NEW CAR ASSESSMENT PROGRAM (NCAP)
DYNAMIC ROLLOVER RESISTANCE TEST

General Motors LLC

2015 Chevrolet Silverado 2500 Extended Cab 4x4 4WD

TEST NUMBER: 15-02

Final Report
28 April 2014

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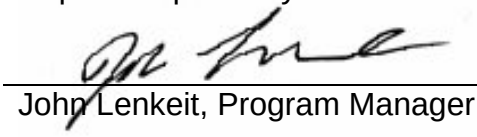
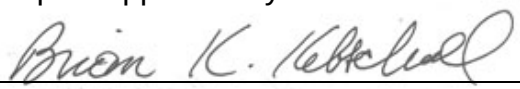


Date: 28 April 2014

John Lenkeit, Program Manager

Report Approved by:



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Brian Kebschull, Principal Engineer

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16. Abstract

An NCAP Dynamic Rollover Maneuver (Fishhook) Test was conducted on a 2015 Chevrolet Silverado 2500 Extended Cab 4x4 4WD at Dynamic Research, Inc. on April 3, 2014. The vehicle did not experience two-wheel lift. The vehicle's steering angle at 0.3g lateral acceleration at 50 mph was 51.2 degrees.

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INTRODUCTION

Beginning with the 2006 fiscal year, the National Highway Traffic Safety Administration (NHTSA) has engaged Dynamic Research, Inc. (DRI) of Torrance, CA to conduct dynamic rollover testing and gather data from that testing as part of NHTSA's New Car Assessment Program (NCAP).

The purpose of the testing reported herein was to determine if a typical 2015 Chevrolet Silverado 2500 Extended Cab 4x4 4WD would experience tip-up, defined as simultaneous two-wheel lift of two inches or more at an entry speed of 50 mph or less in the Fishhook Procedure developed by NHTSA. This procedure may be found at www.regulations.gov, docket item NHTSA-2006-26555-0136.

The testing reported herein was accomplished under contract DTNH22-08-D-00117. The task order is entitled, "New Car Assessment Program (NCAP) Non-Destructive Vehicle Testing and Data Gathering."

Section II
VEHICLE PREPARATION

A. TEST VEHICLE

The test vehicle was new or in as-new condition, meaning the vehicle had been driven no more than 500 miles prior to the start of dynamic rollover testing. It was acquired through a commercial rental/leasing company. Details of the test vehicle are given in Table 1.

B. TIRES

All tires used were new, and of the same make, model, size, and DOT specification of those installed on the vehicle when purchased new. Tire inflation pressures were in accordance with the recommendations indicated on each vehicle's identification placard. To reduce the possibility of tire debeading during Fishhook testing, an appropriately sized inner tube was installed in each tire. To further reduce the possibility of tire debeading, the tires were mounted to the rims without the use of tire mounting lubricant. Tire specifications are listed in Table 2.

C. VEHICLE LOADING

The multi-passenger load, described in the Fishhook Procedure, was used for all tests. The load and positioning of the load in the vehicle are listed in Table 3.

In addition to water dummies, the loading included instrumentation, a steering machine, and outriggers. Test vehicle bumper assemblies were removed for outrigger installation. The reduction in vehicle weight due to the removal of the bumpers was offset by the additional weight of the outriggers and their mounting system. The outrigger system typically outweighs the bumper assemblies.

Table 1. Test Vehicle Data

General Data					
Model year, make, model	2015 Chevrolet Silverado 2500 Extended Cab 4x4 4WD				
VIN	1GC2KWE81FZ10xxxx				
Body style	Ex. Cab Pickup				
Number of doors	4				
Trim level	LTZ Z71				
Seating positions	Front:	2nd row	3rd row	4th row	5th row
	2	3			
Electronic stability control	Yes				
4-Wheel ABS (Yes/No)	Yes				
Power steering (Yes/No)	Yes				
Major optional equipment	Allison 6-speed automatic trans Driver alert package: L TZ plus package: Heated & cooled seats driver & front passenger Z71 off-road package: 18" all-terrain blackwall tires				
Odometer at start of testing	12 miles				
Drivetrain					
Engine cylinder arrangement	V-8				
Engine displacement	6.6 L				
Transmission type	6 Speed Automatic				
Drive arrangement	4WD				
Chassis					
Track width	F: 68.6 in (1742.4 mm) , R: 67.4 in (1712 mm)				
Wheelbase	144.6 in (3672.8 mm)				
Curb weight	7030 lb (3188.8 kg)				
Certification Data from Vehicle's Label					
Vehicle manufactured by	General Motors LLC				
Date of manufacture	01/14				
GVWR	10000 lb (4536 kg)				
GAWR Front	5200 lb (2359 kg)				
GAWR Rear	6200 lb (2812 kg)				

Table 2. Tire Information

Tire Manufacturer	Michelin
Tire Model	LTX A/T
Tire Size	Front: LT265/70R18 Rear: LT265/70R18
Load rating	Front: E Rear: E
Speed rating	Front: NA Rear: NA
Treadwear grade	Front: NA Rear: NA
Traction grade	Front: NA Rear: NA
Temperature grade	Front: NA Rear: NA
Location of “Recommended Tire Pressure” label	Driver side door jamb
Recommended cold tire pressure	Front: 60 psi, (420 kPa) Rear: 70 psi, (480 kPa)
First 8 digits of DOT code	Front: B3AC 001X Rear: B3AC 001X

Table 3. Vehicle Loading

Water dummy and other loading	3 water dummies in second row
Water dummy weight	525 lb (238.1 kg)
Fuel level	Full
Weight as Tested	
Left front	2521 lb (1143.5 kg)
Right front	2434 lb (1104 kg)
Left rear	1740 lb (789.3 kg)
Right rear	1660 lb (753 kg)

D. STEERING CONTROLLER

A programmable steering machine was installed which generates handwheel steering inputs for all test maneuvers. The machine provides at least 35 lb-ft of torque at a handwheel rate of 720 deg/sec, is capable of actuating the vehicle's steering system through its full range, and accepts angular rate sensor feedback input for roll rate-induced steering reversals.

E. INSTRUMENTATION AND DATA COLLECTION

The test vehicle was instrumented with an angle encoder, located in the steering controller; a 3-axis inertial measurement unit to measure roll, pitch, and yaw rates, and longitudinal, lateral, and vertical acceleration; two ultrasonic distance measuring sensors to measure vehicle roll angle; and a radar speed sensor to measure vehicle speed. The brake light circuit was monitored to verify that there was no brake pedal application during any test.

A list of the sensors is given in Table 4. A 3B signal conditioning and power rack was used to provide any necessary sensor power, excitation, gain, and offset. Two pole Butterworth anti-alias filters were used for all analog data channels, using a corner frequency of 20 Hz. Data were collected at 200 samples/sec, using a Measurement Computing Corp. PCI-DAS6402/16 A/D board.

Two video cameras were used to record the Fishhook runs. They were positioned nominally as shown in Figure 1. The recorded videotapes were reviewed after the Fishhook runs to check for any two wheel lift. If any two wheel lift was observed, eight infrared distance measuring sensors for measurement of wheel lift (two sensors at each wheel) were then mounted for use in subsequent confirmation Fishhook tests.

F. OTHER VEHICLE PREPARATION

In addition to installation and preparation discussed above, the test vehicle was prepared as follows:

- Front and rear bumpers were removed
- Outrigger mounts were installed in the bumper locations and titanium outriggers were fastened to these mounts
- A five point safety harness was installed.
- Airbags were removed or otherwise disabled

Photographs of the vehicle tested are given in Appendix A.

Table 4. Sensors

Data Measured	Type	Range	Manufacturer	Model Number
Handwheel angle	Encoder	Infinite	Automotive Testing, Inc.	Angle encoder integral with steering controller
Brake pedal actuation	Tape Switch	On/Off	Vericom Computers	VC3000
Longitudinal, lateral, and vertical acceleration	Multi-axis inertial sensing system	±2 g	BEI Technologies, Inc., Systron Donner Inertial Division	MP-1
Roll, pitch, and yaw rate		±100 deg/s		
Left and right side vehicle ride height (to measure roll angle)	Ultrasonic distance measuring system	4 - 40 inches	Massa Products Corp.	M-5000/220kHz
Vehicle speed	Radar speed sensor	0.1 - 125 mph	B+S Software und Messtechnik GmbH	DRS-6
Wheel lift (via resolution of two measured distances spaced a known distance apart), used for confirmation tests only	Analog displacement measuring system (Infrared; 880 mm)	13.8 - 33.5 in	Wenglor Sensors, Ltd.	HT 66MGV80

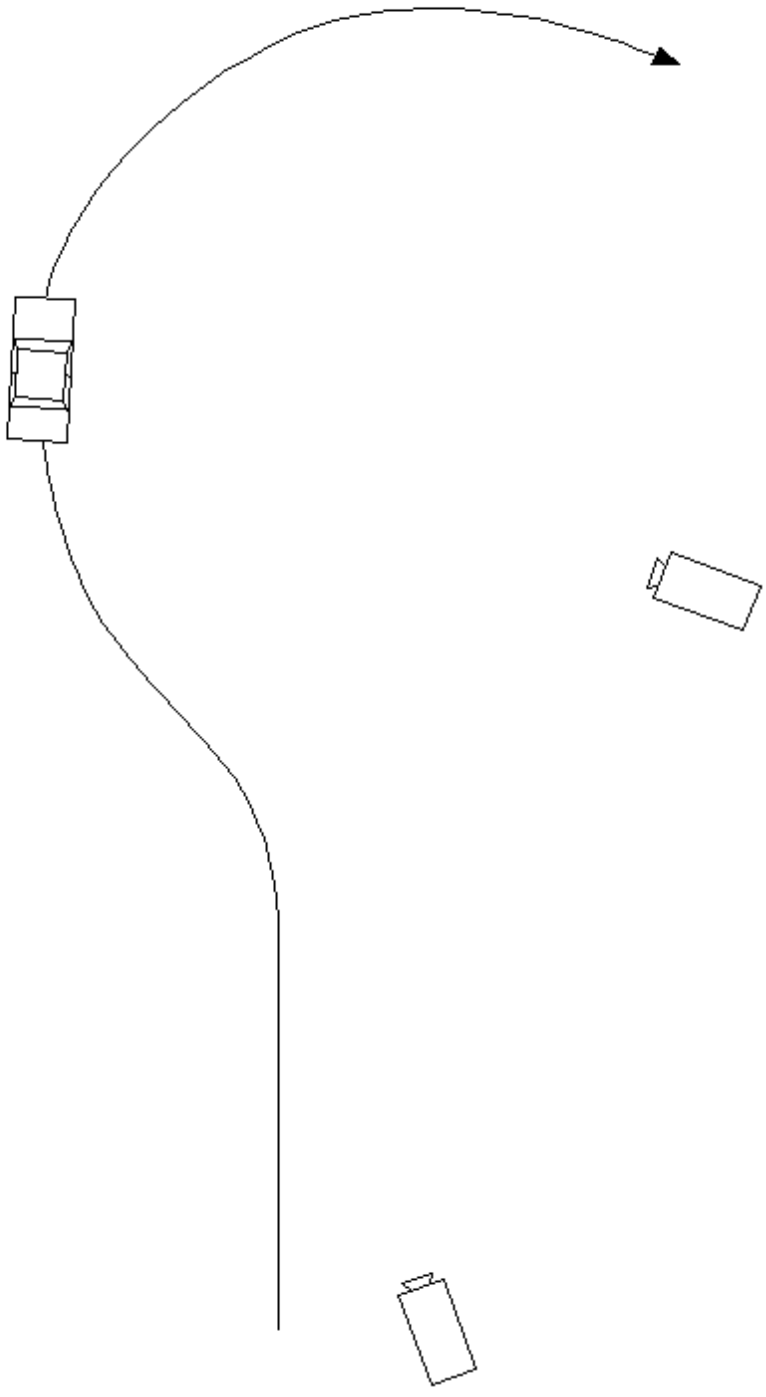

Figure 1. Nominal Position of Video Cameras for Fishhook Tests

Section III
TEST PROCEDURES

This section includes a general overview of the test procedures and details of the particular test.

A. TEST PROCEDURE OVERVIEW

This test was conducted in accordance with NHTSA's NCAP Rollover Resistance Test Procedure (Fishhook) as described in the Federal Register (68 FR 59250). Detailed descriptions of the test procedure, pass/fail criteria, and data acquisition specifications may be found at docket NHTSA-2001-9663.

There are two major components of the test procedure, the Slowly Increasing Steer (SIS) pre-test and the Fishhook test.

The Slowly Increasing Steer (SIS) maneuver was used to characterize the steady state lateral dynamics of each vehicle, and is based on the "Constant Speed, Variable Steer" test defined in SAE J266. The maneuver is used to determine the handwheel angle that produces a lateral acceleration of 0.3 g at 50 mph. This handwheel angle is then used to determine the magnitude of steering to be used for the NHTSA Fishhook maneuver.

SIS tests were performed at a constant speed of 50 mph. Handwheel angle was input at a rate of 13.5 deg/sec, from 0 to an angle that provided at least 0.55 g. Three tests were conducted in each direction, and the data for the six runs were averaged to obtain the handwheel angle that produced 0.3 g at 50 mph.

The Fishhook test is a programmed steering maneuver that is implemented via the steering controller. The vehicle was initially steered in one direction and then the steering was reversed. The timing, magnitude and rate of the steering were prescribed by the Fishhook Procedure.

To begin the maneuver, the vehicle was driven in a straight line at a speed slightly greater than the desired entrance speed. The driver then released the throttle. When the vehicle was at the target speed, the steering controller automatically initiated the steering maneuver. Following completion of the steering reversal the handwheel position was maintained for three seconds, and then returned to zero angle in 1 second.

The tests were conducted in both left-right and right-left directions. The “Default” test series used a handwheel angle equal to 6.5 times the handwheel angle that produced 0.3 g at 50 mph in the SIS tests, and initial vehicle speeds beginning at 35 mph and concluding up to 50 mph (if no two-wheel lift occurs). Supplemental tests were also done, as specified in the Fishhook Procedure.

B. TEST CONDITIONS

1. Test Surface

The tests were conducted on the Vehicle Dynamics Area at DRI’s Minter Field facility, located near Bakersfield, California, on 4/3/2014. The VDA has a smooth, flat (slope less than 0.5% throughout) asphaltic concrete surface. Its dimensions are as shown in Figure 2. It was built in the spring of 2005.

VDA surface friction measurements were accomplished using the DRI Mobile Tire Tester. Three runs were done, one at each of three previously determined locations. Each run provided for a minimum of 3 seconds of tire friction at constant normal load, slip angle, and speed in a free rolling condition. The test was accomplished using an ASTM E1136 tire with an inflation pressure of 35 (±0.5) psi at a test speed of 40 (±0.5) mph. The net slip angle of the test tire for each test run was 7.5 deg. The test tire was no older than 6 months from the date of manufacture. The surface friction measurement results are shown in Table 5.

Table 5. Surface Friction

Date of surface friction measurements	4/3/2014
Average normalized lateral force	0.83

2. Fishhook Handwheel Angles

The 0.3g handwheel angle obtained from the SIS tests and the handwheel angles used in the Fishhook tests are shown in Table 6.

Table 6. Handwheel Angles

0.3g handwheel angle (from SIS tests at 50 mph)	51.2 º
5.5 scalar handwheel angle for Fishhook Test	333 º
6.5 scalar handwheel angle for Fishhook Test	282 º

3. Weather Conditions

The weather conditions, recorded at the end of testing, are shown in Table 7.

Table 7. Weather Conditions

Ambient temperature	66 ºF (18.9 ºC)
Wind Speed	5 mph (2.2 m/s)
Wind Direction	N-NW

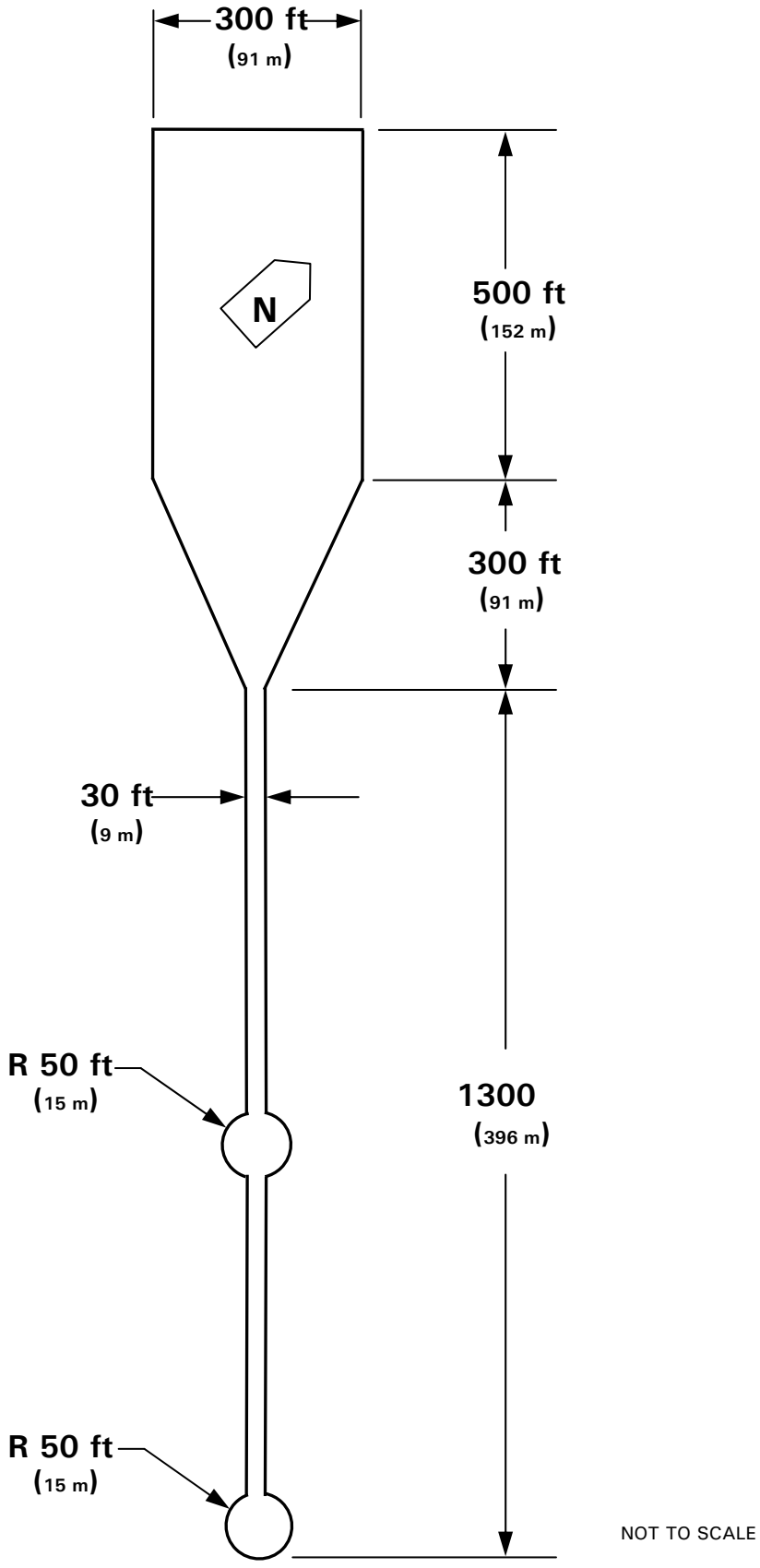

Figure 2. DRI-Minter Vehicle Dynamics Area

Section IV
RESULTS

The test run log is given in Appendix B. The Slowly Increasing Steer Test Worksheet is given in Appendix C. Appendix D contains time history plots for the 50 mph runs and any runs which resulted in two-wheel lift. For the 2015 Chevrolet Silverado 2500 Extended Cab 4x4 4WD, there was no two-wheel lift at any test condition.

APPENDIX A

Photographs

LIST OF FIGURES

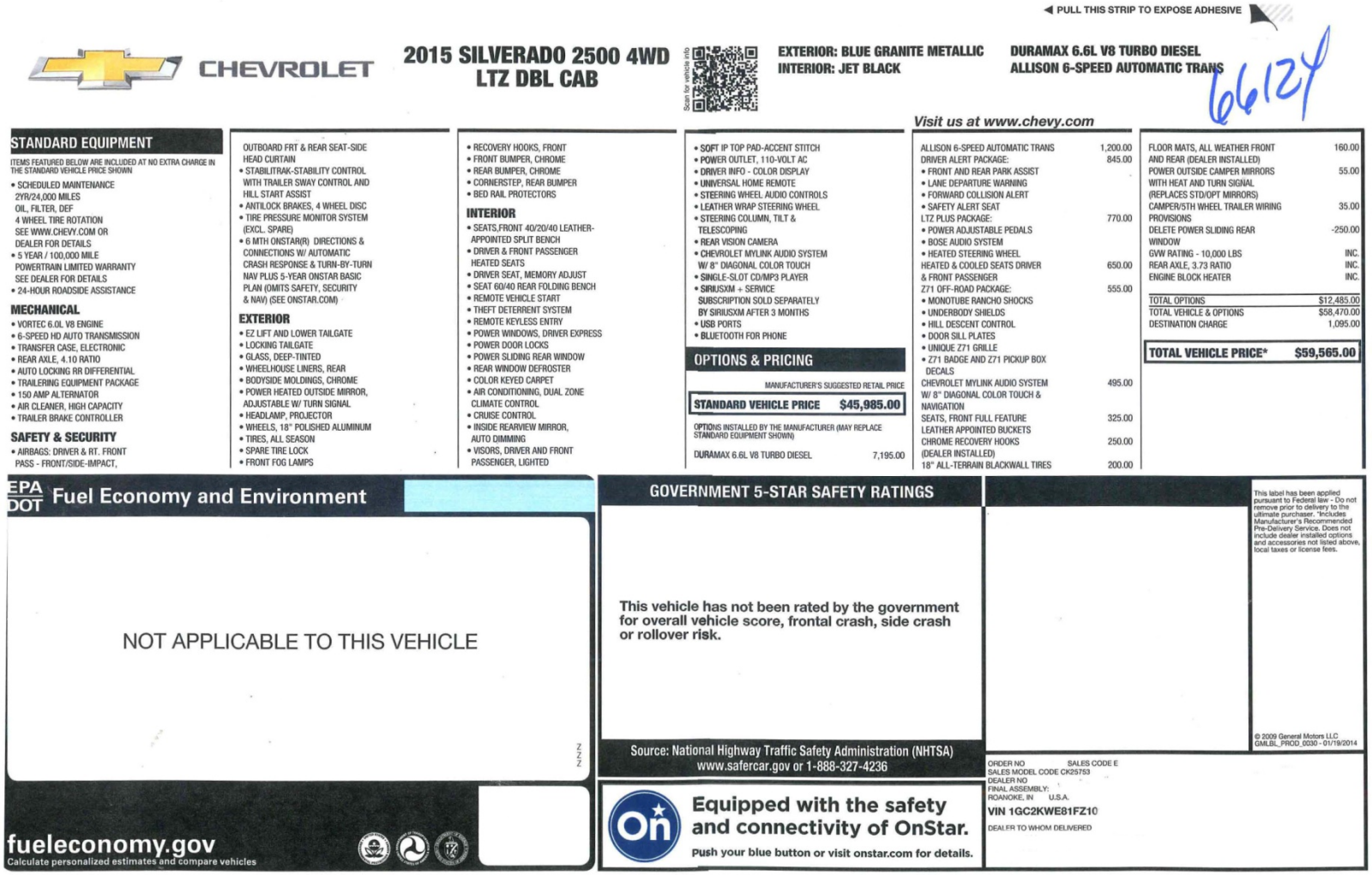

Figure A1. Window Sticker

Figure A2. Front View, Test Vehicle as Delivered

Figure A3. Rear View, Test Vehicle as Delivered

Figure A4. Front View, Test Vehicle in Test Condition

Figure A5. Rear View, Test Vehicle in Test Condition

Figure A6. Instrumentation in Test Vehicle

Figure A7. Ballast Condition

APPENDIX B

Test Run Log

Vehicle: **2015 Chevrolet Silverado 2500 Extended Cab 4x4 4WD** Driver: **Brian Kebschull** Date: **4/3/2014**

Run Number	Test Type	Speed (mph)	Handwheel Angle (deg)	Dir. of First Steer	2 Wheel Lift	Notes
0	Distance		0	NA	NA	Distance Calibration (ft): 998.6
1	Tire Warm-Up	35	160	NA	NA	NG
2	Tire Warm-Up	35	160	NA	NA	
3	Tire Warm-Up	35	160	NA	NA	
4	Tire Warm-Up	35	160	NA	NA	
5	Tire Warm-Up	35	160	NA	NA	
6	Static	0	0	NA	NA	
7	Dynamic	50	0	NA	NA	
8	SIS	50	160	Left	NA	
9	SIS	50	160	Left	NA	
10	SIS	50	160	Left	NA	
11	SIS	50	160	Right	NA	
12	SIS	50	160	Right	NA	
13	SIS	50	160	Right	NA	
14	Fishhook	35	333	Left	No	6.5 x scalar
15	Fishhook	40	333	Left	No	
16	Fishhook	45	333	Left	No	
17	Fishhook	47.5	333	Left	No	
18	Fishhook	50	333	Left	No	
19	Fishhook	35	333	Right	No	
20	Fishhook	40	333	Right	No	
21	Fishhook	45	333	Right	No	
22	Fishhook	47.5	333	Right	No	
23	Fishhook	50	333	Right	No	

Vehicle: **2015 Chevrolet Silverado 2500 Extended Cab 4x4 4WD** Driver: **Brian Kebschull** Date: **4/3/2014**

Run Number	Test Type	Speed (mph)	Handwheel Angle (deg)	Dir. of First Steer	2 Wheel Lift	Notes
24	Fishhook	45	282	Right	No	5.5 x scalar
25	Fishhook	47.5	282	Right	No	
26	Fishhook	50	282	Right	No	
27	Fishhook	45	282	Left	No	
28	Fishhook	47.5	282	Left	No	
14	Fishhook	35	333	Left	No	6.5 x scalar
15	Fishhook	40	333	Left	No	
29	Fishhook	50	282	Left	No	

APPENDIX C

Slowly Increasing Steer Test Worksheet

NCAP, 2015 Chevrolet Silverado 2500 Extended Cab 4x4 4WD, Multi-Passenger Load,
Test Date: 4/3/2014

SIS_out_v2

Run	Dir of Steer	Start Speed (mph)	End Speed (mph)	Speed Red. (%)	Index of ay @ 0.3g	HW Angle (deg) at 0.3g	ay (g) @ 0.3g index	6.5x HW Angle (deg)	Ramp Time (sec) at 6.5x	5.5x HW Angle (deg)	Ramp Time (sec) at 5.5x	R2	Zero Begin Index	Zero End Index
8	1	50.3	3.4	93.1	1445	-51.3	-0.311	-333.4	-0.4631	-282.1	-0.3918	0.9913	505	705
9	1	50.3	0.4	99.2	1425	-50.7	-0.303	-329.8	-0.4581	-279.1	-0.3876	0.9924	496	696
10	1	50.4	3.8	92.5	1432	-52.8	-0.299	-343.2	-0.4767	-290.4	-0.4034	0.9943	471	671
11	0	50.4	0.0	100.0	1405	49.7	0.289	322.9	0.4485	273.2	0.3795	0.9924	470	670
12	0	50.2	0.2	99.7	1430	50.7	0.296	329.3	0.4574	278.6	0.3870	0.9935	494	694
13	0	50.4	0.2	99.7	1462	52.3	0.301	339.6	0.4717	287.4	0.3991	0.9950	496	696
					Mean:	51.2	0.3	333	0.463	282	0.391			

Steering Controller Input Values

Scalar 6.5 values:

Initial HW angle:	333	deg
Initial time:	0.463	s
Reversal HW angle:	-333	deg
Reversal time:	0.925	s

Scalar 5.5 values:

Initial HW angle:	282	deg
Initial time:	0.391	s
Reversal HW angle:	-282	deg
Reversal time:	0.783	s

APPENDIX D

Time History Plots

LIST OF FIGURES

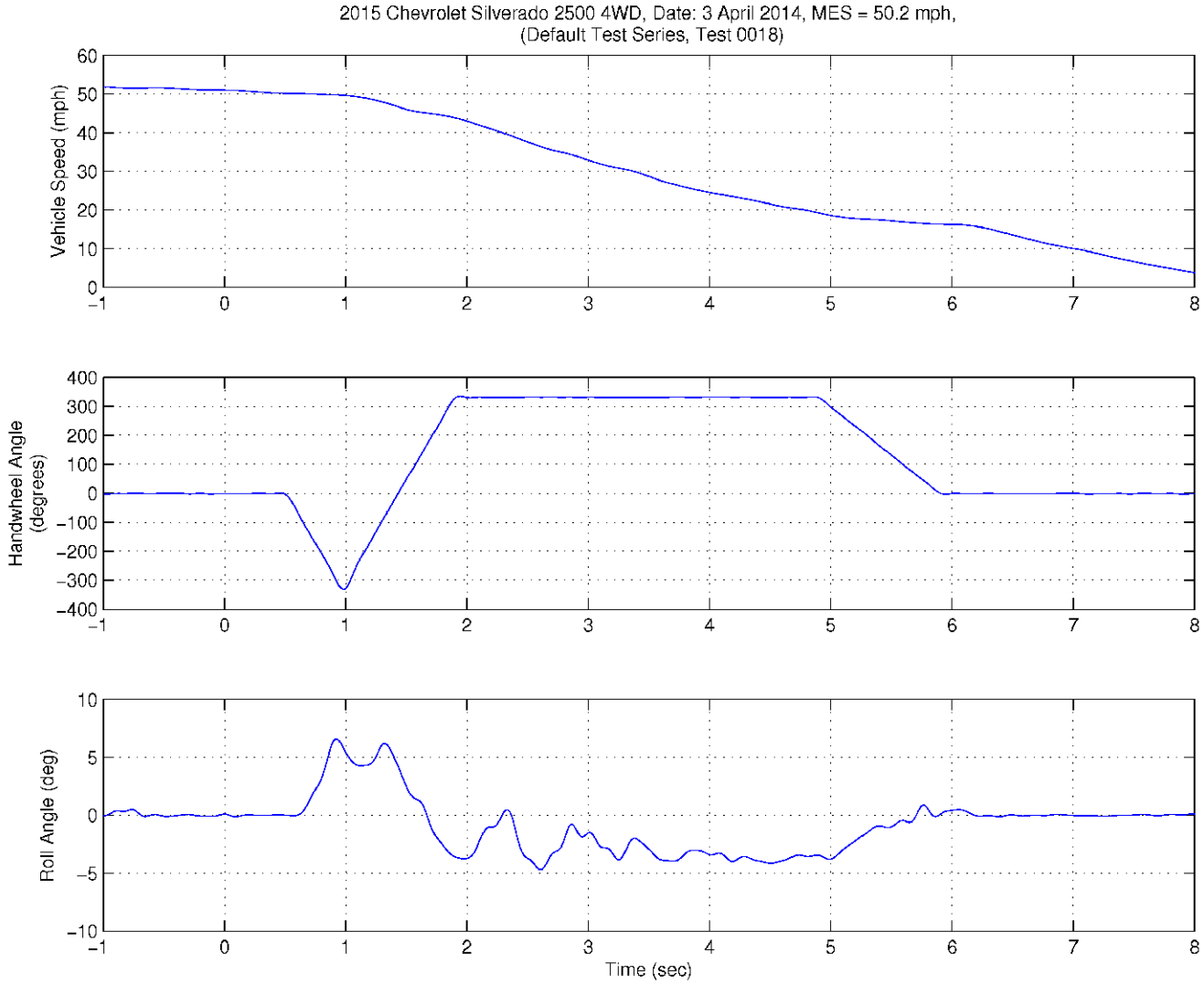

Figure D1. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Default Test Series, L-R, 50 mph

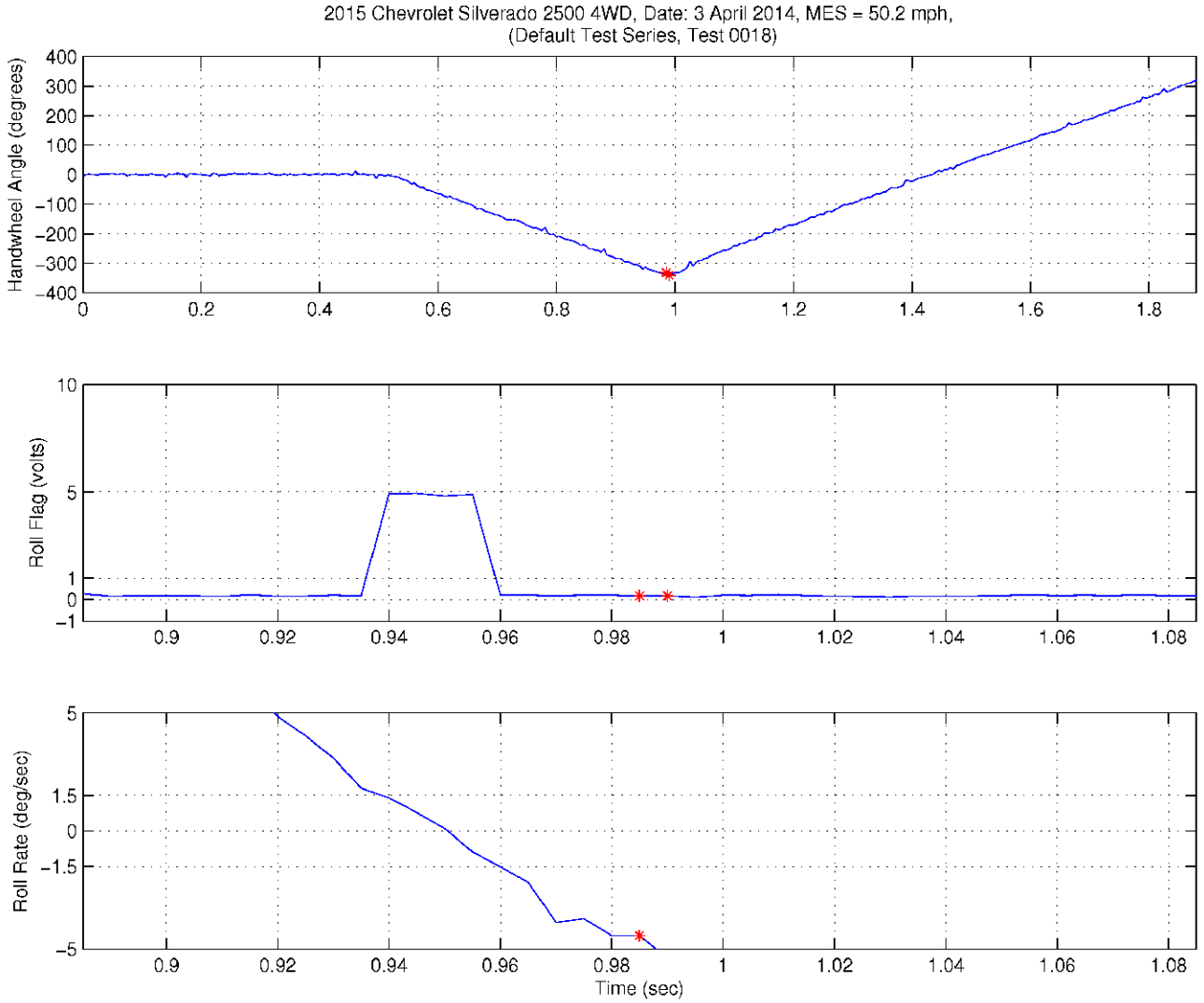

Figure D2. Steering Machine Operation Time History Plots for Default Test Series, L-R, 50 mph

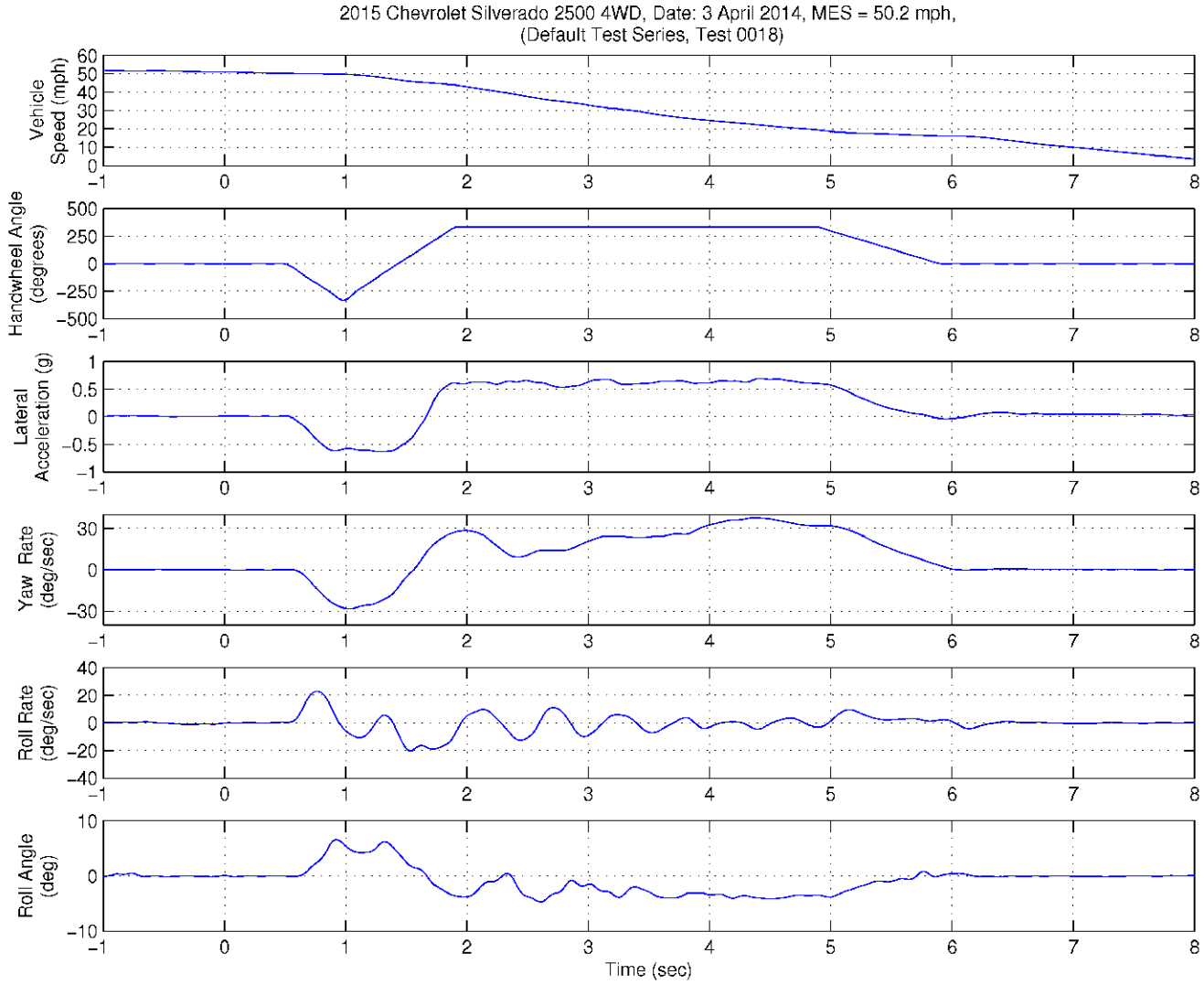

Figure D3. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots For Default Test Series, L-R, 50 mph

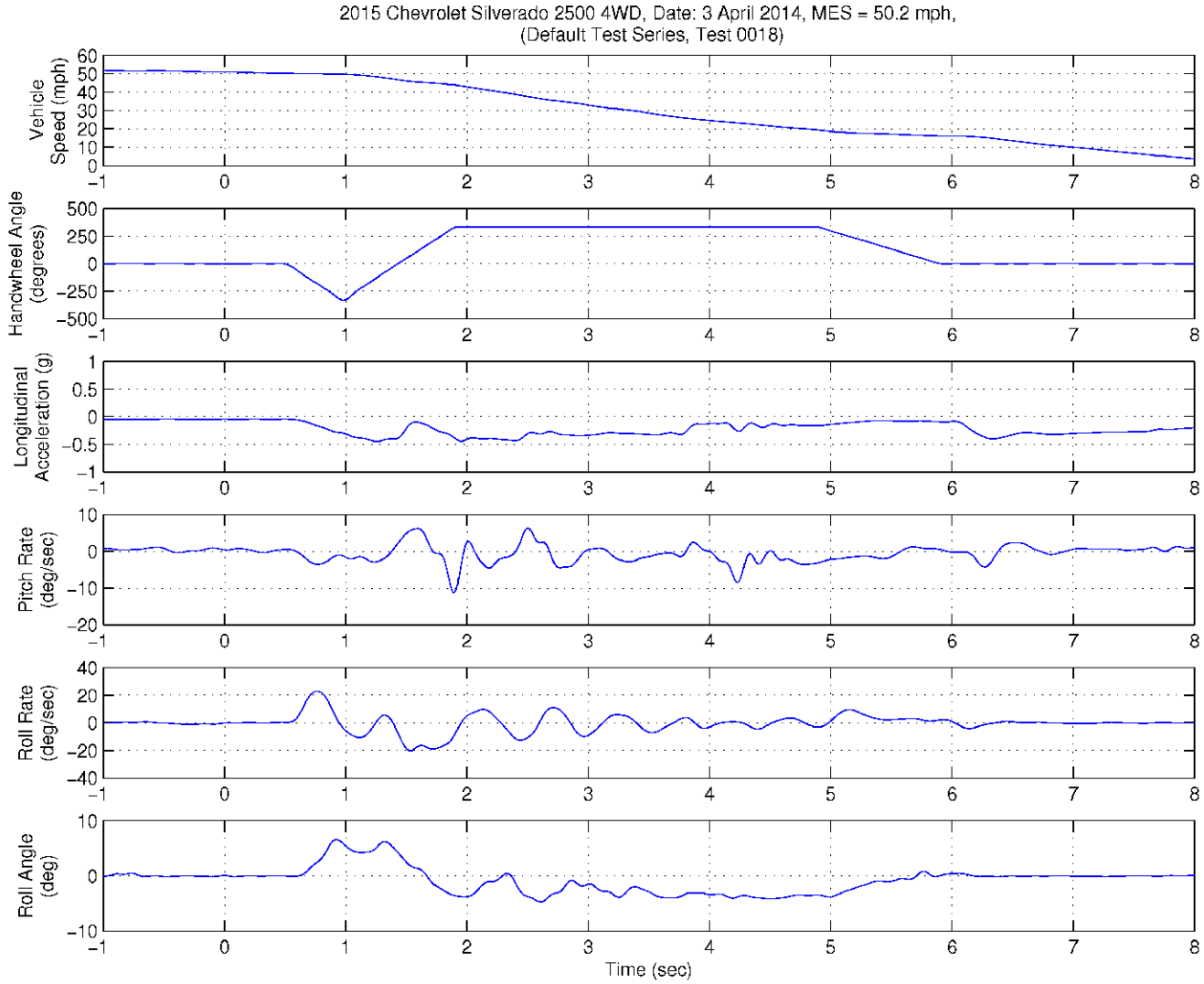

Figure D4. Pitch Rate and Longitudinal Acceleration Time History Plots for Default Test Series, L-R, 50 mph

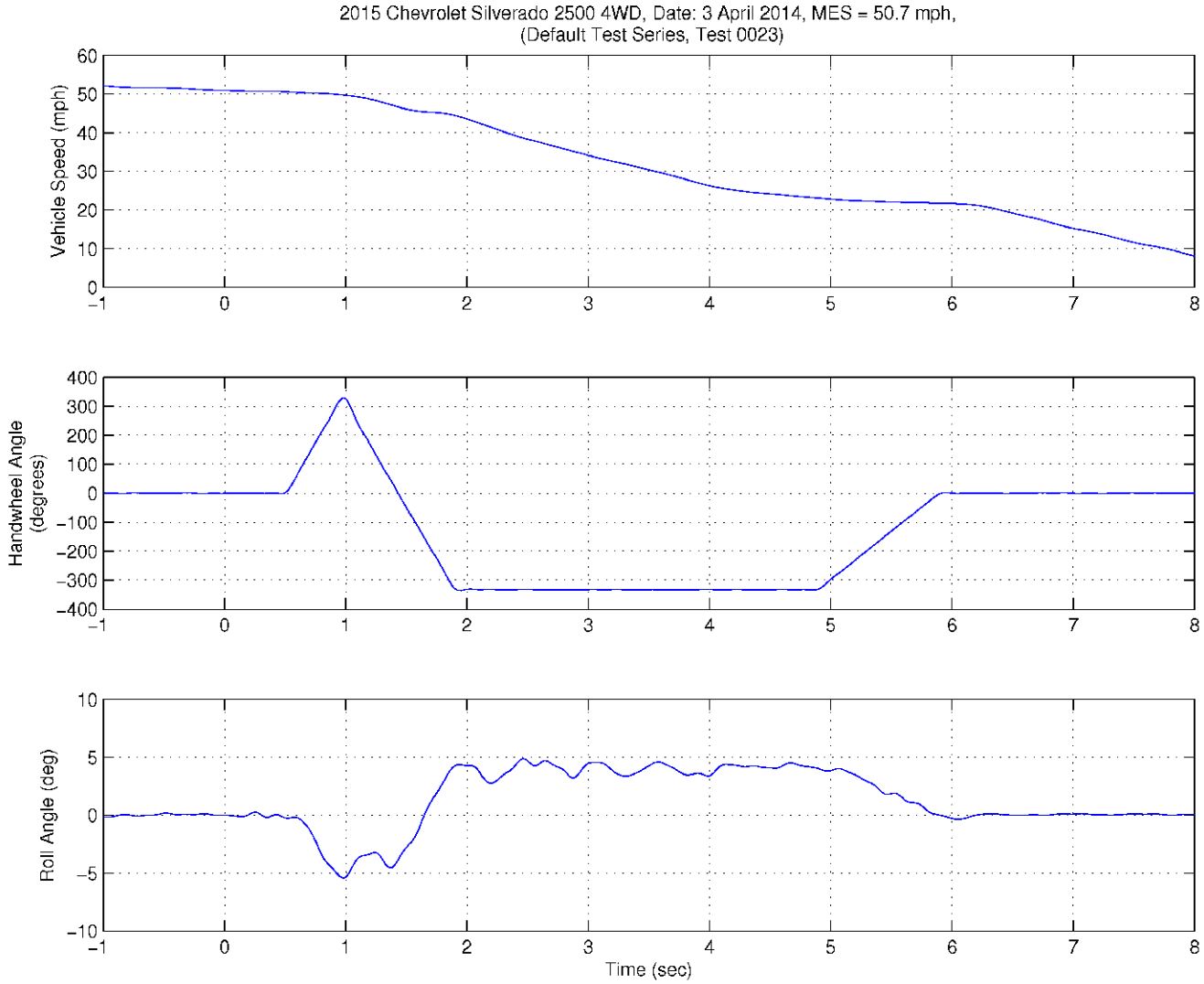

Figure D5. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Default Test Series, R-L, 50 mph

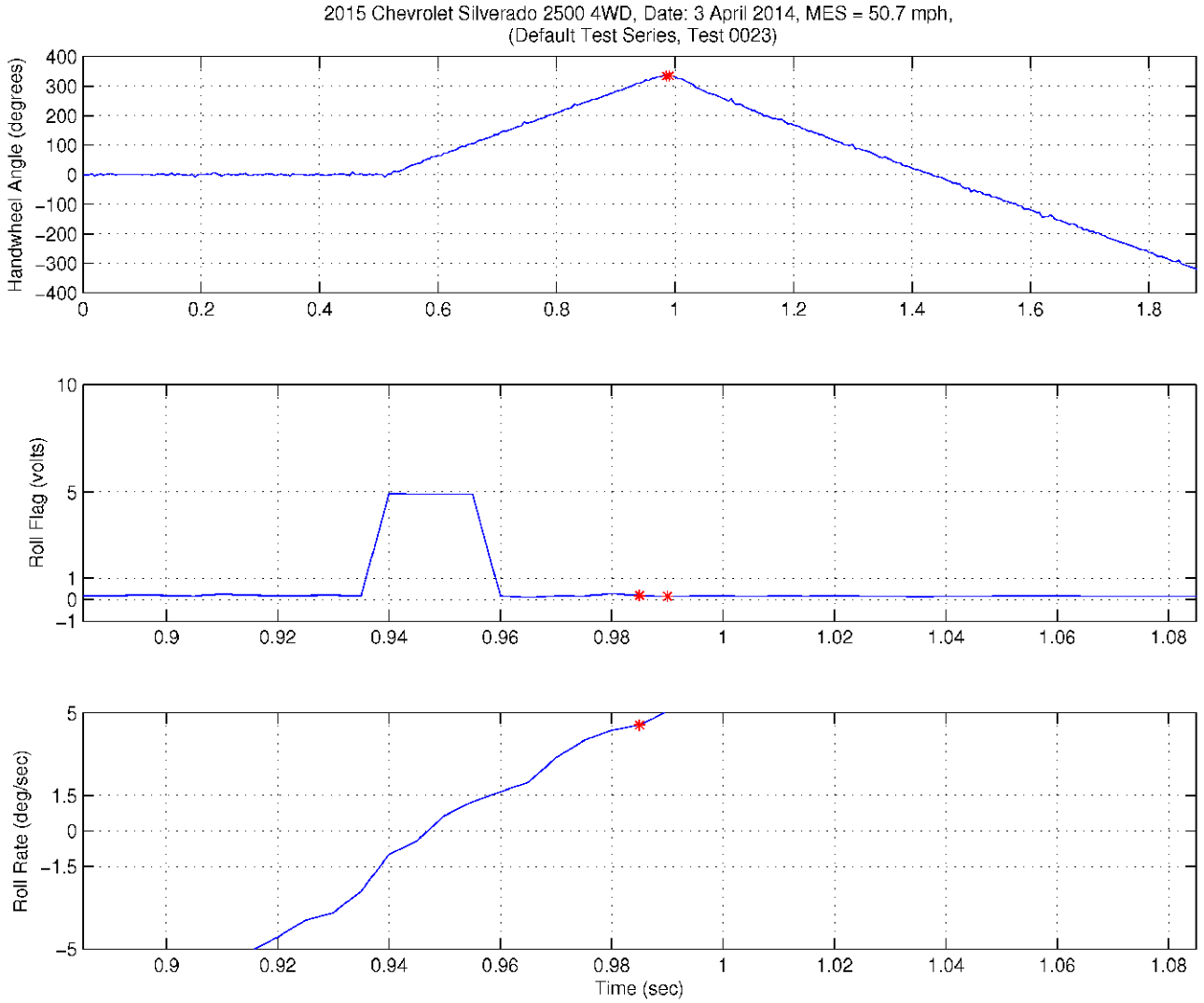

Figure D6. Steering Machine Operation Time History Plots for Default Test Series, R-L, 50 mph

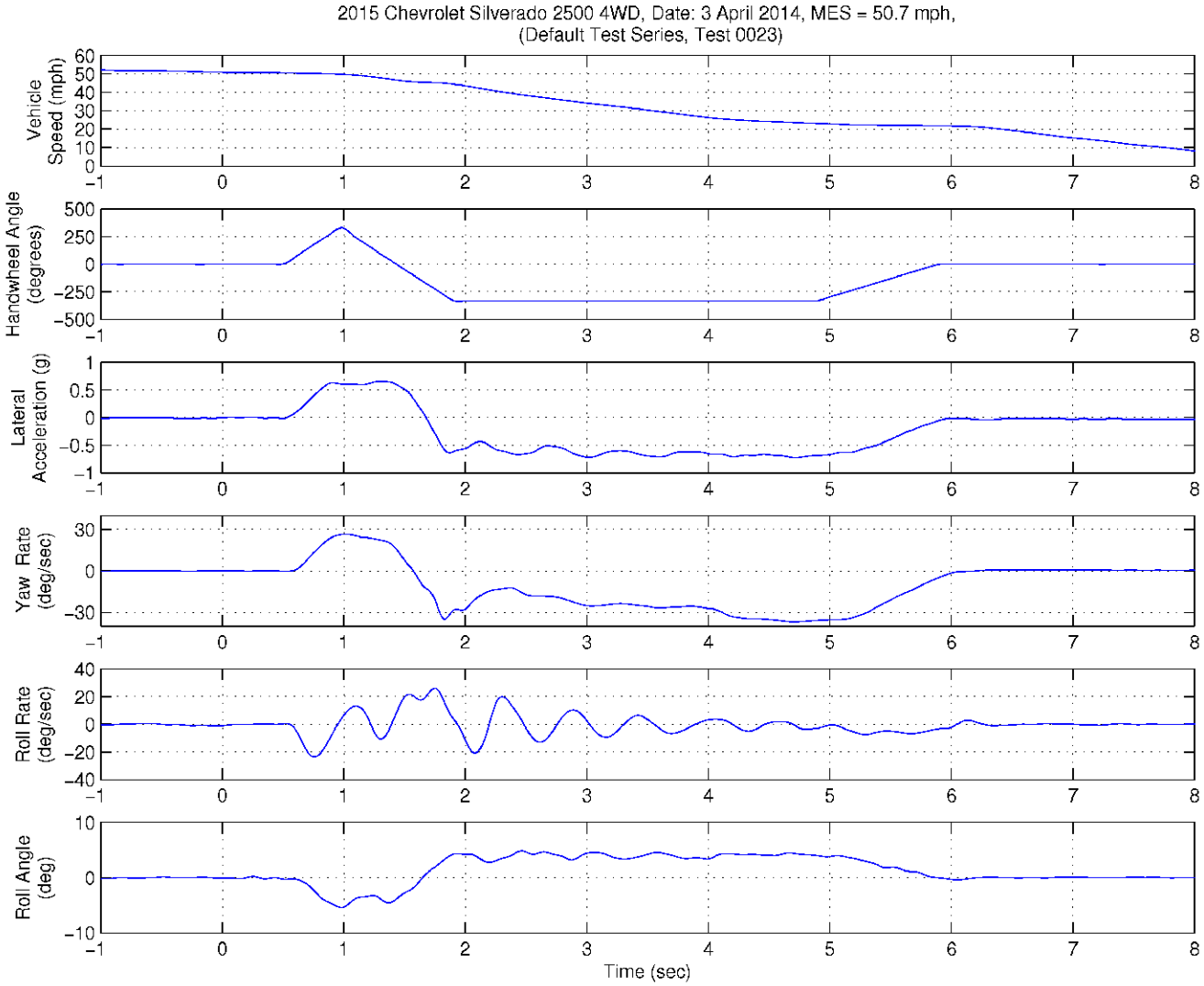

Figure D7. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots for Default Test Series, R-L, 50 mph

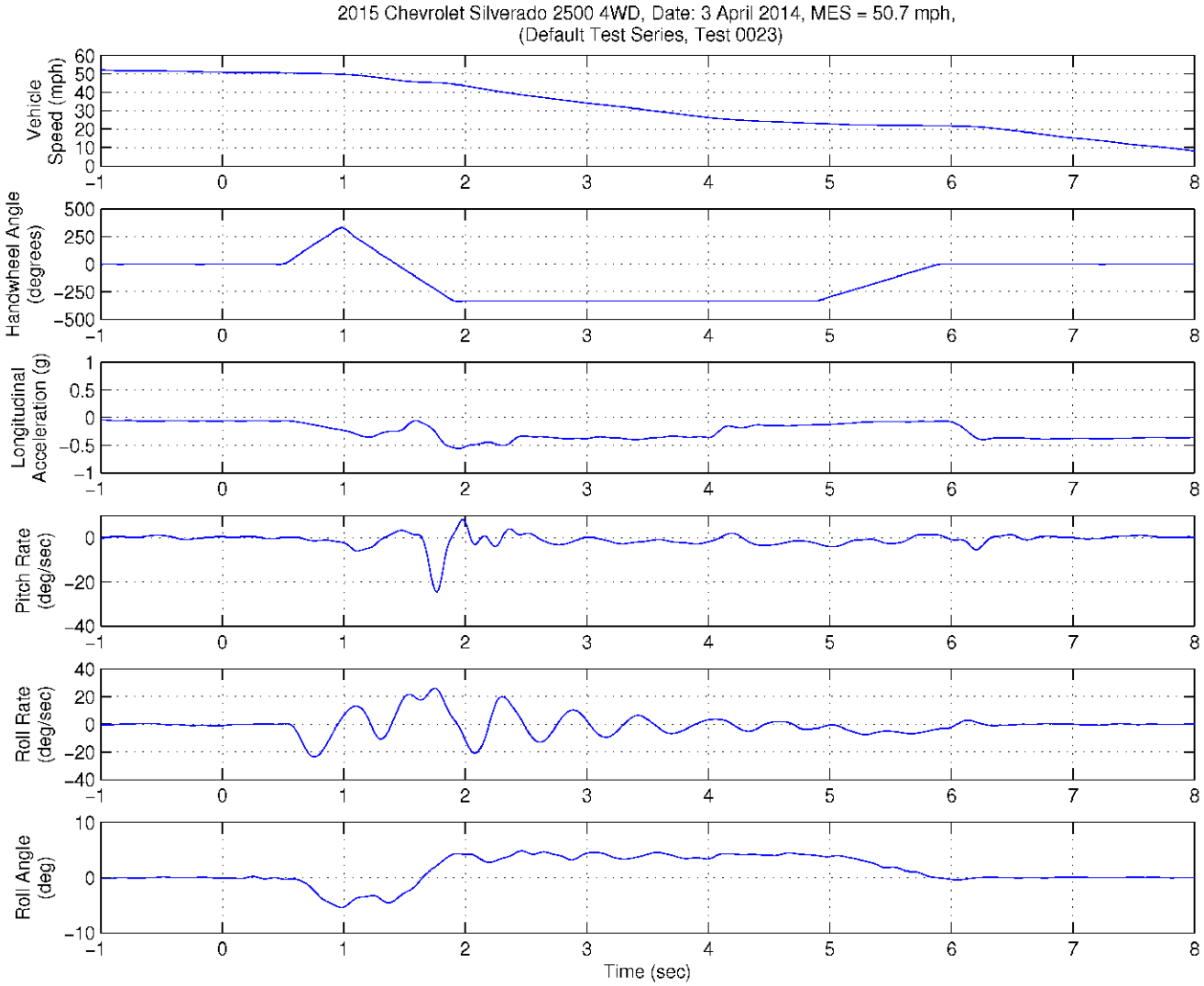

Figure D8. Pitch Rate and Longitudinal Acceleration Time History Plots or Default Test Series, R-L, 50 mph

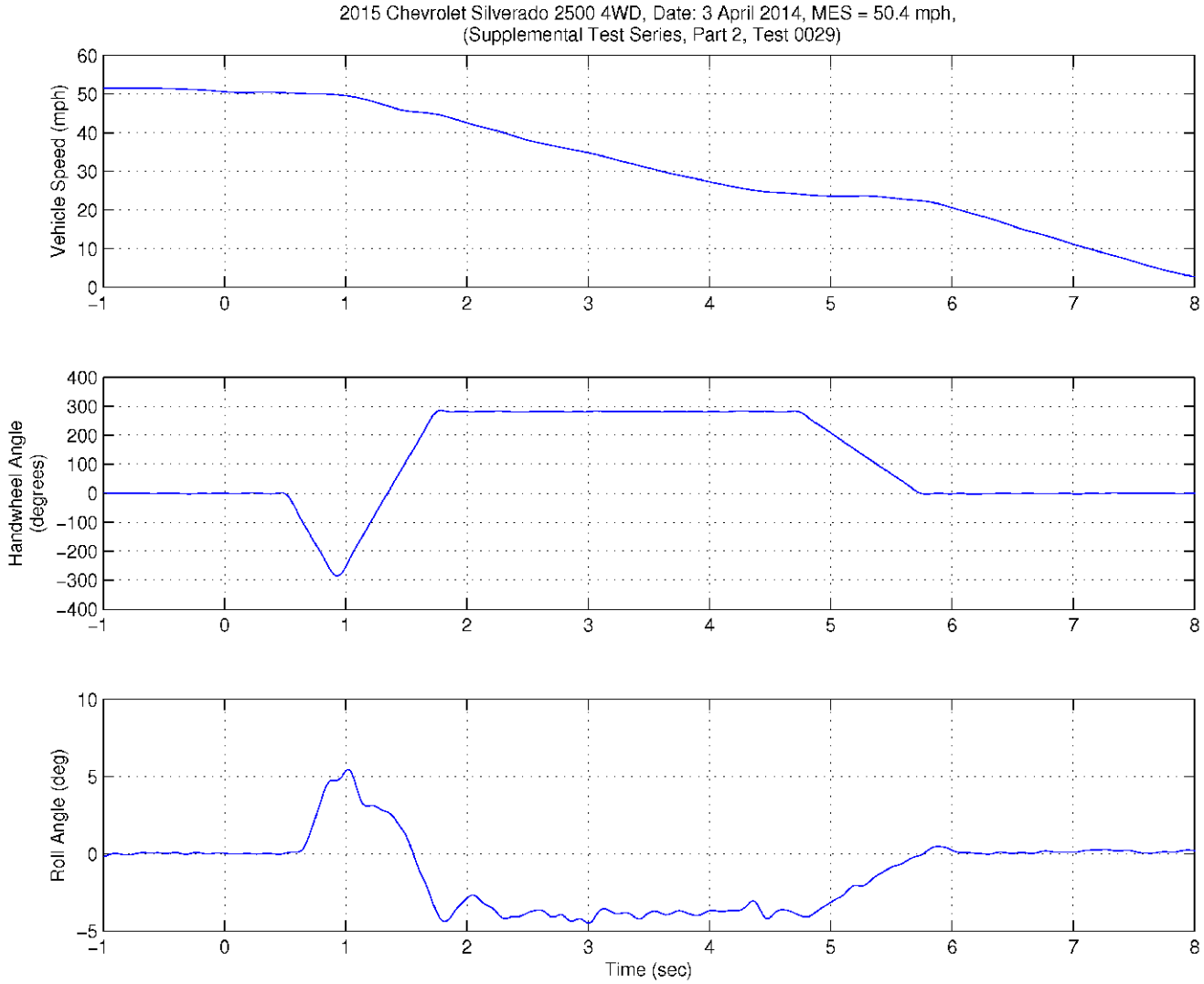

Figure D9. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

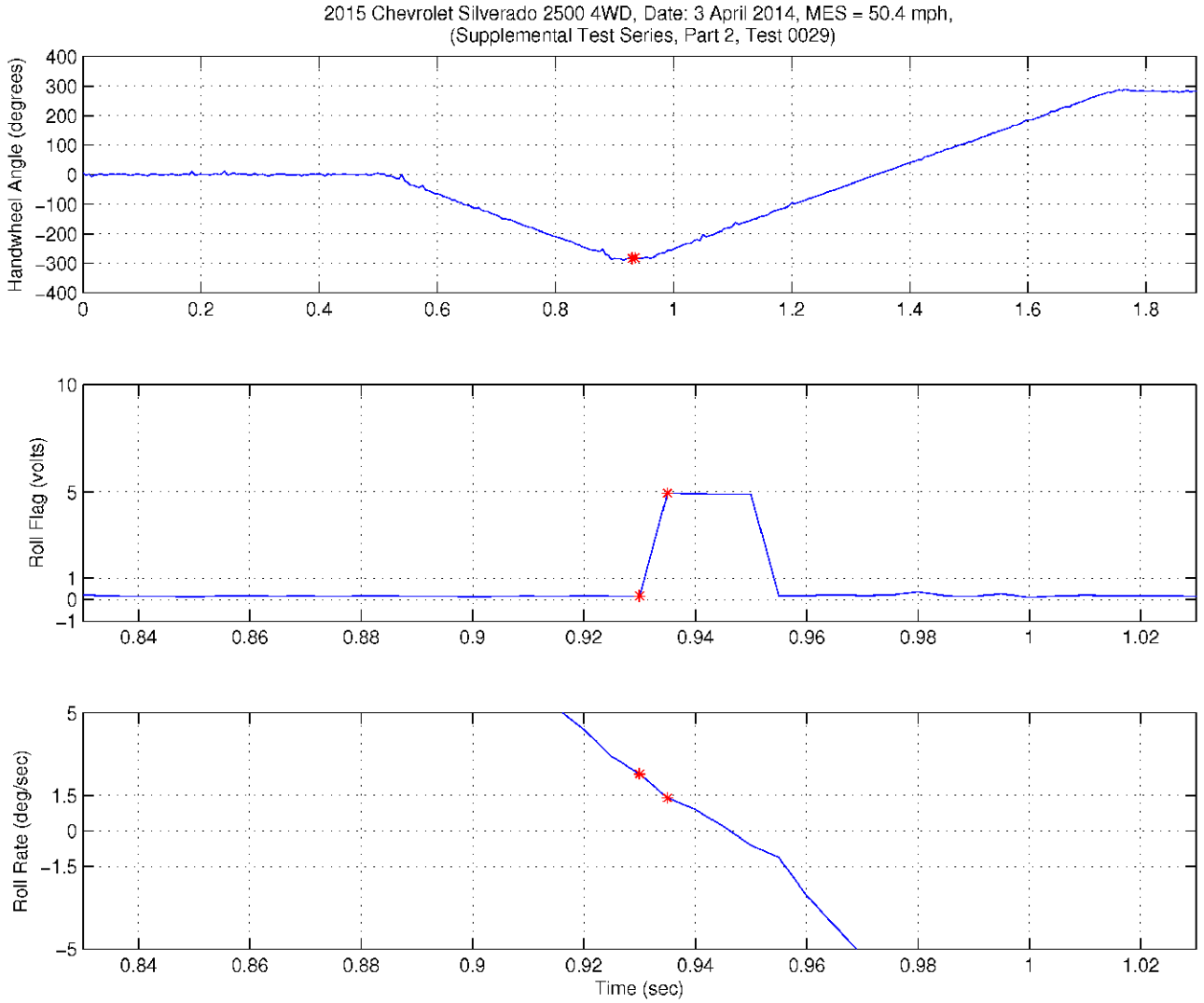

Figure D10. Steering Machine Operation Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

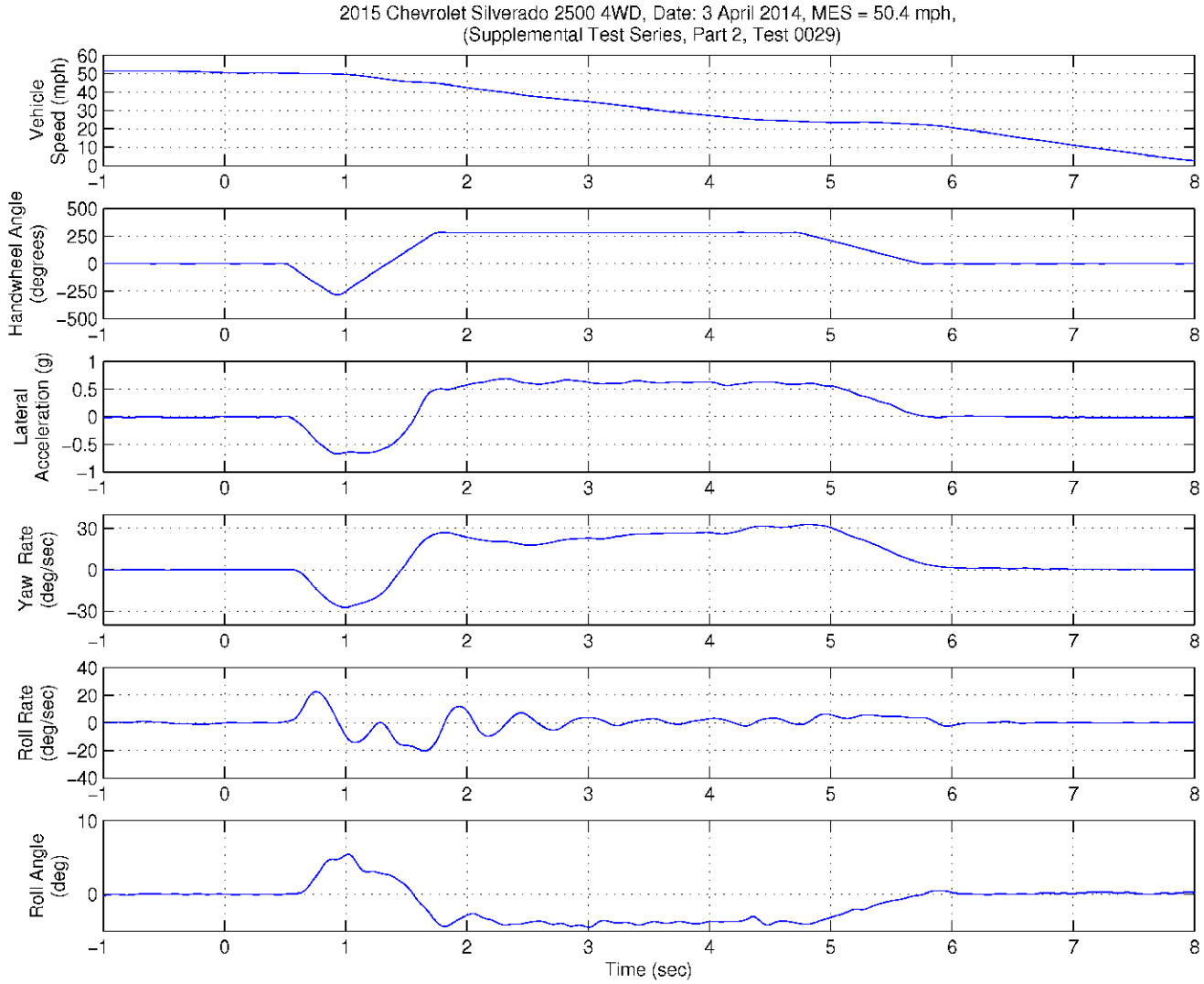

Figure D11. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

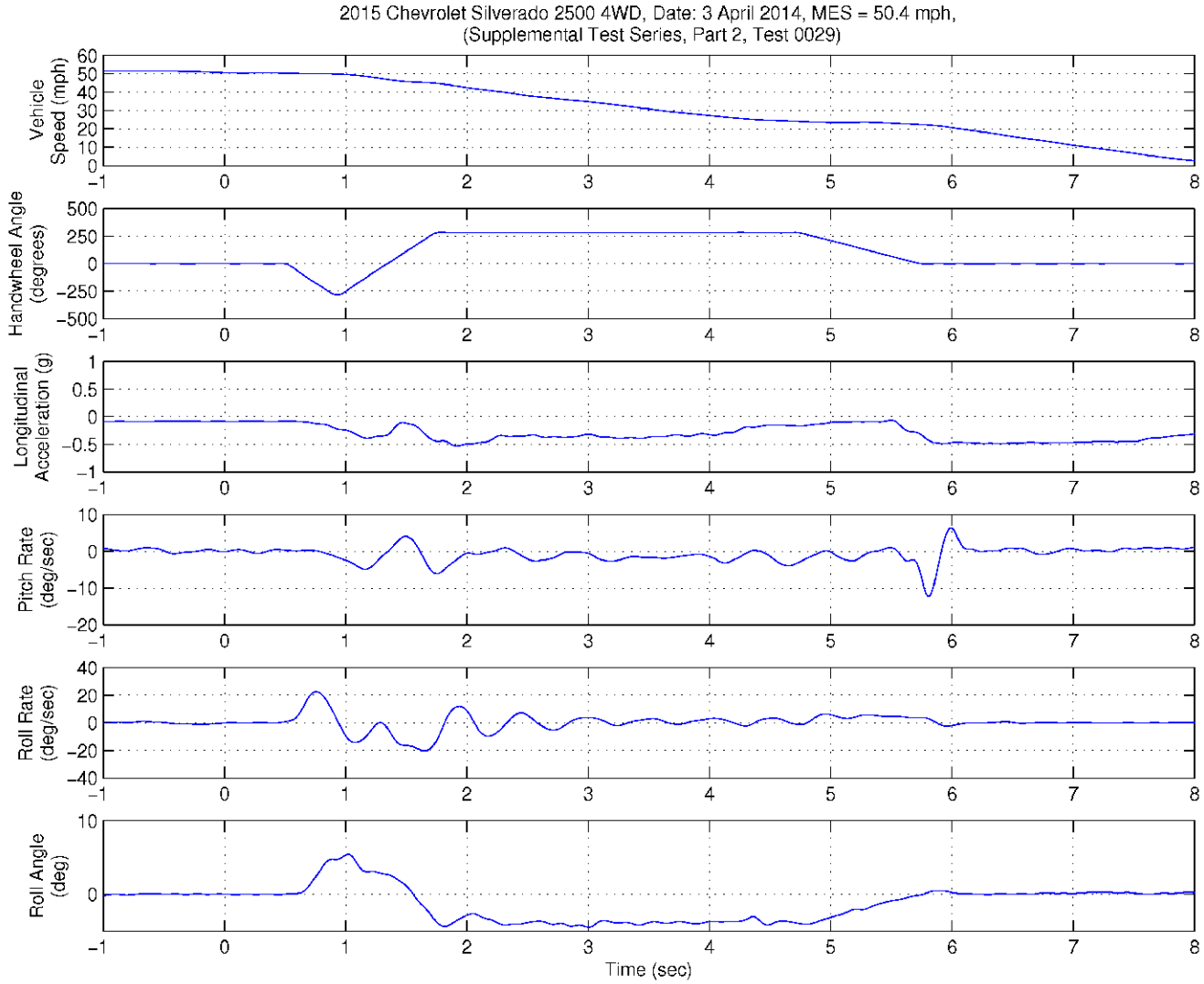

Figure D12. Pitch Rate and Longitudinal Acceleration Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

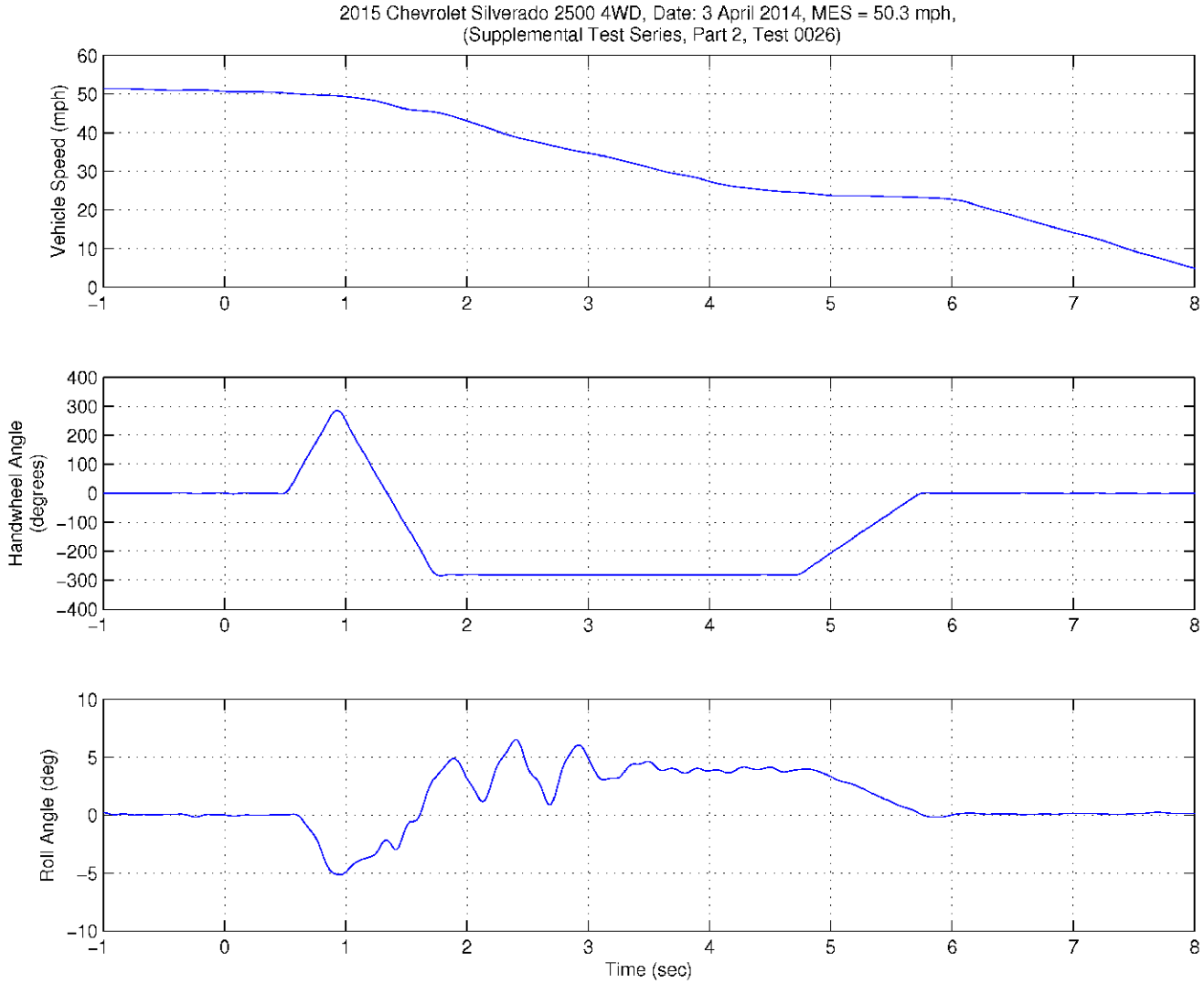

Figure D13. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Supplemental 2 Test Series, R-L, 50 mph

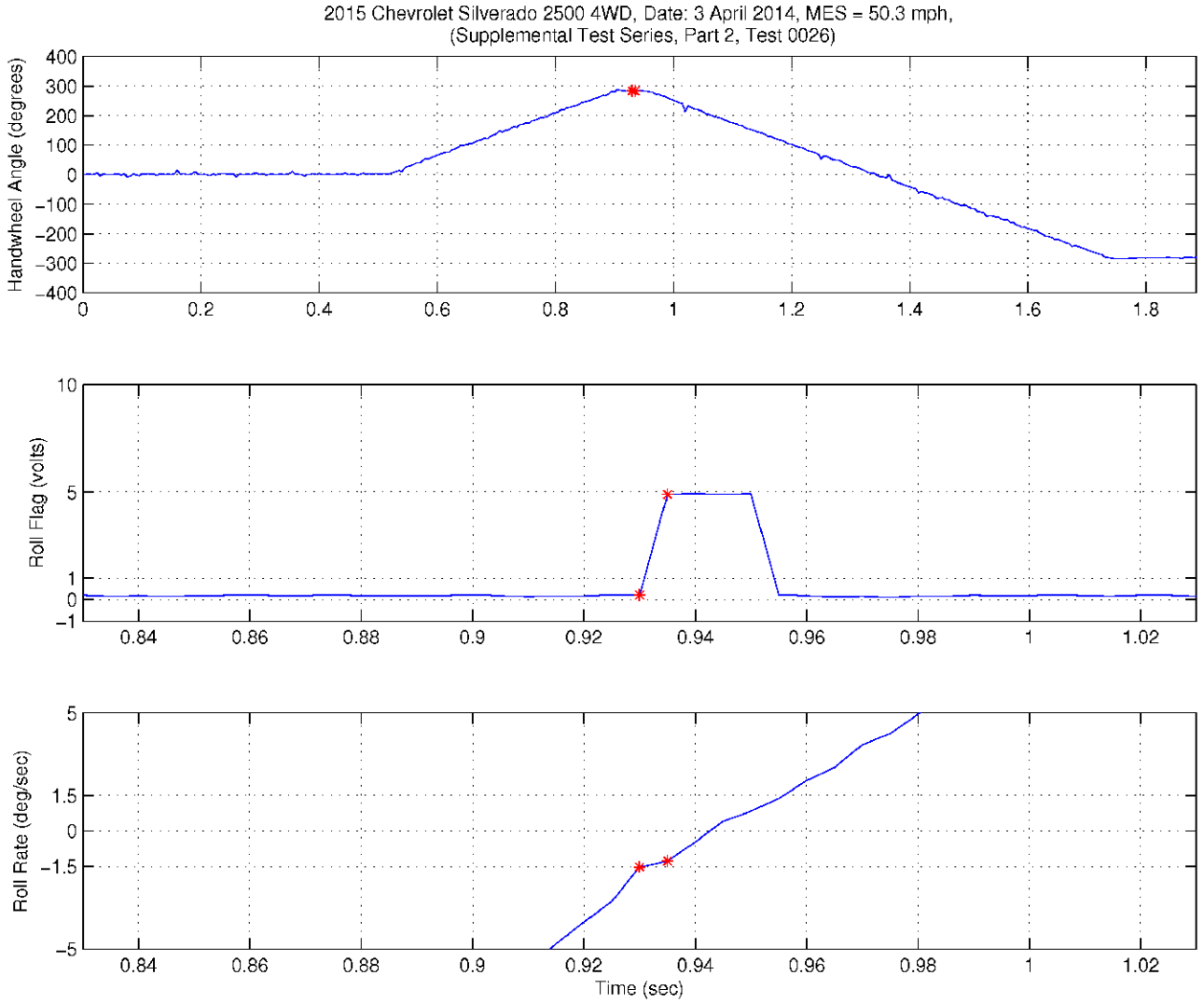

Figure D14. Steering Machine Operation Time History Plots for Supplemental 2 Test Series, R-L, 50 mph

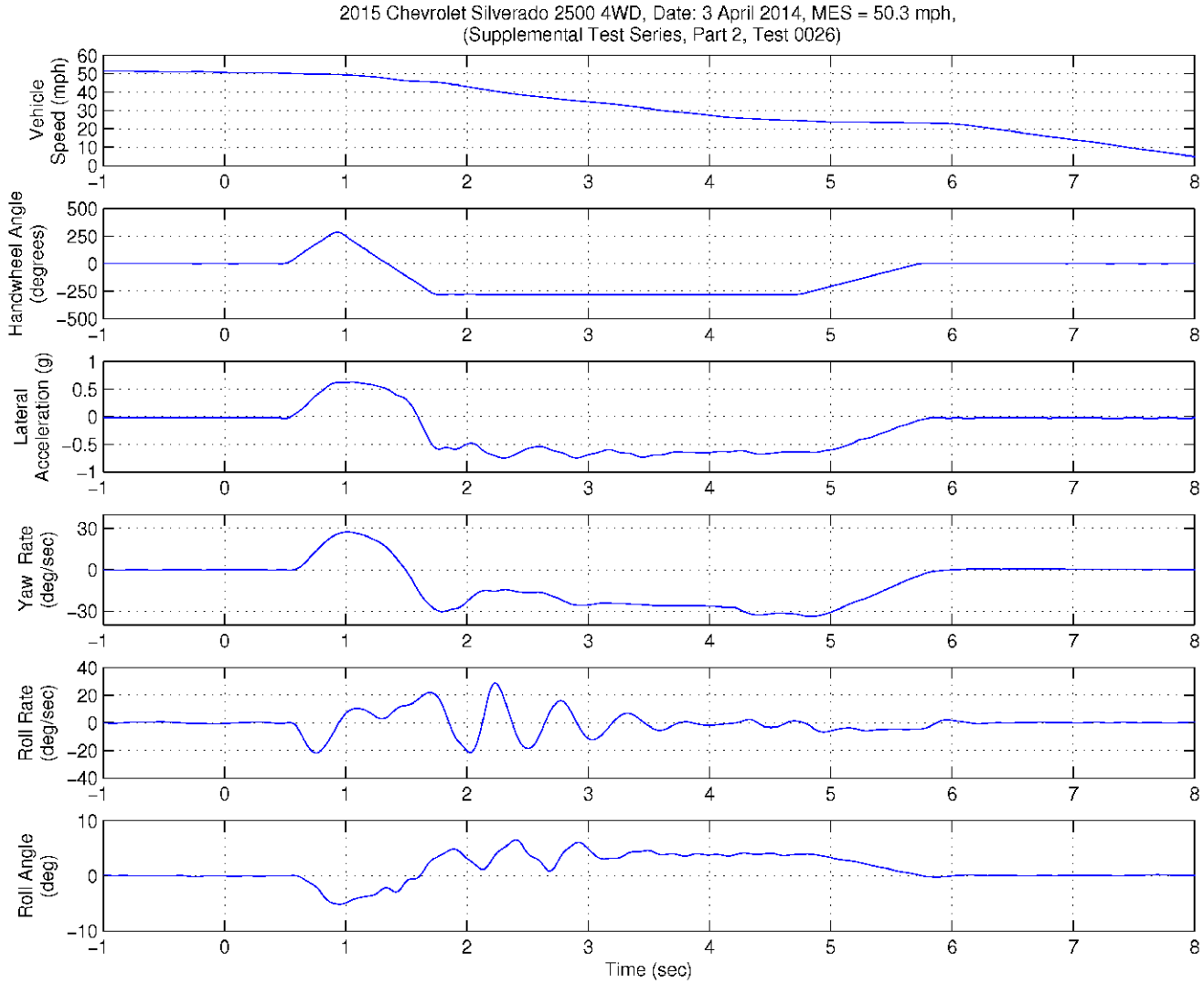

Figure D15. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots for Supplemental 2 Test Series, R-L, 50 mph

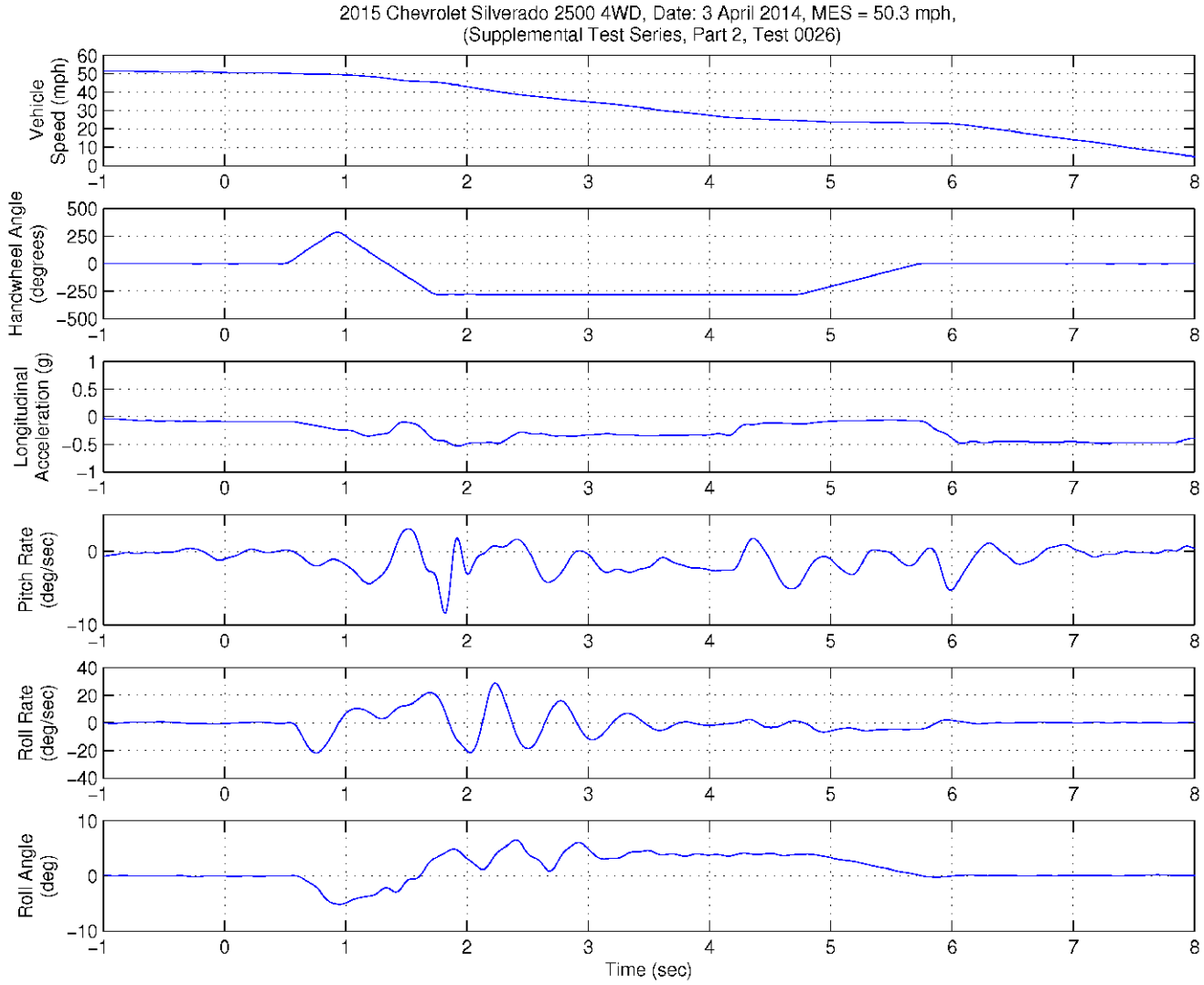

Figure D16. Pitch Rate and Longitudinal Acceleration Time History Plots for Supplemental 2 Test Series, R-L, 50 mph