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Performance of Event Data Recorders Found in Toyota Airbag Control Modules in High Severity Frontal Oblique Offset Crash Tests

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Abstract

This paper presents an in-depth analysis of the performance of Event Data Recorders (EDRs) found in the Airbag Control Modules (ACMs), as tested in support of the National Highway Traffic Safety Administration's Frontal Oblique Offset Program. Previous studies have examined EDR performance in high severity full-frontal barrier crash tests and moving deformable barrier side impact tests. This paper presents data from a high severity oblique frontal impact test in which the vehicle was struck by a moving deformable barrier. This paper examines the results of EDR data downloaded from two 2015 model year Toyota Highlanders, and the results of EDR reported change in velocity (delta-v), to vehicle mounted accelerometers and reference instrumentation. This paper will analyze EDR performance in reporting:

- Seatbelt buckle status,
- Occupant Size Classification, Front Passenger,
- Airbag and seatbelt pretensioner deployment time(s),
- Longitudinal delta-v, and
- Lateral acceleration/crash pulse.

Introduction

EDR reported frontal delta-v (ΔV) accuracy has been tested and reported in numerous publications. In 2013, Tsoi, et al. published a study validating longitudinal delta-v (ΔV) EDR data in high severity frontal crash tests [1]. This study evaluated the accuracy of EDRs extracted from 41 model year 2012 General Motors, Ford, Honda, Mazda, Toyota and Volvo vehicles, that had been subjected to NHTSA's New Car Assessment Program (NCAP) 56 kph (35 mph) full-frontal barrier crash tests. Tsoi, et al. concluded the average absolute error in final longitudinal ΔV between the EDR reported value and reference instrumentation was 6.6%, or 4.20 kph (2.6 mph). Tsoi, et al. also concluded that the EDRs correctly reported driver and right front passenger airbag deployments and belt buckle status for front seat occupants.

In 2014, Tsoi, et al. published a study validating lateral delta-v (ΔV) EDR data in side-impact crash tests [2]. This study evaluated the accuracy of EDRs extracted from 75 model year 2010 to 2012 Chrysler, Ford, General Motors, Honda, Mazda and Toyota vehicles, that had been subjected to NHSTA's Side-Impact New Car Assessment Program (SINCAP) side-impact moving deformable barrier crash tests. Tsoi, et al. concluded the average absolute error in final lateral ΔV between the EDR reported value and reference instrumentation was 15.9%, or 4.05 kph (2.5 mph). The average arithmetic error was -13.8%, or -3.59 kph (-2.2 mph) and the root mean square error was 19.8%, or 4.88 kph (3.0 mph). Tsoi, et al. also concluded that the EDRs correctly reported side torso, side curtain and frontal airbag deployments, and belt buckle status for front seat occupants.

In 2013, Haight and Haight evaluated small overlap barrier crash tests to compare data from an Event Data Recorder and test instrumentation data [3]. The authors concluded that there may be a significant difference between the accelerations and the lateral delta-V values from the Event Data Recorder and test instrumentation data. They determined this discrepancy was caused by rotational effects sensed by the ACM accelerometers, versus the reference instrumentation which are located at different positions within the vehicle, not a measurement error. The authors presented a method, based on principles of rotational motion, to reconcile this discrepancy.

In 2007, Wilkinson, et al. published a paper examining accuracy of EDR data from General Motors vehicles in a series of NHTSA crash tests [4]. This study included 21 flat rigid barrier tests, a rigid offset barrier test and an offset, angled vehicle-to-vehicle crash test. The offset angled test (NHTSA test 4955) was performed by crashing a 2000 Cadillac Seville into a 1997 Honda Accord. The closing speed between the two vehicles was approximately 113.3 km/h (70.4 mph) and the reported alignment was 50% offset and 30 degrees oblique to the left front side. Wilkinson, et al. reported that the ACM in the Cadillac underestimated the longitudinal speed change by 10.4 km/h to 10.8 km/h (6.5 mph to 6.7 mph). Wilkinson, et al. concluded that the underestimation of the EDR reported speed change was the result of three factors; the ACM did not record the entire duration of the crash, rotational effects and the placement of this ACM compared to the center of gravity of the vehicle, and the ACM from the Cadillac involved in the crash test did not record any lateral speed changes.

The EDRs installed in Toyota vehicles specifically have been examined in several other studies [5, 6, 7, 8, 9, 10, 11].

Objective

The goal of this paper was to determine whether the EDR correctly reported restraint usage, correctly identified front passengers, correctly reported restraint deployments and deployment times, and whether the EDR reported speed changes (longitudinal and lateral) feel within the stated accuracy described in previous studies.

NHTSA Frontal Oblique Crash Tests

Two separate crash tests (9480 and 9481) were conducted and analyzed by NHTSA to obtain data on vehicle response to collision and restraint system performance [12, 13]. Both tests were conducted between a 2015 Toyota Highlander SUV and an Oblique Moving Deformable Barrier (OMDB). Each test was documented by two real time and 15 high speed video cameras. The tests were run at ±15 degrees, relative to the front of the target vehicle and offset 35% percent to the driver (Test 9480), and 35% to the passenger side (Test 9481). The test vehicle contained one 50% adult male THOR-NT anthropomorphic test device (ATD) in the driver's seat and one 50% adult male THOR-NT ATD in the front-right passenger seat. Both test vehicles were equipped with Toyota's "13EDR" generation Event Data Recorder.

Crash Test 9480

The first crash test that was analyzed involved a stationary 2015 model year Toyota Highlander that was struck by an OMDB traveling 90.12 km/h (56 mph). The OMDB was positioned such that it contacted the Toyota offset 35% to the passenger side of the vehicle, and at a 15° angle (12:30 on the clock face), relative to the front of the vehicle. Table 1 contains a summary of the test parameters. The photographs and images in Figure 1, Figure 2 and Figure 3 depict the pre-crash, crash and post-crash configurations of the vehicles.

After the crash test, EDR data from the Toyota ACM was imaged with the Bosch Crash Data Retrieval (CDR) system. The report generated by the CDR software recovered the one frontal event, two side events and a rollover event. Figure 4 contains an excerpt from the CDR report detailing the chronology of the various event triggers.

TABLE 1 Crash Test 9480: Test Specifications

Crash Test: 9480	
Test Date	September 21, 2015
Vehicle Tested	Toyota Highlander
Model Year	2015
VIN	5TDBKRFH5FS175984
Occupants	(2) 50% Male THOR-NT
Target Vehicle Weight	2,317 kg (5,108 lbs)
Target Vehicle Speed	0 mph
OMDB Weight	2,519 kg (5,553 lbs)
OMDB Speed	90.12 kph (56 mph)
Orientation of Impact	15 degrees
Collision Offset	35% (Passenger Side)

FIGURE 1 Crash Test 9480: Test Set Up

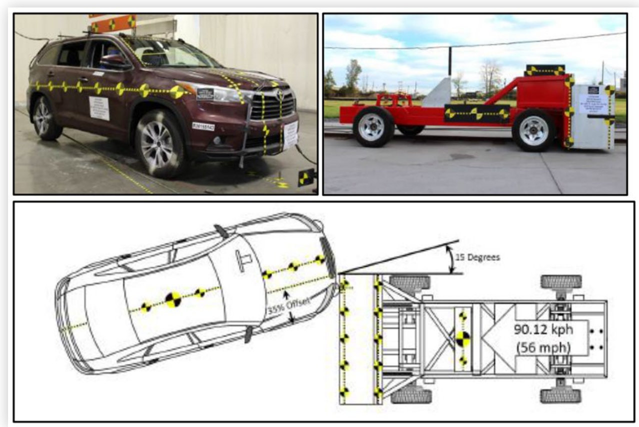
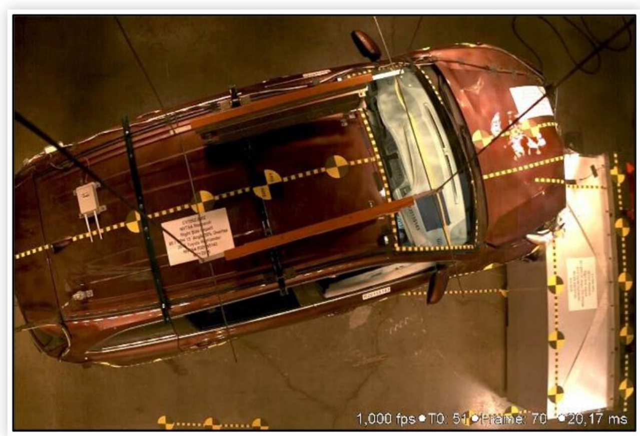


FIGURE 2 Crash Test 9480: Still Frame from Overhead Video at Impact

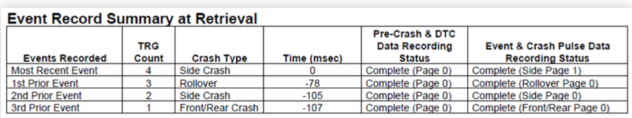


Crash Test 9481

The second crash test that was analyzed involved a stationary 2015 model year Toyota Highlander that was struck by an OMDB traveling 90.12 km/h (56 mph). The OMDB was positioned such that it contacted the Toyota offset 35% to the driver side of the vehicle, and at a -15° angle (11:30 on a clock face), relative to the front of the vehicle. Table 2 contains a summary

FIGURE 3 Crash Test 9480: Post-Crash Photographs

FIGURE 4 Crash Test 9480: EDR Event Record Summary



Event Record Summary at Retrieval

Events Recorded	TRG Count	Crash Type	Time (msec)	Pre-Crash & DTC Data Recording Status	Event & Crash Pulse Data Recording Status
Most Recent Event	4	Side Crash	0	Complete (Page 0)	Complete (Side Page 1)
1st Prior Event	3	Rollover	-78	Complete (Page 0)	Complete (Rollover Page 0)
2nd Prior Event	2	Side Crash	-105	Complete (Page 0)	Complete (Side Page 0)
3rd Prior Event	1	Front/Rear Crash	-107	Complete (Page 0)	Complete (Front/Rear Page 0)

TABLE 2 Crash Test 9481: Test Specifications

Crash Test: 9481	
Test Date	October 16, 2015
Vehicle Tested	Toyota Highlander
Model Year	2015
VIN	5TDBKRFH5FS179100
Occupants	(2) 50% Male THOR-NT
Target Vehicle Weight	2,306 kg (5,084 lbs)
Target Vehicle Speed	0 mph
OMDB Weight	2,519 kg (5,553 lbs)
OMDB Speed	90.12 kph (56 mph)
Orientation of Impact	-15 degrees
Collision Offset	35% (Passenger Side)

of the test parameters. The photographs and images in Figure 4, Figure 5 and Figure 6 depict the pre-crash, crash and post-crash configurations of the vehicles.

After the crash test, EDR data from the Toyota ACM was imaged with the Bosch Crash Data Retrieval (CDR) system. The report generated by the CDR software recovered the one frontal event, one side event and a rollover event. During crash test #9481, the first triggering event (the frontal crash event) was completely recorded. The second triggering event (the

FIGURE 4 Crash Test 9481: Test Set Up

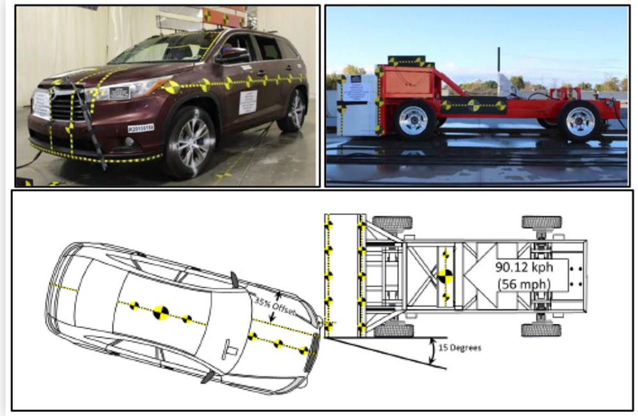


FIGURE 5 Crash Test 9481: Still Frame from Overhead Video at Impact

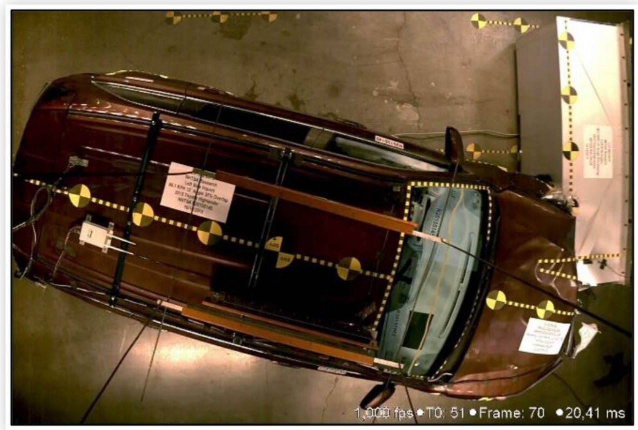


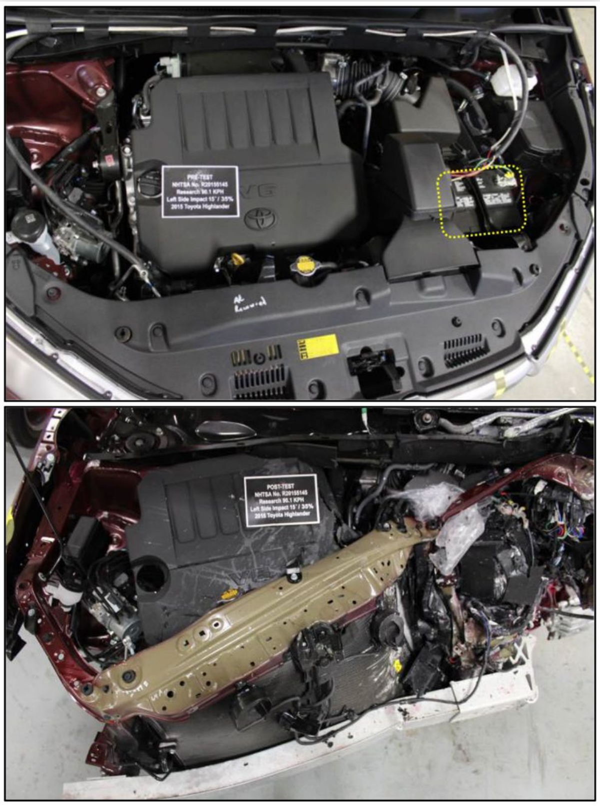
FIGURE 6 Crash Test 9481: Post-Crash Photographs

FIGURE 7 Crash Test 9481: EDR Event Record Summary

Event Record Summary at Retrieval

Events Recorded	TRG Count	Crash Type	Time (msec)	Pre-Crash & DTC Data Recording Status	Event & Crash Pulse Data Recording Status
Most Recent Event	2	Side Crash	0	Complete (Page 0)	Complete (Side Page 0)
1st Prior Event	1	Front/Rear Crash	-2	Complete (Page 0)	Complete (Front/Rear Page 0)
TRG Invalid #1	N/A	Rollover	N/A	N/A	Incomplete (Rollover Page 0)

FIGURE 8 Crash Test 9481: Engine Compartment/ Battery Damage



side crash event) was also completely recorded, however, a Rollover triggering event was not completely recorded. Figure 7 contains an excerpt from the CDR report detailing the chronology of the various event triggers. As seen in Figure 7, the Rollover event was reportedly "Incomplete."

For the 2015 model year Toyota Highlander, the battery is located on the driver side of the engine compartment. As crash test #9481 was offset to the driver's side, the battery was in the crush zone and damaged as a result of the crash. This crash related battery damage and subsequent power interruption is likely the reason the rollover event was not completely recorded. Figure 8 shows the location of the battery and post-crash damage for crash test #9481. The location of the battery has been outlined with a yellow line in the first image of Figure 8.

Results and Analysis

The data from the ACM in the EDR report contained data elements pertaining to the following parameters that were examined in this study:

- Safety Belt Status, Driver
- Safety Belt Status, Front Passenger
- Occupant Size Classification, Front Passenger
- Restraint Deployment Times
- Longitudinal Delta-V
- Lateral Acceleration at the Floor Sensor (Airbag ECU)

These values were compared to test documentation, photographs, video and reference instrumentation.

The EDR for this vehicle was configured with a floor sensor at the airbag ECU (under the center console), a side satellite sensor at the front door and a side satellite sensor at the C-pillar. Figure 9 shows the locations of reference instrumentation accelerometers (numbered 1 through 8) in the test vehicle. As seen in Figure 9, the airbag ECU is in the same general location as the reference accelerometer at the vehicle CG (#4), the rear sill reference accelerometers are near the c-pillar.

The test vehicle was stationary at impact, the pre-crash vehicle speed reported by the EDR correctly reported 0 km/h (0 mph) for both tests.

Seatbelt Status and Occupant Size Classification

In both tests, one 50% adult male THOR-NT anthropomorphic test device (ATD) was seated in the left front (driver) seating position, and one 50% adult male THOR-NT anthropomorphic test device was seated in the right front passenger seating position. Both of the ATDs were properly restrained with lap and shoulder belts, as seen in Figure 10. The EDR in the Toyota ACM correctly reported the safety belt status for both occupants. The EDR in the Toyota ACM also correctly reported the front passenger Occupant Size Classification as "AM50 (Not Child)." Excerpts from the EDR reports are shown in Figure 11.

FIGURE 9 Crash Test 9481: Engine Compartment/ Battery Damage

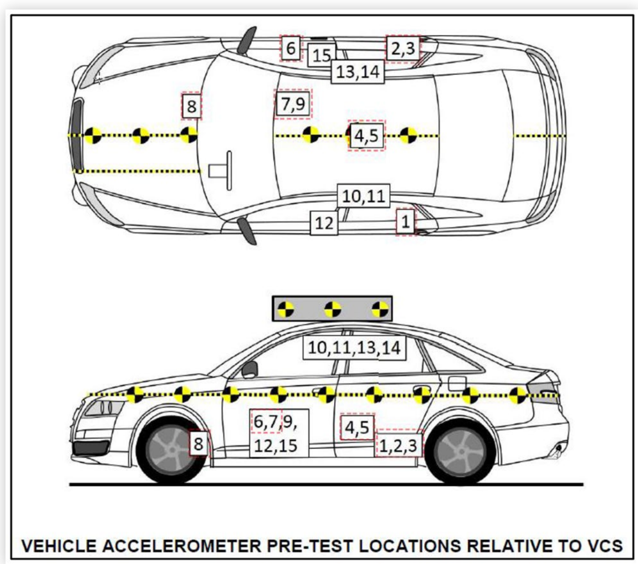


FIGURE 10 Occupant/Dummy Photographs (Test #9480 - Left, Test #9481 - Right)

FIGURE 11 EDR Excerpts: Safety Belt Status and Occupant Size Classification (Test #9480 - Top, Test #9481 - Bottom)

Pre-Crash Data, 1 Sample (Most Recent Event, TRG 4)

Recording Status, Pre-Crash/Occupant	Complete
Time from Pre-Crash to TRG (msec)	400
TRG Count when Pre-crash TRG was Established (times)	1
Safety Belt Status, Driver	ON
Safety Belt Status, Front Passenger	ON
Occupant Size Classification, Front Passenger	AM50 (Not Child)
Frontal Airbag Suppression Switch Status, Front Passenger	SNA
RSCA Disable Switch	SNA
Seat Track Position Switch, Foremost, Status, Driver	No
Airbag Warning Lamp, On/Off	OFF
Ignition Cycle ,Crash (times)	70

Pre-Crash Data, 1 Sample (Most Recent Event, TRG 2)

Recording Status, Pre-Crash/Occupant	Complete
Time from Pre-Crash to TRG (msec)	450
TRG Count when Pre-crash TRG was Established (times)	1
Safety Belt Status, Driver	ON
Safety Belt Status, Front Passenger	ON
Occupant Size Classification, Front Passenger	AM50 (Not Child)
Frontal Airbag Suppression Switch Status, Front Passenger	SNA
RSCA Disable Switch	SNA
Seat Track Position Switch, Foremost, Status, Driver	No
Airbag Warning Lamp, On/Off	OFF
Ignition Cycle ,Crash (times)	74

Deployments

As a result of the crash, the EDR reported deployments for the following supplemental restraints:

- Driver/Passenger Pretensioner
- Driver Airbag
- Passenger Airbag
- Driver Curtain-Shield Airbag (CSA)
- Passenger Curtain-Shield Airbag (CSA)
- Driver Side Airbag (SAB)
- Passenger Side Airbag (SAB)
- Driver 2nd Stage Airbag
- Passenger 2nd Stage Airbag

Figure 12 contains a sample from the EDR report in which the deployment commands are plotted along with the crash pulse for various event triggers. These deployment times are also explicitly stated in "System Status at Event" tables corresponding to each event in the EDR report.

These ACM reported deployments and deployment times were compared to crash test video, post-crash photographs and crash test instrumentation.

For these crash tests, an external sensor was installed that monitored electrical current versus time, and a "time to fire" was reported for various supplemental restraints. Figure 13 contains a sample of the data plots monitoring electrical current versus time for these restraint signal monitors. The "Time to fire" is listed in red in Figure 13.

FIGURE 12 EDR Report Excerpt: Deployment Time(s) and Crash Pulse (Test #9480 - Top, Test #9481 - Bottom)

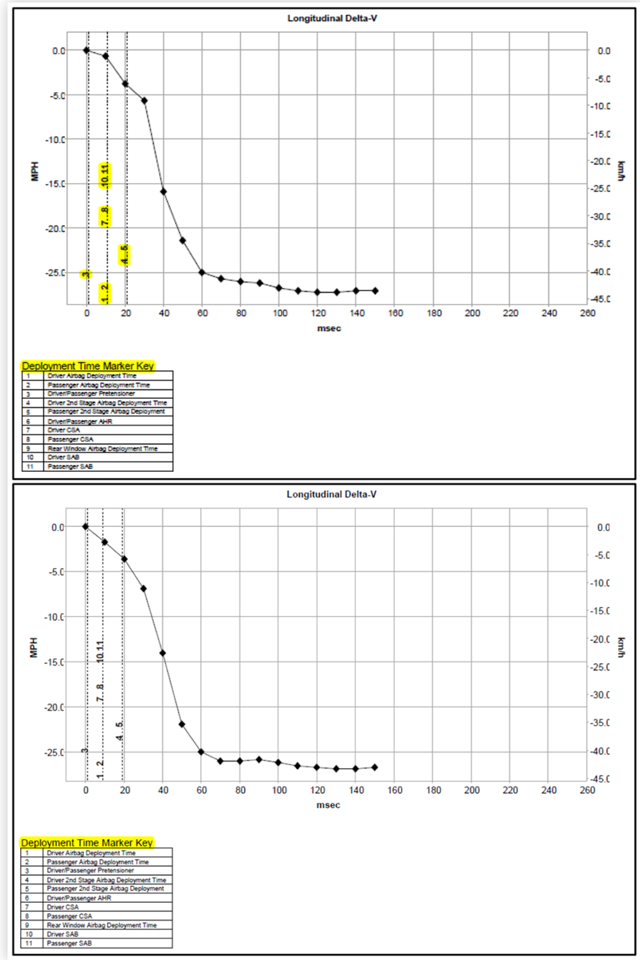
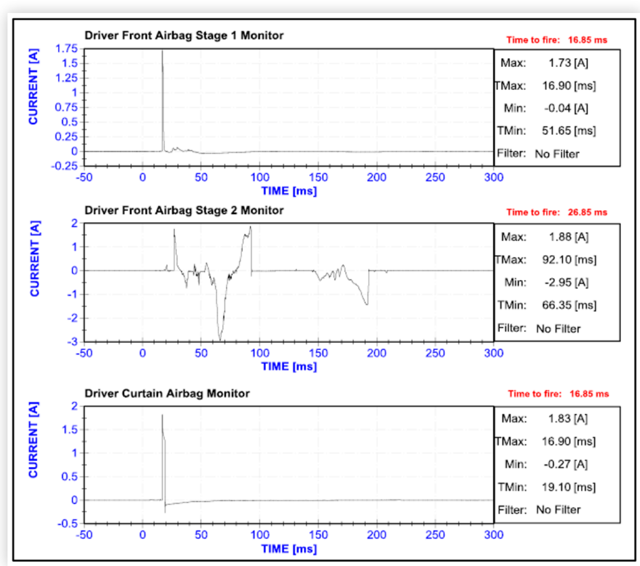


FIGURE 13 Reference Instrumentation Excerpt: Restraint Monitor (Test #9480)



For both tests, curtain shield airbag (CSA) and side airbag (SAB) deployment times were reported by the ACM for both the driver and passenger side of the vehicle (items 7 & 8, 10 & 11 in Figure 12). Furthermore, the reference instrumentation recorded a corresponding electrical signal that was received by these restraints. However, reviewing the video and post-crash photographs from each test, the curtain shield airbag (CSA) and side airbag (SAB) only physically deployed on the struck side; the passenger side for Test #9480 and the driver side for Test #9481. Since deployment commands were sent by the ACM and an electrical signal was received by the restraint, yet the CSA and SAB on the far (non-struck) side of the vehicle did not physically deploy, it appears that another signal (i.e. the closing of a safing sensor on the struck side) must be also received for these restraints to physically fire [14].

In Test #9481, the reference instrumentation contained restraint monitors for the passenger front airbag labeled Stages 1, 2, and 3. Whereas the EDR report only listed two stages for the passenger frontal airbag. It appears that the reference instrumentation contained redundant monitors for the passenger first stage airbag.

EDR report does not report a deployment time for the driver knee bolster airbags. In Test #9480, the reference instrumentation restraint monitor received a signal to deploy the driver knee bolster airbag at the same time the driver 1st stage frontal airbag was received. For Test #9481, there was no reference instrumentation restraint monitor for the knee bolster airbag.

Time Zero Alignment

Figure 13 is an example of reference instrumentation electrical current, versus time plots which report "Time to fire" for various restraints within the vehicle. This "Time to fire" is relative to contact between the two vehicles and the closing of a tape switch mounted in the contact zone.

However, the EDR does not have a similar tape switch to determine when contact is first made. According to the Data Limitations section of the EDR Generation 13 report, the EDR "time zero" is defined as:

> *"In frontal and rear collision events, the first point where a longitudinal cumulative delta-V of over 0.8 km/h (0.5 mph) is reached is regarded as time zero for the recorded data. In side impact collision and rollover events, the point in time at which the recording trigger is established is regarded as time zero for the recorded data."*

The EDR "time zero" is some time after the algorithm enable, or event trigger (TRG), in which the algorithm "woke up" and calculated a cumulative delta-V in excess of 0.8 km/h. Lee, et al. described the algorithm enable, or trigger threshold, to be the point at which the peak acceleration exceeded a value of approximately 2g [10]. Both the algorithm enable threshold and the "time zero" threshold criteria occur some time after contact between the two vehicles was made, closing the tape switch in the reference instrumentation.

To synchronize the EDR data and the reference instrumentation, a common point in time was needed. These common points were the restraint deployment times from the reference instrumentation and the EDR report. An "alignment time" was calculated by subtracting the EDR reported "Time from Time Zero to TRG" time, and EDR reported deployment time from the "Time to fire" from the reference instrumentation [1].

Figure 14 contains excerpts from the reference instrumentation and the EDR report that exemplify the calculation of the alignment time for test 9480.

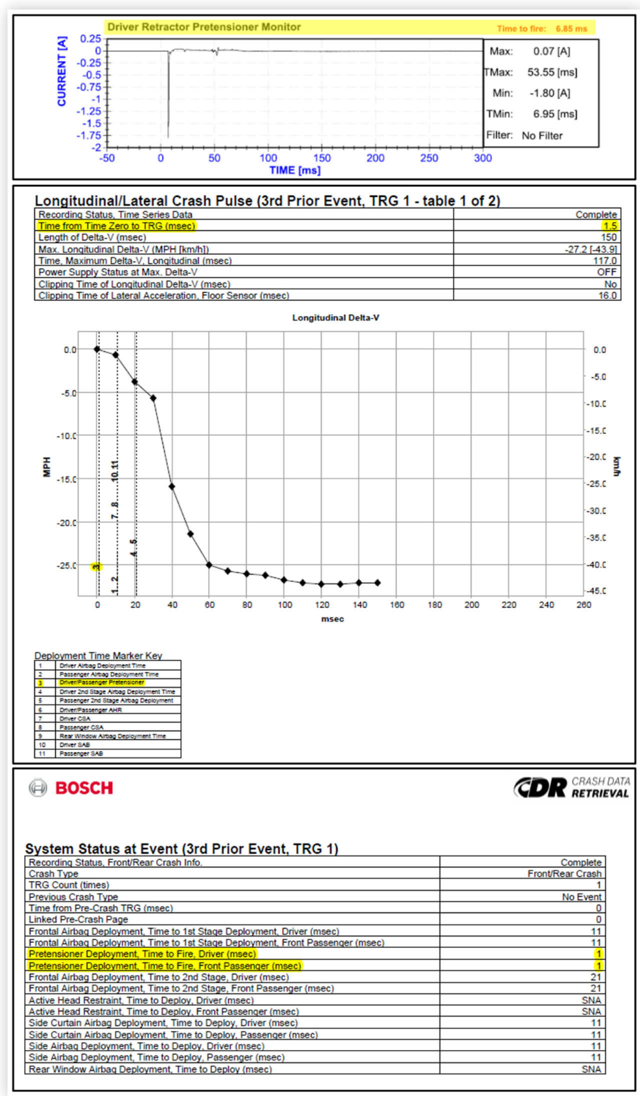
$$t_{alignment} = t_{deployment,ref} - \left('Time\ Zero\ to\ TRG'_{EDR} + t_{deployment,EDR} \right) \quad [1]$$

e.g: Driver Pretensioner deployment

$$t_{alignment} = 6.85\,ms - (1.5\,ms + 1\,ms)$$

This "alignment time" was calculated for each restraint deployment command from the EDR report and its corresponding deployment time from the reference instrumentation. This alignment time was calculated as 4.35 milliseconds for Test #9480 and 4.15 milliseconds for Test #9481.

FIGURE 14 Example Calculation: Alignment Time (Test #9480)



Longitudinal ΔV

As expected in an oblique frontal crash, the first triggering event (TRG 1) for each crash test was a Front/Rear Crash event. The EDR reported a longitudinal Delta-V versus time plot and data table for these events. This longitudinal Delta-V from the EDR was compared to integrated accelerometer data from the reference instrumentation. This accelerometer data was filtered with a Butterworth filter, Channel Filter Class (CFC) 60. A two-channel filter was run twice; once forwards and once backwards to prevent phase shift [15, 16]. Figure 15 and Figure 16 both show the Delta-V data from the EDR report versus the integrated reference accelerometer data for test 9480 and 9481, respectively.

As seen in Figure 15 and Figure 16, the longitudinal ΔV reported by the EDR slightly underreports the reference instrumentation. The error for each test is:

- Test #9480
  - EDR Reported Max. $\Delta V_{Long.}$: -43.9 km/h (-27.2 mph)
  - Reference Max. $\Delta V_{Long.}$: -44.3 km/h (-27.5 mph)
  - Max. $\Delta V_{Long.}$ Error: 0.4 km/h (0.3 mph)
  - Max. $\Delta V_{Long.}$ Percent Error: -0.9%
  - EDR Final $\Delta V_{Long.}$: -43.6 km/h (-27.1 mph)
  - Reference Final $\Delta V_{Long.}$: -43.8 km/h (-27.2 mph)
  - Final $\Delta V_{Long.}$ Error: 0.2 km/h (0.1 mph)
  - Final $\Delta V_{Long.}$ Percent Error: -0.5%
- Test #9481
  - EDR Reported Max. $\Delta V_{Long.}$: -43.3 km/h (-26.9 mph)
  - Reference Max. $\Delta V_{Long.}$: -44.5 km/h (-27.6 mph)
  - Max. $\Delta V_{Long.}$ Error: 1.2 km/h (0.74 mph)
  - Max. $\Delta V_{Long.}$ Percent Error: -2.7%
  - EDR Final $\Delta V_{Long.}$: -43.0 km/h (-26.7 mph)
  - Reference Final $\Delta V_{Long.}$: -44.1 km/h (-27.4 mph)
  - Final $\Delta V_{Long.}$ Error: 1.1 km/h (0.71 mph)
  - Final $\Delta V_{Long.}$ Percent Error: -2.6%

FIGURE 15 Longitudinal Delta-V (Test #9480)

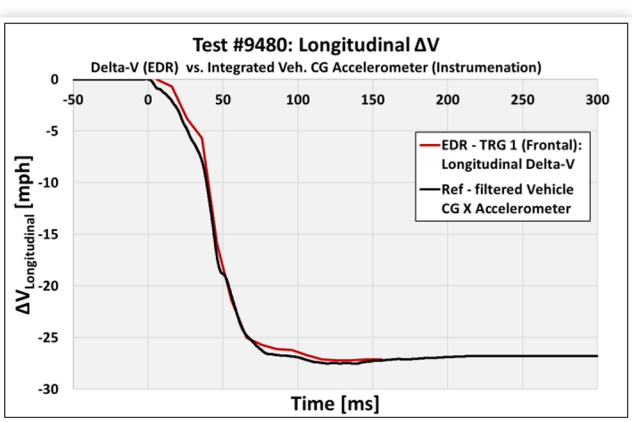
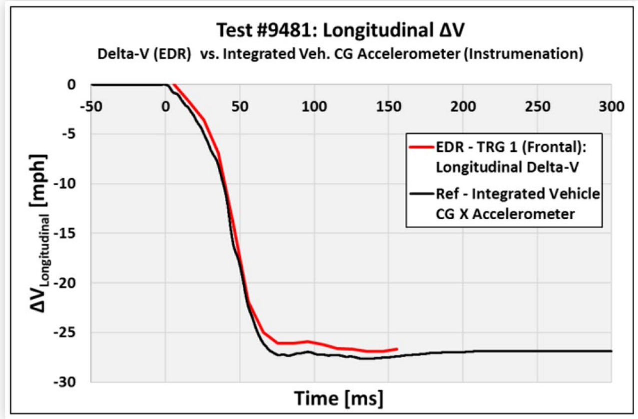


FIGURE 16 Longitudinal Delta-V (Test #9481)



The final longitudinal ΔV for the tests was found to be more accurate than previous frontal testing, which had an average absolute error of 4.2 km/h (6.6%) [2].

Lateral Acceleration

Unlike the longitudinal events, the Toyota generation 13EDR in the test vehicles did not report a Delta-V in Side Crash or Rollover events. For Side Crash and Rollover events, the lateral crash pulse or lateral accelerations at various sensors were reported. For this study, the EDR reported lateral crash pulse from the Floor Sensor/Airbag ECU sensor has been compared to the lateral accelerometer data from the reference instrumentation at the vehicle's center of gravity (aka the Vehicle CG-Y accelerometer).

Figure 16 contains a plot of the reference instrumentation lateral acceleration, versus the EDR reported lateral acceleration pulse for the Front/Rear (TRG 1) and Side Crash (TRG 2 and TRG 4) events for test #9480. The shape of the EDR reported lateral crash pulse generally correlates to the reference instrumentation but underestimate the peak accelerations.

As seen in Figure 16, the peak acceleration of approximately -300 m/sec^2 (-30.5 g) occurred at approximate 45 ms and a second, localized peak of approximately -33 m/sec^2 occurred at approximately 110 ms. TRG 1 and TRG 3 captured

FIGURE 16 Lateral Crash Pulse from Frontal and Side Crash Events (Test #9480)

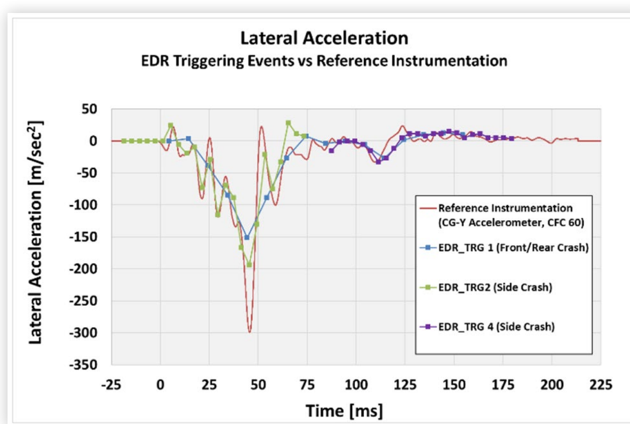
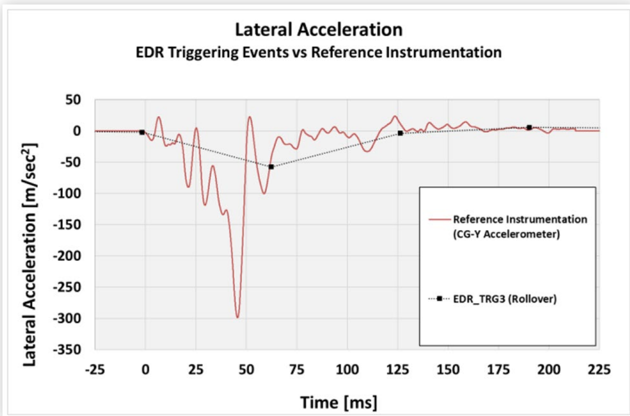


FIGURE 17 Lateral Crash Pulse from Rollover Event (Test #9480)

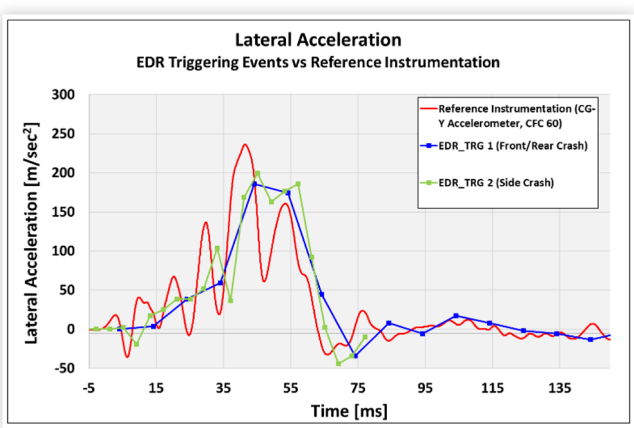


the general shape of the pulse but underreported the peak lateral acceleration by a percent error of approximately 49% and 35%, respectively. TRG 1 and TRG 4 also captured the general shape of the second, localized peak but underreported the lateral acceleration by a percent error of 19% and 1.4% respectively. This could be a result of sampling frequency, as the reference instrumentation records at 20,000 Hz, whereas the EDR reports lateral accelerations at 100 Hz for Front/Rear Crashes and 250 Hz for Side Crashes.

Figure 17 contains a plot of the lateral acceleration associated with the Rollover event (TRG 3). The lateral crash pulse from this trigger was reported by the EDR at approximately 15.6 Hz, or every 64 ms. At this reporting frequency, the peak acceleration was not captured. The percent error for this peak acceleration from TRG 3 was approximately -81%.

Figure 18 compares the EDR reported lateral accelerations to the reference instrumentation for Test #9481. As seen in Figure 18, the peak acceleration of approximately +235 m/sec^2 occurred at approximate 40 ms. TRG 1 (Front/Rear Crash) and TRG 2 (Side Crash) captured the general shape of the pulse, but underreported the peak lateral acceleration by a percent error of approximately 21% and 16%, respectively. As stated earlier, the Rollover event from crash test #9481 was not completely captured and did not report any lateral acceleration data.

FIGURE 18 Lateral Crash Pulse from Frontal and Side Crash Events (Test #9481)



While the EDR reported lateral crash pulse underestimated the peak lateral crash pulse for each test, the EDR report acknowledged clipping of lateral acceleration in each test. For Test #9480, the floor sensor reported 16.0 ms (TRG1) and 14.5 ms (TRG2) of clipping of lateral acceleration. For Test #9481, the floor sensor reported 8.5 ms (TRG 1) and 7.0 ms (TRG2) of clipping of lateral acceleration.

While the lateral ΔV was not explicitly reported by the EDR, it can be calculated from the EDR reported lateral crash pulse, and compared to calculations of lateral ΔV from the reference instrumentation over the same recording duration. The calculated maximum lateral ΔV and error for various triggering events in each test is:

- Test #9480
  - EDR Calculated Max $\Delta V_{Lateral}$ TRG1 (Front/Rear Crash): -14.9 km/h (-9.2 mph)
  - Reference Max $\Delta V_{Lateral.}$: -18.2 km/h (-11.3 mph)
  - Max $\Delta V_{Lateral}$ TRG1 (Front/Rear Crash) Error: 3.3 km/h (2.1 mph)
  - Max $\Delta V_{Lateral}$ TRG1 (Front/Rear Crash) Percent Error: -18.3%
  - EDR Calculated Max $\Delta V_{Lateral}$ TRG2 (Side Crash): -14.2 km/h (-8.8 mph)
  - Reference Max $\Delta V_{Lateral.}$: -16.6 km/h (-10.3 mph)
  - Max $\Delta V_{Lateral}$ TRG2 (Side Crash) Error: 2.4 km/h (1.5 mph)
  - Max $\Delta V_{Lateral}$ TRG2 (Side Crash) Percent Error: -14.6%
- Test #9481
  - EDR Calculated Max $\Delta V_{Lateral}$ TRG1 (Front/Rear Crash): 17.9 km/h (11.1 mph)
  - Reference Max $\Delta V_{Lateral.}$: 17.1 km/h (10.6 mph)
  - Max $\Delta V_{Lateral}$ TRG1 (Front/Rear Crash) Error: 0.8 km/h (0.5 mph)
  - Max $\Delta V_{Lateral}$ TRG1 (Front/Rear Crash) Percent Error: 4.8%
  - EDR Calculated Max $\Delta V_{Lateral}$ TRG2 (Side Crash): 18.4 km/h (11.4 mph)
  - Reference Max $\Delta V_{Lateral.}$: 17.1 km/h (10.6 mph)
  - Max $\Delta V_{Lateral}$ TRG2 (Side Crash) Error: 1.3 km/h (0.8 mph)
  - Max $\Delta V_{Lateral}$ TRG2 (Side Crash) Percent Error: 7.8%

For Test #9480, due to the reporting rate, the magnitude of the peak lateral acceleration was underreported and the calculated lateral ΔV underestimated the reference instrumentation by 14.6% to 18.3%.

For Test #9481, the reporting rate also lead to underreporting of the magnitude of the peak lateral acceleration. However, aliasing[1] resulted in the overreporting of the calculated lateral ΔV by 4.8 to 7.8%, as seen in Figure 17.

[1] https://zone.ni.com/reference/en-XX/help/371361P-01/lvanlsconcepts/aliasing/

The error in lateral ΔV calculated from EDR reported lateral crash pulse was comparable to the ranges of errors reported by Tsoi (2).

Summary/Conclusions

The findings in this paper are limited to the two crash tests that were analyzed. An analysis of the data reported by the two 2015 Toyota Highlanders equipped with the Toyota "Gen 13" EDR in a high severity frontal oblique offset crash tests revealed:

- The EDR correctly reported the Safety Belt Status.
- The EDR correctly reported the Occupant Size Classification for the right front seated location.
- The EDR correctly reported the deployment times for supplemental restraints. However, some restraints (i.e. far side SAB and CSA) may be commanded to deploy by the ACM, but likely require a redundant signal to fire.
- The EDR reported Longitudinal ΔV may be slightly underreported but compared favorably to reference instrumentation (percent error between -0.5% to -2.6%).
- As reported, the Lateral Accelerations do not appear to report at high enough sampling rates to capture peak accelerations. For Test #9480, the reporting rate of lateral acceleration resulted in the EDR underreporting the calculated lateral ΔV by -14.6 to 18.3%. However, the reporting rate in test #9481 resulted in aliasing, which overreported the calculated lateral ΔV by 4.8 to 7.8%.

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