

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

FCA US LLC

2020 Jeep Wrangler Sport 4x4

TEST NUMBER: NCAP-DRI-RR-20-10

Final Report  
17 June 2020



Prepared by:

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Date: 17 June 2020

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16. Abstract  An NCAP Dynamic Rollover Maneuver (Fishhook) Test was conducted on a 2020 Jeep Wrangler Sport 4x4 at Dynamic Research, Inc. on December 5, 2019. The vehicle did not experience two-wheel lift. The vehicle's steering angle at 0.3 g lateral acceleration at 50 mph was 41.2 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 2020 Jeep Wrangler Sport 4x4 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](http://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, "NCAP Dynamic Rollover Testing."

## 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 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	2020 Jeep Wrangler Sport 4x4				
VIN	1C4GJXAG0LW12xxxx				
Vehicle type/Body style	MPV/MPV				
Number of doors	2				
Trim level	SPORT 4X4				
Seating positions	Front:	2 <sup>nd</sup> row	3 <sup>rd</sup> row	4 <sup>th</sup> row	5 <sup>th</sup> row
	2	2	0	0	0
Electronic stability control	Yes				
4-Wheel ABS (Yes/No)	Yes				
Power steering (Yes/No)	Yes				
Major optional equipment	Customer Preferred Package 24S 17-Inch x 17.5-Inch Tech Silver Aluminum Wheels, Air Conditioning, Technology Group, 8-Speed Automatic 850RE Transmission, Black 3-Piece Hard top.				
Odometer at start of testing	27 miles				
Drivetrain					
Engine cylinder arrangement	V-6				
Engine displacement	3.6 L				
Transmission type	Automatic				
Drive arrangement	4WD				
Chassis					
Track width	F: 63 in (1600.2 mm), R: 63 in (1600.2 mm)				
Wheelbase	96.5 in (2451.1 mm)				
Curb weight	3979 lb (1804.8 kg)				
Certification Data from Vehicle's Label					
Vehicle manufactured by	FCA US LLC				
Date of manufacture	8-19				
GVWR	5000 lb (2268 kg)				
GAWR Front	2700 lb (1225 kg)				
GAWR Rear	3000 lb (1361 kg)				

**Table 2. Tire Information**

Tire Manufacturer	Michelin
Tire Model	LTX M/S2
Tire Size	Front: 245/75R17 Rear: 245/75R17
Load rating	Front: 112 Rear: 112
Speed rating	Front: S Rear: S
Treadwear grade	Front: 720 Rear: 720
Traction grade	Front: A Rear: A
Temperature grade	Front: A Rear: A
Location of "Recommended Tire Pressure" label	Driver's door jamb
Recommended cold tire pressure	Front: 36 psi, (250 kPa) Rear: 36 psi, (250 kPa)
First 8 digits of DOT code	Front: M3CW 02AX Rear: M3CW 02AX

**Table 3. Vehicle Loading**

Water dummy and other loading	2 water dummies in second row
Water dummy weight	175 lb (79.4 kg)
Fuel level	Full
<b>Weight as Tested</b>	
Left front	1090 lb (494.4 kg)
Right front	1104 lb (500.8 kg)
Left rear	1304 lb (591.5 kg)
Right rear	1345 lb (610.1 kg)

## **D. Steering Controller**

Precise controlled steering is accomplished using a steering machine designed and constructed by DRI. DRI has used its Automated Vehicle Controller (AVC) steering machine for many vehicle tests including FMVSS 126 tests. It can provide up to 65 ft-lb torque and rates over 1300 deg/sec. The integrated angle encoder has an unlimited range with a resolution of 0.045 degrees and an accuracy of  $\pm 0.045$  degrees. The steering motor is controlled by a MicroAutoBox II from dSPACE, which also acts as the data acquisition system.

## **E. Real-Time Controller and Data Acquisition**

Data acquisition is achieved using a MicroAutoBox II from dSPACE, which also serves as the real-time system for the steering controller. Data from the Oxford IMU, including Longitudinal, Lateral, and Vertical Acceleration, Roll, Yaw, and Pitch Rate, Forward and Lateral Velocity, Roll and Pitch Angle, are sent over Ethernet to the Micro AutoBox. The Oxford IMUs are calibrated per the manufacturer's recommended schedule (Table 5). The MicroAutoBox II specifications are:

Model: dSPACE Micro-Autobox II 1401/1513  
Base Board SN 549068  
I/O Board SN 588523

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. Equipment Weight**

Table 4 lists the equipment and associated weights outlined in the NHTSA Laboratory Test Procedure for Dynamic Rollover and the equipment at DRI used for this specific test program. The equipment used at DRI for this test program differs slightly from the equipment that was previously used by NHTSA for rollover testing. Because DRI's equipment is lighter than NHTSA's equipment, DRI uses ballast to maintain a consistent weight and weight distribution in the vehicle.

**Table 4. Weight of In-Cab Test Equipment**

Equipment	Location	Equipment Weight (lb)	
		NHTSA*	DRI
Data Acquisition System	Front passenger seat	58	
Steering Machine	Handwheel	31	31
Steering Machine Electronics Box	Passenger row foot well behind the front passenger seat. If vehicle does not have a rear passenger row foot well, the Electronics Box should be placed in the front passenger seat foot well.	39	
MABX, and laptop	Front passenger seat		21
Motor control and power supply	Front passenger footwell		26
Ballast	Front passenger footwell		50
<b>Total</b>		<b>128</b>	<b>128</b>

\* Table A.1 from US DOT NHTSA - Laboratory Test Procedure for Dynamic Rollover - The Fishhook Maneuver Test Procedure - New Car Assessment Program (NCAP) - March 2013

## **G. Sensors**

A list of the sensors is given in Table 5.

## **H. 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
- Airbags were removed or otherwise disabled
- Photographs of the vehicle tested are given in Appendix A.

**Table 5. Sensors**

Measured Variable	Sensor	Range	Resolution	Accuracy	Specifics	Serial Number	Calibration
Vehicle Tire Pressure	Tire Pressure Gauge	0-100 psi 0-690 kPa	0.01 psi 6.89 kPa	< 1% error between 20 and 100 psi	Omega DPG8001	17042707002	By: DRI Date: 7/3/2019 Due: 7/3/2020
Vehicle Total, Wheel, and Axle Load	Platform Scales (Minter)	1200 lb/platform 5338 N/platform	1 lb 4.4 N	0.5% of applied load	Intercomp SWI	1110M206352	By: DRI Date: 1/3/2019 Due: 1/3/2020
	Platform Scales (Torrance)	1500 lb/platform 6672 N/platform	1 lb 4.4 N	0.5% of applied load	Intercomp SWI	24032361	By: DRI Date: 12/11/2018 Due: 12/11/2019
Handwheel Angle	Steering Angle Encoder (Automated Steering Controller)	±800 deg	0.045 deg	±0.045 deg	DRI Automatic Vehicle Controller using dSPACE Micro-Autobox II	NA	Verified by DRI at installation <sup>1</sup>
Longitudinal, Lateral, and Vertical Acceleration Roll, Yaw, and Pitch Rate, Forward and Lateral Velocity, Roll and Pitch Angle	Multi-Axis Inertial Sensing System	Accels ± 5 g, Angular Rate ±300 deg/s, Angle >45 deg, Velocity >200 km/h	Accels .001 g, Angular Rate 0.01 deg/s, Angle 0.05 deg, Velocity 0.1 km/h	Accels .001g, Angular Rate 0.01 deg/s, Angle 0.05 deg, Velocity 0.1 km/h	Oxford xNav 550	015386	By: Oxford Technical Solutions Date: 8/8/2019 Due: 8/8/2021

<sup>1</sup> . The steering encoder is checked prior to beginning tests to verify that there are no faults. The steering controller is installed in the vehicle and the steering wheel is turned through two complete revolutions while recording data. The data are then reviewed for any dropouts or other nonlinearities that would indicate dust intrusion or faulty sectors.

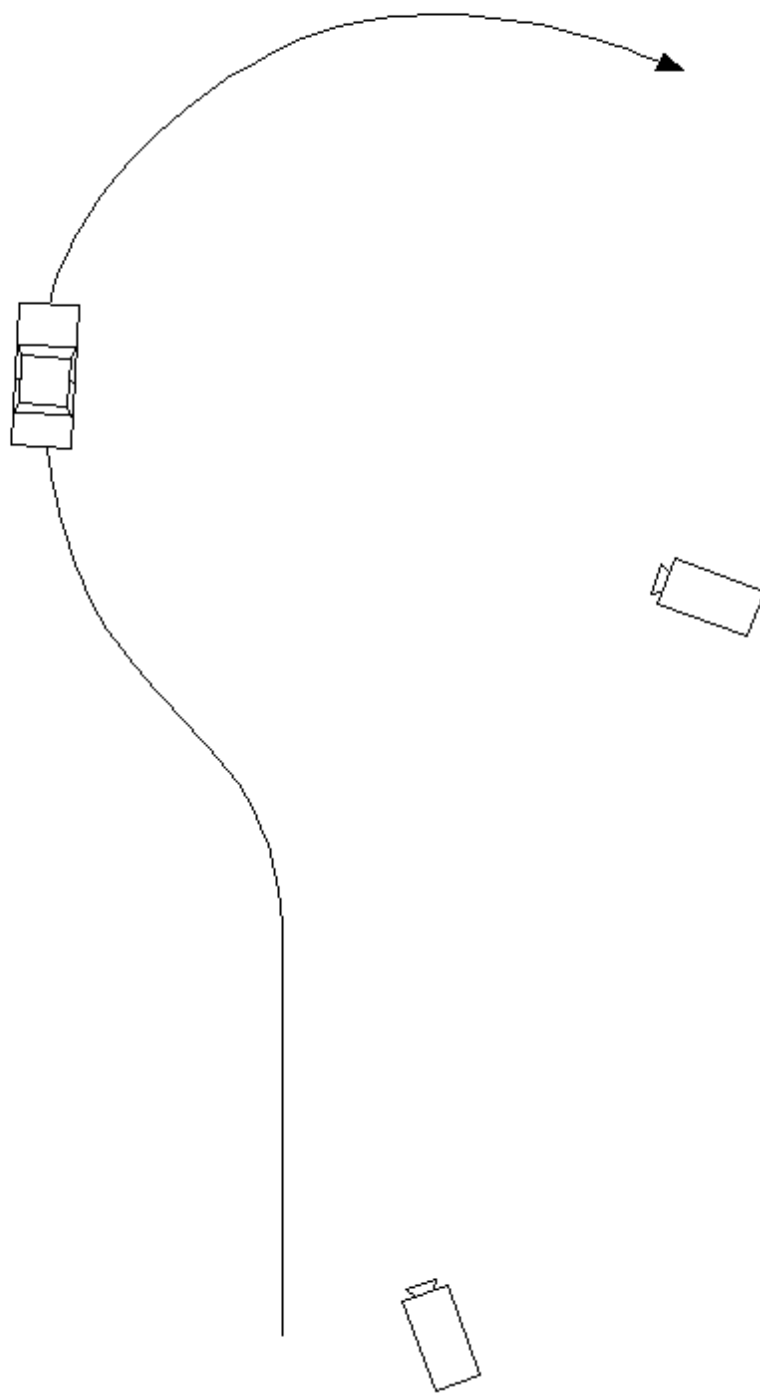


Figure 1. Nominal Position of Video Cameras for Fishhook Tests

## 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 12/5/2019. 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 ( $\pm 0.5$ ) psi at a test speed of 40 ( $\pm 0.5$ ) 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 6.

**Table 6. Surface Friction**

Date of surface friction measurements	12/6/2019
Average normalized lateral force	0.834

### **2. FISHHOOK HANDWHEEL ANGLES**

The 0.3 g handwheel angle obtained from the SIS tests and the handwheel angles used in the Fishhook tests are shown in Table 7.

**Table 7. Handwheel Angles**

0.3 g handwheel angle (from SIS tests at 50 mph)	41.2°
5.5 scalar handwheel angle for Fishhook Test	227°
6.5 scalar handwheel angle for Fishhook Test	268°



### 3. WEATHER CONDITIONS

The weather conditions, recorded at the end of testing, are shown in Table 8.

**Table 8. Weather Conditions**

Ambient temperature	57.2° F (14° C)
Wind Speed	0 mph (0 m/s)
Wind Direction	Calm

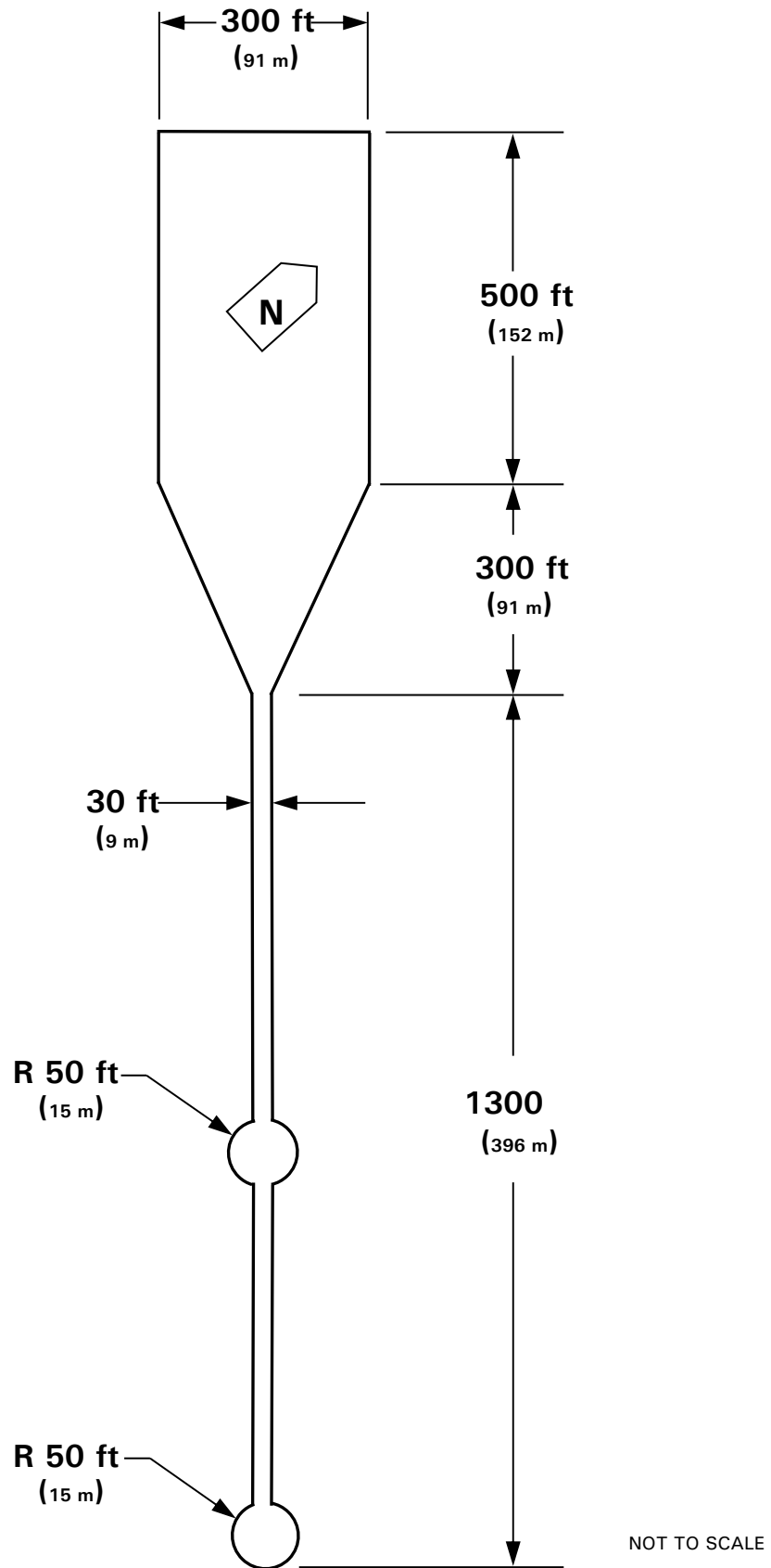


Figure 2. DRI-Minter Vehicle Dynamics Area

## 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. There was no two-wheel lift at any test condition for the 2020 Jeep Wrangler Sport 4x4.

## APPENDIX A

### Photographs

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# **Jeep** 2020 MODEL YEAR **WRANGLER SPORT 4X4**

THIS VEHICLE IS MANUFACTURED TO MEET SPECIFIC UNITED STATES REQUIREMENTS. THIS VEHICLE IS NOT MANUFACTURED FOR SALE OR REGISTRATION OUTSIDE OF THE UNITED STATES.

## **MANUFACTURER'S SUGGESTED RETAIL PRICE OF THIS MODEL INCLUDING DEALER PREPARATION**

**Base Price: \$28,295**

### **JEEP WRANGLER SPORT**

Exterior Color: Billet Silver Metallic Clear-Coat Exterior Paint  
Interior Color: Black Interior Color  
Interior: Cloth Low-Back Bucket Seats  
Engine: 3.6L V6 24V VVT Engine Upp J w/ESS  
Transmission: 8-Speed Automatic 850RE Transmission

### **STANDARD EQUIPMENT (UNLESS REPLACED BY OPTIONAL EQUIPMENT)**

#### **FUNCTIONAL/SAFETY FEATURES**

ParkView® Rear Back-Up Camera  
Command-Trac® Part-Time 4WD System  
3.45 Overall Top Gear Ratio  
Fuel Tank Skid Plate Shield  
Transfer Case Skid Plate Shield  
Transmission Skid Plate  
Anti-Lock 4-Wheel Disc Brakes  
Electronic Stability Control  
Electronic Roll Mitigation  
Trailer Sway Damping  
Hill Start Assist  
Push-Button Start  
Sentry Key® Theft Deterrent System  
Tire Pressure Monitoring Display  
Advanced Multistage Front Air Bags  
Supplemental Front Side Air Bags

#### **INTERIOR FEATURES**

Uconnect® 3 with 5-Inch Display  
Cluster 3.5-Inch TFT Blank and White Display  
Vehicle Information Center  
8-Speakers  
Media Hub (USB, Aux)  
Integrated Voice Command with Bluetooth®  
12-Volt Auxiliary Power Outlet  
Tilt / Telescope Steering Column  
Steering Wheel Mounted Audio Controls  
2-Way Manual Lumbar Adjustable Driver Seat  
Driver and Passenger Assist Handles  
Manual Door Locks  
Rear Compartment Storage Tray

#### **EXTERIOR FEATURES**

Black Sunrider® Soft Top (NA w/Sky 1-Touch Pwr Top)  
17-Inch x 7.5-Inch Black Steel Styled Wheels  
245/75R17 All-Season Tires  
Full-Size Spare Tire  
Matching Spare Wheel  
2-Front and 1-Rear Tow Hooks  
Halogen Headlamps  
Headlamp On Time Delay  
Front Fog Lamps

### **Incandescent Tail Lamps**

#### **OPTIONAL EQUIPMENT (May Replace Standard Equipment)**

##### **Customer Preferred Package 24S**

17-Inch x 7.5-Inch Tech Silver Aluminum Wheels  
Leather-Wrapped Steering Wheel  
Sun Visors with Illuminated Vanity Mirrors  
Power-Heated Mirrors  
Remote Keyless Entry  
Air Conditioning  
Deep Tint Sunscreen Windows  
Security Alarm  
Speed-Sensitive Power Locks  
Power Front Windows with 1-Touch Down  
Automatic Headlamps  
Technology Group  
Uconnect® 4 with 7-Inch Display  
Cluster 7.0-Inch TFT Color Display  
Google Android Auto™  
Apple CarPlay®  
SiriusXM® with 1-Year Radio Subscription  
Air Conditioning with Automatic Temperature Control  
Hardtop Headliner by Mopar®  
8-Speed Automatic 850RE Transmission  
Hill Descent Control  
Tip Start  
Black 3-Piece Hard Top  
Freedom Panel Storage Bag  
Rear Window Deteroster  
Rear Window Wiper/Washer  
No Soft Top

**\$3,200**

**\$995**

**\$495**

**\$2,500**

**\$1,195**

#### **DESTINATION CHARGE**

**\$1,495**

**TOTAL PRICE: \* \$38,175**

#### **WARRANTY COVERAGE**

5-year or 60,000-mile Powertrain Limited Warranty.  
3-year or 36,000-mile Basic Limited Warranty.  
Ask Dealer for a copy of the limited warranties or see your owner's manual for details.

**5 YEAR / 60,000 MILE  
POWERTRAIN WARRANTY**

Assembly Point/Port of Entry: TOLEDO, OHIO, U.S.A.

SHIP TO:

SOLE TO:

VIN: 1C4GJXAG0LW-12

LA-VON: 0217

0901



THIS LABEL IS ADDED TO THIS VEHICLE TO COMPLY WITH FEDERAL LAW. THIS LABEL CANNOT BE REMOVED OR ALTERED PRIOR TO DELIVERY TO THE ULTIMATE PURCHASER.  
\* STATE AND/OR LOCAL TAXES, IF ANY, LICENSE AND TITLE FEES AND DEALER SUPPLIED AND RETAIL AD-ONS AND ACCESSORIES ARE NOT INCLUDED IN THIS PRICE. DISCOUNT, IF ANY, IS BASED ON PRICE OF OPTIONS IF PURCHASED SEPARATELY.

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FCA US LLC

## **EPA DOT Fuel Economy and Environment**

**Gasoline Vehicle**

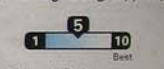
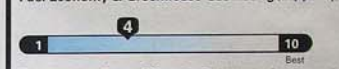
**Fuel Economy** These estimates reflect new EPA methods beginning with 2017 models.  
**20** **MPG** Small SUV 4WD range from 18 to 120 MPGe.  
combined city/hwy city highway  
**5.0** gallons per 100 miles

**You spend**  
**\$2,500**  
**more in fuel costs**  
**over 5 years**  
compared to the  
average new vehicle.

**Annual fuel cost**  
**\$2,000**

#### **Fuel Economy & Greenhouse Gas Rating (tailpipe only)**

#### **Smog Rating (tailpipe only)**



This vehicle emits 440 grams CO2 per mile. The best emits 0 grams per mile (tailpipe only). Producing and distributing fuel also creates emissions. Learn more at [fuelconomy.gov](http://fuelconomy.gov)

Actual results will vary for many reasons, including driving conditions and how you drive and maintain your vehicle. The average new vehicle gets 27 MPG and cost \$7,500 to fuel over 5 years. Cost estimates are based on 15,000 miles per year at \$2.79 per gallon. MPGe is miles per gasoline gallon equivalent. Vehicle emissions are a significant cause of climate change and smog.

**fuelconomy.gov**

Calculate personalized estimates and compare vehicles



### **GOVERNMENT 5-STAR SAFETY RATINGS**

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

Source: National Highway Traffic Safety Administration (NHTSA)  
[www.safercar.gov](http://www.safercar.gov) or 1-888-327-4236

### **PARTS CONTENT INFORMATION**

**FOR VEHICLES IN THIS CARLINE:**  
**U.S./CANADIAN PARTS CONTENT: 58%**  
**MAJOR SOURCES OF FOREIGN PARTS**

**CONTENT:**

**MEXICO: 19%**

NOTE: PARTS CONTENT DOES NOT INCLUDE FINAL ASSEMBLY DISTRIBUTION, OR OTHER NON-PARTS COSTS.

**FOR THIS VEHICLE:**  
**FINAL ASSEMBLY POINT:**  
**TOLEDO, OHIO, U.S.A.**

**COUNTRY OF ORIGIN:**  
**ENGINE: MEXICO**  
**TRANSMISSION: UNITED STATES**



Ask for Mopar Vehicle Protection for your vehicle. We Built It. We Back It.

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



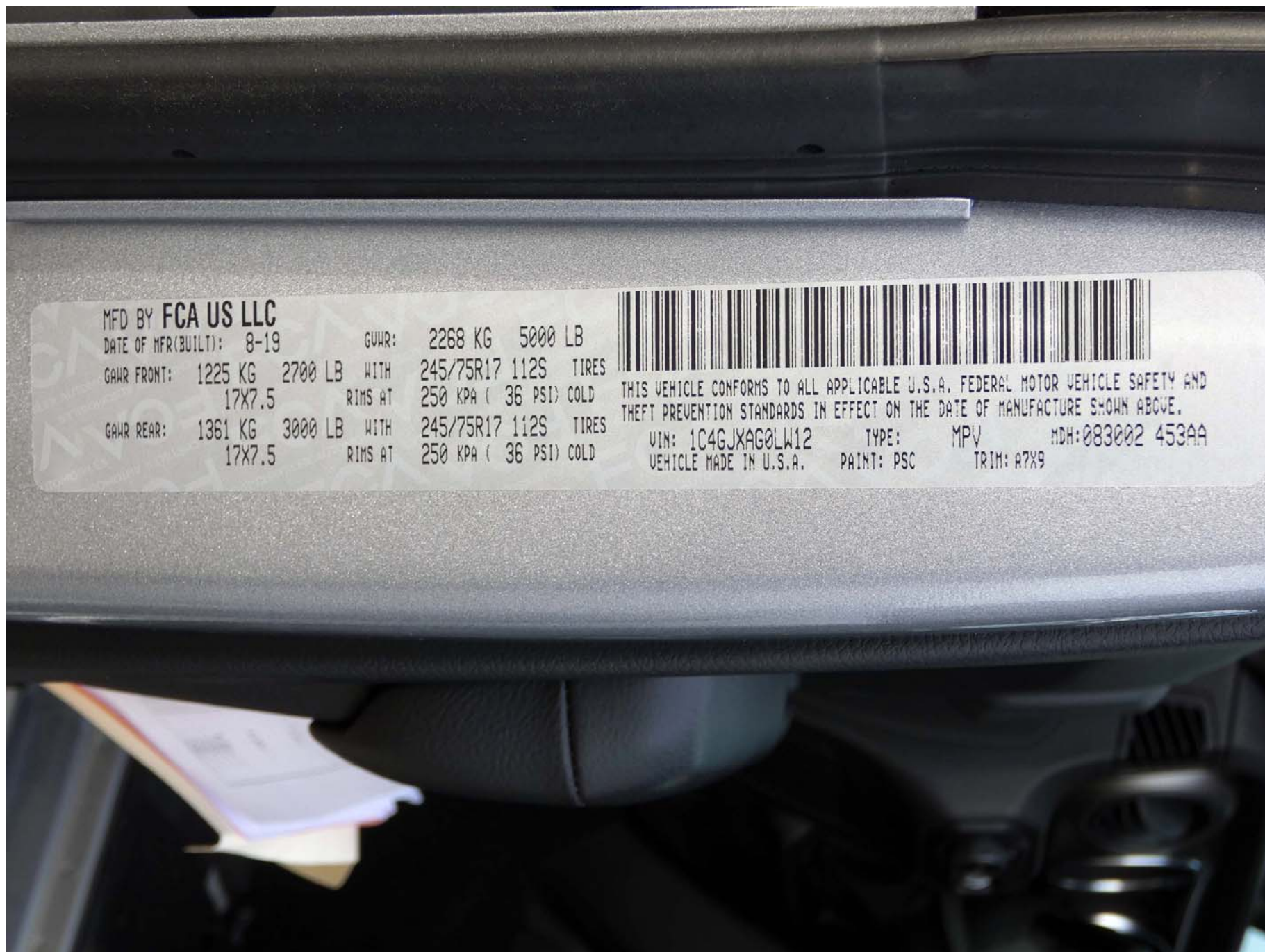


Figure A6. Certification Label

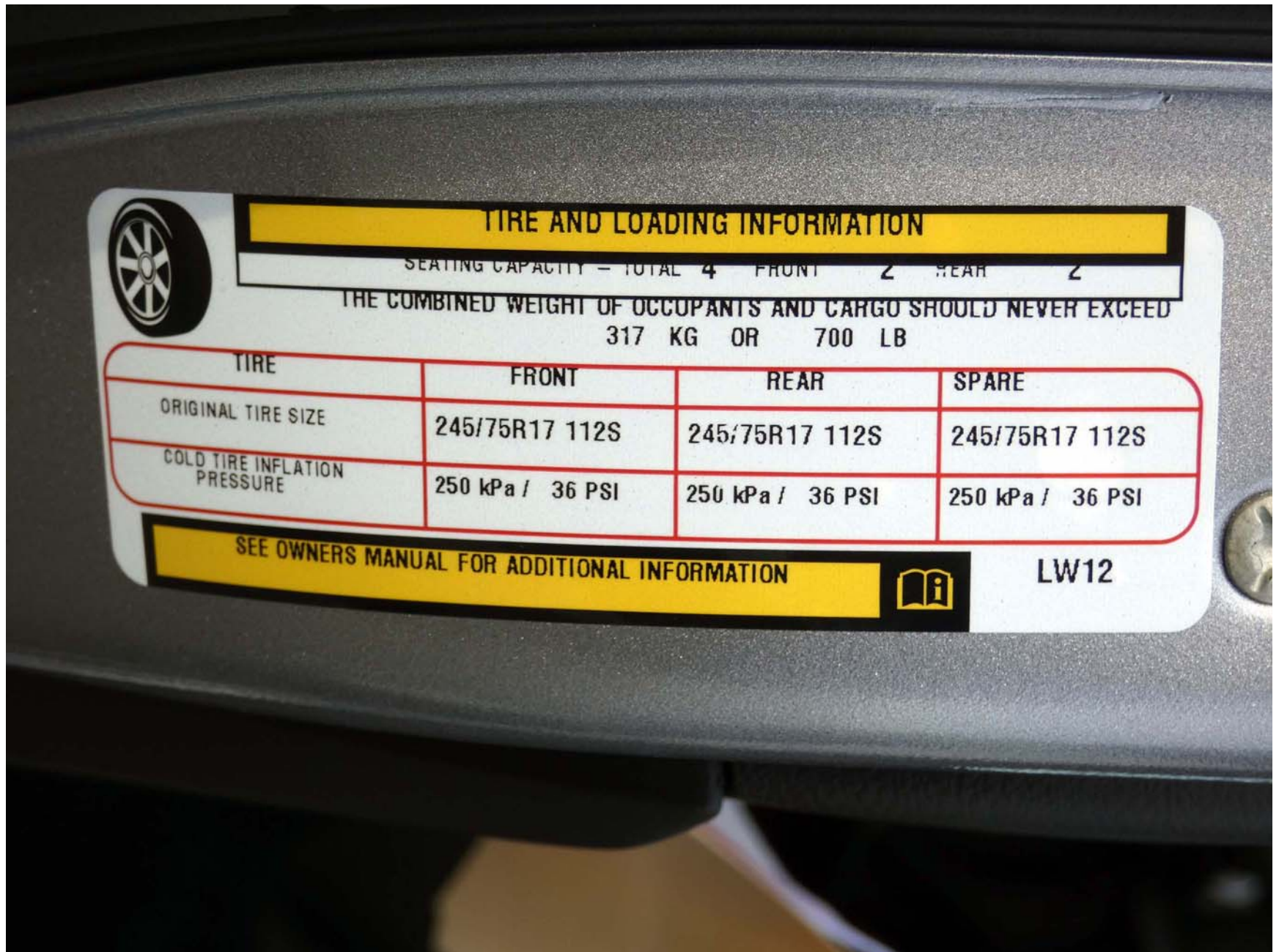


Figure A7. Tire Placard





Figure A8. Instrumentation in Test Vehicle



Figure A9. Steering Controller and Computer





Figure A10. Ballast Condition

## APPENDIX B

### Test Run Log



Vehicle: **2020 Jeep Wrangler Sport 4x4**Driver: **Jonathan Robel** Test Date: **12/5/2019**

Run Number	Test Type	Speed (mph)	Handwheel Angle (deg)	Dir. of First Steer	2 Wheel Lift	Notes
1	<b>Tire Warm-Up</b>	35	60	Right	NA	
2	"	"	80	"	"	
3	"	"	"	"	"	
4	"	"	"	"	"	
5	2x SWA last cycle	"	"	"	"	
6	Static	0	0		"	
7	Steady State	50	0		"	
8	<b>Slowly Increasing Steer</b>	50	50	Left	"	
9	"	"	60	Left	"	
10	"	"	"	Left	"	
11	"	"	"	Left	"	
12	"	"	"	Right	"	
13	"	"	"	Right	"	
14	"	"	"	Right	"	
15	<b>Fishhook 6.5 Scalar</b>	35	268	Left	No	
16	"	40	"	"	"	
17	"	45	"	"	"	
18	"	47.5	"	"	"	
19	"	50	"	"	"	
20	<b>Fishhook 5.5 Scalar</b>	45	227	Left	No	
21	"	47.5		"	"	
22	"	50		"	"	

Run Number	Test Type	Speed (mph)	Handwheel Angle (deg)	Dir. of First Steer	2 Wheel Lift	Notes
23	<b>Fishhook 6.5 Scalar</b>	35	268	Right	No	
24	"	40	"	"	"	
25	"	45	"	"	"	
26	"	47.5	"	"	"	
27	"	50	"	"	"	
28	<b>Fishhook 5.5 Scalar</b>	45	227	Right	No	
29	"	47.5	"	"	"	
30	"	50	"	"	"	

## APPENDIX C

### Slowly Increasing Steer Test Worksheet

NCAP, 2020 Jeep Wrangler Sport 4x4, Multi-Passenger Load

Test Date: 12/5/2019

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
9	L	49.8	0.1	99.9	1413	-41.0	-0.305	-266.4	-0.3700	-225.4	-0.3131	0.9979	601	800
10	L	49.9	2.3	95.4	1406	-40.5	-0.303	-263.2	-0.3656	-222.7	-0.3093	0.9968	600	800
11	L	50.1	-0.2	100.4	1403	-40.3	-0.308	-261.8	-0.3637	-221.6	-0.3077	0.9964	600	800
12	R	50.5	1.3	97.4	1433	42.3	0.291	274.8	0.3817	232.5	0.3230	0.9965	601	800
13	R	50.2	2.1	95.8	1424	41.7	0.298	271.0	0.3763	229.3	0.3184	0.9939	600	800
14	R	50.1	1.5	97.0	1423	41.6	0.303	270.6	0.3758	229.0	0.3180	0.9942	600	800

Mean: 41.2 0.301 268 0.372 227 0.315

Steering Controller Input Values

Scalar 6.5 values:

Initial HW angle: 268 deg  
 Initial time: 0.372 s  
 Reversal HW angle: -268 deg  
 Reversal time: 0.744 s

Scalar 5.5 values:

Initial HW angle: 227 deg  
 Initial time: 0.315 s  
 Reversal HW angle: -227 deg  
 Reversal time: 0.63 s

## APPENDIX D

### Time History Plots

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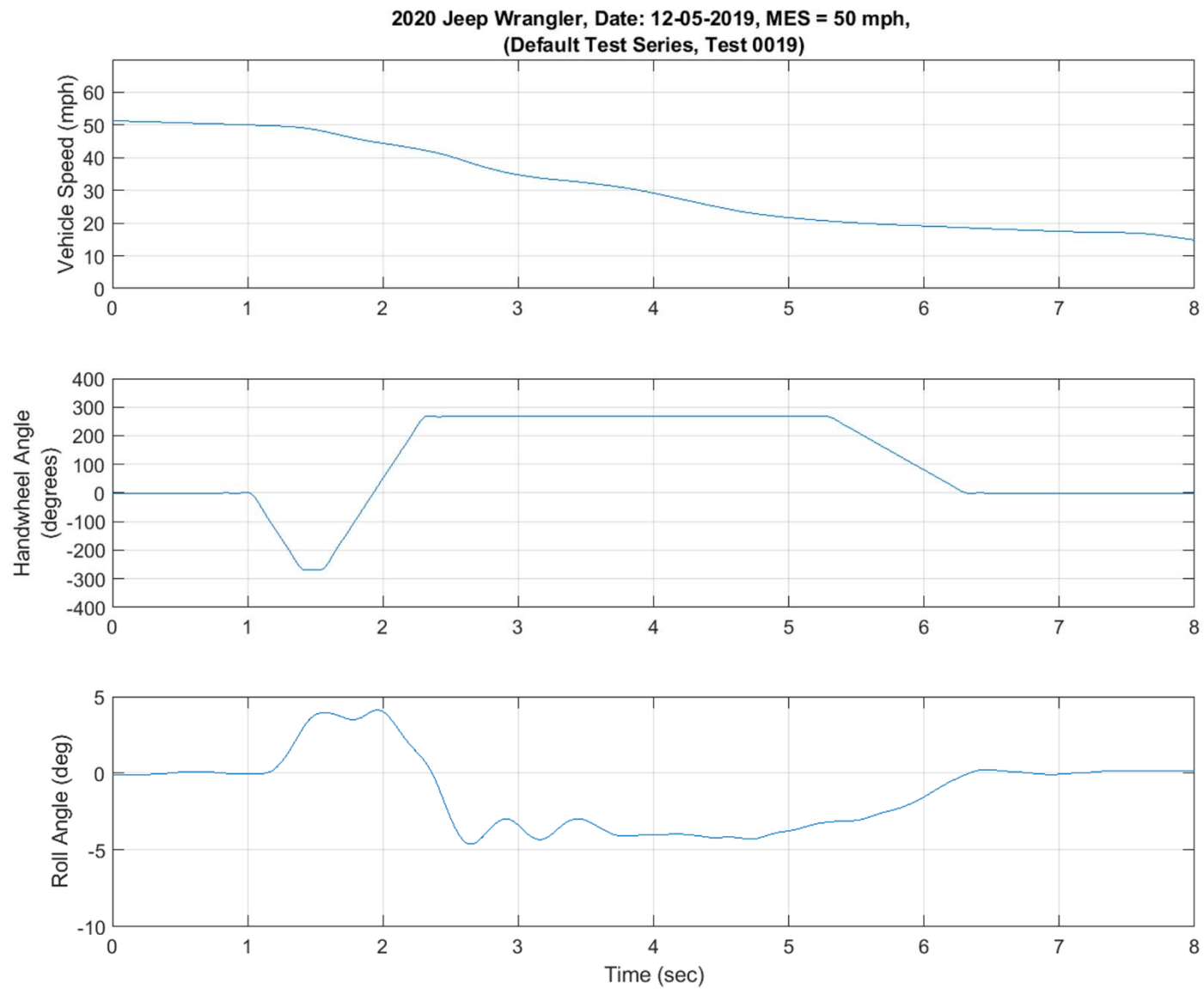


Figure D1. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Default Test Series, L-R, 50 mph

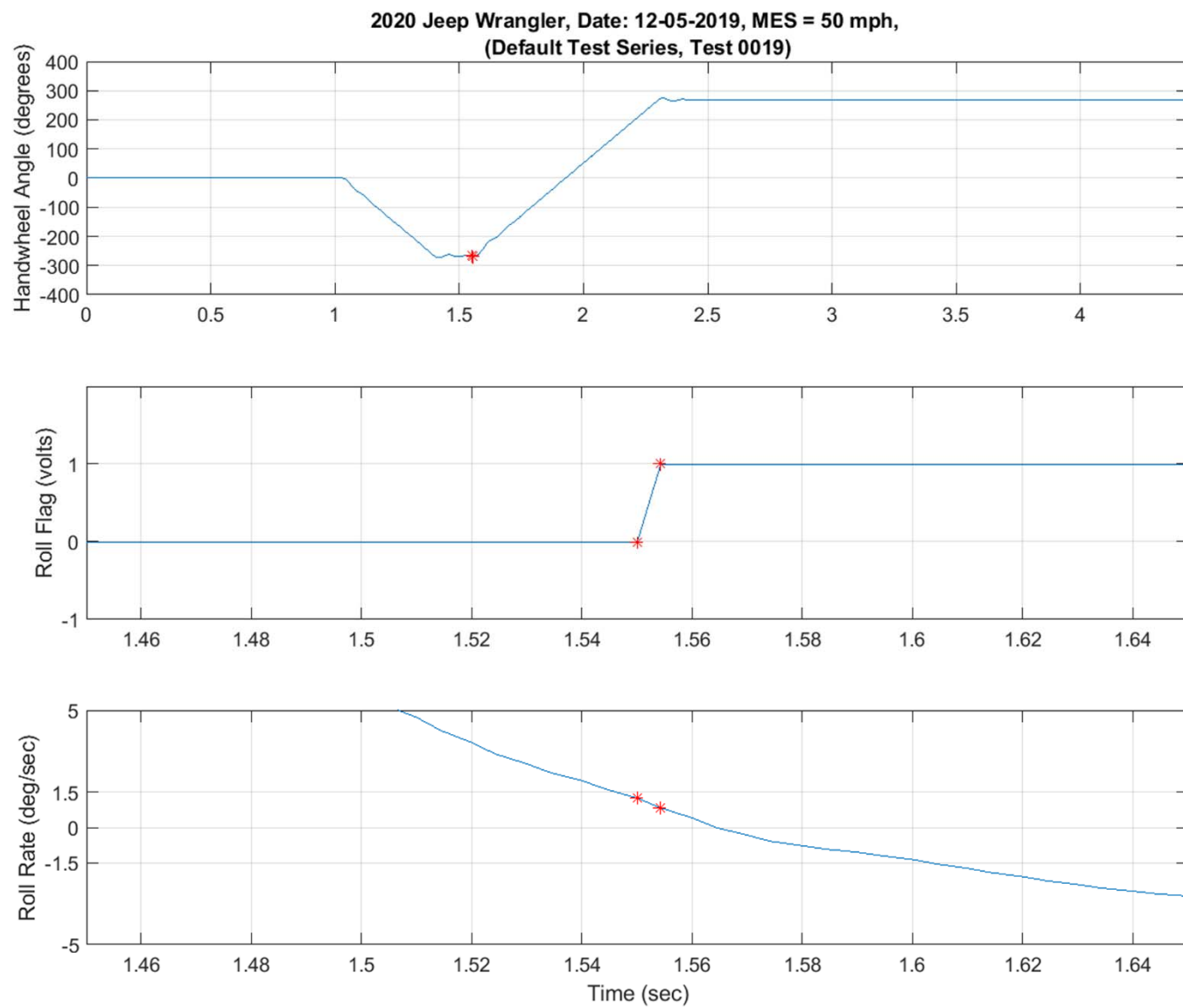


Figure D2. Steering Machine Operation Time History Plots for Default Test Series, L-R, 50 mph



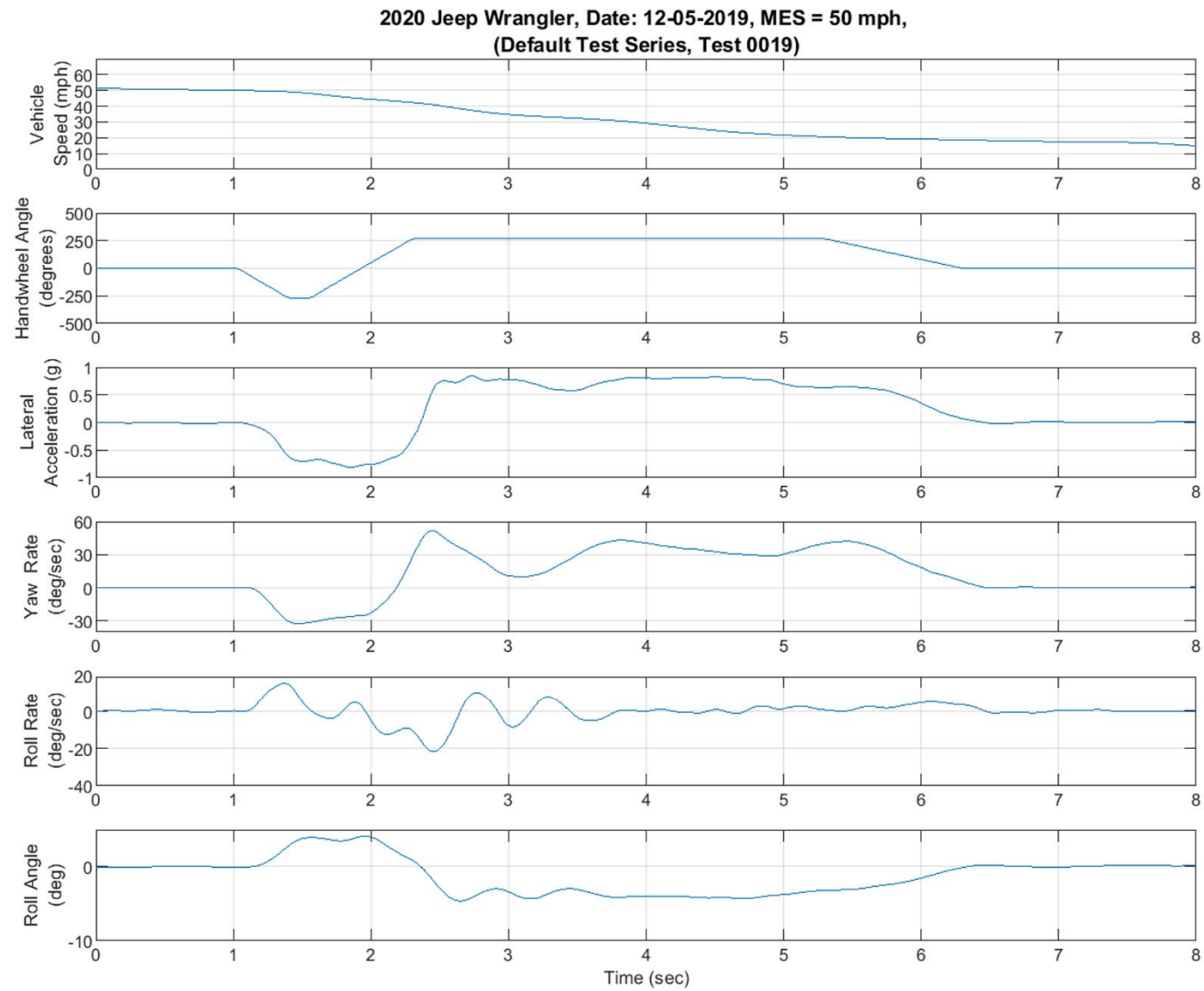


Figure D3. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots For Default Test Series, L-R, 50 mph

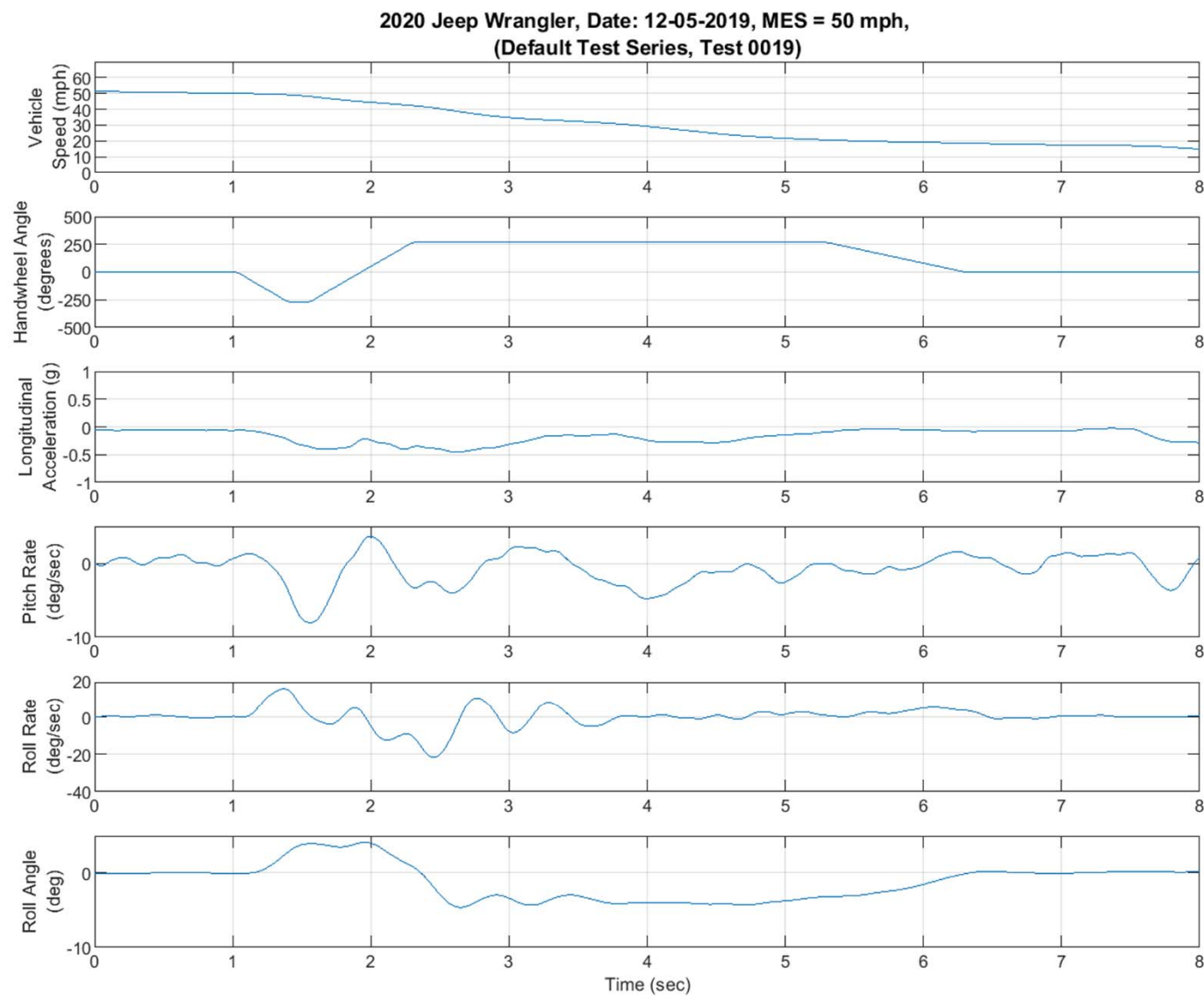


Figure D4. Pitch Rate and Longitudinal Acceleration Time History Plots for Default Test Series, L-R, 50 mph

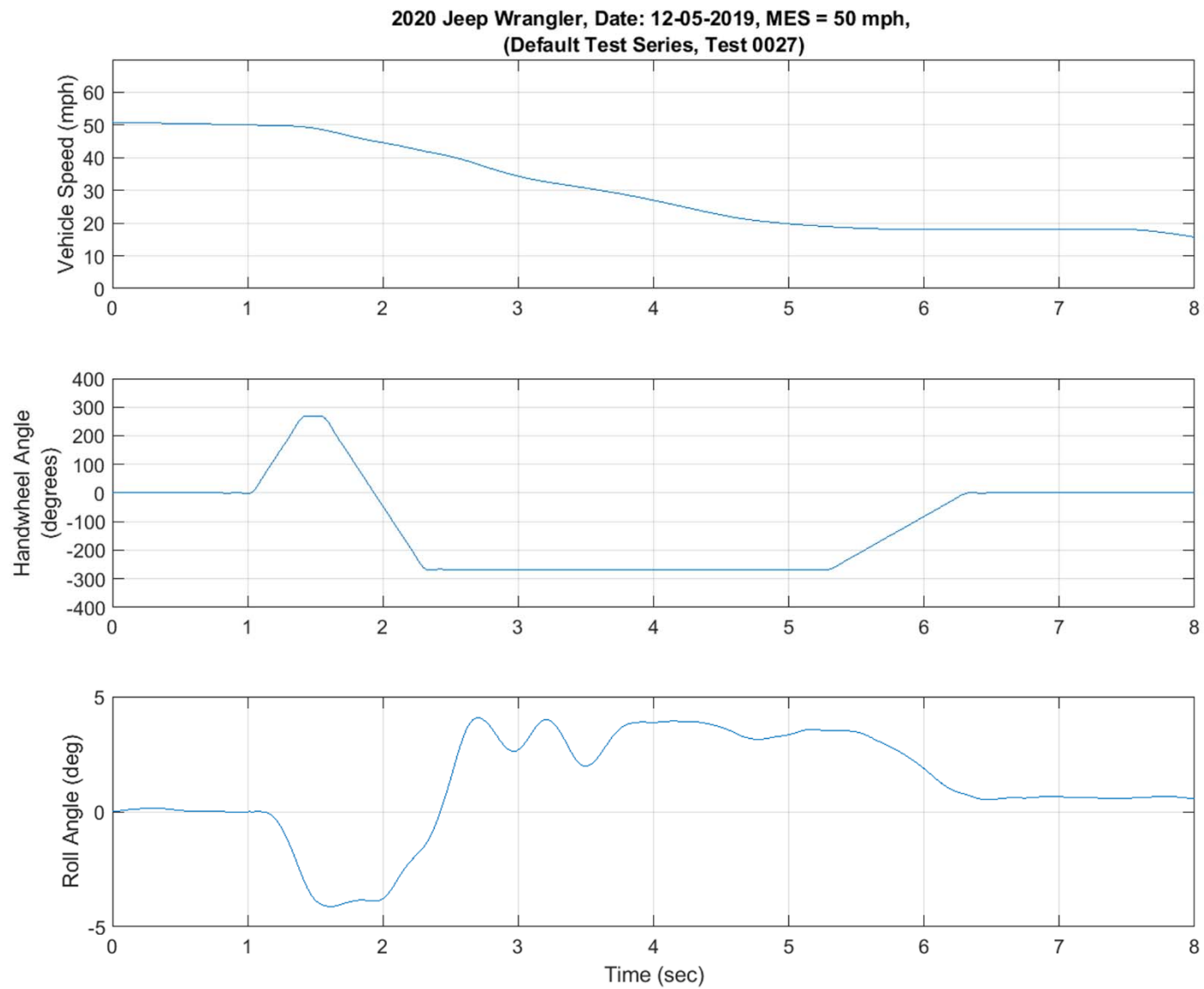


Figure D5. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Default Test Series, R-L, 50 mph

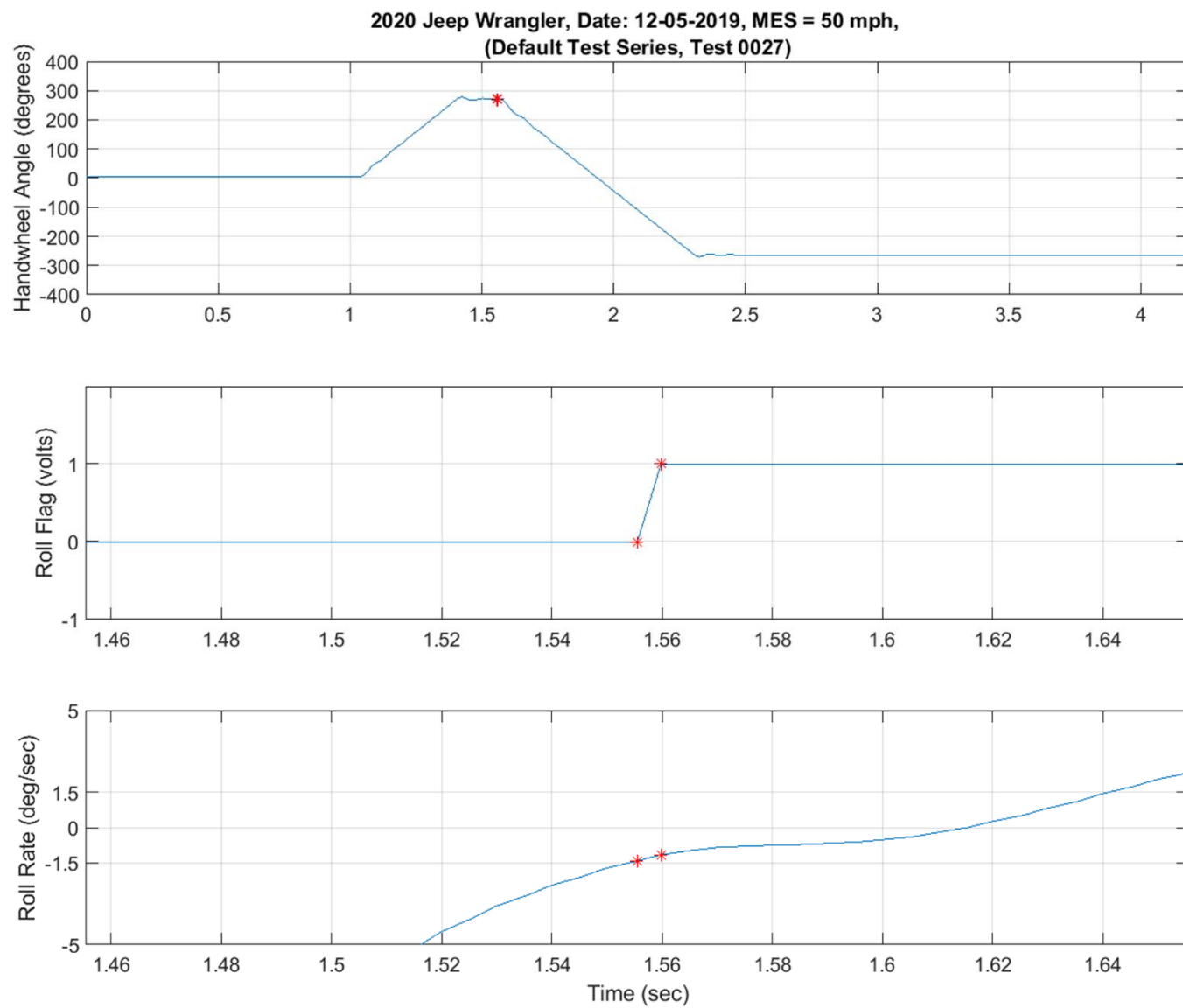


Figure D6. Steering Machine Operation Time History Plots for Default Test Series, R-L, 50 mph

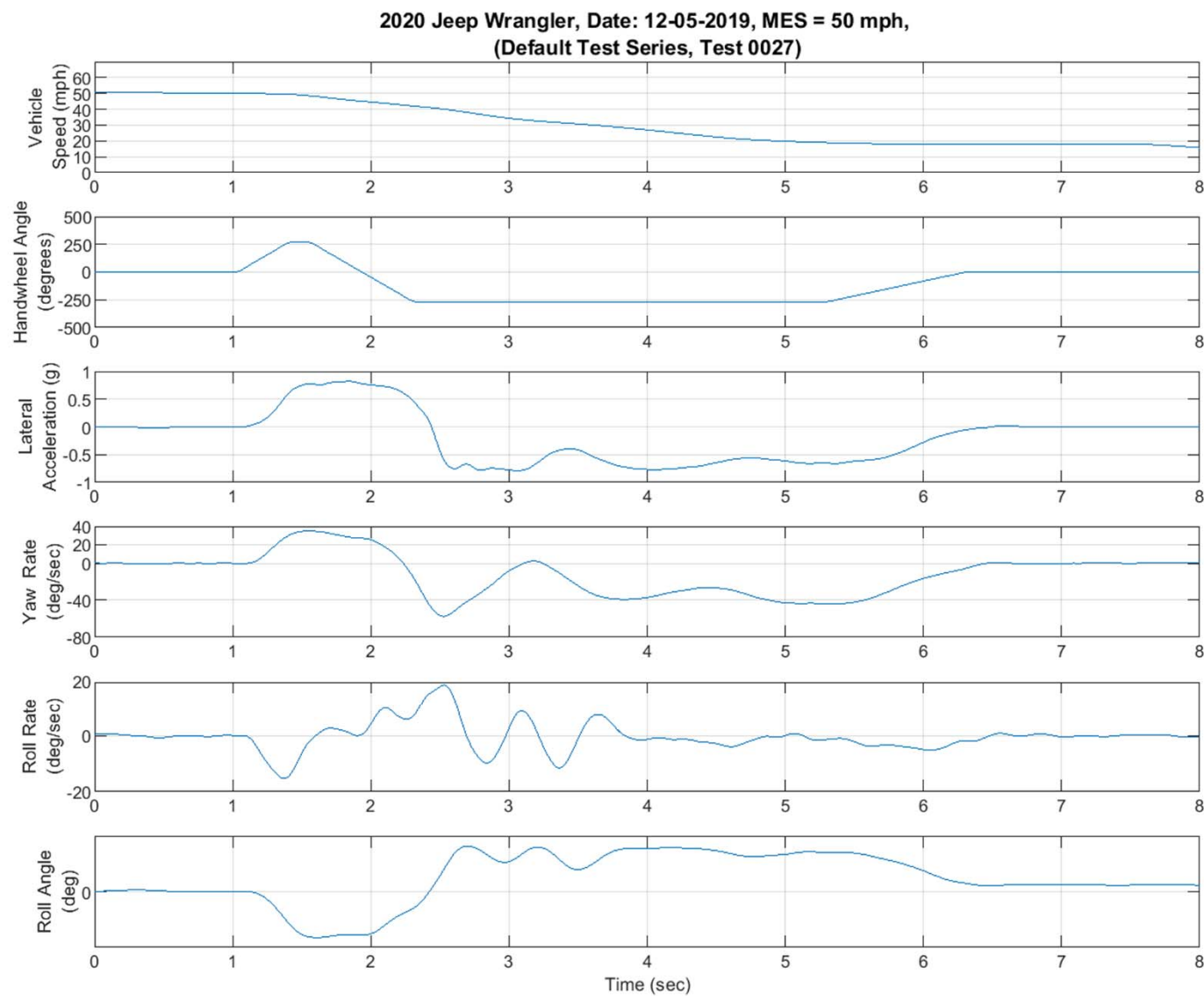


Figure D7. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots for Default Test Series, R-L, 50 mph

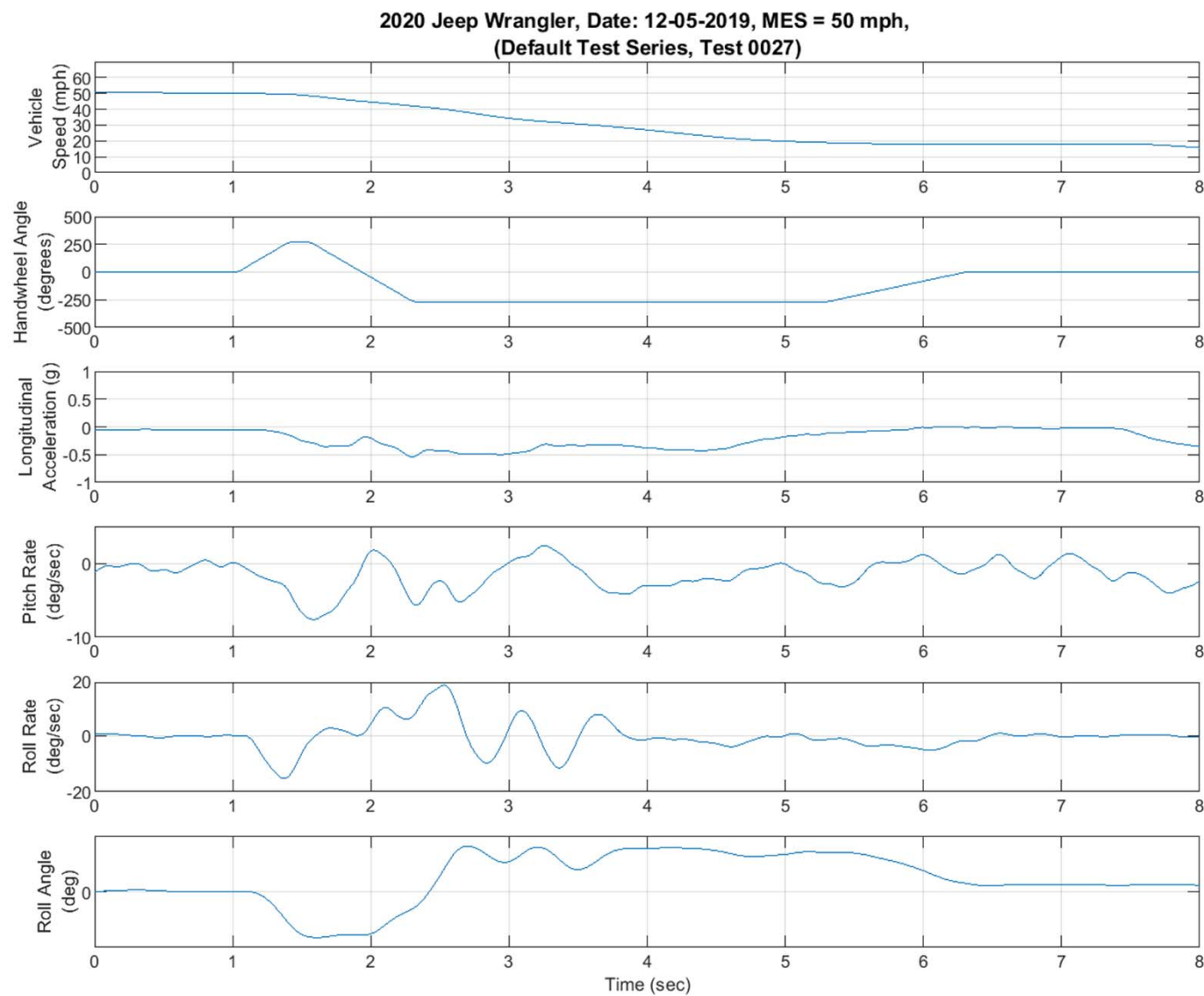


Figure D8. Pitch Rate and Longitudinal Acceleration Time History Plots or Default Test Series, R-L, 50 mph

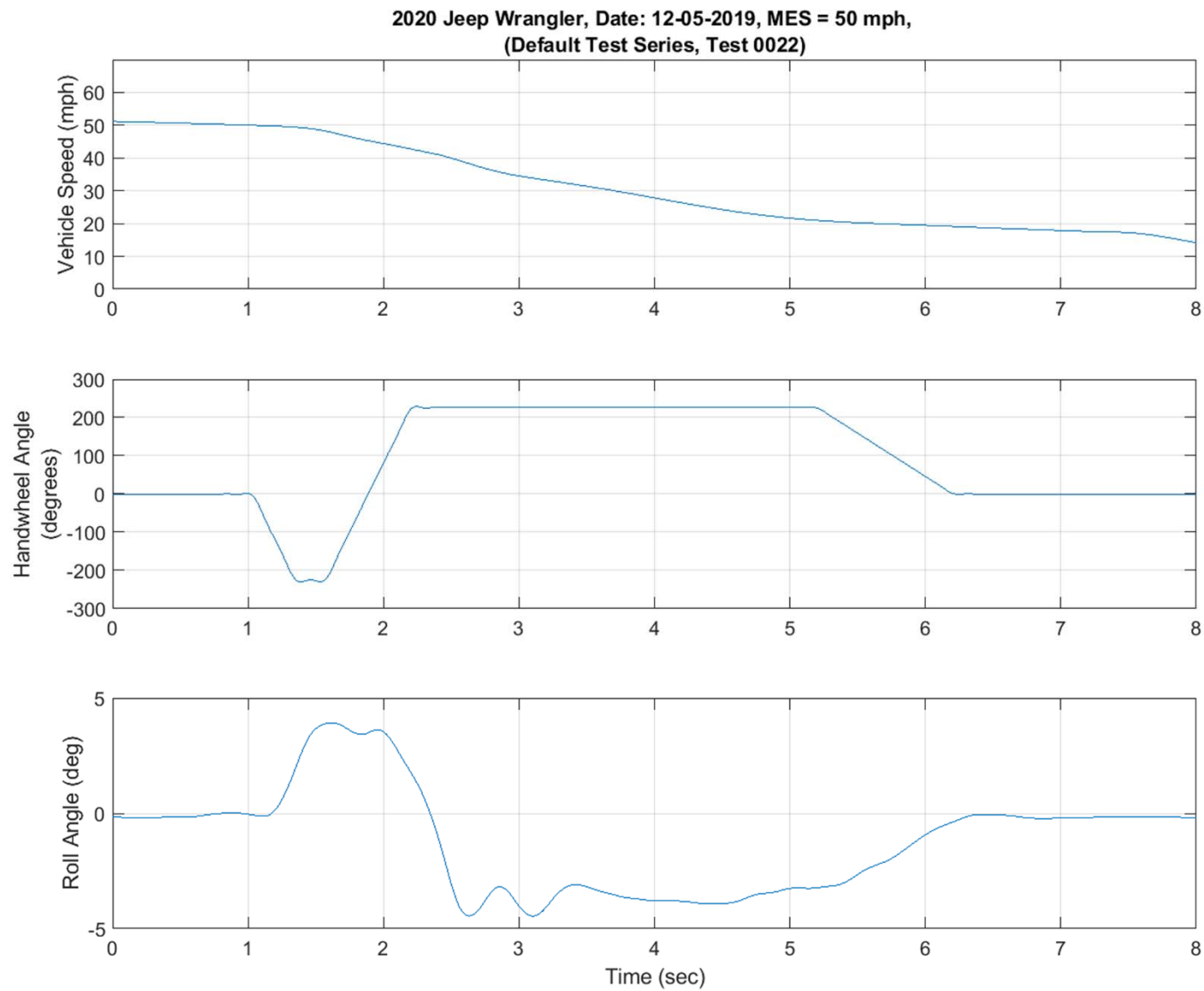


Figure D9. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

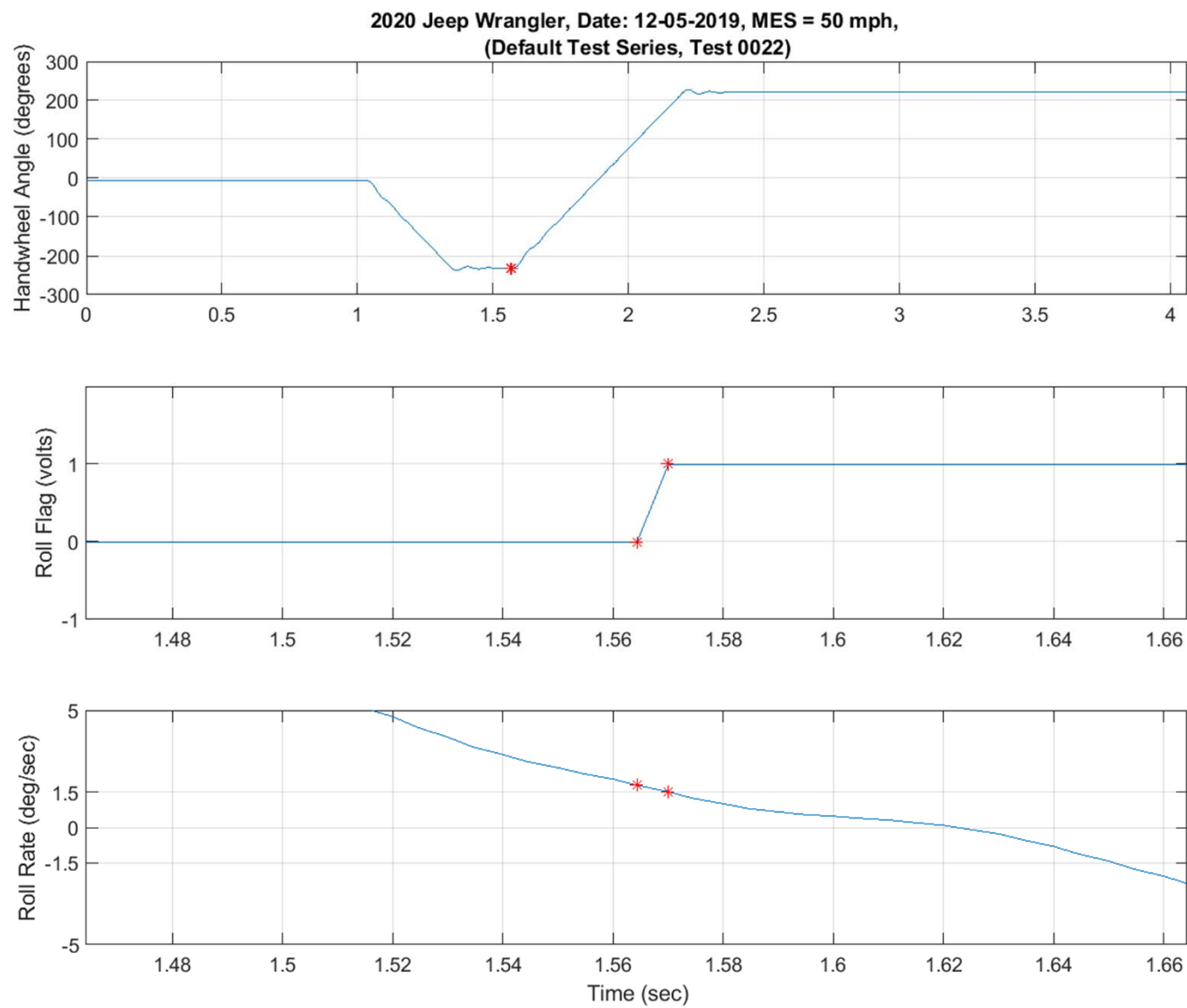


Figure D10. Steering Machine Operation Time History Plots for Supplemental 2 Test Series, L-R, 50 mph



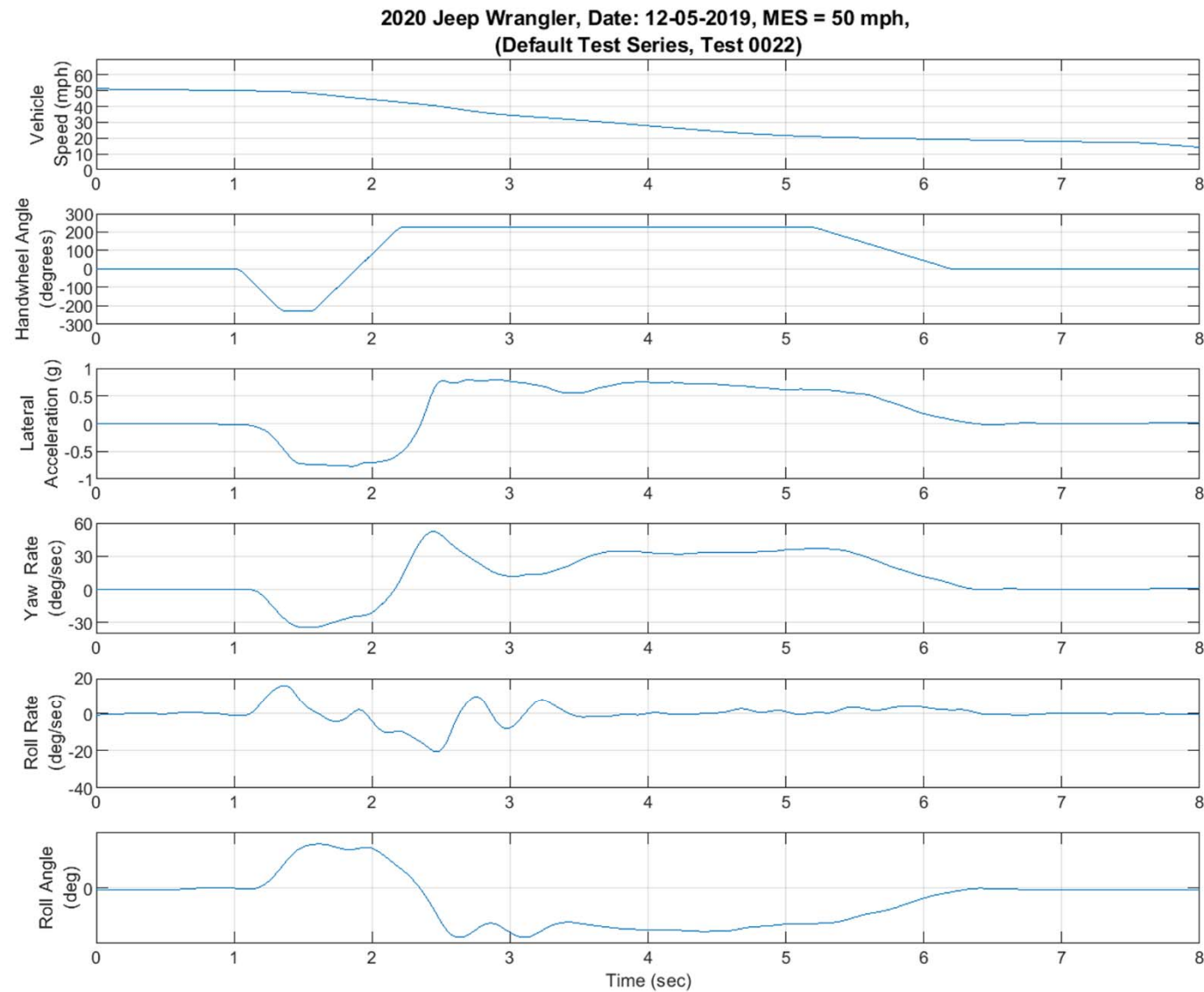


Figure D11. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

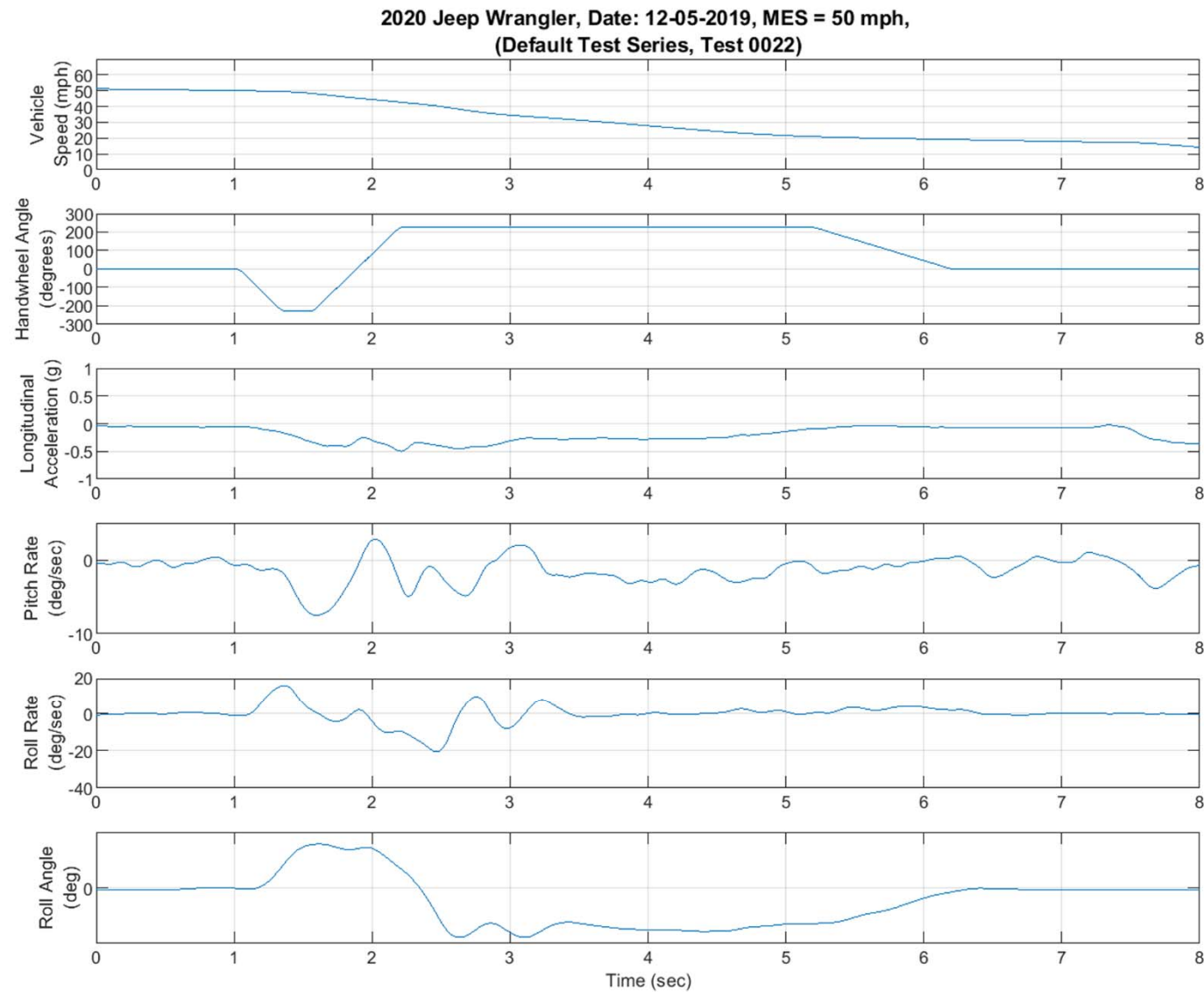


Figure D12. Pitch Rate and Longitudinal Acceleration Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

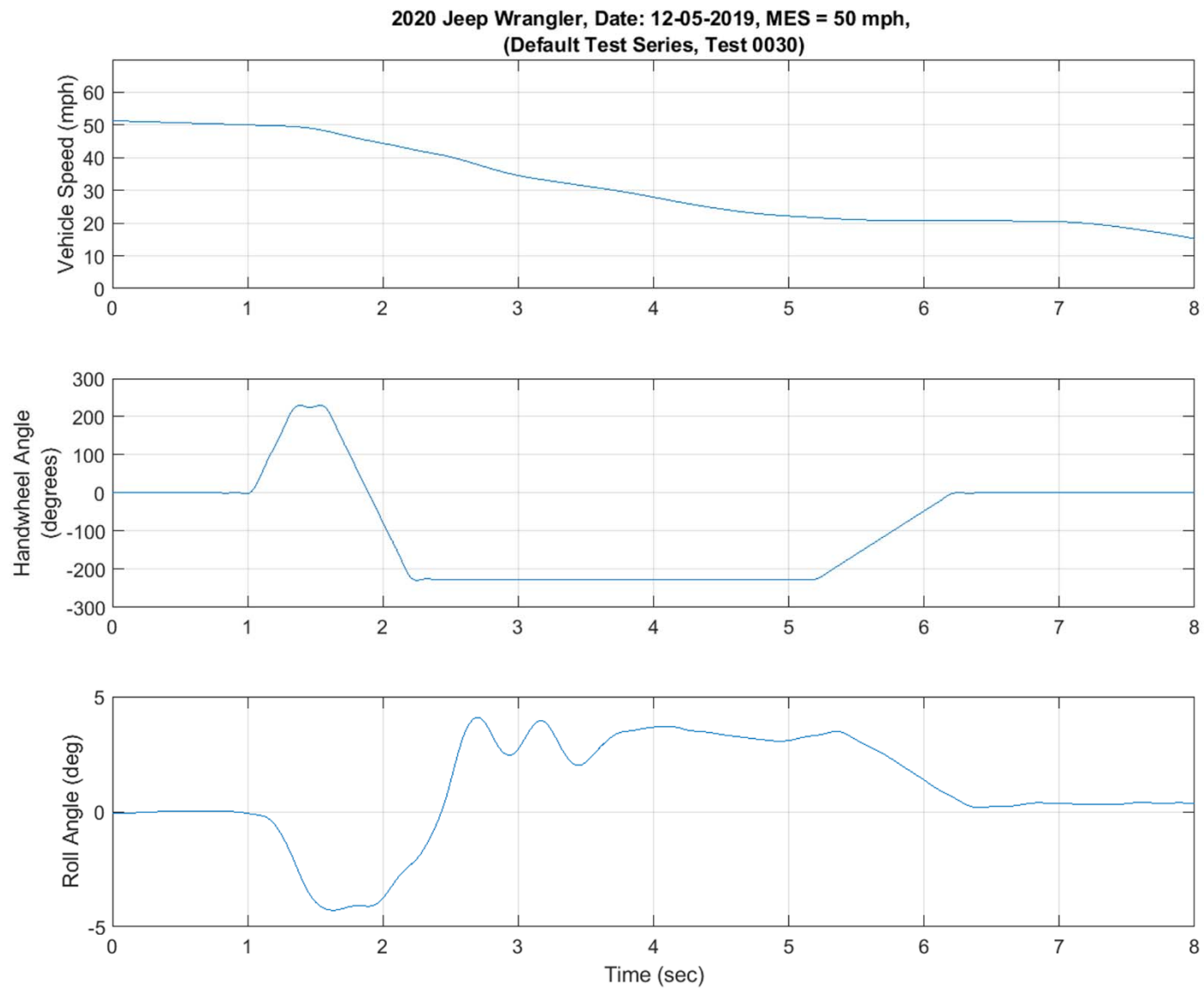


Figure D13. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Supplemental 2 Test Series, R-L, 50 mph

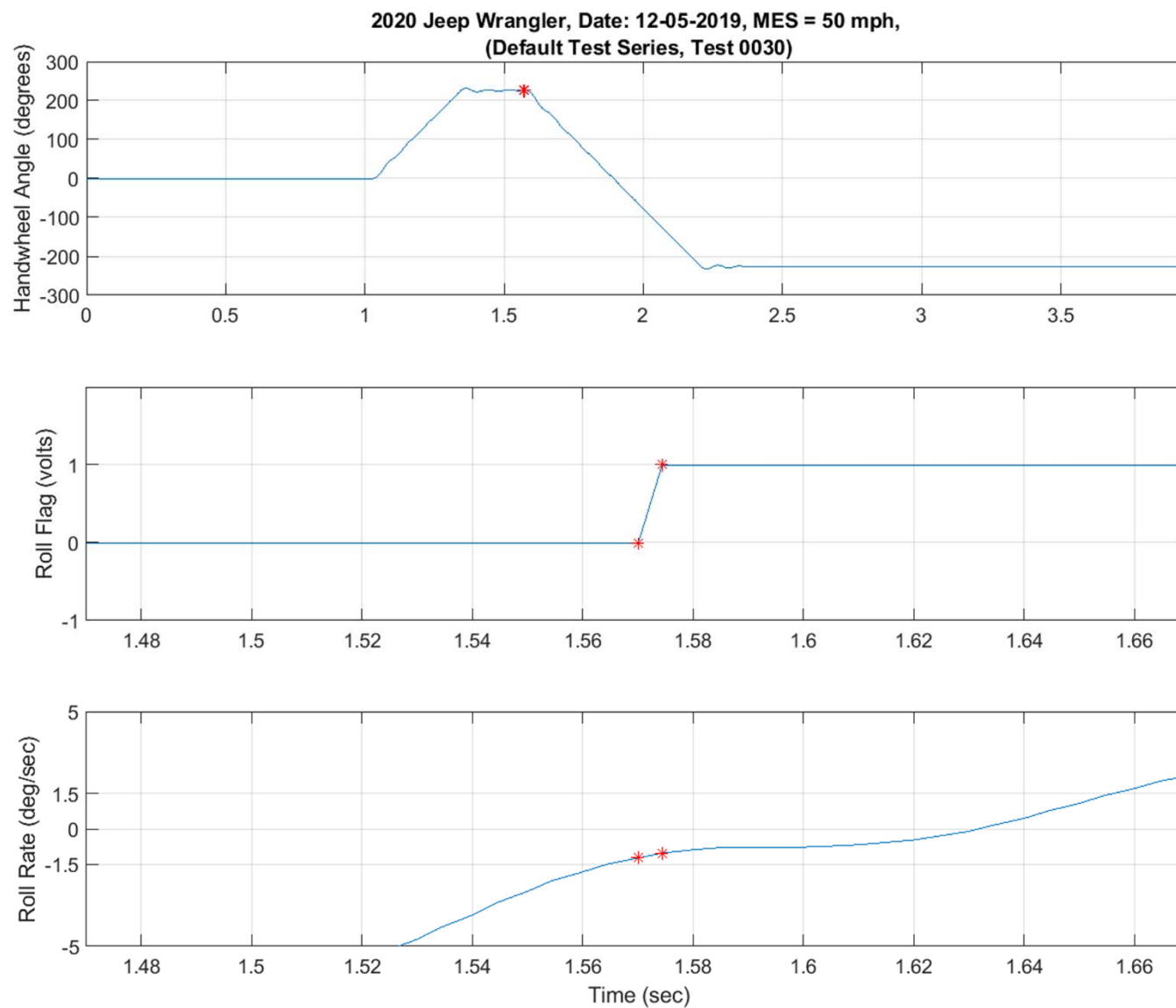


Figure D14. Steering Machine Operation Time History Plots for Supplemental 2 Test Series, R-L, 50 mph

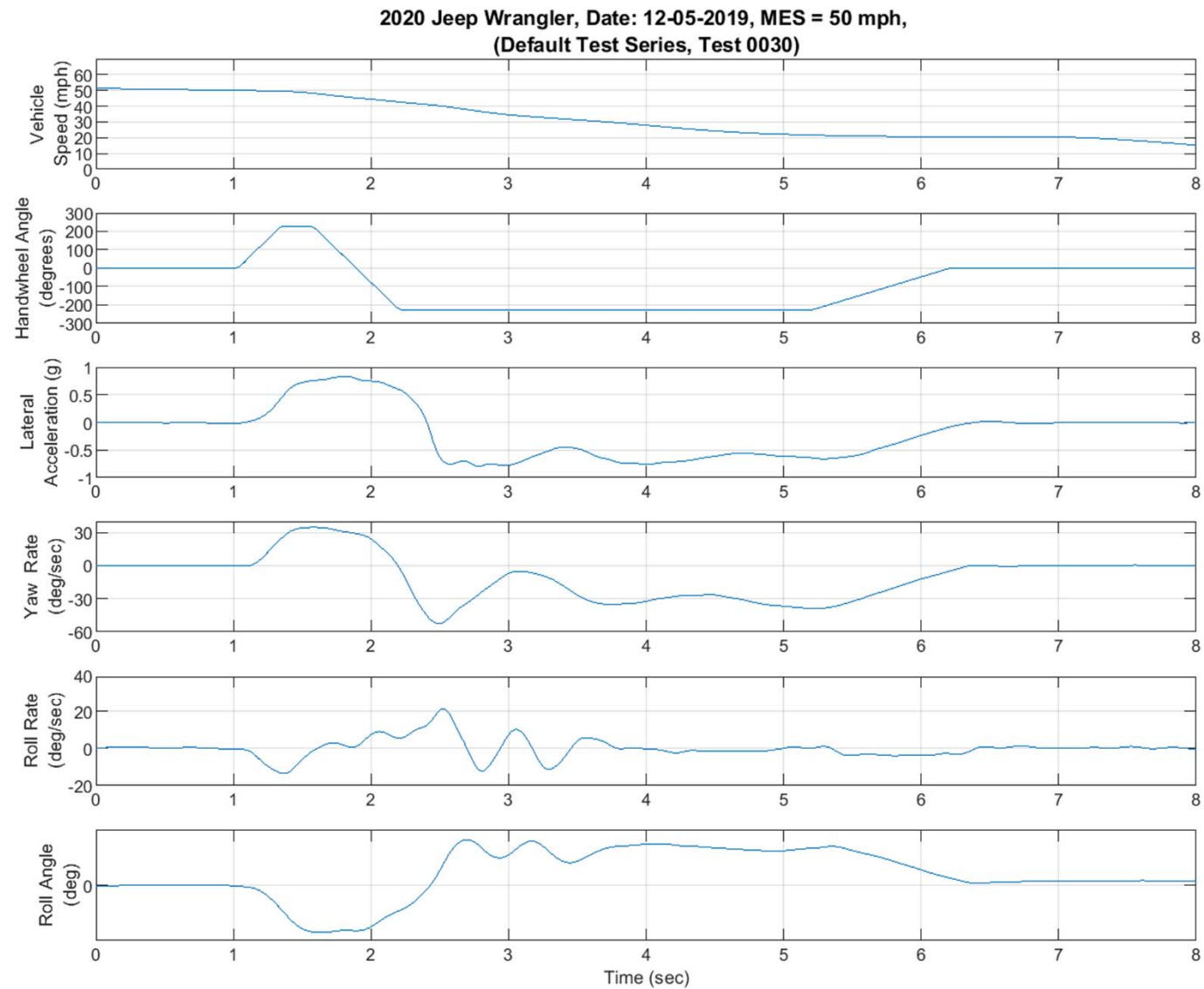


Figure D15. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots for Supplemental 2 Test Series, R-L, 50 mph

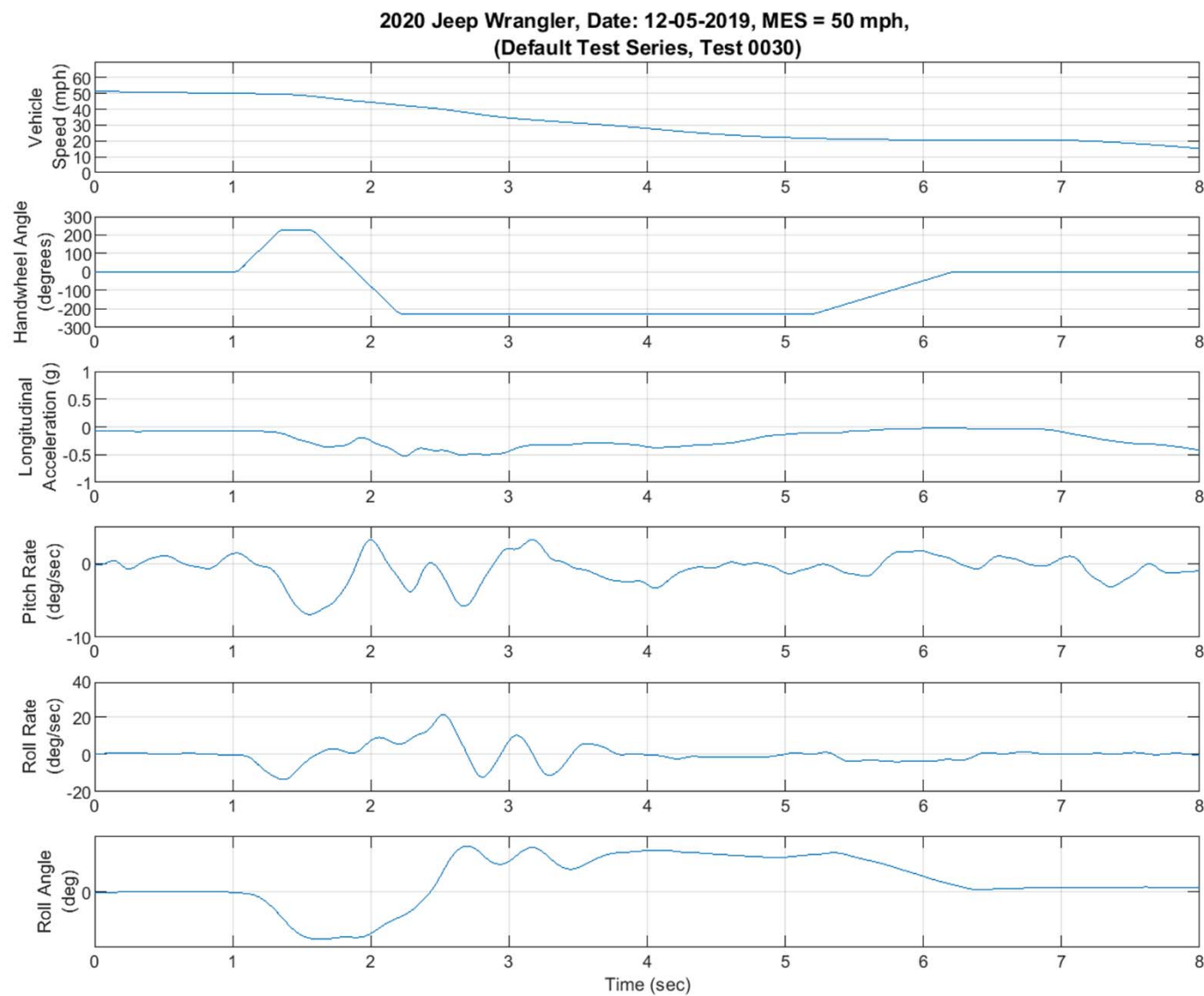


Figure D16. Pitch Rate and Longitudinal Acceleration Time History Plots for Supplemental 2 Test Series, R-L, 50 mph