A COMPARISON OF REAL WORLD FRONTAL IMPACTS AND STAGED CRASH TESTS

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Abstract

Real world evaluations of motor vehicle crash protection safety features require measures for quantifying impact severity. Velocity change (delta-V) is the primary descriptor of collision severity used in most databases of real world crash information. Historically, the delta-V has been calculated using conventional accident reconstruction techniques such as damage or momentum analysis. A major shortcoming of the sole use of delta-V as a measure of crash severity is the lack of information on the timing of the velocity change, the delta-T of the collision event. Late model vehicles equipped with event data recorders record the time history of the delta-V during the crash pulse. The average deceleration that occurs over different time durations can often be readily calculated from the data recorded by the EDR. This paper examines the recorded longitudinal delta-V data for 104 real world collisions involving 1996 to 2005 Chevrolet Cavaliers and Pontiac Sunfires that were equipped with event data recorders. The real world crash pulse data is compared to similar data for staged crash tests. The relationship between longitudinal delta-V and deceleration is evaluated for different frontal impact modes.

Résumé

Des évaluations concrètes des dispositifs de protection des véhicules automobiles contre les impacts exigent des mesures afin de quantifier la sévérité des impacts. La variation de vitesse (delta V) constitue la description principale de la sévérité des collisions utilisée dans la plupart des bases de données sur les collisions réelles. De par le passé, le facteur delta V a été calculé à l'aide de techniques classiques de reconstitution d'accidents, comme par exemple l'analyse des dégâts ou du momentum. Une lacune importante de l'utilisation du seul facteur delta V comme mesure de sévérité de collision est l'absence d'information sur la durée de variation de vitesse, le facteur delta t de la collision. Les modèles récents de véhicules munis d'enregistreurs de données de conduite enregistrent l'historique du facteur delta V dans le temps lors de la secousse causée par la collision. La décélération moyenne qui se produit sur diverses durées de temps peut souvent être calculée facilement à partir des données contenues dans l'enregistreur de données de conduite. Le présent article examine les données enregistrées de facteurs delta V sur le plan longitudinal sur 104 collisions réelles qui impliquaient des berlines Chevrolet Cavalier et Pontiac Sunfire des années 1996 à 2005, qui comportaient des enregistreurs de données de conduite. Les données des secousses produites par ces collisions réelles sont comparées à des données similaires pour des essais de collisions simulées. La relation entre le facteur delta V sur le plan longitudinal et la décélération est évaluée pour divers modes d'impact frontal.

INTRODUCTION

Many late model vehicles are equipped with an event data recorder (EDR) that records the time history of the delta-V during the crash pulse**.** [1] [2] [3] [4] [5] The recorded forward or longitudinal delta-V is available for most late model General Motors' vehicles and can be downloaded using the Vetronix Crash Data Retrieval System.[6] The on-board EDR continuously monitors the vehicle's acceleration. When deceleration exceeds a threshold of approximately 1-2 g, the algorithm enable (AE) condition is met and the recording process commences. Consequently, there is a small time lag between the impact that triggers the recording, the occurrence of AE, and the commencement of the actual recording process. The cumulative forward delta-V is determined by integrating the average of four acceleration samples over each 1.25 millisecond period and is recorded every 10 milliseconds.

Research has shown that General Motors' EDR's generally produce delta-V values within the stated uncertainty tolerances. In a study conducted by Transport Canada and General Motors (GM), Comeau et al examined the accuracy of the delta-V versus time data recorded by GM EDRs. The study compared the data from eight separate crash tests involving three vehicle models. EDR delta-V was reported to be ± 10% of the delta-V as measured by the crash test instrumentation. The authors reported that under normal circumstances, the crash investigator would expect the EDR-based delta-V to be a reasonable approximation to the actual delta-V experienced by a vehicle in a frontal crash. The delta-V values were noted to be accurate and somewhat conservative.[7]

Niehoff et al. evaluated the performance of EDRs in laboratory crash tests across a wide spectrum of impact conditions. They concluded that, if the EDR recorded the full crash pulse, the EDR average error in frontal crash pulses was just under 6% when compared with crash test accelerometers. The authors also reported an average error of about 6% in the longitudinal delta-V at 100 ms. In nearly all cases, the delta-V recorded by the EDR was found to be less than the true delta-V. They further noted that the majority of the EDRs did not record the entire event and in one-third of the GM crash tests (10 of 30), 10% or more of the crash pulse duration was not recorded.[8]

Chidester et al. examined the performance of EDRs from model year 1998 GM passenger vehicles. Accuracy was considered to be acceptable, however occasionally the EDRs would report slightly lower velocity changes than those determined from the crash test accelerometers.[9] Lawrence et al. evaluated the performance of GM EDRs in low-speed collisions and found that the EDRs underestimated delta-V. Large errors were observed during collisions with a delta-V of 4 km/h. However, they noted that these errors declined at higher delta-Vs. [10]

One must use caution when incorporating the EDR delta-V data in the analysis of real world collisions. In some cases current EDRs will not record the complete crash pulse which can result in a substantial underestimate of delta-V. The onset and length of the crash pulse may also be such that certain EDRs are incapable of recording the entire event. In addition, severe crashes or other adverse collision configurations may disrupt the electrical power supply to the EDR which can result in some data loss. The accelerometers in GM's early crash recorders are uni-axial, and oriented to capture acceleration along the longitudinal axis only. In real-world crashes, the forces and accelerations may well be off axis, such that the EDR will only capture the longitudinal component of delta-V. In a comparison of EDR-recorded delta-Vs to those calculated using damage analysis excellent agreement was found for those cases where the impact was relatively central. However, in off central impacts the agreement was less good, possibly reflecting the effects of vehicle rotation and changing force direction during the crash pulse.[11]

The objective of this paper was to compare crash pulse timing and decelerations in real world collisions to those that occur in staged crash tests. While delta-V is a common measure of crash severity, its relationship with delta-T and deceleration for different crash modes is not well documented.

METHODOLOGY

EDR data from real world crashes were compared to crash test data. Vehicle acceleration data were obtained from 11 staged collisions conducted by Transport Canada that involved Chevrolet Cavaliers and Pontiac Sunfires equipped with event data recorders. Most of the test crashes were conducted at test speeds of 40 km/h or more. The tests involved full-frontal impacts into stiff rigid barriers, offset frontal impacts into deformable barriers, and front underride type crashes into underride guards. Further information on the test crashes can be found in the literature. [7]

A series of real-world motor vehicle collisions subject to conventional in-depth investigation and reconstruction techniques, have been included in this study. The individual cases were drawn from Transport Canada's on-going collision investigation programme. They include investigations focused on airbag deployment crashes, moderately-severe side impacts, and a series of special investigations. A common element to the cases was the availability of cumulative delta-V data downloaded from event data recorders in 1996 to 2005 model year Chevrolet Cavaliers and Pontiac Sunfires. The present study included 104 real world cases where the EDR-equipped case vehicles sustained an impact in which the front airbags deployed.

Data recorded by these early generation EDRs were not standardized and there was considerable variation in the models years. In the 1996 to 1999 Cavaliers and Sunfires, the cumulative delta-V data was recorded for up to 300 milliseconds after AE for both deployment and non-deployment events. On the later models, it was recorded for up to 150 milliseconds during deployment and non-deployment events. For deployment events, the EDR recorded 100 milliseconds of data after the deployment criteria was met and up to 50 milliseconds before deployment criteria.

Maximum recorded delta-Vs were identified for each of the cases. In some cases the maximum delta-V and the time from AE to maximum delta-V was recorded directly by the EDR while in other cases these data had to be determined from the cumulative delta-V data . The average decelerations were calculated for 10 ms and 50 ms intervals during the crash pulse. The maximum average deceleration during the crash pulse was determined based on 10 ms and 50 ms intervals. These maximum decelerations were then compared to the maximum recorded delta-Vs for each of the impacts.

Crash Tests

Details of the test crashes (N = 11) are shown in Table 1. The tests were conducted with 1998 (N = 7), 1999 (N = 2) and 2004 (N = 1) model Chevrolet Cavaliers and a single 2004 Pontiac Sunfire. Airbag deployment occurred in each of the crash tests including the low severity bumper test (TC04-103). The underride tests were done under different test conditions with different vehicle engagement geometry and the crash pulses differed considerably.

The 1996 to 1999 model Sunfires and Cavaliers (N = 9) captured a maximum 300 ms of cumulative longitudinal delta-V while the 2000 to 2005 models (N = 2) captured a maximum of 150 ms of data. Power loss (PL) occurred in three of the test crashes. In TC98-506 the power loss occurred at 200 ms before the entire delta-V was captured. In the other two cases the delta-V was captured before power loss occurred.

The estimated time until maximum engagement (V = 0 km/h) was determined for the crash tests. In the rigid barrier crash tests maximum engagement was reached less than 100 ms after AE. Maximum engagement was achieved after approximately 70 ms in the low speed 8 km/h full frontal test (TC 04-103) which was the shortest time interval. In the offset-frontal tests maximum engagement was reached in the 130 to 140 ms range after AE. As one would expect, in the underride tests the crash pulse tended to be much longer with significantly lower maximum decelerations.

Table 1 Crash Test Data

Case #	Year	Model	Test type	Test speed (km/h)	DV max (km/h)	DV at 100 ms (km/h)	Delta-T (ms)	Delta-T at V = 0 (ms)	Length of data capture (ms)	Max 10 ms decel (g)	Max 50 ms decel (g)
TC04-103	2004	Sunfire	Rigid barrier	8	-10.59	-10.59	130.0	70.0	140.00	-6.0	-4.4
TC04-118	2004	Cavalier	Rigid barrier	50	-51.53	-50.83	107.5	100.0	110.00	-24.0	-19.2
TC99-236	1999	Cavalier	Rigid barrier	50	-51.53	-51.18	100.0	90.0	300.00	-26.0	-20.0
TC99-238	1999	Cavalier	Rigid barrier	48	-50.47	-50.12	100.0	90.0	300.00	-22.0	-19.8
TC98-212	1998	Cavalier	Offset deform	40	-46.59	-28.24	170.0	130.0	300.00	-13.0	-11.6
TC98-213	1998	Cavalier	Offset deform	40	-43.42	-24.00	170.0	140.0	300.00	-14.0	-11.8
TC98-214	1998	Cavalier	Offset deform	40	-42.36	-24.71	170.0	140.0	300.00	-13.0	-12.0
TC98-501	1998	Cavalier	Underride	49	-50.47	-32.47	240.0	220.0	240 PL	-13.0	-11.4
TC98-502	1998	Cavalier	Underride	48	-49.43	-16.94	260.0	240.0	300.00	-11.0	-7.2
TC98-506	1998	Cavalier	Underride	65	-56.83	-34.24	U/K	U/K	200 PL	-14.0	-11.6
TC98-507	1998	Cavalier	Underride	65	-64.95	-56.83	130.0	130.0	200 PL	-24.0	-21.2

Test speed: impact speed into barrier or guard	**DV max: maximum longitudinal recorded delta-V**
DV at 100 ms: longitudinal recorded delta-V at 100 ms after AE	**Delta-T: approximate duration of impact**
Delta-T at V = 0: approximate time of maximum engagement	**Max 10 ms decel: Maximum decel. average over a 10 ms interval**
Max 50 ms decel: Maximum decel. average over a 50 ms interval	**U/K = unknown P/L = power loss**

RESULTS

Real World Collisions

There were 104 real world impacts in the series and each involved front airbag deployment. The majority of the impacts were frontals (N= 76). However, there were a number of right side impacts (N = 11) and left side impacts (N = 11) and undercarriage or wheel strikes (N = 6). In most of the impacts the object struck was another vehicle (N = 83). These vehicles included passenger cars or minivans (N = 66), pickup trucks / SUV / vans (N = 14) and heavy trucks / tractors (N = 3). Fixed object strikes were also common (N = 19) involving guardrails (N = 2), concrete barriers (N = 3), trees (N = 2), various poles (N = 5) and curb or ground impacts (N = 7). There were also 2 impacts with deer that resulted in airbag deployment. Tables 2 and 3 in Appendix I summarize the real world cases.

Longitudinal Delta-V

The maximum delta-V recorded by the EDR for the 104 front airbag deployment crashes ranged from 3.5 km/h to 90 km/h. The maximum delta-V distribution is shown in Figure I. The two highest-severity crashes had maximum recorded delta-Vs of 90 and 83 km/h and both resulted in driver fatality. Most of the deployment events occurred in crashes where the maximum recorded longitudinal delta-V was under 20 km/h. The maximum recorded longitudinal delta-V distribution is shown for each of the model years in Figure II. There were 21 cases where the maximum recorded delta-V was less than 10 km/h and 45 cases where the maximum recorded delta-V was in the 10 to 20 km/h range. Airbag deployment in collisions with a maximum recorded delta-V under 20 km/h occurred in all of the model years.

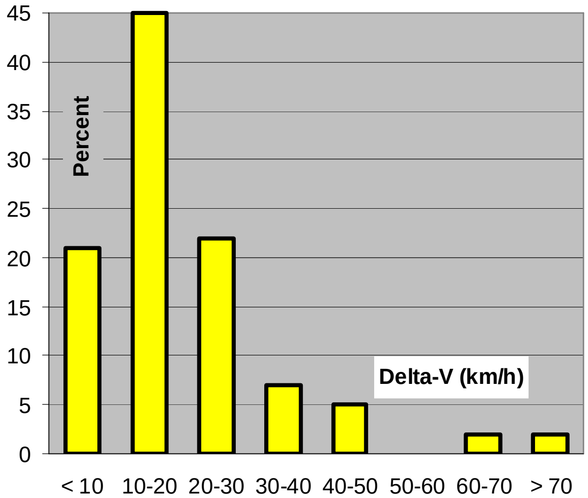

Figure I Maximum Delta-V

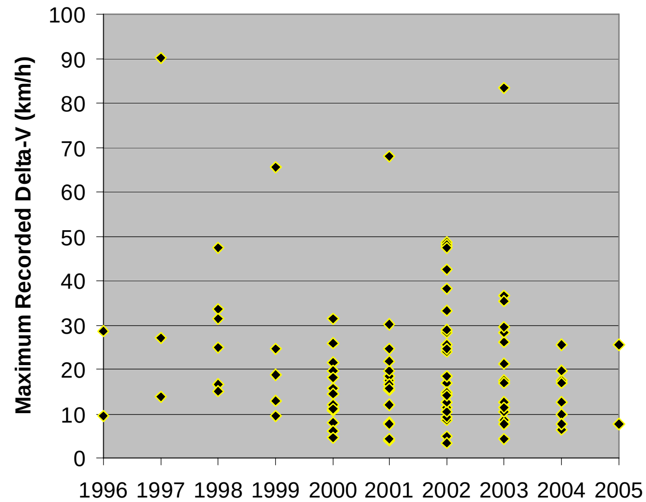

Figure II Maximum Delta-V by Model Year

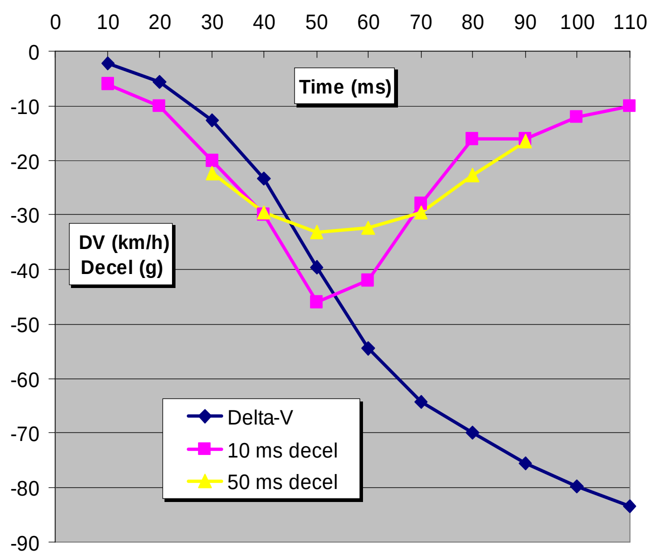

Figure III DV and Deceleration

Maximum Longitudinal Deceleration

The average decelerations over 10 ms and 50 ms intervals were calculated for each crash and the maximum selected. Figure III shows the average deceleration and cumulative delta-V for a severe offset frontal impact.

Figure IV compares the maximum longitudinal delta-V to the maximum deceleration in the 10 ms and 50 ms intervals for all the cases. The relationships were found to be reasonably linear with little scatter. Trend lines are shown for this real world crash data.

The maximum average longitudinal deceleration in a 10 ms interval ranged from 3 g (N = 1) to 50 g (N = 1) for the 104 deployment events. A maximum 10 ms deceleration of just 4 g occurred in almost 10% of the crashes (N = 10). In just 1 side impact collision (ACR51809) the maximum 10 ms deceleration was less than 4 g. The majority of crashes (63%) had a maximum 10 ms deceleration below 10 g and many (44%) had a maximum deceleration below 8 g.

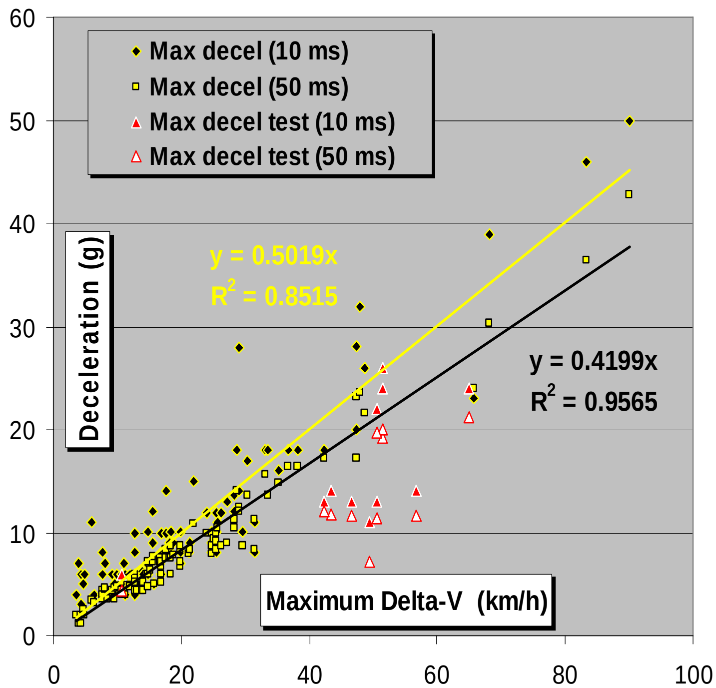

Figure IV Comparison of delta-V and deceleration

Delta-T

The delta-T was determined for the recorded crash pulses. Since the vehicle would often be sliding at the end of the impact and thus decelerating, a criteria to specify the end of impact was developed. The impact was considered to be complete when the average deceleration in a 10 ms interval dropped to 1 g or less.

In the cases involving the 2002 to 2005 models and some 2001 models the time from AE to the maximum delta-V was recorded (N = 67). The time from AE to maximum delta-V ranged from 60 to 165 ms with an average of 122 ms (standard deviation = ± 21 ms). There were 15 cases with a recorded delta-T of 140 ms or greater.

The 1996 to 1999 models (N = 16) provided 300 ms of cumulative delta-V data from AE. In 14 cases the crash pulse duration ranged from 80 to 140 ms (N = 13) with one run-off-the-road event ending at 240 ms after AE. In two high severity impacts there was power loss at 140 ms. The average deceleration in the last interval of capture was sufficiently low to allow estimation of the impact duration to be 150 ms in both cases. The average crash pulse duration for the 1996 to 1999 models was 123 ms not including the exceptional long duration run-off-the road event.

Incomplete Recording of Crash Pulse

The EDR recorded from 110 ms to 150 ms of data during deployment and non-deployment events on the 2000 model and newer vehicles in this study. The length of data capture depended on when the airbag deployment criteria was met. The EDR recorded 100 ms of data after the deployment criteria was met and up to 50 ms before deployment criteria. The deceleration of the vehicle in the last interval of the recording was examined in order to identify those cases where the impact was likely incomplete at the end of the recording. In 11 cases the vehicle was decelerating at more than 4 g at the end of the recording. The cases where the vehicle was still undergoing significant deceleration at the end of the recording tended to be severe crashes. In these severe impacts deployment was typically commanded early on and only 110 ms of data were captured. In 7 of the 11 cases where the complete crash pulse was not captured the maximum longitudinal delta-V was greater than 30 km/h.

Acceleration Recorded During Crash Pulse Feature

In 25% of the 104 cases (N = 26) the EDR recorded a 1 g to 9 g average ***acceleration*** in a 10 ms interval during the first 150 ms of the recorded crash pulse. Impacts that result in airbag deployment usually involve significant deceleration. All cases where there was 3 g or greater acceleration during the crash pulse involved 2000 or 2001 Cavaliers and Sunfires. While not all of the thirty 2000 and 2001 models had this acceleration feature, it was noted in 17 cases with these vehicles. In these cases the magnitude of the delta-V would increase until 50 to 100 ms after AE at which time the magnitude of the delta-V would begin to dramatically decrease indicating that there was acceleration. Figure V shows the cumulative delta-V for a number of the cases where acceleration was recorded during the crash pulse.

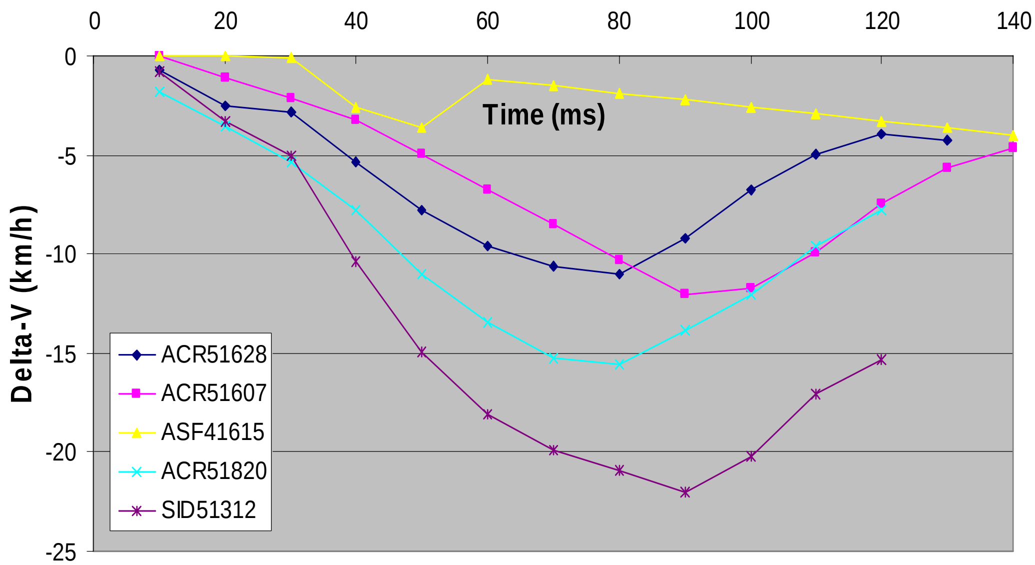

Figure V Cumulative delta-V for cases with acceleration recorded during crash pulse

DISCUSSION

Rigid Barrier Crash Tests and Real World Frontal Impacts

The decelerations that occurred in the rigid barrier crash tests were compared to the real world frontal impacts. The average decelerations over 10 ms and 50 ms intervals were calculated for each crash pulse and the maximum selected. Unusual real world crash pulses such as deer hits (N = 2) that result in a rapid deceleration spike were not included. Cases where there were instances of acceleration of 2 g or more during the first 150 ms of the crash pulse (N = 13) were also not included. Figure VI compares the maximum delta-V to the maximum averaged deceleration for the rigid barrier tests and 61 of the 76 frontal impacts. The relationship between deceleration and delta-V for the real world frontal impacts was found to be similar to the rigid barrier tests. Similarly, the delta-T in the real world frontal impacts was similar to that in the full-frontal rigid barrier crash tests.

The maximum recorded longitudinal delta-V was observed to be a good predictor of the maximum longitudinal vehicle deceleration that occurred during the frontal impacts. In the real world frontal impacts the maximum 10 ms deceleration (g) that occurred during the crash pulse was approximately 49% of the maximum delta-V (km/h) while the maximum 50 ms deceleration (g) was approximately 37% of the maximum delta-V (km/h). Thus, a 52 km/h maximum delta-V would be associated with a 25 g maximum deceleration over a 10 ms interval and a 19 g maximum deceleration over a 50 ms interval. Note that the maximum 10 ms deceleration in the 50 km/h rigid barrier crash tests was in the 22 to 26 g range while the maximum 50 ms deceleration was in the 19 to 20 g range.

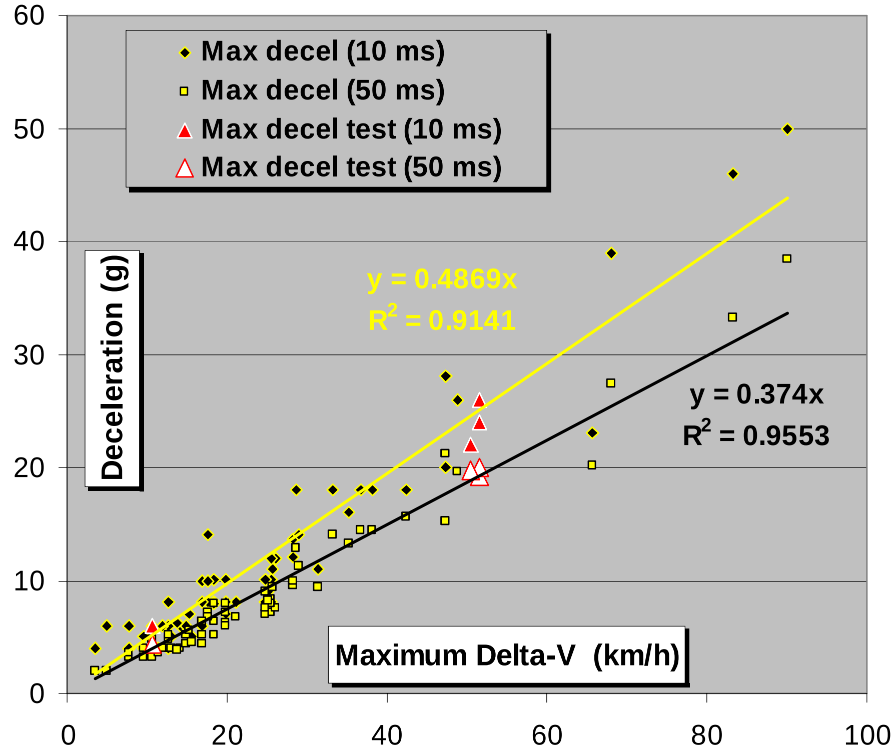

Figure VI Comparison of delta-V and deceleration for frontal impacts

Comparison of Deformable Barrier Crash Tests and Real World Frontal Impacts

The rigid barrier tests provided crash pulses that were generally the most similar to the majority of real world frontal impacts. However, a wide range of crash pulses were observed in the real world. The 40 km/h impacts into a deformable barrier tests provided maximum decelerations that were similar to the general population of frontal impacts. The maximum decelerations in these "soft pulse" tests were more like those that would occur in real world frontal impacts with a maximum delta-V of approximately 25 km/h. The offset crash tests had a considerably longer delta-T than was observed in the majority of the real world crashes. These tests also had a very gradual rise in the magnitude of the deceleration with maximums occurring quite late in the crash pulse in comparison to the real world crashes. In the real world crashes the maximum 10 ms deceleration typically occurred in the 50 to 70 ms range while in the offset tests it was delayed until the 110 to 130 ms range.

Engagement and Rebound Phases

In the full-frontal and offset-frontal crash tests the engagement phase of the impacts could be readily identified as the test speeds were known. In these tests the condition of maximum engagement would correspond with when the vehicles' centre of mass comes to a common velocity with the fixed barrier and the longitudinal delta-V is near the impact speed.

In the crash tests one would often observe a dramatic decline in the magnitude of the vehicle deceleration as the end of the engagement phase was reached. This decline in the deceleration identified the transition between the engagement phase and rebound phase of the impacts. While the rebound phase of these barrier impacts typically had much lower magnitude decelerations than in the engagement phase, in the low speeds test the transition was less apparent.

In the real world collisions, a dramatic drop in the magnitude of the longitudinal deceleration was often observed towards the end of the crash pulse. This transition again tended to be more pronounced in the high severity crashes. Maximum engagement could often be identified in the real world crashes by a flattening of the cumulative delta-V curve.

The average crash pulse duration for the engagement and rebound phases was approximately 120 ms. Incomplete recording of the crash pulse was particularly noticeable in the severe impacts where the deployment command was given soon after AE and the recording duration was limited to 110 ms. It was typically the rebound phase of the crash that was not caught within the recording window. Decelerations in the initial engagement phase of the impact also tended to be much greater in magnitude than in the subsequent rebound phase.

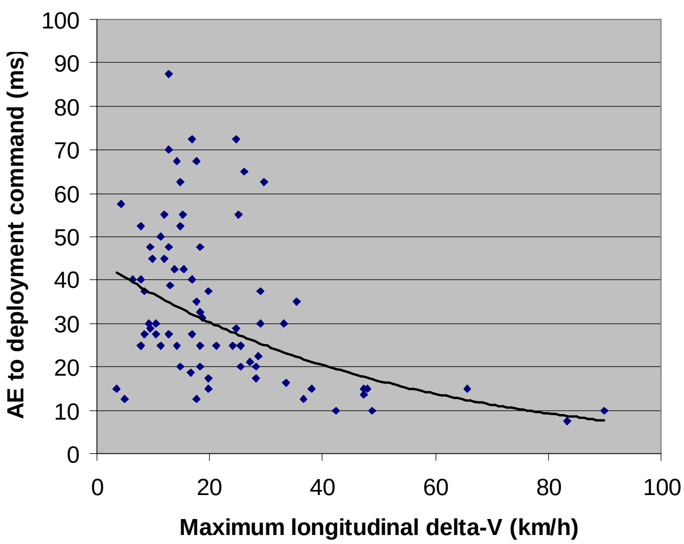

Figure VII Airbag deployment command timing versus delta-V

Airbag Deployment

Airbag deployments in crashes with low recorded maximum delta-V's were very common in this series. In 63% of the real world cases (N = 66) the maximum recorded longitudinal delta-V was less than 20 km/h and in 84% of cases (N = 87) it was less than 30 km/h. Note that the EDR-recorded driver seatbelt usage rate was approximately 90% for the impacts with a maximum recorded longitudinal delta-V less than 30 km/h.

In 103 of the 104 real world crashes and all test crashes the maximum average acceleration in a 10 ms interval was greater than or equal to 4 g. In one case the maximum average acceleration in a 10 ms interval was 3 g. While there are various criteria for airbag deployment, one of the criteria for deployment for this vehicle platform appeared to be related to a 4 g average deceleration in a 10 ms interval. Figure VII shows when airbag deployment was commanded for those cases where this data was available. Generally the airbag deployment was commanded much earlier in the crash pulse for the higher severity impacts. Despite the low deployment thresholds that were noticed with these vehicles, airbag deployment was frequently commanded more than 40 ms after AE.

Advanced airbag systems common on some model vehicles have higher deployment threshold levels for belted occupants. These systems also utilize dual or multiple inflation stages depending on belt use and the severity of the impact predicted by the crash sensors. Advanced airbags with increased deployment thresholds for belted occupants could significantly reduce the frequency of airbag deployments in crashes with low maximum delta-Vs. While higher deployment thresholds will result in fewer airbag deployments, they could potentially result in airbag deployment occurring later during the crash pulse in some frontal impacts. This could increase the frequency of negative interaction with front airbags in the higher severity crashes for improperly belted or short stature occupants. Front occupants would be particularly vulnerable in "soft pulse" high delta-V crashes with a relatively long delta-T. This demonstrates the need for tests such as the offset deformable test.

CONCLUSIONS

The major goal of this preliminary study was to explore the relationship between delta-V, delta-T and deceleration in real world collisions. The study was conducted using real world crash data recorded by event data recorders and was limited to 104 cases involving 1996 to 2005 model Chevrolet Cavaliers and Pontiac Sunfires. The EDR data from real world crashes were compared to crash test data. EDR data were obtained from 11 staged collisions conducted by Transport Canada that involved Chevrolet Cavaliers and Pontiac Sunfires equipped with event data recorders.

The relationship between maximum longitudinal delta-V and deceleration in frontal impacts was found to linear with moderate scatter and was most similar to that observed in the full-frontal rigid barrier test crashes. The 50 km/h rigid barrier test crashes provided an important benchmark for comparison to the real world collisions. The average delta-T for the engagement and rebound phases was approximately 120 ms with the delta-T for the engagement phase of the impact typically being less than 100 ms. However, there was considerable variance as many different crash pulses were observed to occur in the real world collisions.

One could often differentiate the engagement and rebound phases of the real world crashes. Typically the transition involved a marked decrease in the magnitude of the deceleration as the vehicles entered the rebound phase of the impact. The highest decelerations were always associated with the engagement phase of the impacts although in the low delta-V cases the transition to rebound was much less obvious.

The EDR data was found to be a powerful tool for the study of motor vehicle impacts and provided important insight into deceleration history and airbag deployment timing. Indeed EDR data is the only way to monitor performance of advanced restraint systems such as front airbags.

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The opinions expressed in this paper are solely those of the authors and do not necessarily represent the views and policies of their respective organizations.

APPENDIX I

Table 2 Real World Crash Data										
Case #	Year	Model	Impact location	Object struck	Maximum delta-V (km/h)	Recorded maximum delta-V (km/h)	AE to maximum delta-V (ms)	AE to deploy command (ms)	Maximum deceleration : 10 ms interval (g)	Maximum deceleration : 50 ms interval (g)
ACR61222	2002	Sunfire	Front	Deer	-3.5	-4.0	92.5	15.0	-4.0	-2.0
ASF41615	2001	Cavalier	Left side	Pickup	-4.0	.	.	.	-7.0	-2.1
ACR61849	2003	Cavalier	Under	Curb	-4.2	-4.8	152.5	57.5	-6.0	-2.0
ACR51809	2001	Sunfire	Right side	Van	-4.3	.	.	.	-3.0	-1.6
ACR51602	2000	Sunfire	Under	Curb	-4.8	.	.	.	-5.0	-2.7
ACR61805	2002	Cavalier	Front	Deer	-4.9	-5.5	110.0	12.5	-6.0	-2.0
ACR51327	2000	Sunfire	Under	Curb	-6.0	.	.	.	-11.0	-3.4
ACR61127	2004	Cavalier	Right side	Car	-6.4	-6.7	100.0	40.0	-4.0	-2.8
ACR51638	2001	Sunfire	Front	Wall	-7.8	-7.9	95.0	40.0	-4.0	-3.2
ACR51653	2001	Cavalier	Front	Car	-7.8	-8.3	85.0	25.0	-4.0	-3.6
ACR61621	2003	Sunfire	Front	Multi-tree	-7.8	-7.9	65.0	52.5	-8.0	-4.0
ACR61647	2005	Cavalier	Front	Pickup	-7.8	-8.2	112.5	25.0	-6.0	-3.6
ACR61648	2004	Sunfire	Right side	Car	-7.8	-8.3	60.0	25.0	-6.0	-4.0
ASF31840	2000	Cavalier	Front	Car	-8.1	.	.	.	-7.0	-4.6
ACR51316	2001	Cavalier	Front	Pickup	-8.1	.	.	.	-7.0	-4.6
ACR51815	2002	Cavalier	Front	Car	-8.5	-8.5	92.5	37.5	-4.0	-3.2
ACR61904	2003	Cavalier	Right side	Car	-8.5	-9.1	127.5	27.5	-4.0	-3.2
ACR61012	2002	Cavalier	Right side	Pole	-9.2	-9.5	127.5	30.0	-6.0	-4.0
ASF31817	1999	Sunfire	Front	Car	-9.5	.	.	28.8	-5.0	-4.0
ASF31834	1996	Sunfire	Front	Car	-9.5	.	.	47.5	-4.0	-3.2
ACR61144	2004	Cavalier	Left side	Car	-9.9	-10.2	92.5	45.0	-6.0	-4.4
ACR61606	2003	Sunfire	Front	Car	-10.6	-10.6	130.0	30.0	-6.0	-3.2
ACR61611	2002	Sunfire	Front	Car	-10.6	-11.2	120.0	27.5	-6.0	-4.8
ACR51137	2000	Cavalier	Front	Car	-10.7	.	.	.	-5.0	-3.4
ACR51628	2000	Sunfire	Left side	Car	-11.0	.	.	.	-7.0	-5.0
ACR51349	2002	Cavalier	Left side	Car	-11.3	-11.5	120.0	25.0	-6.0	-3.6
ACR61816	2003	Sunfire	Front	Car	-11.3	-11.5	150.0	50.0	-4.0	-3.6
ASF31841	2001	Sunfire	Front	Car	-12.0	-12.6	120.0	45.0	-6.0	-4.0
SID51209	2001	Cavalier	Left side	Car	-12.0	-12.5	150.0	55.0	-6.0	-4.4
ACR51607	2000	Cavalier	Front	Car	-12.1	.	.	.	-5.0	-5.0
ACR51926	2002	Cavalier	Front	SUV	-12.7	-13.2	150.0	87.5	-6.0	-4.8
ACR61120	2003	Cavalier	Front	Barrier	-12.7	-13.1	147.5	47.5	-4.0	-4.0
ACR61357	2004	Sunfire	Front	Tree	-12.7	-13.0	122.5	27.5	-4.0	-4.0
ACR61602	2002	Cavalier	Front	Multi-pole	-12.7	-13.1	157.5	70.0	-10.0	-5.6
ACR61806	2002	Sunfire	Front	Car	-12.7	-12.9	102.5	27.5	-8.0	-5.2
ASF31811	1999	Cavalier	Front	Pickup	-13.1	.	.	38.8	-5.0	-4.0
ACR41145	1997	Sunfire	Front	Off road	-13.8	.	.	42.5	-6.2	-3.8
ACR61321	2002	Sunfire	Front	Minivan	-14.1	-14.6	117.5	25.0	-6.0	-4.0
SID51901	2002	Sunfire	Right side	SUV	-14.1	-14.4	157.5	67.5	-6.0	-4.8
ACR51637	2000	Cavalier	Front	Car	-14.6	.	.	.	-7.0	-5.4
ACR61124	2002	Sunfire	Right side	Car	-14.8	-14.9	105.0	20.0	-10.0	-6.4
ACR61226	2002	Sunfire	Front	Car	-14.8	-15.0	145.0	52.5	-6.0	-4.4
ACR61819	2002	Cavalier	Front	Minivan	-14.8	-15.3	147.5	62.5	-6.0	-5.2
SID51810	1998	Sunfire	Front	Car	-15.2	.	.	55.0	-7.0	-5.6
CHI29614	2001	Cavalier	Left side	Pickup	-15.5	-16.0	140.0	42.5	-12.0	-7.2
ACR51820	2001	Sunfire	Front	Minivan	-15.6	.	.	.	-9.0	-6.6
ACR51135	2000	Cavalier	Front	Car	-15.7	.	.	.	-5.0	-4.5
ACR51819	1998	Cavalier	Left side	Car	-16.6	.	.	18.8	-7.0	-6.6
ASF31842	2001	Cavalier	Front	Pickup	-16.7	.	.	.	-7.0	-6.2
ACR51348	2002	Cavalier	Front	Car	-16.9	-17.4	137.5	40.0	-6.0	-4.4
ACR61113	2002	Cavalier	Front	Car	-16.9	-17.2	122.5	40.0	-6.0	-5.2
ACR51135	2000	Cavalier	Front	Car	-15.7	.	.	.	-5.0	-4.5

Table 3 Real World Crash Data

Case #	Year	Model	Impact location	Object struck	Maximum delta-V (km/h)	Recorded maximum delta-V (km/h)	AE to maximum delta-V (ms)	AE to deploy command (ms)	Maximum deceleration : 10 ms interval (g)	Maximum deceleration : 50 ms interval (g)
ACR61624	2004	Sunfire	Front	Car	-16.9	-17.2	117.5	27.5	-8.0	-6.4
ACR51644	2001	Cavalier	Front	Minivan	-17.6	-17.8	142.5	67.5	-14.0	-7.2
ACR61112	2003	Cavalier	Front	Car	-17.6	-18.2	112.5	12.5	-8.0	-7.2
ACR61364	2004	Cavalier	Front	Tractor	-17.6	-17.7	132.5	35.0	-10.0	-6.8
SID51604	2000	Sunfire	Left side	Minivan	-18.1	.	.	.	-9.0	-6.6
ACR51645	2001	Cavalier	Front	Car	-18.4	-18.9	115.0	20.0	-8.0	-6.4
ACR51805	2002	Sunfire	Left side	Pickup	-18.4	-18.7	107.5	25.0	-10.0	-8.0
ACR51806	2002	Sunfire	Front	Car	-18.4	-19.0	140.0	47.5	-8.0	-5.2
ACR51927	2002	Sunfire	Front	Minivan	-18.4	-18.7	127.5	32.5	-10.0	-8.0
ACR61341	1999	Sunfire	Left side	Car	-18.7	.	.	31.3	-9.0	-6.8
ACR51272	2001	Sunfire	Front	Pickup	-19.8	-20.2	132.5	37.5	-8.0	-6.0
ACR61637	2004	Cavalier	Front	Minivan	-19.8	-20.1	115.0	17.5	-8.0	-7.2
ACR61652	2004	Cavalier	Front	Minivan	-19.8	-20.1	105.0	15.0	-10.0	-8.0
ASF41603	2000	Cavalier	Front	Car	-19.8	.	.	.	-7.0	-6.2
ACR61631	2003	Sunfire	Front	Car	-21.2	-21.4	120.0	25.0	-8.0	-6.8
ACR51622	2000	Cavalier	Front	Car	-21.4	.	.	.	-9.0	-7.0
SID51312	2001	Sunfire	Right side	Truck	-22.0	.	.	.	-15.0	-9.8
ACR51824	2002	Cavalier	Right side	Minivan	-24.0	-24.3	122.5	25.0	-12.0	-9.2
ACR51922	2002	Sunfire	Front	Barrier	-24.7	-24.8	165.0	72.5	-8.0	-7.6
SID51210	1999	Cavalier	Front	Car	-24.7	.	.	28.8	-10.0	-9.0
ACR51650	2001	Sunfire	Front	Pole	-24.8	.	.	.	-9.0	-7.0
ASF31619	1998	Sunfire	Front	Minivan	-25.1	.	.	55.0	-9.0	-8.2
ACR51350	2002	Cavalier	Front	Car	-25.4	-25.8	122.5	25.0	-10.0	-8.0
ACR51655	2002	Cavalier	Front	Pole	-25.4	-25.6	122.5	25.0	-8.0	-7.2
ACR61368	2005	Cavalier	Front	Guardrail	-25.4	-25.6	117.5	20.0	-10.0	-8.4
ACR61653	2004	Sunfire	Front	Minivan	-25.4	-25.5	120.0	25.0	-12.0	-8.0
ACR51606	2000	Sunfire	Front	Car	-25.7	.	.	.	-11.0	-9.4
ACR61347	2003	Cavalier	Front	Pole	-26.1	-26.3	157.5	65.0	-12.0	-7.6
ASF39608	1997	Sunfire	Under	Off road	-27.2	.	.	21.3	-13.0	-8.0
ACR61304	2002	Sunfire	Front	Car	-28.2	-28.4	112.5	17.5	-13.7	-9.5
ACR61628	2003	Cavalier	Front	SUV	-28.2	-28.4	115.0	20.0	-12.0	-10.0
ACR51646	1996	Cavalier	Front	Car	-28.6	.	.	22.5	-18.0	-12.8
ACR61206	2002	Cavalier	Front	Tree	-28.9	-29.5	127.5	30.0	-14.0	-11.2
ACR61306	2002	Sunfire	Left side	Pole	-28.9	-29.3	130.0	37.5	-28.0	-12.0
ACR61126	2003	Sunfire	Under	Off road	-29.7	-30.2	155.0	62.5	-10.0	-7.6
ACR61142	2001	Sunfire	Front	Car	-30.3	.	.	.	-17.0	-12.6
ASF31807	1998	Sunfire	Under	Off road	-31.4	.	.	128.8	-8.0	-7.2
SID51810	2000	Cavalier	Front	Car	-31.4	.	.	.	-11.0	-9.4
ACR61618	2002	Sunfire	Front	Minivan	-33.2	-33.2	120.0	30.0	-18.0	-14.0
ACR61330	1998	Sunfire	Right side	Minivan	-33.5	.	.	16.3	-18.0	-11.8
ACR61325	2003	Cavalier	Front	Guardrail	-35.3	-35.5	135.0	35.0	-16.0	-13.2
ACR61142	2003	Cavalier	Front	Car	-36.7	-36.7	105.0	12.5	-18.0	-14.4
ACR51810	2002	Cavalier	Front	Car	-38.1	-38.3	107.5	15.0	-18.0	-14.4
ACR61619	2002	Cavalier	Front	Car	-42.4	-42.8	107.5	10.0	-18.0	-15.6
ACR61617	2002	Cavalier	Front	Car	-47.3	-47.7	107.5	15.0	-28.0	-21.2
ASF39630	1998	Sunfire	Front	Minivan	-47.3	.	.	13.8	-20.0	-15.2
ACR51646	2002	Cavalier	Right side	Car	-48.0	-48.0	107.5	15.0	-32.0	-22.4
ACR51356	2002	Cavalier	Front	Car	-48.7	-49.1	102.5	10.0	-26.0	-19.6
ACR71604	1999	Sunfire	Front	Car	-65.7	.	.	15.0	-23.0	-20.2
ACR51318	2001	Sunfire	Front	Car	-68.1	.	.	.	-39.0	-27.4
ASF41620	2003	Sunfire	Front	Car	-83.3	-83.4	105.0	7.5	-46.0	-33.2
ASF31312	1997	Sunfire	Front	Truck	-90.0	.	.	10.0	-50.0	-38.4

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