CHARACTERIZATION OF ADVANCED AIR BAG FIELD PERFORMANCE USING EVENT DATA RECORDERS

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ABSTRACT

This paper characterizes the field performance of occupant restraint systems designed with advanced air bag features including those specified in the US Federal Motor Vehicle Safety Standard (FMVSS) No. 208 for advanced air bags, through the use of Event Data Recorders (EDRs). 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. The study was based on advanced air bag cases extracted from NASS/CDS 2000-2005 with associated EDR data. The paper presents the characteristics of advanced air bag deployment (number of stages and trigger time) as a function of crash severity and seating location, the characteristics of delayed deployments, and the frequency and characteristics of frontal crashes in which the air bag did not deploy.

INTRODUCTION

In the U.S., 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, pretensionsers, 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 is to characterize the performance of advanced frontal air bags in real world crashes. The paper will include 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 Virginia Tech EDR (VT EDR Database) database. The VT EDR Database contains 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 (CDR) retrieval system.

CHARACTERIZATION OF DATA SET

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 General Motors (GM) passenger cars, light trucks, and vans. Table 1 shows the distribution of cases by EDR module type.

Table 1. 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 1 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.

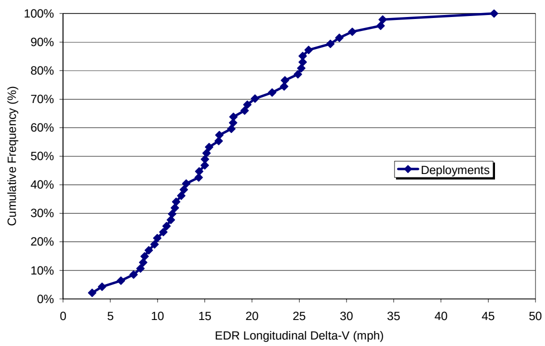

Figure 1. Distribution of Longitudinal Delta-V Values in Deployment Events

As shown in Figure 2, a frontal impact was the most harmful event in over 90% of the CAC air bag deployment cases.

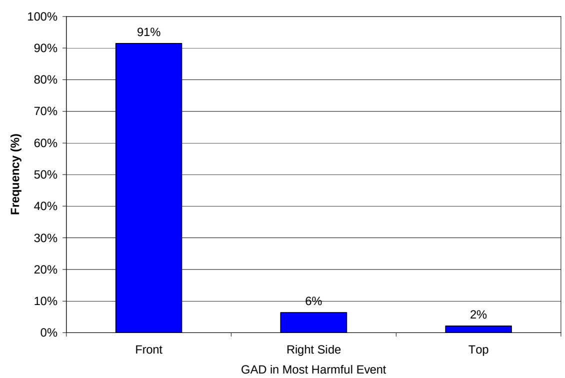

Figure 2. General Area of Damage in Most Harmful Event in Deployment Crashes

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 which triggered the air bag. The most harmful event may not be the event which triggers the airbag. Unfortunately, in a multiple event crash, the event which triggered the air bag cannot always be determined. As shown in Figure 3, NASS investigators recorded that over 50% of the CAC air bag deployment cases involved multiple events. Not all of these events necessarily have a longitudinal component of sufficient magnitude to deploy the air bag.

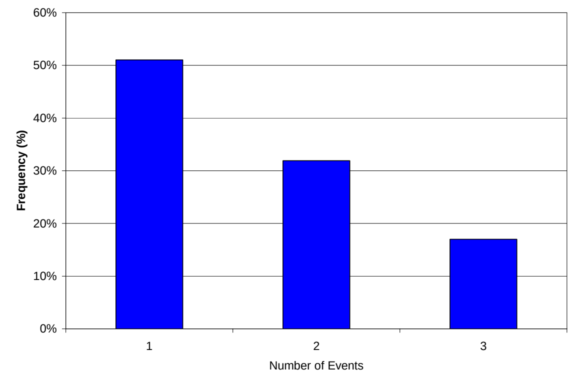

Figure 3. Number of Impact Events in Each Crash Involving a Frontal Air Bag Deployment as Observed by NASS investigator

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 which involved a longitudinal component of delta-V. In our sample of 47 deployments, 44 were SDMGF2002 modules. Figure 4 below shows that in over 80% 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.

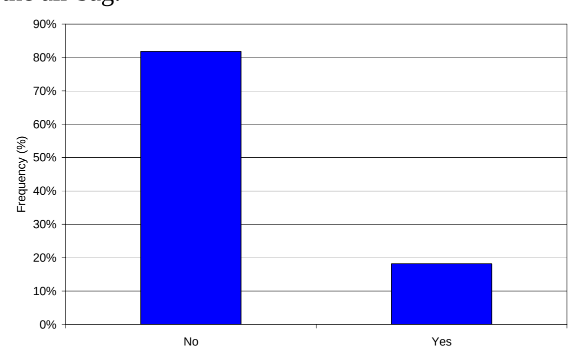

Figure 4. Number of Deployment Crashes with Multiple Events Involving Longitudinal Delta-v Component as Recorded by EDR

Belt Use and Air Bag Deployment

Table 2 presents the distribution of driver belt buckle status in deployment cases. In approximately half of the cases, the EDR recorded that the driver 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.

Table 2. 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 3 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 3.

Table 3. 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 4 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 4. 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 driver air bag was deployed. NASS investigators observed however 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.

Vehicle Speed just Prior to Impact

The GM EDRs in our dataset recorded 5 seconds of precrash data in one second intervals on 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 5 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.

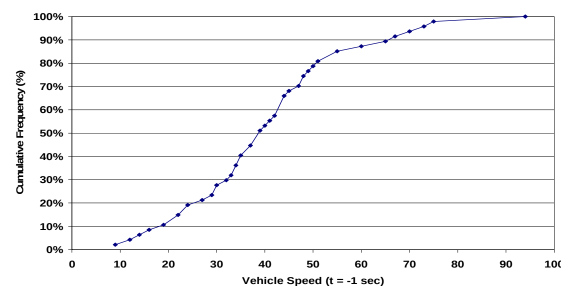

Figure 5. Distribution of Vehicle Speed approximately One Second before impact in Deployment Events

RESULTS

Figure 6 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 which resulted in a deployment, 2) those crashes not sufficiently severe to deploy the airbag, 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% for a longitudinal delta-V of 8 mph.

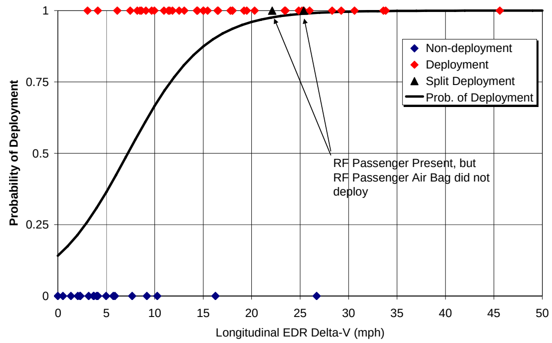

Figure 6. Probability of Deployment of Driver Air Bag by Longitudinal Delta-V

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 7 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 crashes 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.

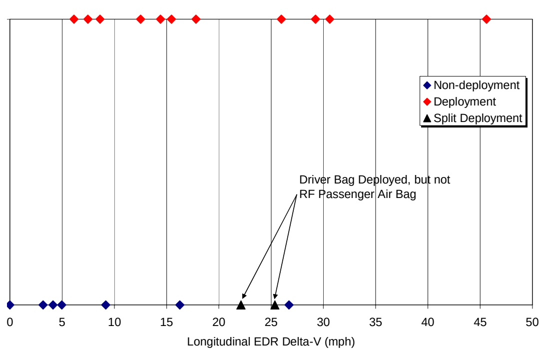

Figure 7. Distribution of Right Front Passenger Air Bag Deployment Decisions by Delta-V

All CAC air bag systems in our data set contained dual stage inflators. Dual stage inflators allow the air bag deployment characteristics to be tailored to the particular crash severity and occupant configuration of a collision. 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 8, both inflator stages were triggered only in higher delta-V crashes.

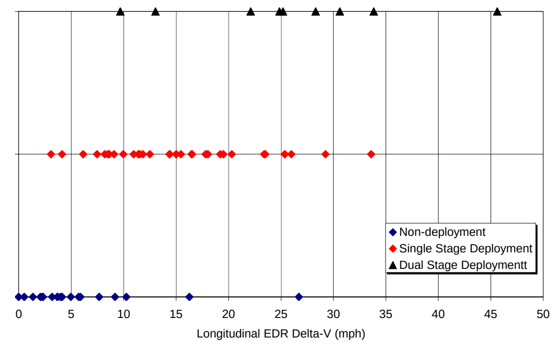

Figure 8. Distribution of Driver Air bag Dual-Stage, Single-Stage, and Non-deployments vs. Delta-V

Figure 9 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.

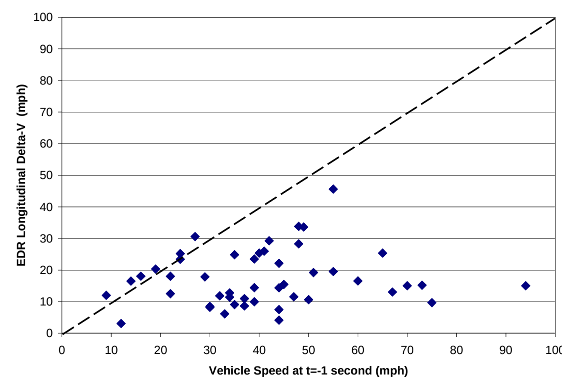

Figure 9. Longitudinal Delta-V vs. Vehicle Speed just before collision in CAC deployment cases

Time Interval from Algorithm Enable to Deployment

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 utilized. 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.

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 Federal motor vehicle safety standard (FMVSS) No. 208 and New Car Assessment Program (NCAP). Data from over thirty vehicles, model year 2002 through 2006, were examined. Deployment times are shown in Figure 10. For these tests, 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) deployed at the same exact time.

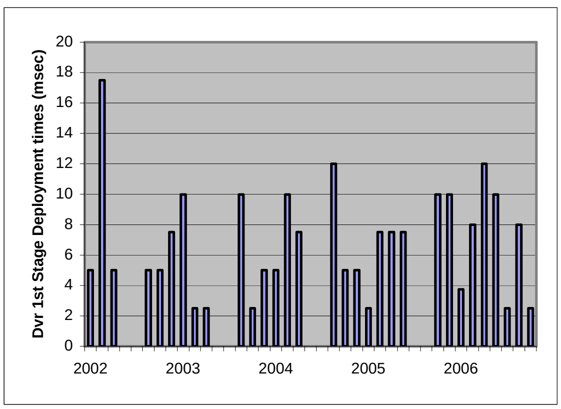

Figure 10. 1st Stage Deployment Times vs. Model Year in Frontal NCAP Tests

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 which deployed, were compiled into a subset of the VT EDR Database. 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 11.

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.

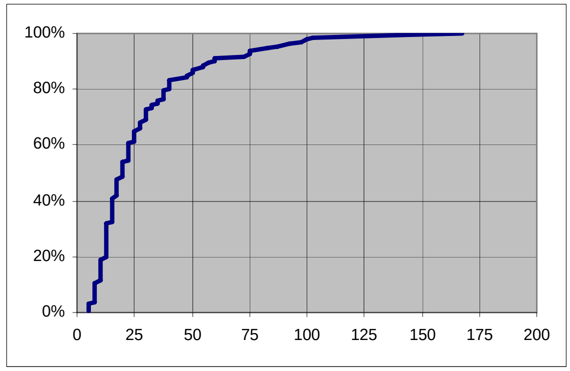

Figure 11. Cumulative Distribution (%) of Driver 1st Stage Air Bag Deployment vs. Deployment Time (msec)

DELAYED DEPLOYMENTS

The VT EDR database 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 5.

Table 5. 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 were reviewed to determine the driver seat belt status, longitudinal delta-V of the case vehicle, and the driver's air bag deployment time. These data are provided in Table 6.

Table 6. Driver Belt Status, Vehicle Longitudinal Delta-V, and Driver Air Bag Deployment Times (* = CAC Vehicle)

NASS Case Number	Dvr Belt Stat	Delta-V (mph)	Dvr A/B Dep 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 which 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 two of the twelve cases investigated, the EDR recorded the vehicle's speed increasing during the impact. In case **2004-50-087**, this was observed. Figure 12 shows these data.

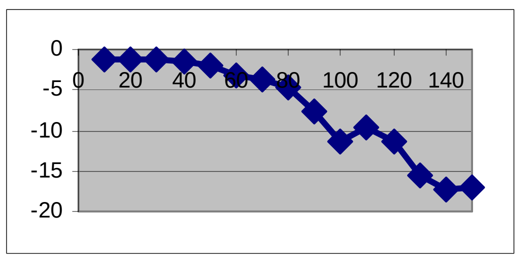

Figure 12. Case 2004-50-087 EDR Delta-V (mph) vs. time (msec)

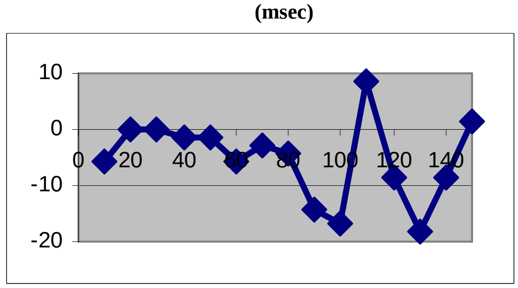

Figure 13. Case 2004-50-087 Differentiated EDR Delta-V (mph) vs. time (msec)

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 13.

From these 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 these 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.

Delayed start of delta-V data: In several cases the data captured and recorded are part of the EDR record related to the deployment file show 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 14 shows the first major separation from 0 mph to be at 60 msec.

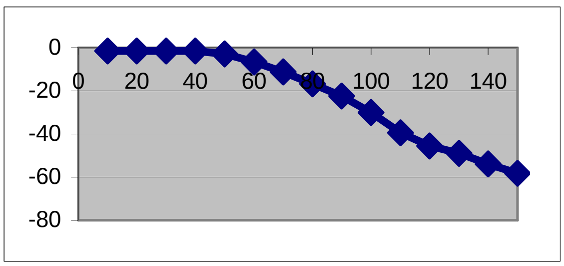

Figure 14. Case 2001-41-133 EDR Delta-V (mph) vs. time (msec)

Findings

The following is a discussion of these twelve 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 twelve 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. These data are shown below.

Table 7. 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 twelve cases.

Narrow/Offset: In many of the cases, the vehicle impacted 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 15 and Figure 16 present examples of these impacts.

Figure 15. Case 2004-12-052 Impact with Small Sign and Pole

Figure 16. 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 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 as the 10 msec data point.

Multi Impact: Many of these twelve cases have earlier non-deployment impacts, as reported by both NASS and the EDR. Table 8 summarizes these characteristics by NASS case number.

Table 8. 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 9 shows the frequency of suppressions 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 9. Frequency of Right Front Passenger Air bag suppression in crashes in which the driver air bag deployed in CAC vehicles

Right Front Passenger	RF Air bag Deployed	RF Air bag Suppressed	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 which 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).

Air bag Suppression 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 9 shows two particular cases of interest in which the passenger air bag was suppressed 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 seat. The subject vehicle, shown in Figure 17, was a 2004 Chevrolet C/K-series pickup truck which 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 3-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 airbag 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 which 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 suppression: 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 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 suppression 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 17. 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 18. 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 described below:

- The study was based on a limited data set vehicles having an advanced air bag. 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 data set. 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.

CONCLUSIONS

This paper has 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 VT EDR database 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 which deployed.

The findings were as follows:

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

2. Delayed Deployments. In twelve 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 Suppression 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.

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. Our initial examination of CAC deployment algorithms has shown that a first priority of future studies should be to investigate the potential safety issues of delayed deployments and suppression of the right front passenger air bag.

REFERENCES

1. Chidester, A., Hinch, J., Mercer, T.C., Schultz, K.S., "Recording Automotive Crash Event Data", National Transportation Safety Board (NTSB) International Symposium on Transportation Recorders, Washington, DC (1999)
2. NHTSA Vehicle Crash Test Database, http://www-nrd.nhtsa.dot.gov/database/nrd-11/veh_db.html (2007)

APPENDIX

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 19. These data were filtered using SAE J211 Class 60.

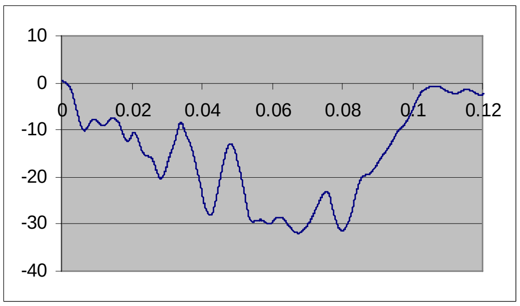

Figure 19. Vehicle longitudinal deceleration (G's) from an NCAP test of a 2005 Chevrolet Equinox vs. time (msec)

The EDR data from this test were extracted and downloaded from the NHTSA Vehicle Crash Test Database. Those data are also available on the NHTSA web page. The deployment file crash delta-V is shown in Figure 20.

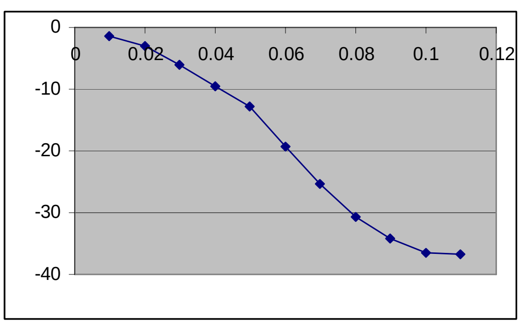

Figure 20. Vehicle EDR longitudinal velocity change (mph) from an NCAP test of a 2005 Chevrolet Equinox vs. time (msec)

These data were 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 21 presents these data.

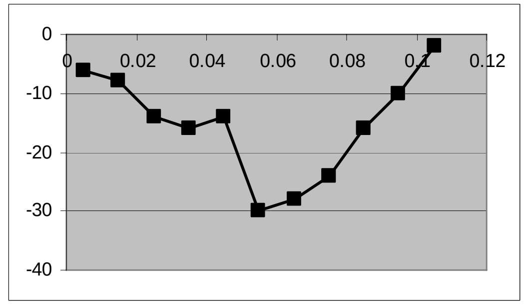

Figure 21. Differentiated vehicle EDR longitudinal velocity change (G's) from an NCAP test of a 2005 Chevrolet Equinox vs. time (msec)

The vehicle accelerometer signal and the differentiated EDR data are compared in Figure 22
.

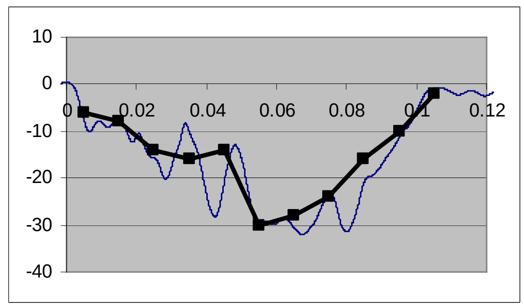

Figure 22. Differentiated vehicle EDR longitudinal velocity change (bold) compared with vehicle accelerometer (G's) from an NCAP test of a 2005 Chevrolet Equinox vs. time (msec)

As can be seen in these 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.