ASSESSMENT OF INJURY PROTECTION PERFORMANCE OF SIDE IMPACT AIRBAGS FOR OUT-OF-POSITION AND OTHER THAN 50TH PERCENTILE ADULT MALE OCCUPANTS

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ABSTRACT

The recent real-world experience with the frontal airbags and their sometimes unfortunate interaction with small size adults and children led to the analytical efforts and the results reported in this paper.

The focus of this paper is an analytical study investigating the side impact protection performance of side airbags in interaction with, out-of-position occupants. The study evaluates interaction of the two extreme size occupants including a 3 year old child, and a small 5th percentile adult female. The objective is to identify any potential problems with the side impact airbags in real world scenarios. To date, a considerable amount of research has been invested in developing and evaluating occupant protection systems for both frontal and side impacts. However, the majority of this research has focused on the 50th percentile adult male occupant size, who is properly seated in his seat. The current study validates the computer model using available test data and then assesses the side impact protection performance of the side airbags for the selected conditions.

A computer modeling system, SIFEM, is used to simulate various side impact scenarios of interest and to evaluate several vehicle designs. Candidate designs include currently on the market side airbag systems and those reported in technical literature. System performance is measured in terms of injury criteria (e.g., HIC, TTI, peak chest acceleration, peak pelvic acceleration, occupant kinematics, etc.).

SIFEM computer model is designed to take advantage of finite element and lumped mass modeling techniques. The model simulates interior occupant protection systems including padding, and airbag systems. Airbag system with user-selected bag shape and inflator flow characteristics are modeled. Simplified stretch and deployment algorithms model the bag deployment and its interaction with the occupants. Bagslap, catapult (membrane) and contact pressure phases are also modeled.

INTRODUCTION

A computer modeling system, SIFEM, was used to simulate selected impact event and to evaluate occupant configuration of interest. This paper is a companion paper with another paper in this conference (Reference 1) by the same two authors. The paper in reference 1 describes in greater detail SIFEM model, restraint configuration and the vehicle impact scenario. Only the highlights of those details are presented in this paper. In this study, SIFEM was used as an evaluation tool.

Crash Scenario

The Crash Scenario used for this study consisted of an actual full scale crash test conducted at the Vehicle Research Test Center of East Liberty, Ohio (Reference 2). The test consisted of a 1988 Hyundai Excel 4-door sedan impacted by NHTSA's moving deformable barrier. The intersection collision simulated an impact with striking vehicle traveling at 30 mph, and struck vehicle at 15 mph, colliding at an angle of 90 degrees on the driver side.

Occupant Simulation

The SIFEM data base includes the basic SID (50^{th} percentile adult male dummy) and SIDIIs dummy (5^{th} percentile adult female dummy). Currently, there are no standard side impact dummies available for 3 year old child and 95th percentile adult male. For those two sizes, we created scaled 'theoretical' dummies. The details of the scaling technique are available in reference 1.

A Cautionary Note

The results presented in this study provide great insight into the problems that were studied. Caution and care, however, must be used in interpreting the results presented in this study, because of its limited nature, and the assumptions made during the course of it. The readers are advised to review references 1 and 2 to fully understand the databases used in this study.

Injury Measures

The occupant model calculates the following injury measures:

- Head Injury Criterion, (HIC);
- Peak Chest Acceleration (3 msec clip);
- Peak Femur Load, (PFL);
- Peak Pelvic Load, (PPL);
- Hip Acceleration;
- Viscous Criterion V*C, (each rib and abdomen);
- Thoracic Trauma Index, TTI;
- Hip Joint Load - Displacement, Velocity and Acceleration, (fore and aft and side to side)
- Neck Moment and Head Rotation (fore and aft and side to side)

SIDE IMPACT AIRBAG DESIGNS

Side impact airbags are relatively new. Information on their configuration, design, sensing, and characteristics is still scarce in the published literature. Currently, there are three main configurations of side airbag designs (References 3 and 4). They are:

1. Inflatable airbags similar in principle to the frontal airbags that are deployed from the seat or the door panel;
2. Curtain type thin airbags that deploy from the doorliner downwards in between A- and C- (or B-) Pillar which keeps door glass out and occupant head inside ; and
3. Head Impact Protection (HPS) which is a sausage type inflated device which provides head protection.

This study considers only the first type described above.

Sensing Techniques

Several sensing techniques are identified for the production and planned airbags (References 3 and 4). These include mechanical triggers, pressure inside door cavity, electronic 'g' sensors, etc. NHTSA-conducted side impact tests appear to indicate that on some of the compliance and NCAP tests both left and right side airbags deployed during impact. On the remaining tests, only the impacted side airbags deployed.

Sensing, Trigger and Deployment Times

Side impact configuration is such that for effective protection; sensing, trigger and deployment times have to be shorter than those available for the frontal impact airbags.

All above factors make the issues involved in side impact protection and use of airbags, demanding, technically challenging and complex.

FRONTAL AIRBAG EXPERIENCE

Several articles (References 5,6,7, 8, and 9) have addressed the issues involved in inadvertent airbag related injuries in frontal impacts. After studying the issues involved the following of those issues are applicable to the side impact airbag scenario. They are:

- Inadvertent airbag firing;
- Out-of-position occupant; and
- Unnecessary airbag firing.

Inadvertent Airbag Firings

As seen in NHTSA crash tests, the non-impacted side airbags may deploy during side impact crashes. Similarly, one or both side airbags may deploy during rollovers crashes.

Also of concern is the issue, if the airbags will deploy for relatively minor side impacts. Rather than waiting for the field experience, side impact protection designers must be looking at these issues right now before it becomes a potential safety and societal cost issue.

One more concern is reported frontal air bag deployment in FMVSS 214 type side impact tests (Reference 6). In those tests the impacted vehicle is stationary, but the crabbed Moving Deformable Barrier (MDB) simulates 90 degree intersection collision with both vehicles moving. The calculated delta-V's for the impacted vehicles appeared to be below the threshold for airbag deployment. One wonders if similar occurrence can manifest itself in side impact airbag real-world environment.

Out-of -Position Occupant

Vehicle occupant can very easily be in a position, that is not similar to a crash test Side Impact Dummy, meticulously positioned by a trained test technician. Even properly restrained vehicle occupant can have his upper or lower extremities in harm's way in the path of the deploying airbag.

A person can be dozing off with head and shoulders against the B-Pillar, door, or against the stowed airbag.

Unnecessary Airbag Deployment

This category is different than the inadvertent deployment category. Included in here are low level side interactions that may cause localized moderate damage, some distance forward or rearward and away from the occupant not necessarily requiring side impact airbag deployment and protection.

Authors have been involved in evaluation of several sideswipe kind crashes (Reference 10). The sideswipes can occur at urban city-driving-speeds and also at freeway speeds. There are instances in which the sideswipes have resulted in substantial dollar damage to the vehicle. The extensive dollar damage results from three factors. The first factor is that relatively weak, side structure is involved in the vehicular interaction. The second factor is that the damage can extend over longer length, covering several expensive parts. The third factor is that even though, at times the damage is superficial with limited depth, the repair and/or replacement cost is higher because of the extent of the overall damage.

Biodynamics Engineering, Inc. conducted a sideswipe crash test involving a passenger car and a garbage truck. An instrumented volunteer was the driver of the passenger car. The test data will be presented in reference 10 conference. The results and the data show that the evaluated sideswipe crash was not injury causing event, despite the high dollar repair costs. The deployed side airbag (or airbags) would have further added to the dollar costs without any need for occupant protection, and may have created some harm to the occupant.

The issues identified here are certainly noteworthy, and side airbag designers must have addressed these in their design. The issue this paper focuses on is the issue of what happens to the out-of-position occupants during the unnecessary airbag deployment.

The two cases considered are:

<u>Case No. 1:</u> A case of 3-year old child, **<u>not-in a child-safety-seat, but in a booster seat,</u>** and leaning to the side against the airbag is considered as a purely theoretical, lower end extreme. The performance comparison is made by simulating side impact airbag, first optimized for the 50th percentile adult male and then for the 3-year old child.

<u>Case No. 2:</u> A case of a 5th percentile adult female is considered. The effect of a deploying airbag is evaluated when she is leaning to the side against the stowed airbag.

The case of 95th percentile adult male was not evaluated in this study. In both considered cases, the occupant is assumed to be restrained. The airbag deployment takes place without any damage to the side structure of the vehicle, to simulate inadvertent airbag deployment. Hence, any trauma imparted to the occupant is solely due to the deployment of the airbag. The side window is assumed to be rolled down and in an open position during the simulation runs.

SIMULATION RESULTS AND DISCUSSION

The kinematics of the selected occupants and the simulation results are presented in Figures 1 to 3 and are summarized in Table 1.

Figure 1 shows kinematics of a 3 year old child, on booster seat, restrained, and leaning against the side when the side airbag is deployed without any side structural damage. The airbag characteristics for this simulation are optimized for the requirements of the of 50th percentile adult male.

Figure 2 shows the kinematics of the same 3-year old, with same seating configuration. In Figure 2, the airbag characteristics are optimized for the requirements of the 3-year old child.

A comparison of the kinematics in Figures 1 and 2, distinctly shows different interaction between the child and the airbag in two cases, and the influence of the higher power airbag in Figure 1. The simulation of 3 year old child is based on SIDIIs family and hence the dummy arm is simulated.

Figure 3 shows the baseline and reference kinematics of a 50th percentile adult male in interaction with the side impact airbag that is optimized for the 50th percentile adult male. A comparison of Figures 1, 2, and 3 gives visual difference and distinct variations between the kinematics of 3 year old and the 50th percentile adult male in interaction with the side airbags with different selected characteristics.

The kinematics of the 5th percentile adult female are not shown here, but, as is to be expected they lie in between the kinematics shown in Figures 1 and 3.

Table 1 has four columns. The first column shows the Injury Measure and the Units. The second column shows the results of the simulation corresponding to the kinematics shown in Figure 1. Hence it is for 3-year old child in interaction with the side airbag that is optimized for the 50th percentile adult male. The column four shows the results corresponding to the kinematics shown in Figure 2. Hence it is for the 3-year old child in interaction with the airbag that is optimized for the 3-year old child.

The third column in Table 1 summarizes the results of the simulation where a 5th percentile female, fully restrained leaning against the side is interacting with side airbag that is optimized for the 50th percentile adult male.

In discussing the results, the known thresholds for the 50th percentile adult male, such as HIC = 1000 are used in the discussion. Most cases the corresponding threshold values for 3-year old child or the 5th percentile adult female are not universally identified and accepted.

3-Year Old Child (Columns 2 and 4, Table 1)

The HIC value is low for both cases. Same is the case with the peak chest 'g' (PCĠ) value.

The Thoracic Trauma Index (TTI) values are high even for the 50th percentile adult male. TTI values are a little lower in column four, but they are still high, particularly for the 3-year old.

Viscous Criterion (V*C) values are low in column four. A value of 1 Meter/second is considered a threshold. In column two, V*C values are low for the upper and middle rib, but is relatively high for the lower rib.

Hip level forces and accelerations appear to be relatively low and not an area of concern in both columns two and four.

Viscous Criterion values for the abdomen taken in conjunction with the force show high value in column two, and this is an area of concern. This occupant is simulated with the arm. It is seen the arm mass interacts with the ribs and the abdominal area and produces high level interaction. As is seen in column four, the optimization of the airbag for the 3-year old, dramatically reduces the injury measures in the abdominal region.

The rib displacement values are moderately high for the 3 year old. Typically, a value of 1.6 inches is considered as a threshold for the 50th percentile adult male as a design guideline.

The hip joint acceleration, velocity and displacement are relatively low, both in columns two and four.

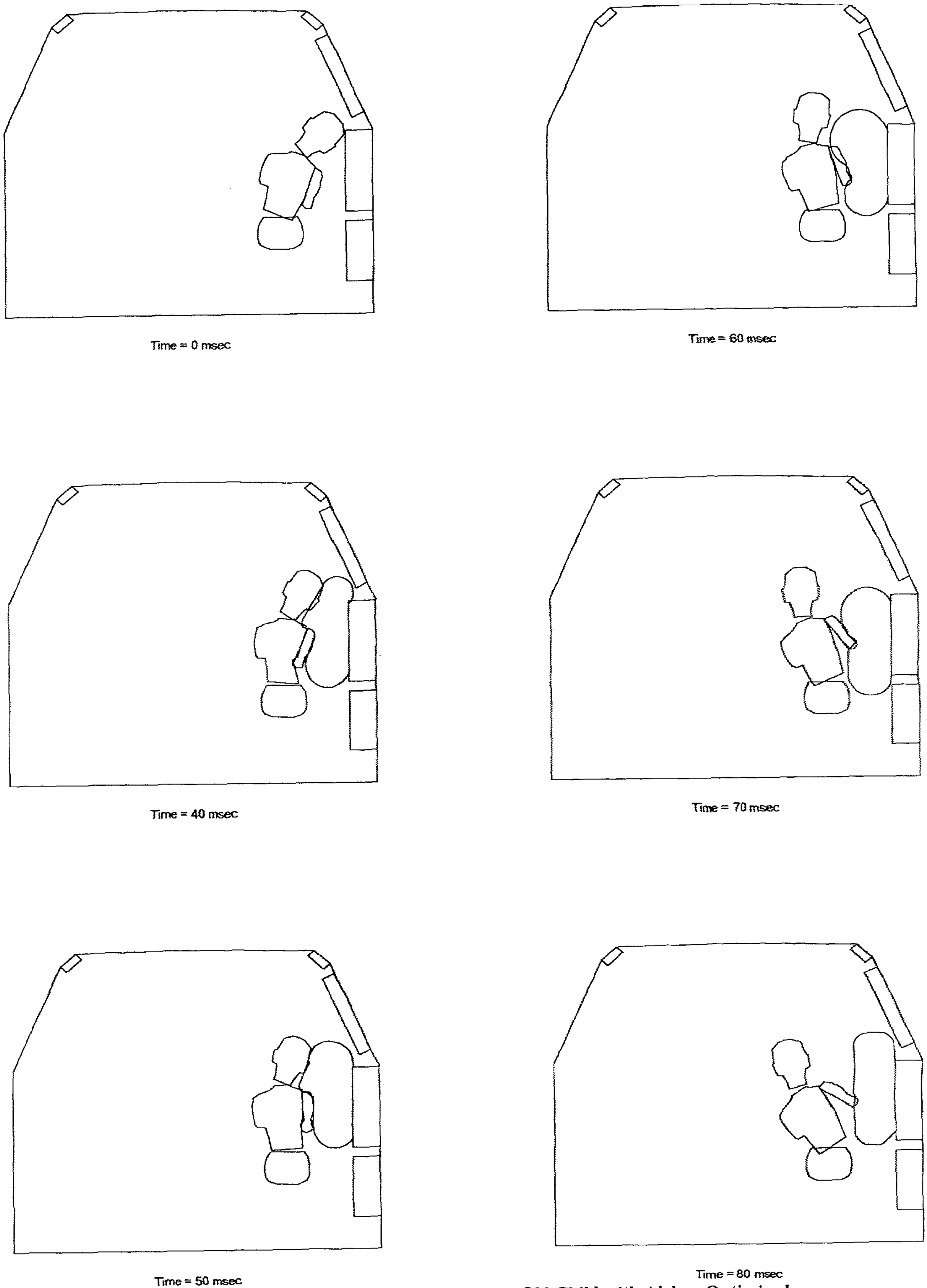

Figure 1. Occupant Trajectory, 3 Year Old Child with Airbag Optimized for 50th Percentile Adult Male

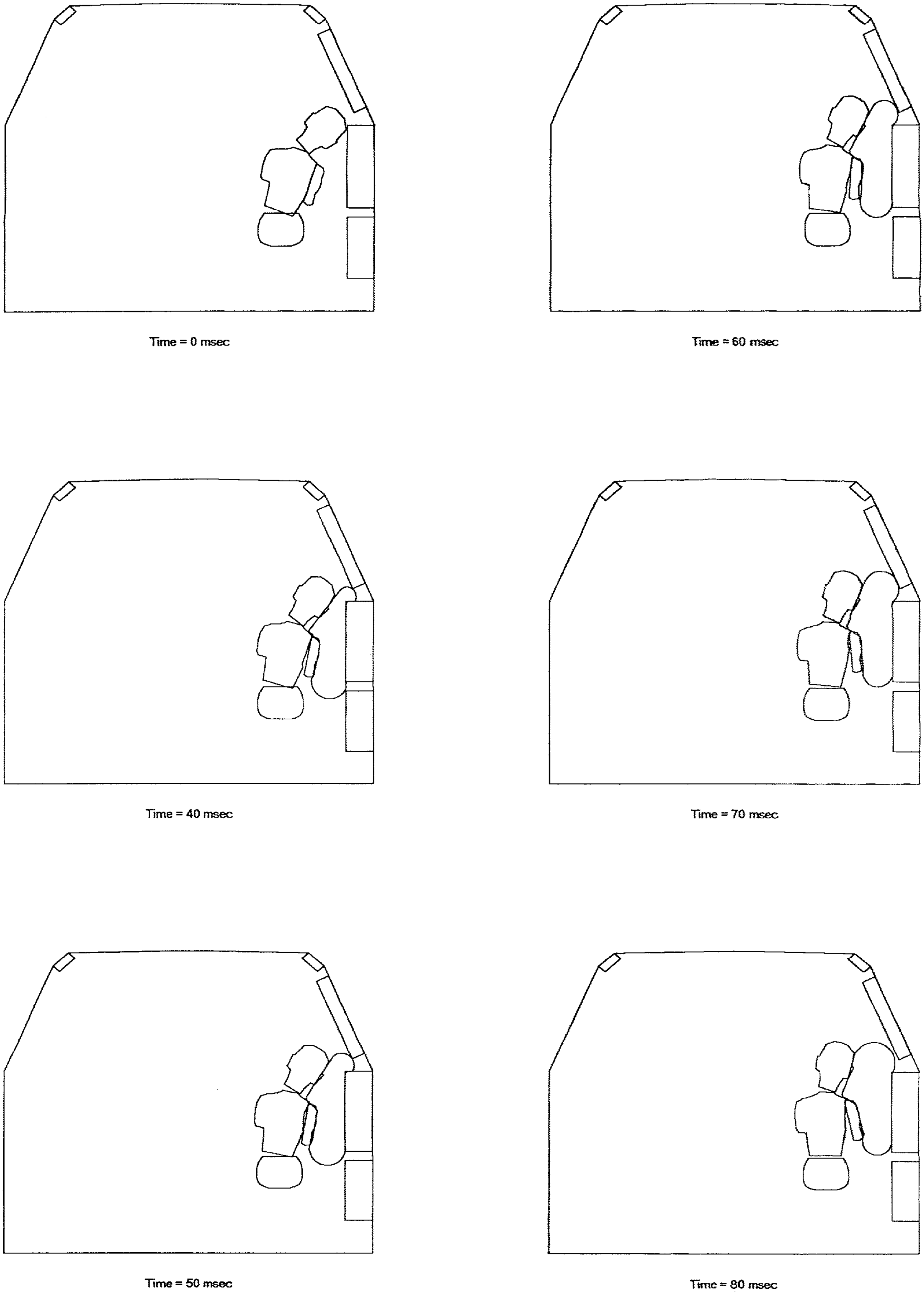

Figure 2. Occupant Trajectory, 3 Year Old Child with Airbag Optimized for 3 Year Old Child

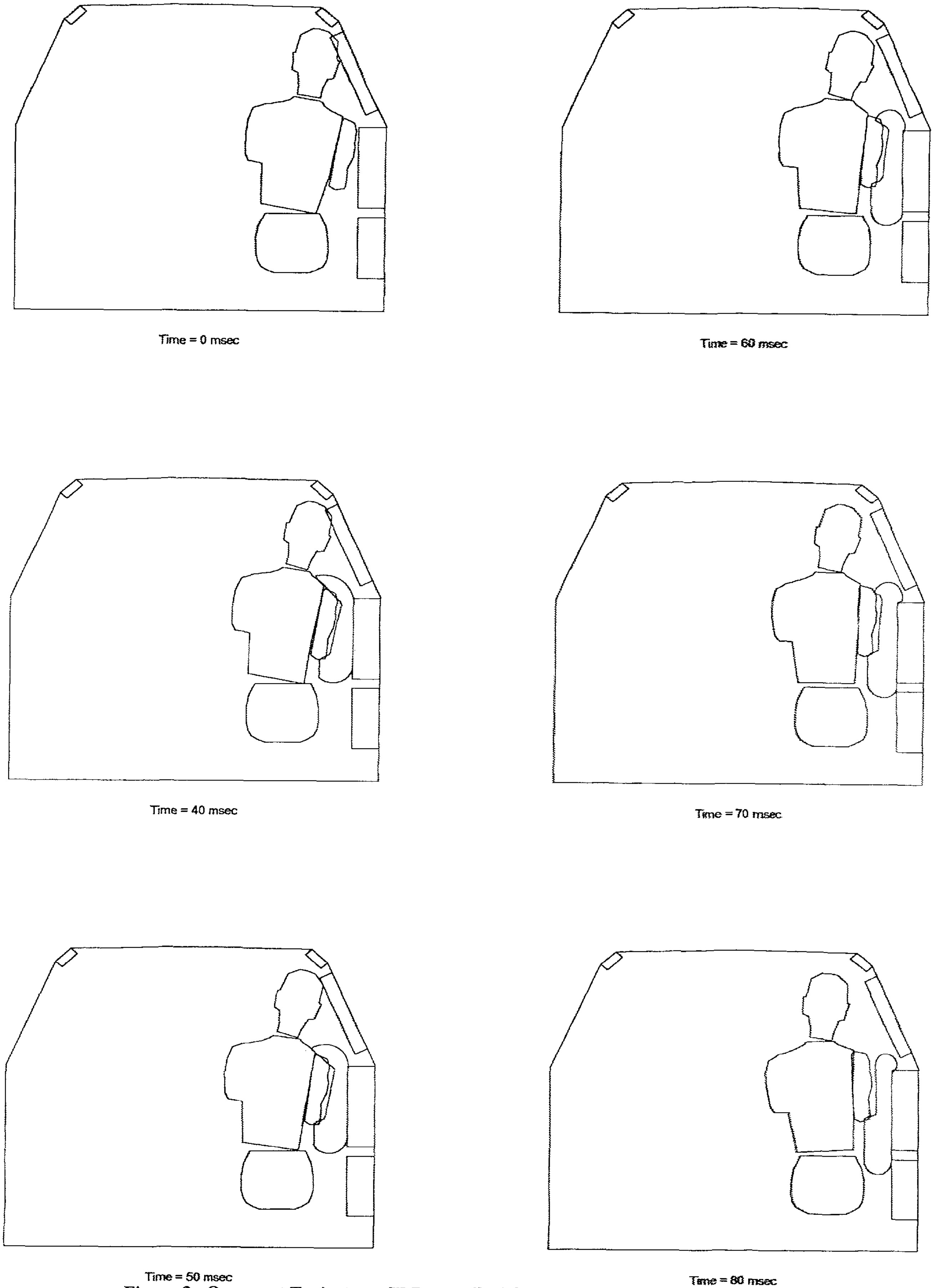

Figure 3. Occupant Trajectory, 5th Percentile Adult Female with Airbag Optimized for 50th Percentile Adult Male

Table 1. Summary of Results

Measure	03 Year Old[1]	05th Percentile[1]	3 Year Old Child[2]
HIC	50.4	37.5	4.9
PCG-3ms (g's)	22.88	19.06	17.34
TTIup (g's)	91.53	64.44	86.54
TTImid (g's)	97.14	65.61	70.26
TTIlow (g's)	105.6	67.61	92.22
V*Cup (M/s)	.1866	.076	.1106
V*Cmid (M/s)	.3902	.115	.1420
V*Clow (M/s)	.7361	.3041	.1633
HipF (lbf)	11.26	0	0
HipA (g's)	+9.5/-9.5	+2.7/-4.0	+3.0/-4.2
AbdF(lbf)	-133.3	-6.5	-3.87
V*Cabd (M/s)	2.481	.5662	.1056
DispRibu (in)	-.4377	-.3434	-.3900
DispRibm (in)	-.7211	-.5155	-.3900
DispRibl (in)	-1.1445	-.8424	-.4186
DispAbd (in)	-1.750	-1.00	-.200
HipJntA (in/s^2)	+22/-16	+2.8/-3.0	+7.5/-10.
HipJntV (in/s)	+10/-12	+5.4/-7.1	+8.9/-9.2
HipJntD (in)	+.05/-.18	-0.2	+.09/-.12
BagP (lb/in^2)	6.5	7.0	2.0
HipRestrY (lbf)	+118/-110	+135/-119	+12/-30
HipRestrZ (lbf)	+180	+210	+39/-7
WSPen (in)	0	0	0

[1]Airbag Optimized for 50th percentile Occupant.

[2]Airbag Optimized for 3 Year Old Child Occupant.

The next line shows the bag pressure, (BagP). This incidentally is not the initial pressure, but is the sustained pressure when the airbag interacts with the occupant.

The next two lines show the hip restraint forces in Y and Z directions. These account for the restraint system and the seat contour and the center console, etc.

The last line shows the side window penetration (WSPen). Obviously, without any side crush the values in all three columns are 0.

5th Percentile Female (Column three in Table 1)

The injury measures for the 5th percentile female are relatively low across all lines and body segments. This statement is true for head, chest 'g', ribs, abdomen, hip joint and hip restraint.

It needs to be reiterated here that these low results are with the airbag left optimized for the 50th percentile adult male.

The presented results show that the SIFEM computer model can be exercised for selected configurations and the results obtained can provide designers meaningful data and information.

The benefits of optimization of the airbag for the 3-year provide only limited benefits when unnecessary or inadvertent airbag deployment takes place.

CONCLUSIONS

1. The 3-year old child, in a booster seat, seat belt restrained, and leaning to the side, does not fair well when a side airbag inadvertently deploys.
2. With a side airbag that is optimized for the 50th percentile adult male, the TTI at all three levels, abdominal interaction and the middle and the lower rib lateral displacement are the areas of concern.
3. The situation is somewhat improved when the side airbag is optimized for the 3-year old. The improvement shows in the abdominal and the rib lateral displacement injury measures. The TTI, however stays relatively high.
4. The 5th percentile female is not that adversely affected, as is the 3 year old, by the inadvertent side airbag deployment.
5. The 3 year old's thoracic interaction with the side airbag needs further evaluation to confirm the results seen in this limited scope study.
6. Versatility and value of the computer model, SIFEM is seen in the types of evaluations undertaken by this study.
7. The analytical effort towards more rigorous validation of the model must be continued.
8. Also to be undertaken will be continued effort in the simulation with more accurate design and performance parameters and the more recent test data. The future efforts will include other scenarios of interest.
9. Once again, it needs to be emphasized, that the results presented here are valid within the constraints of the database used in this model.

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