STUDY OF VEHICLE DYNAMICS AND OCCUPANT RESPONSE IN SIDE IMPACT CRASH TESTS

Brock Watson
Duane Cronin
Brett Campbell
University of Waterloo
Canada
Paper Number 09-0016

ABSTRACT

Side impact crash is a leading cause of fatalities on the roadways of the industrialized world. In the mid 1990's NHTSA implemented a new car assessment program testing the lateral crashworthiness of vehicles entering the market with a moving deformable barrier. Previous work has been done in an attempt to distill these tests into finite element simulations using specific vehicle test results; however there has not been a comprehensive study attempting to develop a model that includes a large number of tests to evaluate trends in vehicle kinematics and how they affect the occupants coupled with finite element simulations. To this end, a study of side NCAP tests was performed on all sedans based on the test results reported in the NHTSA Vehicle Crash Test Database since the introduction of the 2005 model year. This data was used to evaluate typical motion of the target vehicle during a regulatory crash test, and the corresponding occupant response. This sample consisted of new models entering the market and nameplates with major redesigns with a sample size of 72 vehicles. From these tests a series of velocity profiles were developed including time versus average velocity plots for vehicle center of gravity, door sill, driver's seat and driver door. These parameters have been shown to be important in occupant response and injury. There was significant variability in the response at several accelerometer locations. It was also found that rotation of the vehicle did not become significant until after 100 ms, after the maximum injury was predicted by the dummy. A parametric finite element analysis was performed using the both the USSID and ES-2re models to study the response of a restrained occupant during a typical crash test. These simulations showed that the velocity of the intruding door had a large effect on the thoracic injury predicted by the side impact dummy models.

INTRODUCTION

The response of vehicle occupants to side impacts has been a major focus of study for automotive safety experts for a number of years. Between 1994 and 1997 the United States government phased in a dynamic side impact compliance test to the Federal Motor Vehicles Safety Standards (FMVSS) to ensure all vehicles sold provided adequate safety performance in side impact [Kahane 2007]. Following the introduction of FMVSS 214, a side impact test was introduced to the New Car Assessment Program (NCAP) with the intention of providing safety information to consumers. Of the 22,716 vehicles involved in fatal crashes in the United Sates in 2007, 24.5% had the vehicles side as the initial point of impact, while 26.6% of injurious collisions had the lateral portion of the vehicle as the initial point of impact [NHTSA 2008a]. In research conducted prior to new side impact testing legislation to be introduced, NHTSA found that in side impacts chest injury accounted for 38% of fatalities and 59% of injuries, face and head injuries accounted for 40% of fatalities and 13% of injuries, and abdominal impact led to 8% of fatalities and 7% of injuries [NHTSA 2004].

During NHTSA's Side NCAP test, a moving deformable barrier (MDB) impacts the driver's side of a stationary target vehicle. The front of the MDB is fitted with a honeycomb structure to simulate the front bumper and crumple zone of an impacting vehicle. The wheels of the 1368 kg barrier are crabbed (turned slightly) 27° in an attempt to simulate relative motion between the target vehicle and the MDB. The nominal forward velocity of the barrier is 61 km/h. In the current version of this test, two DOT-SIDs (Side Impact Dummies) are placed in the vehicle on the struck side to measure the impact loads on driver and rear driver's-side passenger. These dummies are instrumented with accelerometers on the dummies upper rib (analogous to the 4th human rib), the lower rib (analogous to the 8th human rib), the lower spine (analogous to the T12 vertebra of a human), the head and the pelvis, along with load cells in the neck. There are 18 locations where accelerometers are mounted on the vehicle to record the response of the vehicle during the impact. Of these 18 locations, 5 on the vehicle door are considered optional [NHTSA 1997] and are often excluded. The Thoracic Injury Criteria (TTI) [Eppinger 1984, Morgan 1986] is the only injury criteria used in the current NCAP test, however if the

Head Injury Criteria (HIC) [Versace 1971] value is excessively high, the vehicle is flagged with a safety concern warning [Safercar.gov 2009]. For model year 2011 [NHTSA 2008c], the dummy used in this test will change to the ES-2re and rib deflection, HIC36, abdominal force and pelvic force will be used to measure the probability of injury to the dummy. This new testing procedure is part of the new NCAP program which will involve measuring the overall safety of a new vehicle by combining a frontal crash test, a side MDB test, a side pole impact test and a rollover test into on metric [NHTSA 2008d].

METHODS

The focus of this study was to investigate NCAP side impact test data and use this data as input conditions for a finite element model of a simplified sled, with a model seat, door and safety belt system. The explicit finite element solver LS-Dyna [LSTC 2007] Version 971 Revision 3.1 was used for all simulations. The desired outcome of this study was to assess the potential for injury on a USSID and ES-2re finite element model, both of which were developed by DYNAmore GmbH and supplied by FTSS [Franz 2002, Franz 2004, Schuster 2004]. The ultimate goal of this study was to understand the difference, if any, in severity of injury predicted by the ES-2re and the USSID finite element models. This work was essentially split into two parts, the first consisting of surveying crash test information from the NHTSA Vehicle Crash Database and the second consisting of using a side impact sled model [Campbell, 2008] with the crash test information to evaluate side impact response in typical crash scenarios. These two methods are outlined below.

NHTSA Database Information

To obtain the vehicle response information required in this study the NHTSA Vehicle Crash Test Database [NHTSA Vehicle Crash Test Database 2008] was surveyed. Of interest in this work were the vehicle and occupant responses in more recent crash tests using the USSID, so only data between model years 2005 and 2009 were studied. Additionally, to reduce any issues arising from a mismatch between the barrier and vehicle door, only 4 door sedans were studied. This meant that a total of 72 vehicles were considered. These vehicles were primarily vehicles which were new to the American marketplace (either new nameplates or cars previously available only in foreign markets), vehicles with major redesigns, or vehicles with the addition of new safety features (such as the inclusion of side airbags). Unfortunately, for all but 12 of the vehicles in the sample set, the door mounted accelerometers were not fitted. This means that the door intrusion velocity was captured during only these 12 tests. These 12 vehicles were all from model year 2005, so an understanding of door intrusion is somewhat limited for newer vehicle designs.

In addition to studying the velocity profiles of the vehicle accelerometers, the front seat dummy response was recorded for each test. This included the Thoracic Trauma Index, the dummy pelvic acceleration, and the Head Injury Criterion. Additionally, the offset between the dummy's arm and the vehicle door (AD distance), and the maximum door crush distance after testing were reviewed to identify trends.

The accelerometer data published in the NHTSA Vehicle Crash Test Database generally begins 20 ms prior to the MDB contacting the door of the target vehicle and lasts for 200-300 ms after the initial impact. The maximum thoracic response, as predicted by TTI, typically occurs in the first 50 ms after the MDB contacts the door. Therefore this study focused on occupant response during the first 100 ms after impact.

The data was filtered following the guidelines laid out in SAE J-211 [SAE 2003]. The velocity of the vehicle was found from each accelerometer by numerically integrating the acceleration trace. The time histories were then subsampled so that all of the traces had a sampling rate of exactly 1000 Hz. From this sub sampled data, 'average' velocity histories were determined using the mean value at each point within the velocity history, along with curves representing one standard deviation above and below the mean.

Initial evaluation of the data suggested that vehicle rotation during impact may be important. To study the rotation of the target vehicles, a simple kinematic analysis was performed. Based on the reported Cartesian position of the vehicle accelerometers, vehicle rotational acceleration was calculated using Equation 1.

$$\alpha = \frac{\Delta_{Rear_y}(a_{CG} - a_{Front}) + \Delta_{Front_y}(a_{Rear} - a_{CG})}{\Delta_{Front_y} \cdot \Delta_{Rear_x} - \Delta_{Rear_y} \cdot \Delta_{Front_x}} \qquad (1).$$

Where 'Δ' refers to the distance between the front and rear right side sill accelerometers and the CG accelerometer location prior to testing in the x and y directions, and 'a' refers to the lateral acceleration at each time step for the front and rear right side sill and center of gravity accelerometers. It is important to

note that this equation assumes that the accelerometers remain in fixed positions relative to each other and there is no local rotation of any accelerometer during the impact, thus these accelerometers were assumed to be moving as a rigid body. The right (non-struck) side sill and CG accelerometers were used to calculate this rotational acceleration since no damage is seen surrounding these positions (unlike the struck vehicle side). There were several tests where this method could not be used due to erroneous data from crash testing (when accelerometer channels failed, for example).

These rotational acceleration traces were then numerically integrated twice to determine the vehicle rotation as a function of time.

Finite Element Model Description

The sled model used in this study (Figure 1) was validated under side impact conditions [Campbell 2008] and included a seat, restraint system and intruding deformable door. The seat of the model consisted of a pair of rigid uprights which were prescribed the velocity of the driver's under-seat accelerometer. These uprights were connected to a deformable seat pan which was modeled using an elastic-plastic material model, as was the seatback. On top of these two surfaces a simplified seat was laid. The material properties for the seat foam were taken from a series of polymeric split Hopkinson pressure bar tests at elevated strain rates [Campbell 2007]. The three restraint system anchorage points for the safety harness were prescribed the velocity of the right front sills from the crash test data. This location was chosen because the CG location from several vehicles included in this study exhibited prominent peaks very early in the velocity time history which meant that at for this portion the method used to calculate the average time history provided a poor representation of most vehicles motion due to the amount of scatter. For this reason the time history of the right side front sill which exhibited very little scatter was used as the input condition for the floor and anchorage points of the simulations. The left sill was not used to represent the motion of the vehicle due to the deformation in this region which would have biased the input. An intruding door was created by using a simplified cross section of the Ford Taurus model provided in the Finite Element Model Archive by the National Crash Analysis Center [NCAC 2009]. The door was modeled as 1.5 mm sheet steel backing with a 3 mm thick plastic door panel, using the elastic-plastic material properties provided with the model. The ends of both the door panel and the metal back were boxed to increase the stiffness of the door. The door was placed so that the front face of the arm rest was at a distance of 800 mm from the centerline of the seat for all simulations. The backside face of the door was prescribed the velocity of the upper centerline accelerometer. The model was tested against NHTSA crash test 3522 of the Ford Taurus, which was used in developing the new version of FMVSS 214, and also an NCAP test of the Ford Five-Hundred to compare the simulated occupant thoracic injury to the tested values. For the Taurus test case The ES-2re dummy used in testing had a maximum rib deflection of 34.5 mm while the simulation predicted a maximum deflection of 31.9 mm. The NCAP test of the Five-Hundred produced a TTI score of 48 G while the model predicted a TTI of 30 G.

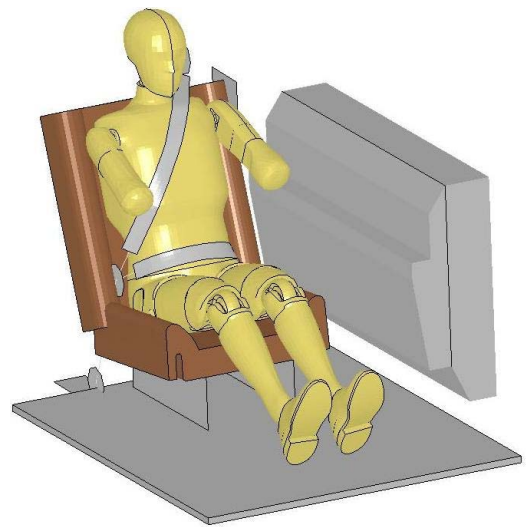

Figure 1. ES-2re Model in Sled

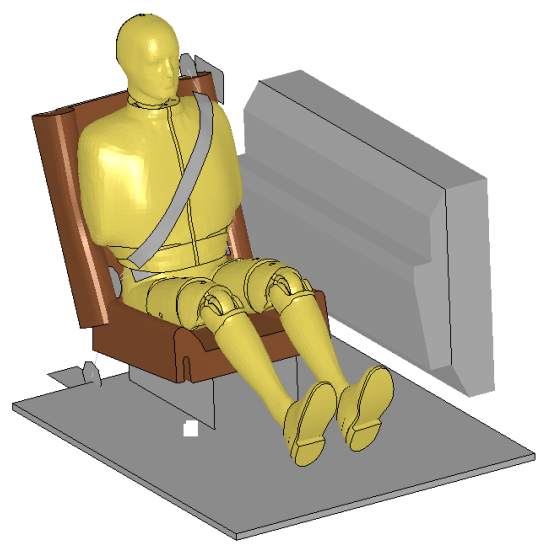

Figure 2. USSID Model in Sled

Response was measured using both the USSID model and the ES-2re model [Franz 2002, Franz 2004, Schuster 2004] as shown in Figures 1 and 2. Prior to the impact simulation the dummies and were sunk into the seat to ensure the stress equalized in the seat foam material. This was done by creating a rigid shell of the occupant and prescribing a displacement such that the occupant's position was at a reasonable position within the seat. A seat belt system was then modeled ensuring that the position of the anchorage points and slip rings were within the positions specific by SAE J383 [SAE 1995]. A pretensioner was used on the seat belt which drew in 100 mm of the seat belt in the first 30 ms of the simulation. An image of the ES-2re model in the sled is shown in Figure 1 while the USSID in the sled model is shown in Figure 2.

The baseline test case was performed first with the average velocities for the door, seat and floor. The door and seat velocities were then varied to plus or minus one standard deviation above or below the mean. Table 1 shows the door and seat velocity combinations simulated.

Table 1: Simulation Input Test Matrix

Simulation	Occupant Model	Door Velocity	Seat Velocity
1	ES-2re	Average	Average
2	USSID	Average	Average
3	ES-2re	+1SD	+1SD
4	USSID	+1SD	+1SD
5	ES-2re	-1 SD	-1 SD
6	USSID	-1 SD	-1 SD
7	ES-2re	+1SD	-1 SD
8	USSID	+1SD	-1 SD
9	ES-2re	-1 SD	+1SD
10	USSID	-1 SD	+1SD

Response was evaluated using risk curves developed by Kuppa et al. [2003] to quantify the injury predicted by both the USSID and ES-2re. These curves were developed from a series of cadaver sled impact tests as well as sled tests with the ES-2re. A logistic regression analysis was then performed to assess the probability of AIS 3 or greater and AIS 4 or greater injury as a function of TTI and maximum rib intrusion. The equations are of the form shown in Equation 2.

$$Probability\ of\ injury = \frac{1}{1+e^{a-b*criteria\ value}} \qquad (2).$$

The coefficients 'a' and 'b' are shown in Table 2 for both AIS 3+ and AIS 4+ injuries for TTI and rib deflection.

The coefficients in Table 2 for rib deflection were based on results from several sled tests performed by Kuppa et al. on ES-2re dummies and were correlated to the cadaveric tests performed, while the coefficients for TTI were found by curve fitting equation 2 to the risk curves provided for the TTI kernel, which ignores the age of the cadaveric subject. Because of this method for obtaining these coefficients there may be some error in the prediction of injury of the USSID.

Table 2: Injury Coefficients [Kuppa 2003]

Injury criteria	AIS	a	b
Chest Deflection [mm]	3+	2.0975	0.0482
	4+	3.4335	0.0482
TTI [G]	3+	6.0027	0.0736
	4+	5.8981	0.0517

RESULTS

NHTSA Database

Figure 3 through Figure 5 show the results of the survey of the NHTSA database which were used as input parameters during finite element modeling (driver's seat track lateral velocity, right front sill lateral velocity, and the upper centerline door lateral velocity). Each velocity history shows the average curve, as well as the upper corridor, lower corridor, and a curve representing the average value plus and minus one standard deviation. When there was an obvious error in the accelerometers recording (such as dislodging), the trace was excluded from the average and standard deviation calculation.

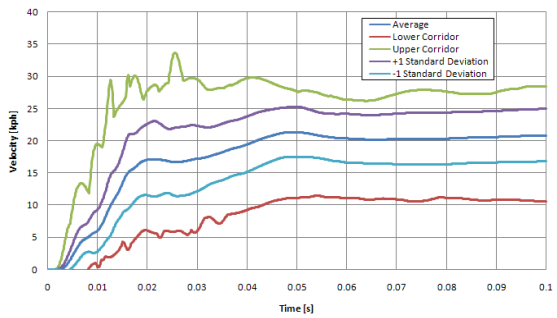

Figure 3. Right Seat Track Lateral Velocity History

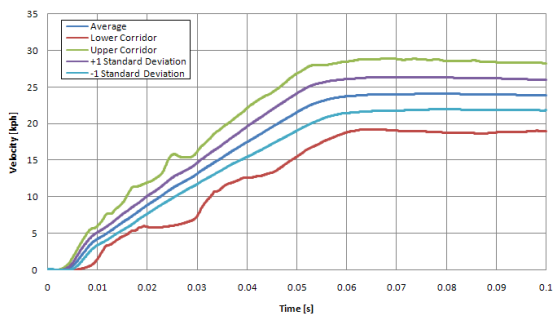

Figure 4. Right Front Sill Lateral Velocity History

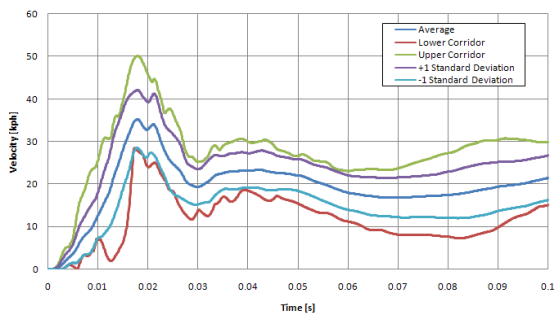

Figure 5. Upper Centerline Door Lateral Velocity History

Figure 6 depicts the calculated average rotation of the vehicle plotted along with the average spinal and rib accelerations of the occupant. This illustrates the small rotation of the vehicle prior to peak injury being predicted and justifies why vehicle rotation was not included in finite element modeling.

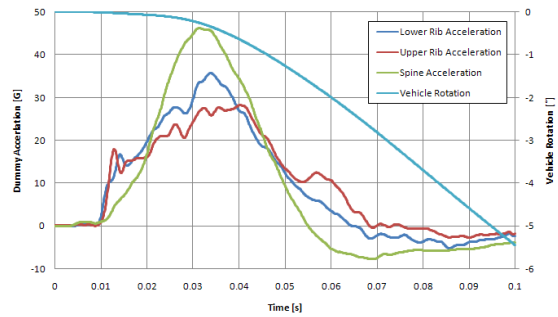

Figure 6. Rotation and Occupant Response Time History

Finite Element Model

Table 3 shows the predicted thoracic response for the simulations performed along with the load conditions. It is important to note that the USSID has only one element with which to measure rib deflections (at the middle rib) while the ES-2re has three. Additionally TTI is not a standard injury criterion for the ES-2re and likewise, maximum rib deflection is not a standard measure of injury for the SID and these values are provided only for comparison. The risk of injury is also shown in this table.

Table 3: Simulation Results

Sim #	Max Rib Deflection [mm]	TTI [G]	Probability of AIS 3+ Injury [%]	Probability of AIS 4+ Injury [%]
1	42.44	48.40	48.70	19.97
2	30.50	40.78	4.74	2.21
3	53.21	53.89	61.48	29.55
4	37.32	55.28	12.63	4.56
5	17.40	26.06	22.11	6.95
6	15.99	26.96	1.77	1.09
7	45.68	73.29	52.60	22.58
8	38.76	57.46	14.50	5.08
9	13.06	39.67	18.73	5.71
10	22.98	28.00	1.90	1.15

Figure 7 and Figure 8 depict the thoracic injury criteria results graphically with simulations with the same inputs grouped together.

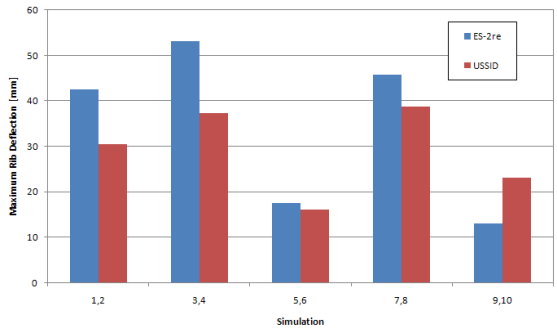

Figure 7. Maximum Rib Deflection Simulation Results

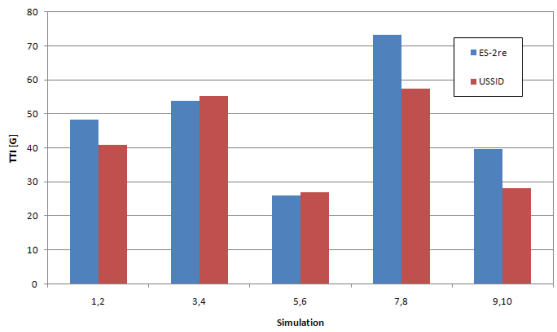

Figure 8. TTI Simulation Results

DISCUSSION

NHTSA Database

The various velocity-time histories determined from the database are in good agreement with the existing literature, including the pronounced peak observed in the door velocity history. This is often attributed to the outer skin of the door collapsing. Once the barrier reaches the outer structure of the door (the A and B pillars) the door velocity decreases and equalizes with the pillar velocity. When these structures collapse the velocity of the door again increases [Payne 1997]. It has also been suggested that as the door begins to collapse, the velocity is elevated until the first peak at which time the interior door contacts the occupant, slowing the door velocity until the occupant is pushed away, at which time the velocity increases again [Chan 1998].

One significant issue to consider with respect to the database is the effect of side airbags on occupant response. A further review of the vehicles tested by NHTSA during the time period of interest for this study showed that there was a significant increase in side airbag installation over the time in which the study has focused. A number of the vehicles in the early part of the data set either were not equipped with side airbags or they were optional equipment for that vehicle. For cases where they were optional equipment, the LINCAP test was often performed twice on the vehicle model; once on a vehicle with side airbags, and once on a vehicle without side airbags. Of the 72 vehicle included in this survey, the average TTI score of the 60 vehicles with at least one side airbag was 53 g while the 12 without side airs scored an average of 74.5 g. The majority of the vehicles without side airbags were from the 2005 and 2006 model years. A search of all cars (sedans, coupes and wagons) tested over the same time period (a total of 119 tests) showed that this phenomena was not limited to sedans. Figure 9 shows that as the average number of side airbags per vehicle for the driver have steadily increased over the past 5 years, the average TTI score has decreased. This finding was highlighted in a NHTSA report [Kahane 2007] which concluded that the large drop in TTI since the inception of the FMVSS 214 regulatory test, upon which the LINCAP test is based, is due in large part to the inclusion of side airbags on an ever increasing number of vehicle models.

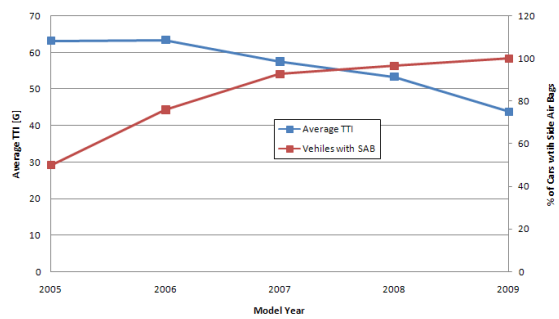

Figure 9. Side Airbag Installation and TTI in Cars between 2005 and 2009

Finite Element Model

The first and most obvious observation that can be made from the simulation results is that there are significant differences in the probabilities of injury predicted by the ES-2re model and the USSID model. This shows that the assumption of cadaveric injury data to develop risk curves for use with the USSID requires further investigation.

As expected the simulations with increased door intrusion speed (Simulations 3, 4, 7 and 8) showed the highest probability of injury for both dummies. The cases with elevated seat and door velocity predicted the highest injury to the ES-2re model, while the USSID predicted the case with higher differential velocities between the seat and door (higher door velocity and lower seat velocity) would

be more injurious. In general, the simulations with the elevated door velocity predicted higher injury than this with lower door velocity. This would indicate that reducing the door velocity would, in general, reduce injury. Interestingly the baseline case, based on average response, also showed an elevated injury potential for the ES-2re.

The maximum rib deflections were consistently higher for the ES-2re model than for the USSID. This is likely due primarily to the lack of a lower rib potentiometer on the USSID. In the simulations performed on the ES-2re the lower rib exhibited the most deflection due to the shape of the door panel. The armrest was at the same height as the position of the lower rib of the dummy leading to contact between the arm rest and the lower rib. The vertical position of the arm rest relative to the occupant may significantly affect injury response.

In addition to the position of the displacement potentiometer on both models and it relation to the position of the arm rest, the rib deflection curves themselves show quite different behaviors. Figure 10 shows the rib deflections of both the USSID and ES-2re models for Simulations 1 and 2. This figure illustrates that the middle rib of the USSID does not rebound in the same manner as the ribs of the ES-2re, but stays in a compressed state much longer. This behavior is seen in all load cases and was also seen in early work on the USSID and EuroSID when Bendjellal et al. [1988] performed several drop tests on both dummies, though in this work the reasons for this difference were not discussed. This figure also shows the degree to which the deformation of the lower rib differs from the upper two ribs on the ES-2re model, though the other load cases do not show this difference to the degree seen here.

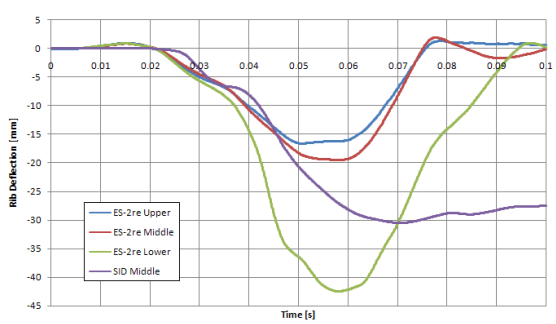

Figure 10. Typical Rib Deflection

In the new NCAP test, the actual risk curve that will be used is shown in Equation 3. This risk curve was developed by reanalyzing the data used by Kuppa et al. to develop the risk curves shown previously and assumes that the AIS 4+ risk curve found during the reanalysis should be used as an AIS 3+ curve.

$$P(AIS3 =) = \frac{1}{1 + e^{5.3895 - 0.0919 * max.rib.deflection}} \quad (3).$$

If the data for predicted the rib compression of the ES-2re model is reanalyzed using this risk curve the predicted results of AIS 3+ injury are shown in Table 4, along with those calculated using the TTI output of the USSID.

Table 4: Comparison of Prediction of Injury Based on NCAP Risk Curve

Sim #	NCAP Probability of AIS 3+ Injury [%]	SID Probability of AIS 3+ Injury [%]
1,2	18.40	4.74
3,4	37.77	12.63
5,6	2.21	1.77
7,8	23.29	14.50
9,10	1.49	1.90

Using this metric to predict risk of injury shows that the ES-2re results are considerably closer to those predicted by the USSID, though the ES-2re still predicts a higher likelihood of injury in most cases. These results show the importance of selecting a proper risk curve when comparing different injury criteria.

The values of TTI predicted by the models suggest that this response of the two dummies to the same load conditions is actually quite close for a number of load cases. This is despite a significant difference in the thoracic anatomy of both models. Indeed one of the concerns when the USSID was introduced was that the effective mass of the ribs on the USSID was too high when compared to EuroSID and the human body [Viano 1987].

CONCLUSIONS

In this study a review of side crash tests of four- door sedans tested by the NCAP program between model year 2005 and 2009 was completed. A series of average velocity profiles revealed that there was a good level of continuity of vehicle response throughout the majority of the tests. Maximum injury to the occupant was shown to occur roughly 35 ms after the movable deformable barrier impacted the target vehicle. The door velocity profiles were

limited in number and only available for the older vehicles in the sample set, thus the understanding of the kinematics of these components is somewhat limited. The average rotation of the vehicles in this dataset was found to be less than 2° prior to maximum injury prediction and was therefore not considered in the modeling aspect of this study.

The results of the survey of the NHTSA crash test database were used as inputs for a simplified side impact scenario, with finite element models of both the USSID and the ES-2re. A door model was prescribed velocity using data from the upper door accelerometer; while a simplified seat model was prescribed the seat track velocity found in the database review. The thoracic injury criteria used by each dummy model were compared using risk curves developed by Kuppa et al. These results, while not directly comparable between dummy models show the same general trends. The maximum injury prediction occurred with the greatest velocities as expected; however the dummy models differed in that the USSID predicted the greatest chance for injury when the differential velocity between the seat and door was the greatest, while the ES-2re predicted the highest probability of injury in the case of the largest velocity of both the door and seat. Future work will involve the inclusion of side airbags to the model, improved seat and door geometry, as well as studying the injury imparted to out of position occupants.

ACKNOWLEDGMENTS

The authors would like to express their appreciation to General Motors of Canada Limited and the Premier's Research Excellence Award for funding this work. The authors would also like to acknowledge First Technology Safety Systems and DYNAmore GmbH for the use of their dummy models in this work and the National Crash Analysis Center for the use of their crash data.

REFERENCES

Bendjellal, F., Tarriere, C., Brun-Cassan, F., Foret-Bruno, J., Callibot, P, Gillet, D. (1988) 'Comparative Evaluation of the Biofidelity of EuroSID and SID Side Impact Dummies' SAE 881717

Campbell, B.M. (2008) 'A Numerical Side Impact Model to Predict Thoracic Injury in Lateral Impact Scenarios', MASc Thesis, University of Waterloo, Waterloo, Ontario, Canada

Campbell, B.M., Cronin, D.S., Salisbury, C.P. (2007) 'High Rate Characterization of Automotive Seat Foams,' Society of Experimental Mechanics Conference, Springfield, MA

Chan, H., Hackney, J.R., Morgan, R.M., Smith, H.E. (1998) 'An analysis of NCAP Side Impact Crash Data' 16th International Technical Conference on the Enhanced Safety of Vehicles Proceedings, Paper 98-S11-O-12

Eppinger, R., Marcus, J., Morgan, R. (1984) 'Development of Dummy and Injury Index for NHTSA's Thoracic Side Impact Protection Research Program', SAE 840885

Franz, U. and Graf, O. (2004) 'Accurate and Detailed LS-DYNA FE Models of the US- and EUROSID: A Review of the German FAT Project', 6th International LS-DYNA Users Conference Proceedings

Franz, U., Schmid, W., Schuster, P. (2002) 'Observations During Validation of Side Impact Dummy Models – Consequences for the Development of the FAT ES2 Model', Nordic LS-DYNA Users' Conference 2002

Kahane, C.J. (2007) 'An Evaluation of Side Impact Protection - FMVSS 214 TTI(d) Improvements and Side Air Bags', DOT HS 810 748

Kuppa, S., Eppinger, R.H., McKoy, F., Nguyen, T., Pintar, F.A., Yoganandan, N. (2003)' Development of Side Impat Thoracic Injury Criteria and Their Application to the Modified ES-2 with Rib Extensions (ES-2re)' Stapp Car Crash Journal Vol. 47, SAE 2003-22-0010

Livermore Software Technology Corporation (LSTC) (2007) 'LS-Dyna Keyword Users Manual'

Morgan, R.M., Marcus, J.H., Eppinger, R.H. (1986) 'Side Impact - The Biofidelity of NHTSA's Proposed ATD and Efficacy of TTI', SAE 861877

National Crash Analysis Center (2009) 'Finite Element Model Archive' http://www.ncac.gwu.edu/vml/models.html

National Highway Traffic Safety Administration (1997) 'Laboratory Test Procedure for New Car Assessment Testing Side Impact Testing', Docket No. NHTSA-1998-3835, Document 0001

National Highway Traffic Safety Administration (2004) 'Federal Motor Vehicle Safety Standards;

Side Impact Protection; Side Impact Phase-In Reporting Requirements; Proposed Rule, Federal Register, Part IV, Department of Transportation 49 CFR Parts 571 and 598', Docket No. NHTSA-2004-17694, Document 0003

National Highway Traffic Safety Administration (2008a) 'Traffic Safety Facts 2006 (Early Edition)', DOT HS 811 002

National Highway Traffic Safety Administration (2008b) 'Revision to the New Car Assessment Program', Docket No. NHTSA-2006-26555, Document 0114

National Highway Traffic Safety Administration (2008c) 'Revision to the New Car Assessment Program', Docket No. NHTSA-2006-26555, Document 0116

National Highway Traffic Safety Administration (2008d) 'Revision to the New Car Assessment Program', Docket No. NHTSA-2006-26555, Document 0115

NHTSA Biomechanics Test Database (2009) http://www.nrd.nhtsa.dot.gov/database/aspx/biodb/querytesttable.aspx

NHTSA Vehicle Crash Test Database (2009) http://www-nrd.nhtsa.dot.gov/database/veh/veh.htm

Payne, A.R., Mohacsi, R., Allan-Stubbs, B. (1997) 'The Effects of Variability in Vehicle Structure and Occupant Position on Side Impact Dummy Response Using the MIRA M-SIS Side Impact Technique', SAE International Congress and Exhibition 1997, SAE 970571

Safercar.gov, NHTSA (2009) 'NCAP FAQs' http://www.safercar.gov

Schuster, P., Franz, U., Stahlschmidt, S., Pleshberger, M., Eichberger, A. (2004), 'Comparison of ES-2re with ES-2 and USSID Dummy – Consideration for ES-2re model in FMVSS Tests' LS-DYNA Forum 2004 Proceedings

Society of Automotive Engineers (SAE) (1995) 'SAE J383 - Motor Vehicle Seat Belt Anchorages--Design Recommendations'

Society of Automotive Engineers (SAE) (2003) 'SAE J211-1 - Instrumentation for Impact - Test Part 1 – Electronic Instrumentation'

Versace, J. (1971) 'A review of the severity index', Proceedings of the 15th Stapp Conference, SAE 710881

Viano, D.C. (1987) 'Evaluation of the SID Dummy and TTI Injury Criterion for Side Impact Testing' SAE 872208