

Chrysler Airbag Control Module (ACM) Data Reliability

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ABSTRACT

Collision data stored in the Airbag Control Module (ACM) of some Chrysler vehicles has become available to accident investigators through the Bosch Crash Data Retrieval (CDR) system, beginning with the 2005 model year. An event data recorder (EDR) that can record pre-deployment vehicle speed and other parameters such as brake pedal application and throttle application is incorporated into the ACM, or Occupant Restraint Controller (ORC) using Chrysler terminology. The accuracy of this data under different driving conditions has not been extensively tested and reported. The primary purpose of this paper is to evaluate the accuracy of the data recorded in the Chrysler ACM under test conditions. Establishing the reliability of this information is important, if it is to be relied upon by the investigator. These results can be used to quantify the accuracy of ACM reported pre-crash data for use in engineering analysis of automobile crashes.

The testing was performed on a 2008 Dodge Grand Caravan, while forcing deployment events in the ACM under known conditions. Various parameters were monitored during the testing for later comparison to the ACM data. The testing involved monitoring the outputs of some vehicle sensors as well as external sensors.

INTRODUCTION

The information that can be recorded on a 2008 Dodge Grand Caravan ACM includes five seconds of pre-crash information which contains vehicle speed, engine rpm, brake status, accelerator pedal status, and many other parameters. The data is provided in 0.2 s (5 Hz) increments from -5.0 s to -0.2 s. Time 0 s represents the waking up of the algorithm in the ACM module as it begins to sense an event is underway.

The key controls on any motor vehicle are throttle, braking and steering, therefore these variables were recorded as part of the testing methodology. Some other settings were noted as well. The variable data was recorded using a Racelogic V-BOX III data collection unit (S/N 001375), set to its highest data-recording frequency of 100 Hz. The V-BOX device has a reported accuracy of 0.1 km/h averaged over four samples.

Methodology

The test vehicle was equipped with frontal airbags, side curtain airbags and front seatbelt pretensioners. These components are designed to deploy if the system determines there is an impact of sufficient severity. The system can also deploy side curtain airbags if the vehicle experiences a rollover, where their deployment might help reduce the chance of occupant injury or occupant ejection. The capability of the ACM module to sense and record data for a rollover event was exploited in this testing.

The location of the ACM module in the test vehicle is below the center stack containing the radio and HVAC controls, secured by three bolts in a flat orientation near the floor. For the testing, it was unbolted and pulled out to the area between the front seats, allowing it to be tipped sideways and safely replicate an actual rollover. Care had to be taken to disable all the pyrotechnic devices (airbags and seatbelt pretensioners) to prevent unwanted deployments. A live pyrotechnic device has an electrical resistance of approximately 2.5 ohms, therefore a 2.5 ohm resistor was substituted for each one of them. Otherwise, simply disconnecting the pyrotechnics was expected to cause the airbag warning light to turn on and a fault to be registered during the system self-check when the ignition was turned on. Before every test run, it was verified that the airbag warning light was off.

Figure 1 shows the test harness that was created. The main components include a connector taken from a spare ACM

module, a portion of a vehicle wiring harness and the dummy resistors which are located inside the plastic box. This harness was inserted between the vehicle harness and the ACM module. For safety purposes, each of the pyrotechnic circuits were shorted out on the vehicle side of the harness, thus replicating the effect of shorting bars normally found on each pyrotechnic device.



Figure 1. Test harness

Figure 2 shows an ACM module connected to the test harness, which is connected to the vehicle harness. The trim covering the module has been removed. To secure the module for the duration of the testing, a simple test fixture was made from two wood panels. The bottom panel rested flat on the floor along the center of the vehicle. The ACM was screwed to the hinged top panel so that it could easily be pivoted by hand along the longitudinal axis of the vehicle. In Figure 2, the ACM is in the flat position and secured with a hand clamp. This allowed the vehicle to be driven without risk of an unwanted deployment as a result of the ACM jostling around. Figure 3 shows the top panel rotated up to trigger a deployment. By flipping it up approximately 90 degrees, it simulated a $\frac{1}{4}$ turn roll toward the driver's side, causing deployment events to be created.

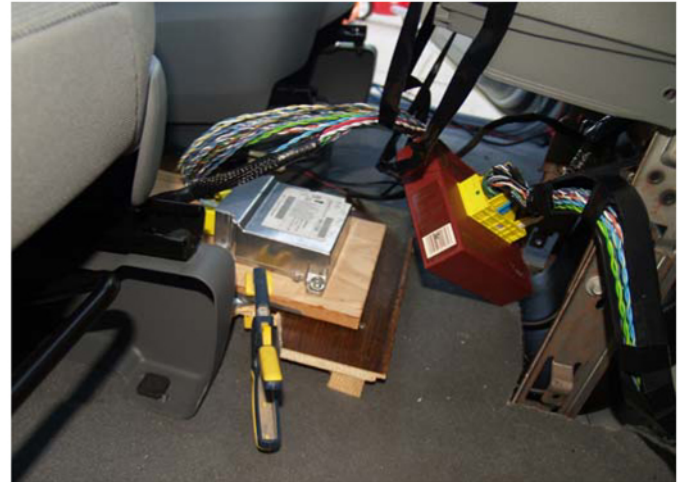


Figure 2. Test fixture and ACM module laying flat, secured with a clamp.



Figure 3. ACM module and top panel rotated approximately 90 degrees, causing a deployment event.

To capture the moment when the ACM module was rotated, a contact switch was used between the top and bottom panel. It is visible in Figure 3, attached to the bottom panel with duct tape. The V-BOX recorded this on/off status change at the instant the top panel began to be rotated. A small period of time elapsed between the moment the switch recorded the trigger and when the module had rotated enough for an event to be created. It is worth noting that earlier attempts to forcibly strike the ACM module in a rearward direction in order to simulate a frontal crash were unsuccessful. It is unknown if a higher striking force could have caused the module to deploy, though a simultaneous strike to one or both of the front crush sensors likely would have caused a deployment.

The V-BOX GPS antenna was mounted on the roof of the vehicle centered laterally on the car and positioned just rearward of the windshield. Testing was done on local roads and parking lots free of overhead structures so as not to interrupt the GPS signal. A total of six test runs were performed, providing 150 data points, summarized in [Figure 5](#).

The steering wheel angle was recorded by the use of a 1.27 m [50 inch] string potentiometer, calibrated in-vehicle so that its variable output could be known relative to the steering wheel angle. The string potentiometer was bolted behind the driver knee bolster and the string attached to the shaft of the steering column. The string potentiometer was supplied with 5 V DC and its variable output was monitored on one channel of the V-BOX. The linear relationship of the steering wheel rotation and voltage output (scaled up for clarity) was confirmed with a straight trend line, as shown in [Figure 4](#). Thus, for any voltage output from the string potentiometer, the corresponding steering wheel angle could be known and in turn compared to the 'Steering Angle' data in the ACM data.

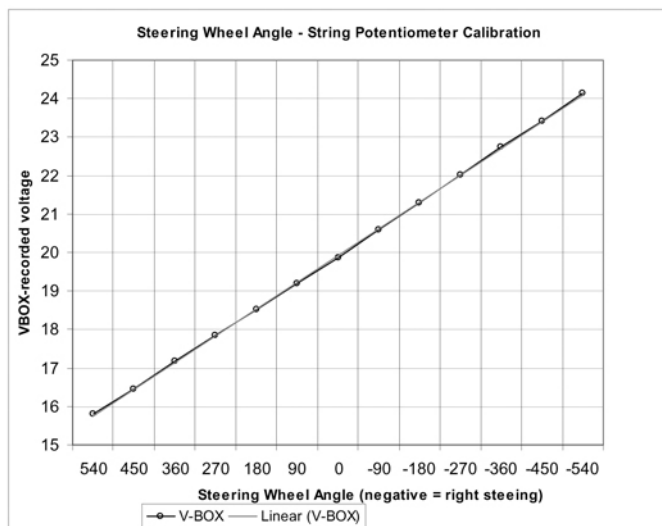


Figure 4. Calibration of the steering wheel angle string potentiometer

The variable voltage output from the vehicle accelerator pedal circuit was monitored by another channel on the V-BOX, using clamp-on leads on the accelerator pedal wiring. To calibrate the accelerator pedal, the voltages were noted for both no pedal application (0 %) and full throttle (100 %). The voltage range was approximately 2 V.

The variable voltage output from the vehicle brake pedal circuit was also monitored by use of clamp-on leads. In this case, the circuit is essentially open or closed, since the voltage output was approximately 9 V when the brake pedal was not pressed and -4 V when it was pressed.

Test Runs

The test runs were designed to include different combinations of steering, braking and throttle application, as well as some variations in some other settings such as seat position and front seat passenger status. Some of the tests involved creating an event while under steady speed conditions, while others had heavy braking and others involved an increase in speed. Steering input was also varied. While the imaged data does not include seatbelt buckle status, seat-track position, or front passenger weight class, these were noted so that if future versions of the CDR software allow this data to be imaged, it would then be possible to re-image these modules and compare the information.

[Figure 5](#) summarizes the test runs. A total of three events were recorded on each module. After the third event was recorded, it was noted that the airbag warning light on the dashboard came on and remained on. Further attempts to create additional events were unsuccessful. The module was later read by a Chrysler service scan tool at a local dealership and showed a 'Crash Record Full' fault code. As such, the maximum number of events on these modules is three, at least in this vehicle application. The names of the recovered events are shown in [Figure 5](#).

As a byproduct of this testing, the operation of the EARS (Enhanced Accident Response) system was observed. If a deployment occurs, the system cuts fuel to the engine and unlocks the doors. It also turns on both the exterior 4-way flashers and interior lights. This was noticed immediately after the ACM module was rotated.

Once an event was created, its name did not change. Consider Run 2, for example. The '1st Prior Event' was created in Run 2 and is therefore newer than the 'Most Recent Event' from Run 1. However, the event names seem to imply the opposite, and the Data Limitations text did not explain this. If an investigator came across this anomaly in real world crash data it could be somewhat difficult to detect, especially as there is no ignition cycle counter or similar variable in the report to help determine the chronological order of stored events. This discovery is believed to have been subsequently reported to Bosch. In any case, when CDR Version 3.3 software became available, a re-imaging of the test modules was done and it confirmed that the anomaly was corrected. The authors did not test other vehicles, and are unaware if the anomaly could have occurred on other vehicles either within the same model line or on other models.

After each test run, the vehicle was stopped and the ACM data was imaged and the V-BOX data was saved.

<[figure 5](#) here>

Throughout this paper, the terms ACM data, ORC data, CDR data or CDR report all refer to the data imaged from the ACM module using the Bosch CDR Version 3.2 equipment. Vehicle speed, engine rpm, and many other parameters in the ACM data are found in the ‘Pre-crash data’ section in the imaged report which covers 5.0 s to 0.2 s before algorithm wakeup.

Results

Prior to each test run, the Electronic Stability Program (ESP) status had been purposefully set to On or Off, via a push-button facing the driver. The ESP system was set to Off for Runs 2 and 4, and On for the other four runs. The ACM data shows this data in the pre-crash section. The ACM data correctly reported the status in all six tests.

Before each run, the cruise control system was set as shown in the summary. Three possible combinations exist: Off, On but not Set, and On and Set to a speed. All three combinations were incorporated. The pre-crash data has two columns pertaining to cruise control. ‘Cruise Control System Status’ indicates if the system was ‘On’ or ‘Off’. This status was correctly reported in all six test runs.

‘Cruise Control System Active’ indicates ‘Yes’ if the system is controlling to a set speed. It correctly showed the status in all six test runs. However, the Data Limitations text of the CDR report explains that Brake Switch #2 Status pertains to the cruise control system while Brake Switch #1 Status is for the service brake. However in Run 4, the cruise system becomes inactive (displaying ‘No’) simultaneous with the change in Brake Switch #1, not Brake Switch #2 as one might expect. This is summarized in [Figure 6](#). Whether due to a reporting delay, or logic, or some other reason, a later release of the CDR software is expected to correct this. In any case a 0.2 s difference is not likely to be significant to an accident investigator.

	Time (s)	Brake Switch #1 Status	Brake Switch #2 Status	Cruise Control System Status	Cruise Control System Active
RUN 4	-5.0 to -1.6	Open	Open	On	Yes
	-1.4	Closed			Closed
	-1.2 to -0.2		Closed		
RUN 5	-5.0 to -3.4	Open	Open	On	Yes
	-3.2 to -0.2	Closed	Closed		No

Figure 6. Brake and Cruise Control Switch Pre-crash data

Synchronization of ACM data to the V-BOX data was done using a combination of the brake, accelerator and steering information. The 100 Hz V-BOX data was the baseline to

which the 5 Hz ACM data was added. The 0.2 s period of the ACM data was the limiting factor for the synchronization, since it provided only one data point for every 20 data points from the VBOX. The contact switch status change from 1 V to 0 V indicated the moment when the pivoting of the ACM had begun. The delay from algorithm wakeup relative to the contact switch ‘trigger’ could not be measured during the test, but after synchronization, it was possible to determine that it ranged from approximately 0.25 s to 1.98 s. These delays are not necessarily similar to what a vehicle would actually experience in a real rollover accident; they are simply the result of rotating the module by hand in an attempt to quickly trigger an event, but without intending to replicate the rate or speed of an actual rollover.

The speeds in the Pre-crash data tables are presented in both English units (mph) and metric units (km/h) but only in whole numbers. For this reason, some amount of error exists if converting between units. To illustrate this, consider data from Run 1. At time -3.2 s the vehicle speed shown is ‘44 mph [70 km/h]’. By considering that 1 km/h = 0.6214 mph, 44 mph actually converts to 70.81 km/h, and similarly 70 km/h is 43.50 mph. In each test run, this calculation was performed. The resulting ‘error’ ranged from virtually zero up to a maximum of 0.81 km/h [0.50 mph]. However, by choosing and using one set of units only, this difference is unlikely to matter to an accident investigator.

The Run 2 data illustrates the findings that the V-BOX speed was typically higher than the pre-crash vehicle speed. For example, in Run 2 the V-BOX recorded a relatively steady speed between 31.94 mph and 32.32 mph, however the ACM data reported a steady 31 mph. In Run 5, in the first 1.5 s the speed was relatively steady at 61.88 mph to 62.2 mph, but the ACM data reported a steady 61 mph.

The Data Limitations text indicates that the vehicle speed resolution for 2008-2009 Dodge Caravan, 2008-2009 Chrysler Town & Country, and 2009 Dodge Journey are 2 mph, and 1 mph for all others. On our test vehicle the actual resolution was better than the expected 2 mph; it was shown as both 1 mph [1.6 km/h], and, 2 km/h. The authors are unaware if this better resolution applies to the other specified vehicle models also, and a subsequent version of the CDR software is likely to correct this as necessary.

After reviewing the results, we began to consider what further useful information could be obtained from the Pre-crash data. In particular, the wheel speed data was of interest because it had a resolution of only 1 rpm. The Data Limitations text in the ACM report explains that vehicle speed is reported as an average of the drive wheels. In other words, the vehicle speed is calculated from the wheel speed sensors on the front axle of the front-wheel-drive test vehicle. To calculate vehicle speed, the tire circumference must be known. Therefore, useable data was found on the manufacturer’s website for the

Bridgestone Turanza P225/65R17 tires on the vehicle. The published revolutions per mile is 731 or 454 revolutions per km, at the rated load and inflation pressure for the tire, and tread depth is listed as 10/32". To calculate vehicle speed, the following equation was used:

Vehicle speed [mph] = (wheel speed [revolutions / minute] / 731 [tire revolutions / mile]) * 60 [minutes / hour]

The drive tires on the test vehicle had like-new tread depth of 10/32" so it was not necessary to consider what effect, if any, tire wear would have on this calculation. Also, the two occupants and test equipment in the vehicle together totaled approximately 225 kg [500 lbs], which is less than the cargo capacity of this seven passenger vehicle. Table 1 summarizes the speed comparison for Run 1, and it is shown graphically in Figure 7.

<table 1 here>

The V-BOX speed represents the baseline actual speed of the vehicle. ‘Pre-crash data’ is the vehicle speed obtained from the imaged ACM data. The ‘Calculated from Wheel Speed’ data was determined using the above-mentioned formula. It became clear that this calculated value was typically closer to the actual value than the ACM vehicle speed. A summary of all runs is included in the Appendix. The bolded numbers highlight the lesser absolute difference of each speed value to the baseline. The last two columns in Table 1 show incremental accelerations using both sources. Not surprisingly, the ACM speed has frequent zero accelerations owing to the repeated speed values, such as at -4.8 s and -4.6 s where the ACM speed is constant at 48 mph yet the average wheel speed has slowed by 6 rpm. The table also summarizes the maximum, minimum and average values of the difference to the baseline for each of the two speeds.

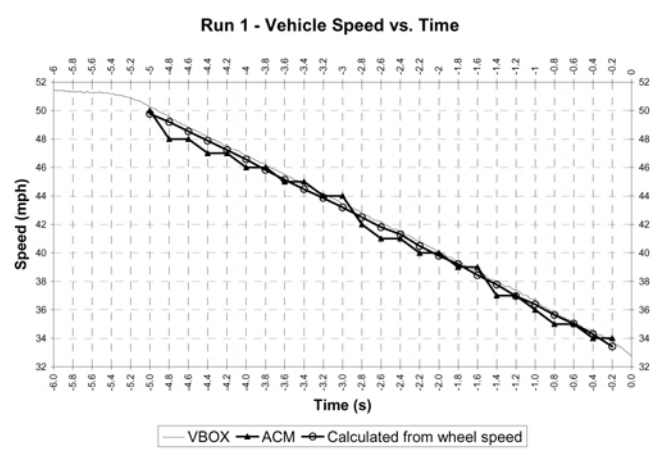


Figure 7. Vehicle Speed vs. Time - Run 1

<table 2A here>

Table 2A shows the results of this comparison for Run 2. The ACM speed is steady at 31 mph, yet the calculated speed is much closer to the actual (baseline V-BOX) speed. It is very apparent when viewed graphically in Figure 8. The calculated vehicle speed follows the small fluctuations in the V-BOX speed fairly well.

The CDR report has speed data in metric as well. Table 2B shows the results of Run 2 using the metric value (51 km/h instead of 30 mph). As before, the calculated vehicle speeds are closer to the V-BOX speed and the resulting average, maximum and minimum values are virtually identical. The ACM speed data is on average approximately 1.6 km/h [1 mph] less than the VBOX speed. Some of this difference might be due to truncation of the ACM data, though there may be other unknown factors occurring. It is worth noting that in earlier work on 2008 Jeep Commander ACM modules (Ruth, Reust, 2008), those authors suggested there might be more accurate information in the powertrain control module than is ultimately reported in the ACM data, specifically mentioning truncation to the nearest whole number.

<table 2B here>

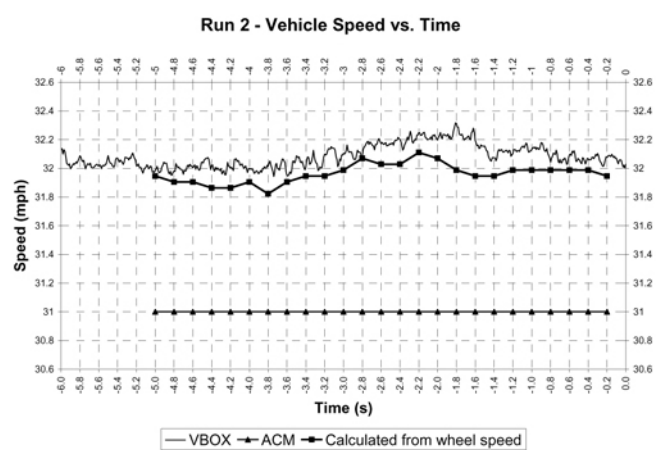


Figure 8. Run 2 - Vehicle Speed Comparison

<table 3 here>

Run 3 results are shown in Table 3. Error is typically lower for the calculated speed than the reported speed. The graph of this data is shown in Figure 9. In this run, the event was created while the vehicle was accelerating, thus there is a moderate increase in speed over the five second period. As in the other runs shown, the calculated speed is overall more representative of the actual speed.

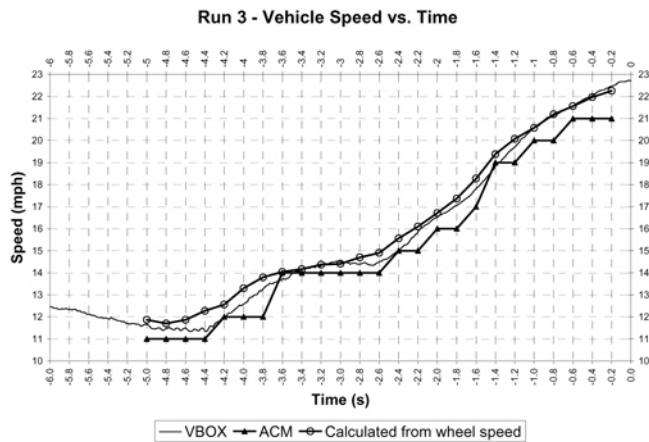


Figure 9. Vehicle Speed Comparison - Run 3

<table 4 here>

Run 6 data is shown in Table 4. In this run, the vehicle speed was steady until approximately -3.6 s, where the brakes were forcibly applied momentarily then released, and reapplied until the vehicle was stopped. The error from the calculated speed is much lower during the initial steady speed portion than the reported speed. However, during heavy braking the calculated speed tends to be under-reported by a larger amount than the ACM speed. This is not surprising, considering that the braking of the wheel can cause it to slip relative to the roadway, in which case the rotation of the wheel slows and therefore any calculation directly proportional to wheel speed is affected. Even anti-lock brakes do not eliminate wheel slip, however such systems do control slip to a finite amount in order to help provide the maximum level of braking and vehicle control possible, at least in certain conditions. The test vehicle was equipped with functioning anti-lock brakes.

An interesting observation was made in the Run 6 data. By time -1.4 s, the brakes had been forcibly applied for approximately 0.5 s and the drive wheel speeds had dropped significantly; enough that the calculated acceleration is -2.08 g. Such acceleration is much higher than what this vehicle can achieve from braking; it is clearly a sign of wheel slip. In comparison, the reported speed yielded an acceleration of only approximately -1.14 g at that instant, which is much closer to the -1.05 g value determined from the V-BOX data. The processing or compensation by the vehicle electronics appears to be correcting for wheel slip fairly well.

Very often, an accident investigator desires to know what the speed of a vehicle was before the accident sequence began, and it could be quite useful to have five seconds of pre-crash information as additional information to the other physical evidence that may exist. Very often, five seconds would be long enough to include pre-impact evasive actions and even

the steady conditions before any driver Perception and Reaction (P&R) had even begun.

As shown here, the method to determine vehicle speed from wheel speed can improve the accuracy of the vehicle speed under certain conditions. Based on these findings, the recommendation can be made to the accident investigator to supplement the Pre-crash speed by calculating speed using wheel speed data in this way. It is important to note the tire size, make and model of drive tires on a vehicle, if this method is to be used, but such information is commonly recorded already when a damaged vehicle is inspected. If manufacturer data is not available for a particular tire (revolutions/mile), it might be determined experimentally. As a check of the published info, the test vehicle was driven slowly forward while on an asphalt surface for three revolutions of the drive tires. The distance covered was $21'8\frac{1}{4}"$, which equates to approximately 730.37 revolutions / mile. This is slightly less than the 731 revolutions / mile published value. Determining the tire size over more than three revolutions would increase confidence and accuracy, if measuring is required.

The accelerator pedal comparison generally showed good correlation between the V-BOX and the Pre-crash information. The accelerator pedal was not pressed in Runs 1, 2 and 5, and this is correctly shown in the ACM data. The V-BOX data showed some variation of less than approximately 0.25 %; negligible given the range of 100 % between released and fully applied. In the other runs, the accelerator pedal was used to varying degrees. Generally, the trend was comparable although the magnitude of the ACM data was generally less than the baseline V-BOX data. Figure 10 shows this in more detail, for Run 3.

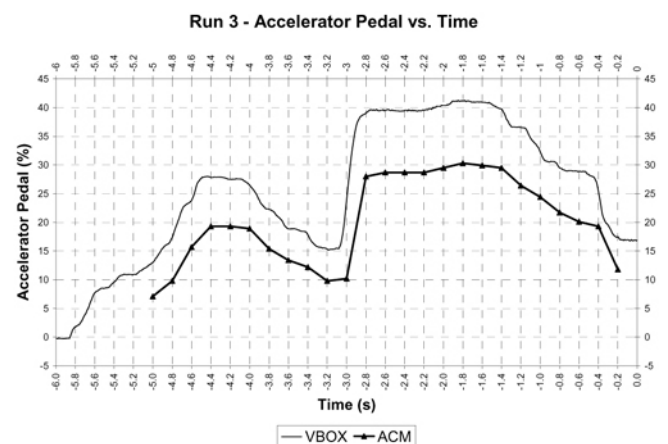


Figure 10. Accelerator Pedal Comparison - Run 3

The Run 3 data shows a consistent difference of approximately 7 %, with a peak of approximately 13.6 % occurring at -3.0 s. The ACM reports the accelerator pedal percentage to decimal precision, and the smallest difference

between any two consecutive readings was 0.4 % and was noted in Run 3.

Figure 11 shows the results from Run 4 and 6, where the peak difference was approximately 6 %, and 22 % respectively. In the latter case, the accelerator had been applied nearly to the maximum.

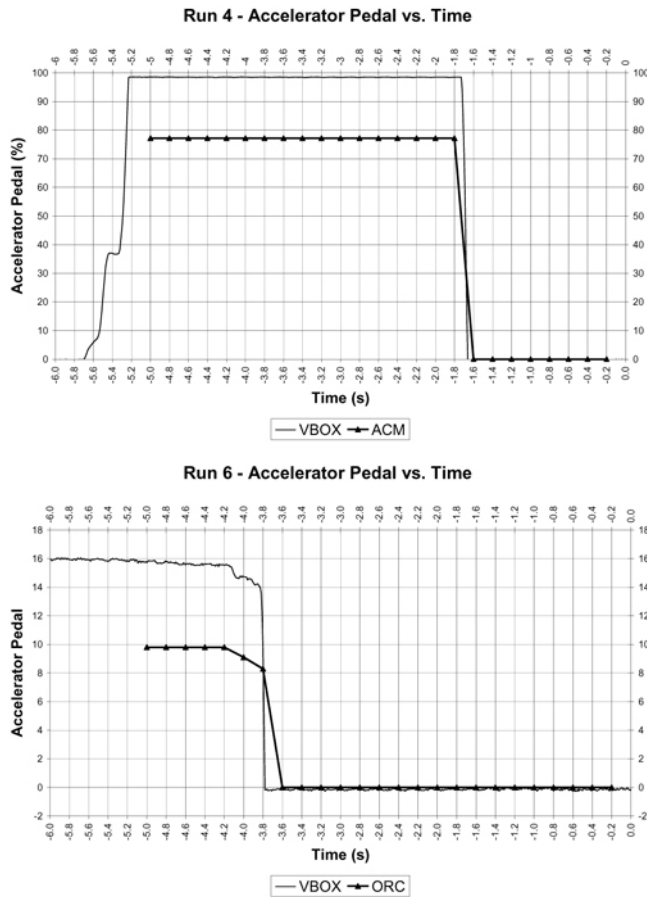


Figure 11. Accelerator Pedal Comparison - Runs 4 and 6

The reason for the magnitude difference is not clear. The pedal had been calibrated at 0 % and 100 %, and while the voltage output was interpreted in a linear fashion, this was not verified in incremental steps as was the steering wheel angle. In any future testing that might be done, that step would be included, and, a string potentiometer would be used on the pedal to provide independent data that could be compared to the ACM data. The differences noted may possibly be due to non-linearity in the output voltage, in processing in the vehicle electronics, or some other reason. It does provide a good indication of the instant the pedal was released.

The brake pedal comparison showed that the ACM data reliably indicated the brake status in all test six runs. In Runs 1 to 3, the brake pedal was not applied and this was properly reflected in the ACM data. In Runs 4 to 6, the data showed all

five status changes from released to applied or applied to released, occurring within one data point to the baseline V-BOX data; within the 0.2 s (5 Hz) reported resolution of the data. Some uncertainty is inherent due to this resolution, but such uncertainty is much less than if the resolution was 1 Hz as it is in many other vehicles. Figure 12 shows the brake data from Run 6.

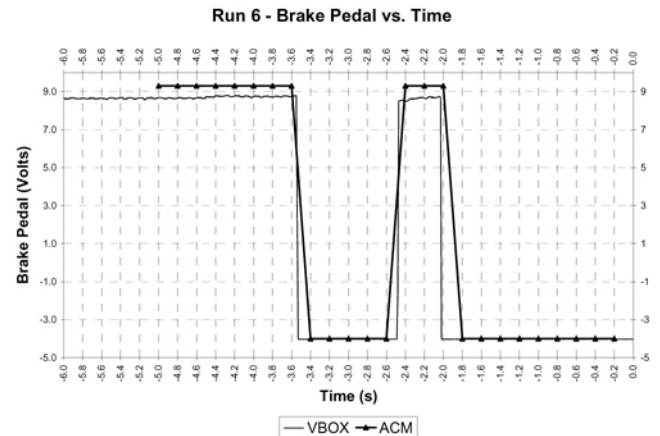


Figure 12. Brake Data Comparison - Run 6