

**NEW CAR ASSESSMENT PROGRAM (NCAP)
DYNAMIC ROLLOVER RESISTANCE TEST**

Volvo Car Corp
2016 Volvo XC90 T8 AWD

TEST NUMBER: 16-14

Final Report
22 July 2016



Prepared by:

Dynamic Research, Inc
355 Van Ness Ave. #200
Torrance, CA 90501

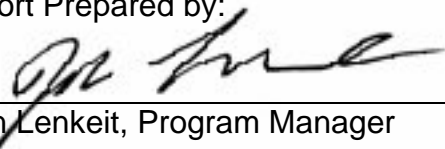
Prepared for:

National Highway Traffic Safety Administration
Office of Crash Avoidance Standards
1200 New Jersey Avenue S.E.
Washington, DC 20590

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Report Prepared by:



John Lenkeit, Program Manager

Date: 22 July 2016

Report Approved by:



Peter Broen, Principal Engineer

Date: 22 July 2016

1. Report No. 16-14	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle NCAP Dynamic Rollover Resistance Maneuver (Fishhook) Test of a 2016 Volvo XC90 T8 AWD SUV		5. Report Date 22 July 2016	6. Performing Organization Code DRI
		8. Performing Organization Report No. DRI- TM-16-147	
7. Author(s) John Lenkeit, Program Manager Peter Broen, Principal Engineer		10. Work Unit No. (TRAIS)	
9. Performing Organization Name and Address Dynamic Research, Inc. 355 Van Ness Ave. #200 Torrance, CA 90501		11. Contract or Grant No. DTNH22-14-D-00332	
		13. Type of Report and Period Covered Final Report March 2016 to July 2016	
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration Office of Crash Avoidance Standards 1200 New Jersey Avenue S.E. Washington, DC 20590		14. Sponsoring Agency Code	
		15. Supplemental Notes	
16. Abstract An NCAP Dynamic Rollover Maneuver (Fishhook) Test was conducted on a 2016 Volvo XC90 T8 AWD at Dynamic Research, Inc. on March 24, 2016. The vehicle did not experience two-wheel lift. The vehicle's steering angle at 0.3g lateral acceleration at 50 mph was 29.1 degrees.			
17. Key Words NCAP Rollover Resistance Ratings Fishhook Test		18. Distribution Statement Copies of this report are available from: National Highway Traffic Safety Admin. Office of Crash Avoidance Standards 1200 New Jersey Ave., S.E., Room W43-461 Washington, DC 20590	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. Number of Pages 50	22. Price

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Section I 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 2016 Volvo XC90 T8 AWD 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 DTNH22-14-D-00332. 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 debanding during Fishhook testing, an appropriately sized inner tube was installed in each tire. To further reduce the possibility of tire debanding, 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	2016 Volvo XC90 T8 AWD				
VIN	YV4BC0PK2G104xxxx				
Body style	SUV				
Number of doors	4				
Trim level	Momentum				
Seating positions	Front:	2 nd row	3 rd row	4 th row	5 th row
	2	3	2		
Electronic stability control	Yes				
4-Wheel ABS (Yes/No)	Yes				
Power steering (Yes/No)	Yes				
Major optional equipment	Vision package: blindspot info assist; crosstraffic alert; 360 deg surround view camera; automatically dimmed inner and outer mirrors; retractable rearview mirrors				
Odometer at start of testing	58 miles				
Drivetrain					
Engine cylinder arrangement	Inline 4				
Engine displacement	2 L				
Transmission type	Automatic				
Drive arrangement	AWD				
Chassis					
Track width	F: 65.8 in (1671.3 mm) , R: 65.9 in (1673.9 mm)				
Wheelbase	117.5 in (2984.5 mm)				
Curb weight	5036 lb (2284.3 kg)				
Certification Data from Vehicle's Label					
Vehicle manufactured by	Volvo Car Corp				
Date of manufacture	1015				
GVWR	6635 lb (3010 kg)				
GAWR Front	3130 lb (1420 kg)				
GAWR Rear	3590 lb (1628 kg)				

Table 2. Tire Information

Tire Manufacturer	Continental
Tire Model	CrossContact
Tire Size	Front: 235/55R19 Rear: 235/55R19
Load rating	Front: 105 Rear: 105
Speed rating	Front: H Rear: H
Treadwear grade	Front: 480 Rear: 480
Traction grade	Front: A Rear: A
Temperature grade	Front: A Rear: A
Location of "Recommended Tire Pressure" label	
Recommended cold tire pressure	Front: 42 psi, (290 kPa) Rear: 42 psi, (290 kPa)
First 8 digits of DOT code	Front: AFE7 D3VM Rear: AFE7 D3VM

Table 3. Vehicle Loading

Water dummy and other loading	3 water dummies in second row
Water dummy weight	175 lb (79.4 kg)
Fuel level	Full
Weight as Tested	
Left front	1520 lb (689.5 kg)
Right front	1479 lb (670.9 kg)
Left rear	1552 lb (704 kg)
Right rear	1478 lb (670.4 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

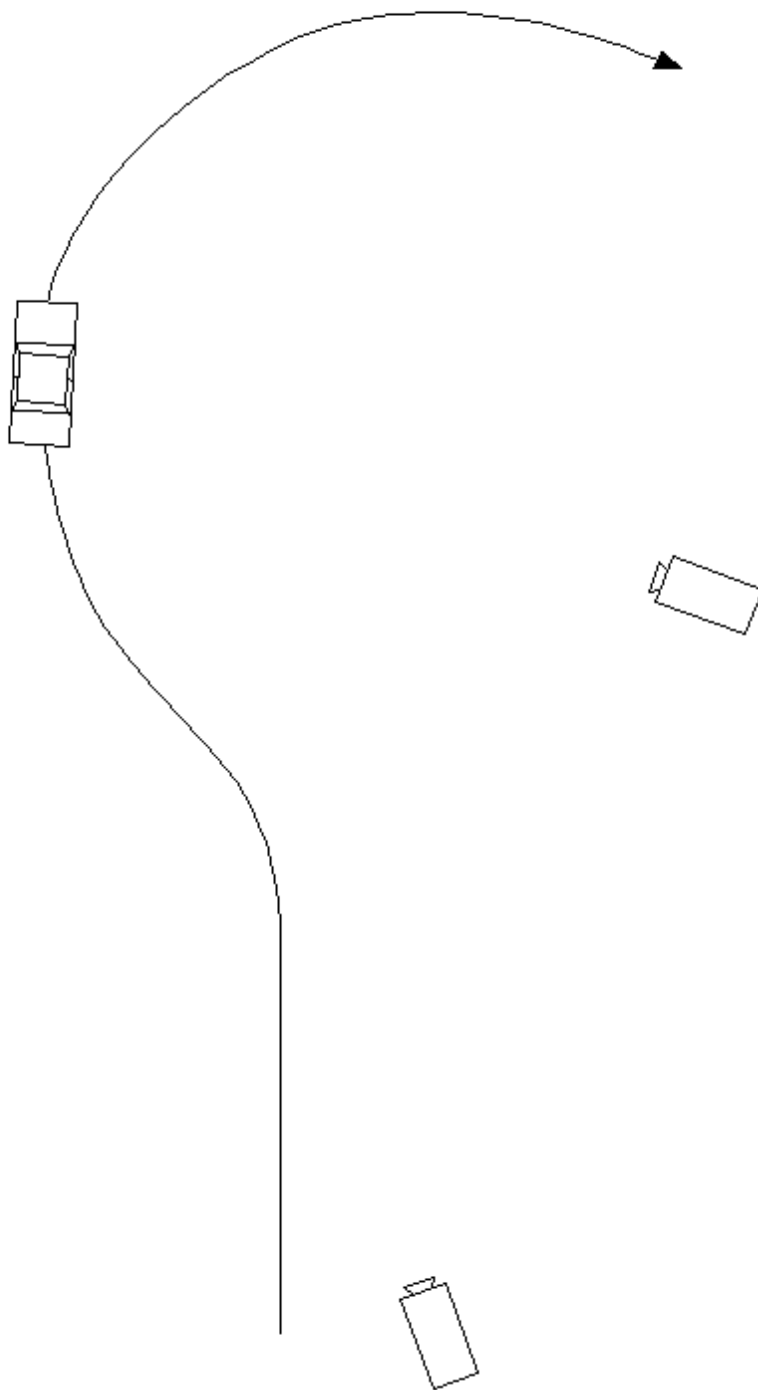


Figure 1. Nominal Position of Video Cameras for Fishhook Tests

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 3/24/2016. 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	4/6/2016
Average normalized lateral force	0.890

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)	29.1 °
5.5 scalar handwheel angle for Fishhook Test	160°
6.5 scalar handwheel angle for Fishhook Test	189 °

3. Weather Conditions

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

Table 7. Weather Conditions

Ambient temperature	59 °F (15 °C)
Wind Speed	3 mph (1.3 m/s)
Wind Direction	S

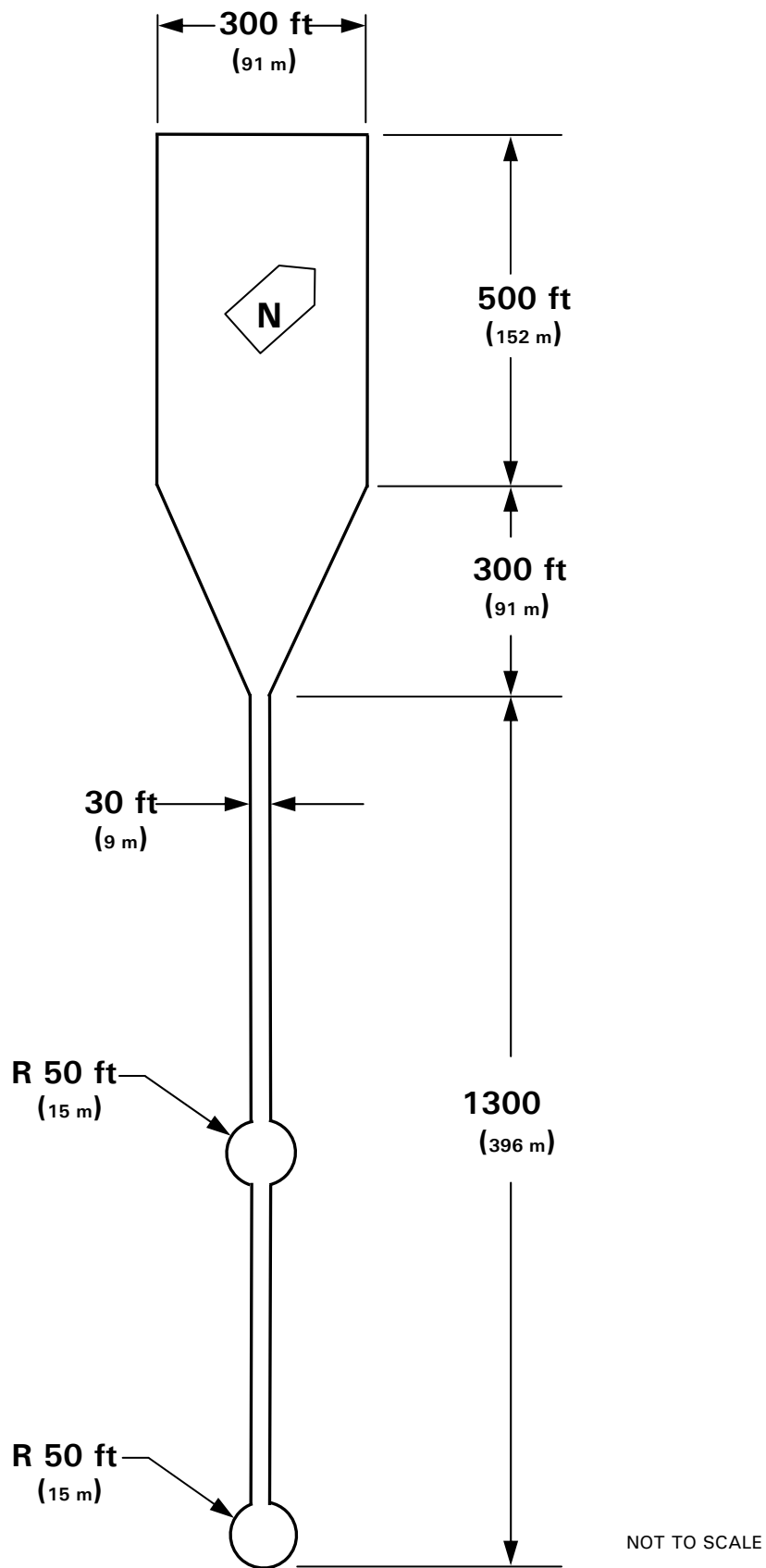


Figure 2. DRI-Minter Vehicle Dynamics Area

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 2016 Volvo XC90 T8 AWD, there was no two-wheel lift at any test condition.

APPENDIX A

Photographs

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2016 Volvo

XC90 T8 MOMENTUM



Volvo Car USA LLC
www.volvocars.com/us

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400 HP Combined and 472 lb-ft Torque
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Destination Charge 995.00

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Sensus Connect w/ 6-Month Complimentary Subscription
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Sensus Navigation
330W High Performance Audio System w/ 10 Speakers
HD Radio / USB & AUX inputs
Bluetooth Hands Free w/ Audio Streaming
SIRIUS Radio w/ 6-Month Complimentary Subscription
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Pedestrian & Cyclist Detection & Avoidance
Run-off Road Protection
Roll Stability Control
Road Sign Information
Lane Departure Warning & Driver Alert Control
Unibody High Strength Steel Safety Cage
Seven, 3-Point Safety Belts w/ Pretensioners
Inflatable Curtain (IC) Head Impact Protection
Side Impact Protection System (SIPS) w/ Driver &
Front Passenger Dual Chamber Side-Impact Airbags
Driver & Front Passenger Dual Stage Supplemental
Restraint System (SRS) - incl Driver Knee Airbag
Whiplash Protection System (WHIPS), Front Seats
Child Safety Locks in Rear Doors
Tire Pressure Monitoring System (TPMS)
LED Daytime Running Lights
LED Headlights w/ High Pressure Cleaning

LUXURY

Laminated Panoramic Moonroof w/Power Sunshade
Leather Upholstery (Seating Surfaces)
3rd Row seating (7 seats)
Heated 10-way, Power Front Seats & Driver Memory
& Power Cushion Extensions
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Hands-free, Power Tailgate
Keyless Entry & Drive
Rear Park Assist
4-zone Electronic Climate Control
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Roof Rails
Front Grille, High-gloss Black
40/20/40 Flat Folding Seats
Crystal Gear Shift Knob by Orrefors®
High-Level Interior Illumination w/ Sail Plates

EPA DOT Fuel Economy and Environment

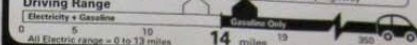
Plug-In Hybrid Vehicle
Electricity-Gasoline

Fuel Economy Standard SUV-4WD range from 12 to 92 MPGe. The best vehicle rates 119 MPGe.

Electricity + Gasoline
Charge Time: 3 hours (240 V)
53 MPGe
0.1 gallons per 100 miles
58 miles per 100 miles
combined city/highway

Gasoline Only
25 MPG
4.0 gallons per 100 miles
combined city/highway

You Save
\$ 500
in fuel costs
over 5 years
compared to the
average new vehicle.



Annual Fuel Cost
\$ 1,700



Actual results will vary for many reasons, including driving conditions and how you drive and maintain your vehicle. The average new vehicle gets 25 MPG and costs \$ 8,000 to fuel over 5 years. Cost estimates are based on 15,000 miles per year at 3.30 per gallon and 50.13 per kWh. This is a dual fueled automobile. MPGe is mile per gallon equivalent. Vehicle emissions are a significant cause of climate change and smog.

fuelconomy.gov

PARTS CONTENT INFORMATION

FOR VEHICLES IN THIS
CARLINE: VOLVO SERIES

U.S./CANADIAN PARTS
CONTENT: 1%

MAJOR SOURCES OF
FOREIGN PARTS CONTENT:
SWEDEN: 40%

FOR THIS VEHICLE:
FINAL ASSEMBLY POINT:
GOTHENBURG, SWEDEN

COUNTRY OF ORIGIN:
ENGINE PARTS:
SWEDEN

TRANSMISSION PARTS:
JAPAN

Note: Parts contents does not include
final assembly, distribution, or other
non-parts costs.

GOVERNMENT 5-STAR SAFETY RATINGS

This vehicle has not been rated by the government for overall
vehicle score, frontal crash or rollover risk.

Star ratings range from 1 to 5 stars (★★★★★) with 5 being the highest.
Source: National Highway Traffic Safety Administration (NHTSA)
www.safercar.gov or 1-888-327-4236

VEHICLE IDENTIFICATION
Type & Chassis: 256 041903
Model Year: 2016
Color: 711 Bright Silver M
VIN: YV4BC0PK2G104

Port of Importation: Husnema, CA
Delivered by: Truck
DELIVERY ADDRESS

YV4BC0PK2G104

The price shown does not include Gasoline, License and Title Fees, State and
Local Taxes and Dealer Installed Options and Accessories. The factory reserves
the right to modify price, designs and equipment without previous notice.



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: **2016 Volvo XC90 T8 AWD**Driver: **Peter Broen**Date: **3/24/2016**

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): 1000.3
1	Tire Warm-Up	35	100	NA	NA	
2	Tire Warm-Up	35	80	NA	NA	
3	Tire Warm-Up	35	80	NA	NA	
4	Tire Warm-Up	35	80	NA	NA	
5	Static	0	0	NA	NA	
6	Dynamic	50	0	NA	NA	
7	SIS	50	60	Left	NA	
8	SIS	50	60	Left	NA	
9	SIS	50	60	Left	NA	
10	SIS	50	60	Right	NA	
11	SIS	50	60	Right	NA	
12	SIS	50	60	Right	NA	
13	Fishhook	35	189	Left	No	6.5x scalar
14	Fishhook	40	189	Left	No	
15	Fishhook	45	189	Left	No	

Vehicle: **2016 Volvo XC90 T8 AWD**Driver: **Peter Broen**Date: **3/24/2016**

Run Number	Test Type	Speed (mph)	Handwheel Angle (deg)	Dir. of First Steer	2 Wheel Lift	Notes
16	Fishhook	47.5	189	Left	No	
17	Fishhook	50	189	Left	No	NG
18	Fishhook	50	189	Left	No	
19	Fishhook	35	189	Right	No	
20	Fishhook	40	189	Right	No	
21	Fishhook	45	189	Right	No	
22	Fishhook	47.5	189	Right	No	
23	Fishhook	50	189	Right	No	
24	Fishhook	45	160	Right	No	NG
25	Fishhook	45	160	Right	No	5.5x scalar
26	Fishhook	47.5	160	Right	No	
27	Fishhook	50	160	Right	No	
28	Fishhook	45	160	Left	No	NG
29	Fishhook	47.5	160	Left	No	NG
30	Fishhook	50	160	Left	No	NG
31	Fishhook	45	160	Left	No	NG
32	Fishhook	45	160	Left	No	
33	Fishhook	47.5	160	Left	No	
34	Fishhook	50	160	Left	No	

APPENDIX C

Slowly Increasing Steer Test Worksheet

NCAP, 2016 Volvo XC90 T8 AWD , Multi-Passenger Load, Test Date: 3/24/2016

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
7	1	49.9	0.3	99.4	1093	-28.2	-0.301	-183.1	-0.2543	-154.9	-0.2152	0.9941	486	686
8	1	49.8	3.4	93.1	1099	-28.5	-0.311	-185.4	-0.2574	-156.8	-0.2178	0.9906	475	675
9	1	49.7	9.6	80.7	1135	-29.4	-0.304	-190.9	-0.2651	-161.5	-0.2243	0.9979	500	700
10	0	50.0	2.5	95.1	1130	29.2	0.303	189.6	0.2633	160.4	0.2228	0.9953	500	700
11	0	50.4	5.8	88.6	1110	29.8	0.302	193.7	0.269	163.9	0.2276	0.9898	500	700
12	0	50.0	6.8	86.3	1110	29.0	0.302	188.8	0.2622	159.7	0.2218	0.9964	483	683

Mean: 29 0.304 189 0.262 160 0.222

Steering Controller Input Values

Scalar 6.5 values:

Initial HW angle: 189 deg
Initial time: 0.262 s
Reversal HW angle: -189 deg
Reversal time: 0.524 s

Scalar 5.5 values:

Initial HW angle: 160 deg
Initial time: 0.222 s
Reversal HW angle: -160 deg
Reversal time: 0.443 s

APPENDIX D

Time History Plots

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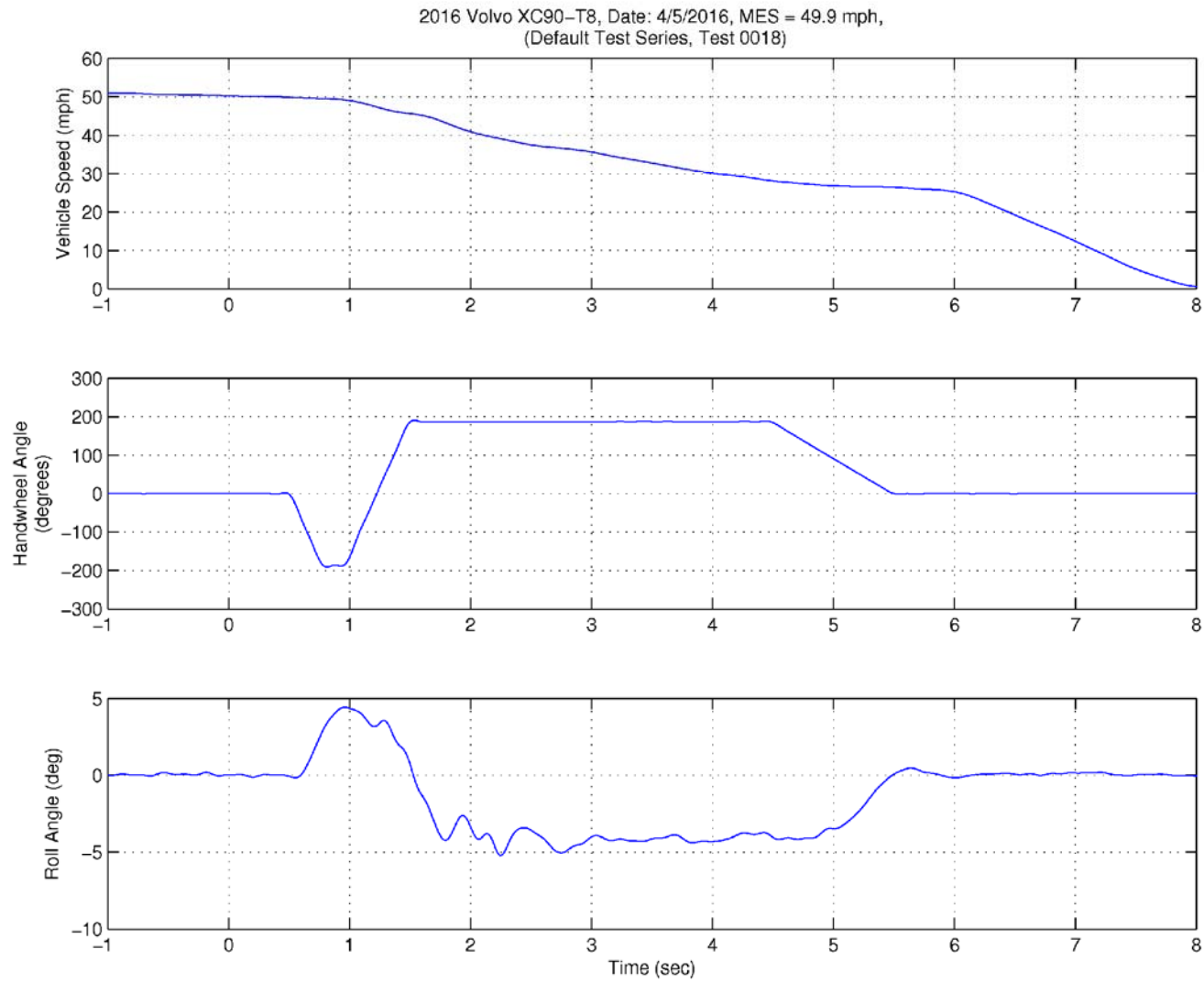


Figure D1. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Default Test Series, L-R, 50 mph

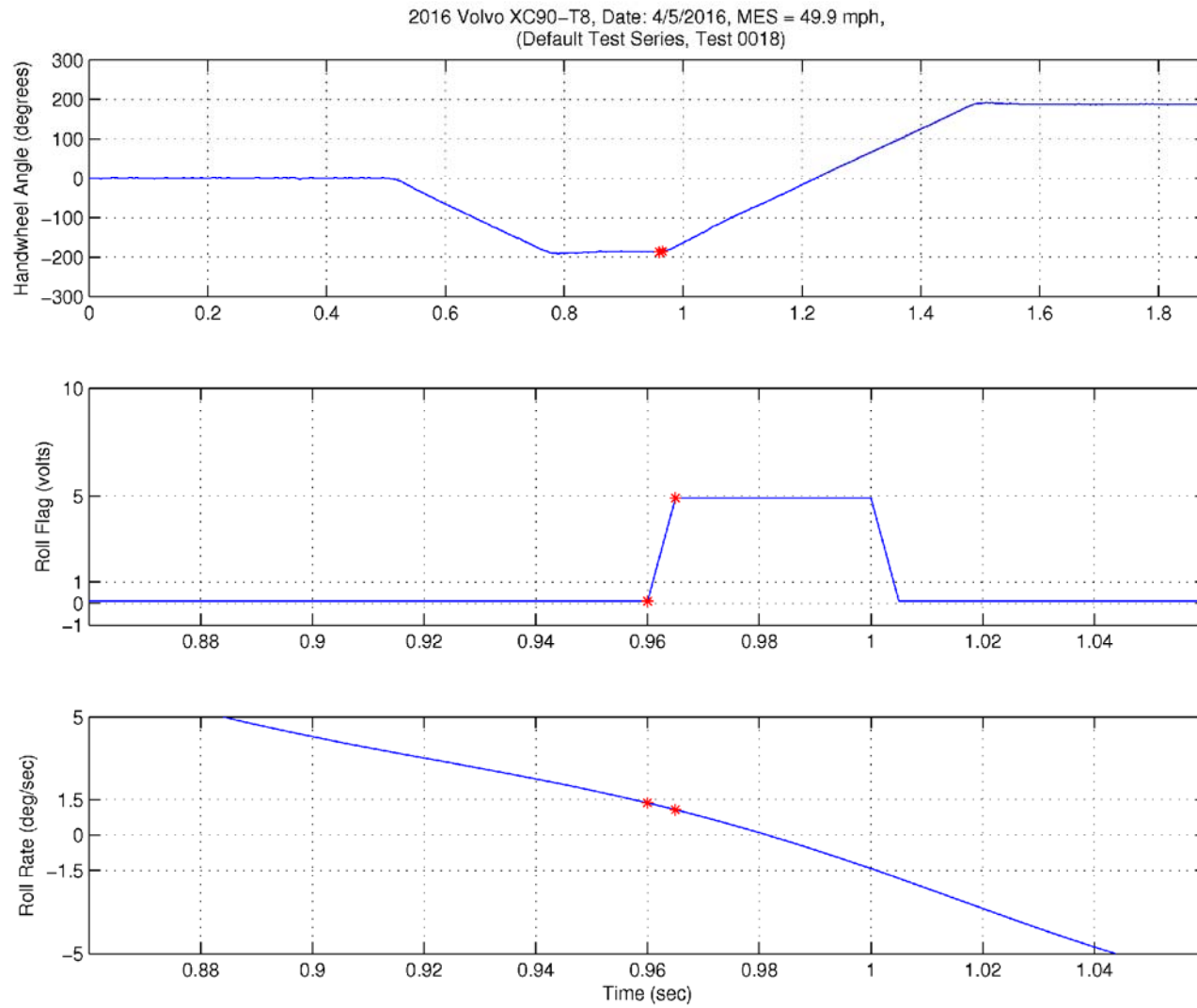


Figure D2. Steering Machine Operation Time History Plots for Default Test Series, L-R, 50 mph

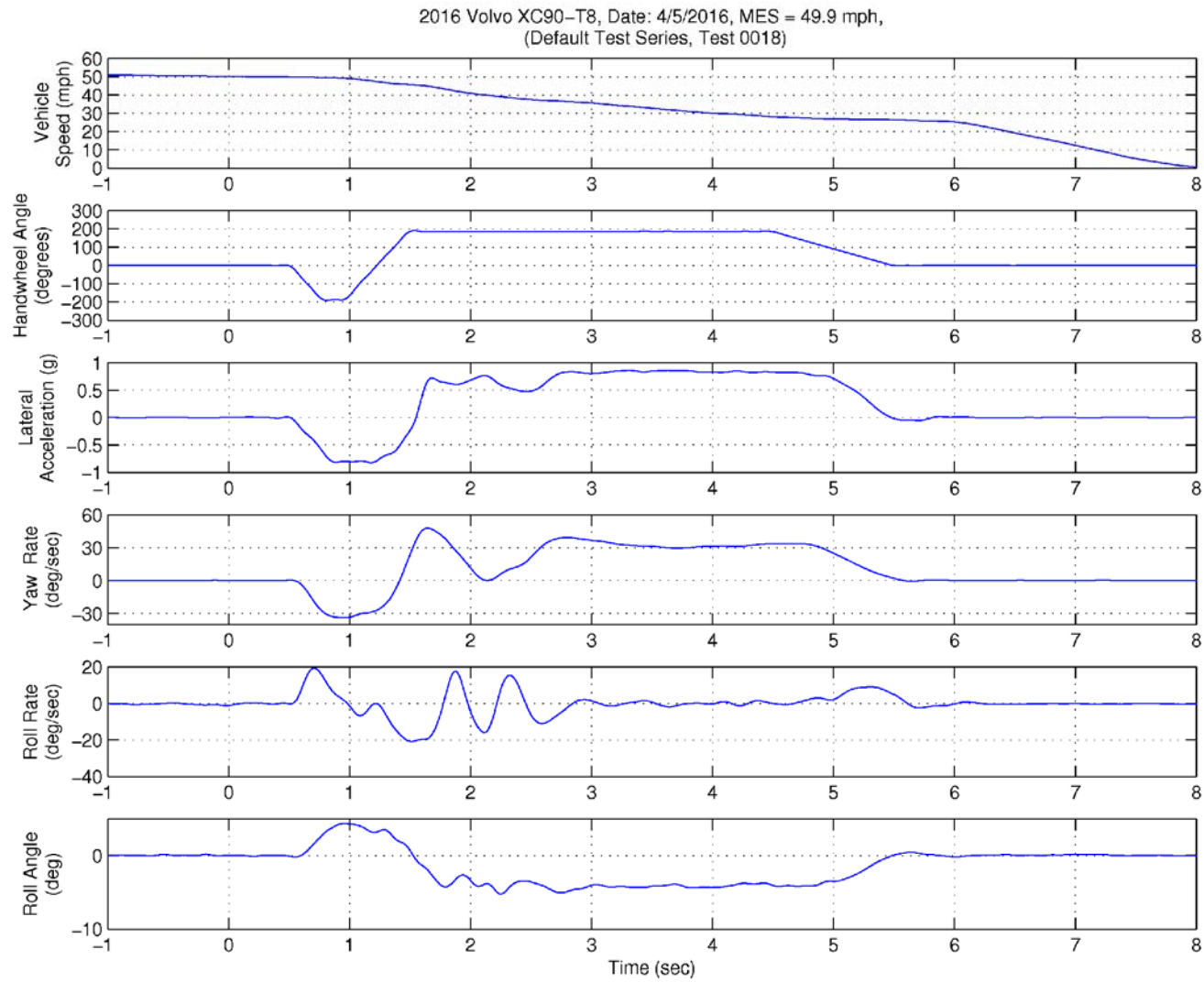


Figure D3. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots For Default Test Series, L-R, 50 mph

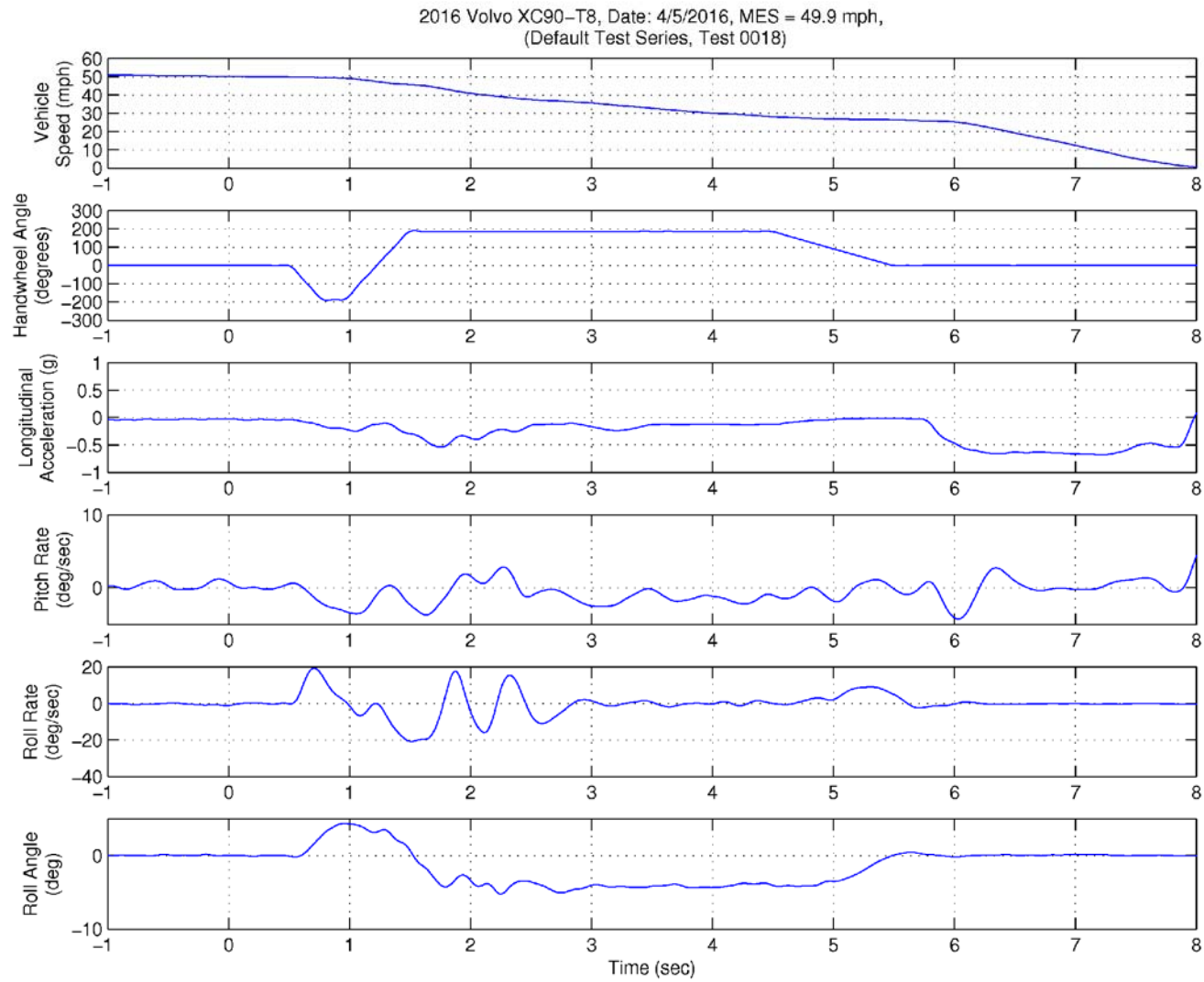


Figure D4. Pitch Rate and Longitudinal Acceleration Time History Plots for Default Test Series, L-R, 50 mph

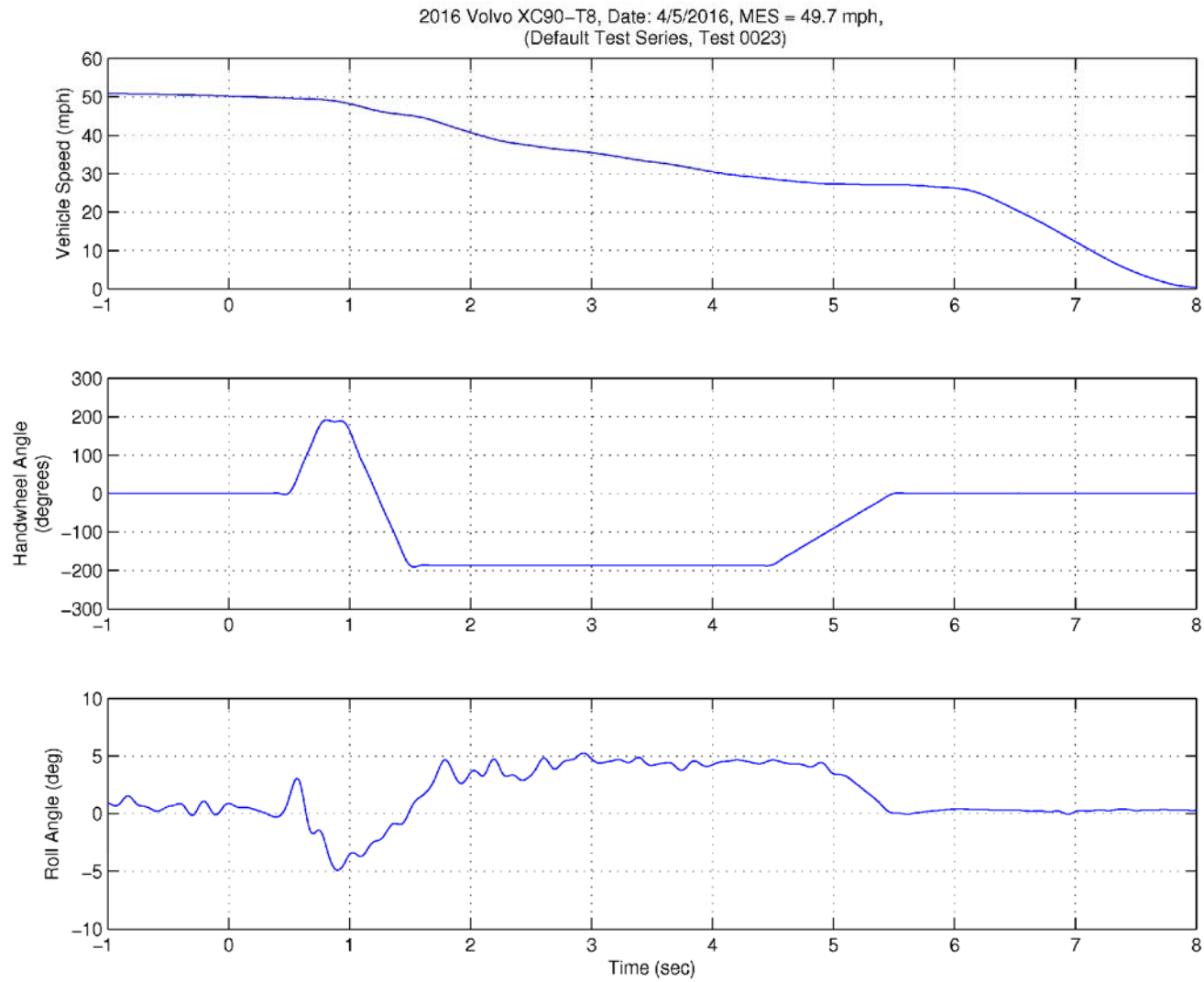


Figure D5. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Default Test Series, R-L, 50 mph

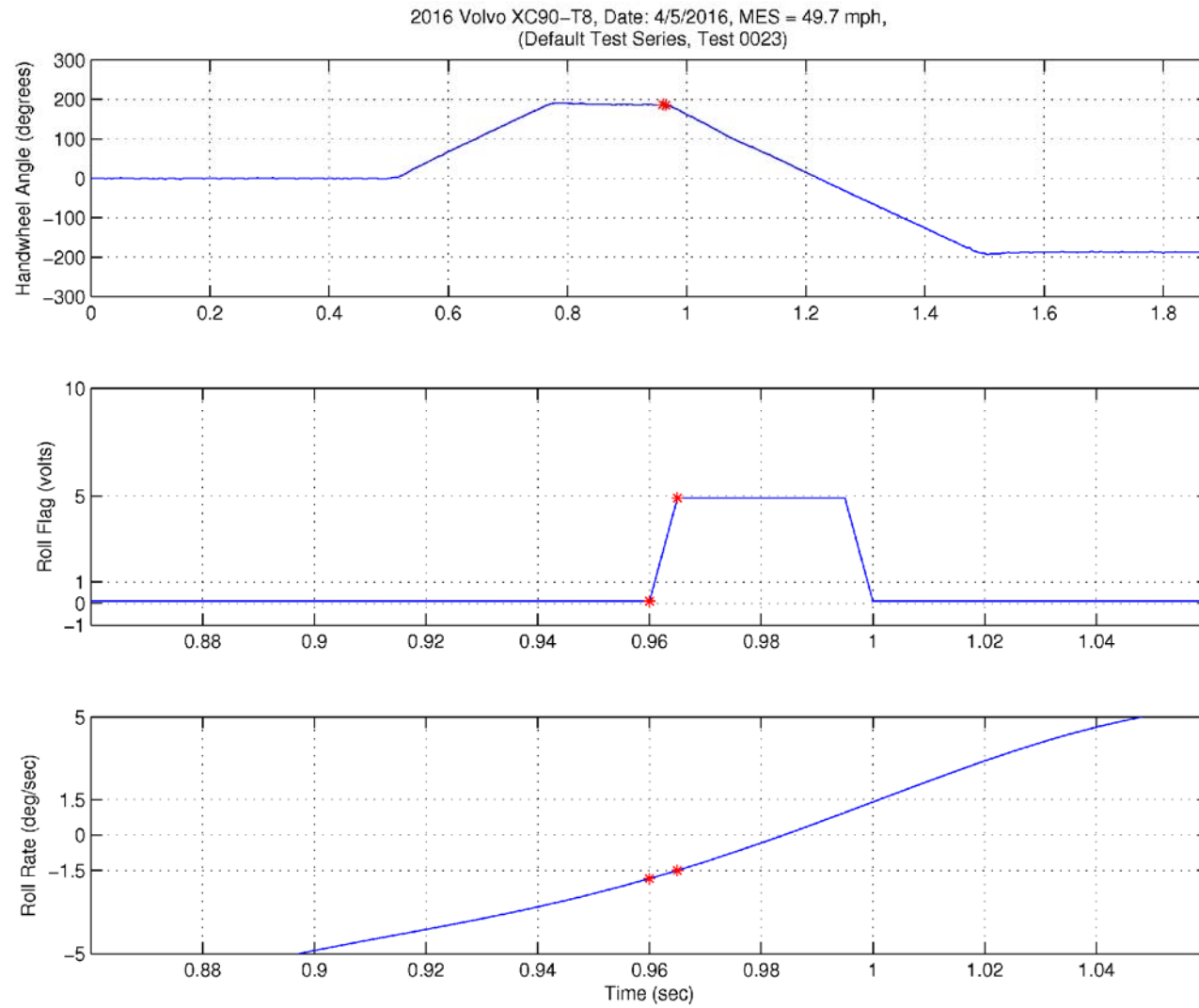


Figure D6. Steering Machine Operation Time History Plots for Default Test Series, R-L, 50 mph

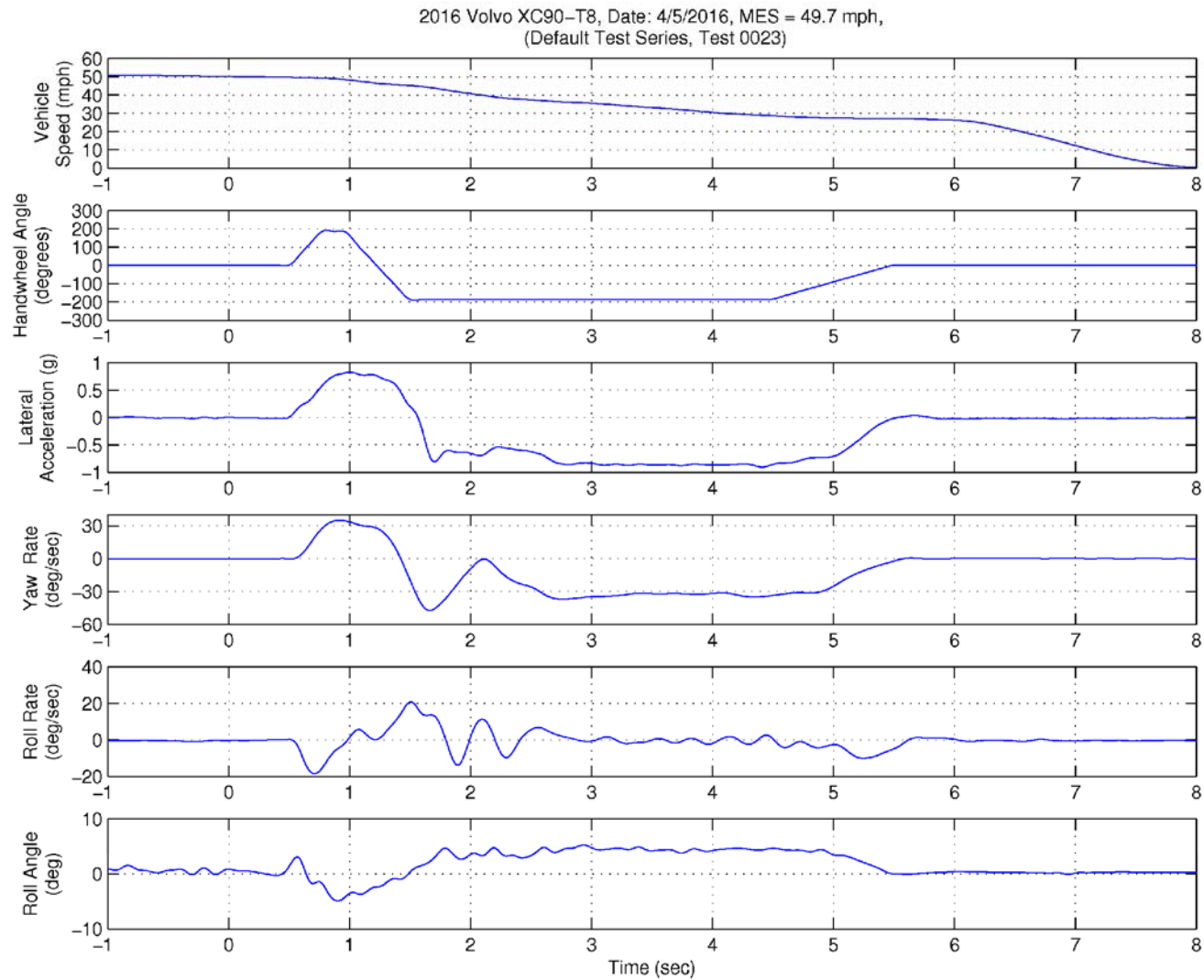


Figure D7. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots for Default Test Series, R-L, 50 mph

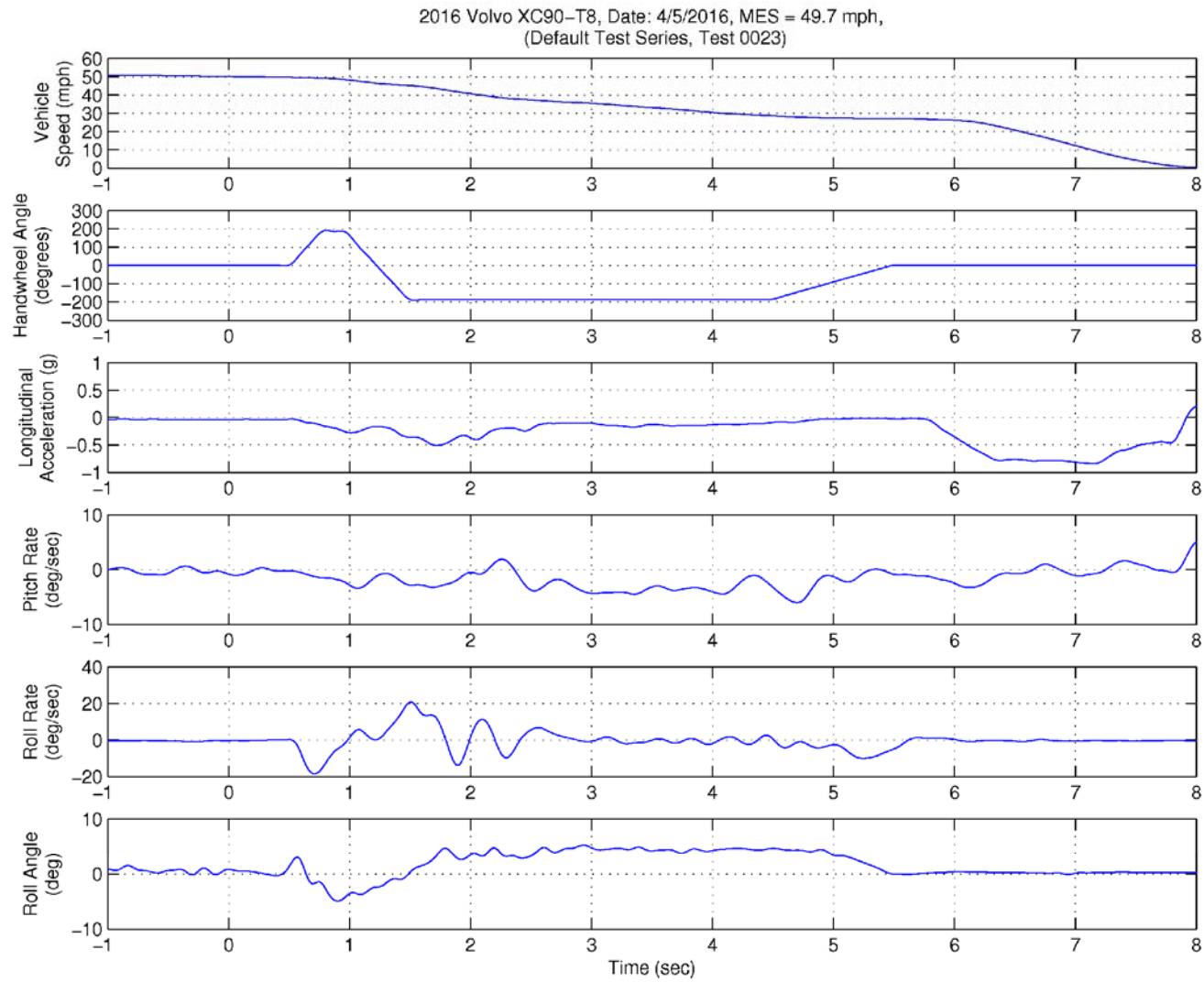


Figure D8. Pitch Rate and Longitudinal Acceleration Time History Plots or Default Test Series, R-L, 50 mph

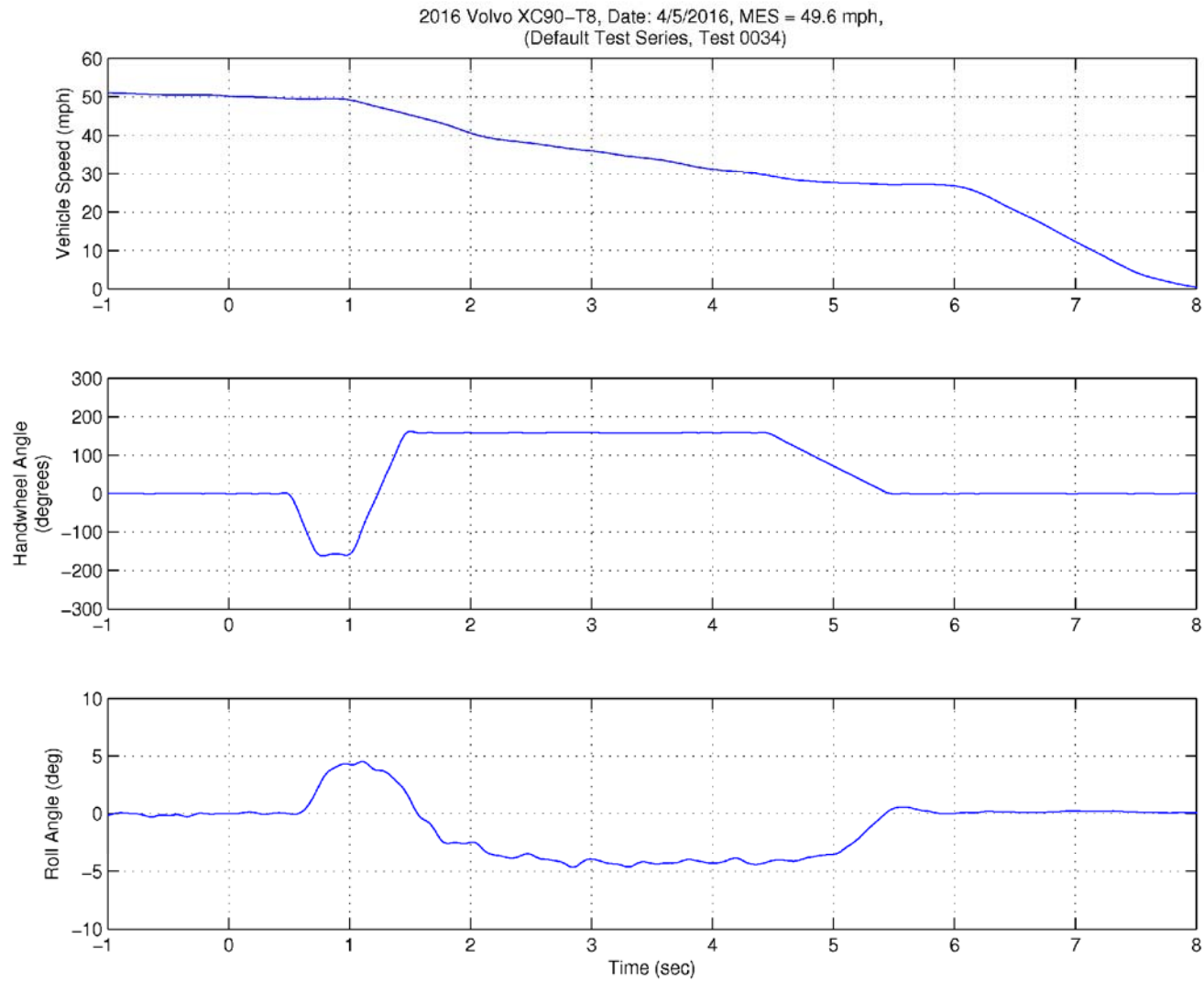


Figure D9. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

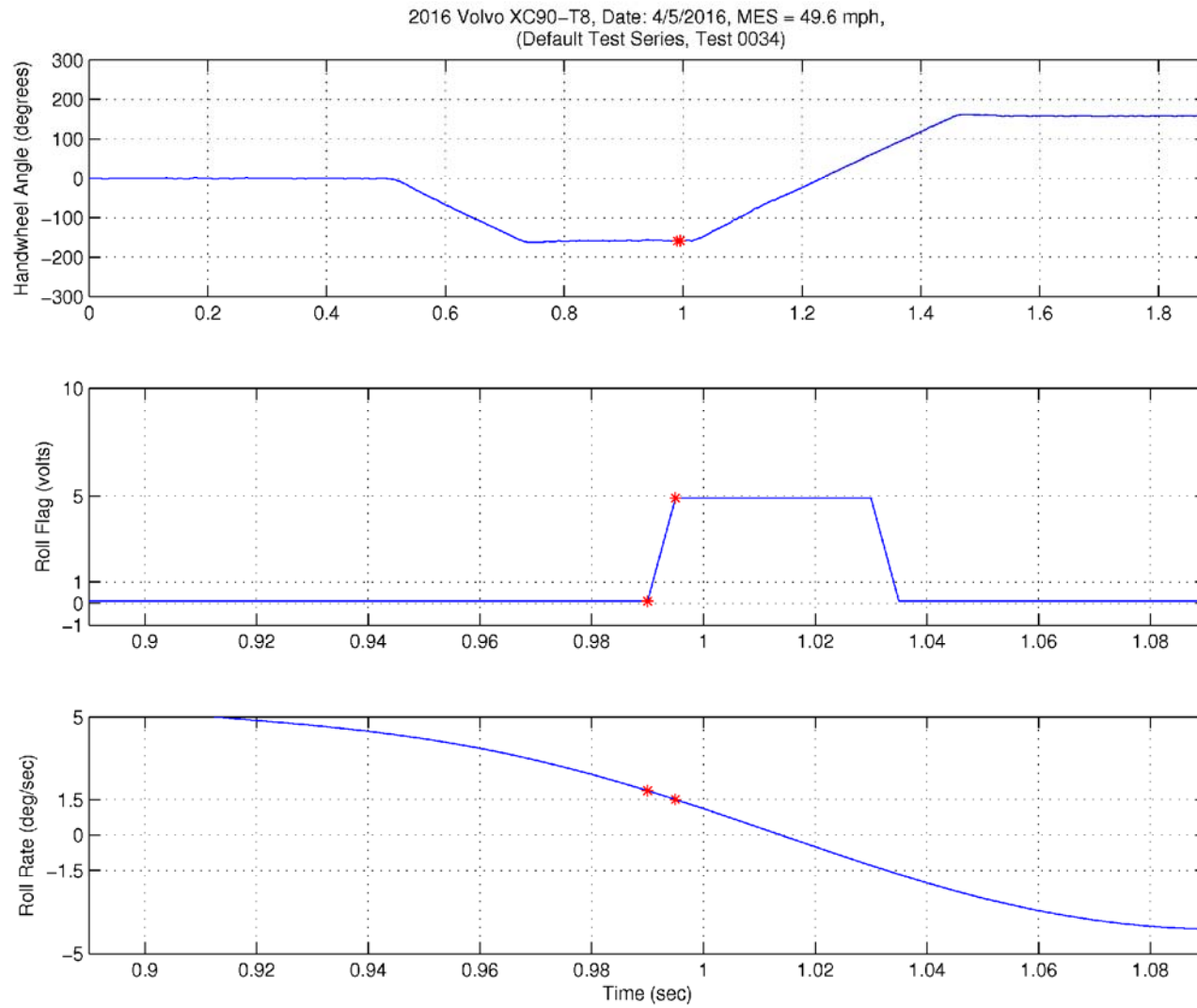


Figure D10. Steering Machine Operation Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

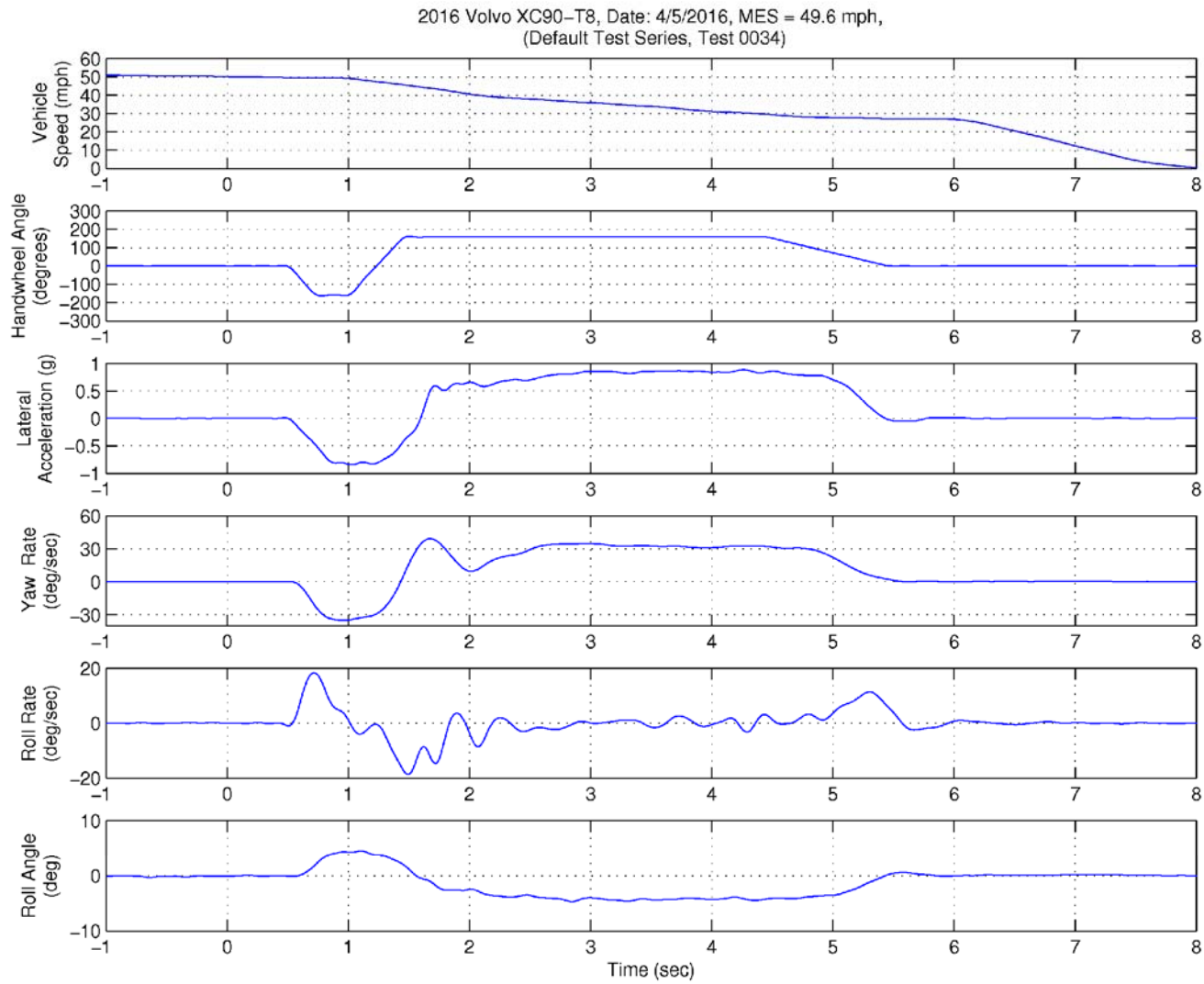


Figure D11. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

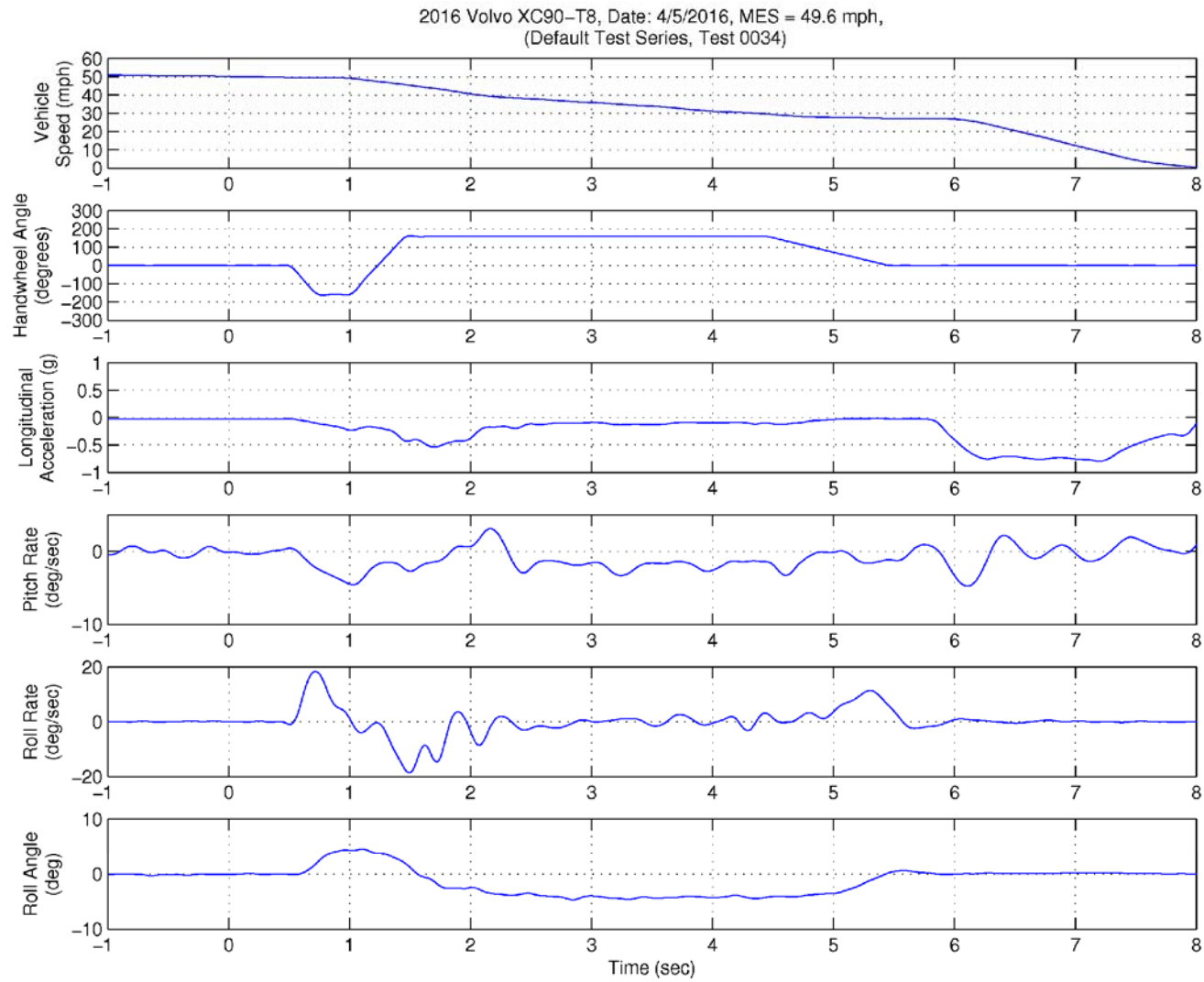


Figure D12. Pitch Rate and Longitudinal Acceleration Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

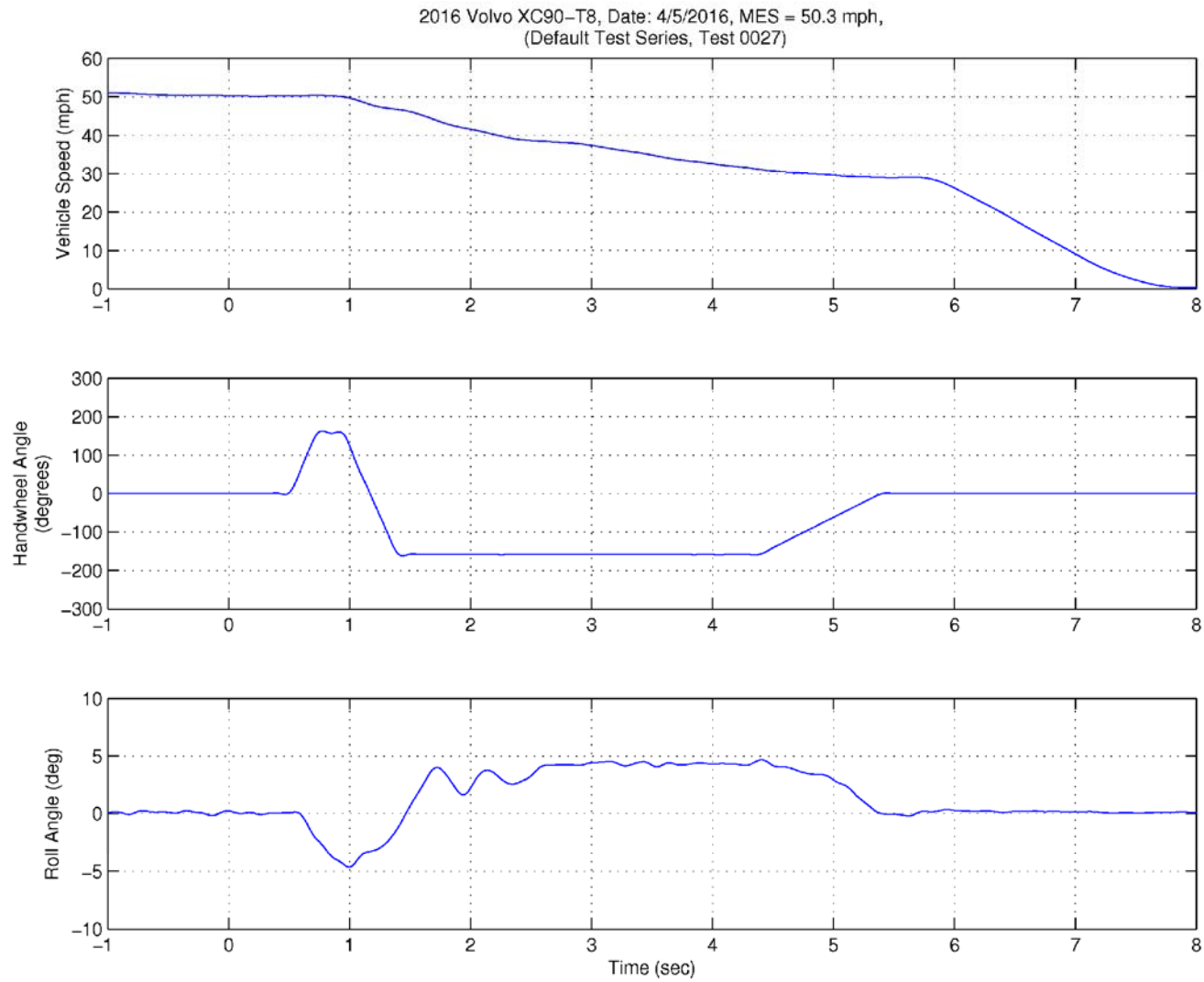


Figure D13. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Supplemental 2 Test Series, R-L, 50 mph

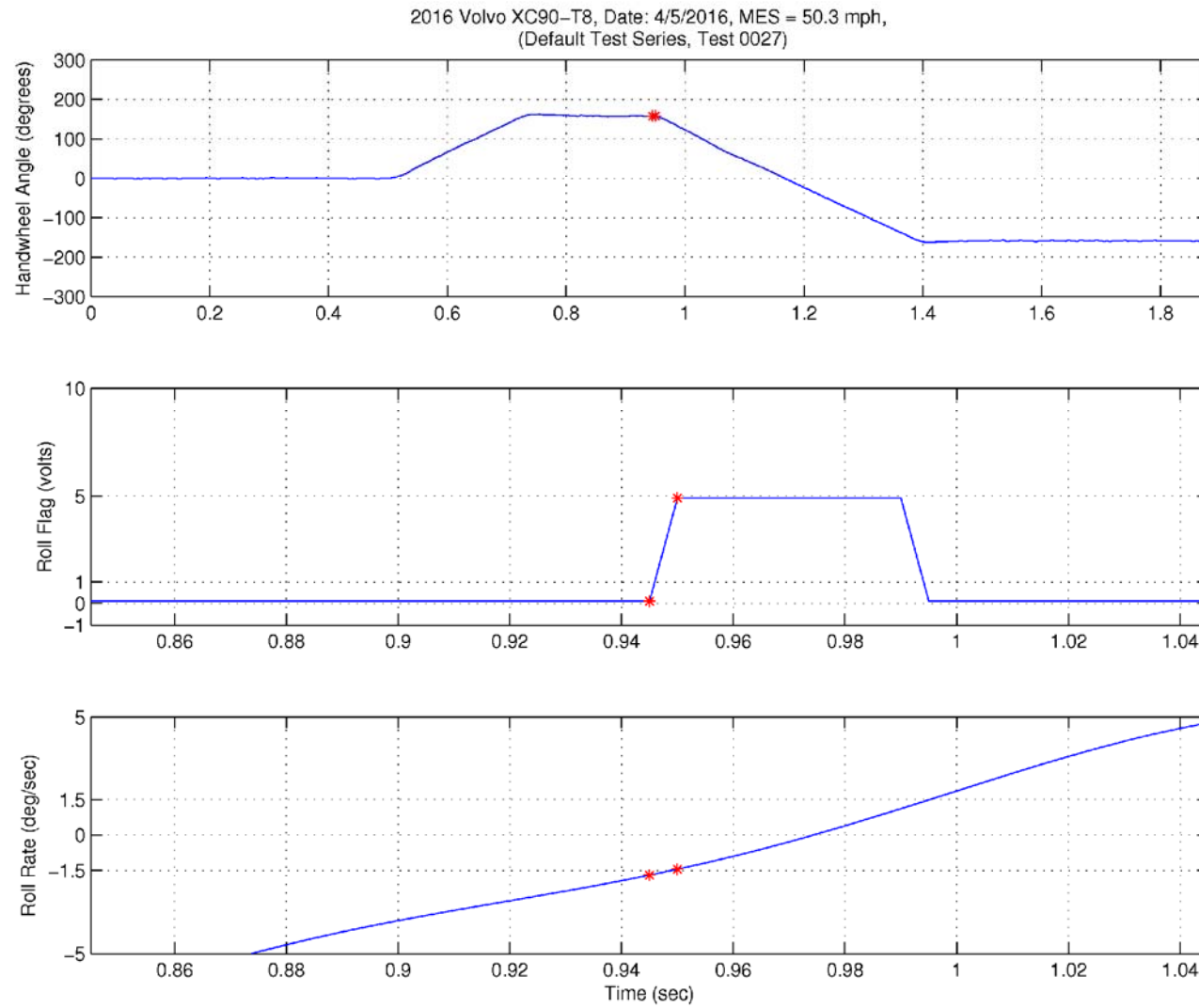


Figure D14. Steering Machine Operation Time History Plots for Supplemental 2 Test Series, R-L, 50 mph

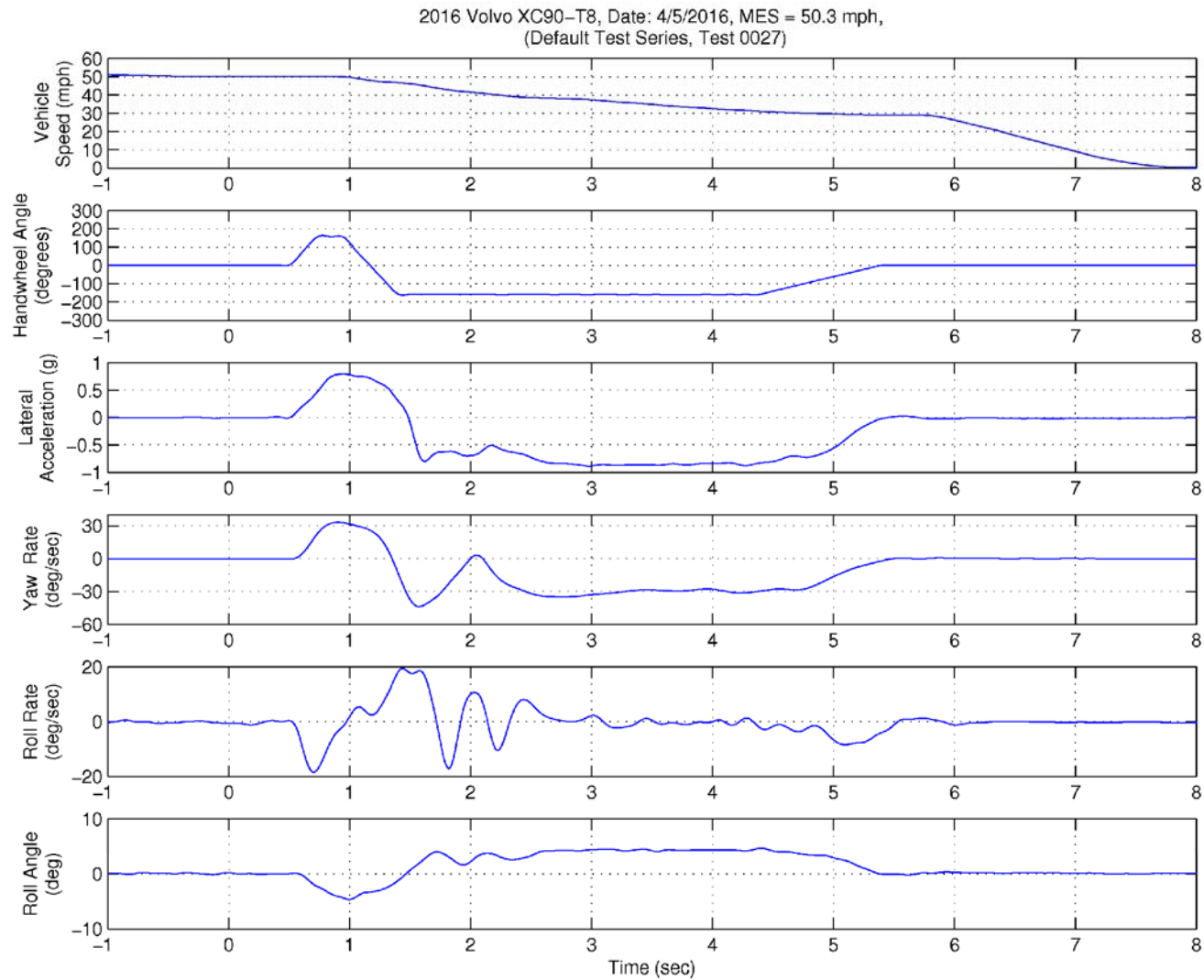


Figure D15. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots for Supplemental 2 Test Series, R-L, 50 mph

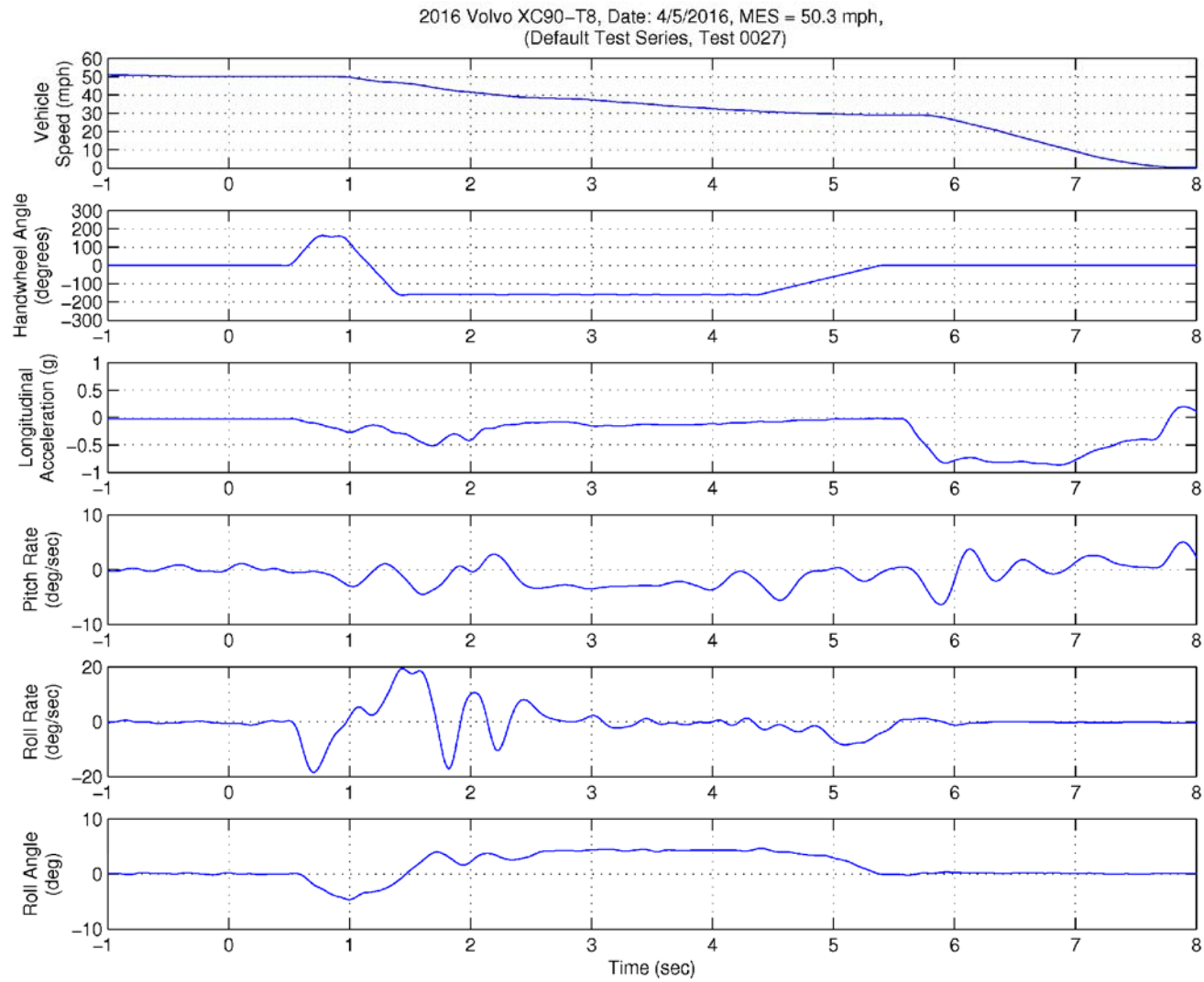


Figure D16. Pitch Rate and Longitudinal Acceleration Time History Plots for Supplemental 2 Test Series, R-L, 50 mph