

Comparison of Crash Pulse Data from Motor Vehicle Event Data Recorders and Laboratory Instrumentation

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Abstract

Frontal barrier crash tests conducted with General Motors' vehicles allowed data relating to the crash pulse to be obtained both from the vehicles' event data recorders (EDR) and from the on-board instrumentation used by Transport Canada's test centre. Three vehicle platforms were used in this study, the Chevrolet Cavalier, Chevrolet Impala, and Chevrolet Trailblazer. Data were obtained for three test configurations. Full frontal impacts into a rigid concrete barrier were conducted at 48 and 56 km/h. Frontal offset collisions into a deformable barrier face were carried out at 40 km/h. In addition, full frontal crashes into a fixed underride guard structure were conducted at 48 and 65 km/h. The laboratory accelerometers sampled the crash pulse at 10 kHz, while the EDR's provided cumulative values of velocity change (delta-V) at 10 ms intervals over a window of either 150 or 300 ms. In order to make a meaningful comparison, the laboratory data were processed to provide a similar sample of point values to those obtained from the EDR. Good agreement was observed between the two datasets; however, in some situations the vehicle EDR was found to be unable to capture the entire collision event. The implications for the use of EDR's in real-world collisions are discussed in the light of these findings.

Résumé

Des essais de collision frontale effectués contre une barrière à l'aide de véhicules fabriqués par General Motors ont permis d'obtenir des données sur l'intensité de la collision à partir des enregistreurs de données de conduite (EDR) des véhicules et des instruments placés à bord par le centre d'essais de Transports Canada. Au cours de cette étude, on a utilisé trois types de véhicules Chevrolet : la Cavalier, l'Impala et le Trailblazer. On a obtenu des données pour trois configurations d'essai. Les collisions frontales perpendiculaires à l'obstacle (une barrière rigide en béton) ont été effectuées à 48 et 56 km/h. Les essais de collision frontale décentrée sur une barrière déformable ont été effectuées à 40 km/h. De plus, les essais de collision frontale perpendiculaire à une structure fixe anti-encastrement ont été effectuées à 48 et 65 km/h. Les accéléromètres du laboratoire ont échantillonné l'intensité de la collision à 10 kHz, alors que les EDR ont mesuré des valeurs cumulatives de variation de vitesse (delta-v) à des intervalles de 10 millisecondes sur une fenêtre de 150 ou de 300 millisecondes. Pour arriver à faire une comparaison significative, les données du laboratoire ont été traitées afin de produire un échantillon de valeurs ponctuelles semblable à celui obtenu par l'EDR. Les deux groupes de données étaient très semblables. Cependant, dans certaines situations, l'EDR n'a pas pu enregistrer toute la collision. À la lumière de ces découvertes, on évalue les implications de l'utilisation d'EDR lors de collisions réelles.

Introduction

In North America, the use of event data recorders on production vehicles has been pioneered by General Motor Corporation (GM). GM's EDR has evolved over several years, and various models can capture the crash pulse and/or certain pre-crash data elements.¹

The EDR forms part of the sensing and diagnostic module (SDM) used to initiate deployment of a

vehicle's air bags in the event of a collision of appropriate severity. The crash pulse record takes the form of the vehicle's cumulative change in velocity (delta-V), measured over intervals of 10 ms for a period of either 150 or 300 ms, depending on the specific type of SDM installed.

Testing conducted by GM has been reported as confirming that crash recordings made by EDR's have been within the published uncertainty limits of these units.¹ A comparison of the impact speeds reported from laboratory instrumentation in a series of crash tests involving GM vehicles, and the delta-V's captured by the EDR's in the test vehicles, has been previously reported by two of the present authors.² In addition, the time history of the delta-V recorded by laboratory instrumentation and the vehicle's EDR in a single crash test has been documented in the literature.³

The current study seeks to expand the knowledge of the time history of the delta-V recorded by EDR's in staged collisions, by comparing the results obtained from laboratory instrumentation installed in the vehicles for collision monitoring purposes, and the EDR's available in the vehicles as original equipment. Two different passenger car platforms, and one light truck, were used in the test series. In addition, tests were conducted with three collision configurations, including both rigid and non-rigid barriers, and a range of impact speeds from 40 to 65 km/h, to provide a spectrum of collision pulses.

It should be noted that the accelerometers used by the test centre, and the accelerometer forming part of GM's EDR, employ different sampling rates. Furthermore, the EDR is part of a microcomputer that processes the signal to compute and record the time history of the delta-V rather than the vehicle's acceleration. Consequently, the resulting data from the two sets of instrumentation do not allow for direct comparison.

Because of the above-noted differences in sampling rate, it was not possible to precisely duplicate the manufacturer's computational strategies to convert

acceleration to delta-V. Recognizing this limitation, the acceleration data recorded by the laboratory instrumentation were processed in a manner so as to reproduce the computation of cumulative delta-V as closely as possible.

Methodology

Vehicle acceleration data were obtained from a series of staged collisions conducted by Transport Canada that involved General Motors' vehicles equipped with event data recorders.

The instrumentation used for the staged collisions conducted at Transport Canada's Motor Vehicle Test Centre included accelerometers with a sampling frequency of 10 kHz. The test vehicle was instrumented with several such accelerometers, the most relevant of which, for the present purposes, were units mounted on the floor at the base of the B-pillars, and on the central tunnel, at the vehicle's centre of gravity. These three accelerometers were in the closest proximity to the vehicle's original-equipment event data recorder which was located either beneath the right-front passenger seat, or on the central tunnel, depending on the vehicle model. A tape switch mounted on the vehicle's front bumper was used to establish the time of first contact with the barrier structure. The impact speed of the vehicle was captured by means of an external speed trap.

All the data from the laboratory instrumentation were sampled over 400 ms, and subsequently filtered in accordance with SAE Recommended Practice J221-1.⁴ For each test vehicle, the data were further processed so as to compare the computed change in velocity of the vehicle with that recorded by the on-board EDR.

Test Vehicles

The three models of vehicles used for the present work were: 1998-99 Chevrolet Cavaliers, 2001-02 Chevrolet Impalas, and 2002 Chevrolet Trail-

blazers. These vehicles came equipped with different versions of the SDM's that provide the event data recorder function. The EDR's in the Cavaliers gave a 300 ms crash pulse window, while the Impalas and Trailblazers both had EDR's that could provide crash pulse data over a 150 ms window. Thus, the two basic types of EDR's used by General Motors Corporation are represented in this study.

Staged Collisions

Transport Canada's crash test programme includes collisions to check for compliance with the motor vehicle safety regulations, and crashes conducted purely for research purposes. For the present study, staged collisions of both types have been included to obtain a spectrum of collision configurations and severities.

Frontal collisions at up to 48 km/h into a rigid barrier are a standard means of testing compliance with a variety of motor vehicle safety regulations including the collision performance of occupant restraint systems.⁵ Generally, compliance tests are conducted close to, but slightly below, the maximum allowable test speed of 48 km/h. Occasionally, the same test configuration may be adopted as part of a research programme that uses higher impact speeds. Several 48 km/h frontal barrier tests, and one such test conducted at 56 km/h, are included in the present series.



Figure 1. Frontal Rigid Barrier Crash Test

A lower severity test has been developed by Transport Canada researchers as a means of promoting more effective air bag deployment characteristics.⁶ This test involves a 40% offset frontal crash into a deformable, aluminum honeycomb, barrier face. The test is designed to be conducted at any impact speed up to 40 km/h. Tests at this nominal impact speed of 40 km/h have been included in the present study since they provide a "soft" crash pulse. This is more representative of a vehicle-to-vehicle collision that might normally be observed in the real world than is the more severe frontal/rigid barrier test configuration.



Figure 2. Offset Deformable Barrier Crash Test

A Transport Canada research programme conducted to support the development of a heavy truck rear underride guard used a fixed structure mounted in front of a rigid barrier to simulate the cargo deck of a tractor semi-trailer.⁷ A number of passenger cars and light-duty trucks were run at various speeds into different guard designs mounted to the test fixture. The tests evaluated the potential of the guards to avoid catastrophic underride while providing some degree of protection to the occupants of the striking vehicles. One of the vehicles used in this series, a Chevrolet Cavalier, was subject to tests at both 48 and 65 km/h impact speeds. These latter tests were included in the current study since data for the Cavalier was also available for both the 48 km/h frontal barrier test and the 40 km/h offset deformable barrier test.



Figure 3. Underride Guard Crash Test

Test Matrix

The combinations of test vehicle, EDR, crash configuration and impact speed used for the data analysis are summarized in Table 1.

Data Processing

Data from all three relevant accelerometers were initially analyzed for the various vehicle types and crash configurations; however, it was found that the results were marked by few differences. Consequently, for simplicity, the results presented here for the test laboratory's accelerometer are those for the unit mounted closest to the vehicle's EDR. For both the Cavalier and Impala, the accelerometer at the base of the right B-pillar was used, while the accelerometer mounted on the central-tunnel was used for the Trailblazer

The data capture method employed by General Motors for their event data recorder has been described previously.¹ Essentially, the vehicle's on-board microcontroller samples the accelerometer at a frequency of 3.2 kHz. Once a collision occurs, the air bag deployment algorithm is enabled, and the EDR goes into a computational/recording mode.

| Test No. | EDR crash pulse window | Test vehicle | Crash type | Impact speed |
|-----------------|-------------------------------|----------------------------|---------------------------|---------------------|
| 99-238 | 300 ms | 1999 Chevrolet Cavalier | Rigid barrier | 48 km/h |
| 98-214 | 300 ms | 1998 Chevrolet Cavalier | Offset deformable barrier | 40 km/h |
| 98-502 | 300 ms | 1998 Chevrolet Cavalier | Underride guard | 48 km/h |
| 98-507 | 300 ms | 1998 Chevrolet Cavalier | Underride guard | 65 km/h |
| 01-128 | 150 ms | 2001 Chevrolet Impala | Rigid barrier | 48 km/h |
| 02-211 | 150 ms | 2002 Chevrolet Impala | Offset deformable barrier | 40 km/h |
| 02-234 | 150 ms | 2002 Chevrolet Trailblazer | Rigid barrier | 48 km/h |
| 02-220 | 150 ms | 2002 Chevrolet Trailblazer | Rigid barrier | 56 km/h |

Table 1 Vehicle/test matrix used in the data analysis

Four acceleration samples are averaged over each 1.25 ms period. The resulting values are then integrated to determine the vehicle's cumulative delta-V. Values of the computed delta-V are stored by the EDR every 10 ms. Depending on the type of EDR, the final delta-V dataset will consist of a crash pulse spanning up to either 150 or 300 ms.

The different sampling frequencies used by the laboratory instrumentation and the vehicle's EDR prevent precise replication of the vehicle manufacturer's computational strategy. To best represent the latter, Transport Canada's data were reduced by averaging ten acceleration samples over each one millisecond period, integrating the resulting values, and recording the resulting delta-V at 10 ms intervals. In essence, the difference in the methodologies is that the General Motors' system provides eight values of average vehicle acceleration over a 10 ms window, whereas Transport Canada's data stream yields ten such samples in the same time frame.

The other difference in the datasets is one of timing. Transport Canada's test protocol uses an electro-mechanical switch to detect the first contact of the test vehicle to the barrier. Consequently, "time zero" for the test data is effectively concurrent with the onset of the crash pulse. By contrast, in the real world, the on-board EDR continuously monitors the vehicle's acceleration. When this 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.

Results

Graphs are provided for each crash test in our series, comparing the cumulative delta-V computed from the laboratory instrumentation to that downloaded from the vehicle's EDR. The average acceleration in each 10 ms period over the duration

of the crash pulse was computed from the delta-V vs. time values for the EDR data. For comparison purposes, similar calculations were made from the computed delta-V curve developed from the test centre's acceleration data. Charts comparing these two sets of average accelerations are provided for the individual tests.

Discussion

The results from the various crash tests involving the Cavalier platform are shown in Figures 4 through 11.

Figure 4 shows the cumulative delta-V's from a rigid barrier test at a nominal impact speed of 48 km/h. The actual test speed for this crash was 47.1 km/h (Table 2). In these test results, there are striking similarities, and some differences, in the characteristics of the crash pulse as demonstrated by the delta-V and acceleration curves. Both systems record a delta-V greater than the actual impact speed, as would be expected, since the collision is partially elastic and some rebound occurs. The GM EDR understates the delta-V in the collision as compared to that computed from the laboratory instrumentation. The maximum delta-V recorded by the EDR was 50.5 km/h while that obtained from the test centre's data was 53.8 km/h, a difference of 3.3 km/h (6%).

Part of this difference is explained by the fact that some of the initial phase of the crash pulse is not included in the EDR's recording and associated delta-V calculations, since GM's system must wait for AE to be triggered by the pre-determined acceleration threshold. In addition, the process of sampling the vehicle's acceleration limits the accuracy with which the delta-V can be determined. The effect of filtering the acceleration data is illustrated in Figure 20 which shows the average accelerations computed from the EDR data versus all of the test centre's acceleration data. From Figure 5, it is apparent that the maximum accelerations recorded by the laboratory

| Test No. | Test Vehicle | Crash Type | Impact Speed (km/h) | TC computed maximum delta-V (km/h) | SDM recorded maximum delta-V (km/h) | TC computed maximum delta-V vs impact speed (km/h) | SDM recorded maximum delta-V vs impact speed (km/h) |
|----------|------------------|----------------|---------------------|------------------------------------|-------------------------------------|--|---|
| 98-502 | 1998 Cavalier | Guard | 48.90 | 52.51 | 49.44 | 3.61 | 0.54 |
| 98-507 | 1998 Cavalier | Guard | 64.60 | 70.8 | 64.97 | 6.20 | 0.37 |
| | | | | | | | |
| 98-214 | 1998 Cavalier | Offset Barrier | 40.30 | 42.74 | 42.37 | 2.44 | 2.07 |
| 02-211 | 2002 Impala | Offset Barrier | 39.90 | 42.08 | 26.20 | 2.18 | -13.70 |
| | | | | | | | |
| 99-238 | 1999 Cavalier | Rigid Barrier | 47.10 | 53.82 | 50.48 | 6.72 | 3.38 |
| 01-128 | 2001 Impala | Rigid Barrier | 47.70 | 54.46 | 49.08 | 6.76 | 1.38 |
| 02-234 | 2002 Trailblazer | Rigid Barrier | 48.02 | 55.09 | 51.34 | 7.07 | 3.32 |
| 02-220 | 2002 Trailblazer | Rigid Barrier | 55.99 | 63.92 | 59.58 | 7.93 | 3.59 |

Table 2. Comparison of Computed and Recorded Delta-V's

instrumentation are somewhat greater than those obtained by the EDR. Consequently, the difference in the computed delta-V's resulting from this effect can be seen to be directionally correct. Overall, the stated accuracy of the delta-V calculations for GM's system is $\pm 10\%$.¹ The current results are well within this tolerance.

Figures 6 and 7 show the cumulative delta-V's and average accelerations for a 40 km/h offset frontal deformable barrier test (Test No. 98-214). The shapes of both the delta-V and acceleration curves are remarkably similar, and the maximum delta-V's almost identical (Table 2). The evident difference between the results in this test is that the curves appear to be shifted with respect to each other in time. Such an effect is not unexpected since the test centre has a "time-zero" reference point, while the GM data are based on the occurrence of AE which, because it is acceleration based, is dependent on the nature of the specific collision event.

Figures 8 and 10 show the delta-V curves for two crashes of Cavaliers into underride guards at 48 and 65 km/h respectively. In Figure 8, the delta-V curves are similar, as are the associated acceleration values, except for a time shifting effect. It is interesting to note how both systems track the details of the somewhat complex crash pulse. In particular, both delta-V curves show a distinct change in slope approximately 90 ms into the event. This is doubtless the result of yielding in the impacting structures, followed by the subsequent engagement of stiffer portions of the striking vehicle and the guard. Also of note in this crash, is the extremely long duration of the pulse. Transport Canada's instrumentation provided data beyond the 300 ms window shown, from which it was determined that the maximum delta-V actually occurred at the 300 ms point. In Figure 10, an abrupt discontinuity in the delta-V curve recorded by the EDR can be seen at 200 ms. This distinctive crash pulse signature is indicative of an electrical

power loss in the vehicle during the event, resulting in the inability of the EDR to record the full crash pulse.

The results for tests involving the Impala platform are shown in Figures 12 through 15. Overall, these show great similarities to those exhibited by the series of tests involving the Cavalier. The notable difference here is that the Impala's SDM is only capable of storing a total of 15 data points over a 150 ms window, rather than the 300 ms system used in the Cavalier. The system is further limited in that it records data for 100 ms after the deployment criteria are met and up to 50 ms before. In each of the two tests shown, the number of points captured by the SDM was less than 15. In the 48 km/h rigid barrier test shown in Figure 12, these were still sufficient to capture the maximum delta-V in the crash, even though the rest of the crash pulse was not recorded. In the 40 km/h offset deformable barrier test the available memory was clearly insufficient to capture the maximum delta-V.

The final curves, Figures 16 through 19, show the results of crash tests involving a 2002 Trailblazer. Both are frontal rigid barrier tests at nominal impact speeds of 48 and 56 km/h. The SDM installed in the Trailblazer is capable of storing information over a 150 ms window. Overall, the results for the Trailblazer show the same trends as those for a similar test with the Impala.

Conclusions

The results of a number of staged collisions of different types and severities show that General Motors' EDR's generally produce delta-V values within the stated uncertainty tolerances. In some of the test situations there were differences between the results from the vehicle's EDR and the laboratory instrumentation. These differences were seen to be due to limitations in the capacity of the vehicle's SDM to capture the details of the collision event or, in one case, because of a collision-related disruption in the electrical power supply to the

SDM. Such limitations are well known and are documented in the information that accompanies the Vetronix Crash Data Retrieval systems used to access the on-board data.⁸

The current results have application to the consideration of data obtained in real-world crashes, where considerably more variable conditions may well be encountered. Under normal circumstances, the investigator may expect the EDR-based delta-V to be a reasonable approximation to the actual delta-V experienced by a vehicle in a frontal crash. In some of the tests in the current series, the delta-V obtained from the EDR was understated. In no cases was a higher value than the test centre's result observed. Thus, the delta-V values are seen to be accurate or, at worst, somewhat conservative.

It should be appreciated that the current test series involved only frontal impacts, where the resulting forces were acting essentially along the vehicle's longitudinal axis. Since the accelerometer in GM's SDM is uni-axial, and oriented to capture acceleration along this axis, one would expect the data in frontal impacts to be faithfully recorded. 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 such cases, the reported change in forward velocity should be considered in the light of other physical evidence related to the collision.

Even in frontal crashes, where the delta-V obtained from the EDR appears to be considerably too low, based on the observed vehicle damage or other physical evidence of a collision, the investigator should pay special attention to the documented limitations of the specific EDR system. As demonstrated by a number of crashes in this series, the onset and length of the crash pulse may be such that certain SDM's are incapable of recording the entire event. In addition, severe crashes or other adverse collision configurations, may disrupt the electrical power supply to the SDM which can result in some data loss.

Converting the EDR-based delta-V values to average accelerations can be a useful technique for evaluating the utility of the results. For example, Figure 15 clearly shows that the acceleration pulse has been cut off prior to the end of the associated collision events, and should cause the investigator to consider how well the recorded delta-V may reflect the maximum value experienced in the crash.

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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.

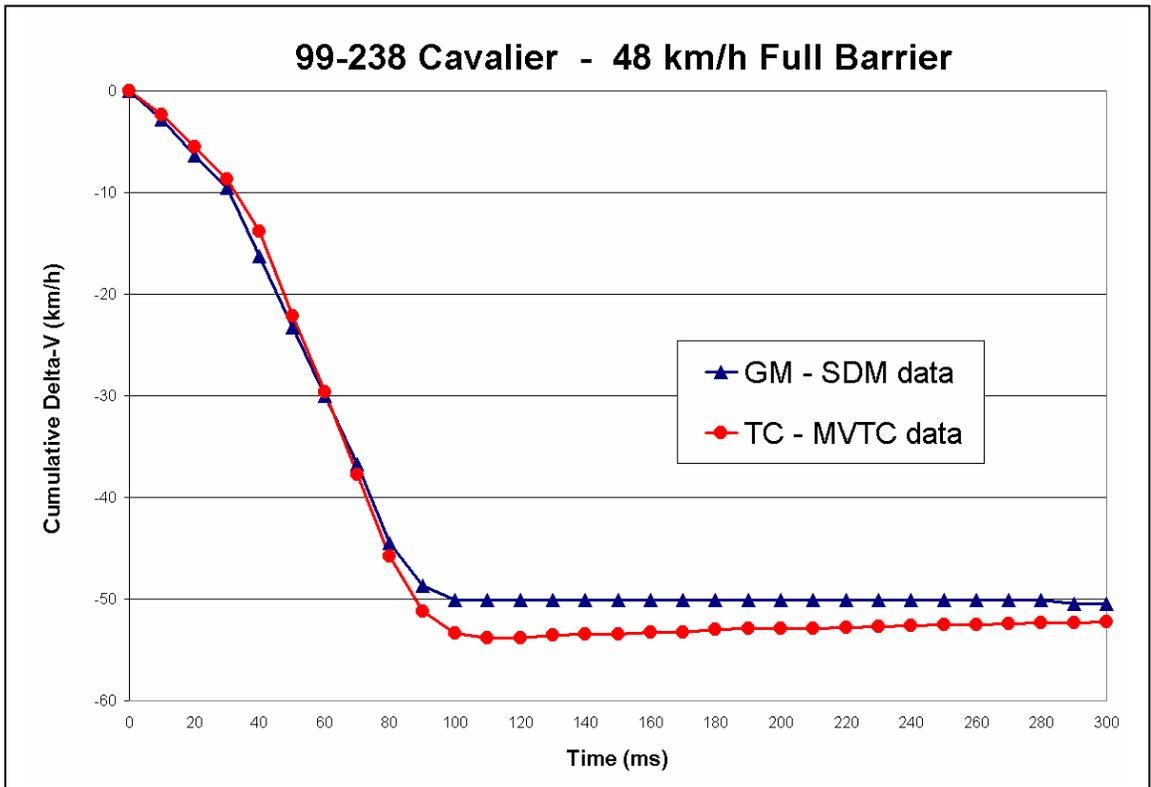


Figure 4. Cumulative Delta-V for Test No. 99-238

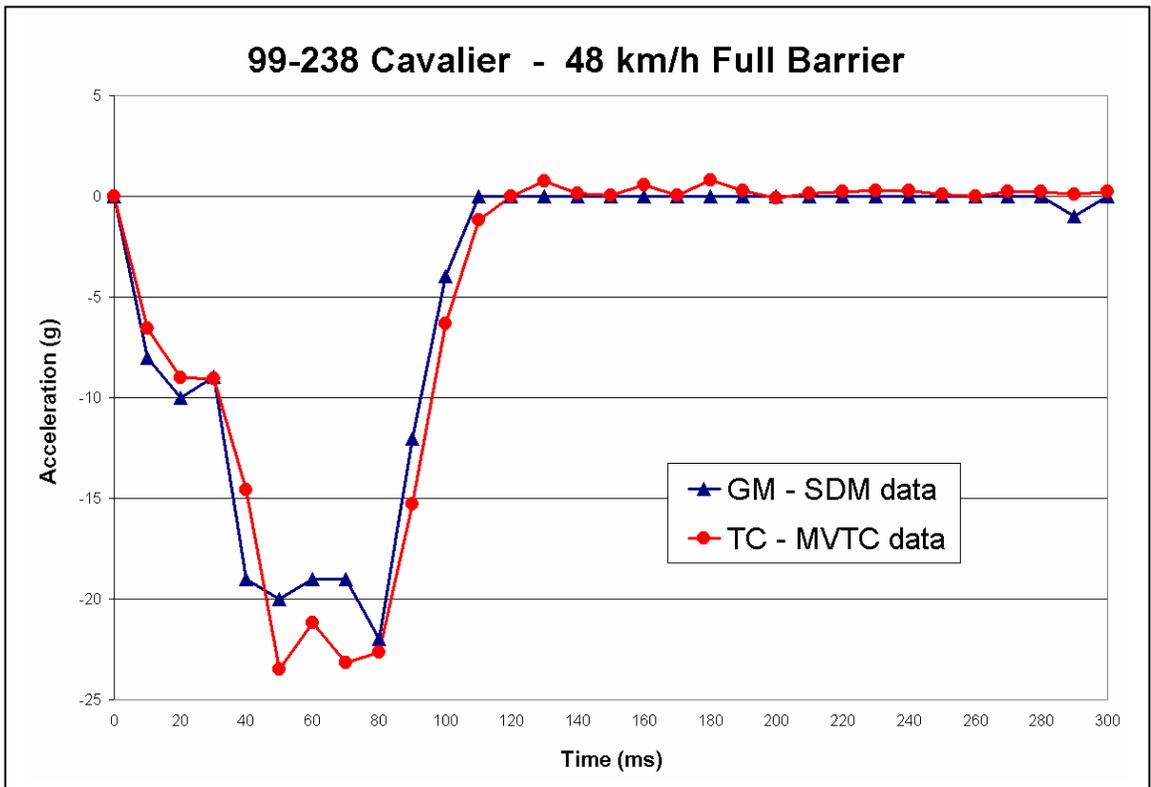


Figure 5. Average Acceleration for Test No. 99-238

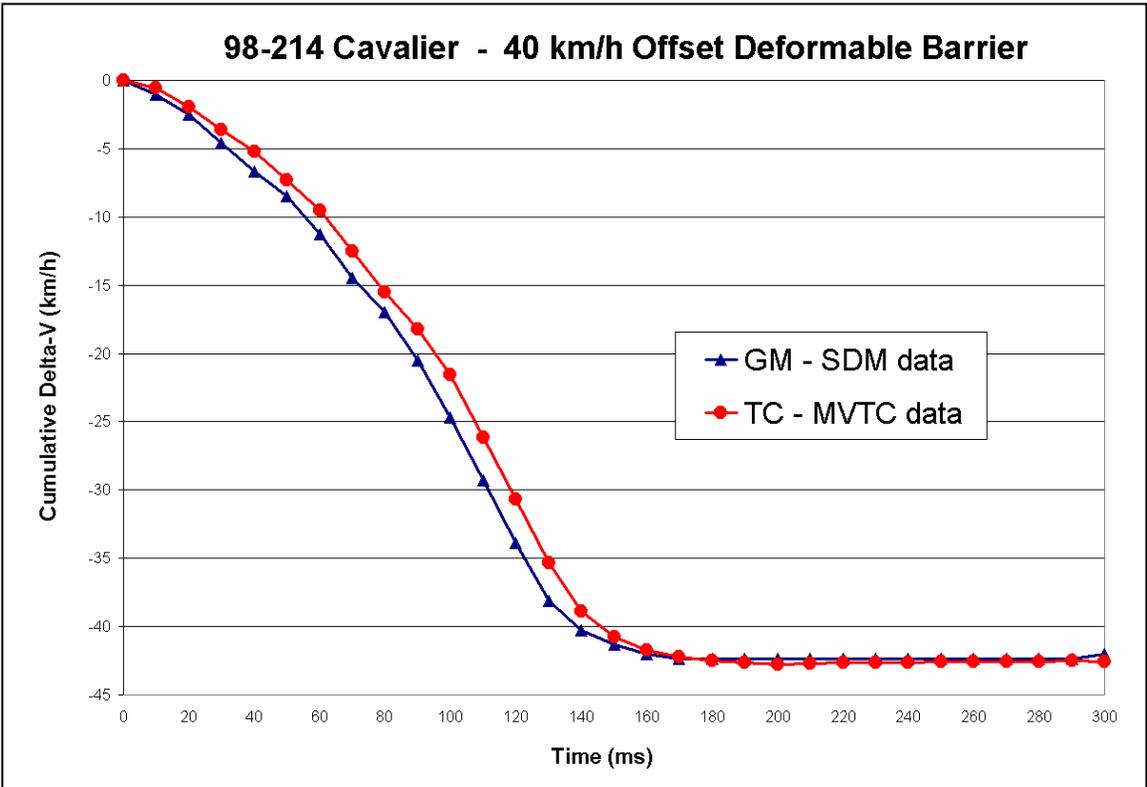


Figure 6. Cumulative Delta-V for Test No. 98-214

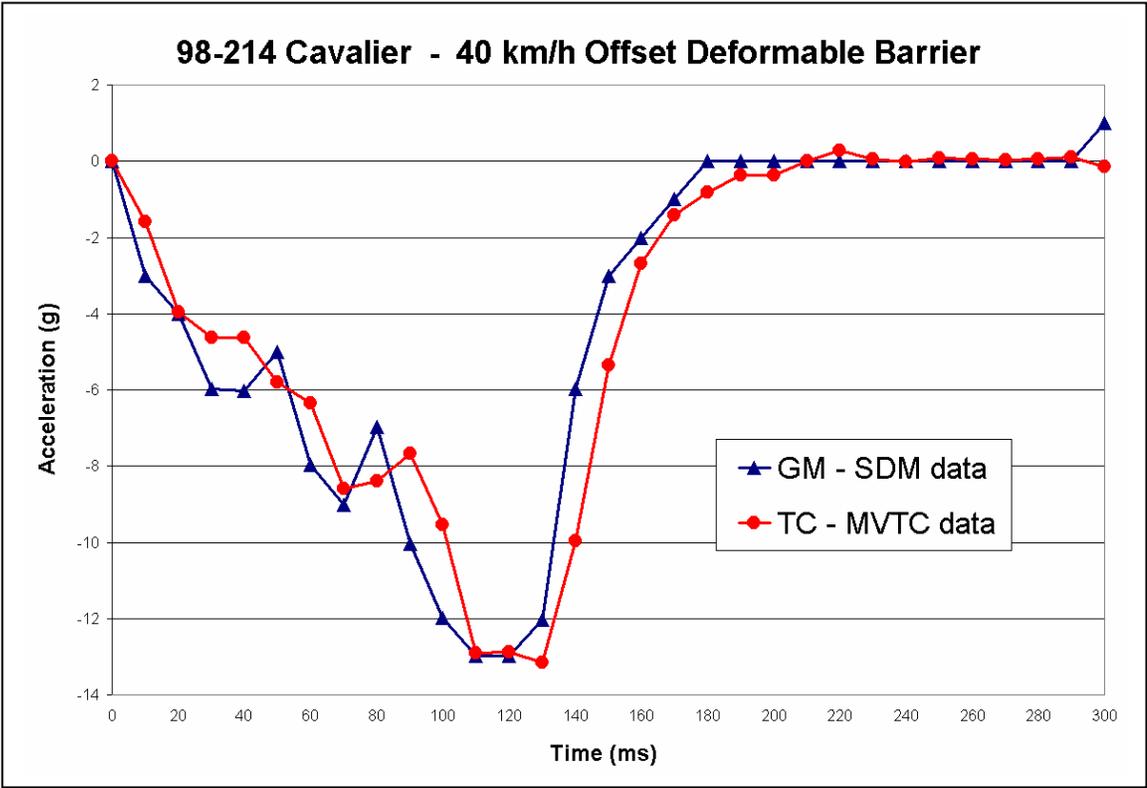


Figure 7. Average Acceleration for Test No. 98-214

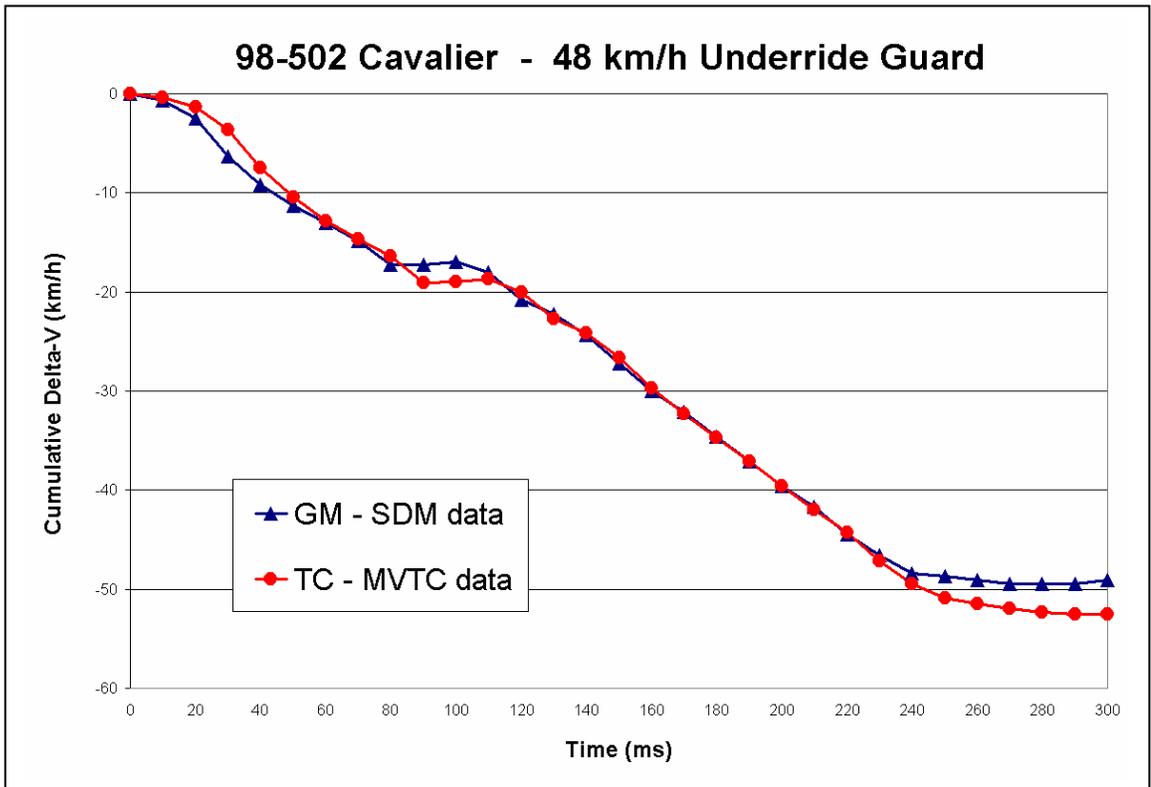


Figure 8. Cumulative Delta-V for Test No. 98-502

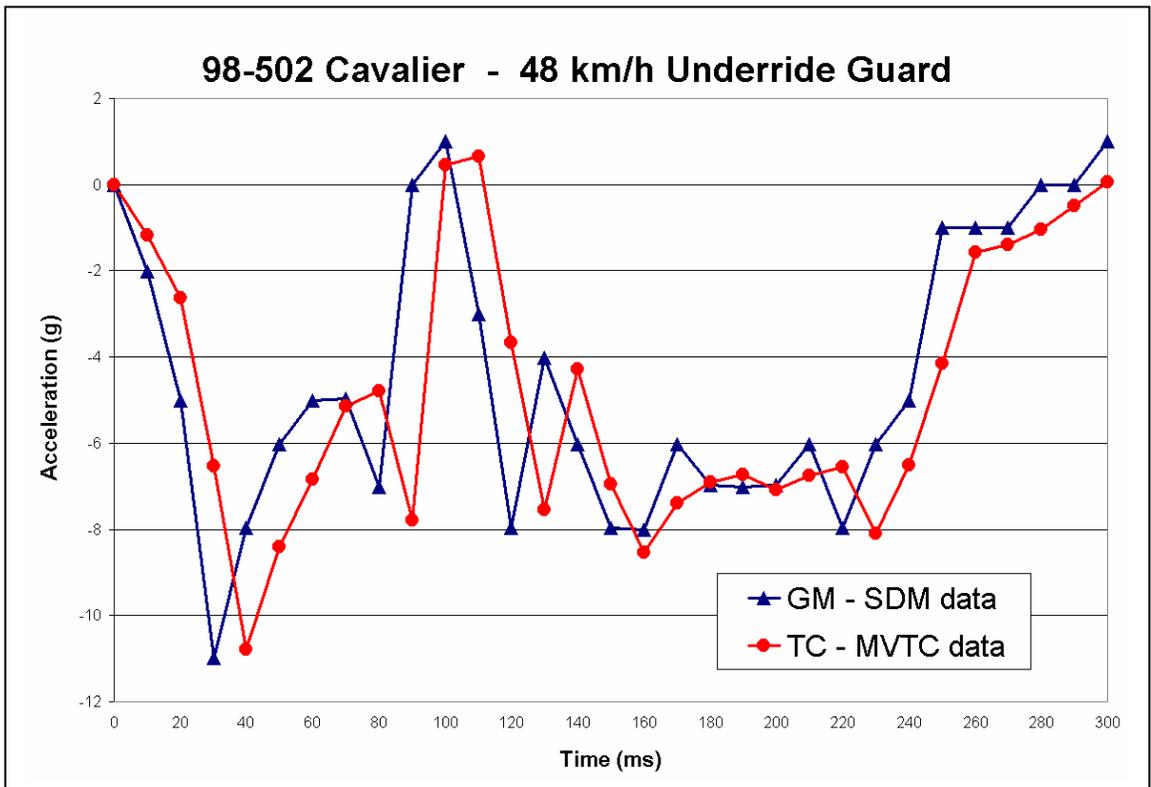


Figure 9. Average Acceleration for Test No. 98-502

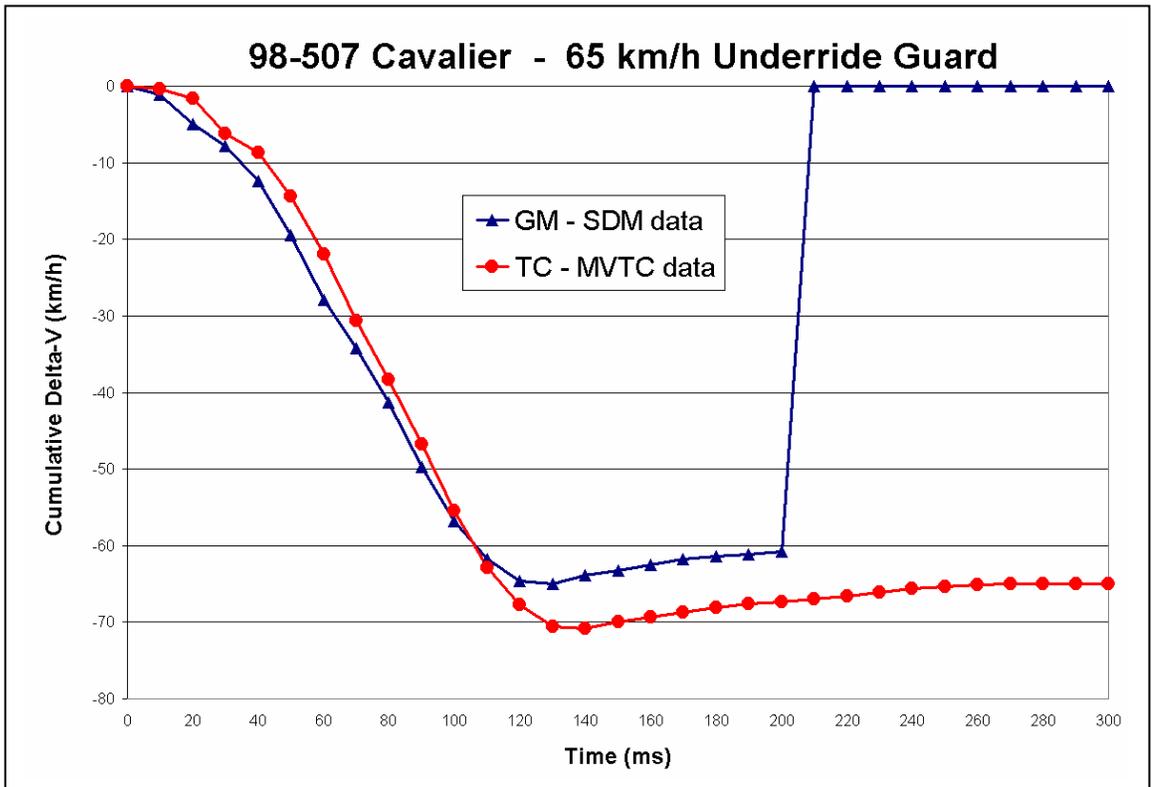


Figure 10. Cumulative Delta-V for Test No. 98-507

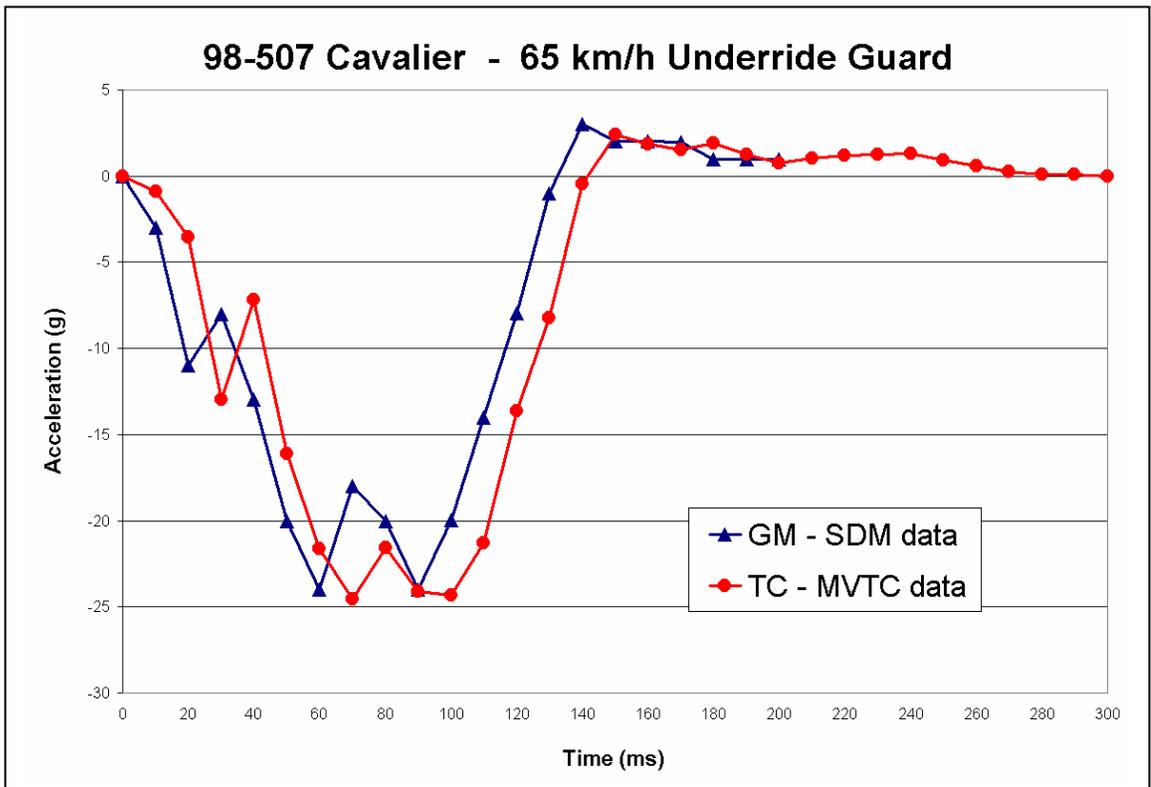


Figure 11. Average Acceleration for Test No. 98-507

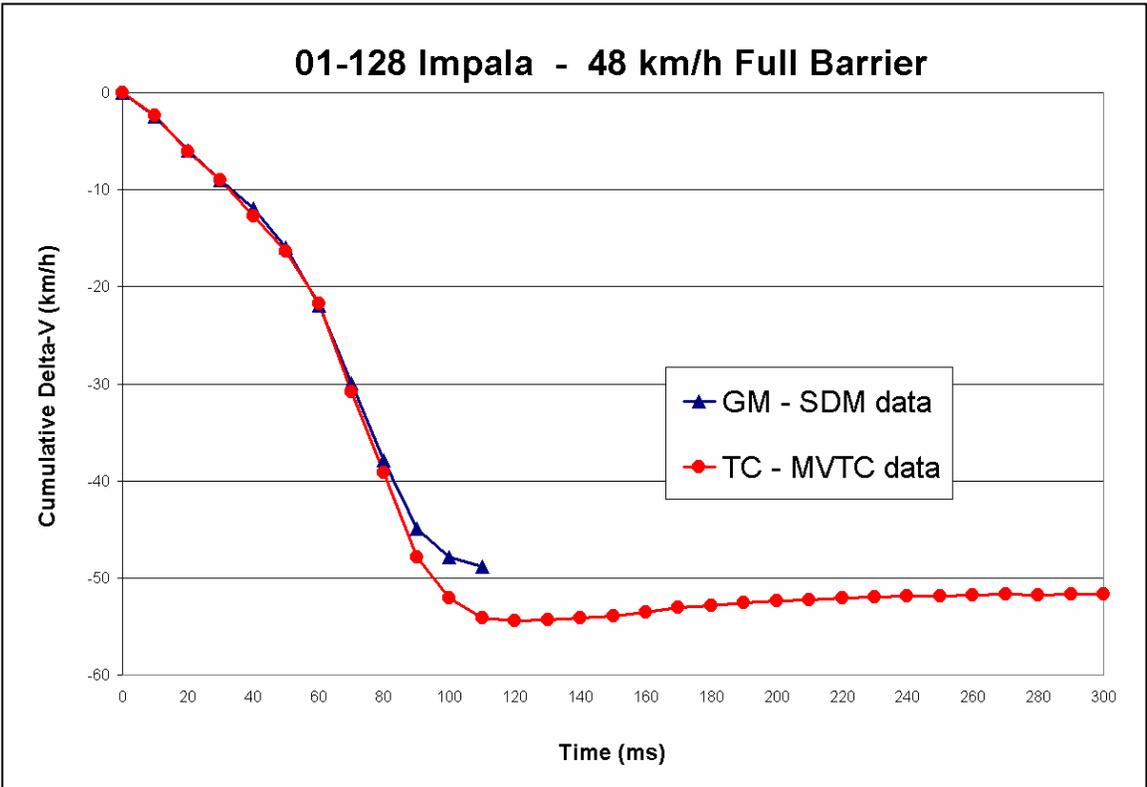


Figure 12. Cumulative Delta-V for Test No. 01-128

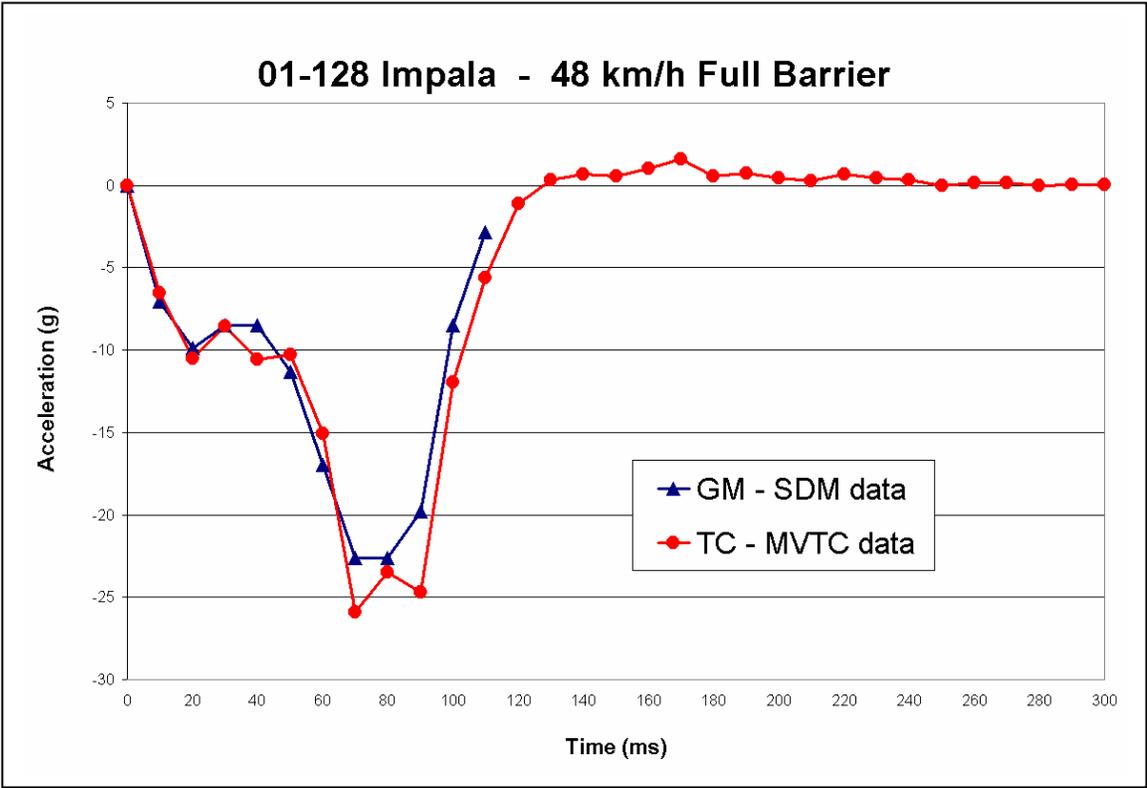


Figure 13. Average Acceleration for Test No. 01-128

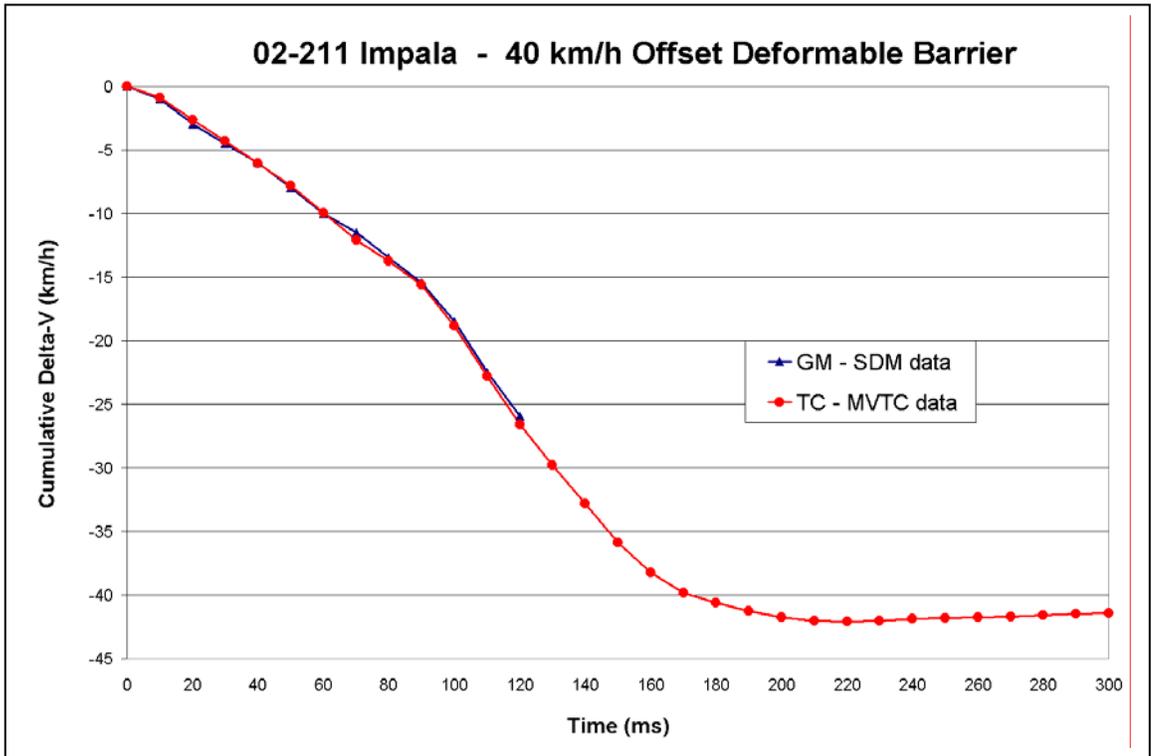


Figure 14. Cumulative Delta-V for Test No. 02-211

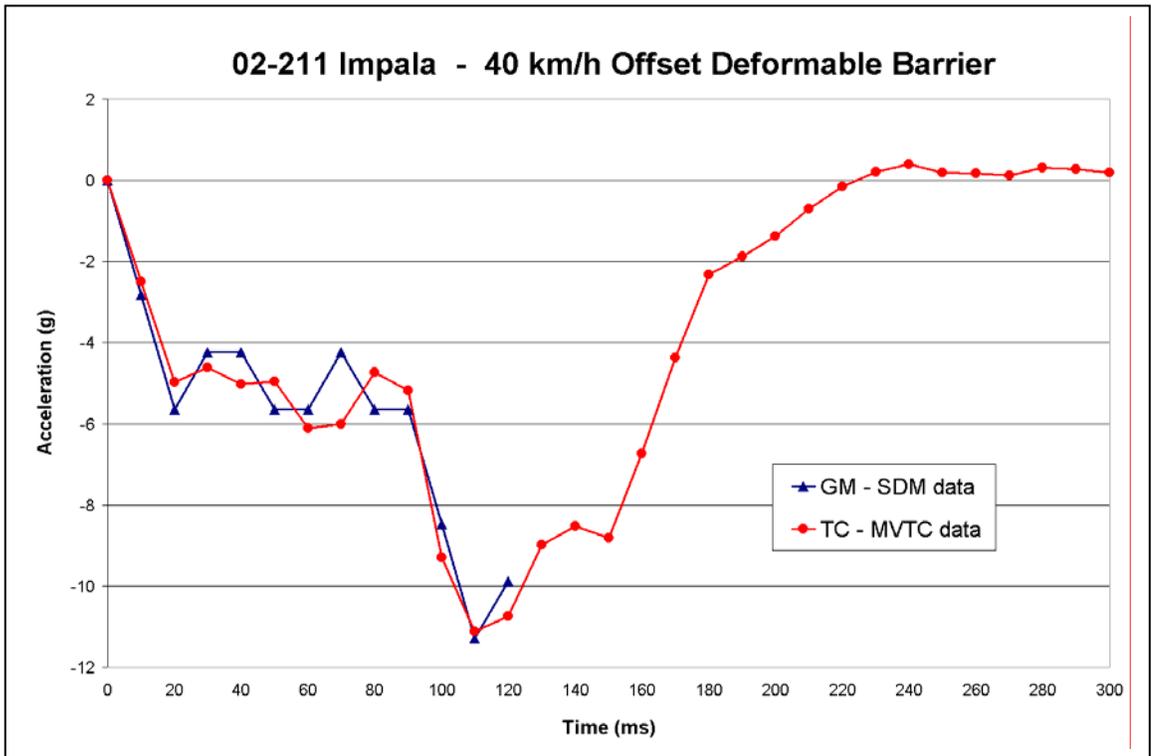


Figure 15. Average Acceleration for Test No. 02-211

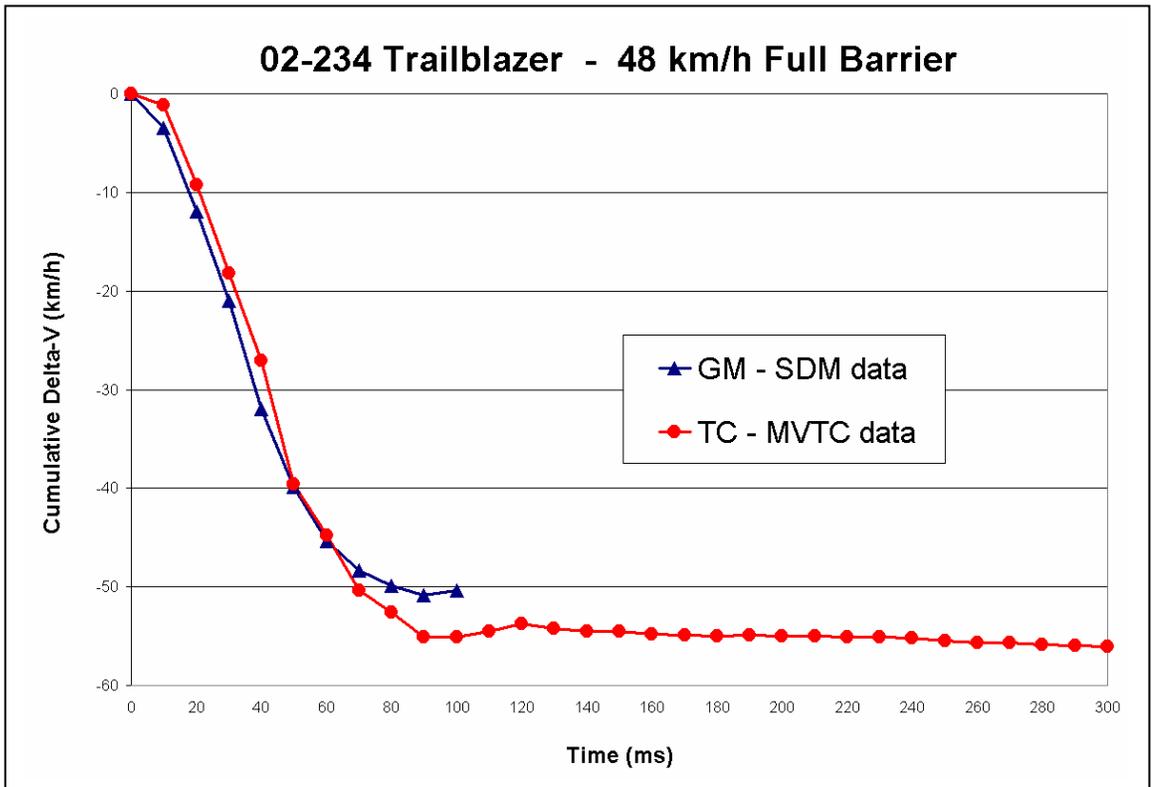


Figure 16. Cumulative Delta-V for Test No. 02-234

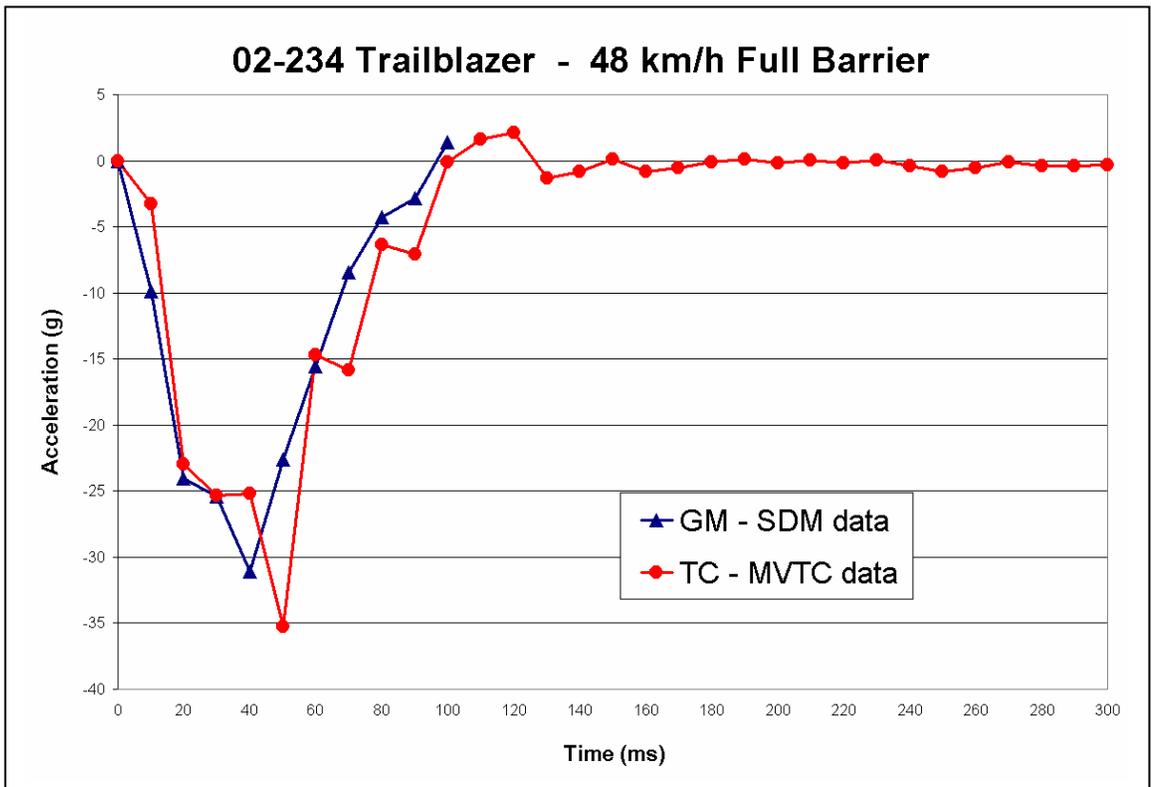


Figure 17 Average Acceleration for Test No. 02-234

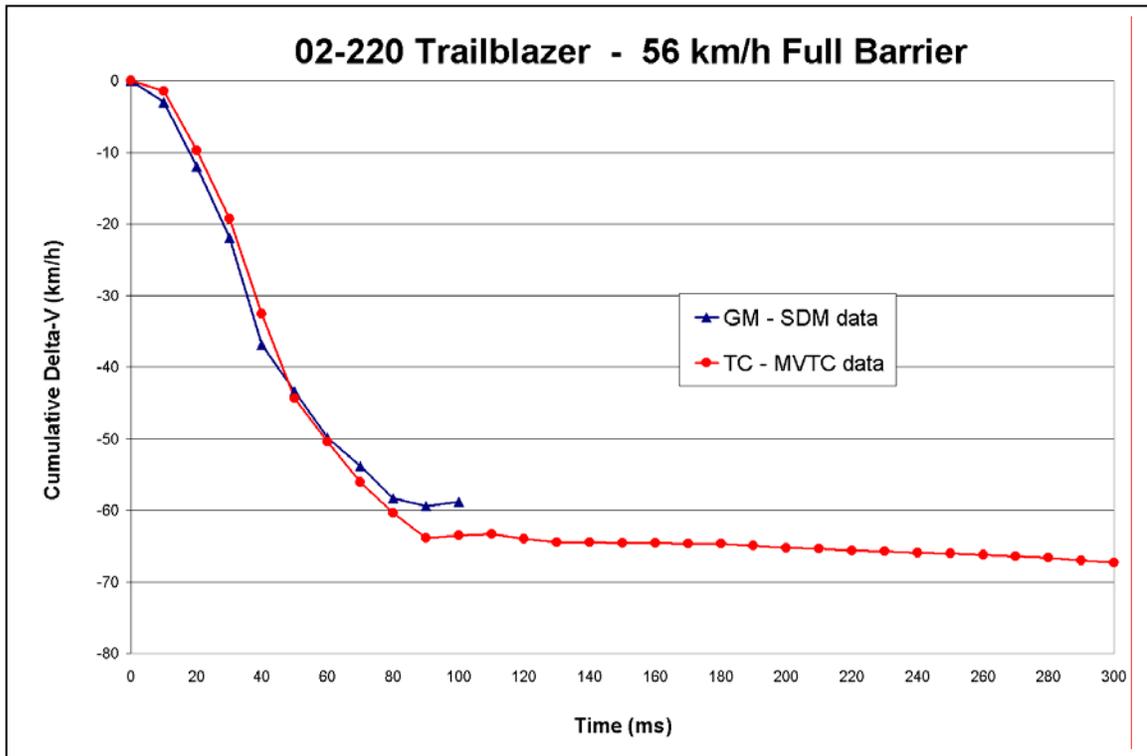


Figure 18. Cumulative Delta-V for Test No. 02-220

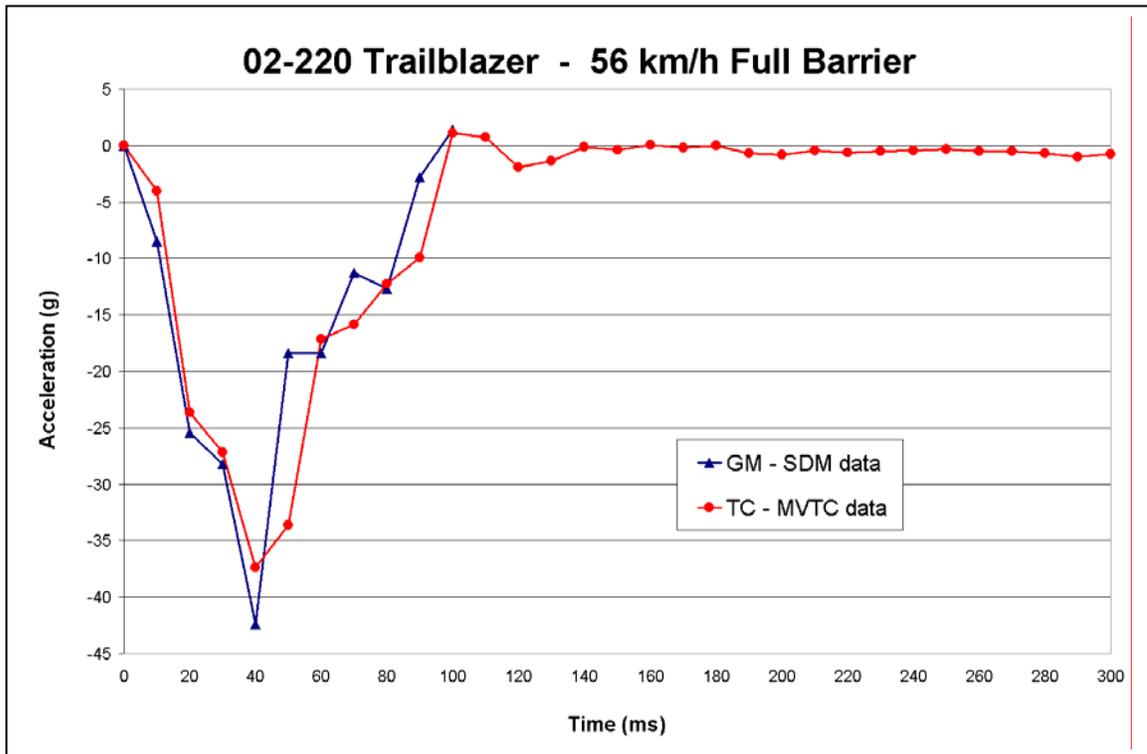


Figure 19. Average Acceleration for Test No. 02-220

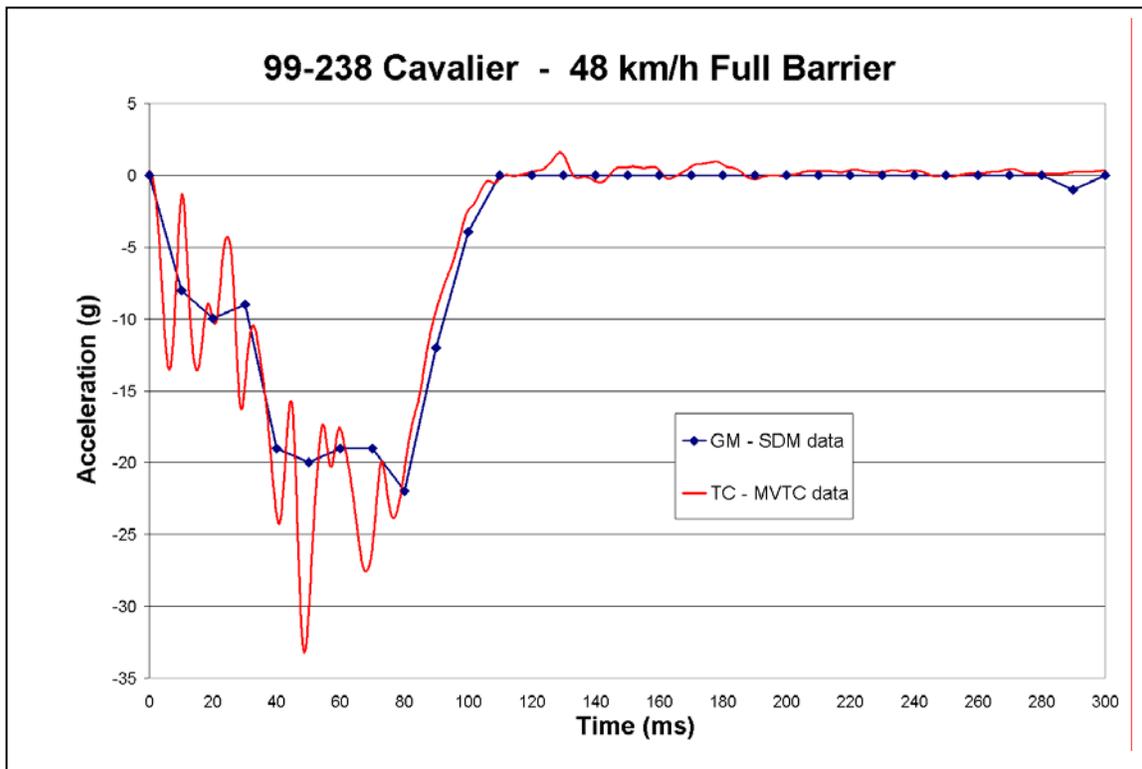


Figure 20. Acceleration recorded by the laboratory instrumentation and average values computed from the EDR