

**REAR-FACING CHILD RESTRAINT DEVICE PERFORMANCE IN SIDE  
IMPACT CRASHES**

by  
Hans W. Hauschild

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Thesis Chair: Dr Alvaro Taveira

The University of Wisconsin – Whitewater

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**The University of Wisconsin – Whitewater**

**Thesis Approval**

**Hans W. Hauschild**

**Thesis Approved on**

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(Date)

Reading and Committee Members

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Dr. Alvaro Taveira, UWW, Thesis Advisor

---

Dr. Sang Choi, UWW

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Dr. Donna Vosburgh, UWW

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Dr. Narayan Yoganandan, MCW

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**Thesis Abstract**

**Hans W. Hauschild**

**Occupational and Environmental Safety and Health**

**Rear-facing Child Restraint Device Performance in Side Impact Crashes**

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**Dr. Alvaro Taveira, Thesis Advisor**

**The University of Wisconsin – Whitewater**

## **Rear-facing Child Restraint Device Performance in Side Impact Crashes**

The purpose of this research project was to examine the performance of rear-facing child restraint devices (RFCRD) involved in side impact crashes. Side impact crashes are the second highest crash mode reported by the National Highway Traffic Safety Administration (NHTSA).

Child restraint devices (CRDs) are being installed in the center seating position of vehicles because it is thought to be the safest position in the vehicle due to the distance from any intrusion. Children are still being injured in side impact crashes due to the child restraint device moving toward the direction of impact and colliding against the intruding sheetmetal and interior components of a vehicle hit in the side. Testing done by the NHTSA in the Side Impact New Car Assessment Program (SINCAP) in 2007 placed RFCRDs in test vehicles. Subjective analysis of the SINCAP high speed video raised the question examined in this research about the excursions and potential injury of the child occupants in side impacts.

The first part of this study examined the maximum head excursion of a 12 month CRABI anthropomorphic test device (ATD) placed in RFCRDs at a change in velocity of 35 km/h (22mph). The change in velocity was determined by using the average of four popular selling small and mid-size vehicles' crash tested by the NHTSA SINCAP program. The purpose of the test series was to determine if a child occupant placed in a



CRD in the center seating position would impact the door of a vehicle involved in a higher speed side impact event, such as the NHTSA SINCAP program where a moving deformable barrier traveling at 62 km/h (38.5 mph) impacts the side of a vehicle.

After determining the excursion of the ATD head, and determining if the head would hit an intruding door during a side impact event, the ATD and CRD were impacted into a simulated door to determine injury potential at 35 km/h (22 mph) change in velocity. Tests impacting the simulated door were also conducted at 29 km/h (18 mph), and 24 km/h (15 mph) to determine injury potential.

In all the sled tests done at 35 km/h (22 mph) the ATD head moved into the crush zone of a sample of smaller and mid-sized vehicles. The potential for severe head injury using all the tested RFCRDs at 35 km/h (22mph) was high when impacting a simulated door. The threshold for lower injury potential was at 24 km/h (15 mph). When the ATD did not impact anything at 35km/h (22 mph) the potential for severe head injury was also low.

This study concludes that testing of CRDs needs to be done at higher speeds to better protect children involved in higher speed side impact crashes. Head injury values and excursions both need to be evaluated for reducing injury potential.

## **Rear-facing Child Restraint Device Performance in Side Impact Crashes**

### **Introduction**

This research project examines the performance of children in rear-facing child restraint devices (RFCRD) or child restraint systems (CRS) secured in the center seating position of compact/small and midsize vehicles involved in side impact crashes. Small children are required to use an additional child restraint device when traveling in a vehicle. Child restraint devices (CRD) are required to meet the National Highway Traffic Safety Administration (NHTSA) Federal Motor Vehicle Safety Standard (FMVSS) 213 for frontal impacts. Currently there are no standards for CRDs in side impact, although the NHTSA has been conducting research aiming at the development of a test method (Sullivan, et al. 2011, and Sullivan, et al. 2009) and other researchers have looked at various issues related to CRDs and side impact protection ( Arbogast et al., 2010; Brown et al., 2007; Charlton et al., 2004; Ghati, et al.,2009; Klinich et al., 2005; Langwieder & Hummel, 1994; Morgan, 2003; and Yoshida et al. n.d.).

Full scale crash testing done by the NHTSA in the 2008 Side Impact New Car Assessment Program (SINCAP) incorporated CRDs in the tests (NHTSA 2007a, 2007b, and 2007c). In those tests CRDs were placed in the right rear outboard seating position or far side of the impact. Far side seating positions can be considered as positions not directly next to the point of impact. The near side position is the seating position closest

to the point of impact. The vehicles were impacted by a moving deformable barrier at a speed of 62 km/h (38.5 mph) on the left side. The SINCAP test is to simulate one vehicle traveling at 27.4 km/h (17 mph) struck in the side by another vehicle traveling at 54.7 km/h (34 mph) (NHTSA, 2004) .

In the SINCAP tests, video review of the child test dummy and the CRD shows the dummy and CRD yawed and rolled toward the impact and moved as far as the left rear outboard, near side, seating position (NHTSA 2007a, 2007b, & 2007c) . No actual measurements of the kinematics or displacement were taken but in those tests it appeared that if the dummy and CRD were placed in the center seating position it could move into the vehicle's intruding sheet metal and interior components.

This research examined the kinematics and potential injury of a test dummy placed in a CRD secured to a test fixture in a center seating position. Testing evaluation initially examined the maximum excursion of the dummy and if it would be possible to impact the intruding door from the center seating position in compact/small and medium sized vehicles. RFCRD models evaluated included combination, convertible and infant type seats. Combination seats can be used from a child's birth as a rear facing and then be turned forward-facing for use as the child gets older and finally used as a booster seat utilizing the vehicle's belt system. Convertible seats are used first as rear facing and then forward facing, but cannot be used as a booster. Infant seats are only used as rear facing up to a certain weight limit specified by the CRD manufacturer. Details and photos of

each seat can be found in the appendix.

Maximum excursion of the child test dummy head were determined when placed in each RFCRD design. Seat designs were chosen based on popularity, other side impact testing research, and indication or marketing of offering side impact protection or testing. Used seats were based on availability. New and used CRDs were evaluated.

The best selling compact/small and midsize cars were evaluated for their specifications of interior size and the amount of intrusion in the NHTSA SINCAP program. Vehicle class is defined by the US Department of Energy (US DOE, n.d.). Four of the vehicles chosen as samples based on size are the 2011 Chevrolet Cruze, 2011 Toyota Corolla, 2011 Honda Civic, and 2012 Ford Focus. The sample vehicles crash accelerations were averaged from data collected during SINCAP testing to create a simulated crash for the sled pulse.

After determining the CRD and occupant motion, then the potential for injury was examined by impacting the CRD and occupant into a simulated door. A simulated door interior based on previous NHTSA research was set up, and from the center seating position the CRDs with an Anthropomorphic Test Device (ATD), crash test dummy, were impacted at different speeds into the simulated door structure. Evaluations were made of the head injury criteria (HIC) and the kinematics of the test dummy. The kinematics evaluation examined if the CRD restrained the child dummy head within the CRD, and if

the head reached the simulated door structure.

## **Literature Review**

### *Seating Position*

Rear-facing child restraint devices are used to restrain children when a vehicle is involved in a crash. The NHTSA (2011c) recommends children up to 12 months old be in RFCRDs, and then for as long as possible. Keeping occupants far from intrusion is the best way to prevent injury in a vehicle crash.

Placing a child restraint device in the center rear seating position is the best place to distance the child from any intrusion during a crash (Kallan et al. 2008). Braver's et al. (1998) study of the NHTSA Fatality Reporting System (FARS) of 1981 – 1996 vehicle data, also concluded the rear seating position was more protective than the front positions for side and frontal crashes, and the “rear center positions appear to provide greater protection than rear outboard positions.” Braver's et al. (1998) study concluded that children seated center rear had a 24% lower risk of dying than children in rear outboard positions.

Howard et al. (2004) reported the “center seat was statistically safer than the rear side seat, particularly for restrained children,” and Kallan et al. (2008) found, “child occupants seated in the center seating position had a 43% lower risk of injury than those children seated in a rear outboard position,” and the “analysis confirmed current recommendations

that the center rear is the safest seat position for children restrained in CRS.” Kallan's et al. (2008) study looked at injuries to children with an abbreviated injury scale (AIS) greater than or equal ( $\geq$ ) to 2.

The AIS was established by the Association for the Advancement of Automotive Medicine. AIS injuries greater than or equal to two are considered a clinically significant injury (Arbogast et al., 2000). The following is the scale used for injury ratings:

<u>AIS score</u>	<u>Injury</u>
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Probably lethal

Table 1  
Abbreviated Injury Scale

Howard et al. (2004) found in their study of the National Automotive Sampling System – Crashworthiness Data System (NASS-CDS) for children involved in side impact crashes that severe injury was more common on the near side (7 per 1,000 children) than children seated in the center (2 per 1,000) or far-side (1 per 1,000). Analysis by the NHTSA of 1991 – 1999 FARS data indicated for the following seating positions, near side occupant fatalities accounted for 65% of fatalities, far side occupants accounted for 21% of fatalities, while the middle position only accounted for 14% of the fatalities (Huntley, 2002).

NHTSA testing done in 2007 on 2008 model year vehicles placed CRDs in the right outboard, or far-side, position of vehicles tested in the SINCAP test program (NHTSA 2007a, 2007b, & 2007c) . In those tests the CRD rolled over and yawed toward the direction of impact. During the test, the child restraint devices moved toward and into the left rear seating position, potentially getting close to the area of intrusion. This motion could potentially cause injury to the child's head impacting the intruding car panel.

The problem was also addressed by Paine and Vertsonis (2001), they stated “the compliant seat may allow excessive yaw motion and expose the occupant to direct contact with the (intruding) interior of the vehicle”. Testing done by Ghati et. al. (2009) found RFCRDs yawed and rolled over in the direction of impact. This motion is similar to that seen in the 2007 NHTSA SINCAP tests.

Arbogast's et al. (2000) case studies found two crashes where a child received AIS  $\geq 2$  head injuries when they were seated in a far side position and properly restrained in CRDs, and it was reported that they hit their head on the interior of the vehicle. In Sullivan and Loudon's analysis of the 1995 - 1996 and 1998 – 2004 NASS-CDS, and 1994 - 2003 FARS data they found “near side and center occupants suffered more severe injuries (AIS 2+) than far-side occupants.”

Center positions are farther from the impact zone making it a safer location to install a



CRD. Kallan et. al. (2008) states “recommendations should continue to encourage families to install CRSs in the center of the rear seat.” Data from Howard et al. (2004) and the NHTSA (Huntley, 2002) also confirm the center seating position as the safest place for children. Sullivan and Loudon's (2009) analysis of NASS and FARS data indicate injuries are still occurring to children seated in the center rear. McCray, et al. (2007) wrote, “the most significant injuries (AIS 3+) are sustained by the near side and center seated occupants,” in their data set examining side impacts over 48 km/h (30 mph) of children ages one to three.

#### *Rear Facing Child Restraint Devices*

Rear facing child restraint devices include combination or “all in one”, convertible, and infant style seats. The combination or “all in one” seats are designed for use from birth through the age/weight appropriate for vehicle belt use, first as a rear-facing infant seat, then forward facing with the CRD belt system, and then as a booster utilizing the vehicle belt system to secure the child occupant. Convertible seats are only used in two phases of the child's development, first as a rear-facing infant seat and then forward facing once the child reaches the proper height and weight, and the child is secured with the CRD belt system. An infant seat is only used as rear facing, up to the manufacturer's specified weight limit, typically 10 to 15 kilograms (22 to 35 lbs.). CRDs can be secured to the vehicle through the LATCH anchor system or using the vehicle belt system.

The LATCH system is a standardized vehicle anchor for securing CRDs. LATCH is the acronym for Lower Anchors and Tethers for Children. The vehicle consists of two anchors, metal loops, at the rear seat bight and an upper anchor loop to attach a tether. The CRD has belt webbing that can be clipped to the anchors, securing the CRD to the vehicle. LATCH systems were required in vehicles built for the United States after September 1, 2002. (NHTSA, 2011b).

Henary et al. (2007) found RFCRDs to be more effective in preventing injuries relative to forward-facing CRDs (FFCRD) involved in side impacts, and especially for “one year olds in all crashes.” Henary et al. (2007), and Durbin (2011) recommend children be in rear-facing seats until their second birthday, while the NHTSA (2011c) current recommendation is to leave children rear-facing for as long as possible.

### *Side Impact Injury*

Side impact is the second leading crash mode. The NHTSA reported in 2011 that side impact accounted for 26% of all fatal crashes, adults and children, while 55% of all fatalities are caused by frontal impacts (NHTSA, 2011a). Arbogast, et al. (2000) reported side impacts accounted for 27% of all occupant fatalities in the 2000 NHTSA FARS database. 2010 European data showed side impacts are 25% of all crashes, but account for over 40% of injury costs (Arbogast, et al., 2010). Vander-Lugt (1999, in Arbogast, et al. 2000) reported side impacts accounted for 19% of crashes and 32 % of fatalities in a

review of police reported crashes. In 2002 the NHTSA reported 40% of fatalities to children ages 0 – 8 were in side impact events (Huntley, 2002). Langwieder and Hummel (1994) reported in 1994 that about 20% of crashes involve side impacts. Side impact crashes involving children need to be studied since this is the second highest mode of crashes with injuries still occurring to child occupants seated in the center rear position.

Griffiths et al., (2004) research in Australia reported head injuries as the most frequent and severely injured region to children involved in side impacts. The Medical College of Wisconsin, Crash Injury Research and Engineering Network (CIREN) program, which studies vehicle occupant injury, also reported they have seen head injuries as the most common injury to children involved in side impact collisions (Pintar, 2012). Arbogast's et al. (2000) study of children in side impacts crashes reported 39% of injuries to all children with an AIS of two or higher involved the head, and 58% of children under four years of age with an AIS over two. McCray's et al, (2007) analysis of the NASS-CDS data for side impact crashes with a change in velocity (delta-V) over 48 km/h (30 mph) for children between the ages of zero and twelve, 52% received head injuries. In 2009, Sullivan and Loundan also reported that most injuries to children were to the head, 57% in their report of NASS-CDS and FARS data. In the case studies appendix of Arbogast et al. (2010) every child in a RFCRD indicated the head as the injured body region, which includes three cases where the RFCRD was mounted in the center position.

Containing the head and preventing injury is important when CRDs are utilized. Brown et

al. (2002) indicated, “head excursion and risk of contact are considered far more important” than dummy injury measurements. The Australian side impact standard requires the restraints prevent any head contact. Brown et al. (2007) writes, “child restraint systems need to minimise contact between occupants and vehicle interior, and if contact occurs minimise the severity”. Sullivan and Loudon (2009) observed, “direct contact with the vehicle interior accounted for 45 % of the injuries while 14.4% were due to contact with the CRS”.

### *Head Injury Criteria*

Head Injury Criteria (HIC) is the measure for potential injury based on the ATD response to a crash or impact test. The injury criteria was developed from experimental analysis of human cadavers, animal testing, computer simulation, and human volunteer testing, and then related to the ATD response. Development of the injury values was mostly done related to adults, and has been scaled through analysis for evaluation on the child ATDs (Eppinger et al., 1999).

HIC is calculated over a time period, between  $t_1$  and  $t_2$ , which will produce the maximum injury value based on the ATD head resultant accelerations. HIC 36 uses a maximum of 36 milliseconds and HIC 15 uses a maximum of 15 milliseconds for the injury calculation, injury calculations can use time periods less than the maximum.

Typically narrow time periods result in high HIC values, and long time periods produce low HIC values. Long time periods and low HIC values are related to “ridedown” time (Morgan, 2003). The higher the HIC value the more likely for more severe injury to occur. Figure 1 below shows the equation used to calculate HIC values. The NHTSA has proposed a HIC 15 of 390 as a maximum value for the CRABI 12 to reduce the potential for severe head injury. Maximum HIC 15 values for an adult ATD to reduce the possibility of severe head injury is 700, and 1000 for HIC 36.

$$HIC = \left\{ \left[ \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t) dt \right]^{2.5} (t_2 - t_1) \right\}_{\max}$$

Figure 1  
HIC equation (NHTSA, 2006)

### *Side Impact Intrusion*

Due to the small distances between the occupant and side of the vehicle, it can be difficult to protect the occupant involved in side impact crashes. The limited space creates less “ridedown” time or a good “crumple zone” than a frontal or rear crash. The limited space can make protecting occupants difficult as they are near the intruding sheetmetal and interior components of the vehicle. Due to the short crumple zone, manufacturers have to prevent intrusion to a certain amount and add some type of padding or other impact absorbing device near the crumple zones. The NHTSA Report to Congress in 2004 noted,

*“Vehicles that performed well in providing side crash protection to adult dummies in side impact NCAP tests also provided better side crash protection to the rear seat children. For example, SUVs and pickup trucks tend to offer better side protection than smaller passenger cars for children.”*

The reduced space and potential movement of the CRD toward the intruding door puts the child occupants at risk of injury. McCray et al, (2007) found that as CRD movement increased the excursion may be sufficient to allow the child occupant to contact the intruding door. They state, “the threat of injury is increased even farther when the occupant is put in motion due to poor restraint and rigid structures are intruding resulting in even less ridedown space.”

To reduce the intrusion the vehicle structure may be made stiffer which can also increase the acceleration pulse felt by the occupants. Morgan (2003) stated in his report on evaluations of CRDs in frontal vehicle crash tests, “ these data appear to support that a child restraint tested in a vehicle with good crash pulse characteristics (i.e., longer time duration or lower peak acceleration) would perform better than the same child restraint tested in a vehicle that does not.”

SINCAP tests done on sample 2011 and 2012 compact and mid-sized vehicles averaged approximately 230 mm (9 inches) of intrusion at the H-point, and mid door levels, and approximately 150 mm (6 inches) of intrusion at the window sill (NHTSA 2011d, 2011e,

2010a, & 2010b). The H-point is a reference point on the adult ATD near the hip used for locating the occupant seating position. Overall average intrusion at the three levels was about 200 mm (8 in.) of the four vehicles used to develop the sled pulse. The vehicles were selected based on their size, sales numbers, and the availability of crash test data. Typically the most common vehicles are crash tested by the NHTSA, and may only be done when there is a major model redesign.

The four sample vehicles examined include:

- 2012 Ford Focus
- 2011 Chevrolet Cruze
- 2011 Toyota Corolla
- 2011 Honda Civic

#### *Other Testing and Research*

Many studies have tested CRDs for frontal impact injury protection, but few have been conducted for side impact and even fewer examining performance of RFCRDs involved in side impact. Arbogast et al. (2000) stated that prior to their study “the role of appropriate versus inappropriate restraint for children in side impact crashes was unclear,” and most efforts were focused on frontal crash restraints. Arbogast et al. (2000) also stated, “The specifics of restraint performance in near and far side crashes for children as well as investigation into whether restraint use is a proxy for another determinant factor deserves additional attention.”

The NHTSA has done limited testing of RFCRDs in its research for developing a CRD side impact test procedure, but has not addressed the issue of the RFCRDs placed in the far or center seating positions, yawing and rolling over, and potentially entering the intruding sheetmetal and interior components. The NHTSA research into developing a side impact test method has concentrated on near side impacts (Sullivan & Loudon, 2009; Sullivan, et al., 2011). Ghati et al. (2009) also noted that side impact test procedure research is concentrated on near side.

In a study by Evans et al. (2009), they found a 50% risk for an AIS of two or greater when there is an average of 200 mm (7.87 in.) of intrusion. Vehicles in Evan's study of child injuries with an AIS of two or greater had a range of 150 mm (5.9 in.) – 290 mm (11.41 in. ) of intrusion. Langwieder and Hummel (1994) found children involved in side impact collisions were nearly twice the risk of AIS 2 + injuries as compared to frontal collisions.

The sample vehicles in this research had a range of intrusion between 153 (6.0 in.) and 230 mm (9.0 in.) at the rear door areas in the NHTSA SINCAP tests (NHTSA 2011d, 2011e, 2010a, and 2010b). This study examined the potential of injury to children in side impacts with a static crush profile of the sample vehicles averaging approximately 200mm (8inches), see table 2 for detailed intrusion data related to the sample vehicles.



<b>Max Intrusion at Rear Door Area</b>						
	Level 2	Occ. H-Point	Level 3	Mid Door	Level 4	Window Sill
	Intrusion (mm)	From Impact Point	Intrusion (mm)	From Impact Point	Intrusion (mm)	From Impact Point
<b>2011 Honda Civic</b>	270	1350	263	1200	194	1350
<b>2011 Toyota Corolla</b>	231	1200	224	1500	90	1350
<b>2011 Chevy Cruze</b>	201	1350	219	1650	147	1650
<b>2012 Ford Focus</b>	214	1650	215	1350	181	1650
<b>Average Intrusion at Level</b>	229		230		153	

Table 2

Sample vehicle maximum intrusion from NHTSA SINCAP tests.

ATDs used for rear facing CRDs testing include newborn, 6 month and 12 month devices. Each device is designed to simulate the child and is used to collect data related to injury potential. The child ATDs are available as a CAMI, CRABI, or Q series depending on the types of data a researcher wants to collect. The ATDs are referred to as CAMI Newborn, CAMI 6, CRABI 6, CRABI 12, Q0, and Q1 depending on the size and weight being utilized (Humanetics, 2010).

Acceleration data was collected in the NHTSA SINCAP tests at various locations in and on the vehicles. The NHTSA (Sullivan & Loudon, 2009; & Sullivan et al., 2011) used the right rear rocker panel sill Y accelerations of 10 vehicles tested in FMVSS 214 side impact compliance tests to determine a sled crash pulse. From the right rear rocker panel sill Y accelerations a velocity was calculated between 27 km/h (17 mph) and 29 km/h (18

mph). The NHTSA was examining near side impacts, therefore a sliding seat mechanism was incorporated in their research to simulate the intruding door, and they also examined placing the seat fixture at different angles from 0 degrees to 20 degrees (Sullivan & Loudan, 2011). A CRABI 12 test dummy was used for their RFCRD tests.

Ghati et al. (2009) did 48 tests examining performance of CRDs in side impact. They examined eight different style CRDs, four forward-facing and four rear-facing seats. The seats were secured to the fixture by two methods, LATCH anchor and by a belt system. Seats were tested at speeds of 24 km/h (15 mph), 29 km/h (18 mph), and 36 km/h (22 mph). Testing was done with the standard FMVSS 213 test seat bench fixture placed at 90 degrees to the impact force. For the rear facing seats Ghati et al (2009) used the 12 month old CRABI test dummy, and evaluated performance of injury criteria and kinematics of the head. Similar testing done in Australia related to CRD mounting was done at 15 km/h (9 mph). (Charlton et al., 2004). Charlton et.al (2004) used a CRABI 6 month ATD for their testing of RFCRDs.

Side impact testing done by Yoshida et al. (n.d.) used a sliding seat configuration with a 25 km/h (15.5 mph) delta-V. The test series examined side impacts of CRDs into deformed and non-deformed vehicle doors, and used a CRABI 6 month old test dummy in RFCRDs.

The NHTSA SINCAP crash tests of the sample vehicles right rear rocker panel sill Y

acceleration produced an average delta-v calculation of 35 km/h (22 mph). The moving deformable barrier during SINCAP tests impacts a test vehicle at 62 km/h (38.6 mph). In case studies done by Arbogast et al. (2000) examining side impact crashes involving children, they found an average delta-v of 19.6 km/h (12 mph) with a range of 3 km/h (2 mph) to 46 km/h (29 mph). McCray et al. (2007) found in their evaluation of injuries of AIS 2+ “occur over a broad range of speeds from 20 – 49 km/h”, (12 – 30 mph).

### *Study Rationale*

The literature shows the problem of injury to children in side impacts. The risk to children in side impact crashes is an issue that needs to be addressed. There are several studies and case study data sets related to FFCRDs, but few for RFCRDs. This may be due to the lack of available case studies for children under 10 kilograms (22 lbs) in RFCRDs, due to the fairly quick graduation to a forward facing seats in the United States. Children using RFCRDs are in an age group that has less tolerance for injury (Henary, et al. 2007), which makes protection of these children important.

There has been little research done examining the performance of RFCRDs in crashes at higher speeds. Most of the focus appears to be related to FFCRDs. The research that has been done on RFCRDs is mostly been examining frontal impact or lower speed side impact. That research has typically been focused on near side impacts. There is limited research into the excursions of the ATD head during side impact events, and examining

the injury potential when impacting an intruding door from middle or far side seating positions.

## **Methods and Procedures**

This research project examined several RFCRDs for side impact protection. The seats included a mixture of combination, convertible and infant CRDs. The project was broken into four series. One series examined maximum excursion and the other three examined injury potential at different speeds. The second, third, and fourth series examined the potential for injury if and when the test dummy and CRD impact an intruded simulated fixed door.

Testing was completed on The Medical College of Wisconsin's Servo Sled at the Neuroscience Research Facility. The Servo Sled is an accelerator type crash simulator sled utilizing a servo brake to create a crash pulse. Test set ups were conducted identically to reduce any variability in the results, with only the CRD and speed changes in each series being a variable.

The first series (series 100) only examined the anthropomorphic test device (ATD), head excursion at 35 km/h (22 mph) and the head injury potential without an impact. The second, third, and fourth series (200, 300, and 400) each examined the injury potential at different delta-vs, 35 km/h (22 mph), 24km/h (15mph), and 29 km/h (18mph), respectively, when the ATD and CRD impacted a simulated door. For series 100 and 200 there was a mixture of new and used seats tested, for series 200 and 300 only new seats were tested. Tests 100 and 101 were shakedown tests, or trial runs, to verify cameras and

the data collection system were working properly and to verify the simulated crash pulse.

If any data was collected it will be presented in the results section.

A standard FMVSS 213 test bench seat fixture was used and secured on an accelerator sled 90 degrees to the principle direction of force (PDOF). Standard center LATCH anchors were used for each test. The anchors were inspected after each test for damage and replaced if they were damaged or bent. The center latch anchors were sourced from 2000 – 2007 Ford Taurus vehicles. The Ford Taurus LATCH mounts were adapted to the middle of the FMVSS 213 test fixture (Photos 1 a & b).

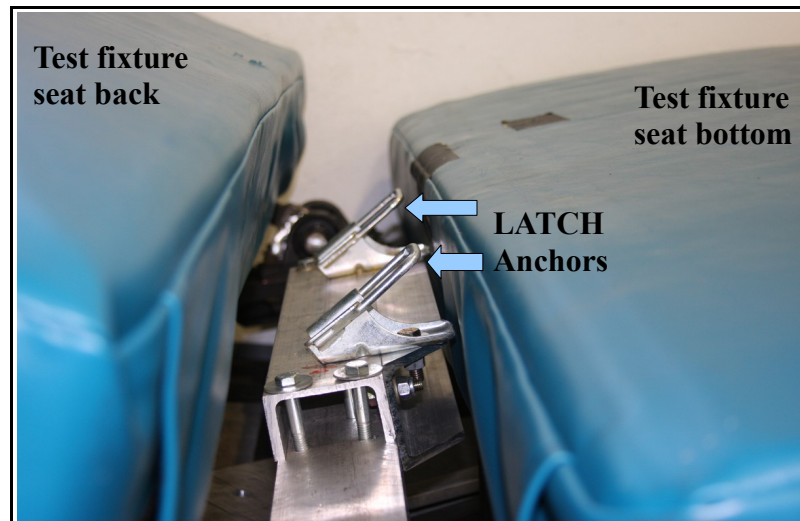


Photo 1a

FMVSS 213 test fixture viewed from right side  
LATCH anchors sourced from 2000-2007 Ford Taurus vehicles.  
See photo below for location of LATCH on FMSS 213 test fixture

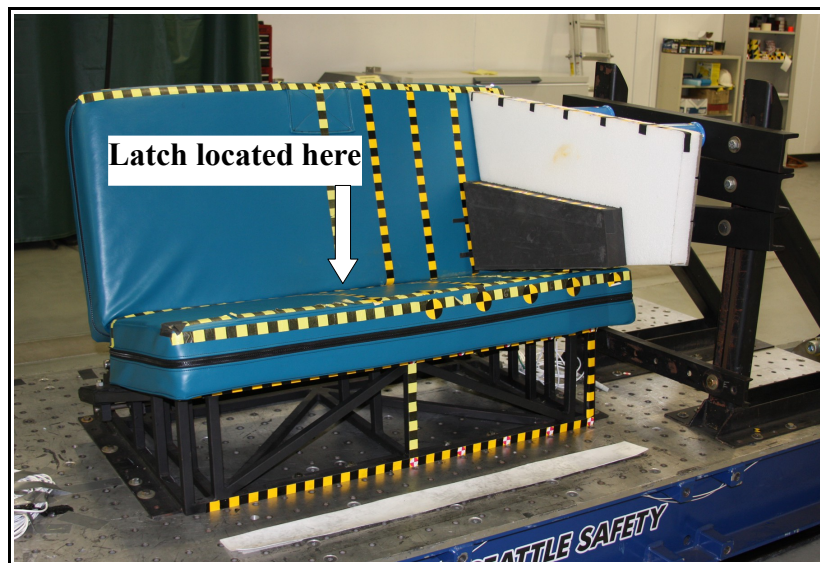


Photo 1b

Targets and inch tape were placed on the seat to locate the seat position as close as possible to the middle. Black and yellow inch tape was placed every six inches toward the left of the FMVSS 213 test fixture centerline. Targets were placed at six inch intervals on the bench's leading edge. Red and white inch tape was placed 24 inches from the test bench centerline. The tape and targets were used to quickly evaluate gross excursions and kinematics. The tape and targets on the seats can not be used for accurate measurements due to the flexing and moving of the seat cushion. A typical setup is depicted in photos 2 and 3.

In the 200, 300, and 400 test series a simulated wall was set up with three segments, upper door, mid door, and armrest (Photos 4 & 5). Tri-axial load cells were placed behind the simulated door. Average padding was used for the door and stiff padding for the armrest. The door padding was 51 mm (2 in.) thick and the armrest padding was 64 mm (2.5 in.) thick. The door padding used was Dow Ethafoam 220, a medium density closed cell foam with a density rated at  $35.2 \text{ kg/m}^3$  ( $2.2 \text{ lbs/ft}^3$ ). The armrest padding used was Armacell OleTex closed cell cross linked foam with a density of  $64.1 \text{ kg/m}^3$  ( $4.0 \text{ lbs/ft}^3$ ). The NHTSA (Sullivan, et al. 2011) used Ethafoam 220 for their testing during evaluation of side impact test procedures, the armrest foam NHTSA used could not be sourced locally so a similar density foam was substituted, Armacell Oletex. The NHTSA research concluded that “the stiffness of the door padding does not appear to have a pronounced effect on dummy injury measures or kinematics” (Sullivan, et al. 2011). For this reason the Armacell Oletex padding was determined to be acceptable.





Photo 2  
FMVSS 213 Test fixture set up for side impact testing  
View looking from the left front of the FMVSS 213 test fixture



Photo 3  
FMVSS 213 Test fixture set up for side impact testing  
View looking over the FMVSS 213 test fixture seatback

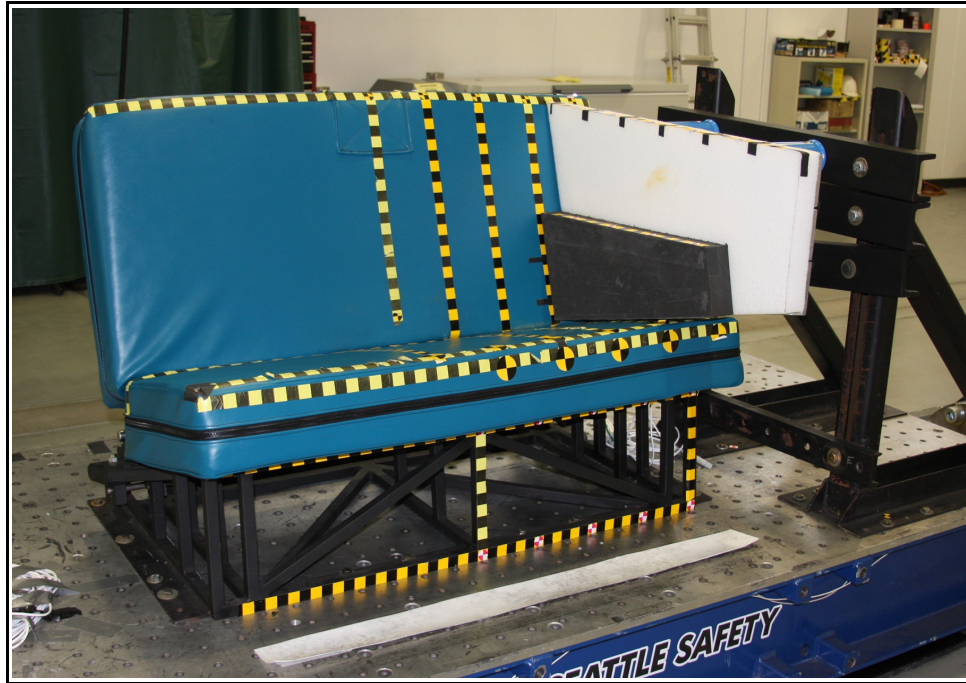


Photo 4

FMVSS 213 Test fixture set up for side impact testing with simulated door, simulated door foam is on left end of seat , shown with intrusion at 451 mm.



Photo 5

FMVSS 213 test fixture with simulated door segments.  
View is looking toward the left side of the test fixture.

The simulated door used by the NHTSA in their evaluation of side impact test procedures of CRDs was determined to be acceptable for measuring injury values when compared to full scale vehicle crash tests (Sullivan et al. 2011). Kraft type paper was placed over the foam to determine the location of impact on each test, and the paper was replaced as needed. Foam was replaced if it was damaged after a test.

The simulated door position was set up based on the four sample vehicles' intrusion in SINCAP tests (NHTSA 2011d, 2011e, 2010a, & 2010b). The compact and mid-sized sample vehicles had an average intrusion of about 230 mm (9 in.) at the H-point and mid door levels and about 150 mm (6 in.) at the window sill. Overall average intrusion was about 204 mm (8 in.). Additionally, Evans et al. (2009) reported AIS 2 injuries occur with over eight inches of intrusion.

The interior specifications for the sample vehicles ranged from 1323 mm (52.1 in.) to 1369 mm (53.9 in) as the specified shoulder room (Table 3). The vehicles averaged 1361 mm (53.6 in) of shoulder room. Hip room for the sample vehicles range from 1115 mm (43.9 in.) to 1339 mm (52.7 in.) with an average of 1259 mm (49.6 in) (Table 3) (InternetAutoguide, 2012). The distance to the center line at the shoulder is 680 mm (26.8 in) and at the hip 629 (24.8 in.). Using the overall average of 204 mm (8 in.) crush and the average hip room of 1259 mm (49.6 in) placed the simulated door at 450 mm (17.7 in) to the left of the centerline. Due to fixturing constraints, the actual simulated door arm rest was 451 mm (17.75 in) to the left of the FMVSS 213 test fixture centerline. .

<b>Sample Vehicle Interior Dimensions</b>				
	<b>Shoulder Room</b>		<b>Hip Room</b>	
	mm	in.	mm	in.
<b>2011 Honda Civic</b>	1323	52.10	1250	49.20
<b>2011 Toyota Corolla</b>	1389	54.70	1115	43.90
<b>2011 Chevy Cruze</b>	1369	53.90	1331	52.40
<b>2012 Ford Focus</b>	1364	53.70	1339	52.70
<b>Average</b>	1361	53.57	1259	49.55
<b>Centerline to Door</b>	680	26.78	629	24.78

Table 3  
Sample vehicle interior dimensions, shoulder and hip room

The NHTSA SINCAP crash tests videos show the maximum intrusion is completed by about 60 milliseconds (NHTSA 2011d, 2011e, 2010a, & 2010b). In all of the 100 series tests, the dummy head CG does not get to the 204 mm (8 in.) intrusion until after 60 milliseconds, and the right side of the head does not get to the intruded door until after 60 milliseconds (NHTSA, 2012). Since the intrusion is complete, or nearly complete by the time the ATD head reached the door, a fixed simulated door was used to determine injury potential.

The NHTSA did testing with a fixed and sliding simulated door (Sullivan & Loudon, 2009; & Sullivan, et al., 2011). This research project utilized a fixed door configuration. In the SINCAP tests the dynamic intrusion of the impacted vehicle structure appears to stop around 60 milliseconds. Sullivan and Loudon (2009) determined “the typical time frame from initial motion of the struck vehicle through peak loading on the near side occupant “ was up to about 60 milliseconds.

The ATD head CG in the 100 series tests on average traveled -375 mm (-14.76 in.) at 60 milliseconds. The head CG to the side outer skin is about 64 mm (2.55 in.), which places the side of the head -439 mm (-17.31 in.) from the centerline; and the CG to top of head is about 16 mm (2.63 in.) (NHTSA 2001). The head would be very near the static crush but would not get the same impact pulse an occupant would see placed at the near side impact which includes an intruding door structure. The child occupant from the center position will impact a static or nearly static interior door structure depending on the vehicle interior dimensions. Examining the dynamic intrusion may be an area of further investigation, this study is limited to the static crush measurements available. In the 100 test series the head CG Y excursion at 60 milliseconds ranged from -367 mm (-14.44 in) to -388 mm (-15.28 in.). The static door structure is a much simpler set up and repeatable test.

A 12 month old CRABI ATD (CRABI 12) was used for the testing. The CRABI 12 ATD weighs 10 kg (22 lbs), and stands 747mm (29 in.) tall (Humanetics, 2012).

Accelerometers were placed in the head in the X, Y and Z directions. 15 millisecond Head Injury Criteria (HIC 15) was calculated for each test, which is the maximum injury value over a 15 millisecond time period. Comparison was made between seats and test configurations and to the NHTSA proposed limit of 390.

A seatbelt load cell was placed on the latch belt far side. One CRD, number 5, required

two belts, therefore it had a load cell attached to each belt, near and far. Marking chalk of two different colors was painted on the right side of the ATD head to determine any impact locations, and head containment (Photo 6). The ATD was secured in the CRD per the manufacturers instructions and FMVSS 213 test procedures.

All analog data from the ATD and load cells was sampled at 20kHz according to Society of Automobile Engineers Standard J211.

Three high speed cameras, (Integrated Design Tools, M3, Tallahassee, FL) were placed offboard, one in front of the test FMVSS 213 fixture, and two overhead, one close up and one overall views. One camera was placed onboard behind the test fixture facing the front of the CRD. The onboard camera was to examine the dummy kinematics and quickly determine, head excursion, head impact and containment. The high speed video cameras recorded the tests at 1000 frames per second (fps).

VICON 3-dimensional (3-D) motion cameras (VICON, T40S, Vicon, CA), recording at 1000 fps were setup overhead around the sled fixture. Retro-reflective tracking markers were placed on the FMVSS 213 test fixture, ATD head, and the CRD. The tracking markers were taped into place on each side of the ATD, two on the head CG, two on top, and one on the face (Photo 6). One additional tracking marker was placed on the ATD face in the 200, 300, and 400 test series because some of the CRDs blocked the VICON cameras from tracking the markers. Tracking markers were placed on the back side of the



FMVSS 213 seat frame, and additional markers were placed on the FMVSS 213 seat cushion, but only used as backup markers if needed. Each CRD had four tracking markers placed on it. The VICON tracking markers were used to determine the maximum excursion of the ATD head. The ATD head, FMVSS 213 test fixture and CRDs were all digitized with a three dimensional measuring device, (Bronze Millennium FaroArm, FARO Technologies, Inc., Lake Mary, FL).



Photo 6  
CRABI 12 head with tracking markers, and marking chalk.

Each CRD was secured in the middle of the FMVSS 213 test bench, each attached through the LATCH anchors and belts following the CRD manufacturers instructions. Belt tension preload was targeted at 70 Newtons (N). Preload is tightening or tensioning of the belt that secures the CRD to the test fixture. The belts securing the CRD to the fixture were tightened at or above the recommended FMVSS 213 specification (65 N – 70 N), except for one test. The seat belt load cell data was recorded, written down, and

also recorded electronically, after the ATD belt was tightened in the bench seat and the ATD was positioned. Each CRD was checked to make sure there was less than one inch of side to side movement. If needed, a pool noodle was used under the CRD near the seat bight to position the CRD at the proper angle. The seat angle and location of measurement were recorded or a photo was taken of the angle indicator if the seat had one.

The tested CRD types included one combination seat, three convertible seats, and two infant type seats. The combination seat can be used as a rear facing infant seat, forward facing with the CRD five point belt restraints, and as a booster seat. The convertible can be used as a rear facing infant seat, or forward facing with the CRD five point belt restraints. Infant seats can only be used in the rear facing position. Two styles were tested, one for infants up to 10 kilograms and 73 cm height, and one larger for children up to 15.9 kilograms (35 lbs) and 81 cm (32 in.) height. The smaller infant seat used was at the maximum rating for the ATD size at ten kilograms (22 lbs) and 73 cm (29in). This infant seat was advertised as best selling and that it was side impact tested. Photos of each seat type can be found in the appendix and the test matrix can be found on page 32.



Test Matrix				
Test #	Seat Number	Seat Type	Side Impact Protection	New/Used
<b>35 km/h – Excursion without Simulated Door</b>				
100	7	Infant Carrier	Foam lining	Previous test
101	2	Convertible	Small wide wings	Used
102	2	Convertible	Small wide wings	Used
103	3	Combination	Small wide wings	New
104	4	Convertible	Large side wings/ energy absorbing	New
105	5	Convertible	Large side wings & energy absorbing cushion exterior to shell	New
106	6	Infant Carrier	Energy absorbing cushion	New
107	7	Infant Carrier	No foam lining	Used
108	3	Combination	Small wide wings	Previous test
<b>35 km/h Simulated Door</b>				
202	2	Convertible	Small wide wings	Used
203	3	Combination	Small wide wings	New
204	4	Convertible	Large side wings/ energy absorbing	New
205	5	Convertible	Large side wings & energy absorbing cushion exterior to shell	New
206	6	Infant Carrier	Energy absorbing cushion	New
207	7	Infant Carrier	Foam lining	New
<b>24 km/h Simulated Door</b>				
303	3	Combination	Small wide wings	New
304	4	Convertible	Large side wings/ energy absorbing	New
305	5	Convertible	Large side wings & energy absorbing cushion exterior to shell	New
306	6	Infant Carrier	Energy absorbing cushion	New
307	7	Infant Carrier	Foam lining	New
<b>29 km/h Simulated Door</b>				
403	3	Combination	Small wide wings	New
404	4	Convertible	Large side wings/ energy absorbing	New
405	5	Convertible	Large side wings & energy absorbing cushion exterior to shell	New
406	6	Infant Carrier	Energy absorbing cushion	New
407	7	Infant Carrier	Foam lining	New

In the first series three infant CRDs, one combination seat, and four convertible seats were tested. Two of the infant seats and two of the convertible seats were used seats. All used seats were inspected for any damage before testing. In the second series two infant seats, one combination seat and three convertible seats were tested. One of the convertible seats was used and all other seats were new in series two. For the third and fourth series two infant seats, one combination seat and two convertible seats were tested, and all seats were new.

The sled pulse was created from the average right side rocker panel sill Y accelerations of four commonly sold compact/mid-sized vehicles; 2011 Chevrolet Cruze, 2011 Honda Civic, 2011 Toyota Corolla, and 2012 Ford Focus tested in the NHTSA SINCAP program (NHTSA 2011d, 2011e, 2010a, & 2010b). The four vehicles had a very similar shaped crash pulse.

The average of the right side sill accelerations created a pulse with an average acceleration of 16.5 gs and a delta-V of 35.5 km/h (22 mph) (Figures 2 & 3). The peak acceleration was about 36 gs, and a pulse width of about 60 milliseconds. This pulse was used for the the first two series. This pulse was used due to it being close to the actual crash pulse generated in SINCAP tests, and it is similar to what the vehicle occupant will experience. Additionally, the vehicle pulse was chosen over a half sine pulse because the pulse shape influences the kinematics of the ATD.

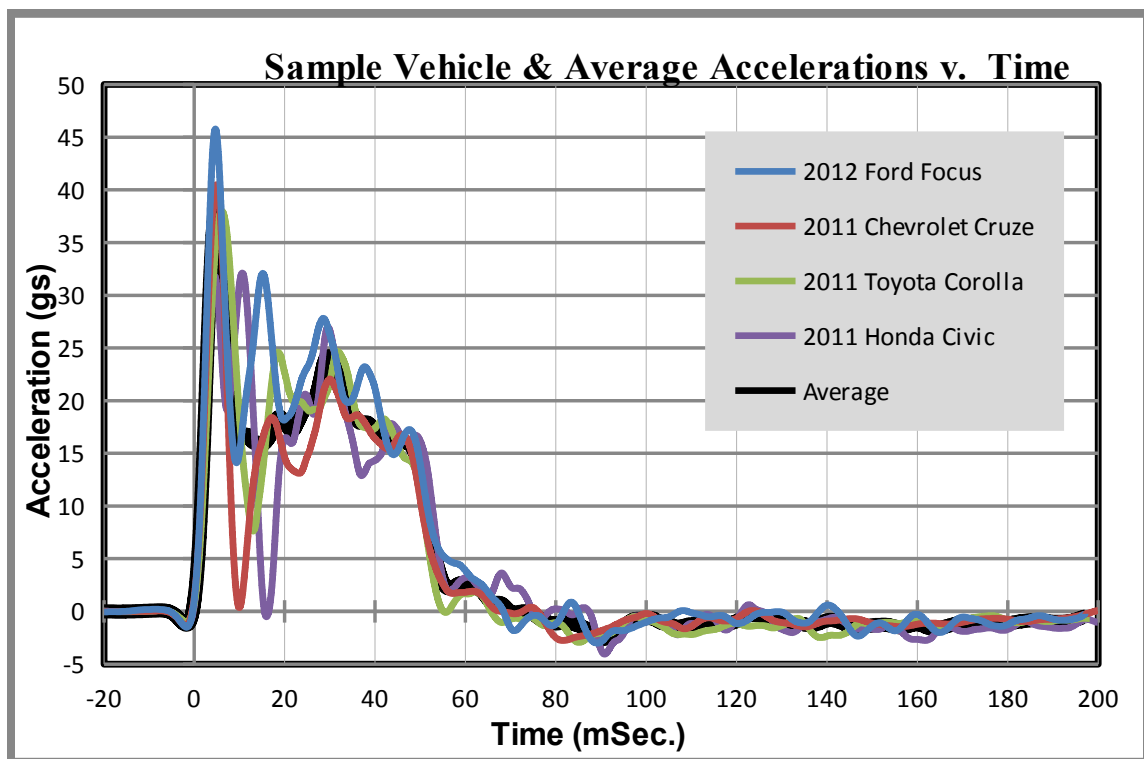


Figure 2

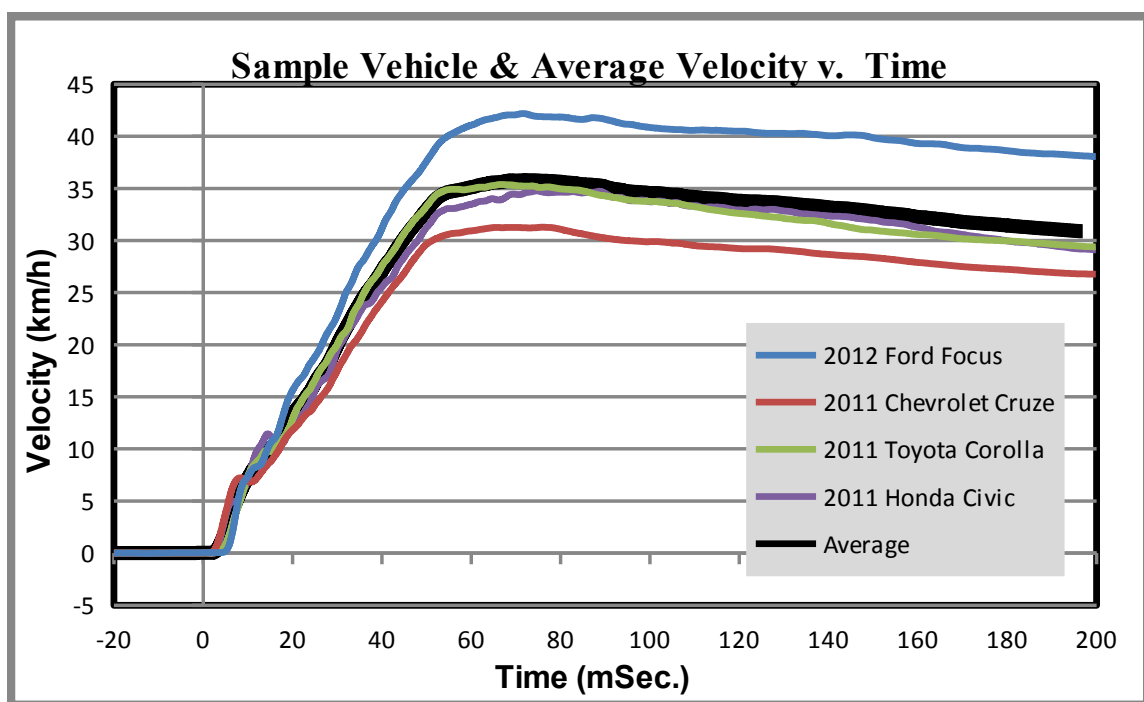


Figure 3

A scaled pulse was used for the third and fourth series. For the third series an average acceleration of 12 gs and a delta-v of 24 km/h (15 mph) was targeted, near the FMVSS 214 compliance speed of some older vehicles, and less energy than the SINCAP delta-V. The peak acceleration target was 25 gs and a pulse width of 60 milliseconds.

During the fourth series an average acceleration of 14 gs and a delta-v of 29 km/h (18 mph) was targeted, because this was between the SINCAP and series 300, and is one of the specifications used by the NHTSA in their evaluation (Sullivan & Loudon, 2009), and had been used by another researcher (Ghati et al., 2009) as a baseline of CRDs in far side lateral sled tests. Additionally 29 km/h (18 mph) was the average speed calculated in the literature review done for this study. The peak acceleration target was 30 gs and a pulse width of 60 milliseconds.

## RESULTS

### *Head Excursions*

The first part of the research program was to determine the maximum head excursion of the ATD in each CRD. The head center of gravity (CG) excursion was determined using the VICON 3-D motion tracking system. The ATD head had five motion tracking markers attached to the head, two on each side of the head at the cg, two on top, and one at the bridge of the nose. The VICON cameras captured the markers motion over 200 milliseconds (mSec.) or until the markers were blocked by the seat. The seats with extra wings blocked the markers when the seat rolled over or the ATD head got buried in the CRD padding. The coordinate system was set up so the ATD moved in a negative Y direction toward the PDOF and simulated door, as shown in figure 4.

The head center of gravity excursions ranged from -584 mm (-23 in.) to -705 mm (-27.77 in.) with just the belt attached to the latch anchors (Figure 4 and Table 5). Adding a tether to seat number 3, test 108, with the tether anchored to the floor, reduced the excursion to -528 mm (-20.77 in) for that seat system. The seat tested in 103 was retested in test 108 and the excursion was reduced by 40 mm (1.57 in.). Average head center of gravity (CG) excursion of all the seats was -614 mm (-24.17 in.). In many of the tests the markers were blocked near the point of maximum excursions.

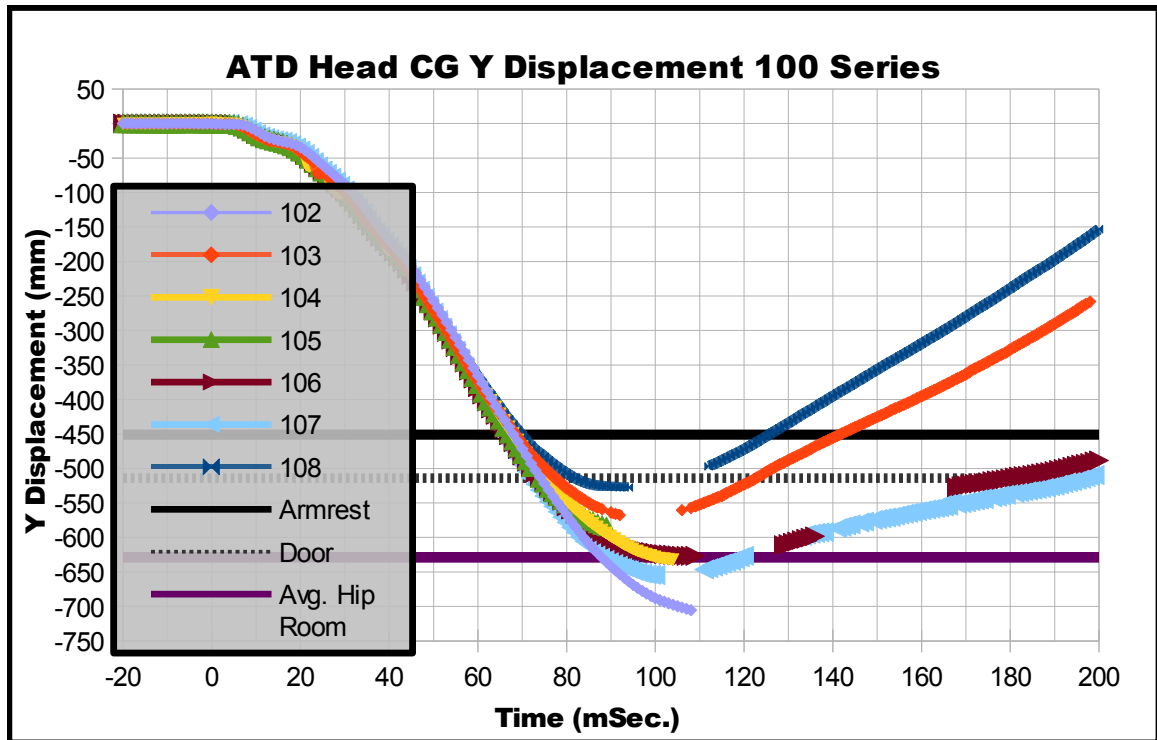


Figure 4

In the 100 series tests, the excursion distance values were spread out, differentiated by 176 mm (6.94 in.) of the maximum, -705 mm (-27.77), and minimum, -529 mm (-20.83 in). The head excursions in the 200 series tests, 35 km/h, were clustered within 25 mm (1 in.) of each other ranging from -424 mm (-16.69 in.) to -449mm (-17.68 in.). In the 300, 24 km/h, and 400, 29 km/h, series tests the excursions were clustered but not as close, within 96 mm (3.78 in.) and 82 mm (3.23 in) respectively. Seat 5 had the lowest excursion of all seats in the 200, 300, and 400 series tests, which is due to its design of large wings near the occupant and large energy absorbing devices on the outside of the seat.

In all the 100 series tests the ATD head CG passed through the plane where the intruding simulated door would be placed on the test fixture, related to the average crush of the sample vehicles tested in the SINCAP program. The ATD head in some of the tested CRDs would hit the interior without any crush of the door. Seats 2, 4, 6, and 7 could have impacted the vehicle door without any intrusion. The straight purple line at -629 mm on figure 4 represents the average hip room of the sample vehicles. The black straight line and dotted line on figure 4 represent the simulated door intrusion on the test fixture.

Two of the subject vehicles' hip room measured 625 mm (24.6 in.) and 558 mm (22 in.) from the centerline. The head CG in all but one test, the tethered seat (test 108), went beyond -558 mm (-22 in.) and only three of the seats were less than -625 mm (-24.6 in.). In the four sample vehicles used for the pulse calculation, the average interior hip room was 1258 mm (49.55 in.), at the hip, the centerline to door would be 629 mm (24.77 in.). Average shoulder room is 1361 mm (53.6 in.), at the shoulder the centerline to door would be 681 mm (26.8 in.).

<b>Test</b>	<b>Seat Type</b>	<b>Max head CG Y (mm)</b>	<b>Max Head CG Y (in)</b>	<b>Time (mSec)</b>	<b>Notes</b>
<b>100</b>	7	No Data	No Data		
<b>101</b>	2	No Data	No Data		
<b>102</b>	2	705	27.77	108	no data after 108 mSec
<b>103</b>	3	568	22.36	92	no data between 93 and 107 mSec.
<b>104</b>	4	633	24.92	104	no data after 104 mSec
<b>105</b>	5	584	23.00	89	no data after 89 mSec
<b>106</b>	6	627	24.68	108	no data between 110 and 128 mSec. & 137 and 167 mSec.
<b>107</b>	7	655	25.77	100	no data between 100 and 110 mSec. & 121 and 132 mSec.
<b>108</b>	3	529	20.83	92	no data between 95 and 111 mSec.
<b>Avg.</b>		614	24	99	
<b>Mean</b>		627	25	100	
<b>Std. Dev.</b>		54	2	7	

Table 5  
Series 100 ATD head CG maximum displacement from VICON tracking markers



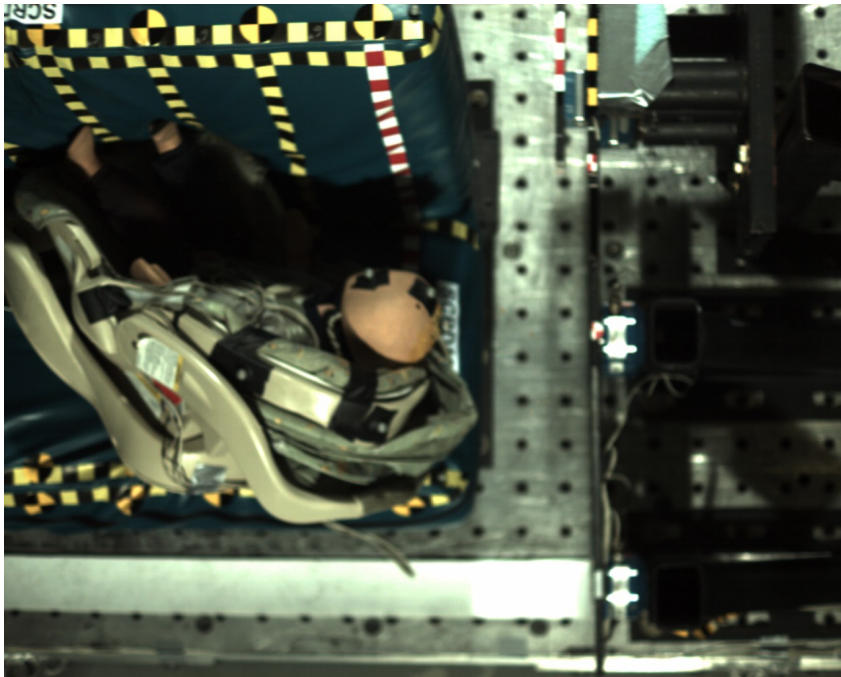


Photo 7 (from high speed video)  
Maximum head excursion, seat 7, test 100, 96 mSec. (est.)

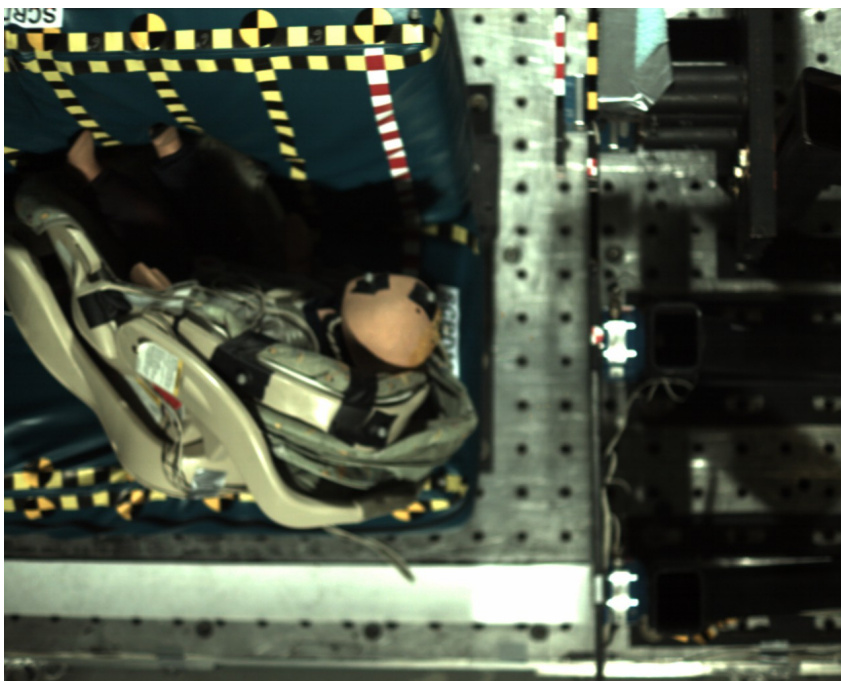


Photo 8 (from high speed video)  
Maximum head excursion, seat 7, test 107, 100mSec.

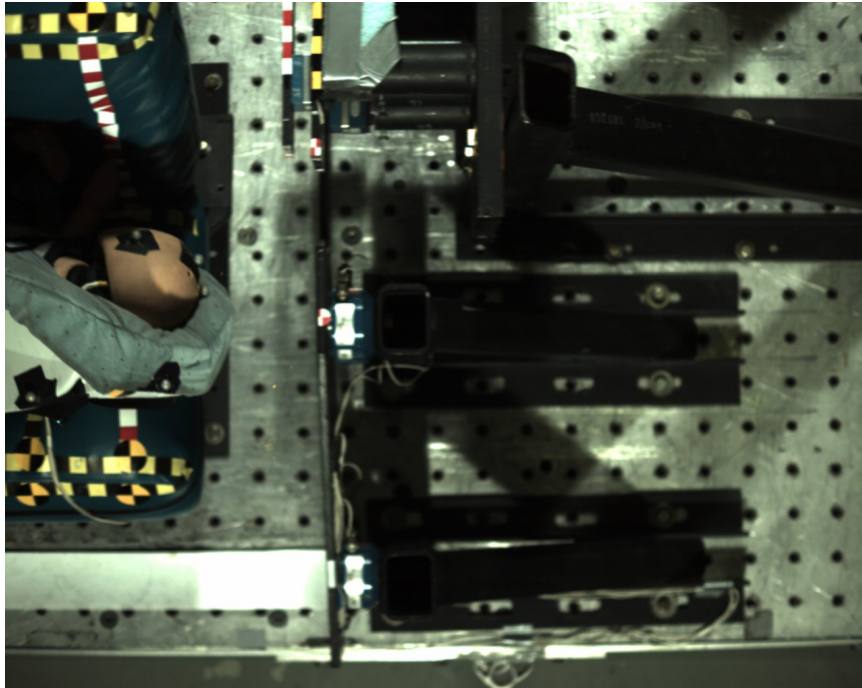


Photo 9 (from high speed video)  
Maximum head excursion, seat 2, test 101, 105 mSec. (est.)

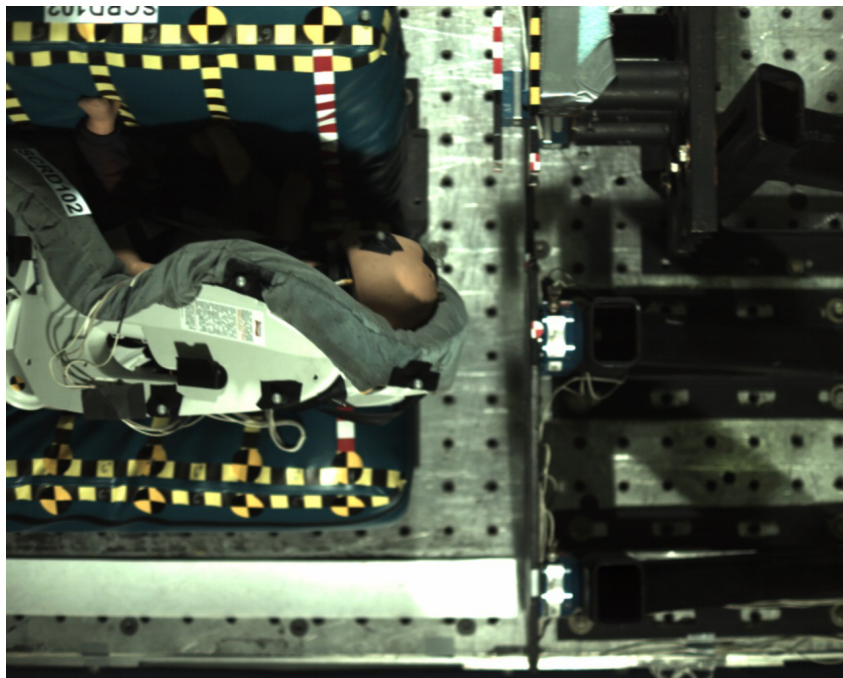


Photo 10 (from high speed video)  
Maximum head excursion, seat 2, test 102, 108 mSec.

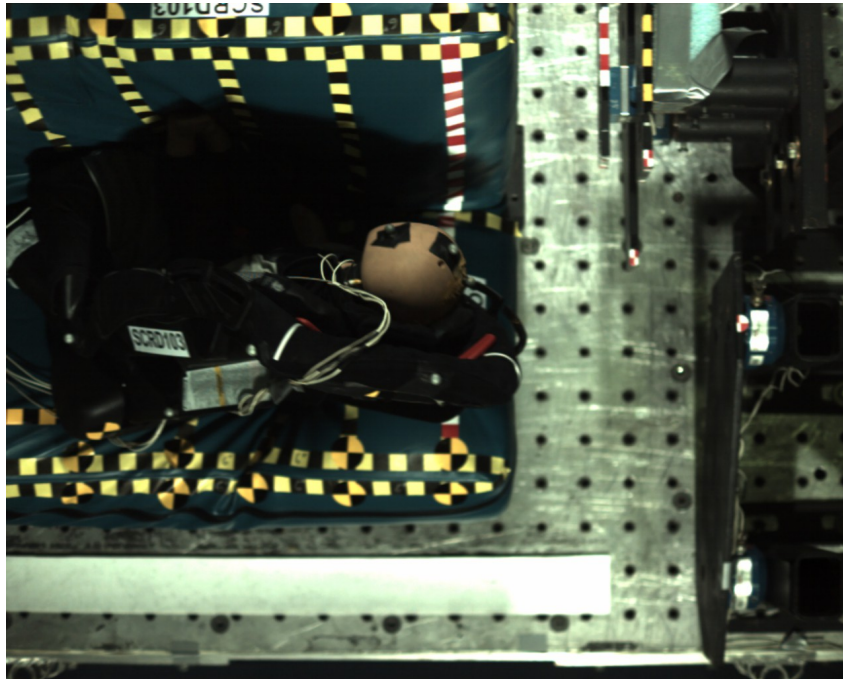


Photo 11 (from high speed video)  
Maximum head excursion, seat 3, test 103, 92 mSec.



Photo 12 (from high speed video)  
Maximum head excursion, seat 3, test 108, 92 mSec.



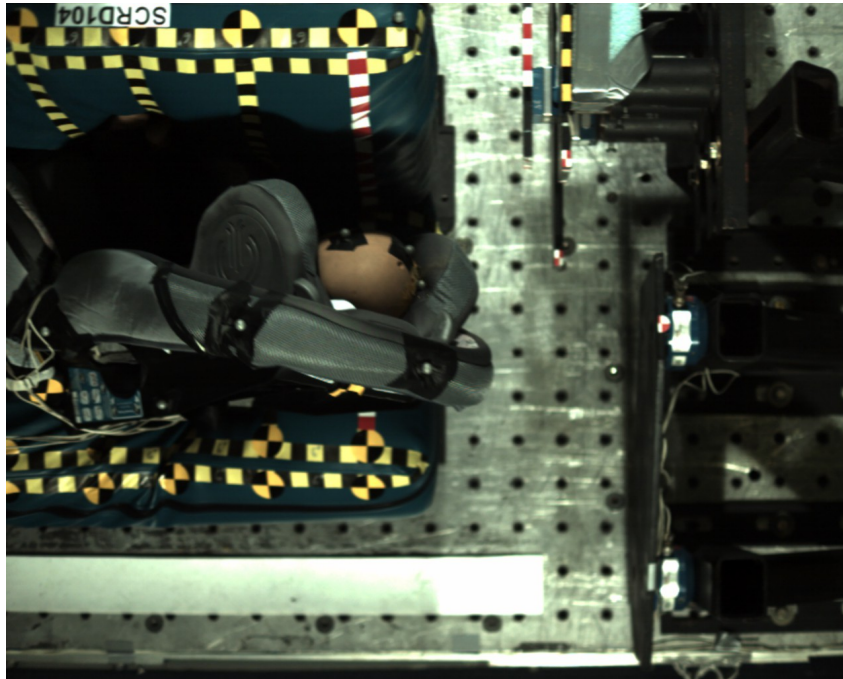


Photo 13 (from high speed video)  
Maximum head excursion, seat 4, test 104, 104 mSec.

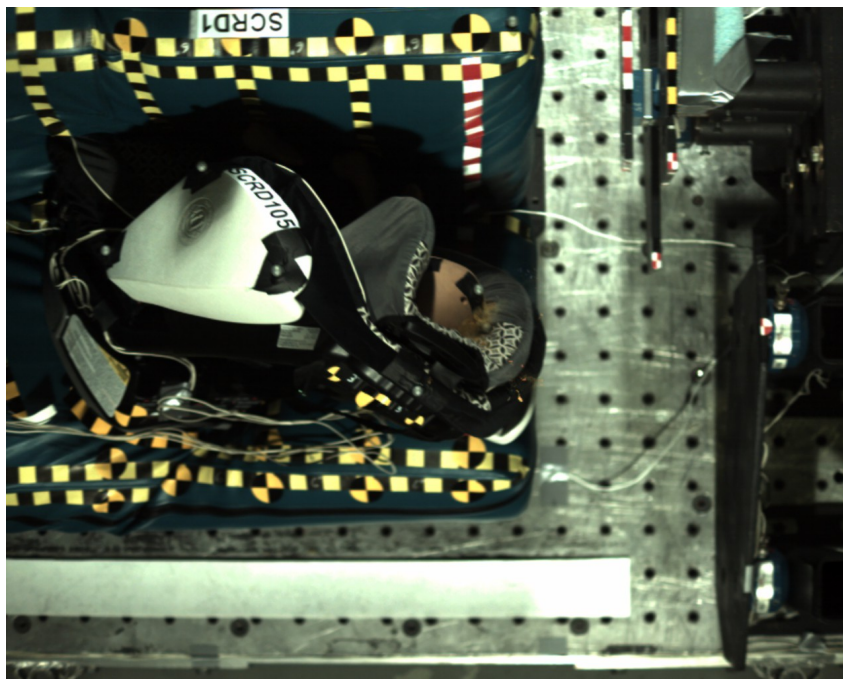


Photo 14 (from high speed video)  
Maximum head excursion, seat 5, test 105, 89 mSec.

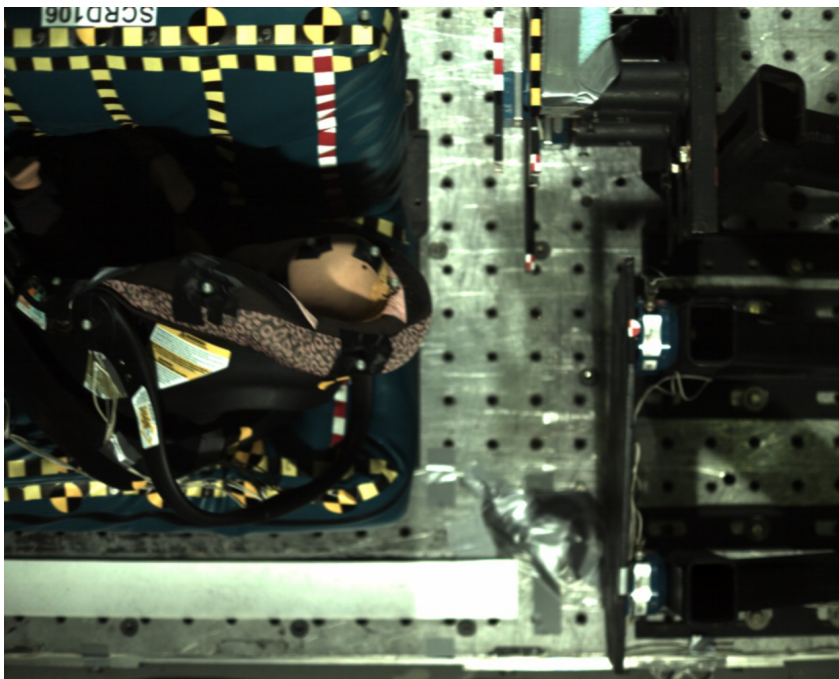


Photo 15 (from high speed video)  
Maximum head excursion, seat 6, test 106, 108 mSec.

### *Head Injury Criteria*

HIC 15 values in the first series of tests ranged from 56 to 157 (Table 6). The time of the HIC 15 values were all 15 milliseconds. Low HIC 15 values were expected because the ATD head did not impact any hard surfaces, but some did impact the CRD. The shoulder belt came off the ATDs far side shoulder during testing of seat number 3. Peak far side belt loads ranged from 2127 N (478 lb-f) to 3380 N (760 lb-f). Belt loads were all higher than in the 100 test series than the 200 series due to the CRD impacting the simulated door in the 200 series tests.

<b>HIC 15 Injury Values and Head Containment</b>						
<b>35 km/h – Excursion without Simulated Door</b>						
<b>Test #</b>	<b>Seat #</b>	<b>HIC 15</b>	<b>t<sub>1</sub></b>	<b>t<sub>2</sub></b>	<b>Total Time</b>	<b>Head Containment</b>
			mSec.	mSec.	mSec.	
100	7	97	88	104	15	N
101	2	73	61	76	15	N
102	2	56	93	108	15	N
103	3	116	90	105	15	N
104	4	90	94	109	15	Y
105	5	157	74	89	15	Y
106	6	87	66	81	15	Y
107	7	131	93	108	15	N
108	3	135	74	89	15	N

Table 6  
Series 100 HIC 15 values and head containment

Head containment of the ATD within the CRD was also examined and recorded for each CRD. In the 100 test series seats 4, 5, and 6 with large side wings contained the head well during the impact event. Seats 5 & 6 contained the head well during impact, but the head moves toward the bench seatback during rebound. Seats without the large side wings, seats 2, 3, and 7, all allowed the head to travel outside the CRD shell (Table 6).

In the second series of the research project, the CRD and ATD were impacted into a simulated door. At the 35 km/h (22 mph) the HIC15 injury values ranged from 806 to 1296 (Table 7). The HIC 15 calculation times ranged from 10 to 12 milliseconds. All the CRDs impacted the door and the ATD impacted the CRD, and in some tests the ATD head also impacted the simulated door. The head was contained by seats 4, 5, and 6, which had the large wings or additional padding. Seats 2, 3, and 7 allowed the dummy head to escape and impact the simulated door. Peak far side belt loads ranged from 1702 N (383 lb-f) to 2270 N (510 lb-f).

The third series of tests were done at 24 km/h (15 mph). The CRD and ATD were impacted into the simulated door. The HIC 15 injury values ranged from 141 to 314, all were 15 mSec (Table 7). The head was contained by seats 4, 5, and 6, while seats 3 and 7 allowed the head to move out of the seat. The peak far side belt loads ranged from 1026 N (231 lb-f) to 1605 N (361 lb-f).

In the fourth series, 29 km/h (18 mph), HIC 15 values ranged from 275 to 604 (Table 7).

The total times for the HIC 15 calculation ranged from 12 to 15 mSec. The head was contained by seats 4, 5, and 6, but not by seats 3 and 7. The peak far side belt loads ranged from 1524 N (343 lb-f) to 2076 N (467 lb-f).

<b>HIC 15 Injury Values and Head Containment</b>						
<b>Test #</b>	<b>Seat #</b>	<b>HIC 15</b>	<b>t<sub>1</sub></b>	<b>t<sub>2</sub></b>	<b>Total Time</b>	<b>Head Containment</b>
			mSec.	mSec.	mSec.	
<b>35 km/h Simulated Door</b>						
202	2	1175 *	70	81	11	N
203	3	804 *	68	79	11	N
204	4	1297 *	67	77	10	Y
205	5	998 *	65	77	12	Y
206	6	921 *	66	79	12	Y
207	7	1036 *	68	79	11	N
<b>24 km/h Simulated Door</b>						
303	3	141	86	101	15	N
304	4	261	83	98	15	Y
305	5	257	76	91	15	Y
306	6	314	80	95	15	Y
307	7	239	86	101	15	N
<b>29 km/h Simulated Door</b>						
403	3	275	75	90	15	N
404	4	445 *	74	89	15	Y
405	5	604 *	71	83	12	Y
406	6	562 *	73	87	15	Y
407	7	516 *	76	91	15	N

Table 7  
Series 200, 300, & 400 HIC 15 values and head containment  
\* indicates HIC 15 over 390 and potential for severe head injury



None of the seats had catastrophic failures. Catastrophic failures would include CRDs that broke away from the belt anchors, separated from the seat bases, or broke into several pieces. CRDs showed signs of impact. Impact indicators on the CRDs included cracked parts, broken parts, and stress marks on the plastic components. Plastic was transferred to the belts at the far side routing slots, and the belt left burnish marks on the plastic. In three tests the LATCH anchors were bent.

## Discussion

This study's purpose was to examine the potential injury to children in center mounted rear facing child restraint devices. In the first series, the research project examined the excursion and kinematics of the ATD head. In all tests the ATD's head CG passed through a plane representing 204 mm (8 in.) of intrusion, which was at -450 mm (-17.75 in) at the armrest and -514 mm (-20.25 in.) at the door interior from the FMVSS 213 seat fixture centerline. The excursion distances of all the seats' ATDs may subject the occupants to potential injury when the vehicle is impacted in the side during higher speed crashes, in compact and medium sized vehicles. Side impact testing done by Ghati et al. (2009) of RFCRDs found the head in some CRDs passed through a plane 610 mm (24 in.) from the starting location.

Occupants in vehicles smaller than compacts, such as subcompacts or “city vehicles”, are also at risk of serious head injury when involved in higher speed crashes as the interior dimensions are smaller than compacts. These smaller vehicles may not contain center seating position or allow for securing of a CRD in the center position, but may be affected in a far side seating position due to the decreased interior size.

Subjective analysis of the sled test videos show that the infant CRDs in the first series of tests appear to have similar kinematics to the ones placed in the 2007 NHTSA SINCAP crash tests (NHTSA, 2007a, 2007b, & 2007c). In both the full scale crash tests and the sled tests, the CRD yawed toward the PDOF and then rolled over, see photos 16 - 19. In

the 2007 SINCAP tests the CRD did not impact the intruding door because the CRD was positioned in the right rear, or far side. Additionally the ATD did not impact any parts of the vehicle. The same model seat was used in sled tests 100 and 107, except the seat in test 107 did not have foam padding. HIC 15 values in the NHTSA SINCAP tests ranged from 69 – 131, sled tests 100 and 107 produced a HIC 15 of 97 and 131 respectively (Table 8).

<b>Infant Carrier Seats HIC 15 Values</b>				
SINCAP TESTS	HIC 15	T1	T2	
2008 Nissan Altima	131	91	105	15
2008 Honda Accord	70	102	117	15
2008 Toyota Scion	69	79	94	15
Vehicle Average	90	91	106	15
SLED TESTS				
SCRD100 (used, foam padding)	97	88	104	15
SCRD107 (used, no foam padding)	131	93	108	15
Sled Average	114	90	106	15

Table 8  
Infant carrier HIC 15 values

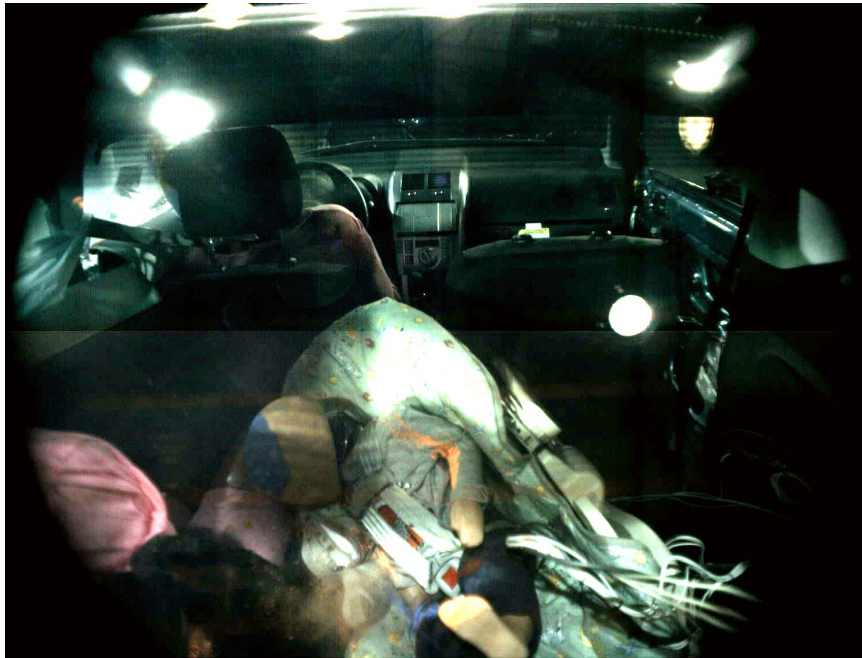


Photo 16 (NHTSA, 2007b, from high speed video)  
Infant carrier, 2008 Toyota Scion TC, NHTSA SINCAP test



Photo 17 (NHTSA, 2007a, from high speed video)  
Infant carrier, 2008 Nissan Altima NHTSA SINCAP test



Photo 18 (from high speed video)  
Infant carrier, seat 7, sled test 100



Photo 19 (from high speed video)  
Infant carrier, seat 7, sled test 107

Head containment was good in seats 4, 5, and 6 during the impact event, but seats 5 and 6 on rebound allow the ATD head to brush the FMVSS 213 bench seatback. Seats, 2, 3, and 7, allow the head to come out of the CRD shell during the impact event. The head coming out of the shell may allow the head to impact the structure of the vehicle. In the 200 series of tests, seats 2, 3, and 7 allowed the ATD head to strike the simulated door. Examination of the high speed video, the ATD in seats 2 and 7 appear to have a significant impact, while seat 3 it glances the simulated door.

Paine and Vertsonis (2001) wrote in their paper :

*"In a 1996 AAAM paper concerning the CAPFA study Henderson described the severe crashes in which restrained children survived with no serious injuries. The paper concluded: "There are few safety devices that are as effective as child restraints. We found in our study that the only injuries caused by deceleration alone were bruising and abrasion from loads imparted from harness and seat belt webbing. The head remains the most important part of the body to be protected. The principal threat to the restrained child is from invasion of the child's space through impact intrusion, collapsing seat backs, flying glass and loose objects. The child is also at risk if allowed to move out of its space and restraint design should place a high priority on the minimisation of excursion of the upper body in order to prevent head contact."*

In the 100 series tests seat 3 in tests 103 and 108, allowed the ATD shoulder to come out of the CRDs left shoulder belt. When the shoulder comes out of the CRD harness there is a potential that the head could also hit something within the occupant interior. Although

this happened, both had the lowest head excursion in the Y direction -529 mm (-20.83 in.) and -568 mm (-22.36 in.) respectively. Seat 3 in test 108 was tested with a tether. The numbers may be slightly higher as there was some data loss at about the peak excursion (see Figure 3, page 34). The figure shows the lateral direction of excursion for seat 3, tests 103 and 108, to be lower than the other seat styles in both tests.

Brown et al. (2007) wrote in their assessment of CRDs for the Australian restraint evaluation program relative to side impact performance:

*“Features affecting performance in side impact were:*

- *side wing height - higher side wings were better able to prevent contact between the dummy’s head and the door;*
- *well positioned sash guides – these appeared to have a role in preventing the dummy’s shoulder, and*
- *the use of a non-frangible material in their construction.”*

Klinich et al. (2005 )concluded that excursions could be reduced through different attachment methods. They found “securing RFCRS with any type of LATCH attachment results in lower peak lateral excursions than when used with any variation of conventional belts, and that the rigid LATCH attachments were more effective in rear-facing configuration than forward-facing configuration at reducing ATD head excursion.”

One problem found during testing was the CRD belt preload, it appeared to be very sensitive to any changes to the CRD position, which may be one reason to use rigid LATCH mounts. Some seats could not be adjusted to the recommended angle, and belt

preload, The belt preload was first established and adjusted as needed, getting the CRD as close as possible to the required angle. The belt preload was sensitive to any adjustments made to the CRD. Belt tension preload was measured after all positioning, measurements, and adjustments were completed.

On two tests there was a variance between the values written down and then later recorded electronically during the pretest belt tensioning. Pretest belt preload was written down during set up, and then a short time later electronically recorded, typically less than 5 minutes. On two tests it varied by 5 N, putting the electronic recording out of the desired specification on one test 202, 60 N v 65 N. This may have been due to the time of recording and the foam setting, or movement of the seat between measurement. It was found that during setup, even kneeling on the fixture cushion bottom that the belt preload can change. The CRD belt preloads were very sensitive to any changes to the CRD positioning. Future consideration should be made to the FMVSS 213 or other testing devices to reduce the chances for potential variability due to the test fixture seat cushions.

Since head injury was the most common injury to children in side impacts and limited instrumentation was available, the only data collected directly related to injury were HIC values. HIC values were low in the tests where the CRDs were evaluated for excursion. Once the CRDs were impacted into the simulated door, the HIC values show there was a high potential for head injury above 29 km/h (18 mph) in almost all CRDs comparing to the maximum HIC 15 value of 390 proposed by the NHTSA.



The low HIC 15 results in series 100 compared to series 200, indicate that if the child's head does not hit anything, the potential for head injury is reduced, even at higher speeds. There is a moderate inverse relationship ( $R^2 = .49$ ) of the head Y CG maximum excursion versus the HIC 15 value. This may be due to the increased ridedown time. As the head travels farther, the distance will help absorb any energy and lower the HIC 15 value. The problem with the longer excursion is the potential of the head to hit interior parts of the vehicle, especially when there is intrusion.

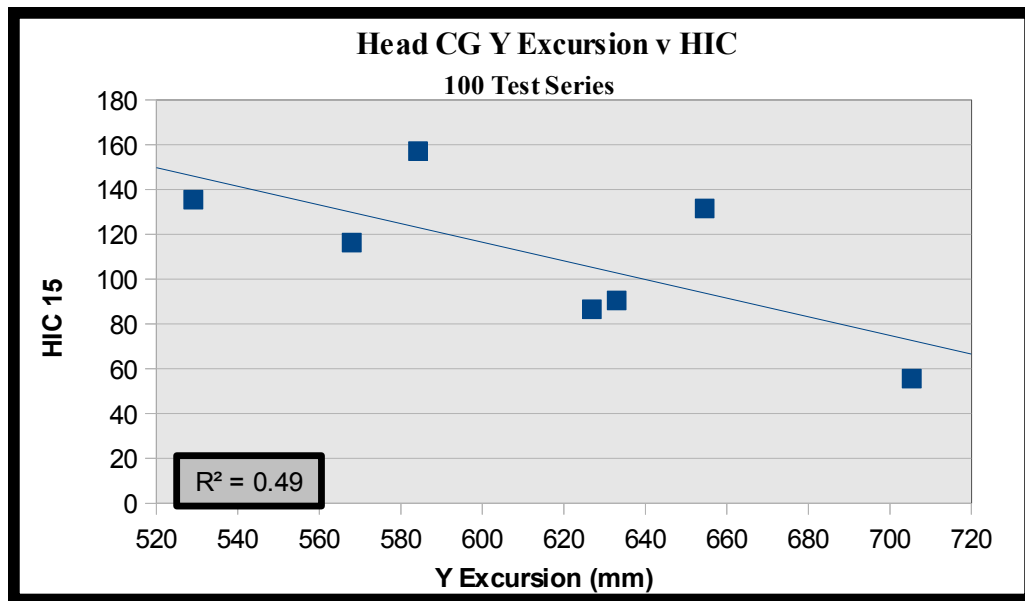


Figure 5

In the 200, 300, and 400 test series there is no relationship between the head Y CG maximum excursion and the HIC 15 value ( $R^2 = .03$ ). This would be due to the CRD hitting the simulated door and the head stopping against the CRD, or rolling out and hitting the simulated door.

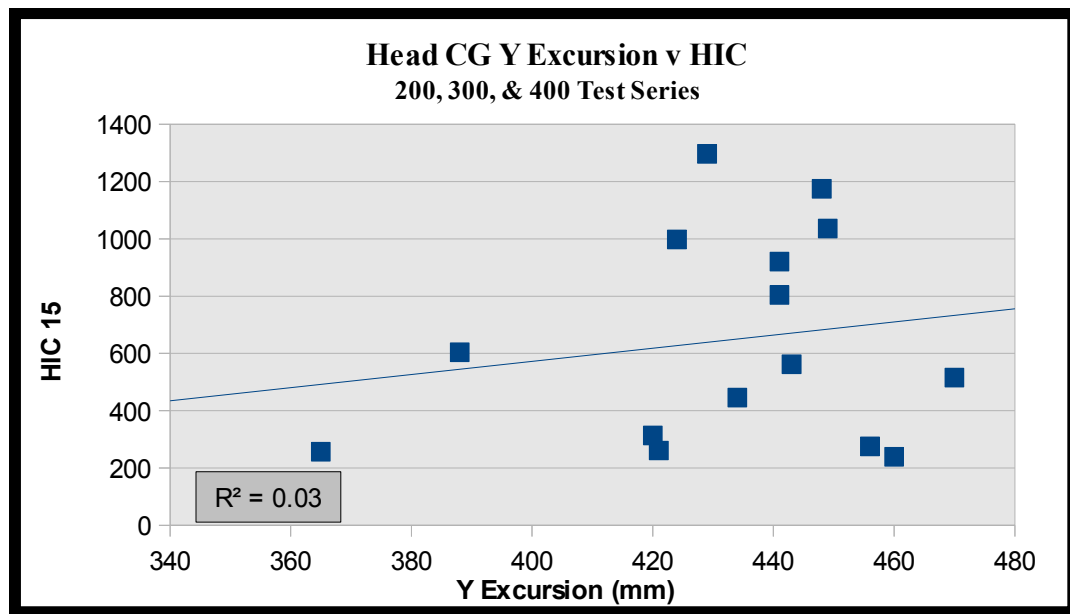


Figure 6

The HIC 15 results where the CRD and ATD impacted the simulated door, as the delta-V was increased, the HIC 15 values also increased. The increased HIC 15 values were the expected result as speeds were increased. In each series of tests there was no large differential in HIC values as to one seat performing better than another except one. The one exception was seat 3 in the 400 series tests with a HIC 15 of 275. Subjective analysis of the video indicates the ATD head is held far enough away from the simulated wall that

there is no major impact. All other seats in the 400 series had HIC 15 values between 516 and 604; higher than the NHTSA proposed maximum of 390. In all tests where the seats impacted the door, seat 3 had the lowest HIC value. Seat 3 only has small side wings that do not contain the head well but appear to move the head in a direction to minimize impact.

The unexpected result was the seats with the additional side impact protection or that had large side wings did not perform better relative to HIC calculations than the seats without additional side impact protection or large side wings. In the test series where the simulated wall was impacted, the HIC 15 value was the largest for one of the seats with large side wings or an additional side impact energy absorbing device. Sullivan and Loudon (2009) found the HIC values tended to be higher in heads that were contained to “more pronounced lateral component to the dummy's head motion (more direct lateral contact with CRS side wing)”. The same trend was observed in most of the tests, except in cases where the head escaped the CRD and it had a large direct impact with the simulated wall. If the ATD head had direct impact into the simulated wall the Y acceleration component, (lateral component) tended to be high. Seats 2, and 7 had direct lateral impact, and seat 3 had a glancing blow in the 200 series tests.

Seat 3 had the lowest HIC 15 in all test series using the simulated door. This seat appears to keep the head from hitting the door or hitting the door directly. The head translates sideways for approximately the first 70 milliseconds, and then rolls out and down the

seat. Although the seat could not be mounted level with the indicator mark on the seat, the kinematics of this seat appears to limit the impact of the head against the simulated door in the test fixture.

Seat 7 impacted the simulated door in all the tests using the door, but did not have the highest HIC value in any of the test series. This suggests that the padding material in a vehicle may be beneficial if located properly. The area where the head hit was on the Ethofoam 220, which is an average density foam the NHTSA used in their evaluations for a side impact test procedure development (Sullivan et al., 2011). The head of the child in a RFCRD typically is more forward and lower in a vehicle than an adult occupant head, which is typically at or above the window sill and closer to the rear part of the door or vehicle C-pillar.

Arbogast et al. (2000) writes,

*“The most ideal countermeasure for side impacts would reduce the energy transferred to the occupant upon impact. ... Increased padding may be another alternative, however there is conflicting evidence of its benefit for reducing thoracic injuries. [Lau 1991] Research has shown that increased padding decreases head injury measures such as peak head acceleration and HIC. [Barbat 1995] More padding where children most likely have head impact may reduce the incidence of these injuries. Further understanding of how children sit with respect to the door structure and subsequent education to encourage safer positioning is necessary.”*

More investigation is needed to examine the effects of padding and HIC. In our test series

there was not much variability of HIC between seat designs. There was variability in containing the head within the CRD, which may be more important and easier to design relative to redesigning a car door to absorb for CRD occupant impacts. Klinich et al. (2005) writes,

*“Unlike injuries and fatalities caused by door intrusion, preventing injuries from far-side impact conditions is almost exclusively an issue of restraint system design. Key elements for obtaining good CRS performance in side impact are keeping the CRS and ATD within the occupant space, retaining the ATD’s head within the CRS, and padding any CRS surface that the ATD is likely to contact.”*

Improvements to CRD design can include reduction of excursion through attachment methods or changes in padding. When the CRD or ATD did not impact the simulated door the HIC values were low, so prevention of impact, by CRD mounting or containing the head, may be more important than additional padding. In this project there did not appear to be a significant difference of HIC injury values for the CRDs with the large side wings or other side impact energy absorbing devices. Sullivan et al. (2011) noted in their research, “HIC 15 outcomes did not show an obvious trend with design of the wings and/or padding of the CRS models.” This may be due to the large swing, roll, and yaw of the rear facing occupant since the head is far from the point of seat attachment. The NHTSA noted in their study (Sullivan et al., 2011) that some seats of same seat designs performed better in a forward facing position. Further investigation is needed to determine this effect.

Although there is no injury criteria for testing with a CRABI 12 in side impact, the NHTSA has proposed a HIC15 value equal to 390 to minimize skull fracture and brain injury (Eppinger et al., 1999). Other researchers have used the CRABI 12 in side impact studies and/or used calculated HIC values for comparison purposes (Sullivan et al., 2009; Sullivan et al., 2011; and Morgan, 2003;). The CRABI 12 and HIC 15 can be used as tools for comparison. More investigation is needed to determine if there is an effect on the HIC for rear facing ATDs tested in side impact.

### *Limitations and Recommendations*

Limitations in this study included the CRABI 12 ATD, limited CRD samples, one test angle used, and only head injury values were examined. Only smaller and medium sized vehicles were considered for the excursions and potential injury due to interior impact.

The CRABI 12 ATD that was secured for testing did not have a neck load cell, and due to availability and financial constraints the neck load cell was not utilized. Use of the neck load cell would have produced some usable insight relative to head excursion, accelerations and neck load injury potential compared to excursions and seat design effect. Future testing could include the neck load cell to determine potential injury. Chest accelerations were not collected because the main focus of this project was examining head injury. In review of the literature, head injury was the most common.

The CRABI 12 ATD was designed for airbag testing and is not calibrated for side impact use. The CRABI 12 ATD was available for testing and other researchers have used it for side impact testing. Future testing may include newer updated side impact child ATDs that are more biomechanical in side impact conditions such as the Q-series child dummies that are used more in Europe.

Due to budget and time considerations, the number of child restraint device designs tested was limited. Although there were some used seats available it was difficult to get four of

the same type of seat. Due to the speed tests were being conducted reruns of seats already tested were only done if an tested seat was not available. Seat 4 was damaged in two of the tests impacting the simulated door, and seat 3 was damaged in 100, 200, and 400 series tests. One style infant seat and one convertible seat were found used. The used infant model CRD, seat 7, tested was able to be purchased new, but the convertible seat 2 was not available new and no used seats were found, so it was not tested in the 300 and 400 series tests.

The simulated door was based on a study done by the NHTSA in their evaluation for a CRD side impact test procedure. Door padding was able to be sourced, but the armrest padding was not from the same manufacturer. The same density foam was used for the armrest. The simulated door that was built also was slightly longer. It was built longer toward the front of the buck to make sure the seat engaged the door. It was built for use as an impactor for both the center and near positions. Load cell data was collected, but due to the size of the door panels there was some vibrations that cause data to be questionable. Future testing with this setup will include a more stable attachment method. The simulated door with load cells was a prototype built for future testing of this kind.

The angle in this test series was done at 90 degrees to the impact direction relative to the seat placement. Other research by the NHTSA, conducted testing with the seat fixture at angles from 90 – 110 degrees relative to the PDOF and got different injury values, depending on the seat and injury criteria, such as HIC 15, neck forces, etc. (Sullivan, et



al., 2011) Future testing could be done to look at the effect of angle on a center mounted CRD.

Testing was done as time allowed on the servo sled. There was limited time to gather data and make significant changes to the set up configuration. More time on the accelerator sled would allow for collecting more data samples of other seats, angles, or a sliding seat.

Future research should include full scale crash testing to compare to the sled testing results. Full scale crash test work was done by the NHTSA in their evaluation of a side impact test procedure, but that work was limited to near side impacts (Sullivan, et al., 2009). The NHTSA testing also examined the padding in vehicles, but just calculated an average to build their simulated door. Future research and more investigation could examine the effect of vehicle interior padding on rear facing CRDs.

Another future consideration would be to examine the effect of attachment mode. This research only attached the seat through the LATCH system. Some research has been done related to different attachment methods such as rigid LATCH, flexible LATCH (which was used in this research), use of vehicle lap belt, and tether use. (Klinich et al, 2005, Ghati, et al., 2009, and Brown, et al., 1997). More time and seat samples would have allowed the testing of the effect of tethers or rigid LATCH mounts. Future research could concentrate on excursions and injury values with the use of tethers and attachment methods.

## Conclusions

All future child restraint side impact regulations should include an excursion requirement. In the 100 test series, all the ATD head CGs excursion went past the average door intrusion line of smaller/mid sized sample vehicles, 451mm (17.75 in.) from the vehicle centerline. It was also shown if the ATD did not impact any vehicle interior surface, HIC 15 values were low and the potential for injury is reduced.

Side impact testing injury criteria of CRDs need to include both an excursion requirement, head containment requirement, and injury value. The excursion requirement needs to be a separate evaluation to assess center and far side placement of CRDs. The injury evaluation should include impact with a standardized simulated door. The containment needs to be evaluated in both types of scenarios, as the head may come out of the CRD on a rebound and hit the seat back or other parts of the vehicle interior.

A child occupant in a center mounted CRD may be subject to head injury when involved in a higher speed side impact such as the SINCAP crash tests where a crash test is simulating a vehicle moving at 27.4 km/h (17 mph) being struck by another at 54.7 km/h (34 mph), while traveling in compact, and medium sized vehicles, or smaller vehicles that have intrusion near or over 204 mm (8 in.).

The RFCRDs do not appear to offer a difference in protection from seat to seat as was

shown relative to the HIC 15 values. Some of the seats tested by the NHTSA appear to perform better in the forward facing mode, which may be an indicator that kinematics are an important factor in reducing injury potential or the seat design is designed to protect in a forward facing position in side impact, but not in rear facing. Another possibility is that the rear facing seat produces an angular acceleration effect due to the head being a distance from the seat attachment location and swings through the event like a ball on the end of a string. Further research is needed in this area.

One seat tested in the research showed a reduction of excursion with the use of a tether. To reduce excursions, tethers should be designed for use in all seat configurations including rear facing.

Using 390 as the maximum HIC value, the threshold for protection is below 29 km/h (18 mph) for reducing the possibility of severe head injury; and any future standardized testing should include protection above 29 km/h (18 mph) and up to 35 km/h (22 mph) because those are the delta-Vs in the occupant compartment observed in the NHTSA compliance and SINCAP test programs. Only one seat in the 400 series (29 km/h; 18 mph) had a HIC value below 390.

Increased ridedown time or preventing any type of impact is the best way to keep HIC values low and reduce the potential for head and skull injuries. Increased ridedown time may increase the excursion which can increase the risk of impacting the vehicle interior

components. There needs to be a balance of ridedown time, maximum excursion, and kinematics to protect rear facing child occupants.

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## **Appendix**

### **List of Abbreviations**

**AIS** – Abbreviated Injury Score

**ATD** – Anthropomorphic Test Device

**CIREN** – Crash Injury Research and Engineering Network

**CG** – Center of Gravity

**CRABI** – Child Restraint Air Bag Interaction

**CRD** – Child Restraint Device

**CRS** – Child Restraint System

**FARS** – Fatality Analysis Reporting System

**FFCRD** – Forward Facing Child Restraint Device

**FMVSS** – Federal Motor Vehicle Safety System

**HIC** – Head Injury Criteria

**LATCH** - Lower Anchors and Tethers for Children

**NASS-CDS** – National Automotive Sampling System – Crashworthiness Data System

**NHTSA** – National Highway Traffic Safety Administration

**PDOF** – Principal Direction of Force

**RFCRD** – Rear-facing Child Restraint Device

**RFCRS** – Rear-facing Child Restraint System

**SINCAP** – Side Impact New Car Assessment Program

**US DOE** – United States Department of Energy

## CRD TYPES



### Seat 2

Type: Convertible.

Use: Rear facing for infant and then forward facing when occupant fits

Weight: 2.3 – 18 kg (5 – 40 lbs)

- rear facing - 2.3 - 15 kg (5 - 33 lbs)
- forward facing using 5 point harness - up to 18 kg. (40 lbs)

Height: less than 1020 mm (40 in)

Side impact protection: Small side wings

Problems: Had to use pool noodle to get proper angle close when securing to test fixture

Test seats were all used

Tests: 101, 102, 202



### Seat 3

Type: Combination

Use: First used as rear facing for infant, turned forward when occupant fits requirements, then can be used as a belt positioning booster.

Weight use: 2.3 – 36.3 kg (5 – 80 lbs)

- rear facing - 2.3 - 16 kg (5 -35 lbs)
- forward facing using 5 point harness - 10.1 -22.6 kg (22 -50 lbs)
- belt positioning booster - 18.1 – 36.3 kg (40 – 80 lbs)

Height use: 480 – 1321 mm (19 – 52 in.)

- rear facing – 480 – 910mm (19 – 36 in.)
- forward facing using 5 point harness – 851 – 1143 mm (34 – 45 in.)
- belt positioning booster – 1101 – 1321 mm (43 -52 in.)

Side impact protection: Small side wings, foam padding

Problems: Not able to get seat positioned level when securing. When the tether was secured to the floor the seat was close to level on the indicator. Pool noodle would not work with this seat.

Test seats were new

Tests: 103, 108, 203, 303, 403





#### **Seat 4**

Type: Convertible

Use: Rear facing for infant and then forward facing when occupant fit requirements.

Weight: 2.3 – 31.8 kg (5 – 65 lbs)

- rear facing - 2.3 - 18 kg (5 - 40 lbs)
- forward facing using 5 point harness - up to 29 kg. 65 lbs)

Height: 1321mm (52in.) or less

- rear facing – 480 – 1016 mm (19 – 40 in)
- forward facing using 5 point harness – 850 – 1321 mm (34 -52 in.) and over 1 year old

Side impact protection: Large side wings

Test seats were new. Seats in test 304 and 404 had different base than 104 and 204.

Tests: 104, 204, 304, 404



### Seat 5

Type: Convertible

Use: Rear facing for infant and then forward facing when occupant fit requirements.

Weight: 2.3 – 31.8 kg (5 – 70 lbs)

- rear facing - 2.3 - 18 kg (5 - 40 lbs)
- forward facing using 5 point harness - 9.1 – 31.8 kg (20 - 70 lbs)

Height: 1245mm (49 in.) or less

- rear facing – until top of head is 254mm below (1 in.) top of seat shell
- forward facing using 5 point harness – 1245 mm (49 in.) or less and when ears are below top of shell and harness straps are at or above child's shoulders, parallel to level ground.

Side impact protection: Large side wings and energy absorbing device outside of shell

Test seats were new.

Tests: 105, 205, 305, 405

**Seat 6**

Type: Infant

Use: Rear facing for infant only

Weight: 1.8 – 15.9 kg (4 – 35 lbs)

Height: up to 812 mm (32 in.)

Side impact protection: “Air cushion” within shell. Advertised as “revolutionary side impact technology”

Test seats were new.

Tests: 106, 206, 306, 406





### Seat 7

Type: Infant

Use: Rear facing for infant only

Weight: 2.3 – 10 kg (5 – 22 lbs)

Height: up to 730 mm (29 in.)

Side impact protection: Foam around shell. New seats advertised as “best selling” , “side impact tested”, and “energy absorbing foam liner”.

Test seats were new and used. Test 107, used seat did not have foam liner.

Tests 100 (used), 107 (used), 207 (new), 307 (new), 407 (new)

## **Foam Specifications**



Density 2.2 pcf (35.2 kg/m<sup>3</sup>)  
 Maximum Loading 2.5 psi (17.5 kPa)  
 Color Black, Natural



**ETHAFOAM™**  
 packaging products

## ETHAFOAM™ 220 Polyethylene Foam

ETHAFOAM™ 220 polyethylene foam is a strong, resilient, medium-density 2.2 pcf (35.2 kg/m<sup>3</sup>), closed-cell foam. It is ideally suited as a component material in products requiring a shock absorbing, vibration dampening, insulating and/or buoyancy component, and as a material for cushioning components in packaging applications for loadings up to 2.5 psi (17.5 kPa).

ETHAFOAM 220 has outstanding recovery characteristics that provide optimal cushioning protection against repeated impacts. It is ideal for cushion packaging and is used in many applications, including computer, automotive, construction and recreation. To achieve optimum performance, Dow recommends that qualified packaging engineers design the total packaging solution.

### Sizes Available in Black (Planks):

2" x 48" x 108"  
 4" x 48" x 108"

### Sizes Available in Natural (Planks):

1.5" x 48" x 108"  
 2" x 48" x 108"  
 2.5" x 48" x 108"  
 3" x 48" x 108"  
 4" x 24" x 108"  
 4" x 48" x 108"

### Product Features

ETHAFOAM™ 220 polyethylene foam is a durable, lightweight, flexible, solid extruded product. As the properties listed on the reverse suggest, ETHAFOAM 220 offers excellent strength, resistance to creep under load, vibration and shock absorbency, and water resistance characteristics.

ETHAFOAM 220 is produced with Dow's patented *RapidRelease* manufacturing process. *RapidRelease* technology delivers a higher quality product with improved dimensional stability and safety. This process technology incorporates a patented CFC- and HCFC-free blowing agent system and an accelerated curing system that reduces residual blowing agents in ETHAFOAM products to trace amounts.

ETHAFOAM 220 meets the requirements of the U.S. Clean Air Act Amendments. It is easily fabricated, impervious to most chemicals, non-abrasive and performs consistently over a wide range of temperatures.

ETHAFOAM 220 is also reusable and completely recyclable because it is made of non-crosslinked polyethylene.

### Flammability

ETHAFOAM™ 220 polyethylene foam has successfully passed FMVSS 302 flammability testing, conducted according to the U.S. Code of Federal Regulations, CFR 49.

**ETHAFOAM™**  
 Product Information

Physical Properties of ETHAFOAM™ 220 Polyethylene Foam			
Physical Properties*	Test Method	Direction	Value
Density	ASTM D3575, Suffix W; Method B; ISO 845		pcf (kg/m <sup>3</sup> ) 2.2 (35.2)
Compression Set	ASTM D3575, Suffix B (50% compr.); EN/ISO 1856 (23°C, 25% compr.)	Vertical	< 20% < 10%
Compressive Creep (1000 hrs @ 73°F [23°C])	ASTM D3575, Suffix BB	Vertical	< 10% @ 2.5 psi (17.5 kPa)
Compressive Deflection @ 10% @ 25% @ 50%	ASTM D3575, Suffix D	Average	psi (kPa) 7 (50) 9 (65) 18 (124)
Thermal Stability	ASTM D3575, Suffix S; ISO 2796		< 1.5% < 2%
Thermal Conductivity @ 75°F (24°C) @ 23°F (-5°C)	ASTM D3575, Suffix V; EN 28301; ISO 2581	Vertical	BTU•in/hr•ft <sup>2</sup> •F (W/m <sup>2</sup> •K) 0.42 (0.06) 0.37 (0.05)
Water Absorption	ASTM D3575, Suffix L; ISO 2896; ASTM C272		lb/ft <sup>3</sup> (kg/m <sup>3</sup> ) 0.3 (1.5) < 3% by volume
Buoyancy	ASTM D3575, Suffix AA		pcf (kg/m <sup>3</sup> ) 58 (930)
Tensile Strength @ peak	ASTM D3575, Suffix T; ISO 1798	Average	psi (kPa) 32 (220)
Tensile Elongation	ASTM D3575, Suffix T; ISO 1798	Average	50%
Tear Strength	ASTM D3575, Suffix G	Average	lb/in (N/mm) 10 (1.75)

\*The data presented for this product are for unfilled ETHAFOAM polyethylene foam products. While values shown are typical of the product, they should not be construed as specification limits.

*For information on products, design assistance  
and testing services available from Dow, contact us at:  
1-866-PKG-FOAMS (754-3626) or [www.ethafoam.com](http://www.ethafoam.com)*

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WARNING: ETHAFOAM polyethylene foam products are combustible and may constitute a fire hazard if improperly used or installed. During transportation, storage, installation and use, these products should not be exposed to open flame or other ignition sources.

ETHAFOAM PACKAGING PRODUCTS  
THE DOW CHEMICAL COMPANY  
P.O. Box 1206 • Midland, MI 48641-1206 • USA  
[www.ethafoam.com](http://www.ethafoam.com)



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ETHAFOAM  
Product Information



**SUBMITTAL SHEET** (effective 06/13/07)  
B-Series Product Line



**BKJN400** Typical OleTex Foam Properties

Standard Test	ASTM D-3575	BKJN400
Density, lb/cu ft	Suffix W	4.0
Tensile Strength, PSI	Suffix T	118
Elongation, %	Suffix T	290
Tear Resistance	Suffix G	20.0
Compression Strength, psi	Suffix D	
10% Deflection		17.0
25% Deflection		20.0
40% Deflection		25.0
50% Deflection		31.0
Compression Set, %	Suffix B	9.5
Thermal Stability, % Change (24 hours @ 158° F)	Suffix S	< 2

Properties are averages of machine and cross direction

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Armacell LLC • 16800 South Canal Street • South Holland, IL 60473  
email: [info.us@armacell.com](mailto:info.us@armacell.com) • [www.armacell.com](http://www.armacell.com)

South Holland, IL • 800-343-1255 • fax: 708-596-9270

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