U.S. Department
of Transportation
National Highway
Traffic Safety
Administration

www.nhtsa.gov

DOT HS 811 015 August 2008

Preliminary Evaluation of Advanced Air Bag Field Performance Using Event Data Recorders

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
DOT HS 811 015	August 2008	Final Report April 2006 – December 2007

4. TITLE AND SUBTITLE	5. FUNDING NUMBERS
Preliminary Evaluation of Advanced Air Bag Field Performance Using Event Data Recorders	HS50/DG048
6. AUTHOR(S) H. Clay Gabler (Virginia Tech), Craig P. Thor (Virginia Tech), and John Hinch (NHTSA)	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Research and Innovative Technology Administration Volpe Center Cambridge, MA 02142	8. PERFORMING ORGANIZATION REPORT NUMBER DOT-VNTSC-NHTSA-08-02
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation National Highway Traffic Safety Administration 1200 New Jersey Avenue SE. Washington, DC 20590	10. SPONSORING/MONITORING AGENCY REPORT NUMBER DOT HS 811 015

11. SUPPLEMENTARY NOTES

Organization contracting to RITA/VNTSC: Virginia Tech, Department of Mechanical Engineering, Blacksburg, VA 24060

12a. DISTRIBUTION/AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
This report is free of charge from the NHTSA Web site at www.nhtsa.dot.gov	

13. ABSTRACT (Maximum 200 words)

This report describes a preliminary evaluation of the field performance of occupant restraint systems designed with advanced air bag features including those specified in the Federal Motor Vehicle Safety Standard No. 208 for advanced air bags, through the use of event data recorders. Although advanced restraint systems have been extensively tested in the laboratory, we are only beginning to understand the performance of these systems in the field. Because EDRs record many of the inputs to the advanced air bag control module, these devices can provide unique insights into the characteristics of field performance of air bags. This research program investigates the feasibility of using EDR data to evaluate advanced air bags. Specifically, this report discusses (1) the development of an expanded EDR dataset based on data retrieved from NASS/CDS 2005, SCI, and CIREN in-depth crash investigations, (2) the validation of the accuracy of EDRs in full-scale crash tests, and (3) the feasibility of using EDRs to monitor the performance of advanced air bag restraints in real-world crashes.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Event data recorder, traffic crash, air bag	68
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

Acknowledgments

The authors wish to acknowledge the U.S. Department of Transportation's Volpe National Transportation Systems Center (Volpe Center) and National Highway Traffic Safety Administration for their support of this research effort. Specifically, we would like to thank Marco daSilva of the Volpe Center.

Special thanks to the Insurance Institute for Highway Safety and NHTSA for contributing the EDRs data from their crash tests for this study. Thanks to Ford and Toyota for retrieving the data from EDRs that the research team could not download with the Vetronix Crash Data Retrieval System. We also wish to acknowledge the crash test organizations that harvested and collected the NHTSA EDRs for this study: Transportation Research Center (East Liberty, OH), Karco Engineering (Adelanto, CA), MGA Research Corporation (Akron, NY), and CALSPAN (Buffalo, NY). Finally, thanks to Ashley Thompson, our Virginia Tech undergraduate research assistant, for her help in the organization and analysis of the EDR data.

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1. Introduction and Background

In the United States, automakers have introduced a new generation of advanced occupant restraints in response to the requirements of the Federal Motor Vehicle Safety Standard (FMVSS) No. 208 upgrade (65 FR 30680). These advanced systems are characterized by multistage air bag inflators, pretensioners, advanced occupant sensors, and complex air bag deployment algorithms. Air bags in those vehicles certified to the FMVSS No. 208 upgrade are referred to in this report as certified advanced compliant (CAC) air bags.

Although these systems have been extensively tested in the laboratory, we are only beginning to understand the performance of these CAC air bags in the field. Because event data recorders (EDRs) record many of the inputs to the advanced air bag control module, these devices can provide unique insights into the performance of air bags in real world crashes.

This research program uses EDR data to investigate the feasibility of using EDR data to evaluate advanced air bags. Specifically, this report discusses (1) the development of an expanded EDR dataset, (2) the validation of the accuracy of EDRs in full-scale crash tests, and (3) the feasibility of using EDRs to monitor the performance of advanced air bag restraints in real-world crashes.

2. Development of the EDR Dataset

Objective

The objective of this task was to develop a dataset of all available EDR data from NASS/CDS 2000-2005, Special Crash Investigation (SCI), and CIREN in-depth crash investigation cases. This dataset was the basis for a comprehensive EDR study conducted by researchers at the Volpe Center (daSilva, 2008).

Approach

Our earlier EDR studies have relied on EDR data from NASS/CDS 2000-2004 (Gabler & Niehoff, 2005). The objective of this effort was to expand this EDR dataset to include NASS/CDS 2005, Special Crash Investigation (SCI) cases and CIREN cases. NHTSA supplied the research team with all available EDR data for NASS/CDS 2005, SCI, and CIREN cases with EDR data.

For each case in the dataset, NHTSA crash investigators had downloaded EDR data from the case vehicle using the Vetronix Crash Data Retrieval (CDR) system. At the time of this report, the Vetronix system could only download General Motors (GM) and Ford EDRs. The Vetronix system displays the contents of the EDR, and outputs a CDR file containing the EDR data in binary form. The CDR files are small (typically a few thousand bytes), can be read again by the Vetronix software, are check-summed to prevent tampering, and provide an excellent method for archiving EDR data.

CDR files are the most reliable form of EDR data, and were the exclusive basis for our development of the EDR dataset. For each case, the research team read each CDR file using the Vetronix CDR software, converted the EDR data into a usable format, and when possible matched each CDR file with the corresponding crash investigation case.

The research team followed a very stringent process in matching the EDR data for each case with the corresponding crash investigation case. For a case to be included in the dataset, we required an exact match of both the case ID (case year, PSU, and case number) and the Vehicle Identification Number (VIN). The name of each CDR file typically contained the case year, PSU, and case number. There was no standard format however for these file names. The CDR file itself contained the full 17-character Vehicle Identification Number (VIN) of the vehicle. The NASS/CDS SAS files only store the first 11 characters of the VIN in order to protect the privacy of the vehicle occupants. Consequently, VIN matching was conducted using the first 11 characters of the VIN. The entire process could only be conducted for NASS/CDS data as only this database was publicly available in a SAS format. This matching method could not be applied to the SCI and CIREN cases as no such SAS files were available.

Results

As shown in Table 1 below, the result was an EDR dataset containing over 2,500 cases.

Table 1. NHTSA EDR Cases by Database

Database	Years	GM Cases	Ford Cases	Total
NASS/CDS	2000-2005	2,283	69	2,352
SCI	2000-2005	125	8	133
CIREN	2002-2005	56	2	58
Total		2,464	79	2,543

Over 90 percent of the cases in the resulting EDR dataset were from NASS/CDS. Almost the entire dataset consists of EDRs from GM vehicles. Only 79 cases in the EDR data were from Ford vehicles.

DaSilva (2008) presents a comprehensive examination of the contents of the expanded EDR dataset. This description will not be repeated in this report. Rather our report will focus on the validity of EDR data as measured in full systems crash tests, and the use of the expanded EDR dataset to examine the performance of advanced air bags in real world crashes.

3. EDR Validation in Full-Systems Crash Tests

Introduction

Before using EDR data to study advanced air bag performance, a key first step was to establish the validity of EDR delta V measurements. Several previous studies have investigated the accuracy of EDRs in earlier model passenger vehicles. The studies can be divided into two groups: low-speed non-deployment evaluations and higher-speed crashes in which the air bag deployed. Accuracy has been found to be very good at the higher speeds (greater than 40 km/hr) typically associated with serious occupant injuries.

Chidester et al. (2001) investigated the accuracy of GM EDRS in MY 1998-era vehicles. Chidester found that in full systems crash tests the EDRs frequently under reported the delta V by a small amount and that some EDR delta V data was incomplete. The paper did not specify the magnitude of this small error or whether the underestimation of delta V was due to incomplete recording. In a large series of low speed tests, Lawrence et al. (2003) also found that GM EDRs understated delta V by a small amount. Comeau et al. (2004) examined the EDRs of three different GM vehicle models involved in eight crash tests and reported the tests to have a delta V error of +/- 10 percent. Niehoff et al. (2005) examined the accuracy of 37 GM, Toyota, and Ford vehicles of MY 2000-2005 in a variety of impact scenarios including full frontal, offset frontal, side impact, and vehicle-to-vehicle angled crash tests. The EDRs in this sample were reported to have an average error of 6 percent for the delta V when the entire crash pulse is recorded. Niehoff reported that the EDRs in his sample frequently did not record the entire event.

Objective

The objective of this section is to examine the accuracy of EDR data in a range of crash test scenarios for model year 2004-2007 cars and light trucks.

Approach

This study examines the accuracy of EDR data downloaded from 48 crash-tested vehicles. Our approach was to evaluate the accuracy of the EDR data by comparison with the corresponding lab-grade instrumentation data from the crash test. Crash tests from both the National Highway Traffic Safety Administration (NHTSA) and the Insurance Institute for Highway Safety (IIHS) were included. Approximately two-thirds of the EDRs in the sample (31 of 48) were from CAC-equipped restraint systems. Table 2 details the crash tests used in this analysis including make, model, crash configuration, impact speed, and testing organization.

Table 2. Crash Tests Included in the Analysis and the Corresponding EDR

Test Number	Vehicle Description	Test Performer	Test Type	Closing Speed (mph)	Impact Angle (deg)	Test Offset (%)	Barrier	CAC	EDR Model
5310	2005 Buick Rendezvous	NHTSA	Full Frontal	34.9	0	0	Rigid	Y	SDMDW2003
5282	2005 Chevrolet Colorado	NHTSA	Full Frontal	35.2	0	0	Rigid	N	SDMGF2002
5265	2005 Chevrolet Express	NHTSA	Full Frontal	34.9	0	0	Rigid	N	SDMGF2002
5324	2005 Pontiac Montana	NHTSA	Full Frontal	34.8	0	0	Rigid	Y	SDMDW2003
5260	2005 Saturn Ion	NHTSA	Side Impact	38.4	270	0	MDB	N	SDMDW2003
5318	2005 Chevrolet Silverado	NHTSA	Full Frontal	34.9	0	0	Rigid	Y	SDMGF2002
5264	2005 Chevrolet Uplander	NHTSA	Full Frontal	34.9	0	0	Rigid	Y	SDMDW2003
5326	2005 Chevrolet Cobalt	NHTSA	Full Frontal	34.9	0	0	Rigid	N	Epsilon
5603	2006 Chevrolet Colorado	NHTSA	Full Frontal	34.9	0	0	Rigid	Y	SDMGF2002
5597	2006 Chevrolet Colorado	NHTSA	Full Frontal	34.8	0	0	Rigid	Y	SDMGF2002
5468	2006 Pontiac Grand Prix	NHTSA	Full Frontal	35.1	0	0	Rigid	N	SDMDW2003
5589	2006 Buick Lucerne CX	NHTSA	Full Frontal	35.1	0	0	Rigid	Y	SDMC2006
5602	2006 Chevrolet HHR	NHTSA	Full Frontal	34.9	0	0	Rigid	Y	Epsilon2006
5547	2006 Chevrolet Impala	NHTSA	Full Frontal	35.2	0	0	Rigid	Y	SDMC2006
5250	2005 Pontiac G6	NHTSA	Full Frontal	35.3	0	0	Rigid	N	Epsilon2005
5140	2004 Chevrolet Avalanche	NHTSA	Full Frontal	35.0	0	0	Rigid	Y	SDMGF2002
5213	2004 Chevrolet Avalanche	NHTSA	Full Frontal	30.1	0	0	Rigid	Y	SDMGF2002
5741	2006 Buick Lucerne	NHTSA	Full Frontal	24.7	0	0	Rigid	Y	SDMC2006
5578	2006 Chevrolet Monte Carlo	NHTSA	Full Frontal	35.0	0	0	Rigid	N	SDMC2006
5569	2006 Cadillac DTS	NHTSA	Full Frontal	35.2	0	0	Rigid	Y	SDMC2006
5567	2006 Hummer H3	NHTSA	Full Frontal	35.0	0	0	Rigid	Y	SDMDS2005
5830	2006 Pontiac G6	NHTSA	Full Frontal	24.7	0	0	Rigid	N	Epsilon2006
5907	2007 Chevrolet Silverado	NHTSA	Full Frontal	35.1	0	0	Rigid	Y	SDMC2006
5844	2007 Saturn Aura	NHTSA	Full Frontal	35.1	0	0	Rigid	Y	Epsilon2006
5859	2007 Pontiac Solstice	NHTSA	Full Frontal	35.0	0	0	Rigid	Y	Epsilon2006
5877	2007 Chevrolet Silverado	NHTSA	Full Frontal	34.8	0	0	Rigid	Y	SDMC2006
CF05003	2004 Chevrolet Malibu	IIHS	Pole	39.7	0	15	Pole	N	Epsilon

Test Number	Vehicle Description	Test Performer	Test Type	Closing Speed (mph)	Impact Angle (deg)	Test Offset (%)	Barrier	CAC	EDR Model
CEF0419	2005 Saturn Ion	IIHS	Frontal Offset	40.0	0	40	Deformable	N	N/A
CEF0506	2005 Chevrolet Colorado	IIHS	Frontal Offset	39.8	0	40	Deformable	N	N/A
CEF0511	2005 Buick LaCrosse	IIHS	Frontal Offset	40.0	0	40	Deformable	Y	N/A
5249	2005 Ford 500	NHTSA	Full Frontal	35.3	0	0	Rigid	Y	N/A
5263	2005 Ford Freestyle	NHTSA	Full Frontal	35.1	0	0	Rigid	Y	N/A
5284	2005 Ford Econoline	NHTSA	Full Frontal	35.0	0	0	Rigid	N	N/A
4928	2004 Toyota Camry	NHTSA	Side Impact	38.4	270	0	MDB	Y	89170-33300
5283	2005 Toyota Camry	NHTSA	Full Frontal	35.1	0	0	Rigid	Y	89170-06260*4-(89170-33310)
5160	2005 Toyota Corolla	NHTSA	Full Frontal	35.1	0	0	Rigid	Y	89170-02420
5157	2005 Toyota Corolla	NHTSA	Side Impact	38.6	270	0	MDB	Y	89170-02410
5209	2005 Toyota Matrix	NHTSA	Full Frontal	35.1	0	0	Rigid	Y	89170-01070
5162	2005 Toyota Matrix	NHTSA	Side Impact	38.6	270	0	MDB	Y	89170-01060
4893	2004 Toyota RAV4	NHTSA	Full Frontal	35.3	0	0	Rigid	N	89170-42160
5269	2005 Toyota Sienna	NHTSA	Full Frontal	35.0	0	0	Rigid	Y	89170-08070
4733	2004 Toyota Sienna	NHTSA	Side Impact	38.2	270	0	MDB	N	89170-08050
5312	2005 Toyota Tacoma	NHTSA	Full Frontal	34.9	0	0	Rigid	Y	89170-04070
5037	2004 Toyota 4Runner	NHTSA	Full Frontal	34.9	0	0	Rigid	N	89170-35190
4933	2004 Toyota Prius	NHTSA	Full Frontal	35.4	0	0	Rigid	N	89170-47380
5218	2005 Toyota Tundra	NHTSA	Full Frontal	35.0	0	0	Rigid	Y	89170-0C160
5239	2005 Toyota Tundra	NHTSA	Full Frontal	35.0	0	0	Rigid	Y	89170-0C190
5217	2005 Toyota Scion TC	NHTSA	Full Frontal	34.9	0	0	Rigid	N	89170-21070

Note: MDB = Movable Deformable Barrier

Results

Table 3 provides a summary of the types of tests from which EDR data was downloaded. The tests were conducted at test speeds ranging from 25 mph to 40 mph. The majority of tests (39 of 48) were full-frontal, rigid-barrier tests performed primarily at 35 mph. The sample also included three 40 percent offset-frontal deformable barrier tests conducted at 40 mph and one 15 percent offset pole test performed at 40 mph. In the five side impact tests, the subject vehicle was struck by a moving deformable impactor at a speed of 38 mph.

EDRs for this study were downloaded from General Motors, Toyota, and Ford vehicles as shown in Table 3. Model years ranged from 2004 to 2007 as shown in Table 4. Most of the EDRs in the sample were from GM vehicles (30 of 48). Over half of the vehicles were from model year 2005 (25 of 48). As shown in Table 5, approximately two-thirds of the EDRs in the sample (31 of 48) were from CAC-equipped restraint systems.

Table 3. Distribution of EDRs in Crash Tests by Test Sponsor and Test Type

Agency	Test Type	Impact Speed (mph)	Number of Cases
NHTSA	Full Frontal Rigid Barrier	35	37
	Full Frontal Rigid Barrier	30	1
	Full Frontal Rigid Barrier	25	1
	Side Impact	38	5
IIHS	40% Frontal Offset	40	3
	15% Offset Pole	40	1
Total			48

Table 4. Distribution of EDRs in Crash Tests by Model Year

Model Year	Number of Cases
2004	8
2005	25
2006	11
2007	4
Total	48

Table 5. Distribution of EDRs in Crash Tests by Vehicle Make and Air Bag Type

Vehicle Make	Non-CAC	CAC	Total
General Motors	11	19	30
Toyota	5	10	15
Ford	1	2	3
Total	17	31	48

GM EDRs from NHTSA tests were downloaded by the research team using the Vetronix Crash Data Retrieval System. IIHS downloaded and provided the EDR data from four of their tests for this study. The EDRs from the Ford and Toyota tests included in this analysis were harvested from the vehicle and sent to the respective companies to be downloaded.

The GM EDRs recorded delta V every 10 ms for recording durations ranging from 100-240 ms. The Ford EDRs recorded both acceleration and delta V every 1 ms for durations up to 209 ms. One model of the Toyota EDR was observed to record every 10 ms for up to 150 ms, while a second Toyota EDR model was observed to record at 10.2 ms intervals for a 154 ms duration.

The crash test data for comparison with the EDR data was obtained from the NHTSA and IIHS crash test databases. The NHTSA crash test data was analyzed using the NHTSA Signal Browser software. Accelerometers mounted within the occupant compartment of each vehicle were selected for comparison with the EDR. The EDR is located within the passenger compartment, often under the front seat or in the center console. All comparisons used accelerometers aligned with the longitudinal axis of the vehicle. An assessment of EDR lateral delta V was not possible as none of the EDRs in side-impact tests recorded lateral delta V. Vehicle acceleration data for the IIHS tests was accessed through the IIHS Tech Data site. The IIHS database did not identify the location of the sensor in the crash.

<u>Time-Shifting of EDR Delta V Data</u>

Air bag deployment is controlled using a microprocessor. Typically vehicle acceleration, often measured at a central vehicle location and near the front of the vehicle, is processed to determine when the vehicle's frontal air bags should be deployed as well as which air bag stage should be used. The air bag processor "wakes up" after it senses a predetermined acceleration threshold has been exceeded. This wake-up is defined as algorithm enable (AE) (Chidester et al, 1999). After AE occurs, the processor continues to monitor and analyze the vehicle's deceleration profile and determines if and when the air bags should be deployed. The time the processor deploys the air bags is often referred to as air bag deployment time and is referenced to AE as a time zero. For instance, if the air bags deployed 25 milliseconds (msec) after AE, common notation would consider this an air bag deployment time of 25 msec.

For an EDR, time zero is the time of algorithm enable or algorithm wakeup. Algorithm enable typically occurs only after the EDR has measured 1-2 G's deceleration – typically a few milliseconds after impact in a frontal barrier crash. One consequence of this recording delay is that because algorithm enable does not happen immediately, a small change in velocity – typically 1 to 2mph – is not recorded. Finally, GM EDRs record for up to 50 ms prior to the air bag triggering.

The crash test data and the EDR data were overlaid on a plot for qualitative comparison. As shown in Figure 1, time zero for the EDR records frequently did not coincide with time zero for the crash test instrumentation. A time shift of the EDR data was required to allow comparison with the crash test instrumentation. The time shifting was conducting manually for each test by visually aligning the EDR data with the crash test data. Improved time shifting may be possible using a numerical technique such as that developed by Niehoff (2005). A vehicle velocity versus time plot containing both the EDR and crash test curves were created for each of the crash tests and are presented in the appendices.

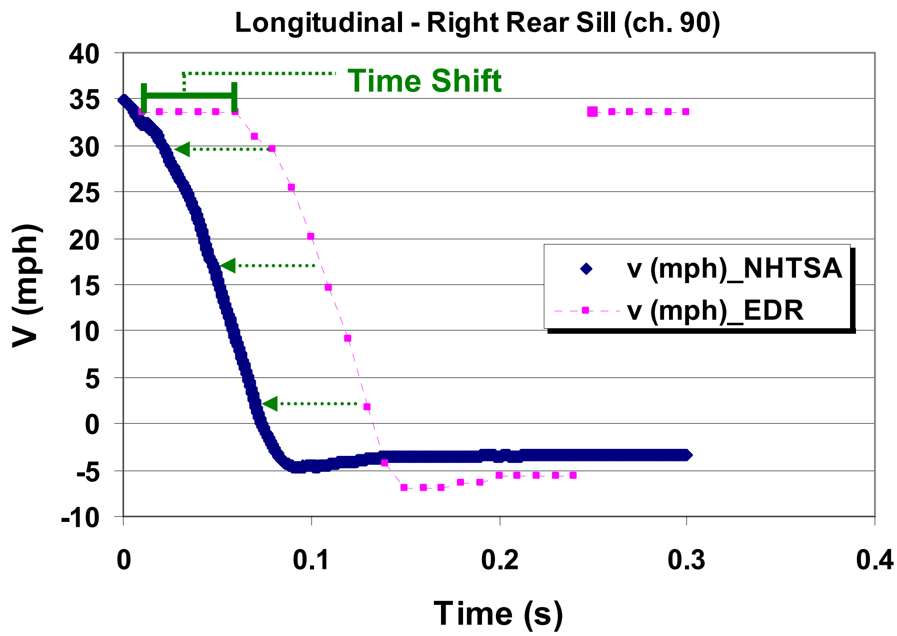

Figure 1. Comparison of Vehicle Velocity versus Time Computed from Crash Test Instrumentation with Associated EDR Data (NHTSA Test 5602)

Crash Pulse Duration

Each of the crash tests was analyzed to determine whether the entire crash pulse was recorded. Most crash pulses in our sample had duration of approximately 100-150 ms. Crash pulse duration was defined to be the time interval between the time of initial impact and the time of maximum delta V. The length of the crash pulse is a strong function of the crash test type. An IIHS 40 percent offset crash test, for example, can last over 200 ms while an NCAP full frontal rigid barrier crash may only last 100-120 ms. Table 6 reveals that the longest crash pulse for a longitudinal impact was indeed an IIHS offset test (204 ms). Hence, an EDR that only has a recording time of 100-150 ms may be missing a large portion of the crash information.

Table 6. Summary of EDR Accuracy Based on Comparison with Crash Tests

Test Number	EDR Max Delta V (mph)	Crash Test Max Delta V (mph)	Max Delta V Error (%)	EDR Delta V @100 ms (mph)	Crash Test Delta V @100 ms (mph)	Delta V Error @ 100ms (%)	Lateral Delta V Recorded (Y/N)	EDR Time Shift (ms)	EDR Recording Time (ms)	Crash Pulse Duration Estimated (ms)	Crash Pulse Duration Error (%)
5310	38.2	39	2%	38.2	37.3	-2%	-	3.5	100	123	-23%
5282	36.6	37.9	3%	35.3	36.9	4%	-	7	100	81	None
5265	35.3	37.7	6%	35.3	36.1	2%	-	3	100	121	-21%
5324	34.2	39.4	13%	34.2	37.5	9%	-	0	100	141	-41%
5260	4.4	4.4	0%	4.0	3.73	-6%	-	0	120	84	None
5318	35.7	41.8	15%	35.7	38.4	7%	-	5	100	140	-40%
5264	36.9	37.8	2%	36.9	37.7	2%	-	2	100	102	-2%
5603	34.4	38.1	10%	33.8	37.2	9%	-	0	100	118	-18%
5597	35.8	38	6%	34.7	37.4	7%	-	5	100	112	-12%
5468	39.1	39.5	1%	37.7	37.9	0%	-	0	110	112	-2%
5589	39.2	39.4	1%	38.5	38.7	1%	Y	56	120	119	None
5602	40.7	39.5	-3%	40.7	39.5	-3%	Y	60	170	93	None
5547	39.2	39.9	2%	37.8	38.1	1%	Y	57.9	170	122	None
5250	41.4	39.5	-5%	41.4	39.5	-5%	Y	48.9	160	95	None
5140	35.0	38.5	9%	37.5	37.3	-1%	-	0	100	141	-41%
5213	30.1	33.9	11%	31.0	32.4	4%	-	0	100	144	-44%
5741	27.1	26.8	-1%	25.7	24.3	-6%	Y	58	120	122	-2%
5578	38.5	39.2	2%	37.8	37.3	-1%	Y	60	180	121	None
5569	39.2	39.4	1%	39.2	39.2	0%	Y	70	230	101	None
5567	37.6	38.8	3%	36.3	37.4	3%	Y	50	240	147	None
5830	28.5	28.2	-1%	28.5	27.5	-4%	Y	48	150	110	None
5907	35	38.5	9%	38.8	40.3	4%	Y	60	240	110	None
5844	42.7	41.7	-2%	42.7	41.1	-4%	Y	50	110	110	None

Test Number	EDR Max Delta V (mph)	Crash Test Max Delta V (mph)	Max Delta V Error (%)	EDR Delta V @100 ms (mph)	Crash Test Delta V @100 ms (mph)	Delta V Error @ 100ms (%)	Lateral Delta V Recorded (Y/N)	EDR Time Shift (ms)	EDR Recording Time (ms)	Crash Pulse Duration Estimated (ms)	Crash Pulse Duration Error (%)
5859	42.7	41.0	-4%	42.7	40.9	-4%	Y	50	110	104	None
5877	40.0	39.7	-1%	40.0	38.2	-5%	Y	60	110	105	None
5326	40.0	39.8	-1%	40.0	39.3	-2%	Y	50	150	145	None
CEF5003	46.1	43.4	-6%	43.3	40.4	-7%	Y	45	230	128	None
CEF0419	35.1	42.8	18%	30.2	31.2	3%	-	0	120	184	-53%
CEF0506	34.7	43.8	21%	31.0	29.9	-4%	-	0	128	204	-59%
CEF0511	34.1	42.8	20%	28.9	27.8	-4%	-	0	113	155	-37%
5249	39.4	39.7	1%	39.4	39.5	0%	Y	0	209	95	None
5263	39.9	39.9	0%	39.5	39.5	0%	Y	0	209	110	None
5284	39.4	39.7	1%	39.3	39.6	1%	Y	0	209	104	None
4928	2.5	1.6	-56%	2.1	1.15	-83%	-	0	150	93	None
5283	35.3	36.2	2%	35.3	35.7	1%	-	0	150	106	None
5160	37.6	38.3	2%	37.4	38.1	2%	-	0	153.6	105	None
5157	3.9	4.3	9%	3.3	4.1	20%	-	0	153.6	64	None
5209	37.4	38.0	2%	37.0	38.0	3%	-	0	153.6	102	None
5162	3.5	4.9	29%	2.8	3.7	25%	-	0	153.6	79	None
4893	40.3	37.3	-8%	39.9	36.7	-9%	-	0	150	89	None
5269	36.5	38.2	4%	35.8	37.7	5%	-	0	150	109	None
4733	2.5	2.6	4%	1.8	2.4	24%	-	0	150	106	None
5312	34.4	36.9	7%	34.0	36.7	7%	-	0	153.6	118	None
5037	38.5	38.5	0%	38.3	38.2	0%	-	0	150	114	None
4933	42.0	38.7	-9%	42.0	38.3	-10%	-	0	150	91	None
5218	36.0	38.4	6%	36.0	38.4	6%	-	0	153.6	101	None
5239	29.5	37.7	22%	29.0	37.5	23%	-	0	150	107	None
5217	43.4	39.1	-11%	43.4	38.8	-12%	-	0	150	90	None

As shown in Figure 2, 14 of 48 EDRs (29.2%) did not record the entire event. This is an improvement however over the findings of the Niehoff study that reported that the majority of the EDRs in its samples did not successfully record the entire event. The worst case was IIHS frontal offset test CEF056 of a 2005 Chevrolet Colorado. In this test, only the first 128 ms of the 204-ms-long crash pulse was recorded by the EDR.

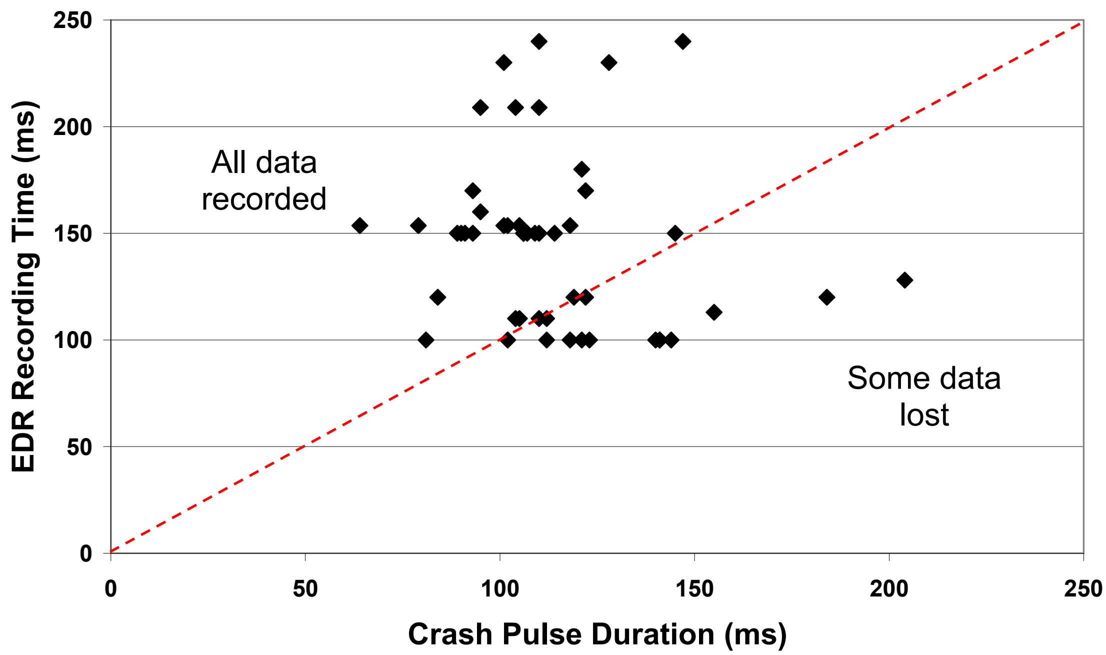

Figure 2. EDR Recording Duration versus Actual Crash Pulse Duration

It should be noted that maximum crash pulse recording duration is simply a function of the amount off computer memory onboard each EDR. The older GM EDRs in our dataset had sufficient memory to store only up to 150 ms of the crash pulse. The GM algorithm in these modules however called for only storing up to 100 ms after air bag triggering. This constraint led to many of the pulse durations below 150 ms. We note that the latest generation GM EDRs can now store up to 300 ms of the crash pulse. We anticipate that this ability to store longer crash pulses will be extended to other GM models as the price of computer memory continues to drop.

Accuracy of EDR Delta V measurements

EDRs that do not record the entire event will underestimate the delta V not because of sensor inaccuracy, but because of recording capacity. To get a better measure of measurement accuracy, we first restricted our analysis to those tests for which the EDR recorded the entire crash pulse or were missing no more than 2 percent of the crash data. In these cases, the EDRs were successful at recording with a significant amount of accuracy as compared to the test instrumentation.

As shown in Figure 3, EDR delta V underestimates true delta V by under 0.5 percent on average for crash pulses that were completely recorded by the EDR. The correlation between EDR delta V and true delta V for this dataset is very high with R^2 = 0.9725. It should be noted that this dataset of complete EDR recordings contains full frontal barrier crash tests, the longitudinal delta V component of side-impact crash tests and a single frontal pole tests. The dataset does not include any frontal-offset crash tests.

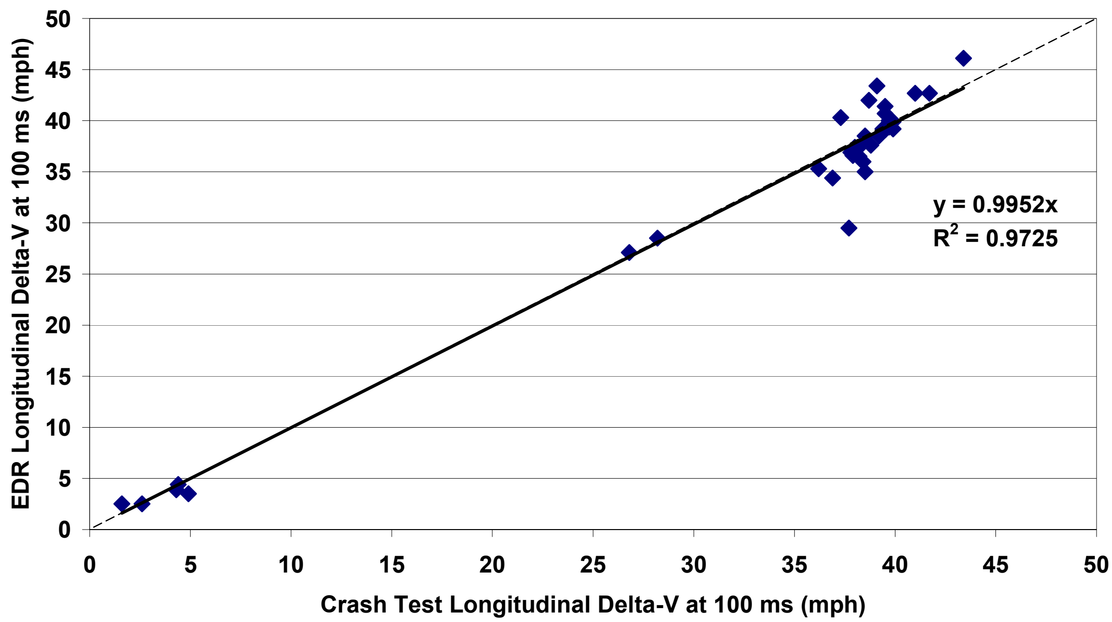

Figure 3. EDR Longitudinal Delta V versus Crash Test Delta V Over Full Crash Pulse Duration

To compare the accuracy of the EDR for all tests, rather than just those tests in which the entire event was recorded, the EDR delta V and crash test delta V were next compared t=100 ms. All EDRs in our dataset recorded at least 100 ms. The analysis at t=100 ms from the EDR included the time shift for each respective test to ensure the point of impact matches for both the EDR and the crash test data.

As shown in Figure 4, EDR delta V underestimates true delta V by under 0.5 percent on average for crash pulses at t=100 ms. The correlation between EDR delta V and true delta V for this dataset is very high with R^2 = 0.964. This analysis included all crash tests in our dataset including the crash pulses from full frontal, frontal-offset and frontal-pole crash tests as well as the longitudinal component of crash pulses from side impact tests.

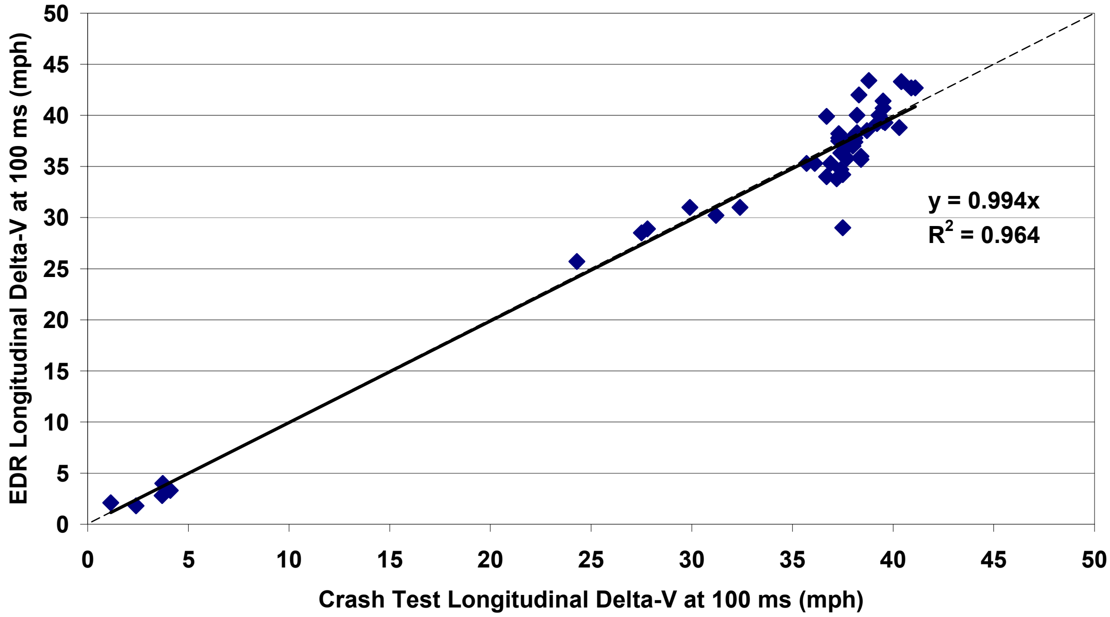

Figure 4. EDR Longitudinal Delta V versus Crash Test Delta V at t=100 ms

Accuracy based on Average Absolute Percent Error

Niehoff (2005) used a different technique to compute EDR accuracy. His approach was to compute the percent difference between the EDR delta V and true delta V for each test, and then average the absolute values of each percent difference. This approach gives a very conservative estimate of EDR error. We repeat the approach on this new dataset for comparison with the Niehoff (2005) results.

Table 7 shows that the average absolute percent difference between EDR and crash test delta V was 4.2 percent. This error is a slight improvement over the 6 percent error reported by Niehoff et al. (2005). Using the Niehoff approach, all averages presented were based on the absolute value of the percent error.

Table 7. Percent Error of the Maximum Longitudinal Delta V for Vehicles That Recorded the Entire Crash Event or Were Missing Less Than 2 percent of the Crash Pulse Data

Fraction of Crash Pulse Duration Unrecorded	All	Frontal Impact– Longitudinal Delta V	Side Impact– Longitudinal Delta V
N	35	32	3
Average loss	4.2%	3.5%	10.8%
Standard Deviation	5.8%	4.1%	12.7%
Minimum loss	0.0%	0.0%	0.0%
Maximum loss	28.6%	21.8%	28.6%

The maximum longitudinal delta V was predicted more accurately in the front tests than in the side impact tests. The side impact tests in our sample had a fairly low longitudinal delta V. When compared in absolute terms instead of percent error, the lateral tests had an average error of only 0.5 mph for the longitudinal delta V. Unfortunately, none of the EDRs with lateral delta V data were subjected to lateral impact crash tests; therefore, that analysis could not be included in this study.

The average absolute value percent error for longitudinal delta V at 100-ms for the crash tests in our dataset are presented in Table 8.

Table 8. Percent Error of the Longitudinal Delta V at 100ms for All Tests

	All Tests	**Front Impact Tests**				**Side Impact Tests**
	-	Full Barrier	40% Offset	Pole	All Front	All
N	48	39	3	1	43	5
Average loss	7.0%	4.3%	3.6%	7.2%	4.3%	30.3%
Standard Deviation	12.6%	4.2%	0.3%	-	4.1%	27.7%
Minimum loss	0.0%	0.0%	3.2%	7.2%	0.0%	0.0%
Maximum loss	82.6%	22.6%	4.0%	7.2%	22.6%	82.6%

The EDR was able to predict the longitudinal delta V in full frontal, frontal-offset, and pole tests with reasonable accuracy. The side impacts did not show the same level of accuracy as the longitudinal tests on a percentage basis, but the average in absolute terms had an error of only 0.7 mph for the lateral impact tests at 100ms.

Accuracy of EDR Pre-Crash Speed

The pre-crash vehicle speed in our sample was evaluated for accuracy by comparison with the known crash test impact speeds. Table 9 shows that the pre-crash speed of the vehicle as recorded by the EDR was always within 3 percent with the exception of test 5310. In test 5310, the EDR underreported the pre-crash speed by 22 percent. The EDR download information provided by Toyota did not provide non-zero, pre-crash vehicle speed for any case except test 5269. It is not known if this is a result of the EDR recording capabilities or simply an artifact of the downloading method. Both tests 5269 and 5310 were New Car Assessment Program (NCAP) full frontal rigid barrier crash tests.

Table 9. Accuracy of Pre-Crash Measurements for the EDR and Crash Test

Test Number	Vehicle Description	Driver Belt Status		Passenger Belt Status		EDR Pre-Crash Vehicle Speed (mph)	Actual Pre-Crash Vehicle Speed (mph)	% Error
		EDR	Test	EDR	Test			
5310	2005 Buick Rendezvous	Y	Y	-	Y	27	34.8	22%
5282	2005 Chevrolet Colorado (ext.cab)	Y	Y	-	Y	34	35.2	3%
5265	2005 Chevrolet Express	Y	Y	-	Y	34	34.9	3%
5324	2005 Pontiac Montana	Y	Y	-	Y	35	34.8	-1%
5260	2005 Saturn Ion	Y	Y	-	N	0	0.0	0%
5318	2005 Chevrolet Silverado (crew cab)	Y	Y	Y	Y	35	34.9	0%
5264	2005 Chevrolet Uplander	Y	Y	-	Y	35	34.9	0%
5603	2006 Chevrolet Colorado (2-DR)	Y	Y	Y	Y	34	34.9	3%
5597	2006 Chevrolet Colorado (4-DR)	Y	Y	Y	Y	35	35.1	0%
5468	2006 Pontiac Grand Prix (4-DR)	Y	Y	-	Y	35	35.1	0%
5589	2006 Buick Lucerne CX	Y	Y	Y	Y	35	35.1	0%
5602	2006 Chevrolet HHR	Y	Y	Y	Y	35	34.9	0%
5547	2006 Chevrolet Impala	Y	Y	Y	Y	35	35.1	0%
5250	2005 Pontiac G6	Y	Y	-	Y	35	35.3	1%
5140	2004 Chevrolet Avalanche	Y	Y	Y	Y	35	35.0	0%
5213	2004 Chevrolet Avalanche	N	N	N	N	30	30.1	0%
5741	2006 Buick Lucerne	N	N	N	N	25	24.7	-1%
5578	2006 Chevrolet Monte Carlo	Y	Y	Y	Y	34	35.0	3%
5569	2006 Cadillac DTS	Y	Y	Y	Y	35	35.2	1%
5567	2006 Hummer H3	Y	Y	Y	Y	34	35.0	3%
5830	2006 Pontiac G6	N	N	N	N	25	24.7	-1%
5907	2007 Chevrolet Silverado	Y	Y	Y	Y	35	35.1	0%
5844	2007 Saturn Aura	Y	Y	Y	Y	35	35.1	0%
5859	2007 Pontiac Solstice	Y	Y	Y	Y	34	35	3%

Test Number	Vehicle Description	Driver Belt Status		Passenger Belt Status		EDR Pre-Crash Vehicle Speed (mph)	Actual Pre-Crash Vehicle Speed (mph)	% Error
		EDR	Test	EDR	Test			
5877	2007 Chevrolet Silverado	Y	Y	Y	Y	35	34.8	-1%
5326	2005 Chevrolet Cobalt	Y	Y	-	Y	35	34.9	0%
CF05003	2004 Chevrolet Malibu	-	Y	-	Y	39	39.7	2%
CEF0419	2005 Saturn Ion	-	Y	-	N	40	40.0	0%
CEF0506	2005 Chevrolet Colorado	Y	Y	-	N	39	39.7	2%
CEF0511	2005 Buick LaCrosse	Y	Y	-	N	39	39.9	2%
5249	2005 Ford 500	Y	Y	Y	Y	35	35.2	0%
5263	2005 Ford Freestyle	Y	Y	Y	Y	35	34.1	-3%
5284	2005 Ford Econoline	-	Y	-	Y	35	34.9	0%
4928	2004 Toyota Camry	Y	Y	N	N	0	0.0	-
5283	2005 Toyota Camry	Y	Y	Y	Y	0	33.9	-
5160	2005 Toyota Corolla	Y	Y	Y	Y	0	33.9	-
5157	2005 Toyota Corolla	Y	Y	N	N	0	0.0	-
5209	2005 Toyota Matrix	Y	Y	Y	Y	0	33.9	-
5162	2005 Toyota Matrix	Y	Y	N	N	0	0.0	-
4893	2004 Toyota RAV4	Y	Y	Y	Y	0	34.1	-
5269	2005 Toyota Sienna	Y	Y	Y	Y	35	33.8	-3%
4733	2004 Toyota Sienna	Y	Y	N	N	0	0.0	-
5312	2005 Toyota Tacoma	Y	Y	Y	Y	0	33.7	-
5037	2004 Toyota 4Runner	Y	Y	Y	Y	0	33.7	-
4933	2004 Toyota Prius	Y	Y	Y	Y	0	34.2	-
5218	2005 Toyota Tundra	Y	Y	Y	Y	0	33.9	-
5239	2005 Toyota Tundra	Y	Y	Y	Y	0	33.7	-
5217	2005 Toyota Scion TC	Y	Y	Y	Y	0	33.7	-

Accuracy of EDR Belt Buckle Status

Table 9 compared the seat belt buckle status used in each test with the belt buckle status recorded by the EDR. As shown in Table 10, the EDR record of driver belt status was available for 45 of 48 tests. Forty-two drivers were belted and 3 were unbelted. In all cases, the EDR correctly recorded the driver buckle status.

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Table 10. Accuracy of EDR Driver Belt Buckle Status

Actual Belt Buckle Status	EDR Belt Status			Total
	Buckled	Unbuckled	NA	
Buckled	42		3	45
Unbuckled		3		3
Total	42	3	3	48

Right-front passenger belt buckle status is a relatively new feature of EDRs. As shown in Table 11, belt buckle status was recorded in 36 of the 48 tests in our sample. In all cases, the EDR correctly recorded the RF passenger buckle status.

Table 11. Accuracy of EDR Right Front Passenger Belt Buckle Status

Actual Belt Buckle Status	EDR Belt Status			Total
	Buckled	Unbuckled	NA	
Buckled	29		8	37
Unbuckled		7	1	8
No Passenger			3	
Total	29	7	12	48

Comparison of Lateral Delta V Accuracy in EDRs

As shown in Table 6, 18 of the 48 vehicles in our EDR sample had the capacity to record lateral delta V in addition to longitudinal delta V. Only 1 vehicle, a 2004 Chevrolet Malibu subjected to a frontal pole test (IIHS Test CF05003) had a non-zero record of lateral delta V. Figure 5 compares the lateral delta V as recorded by the EDR with lateral delta V as measured by crash test instrumentation.

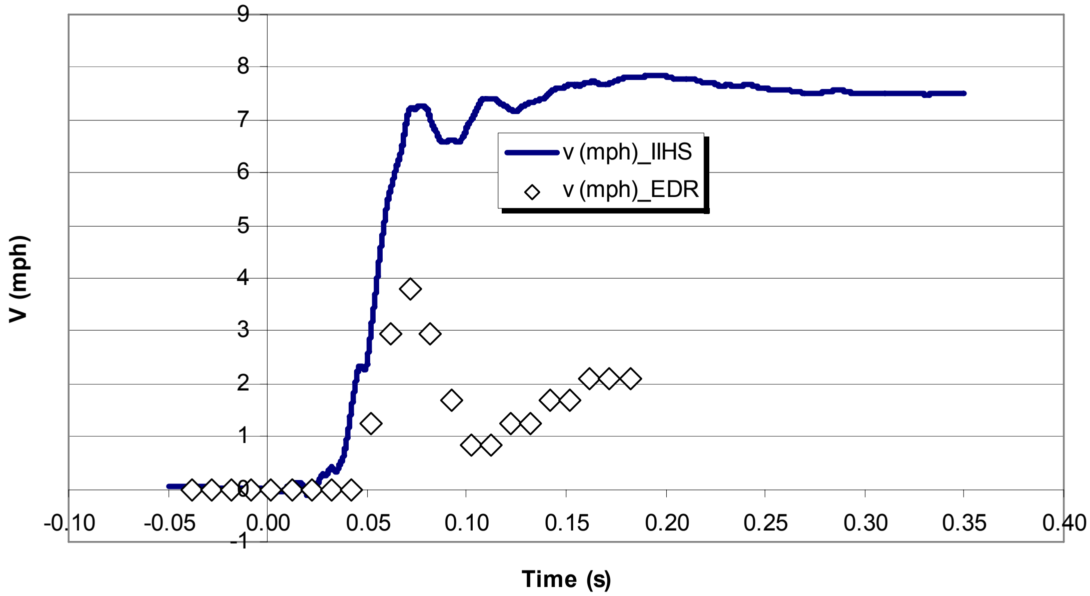

Figure 5. Lateral Delta V of 2004 Chevrolet Malibu in Frontal Pole Test (IIHS Test CF05003)

Agreement between the EDR and crash test instrumentation is reasonably good for the first 50 ms of the event. However agreement is poor after 50 ms. Niehoff (2005) made a similar observation about the accuracy of the lateral delta V recorded by a 2004 Chevrolet Malibu subjected to a side impact. Because our sample contained only one EDR with a non-zero lateral delta V, it is unknown whether this finding generalizes to later model vehicles with newer generations of EDRs.

4. Evaluation of the Field Performance of Advanced Air Bags

Introduction

In the United States, automakers have introduced a new generation of advanced occupant restraints, including those specifically introduced in response to the requirements for advanced air bags, as specified in the FMVSS No. 208 upgrade (49 CFR 571.208 [65FR30680]). These advanced systems are characterized by multi-stage air bag inflators, pretensioners, advanced occupant sensors, and complex air bag deployment algorithms. Although these systems have been extensively tested in the laboratory, we are only beginning to understand the performance of these systems in the field. Because EDRs record many of the inputs to the advanced air bag control module, these devices can provide unique insights into the performance of air bags in the field.

Objective

The objective of this study was to characterize the performance of advanced frontal air bags in real-world crashes. The study included both vehicles certified to the FMVSS No. 208 advanced air bag regulation, and vehicles having dual-stage frontal air bags.

Approach

The analysis was based upon EDR records extracted from the NHTSA EDR dataset. NHTSA now has the records from over 2,200 EDRs downloaded as part of National Automotive Sampling System/Crashworthiness Data System (NASS/CDS) 2000-2005 crash investigations. All cases were downloaded by NASS investigators in the field using the Vetronix crash data recorder retrieval system.

Characterization of Dataset

This study included only EDR cases from vehicles having a dual-stage frontal air bag. The resulting sample contained the EDR records from 106 vehicles having air bags of the advanced type, also referred to as certified advanced compliant (CAC) air bags. CAC air bags are defined as air bags in those vehicles certified to the FMVSS No. 208 upgrade. The sample was composed entirely of GM passenger cars, light trucks, and vans. Table 12 shows the distribution of cases by EDR module type.

Table 12. Distribution of CAC Air Bag Cases by EDR Module Type

EDR Module Type	Deployment	Non-Deployment	Total
SDMDW2003	3	3	6
SDMGF2002	44	56	100
Total	**47**	**59**	**106**

GM EDRs record longitudinal delta V versus time for up to two events. Figure 6 presents the distribution of maximum longitudinal delta V recorded by each of 47 the CAC EDRs in which the frontal air bag deployed. The median longitudinal delta V in our sample was approximately 15 mph.

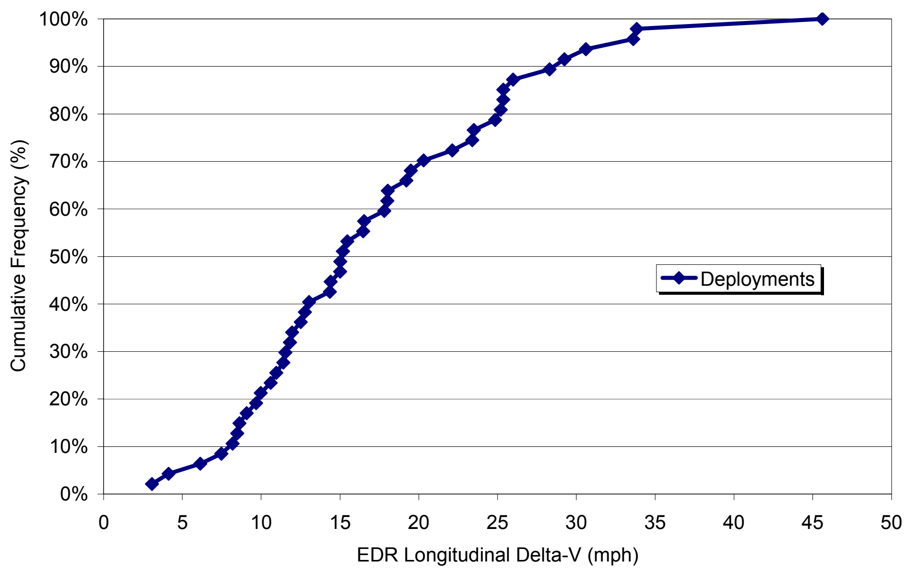

Figure 6. Distribution of Longitudinal Delta V Values in Deployment Events

As shown in Figure 7, a frontal impact was the most harmful event in over 90 percent of the CAC air bag deployment cases.

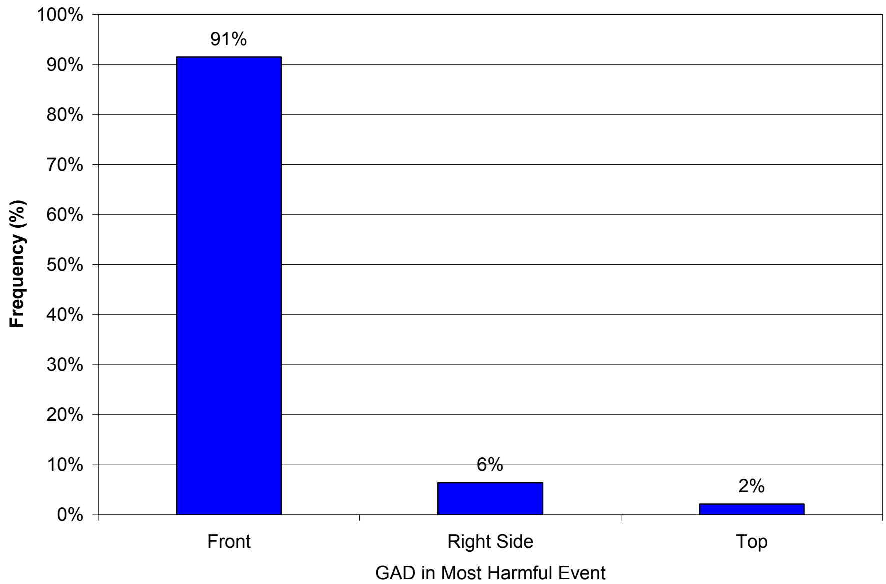

Figure 7. General Area of Damage in Most Harmful Event in Deployment Crashes

More useful than knowing the "general area of damage" (GAD) of the most harmful event however would be to know the GAD of the event that triggered the air bag. The most harmful event may not be the event that triggers the air bag. Unfortunately, in a multiple-event crash, the event that triggered the air bag cannot always be determined. As shown in Figure 8, NASS investigators recorded that approximately half of the CAC air bag deployment cases involved multiple events. Not all these events necessarily have a longitudinal component of sufficient magnitude to deploy the air bag.

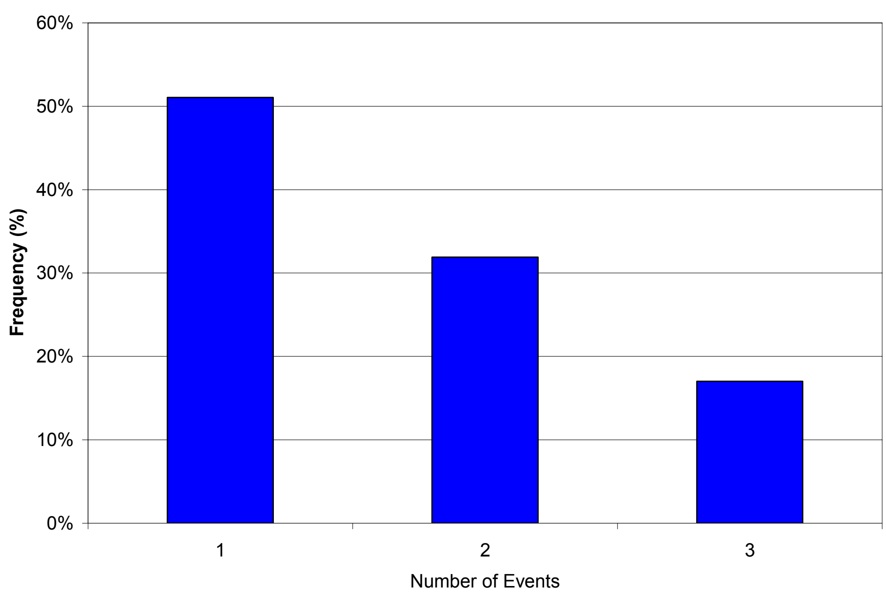

Figure 8. Number of Impact Events in Each Crash Involving a Frontal Air Bag Deployment As Observed by NASS Investigator

The EDR data indicated that the majority of the deployment cases in our sample involved only a single event having a longitudinal component of delta V. The SDMGF2002 module records a count of the number of events in each crash that involved a longitudinal component of delta V. In our sample of 47 deployments, 44 were SDMGF2002 modules. Figure 9 below shows that in over 80 percent of the cases, the EDR detected only a single impact with any longitudinal component. This observation does not however mean these events were frontal impacts. Although events with strong longitudinal components are typically frontal impacts, it is possible for other crash modes including side impacts to have a significantly severe longitudinal component to deploy the air bag.

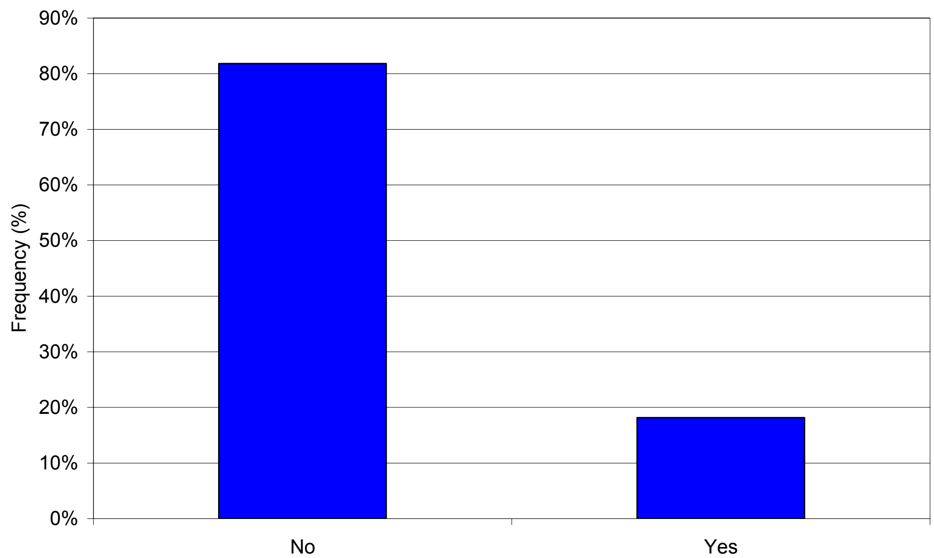

Figure 9. Frequency of Deployment Crashes with Multiple Events Involving Longitudinal Delta V Component as Recorded by EDR

Belt Use and Air Bag Deployment

Table 13 presents the distribution of driver belt buckle status in deployment cases. In approximately half of these real-world crashes, the EDR recorded that the driver's seat belt was buckled. In our sample, the EDR driver seat belt buckle status frequently did not agree with the belt use status determined by the NASS investigator. In 9 of the 31 cases in which NASS investigators believed that the driver was belted, the EDR recorded that the driver belt was unbuckled. Note that this finding is in sharp contrast to our observation of EDRs downloaded from late-model crash tests. In crash tests, driver and passenger belt buckle status – either buckled or unbuckled – was correctly recorded by the EDRs in all cases for which seat belt buckle status was available.

Table 13. Driver Belt Buckle Status

EDR Buckle Status	NASS – Belted	NASS - Unbelted	Not Inspected by NASS	Total
Buckled	22	1	2	25
Not Buckled	9	12	1	22
Total	31	13	3	47

Table 14 shows that in half of the cases in which a right-front passenger was present, the EDR recorded that the passenger was buckled. Because the EDR passenger buckle status is not a data element recorded by the SDMDW2003 module, the three SDMDW2003 cases are not tabulated in Table 14.

Table 14. Right Front Passenger Belt Buckle Status

EDR Buckle Status	NASS – Belted	NASS - Unbelted	Total
Buckled	2	1	3
Not Buckled	2	1	3
Total	4	2	6

Table 15 compares the records of driver air bag deployment as indicated by the NASS investigator and recorded by the EDR. In all but one of the deployments, the EDR and NASS investigators agreed the air bag deployed. In all non-deployment cases, EDR and NASS investigators agreed that the bag had not deployed.

Table 15. Driver Air Bag Deployment Status

EDR Deployment Status	NASS-Not Inspected	NASS-Bag Deployed	NASS-No Deploy	Total
Deployed	3	43	1	47
Non-deploy	15	-	44	59
Total	18	43	45	106

In case 2002-12-150, a 2003 Chevrolet Suburban was involved in a crash in which the EDR recorded that the air bag controller commanded the driver air bag to deploy. However, NASS investigators observed that the driver air bag did not deploy. Inspection of the photos from the investigation confirms the NASS observation that the bag did not deploy. The EDR recorded that the Chevrolet Suburban experienced a longitudinal delta V of 12 mph in this crash.

Vehicle Speed Just Prior to Impact

The GM EDRs in our dataset recorded 5 seconds of pre-crash data in one second intervals for vehicle speed, engine speed, engine throttle setting, and brake status. The vehicle speed data at one second before algorithm enable provides an estimate of vehicle speed approximately one second before impact. Figure 10 provides a distribution of vehicle speed at t = - 1 second for the CAC deployment cases in our sample. Although the EDRs in our dataset did not record impact speed, this measure provides an estimate of vehicle speed just before impact. The median vehicle speed approximately 1 second before impact was 38 mph.

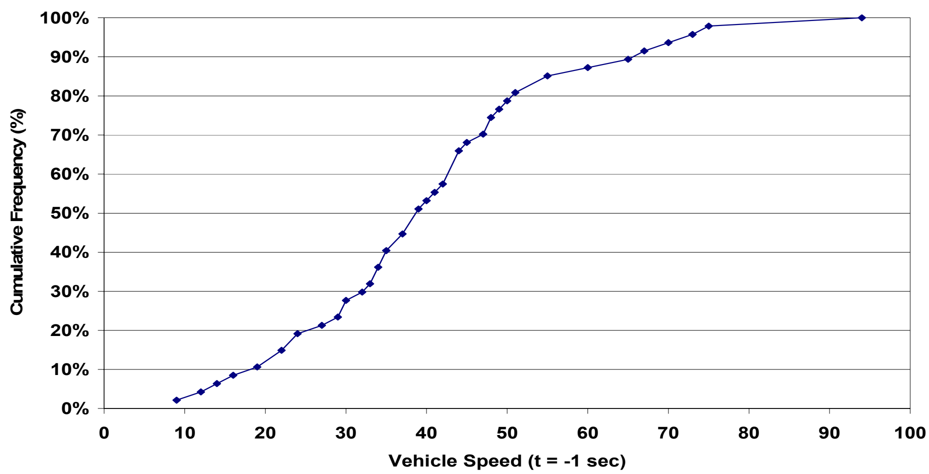

Figure 10. Distribution of Vehicle Speed Approximately One Second Before Impact in Deployment Events

RESULTS

Figure 11 compares the distribution of the driver air bag deployments and non-deployments by peak longitudinal delta V. All cases in this analysis had incurred a frontal impact in the most harmful event. The cases were aggregated into three groups: (1) those crashes that resulted in a deployment, (2) those crashes not sufficiently severe to deploy the air bag, and (3) split deployments. Split deployments are those cases in which the driver air bag deployed, but the right front passenger air bag did not deploy despite the presence of a passenger. There were no cases in which the passenger air bag deployed, but the driver air bag did not deploy. Of the 106 CAC cases, there were 41 deployments, 2 split deployments, and 19 non-deployments in which the general area of damage was frontal.

The driver frontal air bag was observed to deploy in crashes having a longitudinal delta V as low as 3-4 mph. The driver bag was observed to not deploy in a crash having a longitudinal delta V of 26 mph. This crash was a long duration crash of approximately 275 milliseconds into an earth and rock embankment.

Logistic regression was performed to determine the probability of driver air bag deployment as a function of longitudinal delta V. For this sample, the probability of driver air bag deployment was 50 percent for a longitudinal delta V of 8 mph.

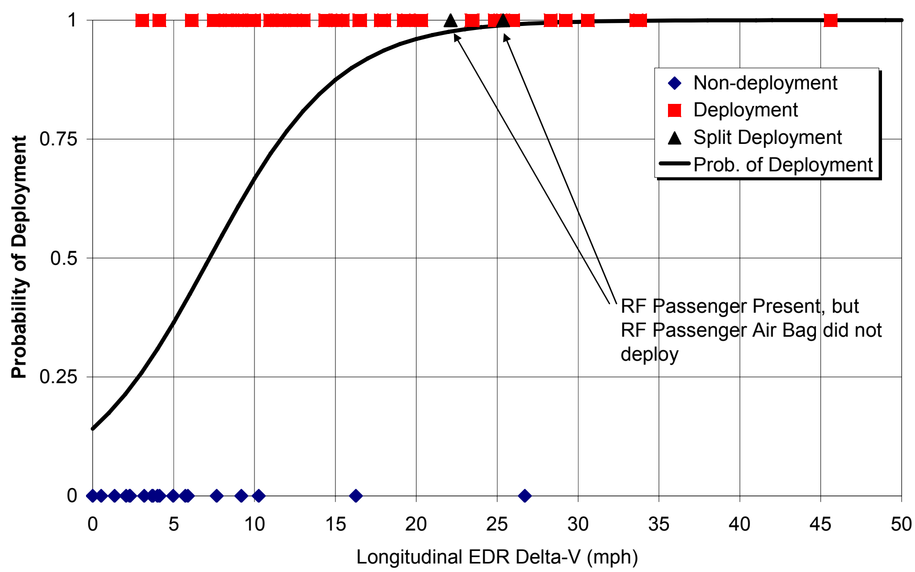

Figure 11. Probability of Deployment of Driver Air Bag by Longitudinal Delta V

In our dataset of 106 CAC cases, there were 20 right front passengers involved in a crash in which a frontal impact was the most harmful event. This 20-case set consisted of 11 deployments, 2 split deployments, and 7 non-deployments. Figure 12 presents the distribution of the right-front air bag deployment decision by longitudinal delta V for these cases. The right-front passenger air bag was observed to deploy in collisions having a longitudinal delta V as low as 6 mph. In general, the passenger air bag did not deploy in low-delta-V crashes. In one crash however, the right-front passenger air bag did not deploy in a crash having a longitudinal delta V of 26 mph. Because our dataset contained only a limited number of right-front passenger cases, a logistic regression computation was not possible for this data subset.

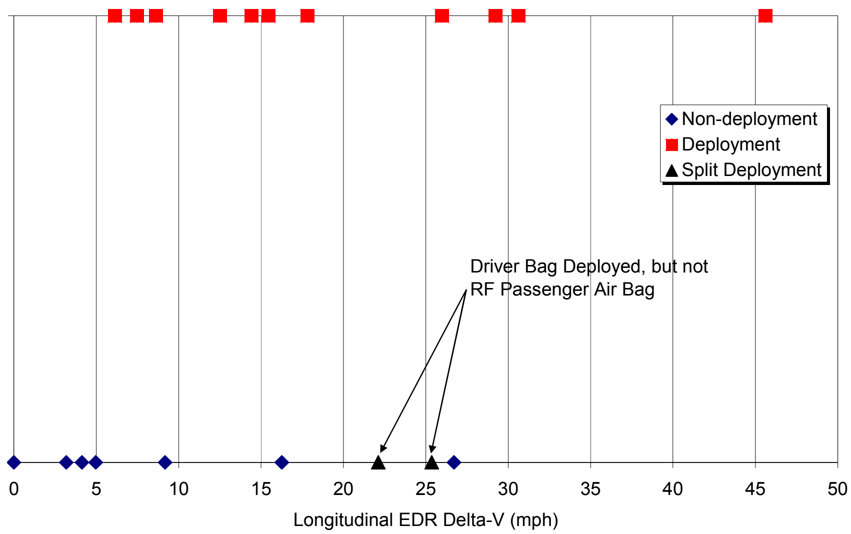

Figure 12. Distribution of Right-Front Passenger Air Bag Deployment Decisions by Delta V

All CAC air bag systems in our dataset contained dual-stage inflators. Dual-stage inflators allow the air bag deployment characteristics to be tailored to the particular crash severity and / or occupant configuration of a collision (including belt usage). Of the106 CAC cases, there were 43 driver air bag deployments and 19 non-deployments in which the most harmful event was a frontal impact. In the 43 deployments, both the first and second stage fired in 9 of the crashes. Only the first stage fired in the remaining 34 cases. In general as shown in Figure 13, both inflator stages were triggered only in higher delta V crashes.

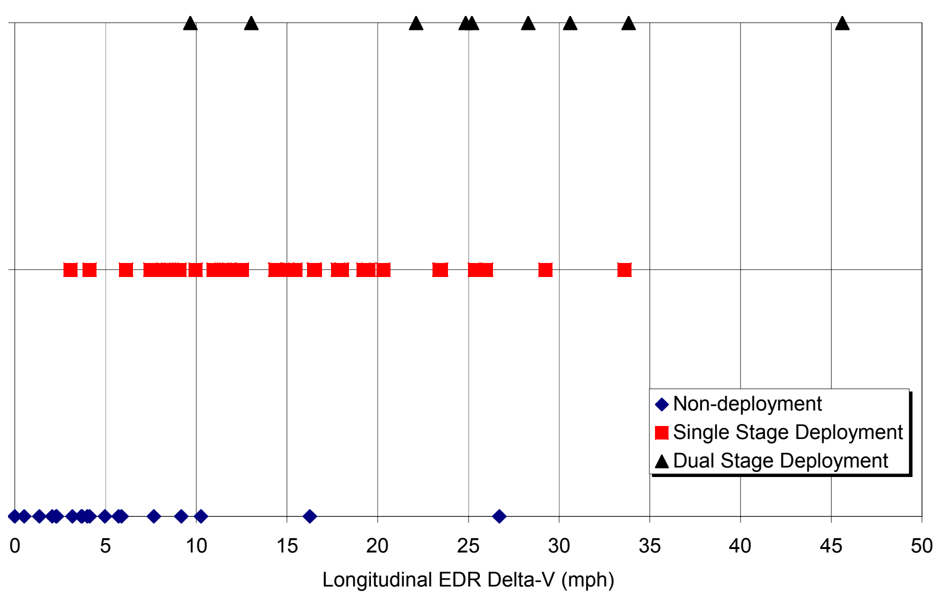

Figure 13. Distribution of Driver Air bag Dual-Stage, Single-Stage, and Non-deployments versus Delta V

Figure 14 presents the relationship between longitudinal delta V and the vehicle speed just prior to impact. In the majority of cases, vehicle speed greatly exceeds longitudinal delta V.

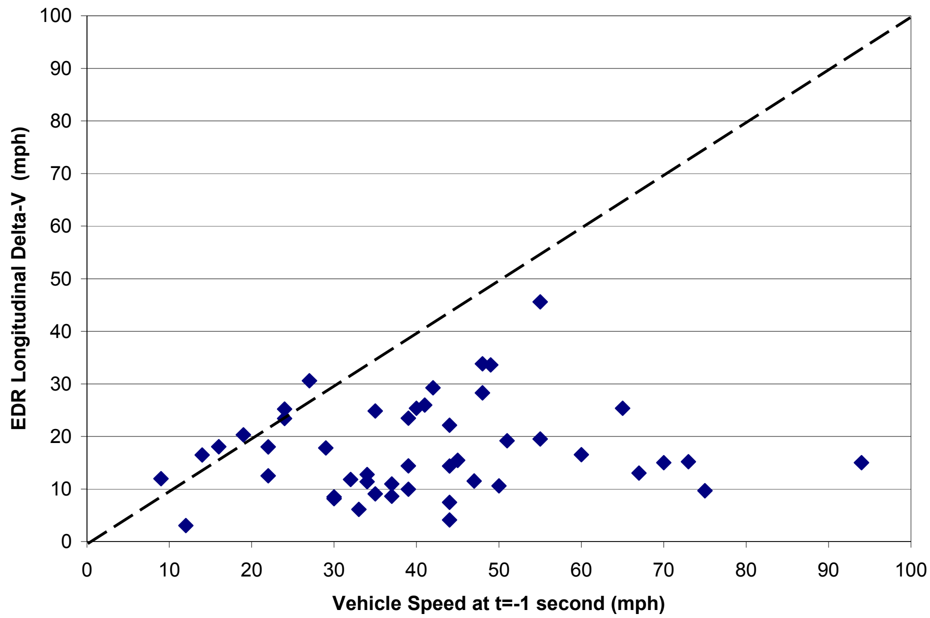

Figure 14. Longitudinal Delta V versus Vehicle Speed Just Before Collision in CAC Deployment Cases

Time Interval from Algorithm Enable to Deployment

To provide context for real world air bag deployment times, EDRs have been used to assess that air bag deployment times during NHTSA's frontal barrier tests, conducted for FMVSS No. 208 and New Car Assessment Program (NCAP). Data from 29 GM vehicles with dual stage inflators, model year 2002 through 2006, were examined. Details on these crash tests and their associated air bag deployments times are provided in appendix B. Note that this dataset is restricted to frontal NCAP tests of GM vehicles. Many of the crash tests in this dataset were also examined in our analysis of EDR data validity in crash tests presented in an earlier chapter.

First-stage deployment times are shown in Figure 15. For the crash tests in this sample, the average deployment time for the first-stage driver air bag was 7 msec, with a range of 2.5 to 17.5 msec. Generally, the driver and right-front passenger air bags (both first and second stages) were triggered at exactly the same time.

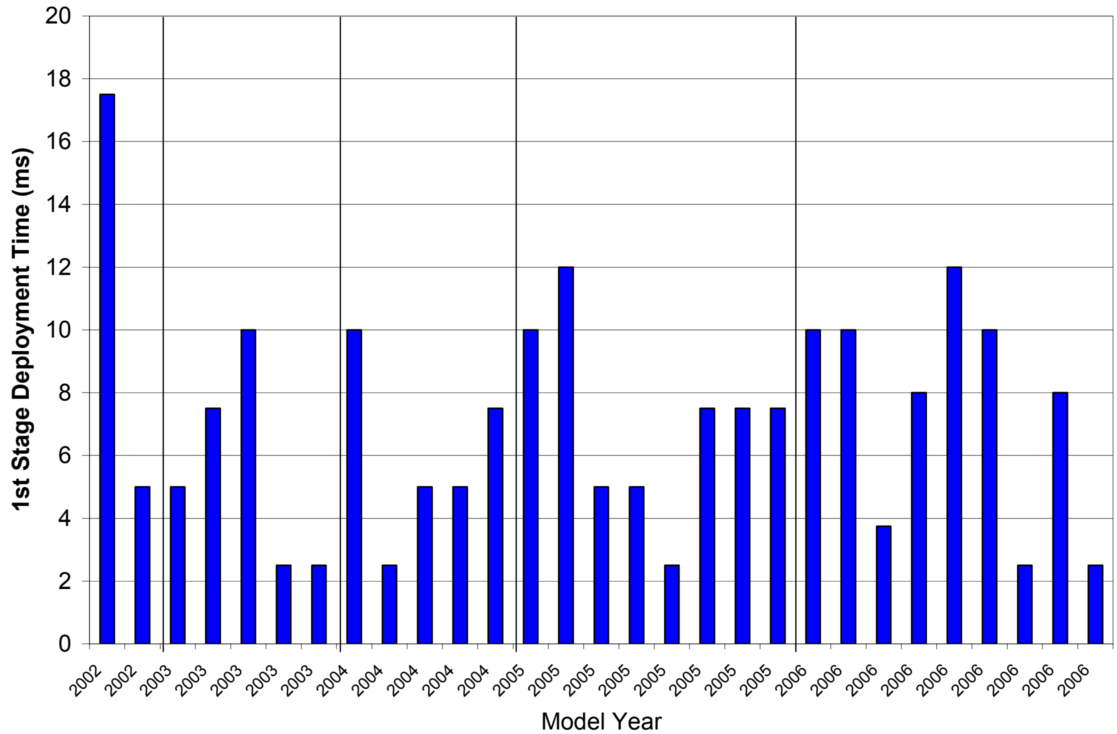

Figure 15. First-Stage Deployment Times versus Model Year in Frontal NCAP Tests

Analyses of air bag deployments from real-world crashes would allow full range analysis of deployment times under many circumstances. Since there were only 47 CAC deployment cases, we extended the analysis of deployment times to include pre-CAC vehicles with dual stage air bags. NASS cases from years 2000 to 2005, which included a complete EDR record, and a GM vehicle with a dual-stage air bag system that deployed, were compiled into a subset of the NHTSA EDR dataset. A total of 132 cases met these criteria. Using the EDR data, air bag deployment times were used to form a cumulative distribution, as seen in Figure 16.

In this sample of GM vehicles, with complete EDR records and equipped with dual air bags, the 50th percentile deployment time is 20 msec while the 75th percentile is 35 msec.

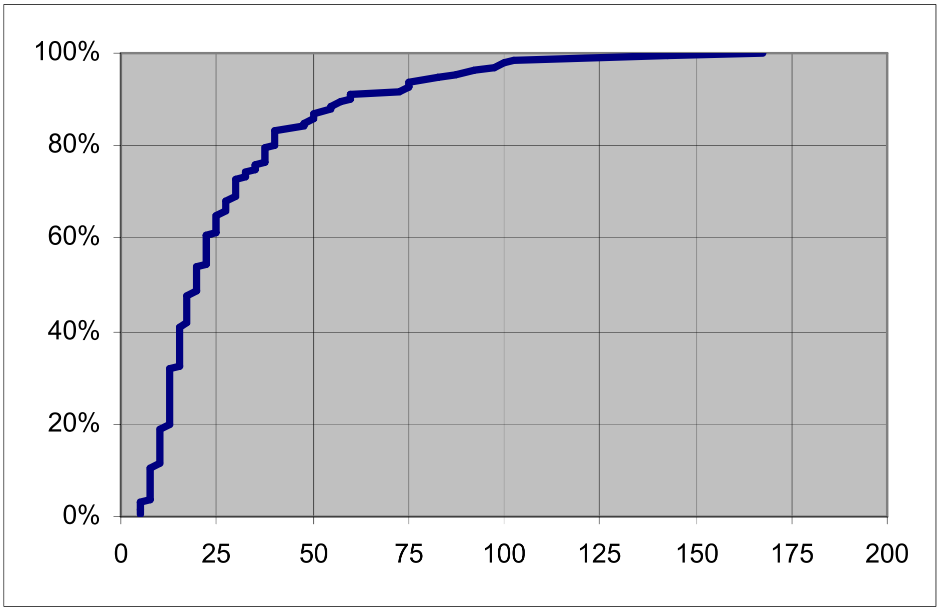

Figure 16. Cumulative Distribution (%) of Driver First-Stage Air Bag Deployment versus Deployment Time (msec)

Delayed Deployments

The NHTSA EDR dataset contained 132 cases involving deployment of an advanced dual-stage air bag. Twelve vehicles had driver deployment times recorded by the EDR of 72.5 msec and longer. Four of the vehicles were CAC. Eight cases were pre-CAC vehicles with dual-stage air bags. For each of these vehicles, the NASS and EDR data were reviewed to determine common characteristics. The GM vehicle model year, make, and model for these cases as reported by NASS are presented in Table 16.

Table 16. Vehicle Model Year, Make and Model (* = CAC Vehicle)

NASS Case Number	Model Year	Make	Model
2004-75-126 *	2003	Chev	Avalanche
2004-50-087 *	2004	Chev	C/K-series pickup
2004-12-052	2001	Pont	Bonneville/Catalina
2005-04-062	2005	Chev	Caprice/Impala
2001-41-133	2001	Chev	Monte Carlo (FWD)
2004-08-108	2004	Saturn	Ion
2004-11-082	2004	Saturn	Ion
2003-12-162	2002	Chev	Caprice/Impala
2005-76-009 *	2004	GMC	C,K,R,V-series P/U
2005-12-149	2005	Chev	Equinox
2004-48-181	2001	Chev	Caprice/Impala
2003-50-110 *	2003	GMC	C,K,R,V-series P/U

For each of these cases, the EDR data was reviewed to determine the driver seat belt status, longitudinal delta V of the case vehicle, and the driver's air bag deployment time. This data is shown in Table 17.

Table 17. Driver Belt Status, Vehicle Longitudinal Delta V, and Driver Air Bag Deployment Times (* = CAC Vehicle)

NASS Case Number	Driver Belt Status	Delta V (mph)	Driver Air Bag Deployment Time (msec)
2004-75-126 *	Buckled	-6.13	167.5
2004-50-087 *	Unbuckled	-19.21	142.5
2004-12-052	Buckled	-28.62	102.5
2005-04-062	Buckled	-58.41	100
2001-41-133	Buckled	-26.21	97.5
2004-08-108	Unbuckled	-10.99	92.5
2004-11-082	Unbuckled	-30.46	87.5
2003-12-162	Buckled	-7.64	82.5
2005-76-009 *	Unbuckled	-17.81	75
2005-12-149	Buckled	-8.10	75
2004-48-181	Buckled	-7.93	75
2003-50-110 *	Unbuckled	-20.31	72.5

NASS Case Discussion

The following presents a short description of the crash, vehicle speed, and longitudinal delta V as reported by the EDR, multi-event as reported by the NASS investigator or the EDR, and some potential reasons for the long reported driver's air bag deployment times. In the discussions that follow, PDOF refers to the principal direction of force, expressed in degrees, where 0 is direct frontal. GAD refers to the general area of damage. GAD = F indicates frontal damage.

2004-75-126

Impact description: Minor vehicle impact, followed by curb hit (EDR N/D event) and then subsequent vehicle impact (EDR D event).
Vehicle speed: EDR @ -1 sec = 33 mph
D event delta V = 6 mph
GAD/PDOF: Frontal/350deg
Multi-event: yes
Potential reasons for late-reported deployment time:

- Low-delta-V event
- Closely spaced D and N/D events

2004-50-087

Impact Description: Multi-event crash – sideswiped small post, offset impact on utility pole (D event) followed by curb hit.

Vehicle speed: EDR @ -1 sec = 51 mph
D event delta V = 19 mph
GAD/PDOF: F/0deg
Multi-event: yes
Potential reasons for late-reported deployment time:

- Extreme low overlap with pole (soft)
- May miss satellite sensor on lower radiator support
- Abnormal delta V increases at 100 msec

2004-12-052
Impact Description: Vehicle front contacted a mailbox and a utility pole and came to rest against the pole.
Vehicle speed: EDR @ -1 sec = 42 mph
D event delta V = 29 mph
GAD/PDOF: F/0deg
Multi-event: yes
Potential reasons for late-reported deployment time:

- Narrow impact (soft)

2005-04-062
Impact Description: Vehicle struck a street sign and a large diameter tree.
Vehicle speed: EDR @ -1 sec = 76 mph
D event delta V = 58 mph
GAD/PDOF: F/0deg
Multi-event: yes
Potential reasons for late-reported deployment time:

- Narrow impact (soft)
- Delayed start of delta V data. No vehicle acceleration from AE to ~40 msec

2001-41-133
Impact Description: Vehicle departed the left side of the road, hit curb, and contacted a concrete utility pole on the median with its front.
Vehicle speed: EDR @ -1 sec = 48 mph
D event delta V = 26 mph
GAD/PDOF: F/350deg
Multi-event: yes
Potential reasons for late-reported deployment time:

- Narrow impact – pole (soft), with broad damage
- Delta V recording shows no vehicle acceleration from AE to ~30 msec

2004-08-108
Impact Description: Vehicle struck a wooden utility pole with its front, shearing the pole, which resulted in the vehicle rolling 6 quarter turns.
Vehicle speed: EDR @ -1 sec = 61 mph
D event delta V = 11 mph

GAD/PDOF: F/20deg
Multi-event: no (yes subsequent to D event)
Potential reasons for late-reported deployment time:

- Low-delta-V event
- Narrow offset impact (soft)

2004-11-082
Impact Description: Vehicle rear-ended stopped vehicle in roadway at stop sign.
Vehicle speed: EDR @ -1 sec = 49 mph
D event delta V = 30 mph
GAD/PDOF: F/0deg
Multi-event: no
Potential reasons for late-reported deployment time:

- Broad damage
- Delta V recording shows no vehicle acceleration from AE to ~20 msec

2003-12-162
Impact Description: Vehicle struck another vehicle on roadway (sideswipe), struck a fire hydrant with its front plane (D event), and then struck a steel sign pole
Vehicle speed: EDR @ -1 sec = 17 mph
D event delta V = 8 mph
GAD/PDOF: F/10deg
Multi-event: yes
Potential reasons for late-reported deployment time:

- Low-delta-V event
- Narrow impact

2005-76-009
Impact Description: Other vehicle swerved to miss debris on roadway and impacted subject vehicle head on with small overlap
Vehicle speed: EDR @ -1 sec = 29 mph
D event delta V = 18 mph
GAD/PDOF: F/340deg
Multi-event: yes
Potential reasons for late-reported deployment time:

- Narrow offset impact
- May miss satellite sensor on lower radiator support
- Abnormal delta V increases at 30 msec
- Delayed start of delta V data. No vehicle acceleration from AE to ~ 50 msec

2005-12-149
Impact Description: Vehicle contacted a signpost, 2 wooden boxes, another post, and a third wooden box.
Vehicle speed: EDR @ -1 sec = 45 mph

D event delta V = 8 mph
GAD/PDOF: F/0deg
Multi-event: yes
Potential reasons for late-reported deployment time:

- Low Delta V event
- Narrow offset impact (soft pliable planter box)
- Delayed start of delta V data. No vehicle acceleration from AE to ~ 20 msec

2004-48-181
Impact Description: Other vehicle crossed center and hit subject vehicle with extreme offset engagement.
Vehicle speed: EDR @ -1 sec = 43 mph
D event delta V = 8 mph
GAD/PDOF: F/0deg
Multi-event: no
Potential reasons for late-reported deployment time:

- Low-delta-V event
- Offset to left side
- Narrow impact
- May miss satellite sensor near hood latch
- Velocity change trace starts at 8 mph at 10 msec

2003-50-110
Impact Description: The right front fender was struck by another vehicle at an intersection followed by the subject vehicle hitting a signal pole
Vehicle speed: EDR @ -1 sec = 19 mph
D event delta V = 20 mph
GAD/PDOF: F/0deg
Multi-event: yes
Potential reasons for late-reported deployment time:

- Pole impact (soft)
- Misses frame rails
- Offset impact (away from satellite sensor, if equipped)

Discussion

Abnormal delta V traces**:** On at least 2 of the 12 cases investigated, the EDR recorded the vehicle's speed increasing during the impact. In case **2004-50-087**, this was observed. Figure 17 shows this data.

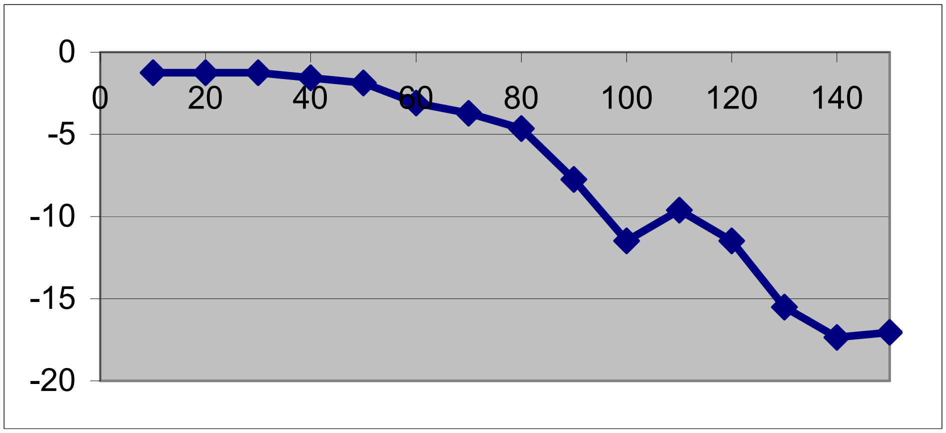

Figure 17. Case 2004-50-087 EDR Delta V (mph) versus Time (msec)

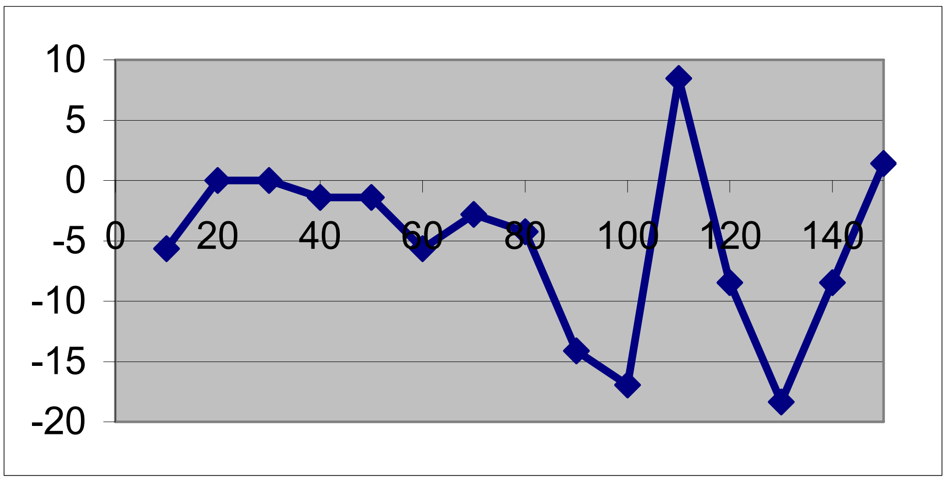

Figure 18. Case 2004-50-087 Differentiated EDR Delta V (mph) versus Time (msec)

A closer examination can be made by differentiating these data to obtain a rather crude representation of the vehicle deceleration. This is shown in Figure 18.

From this data there is clear vehicle acceleration at 110 msec. While it is not unusual to see positive acceleration in the high-frequency acceleration data, it is unusual to see it in low-frequency data. Since this data represent very low-frequency data, an occurrence of this type should be considered abnormal. A review and validation of this process is found in the Appendix.

<u>Delayed start of delta V data</u>: In several cases the data captured and recorded is part of the EDR record related to the deployment file shows rather long delays between AE and significant changes in vehicle delta V. An example of this is found in case **2001-41-133**, where the delay was about 50 milliseconds. Figure 19 shows the first major separation from 0 mph to be at 60 msec.

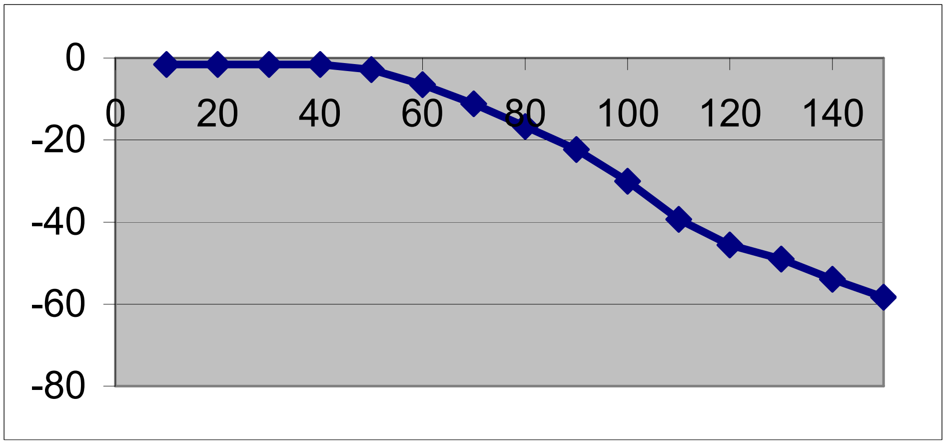

Figure 19. Case 2001-41-133 EDR Delta V (mph) versus Time (msec)

Findings

The following is a discussion of these 12 cases. Because this is a very small sample and because case counts are used, rather than weighted data, generally only qualitative statements are made.

A review of the model years for these 12 case vehicles shows fairly even distribution, given the small sample and the fact that newer vehicles were not available for selection in the earlier case years. This data is shown below.

Table 18. Distribution of Model Years in Delayed Deployment Cases

Vehicle MY	Number of Cases
2001	3
2002	1
2003	2
2004	4
2005	2

A review of the vehicle type also shows no trends. Both trucks and passenger vehicles had long recorded driver's air bag deployment times. Also, several GM brands were found in the list, as were various sizes of passenger vehicles. Furthermore, driver seat belt status varied between the cases as did crash severity, ranging from 6 mph to nearly 60 mph.

Several common characteristics were found among these 12 cases.

Narrow/Offset: In many of the cases, the vehicle hit something narrow, such as a pole. Others had significant offset impacts, typically engaging a small portion of the vehicle. Narrow impacts tend to be softer because they may not involve the frame rails. Figure 20 and Figure 21 present examples of these impacts.

Figure 20. Case 2004-12-052 Impact With Small Sign and Pole

Figure 21. Case 2003-12-162 Showing Fire Hydrant Damage on Vehicle's Right

Low Delta V: Several cases had low-delta-V crashes. These crashes are in the zone where the air bag may or may not deploy. For some of these crashes, more time may be needed for the air bag controller to predict the need for air bags deployment, hence the longer deployment times.

Abnormal data: As mentioned in the case description section above, some cases had what might be construed as abnormal or unexpected data. There were at least three categories of abnormal data. Two of these were discussed earlier in the Discussion section.

- Delayed onset of significant changes in velocity after time zero, also referred to as AE.
- Reversal in the delta V characteristic
- High starting point for the delta V trace, as reported at the 10 ms data point.

Multi-Impact: Many of these 12 cases have earlier non-deployment impacts, as reported by both NASS and the EDR. Table 19 summarizes these characteristics by NASS case number.

Table 19. Summary of Delayed Deployments (* = CAC Vehicle)

NASS Case Number	Narrow/ Offset	Low DV	Abnormal data	Multi-Impact
2004-75-126 *	✓	✓	✓	✓
2004-50-087 *	✓		✓	✓
2004-12-052	✓			✓
2005-04-062	✓		✓	✓
2001-41-133	✓		✓	✓
2004-08-108	✓	✓		✓
2004-11-082			✓	
2003-12-162	✓	✓		✓
2005-76-009 *	✓		✓	
2005-12-149	✓	✓	✓	✓
2004-48-181	✓	✓	✓	
2003-50-110 *	✓			✓

Advanced Air Bag Suppression Performance

The driver and front-passenger restraints can operate independently in an advanced air bag system. Deployment of the driver air bag does not always imply that the passenger air bag will also be deployed. Deployment of the right-front passenger air bag can be suppressed under certain conditions. A manufacturer may choose, for example, to not deploy the passenger air bag if there is no occupant seated in the right-front passenger location. More importantly, the air bag may be suppressed if a child is detected.

Table 20 shows the frequency of non-deployments for right-front passenger air bags in crashes sufficiently severe to deploy the driver frontal air bag. All cases in this table involve CAC vehicles. In three of the cases, occupant descriptions were not available as the vehicles were not inspected by NASS investigators. Right-front passengers were present in 14 of the 44 remaining cases.

Table 20. Frequency of Right-Front Passenger Air Bag Non-Deployments in Crashes in Which the Driver Air Bag Deployed in CAC Vehicles

Right-Front Passenger	RF Air Bag Deployed	RF Air Bag Non-Deployment	Total
Adult	12	1	13
Child	-	1	1
None	3	27	30
Total	**15**	**29**	**44**

When the passenger seat was vacant, the passenger air bag did not deploy in the majority of the cases (27 of 30). This indicates the presence of sophisticated occupant sensors that are characteristic of advanced air bag systems. This behavior, however, can be dependent on the air bag control module as automakers have the flexibility to implement or not implement this non-safety-related feature. Only the SDMFG2002 module suppressed the air bag if the passenger seat was vacant (27 of 27). The SDMDW2003 module on the other hand deployed the right-front air bag despite the fact that no occupant was seated at that location (3 of 3). We believe that this is the result of how the air bag control module was programmed, rather than an error by the air bag control module.

Air Bag Non-Deployment in the Presence of a Right Front Passenger

Deployment of the driver air bag does not always imply that the passenger air bag will also be deployed. Table 20 shows two particular cases of interest in which the passenger air bag did not deploy despite the presence of a right-front passenger. In both cases, the driver bag deployed. In both cases, the passengers were subjected to a longitudinal delta V of over 20 mph. Earlier in this paper, these cases were referred to as split deployments.

In the first case (NASS/CDS case **2005-42-106**), the right-front passenger was a 5-year-old male child weighing 20 kg. The child was not seated in a child safety seat. The subject vehicle, shown in Figure 22, was a 2004 Chevrolet C/K-series pickup truck that struck a guardrail and then suffered a rollover. The EDR recorded a longitudinal delta V of 25.3 mph in the guardrail impact. NASS investigators estimated a PDOF of 30 degrees. The NASS investigator indicated that the child was restrained by a three-point belt. The EDR however recorded that the right-front passenger belt was not buckled. The air bag on/off switch was in the “auto” position. However, when a child is detected, CAC vehicles are designed to either suppress the air bag or deploy the air bag in a low-risk manner. In this case, the system appears to have detected the child and correctly suppressed the passenger air bag.

In the second case (NASS/CDS case **2003-09-224**), the right-front passenger was a 29-year-old male restrained by a three-point belt. The subject vehicle was a 2003 GMC C/K-series pickup truck that was subjected to a frontal crash with a longitudinal delta V of 22 mph at a PDOF of 10 degrees. As with the previous case, three reasons were investigated for air bag nondeployment: air bag on/off switch, failure of weight sensor, and a forward-located seat.

NASS investigators noted that the air bag on/off switch was in the "auto" position. Vehicle interior photos also showed the switch clearly in the "auto" position. The passenger had a weight of 79 kg and height of 175 cm. There is little chance that a properly functioning weight sensor would not have detected this occupant. The EDR recorded that the passenger seat position was in the rearward position making this also an unlikely reason for air bag suppression. One other possible scenario is that the auto/off switch status was tampered with post-crash. Unfortunately, the EDR data as downloaded with the Vetronix reader only indicates that the right-front passenger air bag was suppressed. The EDR does not indicate whether the nondeployment was due to the auto/off switch being set in the off position or whether the nature of this particular crash did not meet the air bag deployment criteria.

	
(a) Frontal and Rollover Damage to 2004 Chevrolet Silverado Subject Vehicle	**(b) Passenger Air Bag On/Off Switch in Auto Position**

Figure 22. Frontal Crash Followed by a Rollover in Which Driver Air Bag Deployed, But Passenger Air Bag Did Not Deploy for a Child in the Right-Front Seat (NASS 2005-42-106)

(a) Frontal Collision Damage of a 2003 GMC Sierra Pickup	(b) Passenger Air Bag On/Off Switch in Auto Position

Figure 23. Frontal Crash in Which Driver Air Bag Deployed, But Passenger Air Bag Did Not in the Presence of an Adult Right-Front Passenger (NASS 2003-09-224)

Limitations

This study has several limitations:

- The study was based on a limited dataset of vehicles having advanced air bags. Because of the small sample currently available, the conclusions of this analysis should be regarded only as an initial indication of the more conclusive findings that can be expected from follow-on studies with a larger EDR sample.

- All vehicles were manufactured by General Motors. The results may not apply to other automakers.

- The frequency distributions presented in this paper apply only to the study dataset. Because the study has not used NASS/CDS case weights, the results should not be interpreted as necessarily representative of the U.S. national crash environment.

5. Conclusions

This research program used EDR data to investigate the feasibility of using EDR data to evaluate advanced air bags. The analysis was based upon a dataset of over 2,500 EDR cases developed as the first task of this research program. Cases in the dataset include 2,352 cases from NASS/CDS 2000-2005, 133 cases from NHTSA Special Crash Investigations, and 58 cases from CIREN in-depth crash investigation cases.

Validation of EDR Accuracy in Crash Tests

To determine the accuracy of the EDR data used in the study, an extensive evaluation of the EDR data from 48 NHTSA and IIHS crash tests was conducted in which the EDR data was compared with the high-precision laboratory-grade instrumentation installed on each crash-tested vehicle. All vehicles were MY 2004-2007. Our findings are as follows:

- For those crash tests in which the EDRs recorded the entire crash event or were missing no more than 2 percent of the crash event, the EDR underestimates true longitudinal delta V by under 0.5 percent on average. The correlation between EDR and crash test delta V was high (R^2 = 0.972). The average absolute percent difference between EDR and crash test delta V for these tests was 4.2 percent.

- In all crash tests, the EDR underestimates true longitudinal delta V by under 0.5 percent on average at t=100 ms.

- The only EDR in our sample that recorded non-zero data in the lateral direction (y-axis) showed poor agreement between the crash instrumentation and the EDR lateral delta V. The vehicle was a 2004 Chevrolet Malibu subjected to a frontal pole crash test.

- Insufficient recording duration continues to be a problem for EDRs. Fourteen of 48 EDRs (29.2 percent) in our sample of crash tests did not record the entire event. This is an improvement, however, over the findings of the Niehoff study that reported that the majority of the EDRs in its samples did not successfully record the entire event.

- In all crash tests for which the EDR recorded seat belt buckle status, driver and passenger belt buckle status – either buckled or unbuckled – was correctly recorded by the EDRs.

- With one exception, the EDR pre-crash speed was in excellent agreement with the crash test impact speed. The average error was less than 3 percent. In one case however, the EDR underreported pre-crash speed by 22 percent.

Evaluation of Advanced Air Bags in Real World Crashes

The research program investigated the field performance of occupant restraint systems, designed with advanced air bag features, including criteria specified in the US FMVSS No. 208 for advanced air bags. The analysis was based upon EDR records extracted from the NHTSA EDR dataset for 106 NASS/CDS cases involving CAC vehicles. The CAC sample was composed of 47 air bag deployments and 59 non-deployments. A separate analysis of air bag deployment times was conducted using 132 cases of both CAC and pre-CAC vehicles having an advanced air bag that deployed.

The findings were as follows:

1. Deployment Characteristics. For this sample, there was a 50-percent probability of driver air bag deployment for a longitudinal delta V of 8 mph. The driver air bag was observed to deploy at longitudinal delta V as low as 3 to 4 mph. The driver air bag was observed to not deploy at longitudinal delta V as high as 26 mph.

2. Delayed Deployments. In 12 advanced frontal air bag cases, driver air bag deployment times recorded by the EDR exceeded 72 milliseconds. Examination of these cases revealed that frequently these delayed deployments were associated with narrow impacts, multiple impacts, lower delta V crashes or cases with abnormal crash pulses.

3. Passenger Air Bag Non-Deployment When No Passenger Was Present. The CAC air bag systems in this study suppressed the passenger air bag in the majority of cases (27 of 30) in which the passenger seat was vacant. This indicates the presence of sophisticated occupant sensors that are characteristic of advanced air bag systems.

4. Air Bag Suppression in Presence of a Right-Front Passenger. In two of the CAC vehicles, the passenger air bag did not deploy despite the presence of a passenger. In both cases, the driver air bag deployed and the air bag on/off switch was in the auto position. One case was for a 5-year-old child and the other case was for a 29-year-old adult.

This study has demonstrated the feasibility of using event data recorders to evaluate the performance of advanced occupant restraint deployment algorithms. Because this study was based upon a small number of cases, the conclusions should be revisited when additional EDR data is available from CAC cases.

6. References

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Appendix A – Comparison of Longitudinal Delta V in EDR Data and Crash Test Instrumentation

The following plots compare the longitudinal delta V recorded by the EDR with the longitudinal delta V measured by the crash test instrumentation.

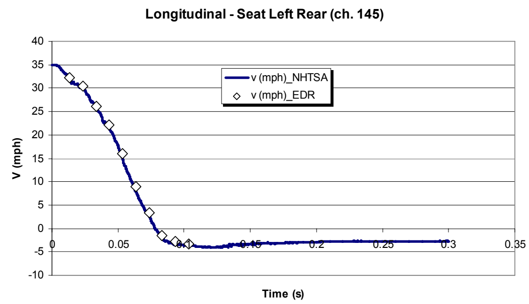

Figure 24. NHTSA Test 5310- 2005 Buick Rendezvous (with EDR time shift of -.0035s)

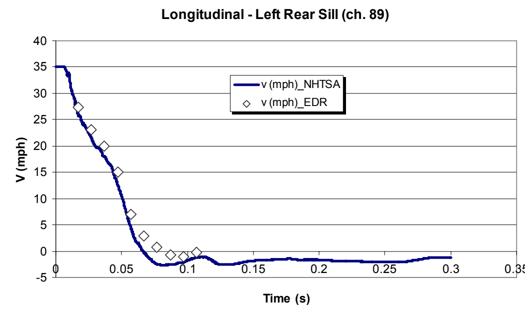

Figure 25. NHTSA Test 5282- 2005 Chevrolet Colorado (ext.cab) (with EDR time shift of -.007s)

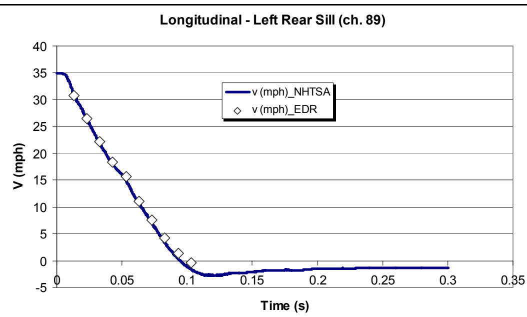

Figure 26. NHTSA Test 5265- 2005 Chevrolet Express (with EDR time shift of -.003s)

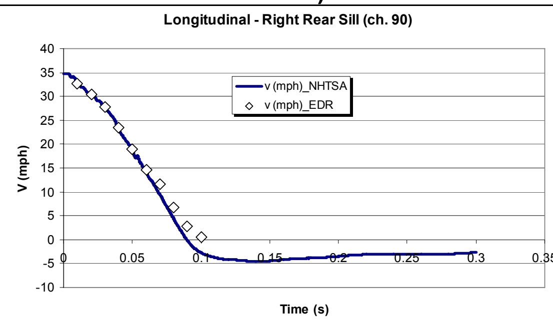

Figure 27. NHTSA Test 5324- 2005 Pontiac Montana (with no EDR time shift)

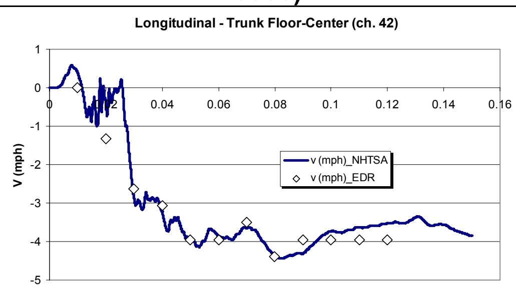

Figure 28. NHTSA Test 5260- 2005 Saturn Ion – Side Impact (with no EDR time shift)

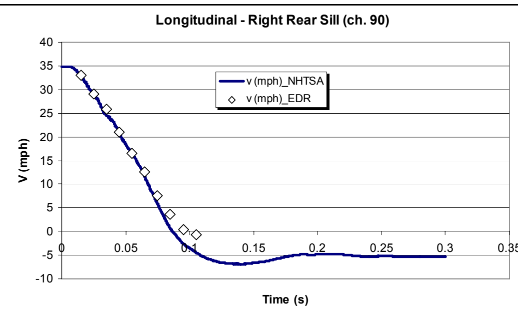

Figure 29. NHTSA Test 5318- 2005 Chevrolet Silverado (EDR time shift of -.005s)

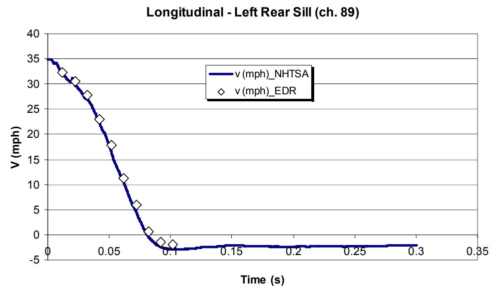

Figure 30. NHTSA Test 5264- 2005 Chevrolet Uplander (with EDR time shift of -.002s)

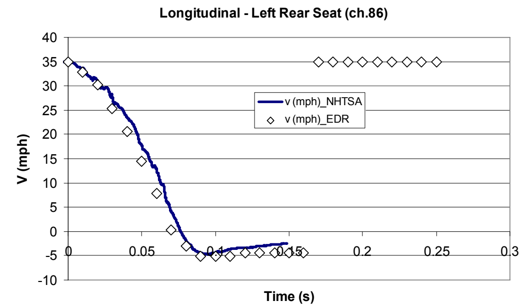

Figure 31. NHTSA Test 5326- 2006 Chevrolet Cobalt (with EDR time shift of .005s)

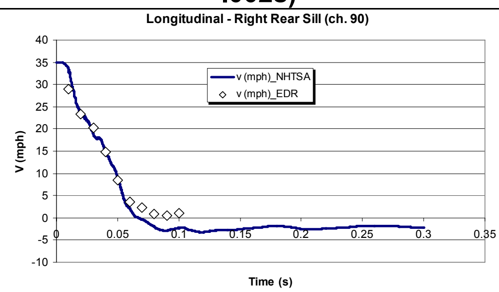

Figure 32. NHTSA Test 5603- 2006 Chevrolet Colorado (2-DR) (with no EDR time shift)

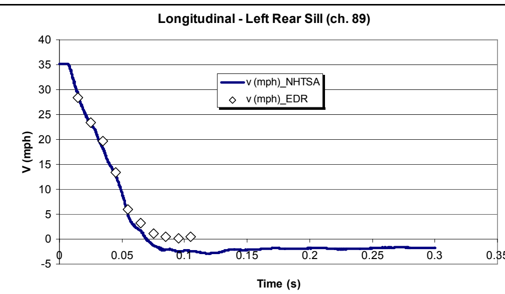

Figure 33. NHTSA Test 5597- 2006 Chevrolet Colorado (4-DR) (with EDR time shift of -.005s)

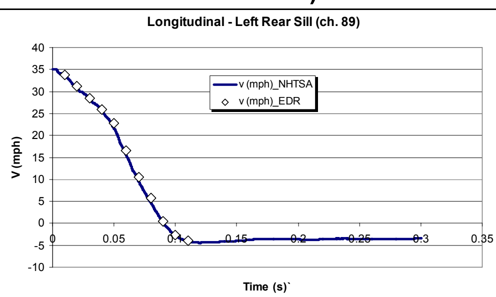

Figure 34. NHTSA Test 5468- 2006 Pontiac Grand Prix (4-DR) (with no EDR time shift)

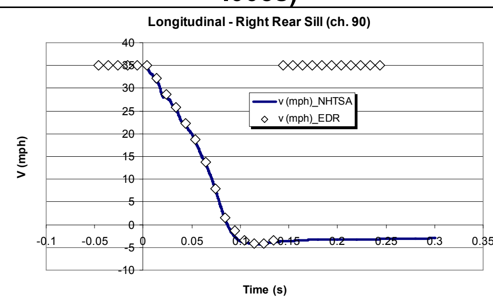

Figure 35. NHTSA Test 5589- 2006 Buick Lucerne CX (with EDR time shift of -0.056s)

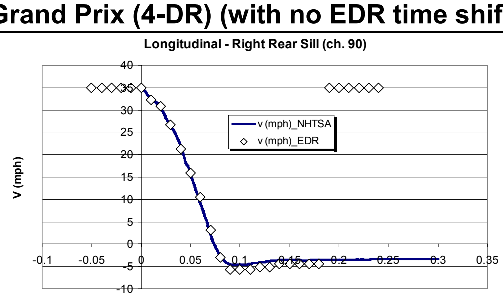

Figure 36. NHTSA Test 5602- 2006 Chevrolet HHR (with EDR time shift of -0.060s)

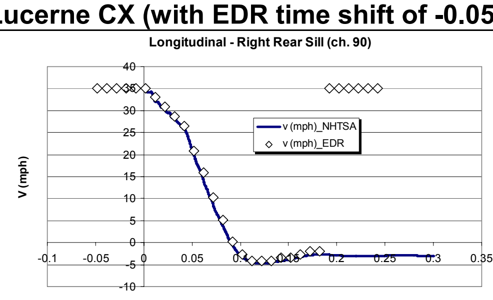

Figure 37. NHTSA Test 5547- 2006 Chevrolet Impala (with EDR time shift of -0.058s)

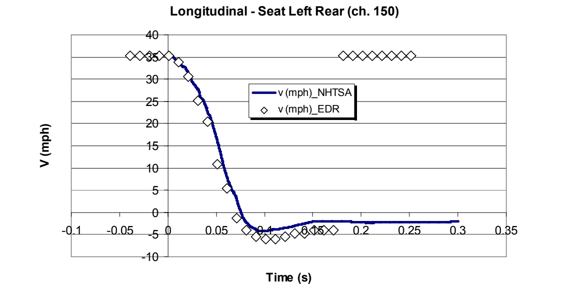

Figure 38. NHTSA Test 5250- 2005 Pontiac G6 (with EDR time shift of -0.049s)

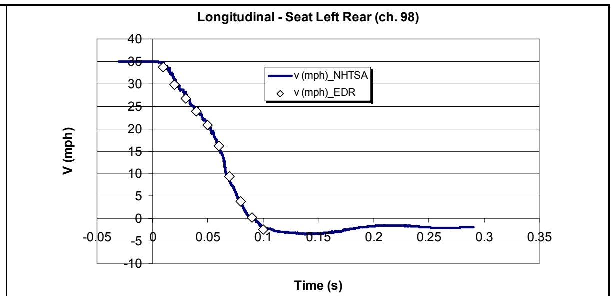

Figure 39. NHTSA Test 5140- 2004 Chevrolet Avalanche (with no EDR time shift)

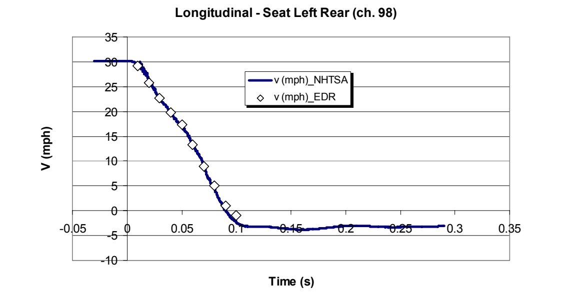

Figure 40. NHTSA Test 5213- 2004 Chevrolet Avalanche (with no EDR time shift)

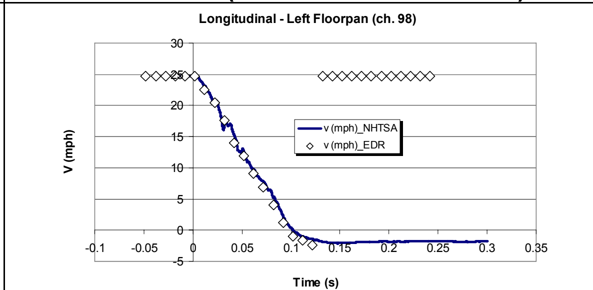

Figure 41. NHTSA Test 5741-2006 Buick Lucerne (with EDR time shift of -0.058s)

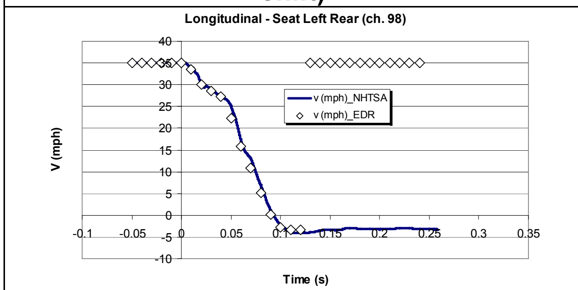

Figure 42. NHTSA Test 5578- 2006 Chevrolet Monte Carlo (with EDR time shift of -0.060s)

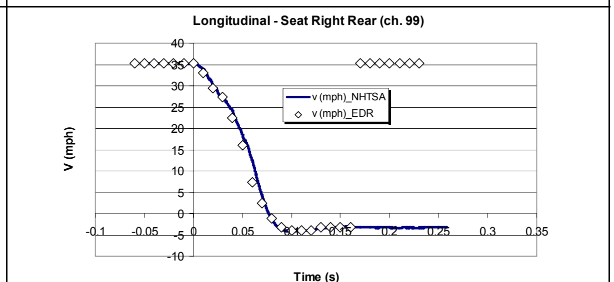

Figure 43. NHTSA Test 5569- 2006 Cadillac DTS (with EDR time shift of -0.070s)

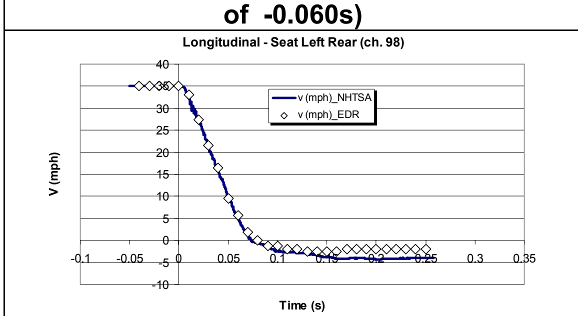

Figure 44. NHTSA Test 5567- 2006 Hummer H3 (with EDR time shift of -0.050s)

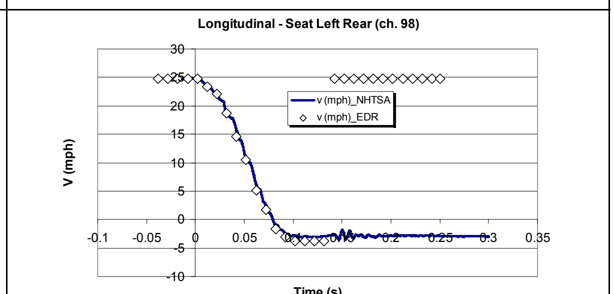

Figure 45. NHTSA Test 5830- 2006 Pontiac G6 (with EDR time shift of -0.048s)

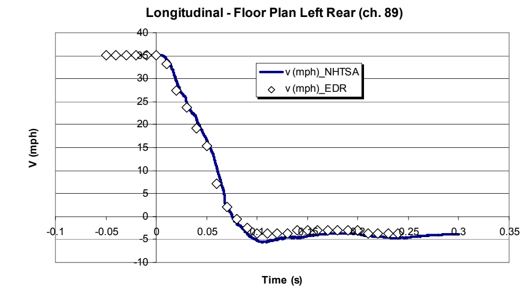

Figure 46. NHTSA Test 5907- 2007 Chevrolet Silverado (with EDR time shift of -0.060s)

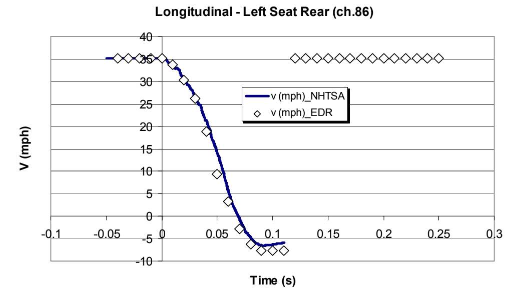

Figure 47. NHTSA Test 5844- 2007 Saturn Aura (with EDR time shift of -0.050s)

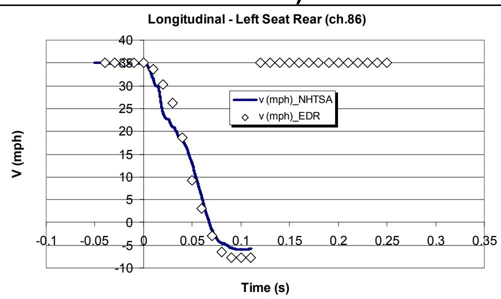

Figure 48. NHTSA Test 5859- 2007 Pontiac Solstice (with EDR time shift of -0.050s)

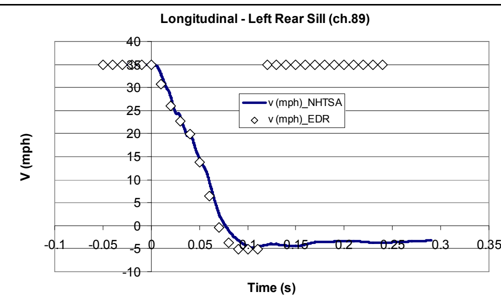

Figure 49. NHTSA Test 5877- 2007 Chevrolet Silverado (with EDR time shift of -0.060s)

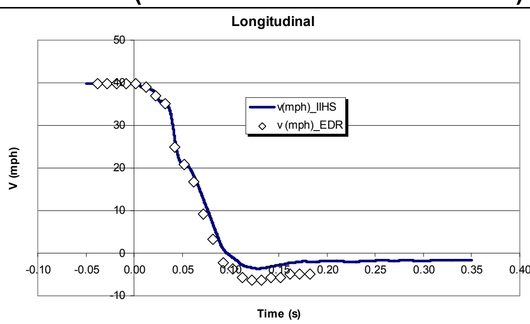

Figure 50. IIHS Test CF05003- 2004 Chevrolet Malibu – Pole Test (with no EDR time shift)

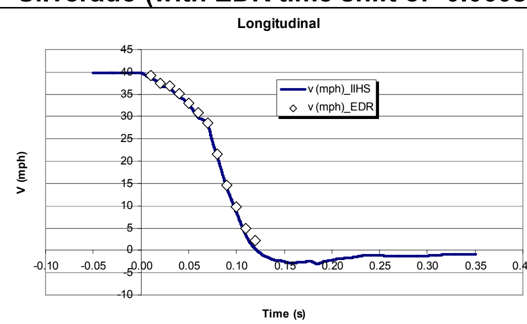

Figure 51. IIHS Test CEF0419- 2005 Saturn Ion (with no EDR time shift)

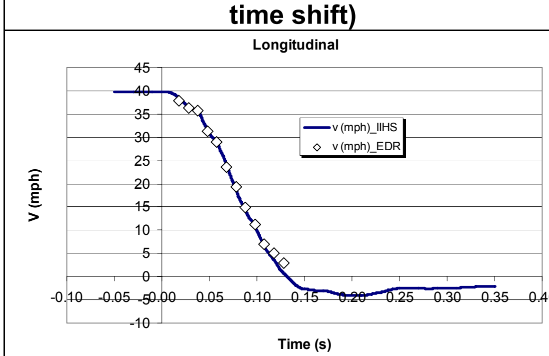

Figure 52. IIHS Test CEF0506- 2005 Chevrolet Colorado (with no EDR time shift)

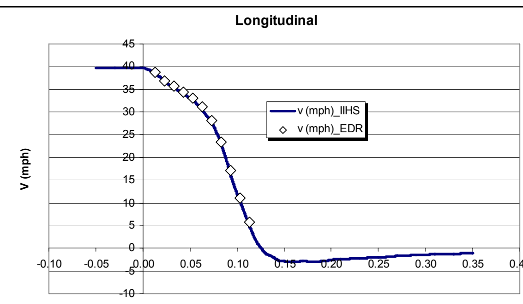

Figure 53. IIHS Test CEF0511- 2005 Buick LaCrosse (with no EDR time shift)

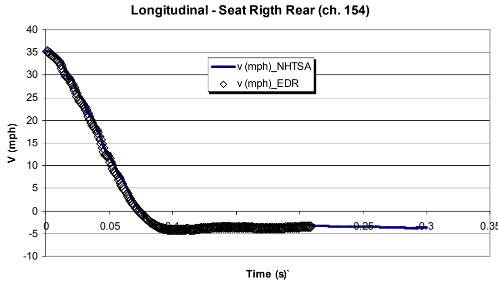

Figure 54. NHTSA Test 5249- 2005 Ford 500 (with no EDR time shift)

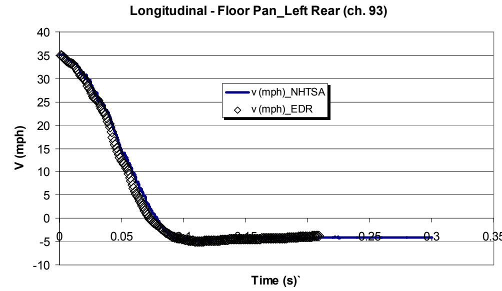

Figure 55. NHTSA Test 5263- 2005 Ford Freestyle (with no EDR time shift)

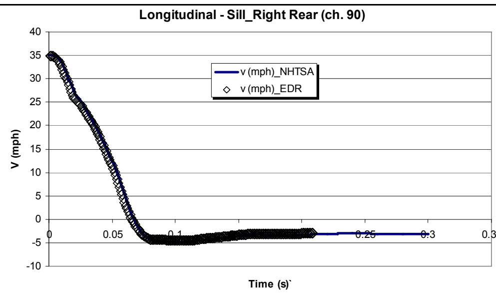

Figure 56. NHTSA Test 5284- 2005 Ford Econoline (with no EDR time shift)

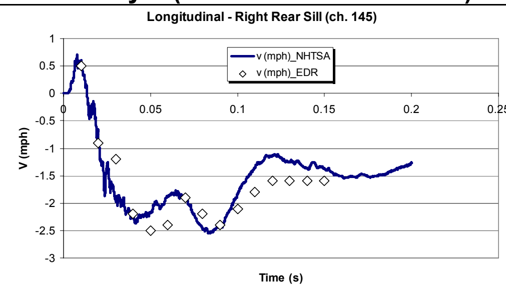

Figure 57. NHTSA Test 4928- 2004 Toyota Camry – Side Impact (with no EDR time shift)

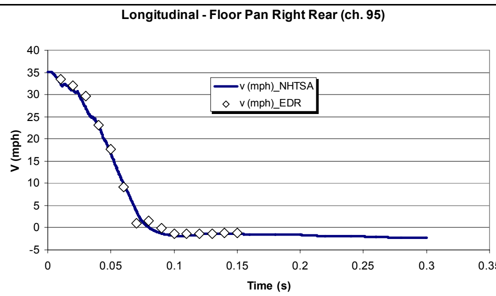

Figure 58. NHTSA Test 5283- 2005 Toyota Camry (with no EDR time shift)

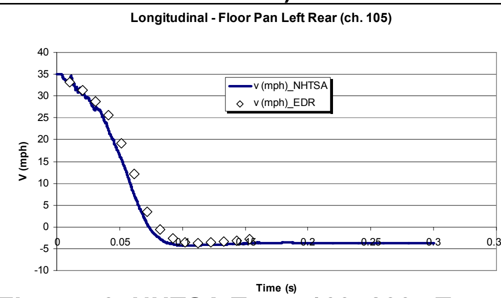

Figure 59. NHTSA Test 5160- 2005 Toyota Corolla (with no EDR time shift)

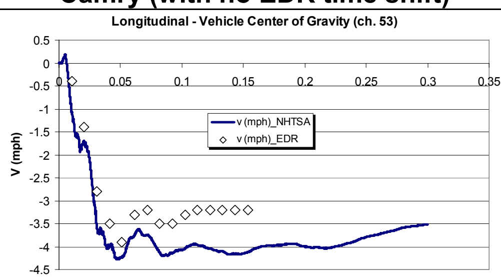

Figure 60. NHTSA Test 5157- 2005 Toyota Corolla – Side Impact (with no EDR time shift)

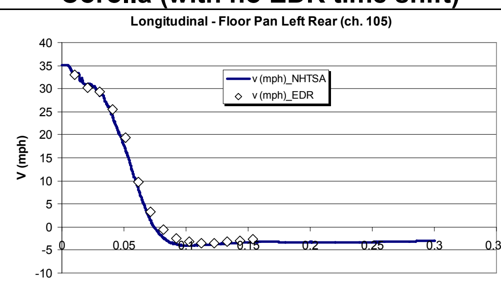

Figure 61. NHTSA Test 5209- 2005 Toyota Matrix (with no EDR time shift)

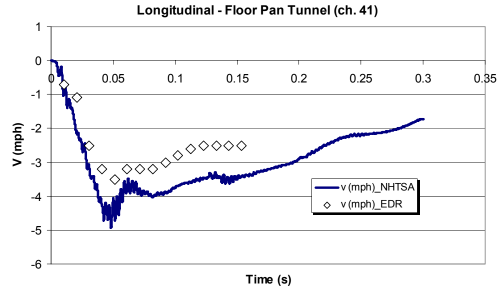

Figure 62. NHTSA Test 5162- 2005 Toyota Matrix – Side Impact (with no EDR time shift)

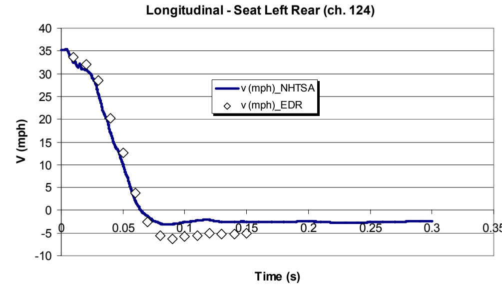

Figure 63. NHTSA Test 4893- 2004 Toyota RAV4 (with no EDR time shift)

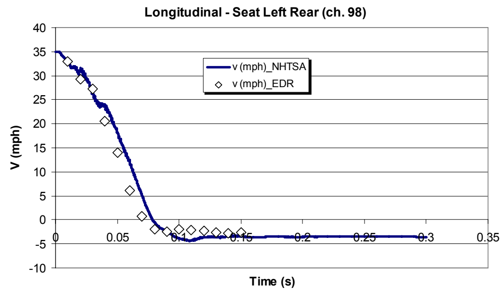

Figure 64. NHTSA Test 5269- 2005 Toyota Sienna (with no EDR time shift)

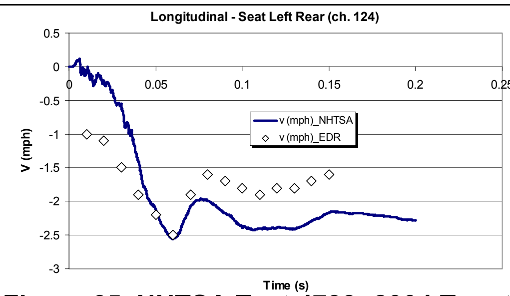

Figure 65. NHTSA Test 4733- 2004 Toyota Sienna – Side Impact (with no EDR time shift)

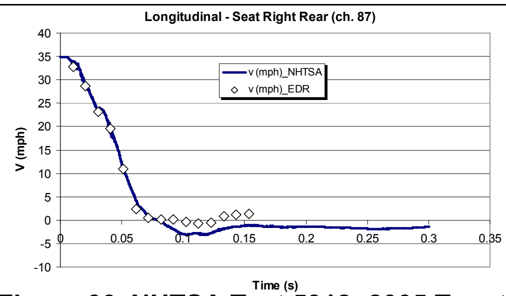

Figure 66. NHTSA Test 5312- 2005 Toyota Tacoma (with no EDR time shift)

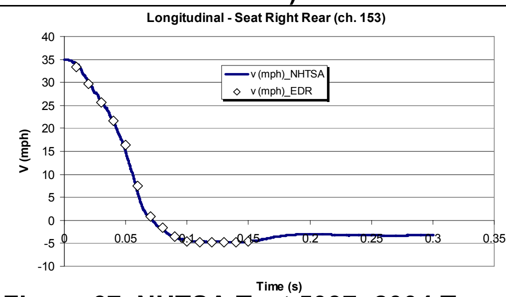

Figure 67. NHTSA Test 5037- 2004 Toyota 4Runner (with no EDR time shift)

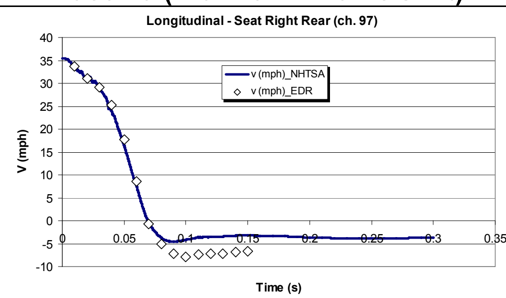

Figure 68. NHTSA Test 4933- 2004 Toyota Prius (with no EDR time shift)

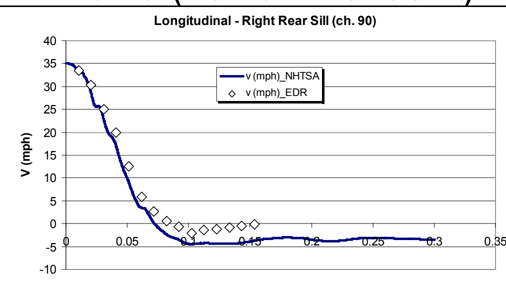

Figure 69. NHTSA Test 5218- 2005 Toyota Tundra (with no EDR time shift)

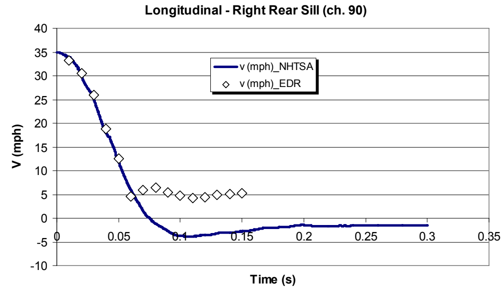

Figure 70. NHTSA Test 5239- 2005 Toyota Tundra (with no EDR time shift)

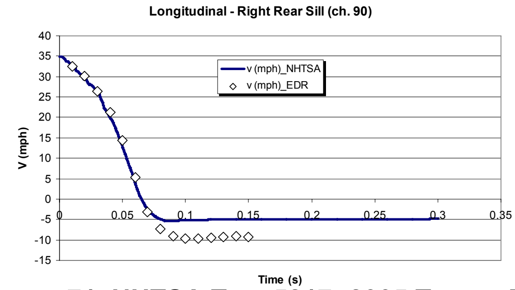

Figure 71. NHTSA Test 5217- 2005 Toyota TC (with no EDR time shift)

Appendix B – Analysis of Frontal NCAP Air Bag Deployment Times

This appendix presents air bag deployment times in NCAP full frontal rigid barrier crash tests. The EDRs in this analysis were downloaded from GM vehicles subjected to NCAP frontal barrier impact tests. The dataset consisted of 29 vehicles ranging from MY 2002-2006. All vehicles in the analysis were equipped with dual-stage frontal air bag systems. Table 21 presents the resulting data:

Table 21. Frontal Air Bag Deployment Times by Model Year in NCAP Frontal Crash Tests

NHTSA Test No.	MY	Make	Model	SDM Module	Deploy Time Driver Stage1 (ms)	Deploy Time Driver Stage2 (ms)	Deploy Time RF Pass Stage1 (ms)	Deploy Time RF Pass Stage2 (ms)
4238	2002	CADILLAC	DE VILLE	SDMGF2002	17.5	20	17.5	20
4244	2002	CHEVROLET	TRAILBLAZER	SDMGT2002	5	7.5	5	7.5
4464	2003	CHEVROLET	AVALANCHE	SDMGF2002	5	10	5	10
4472	2003	CHEVROLET	SILVERADO	SDMGF2002	7.5	17.5	7.5	17.5
4487	2003	SATURN	ION	SDMDW2003	10	25	10	25
4549	2003	CHEVROLET	TAHOE	SDMGF2002	2.5	7.5	2.5	7.5
4567	2003	CHEVROLET	SUBURBAN	SDMGF2002	2.5	5	2.5	5
4775	2004	PONTIAC	GRAND PRIX	SDMDW2003	10	12.5	10	12.5
4899	2004	CHEVROLET	COLORADO	SDMGF2002	2.5	7.5	2.5	7.5
4918	2004	GMC	ENVOY XUV	SDMGT2002	5	7.5	5	7.5
4923	2004	CADILLAC	SRX	SDMGF2002	5	7.5	5	7.5
4985	2005	CHEVROLET	EQUINOX	SDMDW2003	10	12.5	10	12.5
5140	2004	CHEVROLET	AVALANCHE	SDMGF2002	7.5	17.5	7.5	17.5
5250	2005	PONTIAC	G6	Epsilon2005	12	14	12	14
5264	2005	CHEVROLET	UPLANDER	SDMDW2003	5	7.5	5	7.5
5265	2005	CHEVROLET	EXPRESS	SDMGF2002	5	7.5	5	7.5
5282	2005	CHEVROLET	COLORADO	SDMGF2002	2.5	7.5	2.5	7.5
5310	2005	BUICK	RENDEZVOUS	SDMDW2003	7.5	7.5	7.5	7.5
5318	2005	CHEVROLET	SILVERADO	SDMGF2002	7.5	15	7.5	15
5324	2005	PONTIAC	MONTANA	SDMDW2003	7.5	7.5	7.5	7.5
5468	2006	PONTIAC	GRAND PRIX	SDMDW2003	10	12.5	10	12.5
5547	2006	CHEVROLET	IMPALA	SDMC2006	10	12	10	12
5567	2006	HUMMER	H3	SDMDS2005	3.75	6.25	3.75	6.25
5569	2006	CADILLAC	DTS	SDMC2006	8	12	8	128*
5578	2006	CHEVROLET	MONTE CARLO	SDMC2006	12	12	12	12
5589	2006	BUICK	LUCERNE	SDMC2006	10	14	10	130*
5597	2006	CHEVROLET	COLORADO	SDMGF2002	2.5	7.5	2.5	7.5
5602	2006	CHEVROLET	HHR	Epsilon2005	8	20	8	20
5603	2006	CHEVROLET	COLORADO	SDMGF2002	2.5	10	2.5	10

* Disposal Time for Second Stage

Description of Deployment Times

Figure 72 presents the first stage deployment times by model year. First stage deployment times ranged from 2.5 ms for a 2004 Chevrolet Colorado to 17.5 ms for a 2002 Cadillac DeVille. For all tests of vehicles having dual-stage air bag systems, both stages fired. For all tests of vehicles having dual-stage air bag systems, except tests 5569 and 5589, the driver and right-front passenger air bag deployment times were identical for both stages. In tests 5569 (2006 Cadillac DTS) and 5589 (2006 Buick Lucerne), the second-stage deployment time for the right-front passenger was 128 ms and 130 ms respectively. In these two cases, the second stage was deployed for disposal rather than occupant protection.

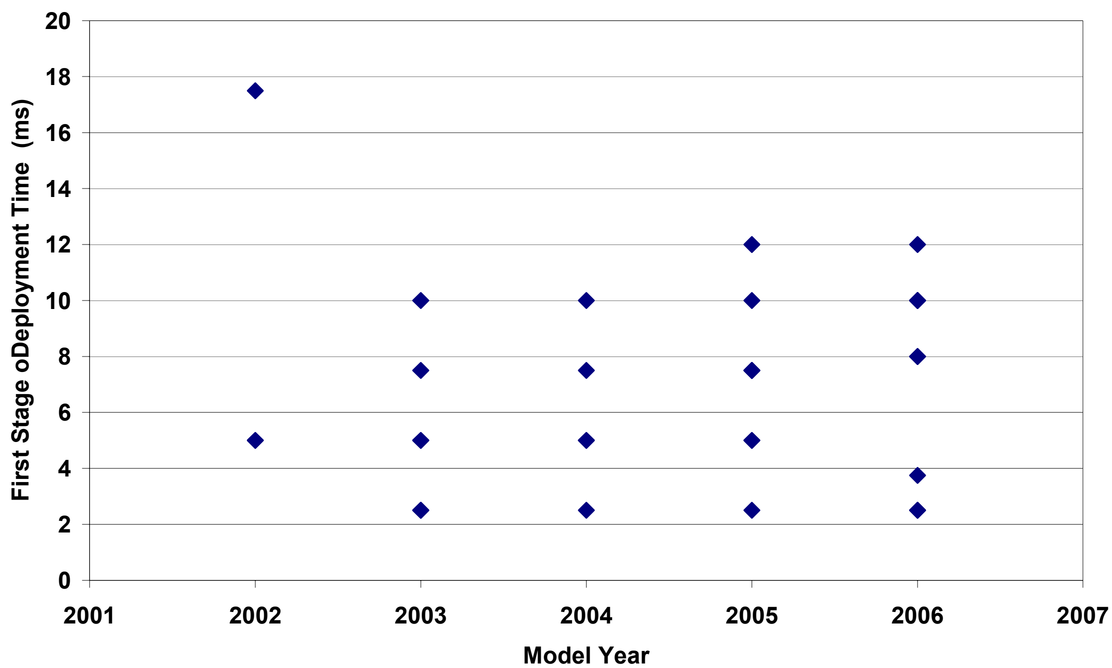

Figure 72. First Stage Deployment Times versus Model Year In Frontal NCAP Tests

Table 22 presents air bag deployment times by SDM Module type. For this dataset, the minimum time to trigger the first stage was 2.5 ms observed for the SDMGF2002 module. Approximately half of SDMGF2002-equipped vehicles fired the first stage at 2.5 ms. One interesting note is that the SDMGF2002 module also had a single case with a fire time of 17.5 ms (a 2002 Cadillac DeVille). In contrast, the SDMC2006 and Episilon2005, two newer modules, triggered the first stage between 8-12 ms.

Table 22. Frontal Air Bag Deployment Times by EDR Module Type in NCAP Frontal Crash Tests

Module Type	Number in Sample	Min 1st Stage Deployment Time (ms)	Max 1st Stage Deployment Time (ms)	Average 1st Stage Deployment Time (ms)
SDMGF2002	13	2.5	17.5	5.38
SDMGT2002	2	5	5	5
SDMDW2003	7	5	10	8.57
SDMS2005	1	3.75	3.75	3.75
Epsilon2005	2	8	12	10
SDMGC2006	4	8	12	10
All	29	2.5	17.5	7.0

Appendix C – Computation of Acceleration From EDR Delta V Data

To determine the efficacy of differentiating the delta V data from the GM EDR to determine the vehicle's deceleration, a case where the vehicle's acceleration was known was examined. During NHTSA's NCAP program, vehicles are always instrumented with accelerometers. This analysis used the data from an NCAP test of a 2005 Chevrolet Equinox. These data are found in the NHTSA Vehicle Crash Test Database, located on the NHTSA Web page (NHTSA, 2007).

The vehicle deceleration is shown in Figure 73. This data was filtered using SAE J211 Class 60.

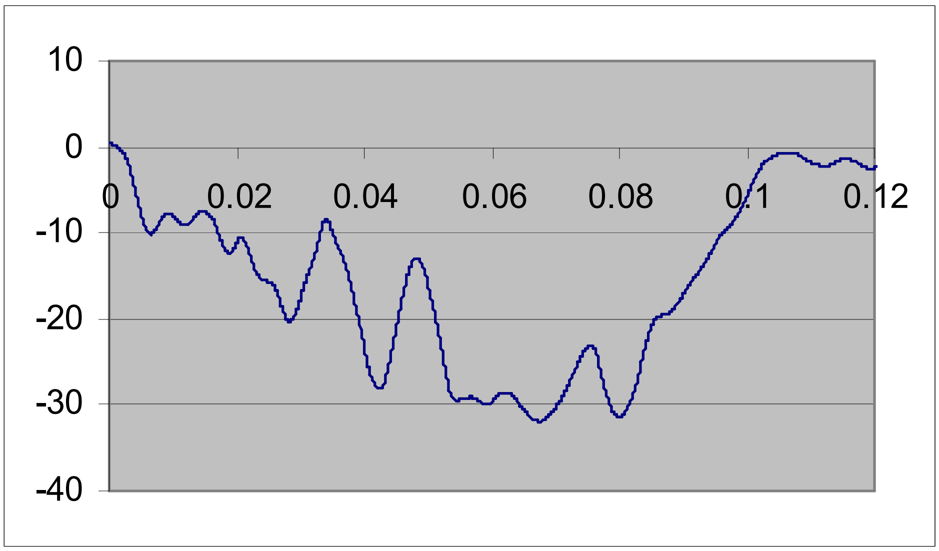

Figure 73. Vehicle Longitudinal Deceleration (G's) From an NCAP Test of a 2005 Chevrolet Equinox versus Time (msec)

The EDR data from this test was extracted and downloaded from the NHTSA Vehicle Crash Test Database. That data is also available on the NHTSA Web page. The deployment file crash delta V is shown in Figure 74.

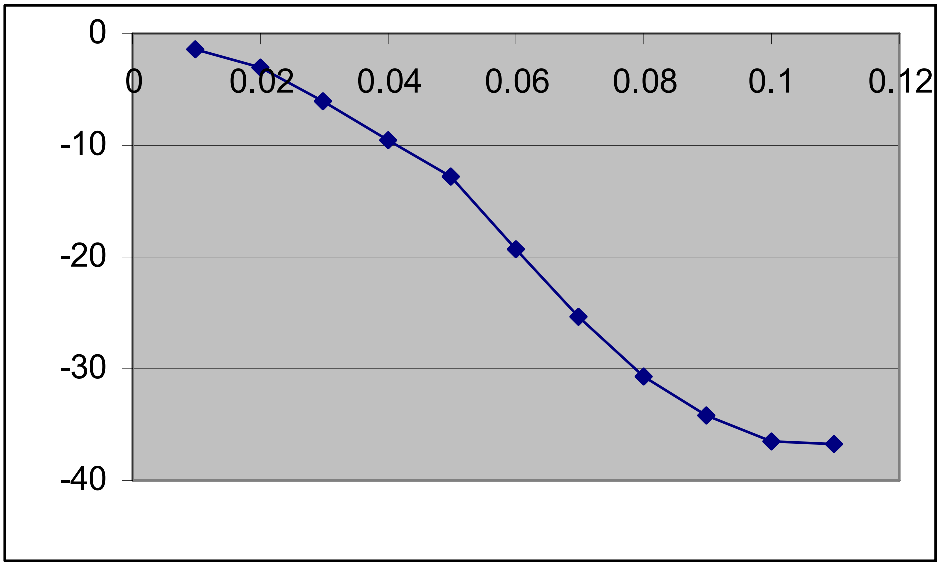

Figure 74. Vehicle EDR Longitudinal Velocity Change (mph) From an NCAP Test of a 2005 Chevrolet Equinox versus Time (msec)

This data was differentiated (using a simple difference method and applying a mid-point time value to each point) to obtain a representation of the vehicle's deceleration. Because the time between samples is 10 msec, the fidelity seen in the vehicle's accelerometer cannot be replicated. Hence we see a somewhat smoothed characteristic. Figure 75 presents this data.

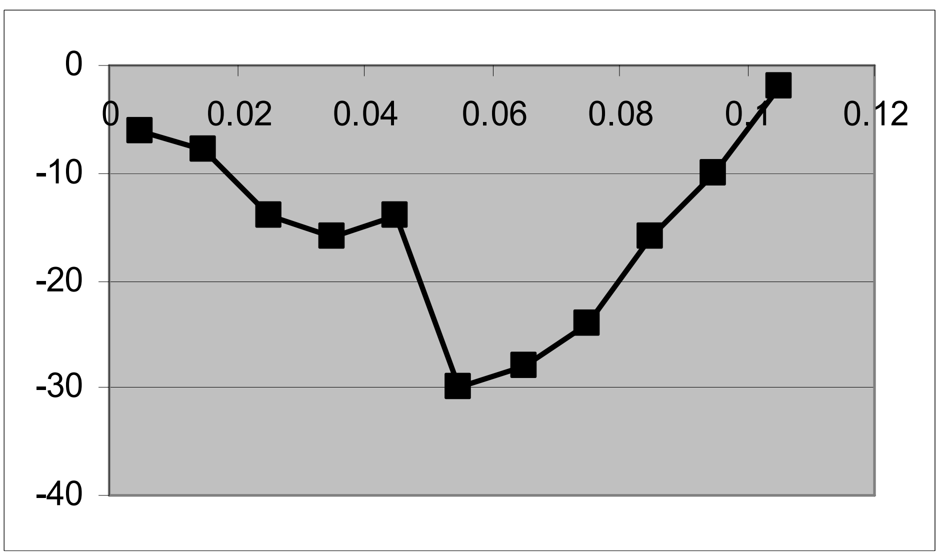

Figure 75. Differentiated Vehicle EDR Longitudinal Velocity Change (G's) From an NCAP Test of a 2005 Chevrolet Equinox versus Time (msec)

The vehicle accelerometer signal and the differentiated EDR data are compared in Figure 76
.

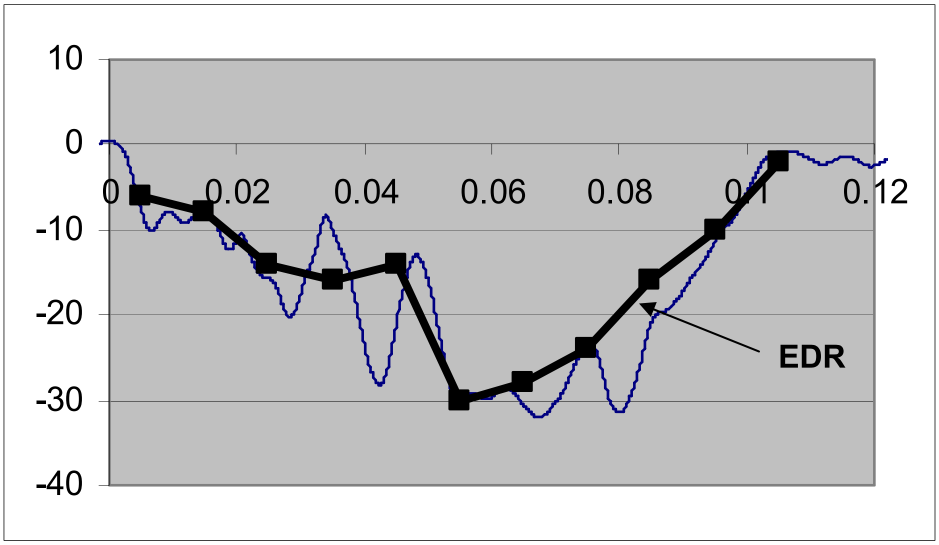

Figure 76. Differentiated Vehicle EDR Longitudinal Velocity Change Compared With Vehicle Accelerometer (G's) From an NCAP Test of a 2005 Chevrolet Equinox versus Time (msec)

As can be seen in this data, the 10 msec delta V data from the GM EDR crash data can be used to generally reconstruct the actual crash pulse, as seen by the vehicle accelerometer. The main different in shape is the loss of the higher frequency content.

DOT HS 811 015
August 2008

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