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Development of NHTSA's Side Impact Test Procedure for Child Restraint Systems Using a Deceleration Sled

Final Report
Part 1

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16. Abstract

This report presents the results of the research and development of the child seat side impact tests performed at Kettering University's Crash Safety Center for NHTSA. The tests were conducted using a deceleration sled. The objective of this testing was to obtain data for the development of a side impact test procedure for child restraint systems.

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1.0 Technical Plan

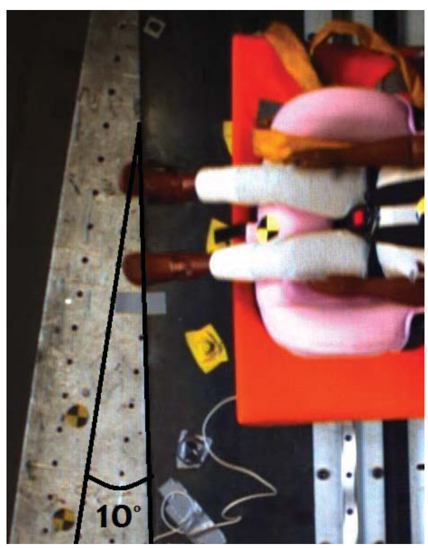
Per contract DTNH22-11-R-00204, the Kettering University Crash Safety Center (KCS) was tasked to complete the following objectives:

1. Construct a side impact test fixture;
2. Conduct sled tests to evaluate the feasibility of a child restraint systems (CRS) side impact test protocol on a deceleration sled;
3. Conduct 18 deceleration sled tests to collect data on the performance of child restraint systems (CRS) using two different anthropomorphic test devices (ATDs);
4. Analyze, transfer, and report test data; and
5. Update drawings and bill-of-materials of the test fixture.

2.0 Sled Buck Construction

The sled fixture was fabricated based on the fixture housed at the NHTSA Vehicle Research and Test Center (VRTC) in East Liberty, Ohio. Engineering drawings were received from the VRTC in PDF format on June 27, 2011. Minor adjustments were made to drawings to incorporate the 19 mm (0.75 in) increased door face height and the holes to locate the fixture at the 10-degree angle on the KCS sled. The completed fixture is shown in Figure 1. The depiction of the 10-degree angle is shown in Figure 2.

Figure 1: Front and side view of the side impact fixture attached to the deceleration sled



Door Impact End

Figure 2: Depiction of the 10-degree secondary sled rotation angle with respect to the longitudinal axis of the primary sled (not to scale)

The side impact fixture consists of two distinct parts: the primary carriage and the secondary carriage. The primary carriage is fixed to the bedplate of the deceleration sled and consists of the fixture base plate, door fixture (with foams), and aluminum honeycomb. The secondary carriage is free to move on a set of linear bearings affixed to the primary carriage base plate. The secondary carriage consists of the generic vehicle seat (with foam and cover), the CRS being tested, and the test ATD. A ratchet gear and pawl are attached to the secondary carriage and interact with a rack affixed to the primary sled. The gear rack is designed to allow the secondary carriage to slide toward the door fixture and to impede the rebound motion.

The specifications for the fixture include:

- Door foam backing: Ethafoam 220, 51 mm (2.0 in) thickness (Figure 3).
- “Armrest” door foam: 4-pound gray foam from United Foam (UF), 64 mm (2.5 in) thickness (Figure 3).
- Door foam and armrest foam was attached using duct tape for baseline testing. For the 18 CRS performance test series, the foams were attached using 3M two-sided foam mounting tape. New foam was used for each CRS performance test.
- Aluminum Honeycomb PAMG-XR1 5052 from Plascore: Test size of 305 mm (depth) by 343 mm by 127 mm (12” x 13.5” x 5”) was used per the HYGE testing performed by NHTSA VRTC.
- ECE R-44 bench foam, supplied by NHTSA, modified to fit the seat back and bottom of the side impact fixture bench.
- ECE R-44 cloth bench foam covering, supplied by NHTSA, formed to fit the bench foam.
- Gear Rack: KHK Gears, Rack SR Series SR3 1480MM LG, Assembly ratchet gear and pawl SRTB3-40.
- Fixture set at a 10-degree fixed angle CCW from longitudinal.
- Camera mounts were not incorporated into the test fixture. Cameras were mounted off-board.

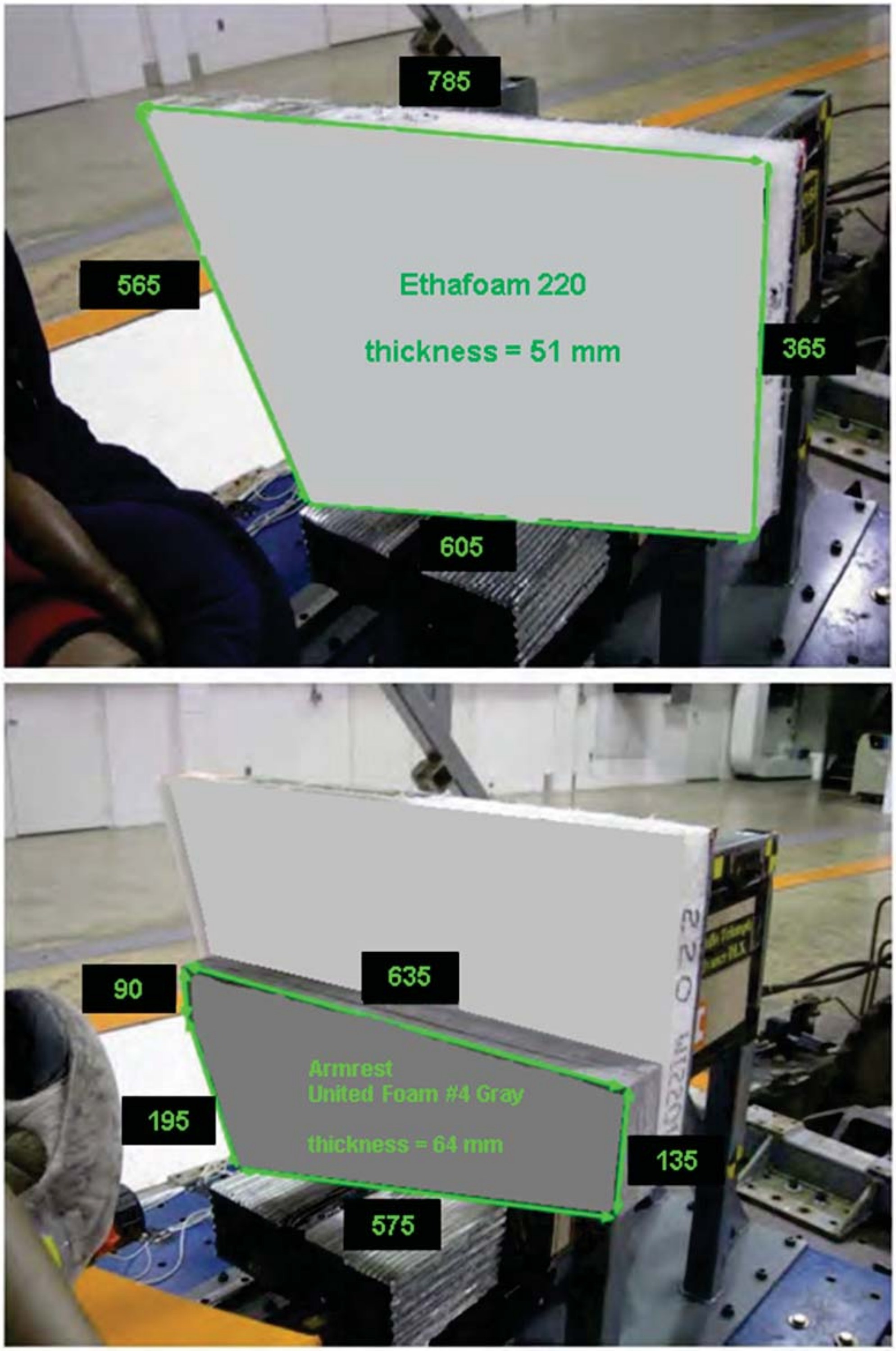


Figure 3: Door foam dimensions (in mm)

3.0 Overview of Deceleration Sled Test

For the 18 CRS performance tests, the secondary carriage was staged 800 mm from the honeycomb face. The honeycomb face was targeted to be 36 mm from the impact plane of the armrest foam (Figure 4). The centerline of the CRS, whether forward-facing or rear-facing, was set at 300 mm from the left side bench edge.

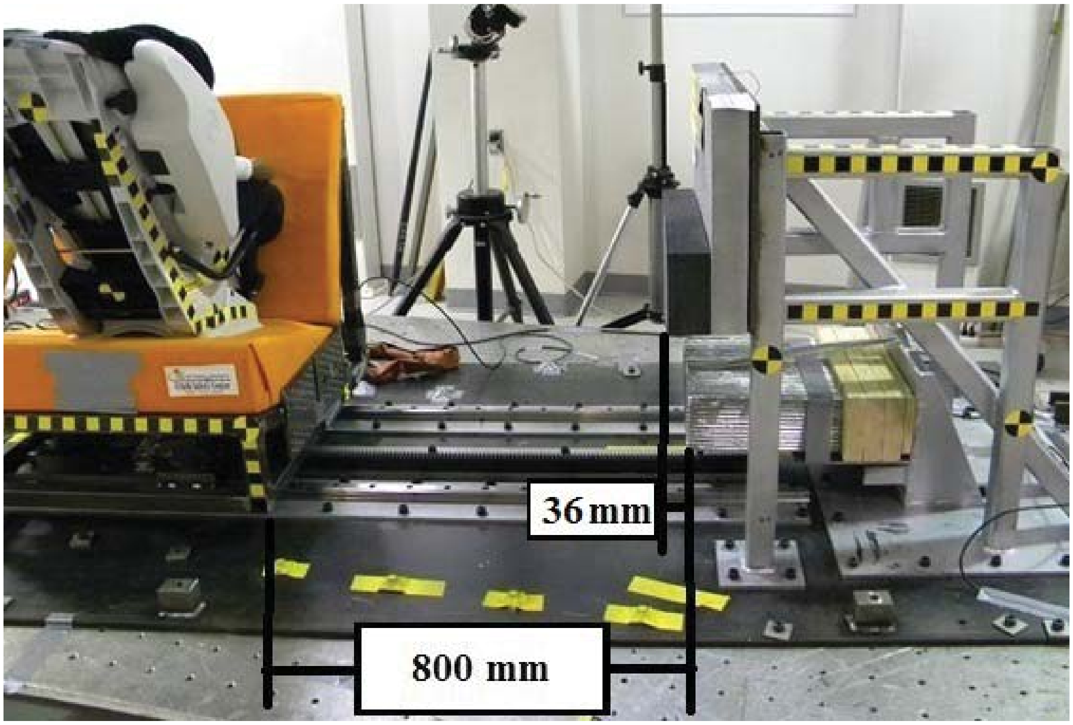


Figure 4: Alignment of the fixture attributes at time zero

In general, when using the fixture on the deceleration sled, both the primary and secondary carriages start from rest. The complete fixture is propelled to the impact end of the sled, attaining a speed of nearly 22 miles per hour. At impact with the decelerator, the primary carriage is brought to rest in 125 milliseconds. During this time, the secondary carriage is free to continue to move on the linear bearings with an initial speed of ~21 mph. Due to friction along the linear rails, the secondary carriage (CRS/vehicle seat) impacts the primary carriage (door/honeycomb) at a reduced speed of ~ 20 mph.

4.0 Baseline Testing

Multiple baseline tests were conducted to evaluate the performance of the primary and secondary carriages during the side impact event. The original, prescribed critical parameters and tolerances (Table 1) were followed and/or evaluated. The sled, fixture, and ATD were instrumented within the test series per Table 2. Not all acceleration channels were evaluated in each baseline test.

Baseline tests were conducted with and without an HIII 3YO ATD in a Cosco Scenera forward-facing CRS. When the ATD was not used, ballast weights were affixed to the seat. The Cosco Scenera CRS was used for multiple impacts during the baseline test series.

Table 1: Original critical parameters and tolerances

The sled speed will be 20 mph (32 kph) ± 0.5 mph (0.8 kph)
The fixture angle will be 10 degrees with an angle tolerance of ± 1 degree
Sled pulse will be a half sine with a peak acceleration (deceleration) of 28 g
A seat-to-honeycomb spacing of 260 to 265 mm*
The sled data channels properly record data during the testing. These channels include the accelerometers located on the front and rear edge of the sliding seat and the accelerometer on the sled interface that is measured for acceleration and velocity (X, Y, and Z directions)
The sled buck and door acceleration/velocity profiles (without the CRS installed) must match baseline kinematics to the VRTC results. When evaluating the time histories, the timing and peak g's must be within ± 3 g

*Due to the nature of the deceleration sled, this parameter was redefined (Section 4.1)

Table 2: Instrumentation used within the baseline test series

Position of Measurement	**Type of measurement**	**Number of channels**
ATD head	Linear acceleration	3
ATD chest	Linear acceleration	3
ATD pelvis	Linear acceleration	3
Sled carriage (primary sled) (longitudinal)	Linear acceleration	1
Bench seat base (secondary sled) (along 10º)	Linear acceleration	1
Bench seat back (secondary sled) (along 10º)	Linear acceleration	1
Sled carriage (longitudinal)	Tri-axial acceleration	3

4.1 Primary and Secondary Sled Pulses

The VRTC confirmed that in the HYGE testing, the primary sled was not accelerating at the point at which the door strikes the secondary sled. Therefore, for the deceleration sled, it was necessary to bring both the primary and secondary sleds to speed and decelerate the primary sled such that the secondary sled impacts the door (fixed on the primary sled) when the primary sled has reached zero velocity. Because the secondary sled must strike the primary sled once it has come to rest, the pulse shape and peak acceleration (g) for the primary sled no longer needed to be defined per the critical parameters. To allow the primary sled to come to rest before the secondary sled impact, the seat-to-honeycomb spacing was set at 800 mm. It was determined that the original 260 to 265 mm critical parameter distance may be adjusted for alternate sled types and setups.

The final acceleration pulses for the primary and secondary sleds filtered with channel frequency class (CFC) 60 are shown in Figure 5. The complete sled and fixture attained an impact velocity of 20.5 mph. The primary sled reached a zero velocity at 120 msec (Figure 6). Subsequently, the secondary sled impacted the door at 136 msec.

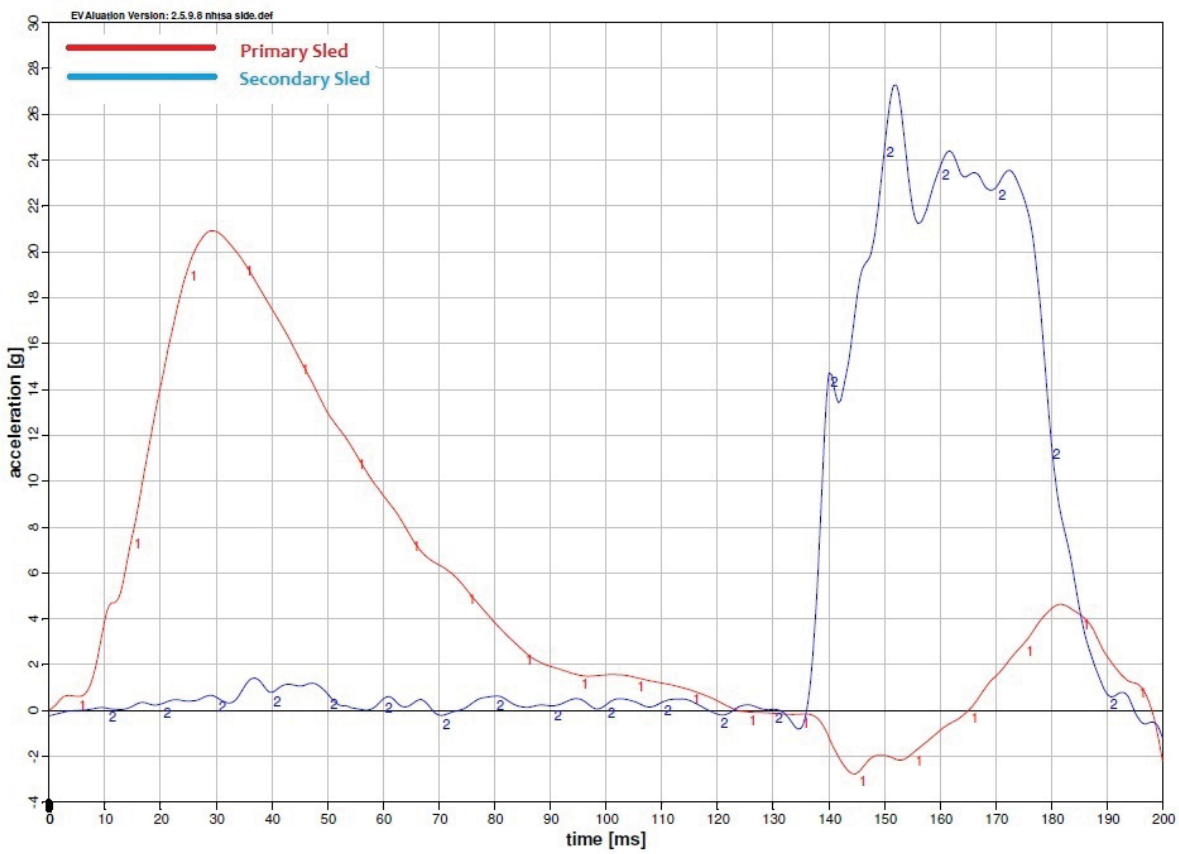


Figure 5: Primary and secondary sled accelerations during the complete side impact event (CFC 60)

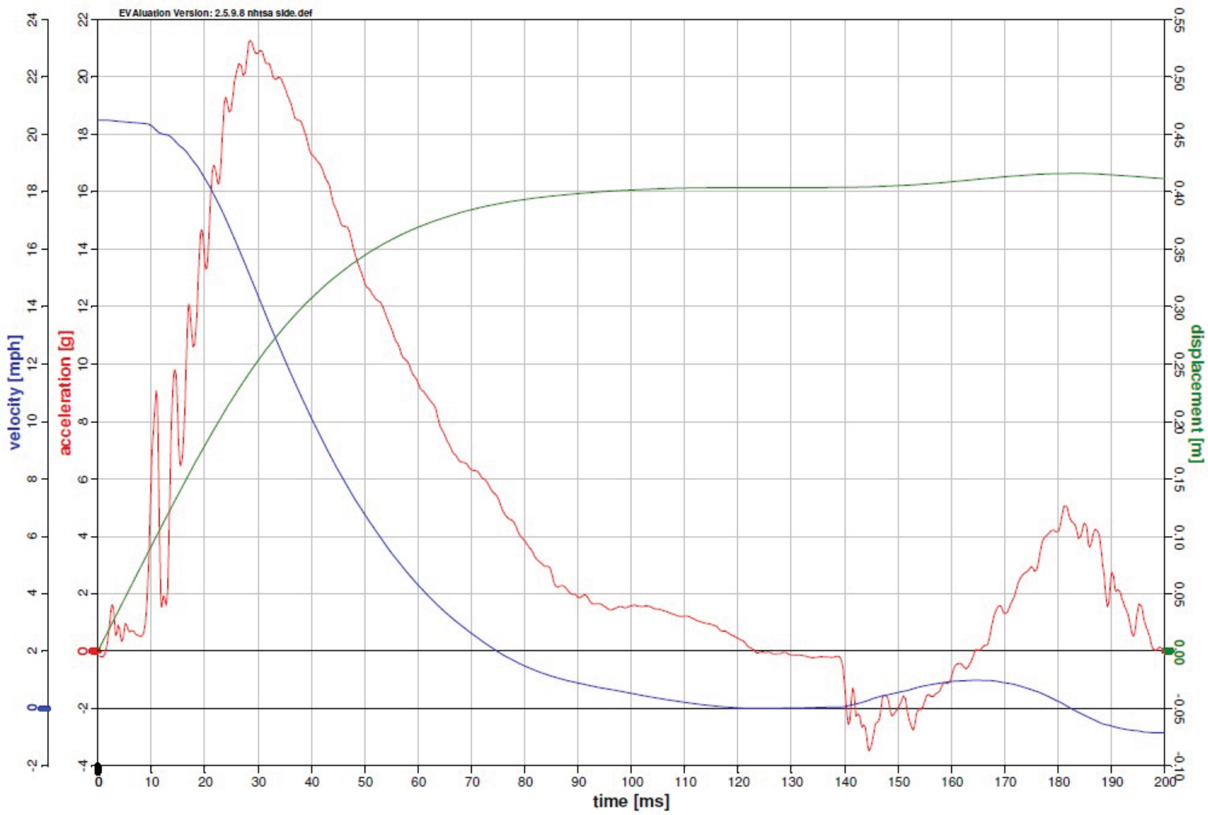


Figure 6: Acceleration, velocity, and displacement of the primary sled (CFC 180)

At time zero, the complete sled and fixture struck the decelerator at 20.5 mph and the secondary sled began to travel along the 800 mm of the linear bearings with this initial speed. Once the primary sled came to rest (120 msec), the secondary sled impacted the door fixture, affixed to the primary sled (136 msec) (Figure 7). Due to friction, the secondary sled slowed to 19.5 mph (Appendix A) when it impacted the door (Figure 8). Note that the motion of the primary sled after 136 msec is due to the impact of the secondary sled.

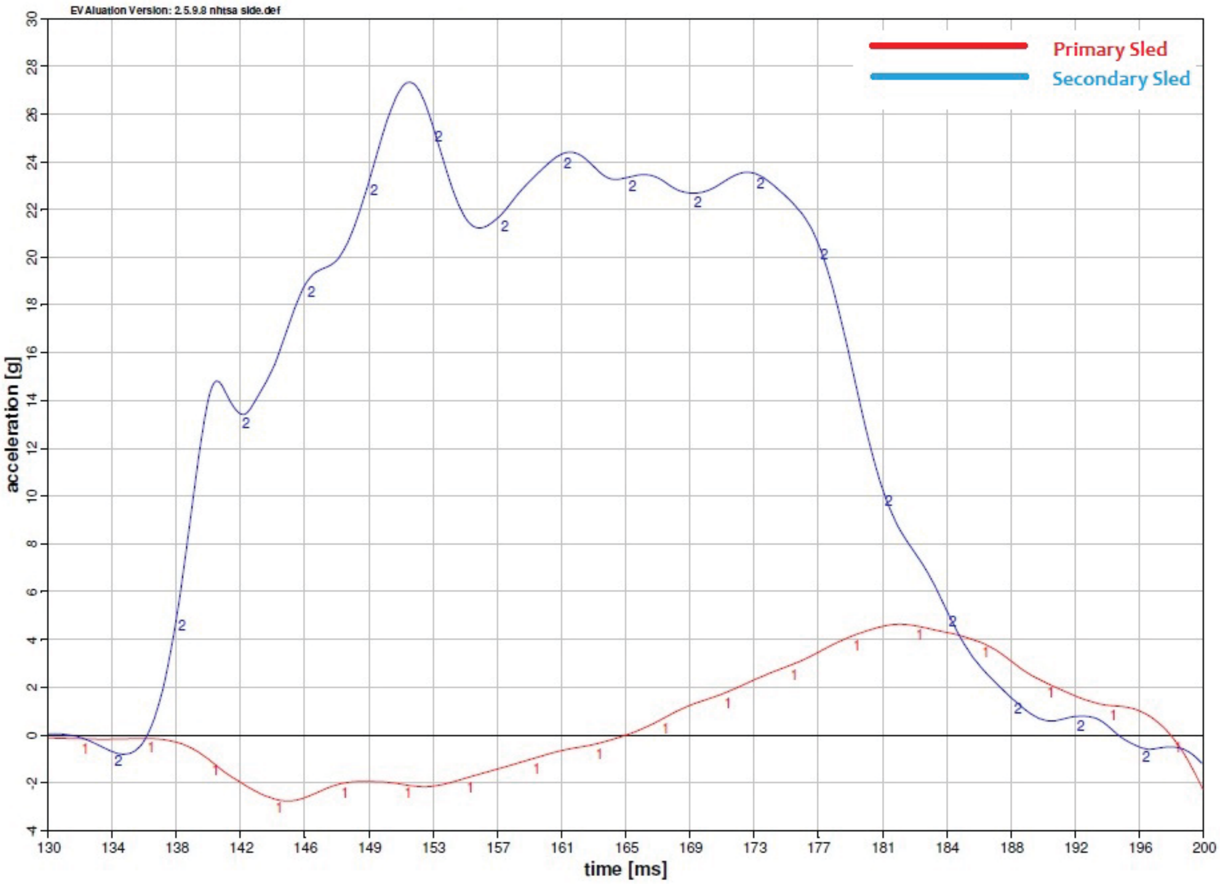


Figure 7: Primary and secondary sled accelerations during the impact of the secondary sled with the door fixture (CFC 60)

The pulse of the secondary sled during impact with the door may be affected by parameters that are CRS dependent such as design width (Section 6.1) and mass of the CRS/ATD combination. Therefore, during the baseline test series, one model of CRS and ATD were used. The CRS was a Cosco Scenera with an instrumented Hybrid III 3-year-old (HIII 3YO). The centerline of the CRS was fastened to the secondary sled bench 300 mm from the bench edge. The honeycomb face was targeted at 36 mm from the impact plane of the armrest foam. Note that due to the design width of the CRS and the fixed honeycomb-to-door face spacing, the primary sled door fixture struck the honeycomb before it came into contact with the side of the CRS.

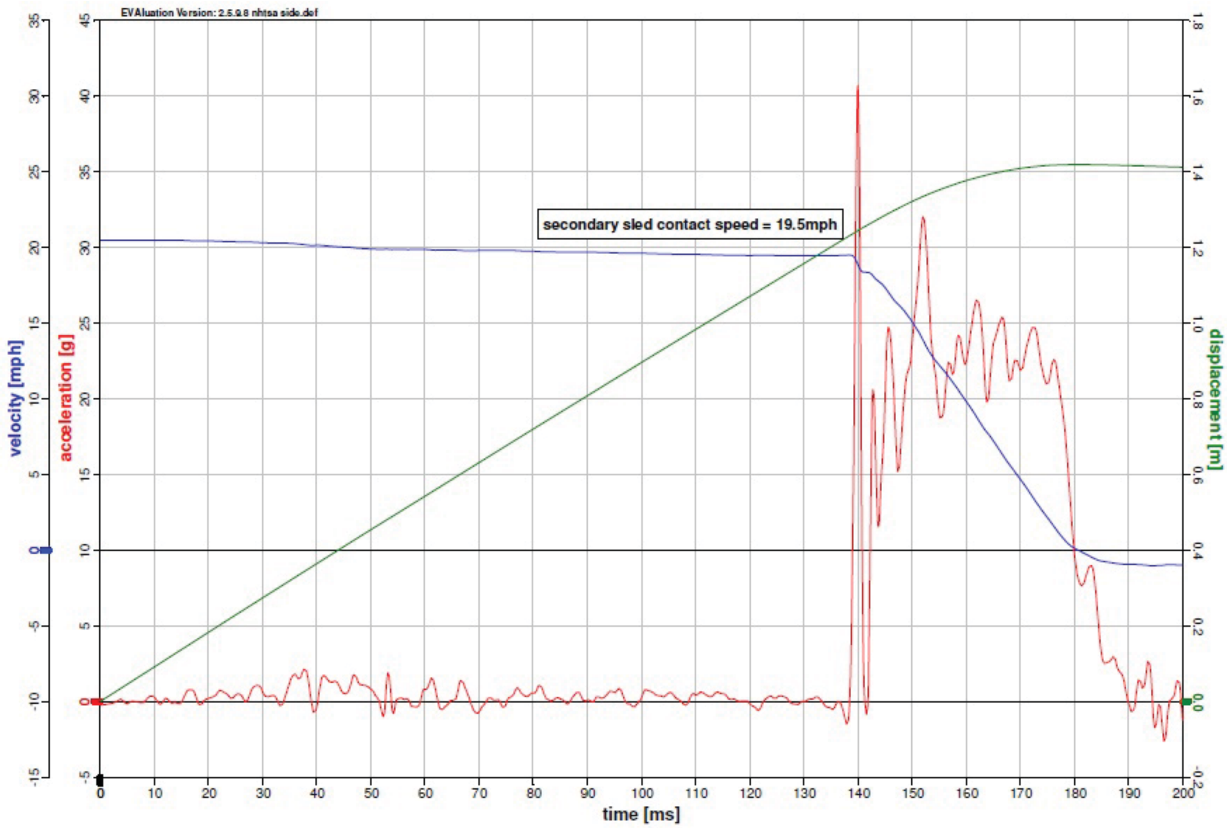


Figure 8: Acceleration, velocity, and displacement of the secondary sled (CFC 180)

Once the parameters of the deceleration testing were confirmed, three consecutive baseline tests were conducted with a primary sled speed of 20.5 mph and a secondary sled impact speed of 19.5 mph. Again, the CRS was a Cosco Scenera with an HIII 3YO. Figure 9 and Figure 10 show the acceleration of the primary and secondary sleds, respectively. It is shown that the side impact tests with the deceleration sled are very repeatable.

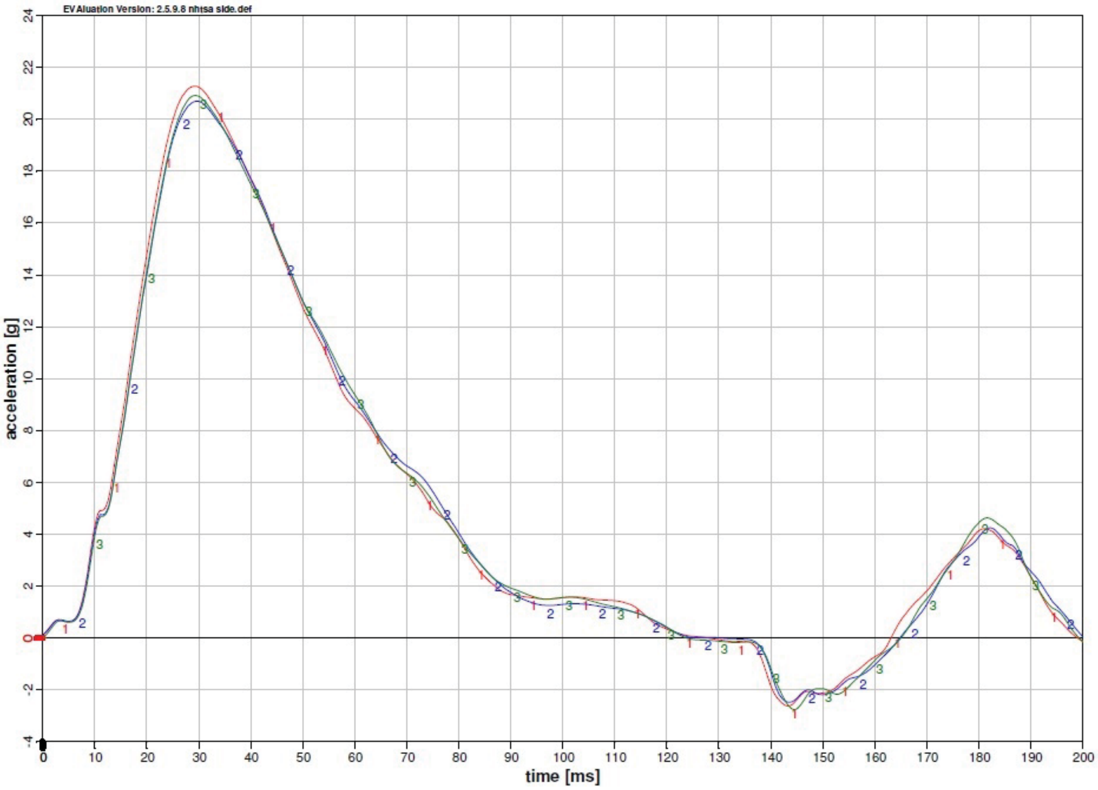


Figure 9: Acceleration of the primary sled for three baseline tests (CFC 60)

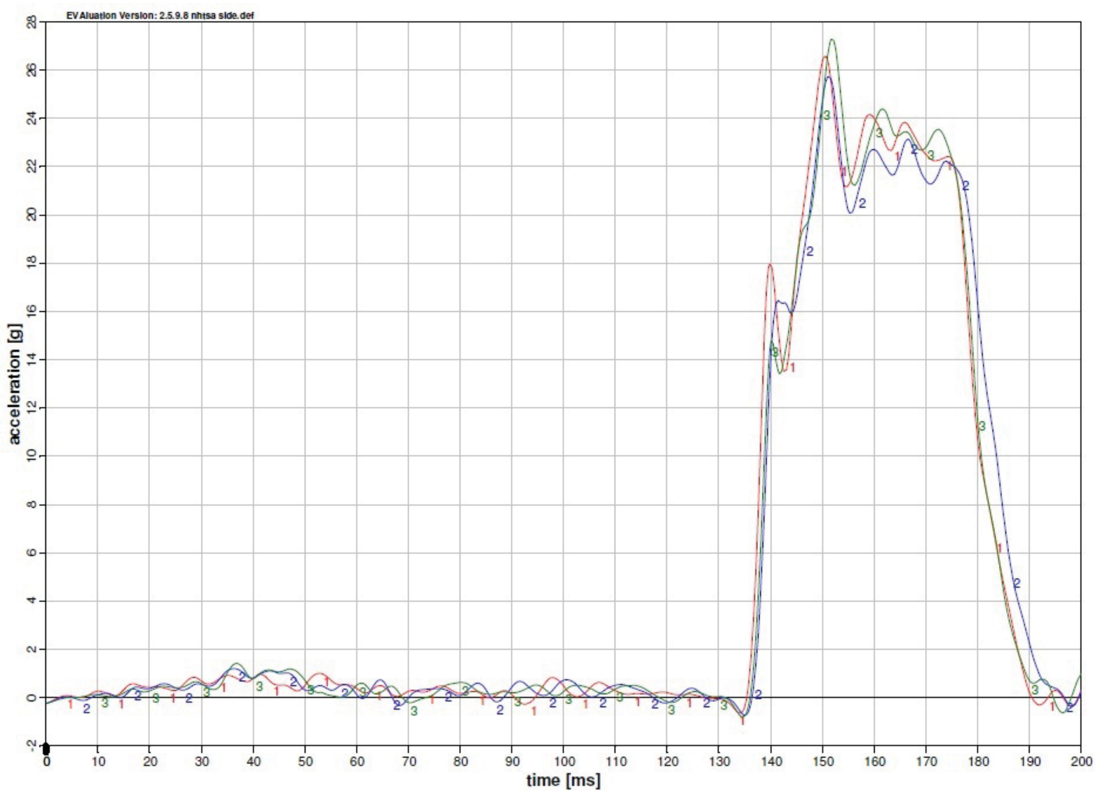


Figure 10: Acceleration of the secondary sled (bench seat base) for three baseline tests (CFC 60)

4.2 ATD Kinematics during Sled Run-up and Primary Carriage Impact

An HIII 3 YO ATD was used in several of the baseline tests to evaluate the pre-impact kinematics. The ATD was instrumented with tri-axial accelerometers in the head, chest, and pelvis. The instrumentation output was recorded from release of the complete fixture from rest through impact of the secondary sled with the door. Figure 11 shows the acceleration traces of the lateral component of the ATD head, chest, and pelvis with the longitudinal acceleration of the bench seat base. Time -3,200 msec indicates the beginning of the motion of the complete test fixture and zero indicates impact with the decelerator. During the initial 300 msec (-3,200 msec to -2,900 msec) there were differences in the accelerations including a timing lag of the head. Overall, nominal lateral head displacement was seen in the high-speed video used for this evaluation.

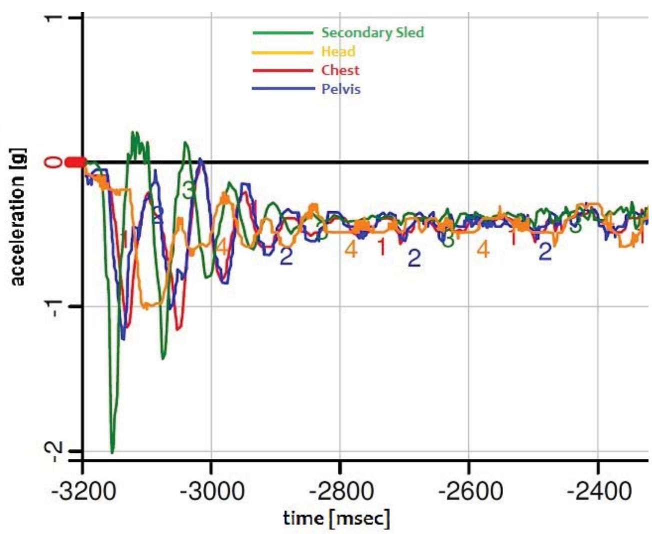
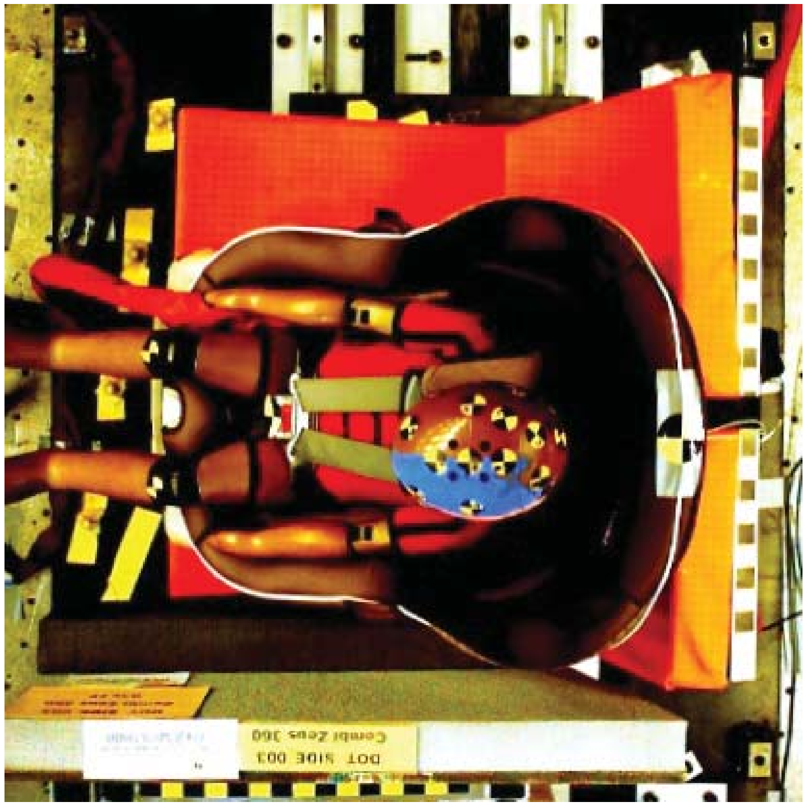


Figure 11: Longitudinal acceleration of the secondary sled compared to the lateral acceleration of the ATD head, ATD chest, and ATD pelvis (CFC 1000)

Lateral motion of the ATD was determined to be minimal during the acceleration phase of the deceleration sled test. But, it was discovered that the ATD head also moves forward (nodding away from the child seat back) during the period when the primary sled impacts the decelerator and the secondary carriage begins to travel along the 10-degree angle. Figure 12 includes an overhead view and inline view of the ATD at time of the child seat to door contact. The forward head displacement is evident.



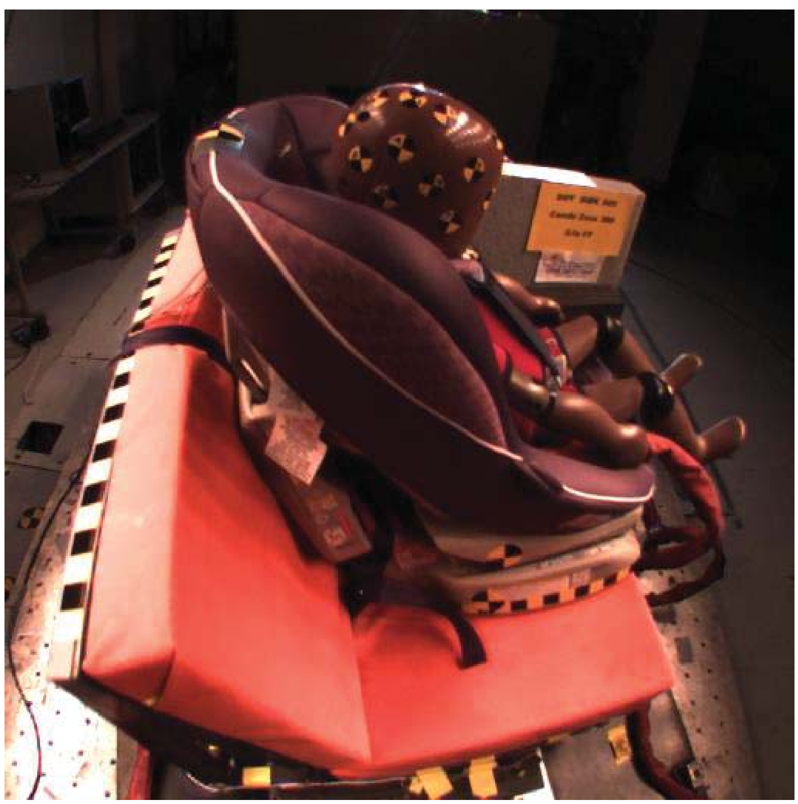


Figure 12: Overhead and inline views of Q3s left at time of impact of CRS with the door foam

5.0 Performance Testing of CRS

Once the test parameters were determined by baseline testing, the prescribed series of 18 side impact tests were performed on the deceleration sled. The test matrix is defined in Table 3.

Table 3: Test matrix for DOT SIDE 001 through 018

Test Number	ATD	Child Restraint System (CRS)	Angle (degrees)	Note
001-003	Q3s (left side)	Combi Zeus 360 – FF	10	LATCH*
004-006	Q3s (left side)	Evenflo Chase – FF	10	LATCH*
007-009	CRABI 12	Britax Advocate – RF	10	LATCH*, lower anchors only
010-012	CRABI 12	Combi Shuttle – RF	10	LATCH*, lower anchors only
013-015	Q3s (right side)	Combi Zeus 360 – RF	10	LATCH*
016-018	Q3s (right side)	Britax Advocate – RF	10	LATCH*, lower anchors only

*Lower Anchors and Tether for Children

5.1 ATD Installation and ATD Instrumentation

The test series called for a total of 18 tests using two different ATDs: 6 tests with the Child Restraint/Air Bag Interaction 12-month-old (CRABI 12) and 12 tests with the Q3s. The instrumentation for the ATDs is listed in Table 4. The instrumentation for the CRABI 12 was supplied by the KCS and calibrated in accordance to the protocol specified in NHTSA's Laboratory Test Procedure for FMVSS No. 213, Child Restraint Systems (TP-213-09 June 7, 2006). The instrumentation for the Q3s was supplied by VRTC along with the ATD. The CRABI 12 was clothed as specified in TP-213-09. Additionally, per protocol, the ATDs were chalk-painted on the near-side of the head in contrasting colors per the applicable head segments.

The instrumentation of the ATD was monitored for all tests. The pelvic acceleration data in the Y direction for the Q3s from test 004 was suspect data (Section 5.5 Results, Figure 16). The output had unexpected oscillations. The accelerometer was inspected post test and no concerns were found. However because of the data fault occurrence, the X and Y direction accelerometers were replaced when the ATD was re-instrumented for right side impacts.

Beginning in test 005, a positive contact switch was used between the head of the ATD and the door to determine if contact was made between the two during impact. A wire mesh cover (supplied by VRTC) was placed over the ATD head and foil tape (McMaster-Carr p/n 761A62, .005" thick by 6" width) was secured to the surface of the door foam. Contact to the door was witnessed on test 004 from the residual chalk marks and confirmed using the video. Head contact was recorded on test 005 and test 006 with the Q3s. Head contact also occurred in test

010, test 011, and test 012 with the CRABI 12. The event signal was not recorded for test 010 due to a fault with the wiring connection to the foil tape on the door trim surface. However head contact with the door was apparent from the residual chalk markings and in the videos for test 010.

Table 4: ATD instrumentation

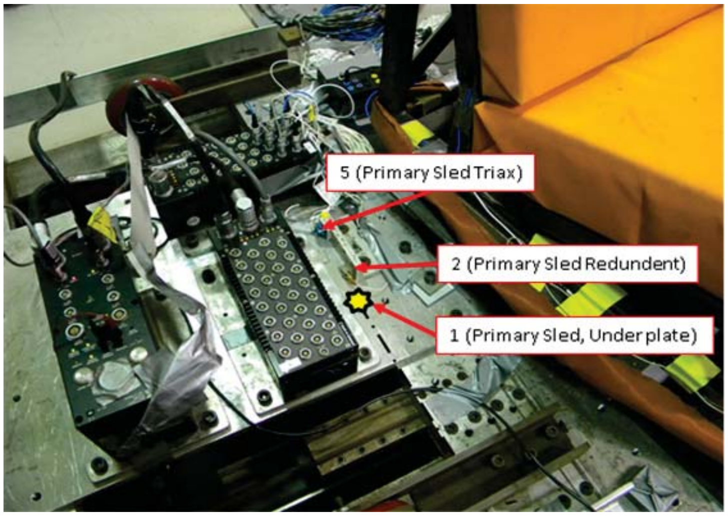
Instrumentation Channel	Q3s (number of channels)	CRABI 12 (number of channels)
Head triaxial accelerometer (cg)	3	3
Neck upper load cell Forces Fx, Fy, Fz Moment Mx, My, Mz	 3 3	 3 3
Shoulder displacement Y	1	-
Chest triaxial accelerometer	-	3
IR-TRACC Displacement	1	-
Spine triaxial accelerometer	3	-
Lumbar spine load cell Forces Fx, Fy, Fz Moment Mx, My, Mz	 3 3	 3 3
Pubic Force Y	1	-
Pelvis triaxial accelerometer (cg)	3	3
Total	**24**	**21**

5.2 Sled and Buck Instrumentation

The deceleration sled and the test buck had 10 channels of instrumentation (Table 5). Locations of the accelerometers are depicted in Figure 13. The child seat triaxial accelerometer was attached using adhesive to a flat area on the back surface of the CRS.

Table 5: Sled and fixture instrumentation

Position of Measurement	Type of measurement	Number of channels
Primary sled carriage (longitudinal)	Linear acceleration	1
Primary sled carriage redundant (longitudinal)	Linear acceleration	1
Secondary sled carriage bench seat base (along 10º)	Linear acceleration	1
Secondary sled carriage bench seat back (along 10º)	Linear acceleration	1
Child seat	Triaxial acceleration	3
Primary sled carriage (longitudinal)	Triaxial acceleration	3
Top tether (when applicable)	Axial belt load	1
Total instrumentation on sled and fixture		**11**



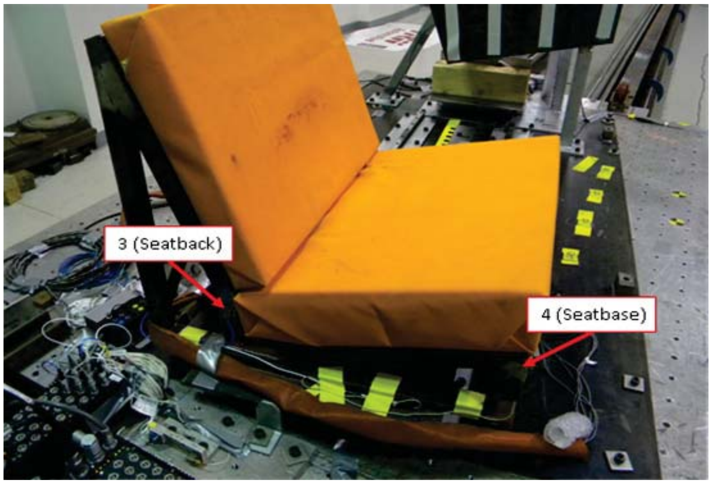


Figure 13: Location of accelerometers on test fixture and child restraint system

5.3 Still Photos and High Speed Video Cameras

Five high-speed, color video cameras were used to record the event (Table 6). Since the primary carriage is not moving during the impact of the secondary carriage to the door, it was not necessary to mount the cameras on the sled. Instead, all of the cameras were stationary (Figure 14).

Table 6: Camera specifications

Camera	Location	Lens	Type
CAMOH	Overhead 1 (wide view)	20 mm	Photron PCI
CAM1	Overhead 2 (tight view)	6 mm	Photron MH4
CAM2	Front	12 mm	Photron MH4
CAM3	In-Line with Secondary Sled	3.5 mm	Photron MH4
CAM4	Front Oblique (forward facing)	12 mm	Photron MH4
CAM4	Door surface (rearward facing	12 mm	Photron MH4

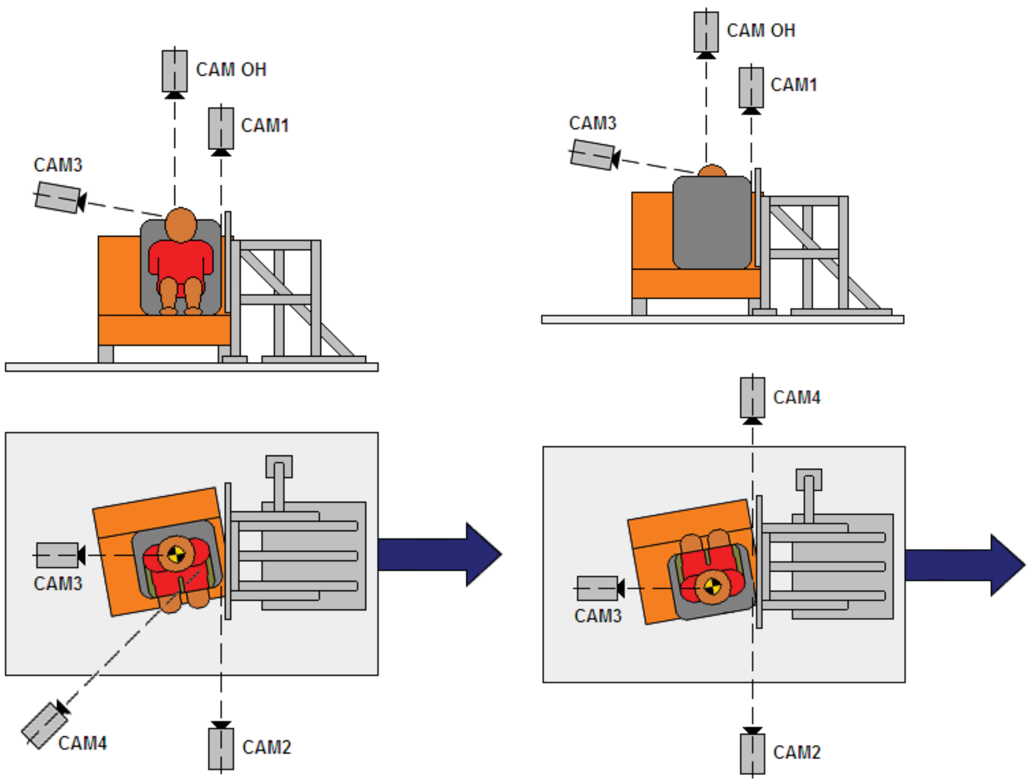


Figure 14: Camera positioning for forward facing CRS and rearward facing CRS tests

Pre- and post-test photos were taken per specifications in TP-213-09 and supplied with the individual test reports.

5.5 Results

The tests were conducted using the procedures specified in TP-213-09 and side impact testing procedures provided by NHTSA found in Appendix B. All data was processed per SAE J211. Data acquisition and analysis were conducted using the Autolab and Eval software, respectively.

The primary and secondary carriage responses for tests DOT SIDE 001 through DOT SIDE 018[1] are listed in Table 7. The incoming speed of the primary sled ranged from 20.7 mph to 21.3 mph. In all cases, the primary sled came to rest prior to the impact with the secondary sled. The secondary sled impact speeds with the door (including the aluminum honeycomb) ranged from 19.8 mph to 20.5 mph. This impact range was within the critical parameter of speed of 20.0 $\pm$ 0.5 mph. When testing the Combi Zeus, Evenflo Chase, and the Combi Shuttle, the secondary sled impacted the aluminum honeycomb before the door foam impacted the CRS. When testing the Britax Advocate, the aluminum honeycomb and the door foam (armrest) contacted the seat nearly simultaneously. The Britax Advocate was the widest of the four seats tested.

The time of peak deceleration of the secondary sled ranged from 137.9 msec to 141.7 msec. Time zero was set with a contact switch at the point of impact of the primary carriage with the decelerator. On average, the secondary carriage impacted the door at 136.6 msec.

[1] These tests can be accessed through the NHTSA vehicle database at http://www-nrd.nhtsa.dot.gov/database/VSR/veh/QueryTest.aspx. The respective test numbers, 8003 to 8020, are in the vehicle database.

Table 7: Primary and secondary carriage response for tests DOT SIDE 001 through DOT SIDE 018

Test #	C R S	ATD impact side right/left	Primary sled and fixture speed-incoming (kph (mph))	Primary sled speed - at impact by secondary sled (m/s)	Secondary sled speed – at impact (kph (mph))	Peak deceleration for secondary sled seat back (Gs)	Time peak secondary sled decel was attained (ms)	Post test depth of honeycomb* (mm)
001	Combi Zeus FF	Q3s left	33.5 (20.8)	0.0	32.2 (20.0)	25.5	141.2	152
002	Combi Zeus FF	Q3s left	33.3 (20.7)	0.0	32.0 (19.9)	27.5	141.7	155
003	Combi Zeus FF	Q3s left	33.3 (20.7)	0.0	31.9 (19.8)	28.1	141.6	153
004	Evenflo Chase FF	Q3s left	33.6 (20.9)	0.0	31.9 (19.8)	26.0	141.1	158
005	Evenflo Chase FF	Q3s left	34.0 (21.1)	0.0	32.2 (20.0)	27.2	139.9	150
006	Evenflo Chase FF	Q3s left	34.2 (21.2)	0.0	32.8 (20.3)	26.6	139.7	150
007	Britax Advocate RF	C12	34.0 (21.1)	0.0	32.2 (20.0)	26.7	138.3	145
008	Britax Advocate RF	C12	34.2 (21.2)	0.0	32.8 (20.3)	25.4	137.9	140
009	Britax Advocate RF	C12	34.0 (21.1)	0.0	32.5 (20.2)	29.3	138.4	155
010	Combi Shuttle RF	C12	34.2 (21.2)	0.0	33.0 (20.5)	29.3	137.9	160
011	Combi Shuttle RF	C12	34.2 (21.2)	0.0	32.5 (20.2)	28.5	138.4	154
012	Combi Shuttle RF	C12	34.2 (21.2)	0.0	32.5 (20.2)	29.3	138.7	160
013	Combi Zeus RF	Q3s right	33.8 (21.0)	0.0	32.5 (20.2)	27.1	139.5	152
014	Combi Zeus RF	Q3s right	34.0 (21.1)	0.0	32.5 (20.2)	26.7	139.1	150
015	Combi Zeus RF	Q3s right	34.0 (21.1)	0.0	32.5 (20.2)	24.8	139.7	150
016	Britax Advocate RF	Q3s right	34.3 (21.3)	0.0	32.8 (20.3)	27.9	138.1	150
017	Britax Advocate RF	Q3s right	34.3 (21.3)	0.0	32.8 (20.3)	26.0	138.0	150
018	Britax Advocate RF	Q3s right	34.2 (21.2)	0.0	32.8 (20.3)	27.2	139.1	150

* Nominal initial depth of the aluminum honeycomb was 305 mm (12 in)

The resulting injury values of the Q3s are summarized in Table 8 and Table 10. Repeatability of the ATD response is apparent in both the timing and magnitude of the injury values within the different child restraint system groups. The child seat design and profile influences the kinematics of the ATD. When testing the forward facing CRS using the Q3s, greater HIC was recorded for tests 004 through 006 which exhibited head impact with the door. The average shoulder displacement for all Q3s tests, both forward facing and rear facing was 19 mm. The average displacement recorded for the IR-TRACC for the forward facing child seats was 19.9 mm and for the rear facing CRS was 22.7 mm. Time history plots comparing the head Y acceleration and pelvic Y acceleration for the Q3s are provided in Figures 15 and 16 and Figures 19 and 20.

The rear facing child restraint system testing conducted with the CRABI 12 also demonstrated system repeatability in both timing and magnitude. The resultant injury values are summarized in Table 9. The occurrence of head contact to the door did not show an increase in HIC for tests 010 through 012. Time history plots comparing the head Y acceleration and pelvic Y acceleration for the CRABI 12 are provided in Figure 17 and 18. Complete time histories for all ATD channels are included in the individual test reports and data were also provided electronically.

Table 8: ATD data for tests DOT SIDE 001 through DOT SIDE 006: Forward facing CRS with Q3s impacted on left side

Test #	CRS	ATD	Impact speed to door (kph(mph))	Head contact? (Y/N)	Max resultant head accel (gs) / time(ms)	HIC 15	HIC 36	Max shoulder disp (mm) / time (ms)	Max IR TRACC disp (mm) / time (ms)	Max resultant upper spine accel (gs) / time (ms)	Max pubic force* (N) / time (ms)	Max resultant pelvis accel (gs) / time (ms)
001	Combi Zeus	Q3s left	32.2 (20.0)	N	89.1/167.6	569	569	18.5/174.3	16.3/159.3	97.8/157.6	904.2/156.1	145.7/158.4
002	Combi Zeus	Q3s left	32.0 (19.9)	N	79.0/167.9	474	477	20.8/176.9	16.3/160.6	97.6/162.6	919.0/156.0	152.7/159.6
003	Combi Zeus	Q3s left	31.9 (19.8)	N	83.0/168.1	525	528	18.0/163.4	14.1/163.0	93.0/163.0	883.1/156.4	146.2/160.2
004	Evenflo Chase	Q3s left	31.9 (19.8)	Y	104.5/163.8	836	836	18.2/159.3	24.2/160.0	114.4/158.4	322.6/152.2	Channel fault
005	Evenflo Chase	Q3s left	32.0 (20.0)	Y	107.2/163.1	884	884	17.8/158.9	26.0/160.3	110.1/158.9	362.9/151.9	184.5/156.1
006	Evenflo Chase	Q3s left	32.8 (20.3)	Y	106.5/164.7	863	863	17.0/165.9	22.6/161.0	118.5/158.9	237.5/152.0	205.0/155.9

* Maximum pubic force may be influenced by a vibration in the ATD caused by knee-to-knee contact (per VRTC)

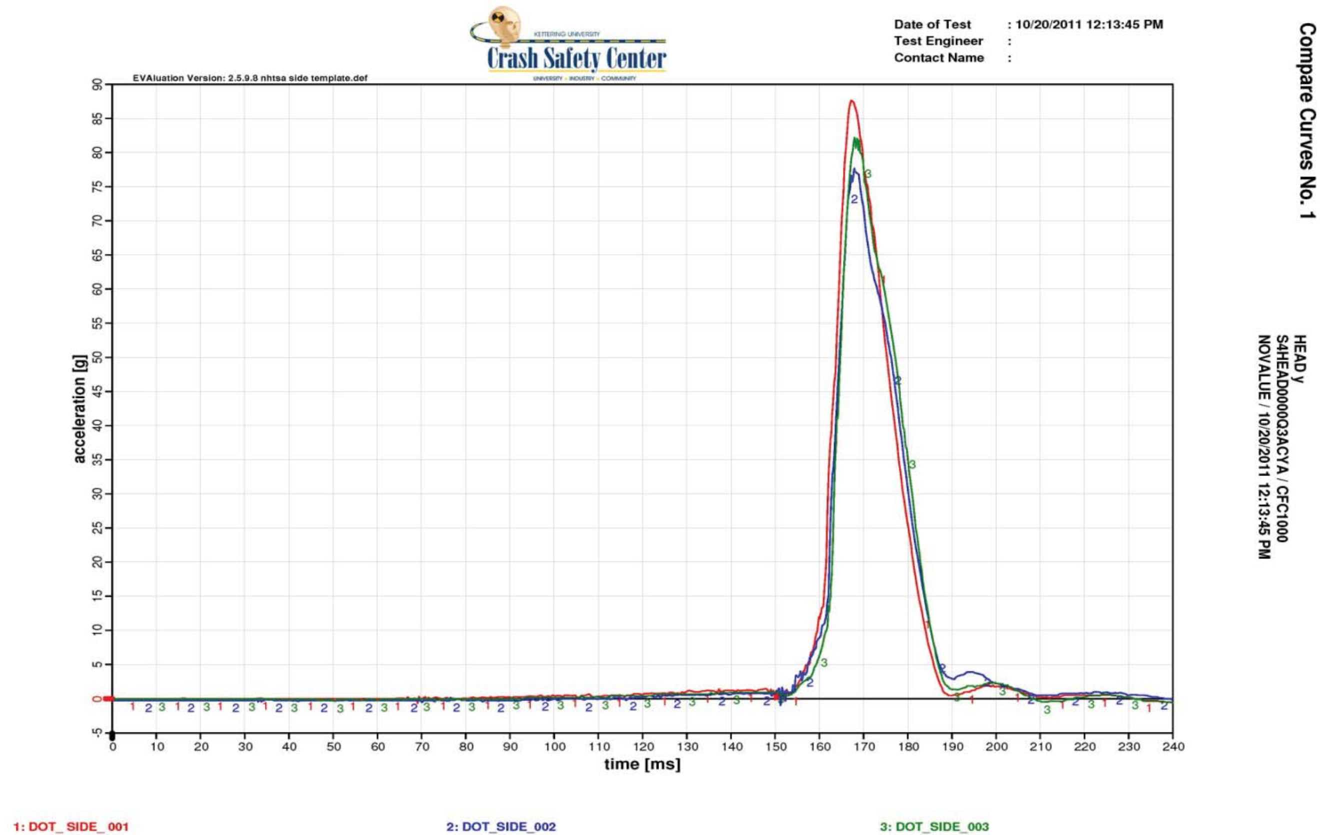
Table 9: ATD data for tests DOT SIDE 007 through DOT SIDE 012: Rear facing CRS with CRABI 12

Test #	CRS	ATD	Impact speed to door (kph(mph))	Head contact? (Y/N)	Max resultant head accel (gs) / time(ms)	HIC 15	HIC 36	Max resultant chest accel (gs) / time (ms)	Max resultant pelvis accel (gs) / time (ms)
007	Britax Advocate	C12	32.2 (20.0)	N	99.3/157.8	620	620	93.9/149.0	100.5/155.9
008	Britax Advocate	C12	32.8 (20.3)	N	109.4/158.7	728	728	104.5/148.2	110.1/153.9
009	Britax Advocate	C12	32.5 (20.2)	N	106.3/158.3	697	697	87.4/149.2	109.1/156.7
010	Combi Shuttle	C12	33.0 (20.5)	Y	96.4/165.3	518	518	76.3/161.2	137.4/152.9
011	Combi Shuttle	C12	32.5 (20.2)	Y	100.6/166.5	597	597	82.2/160.8	132.9/152.9
012	Combi Shuttle	C12	32.5 (20.2)	Y	99.3/168.0	586	586	86.8/161.9	134.2/153.9

Table 10: ATD data for tests DOT SIDE 013 through DOT SIDE 018: Rear facing CRS with Q3s impacted on right side

Test #	CRS	ATD	Impact speed to door (kph (mph))	Head contact? (Y/N)	Max resultant head accel (gs) / time(ms)	HIC 15	HIC 36	Max shoulder disp (mm) / time (ms)	Max IR TRACC disp (mm) / time (ms)	Max resultant upper spine accel (gs) / time (ms)	Max pubic force* (N) /time (ms)	Max resultant pelvis accel (gs) / time (ms)
013	Combi Zeus	Q3s right	32.5 (20.2)	N	61.8/168.6	312	331	19.1/166.5	18.8/165.0	103.7/157.4	923.7/153.8	141.0/158.4
014	Combi Zeus	Q3s right	32.5 (20.2)	N	69.1/165.9	366	376	18.5/168.6	20.1/163.0	109.4/155.7	739.8/153.8	150.9/157.7
015	Combi Zeus	Q3s right	32.5 (20.2)	N	74.9/166.1	426	429	19.2/165.7	20.7/162.3	108.2/155.4	889.1/152.7	152.2/157.8
016	Britax Advocate	Q3s right	32.8 (20.3)	N	85.4/160.1	607	607	20.8/153.8	26.5/157.0	78.8/154.6	491.9/148.3	107.4/155.2
017	Britax Advocate	Q3s right	32.8 (20.3)	N	92.0/157.0	671	671	20.3/153.0	25.7/157.3	81.1/153.5	579.6/148.0	105.1/153.8
018	Britax Advocate	Q3s right	32.8 (20.3)	N	91.8/159.1	639	639	18.1/156.5	24.4/158.6	78.9/154.9	489.8/148.4	105.9/156.0

* Maximum pubic force may be influenced by a vibration in the ATD caused by knee-to-knee contact (per VRTC)



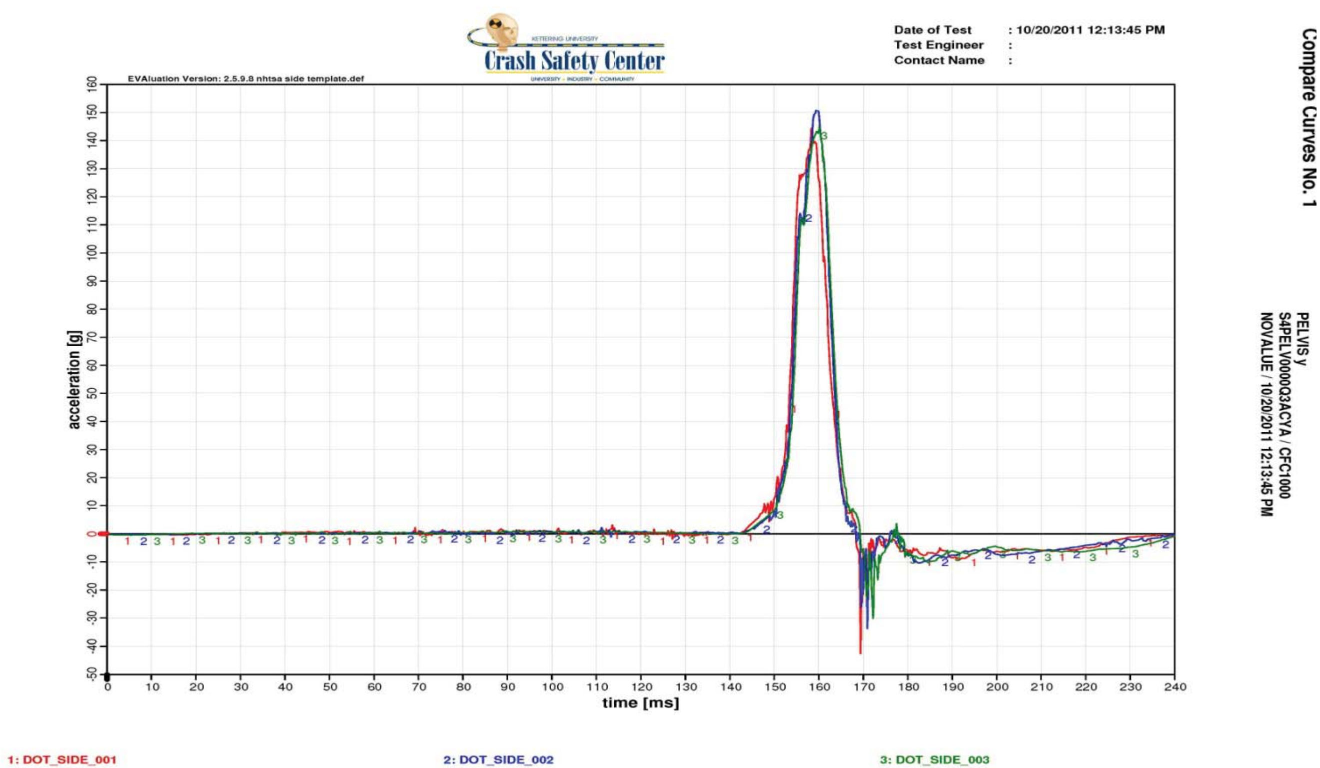
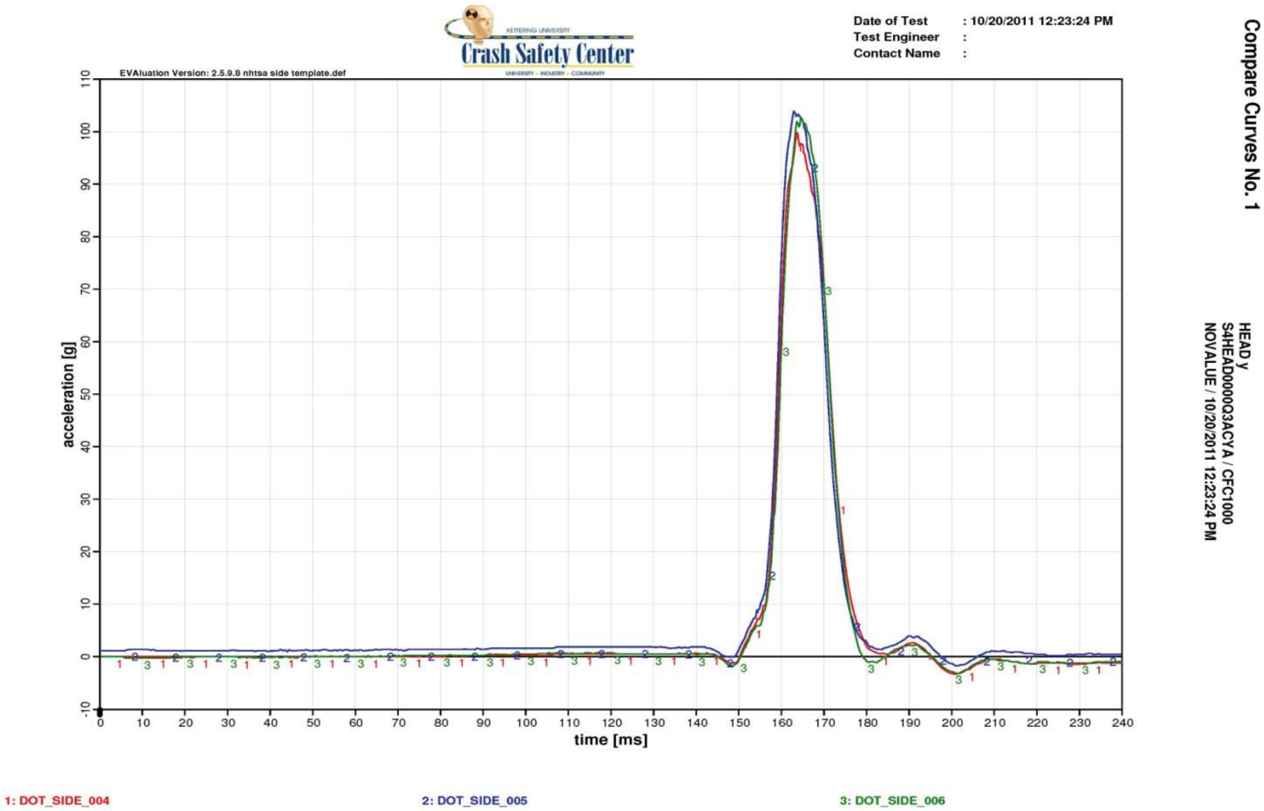


Figure 15: Lateral head and pelvis acceleration plots for SIDE 001 – SIDE 003 using Q3s FF



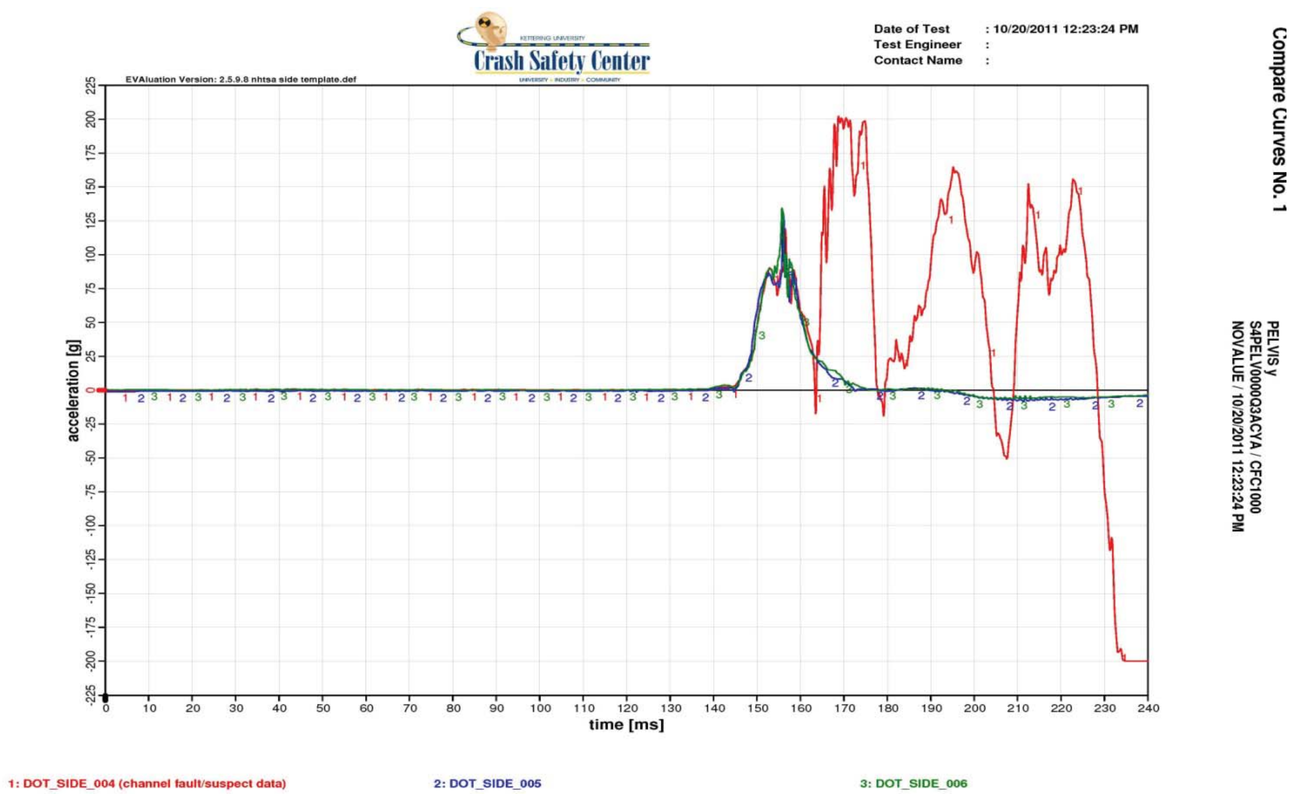
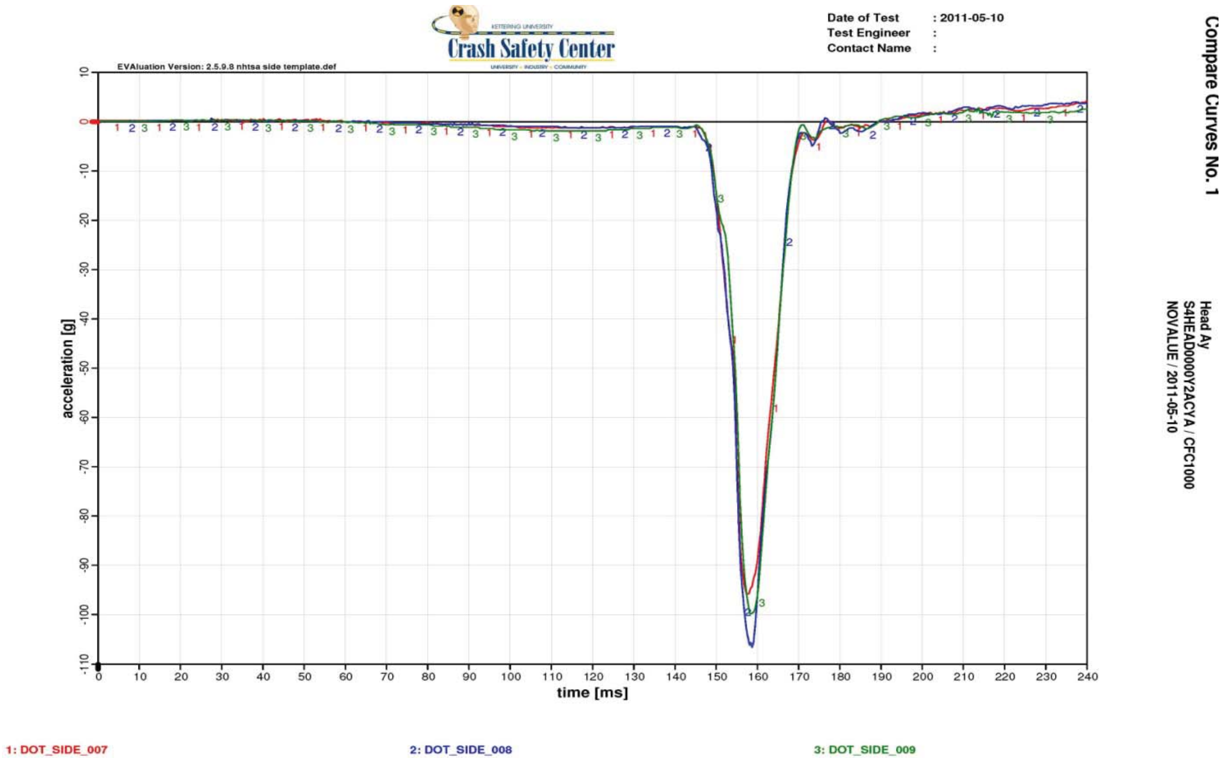


Figure 16: Lateral head and pelvis acceleration plots for SIDE 004 – SIDE 006 using Q3s FF



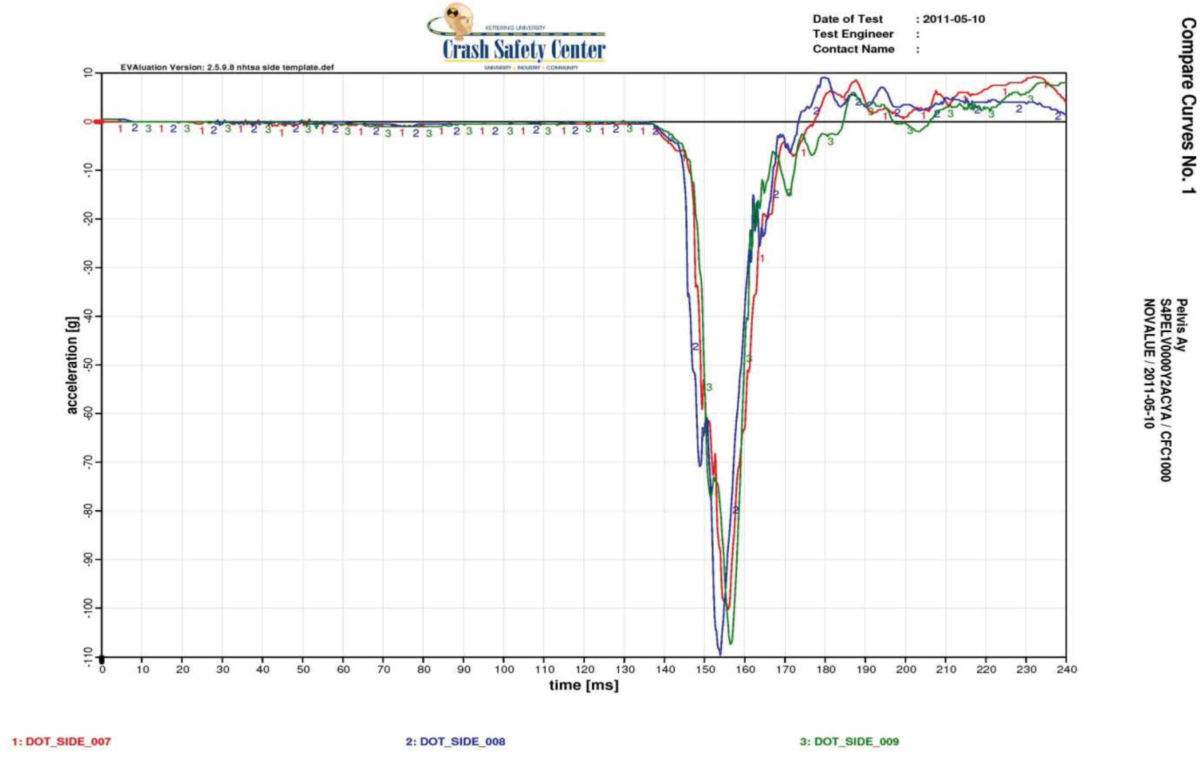
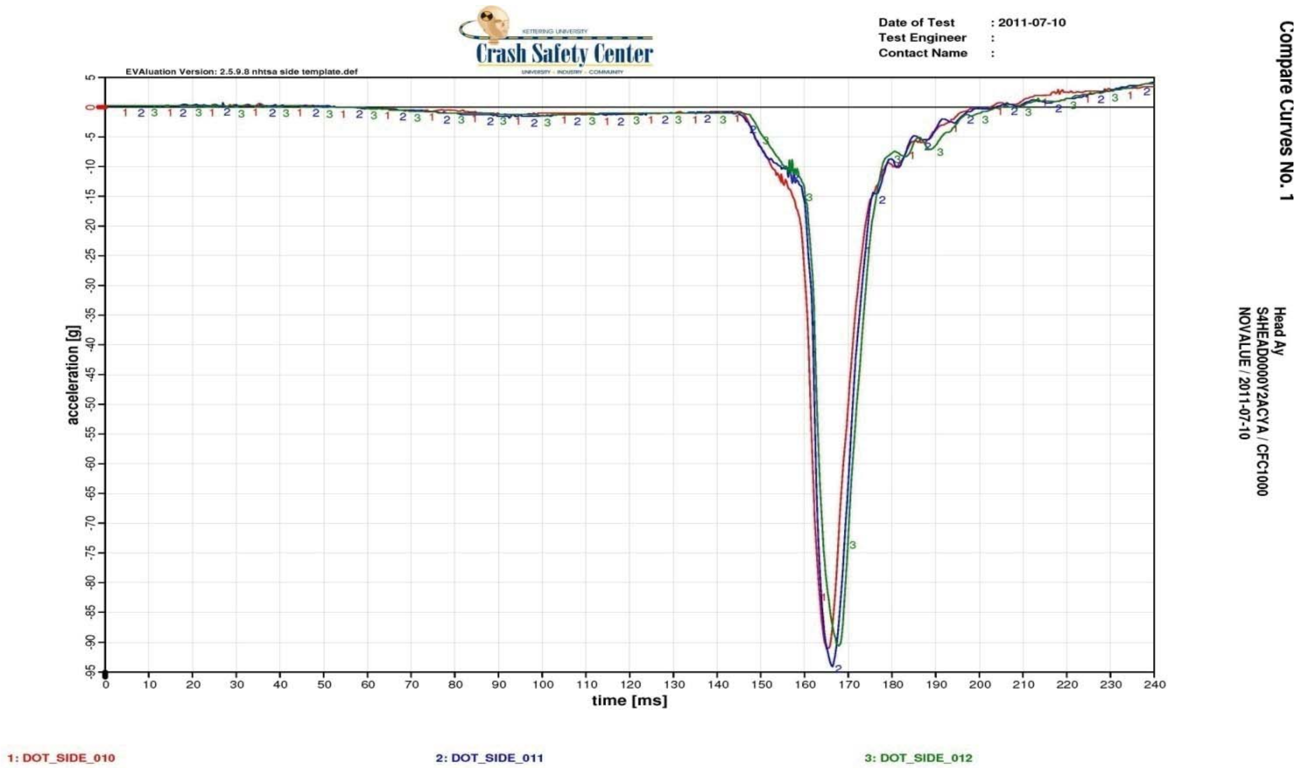


Figure 17: Lateral head and pelvis acceleration plots for SIDE 007 – SIDE 009 using CRABI 12 RF



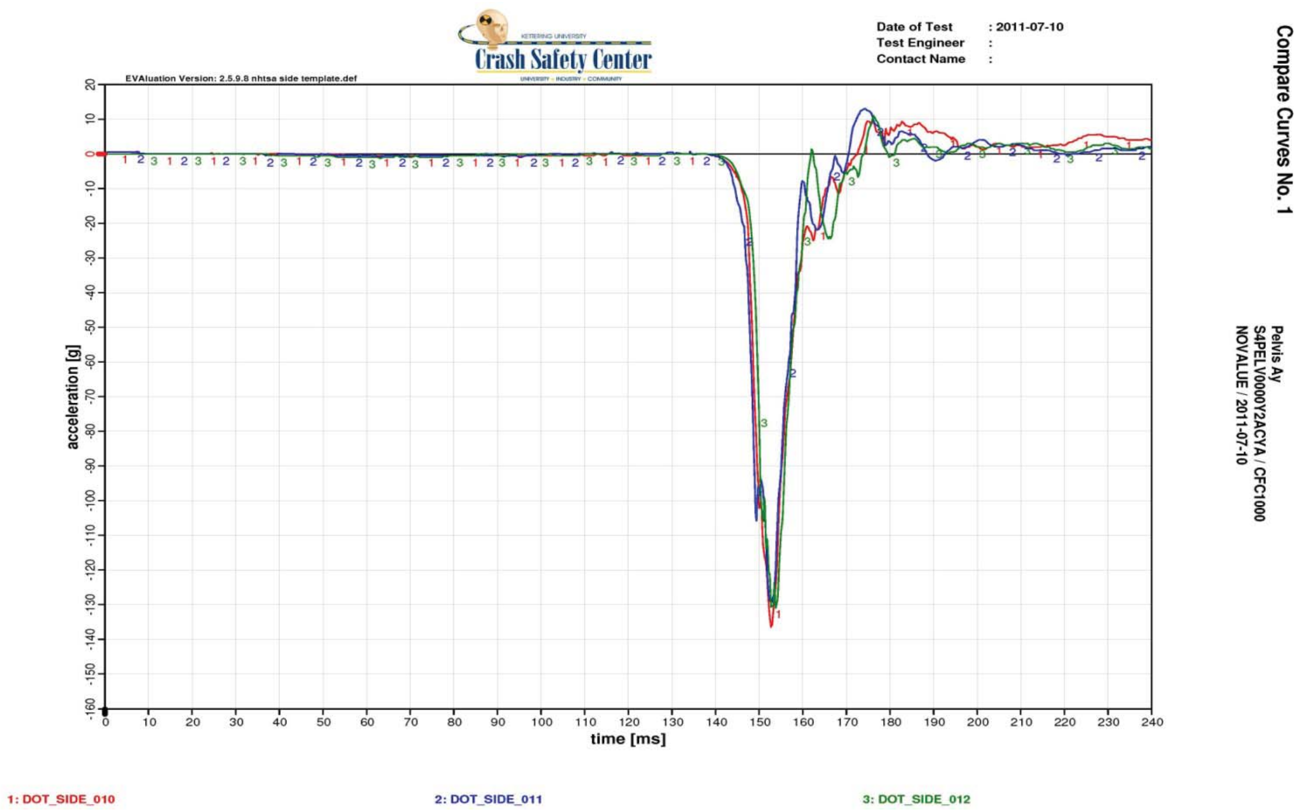
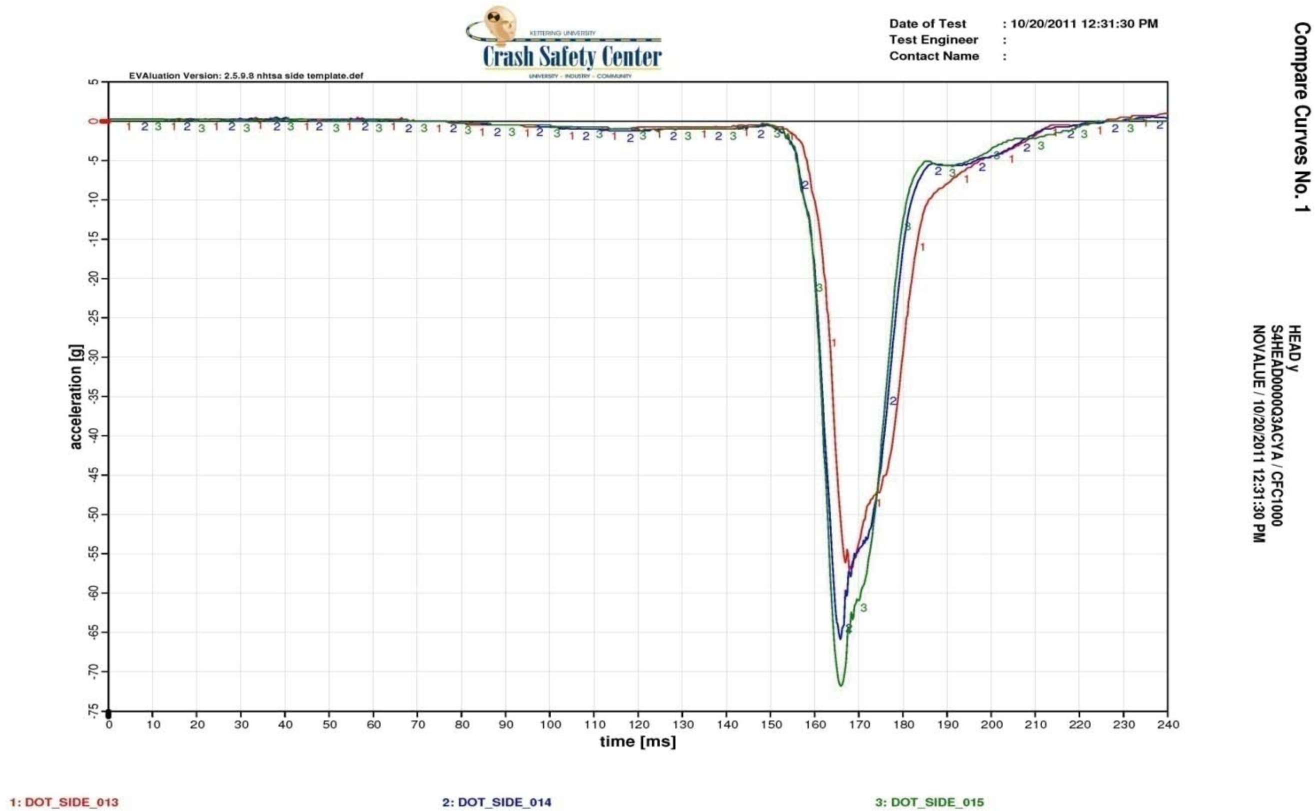


Figure 18: Lateral head and pelvis acceleration plots for SIDE 010 – SIDE 012 using CRABI 12 RF



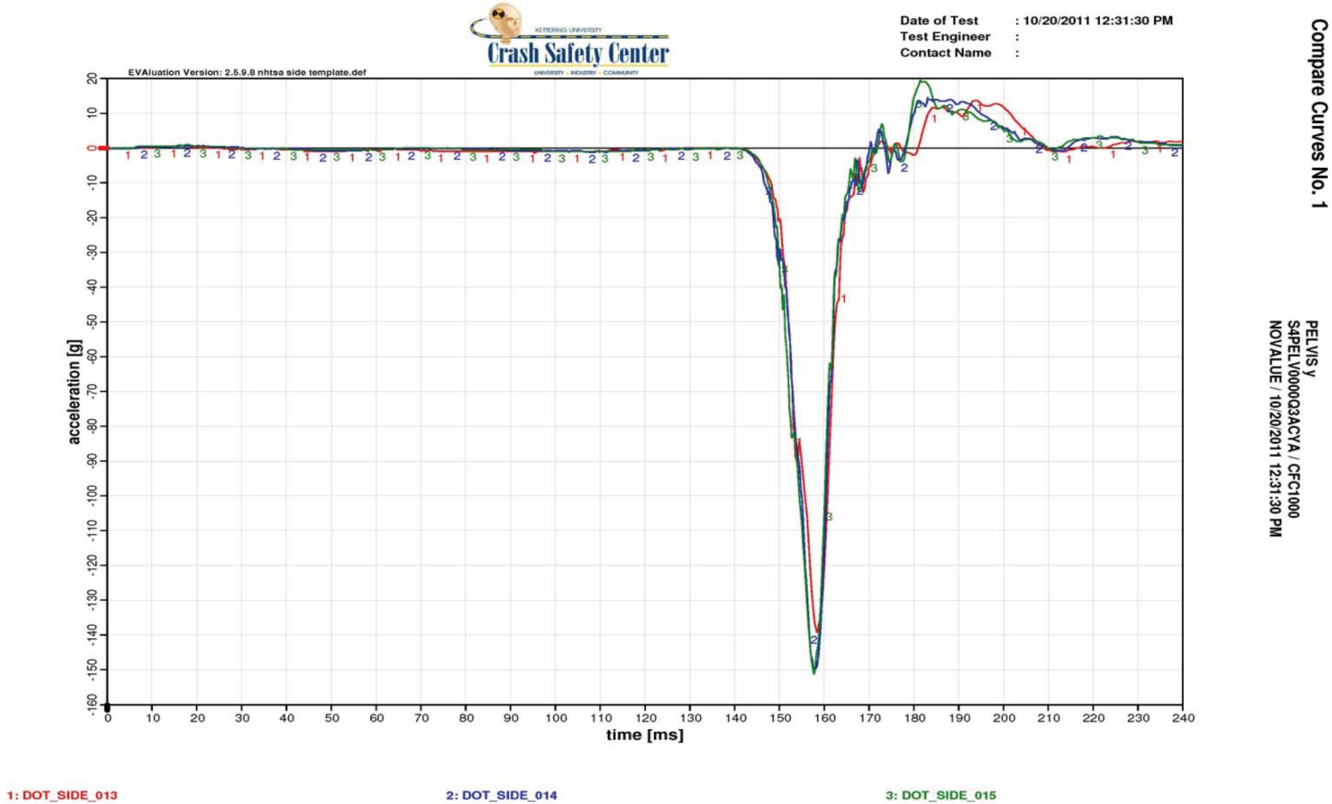
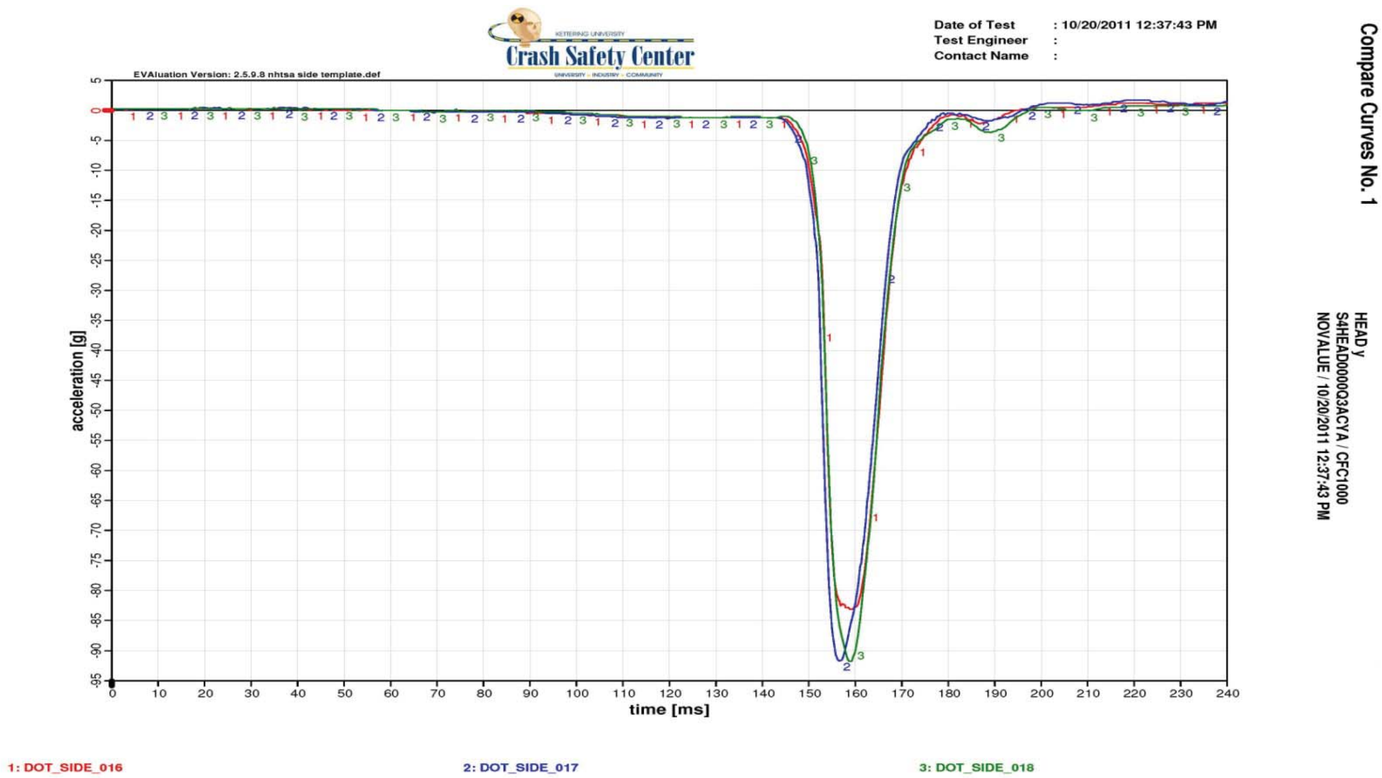


Figure 19: Lateral head and pelvis acceleration plots for SIDE 013 – SIDE 015 using Q3s RF



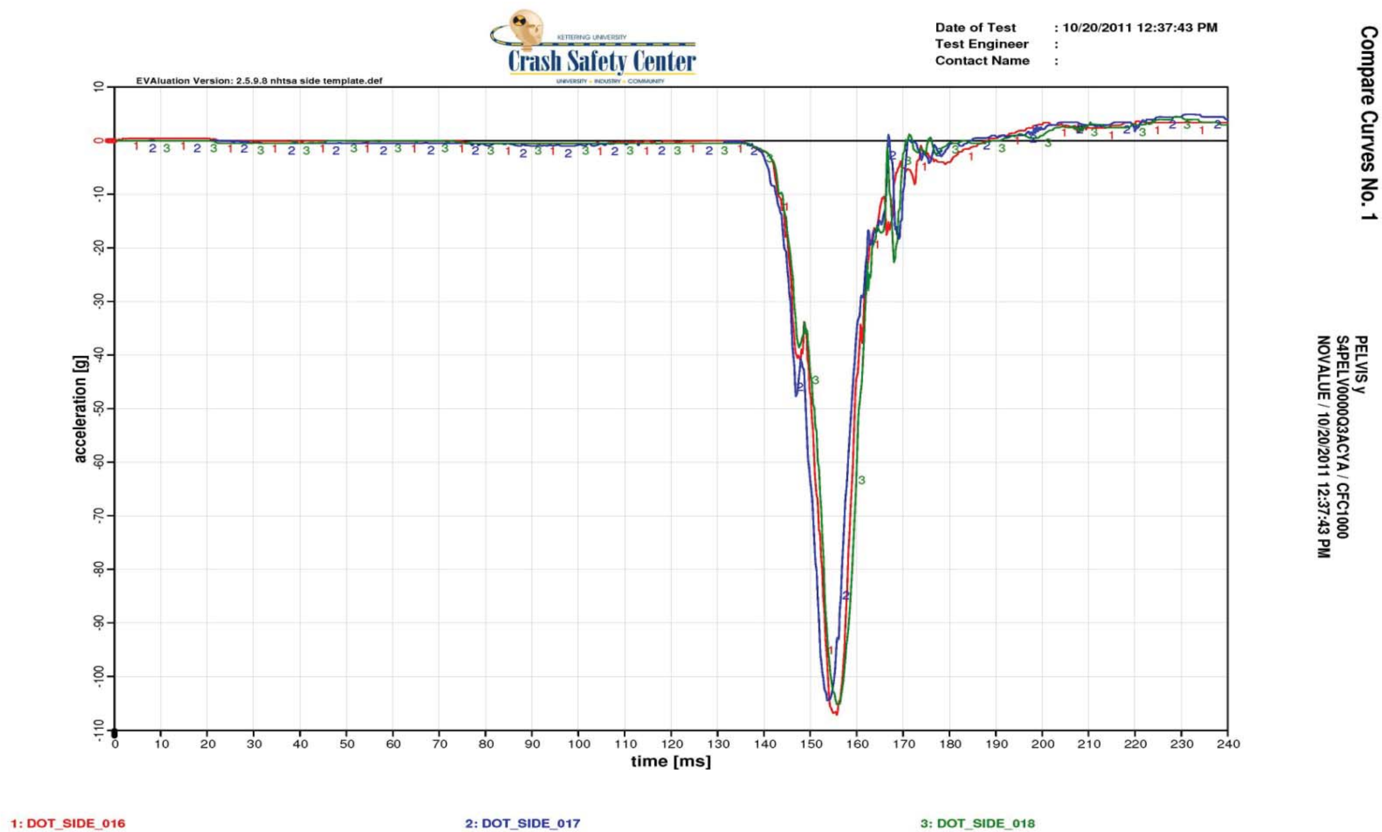


Figure 20: Lateral head and pelvis acceleration plots for SIDE 016 – SIDE 018 using Q3s RF

6.0 Discussion of Test Protocol

6.1 Aluminum Honeycomb Spacing with Respect to the Door Face

The spacing of the aluminum-honeycomb-impact-face to the door-foam-impact-face was targeted to be 36 mm (Figure 21). Subsequently, the spacing on the fixture in this test series averaged at 42 mm. The variations may have occurred due to compression in the wood block spacer backing the honeycomb and/or manufacturing variability in the thickness of the door foams and honeycomb.

During impact of the secondary sled with the primary sled door, the spacing between the honeycomb face and the leading edge of the door foam can be critical. Per the procedure, the centerline of the CRS is placed at 300 mm from the left edge of the bench. Depending on the width of the CRS being tested, the impact sequence will differ from CRS-to-CRS. A wider CRS may be struck by the foam door prior to the secondary carriage impacting the aluminum honeycomb. A narrower seat could take advantage of a significant amount of honeycomb crush prior to the door impacting the CRS. In the case of a narrower seat, the door would not impact the CRS at the target 20 mph nor would the same amount of energy be transferred to the CRS structure.

The amount of honeycomb crush prior to impact with the CRS can be measured from the test apparatus or calculated from the set-up procedure measures. The apparatus can be assessed pre-test by placing the secondary and primary carriages together until contact is made either between the foam door and CRS or the honeycomb and the bench seat impact plate. If the honeycomb contacts the bench seat impact plate, the distance measured from the foam door/armrest face to the side of the CRS is the amount of honeycomb crush that must occur before the two surfaces impact. To calculate the honeycomb crush, subtract half of the width of the CRS from 300mm (distance from the left edge of the bench to the centerline of the CRS, Figure 21). This distance will be the distance from the side of the CRS to the edge of the bench seat. Subtracting the overhang of the door face of 36mm, establishes the distance that must be crushed within the honeycomb in order for the door face to reach the CRS. Note that if the CRS upper structure is widest, the foam door/armrest may be bypassed and the foam door backing could strike the CRS first. This would alter the impact timing sequence. In this test series, the foam door/armrest was struck prior to the foam door backing with all CRS types.

In this test series, the CRS widths ranged from 430 mm to 520 mm (Table 11). The Combi Shuttle, the narrowest of the CRS tested, would have the advantage of 49 mm (1.9 in) of honeycomb crush before being struck by the door structure. If the intent is to keep the impact environment the same for each CRS being tested, the spacing between the aluminum-honeycomb-impact-face and the foam-door-impact-face would need to be adjusted so that the CRS and honeycomb are struck simultaneously.

Table 11: Width of tested CRSs and calculated aluminum honeycomb crush prior to impact

CRS	Seat Width (mm)	Honeycomb Crush Prior to Impact With the CRS (mm)	Location of Maximum Width
Combi Zeus	480	24	Head/Shoulder (wing) area
Evenflo Chase	460	34	At front of lap belt path near waist/hip level
Britax Advocate	520	4	Head/Shoulder (wing) area
Combi Shuttle	430	49	At handle

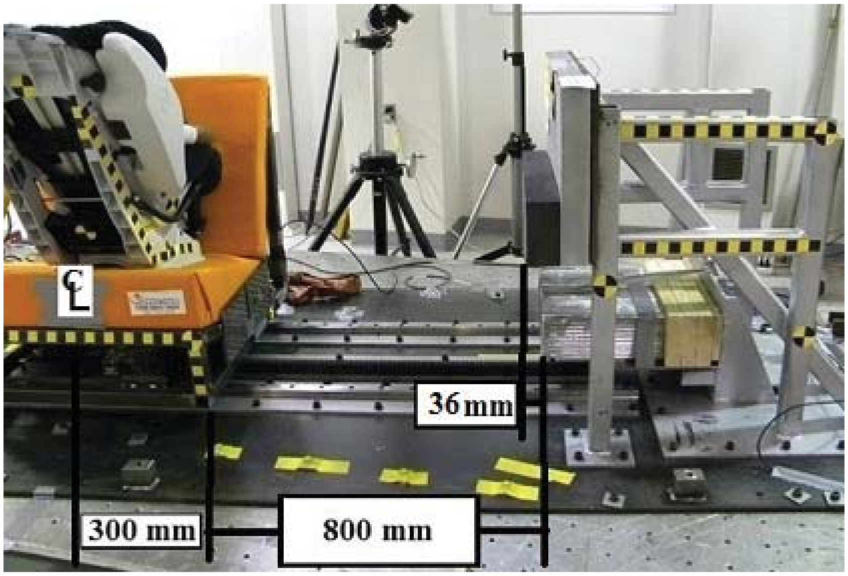


Figure 21: Alignment of the fixture attributes at time zero

6.2 Aluminum Honeycomb Performance

Aluminum Honeycomb PAMG-XR1 5052 from Plascore was used for all tests. Test sample size of 12" (depth) by 13.5" by 5" (305 mm x 343 mm x 127 mm) was used per the HYGE testing at VRTC. The size and type of honeycomb was not varied to ensure consistency between test protocols (HYGE vs. decel).

The pre-test length of the aluminum honeycomb was 305 mm. The final length of the honeycomb varied from 140 mm to 162 mm (Table 12). Therefore, the amount of crush varied from 143 mm to 165 mm; a 15-percent difference from minimum to maximum. One source of test-to-test variation in the amount of crush of the aluminum honeycomb may be the irregular crush profile across the face of the leading edge of the honeycomb (Figure 22). The leading edge of the honeycomb interacts with a steel face designed with a pattern of holes of various sizes (Figure 23). During crush, sections of the honeycomb protrude through the holes and do not absorb energy. The amount of protrusion is not consistent from test-to-test.

During the testing it was determined that the honeycomb crushed on both faces: leading end and attachment end. From previous experience with aluminum honeycomb used for crash events, only the leading edge would stack-up. Therefore, for one of the tests, the centerline of the honeycomb was marked and the final length was measured overall and with respect to the centerline. The total crush for the test was 145mm with the front section crushing 88 mm and the back 57 mm.

Table 12: Aluminum honeycomb crush data

Test Number	Secondary Carriage Impact Speed (mph)	Honeycomb Length Post Test (mm)	Total Crush (mm)
Baseline 001	19.5	152	153
Baseline 002	19.5	162	143
Baseline 003	19.5	160	145
SIDE 001	20.0	152	153
SIDE 002	19.9	155	150
SIDE 003	19.8	153	152
SIDE 004	19.8	158	147
SIDE 005	19.9	150	155
SIDE 006	20.3	150	155
SIDE 007	20.0	145	160
SIDE 008	20.3	140	165
SIDE 009	20.2	155	150
SIDE 010	20.5	160	145
SIDE 011	20.2	154	151
SIDE 012	20.2	160	145
SIDE 013	20.2	152	153
SIDE 014	20.2	150	155
SIDE 015	20.2	150	155
SIDE 016	20.3	150	155
SIDE 017	20.3	150	155
SIDE 018	20.3	150	155

Figure 22: Post-test aluminum honeycomb block showing the irregular profile

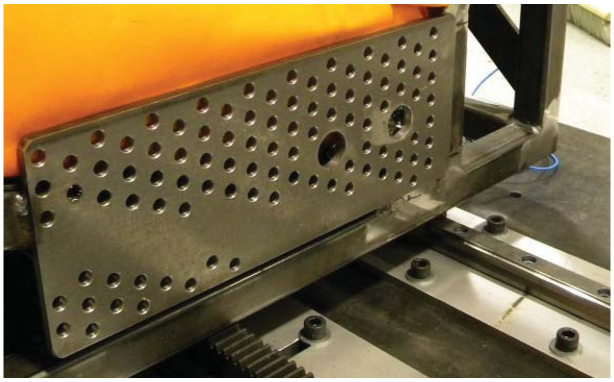


Figure 23: Fixture section that interacts with the aluminum honeycomb

6.3 Gear Rack Performance

During validation testing it was determined that the integrity of the gear rack system was not maintained for the duration of the test series. The system was machined according to the drawings which called for set screws to be used to lock the gears onto the shaft. The set screws separated from the shaft allowing for the secondary sliding bench to rebound away from the door fixture after impact. To repair the fixture, the gears were tack welded to the axle. It was determined the separation of the set screws did not have an effect on the ATD performance because it occurred after the crush of the aluminum honeycomb and the crush of the door foam.

7.0 Observations

Per contract DTNH22-11-R-00204, the Kettering University Crash Safety Center completed the following objectives: (1) constructed a side impact test fixture; (2) evaluated the feasibility of a child restraint systems (CRS) side impact test protocol on a deceleration sled; and (3) conducted 18 deceleration sled tests to collect data on the performance of child restraint systems (CRS) using two different anthropomorphic test devices (ATDs). The data from all of the tests was analyzed, transferred, and reported. The updated drawings of the test fixture were also supplied.

- Excellent repeatability for both primary and secondary sled impact speeds was observed during three consecutive baseline tests conducted with a primary sled speed of 20.5 mph and a secondary sled speed of 19.5 mph. The tests included a Cosco Scenera CRS with an HIII 3YO.

- The ATD does not have significant motion as the deceleration sled accelerates to its impact speed. But, the ATD head does move forward (flexion) during the deceleration of the primary carriage, prior to impact with the foam door.

- Repeatability of the ATD response is apparent in both the timing and magnitude of the injury values within the different child restraint system groups.

- The spacing between the impact face of the aluminum honeycomb and the impact face of the door foam (armrest) was set to a fixed distance of 36 mm. Since the CRSs vary in width, the impact sequence (foam door, honeycomb, CRS) can be effected. A wider CRS may be struck by the foam door prior to the secondary carriage impacting the aluminum honeycomb. For a narrower seat, the secondary carriage may impact (and crush) the honeycomb prior to the door impacting the CRS.

- The spacing of the aluminum-honeycomb-impact-face to the door-foam-impact-face was targeted to be 36 mm subsequently averaged in the test series at 42 mm. The variations may have occurred due to compression in the wood block spacing backing the honeycomb and/or manufacturing variability in the thickness of the door foams and honeycomb.

- The aluminum honeycomb reaction surface attached to the secondary carriage may warrant further review to determine the role that the hole pattern has on the variability of the honeycomb crush.

- The gear rack that is specified on the fixture does not have the durability to withstand the rigors of multi-use side impact testing. This issue may be more pronounced on the deceleration sled than the HYGE sled due to the impact dynamics.

- Side impact testing of a CRS using a deceleration sled is feasible and repeatable.

Appendix A

Primary and Secondary Sled Data Post Processing Procedure

The velocity of the primary and secondary carriages was determined by integrating, with respect to time, the time history acceleration of each carriage. Prior to integration, the data was offset to reflect when the deceleration sled was stationary. This occurred between times -3275 msec and -3250 msec.

Analysis of primary sled (accelerometer 1).

To minimize the amount of error due to integration, the integration analysis intervals were isolated to the area of interest of the impact event. For the baseline test, the interval used was -5 msec to 124 msec, or zero crossing of the acceleration trace. The primary sled incoming velocity was calculated as $V_{primary}$ = 20.5 mph at 0 msec, which is time of contact of the primary sled with the decelerator. (Figure A-1).

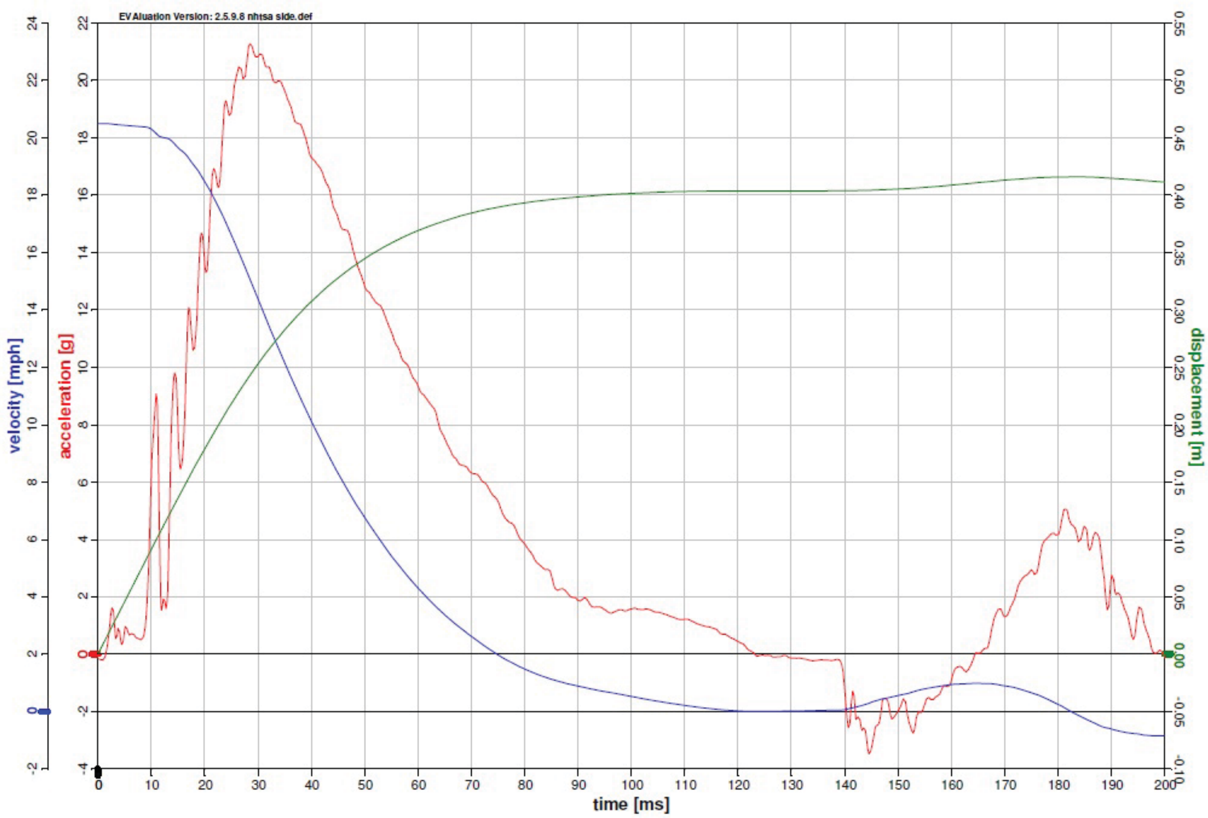


Figure A-1: Acceleration, velocity, and displacement of the primary sled (CFC 180)

Analysis of secondary sled seat base (accelerometer 04).

Because the secondary sled is attached to the primary sled, $V_{initial}$ of the secondary sled was equal to the calculated velocity $V_{primary}$ at t = 0 msec. The integration interval used for the secondary sled was -5 msec to the final zero crossing of the acceleration trace of the secondary sled. For baseline testing, the zero crossing was approximately 190msec (Figure A-2). Applying this analysis, the secondary sled velocity was calculated as $V_{secondary}$ = 19.5 mph at the time of contact with the aluminum honeycomb and/or the door foam affixed to the primary sled.

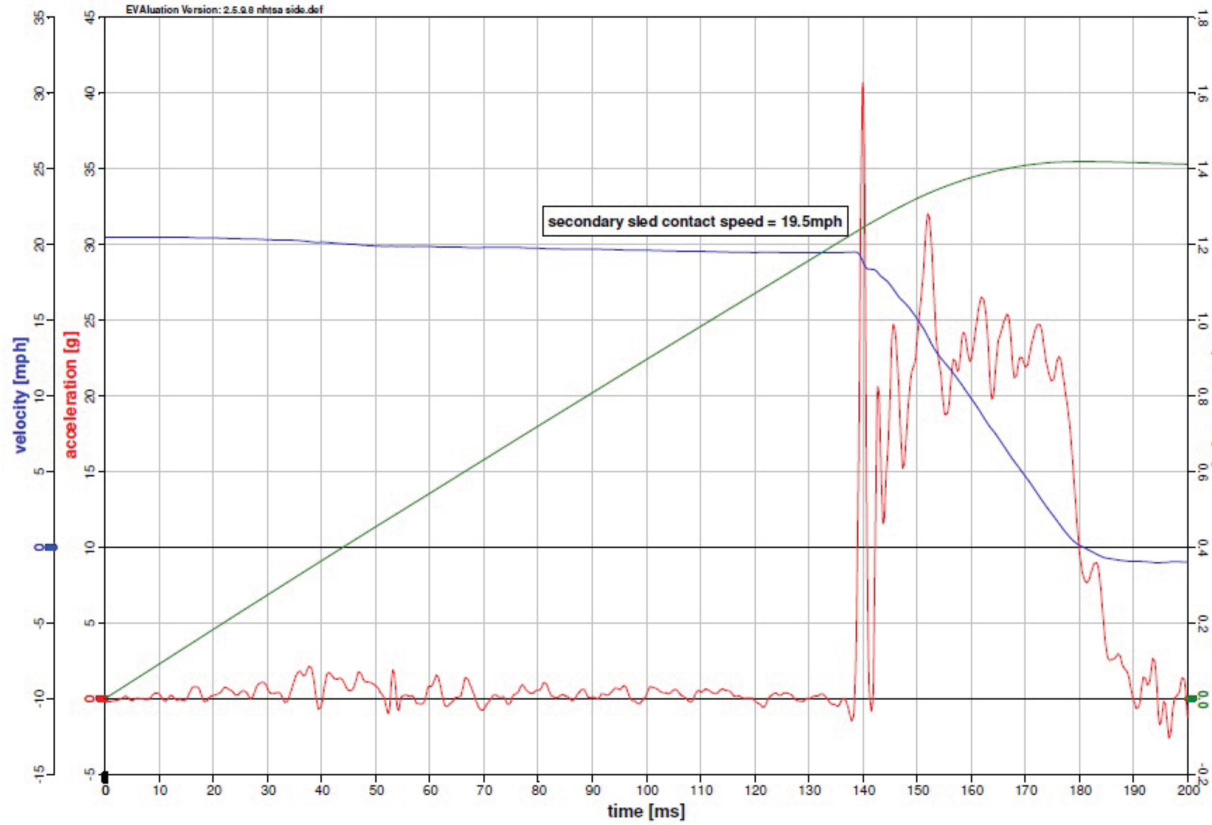
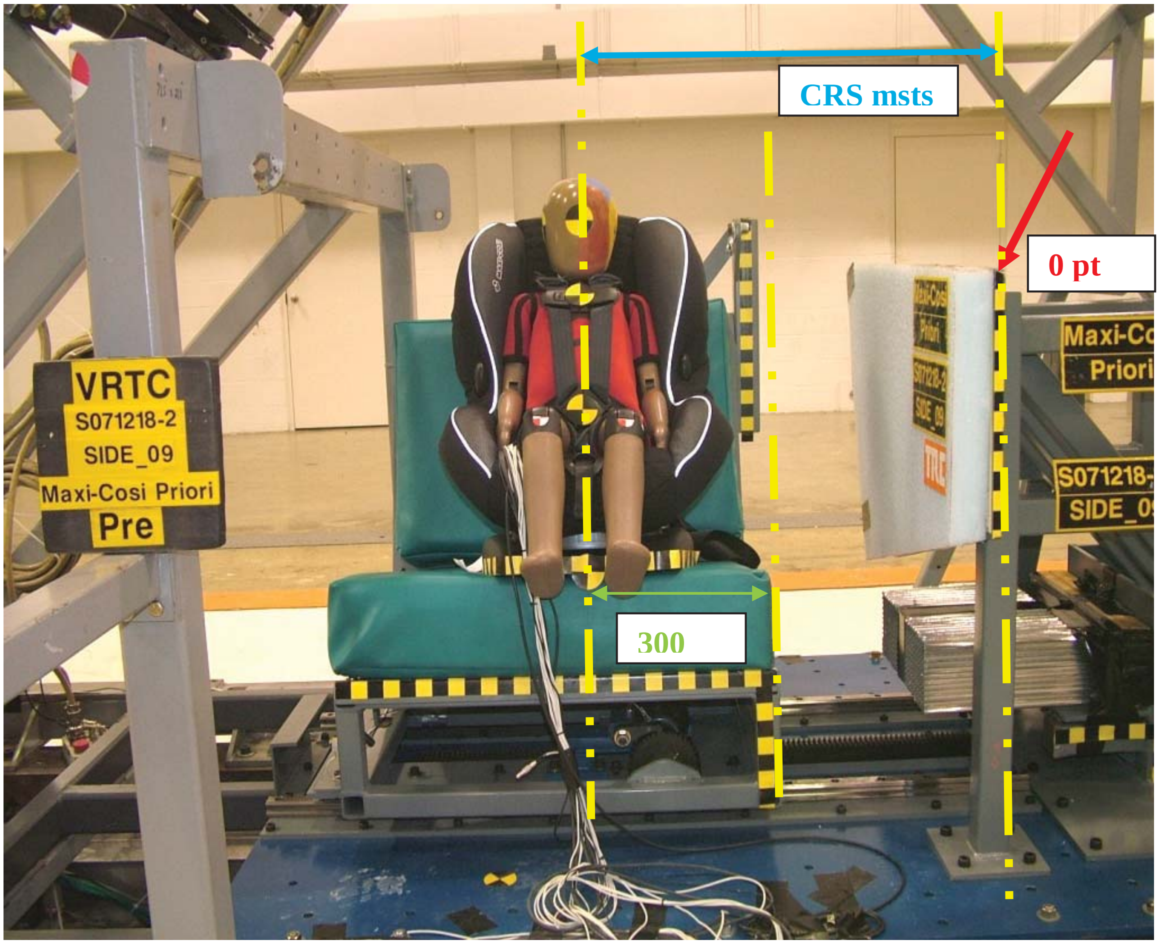


Figure A-2: Acceleration, velocity, and displacement of the secondary sled (CFC 180)

Appendix B

<u>NHTSA Draft Side Impact Test Procedure</u>
<u>(Subject to Further Development)</u>



Initial setup:
Sliding seat 265 mm from honeycomb.

CRS should be placed on the sliding seat 300 mm from edge (centered with the latch anchors). Seat should be installed according to the directions from the manufacturer. Install child dummy with the upper arms aligned with the torso, and the hands resting on CRS seat cushion. Route the data umbilical along the side of the dummy's upper leg, between the dummy and the CRS side interior. Position dummy so that the full torso is in contact with the back of the seat and top of head should be aligned with the target on the top and bottom of the CRS. Using the flat square surface of a force gauge, apply a force of 177N (40 lbs) perpendicular to the back of the CRS, first against the dummy's lower pelvis and then at the dummy's thorax on the mid-sagittal plane of the ATD. Tighten the CRS internal harness (1.5 to 3 lbs). Tighten and check loads of the lower latch anchors (12 to 15 lbs) and top tether (approximately 9 to 12 lbs, where applicable).

Dimensions should be taken at 0 point, which is located at the corner of the steel plate that represents the door.

CRS Measurements
Top of seat to wall
Bottom of seat to wall
Side base of seat to wall
Side wing to wall

Dummy measurements
Top of head to wall
Head CG to wall
Front of face (center target) to wall
Center of Knee to Center of Knee spacing should be150 ± 13 mm

Measurements shall also be dimensioned using a CCM (i.e. FARO arm) for repeat testing.

Post Test Measurements need to be taken from the seat edge to honeycomb.

Photography/Video Coverage:
Pre/Post Test photos of all sides and overhead of sled buck +CRS with placard in view
Pre Test close-up of CRS- Document where all targets are on CRS
Manufacture Label (s)
Pre/Post Test close-up of dummy in CRS
Post Test chalk marks on seat and door
Post Test of honeycomb crush
Post Test any damage CRS
Post Test any damage to sled buck (cushions, rail)

Document test with high speed videos (1000 frames/sec)
Overhead view- wide and tight
Front View perpendicular to the plane of the sliding seat movement
- View of overall sled and CRS kinematics
See below for placard info and front view

NOTE: For rear-facing CRS tests camera views need adjusting and documentation. Also, additional contact tape is required to determine contacts, etc.

Instrumentation

Sled:

Accels in X- and Y-axis on sliding seat (primary and redundant)

Accels in X-and Y-axis on wall

Redundant Accels in X-and Y-axis on sled

Top Tether Load Cell

Lower Anchor Load Cells

CRS Top X-and Y-axis accels

CRS Bottom X-and Y-axis accels

Accels in X- and Y-axis on sliding seat (primary and redundant)

Dummy Instrumentation:
One (1) Q3s dummy, with the following instrumentation:

- head triaxial accel
- upper chest (T3) triaxial accel
- chest displacement IR-Tracc (1 channel)
- pelvis triaxial accel
- upper neck load cell (3 forces, 3 moments)
- shoulder string pot (1 channel)
- lumbar spine load cell (3 forces, 3 moments)
- lateral pubic load cell (1 channel)

One (1) 12-month-old CRABI dummy, with the following instrumentation:

- head triaxial accel
- chest triaxial accel
- pelvis triaxial accel
- upper neck load cell (3 forces, 3 moments)
- lumbar spine load cell (3 forces, 3 moments)

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