Paper Number 03DHM-32

Experimental Verification of Biomechanical Occupant Response Predictions for Front & Rear Seated Passengers Subjected to Rear Impacts

Kenneth J. Saczalski, Ph.D.
Environmental Research & Safety Technologists, Inc.

Jay Saul
The Art of Engineering

Joseph Lawson Burton, M.D. & Paul R. Lewis, Jr.
Burton & Associates

ABSTRACT

Airbag induced injuries to front seated infants and children have resulted in US government recommendations that suggest, among other things, the placement of children into the rear seat area of motor vehicles. During a rear impact, however, most conventional automotive front seats occupied by adults will collapse into the rear seat area. This exposes the rear-seated children to other risks of injuries. Rearward load strength tests run on a wide variety of commercially available automotive front seat systems, such as the single or dual sided recliner types and the stronger belt integrated types, demonstrate a wide range of occupant load resistance. Digital human simulation offers a cost effective, efficient, and accurate means for predicting occupant response and interactions influenced by various types of non-linear deforming seat systems, as well as various types of restraints, and vehicle interior structures. In this study, several computer simulations of rear impacts were performed with an available ATB (Articulated Total Body) computer code to demonstrate an efficient and accurate means for assessing the safety performance and hazards associated with occupied front seat collapse into a rear seat area occupied by children. The analysis considered a wide range of different sized front-seated adults (i.e. 50 kg females to 110 kg males), various types of front seats with a range of ultimate non-linear collapse strengths (i.e. 3,220 N up to the 14,500 N level of a Belt-Integrated-Seat), and various impact severities with speed changes between 22 to 43 kph. After performing the analysis several actual sled-buck experimental tests were made, with the same parameter range and a full vehicle interior, to verify and validate the human model predictions for the range of parameters described above.

INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA) has, since about 1996, warned of the airbag deployment risk to front seated children and infants, during a frontal impact, and the agency has recommended that children and infants be placed in the rear seat area in order to alleviate the airbag hazard. Unfortunately, as noted in previous studies [1, 2], most conventional automotive front seats occupied by adults will collapse into the rear seat area during rear impacts. As a result, the rear-seated children, whose seats are not likely to collapse, are at risk of being trapped and injured from impact by the rearward collapsing front seat adult occupant. Numerous factors influence whether or not an occupied collapsing front seat will cause injury to a rear-seated occupant. For instance, quasi-static strength tests run on a wide variety of commercially available automotive front seat systems, such as single sided recliner types on up to the much stronger “belt-integrated” seat types, demonstrate a wide range of occupant load resistance during rear loading. Table 1 summarizes some average seat test data for the three major types of automotive front seat designs (i.e. Single Recliner, Dual Recliner and “Belt-Integrated” type seats) as reported in the earlier studies [1,2]. Figure 1 illustrates the more realistic body block test device used to measure the quasi-static seat strength parameters shown in Table 1.

In addition to the wide range of seat parameters, there are also several other factors or variables that influence seat system performance and injury risk to rear seated occupants and these include, among other things, the weight of the front seat occupant and the severity of the rear impact.

Full scale dynamic vehicle crash tests, with instrumented surrogates, offers one means for assessing the front seat system safety performance as it relates to multi-variable effects including various size front and rear seated occupants during realistic rear-impact recreations. Unfortunately, these full-scale tests are expensive and only provide limited information for a specific scenario.

Table 1. Variation in Seat Strength Parameters

SEAT TYPES	Seat Wt. -Kg (lbs)	Average Horizontal Load- kN (lbs)	Average Stiffness- kN/m (lbs/inch)	Average Structural Torque- N-m (foot-lbs)
Single Recliner Types (N = 17)	18.8 (41)	3.22 (724)	26.6 (152)	993 (733)
Dual Recliner Types (N = 13)	19.7 (43)	6.00 (1349)	52.1 (298)	1747 (1291)
Belt Integrate (BIS) (N = 9)	30.6 (67)	15.25 (3429)	118.6 (677)	5081 (3754)

Note: N equals number of seats tested in a category

Fig 1. Quasi-static Body Block Strength Test Set-up

Digital human simulation offers a cost effective, efficient, and accurate means for predicting occupant response interactions influenced by a large number of variables such as the various types of non-linear deforming seat systems, as well as various types of restraints, occupant weights, impact severity and space of vehicle interior structures. Experimental verification of the Occupant Simulation Codes is essential for establishing confidence in the use of digital human simulation models to accurately predict multi-variable occupant response and "injury potential".

MULTI-VARIABLE OCCUPANT SIMULATION METHOD AND EXPERIMENTAL VERIFICATION

In this study, digital occupant simulation modeling and a two-level factorial approach were employed to examine multi-variable effects that influence seat system performance as it relates to injury potential of rear seated occupants, such as children, during rear impacts [4]. Computer simulations of various rear impact conditions were performed using the Wright Patterson Air Force base ATB (Articulated Total Body) computer code (Windows version 1.3 by Varidian Engineering) [5]. In this demonstration of the multi-variable analysis methodology, the rear-seated occupant was chosen to be a 3 year-old child seated on a booster seat behind various sizes of front-seated adult occupants. Figure 2 illustrates a typical ATB model configuration used in this study, and Figure 3 shows a corresponding "sled-buck" test arrangement using a popular minivan buck.

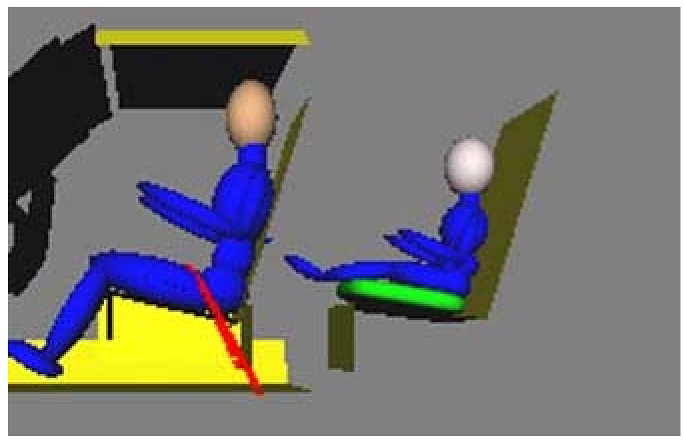

Fig 2. Typical ATB Model for Rear-impact Study

Fig 3. Corresponding Minivan Sled-Buck Configuration

As noted, the analysis and tests considered a wide range of different sized front-seated adults (i.e. 50 kg females to 110 kg males), seated in various types of front seats with a range of ultimate non-linear collapse strengths (i.e. 3,220 N for single sided recliner types on up to the 14,500 N level of a Belt-Integrated-Seat), and subjected to various impact severities with speed changes ranging between about 22 to 43 kph. After performing the analysis several actual sled-buck experimental tests were then made, with the same parameter range and a full vehicle interior, to verify and validate the human model predictions for the range of parameters described above. Comparisons were made of the digital predicted Head Injury Criteria (HIC) for the rear seated child and the experimental HIC data obtained from a Hybrid-III 3-year-old child surrogate seated behind front seats occupied by various size adult surrogates subjected to a range of rear impact severities. Both the digital and experimental HIC data for the child were then put into a 2-level factorial polynomial coefficient form that enabled the development of a specific HIC curve at the 900 "injury level", for both the simulation and the experimental child head injury data, as a function of front occupant weights and impact severity (i.e. change in velocity) for an average strength single sided recliner type seat system. Finally, a test and analysis comparison was made of the performance of the average strength seat versus the stronger belt-integrated type seat under the most severe conditions of high-speed change and heavy occupant.

TEST AND ANALYSIS PARAMETERS

Three independent variables were considered in this study: X1 = Impact Severity (i.e. change in velocity); X2 = Front Seat Occupant Weight; and X3 = front seat strength. Six analysis and test conditions were run for the purpose of demonstrating the multi-variable analysis methodology. Five of the six conditions relate to the effects of average strength front seats, and the last condition is related to comparing the performance of the average strength seat with a much stronger "belt-integrated" seat type under the most severe impact and occupant weight condition. Table 2 summarizes the "impact-severity" and "front occupant weight" parameters for all six cases studied. Note the parameter "high", "low", and "average" values are equally spaced.

Table 2. Analysis and Test Parameter Configurations

TEST & ANALYSIS SET-UP	**Seat Type**	**Variable-X1** Speed Change (kph)	**Variable-X2** Front Occup. Weight (kg)
1	Ave. SR	32.5	80
2	Ave. SR	22.5	50
3	Ave. SR	42.5	50
4	Ave. SR	22.5	110
5	Ave. SR	42.5	110
6	RF Belt-integrated	42.5	110

Note: SR = Single Recliner; and RF = right front

Note also that the high, low, and average parameter levels of occupant weight and impact severity are essentially equally proportioned so as to enable the use of a "two-level" factorial analysis of the resulting injury data. This method provides a means for combining a limited number of test or analysis results into a "polynomial response function" that enables evaluation of results between or beyond the limited number of actual test or analysis conditions. With regard to impact severity, in all cases of analysis and test, the peak pulse was modeled to approximate the actual pulse of the minivan vehicle used in the sled-buck tests. Figure 4 illustrates typical crash pulses employed in both the test and the analysis phases of this study.

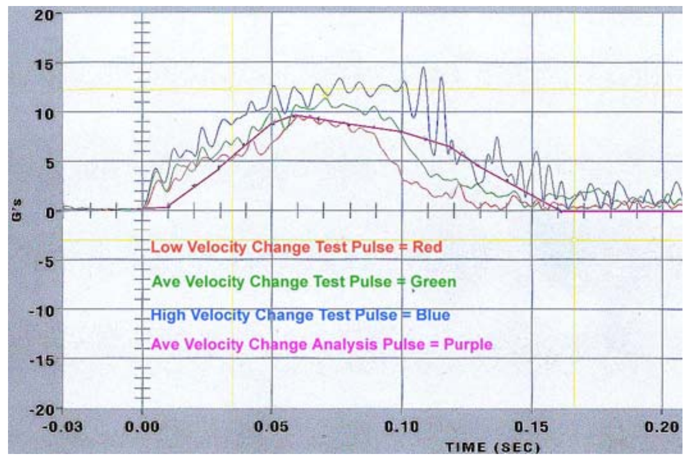

Fig 4. Range of Crash Pulses for Test and Analysis

The "Analysis" crash Pulses were estimated prior to the sled-buck tests and, as noted, were based on actual vehicle-to-vehicle crash tests. During the sled-buck testing, however, the experimental crash pulses shown in Figure 4 were generated through the use of a crushable "honeycomb" barrier that decelerated the rearward moving sled-buck system and, as a result, slight differences were noted between the test and analysis impact severity parameters. Table 3 shows a test and analysis comparison of the 3 levels of "speed changes", and corresponding "G" levels for each.

Table 3. Comparison of Assumed Pulses and Test Data

SPEED CHANGE LEVEL	**ANALYSIS DELTA (kph) / G LEVEL PEAK**	**TEST DELTA (kph) / G LEVEL PEAK**
LOW	23.8 kph/ 9.5 G	22.7 kph/ 8.2 G
AVERAGE	32.3 kph/ 9.5 G	32.5 kph/ 9.6 G
HIGH	44.8 kph/ 9.5 G	43.0 kph / 11.1 G

It should also be noted that during both the analysis and the tests, the front seat positions remained in the same location from case to case.

ATB Model Parameters

The ATB Occupant Simulation model requires several unique parameters in order to reasonably replicate a real-life rear-impact situation involving front and rear seat occupant interactions. As noted, Table 3 and Figure 4 depict typical rear-impact pulse characteristics for the minivan configuration used in the sled-buck test series of this study. Each vehicle occupant was modeled by using 15 segments, and 14 corresponding joints, to simulate occupant body parameters such as body segment weights, inertia parameters, and geometric sizes for the three sizes of front seat occupants listed in Table 2 (i.e. 50 kg small female, 80 kg average size male, and a 110 kg large adult). Joint types were either “free” or “pin joints”. No detailed special models of the neck were used in this study.

Since two occupants were involved, two sets of body parameters were incorporated into the model to account for the front seat adult and the rear seated 3 year-old child surrogate. Several geometric contact “panels” were used to model the vehicle interior structures such as “floor”, “dash”, “roof”, “roof headers”, “sides”, “windows”, “seat cushions”, “restraints”, and so on. Perhaps the most important parameter of the ATB model in this study is the “non-linear” front seatback model.

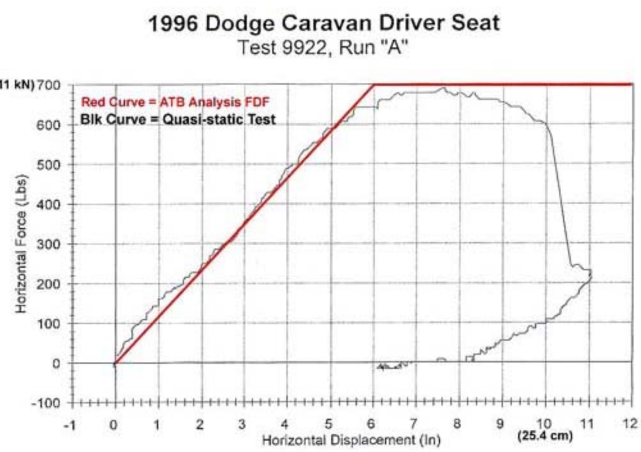

Fig 5. Non-Liner Model of Average Seat Based on Test

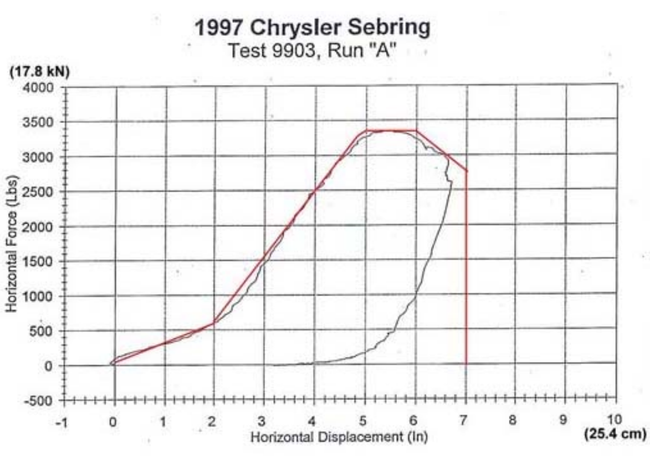

Fig 6. High Strength “belt-Integrated” Seat Data

Figures 5 and 6 illustrate, respectively, the non-linear “force versus deflection” curves, measured and then modeled in a piece-wise linear manner, for the “average” strength seat 1996 Dodge Caravan and a much stronger “belt-integrated” seat (i.e. 1997 Chrysler Sebring). This data was generated from the “body-block” test method illustrated in Figure 1 (showing the Dodge Caravan seat). The data from Figures 5 and 6 were used to generate “Force-Deflection-Functions” (FDF) for panels that were modeled to simulate seatbacks with integrated headrests like those found on the average strength seat shown in Figure 1.

In addition to the FDF characteristics, the seatback “panel” must also be modeled to enable rearward “rotation” with torsional resistance about a “pivot point” located near the seat junction of the seatback and the seat cushion. In order to accomplish this a third body segment (i.e. in addition to the front occupant multi-segment body and the rear seated child multi-segment body) was added to the model to simulate the weight, inertia, and “joint” rotational characteristics of the rotating seatback.

The seatback “body segment” model incorporated a “joint stop” and “flexural/torsional resistance” for the non-linear, collapsible, seatback segments. A joint stop of 75 degrees was used for the non-linear seatbacks of figures 5 and 6. Also, “flexural” linear coefficients of 15.8 Newton meters (Nm) per degree of rotation were used for the average strength seat and a value of 71.1 Nm per degree of rotation was used for the stronger “belt-integrated” seat.

In order to connect the deflecting seatback “segment” to the occupant and the seatback “panel” FDF it is necessary that appropriate “plane” and “segment” “contact-interactions” be specified, and therefore the seatback “panel” is attached to the seatback segment “body segment” rather than the standard “vehicle segment”. Also, all occupant body segments and corresponding contact ellipses (i.e. torso, head, and neck) making contact with the non-linear seatback system must than be specified for that particular rotating seatback “panel”.

With regard to occupant “head-to-head” contact interactions, it was also necessary to specify a body contact FDF. A bi-linear representation was used in this study as an estimate of the body-to-body contact FDF. The first level of loading was assumed to be linear from zero up to about 8.9 kN at about 7.5 cm, and then increased linearly at a rate of about 2.6 kN per centimeter.

With regard to restraints, the analysis only modeled a generic lap belt on the front adult occupants for each case since during rear-impacts the front seat occupants tend to fall backward away from shoulder restraints mounted to the vehicle “B” pillars. The rear-seated child was modeled on a replica of a “built-in” booster seat similar to that provided in the test vehicle.

Sled-Buck Test Parameters

The vehicle body of a 1996 Dodge Caravan was mounted onto a movable sled device for the test portion of this study. A 3-point restrained adult Hybrid-III surrogate was placed in the front seat position and a Hybrid-III 3 year-old surrogate was placed on a “built-in” booster seat located behind the adult surrogate as shown in Figure 3. The sled-buck arrangement was then towed rearward, at a speed slightly less than the desired “speed change”, into a crushable barrier that provided the crash pulses shown in Figure 4 and the corresponding speed changes listed in Table 3 for the three impact levels achieved (i.e. 22.7, 32.5, and 43 kph). Table 2 provides the configurations of speed changes and front adult occupant weights used for each test. All surrogates were instrumented.

The tests were run after the ATB occupant analysis was performed for each of the configurations cited in the Table 2. For the “low” weight front surrogate (i.e. 50 kg) a standard Hybrid-III small female surrogate was used. For the “average” weight front surrogate (i.e. 80 kg) a standard 50 percentile Hybrid-III male surrogate was used. In order to achieve the “high” weight front surrogate (i.e. 110 kg) a standard 50 percentile Hybrid-III male surrogate was ballasted up to the desired weight through the addition of lead weights distributed through out the body to simulate the proper weight distribution of a large adult greater than a 95 percentile male.

ANALYSIS AND TEST KINEMATIC COMPARISONS

The first “Test and Analysis” configuration of Table 2 represents an “average” rear-impact situation with an “average” size adult male seated in an “average” strength front seat, located in front of an “average” size 3 year-old child on a built-in booster seat. Figures 7 and 8 illustrate, respectively, the sled-buck system for the above test configuration at the start of impact and at about 150 milliseconds into the crash scenario when the collapsed front seat has allowed head-to-head contact between the front seated adult and the rear-seated child.

Fig 7. First Test Configuration at Start of Impact

Fig 8. First Test Configuration at Head-to-Head Impact

Figures 9 and 10 illustrate the comparable images from the previously run ATB occupant simulation model with the non-linear seat characteristics for the parameters of the “first” configuration (i.e. Average rear impact, etc.).

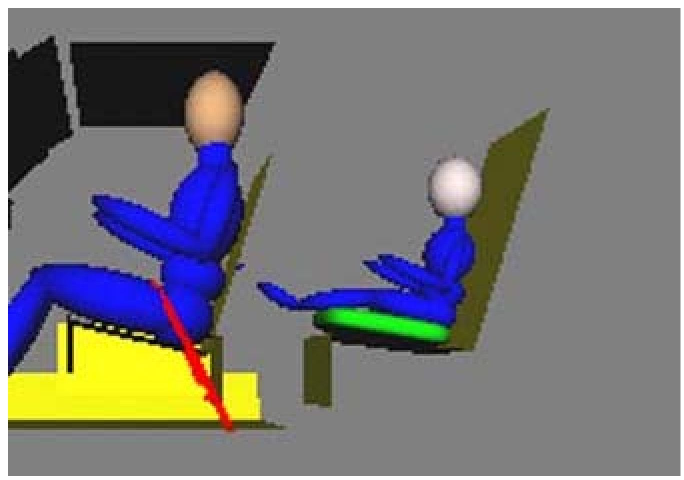

Fig 9. ATB Model for First Analysis Configuration (i.e. Average Conditions)

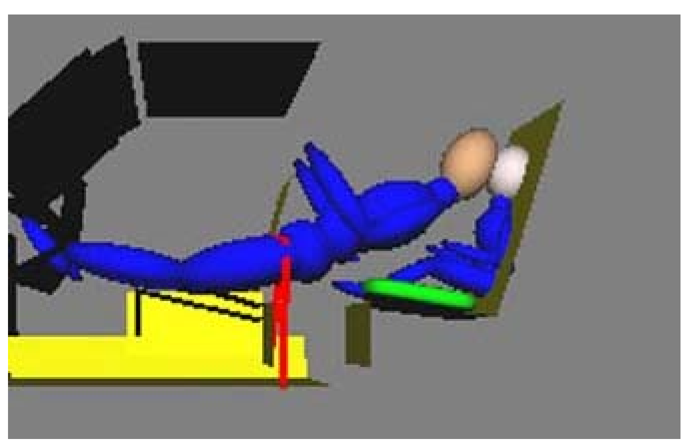

Fig 10. First Analysis Configuration ATB Model at Head-to-Head Contact

Comparison of Figures 8 and 10 indicate that there is generally good agreement between the test and analysis kinematics for this case. It is noted, however, that the head and neck of the analysis front surrogate is more in flexion than the comparable test surrogate.

The second case of the Test and Analysis Setup represents a low impact severity situation (i.e. 22.5 kph speed change) with the lightest front seat adult surrogate (i.e. 50 kg small female) also in an average strength front seat like that used in the first configuration. Figures 11 and 12 illustrate the ATB analysis set-up for the second case at the initiation of impact (i.e. time zero) and at the “maximum” rearward displacement of the front seat occupant.

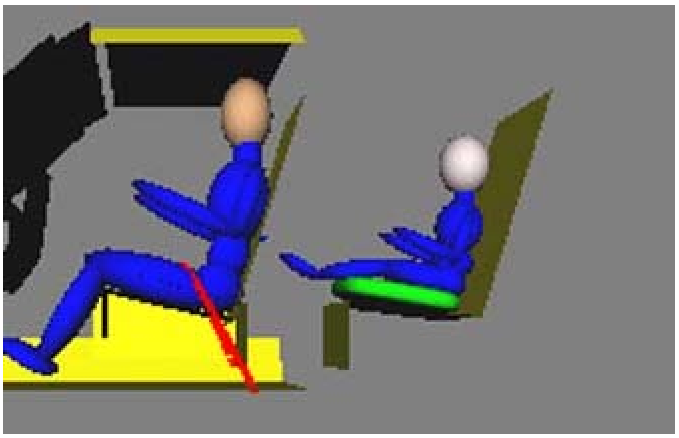

Fig 11. ATB Model for Second Analysis Configuration

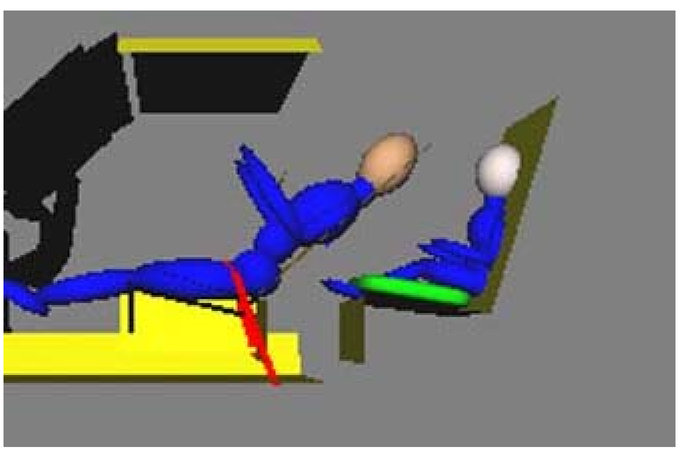

Fig 12. Second Analysis at Maximum Seat Rotation

Figures 13 and 14 illustrate the corresponding images from the test of the second configuration of “low” weight front occupant, “low” impact severity, and the same type “average” strength front seat as that used in the first Test and Analysis Setup configuration. In this test and analysis kinematic comparison it is noted that the front seat occupant does not make head to head contact with the rear-seated child even though the front seat displaces rearward. In this case the only head loads experienced by the rear-seated child are those developed as a result of the interaction of the child head with the seatback of the rear “booster” seat that the child is seated in.

Fig 13. Second Test Configuration at Start of Impact

Fig 14. Second Test at Maximum Front Seat Rotation

As in the previous case there was generally good agreement with respect to the occupant kinematics between the ATB model and the test. For instance the model predicted before the test was run that the front seat adult surrogate in this configuration would not likely make “head-to-head” contact with the rear seated child, and that was found to be the situation when the actual test was run. Contrary to this second test and analysis configuration, “head-to-head” contact was made between the front seated adult and the rear seated child in all of the three remaining cases involving the “high” and “low” combinations of impact severity and front occupant weights as defined in Table 2. These results look similar to that illustrated in Figures 8 and 10. As before, these cases also demonstrated good kinematic agreement between the test and analysis.

The last case involving the “average” strength front seat was the most severe test since the heaviest front occupant (i.e. 110 kg) was subjected to the most severe level of impact (i.e. 43 kph) while seated in an “average” strength front seat. This case produced the highest and most severe loading to the head of the rear-seated child. The counter to this configuration was the last set-up that employed a much stronger “belt-integrated” type front seat with the heavy surrogate subjected to the severe “high” level of impact. In this case the ATB model employed the Figure 6 seat data and the higher values of “flexural/torque” parameters described earlier for the seatback “segment” joint. Figures 15 and 16 show the comparison of analysis and test results for the kinematic position of maximum reward displacement of the heavy adult under the severe impact scenario. Note that there is no head-to head contact for this case and as such the child head loads are similar to those of the second case involving the light weight front surrogate in the average strength seat subject to a low level impact.

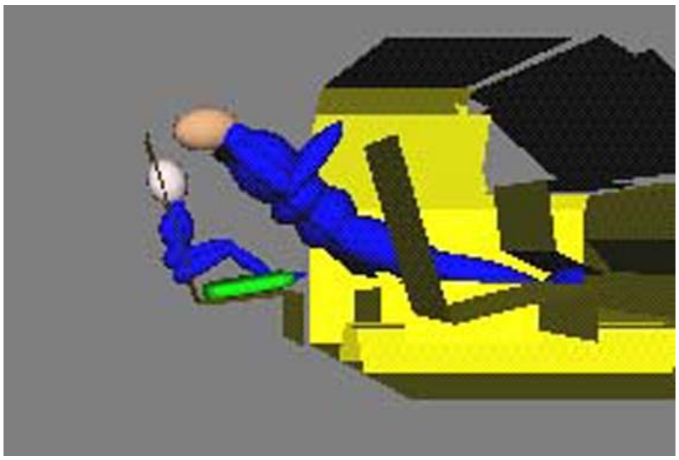

Fig 15. Maximum Rear Rotation for Strong Seat Analysis with Heavy Surrogate and High Rear impact

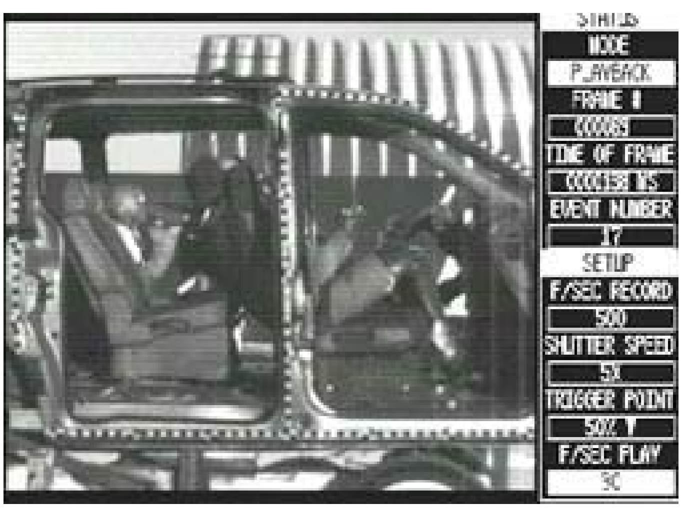

Fig 16. Comparison Test Results for last Configuration involving Stronger Seat Study

TEST & ANALYSIS CHILD HEAD-INJURY RESULTS

Table 4 summarizes the analysis and test “head injury criteria” (HIC) data for the rear-seated child in each of the configurations listed in Table 2.

Table 4. Child Head-Injury Results – Analysis and Test

TEST & ANALYSIS SET-UP	Seat Type	ANALYSIS Child HIC	TEST Child HIC
1	Ave. SR	1220.4	1904.0
2	Ave. SR	87.8	47.4
3	Ave. SR	136.3	178.3
4	Ave. SR	1556.1	2335.2
5	Ave. SR	4216.5	8516.0
6	RF Belt-integrated	98.9	178.3

Note: SR = Single Recliner; and RF = right front

Configurations 2 through 5 of Table 4 provide data for the development of a “2-Level factorial” polynomial description of the Child HIC over a wide range of front occupant weights and impact severities related to the “average” strength front seat. The methodology has been discussed in previous research [4,6] and is briefly summarized here for the “analysis” data. The same methodology is then used to obtain a similar Child HIC curve from the experimental data for the purposes of comparison between “analysis” predictions and “experimental” test data using Hybrid-III surrogates. Table 5 illustrates the “computation matrix” used to develop the polynomial coefficients.

Table 5 Polynomial Coefficient Matrix for Child HIC

ANALYSIS SET-UP	A0	A1	A2	A12	ANALYSIS CHILD HIC Result
2	+	−	−	+	**87.8**
3	+	+	−	−	**136.3**
4	+	−	+	−	**1556.1**
5	+	+	+	+	**4216.5**
$\sum$	5997	2709	5549	2612	
$\sum$ / 4	1499	677	1387	653	

For any given polynomial coefficient column simply multiply the “result” column HIC values by the appropriate plus or minus signs of each row in a given column and then sum the values in a column. Divide the sum by 4 and the result gives the polynomial coefficient.

Thus based on the Table 5 results the Child Head-Injury-Criteria HIC polynomial based on the Analysis results is:

ANALYSIS HIC = 1499 + 677 X1 + 1387 X2 + 653 X1X2;

Where the X1, X2, and X12 polynomial coefficients represent dimensionless parameters, respectively, for the impact severity (i.e. speed change), front occupant weight, and interactions between the weight and severity. For instance, the low weight of 50 kg would represent an X2 value of –1. Likewise the average and high weights would yield X2 values of "0" and "+1". Values between or beyond the test values are extrapolated. For instance, a weight of 65 kg would be represented as an X2 value of "-1/2", etc.

Thus, in order to develop the HIC curve for an injury level of 900, as an example, all that is necessary is to select a given weight of occupant (in X2 dimensionless form) and solve for the remaining speed variable X1 in dimensionless form. Figure 17 shown below illustrates the plot comparison of Child HIC "900" curve, generated from both the test and analysis data, and plotted as a function of the front occupant weight and impact severity for the case of the average strength seat.

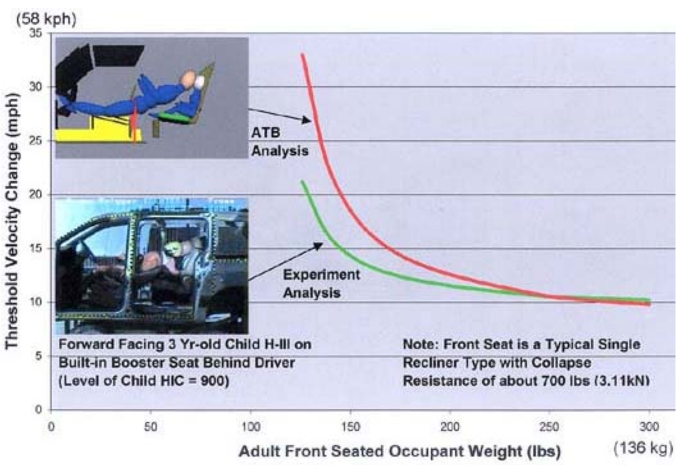

Fig 17. Comparison of Test and Analysis for Child HIC

The "900 HIC" injury curve based on analysis data predictions compares well with the experimentally derived "900 HIC" curve, although the experimental data gives a slightly more conservative boundary on the Child HIC (i.e. lower threshold) at the lower levels of front occupant weights. Also note that both curves indicate a non-injury region for Child head contact if the weight of the front occupant is less than about 55 kg (i.e. 120 lbs) when seated in an average strength front collapsing seat. The analysis and test set-up of the second configuration listed in Table 2 verified this condition, and was shown graphically in Figures 12 and 14. Finally, reference 3 contains several actual accident case studies involving rear seated children who received serious to fatal head injuries when seated behind collapsing, occupied, front seats of the same strength level as that used to develop the Figure 17 "900 HIC" injury curves. Plotting the front occupant weight and impact severities for these cases involving head injury to children between the ages of two to seven years (i.e. Cases 1A, 1B, 2B, 4A, 5A, 5B, and 6A from reference 3) indicates that the Figure 17 provides a reasonable threshold of child head injury and seems to further validate the analysis predictions. Figure 18 illustrates the plot of the injury cases on the "900 HIC" curves.

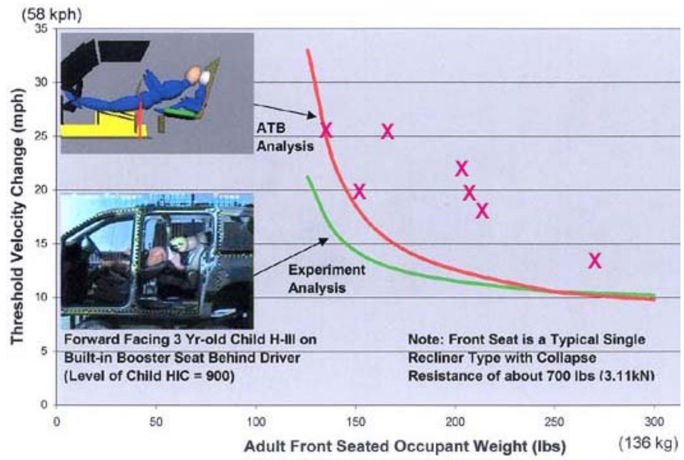

Fig 18. Comparison of Rear Child "900 HIC" Curves with Case Studies of Reference 3 for Average Strength Seat

ENHANCED DIGITAL MODELING OF ATB ANALYSIS

Using a limited number of still images from the ATB analysis program in conjunction with the "Softimage XSI" 3D graphics program, that includes "Mental Ray" animation software, enables a more realistic representation of the ATB output.

Fig 19. Enhanced Digital Model of ATB Occupants

Human models were scaled from baseline existing models, and then the XSI software "inverse kinematic" skeletons were inserted into the more realistic human models. These "skeletons" then deform the models as they are moved around to the different positions of the

ATB images. This enhanced software then smoothes motion of the detailed model as it moves between ATB frames. These models are then combined with more realistic digitized vehicle interiors and exteriors.

Fig 20. Digitized Vehicle Exterior and Interior Subjects

Fig 21. Configuration one Enhanced Model Pre-Impact

Fig 22. Head-to-Head Contact with Enhanced Model

Figures 19 through 22 illustrate the more enhanced digital modeling applied to the first configuration set-up (i.e. Average rear impact scenario). Side-by-side comparison of the enhanced ATB analysis with the corresponding tests shows good kinematic agreement between the ATB predictions and tests.

CONCLUSIONS

The results of the study indicate that that the digital simulation models, such as the ATB code, provide a cost effective, efficient, and reasonably accurate means for assessing seat safety system performance as it relates to injury of children seated behind collapsing occupied front seats during rear-impacts. Also, strong front seat systems like the “belt-integrated” designs offer improved protection to rear seated occupants.

REFERENCES

1. Saczalski, K., Burton, J., Lewis, P., Saczalski, T., Baray, P., ” Belt Integrated Vehicular Seat Rear Impact Studies”, Paper Number F2000G279, Seoul 2000 FISITA World Automotive Congress, Seoul, Korea, June 12-15, 2000.
2. Saczalski, K., Burton, J., Lewis, P., Saczalski, T., Baray, P., ”Evaluation of Rear Impact Seat System Performance Using a Combined Load Neck Injury Criteria and Hybrid III Surrogates”, Paper Number IMECE2991/AMD-25444, 2001 ASME International Mechanical Engineering Congress and Exposition, Nov. 11-16, 2001.
3. Saczalski, K., Burton, J., Lewis, P., Friedman, K., Saczalski, T, ”Study of Seat System Performance Related to Injury of Rear Seated Children & Infants in Rear Impacts”, Paper Number IMECE2002-AMD-33517, 2002 ASME International Mechanical Engineering Congress and Exposition, Nov. 17-22, 2002
4. Saczalski, T, Lucht, B., Saczalski, K.,”Experimental Design Methods for Assessment of Composite Damage in Recreational Structures”, ASTM Publication STP 1285, June 1997, pp 45 – 69.
5. Chang, H., Rizer, A. L., Obergefell, L. A., “Articulated Total Body Model Version V; User’s Manual”, Wright-Patterson Air Force Base, Ohio, USA, 1998, Rpt No. AFRL-HE-WP-TR-1998-0015.
6. Saczalski, K., Hannon, P., “Multi-Variable Effects of Side Impact Passive Occupant Protection Materials”, SAE paper No. 880397, published in SAE Volume SP-736, pp 41-53, 1988.