Evaluation of Advanced Air Bag Deployment Algorithm 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 164 advanced air bag cases extracted from NASS/CDS 2002-2006 with associated EDR data. In this dataset, advanced driver air bags were observed to deploy with a 50% probability at a longitudinal delta-V of 9 mph for the first stage, and at 26 mph for both inflator stages. In general, advanced air bag performance was as expected, however, the study identified cases of air bag deployments at delta-Vs as low as 3-4 mph, non-deployments at delta-Vs over 26 mph, and possible delayed air bag deployments.

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)]. Multi-stage air bag inflators, pretensioners, advanced occupant sensors, and complex air bag deployment algorithms can characterize these advanced systems. To minimize risk from air bag-induced injury, the systems are designed to either suppress or deploy the air bag in a low risk manner. Phase-in of the rule began with model year 2004 passenger vehicles. Full implementation of Phase 1 of this rule was required for all passenger vehicles by model year 2007.

These advanced occupant restraint systems are sometimes referred to as smart air bags because these systems can adapt their deployment strategies to the occupant belt status, occupant seating position, crash severity and other factors. The system may choose to trigger the frontal air bags at different times and with a differing number of stages in order to optimize air bag performance.

Although these systems have been extensively tested in the laboratory, we are only beginning to understand how well these complex deployment strategies perform 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 real world crashes. The objective of this study is to characterize the performance of advanced air bag deployment algorithms in the real world crashes.

METHODS

The study was based on cases extracted from the National Automotive Sampling System / Crashworthiness Data System (NASS/CDS) 2002-2006 with associated EDR data. NHTSA now has the records of over 2,700 EDRs downloaded during NASS/CDS crash investigations. All cases were downloaded by NASS investigators in the field using the Bosch Crash Data Retrieval (CDR) system.

Composition of Data Set

This study included only EDR cases from vehicles having a dual-stage frontal air bag certified to the FMVSS No. 208 upgrade. The resulting sample contained the EDR records from 164 vehicles having these advanced air bags, hereafter referred to as certified advanced compliant (CAC) air bags. The sample was composed entirely of General Motors (GM) passenger cars, light trucks, and vans.

As shown in Figure 1, the EDRs in GM vehicles with advanced air bags can record longitudinal delta-V and the time of both the first and second stage deployment. GM EDRs can record longitudinal delta-V versus time for two types of events: deployment and non-deployment events. These advanced EDRs record the time of deployment for the first stage, the time of deployment for the second stage, and belt buckle status. For the passenger, the EDR also records the seat track position (forward or rearward) and whether the air bag was suppressed.

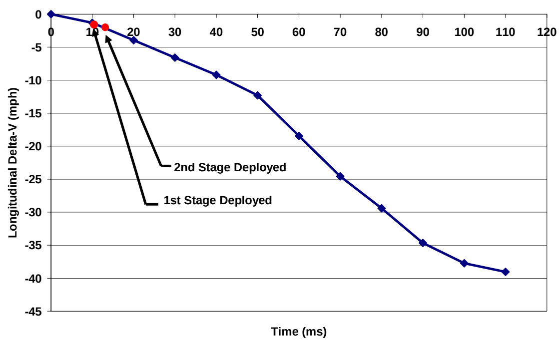

Figure 1. EDR data recorded in a 39 mph delta-V frontal crash of a 2006 Pontiac Grand Prix (NHTSA Crash Test 5468)

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. These precrash parameters are not measured synchronously (Chidester et al, 1999). Also, their time of measurement may differ from the timing indicated in the Bosch CDR download. In tests of GM EDRs, Wilkinson et al (2006) found that vehicle speed measurements could actually be 1.5 seconds closer to the air bag module wake up than reported by the EDR.

Previous studies have noted that EDR data can be lost or recorded incompletely if the vehicle loses power in the crash [Chidester et al, 1999; Comeau et al, 2004]. Later models EDRs now record a software flag indicating whether event recording was completed. Our dataset of CAC deployment cases included only EDR downloads in which recording was complete.

Approach

The first step of our analysis was to characterize the data set in terms of the deployment frequency, EDR module type, delta-V distribution as recorded by the EDR, and the distribution of vehicle speed immediately before impact in deployment events.

The second step in our analysis was to determine the timing of deployment of the first stage as a function of maximum longitudinal delta-V. Because the deployment decisions for the driver and passenger are independent of one another, the analysis was conducted separately for the driver and passenger seating position. A binary logistic regression model was fit to the deployment / non-deployment data to determine the probability of deployment as a function of peak longitudinal delta-V. A separate logistic regression analysis was conducted to determine the deployment probability vs. delta-V for the second air bag stage.

Finally, the distributions of air bag deployment trigger times were examined to identify air bag deployment decisions which deviate from the norm. Specifically, the study will investigate delayed deployments (defined as a deployment at 70 msec or later after impact), non-deployments at high delta-V (over 20 mph), deployments at low delta-V (under 5 mph), and front passenger air bag suppression.

RESULTS

Table 1 shows the distribution of cases by deployment status and EDR module type. Our sample contained 78 cases in which the frontal air bag deployed and 86 cases in which the air bag did not deploy. Our sample contained two EDR module types: the SDMDW2003 and the SDMGF2002 module.

Most vehicles in our dataset were light trucks (93%). The front of the vehicle was the general area of damage in 92% of the deployment cases. A little over a third (37%) of all cases had a right front passenger in addition to a driver. Belt usage was determined by the NASS investigators. In 15% of the cases (24 of 164), NASS investigators were not able to conduct a full vehicle inspection, but the EDR data were nevertheless downloaded. These vehicles were not fully inspected either because they were repaired before the inspection could be completed, the owners refused a complete inspection, or the vehicles were not towed from the crash scene. For cases without a complete inspection, full occupant information, e.g. belt status or injury severity, was not available. Most, but not all, deployments were towed (74 of 78). Approximately 30% of the non-deployments were towed from the crash scene.

Figure 2 presents the distribution of maximum longitudinal delta-V recorded by each of the 78 CAC EDRs in which the frontal air bag deployed. The median longitudinal delta-V in our sample was approximately 15 mph. Longitudinal delta-V varied from 3 mph to 51 mph for these deployment events. Figure 2 also presents the distribution of vehicle speed at t = - 1 second for the CAC deployment cases in our sample. This measure provides an estimate of vehicle speed just before impact. The median vehicle speed approximately 1 second before impact was 39 mph.

Table 1. Composition of the Advanced Air Bag EDR Data Set (NASS/CDS 2000-2006)

Variable	Deployment Cases	Non-Deployment Cases	Total
All	78	86	164
Model Year			
2003	25	42	67
2004	30	26	56
2005	16	15	31
2006	7	3	10
EDR Module Type			
SDMDW2003	14	6	20
SDMGF2002	64	80	144
General Area of Damage - Most Harmful Event			
Front	72	30	102
Side	4	23	27
Top	2	11	13
Rear	-	16	16
Unknown	-	6	6
Driver Belt Status			
Belted	54	51	105
Unbelted	19	15	34
Unknown	1	-	1
Incomplete Inspection	4	20	24
Right Front Passenger Belt Status			
Belted	17	11	28
Unbelted	5	5	10
No Passenger	52	50	102
Incomplete Inspection	4	20	24
Vehicle Body Type			
Cars	8	4	12
Lt. Trucks/Vans	70	82	152
Vehicle Disposition			
Towed	74	20	94
Not Towed	4	66	70

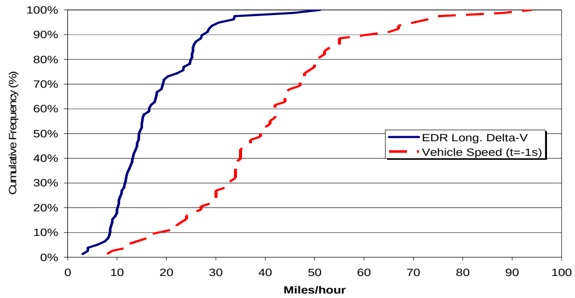

Figure 2. Distribution of Longitudinal Delta-V and Pre-Crash Vehicle Speed in Deployment Events

Figure 3 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.

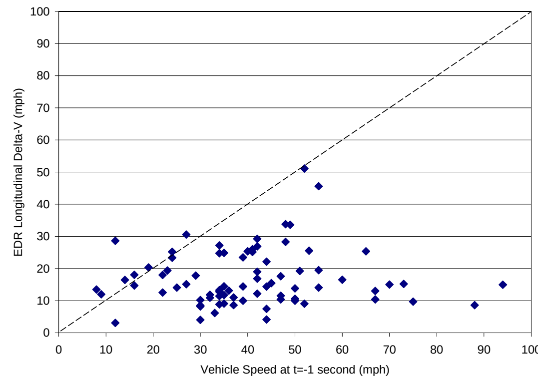

Figure 3. Longitudinal Delta-V vs. Vehicle Speed just before collision in CAC deployment cases

Probability of Deployment by Peak Longitudinal Delta-V

Figure 4 compares the distribution of the driver air bag deployments and non-deployments versus 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 which did not result in a deployment, 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 in the presence of a passenger. There were no cases in which the passenger air bag deployed, but the driver air bag did not deploy. For those cases in which the general area of damage was frontal, there were 70 deployments, 2 split deployments, and 30 non-deployments.

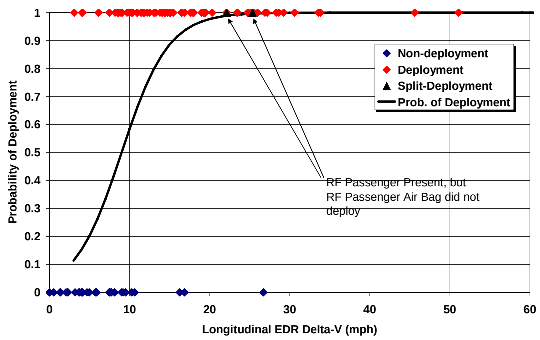

Figure 4. Probability of Deployment of Driver Air Bag by Peak Longitudinal Delta-V

The driver frontal air bag was observed to deploy in crashes having a longitudinal delta-V as low as 3-4 mph. For example, in NASS case 2005-73-132, a 2004 Chevrolet Tahoe turned left at an intersection into the side of an oncoming car. The longitudinal delta-V of the Tahoe was only 3.1 mph, but the frontal air bags deployed. At the other extreme, in NASS case 2004-76-076, the driver bag did not deploy in a crash having a longitudinal delta-V of 26 mph. This case was a long duration crash of approximately 275 milliseconds into an earth and rock embankment.

Logistic regression was performed, using NASS case weights, to determine the probability of driver air bag deployment as a function of peak longitudinal delta-V. As shown in Figure 4, in our sample, the probability of driver air bag deployment was 50% for a longitudinal delta-V of 9 mph.

In our dataset, there were 29 right front passengers involved in a crash in which a frontal impact was the most harmful event. This passenger data subset consisted of 18 deployments, 2 split deployments, and 9 non-deployments. Figure 5 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 4 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.

There were insufficient cases to perform a logistic regression for the passenger. However, because both the driver and passenger air bags fired in all but the two split deployments when a passenger was present, we can assume that the probability of deployment for the passenger air bag was similar to that for driver air bag.

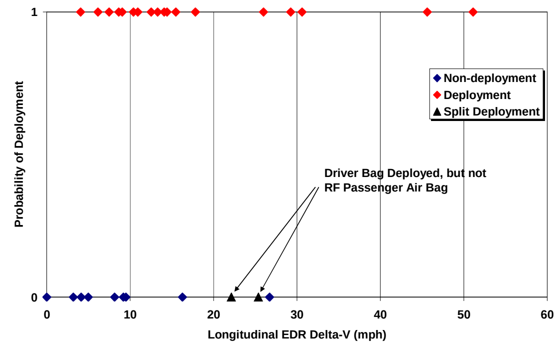

Figure 5. Distribution of Right Front Passenger Air Bag Deployment Decisions by Peak Longitudinal Delta-V

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/or occupant configuration of a collision. In our dataset, there were 72 driver air bag deployments and 30 non-deployments in which the most harmful event was a frontal impact. In the 72 deployments, both the first and second stage fired in 17 of the crashes. Only the first stage fired in the remaining 55 cases. In general as shown in Figure 6, both inflator stages were triggered only in higher delta-V crashes.

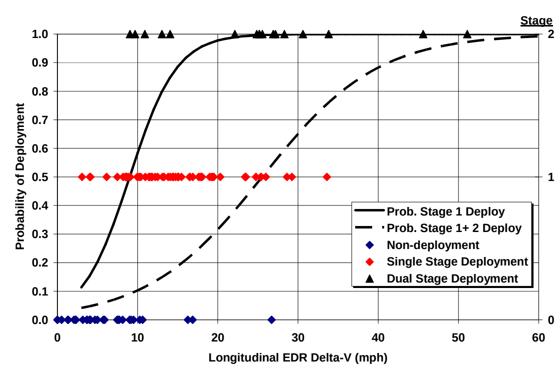

Figure 6. Distribution of Driver Air bag Dual-Stage, Single-Stage, and Non-deployments vs. Peak Longitudinal Delta-V

Logistic regression was performed, using NASS case weights, to determine the probability of deploying both the driver air bag stage 1 and 2 inflators as a function of longitudinal delta-V. The results of the logistic regression for deploying both stage 1 and 2 are shown as the dashed line in Figure 6. For this sample, the probability of dual stage driver air bag deployment was 50% for a longitudinal delta-V of 26 mph. The probability of deploying the first stage (with or without the second stage) is also plotted on this figure for comparison.

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. For GM vehicles, 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 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 GM vehicles, model year 2002 through 2006, were examined. Deployment times are shown in Figure 7. 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.

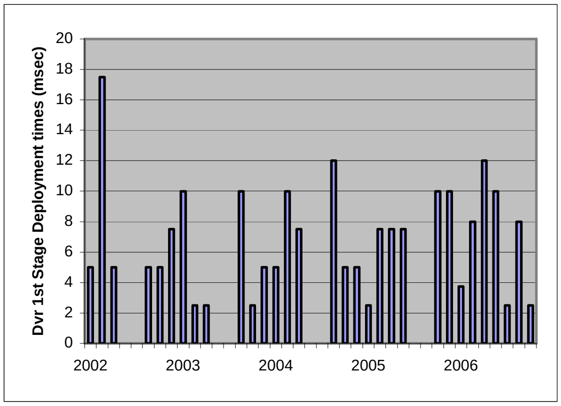

Figure 7. 1st Stage Deployment Times vs. Model Year in Frontal NCAP Tests

Analyses of air bag deployments from real world crashes would allow full range analysis of deployment times under many circumstances. Using the EDR data, first stage air bag deployment times were used to form a cumulative distribution, as seen in Figure 8. In this sample of GM vehicles, with complete EDR records and equipped with dual air bags, the 50th percentile deployment time was 15 msec while the 75th percentile was 22.5 msec.

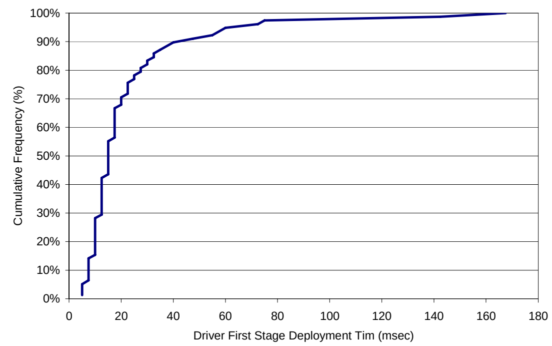

Figure 8. Cumulative Distribution (%) of Driver 1st Stage Air Bag Deployment vs. Deployment Time (msec)

Delayed deployments

Four vehicles had driver deployment times recorded by the EDR of 72.5 msec or longer. For each of these vehicles, the NASS and EDR data were reviewed to determine common characteristics. Table 2 reports the GM vehicle model year, make, and model, driver air bag deployment time, driver belt buckle status, time between crash events, vehicle speed, and longitudinal delta-V as reported by the EDR (Data are shown in the same units as reported by the Bosch CDR tool.). Table 3 presents a short description of the crash, whether the crash involved multiple events as reported by the NASS investigator or the EDR, and the injury outcome for the driver. In the last column, we have listed some unusual conditions as 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. Because this is a very small sample and because case counts are used, rather than weighted data, generally only qualitative statements are made.

Table 2. Vehicle Model Year, Make, and Model with Delayed Deployments

NASS Case Number	Model Year	Make	Model	EDR Module Type	Driver Belt Status	Driver A/B Dep Time (msec)	Time between Non-Deployment and Deployment Events (sec)	Maximum Delta-V (mph)	Vehicle speed: EDR @ -1 sec (mph)
2004-75-126	2003	Chev	Avalanche	SDMGF2002	Buckled	167.5	0.1	-6.13	33
2004-50-087	2004	Chev	C/K-series Pickup	SDMGF2002	Unbuckled	142.5	0.4	-19.21	51
2005-76-009	2004	GMC	C,K,R,V-series P/U	SDMGF2002	Unbuckled	75	--	-17.81	29
2003-50-110	2003	GMC	C,K,R,V-series P/U	SDMGF2002	Unbuckled	72.5	1.2	-20.31	19

Table 3. Review for Delayed Deployment Cases

NASS Case Number	Impact Description	Multi-Event	GAD	PDOF	Driver MAIS	Unusual conditions as potential reasons for late reported deployment time
2004-75-126	Minor vehicle impact, followed by curb hit (EDR non-deployment event) and then subsequent vehicle impact (EDR deployment event).	Y	F	350	1	• Low delta-V event • Closely spaced deployment and non-deployment events
2004-50-087	Multi event crash – sideswiped small post, offset impact on utility pole (deployment event) followed by curb hit.	Y	F	0	2	• Extreme low overlap with pole (soft) • May miss satellite sensor on lower radiator support • Abnormal delta-V increases at 100 msec
2005-76-009	Other vehicle swerved to miss debris on roadway and impacted subject vehicle head on with small overlap.	N	F	340	3	• Narrow offset impact • May miss satellite sensor on lower radiator support • Abnormal delta-V increases at 30 msec
2003-50-110	The right front fender was struck by another vehicle at an intersection followed by the subject vehicle hitting a signal pole, causing the air bag to deploy.	Y	F	0	1	• Pole impact (soft) • Misses frame rails • Offset impact

Driver injury in these cases ranged from minor (AIS=1) to moderate (AIS=2). In all but one case, the driver was unbuckled.

Delayed deployments all occurred in vehicles with the SDMGF2002 EDR module type. All of these subject vehicles were light trucks. Three of the four cases were Chevrolet/GMC C-K pickup trucks while the fourth was a Chevrolet Avalanche. In three of four cases the driver was unbelted. Delta-V varied from 6 mph to 20 mph. In addition, the following common characteristics were found among the delayed deployment cases:

Abnormal delta-V traces: Some cases had what might be construed as abnormal or unexpected data. The following provides some examples:

- Delayed onset of significant changes in velocity after time zero, also referred to as AE.

- Reversal in the delta-V characteristic as shown in Figure 9.

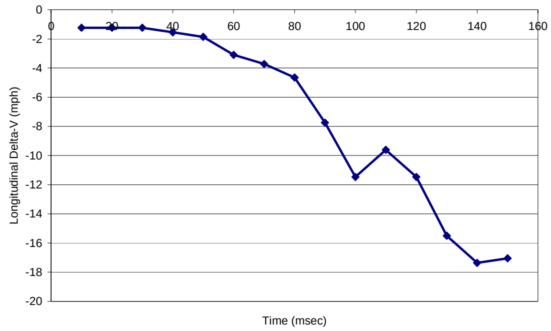

Figure 9. Case 2004-50-087 EDR Delta-V (mph) vs. time (msec)

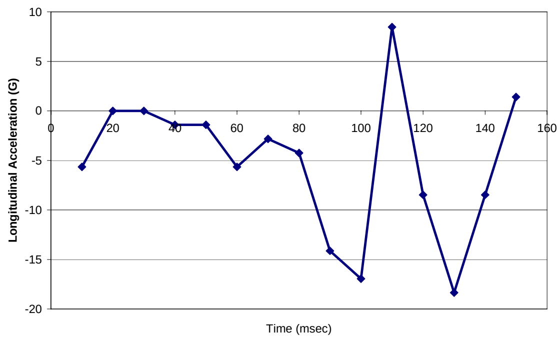

Figure 10. Case 2004-50-087 Estimated Acceleration vs. time (msec)

A closer examination was made by differentiating these data to obtain a rather crude representation of the vehicle deceleration as shown in Figure 10. 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.

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 11 and Figure 12 present examples of these impacts.

Low Delta-V: One case was a low delta-V crash. A low delta-V crash is 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.

Figure 11. Case 2003-50-110 Impact with Signal Pole

Figure 12. Case 2005-76-009 Small overlap frontal crash with another vehicle

Multi Impact: Many of the cases involved multiple impacts, as reported by both NASS investigators and the EDR. Time between the events is reported by the EDR and ranged from 0.1 second to 1.2 seconds for these cases.

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 4 shows the frequency of suppressions for right front passenger air bags in crashes sufficiently severe to deploy the driver frontal air bag. In 4 of the cases, occupant descriptions were not available as the vehicles were not fully inspected by NASS investigators. Right front passengers were present in 22 of the 74 remaining cases.

Table 4. 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	20	1	21
Child	-	1	1
None	14	38	52
Incomplete Inspection	2	2	4
Total	36	42	78

Table 5. Right Front Passenger Air bag Suppression Frequency by CDR Module in crashes in which the driver air bag deployed in CAC vehicles

EDR Module Type	Cases with no passenger	Passenger Air Bag Suppressed and No Passenger
SDMGF2002	43	38
SDMDW2003	9	-
Total	52	38

Air bag Suppression in the Absence of a Right Front Passenger

When the passenger seat is vacant, restraint designers have the flexibility to suppress the passenger air bag. As shown in Table 4, if there was no passenger, the passenger air bag did not deploy in the majority of the cases (38 of 52) in our dataset. As shown in Table 5, this behavior was dependent on the air bag control module. The SDMDW2003 module deployed the right front air bag regardless of whether there was a passenger seated at that location or not (9 of 9). The SDMGF2002 module suppressed the air bag in the majority of cases in which the passenger seat was vacant (38 of 43).

Air bag Suppression in the Presence of a Right Front Passenger

Table 4 shows two particular cases of interest in which the passenger air bag was suppressed in the presence of a right front passenger. In both cases, the passengers were subjected to a longitudinal delta-V of over 20 mph. The driver bag deployed, but the passenger bag did not deploy. In both cases, the EDR was of type SDMGF2002. Earlier in this paper, these cases were referred to as split deployments.

NASS/CDS case 2005-42-106. In this case, 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 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 a 3-point belt restrained the child. 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.

The child occupant in this case sustained a serious head injury (AIS 3). The driver suffered only a minor injury (AIS 1).

NASS/CDS case 2003-09-224. In the second case, 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. Beyond a defect in the system, another possible scenario is that the auto/off switch status was tampered with post-crash. Unfortunately, the EDR data as downloaded with the Bosch CDR 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.

The right front passenger in this case sustained a serious lower extremity injury (AIS 3). The driver was uninjured (AIS 0).

DISCUSSION

Advanced air bags were designed to tailor restraint deployment to each crash and each occupant so that the risk of air bag induced injury is reduced. In this study, we have sought to better understand how well these systems have achieved this goal by examining the performance of advanced air bag deployment strategies in real world crashes. In this section, we discuss the performance of each of the features of these advanced systems.

Probability of Deployment by Peak Longitudinal Delta-V. Our hypothesis when we began this study was that deployment would occur at higher delta-Vs than earlier generation systems. It should be emphasized that air bag trigger algorithms are based on much more complex algorithms than a simple go/no-go threshold. However, the algorithms are proprietary and are not publicly available. For this study, we used a 50% probability of deployment as a function of peak longitudinal delta-v as a simple measure. In our dataset there was a 50% probability that the driver air bag would fire for a delta-V of 9 mph.

First vs. Second Stage Deployment. Advanced systems are often equipped with two air bag inflators which allow two levels of inflation. Advanced systems can deploy only a single inflator in a less severe crash or both inflators in a more severe crash. In our dataset, the vast majority of advanced air bag deployments fired only the first stage (76%). The second stage was typically fired only in more severe, higher delta-V crashes. Although this study has not focused on injury, presumably the preponderance of benign first stage only deployments will greatly reduce the risk of air bag induced injury.

We expected that only the first stage would fire in lower severity crashes and that both stages would fire in more severe, higher delta-V crashes. In general, this was true. However, both stages were observed to deploy for some low delta-V crashes below 10 mph. In one case, only the first stage was observed to deploy for a delta-V which exceeded 30 mph.

Passenger Air Bag Suppression. 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. Our sample contained 52 cases in which the driver air bag deployed, but there was no right front seat passenger. In 73% of these cases (38 of 52), the passenger air bag did not deploy. This indicates the presence of sophisticated occupant sensors which are characteristic of advanced air bag systems.

More importantly, advanced air bags may be suppressed if a child is detected in the front seat. Our sample contained one five-year old front seat occupant. The passenger air bag was correctly suppressed in this case. Unfortunately, the child suffered an AIS3 head injury in this crash most likely due to the rollover aspect of the crash and the lack of a child restraint.

Air Bag Performance. In general, advanced air bag performance was as expected; however, the study identified a number of possible performance issues. Examples discussed in this paper include cases of air bag deployments at delta-Vs as low as 3-4 mph and non-deployments at delta-Vs over 26 mph. Our analysis has suggested several potential reasons for this performance including multiple impacts, narrow object collisions, and soft long crash pulses into comparatively soft structures, e.g. guardrail or earthen embankments.

Limitations

This study has several limitations described below:

- The study was based on a limited data set of vehicles having an advanced air bag. The frequency distributions presented in this paper apply only to the study data set. 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.

- This study did not compare the performance of advanced air bag systems with previous generations of air bags. The findings should not be interpreted to imply that the deployment strategies of these advanced systems are either better or worse than earlier systems.

- This dataset is based on NASS / CDS crashes; hence, while at least one of the vehicles in the crash was towed from the scene, the vehicle with the EDR data may or may not have been towed from the scene. Our sample does not include the many low delta-V crashes in which the vehicles were not towed and the air bags did not deploy. However, our sample does include low delta-V crashes in which the air bag did deploy. It is likely that in many of these low delta-V cases, the vehicle was towed not because of structural damage, but because the air bag had deployed. Thus, the proportion of low delta-V crashes with air bag deployment in the study sample likely overestimates the probability of air bag deployment in low delta-V crashes in the field.

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 164 NASS/CDS cases involving CAC vehicles. The CAC sample was composed of 78 air bag deployments and 86 non-deployments.

The findings were as follows:

1. Deployment Characteristics. For this dataset, there was a 50% probability of driver air bag deployment at a longitudinal delta-V of 9 mph. There was a 50% probability of deploying both inflator stages at a delta-V of 26 mph.

2. Low delta-V deployments and High delta-V non-deployments. 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.

3. Delayed Deployments. In four 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. None of these delayed deployments resulted in serious driver injury.

4. 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 (38 of 52) in which the passenger seat was vacant. This behavior however was found to be module-dependent.

5. 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. In addition, NASS investigators reported that in both cases, 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 restraints. 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.

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