NEW CAR ASSESSMENT PROGRAM (NCAP)
DYNAMIC ROLLOVER RESISTANCE TEST

Fuji Heavy Industries

2015 Subaru Outback AWD

TEST NUMBER: 15-09

Final Report
20 November 2015

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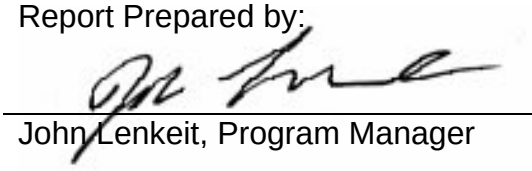
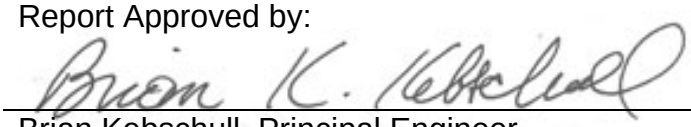


Date: 20 November 2015

John Lenkeit, Program Manager

Report Approved by:



Date: 20 November 2015

Brian Kebschull, Principal Engineer

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16. Abstract

An NCAP Dynamic Rollover Maneuver (Fishhook) Test was conducted on a 2015 Subaru Outback AWD at Dynamic Research, Inc. on November 21, 2014. The vehicle did not experience two-wheel lift. The vehicle's steering angle at 0.3 g lateral acceleration at 50 mph was 23.7 degrees.

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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 2015 Subaru Outback 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 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 Subaru Outback AWD				
VIN	4S4BSACC1F323xxxx				
Body style	SUV				
Number of doors	4				
Trim level	Premium				
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	Rear Bumper Covers, Splash Guards, All Weather Floor Mats, Ext Auto Dim Mirror with Light, Mirror Compass with Light				
Odometer at start of testing	6 miles				
Drivetrain					
Engine cylinder arrangement	Opposed 4				
Engine displacement	2.5 L				
Transmission type	CVT				
Drive arrangement	AWD				
Chassis					
Track width	F: 61 in (1549.4 mm) , R: 61 in (1549.4 mm)				
Wheelbase	107.9 in (2740.7 mm)				
Curb weight	3648 lb (1654.7 kg)				
Certification Data from Vehicle's Label					
Vehicle manufactured by	Fuji Heavy Industries				
Date of manufacture	10/14				
GVWR	4695 lb (2130 kg)				
GAWR Front	2535 lb (1150 kg)				
GAWR Rear	2645 lb (1200 kg)				

Table 2. Tire Information

Tire Manufacturer	Bridgestone
Tire Model	Dueller H/P Sport AS
Tire Size	Front: 225/65R17 Rear: 225/65R17
Load rating	Front: 102 Rear: 102
Speed rating	Front: H Rear: H
Treadwear grade	Front: 500 Rear: 500
Traction grade	Front: A Rear: A
Temperature grade	Front: A Rear: A
Location of “Recommended Tire Pressure” label	Driver side door jamb
Recommended cold tire pressure	Front: 35 psi, (240 kPa) Rear: 33 psi, (230 kPa)
First 8 digits of DOT code	Front: OB2YHP8 Rear: OB2YHP8

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	1263 lb (572.9 kg)
Right front	1150 lb (521.6 kg)
Left rear	1142 lb (518 kg)
Right rear	1091 lb (494.9 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

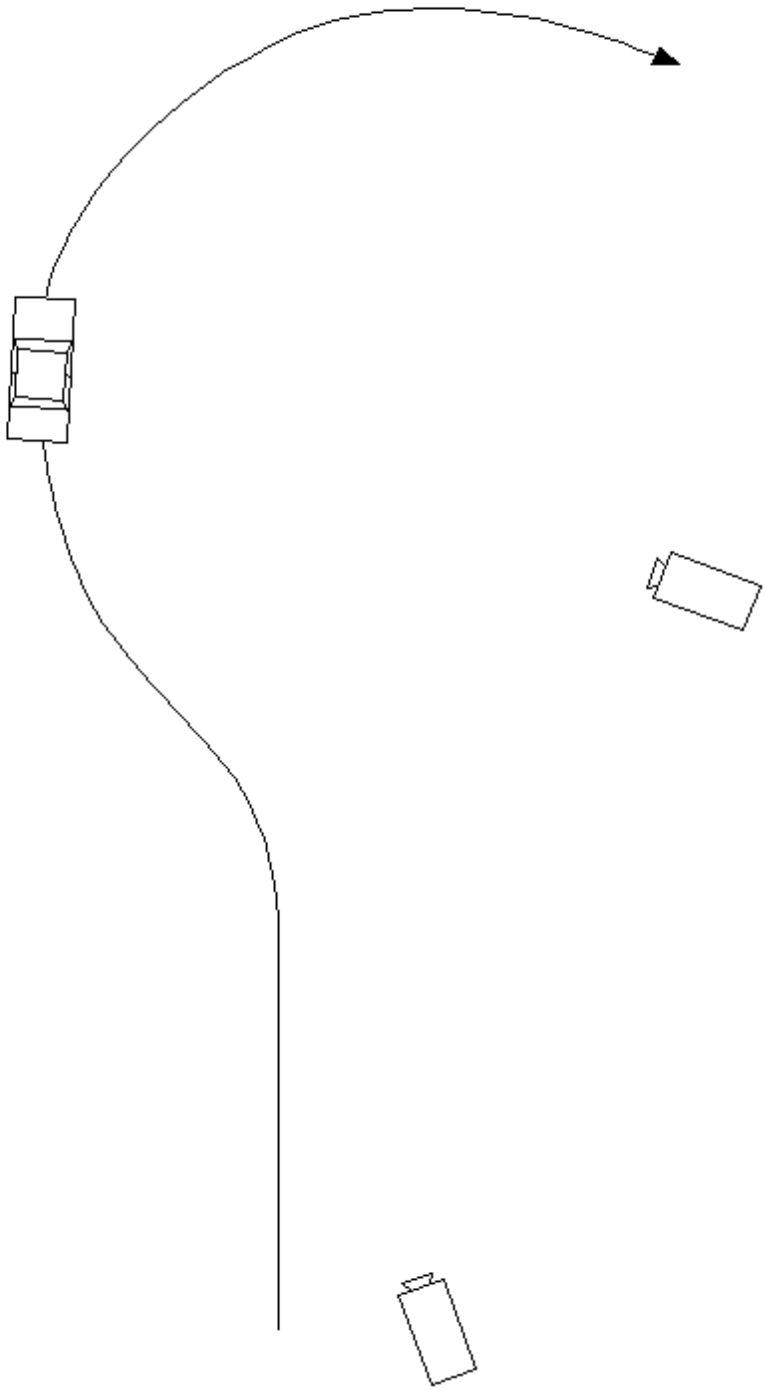

Figure 1. Nominal Position of Video Cameras for Fishhook Tests

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 11/21/2014. 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	11/21/2014
Average normalized lateral force	0.876

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)	23.7 º
5.5 scalar handwheel angle for Fishhook Test	130º
6.5 scalar handwheel angle for Fishhook Test	154 º

3. Weather Conditions

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

Table 7. Weather Conditions

Ambient temperature	52 ºF (11.1 ºC)
Wind Speed	4 mph (1.8 m/s)
Wind Direction	NW

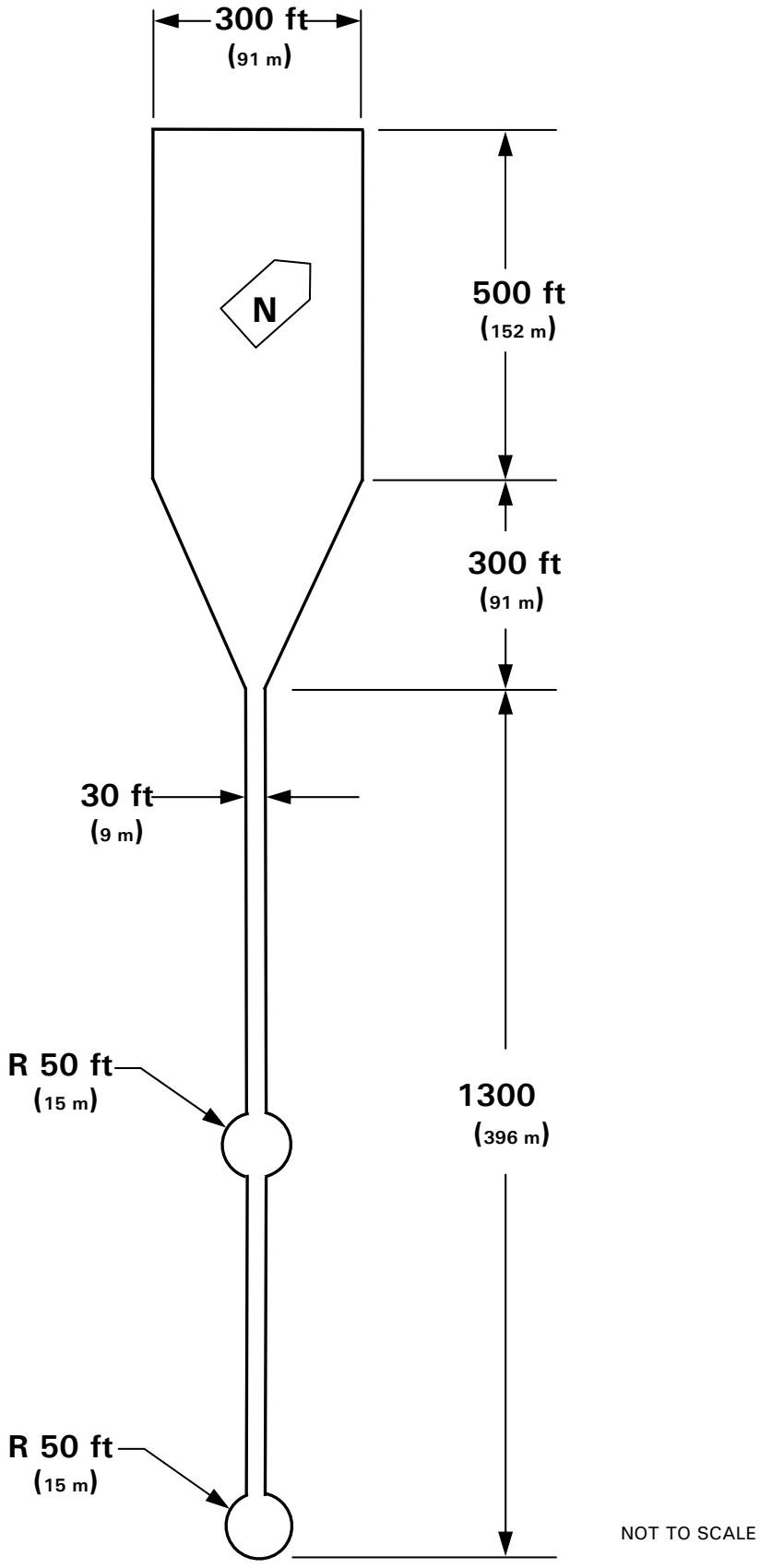

Figure 2. DRI-Minter Vehicle Dynamics Area

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 Subaru Outback AWD, there was no two-wheel lift at any test condition.

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Photographs

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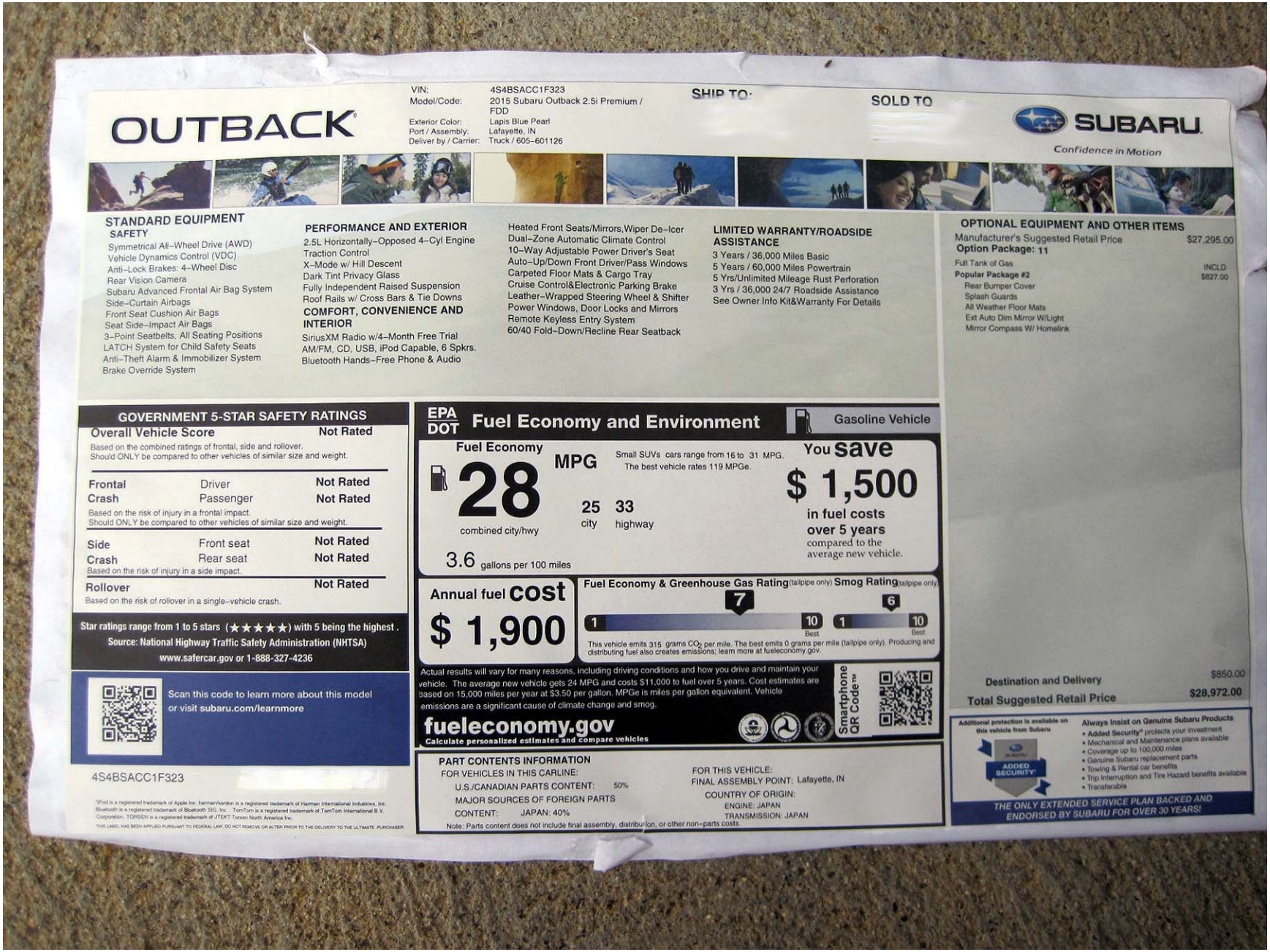

OUTBACK

VIN: 4S4BSACC1F323
Model/Code: 2015 Subaru Outback 2.5i Premium / FDD
Exterior Color: Lapis Blue Pearl
Port / Assembly: Lafayette, IN
Deliver by / Carrier: Truck / 605-601126

SHIP TO:

SOLD TO

SUBARU
Confidence in Motion

STANDARD EQUIPMENT

SAFETY
Symmetrical All-Wheel Drive (AWD)
Vehicle Dynamics Control (VDC)
Anti-Lock Brakes: 4-Wheel Disc
Rear Vision Camera
Subaru Advanced Frontal Air Bag System
Side-Curtain Airbags
Front Seat Cushion Air Bags
Seat Side-Impact Air Bags
3-Point Seatbelts, All Seating Positions
LATCH System for Child Safety Seats
Anti-Theft Alarm & Immobilizer System
Brake Override System

PERFORMANCE AND EXTERIOR
2.5L Horizontally-Opposed 4-Cyl Engine
Traction Control
X-Mode w/ Hill Descent
Dark Tint Privacy Glass
Fully Independent Raised Suspension
Roof Rails w/ Cross Bars & Tie Downs

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Bluetooth Hands-Free Phone & Audio
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Dual-Zone Automatic Climate Control
10-Way Adjustable Power Driver's Seat
Auto-Up/Down Front Driver/Pass Windows
Carpeted Floor Mats & Cargo Tray
Cruise Control&Electronic Parking Brake
Leather-Wrapped Steering Wheel & Shifter
Power Windows, Door Locks and Mirrors
Remote Keyless Entry System
60/40 Fold-Down/Recline Rear Seatback

LIMITED WARRANTY/ROADSIDE ASSISTANCE
3 Years / 36,000 Miles Basic
5 Years / 60,000 Miles Powertrain
5 Yrs/Unlimited Mileage Rust Perforation
3 Yrs / 36,000 24/7 Roadside Assistance
See Owner Info Kit&Warranty For Details

OPTIONAL EQUIPMENT AND OTHER ITEMS

Manufacturer's Suggested Retail Price $27,295.00
Option Package: 11
Full Tank of Gas INCLD
Popular Package #2 $827.00
Rear Bumper Cover
Splash Guards
All Weather Floor Mats
Ext Auto Dim Mirror W/Light
Mirror Compass W/ Homelink

Destination and Delivery $850.00
Total Suggested Retail Price $28,972.00

Additional protection is available on this vehicle from Subaru

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- Coverage up to 100,000 miles
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- Trip Interruption and Tire Hazard benefits available
- Transferable

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GOVERNMENT 5-STAR SAFETY RATINGS

Overall Vehicle Score Not Rated
Based on the combined ratings of frontal, side and rollover.
Should ONLY be compared to other vehicles of similar size and weight.

Frontal Crash	Driver	Not Rated
	Passenger	Not Rated

Based on the risk of injury in a frontal impact.
Should ONLY be compared to other vehicles of similar size and weight.

Side Crash	Front seat	Not Rated
	Rear seat	Not Rated

Based on the risk of injury in a side impact.

Rollover Not Rated
Based on the risk of rollover in a single-vehicle crash.

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

Scan this code to learn more about this model or visit subaru.com/learnmore

4S4BSACC1F323

EPA DOT Fuel Economy and Environment

Gasoline Vehicle

Fuel Economy
28 MPG
combined city/hwy
25 city 33 highway
3.6 gallons per 100 miles

Small SUVs cars range from 16 to 31 MPG.
The best vehicle rates 119 MPGe.

You save $ 1,500
in fuel costs over 5 years compared to the average new vehicle.

Annual fuel cost
$ 1,900

Fuel Economy & Greenhouse Gas Rating (tailpipe only) **Smog Rating** (tailpipe only)
7 (1 – 10 Best)
6 (1 – 10 Best)
This vehicle emits 315 grams CO_2 per mile. The best emits 0 grams per mile (tailpipe only). Producing and distributing fuel also creates emissions; learn more at fueleconomy.gov.

Actual results will vary for many reasons, including driving conditions and how you drive and maintain your vehicle. The average new vehicle gets 24 MPG and costs $11,000 to fuel over 5 years. Cost estimates are based on 15,000 miles per year at $3.50 per gallon. MPGe is miles per gallon equivalent. Vehicle emissions are a significant cause of climate change and smog.

fueleconomy.gov
Calculate personalized estimates and compare vehicles

Smartphone QR Code™

PART CONTENTS INFORMATION

FOR VEHICLES IN THIS CARLINE:
U.S./CANADIAN PARTS CONTENT: 50%
MAJOR SOURCES OF FOREIGN PARTS CONTENT: JAPAN: 40%

FOR THIS VEHICLE:
FINAL ASSEMBLY POINT: Lafayette, IN
COUNTRY OF ORIGIN:
ENGINE: JAPAN
TRANSMISSION: JAPAN

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

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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 Subaru Outback AWD** Driver: **Peter Broen** Date: **11/21/2014**

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):
1	Tire Warm-Up	35	120	NA	NA	
2	Tire Warm-Up	35	120	NA	NA	
3	Tire Warm-Up	35	100	NA	NA	
4	Tire Warm-Up	35	100	NA	NA	
5	Static	0	0	NA	NA	
6	Dynamic	50	0	NA	NA	
7	SIS	50	70	Left	NA	
8	SIS	50	50	Left	NA	
9	SIS	50	50	Left	NA	
10	SIS	50	50	Left	NA	
11	SIS	50	50	Right	NA	
12	SIS	50	50	Right	NA	
13	SIS	50	50	Right	NA	
14	Fishhook	35	154	Left	No	6.5x scalar
15	Fishhook	40	154	Left	No	
16	Fishhook	45	154	Left	No	
17	Fishhook	47.5	154	Left	No	
18	Fishhook	50	154	Left	No	
19	Fishhook	45	131	Left	No	5.5x scalar
20	Fishhook	47.5	131	Left	No	
21	Fishhook	50	131	Left	No	
22	Fishhook	35	154	Right	No	6.5x scalar
23	Fishhook	40	154	Right	No	

Vehicle: **2015 Subaru Outback AWD** Driver: **Peter Broen** Date: **11/21/2014**

Run Number	Test Type	Speed (mph)	Handwheel Angle (deg)	Dir. of First Steer	2 Wheel Lift	Notes
24	Fishhook	45	154	Right	No	
25	Fishhook	47.5	154	Right	No	
26	Fishhook	50	154	Right	No	
27	Fishhook	45	131	Right	No	5.5x scalar
28	Fishhook	47.5	131	Right	No	
29	Fishhook	50	131	Right	No	

APPENDIX C

Slowly Increasing Steer Test Worksheet

NCAP, 2015 Subaru Outback AWD , Multi-Passenger Load, Test Date: 11/21/2014

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	50.1	0.1	99.7	1037	-23.3	-0.294	-151.4	-0.2102	-128.1	-0.1779	0.9944	501	701
9	1	50.4	0.5	99.0	1015	-23.3	-0.306	-151.2	-0.2101	-128.0	-0.1777	0.9918	468	668
10	1	49.9	4.1	91.7	1034	-23.1	-0.307	-150.1	-0.2084	-127.0	-0.1764	0.9930	496	696
11	0	50.3	0.6	98.7	1037	23.9	0.304	155.3	0.2157	131.4	0.1826	0.9887	497	697
12	0	50.4	0.3	99.4	1023	24.7	0.294	160.4	0.2228	135.7	0.1885	0.9913	450	650
13	0	50.3	0.2	99.5	1043	24.3	0.300	157.7	0.2191	133.5	0.1854	0.9965	502	702
					Mean:	23.7	0.301	154	0.214	131	0.181			

Steering Controller Input Values

Scalar 6.5 values:

Initial HW angle:	154	deg
Initial time:	0.214	s
Reversal HW angle:	-154	deg
Reversal time:	0.429	s

Scalar 5.5 values:

Initial HW angle:	131	deg
Initial time:	0.181	s
Reversal HW angle:	-131	deg
Reversal time:	0.363	s

APPENDIX D

Time History Plots

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D12. Pitch Rate and Longitudinal Acceleration Time History Plots for Supplemental 2 Test Series, L-R, 50 mph D-14
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D16. Pitch Rate and Longitudinal Acceleration Time History Plots for Supplemental 2 Test Series, R-L, 50 mph D-18

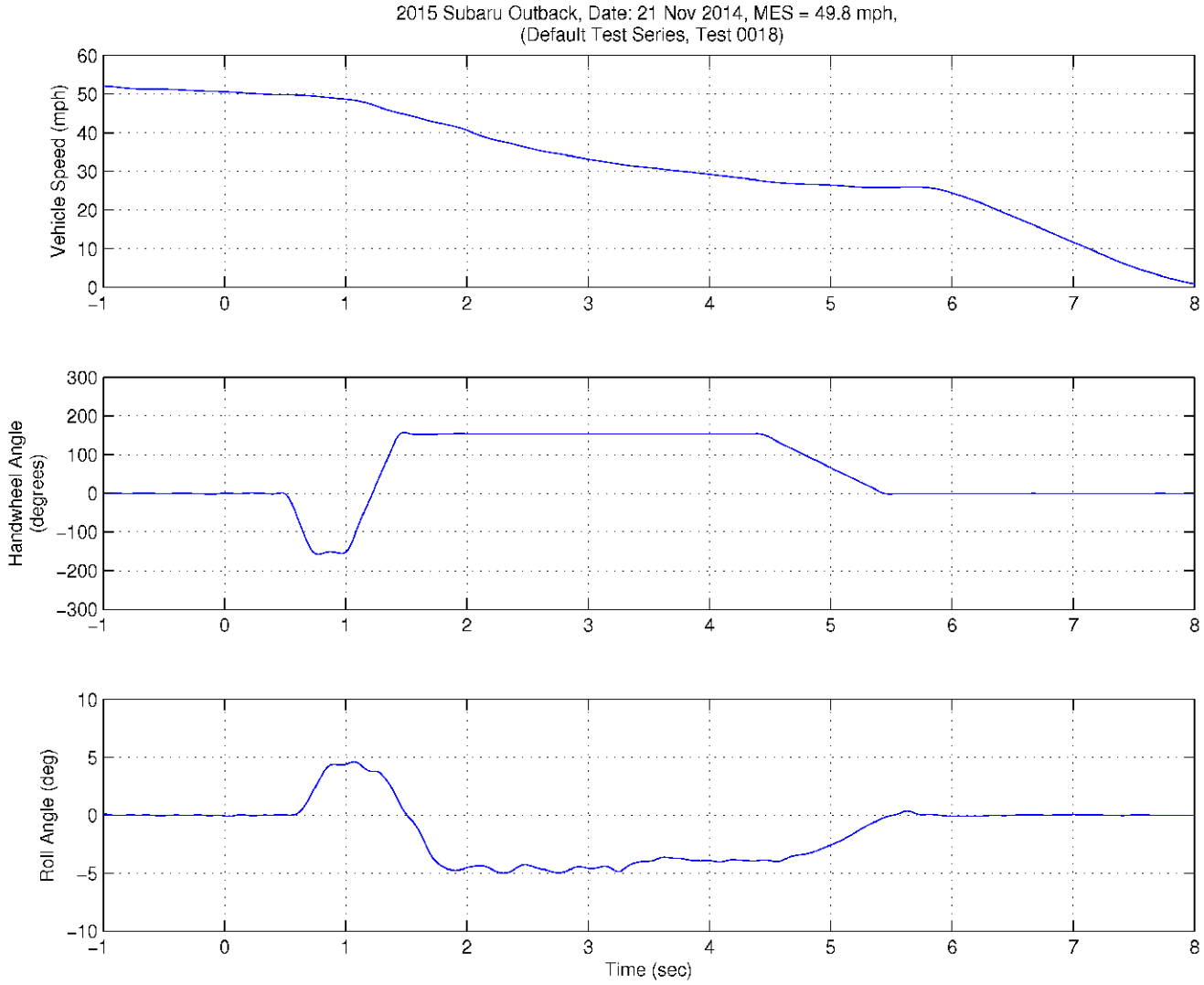

Figure D1. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Default Test Series, L-R, 50 mph

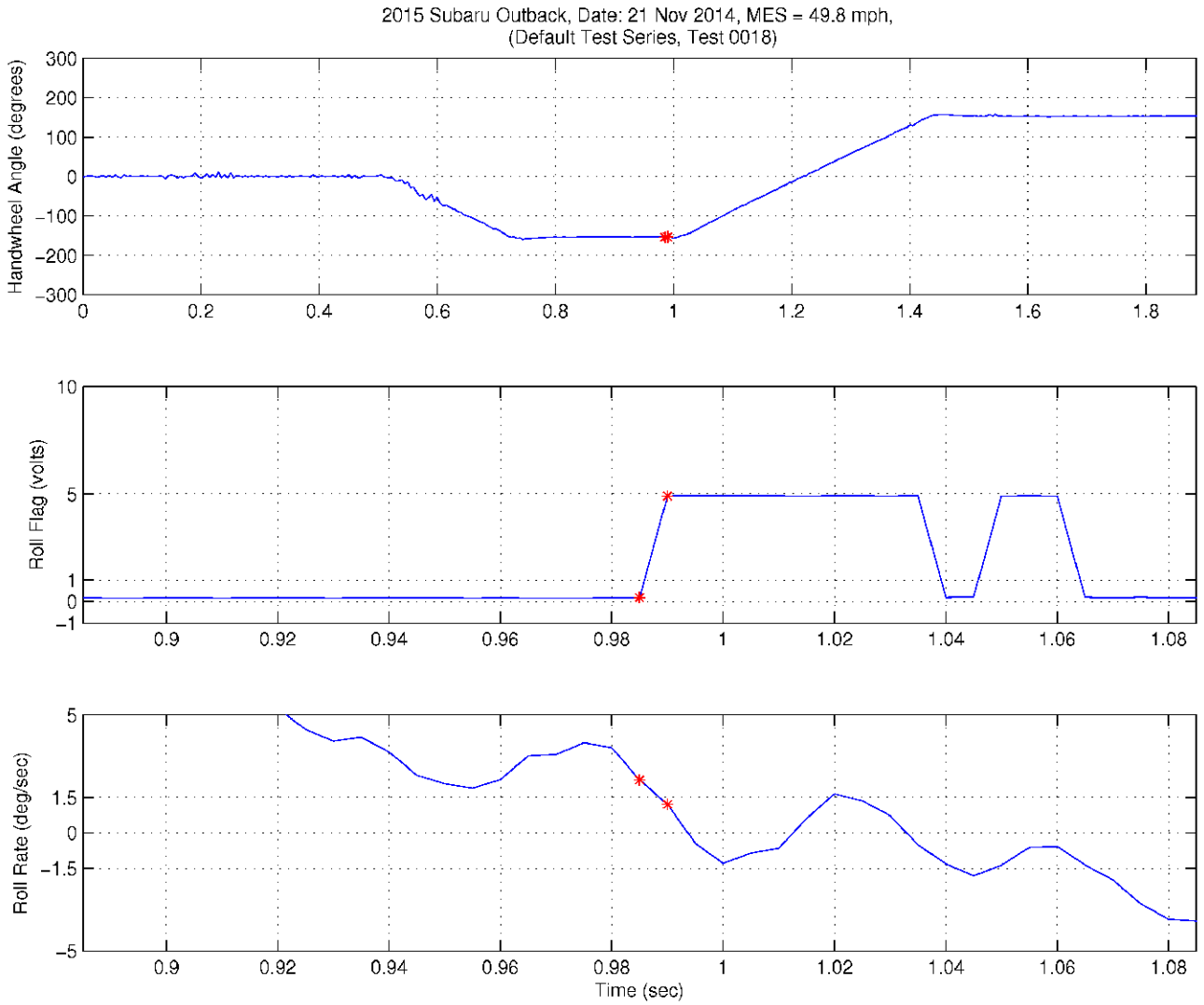

Figure D2. Steering Machine Operation Time History Plots for Default Test Series, L-R, 50 mph

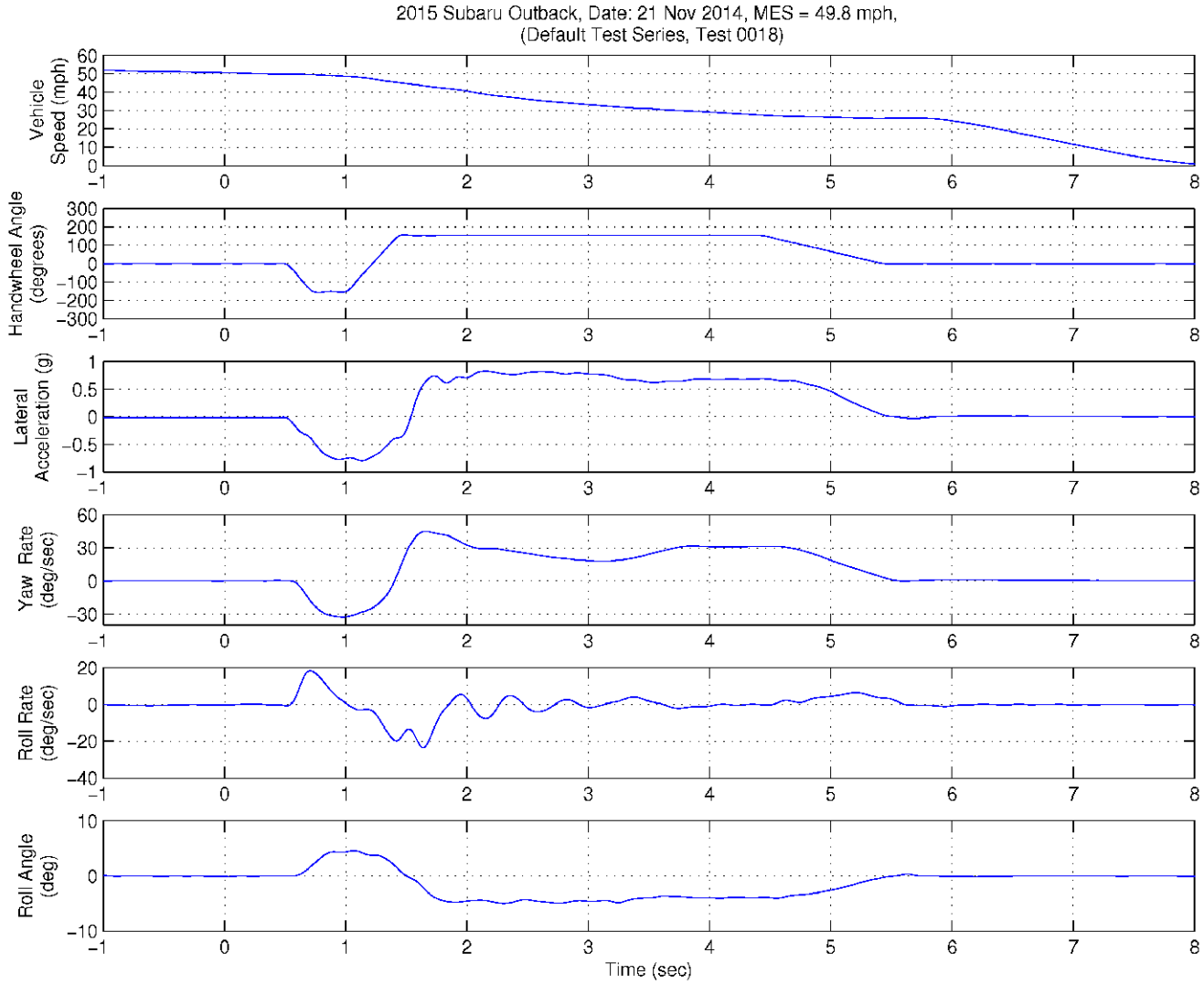

Figure D3. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots For Default Test Series, L-R, 50 mph

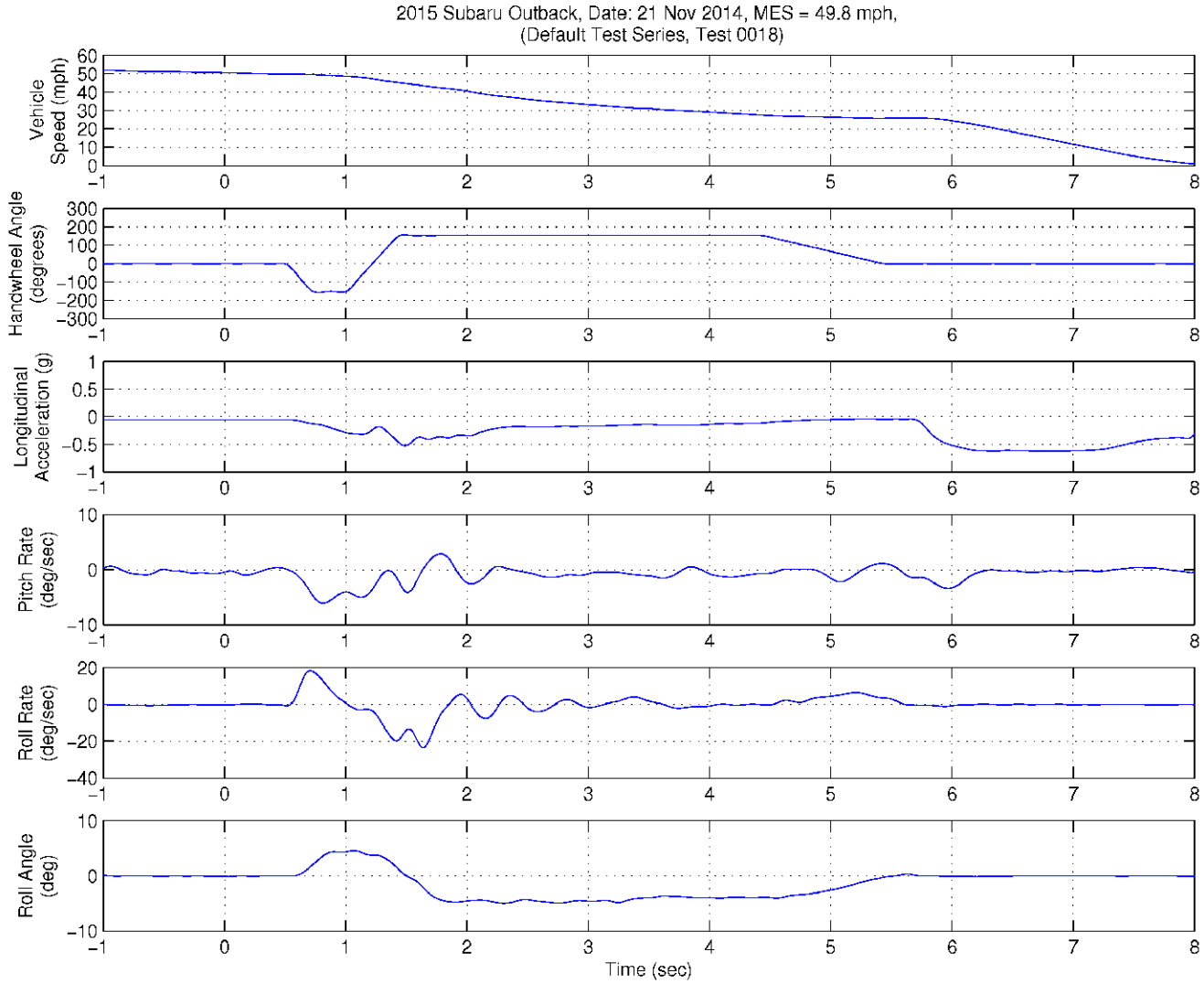

Figure D4. Pitch Rate and Longitudinal Acceleration Time History Plots for Default Test Series, L-R, 50 mph

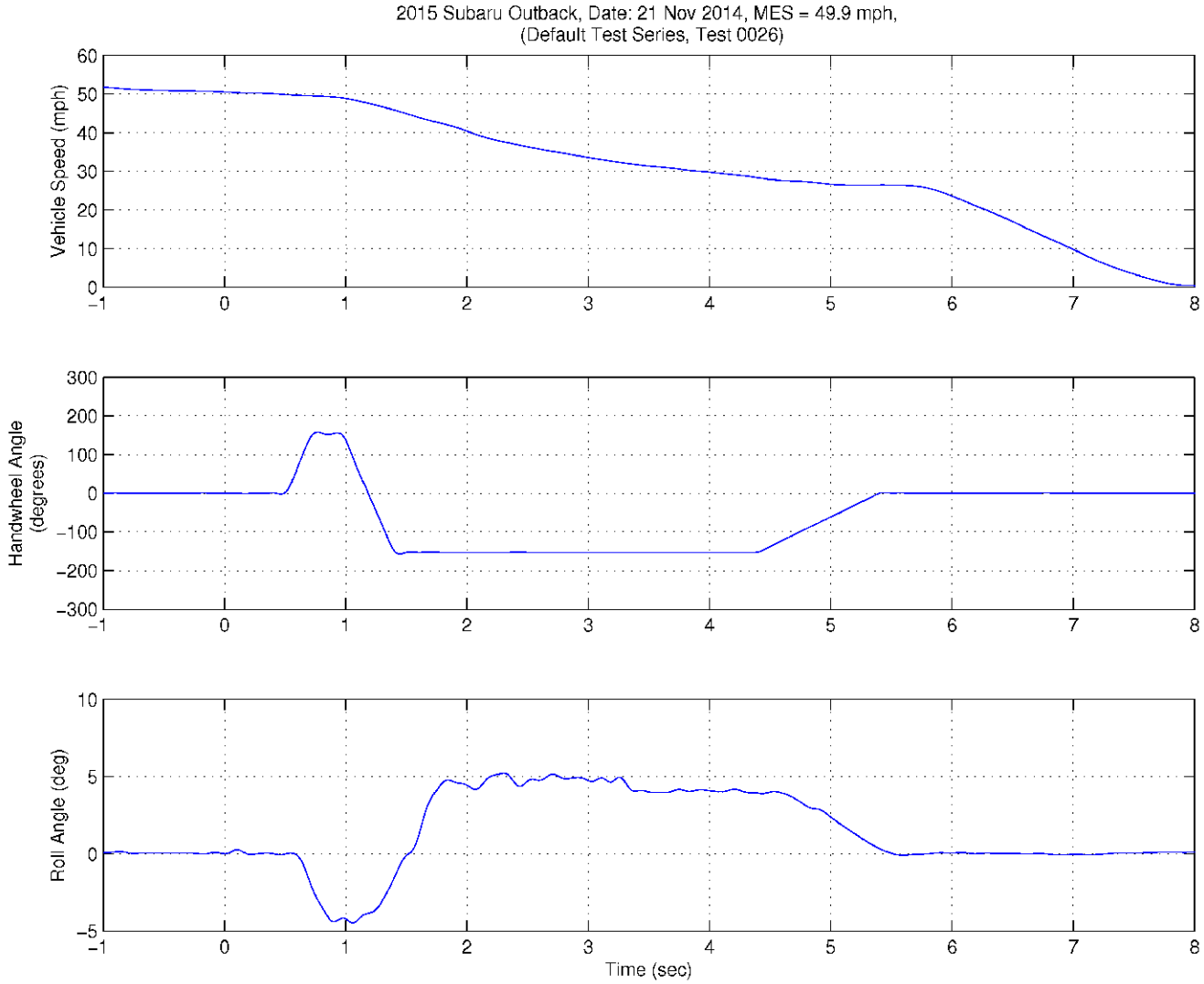

Figure D5. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Default Test Series, R-L, 50 mph

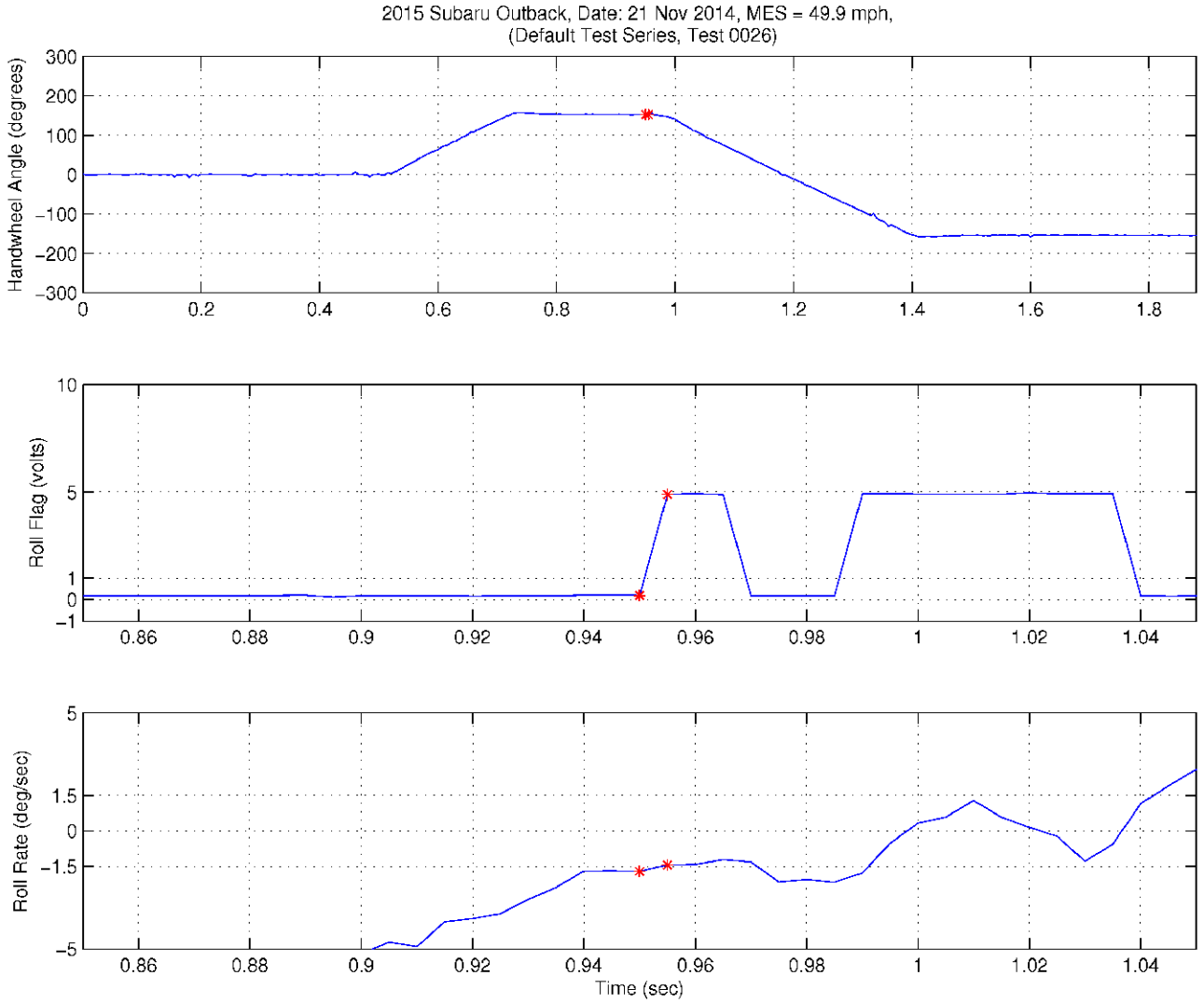

Figure D6. Steering Machine Operation Time History Plots for Default Test Series, R-L, 50 mph

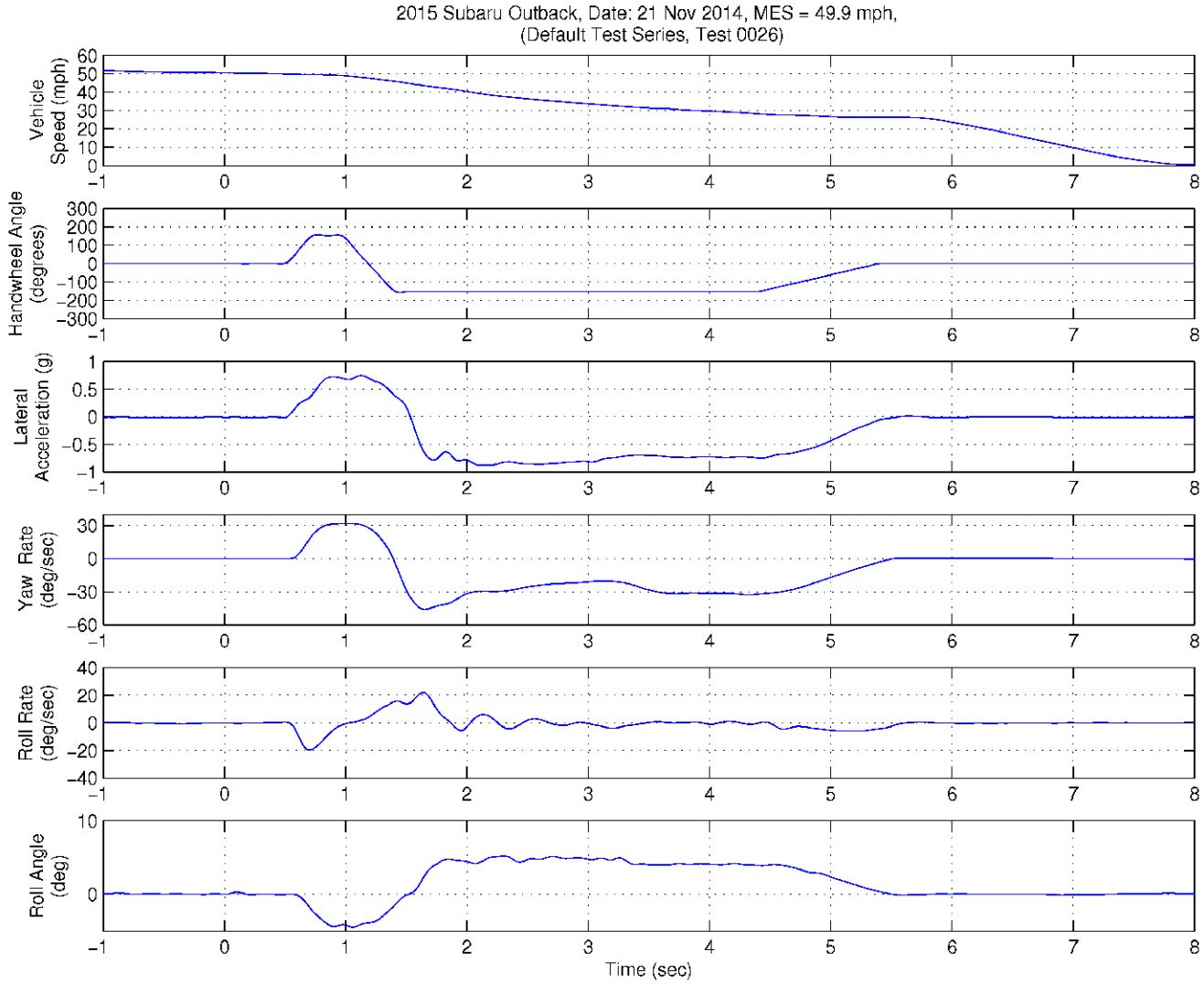

Figure D7. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots for Default Test Series, R-L, 50 mph

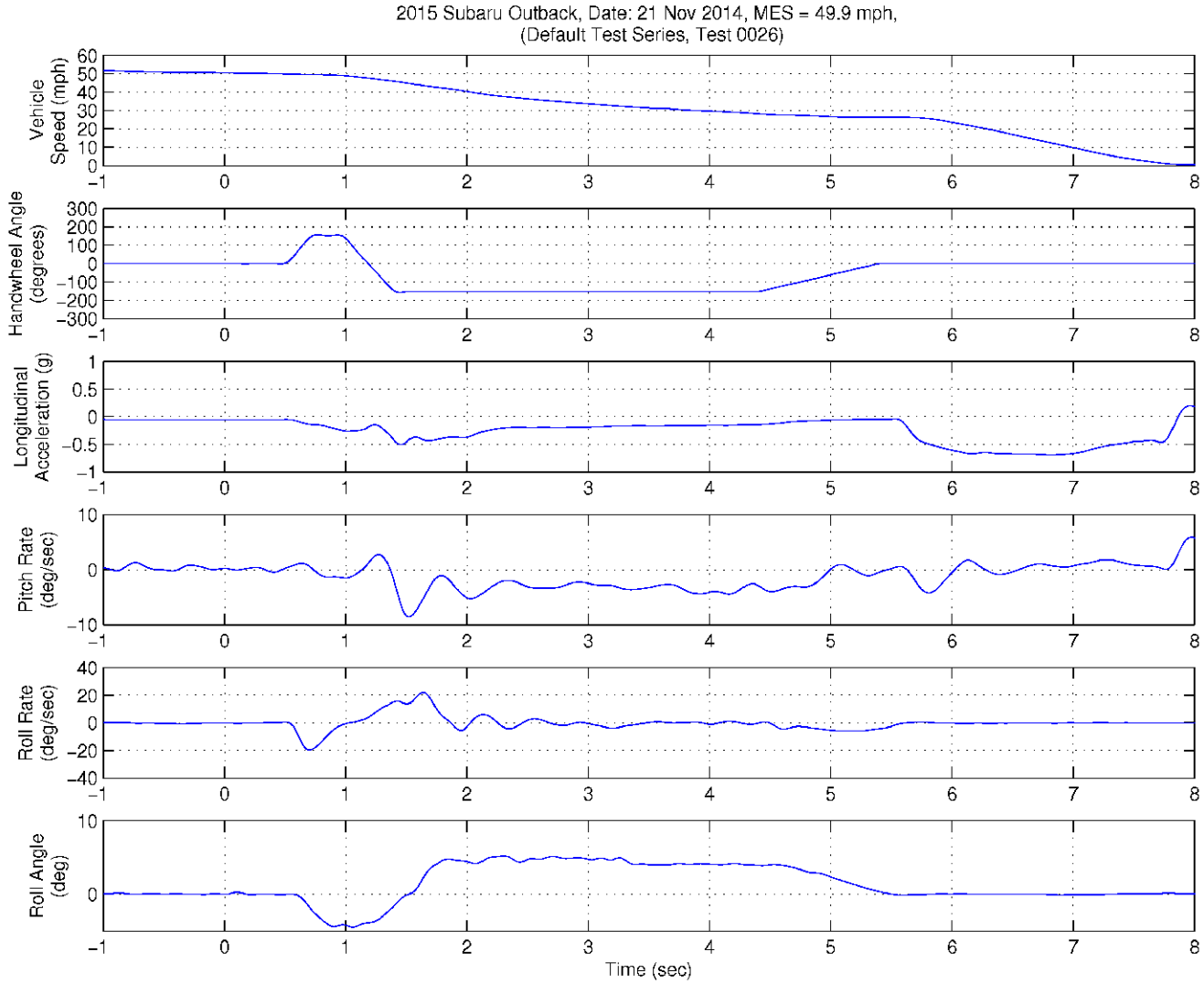

Figure D8. Pitch Rate and Longitudinal Acceleration Time History Plots or Default Test Series, R-L, 50 mph

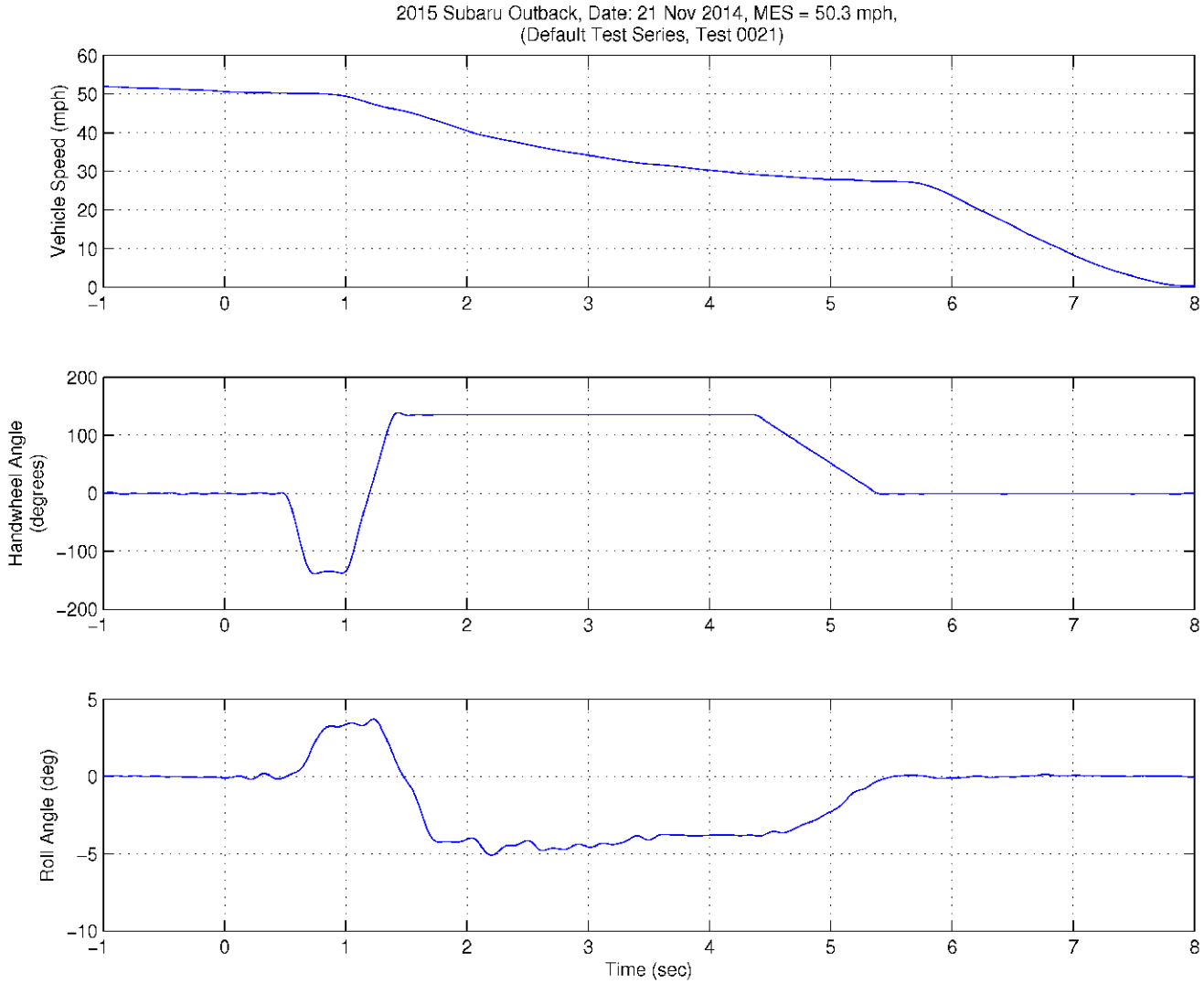

Figure D9. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

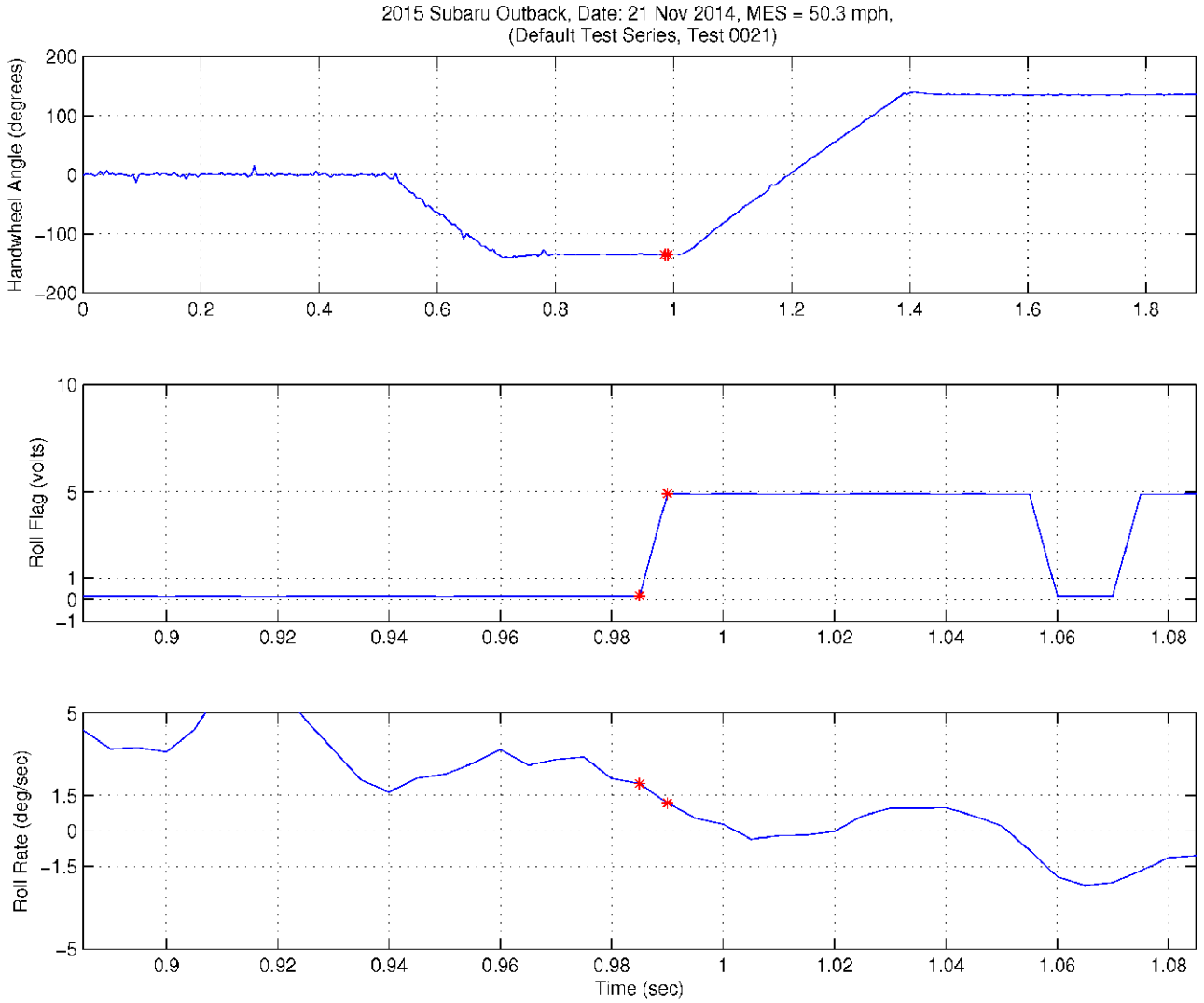

Figure D10. Steering Machine Operation Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

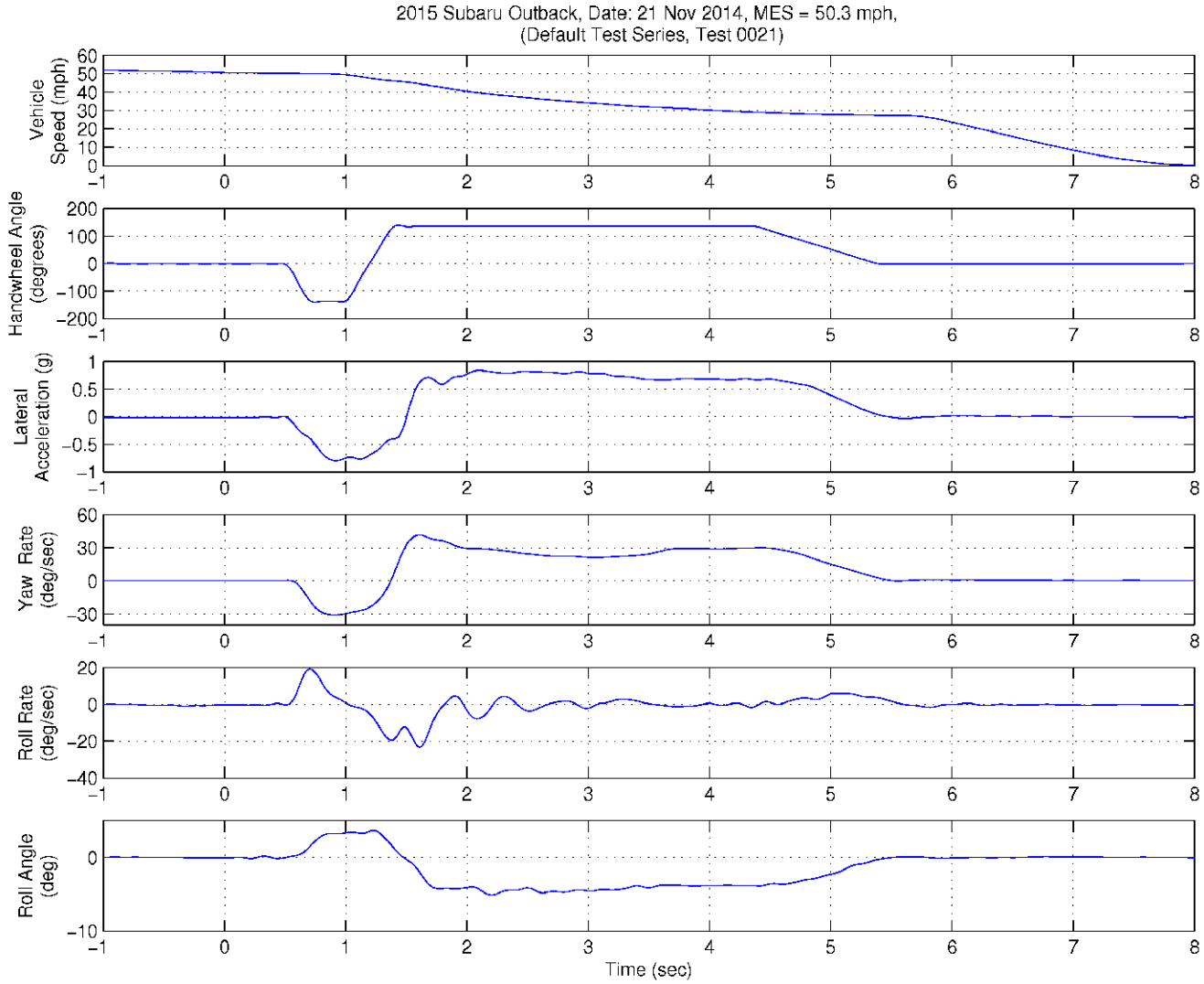

Figure D11. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

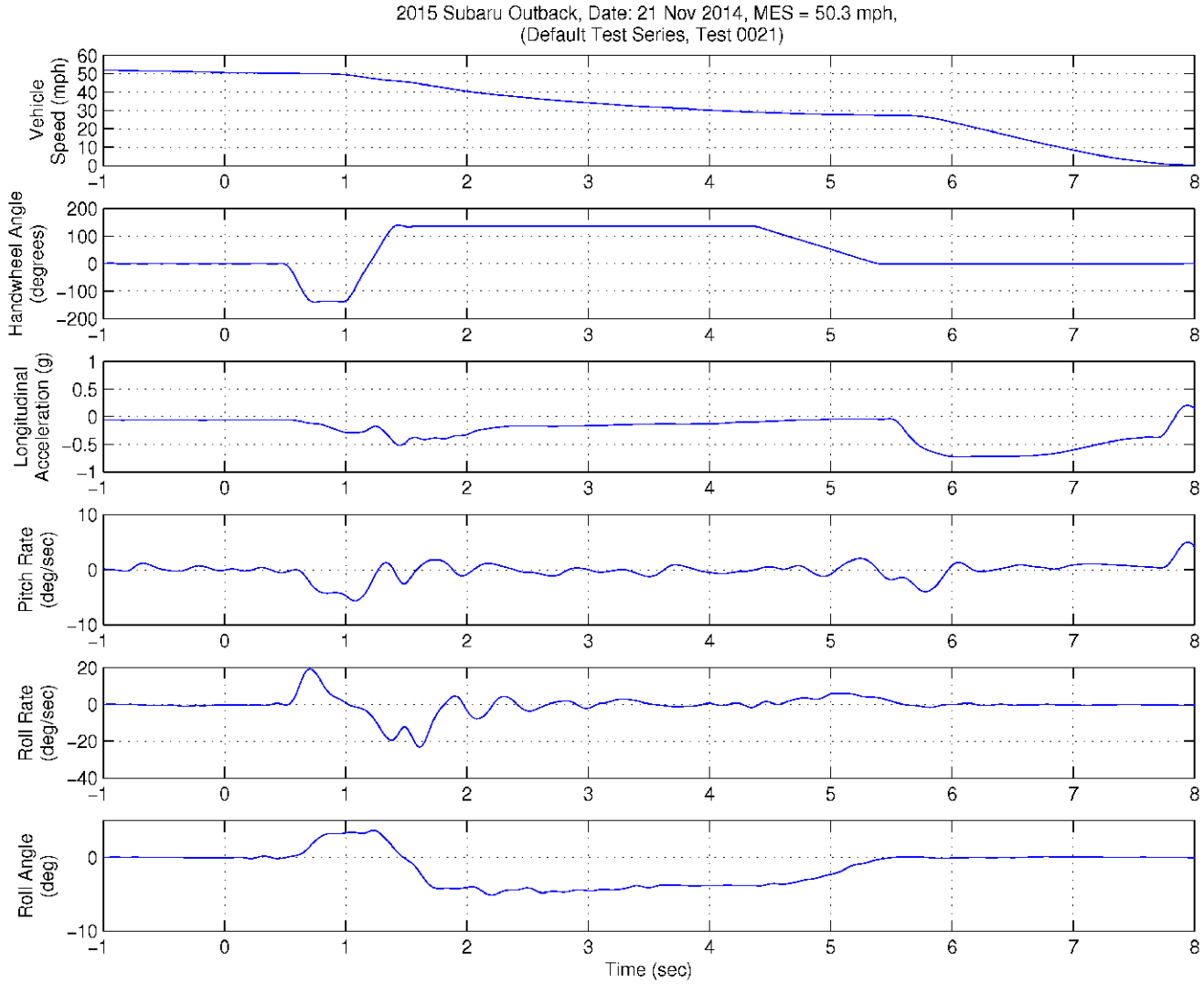

Figure D12. Pitch Rate and Longitudinal Acceleration Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

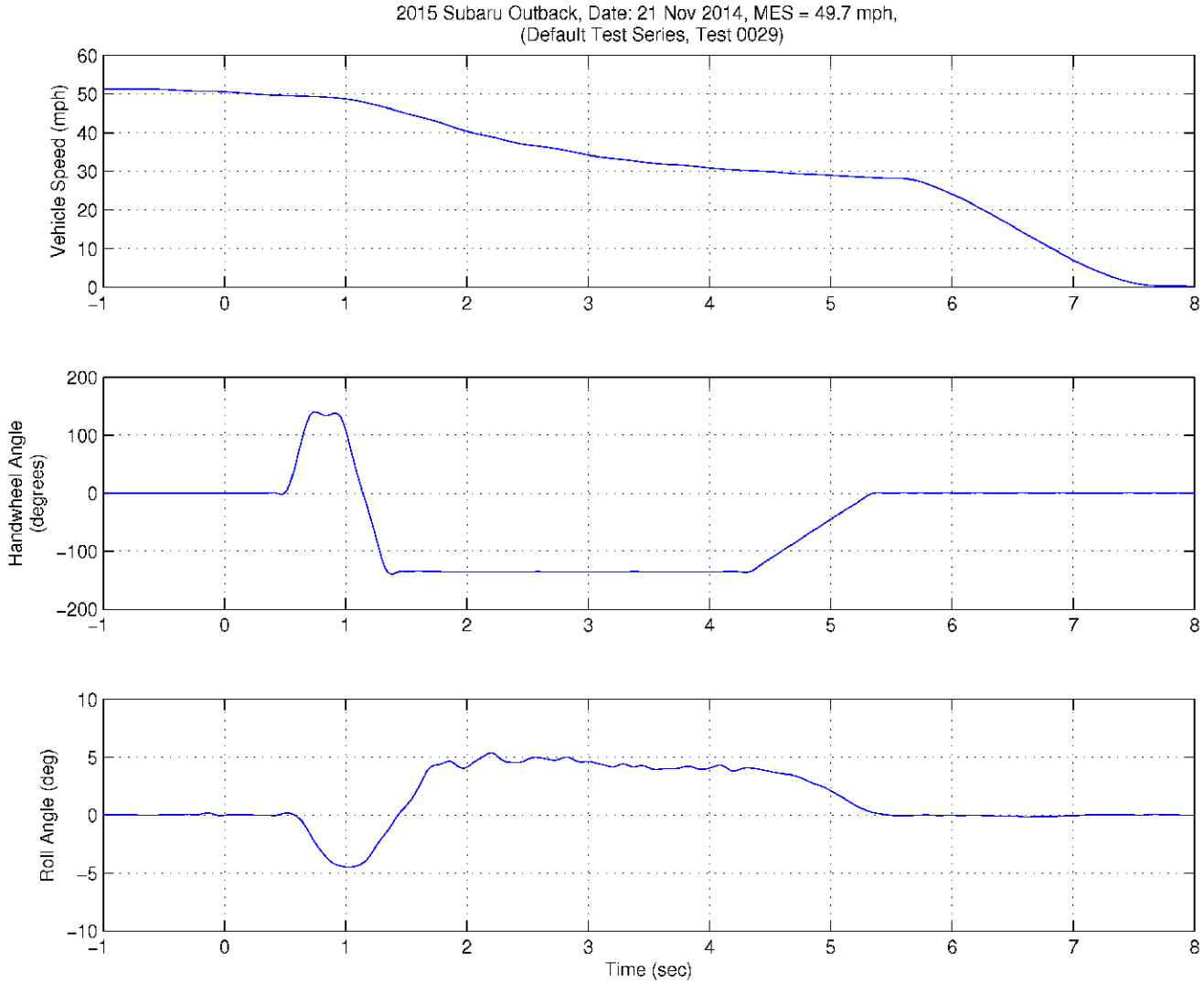

Figure D13. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Supplemental 2 Test Series, R-L, 50 mph

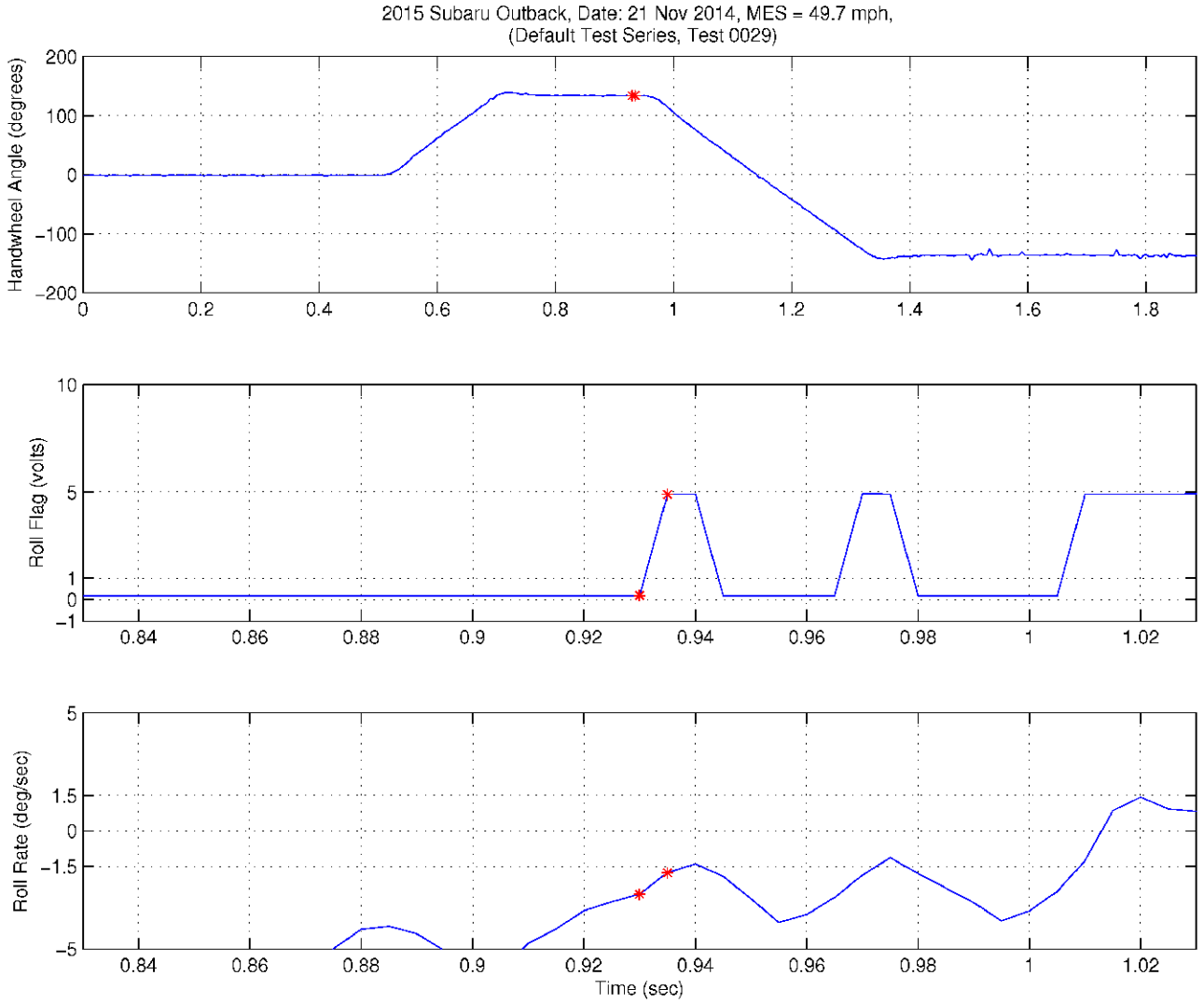

Figure D14. Steering Machine Operation Time History Plots for Supplemental 2 Test Series, R-L, 50 mph

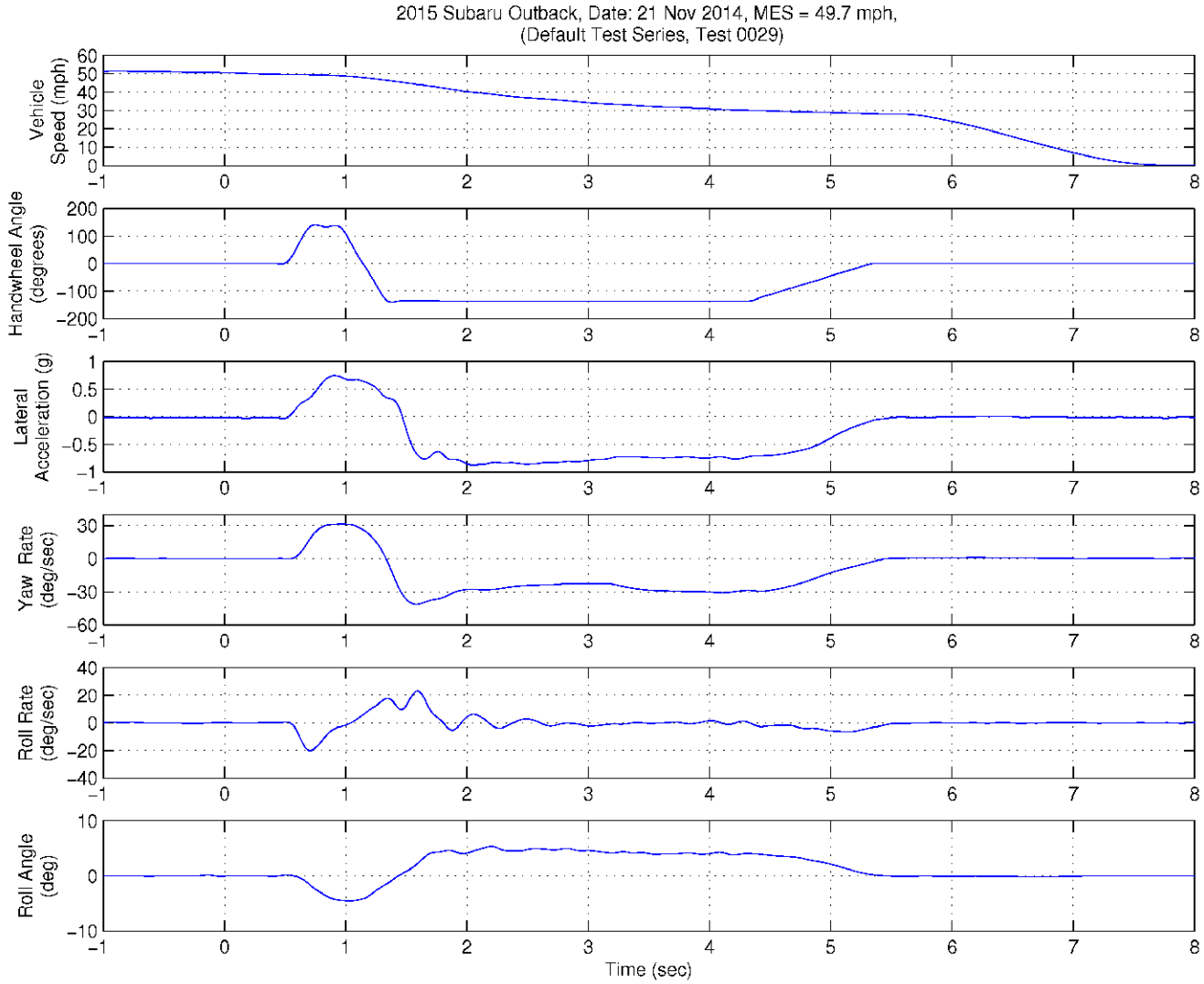

Figure D15. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots for Supplemental 2 Test Series, R-L, 50 mph

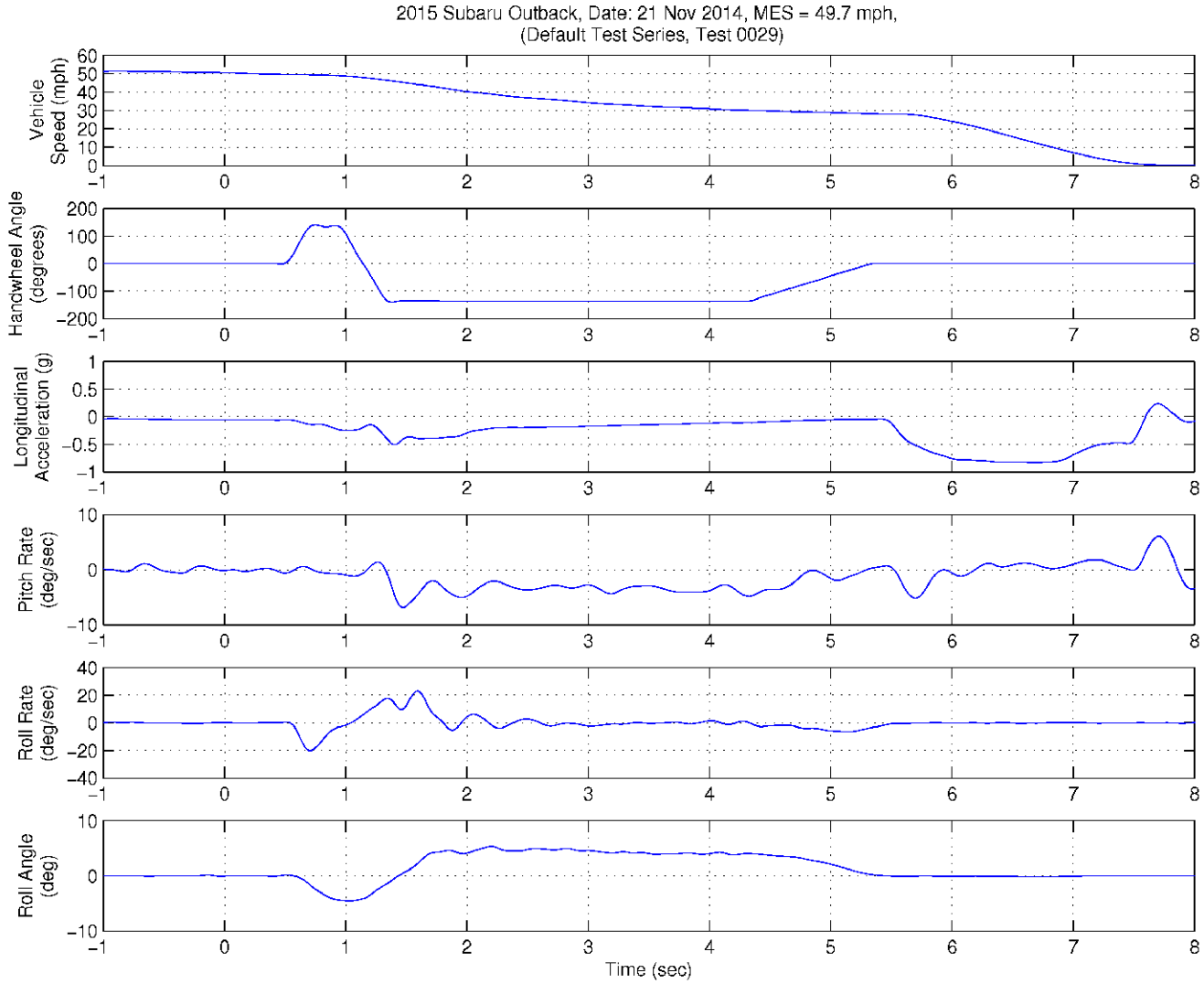

Figure D16. Pitch Rate and Longitudinal Acceleration Time History Plots for Supplemental 2 Test Series, R-L, 50 mph