ABSTRACT

An instrumented 2005 Ford Explorer was used to evaluate speed data provided from its Powertrain Control Module (PCM) at high slip angles. PCM speed was compared to speed and slip angle collected from a calibrated Datron S-400 velocity sensor. In addition to speed, slip angle and other standard handling test measurements the vehicle brake switch and throttle were recorded so PCM data could be synchronized. After each test run the vehicle ignition was turned off and the PCM was downloaded using commercially available Bosch hardware and software. The principal maneuver was the National Highway Traffic Safety Administration (NHTSA) sine-with-dwell test consisting of a 0.7 HZ sinusoidal steer with a 0.5 second dwell at the steer reversal peak. Runs were conducted with the vehicle’s Electronic Stability Control (ESC) disengaged so that the test vehicle would achieve large slip angles. Other dynamic maneuvers included: NHTSA’s sine-with-dwell with ESC engaged; 100% accelerator to 80 mph with 0.5G braking to stop; and acceleration to 50 mph with maximum ABS braking to stop. Results demonstrate agreement between the speed recorded by the calibrated instrumentation and speed recorded by the vehicle’s PCM for conditions when the vehicle slip angle and rear wheel slip were near zero. PCM speed was lower than instrumented speed in high slip angle maneuvers. Other dynamic maneuvers included: NHTSA’s sine-with-dwell with ESC engaged; 100% accelerator to 80 mph with 0.5G braking to stop; and acceleration to 50 mph with maximum ABS braking to stop. Results demonstrate agreement between the speed recorded by the calibrated instrumentation and speed recorded by the vehicle’s PCM for conditions when the vehicle slip angle and rear wheel slip were near zero. PCM speed was lower than instrumented speed in high slip angle maneuvers.

INTRODUCTION

The primary purpose of the reported tests was to determine the extent to which the Ford Powertrain Control Module (PCM) misstated vehicle speed during high slip-angle maneuvers. Other tests were conducted for insight into the accuracy of the Ford PCM in acceleration and braking maneuvers. Compared to the first vehicle-data recording systems, the Ford PCM provides more information useful to crash analysts. For example, without the necessity of air bag deployment or near deployment, it records and makes available a full array of data for the approximately 25 seconds of vehicle operation leading up to the most recent ignition-off. This data, collected at 0.2 second intervals, includes drive-wheel-indicated speed, accelerator-pedal-depression percentage, engine throttle percentage, brake switch status, and 12 other variables.

METHOD

The test vehicle was a 2005 Ford Explorer with VIN 1FMZU63W85ZA02141, August 2004 manufacture date and an odometer reading of 51368 miles. The vehicle was equipped with a California emissions 4.6L V-8 engine, 4-speed automatic transmission, AdvanceTrac® with Roll Stability Control™ (RSC) and 2-wheel drive.

1 AdvanceTrac® with RSC™ was Ford’s second generation ESC and adds a second gyroscopic roll sensor. If this roll rate sensor detects that the vehicle is about to roll, the system automatically applies additional countermeasures – such as reducing engine power 15 percent and/or applying brakes to one or more wheels (Ford, 2006).
Ford’s AdvanceTrac® with RSC will be referred to as Electronic Stability Control (ESC) from this point forward. The tires were Michelin Cross Terrain P235/70R16 inflated to 35 PSI at the front and rear. The tires were mounted to alloy OEM 16X7 rims with a 44 mm offset. Prior to fitment for testing the vehicle was researched, inspected and measured by a certified body shop to assure no prior collision or major repair and restored or repaired to compliance with OEM specification by a certified mechanic.

As tested, the vehicle’s weight was 4867 lbs (F/R: 2515/2352). This included the driver (175 lbs) and the instrumentation (77.5 lbs) which was placed on the right front seat. The vehicle was fitted with an AB Dynamics steering robot. Calibrated instruments measured speed, slip angle and yaw rate. In addition, wheel brake line pressure, brake switch status, PCM - vehicle speed output (PCM - VSO) and accelerator pedal position were simultaneously recorded at 200Hz. Brake switch status was monitored through a wire connected to a switch at the brake pedal. Gas pedal position was monitored from the vehicle’s pedal potentiometer. PCM - VSO was monitored by feeding the PCM pulse output signal through a DataForth isolation/conversion module.

Velocity was measured with a Datron S-400 velocity sensor and a VBOX200SL Differential GPS datalogger. The Datron S-400 velocity sensor is an optical sensor that measures longitudinal and lateral velocity every 4ms, calculates slip angle over a range of ±40 degrees and provides an analog output. The Datron S-400 was programmed at the default setting to preprocess data using a 32 point moving average. Correction for Center of Gravity (CG) offset and time delay was made to the Datron velocity and slip angle measurements as described by the instrument’s manufacturer (Haus, 2002; Neudecker, 2004). The VBOX200SL Differential GPS datalogger is a vehicle speed sensor which uses a GPS engine to calculate vehicle speed 20 times a second using the Doppler effect (frequency shift of the GPS satellite carrier signal). The output is not interpolated, and represents a true 20Hz update of the vehicle’s speed. The VBOX Speed sensor is designed to output velocity as an analog voltage. The VBOX200SL’s antennas were mounted on the roof over the vehicle’s CG. A 31.5ms time correction was applied to the VBOX data for time delays due to processing latencies described by the instrument’s manufacturer (Lau, 2008).

Signals from all instruments, velocity sensors and vehicle circuits were recorded with an onboard data acquisition system at 200 samples per second. Velocity and slip angle data from the onboard instrumentation were post processed with a 6Hz, 12-pole, phaseless digital Butterworth filter and zeroed.

Prior to tire break-in and testing, tire pressures were set to the manufacturer’s recommended 35 PSI pressure at the front and rear. Tires were broken-in using protocol dictated by the National Highway Traffic Safety Administration’s (NHTSA’s) New Car Assessment Program (NCAP) fishhook test procedure. The same tires were used in all testing and were not rotated or changed. Tire pressure was monitored but not changed to ensure that no pressure loss occurred from test to test.

The test maneuver used for the high slip angle speed comparison was NHTSA’s 0.7 Hz, sine-with-dwell maneuver (NHTSA, 2006). The AB Dynamics steering robot generated the same steering inputs for each run while the driver controlled the initial speed. The steer magnitude was 174.9 degrees. Tests were conducted at 50 mph and throttle was dropped prior to steer initiation. The maneuver was chosen because it was known to cause yaw response associated with spinout without the intervention of ESC. Steer magnitude was determined by conducting pre-tests with ESC off at incrementally greater steer magnitudes until spinout occurred. Figure 1 shows the steer profile. The pre-tests are lettered F, G and H and results were not analyzed or presented. Three identical tests were conducted with ESC off. The ESC off condition was produced by turning off the stability control switch on the vehicle console. Non-actuation of the system was confirmed by observing the warning lamp in the instrument cluster and by monitoring individual wheel brake line pressures.

Figure 1. Sine-with-dwell steer profile.

Signals from all instruments, velocity sensors and vehicle circuits were recorded with an onboard data acquisition system at 200 samples per second. Velocity and slip angle data from the onboard instrumentation were post processed with a 6Hz, 12-pole, phaseless digital Butterworth filter and zeroed.

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2 The PCM-VSO is monitored by wiring to pin C175B pin 1 ckt 679 (GY/BK) VSS + (middle connector) on the PCM. This was a pulse output, and the conversion module changed this to a voltage.

3 Spin out was defined as the failure of a vehicle’s measured yaw rate to drop below 35 percent and 20 percent of its peak at 1 seconds and 1.75 seconds, respectively. Time zero was the steering wheel’s return to zero (NHTSA, 2006).
A listing of all tests is provided in Table 1. Other conducted tests included:

- Three (3) tests with ESC on with identical speed and steer to the ESC off maneuvers,
- three (3) tests with ABS engaged from 60 mph to nominally 80 mph including phases with the accelerator pedal at 100% followed by braking to stop at a nominal deceleration of 0.5G and
- three (3) tests with ABS engaged to 50 mph at approximately 0.2G acceleration followed by maximum braking to full stop.

All tests were conducted on flat roadway and parking lot surfaces at the Southwestern International Raceway near Tucson, Arizona. Testing at high slip angles and max braking were conducted on a flat asphalt surface with 0.9 or greater friction, determined pursuant to the ASTM surface friction characterization protocol. The highway speed tests were conducted on a straight and level high coefficient of friction roadway with a traveled asphalt surface.

At the conclusion of each test run the ignition was turned off, preserving the last 25 seconds of stored accessible data in the PCM. PCM data was downloaded using commercially available Bosch hardware and software. The data was then time-corrected from its raw form.

Time synchronization of the PCM data with the calibrated instrumentation data was performed by comparing the brake switch status signals for each data set. In both data sets, brake switch status was Boolean, either “on” or “off”. The instrumentation recorded data at 0.005 second intervals, 40 times the rate of the PCM. At brake application, the monitored brake circuit voltage dropped from approximately five volts to zero volts in less than 0.01 seconds (one or two time steps). In the PCM data the switch status changes during 0.2 seconds. The two data streams were synchronized by aligning the time of the last indication of brakes-off in the PCM data plus 0.1 seconds with the time of the last indication of brakes-off in the unfiltered monitored brake circuit data.

The synchronizing method had a potential error of ±0.1 seconds. The synchronizing method was similar to prior published work (Ruth, 2008) except after synchronization was established the prior 20 calibrated velocity data points were not averaged. The higher sample rate of the calibrated instruments produced 40 speed measurements for every PCM measurement. Because dynamic tests were conducted and the potential for up to ±0.1 seconds of synchronization error, uncertainty in the calibrated speed measurement for comparison to the PCM speed measurement occurred. For example: the calculated speed change at 0.8G braking in 0.1 seconds was 1.75 mph (2.82 kph). In addition to the uncertainty associated with the sync error, there were minor, but cumulative uncertainties associated with the accuracy of the calibrated instrument (0.1%) and the vehicle speed sensor (measured to 1/128 of a mile per hour and reported to a resolution of 0.1 mph.) The resulting uncertainty was called the speed sync uncertainty and the PCM speed error sync uncertainty. The sync uncertainty effectively forms a speed sync uncertainty band around the calibrated speed measurement determined by finding the minimum and maximum speed from the prior 20 and following 19 calibrated speed measurements.

The PCM speed error was calculated by subtracting calibrated speed from PCM speed at the sync time (PCM speed error = PCM speed - calibrated speed). The PCM speed error sync uncertainty was determined from the difference between the calibrated speed and the minimum and maximum speed of corresponding speed sync uncertainty at the sync time. Negative speed difference indicates less than the calibrated speed. PCM speed error was not calculated at calibrated speeds below 5 mph because as the vehicle starts and comes to a stop, pitching and other factors influencing the instruments introduced measured speed and slip angle values that did not represent the true motion of the vehicle.

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Test Description</th>
<th>Speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-1202</td>
<td>0-80 mph highway speed test</td>
<td>0-80 mph</td>
</tr>
<tr>
<td>D-1203</td>
<td>0-80 mph highway speed test</td>
<td>0-80 mph</td>
</tr>
<tr>
<td>E-1204</td>
<td>0-80 mph highway speed test</td>
<td>0-80 mph</td>
</tr>
<tr>
<td>I-1701</td>
<td>NHTSA sine-with-dwell left - right sequence, ESC off</td>
<td>50 mph</td>
</tr>
<tr>
<td>J-1702</td>
<td>NHTSA sine-with-dwell left - right sequence, ESC off</td>
<td>50 mph</td>
</tr>
<tr>
<td>K-1703</td>
<td>NHTSA sine-with-dwell left - right sequence, ESC on</td>
<td>50 mph</td>
</tr>
<tr>
<td>L-1704</td>
<td>NHTSA sine-with-dwell left - right sequence, ESC on</td>
<td>50 mph</td>
</tr>
<tr>
<td>M-1705</td>
<td>NHTSA sine-with-dwell left - right sequence, ESC on</td>
<td>50 mph</td>
</tr>
<tr>
<td>N-1706</td>
<td>NHTSA sine-with-dwell left - right sequence, ESC off</td>
<td>50 mph</td>
</tr>
<tr>
<td>O-1205</td>
<td>Max braking ABS enabled</td>
<td>0-50 mph</td>
</tr>
<tr>
<td>P-1206</td>
<td>Max braking ABS enabled</td>
<td>0-50 mph</td>
</tr>
<tr>
<td>Q-1207</td>
<td>Max braking ABS enabled</td>
<td>0-50 mph</td>
</tr>
</tbody>
</table>

Table 1. List of tests.
One purpose of the testing was the evaluation of a correction factor for PCM speeds in high slip angle tests. Thus, the correction factor: corrected PCM speed = PCM speed / COS(slip angle), was applied to the PCM speed in the high slip angle tests. This method of interpreting tire motion and forces was consistent with reconstruction methods described by Orlowski (Orlowski, 1987) and restated by Martinez (Martinez, 1996) in which a correction factor is utilized to calculate the drag of a freely rotating (no brakes applied) tire when a vehicle is side slipping: \( u_{eff} = u \cdot \sin(\text{slip angle}) \) (where, \( u_{eff} \) is the coefficient of friction from the lateral component of tire forces and \( u \) is the sliding friction between the road and tire). Since the rear tire is aligned with the longitudinal axis of the vehicle and its free (no brakes applied) rotation rate is proportional to the PCM speed measured at the output of the transmission, the PCM output speed is assumed equal to the longitudinal vehicle velocity component.

RESULTS

Both a Datron S-400 and a VBOX20SL Differential GPS for measuring speed and slip angle were used in testing; however, after analysis only Datron calibrated speed was used. Speed reported by the VBox was essentially identical to the Datron for all conditions in all tests. The Datron was chosen for numerous reasons including: in two of the high slip angle tests the recorded slip angle from the VBox differed substantially from the Datron and discussion with instrument manufacturers did not explain differences; The raw recorded signals of the Datron were within its specified linear range of operation; there was a general familiarity and usage history with the Datron; and finally, the Datron had a general acceptability in vehicle handling testing and a calibration record traced to international standard.

A chart of calibrated Datron speed and PCM speed versus time and a chart of PCM speed error versus time for all tests utilized in the analysis presented in this paper are in the Appendix. The charts with speeds versus time also display the speed sync uncertainty as upper and lower bands about the calibrated speed line. The Charts with PCM speed error also display the difference in minimum and maximum speed associated with the speed sync uncertainty. Interpretation of the upper and lower lines on the chart with PCM speed error was: PCM speed error was detectable for results that fall above or below the lines of PCM speed error sync uncertainty. Detectable PCM speed error was the difference between PCM speed error and the corresponding PCM speed error sync uncertainty at the sync time.

HIGH SLIP ANGLE WITHOUT ESC - The charts for sine-with-dwell tests with ESC engaged are shown in the Appendix K-1703, L-1704 and M-1705. In addition to the substantial ESC effect on preventing oversteer, these charts show the momentary discontinuity in PCM speed due to ESC interventions. The ESC intervention applied individual wheel brake’s causing slipping of the rear tires. With ESC enabled the maximum PCM speed error was -6.24 mph (-10.04 kph) in test M-1705 at 37.0 mph (59.3 kph) and 10.3 degree slip angle. The maximum detectable PCM speed error was at the same

The maximum measured PCM speed error was -5.44 mph (-8.75 kph) in test J-1702 in a decreasing slip angle phase at 15.6 mph (25.1 kph) and 18.7 degrees slip angle. The maximum recorded PCM speed error in a decreasing slip angle phase should be discounted because of vehicle oscillations that influenced velocities recorded by the Datron sensors. The maximum PCM speed error during an increasing slip angle phase was -4.60 mph (-7.40 kph) in test J-1702 at 27.1 mph (43.6 kph) and 33.3 degrees slip angle. The maximum detectable PCM speed error was -3.67 mph (-5.91 kph) in test N-1706 in an increasing slip angle phase at 29.9 mph (48.1 kph) and 33.2 degrees slip angle. The first test, I-1701, had a speed signal drop that was probably associated with the Datron’s optical sensors moving too far from the ground and out of its operating range at peak slip angle.

HIGH SLIP ANGLE WITH ESC - The charts for sine-with-dwell tests with ESC engaged are shown in the Appendix K-1703, L-1704 and M-1705. In addition to the substantial ESC effect on preventing oversteer, these charts show the momentary discontinuity in PCM speed due to ESC interventions. The ESC intervention applied individual wheel brake’s causing slipping of the rear tires. With ESC enabled the maximum PCM speed error was -6.24 mph (-10.04 kph) in test M-1705 at 37.0 mph (59.3 kph) and 10.3 degree slip angle. The maximum detectable PCM speed error was at the same

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![Figure 2. Analysis of PCM speed error in 60 mph to 80 mph at 100% accelerator.](image-url)
point and was -5.03 mph (-8.09 kph). If the six data points obviously associated with ESC intervention were eliminated, the maximum PCM speed error was -2.44 mph (-3.93 kph) in test L-1704 at 41.0 mph (65.98 kph) and 7.9 degree slip angle. The maximum detectable PCM speed error was at the same point and was -1.13 mph (-1.82 kph).

80 MPH ACCELERATING AND BRAKING DYNAMIC MANEUVERS - Analysis of the braking and accelerating dynamic maneuvers plotted PCM speed error versus calibrated speed. Since each of these dynamic maneuvers was at a nominally constant acceleration/deceleration rate, PCM speed error sync uncertainty was plotted as a value representing the 85th percentile of the PCM speed error sync uncertainty variance. Plotted PCM speed error values that lie between the upper and lower bounds have no detectable error, whereas plotted PCM speed error values that lie below the lower bound and above the upper bound are referred to as detectable speed errors.

The 80 mph tests included phases with the accelerator pedal at 100%, followed by braking to stop at a nominal deceleration of 0.5G, and were analyzed for these phases. The first phase was during acceleration from nominally 0 mph to 80 mph when the accelerator pedal was recorded by the PCM in the range of 29.0% to 52.5%. Analysis is shown in Figure 2. In the acceleration phase of the 80 mph tests, the PCM speed error was above the 85th percentile PCM speed error sync uncertainty upper bound for all readings and above the lower bound except for some readings above 73.7 mph (118.6 kph). A linear relationship between PCM speed and calibrated speed was determined for the speed range of 60 mph to 80 mph as: calibrated speed (mph) = 1.03 * PCM speed - 2.53 mph, R² = 0.999. A linear relationship forced through zero intercept was determined as: calibrated speed (mph) = PCM speed, R² = 0.998. The maximum PCM speed error was -0.83 mph (-1.34 kph) in test C-1202 at 79.8 mph (128.4 kph). The maximum detectable PCM speed error was -0.67 mph (-1.08 kph) in test D-1203 at 79.4 mph (127.8 kph).

The second phase was continuous braking from 80 mph to stop at a nominal deceleration of 0.5G. Analysis is shown in Figure 3. For the entire speed range during the 0.5G braking, calculated PCM speed error was detectable below the PCM speed error sync uncertainty. A linear relationship between PCM speed and calibrated speed was determined for the speed range of 80 mph to 5 mph as: calibrated speed (mph) = 1.04 * PCM speed + 0.60 mph, R² = 0.999. A linear relationship forced through zero intercept was determined as: calibrated speed (mph) = 1.05 * PCM speed, R² = 0.999. The maximum PCM speed error was -5.38 mph (-8.67 kph) in test E-1204 at 69.3 mph (111.5 kph). The maximum detectable PCM speed error was at the same point and was -4.34 mph (-6.98 kph).

50 MPH ACCELERATING AND MAXIMUM BRAKING DYNAMIC MANEUVERS - Tests involving acceleration to 50 mph followed by maximum ABS braking to full stop were also analyzed in two phases. Analysis below 5 mph was not conducted. The first phase was acceleration from 0 mph to nominally 50 mph at approximately 0.2G. The accelerator pedal was recorded by the PCM in the range of 29.0% to 52.5%. Analysis is shown in Figure 4. In the acceleration phase of the 50 mph tests, the PCM speed error was above the
The second phase was the maximum ABS braking phase from nominally 50 mph to stop. The charts in the Appendix, O-1205, P-1206 and Q-1207 - show the results. In the maximum ABS braking phase, the PCM speed error was below the 85th percentile PCM speed error sync uncertainty upper bound for all readings and the maximum PCM speed error was -5.30 mph (-8.53 kph) in test O-1205 at 24.7 mph (39.8 kph). The maximum detectable PCM speed error was at the same point and was -3.7 mph (-6.0 kph). The second and third largest PCM speed errors were -4.58 mph (-7.37 kph) in test P-1206 at 39.2 mph (63.1 kph) and -4.37 mph (-7.03 kph) in test O-1205 at 10.1 mph (16.3 kph), respectively. The average PCM speed error was -2.35 mph (-3.78 kph). The average detectable PCM speed error was -1.35 mph (-2.17 kph). For the entire range of test speeds some of the PCM speed errors were within the PCM speed error sync uncertainty. A possible PCM speed error of -4 mph (-7 kph) was measured in maximum ABS braking.

DISCUSSION

In this study, results reported as detectable PCM speed error were preferred to results reported as PCM speed error with a +/− uncertainty. Since uncertainty was associated with synchronization of the two signals, reporting an uncertainty in the speed error may have misrepresented the accuracy of the PCM. Uncertainty was caused by an artifact of the test and analysis versus a known deficit in the PCM speed.

Tests with ESC turned off resulted in transient oversteer. Oversteer was recorded in yaw rate and slip angle and resulted in greater roll angles and complex oscillatory behavior of the vehicle. The effect of oscillatory vehicle motions was best observed in the decreasing slip angle phase of speed and slip angle plots for tests I-1701, J-1702 and N-1706. Test J-1702 resulted in an outrigger contact. The testing did not characterize the handling or rollover performance of the vehicle with or without ESC since tire changing and test sequencing procedures were not utilized. The speed and slip angle record for test I-1701 had a drop that was probably associated with the Datron optical sensor moving too far from the ground and out of its operating range due to the vehicle’s oversteer induced roll and oscillatory motions.

The correction applied to PCM speed of the without ESC vehicle in the turn induced high slip angle tests was consistent with the method for analyzing effective vehicle deceleration in non-braked high slip angle speed reconstruction. The correction improved PCM speed in the increasing slip angle phase of the test when vehicle oscillations did not influence velocity sensor’s motion and measured vehicle speeds. Reconstruction slip angle analysis based upon tire mark measurements probably would effectively damp the measured vehicle oscillation in decreasing slip angle motion, and may improve a correction in this application. Applying a slip angle correction to PCM recorded speeds for vehicles without ESC should increase accuracy of PCM speed for portions of vehicle motion when the slip angle is increasing and absent braking.

In testing with ESC enabled, speed error was associated with ESC intervention. The Ford Explorer involved in the test was equipped with RSC, which was a second generation ESC system that may provide a more aggressive intervention. It is not known if the speed errors from the subject vehicle with ESC actuation would be expected for all vehicles with ESC. Correction of speed error with ESC did not improve the PCM speed because the speed error is associated with wheel slip from brake applications in the ESC intervention. PCM speed from vehicles with ESC in aggressive turn induced maneuvers should be evaluated with consideration to ESC intervention related error. A Ford PCM download which provides recorded speed every 0.2 seconds appears to provide enough data that an accurate speed trend can be discriminated.

Analysis of maximum braking with ABS tests showed the maximum detectable PCM speed error was -3.7 mph (-6.0 kph) at 24.7 mph (39.8 kph) and that a -4 mph (-7 kph) PCM speed error was measured at a variety of instances along the 50 mph to 5 mph speed range. The maximum detectable percent error was -15.0% at 24.7 mph (39.8 kph). Results reported by Reust (2008) described PCM speeds underreported during maximum brake application with an ABS system by approximately 0.5% to 14.3% for PCM speeds of 20 mph or higher.

For all testing, most of the calculated PCM speed errors were within bands of uncertainty or below. This occurrence was consistent with the operation of a calibrated vehicle speed sensor that operates by sensing rotation at the output of the transmission. The six positive speed errors measured above the 85th percentile PCM speed error sync uncertainty upper bound in the 5 mph to 50 mph tests at approximately 0.2G acceleration were less than 0.5%, 0.09 mph (0.14 kph) in test O-1205 at 23.8 mph (38.2 kph). The very small positive detectable PCM speed errors in the 0.2G acceleration are also due to the relatively narrow band of speed sync uncertainty associated with low deceleration and low acceleration dynamics. Some additional positive PCM speed errors were detected; however these errors principally appear to be associated with transitions caused by accelerator or brake application and/or may occur randomly. The 5 sample per second rate of the
Ford PCM should allow for discrimination of significant speed errors.

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REFERENCES

7. Lau, J., (May 8, 2008), Personal Correspondence.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

**PCM speed error** - The difference between PCM speed and calibrated Datron speed at the sync time. Calculated by subtracting calibrated speed from PCM speed at the sync time (PCM speed error = PCM speed - calibrated speed.)

**Speed sync uncertainty** - Determined by finding the minimum and maximum calibrated speed from the prior 20 and following 19 calibrated speed measurements (- 0.100 seconds to +0.095 seconds) at sync time for each 0.2 second PCM interval.

**PCM speed error sync uncertainty** - The difference between the calibrated speed at sync time and the minimum and maximum speed of corresponding speed sync uncertainty.

**Detectable PCM speed error** - The difference between a corresponding PCM speed error sync uncertainty and PCM speed error.
Sine-with-dwell ESC disabled
Test 101j - 1702

Appendix. Test J-1702.
Appendix. Test N-1706.
Appendix. Test K-1703.

Sine-with-dwell ESC enabled
Test 101k - 1703
Appendix. Test L-1704.
Appendix. Test M-1705.
Highway Speed
Test 101c - 1202

Appendix. Test C-1202.
Highway Speed
Test 101d - 1203

Appendix. Test D-1203.
Appendix. Test E-1204.
Maximum ABS Braking
Test 1010 - 1205

Appendix. Test O-1205.
Appendix. Test P-1206.
Appendix. Test Q-1207.