

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

Toyota Motor Manufacturing, Indiana, Inc.

2020 Toyota Highlander LE - V6 FWD

TEST NUMBER: NCAP-DRI-RR-20-22

Final Report
27 July 2020



Prepared by:

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Prepared for:

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Report prepared by:

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Date: 27 July 2020

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| | | | |
|---|--|---|-----------|
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| | | 14. Sponsoring Agency Code NRM-110 | |
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| 16. Abstract An NCAP Dynamic Rollover Maneuver (Fishhook) Test was conducted on a 2020 Toyota Highlander LE - V6 FWD at Dynamic Research, Inc. on March 9, 2020. The vehicle did not experience two-wheel lift. The vehicle's steering angle at 0.3 g lateral acceleration at 50 mph was 28.6 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 Toyota Highlander LE - V6 FWD 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, "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 Toyota Highlander LE - V6 FWD | | | | |
| VIN | 5TDZZRAH5LS00xxxx | | | | |
| Vehicle type/Body style | MPV/SUV | | | | |
| Number of doors | 4 | | | | |
| Trim level | LE | | | | |
| Seating positions | Front: | 2 nd row | 3 rd row | 4 th row | 5 th row |
| | 2 | 3 | 3 | | |
| Electronic stability control | Yes | | | | |
| 4-Wheel ABS (Yes/No) | Yes | | | | |
| Power steering (Yes/No) | Yes | | | | |
| Major optional equipment | | | | | |
| Odometer at start of testing | 4 miles | | | | |
| Drivetrain | | | | | |
| Engine cylinder arrangement | V-6 | | | | |
| Engine displacement | 3.5 L | | | | |
| Transmission type | Automatic | | | | |
| Drive arrangement | 2WD (FWD) | | | | |
| Chassis | | | | | |
| Track width | F: 64.4 in (1635.8 mm), R: 64.6 in (1640.8 mm) | | | | |
| Wheelbase | 112 in (2844.8 mm) | | | | |
| Curb weight | 4143 lb (1879.2 kg) | | | | |
| Certification Data from Vehicle's Label | | | | | |
| Vehicle manufactured by | Toyota Motor Manufacturing, Indiana, Inc. | | | | |
| Date of manufacture | 01/20 | | | | |
| GVWR | 5830 lb (2645 kg) | | | | |
| GAWR Front | 3605 lb (1635 kg) | | | | |
| GAWR Rear | 3605 lb (1635 kg) | | | | |

Table 2. Tire Information

| | |
|---|---|
| Tire Manufacturer | Bridgestone |
| Tire Model | Alenza Sport A/S |
| Tire Size | Front: 235/65R18 Rear: 235/65R18 |
| Load rating | Front:106 Rear:106 |
| Speed rating | Front: V Rear: V |
| 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's door jamb |
| Recommended cold tire pressure | Front: 36 psi, (250 kPa) Rear: 36 psi, (250 kPa) |
| First 8 digits of DOT code | Front: IW2 LMALAI Rear: IW2 LMALAI |

Table 3. Vehicle Loading

| | |
|-------------------------------|-------------------------------|
| Water dummy and other loading | 3 water dummies in second row |
| Water dummy weight | 575 lb (260.8 kg) |
| Fuel level | Full |
| Weight as Tested | |
| Left front | 1387 lb (629.1 kg) |
| Right front | 1334 lb (605.1 kg) |
| Left rear | 1242 lb (563.4 kg) |
| Right rear | 1189 lb (539.3 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 ± 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 |
| Total | | 128 | 128 |

* 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: 1/6/2020 Due: 1/6/2021 |
| | Platform Scales (Torrance) | 1200 lb/platform 5338 N/platform | 1 lb 4.4 N | 0.5% of applied load | Intercomp SW500 | 0828MA19001 | By: DRI Date: 9/12/2019 Due: 9/12/2020 |
| 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 ¹ |
| Longitudinal, Lateral, and Vertical Acceleration Roll, Yaw, and Pitch Rate, Forward and Lateral Velocity, Roll and Pitch Angle | Multi-Axis Inertial Sensing System | Accels ± 10g, Angular Rate ±100 deg/s, Angle >45 deg, Velocity >200 km/h | Accels .001g, Angular Rate 0.01 deg/s, Angle 0.05 deg, Velocity 0.1 km/h | Accels .01g, Angular Rate 0.05 deg/s, Angle 0.05 deg, Velocity 0.1 km/h | Oxford Inertial + | 2182 | By: Oxford Technical Solutions Date: 9/16/2019 Due: 9/16/2021 |

¹ . 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.

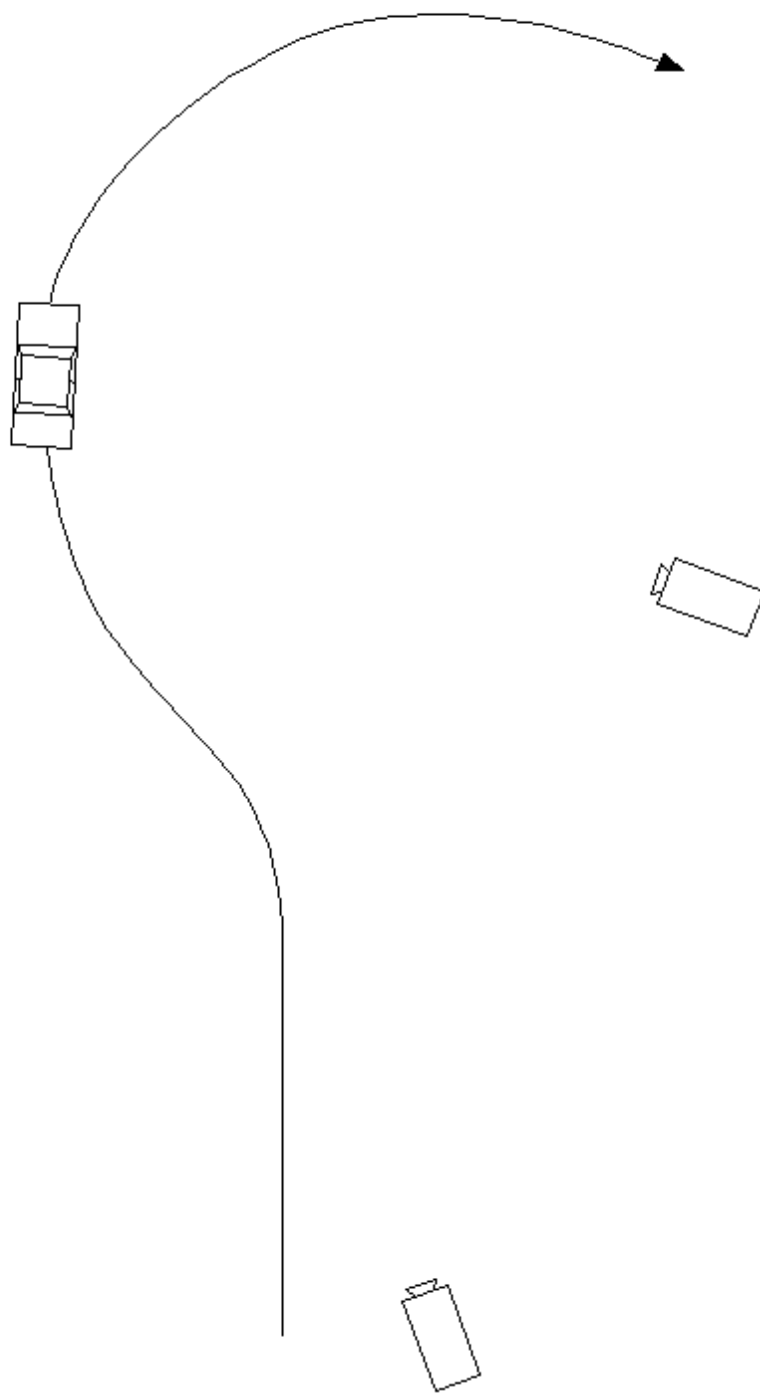


Figure 1. Nominal Position of Video Cameras for Fishhook Tests

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 3/9/2020. 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 6.

Table 6. Surface Friction

| | |
|---------------------------------------|-----------|
| Date of surface friction measurements | 3/13/2020 |
| Average normalized lateral force | 0.815 |

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) | 28.6° |
| 5.5 scalar handwheel angle for Fishhook Test | 157° |
| 6.5 scalar handwheel angle for Fishhook Test | 186° |

3. WEATHER CONDITIONS

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

Table 8. Weather Conditions

| | |
|---------------------|-------------------|
| Ambient temperature | 69.8° F (21° C) |
| Wind Speed | 4.9 mph (1.9 m/s) |
| Wind Direction | SSE |

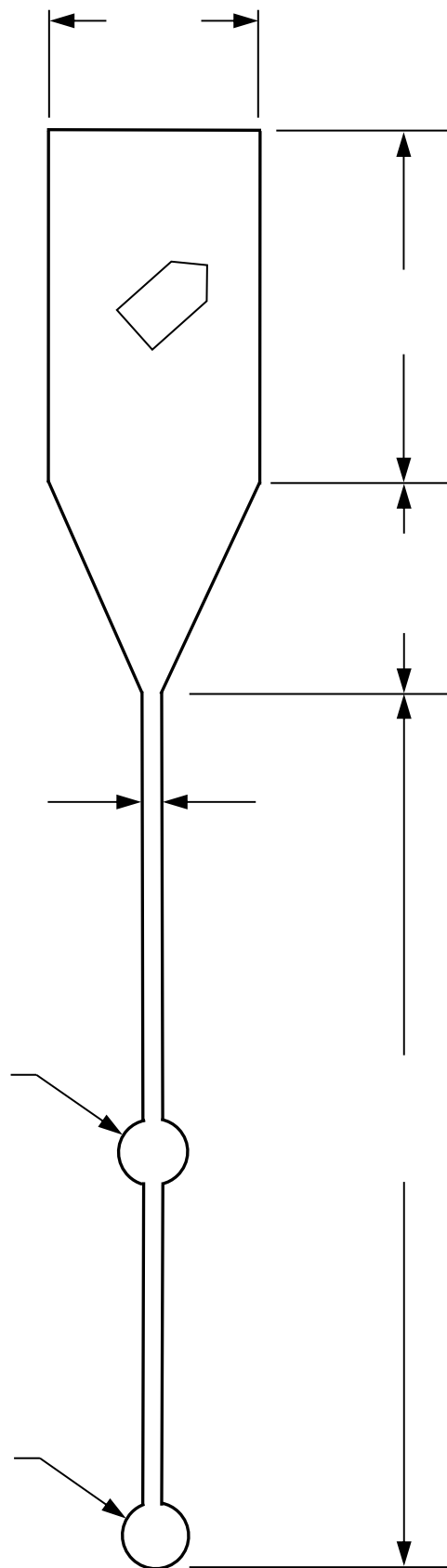


Figure 2. DRI-Minter Vehicle Dynamics Area

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 Toyota Highlander LE - V6 FWD.

APPENDIX A

Photographs

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DESC.: **HIGHLANDER** LE - V6 FWD
VIN: **5TDZZRAH5LS00**
YR/MDL: 2020/6946A
CLR: MIDNIGHT BLACK METAL/FR10 (0218/10)
FINAL ASSEMBLY POINT: PRINCETON, INDIANA, U.S.A.

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.

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



Fuel Economy and Environment

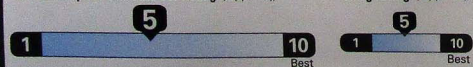
Fuel Economy
24 MPG
combined city/hwy
4.2 gallons per 100 miles
21 city 29 highway

Small SUVs range from 16 to 120 MPG.
The best vehicle rates 136 MPG.

You spend
\$ 1,000
more in fuel costs
over 5 years
compared to the
average new vehicle.

Annual fuel cost
\$ 1,700

Fuel Economy & Greenhouse Gas Rating (tailpipe only)



The vehicle emits 372 grams CO2 per mile. The best emits 0 grams per mile (tailpipe only). Producing and distributing fuel also create emissions. Learn more at 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 costs \$7,560 to fuel over 5 years. Cost estimates are based on 15,000 miles per year at \$2.72 per gallon. MPG is miles per gallon equivalent. Vehicle emissions are a significant cause of climate change and smog.

fuelconomy.gov

Calculate personalized estimates and compare vehicles

STANDARD EQUIPMENT

MECHANICAL & PERFORMANCE
- 3.5L V6 Engine; 8-Speed Automatic
SAFETY & CONVENIENCE
- Toyota Safety Sense 2.0: Pre-Collision System w/Pedestrian Detection, Full-Speed Range Dynamic Radar Cruise Control, Lane Departure Alert w/Steering Assist, Lane Tracing Assist, Automatic High Beams, Road Sign Assist
- 8 Airbags: Star Safety System
- Blind Spot Monitor w/ Rear Cross Traffic Alert
- LATCH-Lower Anchor & Tether for Children
- Safety & Remote Connect w/1-Year Trial
EXTERIOR
- 18" Alloy Wheels w/Temporary Spare
- LED Headlights, Taillights, Fog Lights
- Heated Power Outside Mirrors
- Power Liftgate
INTERIOR
- Power Driver Seat
- 3rd Row 60/40 Split Fold-Flat Seats
- Audio Plus - 8" Touch Screen, 6 Speakers, USB Media Port, 4 USB Charge-Ports, SiriusXM w/3-Month All Access Trial, Android Auto & Apple CarPlay Compatible
- Smart Key System w/Push Button Start
- For Full Product Details, Please Visit Toyota.com/Highlander
Full Tank of Gas

MANUFACTURER'S SUGGESTED RETAIL PRICE \$36,800.00

| OPTIONAL EQUIPMENT | | |
|--------------------|--------------------------------|--------|
| FE | 50 State Emissions | 350.00 |
| 3T | Cargo Cross Bars | 135.00 |
| 3Y | Rear Bumper Protector - Chrome | 125.00 |
| D5 | Door Edge Guards | |

DELIVERY PROCESSING AND HANDLING FEE 1,120.00

TOTAL \$38,530.00

The New Vehicle Limited Warranty provides 3-year/36,000 mile basic coverage. 5-year/60,000 mile powertrain coverage, plus 5-year/unlimited mile corrosion perforation coverage. See Warranty and Maintenance Guide for details. An extended service contract may be available for the vehicle. Manufacturer's suggested retail price includes manufacturer's recommended pre-delivery service. Gasoline, license and title fees, applicable federal, state and local taxes and dealer and distributor installed options and accessories are not included in the manufacturer's suggested retail price. ToyotaCare, which covers normal factory scheduled maintenance for two years or 25,000 miles, whichever occurs first, is included as part of the sales price of the vehicle for qualifying buyers. See participating dealer for eligibility and coverage details.



Figure A1. Window Sticker



Figure A2. Front View, Test Vehicle as Delivered



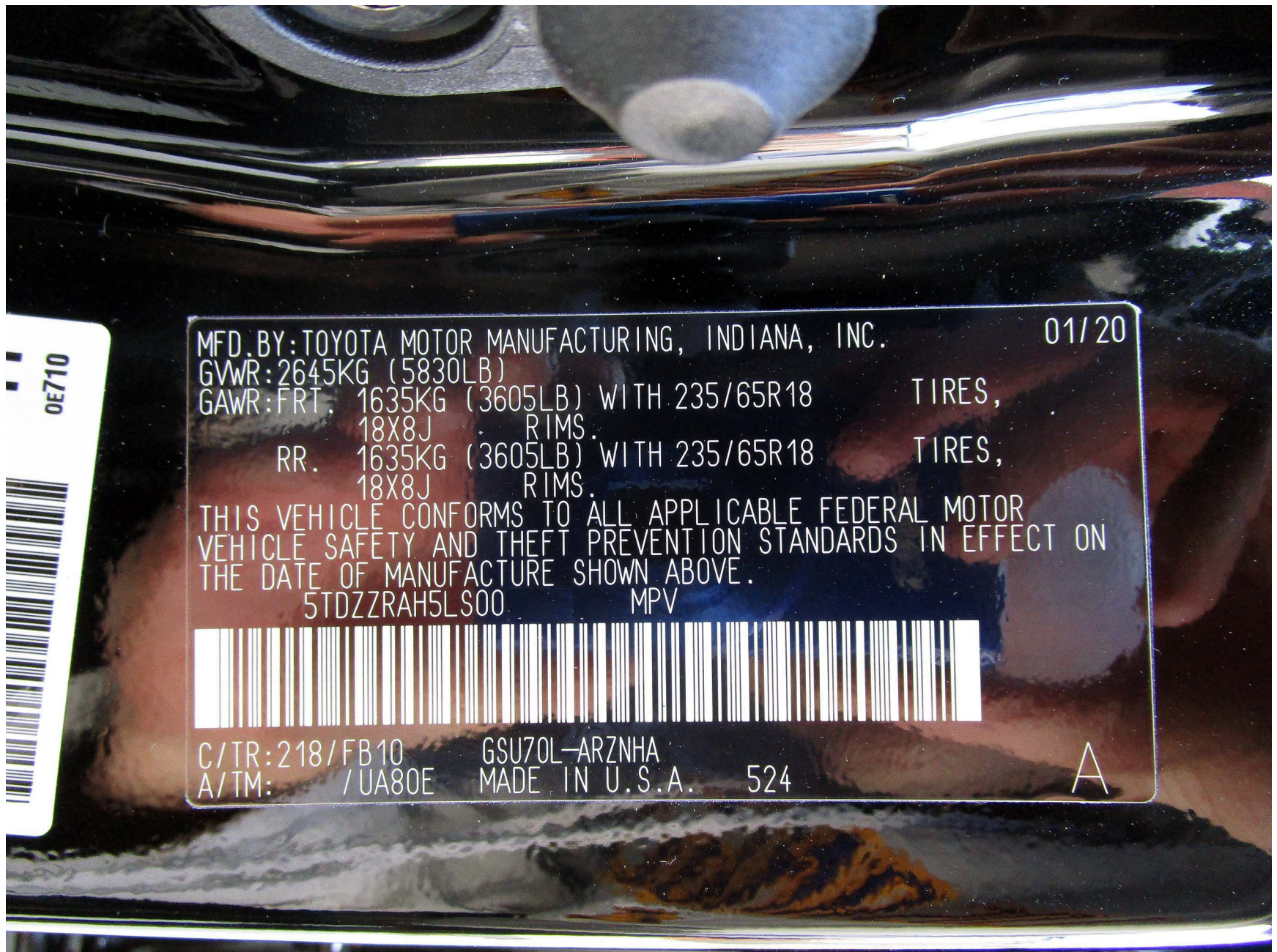
Figure A3. Rear View, Test Vehicle as Delivered



Figure A4. Front View, Test Vehicle in Test Condition



Figure A5. Rear View, Test Vehicle in Test Condition



MFD. BY: TOYOTA MOTOR MANUFACTURING, INDIANA, INC.

01/20

GVWR: 2645KG (5830LB)

GAWR: FRT. 1635KG (3605LB) WITH 235/65R18 TIRES,

18X8J RIMS.

RR. 1635KG (3605LB) WITH 235/65R18 TIRES,

18X8J RIMS.

THIS VEHICLE CONFORMS TO ALL APPLICABLE FEDERAL MOTOR
VEHICLE SAFETY AND THEFT PREVENTION STANDARDS IN EFFECT ON
THE DATE OF MANUFACTURE SHOWN ABOVE.

5TDZZRAH5LS00

MPV



C/TR: 218/FB10

GSU70L-ARZNHA

A/TM: /UA80E


MADE IN U.S.A. 524

A

Figure A6. Certification Label

CAUTION: LOAD
CARRYING CAPACITY
REDUCED
Modifications to this
Vehicle have been made
S007260

TIRE AND LOADING INFORMATION
RENSEIGNEMENTS SUR LES PNEUS ET LE CHARGEMENT

 SEATING CAPACITY TOTAL: 8 FRONT: 2 REAR: 6
NOMBRE DE PLACES TOTAL : 8 AVANT : 2 ARRIÈRE : 6

The combined weight of occupants and cargo should never exceed 630 kg or 1390 lbs.
Le poids total des occupants et du chargement ne doit jamais dépasser 630 kg ou 1390 lb.

| TIRE PNEU | SIZE DIMENSIONS | COLD TIRE PRESSURE PRESSION DES PNEUS À FROID |
|---------------------|--------------------|--|
| FRONT AVANT | 235/65R18 | 250 kPa, 36 PSI |
| REAR ARRIÈRE | 235/65R18 | 250 kPa, 36 PSI |
| SPARE DE SECOURS | T165/90D18 | 420 kPa, 60 PSI |

SEE OWNER'S
MANUAL FOR
ADDITIONAL
INFORMATION
VOIR LE MANUEL
DE L'USAGER
POUR PLUS DE
RENSEIGNEMENTS

0E710




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 Toyota Highlander LE - V6 FWD**Driver: **Stephen Rhim**Test Date: **3/9/2020**

| Run Number | Test Type | Speed (mph) | Handwheel Angle (deg) | Dir. of First Steer | 2 Wheel Lift | Notes |
|------------|--------------------------------|-------------|-----------------------|---------------------|--------------|-------|
| 1 | Tire Warm-Up | 35 | 60 | Right | NA | |
| 2 | " | " | " | | " | |
| 3 | " | " | " | | " | |
| 4 | " | " | " | | " | |
| 5 | 2x SWA last cycle | " | " | | " | |
| | | | | | | |
| 6 | Static | 0 | 0 | | " | |
| 7 | Steady State | 50 | 0 | | " | |
| | | | | | | |
| 8 | Slowly Increasing Steer | 50 | 60 | Left | NA | |
| 9 | " | " | 50 | Left | " | |
| 10 | " | " | " | Left | " | |
| 11 | " | " | " | Left | " | |
| 12 | " | " | " | Right | " | |
| 13 | " | " | " | Right | " | |
| 14 | " | " | " | Right | " | |
| | | | | | | |
| 15 | 6.5 Scalar Fishhook | 35 | 186 | Left | No | |
| 16 | " | 40 | " | " | " | |
| 17 | " | 45 | " | " | " | |
| 18 | " | 47.5 | " | " | " | |

| Run Number | Test Type | Speed (mph) | Handwheel Angle (deg) | Dir. of First Steer | 2 Wheel Lift | Notes |
|------------|----------------------------|-------------|-----------------------|---------------------|--------------|-------|
| 19 | " | 50 | " | " | " | |
| 20 | 5.5 Scalar Fishhook | 45 | 157 | Left | No | |
| 21 | " | 47.5 | " | " | " | |
| 22 | " | 50 | " | " | " | |
| | | | | | | |
| 23 | 6.5 Scalar Fishhook | 35 | 186 | Right | No | |
| 24 | " | 40 | " | " | " | |
| 25 | " | 45 | " | " | " | |
| 26 | " | 47.5 | " | " | " | |
| 27 | " | 50 | " | " | " | |
| | | | | | | |
| 28 | 5.5 Scalar Fishhook | 45 | 157 | Right | No | |
| 29 | " | 47.5 | " | " | " | |
| 30 | " | 50 | " | " | " | |

APPENDIX C

Slowly Increasing Steer Test Worksheet

NCAP, 2020 Toyota Highlander, Multi-Passenger Load,

Test Date: 3/9/2020

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 | Left | 49.8 | 2.9 | 94.2 | 1224 | -28.1 | -0.311 | -182.8 | -0.2538 | -154.6 | -0.2148 | 0.9951 | 600 | 800 |
| 10 | Left | 50.2 | 2.0 | 96.0 | 1223 | -28.1 | -0.311 | -182.5 | -0.2534 | -154.4 | -0.2144 | 0.9939 | 600 | 800 |
| 11 | Left | 50.0 | 3.4 | 93.2 | 1220 | -27.9 | -0.294 | -181.1 | -0.2516 | -153.3 | -0.2129 | 0.9951 | 600 | 800 |
| 12 | Right | 50.0 | 2.7 | 94.5 | 1232 | 28.7 | 0.308 | 186.6 | 0.2592 | 157.9 | 0.2193 | 0.9961 | 600 | 800 |
| 13 | Right | 49.6 | 3.5 | 92.9 | 1245 | 29.6 | 0.310 | 192.3 | 0.2671 | 162.7 | 0.226 | 0.996 | 600 | 800 |
| 14 | Right | 49.8 | 1.9 | 96.2 | 1242 | 29.4 | 0.296 | 190.9 | 0.2652 | 161.6 | 0.2244 | 0.9979 | 600 | 800 |

Mean: 28.6 0.305 186 0.258 157 0.219

Steering Controller Input Values

Scalar 6.5 values:

Initial HW angle: 186 deg
 Initial time: 0.258 s
 Reversal HW angle: -186 deg
 Reversal time: 0.517 s

Scalar 5.5 values:

Initial HW angle: 157 deg
 Initial time: 0.219 s
 Reversal HW angle: -157 deg
 Reversal time: 0.437 s

APPENDIX D

Time History Plots

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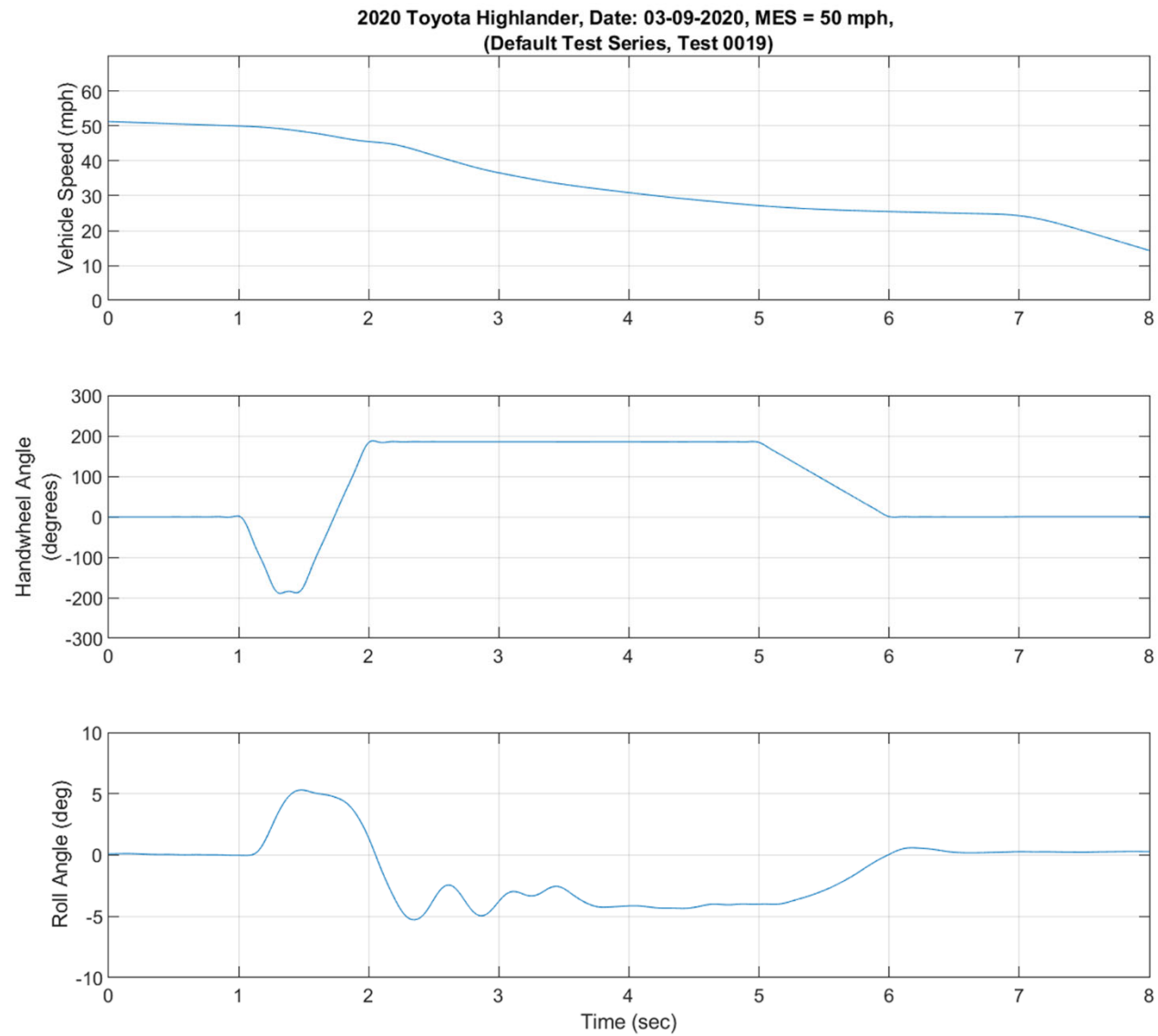


Figure D1. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Default Test Series, L-R, 50 mph

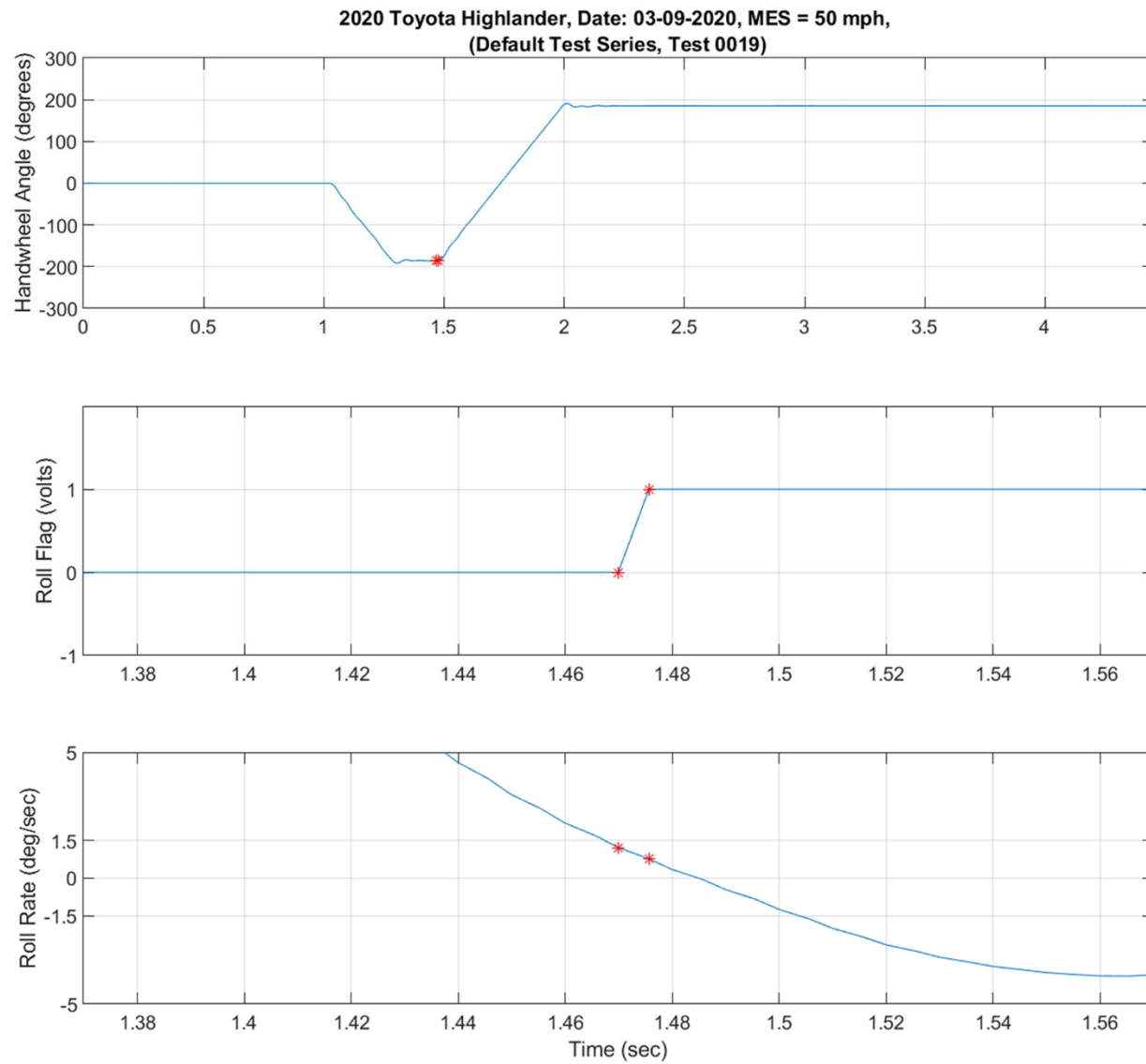


Figure D2. Steering Machine Operation Time History Plots for Default Test Series, L-R, 50 mph

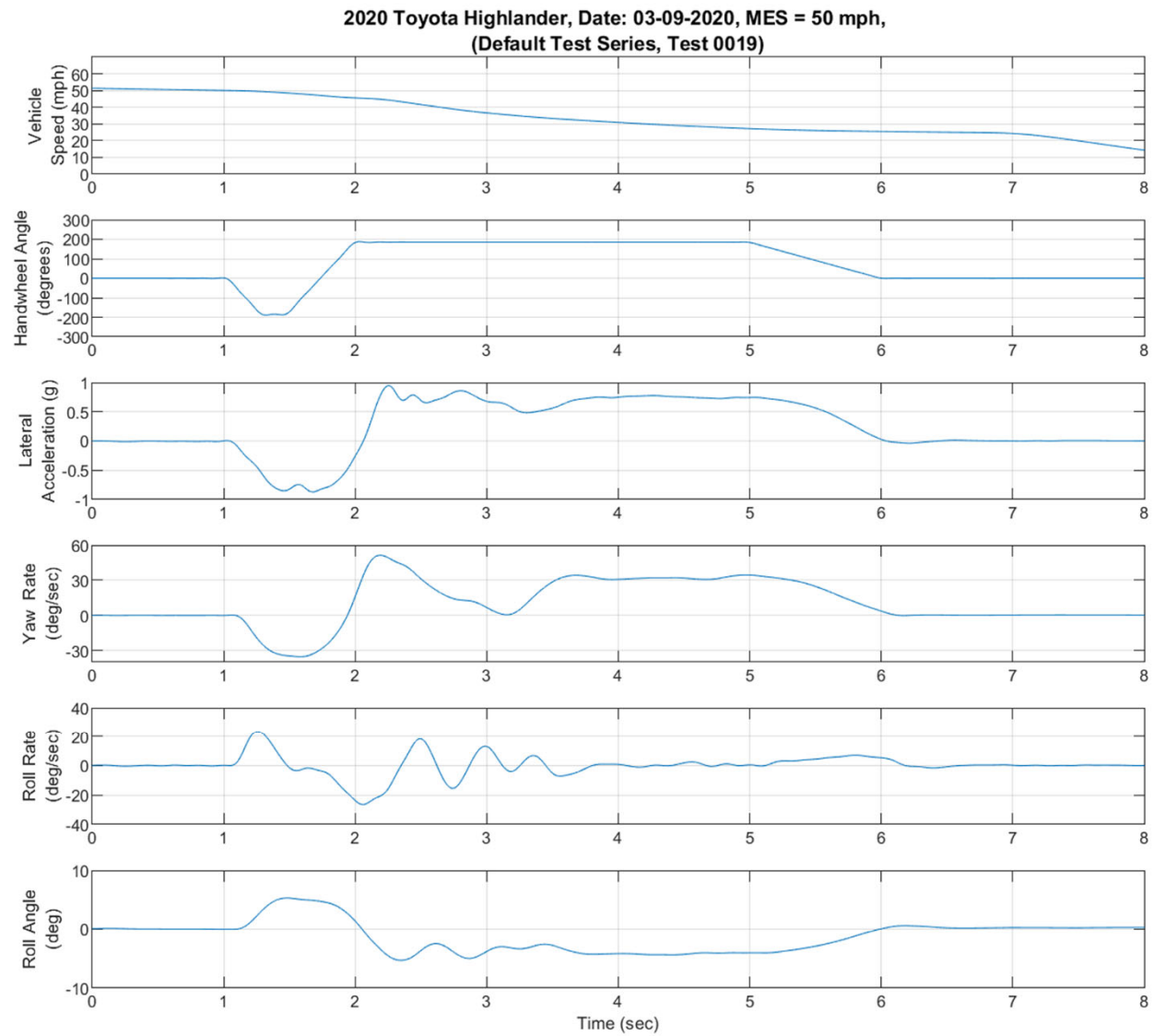


Figure D3. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots For Default Test Series, L-R, 50 mph

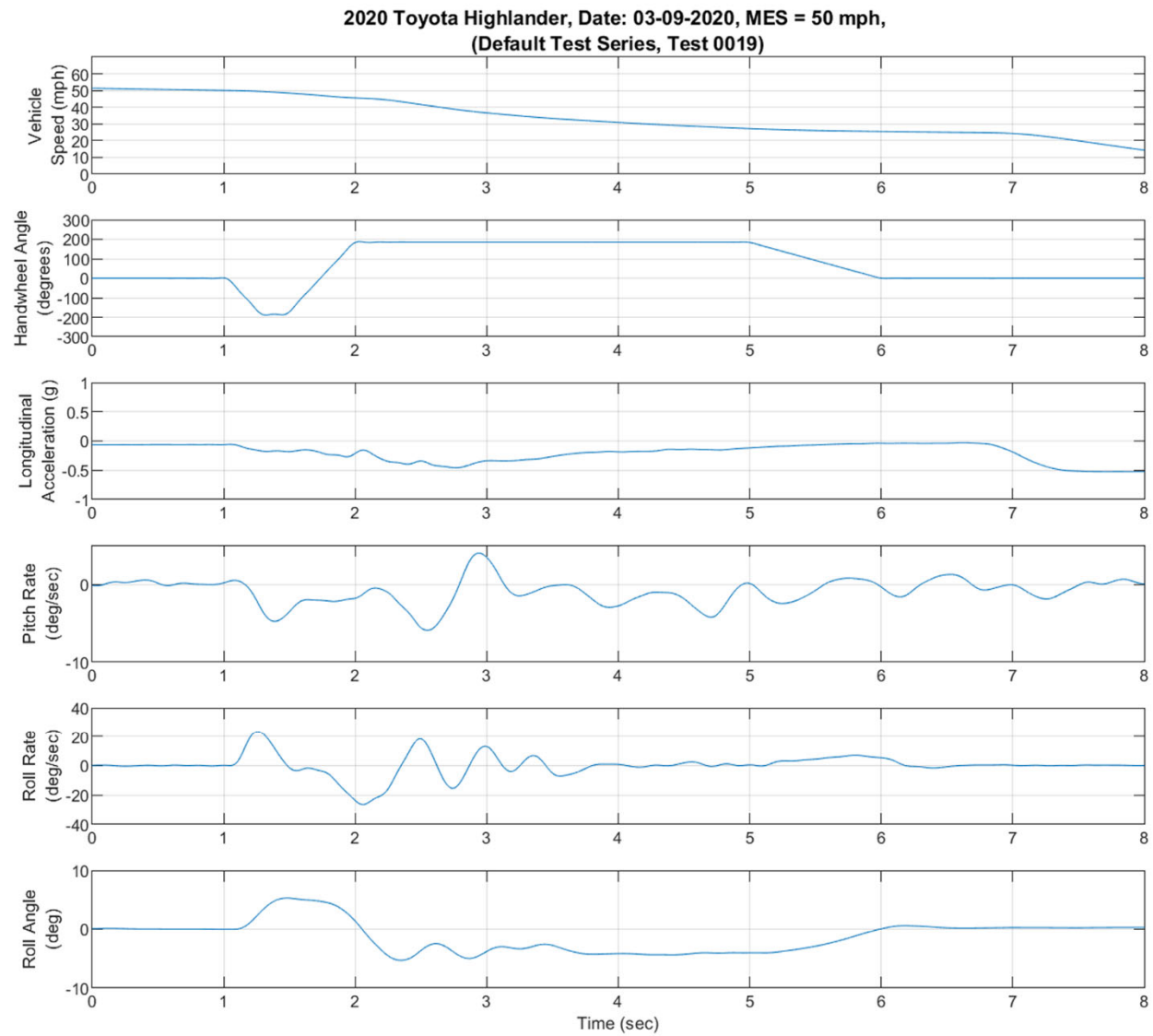


Figure D4. Pitch Rate and Longitudinal Acceleration Time History Plots for Default Test Series, L-R, 50 mph

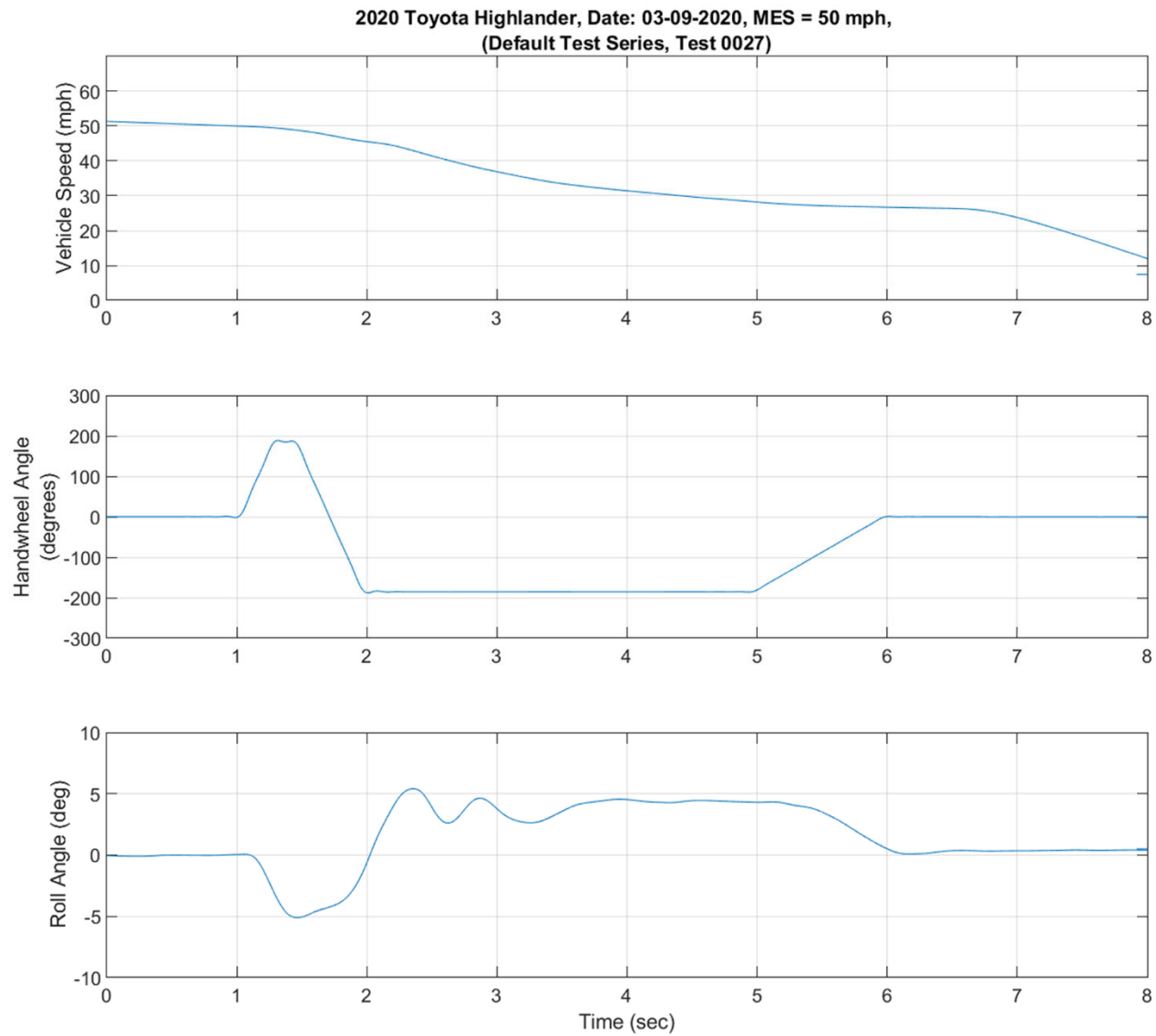


Figure D5. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Default Test Series, R-L, 50 mph

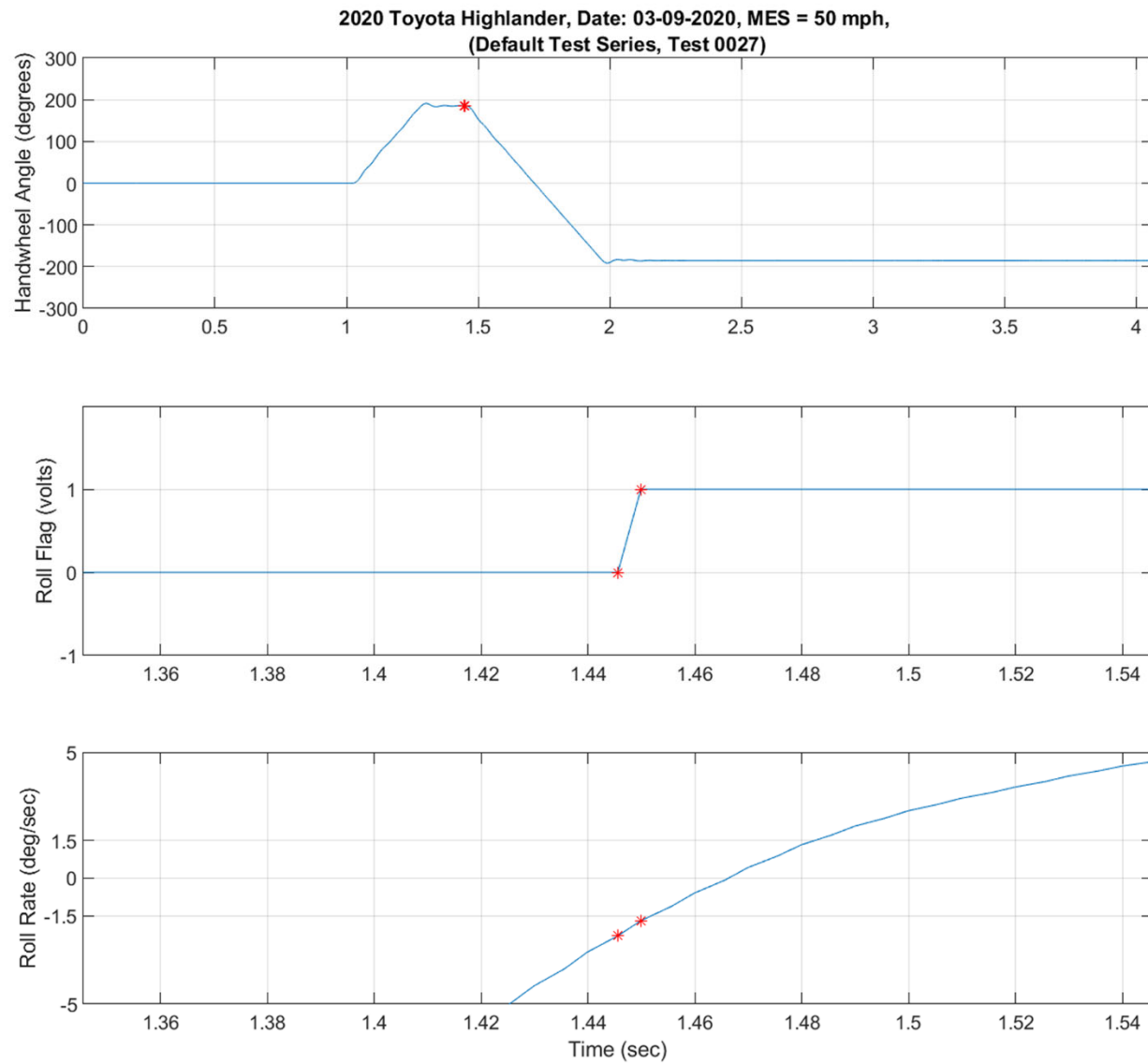


Figure D6. Steering Machine Operation Time History Plots for Default Test Series, R-L, 50 mph

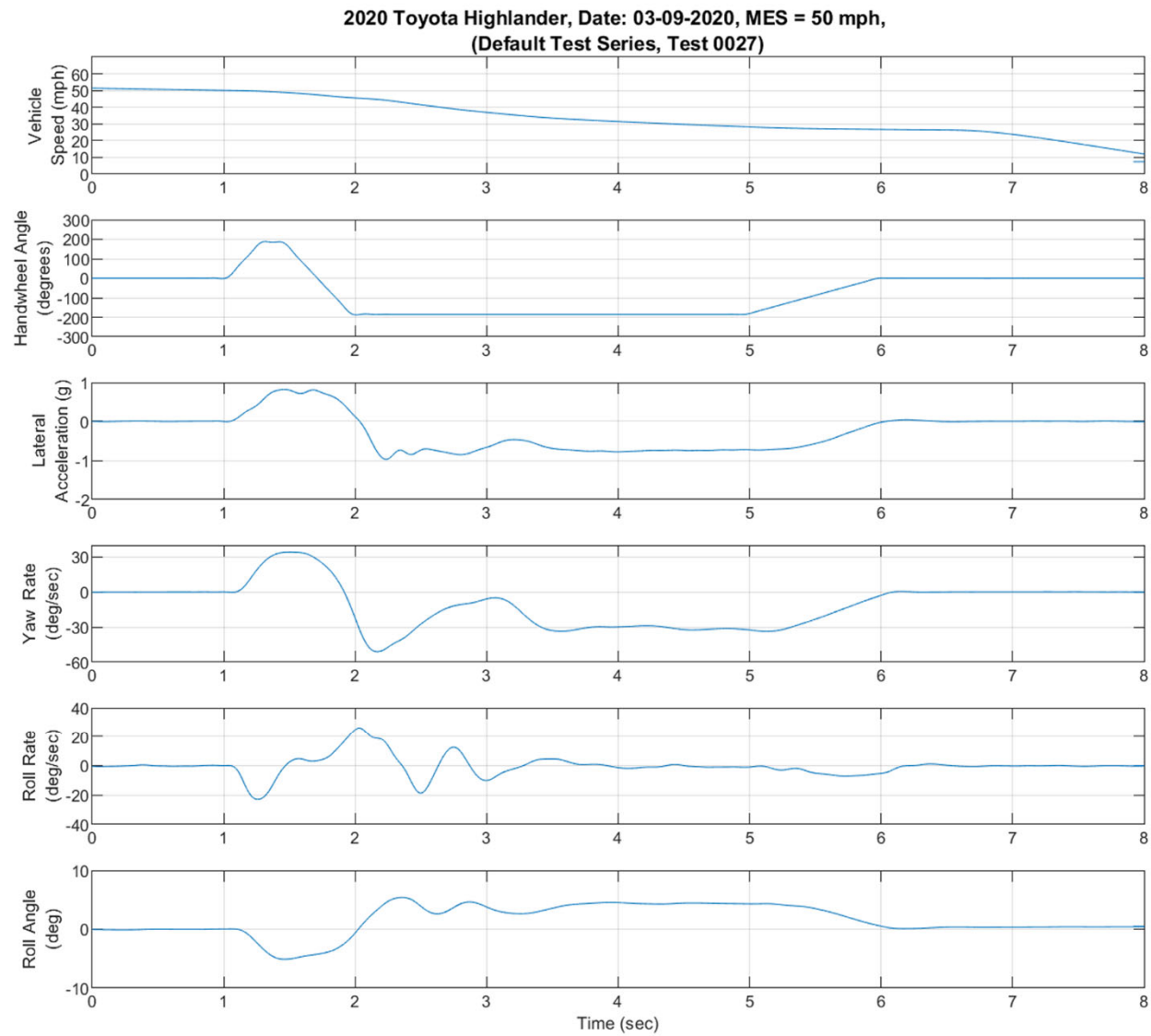


Figure D7. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots for Default Test Series, R-L, 50 mph

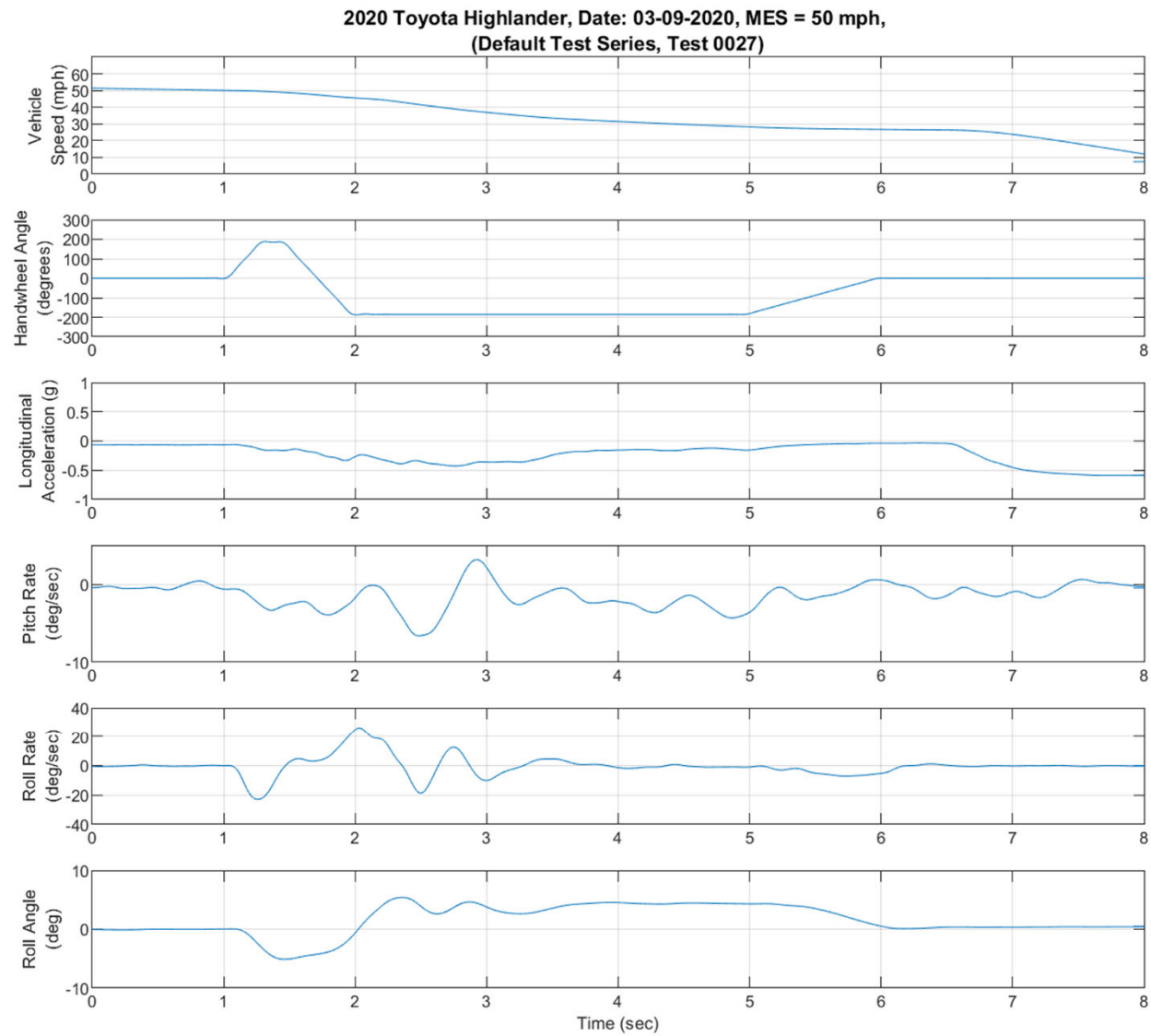


Figure D8. Pitch Rate and Longitudinal Acceleration Time History Plots or Default Test Series, R-L, 50 mph

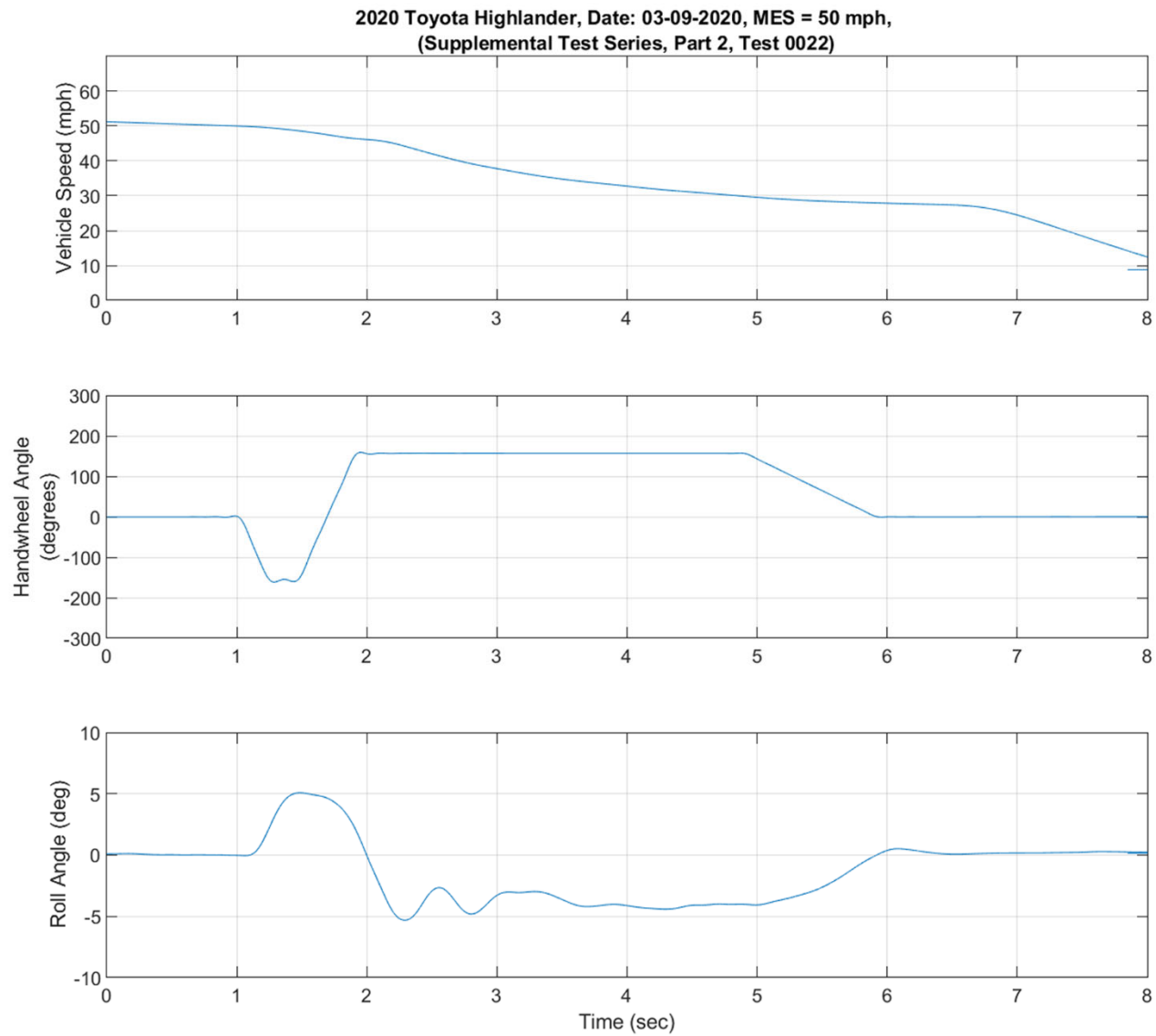


Figure D9. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

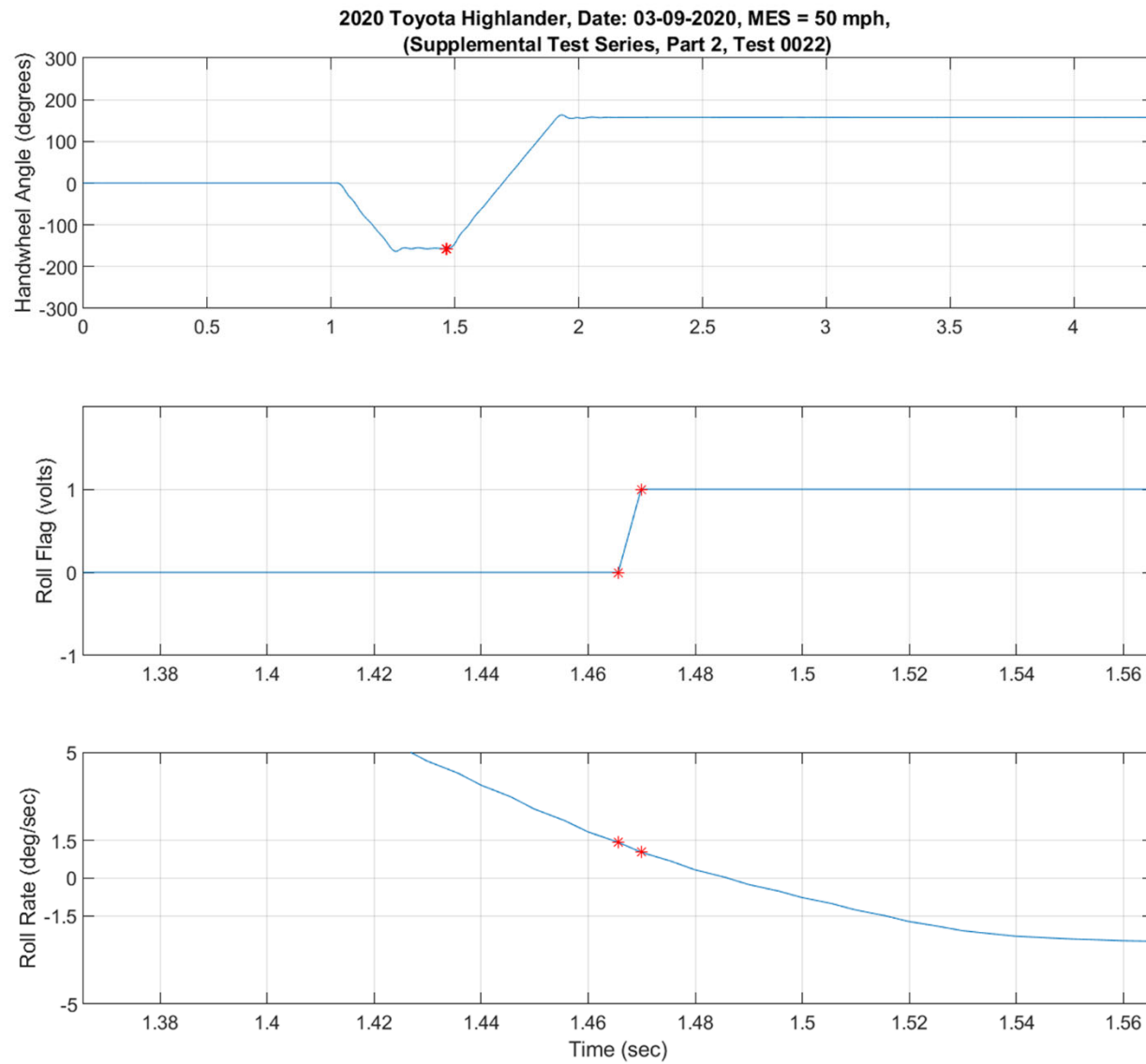


Figure D10. Steering Machine Operation Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

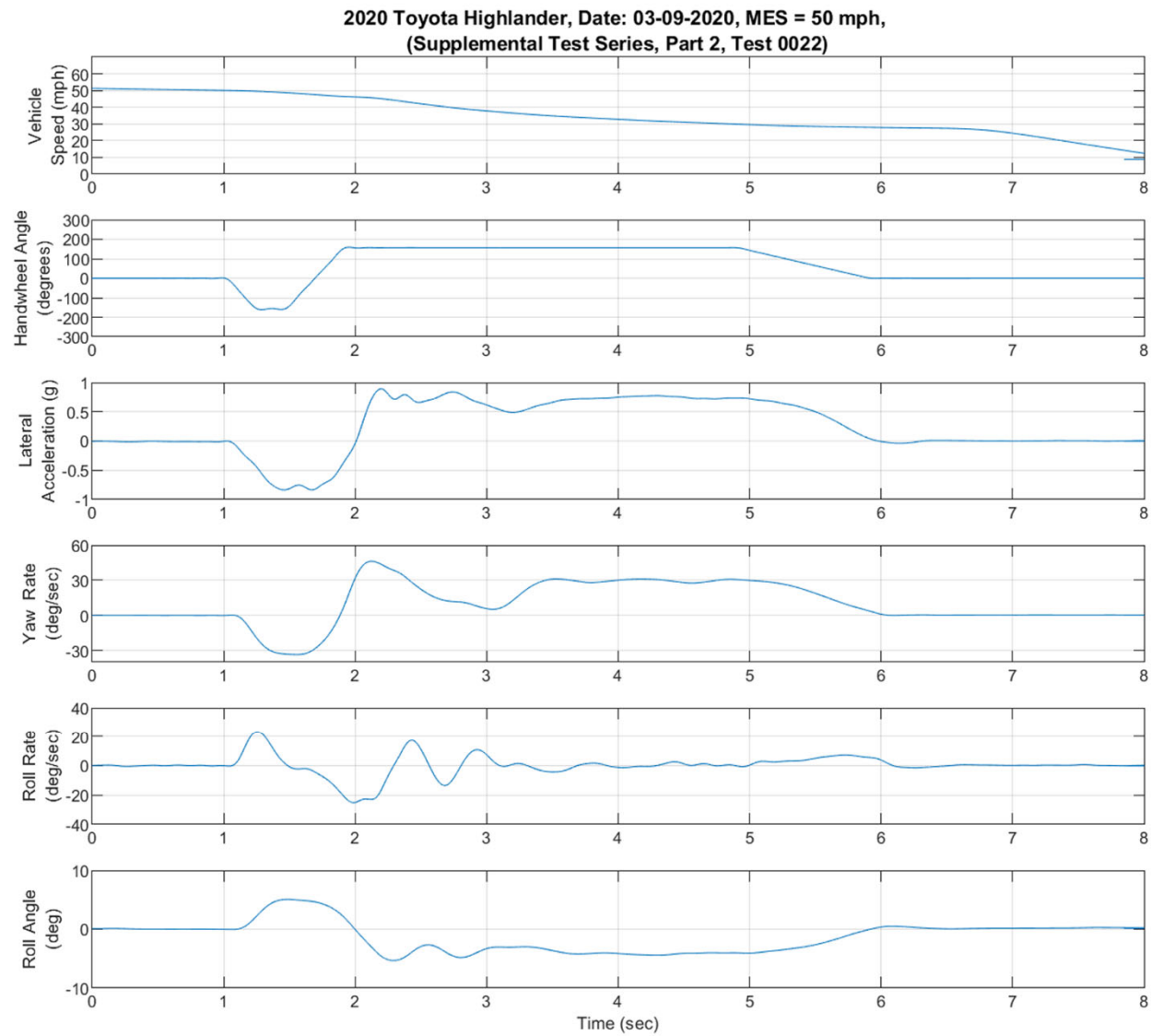


Figure D11. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

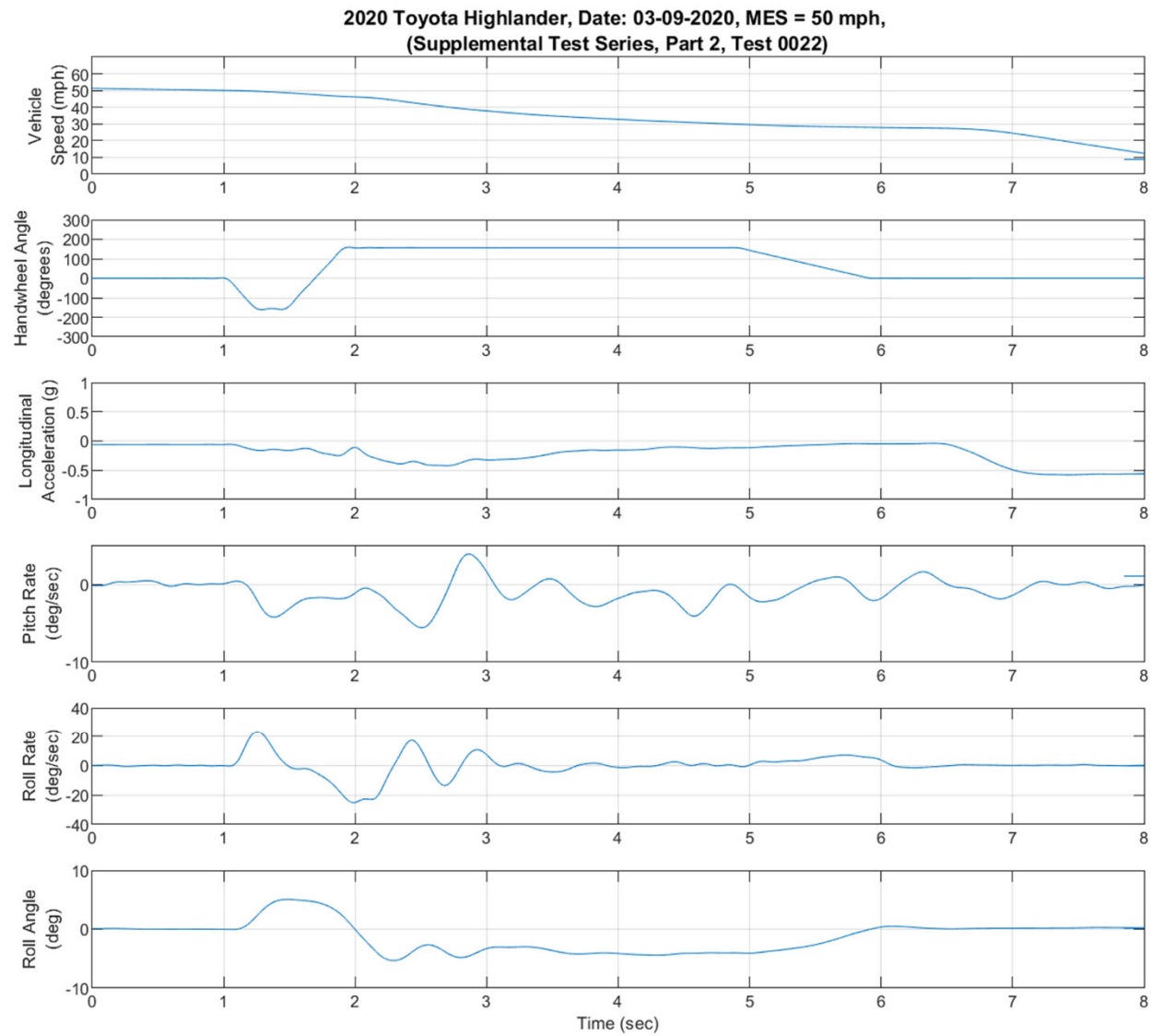


Figure D12. Pitch Rate and Longitudinal Acceleration Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

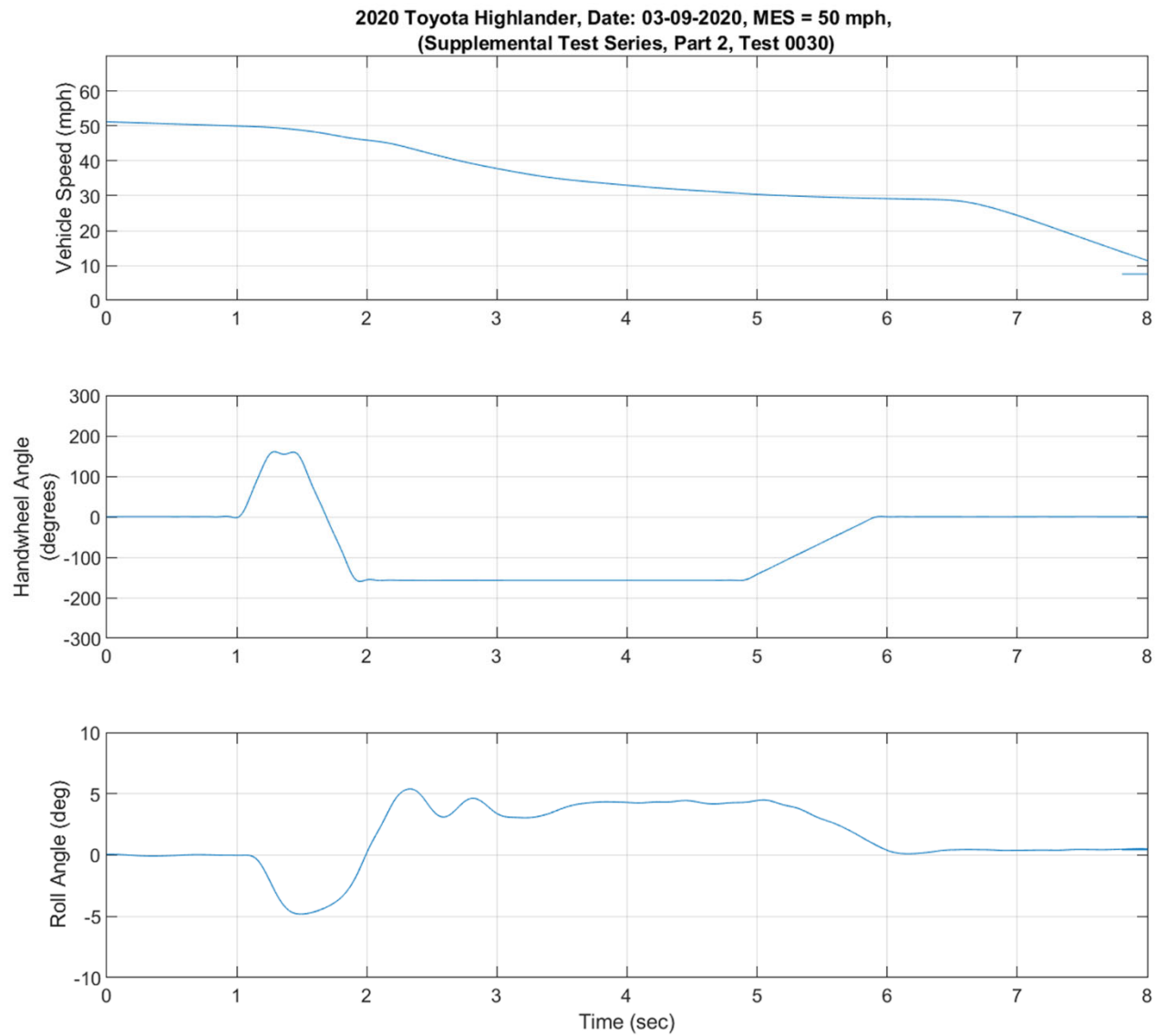


Figure D13. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Supplemental 2 Test Series, R-L, 50 mph

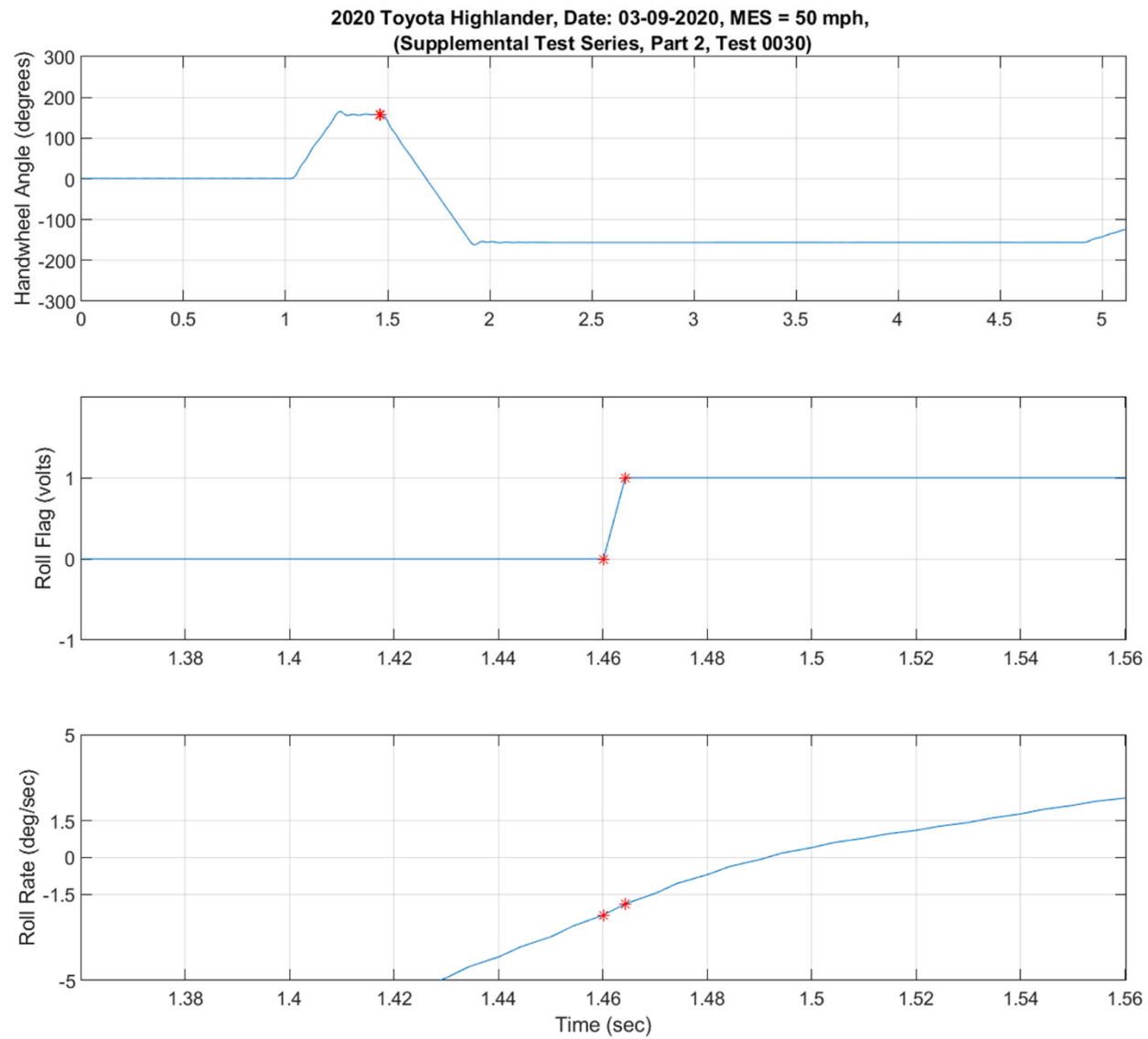


Figure D14. Steering Machine Operation Time History Plots for Supplemental 2 Test Series, R-L, 50 mph

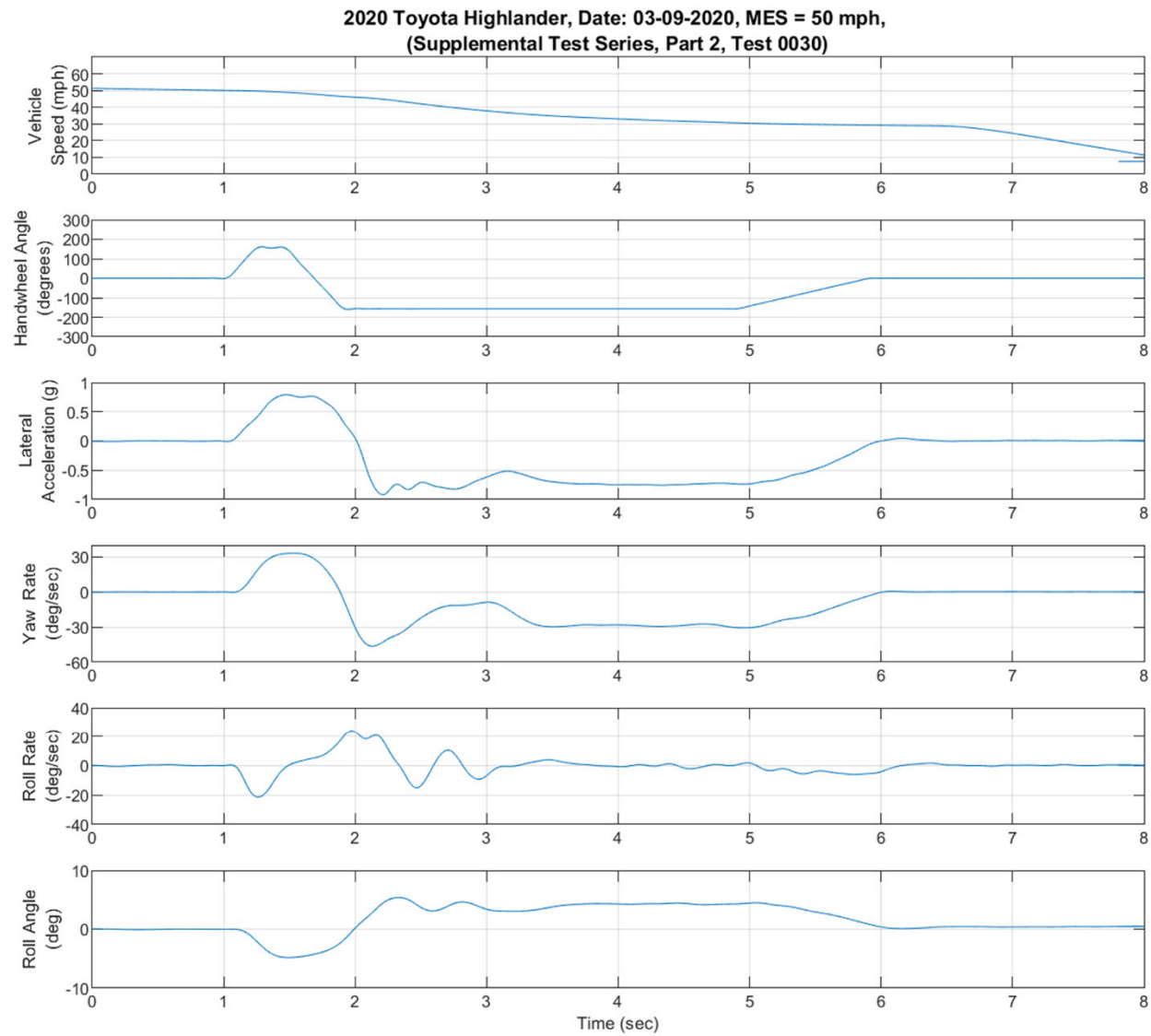


Figure D15. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots for Supplemental 2 Test Series, R-L, 50 mph

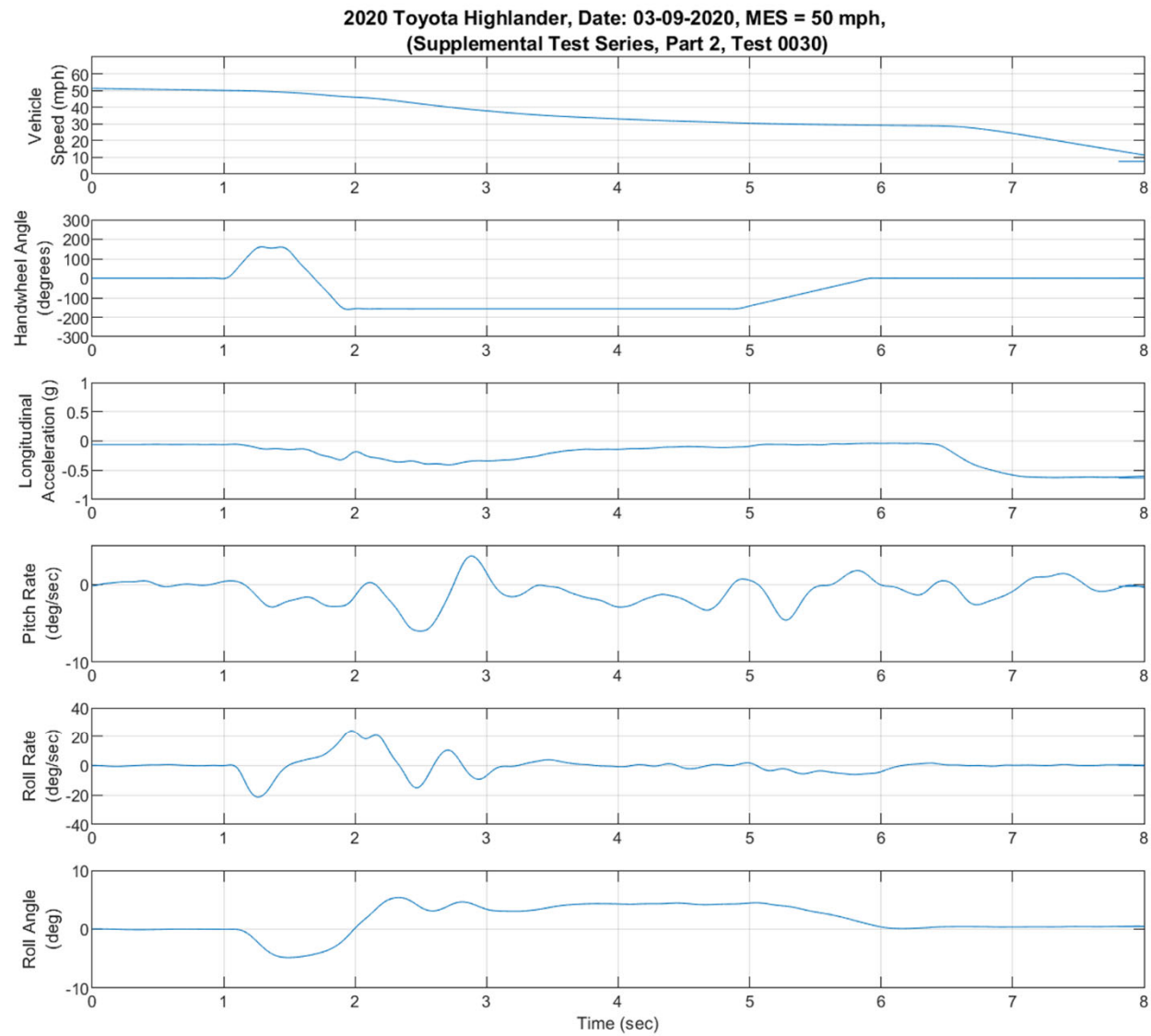


Figure D16. Pitch Rate and Longitudinal Acceleration Time History Plots for Supplemental 2 Test Series, R-L, 50 mph