HVE-WP-2015-4

Evaluation of the Automatic Transmission Model in HVE Version 10.1

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ABSTRACT

Prompted by the addition of a driveline slip algorithm, the performance of the SIMON Automatic Transmission Model (ATM) within Version 10.1 of the HVE suite is revisited in this follow-up to a 2010 study by the author. SIMON's ATM is evaluated against test data acquired from a vehicle equipped with an automatic transmission, thereby assessing the performance of the ATM driveline slip algorithm, which was introduced after the prior study. Correlation parameters examined include vehicle speed, engine speed, engine throttle, transmission gear, driveline slip, as well as brake pressure. Good correlation was found between the simulation model and the test data in the case of a wide open throttle test run, thereby verifying the functionality of the driveline slip feature within the SIMON ATM under this condition.

INTRODUCTION

With the introduction of HVE Version 7 in the summer of 2009, an Automatic Transmission Model (ATM) became available for users of the SIMON physics module. This model allowed SIMON users to designate the transmission of the simulated vehicle as being "automatic", thereby allowing the SIMON transmission to shift "automatically" based on user-entered parameters regarding transmission shift points. A detailed discussion of the functioning of the HVE ATM is provided in [1].

The initial ATM did not allow for driveline slip, thus, as documented by this author in reference [2], the model was limited in its capability to model a vehicle starting from a stop. With the introduction of HVE Version 8 in the summer of 2010, the HVE Drivetrain Module was equipped with a virtual clutch (or, in the case of an automatic transmission-equipped vehicle, a virtual torque converter) which "allows slippage between the engine and the transmission that allows greater torque to be transmitted to the drive wheels." [3]

The functioning of the current clutch-equipped HVE ATM is presently evaluated by comparing a SIMON simulation against data captured from the powertrain of a test vehicle subjected to straight-line acceleration runs.

TEST VEHICLE

The test vehicle for the current study was the 2012 Ford Fusion SE depicted in Figure 1.

Data acquisition was accomplished via the aftermarket data logging device depicted in Figure 2. The "OBD Mini Logger" manufactured by HEM Data [4] connects to the vehicle's data bus via the Onboard Diagnostic (OBD) connector located on the vehicle's knee bolster beneath the steering wheel. Using a specially-purchased HEM software database for Ford vehicles to prepare the logger, this device was able to monitor a variety of parameters specific to the test vehicle.

For this series of tests, a total of ten parameters were monitored at an acquisition rate of approximately, 3 to 4 Hz each. The parameters monitored included: accelerator pedal position, commanded transmission gear, torque converter turbine shaft speed, torque converter slip, transmission slip ratio, transmission output shaft speed, engine speed, vehicle speed, engine throttle position and brake system pressure.

Figure 1 – 2012 Ford Fusion SE test vehicle

Figure 2 – "OBD Mini Logger" manufactured by HEM Data Corporation

SIMULATION VEHICLE

The 2012 Ford Fusion SE is contained within the Vehiclemetrics HVE Vehicle Database [5], as depicted in Figure 3. The Vehiclemetrics vehicle allowed for a robust starting configuration from which to model the full-scale test vehicle.

Figure 3 – Simulated vehicle from the Vehiclemetrics HVE Vehicle Database

Relevant specifications for the vehicle in the Vehiclemetrics database were independently confirmed by the author against published references and were modified in the following areas, only:

WEIGHT AND LONGITUDINAL CG LOCATION - Were adjusted for the presence of one occupant, test equipment, and a ¼-full fuel tank.

TRANSMISSION - The default upshift and downshift curves provided in in the Vehiclemetrics database for the Ford Fusion as depicted in Figure 4 were modified based on data collected from the test vehicle, as discussed later.

BRAKE SYSTEM – The simulated vehicle's Brake Pedal Ratio (BPR) as well as the Brake Torque Ratios (BTR's) were modified based upon specialized testing conducted by Vehiclemetrics on a Ford Fusion SE to allow for the analysis of the brake pressure data collected in the current study. Based on the results of this testing, the BPR was set to 23.25 kPa/N, the front wheel BTR's were set to 0.609 N-m/kPa, and the rear wheel BTR's were set to 0.320 N-m/kPa with a proportioning ratio of 0.14.

The Vehicle Data report for the vehicle used to simulate Test Run 01 is provided in the Appendix.

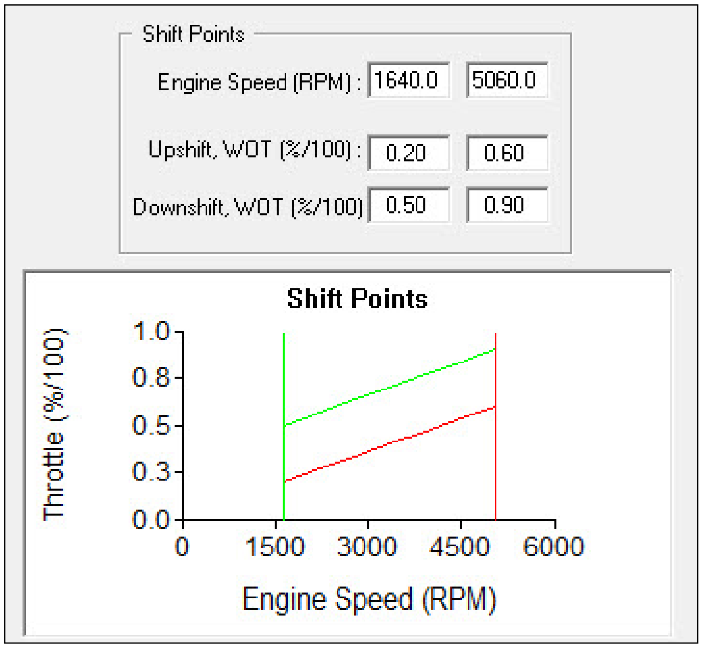

Figure 4 – Default shift points for the Ford Fusion SE in the Vehiclemetrics database

TEST METHODOLOGY

The test vehicle was taken to an approximately straight and level roadway and subjected to a straight line acceleration maneuver, followed by braking to bring the vehicle to a stop during each run.

A total of 12 runs during which data were collected were made, with peak speeds ranging from 22 to 81 miles per hour. Attempts were made to undertake runs involving varying throttle application rate as well as runs involving periods of steady-state throttle application.

TEST DATA

The data from two test runs was evaluated via simulation: Run 01, a "wide open throttle" run ("75%" reported engine throttle, 79 mph peak speed), and Run 05, a "restrained" steady-state throttle application run ("24%" reported engine throttle, 53 mph peak speed).

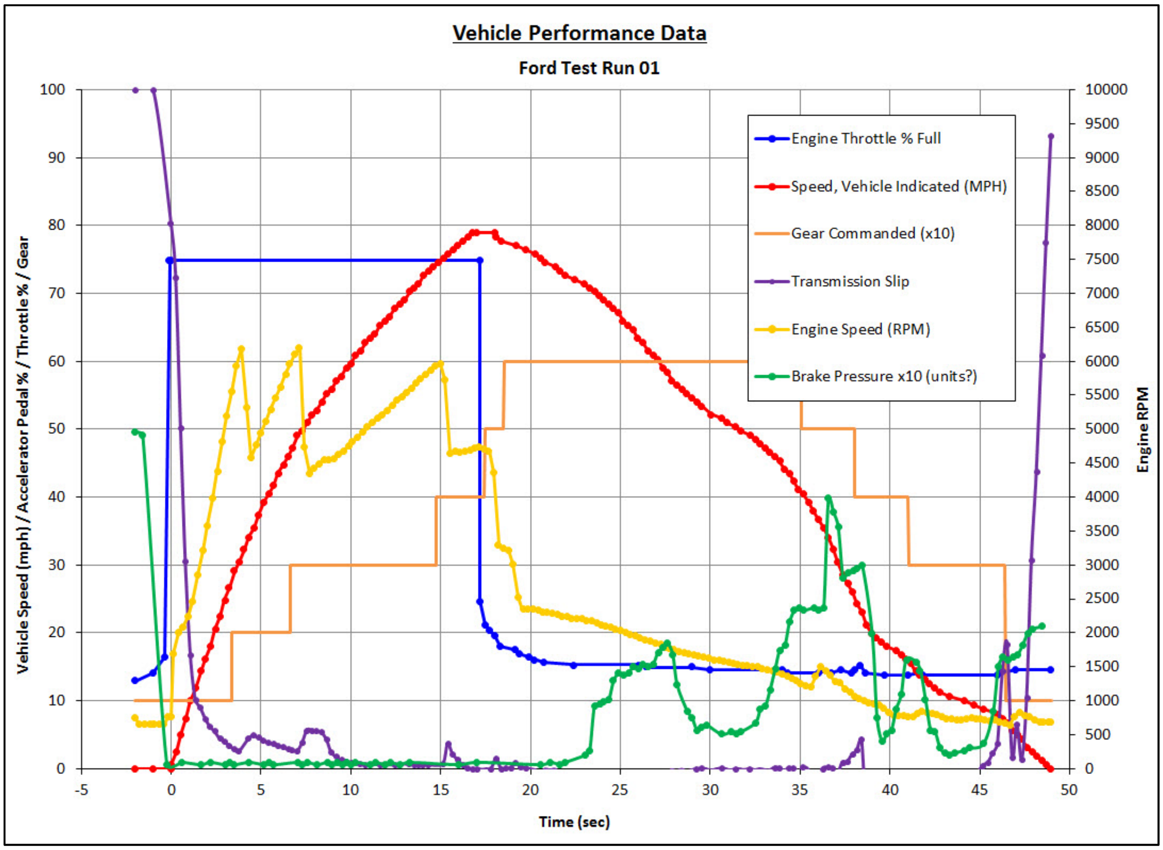

Figure 5 – Data collected from the test vehicle during Test Run 01

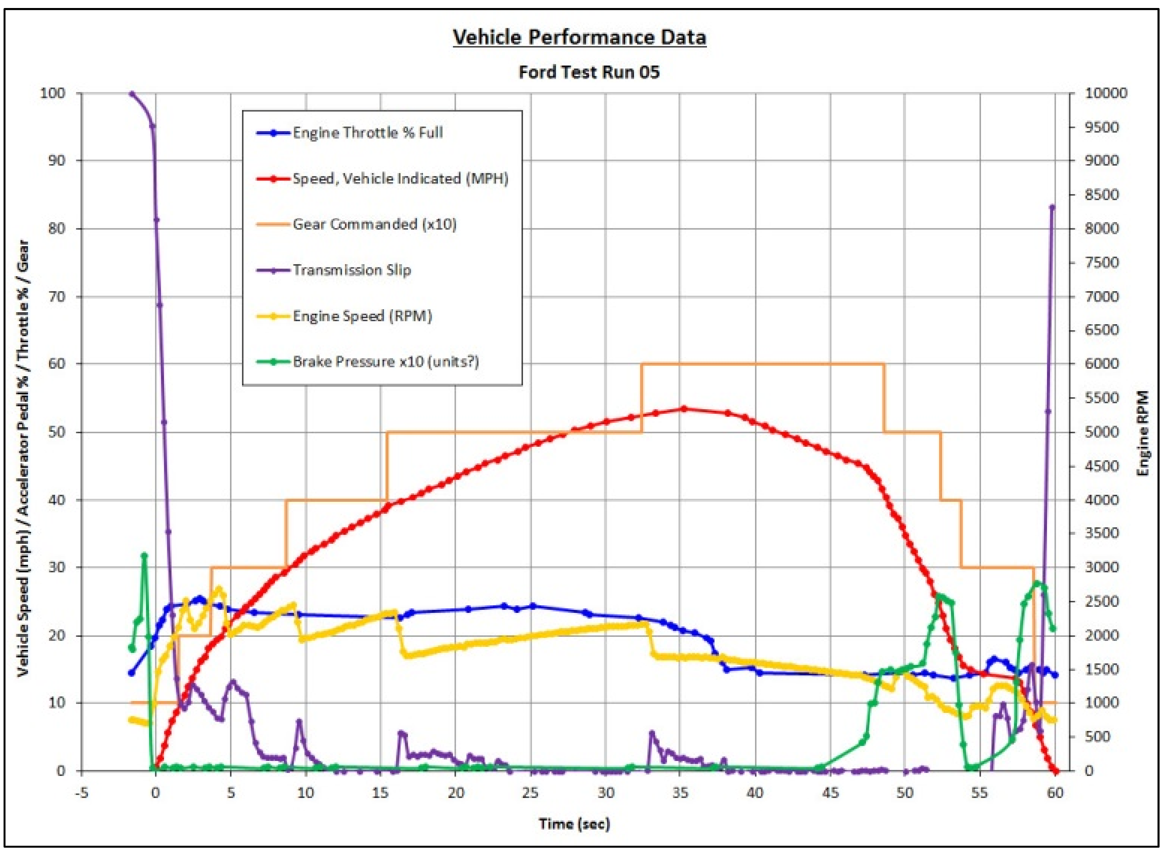

Figure 6 – Data collected from the test vehicle during Test Run 05

Relevant test data collected during Run 01 and Run 05 is depicted in Figures 5 and 6, respectively. Of particular benefit in the current study as compared to the prior study, the author was able to directly acquire data relating to transmission slip, the transmission gear commanded by the vehicle's powertrain control module, as well as system brake pressure.

SIMULATION INPUTS

Based upon the results of the author's 2010 study, the engine "Throttle Position %" parameter recorded by the HEM logger was used as the basis for throttle input values in the Driver Controls dialog for each test run evaluated.

Further, the data channel identified as "Main Brake Pressure" in the HEM data was used as the basis for the entries in the Brake Pedal Force table in the Driver Controls dialog in the Event Editor. As the brake pressure data recorded by the HEM logger was not scaled to any particular physical unit, the values of brake pedal force in SIMON were adjusted to follow the waveform of the recorded brake pressure data and then scaled such that the vehicle's speed trace was adequately matched.

As mentioned previously, the transmission "upshift map" (the combination of engine speed and throttle position which results in an upshift) in the HVE Transmission Data dialog was adjusted based on the collected test data. Each of the 12 total test runs were analyzed to identify readily-determined points at which transmission upshifts occurred, and the engine speed and engine throttle values for each shift were noted. It was interesting to note that the points in time where the gear changes actually occurred (based on the RPM traces) typically happened approximately 0.2 to 0.5 seconds after the gear changes noted in the "Gear Commanded" data traces.

Based on the collected data, an upshift curve for the 2012 Ford Fusion SE test vehicle was developed, and is shown in Figure 7. As noted, with the exception of a few points recorded during rapid change in throttle position (during which the exact throttle value at a particular engine speed may not be readily identifiable), and a few points recorded at maximum throttle and engine speed (which serve only to identify the maximum engine speed at which upshifts will always occur), the bulk of the data points seem to follow a relatively linear relationship. A line estimating the relationship of throttle to engine speed was passed among the primary group of data points, without attempt at a regression analysis. This relationship was used as the basis for the upshift maps used in each of the two simulations runs.

Figure 8 depicts the shift map used in Run 01 while Figure 9 depicts the shift map used in Run 05, as viewed in the HVE Transmission Data dialog. Note that the shift maps for each of these runs share the same slopes and low end RPM limit, but the upper end of the RPM range for the shift map for Run 05 was reduced from 6,200 RPM to 2,500 to adequately model the behavior of the test vehicle under the relatively restrained throttle application regime in which it was operating during the test.

The downshift curve was defined in each run by the same RPM limits as the upshift curve, and the throttle opening for the lower limit was adjusted from the Vehiclemetrics default of 50% to a value of 60%. The Vehiclemetrics upper throttle opening of 90% was left unchanged.

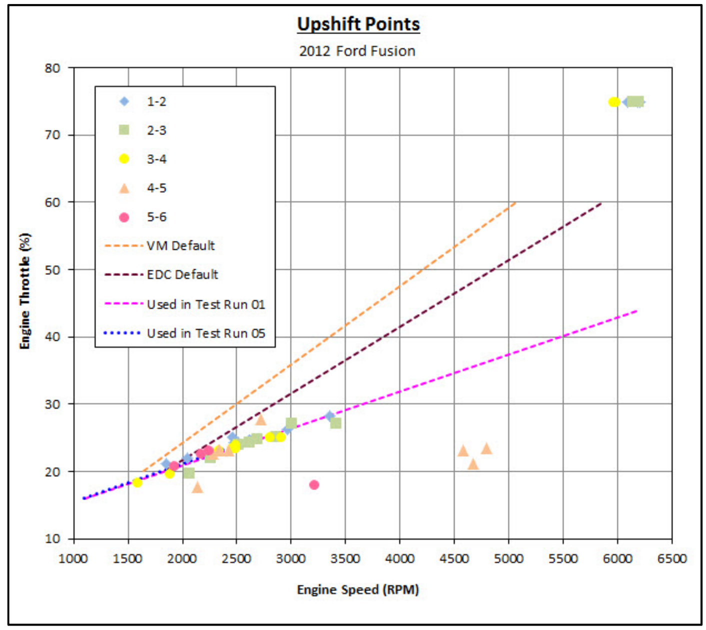

Figure 7 – Upshift points collected during vehicle testing along with shift curves provided by EDC and Vehiclemetrics and those used in simulating Test Runs 01 and 05

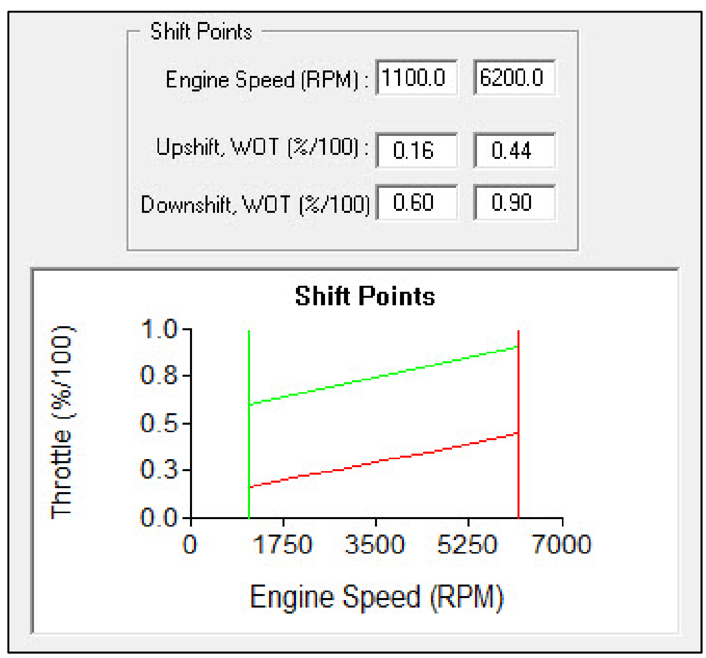

Figure 8 – Shift points used during simulation of Test Run 01

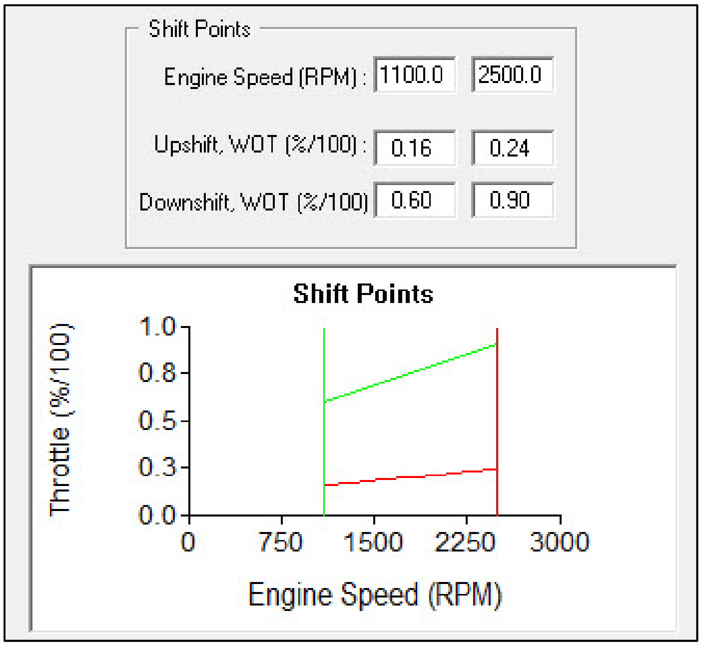

Figure 9 – Shift points used during simulation of Test Run 05

COMPARISON OF SIMULATION RESULTS TO TEST DATA

TEST RUN 01 - Presented in Figure 10 is the HVE simulation data as plotted against the collected test data from Run 01. Run 01 was in essence a "wide-open throttle" run to approximately 79 mph, followed by braking to a stop, all of which occurred over a total period of 49 seconds.

As observed in this plot, the simulation data is well-correlated to the collected test data. The simulated vehicle speed trace follows the test trace to within several miles per hour along its length, reaching to within 0.5 mph of the highest test speed at the same moment in time as the test data, 17 seconds into the test.

The HVE vehicle upshifts occurred within 1 second of the test vehicle, with all of the HVE vehicle upshifts leading the test vehicle's gear changes. Interestingly, the simulated vehicle shifted directly from 4th to 6th gear whereas the test vehicle experienced a brief shift into 5th gear between 4th and 6th. Peak RPM's during the simulated vehicle's upshifts were with 100 RPM of the data from the test vehicle.

Four of the five simulated downshifts occurred within 1 second of the test vehicle, however, the simulated gear change from 3rd to 2nd gear led the test vehicle by 4.8 seconds. In general, the simulated downshifts both led and lagged the test vehicle's shifts. Simulated engine RPM's during downshifts at lower speeds were not well-correlated to the test data, however this is theorized to be related to the interpretation of the condition of "closed throttle" by SIMON as compared to "idle throttle" in the test vehicle.

The phasing of driveline slip in the simulation matched well with that of the test vehicle, with the majority of the simulated transition from 100% slip to low-level slip occurring essentially coincidentally with the test vehicle during the start of vehicle motion, and with the simulated transition from low-level slip to maximum slip occurring about 0.6 seconds ahead of the test vehicle data as the vehicles came to a stop at the end of the run.

It was noted that whereas the SIMON ATM gearshifts occur instantaneously, the test data reflect that the test vehicle underwent upshifts which occurred over a period of 0.3 to 0.5 seconds. Associated with the finite duration of the test vehicle's upshifts were periods of non-zero driveline slip which were not reflected in the SIMON vehicle's data, as the simulated vehicle's gear changes were instantaneous in nature. The durations of downshifts in the test vehicle were not discernible from the test data.

The SIMON brake Pedal Force v. time table was programmed to follow the waveform of the brake pressure signal recorded on the test vehicle, and the SIMON brake pressure wave thus similarly reflects the test data. However, because the collected brake pressure data was not associated with a known scaled unit, it was found that the test brake pressure data was approximately 2.8 times as large as the simulated pressure data, which were provided in units of psi. This would suggest that the brake pressure data recorded by the HEM logger were in units of approximately 2 Newtons per square centimeter. Of most importance though, is that by programming the SIMON brake pedal force to match the shape of the waveform of the recorded pressure data, the shape of the simulated vehicle speed trace then also matched the particular shape of the recorded speed trace and the simulated vehicle came to a stop at the same time as the test vehicle did, thus confirming that the test brake pressure data is reflective of the actual brake system pressure present during the test run.

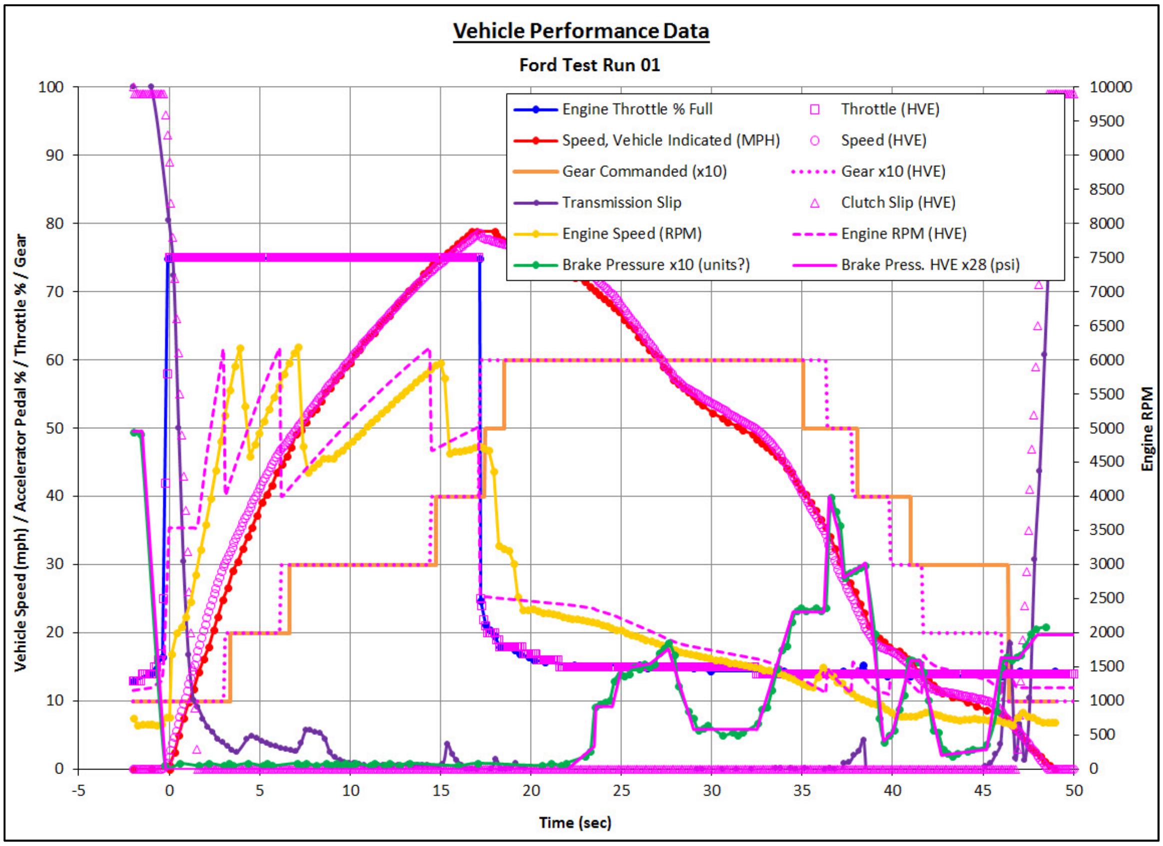

Figure 10 – Simulation output plotted against test data for Test Run 01

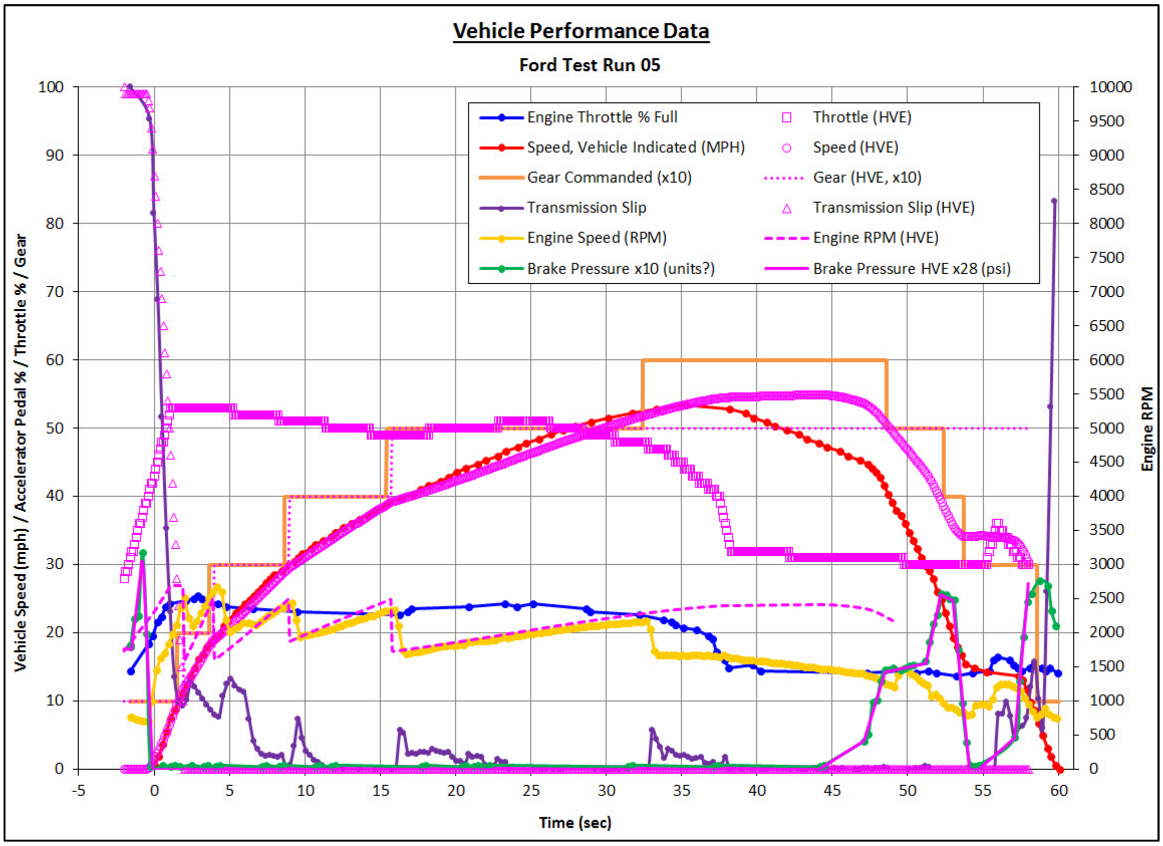

Figure 11 – Simulation output plotted against test data for Test Run 05

TEST RUN 05 - Presented in Figure 11 is the HVE simulation data as plotted against the collected test data from Run 05. Run 05 was in essence a "restrained throttle" run to approximately 53 mph, followed by braking to a stop which occurred over a total period of 60 seconds.

It was found that, when programming the simulation with engine throttle values which matched the numerical values of the "Throttle Position" parameter recorded on the test vehicle, the resulting simulation significantly underestimated the speed history of the test vehicle. It was found that multiplying the test throttle data by a factor of 2.1 resulted in very good correlation between the test data and all of the simulated vehicle parameters, including vehicle speed, engine speed, driveline slip and gear changes during almost all of the acceleration phase of the vehicle's motion.

Based on this observation, it is theorized that unlike the SIMON drivetrain model, which presumes a linear relationship between engine torque and throttle position, the relationship between engine torque and throttle position in an actual vehicle is not linear throughout the range of throttle opening, perhaps either as a result of throttle geometry or as a result of programming of the vehicle's powertrain control module. Thus, it may not be surprising to find that the throttle data collected during a non-wide-open-throttle test may have to be multiplied in some fashion to produce meaningful results in a computer simulation based on a linear throttle-to-engine torque relationship.

As observed in this plot, the simulation data provides good correlation to the collected test data on the "front side" of the speed trace, during the acceleration phase of the test vehicle's motion.

The simulated vehicle speed trace follows the test trace to within 2 miles per hour along its length during the acceleration phase, reaching the exact test vehicle speed of 53 miles per hour at the same time as the test vehicle, 35.2 seconds into the test.

The HVE vehicle upshifts in Run 05 occurred even closer in time to the test vehicle's upshifts than in Run 01, with the simulated shifts occurring within 0.2 seconds of the test vehicle during the first four upshifts, with all of the HVE vehicle upshifts lagging the test vehicle's gear changes. The simulated vehicle "missed" the shift from 5th to 6th gear that the test vehicle undertook, and no amount of adjustment of the HVE shift map would result in an upshift into 6th gear at the same time as the test vehicle while also maintaining the timing of the prior upshifts. It is theorized that the test vehicle's behavior is reflective of powertrain control module programming which may adjust the shift map "on the fly" based upon driver behavior (e.g., accelerator pedal position and rate).

Because of the "missed shift" from 5th to 6th gear in the simulation, the correlation between the simulated and test parameters on the "back half" of the speed trace is relatively poor and, due to the apparently variable behavior of the test vehicle transmission at less than wide open throttle, no further attempt was made to improve this portion of the test run.

DISCUSSION

The goal of the SIMON Drivetrain Model is to calculate the drive torque for a given throttle input under given vehicle conditions at any point in time during a simulation. SIMON's algorithm for calculating drive torque is described in detail in [6].

As mentioned earlier, with the introduction of the simulated clutch since the prior study, the simulated engine RPM's no longer need to follow in lock step with the speed of the simulated vehicle. Thus, as in a full-scale vehicle, there is slip allowed in the driveline.

It was noted in the simulation of Test Run 01 that SIMON's calculation and management of driveline slip (as discussed in [6]) results in an engine RPM "plateau" near the beginning of the simulated vehicle's motion that is not present in the test vehicle data. In this way, the driveline slip model behaves more as a true clutch in a full scale vehicle equipped with a manual transmission rather than a torque converter in a vehicle with an automatic transmission.

As observed in Figure 10, the manner of the clutch model's operation leads to the simulated engine speed rising in two sharp steps rather than gradually as in the test vehicle. As a result, the simulated vehicle's engine RPM and gear change data tends to lead the test data throughout the acceleration phase of the vehicle's motion.

OBSERVATIONS AND CONCLUSIONS

Based on the testing and analysis undertaken in the current research, it is observed that:

- The HVE-SIMON Automatic Transmission Model (ATM) with the clutch feature engaged will properly model the shift timing and vehicle speed history of a full-scale vehicle under the condition of wide open throttle acceleration, given appropriate shift points in the Transmission Data tables.

- Vehicle data in the Vehiclemetrics HVE Database for the particular vehicle tested were found to be accurate in aspects such as gear ratios, tire sizes and engine data. Additional brake system data specially-provided by Vehiclemetrics was found to provide good correlation between the simulated braking phase of the vehicle test under review and the data collected during the full-scale test.

- Confirming the author's earlier study, the automatic transmission shift map of a modern vehicle may vary based on the extent and speed at which accelerator pedal inputs are made by the driver. The fixed and linear relationship between throttle and engine speed which forms the basis for the shift map in the Transmission Data table in HVE may not fully describe the shift map in vehicles with non-linear shift programs under less than wide open throttle conditions.

- Appropriate adjustment of engine throttle data collected during a full-scale test under conditions other than wide-open throttle may be required to properly simulate the behavior of the test vehicle when using the SIMON simulation model.

REFERENCES

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ACKNOWLEDGMENTS

The author would like to grateful acknowledge the efforts of the staff at Vehiclemetrics, Inc. for their work in locating and testing exemplar Ford Fusion vehicles to establish brake system parameters for use in this study.

The author would also like to acknowledge the efforts of Karoline Kautz of Dial Engineering for her work in organizing, filtering, and plotting the test data relied upon in this study.

CONTACT

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APPENDIX

The Vehicle Data report for the vehicle used to simulate Test Run 01 follows.

VEHICLE DATA

General Information ---

Vehicle Name:	Ford Fusion Sedan SE / VM
Vehicle Type:	Passenger Car
Vehicle Make:	Ford
Vehicle Model:	Fusion
Vehicle Year:	2010 - 2012
Vehicle Body Style:	Sedan SE
Version No:	V 9.00 (RCS $Revision: 1.0
Number of Axles:	2
Driver Location:	Left Side
Engine Location:	Front Engine
Drive Axle(s):	Axle 1

Steady-State Handling Properties ---

Total Understeer Gradient (deg/g):	0.17
Steering Wheel Sensitivity (deg/g):	37.02
Roll Gradient (deg/g):	1.87
Roll Couple Distribution, F/R (%/100):	0.63
Weight Distribution, F/R (%/100):	0.59
Static Weight, Front Tires (N):	9201.27
Static Weight, Rear Tires (N):	6375.30

Sprung Mass Dimensional Data ---

Overall Length (cm):	485.22
Overall Width (cm):	184.35
Overall Height (cm):	145.77
Ground Clearance (cm):	22.12
Wheelbase (cm):	272.35
CG to Front Axle (cm):	110.03
CG to Back Axle (cm):	-162.32
CG Height (cm):	58.80
Front Overhang (cm):	102.46
Rear Overhang (cm):	110.40

Sprung Mass Inertial Data ---

Total Weight (N):	15576.58
Sprung Weight (N):	14720.74
Sprung Mass (kg):	1499.89
Sprg Mass Rot Inertia (kg-m^2) - Roll:	546.93
Pitch:	2680.01
Yaw:	2716.54
XZ Product:	0.00

Sprung Mass Aerodynamic Parameters ---

Surface Name:	Bottom
Drag Coefficient:	0.0000
Proj. Surface Area (cm^2):	82557.16
Center of Pressure (cm) - x:	0.00
y:	0.00
z:	36.68

Brake System Data ---

Brake Pedal Ratio (kPa/N):	23.25
ABS System:	Tire Slip Algorithm
ABS Controller Location:	This Vehicle
Sample Method:	Wheel-Based
Delay Method:	Wheel-Based
Threshold Pressure (kPa):	68.95
Threshold Velocity (km/h):	6.44

Steering System Parameters ---

First Axle:	Steerable	
Steering Gear Ratio (deg/deg):	16.08	
Ackermann Steering Option:	On	

	Right Side	Left Side
Caster (deg):	3.90	4.00
Inclination Angle (deg):	4.50	3.80
Steering Offset (cm):	0.00	0.00
Stub Axle Length (cm):	2.82	2.12
Initial Steer Axis Coord (cm) - x:	110.03	110.03
y:	74.85	-75.20
z:	26.01	26.03

Second Axle: Not Steerable

Drivetrain Parameters ---

Engine Description:	2.5L_I4_
Maximum Power (kW):	131
Maximum Torque (N-m):	233
Transmission Forward Speeds:	6
Differential Speeds:	1

Wide-open Throttle, Speed (RPM):	500	2000	4500	6000	6200
Power (kW):	4	45	110	131	130
Torque (N-m):	71	214	233	208	200

Closed Throttle, Speed (RPM):	500	2000	4500	6000	6200
Power (kW):	-0	-6	-31	-55	-59
Torque (N-m):	-7	-30	-66	-88	-91

Transmission Type: Automatic

Shift Points -	Min	Max
Engine Speed (RPM):	1100	6200
Shift Up, WOT (%/100):	0.16	0.44
Shift Down, WOT (%/100):	0.60	0.90

Transmission Gear:	Rev	1st	2nd	3rd	4th	5th	6th
Numerical Ratio:	-3.39	4.58	2.96	1.91	1.44	1.00	0.74

Differential Gear Ratio: 3.200

Electronic Stability Systems Properties ---

(No ESS Systems Installed.)

Wheel Location Information, First Axle ---

	Right Side	Left Side
Initial Wheel Coordinates (cm) - x:	110.03	110.03
y:	77.66	-77.32
z:	26.03	26.03

Suspension Information, First Axle ---

Suspension Type:	Independent
Auxiliary Roll Stiffness (N-m/deg):	832.94

Right Side	Left Side

Wheel Rate (N/cm):	338.70	338.70
Viscous Damping (N-sec/m):	875.46	875.46
Coulomb Friction (N):	222.41	222.41
Friction Null Band (cm/sec):	12.70	12.70
Deflection to Jounce Stop (cm):	-14.35	-14.35
Stop Linear Rate (N/cm):	525.38	525.38
Stop Cubic Rate (N/cm^3):	162.87	162.87
Stop Energy Ratio (%/100):	0.50	0.50
Deflection to Rebound Stop (cm):	7.58	7.58
Stop Linear Rate (N/cm):	525.38	525.38
Stop Cubic Rate (N/cm^3):	162.87	162.87
Stop Energy Ratio (%/100):	0.50	0.50
Roll Steer Const. Coef (deg):	-0.01	0.15
Roll Steer Linear Coef (deg/cm):	-0.08	-0.00
Roll Steer Quadratic Coef (deg/cm):	-0.00	-0.00
Roll Steer Cubic Coef (deg/cm):	0.00	-0.00

Camber and Half-track Tables

-------- Right Side -------			-------- Left Side --------		
Susp Defl (cm)	Camber (deg)	1/2-track Change (cm)	Susp Defl (cm)	Camber (deg)	1/2-track Change (cm)
-6.38	-1.50	-0.35	-5.99	-1.10	-0.35
-4.78	-1.10	-0.15	-4.54	-0.70	-0.15
-2.75	-0.80	0.00	-2.59	-0.30	0.00
0.00	-0.40	0.00	0.00	0.10	0.00
2.72	-0.10	-0.25	3.15	0.40	-0.25
4.70	0.10	-0.55	5.14	0.50	-0.55
6.19	0.10	-0.90	6.65	0.60	-0.90
7.10	0.10	-1.15	7.46	0.60	-1.15
7.29	0.10	-1.20	7.62	0.70	-1.20

Tire Information, First Axle ---

	Right Side	Left Side
Tire Name:	Generic P225/50R1	Generic P225/50R1
Tire Manufacturer:	Generic	Generic
Tire Model:	Generic	Generic
Tire Size:	P225/50R17	P225/50R17
Version No:	PC.db	PC.db
Unloaded Radius (cm):	32.84	32.84
Static Loaded Radius (cm):	31.09	31.09
Nominal Width (cm):	22.50	22.50
Tread Width (cm):	18.01	18.01
Init. Radial Stiffness (N/cm/tire):	2626.90	2626.90
2nd Radial Stiffness (N/cm/tire):	26269.03	26269.03
Defl. @ 2nd Stiffness (cm):	9.02	9.02
Max Deflection (cm):	11.25	11.25
Rebound Energy Ratio (%/100):	1.00	1.00
Spin Inertia (Tire+Whl+Brk, kg-m^2/tire)	1.37	1.37
Steer Inertia (Tire+Whl+Brk, kg-m^2/tire	0.68	0.68
Weight (Tire+Whl+Brk, N/tire):	213.96	213.96
Roll Resistance Const:	0.01	0.01
Roll Resististance Linear Coef (sec/m):	0.00	0.00
Min Fz For Skidmark (N):	1593.80	1593.80
Pneumatic Trail (cm):	-1.75	-1.75

Cornering Stiffness (N/deg/tire):	Right Side			Left Side		
Loads (N):	3187.2	6374.3	9561.5	3187.2	6374.3	9561.5
Speeds (m/sec):	13.4			13.4		

Load No.:	1	2	3	1	2	3
Speed No. 1:	804.9	1506.0	1757.5	804.9	1506.0	1757.5

Camber Stiffness (N/deg/tire):	Right Side			Left Side		
Loads (N):	3187.2	6374.3	9561.5	3187.2	6374.3	9561.5
Speeds (m/sec):	13.4			13.4		
Load No.:	1	2	3	1	2	3
Speed No. 1:	80.5	150.6	175.8	80.5	150.6	175.8

Tire Friction Table:	Right Side			Left Side		
Loads (N):	3187.2	6374.3	9561.5	3187.2	6374.3	9561.5
Speeds (m/sec):	13.4			13.4		
Speed No. 1, Load No.:	1	2	3	1	2	3
Peak Mu:	1.1500	1.1000	1.0500	1.1500	1.1000	1.0500
Slide Mu:	0.9000	0.8500	0.8000	0.9000	0.8500	0.8000
Slip @ Peak Mu (%/100):	0.1600	0.1600	0.1600	0.1600	0.1600	0.1600
Long. Stiffness (N/slip):	31137.6	57826.9	80068.0	31137.6	57826.9	80068.0

Brake Information, First Axle ---

	Right Side	Left Side
Brake Assembly Type:	Generic Brake	Generic Brake
Brake Time Lag (sec):	0.0000	0.0000
Brake Time Rise (sec):	0.0000	0.0000
Pushout Pressure (kPa):	0.00	0.00
Nominal Brake Torque Ratio (N-m/kPa):	0.61	0.61
ABS Parameters ---		
Min Wheel Lin Vel (km/h):	6.44	6.44
Min Wheel Slip (%/100):	0.0500	0.0500
Max Wheel Slip (%/100):	0.1500	0.1500
Apply Delay (sec):	0.0500	0.0500
Pri Apply Rate (kPa/sec):	34473.78	34473.78
Sec Apply Rate (kPa/sec):	3447.38	3447.38
Release Delay (sec):	0.0500	0.0500
Release Rate (kPa/sec):	68947.57	68947.57

Wheel Location Information, Second Axle ---

	Right Side	Left Side
Initial Wheel Coordinates (cm) - x:	-162.32	-162.32
y:	77.36	-77.02
z:	25.85	25.85

Suspension Information, Second Axle ---

Suspension Type: Independent
Auxiliary Roll Stiffness (N-m/deg): 198.79

	Right Side	Left Side
Wheel Rate (N/cm):	261.29	261.29
Viscous Damping (N-sec/m):	563.73	563.73
Coulomb Friction (N):	222.41	222.41
Friction Null Band (cm/sec):	12.70	12.70
Deflection to Jounce Stop (cm):	-16.30	-16.30
Stop Linear Rate (N/cm):	525.38	525.38
Stop Cubic Rate (N/cm^3):	162.87	162.87
Stop Energy Ratio (%/100):	0.50	0.50
Deflection to Rebound Stop (cm):	6.59	6.59
Stop Linear Rate (N/cm):	525.38	525.38
Stop Cubic Rate (N/cm^3):	162.87	162.87

Stop Energy Ratio (%/100):	0.50	0.50
Roll Steer Const. Coef (deg):	-0.10	0.08
Roll Steer Linear Coef (deg/cm):	0.08	-0.07
Roll Steer Quadratic Coef (deg/cm):	0.02	-0.01
Roll Steer Cubic Coef (deg/cm):	0.00	-0.00

Camber and Half-track Tables

-------- Right Side -------			-------- Left Side --------		
Susp Defl (cm)	Camber (deg)	1/2-track Change (cm)	Susp Defl (cm)	Camber (deg)	1/2-track Change (cm)
-6.38	-2.20	0.60	-5.67	-2.50	0.60
-4.23	-1.80	0.60	-3.80	-2.00	0.60
-2.05	-1.50	0.50	-1.80	-1.60	0.50
0.00	-1.30	0.00	0.00	-1.30	0.00
3.27	-0.90	-1.30	3.72	-1.00	-1.30
4.26	-0.80	-1.90	4.71	-0.90	-1.90
5.17	-0.80	-2.40	5.53	-0.80	-2.40
6.04	-0.80	-3.00	6.36	-0.80	-3.00
6.31	-0.70	-3.20	6.62	-0.70	-3.20

Tire Information, Second Axle ---

	Right Side	Left Side
Tire Name:	Generic P225/50R1	Generic P225/50R1
Tire Manufacturer:	Generic	Generic
Tire Model:	Generic	Generic
Tire Size:	P225/50R17	P225/50R17
Version No:	PC.db	PC.db
Unloaded Radius (cm):	32.84	32.84
Static Loaded Radius (cm):	31.63	31.63
Nominal Width (cm):	22.50	22.50
Tread Width (cm):	18.01	18.01
Init. Radial Stiffness (N/cm/tire):	2626.90	2626.90
2nd Radial Stiffness (N/cm/tire):	26269.03	26269.03
Defl. @ 2nd Stiffness (cm):	9.02	9.02
Max Deflection (cm):	11.25	11.25
Rebound Energy Ratio (%/100):	1.00	1.00
Spin Inertia (Tire+Whl+Brk, kg-m^2/tire)	1.37	1.37
Steer Inertia (Tire+Whl+Brk, kg-m^2/tire	0.68	0.68
Weight (Tire+Whl+Brk, N/tire):	213.96	213.96
Roll Resistance Const:	0.01	0.01
Roll Resististance Linear Coef (sec/m):	0.00	0.00
Min Fz For Skidmark (N):	1593.80	1593.80
Pneumatic Trail (cm):	-1.75	-1.75

Cornering Stiffness (N/deg/tire):	Right Side			Left Side		
Loads (N):	3187.2	6374.3	9561.5	3187.2	6374.3	9561.5
Speeds (m/sec):	13.4			13.4		
Load No.:	1	2	3	1	2	3
Speed No. 1:	804.9	1506.0	1757.5	804.9	1506.0	1757.5

Camber Stiffness (N/deg/tire):	Right Side			Left Side		
Loads (N):	3187.2	6374.3	9561.5	3187.2	6374.3	9561.5
Speeds (m/sec):	13.4			13.4		
Load No.:	1	2	3	1	2	3
Speed No. 1:	80.5	150.6	175.8	80.5	150.6	175.8

Tire Friction Table: Right Side Left Side

Loads (N):	3187.2	6374.3	9561.5	3187.2	6374.3	9561.5
Speeds (m/sec):	13.4			13.4		
Speed No. 1, Load No.:	1	2	3	1	2	3
Peak Mu:	1.1500	1.1000	1.0500	1.1500	1.1000	1.0500
Slide Mu:	0.9000	0.8500	0.8000	0.9000	0.8500	0.8000
Slip @ Peak Mu (%/100):	0.1600	0.1600	0.1600	0.1600	0.1600	0.1600
Long. Stiffness (N/slip):	31137.6	57826.9	80068.0	31137.6	57826.9	80068.0

Brake Information, Second Axle ---

	Right Side	Left Side
Brake Assembly Type:	Generic Brake	Generic Brake
Brake Time Lag (sec):	0.0000	0.0000
Brake Time Rise (sec):	0.0000	0.0000
Pushout Pressure (kPa):	0.00	0.00
Nominal Brake Torque Ratio (N-m/kPa):	0.32	0.32
Brake Proportioning Pressure (kPa):	2757.90	2757.90
Brake Proportioning Ratio:	0.14	0.14
ABS Parameters ---		
Min Wheel Lin Vel (km/h):	6.44	6.44
Min Wheel Slip (%/100):	0.0500	0.0500
Max Wheel Slip (%/100):	0.1500	0.1500
Apply Delay (sec):	0.0500	0.0500
Pri Apply Rate (kPa/sec):	34473.78	34473.78
Sec Apply Rate (kPa/sec):	3447.38	3447.38
Release Delay (sec):	0.0500	0.0500
Release Rate (kPa/sec):	68947.57	68947.57