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COMPUTER SIMULATION OF REAR IMPACT BIOMECHANICAL OCCUPANT RESPONSE PREDICTIONS FOR FRONT & REAR SEATED PASSENGERS

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ABSTRACT - Many variables, each with a wide parameter range, influence the performance limits and occupant injury protection levels provided by a motor vehicle safety system. Full scale crash tests offer one means to study safety system performance, but such tests are expensive and only provide limited data related to the influencing variables or factors. Commercially available occupant computer simulation codes, in conjunction with efficient "multi-variable" analysis techniques like the "2-level factorial" method, offer a cost-effective means for "multi-variable" evaluation of a given safety system. The current study uses a "Articulated Total Body" (ATB) computer code, with a "high-low" (i.e. 2-level) "factorial" method, to study "multi-variable" effects of motor vehicle adult occupied "front seat system performance" as it relates to child head injury potential (i.e. HIC) of rear seated children during rear impacts. Of primary interest is: whether or not a adult occupied front seat will collapse into a child seated behind, and; if front to rear contact is made, under what conditions will it result in head injury to the rear child. Variables studied included: non-linear seat strength; impact severity (i.e. speed change); front adult occupant size; rear child size; and 2 vehicle types. Front seat strength levels ranged from about 3.1 kN, for a typical single recliner seat, on up to about 14.7 kN for a commercially available "belt-integrated" seat design. Impact severity levels ranged from about 20-kph on up to 50-kph speed changes. Front adult sizes ranged from a small female (i.e. 50 kg) on up to a larger male of about 110 kg. Rear child sizes included a 3 year-old, seated in the "built-in" booster seat of a minivan, and a 6 year-old, seated in the rear bench seat of a 4 door sedan. Analysis of the 3 year-old child head injury potential was conducted prior to the running of sled-buck validation tests. Refinements were made to the non-linear front seat computer model for the study of the 6 year-old. Sled-buck tests were also run for this case. The predicted and test HIC curves compared well in each case. Finally, the child HIC data was plotted over a range of variables (i.e. front occupant weight versus rear impact severity) and the results were compared with data from actual accident cases to validate the analysis.

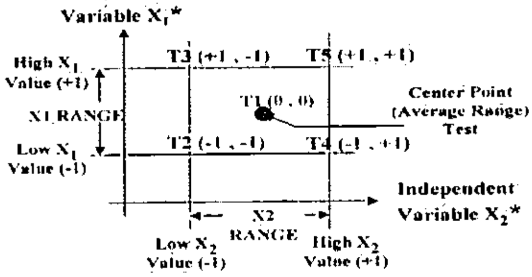
MAIN SECTION – In a rear impact an occupied front seat may collapse into the rear occupant area where it has been recommended that children and infants be placed so as to avoid airbag hazards in frontal impact (1). In such a situation it would be of interest to know whether or not the occupied collapsing front seat system would allow contact and possible injury to a rear-seated child, and over what range of key parameters or variables would the safety system provide protection. Severe or fatal head injury to the rear child is the most common hazard related to rear impact seat collapse. An accident analysis study conducted by the Insurance Institute for Highway Safety (2) has indicated that children in the rear area were *safer* for all modes of impact except for rear impact where *"in rear impacts, children seated in back had a 61 percent higher risk of fatal injury than children in the front"*.

In order to address the issue of front seat performance as it relates to rear child head injury potential there are several variables, each with a wide parameter range, which must be considered. For instance, quasi-static seat strength tests run on a variety of commercially available motor vehicle front seats, ranging from the weaker single recliner types on up to the stronger "belt-integrated" types, demonstrate a wide latitude of occupant load resistance (i.e. about 3 kN for single recliner types (SR) and as high as 20 kN for a "belt-integrated" type (BIS)) during rear loading (3, 4). Other variables include, among other things, the size and weight of the front seat occupant, and the severity of the rear impact. Each of these factors also encompasses a wide parameter range. Front adult occupant sizes can range from as small as a 5th percentile female of about 50 kg on up to larger adult occupants weighing more than double that amount. The size of the rear-seated child, and type of child restraint, can also affect the out come of safety system performance. Some recent experimental and analytical work (3-6) has investigated the rear occupant injury potential problem. Most rear-impact studies, however, have focused on front occupants and whiplash (7-13).

MULTI-VARIABLE OCCUPANT COMPUTER SIMULATION METHOD - Commercially available occupant computer simulation codes, in conjunction with efficient "multi-variable" analysis techniques like the "2-level factorial" method (14), offer a cost-effective means for performing "multi-variable" safety system evaluation. The "2-level factorial" method requires a minimum number of analysis or test combinations to be evaluated, based on the number of variables "X" being considered, so as to develop a "polynomial" response function "Y" of the output variables of interest such as "head injury criteria" (HIC). The minimum number of combinations "T" required for "X" independent variables in the "two-level" (High-Low) factorial method for development of the "response" polynomial "Y" is $T = 2^X$. The statistical significance of the polynomial factors can be evaluated by running random repeats of each of the analysis configurations (14). Once the "polynomial" response function "Y" has been developed combinations of parameters not tested can be evaluated.

Independent Variable X1 = Impact Severity Defined by Delta Velocity Levels of :
Low = 13.5 mph (22.5 kph);
Ave. = 19.5 mph (32.5 kph);
High= 25.5 mph (42.5 kph).

Independent Variable X2 = Front Adult Weight (Seated in SR Collapsing Seat):
Low = 110 lbs (50 kg);
Ave. = 175 lbs (80 kg);
High= 240 lbs (110 kg).



$$\boxed{Y(\text{Child HIC}) = A_0 + A_1X_1 + A_2X_2 + A_{12}X_1X_2}$$

Fig. 1 – Analysis Combinations for a 2-Level Factorial Series with Two Variables

Figure 1 illustrates the combinations of analysis configurations "T" for a two variable study, using the "high-low" 2-level factorial method, where one variable represents "rear impact severity" (X1) and the other represents front seat "adult occupant weight" (X2). The independent variables X1 and X2 are non-dimensionalized in the response polynomial "Y" by equation 1 so that the maximum, minimum and average values are represented as +1, –1, and 0, respectively. Any values between or beyond the maximum and minimum are also scaled by equation 1. For instance, a 65 kg occupant weight would be represented by a dimensionless X2 value of "-0.5".

$$Xi\ (\text{dimensionless}) = \{Xi(\text{desired}) - (Xi(\text{hi}) + Xi(\text{lo}))/2\} \,/\, \{(Xi(\text{hi}) - Xi(\text{lo}))/2\} \quad (\text{eq\#1})$$

In this study, computer occupant simulations of the various combinations of the "high-low" (i.e. 2-level) "factorial" configurations "T" were performed using the Wright Patterson Air Force base ATB (Articulated Total Body) computer code (15). The left side of figure 2 illustrates an ATB image taken from a previously reported study by the authors (6). This figure shows a side by side comparison of an ATB prediction and corresponding sled-buck test for the "T1" configuration (at time of head-to-head impact) for a 3 year-old seated in a minivan "built-in" booster seat, located behind an average size male seated in a typical single recliner front seat, when subjected to a 32.5 kph (19.5 mph) rear impact severity.

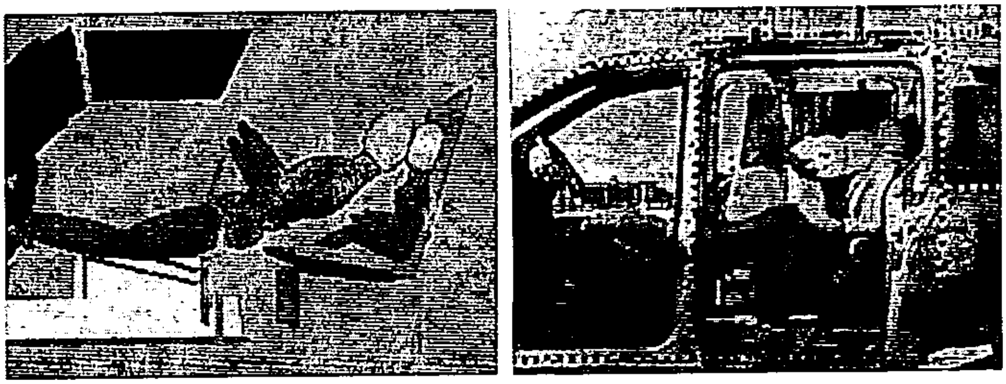
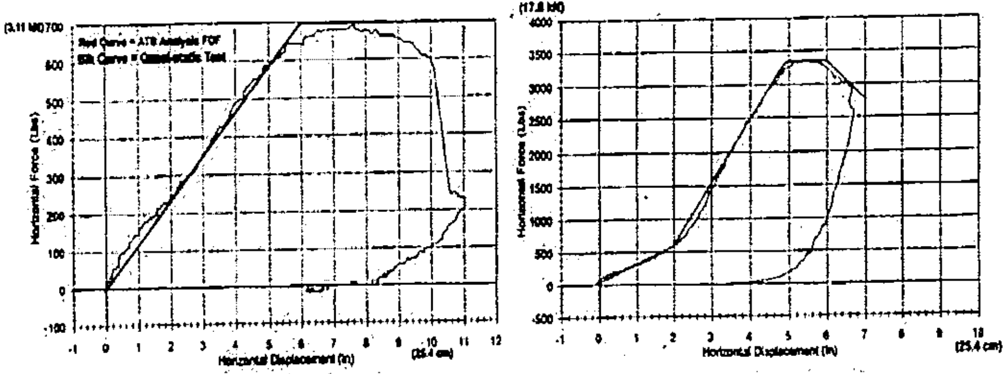


Fig. 2 – ATB Prediction and Test Result for "T1" Configuration of 3 Yr-old Study

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. For instance, each vehicle occupant is modelled 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 as listed for variable "X2" in figure 1 (i.e. 50 kg small female, 80 kg average size male, and a 110 kg large adult). Joint types selected were either "free" or "pin joints". No detailed special models of the neck or spine were used.

Two sets of body parameters were incorporated into the model to account for the front-seated adults and the rear seated children. Flat contact "panels" were used to model the vehicle interior structures such as "floor", "dash", "roof", "roof headers", "sides", "windows", "seat cushions", and so on. Another important parameter of the ATB rear impact simulation is the modelling of the "non-linear" front seatback panel.

Figure 3 illustrates the non-linear "force versus deflection" curves, measured and then modelled in a piece-wise linear manner, for an "average" strength typical minivan single recliner seat (SR) and a much stronger "belt-integrated" seat (BIS) design (6).



a. Typical Single Recliner Seat Strength

b. Belt-integrated (BIS) Seat Strength

Fig. 3 – Force Deflection Curves for Typical SR Seat and Stronger BIS Design

The data from figure 3 was used to generate "Force-Deflection-Functions" (FDF) for panels that modelled the strengths of both the weaker single recliner seatbacks and the much stronger BIS versions. The curves show a peak load of 3.1 kN (700 lb.) for the SR type seat versus about 14.7 kN (3,300 lb.) for the stronger BIS design.

In addition to the FDF characteristics, the seatback "panel" must also be modelled 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 "flexion-torsion resistance" for the non-linear, collapsible, seatback segments. A joint stop of 75 degrees was used for the non-linear seatbacks of figure 3. Also, "flexural" linear coefficients of 15.8 Newton meters (Nm) per degree of rotation were used for the average strength SR seat and a value of 71.1 Nm per degree of rotation was used for the stronger "belt-integrated" seat. All front seats were modelled and tested in a track position of about ¼ forward of full rear, and seatback angle of 20 to 22^0 from vertical.

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 then be specified for that particular rotating seatback "panel". All panels allow edge contact interaction.

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. Measurements made by the authors indicate a significant difference between the head-to-head FDF of an adult head with the 3 year-old versus 6 year-old H-III surrogate. For the 3 year-old, the first level of loading was modelled 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 centimetre. The 6 year-old head-to-head contact resistance was much greater than the 3 year-old, and in this case the 6 year-old stiffness values were increased by a factor of approximately 2.3 times.

Regarding restraints, the analysis only modelled 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 3 year-old rear-seated child was modelled on a replica of a "built-in" booster seat similar to that provided in the actual minivan design. The 6 year-old rear-seated child was modelled on a rear bench seat similar to that provided in a typical mid-size sedan.

Finally, the vehicle crash pulse must be specified and applied to the vehicle panels and occupants. Figure 4 illustrates some of the analysis and sled-buck test pulses used in the 3 year-old study. The analysis pulse for the 3 year-old study was estimated prior to testing by modelling to achieve the "speed change" levels X1 shown in figure 1. The analysis crash pulses used in the later conducted 6 year-old studies were matched more closely to the actual sled-buck pulses. The sled-buck tests were run at the same configuration parameter levels "T" so as to validate the analysis method. The actual sled-buck pulses were achieved by using crushable barriers that provided forces to the sled buck system that matched those of the actual vehicle type being modelled. Using a sled-buck system was more economical than using several full-scale vehicle crash tests to verify each configuration "T". Some full-scale tests were run, however, as a means for verifying both the analysis method and the sled-buck approach.

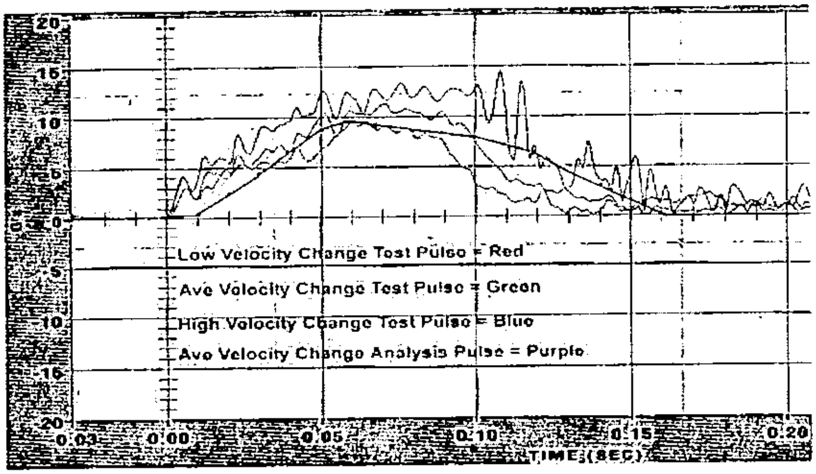


Fig. 4 – Comparison of Some Analysis and Sled-Buck Verification Crash Pulses

Once the basic ATB model has been set-up, the sizes of surrogates and levels of impact severity could be easily adjusted to the various "high-low" factorial levels of configurations "T", similar to those contained in figure 1, and solved to determine key output parameters, such as the head response and HIC for each surrogate model. The output results can then be cast into a polynomial response function form "Y" (similar to the polynomial shown in figure 1 for the two variable example) and the resultant "multi-variable" output polynomial function "Y" can than be used to study combinations of parameters not tested and also establish combinations of the parameters that delineate a specific level of "Y". The following sections of the paper describe the analysis procedure with applications applied to the 3 year-old in the minivan "built-in" booster seat and a 6 year-old seated in the rear bench seat of a 4-door sedan. In each case (i.e. 3 and 6 year-old study) sled-buck tests were run at the same configuration levels "T" used in the computer simulations so as to validate the model results. The 3 year-old study was conducted first and the analysis was done prior to testing. Although the HIC curves correlated well between test and analysis for the 3 year-old study, it was noted that there was about a 25 ms time lag between the model predicted peak head impact loads and the test surrogates. As a result, the seatback deformation model was enhanced by adding a "lower back support" which seemed to improve the time difference issue when applied to the 6 year-old study. As noted, the sled-buck test systems used full vehicle bodies and were towed rearward into a deformable barrier that matched the crash pulse of the vehicle being analysed.

TWO LEVEL FACTORIAL STUDY OF 3 YEAR-OLD IN MINIVAN BOOSTER - The authors used the "2-level factorial method" in a prior study (5) to examine the rear impact seat system performance of a common type of "single recliner (SR)" front seat as it related to the study of a 900 HIC head injury level for a 3 year-old child surrogate in a "built-in" minivan child booster seat located behind a typical SR collapsing front seat. As shown by figure 1, only 5 tests are necessary to establish front seat performance, and rear child head injury potential, of a given seat type as a function of 2 variables. Reference 14 gives examples with more than two variables.

Table 1 lists the test configurations, seat types tested, independent parameter levels, and results of the computer generated and test measured HIC values for the 3 year-old child study. Six configurations are listed in the Table. The first test configuration of the table represents an "average value" rear impact situation for the typical SR type of collapsing front seat. The results of this "average value" are used to check on predictive accuracy of the "polynomial" functions "Y" generated from configurations 2 through 5. Configurations 2 through 5 of Table 1 provide "high-low" data necessary for the development of the "2-level factorial" polynomial description of the rear seated child HIC, or other such parameters, related to the weaker (but more common) SR seat type. The last configuration in Table 1 (i.e. T5+) is a repeat test at the most severe conditions shown in configuration T5, except that in this case the weaker single recliner seat has been replaced by a much stronger "belt-integrated" (BIS) seat design. The resulting drop in the child head injury HIC for this case is dramatic compared to the more common, but weaker, SR front seat of configuration T5.

Table 1 – Test Configurations, Variable Parameters, & 3 Yr-old Child HIC Measures

ANALYSIS & TEST SETUP	FRONT SEAT TYPES / STRENGTH in "kN" units	VARIABLE X1 "Speed Change" in "kph" units	VARIABLE X2 "Occupant Wgt." in "kg" units	ANALYSIS RESULTS 3 Year-old Child HIC	SLED TEST RESULTS 3 Year-old Child HIC
T1	SR / 3.1	32.5	80	1220.4	1904.0
T2	SR / 3.1	22.5	50	87.8	47.4
T3	SR / 3.1	42.5	50	136.3	178.3
T4	SR / 3.1	22.5	110	1556.1	2335.2
T5	SR / 3.1	42.5	110	4216.5	8516.0
T5+	BIS / 14.7	42.5	110	98.9	178.3

Note: SR indicates single recliner seat design; BIS indicates "belt-integrated" design

The results of the T1 configuration (i.e. "average" ranges) with the SR seat, as shown by figure 2, indicate that head-to-head contact is made with the rear child and the levels are severe enough to reach well above government recommend threshold levels (16). The second configuration T2 represents a low impact severity situation (i.e. 22.5 kph speed change) with the lightest front seat surrogate (i.e. 50 kg small female) also in the more common SR type front seat. In this case however, the occupant in the front seat collapses rear but does not collapse far enough rearward to make head-to-head contact with the rear-seated child. Thus the only head loads experienced by the rear-seated child in this configuration are those developed as a result of the inertial interaction of the child head with the seatback of the rear "booster" seat that the child is seated in. Figure 5 illustrates the T2 configuration ATB predicted response at "maximum" rearward front seat displacement and the comparison response for the "sled-buck" validation test for the 3 year-old in the minivan "built-in" booster seat.

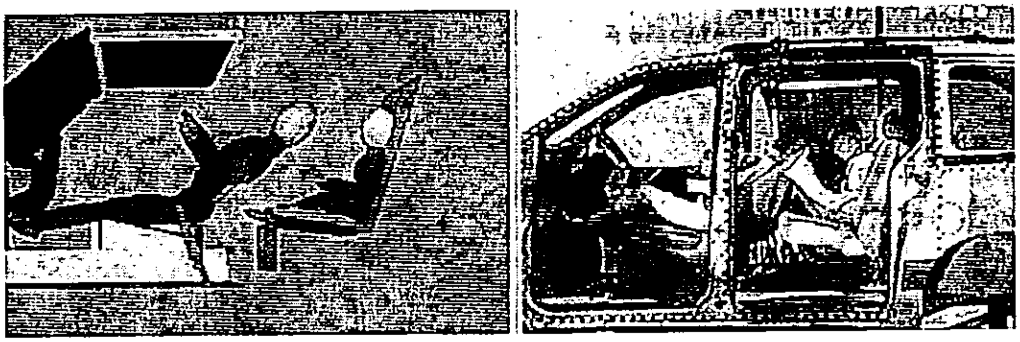


Fig. 5 – Maximum SR Seat Rotation for "T2" Configuration of 3 Yr-old Study

For the remaining 3 cases (i.e. T3, T4, T5), involving "high" and "low" combinations of the independent variables and SR seat, "head-to-head" contact was made between the front seated adult and the rear seated child. The "head-to-head" contact and kinematic comparisons of the ATB predictions and the sled tests for these three cases looked similar to the response shown in figure 1. As noted, however, the ATB time of "peak" head load for the 3 year-old occurred about 25 ms later than in the sled tests.

The T5+ configuration was a repeat of the T5 variables of "high" impact severity X1 and "large" front occupant size X2, except that in this case a much stronger BIS seat replaced the weaker SR type seat. The results show that the BIS design reduced seat rotation and the child head injury potential. Also, data related to the front occupant showed lower loads for the BIS occupant in comparison to the SR seat occupant.

Table 2 provides data for the development of the polynomial coefficients and the "multi-variable" polynomial equation "Y" representation of the "analysis" HIC response for the 3 year-old in the minivan rear "booster" seat. Only the T2 through T5 configurations are used to calculate the coefficients for the 2 variable polynomial. In order to calculate a given polynomial coefficient, 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. Then, divide the column sum by 4 (i.e. the number of configurations used in the calculation) and the resultant gives the polynomial coefficient "Ai".

Table 2 – Factorial (high-low) Polynomial Computation Matrix for 3 Yr-old Analysis

Configuration SET-UP	A0	A1	A2	A12	ANALYSIS HIC (3 Year-old Child)
T2	+1	-1	-1	+1	87.8
T3	+1	+1	-1	-1	136.3
T4	+1	-1	+1	-1	1556.1
T5	+1	+1	+1	+1	4216.5
Σ (Column Sum)	5997	2709	5549	2612	
Ai (Σ ÷ by 4)	1499	677	1387	653	

Thus, from the results of the last row of Table 2, the "analysis" HIC polynomial for the 3 year-old in the minivan "booster" located behind a typical collapsing SR seat is:

$$Y\ (\text{Child-3 analysis HIC}) = 1499 + 677 * X1 + 1387 * X2 + 653 * X1 * X2 \qquad (\text{eq\#2})$$

Using the same procedure with the sled-buck test measured child HIC data yields:

$$Y\ (\text{Child-3 test HIC}) = 2769.2 + 1577.8 * X1 + 2656.4 * X2 + 1512.5 * X1 * X2 \qquad (\text{eq\#3})$$

In these equations the X1, X2, and X12 variables are represented as dimensionless parameters, respectively, for the impact severity (i.e. speed change), front occupant weight, and interactions between the weight and severity. For instance, as noted earlier, 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.

In order to develop the HIC curve for an injury level, such as a level of 700, all that is necessary is to set the left hand side of the HIC polynomial equations to a value of 700 and then select a given weight of occupant (in X2 dimensionless form) and subsequently solve for the unknown speed variable X1 in dimensionless form. Repeating this procedure results in several pairs of data points X1 and X2 that correspond to the 700 HIC level and can be plotted as a curve in the X1-X2 plane.

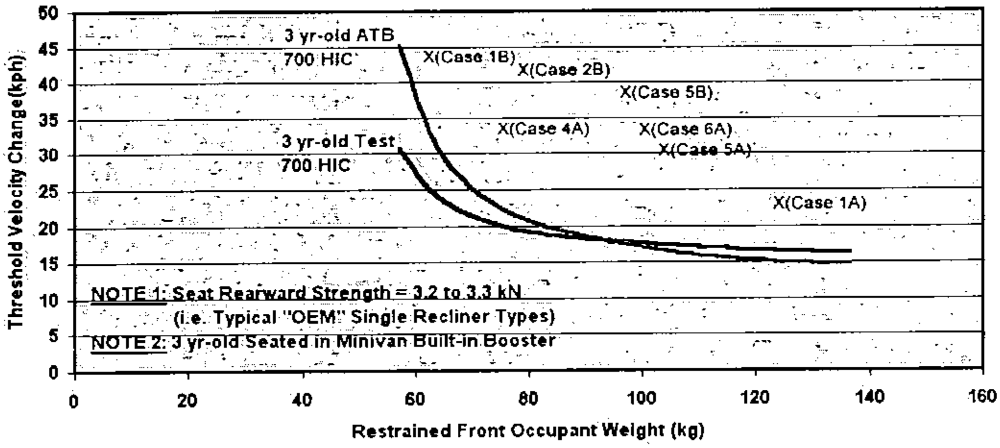


Fig. 6 – Comparison of 3 yr-old ATB 700 HIC Curve with Test & Actual Cases

Figure 6 illustrates a plot comparison of the resulting 700 child HIC curves derived from equations 2 and 3. Also shown on the figure are plots of data from actual accident cases involving serious or fatally head injured rear seated children between the ages of 2.5 to 4 years old. Details of these cases are covered in reference 4. The ATB predicted "700 level" HIC curve compares reasonably well with the sled-test curve for the 3 year-old surrogate when plotted as functions of the two primary variables, "impact severity" (i.e. speed change) and "front occupant weight". Both curves also provide reasonable head injury lower "threshold" levels when compared to the plots of X1 and X2 parameters from actual accident cases (4).

TWO LEVEL FACTORIAL STUDY OF 6 YEAR-OLD IN SEDAN REAR SEAT – Table 3 presents the analysis and test configurations, variable parameter levels, and the corresponding child HIC results for a 6 year-old seated in the rear bench seat of a typical 4-door sedan. In this study the "high-low" range for the X1 "impact severity" (i.e. speed change) variable was increased slightly as compared to the 3 year-old study. The "high-low" range for the X2 front "occupant weight" parameter is the same as in the 3 year-old study. The weight of the average size front surrogate, however, was slightly lower than in the previous case, due to an interest in the results of that specific weight at the new high impact severity level (i.e. 50 kph) as listed for the T6 and T6+ configurations. The T6 configuration represents a severe rear impact scenario (i.e. 50 kph speed change) with an average size male in a SR front seat. As in the 3 year-old study, the replacement of the SR seat with a BIS design reduced the rearward rotation of the front seat such that the child seated behind was spared from severe head-to-head impact and high injury producing head loads (i.e. HIC values).

Table 3 – Test Configurations, Variable Parameters, & 6 Yr-old Child HIC Measures

ANALYSIS & TEST SETUPS	FRONT SEAT TYPES / STRENGTH in "kN" units	VARIABLE X1 "Speed Change" in "kph" units	VARIABLE X2 "Occupant Wgt." in "kg" units	ANALYSIS RESULTS 6 Year-old Child HIC	TEST RESULTS 6 Year-old Child HIC
T1	SR / 3.1	37.5	74	1153.2	1572.9
T2	SR / 3.1	25.0	50	74.5	22.6
T3	SR / 3.1	50.0	50	111.8	68.4
T4	SR / 3.1	25.0	110	280.6	135.8
T5	SR / 3.1	50.0	110	3523.3	5692.1
T6	SR / 3.1	50.0	74	1997.1	2032.1
T6+	BIS / 12.0	50.0	74	139.1	48.1

Note: SR indicates single recliner seat design; BIS indicates "belt-integrated" design

Table 4 – Factorial (high-low) Polynomial Computation Matrix for 6 Yr-old Analysis

Configuration SET-UP	A0	A1	A2	A12	ANALYSIS HIC (6 Year-old Child)
T2	+1	-1	-1	+1	74.5
T3	+1	+1	-1	-1	111.8
T4	+1	-1	+1	-1	280.6
T5	+1	+1	+1	+1	3523.3
Σ (Column Sum)	3990.2	3280.0	3617.6	3205.4	
Ai ($\Sigma \div$ by 4)	997.6	820.0	904.4	801.4	

Table 4 provides data for the development of the polynomial coefficients and the "multi-variable" polynomial equation "Y" representation of the "analysis" HIC response for the 6 year-old in the sedan rear bench seat. As before, only the T2 through T5 configurations are used to calculate the coefficients for the 2 variable polynomial. Using the same approach outlined in the previous section, the "analysis" HIC polynomial for the rear seated 6 year-old located behind a typical 4-door sedan collapsing SR front seat is:

$$Y \text{ (Child-6 analysis HIC)} = 997.6 + 820.0*X1 + 904.4*X2 + 801.4*X1*X2 \qquad \text{(eq\#4)}$$

Using the same procedure with the sled-buck "test" measured child HIC data yields:

$$Y \text{ (Child-6 test HIC)} = 1479.7 + 1400.5*X1 + 1434.2*X2 + 1377.6*X1*X2 \qquad \text{(eq\#5)}$$

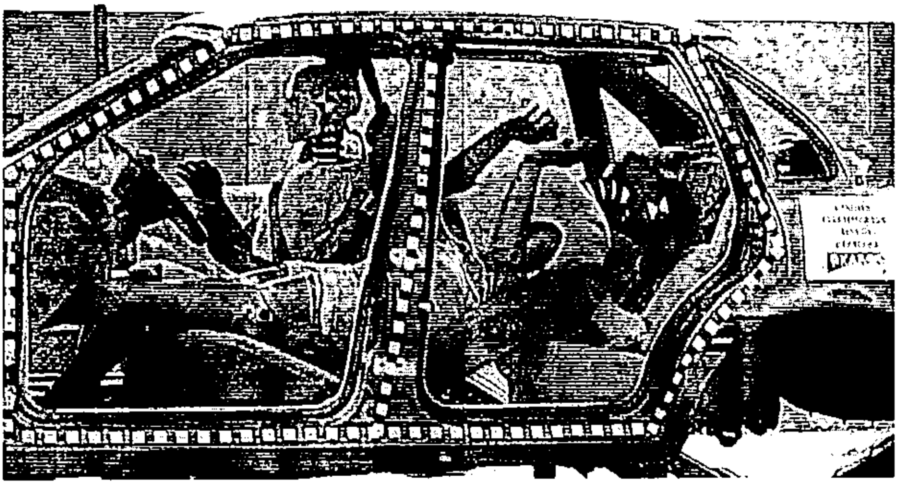


Fig. 7 – T6 & T6+ Configuration Comparison for 6 year-old Study (Sedan - 50 kph)

The T6 and T6+ configurations were tested side-by-side in a single sled-buck set-up. Figure 7 shows a film clip at severe head-to-head contact for the six year-old behind the SR seat of this configuration. In contrast, the child surrogate behind the occupant of the BIS design was not contacted or injured. Figure 8 shows images from the corresponding ATB runs for the T6 and T6+ configurations.

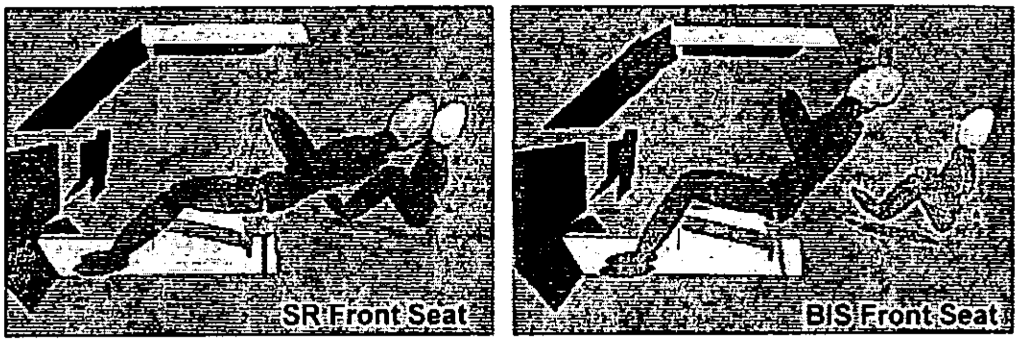


Fig. 8 – ATB Clips for T6 (left) & T6+ (right) Runs at 50 kph with 74 kg Front Adult

Figure 9 illustrates a comparison of the T6 test-measured data (solid curve) and the ATB analysis (dashed curve) data for the resultant "head acceleration" responses experienced by the rear 6 year-old child seated behind the collapsing SR seat.

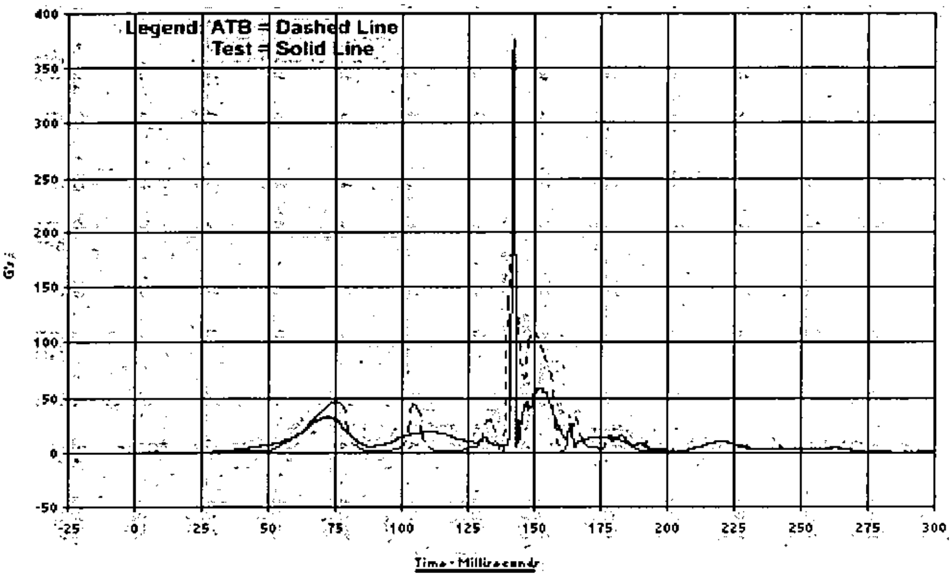


Fig. 9 – Rear Child ATB & Test Resultant Head Accelerations for T6 Configuration

As in the 3 year-old study, development of the HIC curve for a specific injury level, such as a level of 700, only requires that the left hand side of the HIC polynomial equations be set to a desired value of HIC and then solve for the pairs of X1 and X2 data points that correspond to the desired HIC level. Figure 10 shows a comparison of the ATB analysis and test 700 level HIC curves for the 6 year-old SR seat study (i.e. 4-door sedan) and the 3 year-old SR seat study (i.e. minivan "built-in" booster seat). Also shown on the figure are data (i.e. "X" points) from 2 cases involving serious and fatal head injury to 7 and 8 year-old males seated in the rear seat of mid-size sedans.

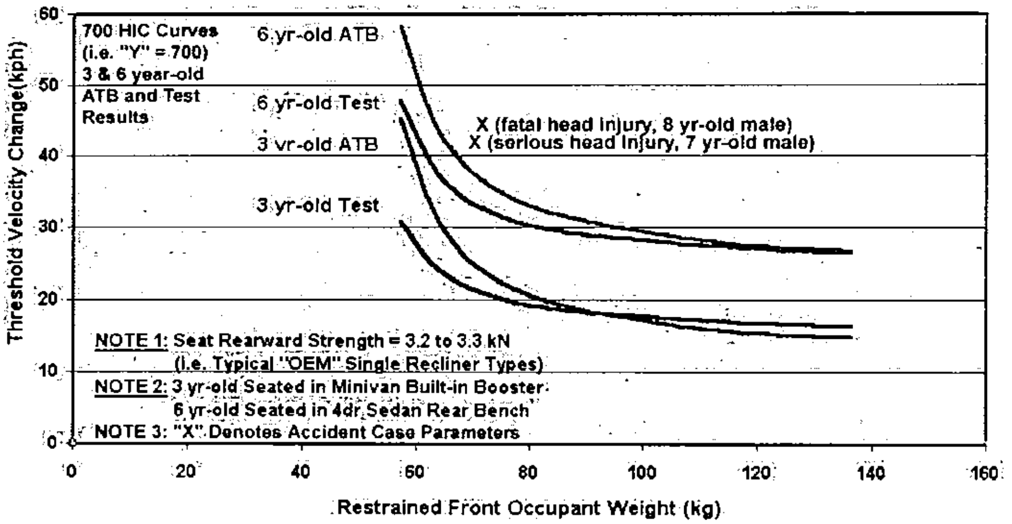


Fig. 10 – ATB & Test 700 HIC Comparisons for 3 & 6 year-old Study with Case Data

As was the case with the accident data shown in figure 6 for the 3 year-old results, the two accident cases (“X”) cited in the 6 year-old study (i.e. figure 10) also plot above the predicted injury threshold level of the 6 year-old ATB, and test generated, 700 level HIC curves. Thus, as before, the ATB computer simulations seem to provide a reasonable lower “threshold” head injury level for both the 3 and the 6 year-old models. Differences in the levels of HIC curves between the 3 and 6 year-old studies can be attributed to several variables which include, among other things: seated height and other size differences between the child surrogates; rear seat geometry (i.e. minivan “built-in” booster seats and sedan rear bench seat configurations); and, “biofidelic” differences (i.e. head stiffness, etc.).

ENHANCED MODELING OF ATB ANALYSIS – A more realistic representation of the ATB computer simulation output may be achieved by the use of 3 dimensional digitised vehicle models, and human digital models, in conjunction with various 3D graphics programs. Figure 11 illustrates a side-by-side comparison between the basic ATB occupant model and an enhanced ATB image made from the “Softimage XSI” 3D computer program. Human models were size scaled from existing baseline models and “inverse kinematic skeletons” from the “XSI” program were inserted into the more realistic digitised human models. These “skeletons” allow easy contortion or movement of the human models to “map’ onto positions that correspond with kinematic positions of the ATB analysed occupant representations at any given time. This enhanced software provides for interpolation and smoothing of human model motion between selected ATB frames so that it is not necessary to map each time frame of the original ATB occupant output.

Fig. 11 – Comparison of ATB Occupant Model with “Enhanced” Human Models

CONCLUSIONS – The primary interest in this study focused on demonstrating the viability of using computer simulations in lieu of expensive full scale tests for performing “multi-variable analysis” and prediction of: whether or not a adult occupied motor vehicle front seat would collapse into a rear seated child during a rear impact; and, if front to rear occupant contact was made, under what conditions, or combinations of variables, would the head contact result in head injury to the rear child. Variables studied included: front seat strength; impact severity (i.e. speed change); front occupant size; rear child size; and vehicle / child seat types. The ATB computer code was used with the “2-level factorial” method to perform occupant response predictions, and the development of “multivariable” polynomial response functions for injury measures, such as HIC. The “factorial method” polynomial response functions provide an efficient means for interpolation and extrapolation at combinations of variables not specifically analysed with the ATB occupant simulation code. Sled-buck verification tests were run and the results compared well with the ATB data for the several variables studied. Head injury 700 level HIC curves were plotted as a function of 2-variables (i.e. "impact severity speed change" X1 and "front adult occupant weight" X2) for the analysis of the more common single recliner (SR) front seat performance as it related to "injury potential" of a 3 year-old in a minivan "built-in" booster seat, and a 6 year-old in the standard rear bench seat of a mid-size 4-door sedan. Actual accident data was compared to the ATB and test generated child head injury curves. In both cases (i.e. 3 year-old and 6 year-old) the accident data seemed to validate the plotted ATB HIC curves for use as lower "injury threshold" levels. Future studies will look at other variable effects, such as seat "position" and rear seat structure "intrusion". Finally, the study indicates that stronger front seat systems, like the BIS designs, offer improved protection to rear seated occupants, like children, when compared to the effects of the more common, but weaker, single recliner motor vehicle front seat designs.

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