Load thresholds [4].

2.4 Lumbar Load Criterion

The maximum compressive load shall not exceed 1500 pounds (6672 N) measured between the pelvis and lumbar spine of a 50th-percentile test dummy for a crash pulse in which the predominant impact vector is parallel to the vertical axis of the spinal column. Also, the compressive load must not exceed 3800 N in a 30 ms interval. This is one of the most widely used criterions in vertical crash and impact testing. If the spinal cord is severely compressed or severed, it can lead to either instant paralysis or fatality. [1, 5-8]

2.5 Head Injury Criterion (HIC)

HIC was proposed by the National Highway Traffic Safety Administration (NHTSA) in 1972 and is an alternative interpretation to the Wayne State Tolerance Curve (WSTC) [4, 7]. It is used to assess forehead impact against unyielding surfaces. Basically, the acceleration-time response is experimentally measured and the data is related to skull fractures. Gadd [9] had suggested a weighted-impulse criterion (GADD Severity Index, GSI) as an evaluator of injury potential defined as:

$$SI = \int_t a^n dt$$

-- (1)

where

SI = GADD Severity Indiex

a = acceleration as a function of time

n = weighting factor greater than 1

t = time

Gadd plotted the WSTC data in log paper and an approximate straight line function was developed for the weighted impulse criterion that eventually became known as GSI.

The Head Injury Criteria is given by:

$$HIC = (t_2 - t_1)\left[\int_{t_2}^{t_1} a(t)dt\right]$$

-- (2)

where

a(t) = acceleration as a function of time of the head center of gravity

t_1,t_2 = time limits of integration that maximize HIC

FMVSS 208 (Federal Motor Vehicle Safety and Standards) originally set a maximum value of 1000 for the HIC and specified a time interval not exceeding 36 milliseconds. HIC equal to 1000 represents a 16% probability of a life threatening brain injury. HIC suggests that a higher acceleration for a shorter period is less injurious than a lower level of acceleration for a higher period of time. As of 2000, the NHTSA final rule specified the maximum time limit for calculating the HIC as 15 milliseconds. [9-15].

2.6 Head Impact Power (HIP)

A recent report included the proposal of a new HIC entitled Head Impact Power (HIP) It considers not only kinematics of the head (rigid body motion of the skull) but also the change in kinetic energy of the skull which may result in deformation of and injury to the non-rigid brain matter. The Head Impact Power (HIP) is based on the general rate of change of the translational and rotational kinetic energy. The HIP is an extension of previously suggested “Viscous Criterion” first proposed by Lau and Viano in 1986, which states that a certain level or probability of injury will occur to a viscous organ if the product of its compression ‘C’ and the rate of compression ‘V’ exceeds some limiting value [4].

2.7 Injury Assessment Reference Values (IARS)

This rule adopts new requirements for specifications, instrumentation, test procedures and calibration for the Hybrid III test dummy [4]. The regulation’s preamble has a detailed discussion of the injury mechanisms and the relevant automotive mishap data for each of the injury criteria associated with the Hybrid III ATD. Military test plans should implement these criteria.

2.8 Neck Injury Criterion (NIC)

The NIC considers relative acceleration between the C1 and T1 vertebra and is given by [16]:

$$NIC(t) = 0.2 x a_{rel}(t) + [V_{rel}(t)]^2 \quad \text{-- (3)}$$

where

$$\begin{aligned} a_{rel}(t) &= a_x^{T1}(t) - a_x^{Head}(t) \\ {}_{rel}(\ ) &= \int a_x^{T1}(t) - \int a_x^{Head}(t) \end{aligned} \quad \text{-- (4)}$$

NIC must not exceed 15 m^2/s^2 [17]. Another criteria NIC_{50} refers to NIC at 50mm of C1-T1 (cervical-thoracic) retraction. Newly proposed N_{ij} criteria by NHTSA combines effects of forces and moments measured at occipital condyles and is a

better predictor of cranio-cervical injuries. N_{ij} takes into account N_{TE} (tension-extension), N_{TF} (tension-flexion), N_{CE} (compression-extension), N_{CF} (compression-flexion). FMVSS specification No.208 requires that none of the four N_{ij} values exceed 1.4 at any point. The generalized NIC is given by [18]:

$$N_{ij} = \left(F_Z \big/ F_{ZC} \right) + \left(M_Y \big/ M_{YC} \right) \quad \text{-- (5)}$$

where F_z = Upper Neck Axial Force (N),
M_y = Moment about Occipital Condyle
F_{zn} = Axial Force Critical Value (N), and
M_{yn} = Moment Critical Value (N-m).

In FMVSS 208 (2000) final rule a neck injury criterion, designated *Nij*, is used. This criterion is based on the belief that the occipital condoyle-head junction can be approximated by a prismatic bar and that the failure for the neck is related to the stress in the ligament tissue spanning the area between the neck and the head. *Nij* must not exceed 1.0 [14, 15, 16, 18].

2.9 Chest Criteria

Peak resultant acceleration will not exceed 60 G's for more than 3 milliseconds (Mertz, 1971) as measured by a Tri-axial accelerometer in upper thorax. Also, the chest compression will be less than 3 inches for the Hybrid III dummy as measured by a chest potentiometer behind the sternum [4, 7].

2.10 Viscous Criterion

Viscous Criterion (V*C) – defined as the chest compression velocity (derived by differentiating the measured chest compression) multiplied by the chest compression and divided by the chest depth. This criterion has been mentioned for the sake of completeness of information; however it is not widely used [4].

2.11 Femur Force Criterion

This criterion states that the compressive force transmitted axially through each upper leg should not exceed a certain value. Impulse loads that exceed this limit can cause complete fracture of the femoral bone as well as sever major arteries that can cause excessive bleeding. Different references state different values for the maximum allowable compressive axial force. Horst et al. [5] uses a maximum of 8000 N for the Tibia Compression Force Criterion. Wayne State University [7] states a maximum allowable value of 10,000 N. The Department of Army [4] states the axial compression force shall not exceed 7562 N in a 10 ms interval and 9074 N at any instant.

In numerical dummies, discrete spring elements of known stiffness are included within the leg model, from which the femur axial compressive force is easily extracted. In actual dummies, load cells are placed on the dummy's leg, which are calibrated to provide the compressive force at the femur.

2.12 Thoracic Trauma Index (TTI)

The Thoracic Trauma Index is given by:

$$TTI(d) = 1/2\,(G_R + G_{LS}) \quad \text{-- (6)}$$

G_R is the greater of the peak accelerations of either the upper or lower rib, expressed in G's. G_{LS} is the lower spine peak acceleration, expressed in G's. The pelvic acceleration must not exceed 130 G's [4].

3. Mine Blast Injury Criteria

U.S. Army's Aberdeen Test Center has established injury criteria for mine blast testing of high mobility wheeled vehicles. The injury criteria can also provide guidance in standard crash impact testing orientations. These criteria are comprehensive and provide a good assessment of injury that takes into account the entire occupant's body subject to any combination of external stimuli associated with a mine blast. A few criteria are listed in Table 5. of reference [4].

4. Methodology

4.1 Energy Absorbing Seat Structure

Axial crushing of cylindrical tubes are a very popular choice as an impact energy absorber because it provides a reasonably constant operating force, has high energy absorption capacity and stroke length per unit mass. Further a tube subjected to axial crushing can ensure that all of its material participates in the absorption of energy by plastic work [19]. The axial crushing can occur in two modes, concertina and diamond. It has been reported that the concertina mode of deformation results in a higher specific energy absorption than the diamond mode of deformation (high D/t ratios, non-axisymmetric) [20]. Figure 1 displays the events that take place during the axial crushing of a cylindrical aluminum tube. For each fold, energy is dissipated during the formation of the three plastic hinges, and circumferential straining of the tube.

The EA seat structure with a Hybrid III dummy is displayed in Figure 2. The support structure rigidly supports two cylindrical steel rails inclined at a 20° angle to the vertical. This rigid connection between the support structure and the two ends of the rails is accomplished by using the *CONSTRAINED _ NODAL _ RIGID _ BODY*. A set of upper and lower cylindrical steel brackets which slide along the rails are rigidly attached to the seat in the same manner. A steel collar is rigidly fixed to each rail. The cylindrical aluminum crush tubes are coaxial with the steel rails and are positioned between the upper brackets and collars. Table 2 lists a few geometrical and material properties of the aluminum tubes used in the EA seat structure. The tubes used in this study have a D/t ratio of 30.7 and are classified as thick tubes (D/t < 80) and deform in a concertina mode. Referring to Figure 2, upon impact during a vertical drop test, the upper brackets move downward along with the seat and crush the aluminum tubes against the fixed collar. This constitutes the primary energy absorption principal used in this study. During a mine blast, the collars move upward along with the support structure and crush the aluminum tubes against the upper brackets which are attached to the seat. The occupant is modeled using a 5^{th} percentile HYBRID III

dummy. An initial time delay of 50 ms is provided in all simulations to allow for gravity settling of the dummy against the seat which ensures proper contact. In addition to the aluminum crush tubes, further energy absorbing elements are added to the design.

A foam cushion provides additional cushioning to the occupant. The part of the cushion behind the dummy's neck and head is made thicker than the rest of the cushion so as to follow the contour of the rear part of the head and neck. This is seen in Figure 2. This will minimize the head recoil distance before contact with the cushion which will reduce acceleration induced injuries of the head and neck that are characterized by parameters such as Head Injury Criteria (HIC) and Neck Injury Criteria (NIC). More details about HIC and NIC can be obtained from [4] and [18] respectively. The material model used for the foam cushion is *MAT_LOW_DENSITY_FOAM* [21]. The material properties are as follows, modulus of elasticity (E) is 0.794 N/mm^2, density (ρ) is 1.22E-7 kg/mm^3, hysteretic unloading factor (Hu) is 0.7, decay constant (β) is 0.0, and tension cut off stress (Tc) is 1 MPa. Figure 3 displays the nominal stress strain plot of the foam material.

Another concept is to use an airbag cushion whose inflation is controlled by a sensor that triggers at a user defined acceleration level can also provide additional cushioning, especially during vehicle slam down after a mine blast. The inflation of the airbag is controlled with a user-defined curve. The initial filled shape of the airbag cushion is identical to the foam cushion.

The application of the real effects of the vertical drop and mine blast tests are through applied pulses that prescribe structural accelerations. Figure 4(a) displays the deceleration pulse that represents vertical impact after freefall, based on data from [3]. Figure 4(b) displays the acceleration pulse that represents a mine blast under an armored vehicle. Both pulses act along the vertical direction. The mine blast pulse includes a peak acceleration of 171 G for a duration of 5 ms. This is followed by a 85 ms duration of negative acceleration to put the final velocity at zero and final displacement at its maximum vertical

position. After that the acceleration stabilizes at -1 G (freefall) until the displacement is zero.

A series of vertical drop test simulations are run using LSDYNA. Numerical data such as seat and torso accelerations are compared to experimental data from [3]. Once the finite element model is validated using the vertical drop test, a series of mine blast simulations are run using LSDYNA. Occupant data such as head and neck accelerations, neck flexion-extension moments, seat and torso accelerations, are collected and examined to assess occupant injury and survivability.

Noise is an inherent feature of impact test data and so filtering of data is required to obtain readable and meaningful results. Filtering is done with a low range Butterworth filter, using a cut-off frequency of 300 Hz. This choice of filtering frequency was made after performing a fast Fourier transform (FFT) on the data collected from the dummy. It is reported in [4] that low frequency filters are recommended for vehicle structure and seat systems during impact testing as they help filter out high frequency spikes that are associated with structural resonance. Reference [4] further provides guidelines for the measurement techniques and choice of filter class that must apply to military vehicle test data, entitled *SAE J211*.

5. Numerical Results and Discussion

Numerical results from the Energy Absorbing Seat simulations have been compared with experimental observations and data from [3]. The results from the simulations are in very good agreement with the experimental data as can be seen from Figure 5. It is important to note the scarcity of further available experimental data for such vertical drop testing of energy absorbing seats with a dummy occupant. Numerous simulations were run using both the seat foam cushion and airbag cushion designs. It was found that both designs proved equally effective in reducing the maximum load transmitted to the occupant. However the foam cushion design proves to be more economically viable. The crushing of the aluminum tubes proved effective in reducing the maximum acceleration pulse transmitted to the occupant. However, the compressive lumbar load also needs to be considered. The peak dynamic crushing load of the aluminum tubes is much larger than the maximum allowable compressive lumbar load. Without a device to limit this compressive load, the lumbar column will get crushed before the aluminum tubes begin to crush leading to instant fatality. This is where the foam cushion and airbag cushion designs play an important role by reducing the vertical contact force between the occupant and seat system, thereby reducing the compressive lumbar load, supporting the head and neck, and generally providing additional cushioning and comfort to the occupant.

5.1 Vertical Drop Tests with HYBRID III Dummy

The peak magnitude of the deceleration pulse has been attenuated from 76 G to 11 G at the lower torso, as displayed in Figure 6. This is well within the injury criteria limit of 17.5 G. According to [4] the resultant head acceleration tolerance limit is 150 G in a 2 ms interval. The contoured foam cushion behind the head ensures that the head is supported at all times during the simulation, so that there is no possibility of injury occurring from the head acceleration criteria. The peak dynamic crushing force of both aluminum tubes is 14300 N. However the compressive lumbar load experienced by the dummy is just 3600 N which is well

below the lumbar load criterion of 6672 N. This is attributed to the load attenuation during compression of the foam cushion.

5.2 Mine Blast Tests with the EA Seat and HYBRID III Dummy

The data extracted from the EA seat structure and HYBRID III dummy are compared to the injury criteria listed in Table 1. The peak magnitude of the acceleration pulse, as seen in Figure 4b, has been attenuated from 171 G to 11 G at the lower torso, as displayed in Figure 7. According to [4] the vertical acceleration of the lower pelvis over a 7 ms interval must not exceed 23 G. The peak magnitude of acceleration obtained is well within this limit. The peak dynamic crushing force of both aluminum tubes is 14640 N. However the compressive lumbar load experienced by the dummy is just 3160 N which is well below the lumbar load criterion of 6672 N. This reduction was brought about by the foam cushion at the base of the seat. The resultant chest acceleration has a peak magnitude of 18 G as seen in Figure 7. This is well below the chest resultant acceleration injury criterion of 60 G in a 3 ms time interval. Figure 8 displays the effect of the contoured foam headrest cushion in providing constant support to the head and neck and minimizing recoil. The peak magnitude of the acceleration is 17 G compare to the higher peak magnitude of 31 G in the case where the cushion was not made thicker behind the head. However both magnitudes are still well within the resultant head acceleration injury criterion limit of 150 G. Figure 9 depicts the head acceleration of the dummy with an EA seat with cushioning and without cushioning. Figure 10 displays the lumbar spine forward flexion and rearward extensional moments, with a peak magnitude of 184 N-m, which is well below the lumbar spine rearward extensional moment injury criterion limit of 370 N-m. An airbag can also be placed between the seat and the dummy bottom as shown in Figure 11. The mass flow rate in the air bag can be controlled in such that it can reduce the pulse transmitted to the dummy. Figure 12. depicts the x and the y-acceleration of the dummy's head using the various concepts presented here in.

6. Conclusions

The presented energy absorbing seat design proves to be effective in occupant survivability during vertical drop and mine blast scenarios. Numerical simulations of the energy absorbing seat subject to vertical drop tests and mine blast tests with a dummy occupant prove to be reliable and a far less expensive alternative to conducting destructive tests. From the numerical results of the simulations, it is evident that the crushing of aluminum tubes provides a controlled, acceptable means of attenuating deceleration pulses to survivable values. The use of a contoured foam cushion helps in additionally attenuating the peak deceleration pulse at the occupant's lower torso, and the compressive lumbar load. The contoured headrest ensures a minimal gap between the head and seat thereby minimizing head rearward accelerations.

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7. References

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TABLE 1: RECOMMENDED INJURY CRITERIA FOR LANDMINE TESTING [4]

HYBRID III Simulant Response Parameter	**Symbol (units)**	**Assessment Reference Values**
Head Injury Criteria Head resultant acceleration	HIC A (G)	750 ~5% risk of brain injury 150 G (2ms)
Neck forward flexion moment Neck rearward extension moment	+ My (N-m) - My (N-m)	190 N-m 57 N-m
Chest resultant acceleration	A (G)	60 G (3ms), 40 G (7ms)
Lumbar spine axial compression force	Fz (N)	3800 N (30ms), 6672 N (0ms)
Lumbar spine flexion moment Lumbar spine extension moment	+ My (N-m) - My (N-m)	1235 N-m 370 N-m
Pelvis vertical acceleration	Az (G)	15, 18, 23 G (low, med, high risk)
Tibia axial compressive force combined with Tibia bending moment	F (N) M (N-m)	F/Fc – M/Mc < 1 where Fc=35,584N and Mc=225N-m
Femur or Tibia axial compression force	Fz (N)	7562 N (10ms), 9074 N (0ms)

TABLE 2: DIMENSIONS AND PROPERTIES OF THE CYLINDRICAL ALUMINUM TUBES

Inner diameter (Di)	26.437 mm
Outer diameter (Do)	28.215 mm
Mean diameter (D)	27.326 mm
Thickness (t)	0.889 mm
Yield Strength (Y)	145 MPa
Length (L)	228.6 mm
Density (ρ)	2.610E-09 ton/mm^3
Young’s modulus of Elasticity	68948.000 N/mm^2
Poisson’s ratio	0.33
LSDYNA Material model	Piecewise Linear Plasticity
Material model number	24

TABLE 3: CHARACTERISTICS OF THE SHELL AND IMPACTOR [15]

Shell Radius (mm)	11.875
Shell Thickness (mm)	1.65
Shell Length (mm)	106.68
Young's Modulus (GPa)	72.4
Yield Stress (MPa)	295
Impact Speed (m/s)	4
Impactor Mass (kg)	262.5

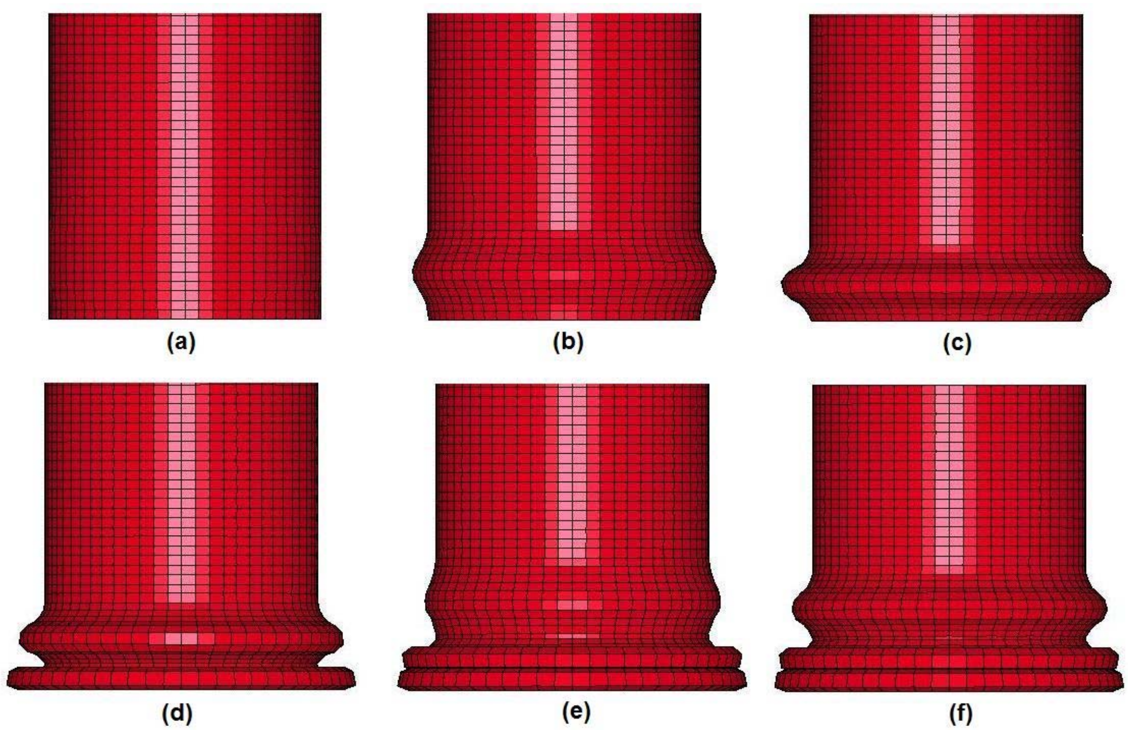


Fig. 1. Axial crushing of cylindrical tube (a) initial configuration (b) initial formation of three plastic hinges (c) formation of first lobe (d) completion of first fold and initiation of second lobe formation (e) completion of first two folds and initiation of third lobe (f) formation of third lobe

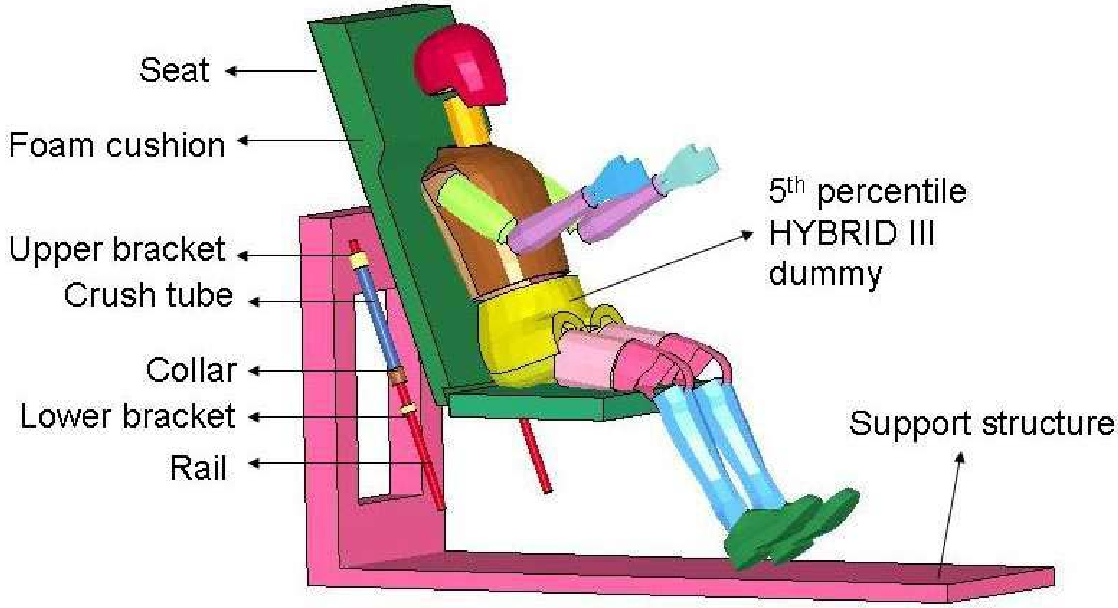


Fig. 2. Energy absorbing seat structure with Hybrid III dummy

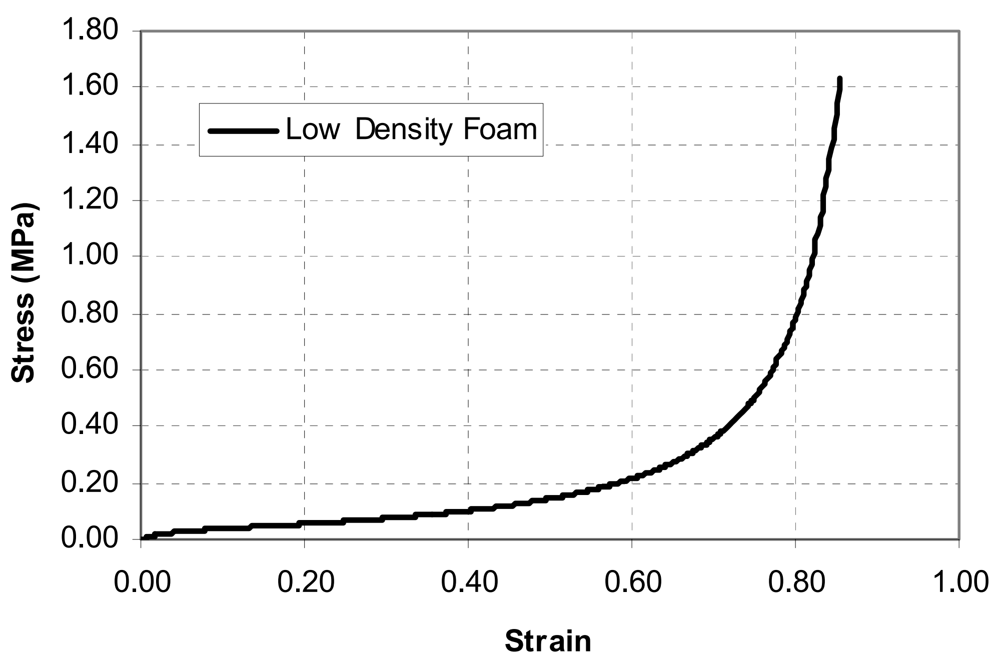


Fig. 3. Nominal stress strain plot of the low density foam used

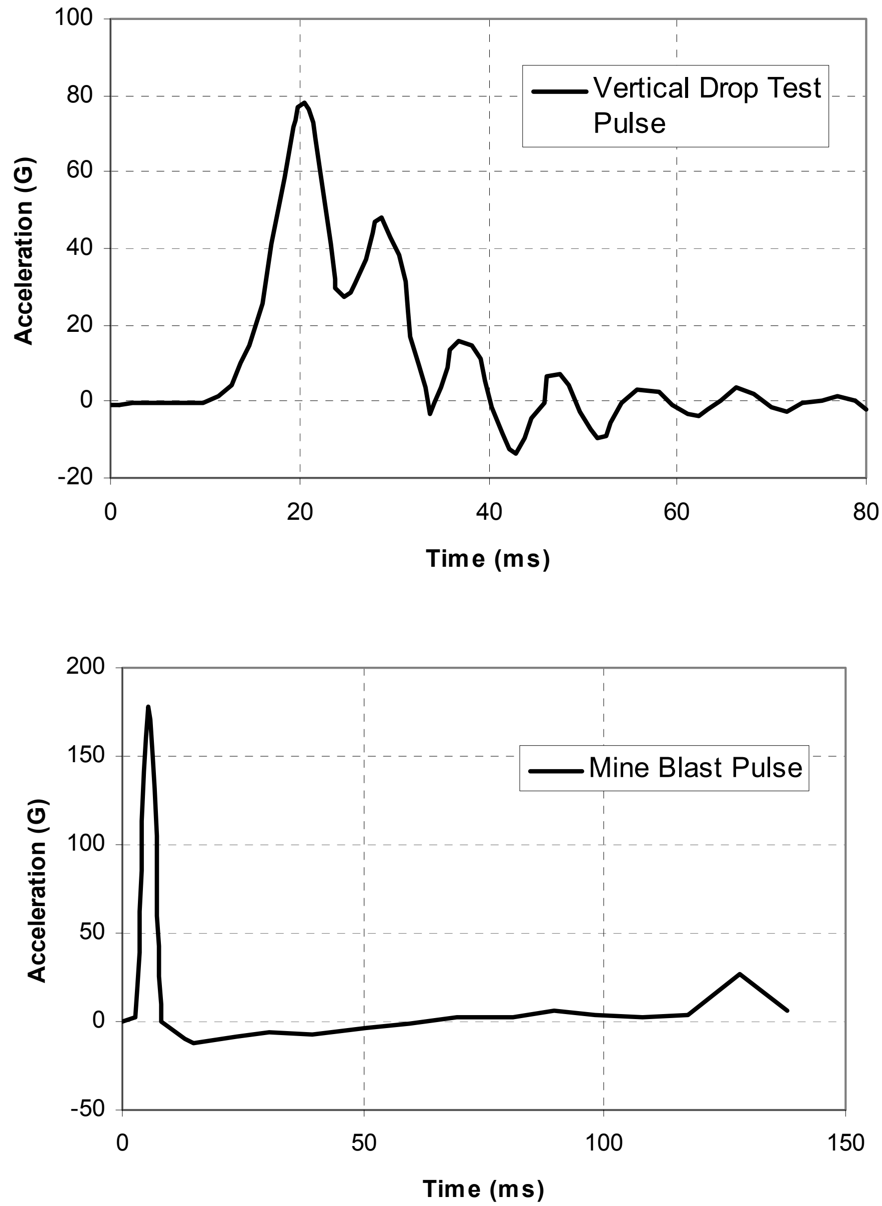
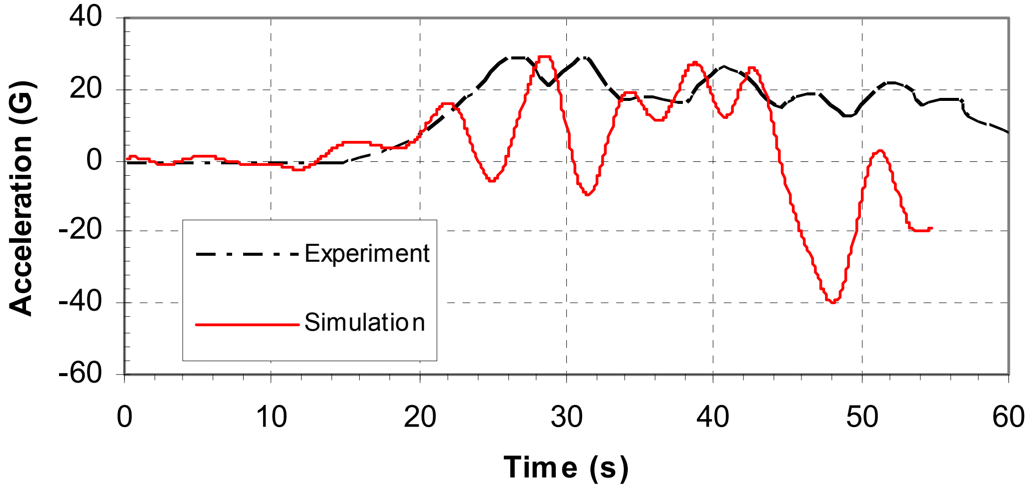


Fig. 4. Applied pulse simulating (a) impact after free fall (b) mine blast under infantry vehicle



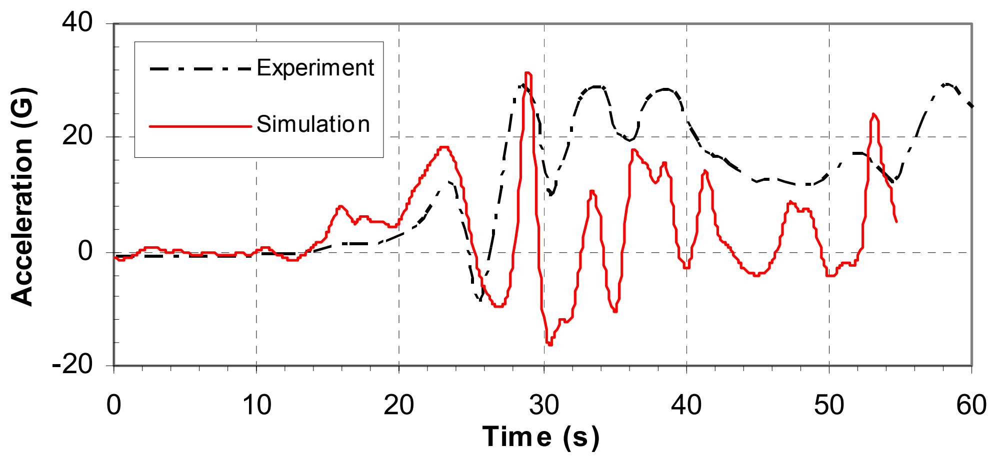


Fig. 5. Comparison of experimental and simulation results (a) seat pulse (b) occupant pulse

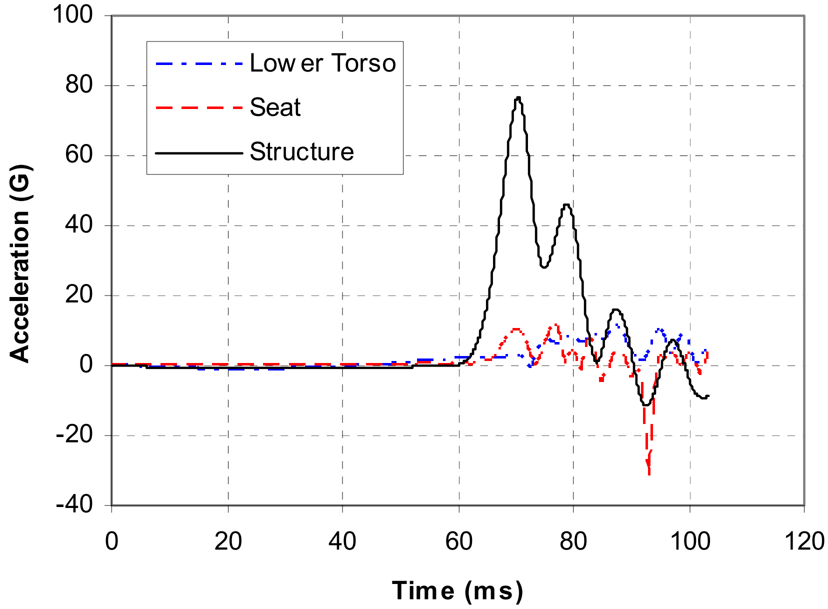


Fig. 6. Vertical drop test simulation results: acceleration

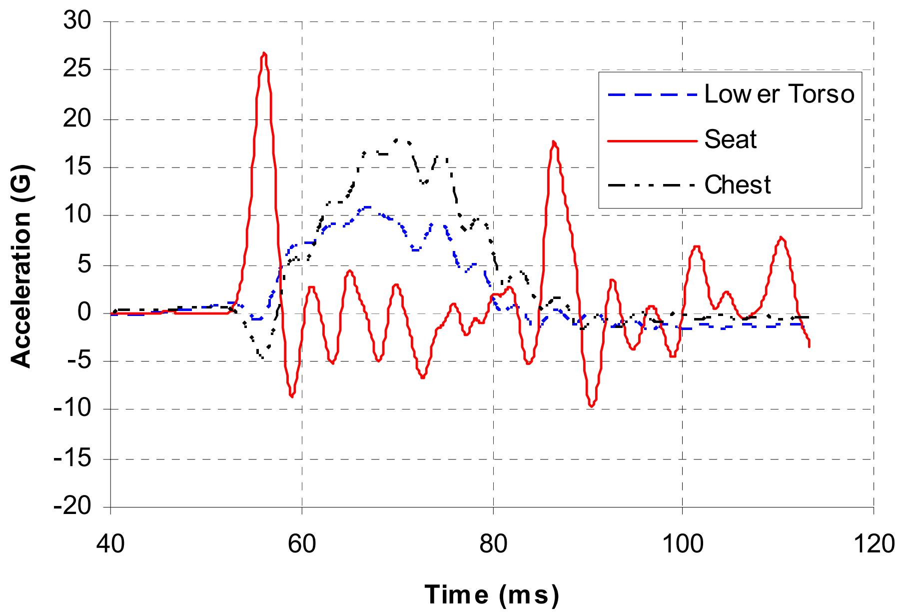


Fig. 7. Mine blast simulation results: acceleration

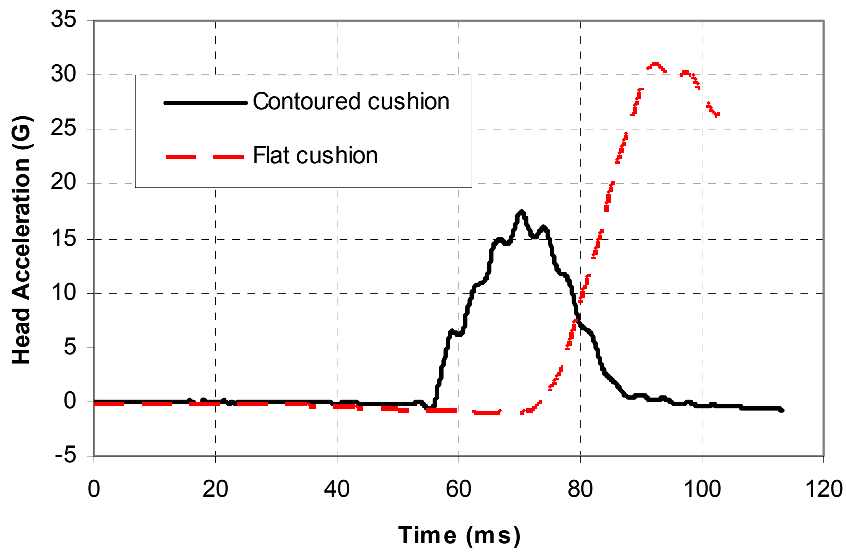


Fig. 8. Mine blast simulation results: effect of cushion shape

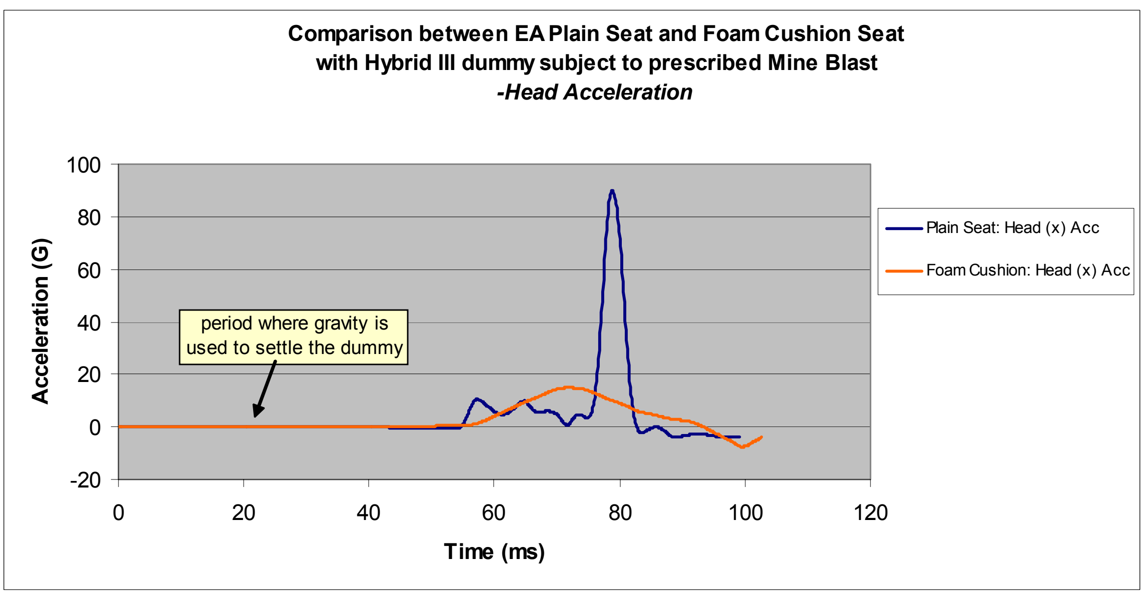


Figure 9. Dummy head acceleration and the effect of foam cushion

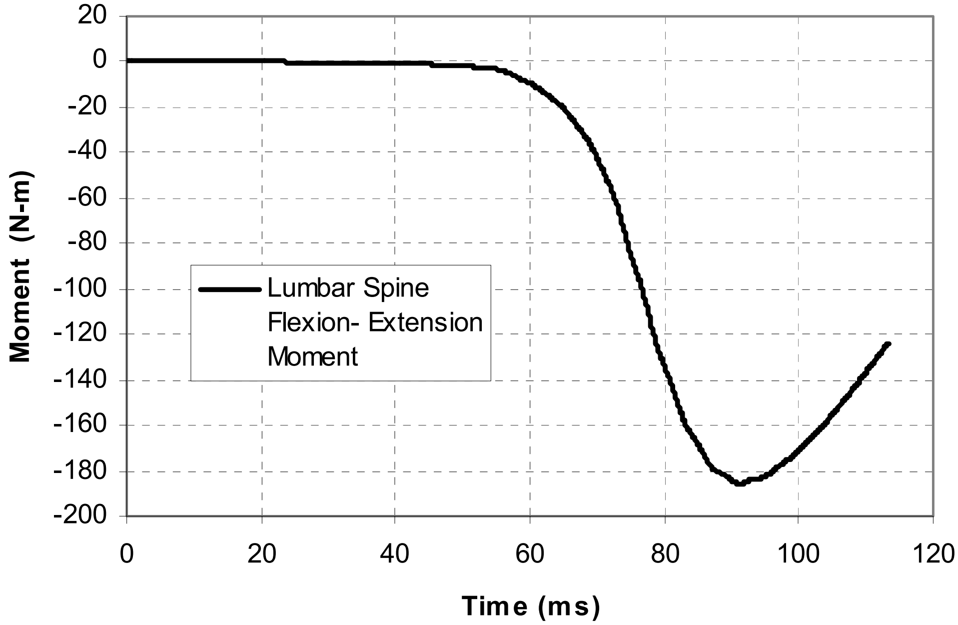


Fig. 10. Mine blast simulation results: lumbar spine flexion-extension moment

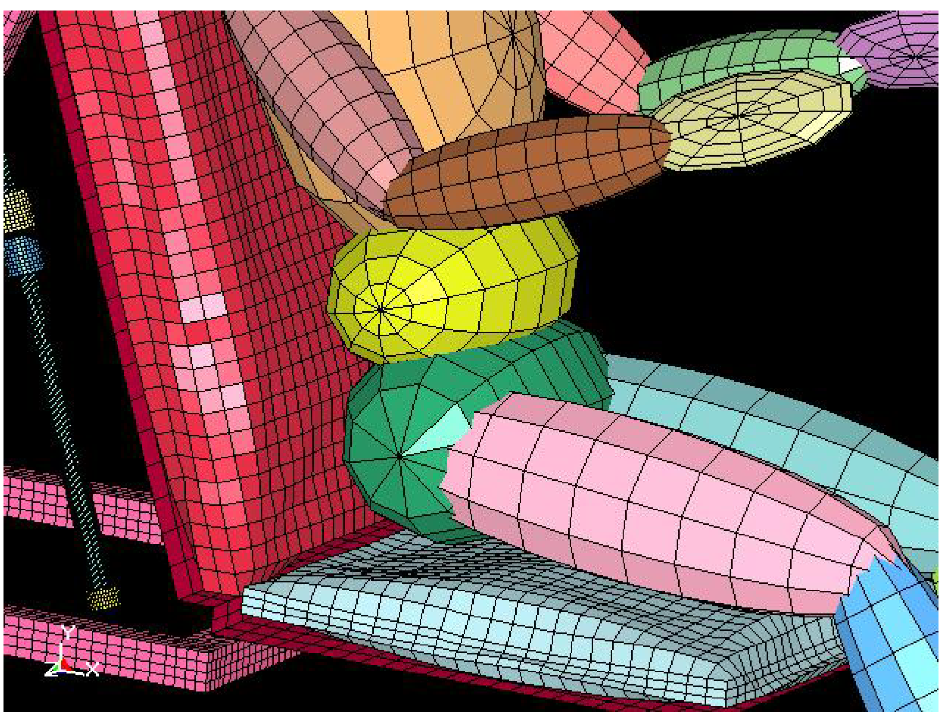


Figure 11. airbag under the dummy

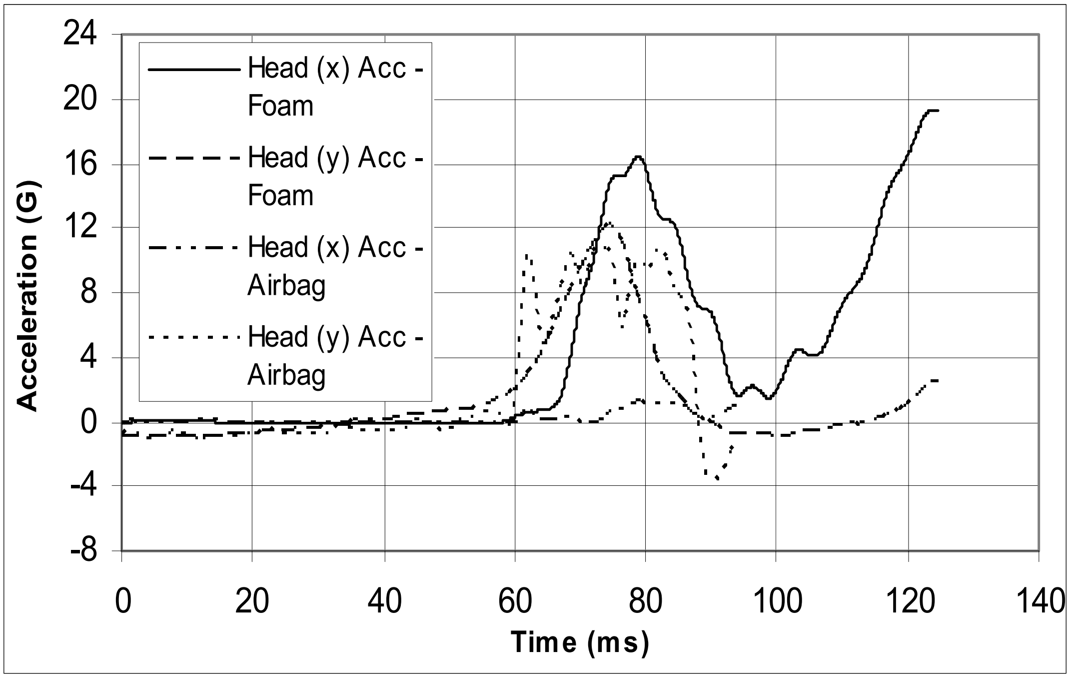


Figure 12. Head (x) and 9y) Acceleration