

The Accuracy and Sensitivity of 2005 to 2008 Toyota Corolla Event Data Recorders in Low-Speed Collisions

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ABSTRACT

Collision related data stored in the airbag control modules (ACM's) of Toyota vehicles can provide useful information to collision investigators, including both front and rear collision severity. Previous studies of ACM's from other manufacturers found that the devices underestimated the actual speed change in low speed frontal collisions. To quantify the accuracy and sensitivity of select 2005 to 2008 Toyota ACM's, in-vehicle crash tests and linear sled tests were performed in both front and rear impact orientations. A 2005 Toyota Corolla with five extra ACM's mounted in the right front seat position underwent a series of vehicle-to-barrier collisions with speed changes of up to 10 km/h. Next, the same six Toyota ACMs underwent a range of crash pulses using a linear sled. In all in-vehicle tests, the speed change reported by the ACM underestimated the actual speed change for frontal collisions, and overestimated the actual speed change for rear-end collisions. The speed change underestimates ranged from 1.3 to 2.6 km/h and the speed change overestimates ranged from 0.6 to 2.2 km/h. The magnitude of the error varied with collision duration and peak acceleration. Threshold accelerations required to initiate the recording of an event were found to be between 2.0 and 2.1g for all of the ACM's tested. A model using the threshold accelerations and a bias was generated to explain the speed change error. This study provides an understanding into the accuracy of the Toyota ACM reported speed change at low speeds and the collision parameters which can affect it.

CITATION: Wilkinson, C., Lawrence, J., Nelson, T. and Bowler, J., "The Accuracy and Sensitivity of 2005 to 2008 Toyota Corolla Event Data Recorders in Low-Speed Collisions," *SAE Int. J. Trans. Safety* 1(2):2013, doi:10.4271/2013-01-1268.

INTRODUCTION

The airbag systems of most modern cars record crash related information that can be used to analyze a collision. The Bosch Crash Data Retrieval system (CDR) allows investigators to download information from select 2002 and newer Toyota airbag control modules (ACM).

Previous studies of General Motors ACMs found that the ACM reported speed change always underestimated the actual vehicle speed change in low speed frontal collisions (Correia et al., 2000; Lawrence et al., 2002, Wilkinson, 2005). The portion of the acceleration pulses below the ACMs threshold acceleration was not included in the integration performed to calculate the speed change. This resulted in a systematic underestimation of the actual vehicle speed change (Lawrence, 2002, Wilkinson, 2004, Lawrence, 2005, Wilkinson, 2005). To date, an evaluation of 2005 to 2008 model year Toyota ACM reported speed change accuracy in low-speed collisions has not been performed.

The primary objective of this study was to evaluate the accuracy of the crash data reported by 2005 to 2008 Toyota ACM's in low speed frontal and rear-end collisions. In order

to apply the data from any recording device, the uncertainty of the reported data has to be quantified and its limitations understood. While ACMs are primarily designed to respond to higher severity collisions, speed change data from a wide range of collision severities is of interest to forensic investigators.

A secondary objective was to determine the sensitivity of the ACMs to specific collision pulse parameters such as duration, peak acceleration and speed change. The overwrite criteria for new trigger events on the ACM was also evaluated. Finally, a variation of a previous threshold acceleration model (Lawrence et al, 2002; Wilkinson, 2005) was applied to the results of the Toyota ACM testing. The results of these investigations provide further understanding into the function of the Toyota ACM and the reliability of the reported crash data for collision investigations.

METHODS

Vehicle crash tests were performed using a 2005 Toyota Corolla (VIN: 2T1BR32E95C914172). Testing was performed using the stock ACM installed in the 2005 Toyota

as well as a 2005 model year replacement ACM purchased from a Toyota dealer and four stock ACMs purchased from 2005 and 2006 Toyota Corollas found in wrecking yards (Table 1). Linear motion sled tests were performed using the same 6 ACMs.

Table 1. Identifying data for the vehicle and stock ACMs used in this study

Box	Vehicle	VIN	ACM Part No.
1	Replacement ACM	N/A	89170-02411
2	2005 Corolla	2T1BR32E25C871584	89170-02410
3	2006 Corolla	2T1BR32EX6C666189	89170-02410
4	2006 Corolla	1NXBR32E46Z745761	89170-02410
5	2005 Corolla	1NXBR32E05Z381546	89170-02410
6	2005 Corolla (Test Vehicle)	2T1BR32E95C914172	89170-02410

Instrumentation

Vehicle speed was measured using a 5th wheel (MacInnis Engineering Associates, Richmond, BC) mounted to the rear door for all vehicle tests. The 5th wheel was calibrated before each test series. For the vehicle tests, an accelerometer (an Endevco 7265A; $\pm 100g$, San Juan Capistrano, CA) was fastened to a custom made bracket and bolted to the vehicle using the ACM's mounting bolts. The five supplemental ACMs were mounted to a board which was secured to the vehicle floor at the right front seat position. An accelerometer (an Endevco 7265A; $\pm 100g$, San Juan Capistrano, CA) was mounted to the board between the ACMs (Figure 1). The sensitive axis of the accelerometers was parallel to the longitudinal axis of the vehicle. A rearward acceleration, in the direction recorded by the ACM, was defined as negative. For the sled tests, the same board mounted accelerometer was mounted to the sled platform with its sensitive axis parallel to the direction of sled motion.

Load Cells were mounted on the rigid barrier to record collision force (2x Sensotek model 41 20,000 lb full scale mounted on barrier). Trigger strips (Nortel Manufacturing, "Controlflex Ribbon Switches" #121BP 6ft long) were mounted to the impacted bumper of the test Corolla to allow synchronization of the data sources.

The 5th Wheel data were acquired at 256 Hz. Accelerometer data were acquired at 2560 Hz using a 12-bit, simultaneous-sample-and-hold Win30 DAQ card (United

Electronics Inc., Watertown, MA). Each data channel conformed to SAE J211, Channel Class 60, with the vehicle accelerometer channel filtered at Channel Class 180 (SAE, 1989).



Figure 1. ACM test setup for the in vehicle tests

Collision data from the ACMs were downloaded through the Diagnostic Link Connector (DLC) using a CDR system (Version 8.0, Bosch). An increased trigger count in the download report indicated that a new event had been generated. If this was the case, the maximum longitudinal speed change (called ΔV_{ACM} herein) from the longitudinal crash pulse data from page 7 of the report was recorded. The data documents the cumulative speed change during the crash pulse at fifteen 10 millisecond intervals. Speed values were taken from the download in units of mph and converted to km/h.

Test Procedure

Vehicle tests

The test Corolla was crashed in both front and rear-into-barrier configurations. The Corolla was towed into a fixed barrier using a winch. The vehicle was perpendicular to the barrier at impact. There were 36 frontal collisions and 35 rear-end collisions performed. In all tests, the winch was disengaged about 1 m before impact and the vehicle was free rolling before and after impact. All tests were conducted on a level, painted concrete surface.

The test vehicle's engine was idling and with its transmission in neutral for each collision. Following each frontal impact, data from the ACMs was downloaded and examined to ensure that it had overwritten a previous event. Several of the crash tests performed were just above or below the threshold for the ACM to start recording so not every crash test generated new data. The ACM trigger number for each test was documented.

There were three test series performed in each direction. In the first series, the severity of the collision was increased with each test starting at about 3 km/h and increasing to about 9.5 km/h. In the second series, the severity of the collision

was decreased with each test over the same range. The final series had a random test order with values in the same range.

Sled tests

The ACMs were tested on a linear sled powered by feedback-controlled linear induction motors. Vehicle wiring for power and data download was reproduced for the ACMs on the sled. A voltage of 13.75 V, the same level measured during the vehicle tests, was supplied to the ACMs. The test vehicle's stock ACM, along with the 5 other ACMs and accelerometer, was mounted to the board used in the in-vehicle tests and the board was mounted on the sled.

To explore the sensitivity of the ACMs to specific pulse parameters and to determine a threshold acceleration for each ACM, sled tests with haversine waves of varying duration (69 to 200 ms), peak acceleration (1.61 to 8.25g) and speed change (2.5 to 15.0 km/h) were used. Since two of these three properties defined a unique haversine wave, no one property could be varied independently of the others.

Haversine pulse sled tests were also performed to assess the repeatability of the ACMs. These tests comprised 8 replications of 3 differing severities (4.8, 8.4, 15.0 km/h) which were all rear-impacts. Because we had multiple (6) ACMs on the sled, this test structure allowed a glimpse of the repeatability of a single ACM over the 8 replicated tests, at the 3 differing impact severities, and in this paper is referred to as the intra-ACM error. Also, for each test performed (at each impact severity) we could observe the variability across the 6 ACMs, herein referred to as the inter-ACM error.

In order to verify that the ACMs were functioning in the same manner on the sled as in the vehicle, the linear sled was programmed to reproduce the acceleration profiles measured in six of the vehicle-to-barrier tests. The chosen tests represented three frontal and three rear impacts with three nominal speed changes of 5, 8, and 10 km/h (Figure 2).

Data reduction

Vehicle speeds were calculated from the position data generated by the 5th wheel using finite differences (16 ms window). Vehicle speed change was then determined from plots of vehicle speed versus time (Siegmund et al., 1996). The speed change calculated from the 5th wheel was confirmed by integrating the accelerometer data from the same collision (King et al., 1998). The speed values from the 5th wheel are accurate within 0.2% (Lawrence et al., 2003). For the vehicle to barrier tests, the 5th wheel speed change measurements were used as the reference against which the ACM-reported speed change data were compared.

The speed change experienced by the ACMs during each sled test was calculated by integrating the measured acceleration of the sled platform.

The speed changes calculated from 5th wheel and accelerometer data were used as the reference speed change (called $\Delta V_{\text{reference}}$ herein) against which the ACM speed change (ΔV_{ACM}) was compared. The difference (ΔV_{error}) between the reference speed change ($\Delta V_{\text{reference}}$) and the ACM-reported speed change (ΔV_{ACM}) was calculated.

The ACM reported speed change was taken as the maximum speed change value (in the same orientation as the crash pulse) from the speed change versus time table in the downloaded CDR report.

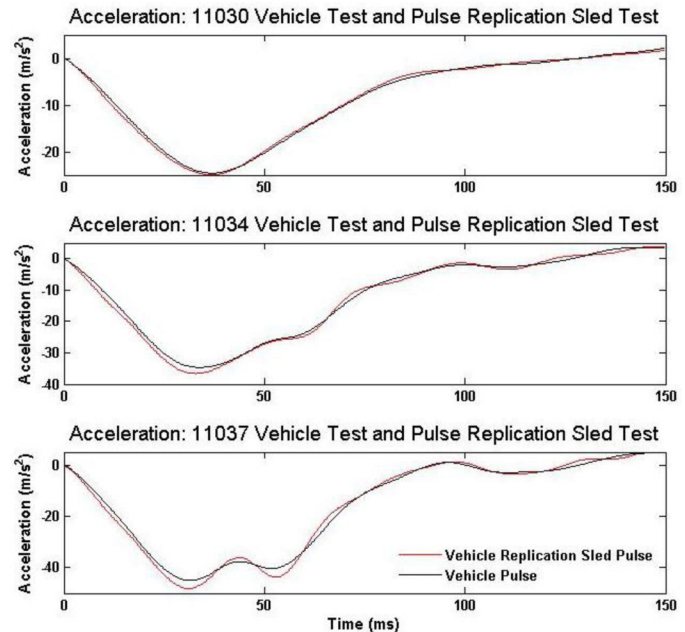


Figure 2. Frontal impact acceleration pulses alongside the programmed vehicle-replication sled pulses.

A model for ACM behaviour was considered to explore possible reasons for differences between the ΔV_{ACM} and $\Delta V_{\text{reference}}$. Based on features of the data collected in the vehicle and sled tests, it was hypothesized that the ACMs started measuring ΔV only after a threshold acceleration value was reached and included a constant acceleration bias (Figure 3). For each test, the speed change according to the hypothesized model (ΔV_{model}) was compared to ΔV_{ACM} to see if the model reproduced the ACM values.

The ACM downloads were reviewed to determine the apparent decision making process used by the Toyota ACMs to determine which existing trigger files get overwritten after each new event.