

Airbag Deployment Thresholds from Analysis of the NASS EDR Database

Matthew Wood, Nicholas Earnhart, and Kelly Kennett
InSciTech Inc.

ABSTRACT

Accident reconstructionists and others use airbag non-deployment thresholds as an indicator of severity in minor- to moderate-severity accidents. The National Automotive Sampling System (NASS) has accessed and recorded the data stored in the airbag control modules of nearly 6,300 vehicles since 2000 and has made these data publicly available. The goal of this study is to ascertain thresholds from the data based on delta-V and seatbelt use, studying how they may differ among manufacturers and over time. Other data is also examined, such as seatbelt pre-tensioner fire times and airbag deployment signal times. These data have been analyzed for use in accident reconstruction for vehicles which may or may not be supported by a publicly available module download tool. While manufacturers at one point published deployment data in owner's manuals, this has not been the case for approximately five to ten years. The dataset analysis will compare the published data for deployment thresholds to real world accidents. Over time, with the addition of occupant classification systems and dual-stage airbags, there has been an increase in variability for airbag deployment times and thresholds. The analysis thus far shows the thresholds from the dataset to be in general agreement with published data.

CITATION: Wood, M., Earnhart, N., and Kennett, K., "Airbag Deployment Thresholds from Analysis of the NASS EDR Database," *SAE Int. J. Passeng. Cars – Electron. Electr. Syst.* 7(1):2014, doi:10.4271/2014-01-0496.

INTRODUCTION

The development and proliferation of Event Data Recorders (EDRs) in passenger vehicles has been impactful in the fields of accident reconstruction and collision research. Notably, there exists increasing capability to obtain in situ pre-crash and impact data from vehicles involved in a wide variety of collisions. The now widely-deployed Crash Data Retrieval (CDR) tool produced by Bosch has been available since 2000, and depending on manufacturer, can download EDR data from vehicles as old as model year 1994. Furthermore, the National Automotive Sampling System (NASS) has been downloading and making EDR reports available since 2000. This sampling of EDR reports has grown from 22 reports in 2000 to more than 1,200 in 2011. As of the 2011 data, four manufacturers are represented: Ford, GM, Chrysler, and Toyota. Vehicles with other marques but are clones of models of these manufacturers have been categorized by the source vehicle. For example, a Mitsubishi Raider for these purposes is considered a Chrysler as it is a direct clone of the Dodge Dakota. There are only five such cases in the present data set. As more vehicles come into compliance with 49 CFR Part 563, the FMVSS regarding CDRs, more manufacturers will be represented. Thus, the sample of recorded data from real-world accidents is growing rapidly and permitting large-scale crash research.

The NASS database has been capturing motor vehicle accidents in the United States since 1988, and "In order for a crash to be eligible for the GES sample a police accident report (PAR) must be completed, it must involve at least one motor vehicle traveling on a traffic way, and the result must be property damage, injury, or death" [1]. Use of the NASS database has been popular as a research tool for some time for studying "real-world" accidents. For example, Brophy et al. used the database, with an emphasis on cases where the EDR download was available, to study the performance of advanced air bags in 2005 [2]. Using a limited number of cases (71, of which 50 had a download available) they broke down the cases in terms of deployment or non-deployment, type of vehicle, delta-V, etc. They followed this up with a similar paper in 2007 [3]. Gabler et al. used data from the NASS EDR database to evaluate NHTSA's WinSMASH algorithm in 2003 [4], and more recently attempted to use EDR data to evaluate side crash delta-V estimates in WinSMASH [5]. Gabler and Hinch studied advanced air bag performance using a limited set of NASS EDR downloads [6,7]. Kusano and Gabler also used NASS EDR data to assess the ability of an EDR to discriminate the principal direction of force (PDOF) compared to the estimate by the investigator [8].

Other valuable research in this area, using the NASS EDR database, is attempting to correlate injury levels with accident severity [9,10]. This paper will focus on the correlation

between delta-V and injury risk, and instead focus solely on airbag deployment thresholds and timings, belt use, and other information. This paper is perhaps most similar to the work by Goertz and Yaek, who created statistical distributions from NASS CDS for accident and injury statistics [11]. This work focuses solely on the data found in the EDR reports available through the NASS system.

This paper will first describe the method used to compile and analyze the data, and provide detailed data limitations about the statistical sampling. Some basic statistics about the NASS EDR database are given, followed by the focus of this paper which is the analysis of airbag deployment thresholds. Then, other analyses are discussed including statistics about pretensioner deployment times, and airbag stage 2 deployment times. A comparison is made between the observed occupant belt use statistics and other NHTSA databases, NOPUS and FARS. Finally, a discussion will be presented of the conclusions that may be drawn from this work.

METHOD

The EDR data analyzed for this paper was obtained from NHTSA and compiled in a database. The information from each report recorded includes the NASS case number, VIN, type of event (categorized into either Deployment or Non-Deployment), Driver's belt status, maximum delta-V and the time at which it occurs for both longitudinal and lateral directions, and pretensioner and airbag stage 1 and stage 2 fire times. Vehicle makes and model years are decoded from the VIN, and a mean longitudinal acceleration was calculated from the time at which the maximum delta-V is reached, converted to g. If a maximum value was not reported, then manual analysis of the deceleration plots was completed for the analysis. In this case, a maximum value was selected when the deceleration pulse first bottoms out or values are repeated. This method is illustrated in Figure 1. Furthermore, not all manufacturers use the beginning of the pulse as time "0," so best efforts are made to compute the max dV time as the time from the start of the pulse to the aforementioned max value. In Figure 1, a red circle at the top left indicates where the start of the pulse has been identified. The deployment times are typically given "from algorithm enable" and are recorded as they are given in the report. For reports where only acceleration was given, a single integration was performed and plotted in order to arrive at a delta-V for the analysis. Plots summarizing all of the reports reviewed and for the individual manufacturers have been depicted in Figure 10, Figure 11, Figure 12, Figure 13 in the Appendix. Data for both Toyota and Chrysler are limited and lack sufficient information to be analyzed independent of the other manufacturers.

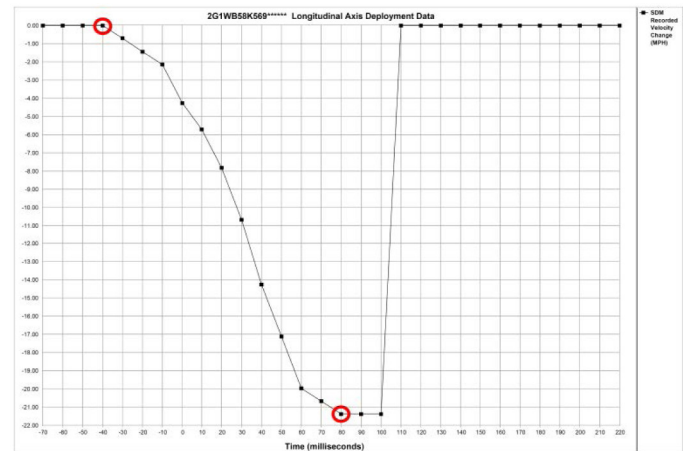


Figure 1. Sample plot of a crash pulse with the starting and ending points identified by red circles.

DATA LIMITATIONS

This is an attempt at wide-scale "data mining" of EDR data to obtain relevant and meaningful statistics on the performance of restraint systems in real-world incidents. In this context, it is inevitable that events will be included that are complex and difficult to analyze by considering merely a subset of the information in the full report. For instance, concatenated events where a deployment occurs after a non-deployment event can show a delayed deployment time. Also, occasionally a deployment event can be recorded when an associated non-deployment event is much more severe, but only the first deployment event is included in this data set. Furthermore, definitions of time "0" vary both by manufacturer and with SDM module version. Best efforts are made to adjust all records for time "0" to be the start of the pulse for uniform recording, as mentioned in the previous section. Additionally, many CDR reports do not capture the entire pulse in terms of delta-V and do not state a maximum delta-V individually, so in these instances the final reported data point is used as the "max dV." While not having a complete pulse does distort the data set to an extent, it will largely not affect whether an event was or should have been a deployment or non-deployment event. With Ford reports, where 78 msec of the event is recorded the shortened pulses artificially lower the average deployment threshold, although these reports are a small fraction of the total. As with any statistical analysis, there will inevitably be outliers to the data, but the advantage of a large data set is that hopefully those outliers are noise to the broader trends.

Furthermore, these data are taken exclusively from the NASS EDR database, where General Motors vehicles are over-represented by a wide margin given their compatibility with the Bosch software for a much longer time, the most model years of compatibility, and their vehicle fleet size. Newer years of EDR data will be more diverse, with Chrysler and its sub-brands available starting in 2009 (with vehicle compatibility back to model year 2006), and with 2011 including Toyota and

its sub-brands with initial vehicle compatibility back to model year 2006. 2001 and newer Toyota vehicles were later supported by the end of December 2011.

Of the 174 Chrysler reports reviewed, 90 contained no data. Many of these “no data” reports are the consequence of some early Chrysler EDRs only recording data in the event of a frontal deployment. The extent of these limitations can be found in the particular EDR report, but as an example, one additional limitation with Chrysler vehicles is particular to the 2005-2010 Dodge Durango. For these vehicles, those equipped with side airbags have data that can be imaged with the Bosch tool, and those without *might* be imaged by the CDR tool. Thus, these “no data” reports were not categorized as non-deployments, as for some vehicles it is implied that a side deployment is still possible without data being recorded.

BASIC STATISTICS

The data represented draws from a total of 6,826 reports obtained from the NASS EDR database. The distribution of data is shown in [Table 1](#). The data categorized as “Other” are downloads that state “None,” “No data,” or “Not retrievable by CDR tool.” Deployment events comprise 44% of all reports reviewed with individual manufacturers following this trend as well, with the exception of Chrysler vehicles with roughly 7% of all reports being deployment events; these data are given in [Table 2](#). As a basic statistic of average accident severity represented in the database, the overall average delta-V are shown in [Table 3](#).

Table 1. Number and distribution of available NASS CDR reports by manufacturer and type of event.

	All	Deployment	Non-Deployment	% of All Records
GM	5582	2529	2855	88.8%
Ford	468	219	216	7.5%
Chrysler	174	12	72	2.8%
Toyota	62	26	36	1.0%
				Other
Total	6286	2786	3179	321

Table 2. Deploy/non-deploy distribution of recorded events by manufacturer in the NASS CDR database.

	Deployment	Non-Deployment
GM	45.3%	51.1%
Ford	46.8%	46.2%
Chrysler	6.9%	41.4%
Toyota	41.9%	58.1%
All	44.3%	50.6%

Table 3. Average delta-V by manufacturer by type of event, in miles per hour.

	Deployment	Non-Deployment
GM	-16.5	-5.1
Ford	-13.3	-6.2
Chrysler	-17.6	-17.5
Toyota	-17.0	-6.8

OBSERVED DEPLOY/NON-DEPLOY TRENDS

Gray Zones in Owner's Manuals

For a number of years, manufacturers reported generic “gray zone” information in owners' manuals. The gray zone, as defined by NHTSA, is the range of speeds between the no-fire and all-fire thresholds in which the airbag may or may not deploy” [12]. Data from GM owners' manuals is particularly prolific, but similar information can also be found in manuals from Ford, Toyota, and Honda. GM usually published a range: as an example, the data for the Pontiac Grand Prix is shown in [Figure 2](#) and indicates that the dual-stage airbags were introduced in 2004. A survey of the EDR database reveals the earliest stage 2 deployment in a 2001 Ford Windstar. While some of the initial published data indicated a threshold range in terms of change in velocity in miles per hour, many were later amended to replace such statements with caveats that an airbag deployment is dependent upon both severity, moderate to severe, and acceleration of the vehicle. As seen in the figure, the deployment “gray zone” has widened from 9-15 mph in 1995 to a two-stage range of 12-16 mph and 18-24 mph. The highest observed first-stage airbag threshold was found in the Owner's Manual for the 2005 Pontiac Aztek, which is given as 21-25 mph. All four previous model years state a threshold of 12-19 mph and the vehicle underwent no structural modifications in that time, so it is unclear if this is a misprint. For GM vehicles, it is of interest to consider the average published deployment thresholds by delta-V and compare these data to that observed in the EDR reports, which are discussed later. For the owner's manual data, the GM first-stage thresholds are shown in [Table 4](#) for model years between 1994-2001 and 2002-2007. Model year 2007 is the last in which airbag thresholds are published. What can be determined from this information, however, is that the average airbag threshold has increased by 0.8 mph using these ranges.

Table 4. Average deployment thresholds, in delta-V, for GM vehicles separated by model year.

	Lower Bound [mph]	Upper Bound [mph]
1994-2001	9.8	15.4
2002-2007	10.6	16.2

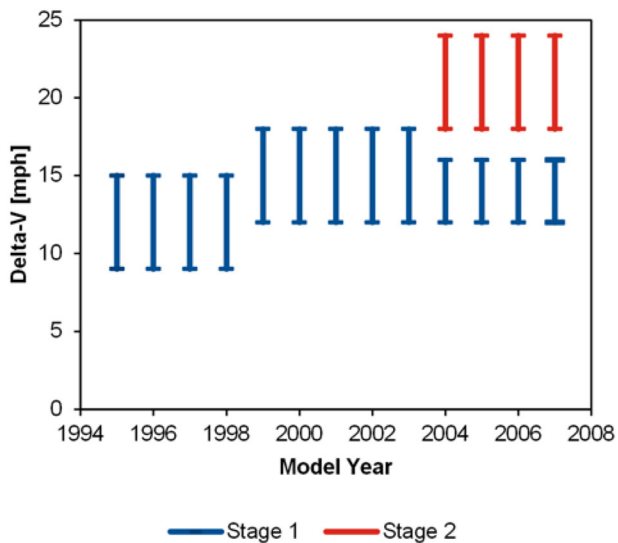


Figure 2. Published airbag deployment "gray zone" information from owner's manuals for the Pontiac Grand Prix from 1995-2007

Observed Deployment Thresholds

The data were analyzed to determine what percent of events were deployments or non-deployments for a given delta-V or acceleration. In review of the GM and Ford data, there are a small percentage of reports which record deployments with a change in velocity of 0.0 mph: these data are excluded from the analysis. With an understanding of the previously mentioned data limitations the data set was analyzed for both delta-V and mean acceleration. Graphs displaying these probabilities are shown in the Appendix as [Figure 14](#), [Figure 15](#), [Figure 16](#), [Figure 17](#), [Figure 18](#), [Figure 19](#). From the data the values for the 10%, 25%, 50%, 75% and 90% probabilities for deployment by delta-V and acceleration were used to arrive at estimated deployment thresholds. The statistics for GM and Ford are shown here in [Table 5](#) and [Table 6](#).

Table 5. Deployment event probability thresholds by delta-V and acceleration for GM vehicles.

	Delta-V [mph]	Acceleration [g]
10%	(-2,-3]	(-1.0,-1.5]
25%	(-4,-5]	(-2.0,-2.5]
50%	(-8,-9]	(-3.0,-3.5]
75%	(-12,13]	(-4.0,-4.5]
90%	(-18,19]	(-5.5,-6.0]

Table 6. Deployment event probability thresholds by delta-V and acceleration for Ford vehicles.

	Delta-V [mph]	Acceleration [g]
10%	(0,-1]	(0.0,-0.5]
25%	(-2,-3]	(-1.5,-2.0]
50%	(-6,-7]	(-3.5,-4.0]
75%	(-11,-12]	(-5.5,-6.0]
90%	(-19,-20]	(-8.0,-8.5]

Deployment Thresholds Over Time

The EDR records for GM vehicles were split into two groups, model years 1994-2001 and 2002-2011. The point of demarcation was chosen as this is the approximate range when advanced restraints with pretensioners and dual-threshold airbags were phasing widely into the vehicle fleet. The differences in the observed thresholds are tabulated in [Table 7](#). The plots representing these data are given in the Appendix, [Figure 20](#) and [Figure 21](#). As observed, the thresholds have increased over time by 2-3 mph at the 25% level and by 3-4 mph at the 75% level. The large increase at 90% is less reliable because of a lack of data for the 2002-2011 model years.

Table 7. Deployment event probability thresholds by delta-V for GM vehicles, separated by ranges of model years.

Model Years	1994-2001	2002-2011
	Delta-V [mph]	Delta-V [mph]
10%	(-2,-3]	(-3,-4]
25%	(-2,-3]	(-5,-6]
50%	(-5,-6]	(-9,-10]
75%	(-9,-10]	(-12,-13]
90%	(-14,-15]	(-21,-22]

MAXIMUM DELTA-V VS. DEPLOYMENT TIME

With the addition of occupant classification systems and dual-stage airbags the need for greater discrimination in deployment of the supplemental restraint system has increased. How and when the system decides to deploy the airbags is dependent upon several factors such as collision severity, vehicle acceleration, seatbelt status, seat position, and occupant size. This is supported by statements in owners' manuals and the presence of such data recorded in the vehicle reports. The relationship between maximum delta-V and deployment time was plotted and reviewed to see if a discernible pattern existed. A plot of all vehicle reports for deployment collisions is shown in [Figure 3](#), with the axes limited to the range indicated.

A general trend can be seen in that the greater the severity of the collision the sooner the airbag deployment is commanded. An analysis of events with first-stage deployment times under 100 msec in 2.5 msec bins and delta-V up to 50 mph in 2.5 mph bins was performed to determine the distribution of deployment times for a given delta-V range. An analysis of the 90th, 75th, and 50th percentile ranges for increasing severity levels in [Figure 4](#) shows the trend in deployment time as a function of crash severity. The 90th and 75th percentiles are highly irregular for large delta-V values because of the small percentage of all accidents that they represent. Nonetheless, the main trend is easily identified, in that deployment times decrease for increasing severity and reveal a range of 10-50 msec. Interestingly, relatively low severity accidents may have

fast deployment times. It is hypothesized that these may largely be events where a deployment event is preceded immediately by a non-deployment event.

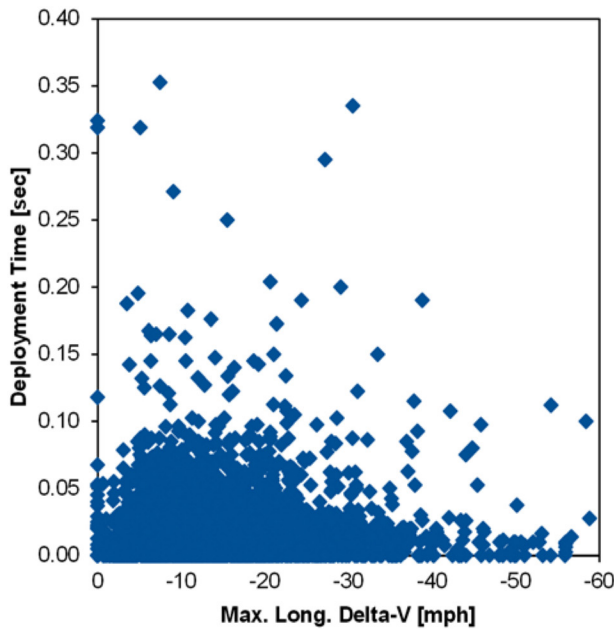


Figure 3. Distribution of deployment time by maximum longitudinal delta-V for all manufacturers.

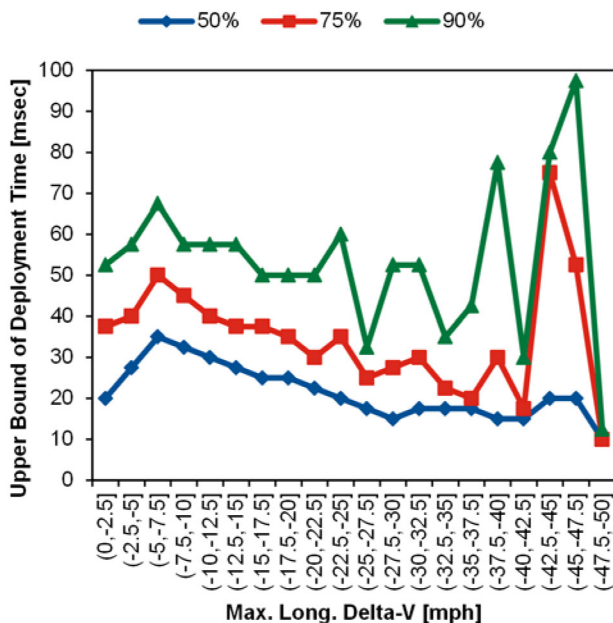


Figure 4. Each deployment event was categorized by both deployment time and delta-V. The lines on the plot indicate the time by which 50%, 75%, or 90% of all deployment events at that severity have been commanded. For example, for the -20 to -22.5 mph bin, 90% of all deployment events have been commanded by 50 msec. The other 10% of the deployments at that severity are commanded at times later than 50 msec.

DEPLOYMENT BY BELT STATUS

The data were also evaluated for patterns in deployment based upon whether the driver was buckled or unbuckled. The probability of a deployment event for a given delta-V and driver belt status for all manufacturers is plotted by delta-V in Figure 5. There is no apparent distinction in deployment by crash severity depending on belt status. There is similarly no distinction by deployment time; these data are not shown. It is recognized also that the deployment time is likely a function of both belt status and delta-V, but there is not enough data to separate the two variables for further analysis. There is a known introduction of deployment thresholds by belt status in the industry around the 2002 model year. Separating the data shown in Figure 5 by model year, shown in the Appendix as Figure 23 and Figure 24 for buckled and unbuckled drivers yields inconclusive results. The deployment probabilities for buckled drivers by model year are very similar, and while those for unbuckled drivers appear to show a decreased likelihood of a deployment for a given delta-V, narrowing the spread of model years erases these differences. In sum, there is not observable evidence in the data of a difference in deployment threshold by driver belt status.

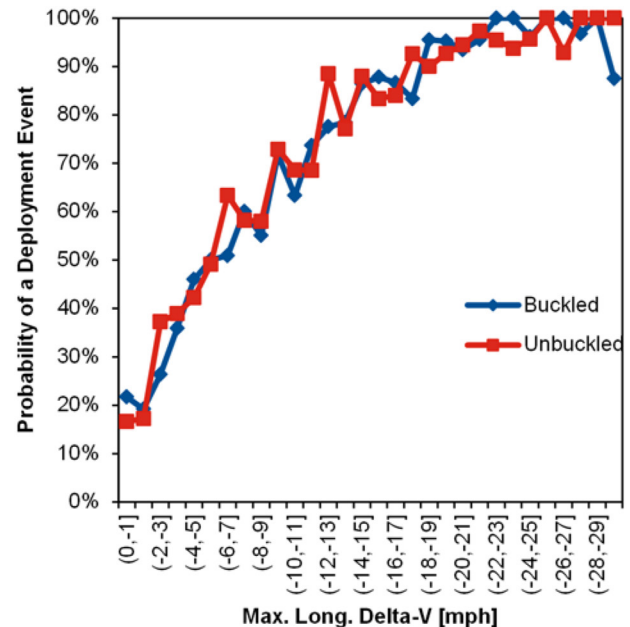


Figure 5. Probability of a deployment event for an event with a given delta-V, by driver belt status.

Statistics on events related to occupant classification systems are not analyzed at this time because of limited data as well as lack of uniformity in the classification nomenclature. Of the reports reviewed, Toyota classifies occupants AM50, AF5, and Child or Not Occupied. Of the General Motors reports reviewed, observed classifications include Large Occupant Type #1, Small Occupant Type #1, and Small Occupant Type #2. Ford vehicles report a wider variety of classification categories. Vehicles model year 2004 and older use simple Adult, Child, or Non Adult identifiers. After this period, Ford vehicles state Child Yes/No followed by the associated