NCAP-KAR-DR-21-06

NEW CAR ASSESSMENT PROGRAM (NCAP)
DYNAMIC ROLLOVER RESISTANCE TEST

TOYOTA MOTOR MANUFACTURING, INDIANA, INC.

2021 TOYOTA SIENNA FWD 5-DOOR MINIVAN

PREPARED BY:

APPLUS IDIADA KARCO ENGINEERING, LLC.

9270 HOLLY ROAD

ADELANTO, CA 92301

MARCH 19, 2021

FINAL REPORT

PREPARED FOR:

U.S. DEPARTMENT OF TRANSPORTATION

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

NEW CAR ASSESSMENT PROGRAM

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15. Supplementary Notes			
16. Abstract An NCAP Dynamic Rollover Maneuver (Fishhook) Test was conducted on a 2021 Toyota Sienna FWD 5-Door Minivan by Applus+ IDIADA KARCO Engineering, LLC. on March 12, 2021. The vehicle did not experience two-wheel lift. The vehicle's steering angle at 0.3 g lateral acceleration at 50 mph was 27.9 degrees.			
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INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA) has engaged Applus+ IDIADA KARCO Engineering, LLC 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 2021 Toyota Sienna FWD 5-Door Minivan 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 Dynamic Rollover Test 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 693JJ920D000011.

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 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	2021 Toyota Sienna				
VIN	5TDXRKEC7MS01xxxx				
Body style	Minivan				
Number of doors	5				
Trim level	XSE				
Seating positions	Front:	2nd row	3rd row	4th row	5th row
	2	2	3		
Electronic stability control	Yes				
4-Wheel ABS (Yes/No)	Yes				
Power steering (Yes/No)	Yes				
Major optional equipment	-				
Odometer at start of testing	69 miles				
Drivetrain					
Engine cylinder arrangement	Inline 4				
Engine displacement	2.5 L				
Transmission type	CVT				
Drive arrangement	FWD				
Chassis					
Track width	F: 68.1 in (1730 mm), R: 68.1 in (1730 mm)				
Wheelbase	120.9 in (3070 mm)				
Curb weight	4688 lb (2126.5 kg)				
Certification Data from Vehicle's Label					
Vehicle manufactured by	Toyota Motor Manufacturing, Indiana, Inc.				
Date of manufacture	1/21				
GVWR	6170 lb (2800 kg)				
GAWR Front	3205 lb (1455 kg)				
GAWR Rear	3205 lb (1455 kg)				

Table 2. Tire Information

Tire Manufacturer	Michelin
Tire Model	Primacy
Tire Size	Front: 235/50R20 Rear: 235/50R20
Load rating	Front: 100 Rear: 100
Speed rating	Front: V Rear: V
Treadwear grade	Front: 540 Rear: 540
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)
DOT code (8 last digits)	Front: 06DX 4420 Rear: 06DX 4420

Table 3. Vehicle Loading

Water dummy and other loading	Multi-Passenger Configuration 2 water dummies in second row, 1 in third row
Water dummy weight	525.1 lb (238.2 kg)
Fuel level	Full
Weight as Tested	
Left front	1513 lb (686.5 kg)
Right front	1472 lb (667.5 kg)
Left rear	1423 lb (645.5 kg)
Right rear	1388 lb (629.5 kg)
Total weight	5796 lb (2629.0 kg)

D. STEERING CONTROLLER

Precise steering control is accomplished using a steering machine designed and constructed by ABD. It can provide up to 45 ft-lb torque and at rates over 1000 deg/sec. The integrated angle encoder has an unlimited range with a resolution of 0.25 degrees and an accuracy of ±0.25 degrees. The steering motor is controlled by RC8 software from ABD, which also acts as the data acquisition system.

E. REAL-TIME CONTROLLER AND DATA ACQUISITION

Data acquisition is achieved using a MOSES Meas X, which also serves as the real-time system for the steering controller. Data from the OXTS, 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 MOSES MeasX. The Oxford IMUs are calibrated per the manufacturer's recommended schedule (Table 5).

Two video cameras were used to record the Fishhook runs. They were positioned nominally as shown in Figure 1. The recorded video was reviewed after the Fishhook runs to check for any two-wheel lift. If any two-wheel lift was observed, four 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 Applus+ IDIADA KARCO Engineering, LLC used for this specific test program.

Table 4. Weight of In-Cab Test Equipment

Equipment	Location	Equipment Weight (lb)	
		NHTSA*	IDIADA
Data Acquisition System	Front passenger seat	58	35
GPS Inertial unit	At the chassis in a flat and rigid surface		7
Steering Machine	Handwheel	31	51
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 footwell.	39	39
	Total	**128**	**132**

* 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. Sensor Specifications

Type	Measured Variable	Sensor	Range	Resolution	Accuracy	Specifics	Serial Number	Calibration	Unit
Multi-Axis Inertial Sensing System *Distance Measuring System* *Radar Speed Sensor* *Data Flag (Roll Rate Flag)*	Longitudinal speed Lateral speed Longitudinal acc. Lateral acc. Roll angle Pitch angle Yaw angle Roll rate Pitch rate Yaw rate	GPS inertial unit	- - ±100 ±100 ±100 ±100 ±100 ±100 ±100 ±100	0.01 º/s 0.01 m/s2	±0.1 ±0.1 ±0.1 ±0.1 ±0.05 ±0.05 ±0.1 ±0.1 ±0.1 ±0.1	OXTS (RT)	1611	By: IDIADA Date: 6/16/2020 Due: 6/16/2022	km/h km/h m/s² m/s² º º º º/s º/s º/s
Angle Encoder[1] *Data Flag (Handwheel Command Flag)*	Steering angle Steering torque	Steering wheel robot	>1000 60	0.25 deg	±0.20 ±0.25	ABD	769/17	By: IDIADA Date: 8/01/2019 Due: 8/01/2021	º Nm
Infrared Distance Measuring System	Tire wheel lift	Height sensors	300-700	0.01 mm	±0.8	OPTImess	OMS 4140-3098 OMS 4140-4506 OMS 4140-4508 OMS 4140-4509	By: IDIADA Date: 7/7/2020 Due: 7/7/2021	mm
Load Cell	Brake Pedal Force	Load Cell	±600	-	±0.5	Novatech	48305	By: IDIADA Date: 3/27/2020 Due: 3/27/2021	N
Acquisition system	-	Acquisition system	200	-	-	IDIADA Moses MEAS X	180749	By: IDIADA Date: 05/21/2020 Due: 05/21/2022	-

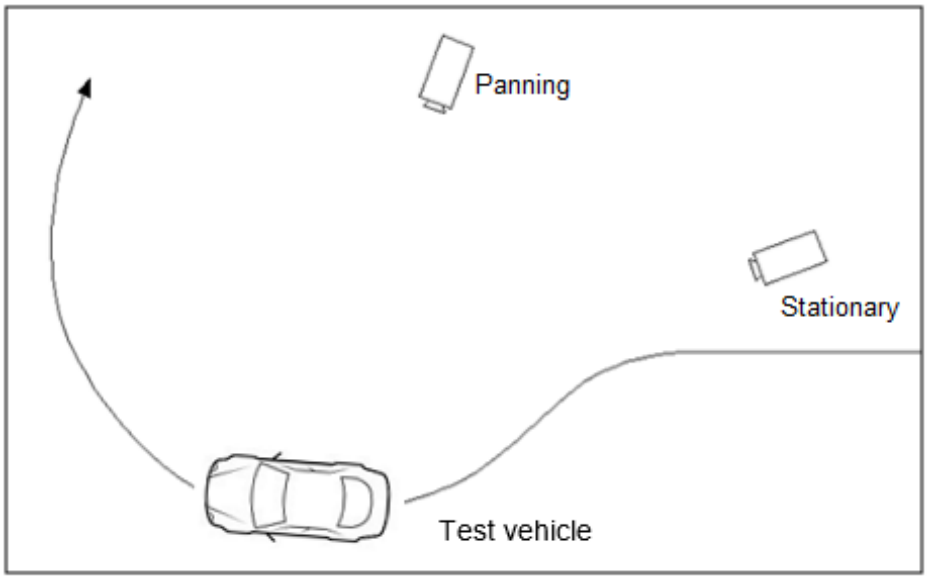

Figure 1. Nominal Position of Video Cameras for Fishhook Tests

SECTION III
TEST PROCEDURES

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 3 seconds, and then returned to zero angle in 2 seconds.

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.

A. TEST CONDITIONS

1. Test Surface

The tests were conducted on the Vehicle Dynamics Area (VDA) at HONDA Proving Center facility, located in Cantil, California, on 3/12/2021. The VDA has a smooth, flat (slope less than 0.5% throughout) asphaltic concrete surface. Its dimensions are as shown in Figure 2. 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 surface friction measurement results are shown in Table 6.

Table 6. Lateral Surface Friction

Date of surface friction measurements	3/12/2021
Average lateral friction coefficient	0.94
Peak braking coefficient	0.92

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)	27.9º
5.5 scalar handwheel angle for Fishhook Test	153.5º
6.5 scalar handwheel angle for Fishhook Test	181.4º

3. Weather Conditions

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

Table 8. Weather Conditions

Ambient temperature	51.2 ºF (10.7 ºC)
Wind Speed	5.8 mph (2.6 m/s)
Wind Direction	N

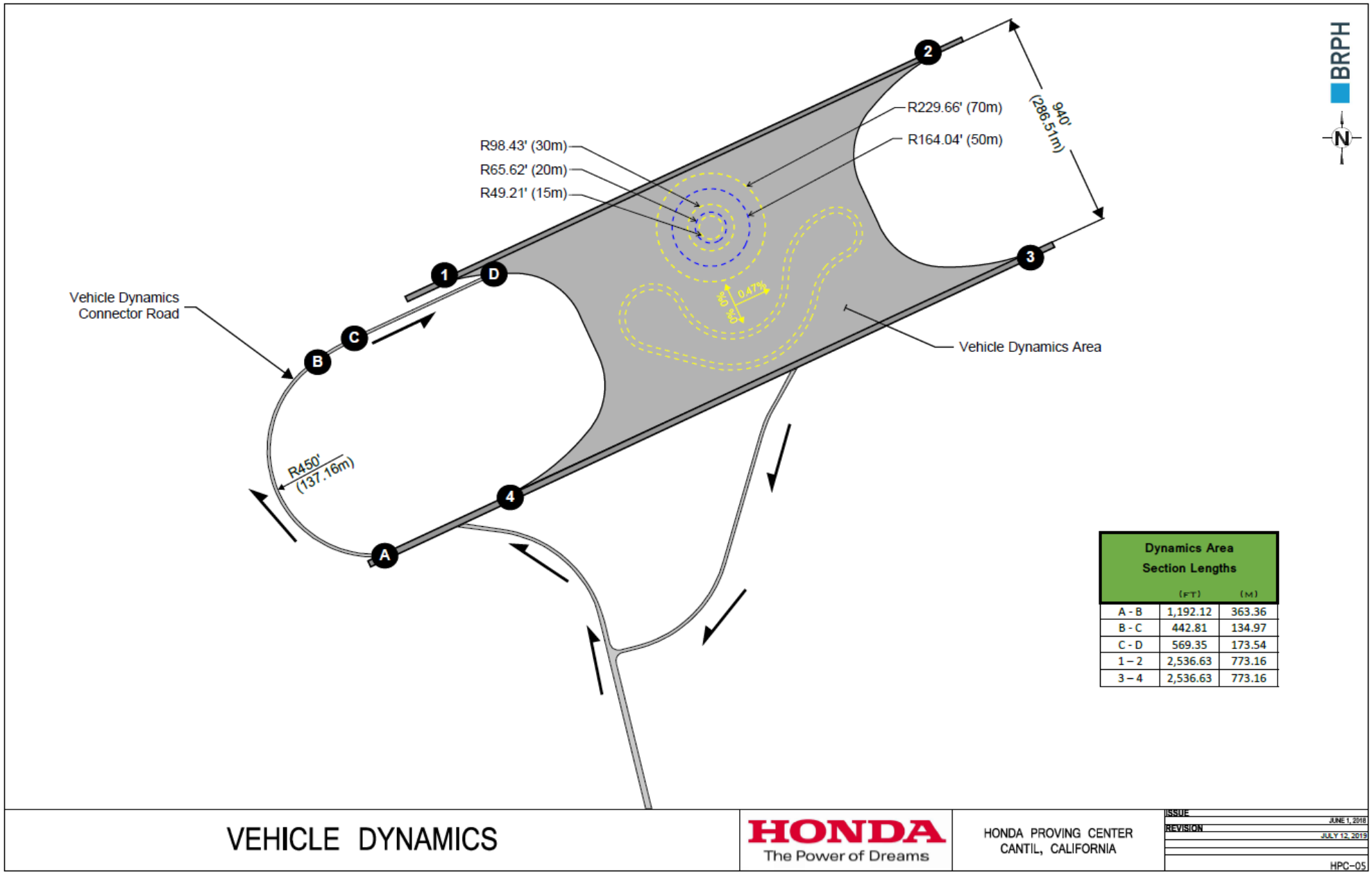

Figure 2. Vehicle Dynamics Area at Honda Proving Center

SECTION IV
RESULTS

There is Appendix A with the photographic documentation. The test run log is given in Appendix B. A summary of the Slowly Increasing Steer Test 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 2021 Toyota Sienna FWD 5-Door Minivan, there was no two-wheel lift at any test condition.

APPENDIX A

PHOTOGRAPHS

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Figure A2. Right Front View, Test Vehicle As-Delivered

Figure A3. Left Rear View, Test Vehicle As-Delivered

Figure A4. Left Front View, Test Vehicle in Test Condition

Figure A5. Right Rear View, Test Vehicle in Test Condition

Figure A6. Vehicle's Certification Label

Figure A7. Vehicle's Tire Information Placard

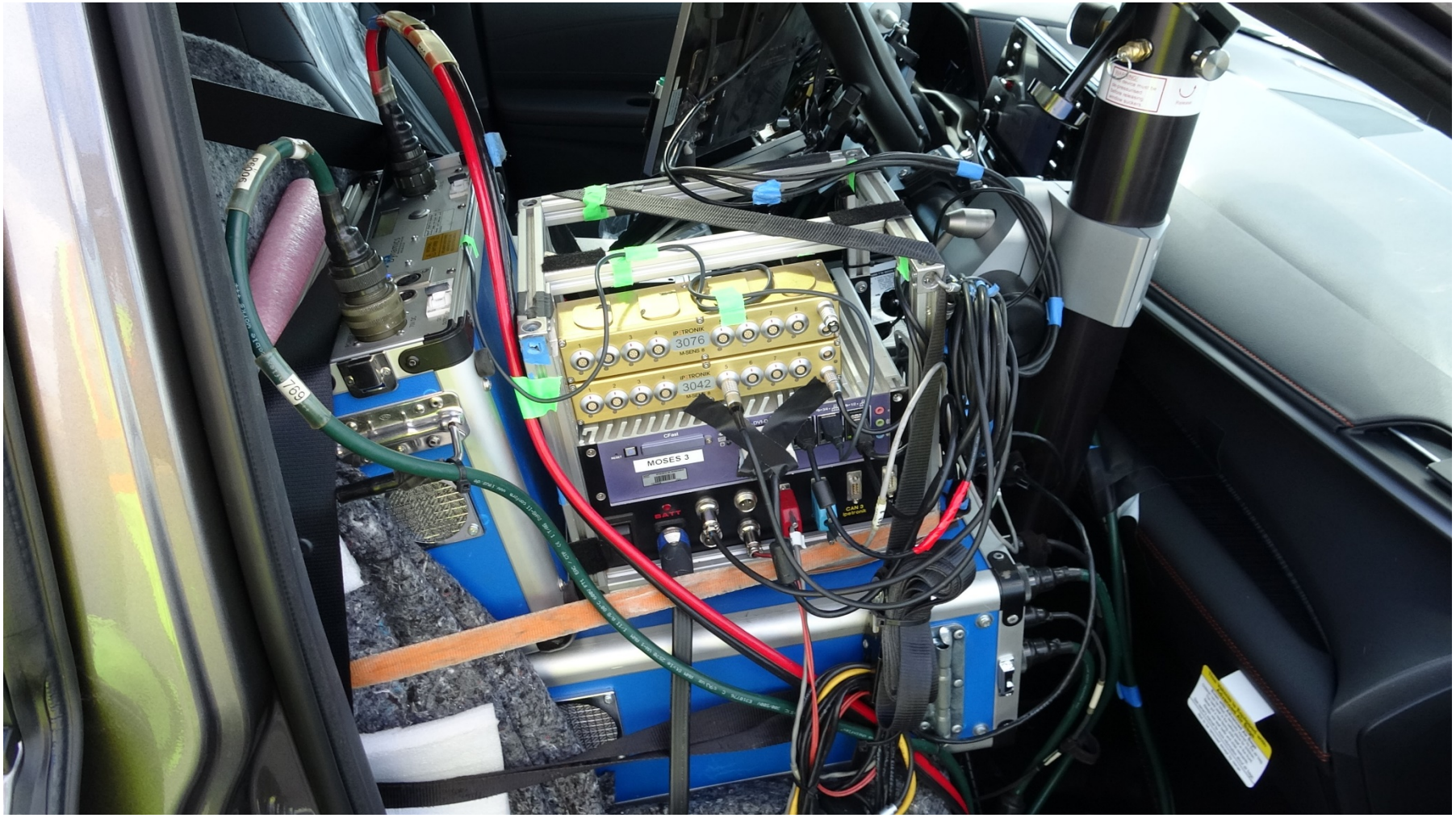

Figure A8. Instrumentation in Test Vehicle

Figure A9. Steering Controller and Computer

Figure A10. Ballast Condition

APPENDIX B

TEST RUN LOG

Vehicle: **2021 TOYOTA SIENNA FWD 5-DOOR MINIVAN** Driver: **Omar Gonzalez** Date: **3/12/2021**

Run Number	Test Type	Speed (mph)	Handwheel Angle (deg)	Dir. of First Steer	2 Wheel Lift	Notes
1	Tire Warm-Up	35	30.0	Left	N/A	Resulted in ay = 0.21g
2	"	"	60.0	"	"	Resulted in ay = 0.34g
3	"	"	"	"	"	
4	"	"	"	"	"	
5	2x SWA last cycle	"	120.0	"	"	2x SWA last cycle
6	Static	0	0	N/A	N/A	
7	Steady State	50	0	N/A	N/A	
8	**Slowly Increasing Steer**	50	30.0	Left	N/A	
9	"	"	39.8	Left	"	HW angle at 0.3 g = -29.3
10	"	"	"	Left	"	HW angle at 0.3 g = -29.1
11	"	"	"	Left	"	HW angle at 0.3 g = -29.3
12	"	"	"	Right	"	HW angle at 0.3 g = 26.1
13	"	"	"	Right	"	HW angle at 0.3 g = 26.2
14	"	"	"	Right	"	HW angle at 0.3 g = 27.2
						Average = **27.9**
15	**Fishhook 6.5 Scalar**	35	181.4	Left	No	
16	"	40	"	"	"	
17	"	45	"	"	"	
18	"	47.5	"	"	"	
19	"	50	"	"	"	
20	**Fishhook 6.5 Scalar**	35	181.4	Right	No	
21	"	40	"	"	"	
22	"	45	"	"	"	

Run Number	Test Type	Speed (mph)	Handwheel Angle (deg)	Dir. of First Steer	2 Wheel Lift	Notes
23	“	47.5	“	“	"	
24	"	50	"	"	"	
25	**Fishhook 5.5 Scalar**	45	153.5	Left	No	
26	"	47.5	"	"	"	
27	"	50	"	"	"	
28	**Fishhook 5.5 Scalar**	45	153.5	Right	No	
29	"	47.5	"	"	"	
30	"	50	"	"	"	

APPENDIX C
SLOWLY INCREASING STEER TEST WORKSHEET

Applus IDIADA

Slowly Increasing Steer

dynasoft

Vehicle: 2021 Toyota Sienna FWD
Test Date: 3/12/2021
Analysis Date: 3/12/2021
Analysed by: EL
Executed by: OG
Configuration: ESC on

Weight Condition: Test condition
Test Track: Dynamic Platform
Test Speed: 50 mph

Run	Dir of Steer	Start speed [mph]	End speed [mph]	Speed red [%]	Index of ay	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
sis_001	L	49.5	0.3	99.3	1042	-29.3	-0.300	-190.2	-0.2642	-160.9	-0.2235	0.9965	389	589
sis_002	L	49.9	0.4	99.3	1040	-29.1	-0.300	-189.0	-0.2625	-159.9	-0.2221	0.9966	383	583
sis_003	L	49.3	-0.0	100.1	1039	-29.3	-0.300	-190.7	-0.2649	-161.4	-0.2241	0.9928	391	591
sis_004	R	50.4	0.3	99.4	995	26.1	0.300	169.8	0.2358	143.6	0.1995	0.9961	344	544
sis_005	R	49.2	-0.2	100.3	1000	26.2	0.300	170.6	0.2370	144.4	0.2005	0.9961	338	538
sis_006	R	49.5	0.1	99.7	1020	27.2	0.300	177.0	0.2459	149.8	0.2081	0.9917	371	571

Mean: 27.9

Steering Controller Input values

Scalar 6.5 values:

Initial HW angle: 181.4 deg

Reversal HW angle: -181.4 deg

Scalar 5.5 values:

Initial HW angle: 153.5 deg

Reversal HW angle: -153.5 deg

APPENDIX D
TIME HISTORY PLOTS

LIST OF FIGURES

FILENAME: FH005

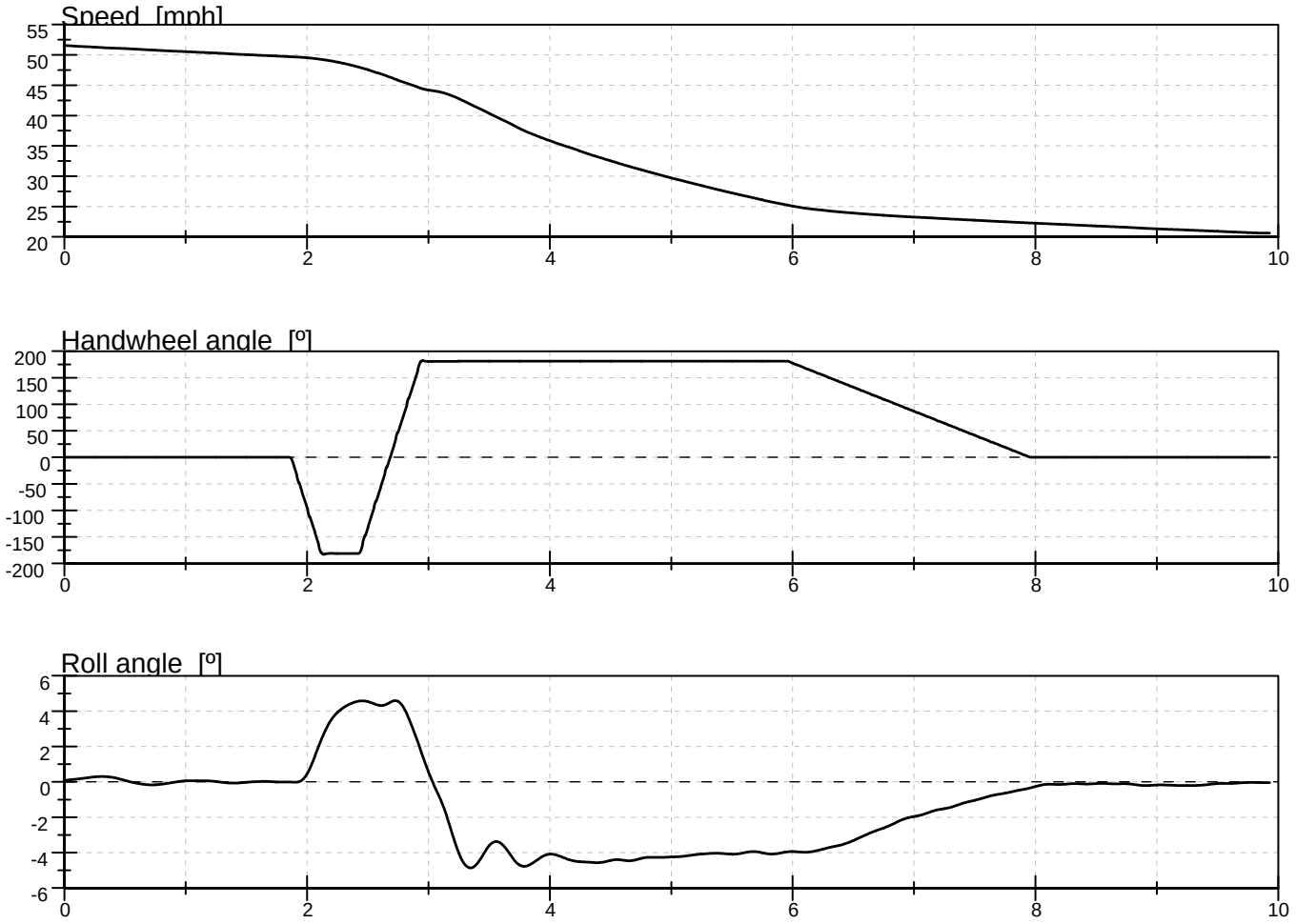

Figure D1. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Default Test Series, L-R, 50 mph

FILENAME: FH005

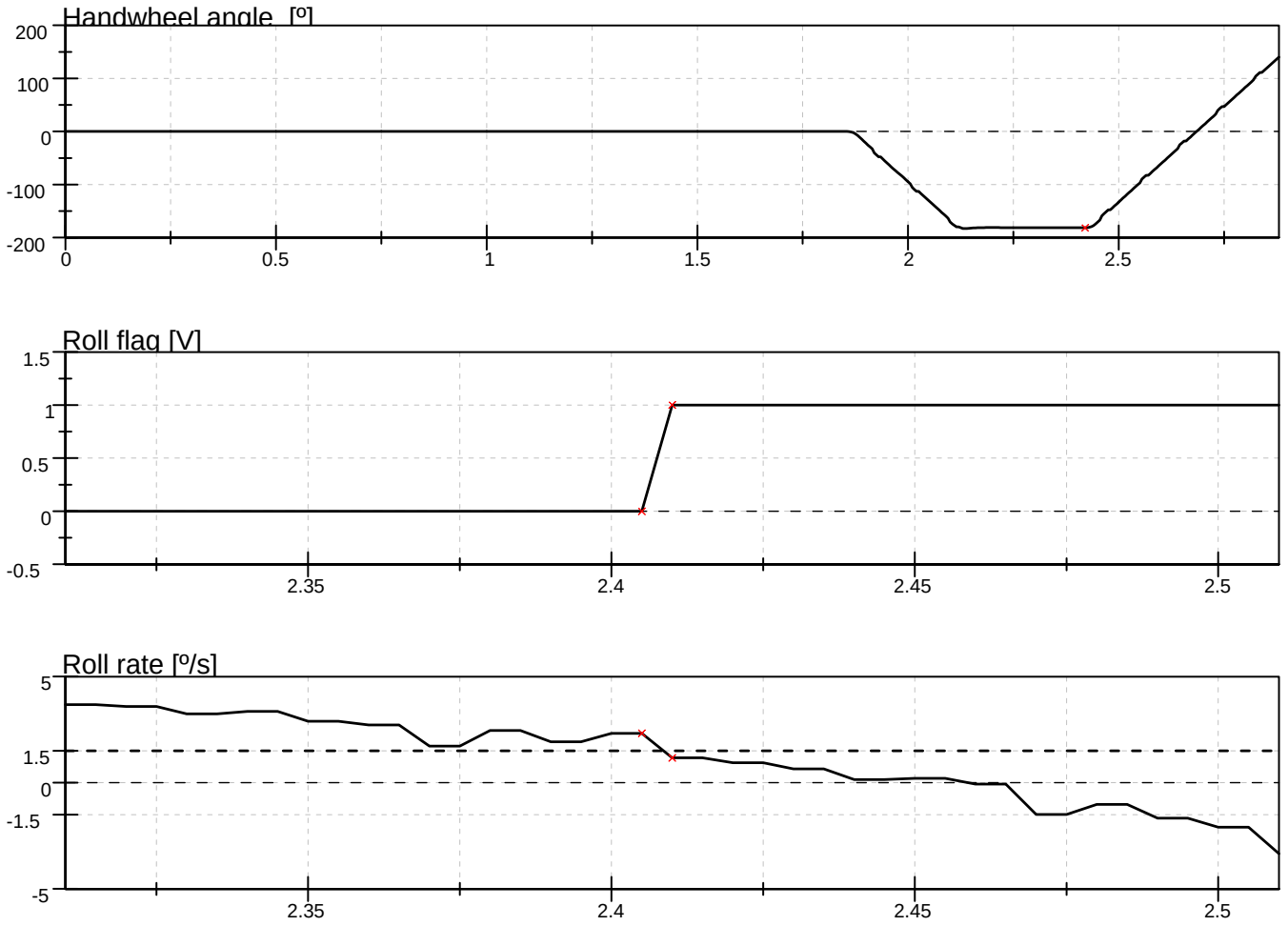

Figure D2. Steering Machine Operation Time History Plots for Default Test Series, L-R, 50 mph

FILENAME: FH005

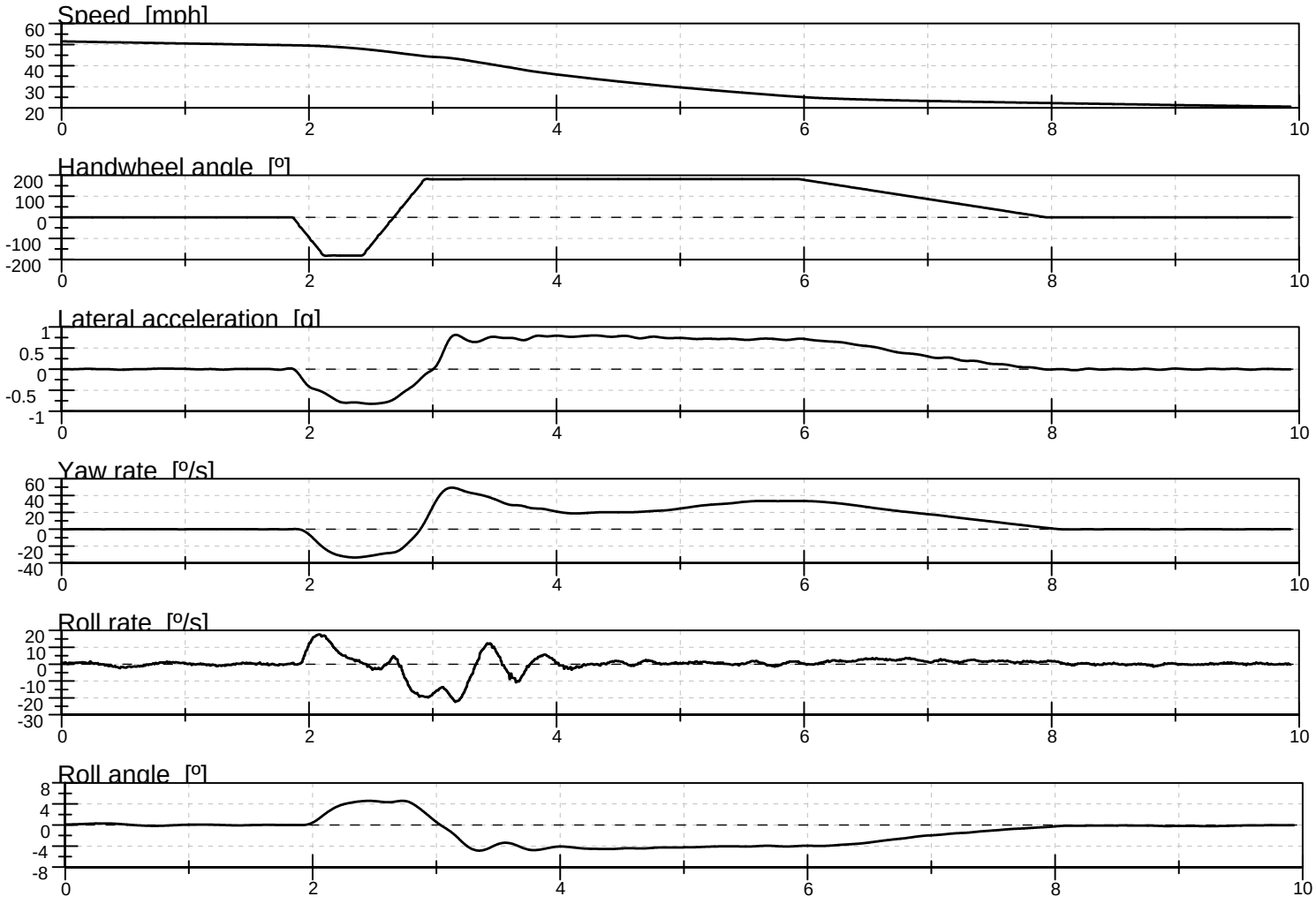

Figure D3. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots For Default Test Series, L-R, 50 mph

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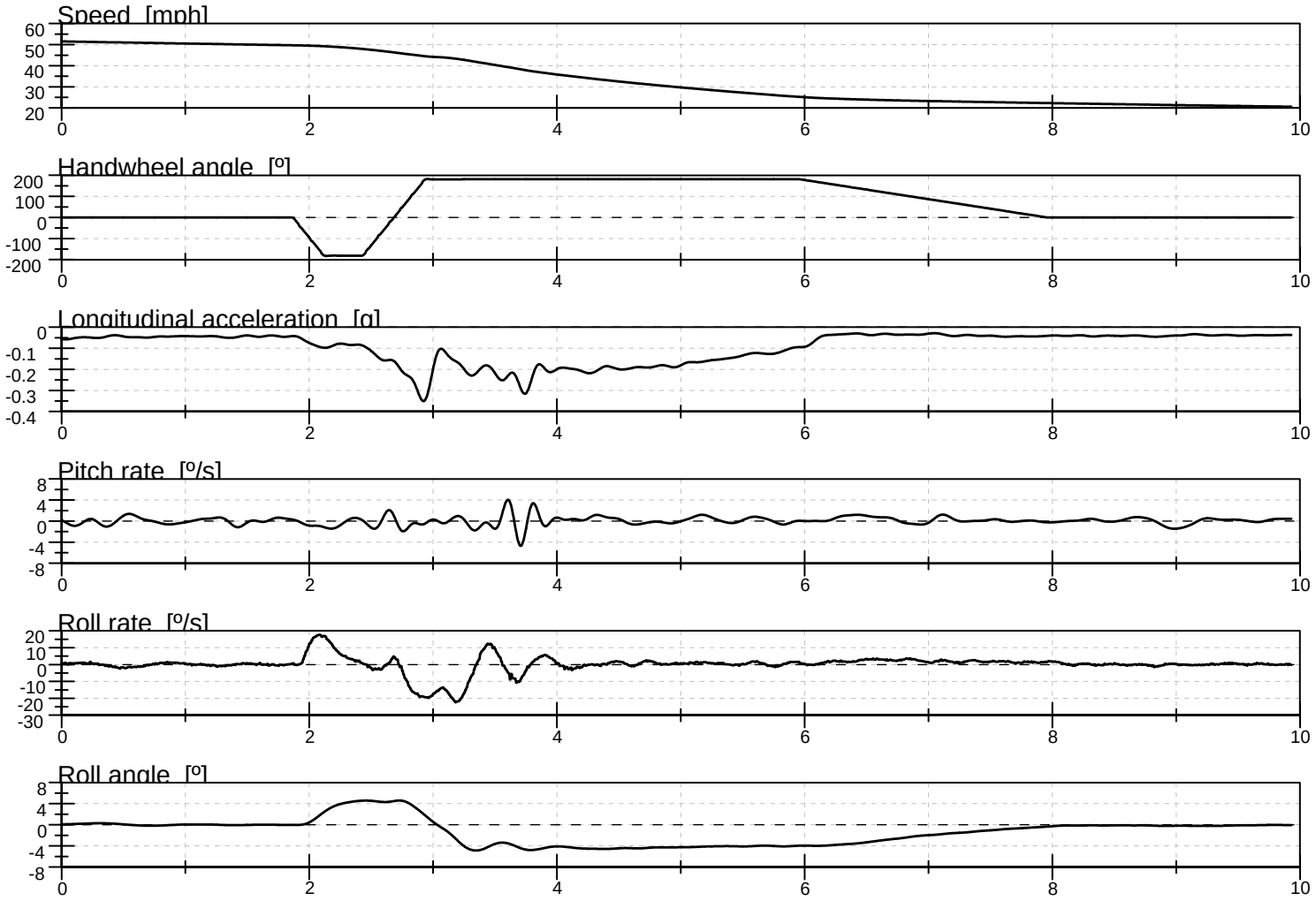

Figure D4. Pitch Rate and Longitudinal Acceleration Time History Plots for Default Test Series, L-R, 50 mph

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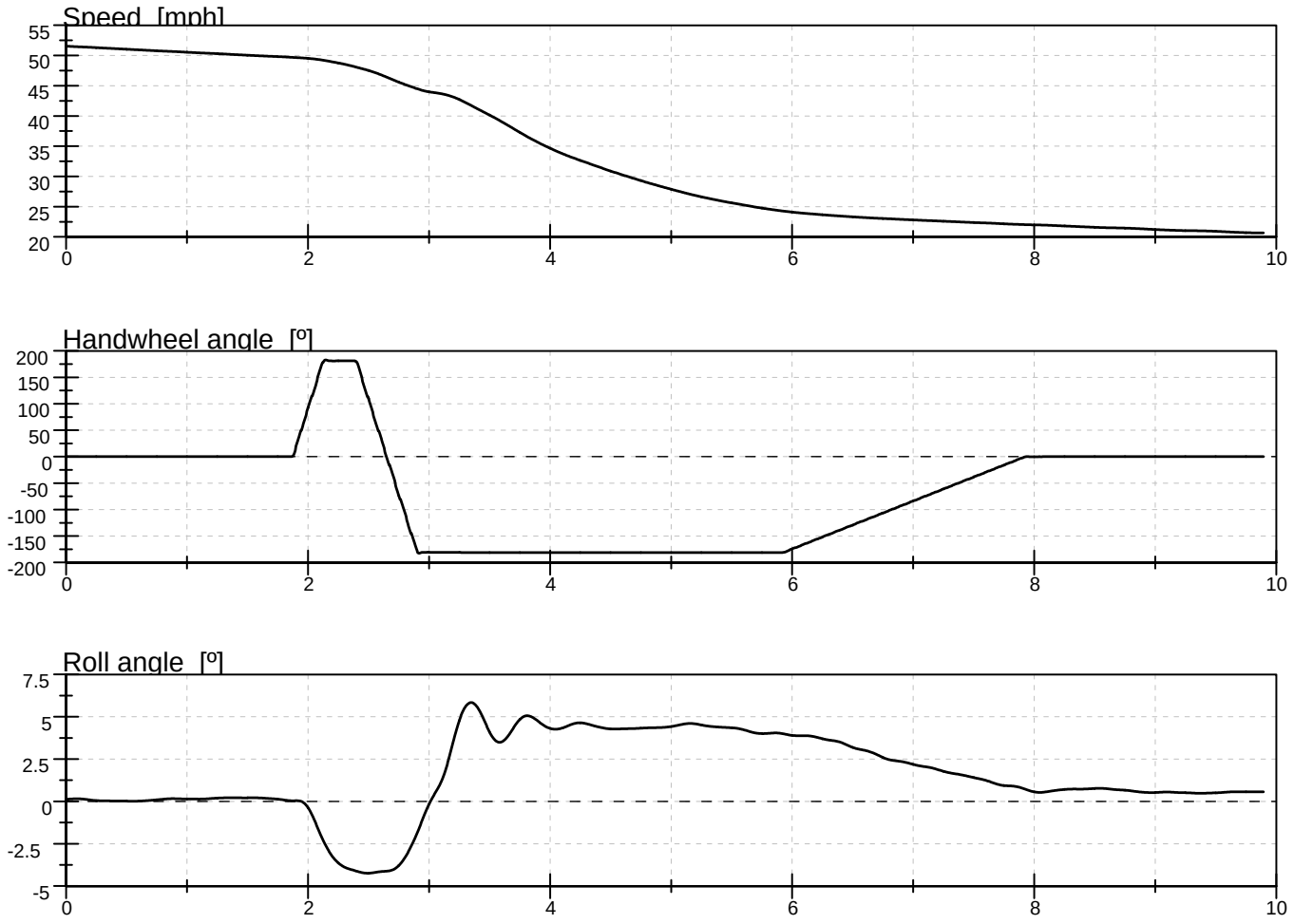

Figure D5. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Default Test Series, R-L, 50 mph

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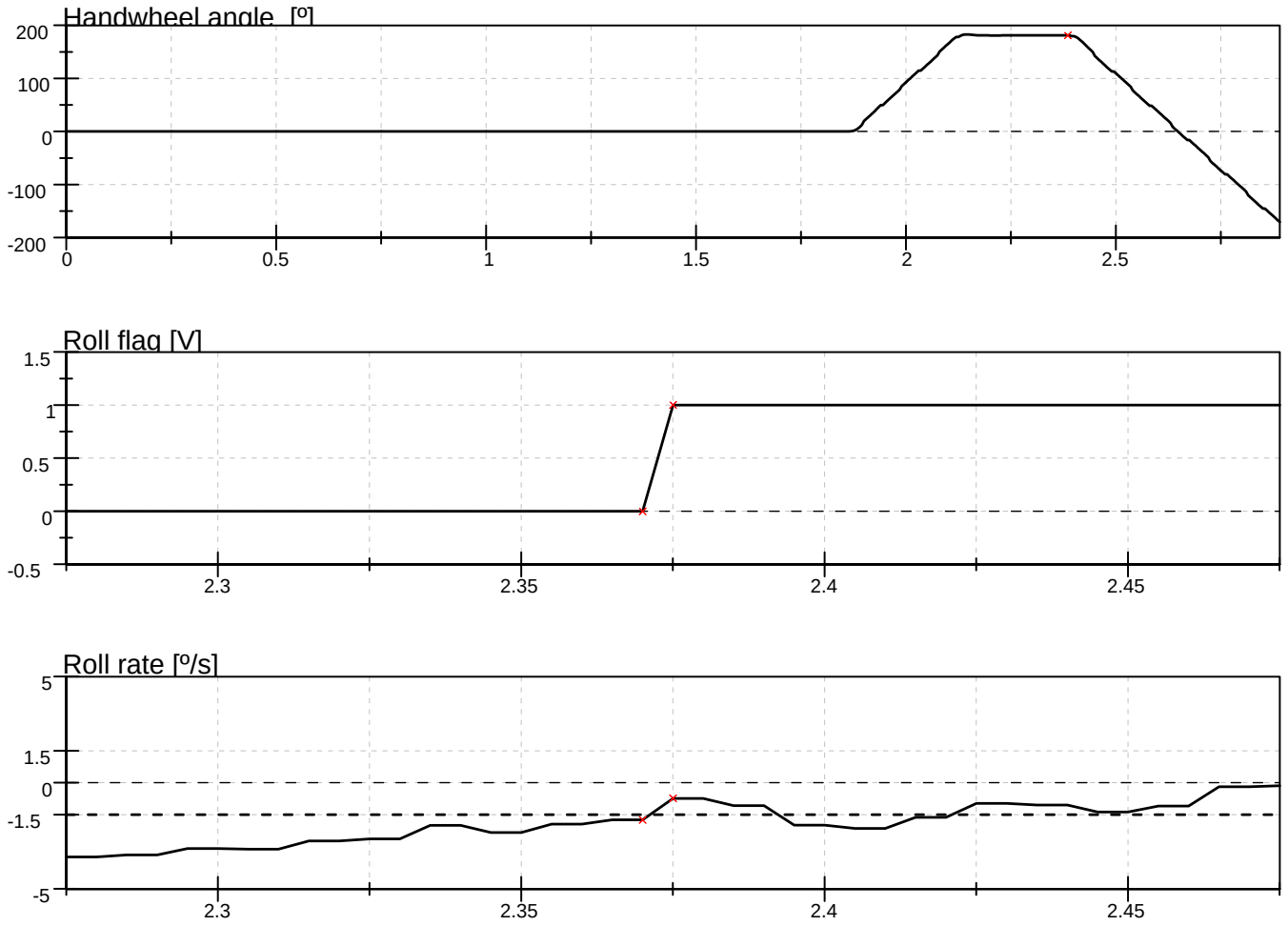

Figure D6. Steering Machine Operation Time History Plots for Default Test Series, R-L, 50 mph

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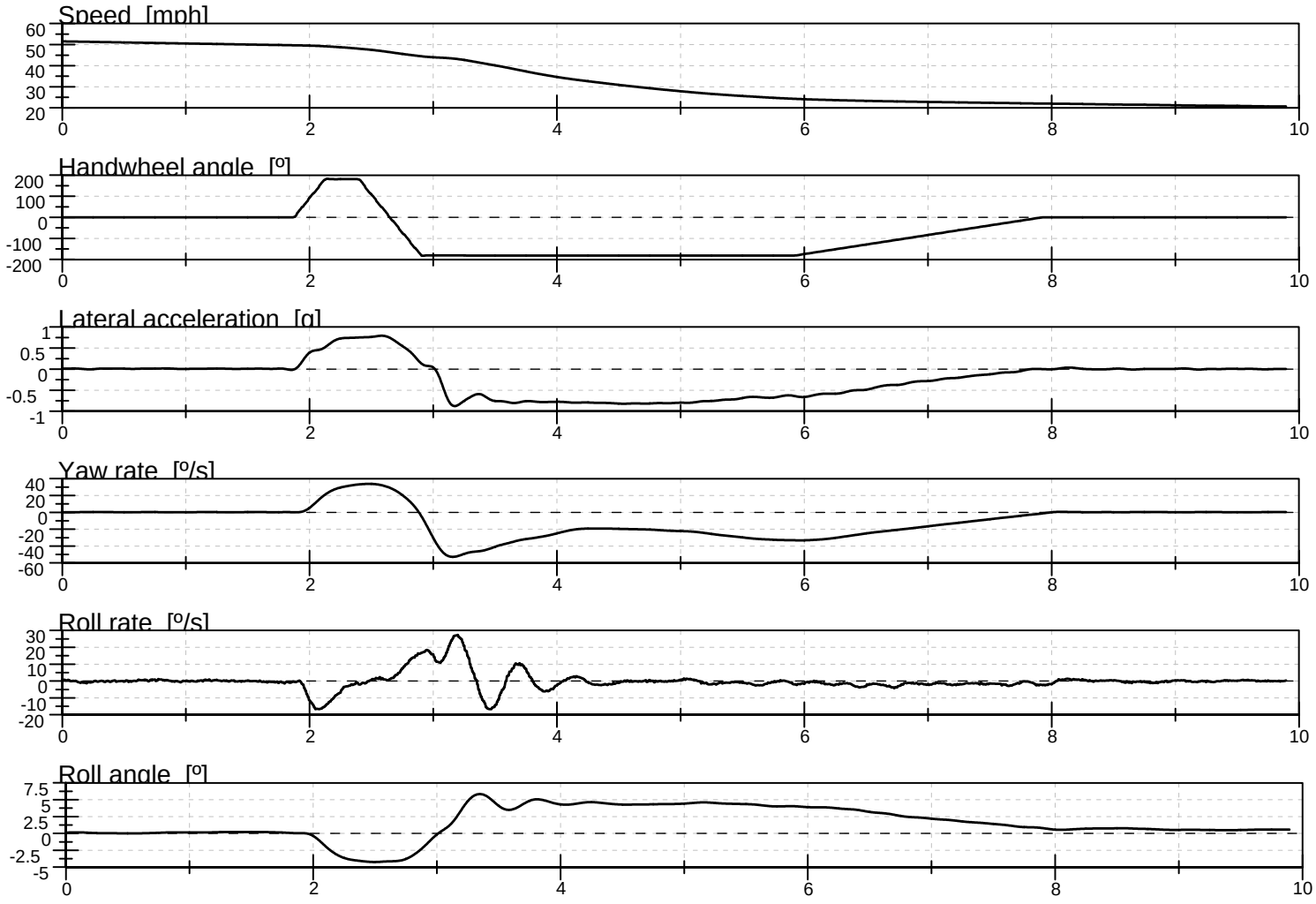

Figure D7. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots for Default Test Series, R-L, 50 mph

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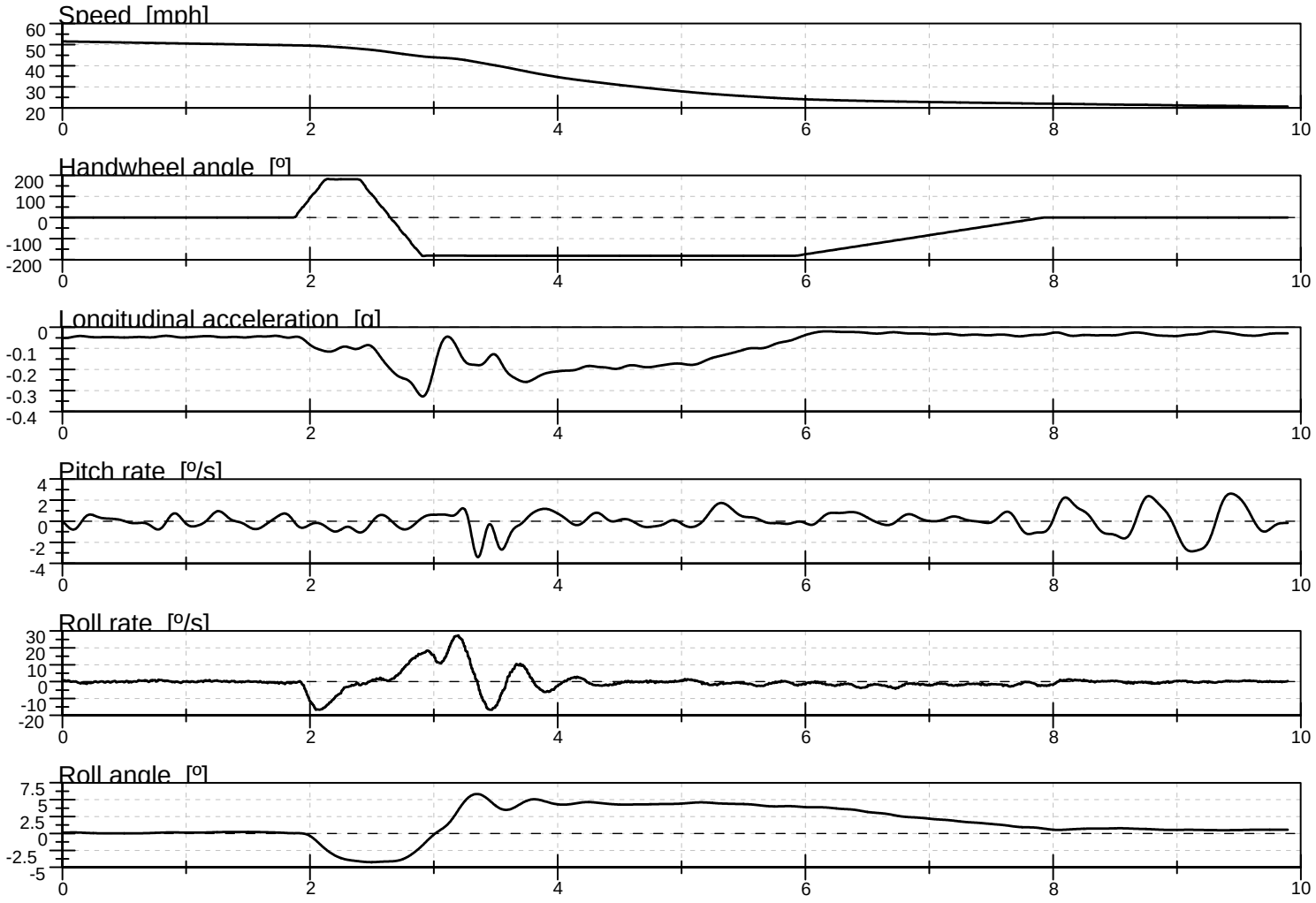

Figure D8. Pitch Rate and Longitudinal Acceleration Time History Plots or Default Test Series, R-L, 50 mph

FILENAME: FH013

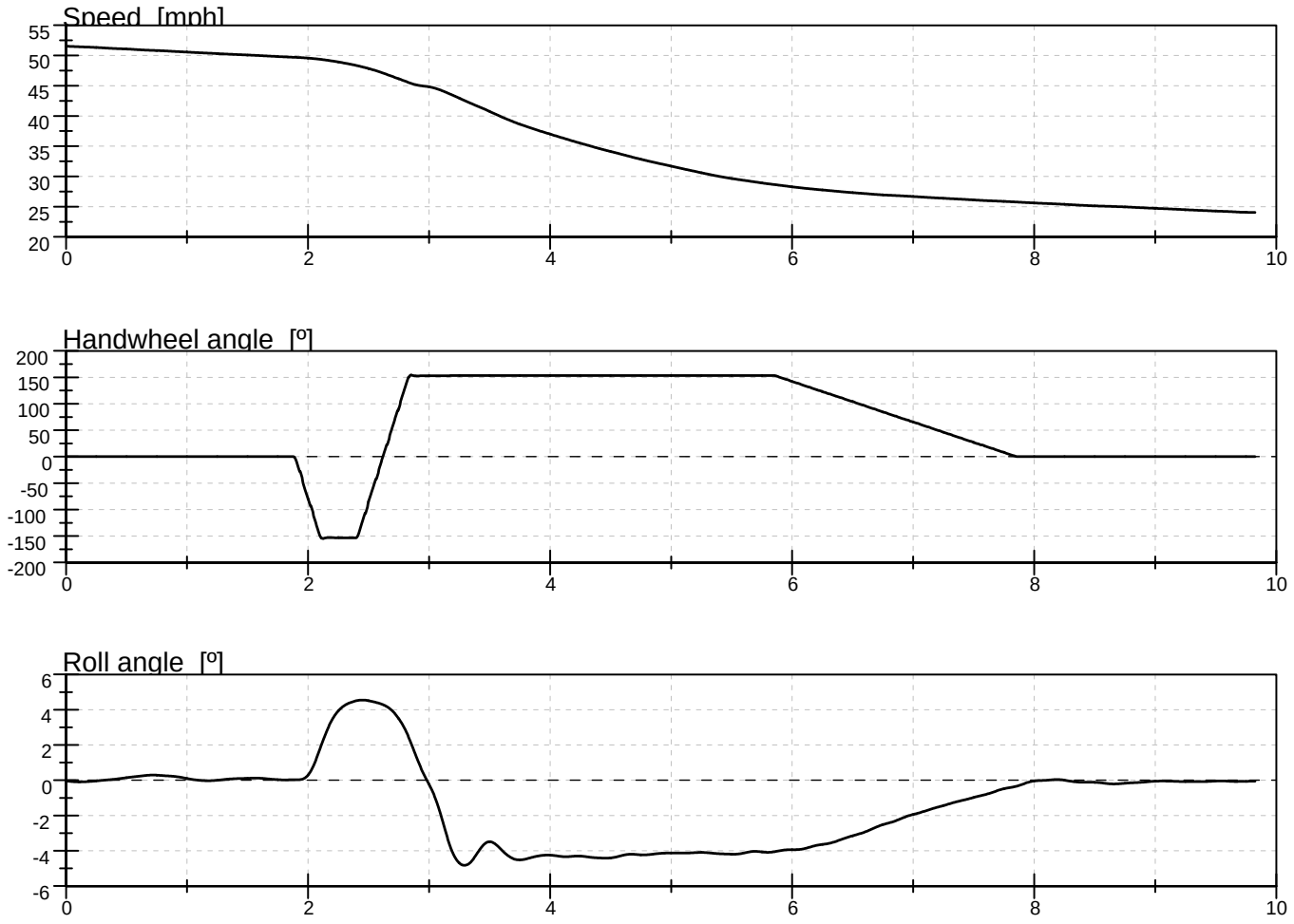

Figure D9. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

FILENAME: FH013

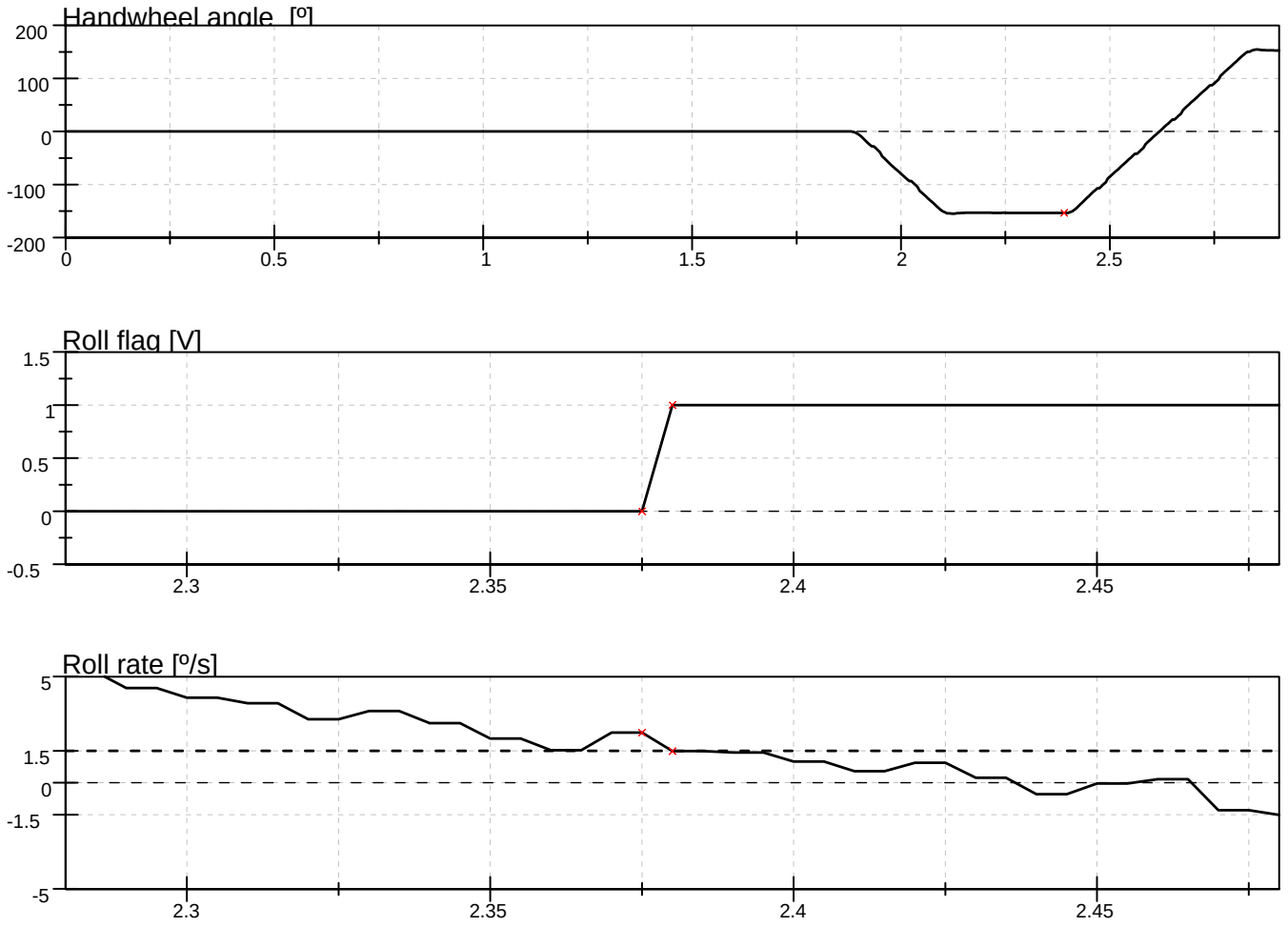

Figure D10. Steering Machine Operation Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

FILENAME: FH013

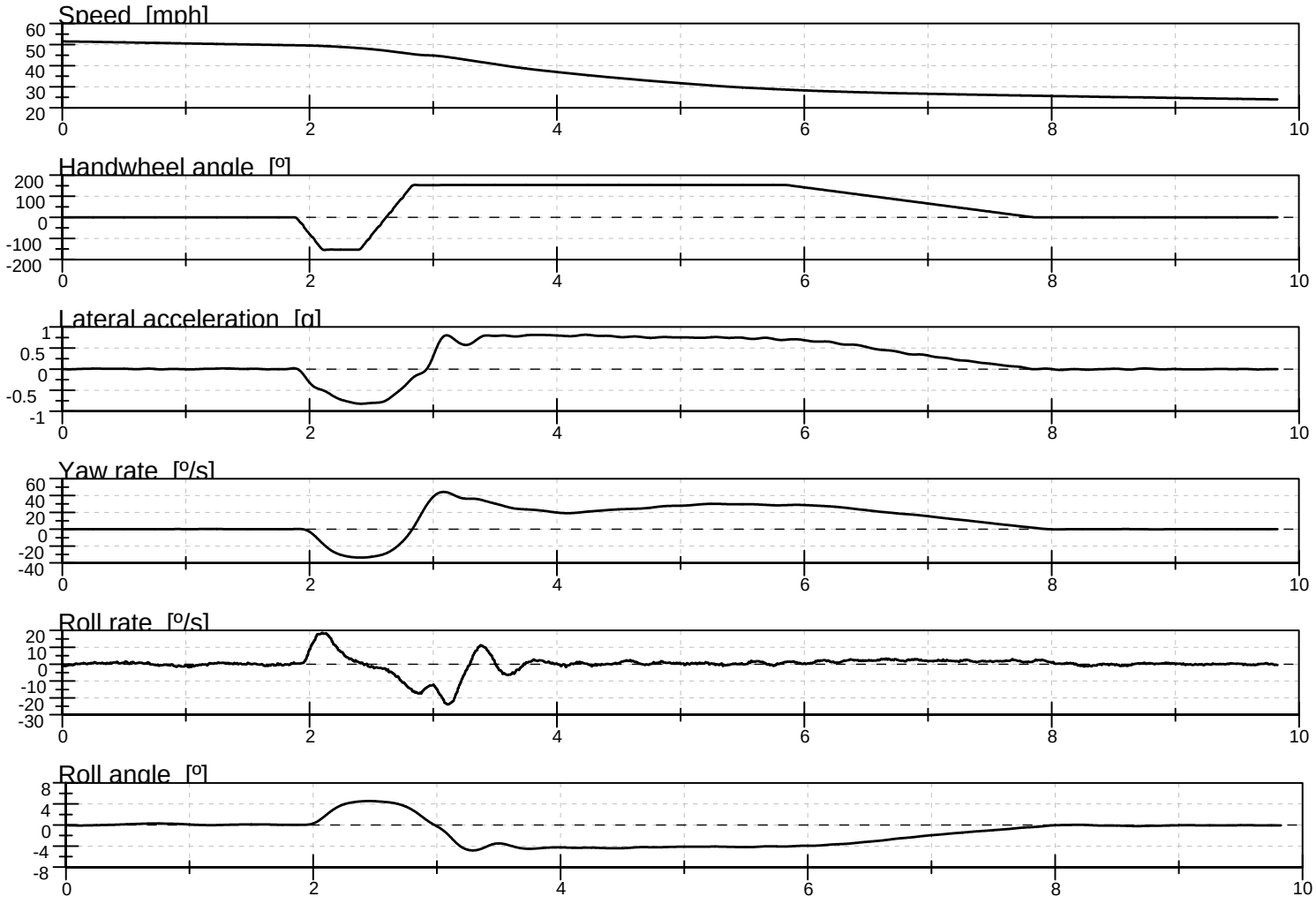

Figure D11. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

FILENAME: FH013

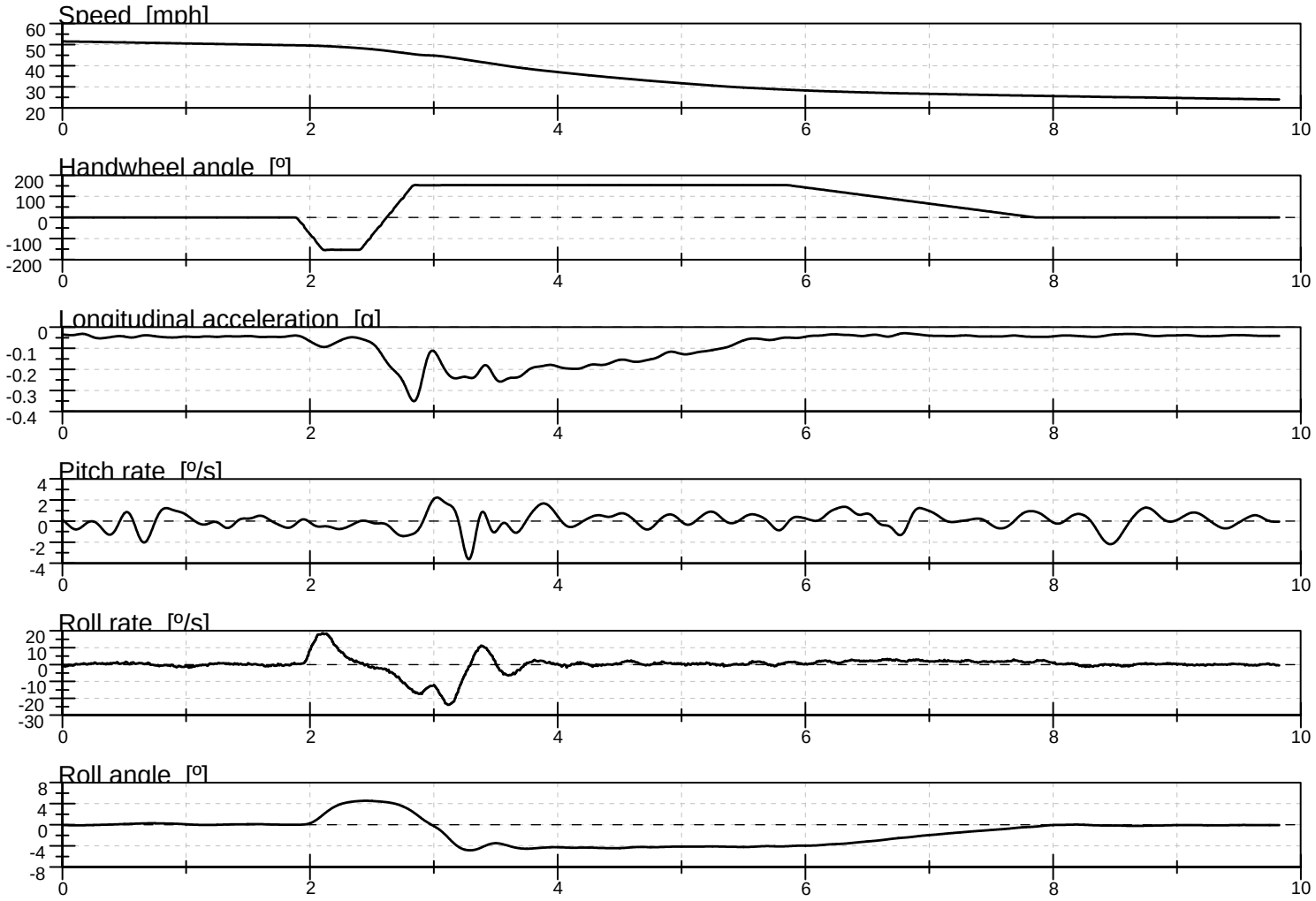

Figure D12. Pitch Rate and Longitudinal Acceleration Time History Plots for Supplemental 2 Test Series, L-R, 50 mph

FILENAME: FH016

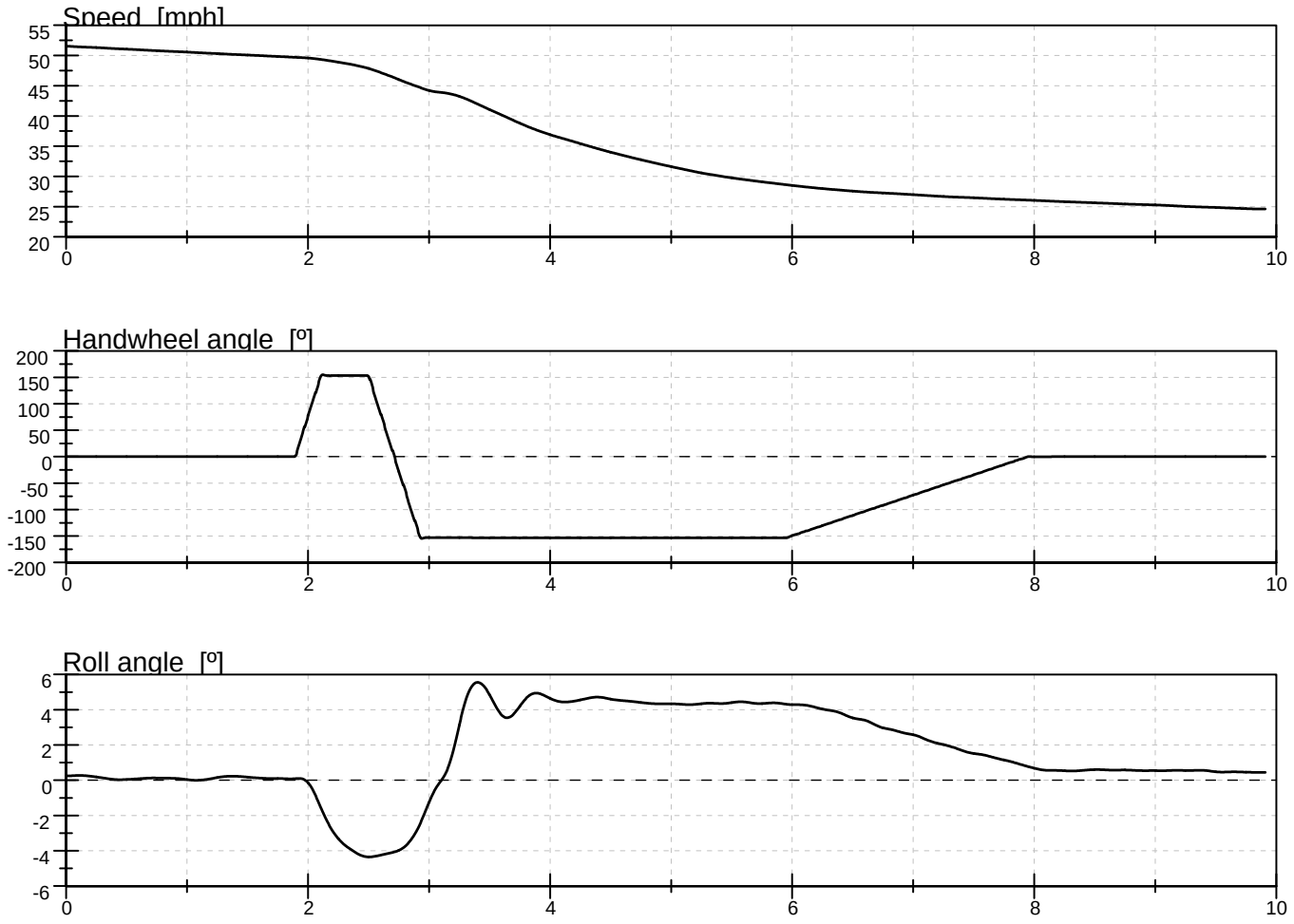

Figure D13. Vehicle Speed, Handwheel Angle, and Roll Angle Time History Plots for Supplemental 2 Test Series, R-L, 50 mph

FILENAME: FH016

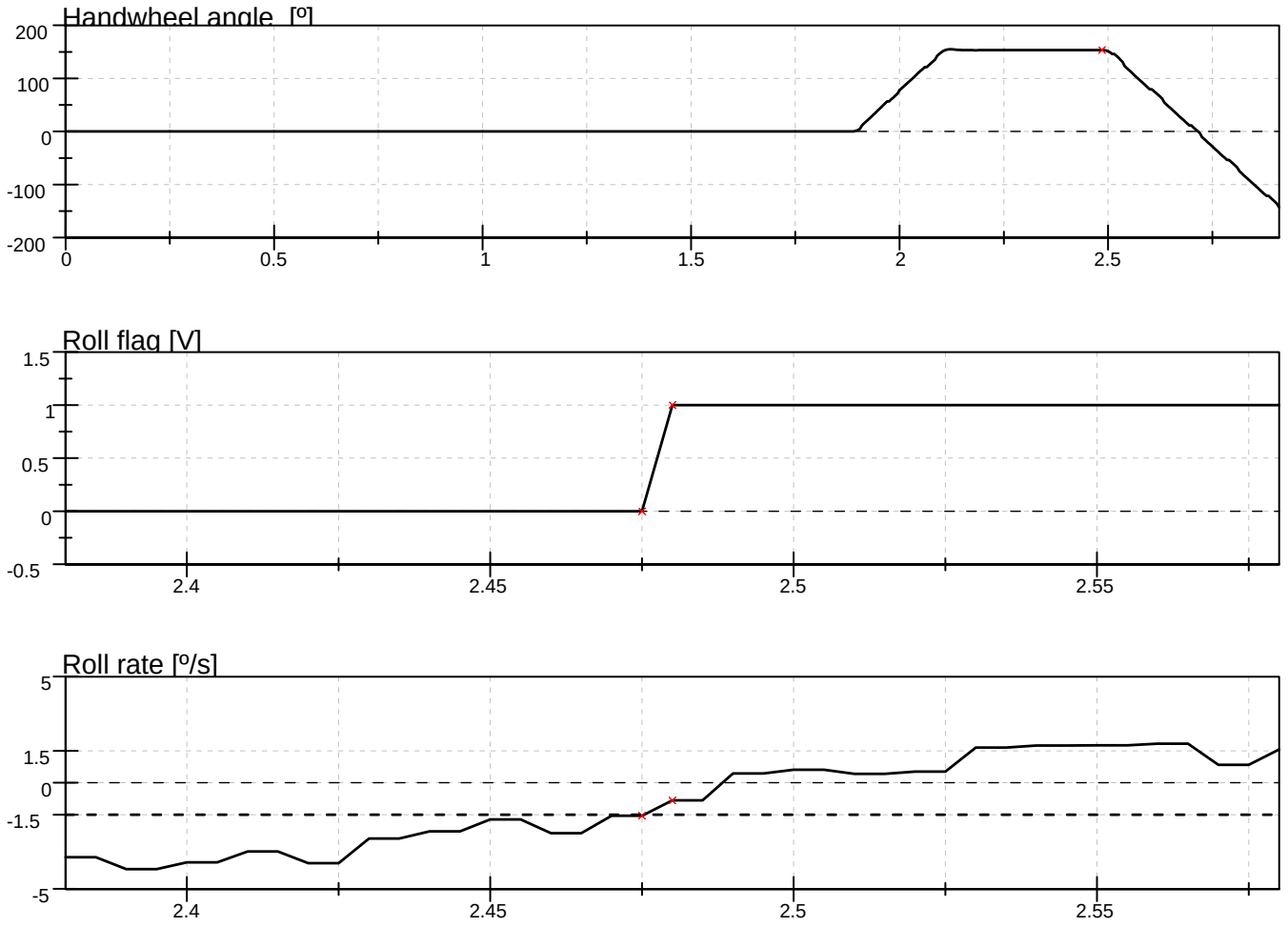

Figure D14. Steering Machine Operation Time History Plots for Supplemental 2 Test Series, R-L, 50 mph

FILENAME: FH016

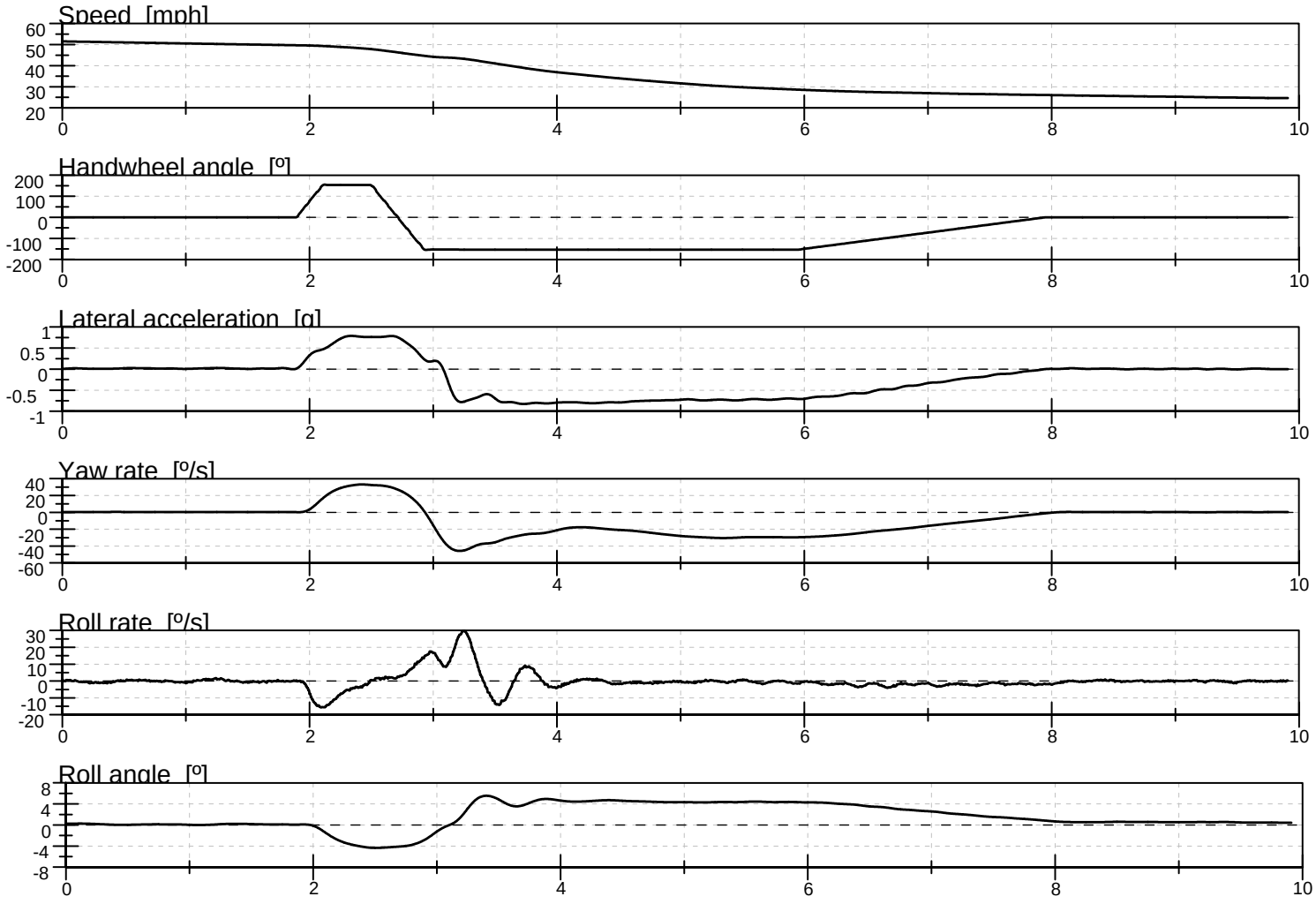

Figure D15. Yaw Rate, Roll Rate, and Lateral Acceleration Time History Plots for Supplemental 2 Test Series, R-L, 50 mph

FILENAME: FH016

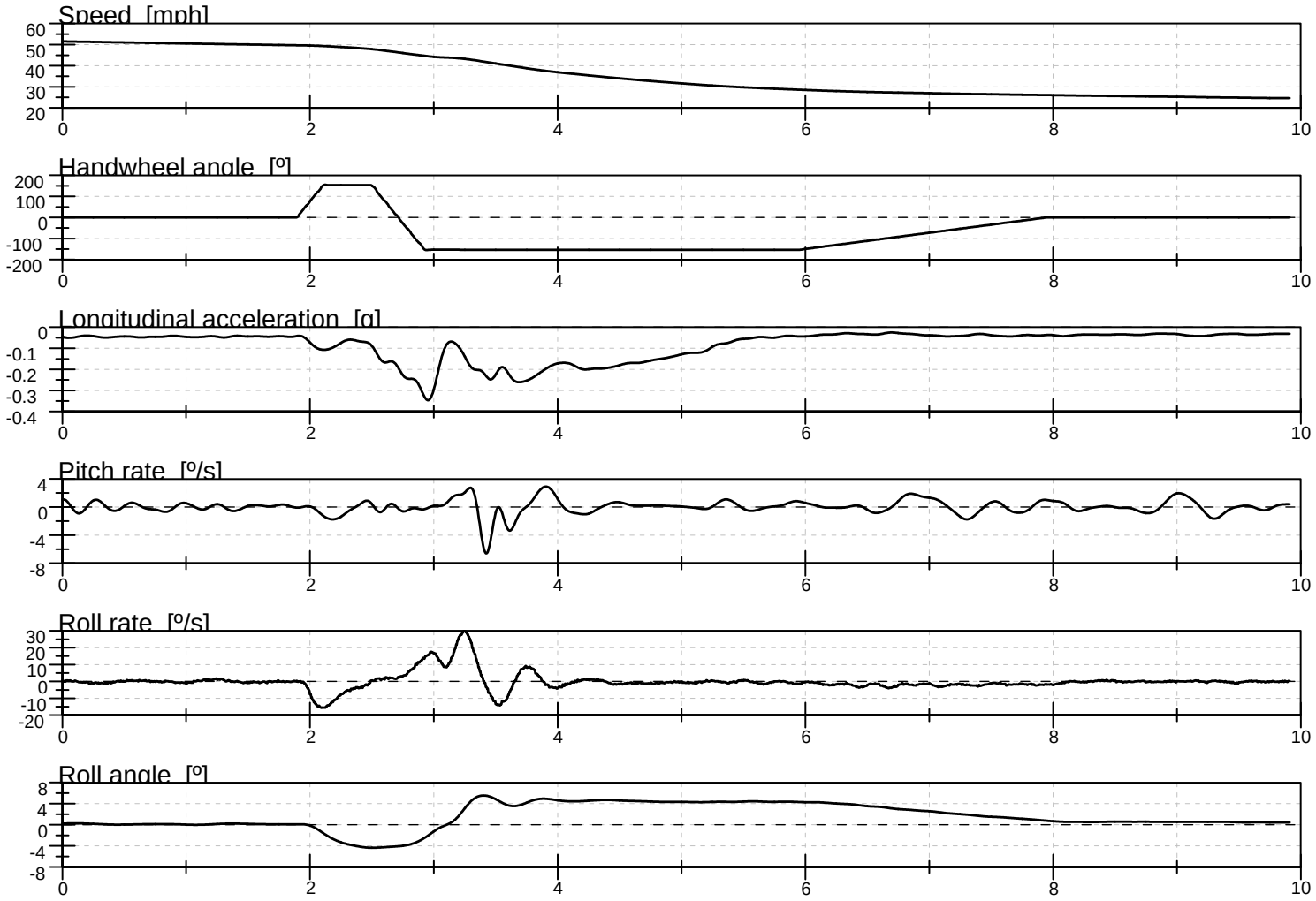

Figure D16. Pitch Rate and Longitudinal Acceleration Time History Plots for Supplemental 2 Test Series, R-L, 50 mph