Memorandum Report
RQ10-004
Electric Power Steering Study
2007 Saturn Ion

Background

The Vehicle Research and Test Center (VRTC) was asked to perform an analysis of a vehicle equipped with electric power steering (EPS). Selected vehicle parameters were measured and recorded, instrumented testing was performed that documented the force required to steer the vehicle at various speeds with and without steering assist, and limited human factors testing was performed that determined driver reaction to a loss of steering assist at low speeds.

Test Vehicle

The test vehicle was a 2007 Saturn Ion (VIN: 1G8AJ55F97Z161XXX) that was leased from an owner who had submitted a Vehicle Owner's Questionnaire (VOQ) regarding loss of power steering assist. Each time the vehicle was driven following an engine start, the EPS was functional for between approximately 100 and 300 yards. After that, the EPS warning light came on, a warning chime sounded, and the EPS became nonfunctional. Stopping and restarting the engine caused the cycle to repeat. If the engine was started, but the vehicle was not driven, the EPS remained functional without experiencing drop-out of the EPS. Figure 1 shows the test vehicle used for this program.

Figure 1
Subject Test Vehicle

Objective Testing

Instrumentation was installed that allowed the monitoring and recording of vehicle speed, hand wheel (steering wheel) force, hand wheel position, and lateral acceleration.

Instrumented testing consisted of sinusoidal steering inputs while driving at steady speeds between 5 mph and 40 mph in 5 mph increments. Hand wheel inputs were approximately 180 degrees left and right or approximately 0.7G lateral acceleration, whichever limit was reached first. Testing was first performed with the original inoperative EPS unit and was then repeated with a new, functional EPS unit.

Disassembly and Inspection of Power Steering Unit

After the original, non-functional EPS unit was tested, it was removed and disassembled for inspection and analysis.

Human Factors Testing

Human factors testing was performed to document the reaction of 15 test subjects when power steering assist was lost without warning while attempting to negotiate a turn. Participants were chosen from VRTC contractor personnel. A screening process eliminated anyone who claimed to have knowledge of the purpose of the test. Each participant was given a verbal explanation of what to expect[1] prior to the test and a short questionnaire[2] to fill out at the conclusion of the test.

The test course consisted of driving the vehicle on a short section of 2-lane roadway, then through a 90º left turn in a simulated intersection onto another simulated 2-lane road[3]. After allowing the test driver to become somewhat familiar with the vehicle, the electrical circuit to the power steering circuit was interrupted just as the test subject entered the simulated intersection for the left turn. Traffic pylons were erected on the outside of the simulated intersection to simulate pedestrians waiting to cross the street or a parked vehicle. The test subjects were instructed to avoid striking all pylons.

[1] A copy of the Explanation to the Driver is provided in Appendix I.
[2] A copy of the driver's questionnaire is provided in Appendix II.
[3] A dimensioned diagram of the simulated intersection is shown in Appendix III.

Test Results

Vehicle Parameters

Table 1 lists the vehicle parameters that were measured, calculated, or found in published data. The tire contact area was determined by spreading ink on the front tires, lowering the tires (mounted on the vehicle) onto a piece of paper, and measuring the area of the resultant contact patch.[4]

Table 1
Vehicle Parameter Data

Vehicle Data		
Make:	Saturn	
Model:	Ion 4-door	
Model Year:	2007	
Date of Manufacture:	10/06	
Mileage:	127,915	
Tire Manufacturer:	Yokohama	
Tire Model:	YK 520	
Tire Size:	195/60R15	
Recommended Tire Pressure: (psi)	30	
Fr. Wheel Arc lock-to-lock: (deg.)	70	
Str. Wheel lock-to-lock: (turns)	3.5	
Steering Ratio: (:1)	16.6	
Avg. Front Tire Contact Area: (in^2)	16.8	
Turning Radius: (ft.)	17.7	
Vehicle Weight as tested: (lb)	**LF**	**RF**
	957	892
Total Front Weight (lb)	1849	
	LR	**RR**
	619	616
Total Rear Weight (lb)	1235	
Total Weight (lb)	3084	
Published Curb Weight: (lb)	2752	

Objective Testing

Table 2 lists the ranges of measured hand wheel forces, with and without power steering assist, for the nine test conditions that were tested.

[4] Front tire contact patches are provided in Appendix IV.

Table 2
Results of Objective Testing

Test Description Nominal Speed (mph)	Measured Force Range Without Assist (lb)	Measured Force Range With Assist (lb)
Stationary (asphalt)	49	4.5
5 mph	21-22	4.5 – 4.8
10 mph	22-23	4.7 – 4.8
15 mph	25-26	4.9 – 5.1
20 mph	27	5.0 – 5.8
25 mph	27	4.9 – 5.7
30 mph	27	No Data
35 mph	25-27	5.1 – 5.6
40 mph	25-26	4.6 – 5.8

Figure 3 shows the lateral acceleration vs. steering wheel force for all testing and highlights the difference in required force between assisted and non-assisted steering effort. The blue line represents average unassisted steering effort while the red line represents average assisted steering effort.

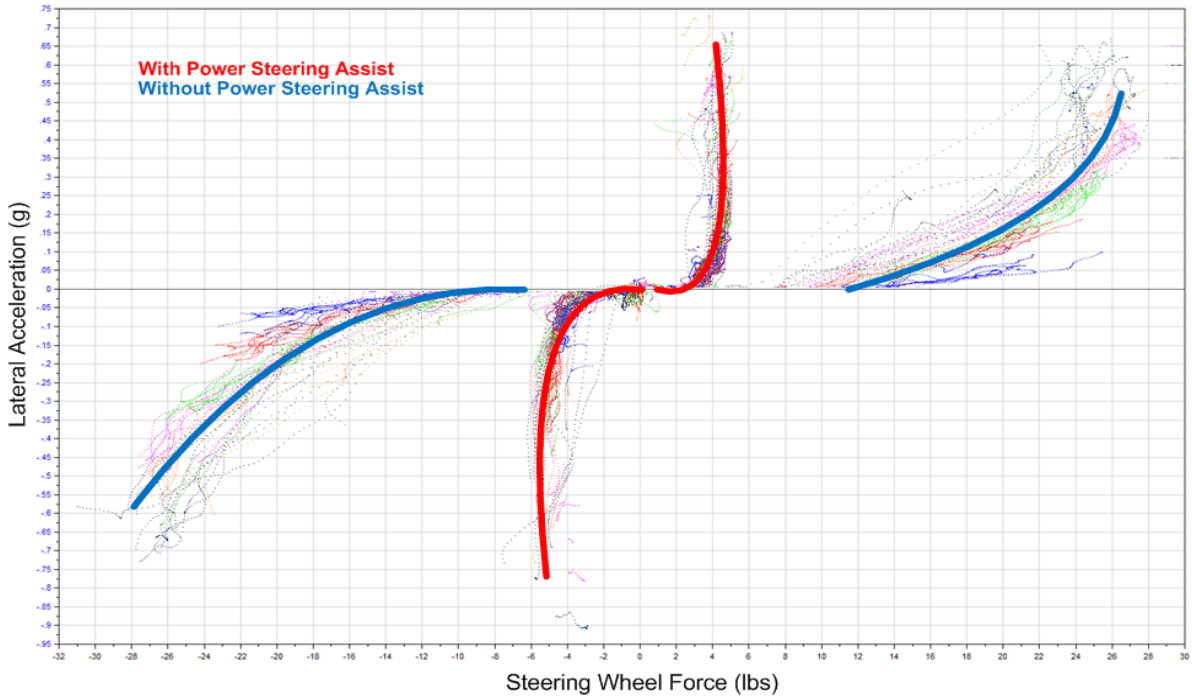


Figure 3
Lateral Acceleration vs. Steering Wheel Force - Assisted and Unassisted

EPS Failure Mode

When the original EPS motor was replaced with a new EPS motor, the drop-out problem disappeared. This suggested that the problem was in the motor and not the control system. Further investigation determined that when the electrical impedance between the motor circuit and the motor case was less than 3k ohms, the control unit interpreted the condition as a ground fault and shut the system down. It was also determined that this ground fault detection could only occur when the motor current was zero, i.e. when there is no torque on the hand wheel.

In other words, for the system to fault, the control unit needed to perceive a ground fault in the EPS motor and the hand wheel input torque needed to be zero, as when driving straight or when passing through zero when changing from right to left turn or left to right turn input.

Human Factors Testing

A summary of the human factors testing is presented in Table 3. Data plots from individual tests are presented in Appendix V.

Each participant stated their height and weight but the numbers were not verified. The subjects ranged in reported height between 4’11½” and 6’2” and in reported weight between 175 lb and 290 lb. The maximum hand wheel force that was exerted by the test subjects during the simulated left turn ranged between 31 and 52 lb. All but one test subject was able to negotiate the left turn without contacting the delineating pylons. While one driver stopped completely and did not proceed, most slowed the vehicle so that it was almost stopped, and then proceeded slowly through the turn. Comments that the test participants provided are included in Table 3.

Table 3
Summary of Human Factors Driver's Questionnaires

Driver #	Gender	Hgt.	Wgt	Feel Safe with P/S	Feel Safe w/o P/S	Reaction to P/S loss	Written Comments	Braking	Handling	Compare to Others	POV	Verbal Comments	Max Force Exerted (lb)
1	M	5'11"	220	Yes	No	Felt out of control	A little shocked at loss of steering	Normal	Normal	Same	2006 Ford Fusion	Very Interesting	31.6
2	F	4'11"	195	Yes	No	Took some effort to turn; unexpected	I said "Oh my, the steering is out."	Normal	Normal	Same	Chrysler Sebring	N/A	33.2
3	M	5'11"	240	Yes	No	Put more force into turning	Difficult to turn the wheel	Normal	Normal	Same	Ford Freestyle	N/A	34.4
4	M	5'8"	206	Yes	No	Applied brakes and attempted to turn harder	Etremely difficult to turn	Normal	Normal	Same	Chev. Silverado	N/A	36.9
5	M	5'10"	190	Yes	Yes	Was used to it from POV	Was prepared from dash warning	Normal	Normal	Same	Chrysler Sebring Hyundai Tiburon	N/A	31.2
6	M	5'9"	195	Yes	Yes	Slowed	None	Normal	Normal	Same	Pontiac Grand Am	N/A	32.6
7	M	5'10"	290	Yes	No	Surprise but able to control	Failure was sudden & reqd. fair amt of steering input to maintain control	Normal	below	No Basis for comparison	Dodge Grand Caravan	N/A	35.4
8	M	5'10"	175	Yes	No	Added required force	None	Normal	Normal	Same	Dodge Intrepid Chrysler 300M	N/A	33.9
9	M	5'9"	225	Yes	Yes	Turned harder	None	Normal	No Opinion	Same	Kia Optima	Steering was worse when P.S deactivated	34.1
10	M	5'10"	255	Yes	No	Stopped immediately	Etremely difficult to turn	Normal	Normal	No Basis for comparison	Ford Taurus	N/A	52.5
11	M	5'6"	230	Yes	No	Very difficult to control	Very difficult to control	Normal	Normal	Same	Toyota Corolla	N/A	34.9
12	M	6'0"	210	Yes	Yes	Dialed in more effort	Only marginally safe	Normal	Normal	Same	Nissan Altima	N/A	32.5
13	M	5'10"	195	Yes	No	Took considerable force to make turn	Slowed quickly and used mirrors to avoid cones	Normal	Normal	Same	Acura TL	N/A	33.6
14	M	5'10"	175	Yes	No	Braked and used more steering effort	None	Normal	below	Same	Ford Ranger	N/A	37.4
15	M	6'2"	175	Yes	No	Slowed and used two hands instead of one	Smaller drivers may not be able to steer	Normal	Normal	Same	Acura Integra	N/A	35.6

Appendix I
Explanation to Driver

Explanation to driver:

The test vehicle has been instrumented to monitor various driver control functions. Although most of the instrumentation is hidden, the most obvious is steering wheel input. We ask is that you follow instructions and operate the vehicle normally. Our intent is to measure driver reactions and vehicle control forces in various slow-speed driving conditions. Traffic pylons have been erected in several locations throughout the test course. The goal is to avoid striking any of the pylons. The test should take about 15 minutes. Feel free to make any comments about the drivability of the vehicle during the test. You will be asked to complete a brief questionnaire at the conclusion of the test.

Appendix II
Driver's Questionnaire

Questionnaire

1) Did you feel that the vehicle was safe to drive when the power steering was active?

Yes _____ No _____

If no, please explain. _____

2) Did you feel that the vehicle was safe to drive when the power steering failed?

Yes _____ No _____

If no, please explain. _____

3) How did you react to the failure of the power steering?

_____

_____

4) How would you classify the braking ability of the car?

Below normal____ Normal_____ Better than normal_____ No opinion_____

5) How would you classify the handling of the car?

Below normal____ Normal _____ Better than normal_____ No opinion_____

6) Have you owned, leased, or otherwise driven a Saturn Ion for an extended period before?

No _____ Yes _____ if yes, how does this Ion compare?

_____

7) How would you compare the steering system of the car compared to other cars this size that you have driven?

Better than others_____ Worse than others_____

Same as others_____ No basis for comparison_____

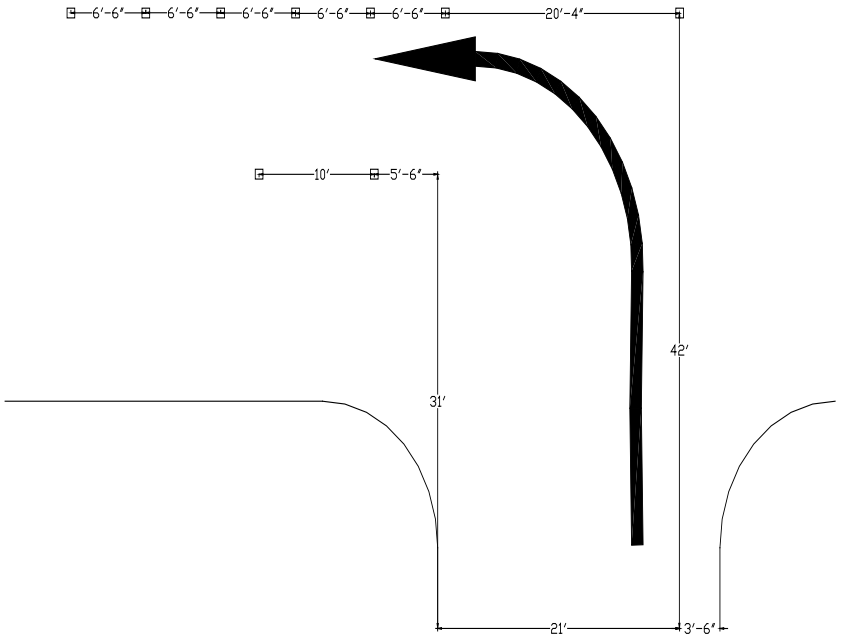
8) Please list the make, model, and year of your personal vehicle that you drive the most?

_____

Additional comments: _____

Thank you for completing this survey. Please return the completed form to the person who conducted your test or to Bob Esser.

Appendix III
Diagram of Simulated Intersection Used for Human Factors Testing


6′-6″
6′-6″
6′-6″
6′-6″
6′-6″
20′-4″
10′
5′-6″
42′
31′
21′
3′-6″

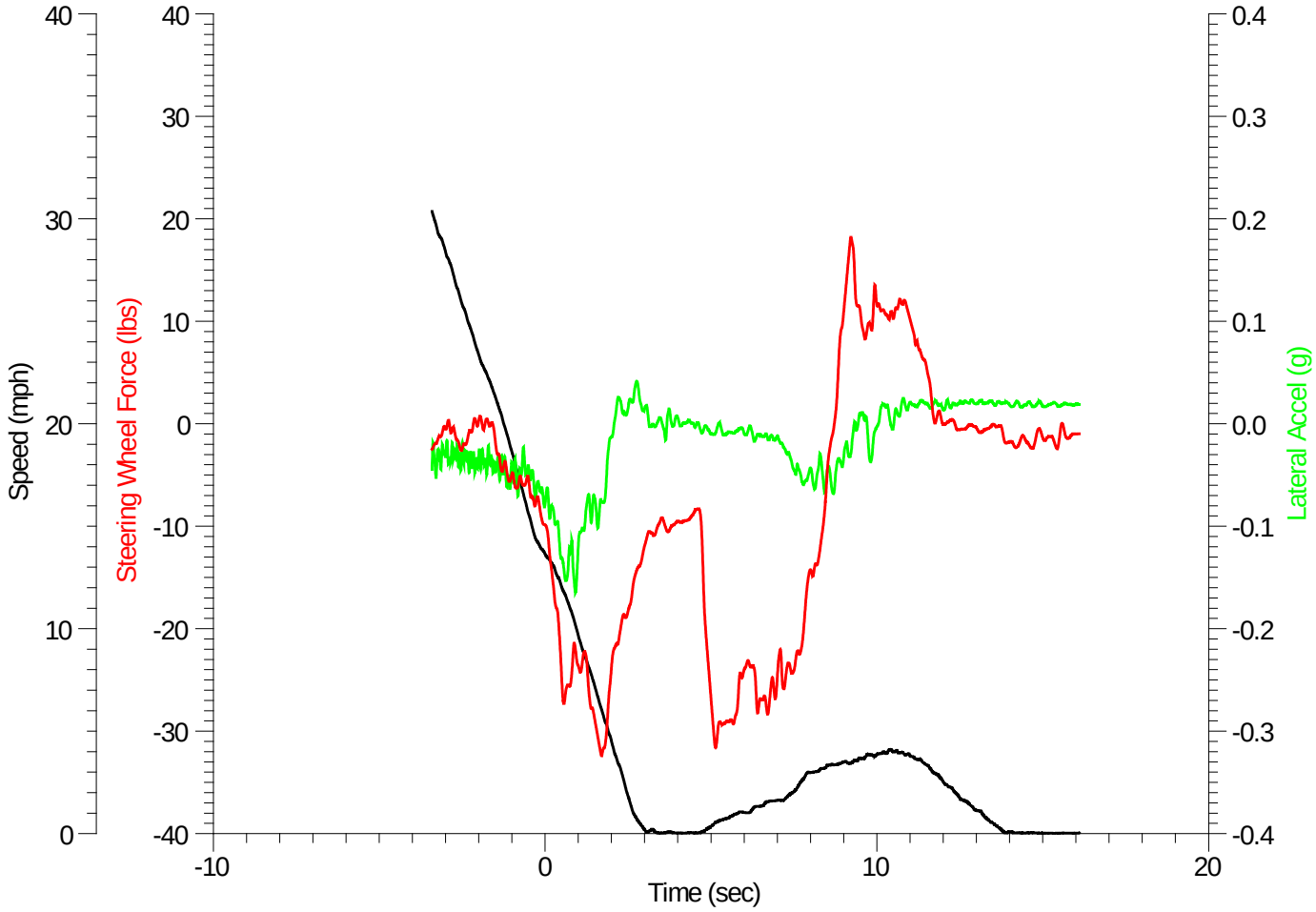
Appendix IV
Front Tire Contact Patches

Left Front Tire Contact Patch

Right Front Tire Contact Patch

Appendix V
Data Plots from Human Factors Testing

Driver No. 1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Steering Wheel Force (lbs)
Lateral Accel (g)
Time (sec)
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-10
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-40
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0.3
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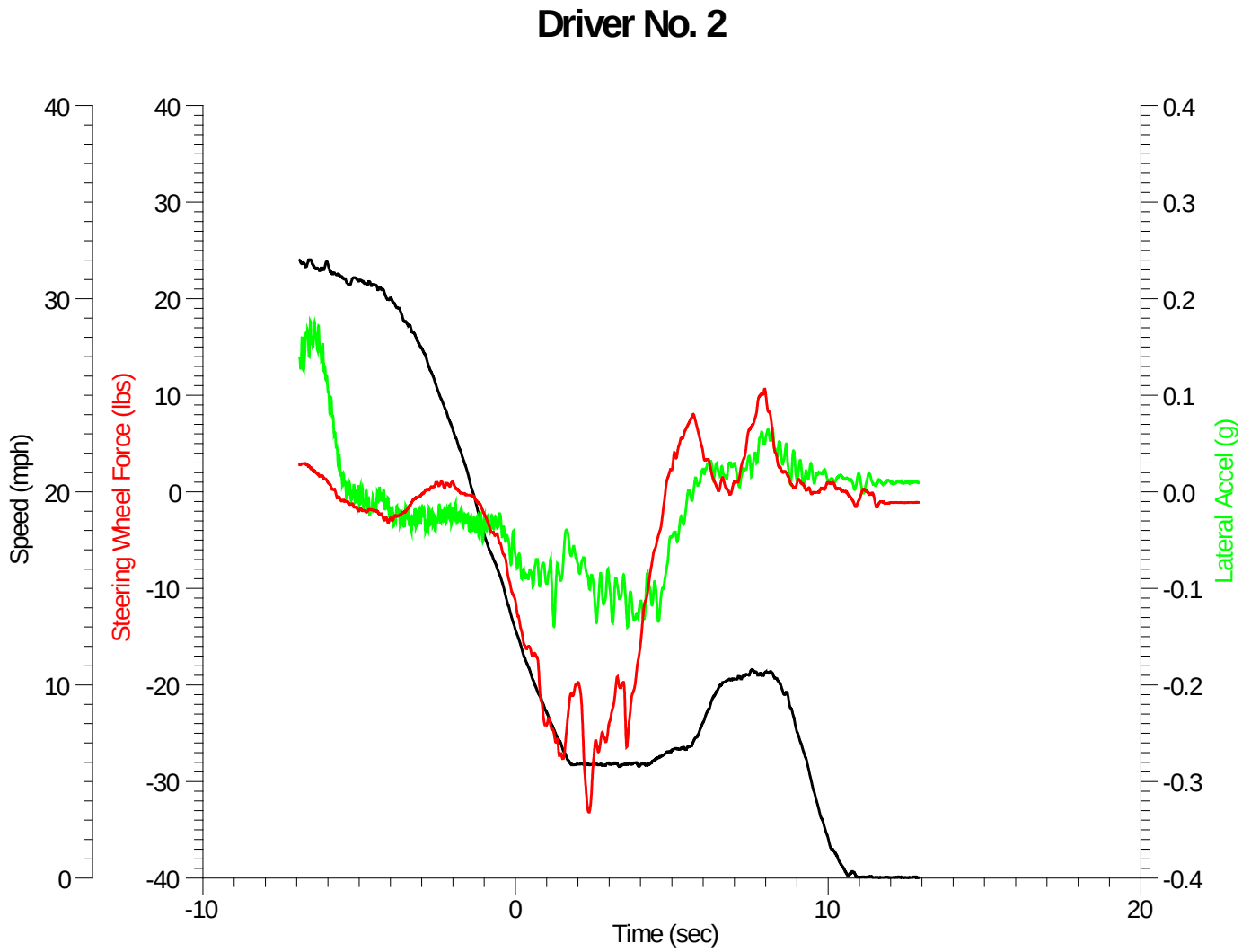
-0.3
-0.4
-10
0
10
20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Steering Wheel Force (lbs)
Lateral Accel (g)
Time (sec)
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10
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-10
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-30
-40
0.4
0.3
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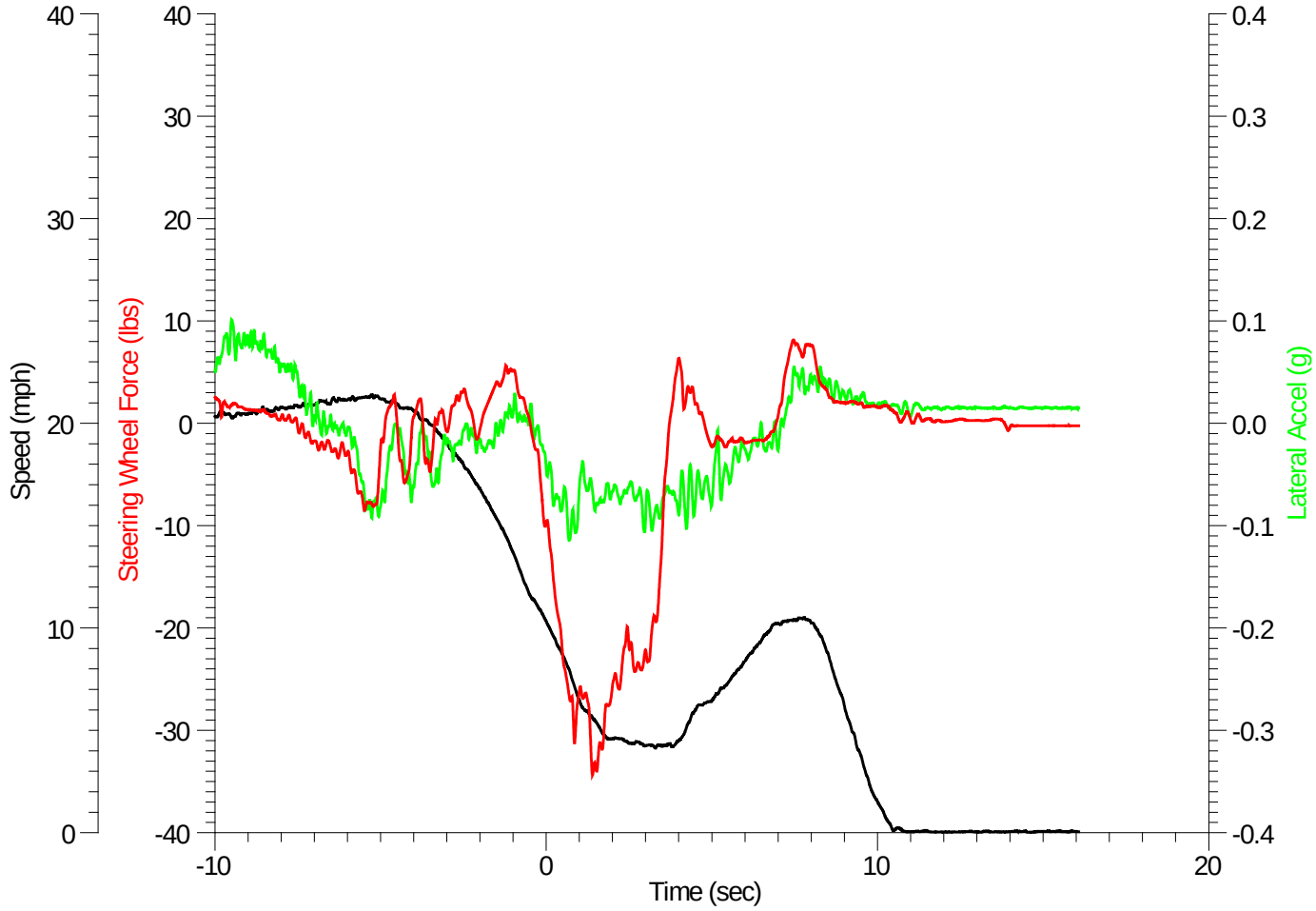
-0.2
-0.3
-0.4
-10
0
10
20

Driver No. 3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Steering Wheel Force (lbs)
Lateral Accel (g)
Time (sec)
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-20
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-40
0.4
0.3
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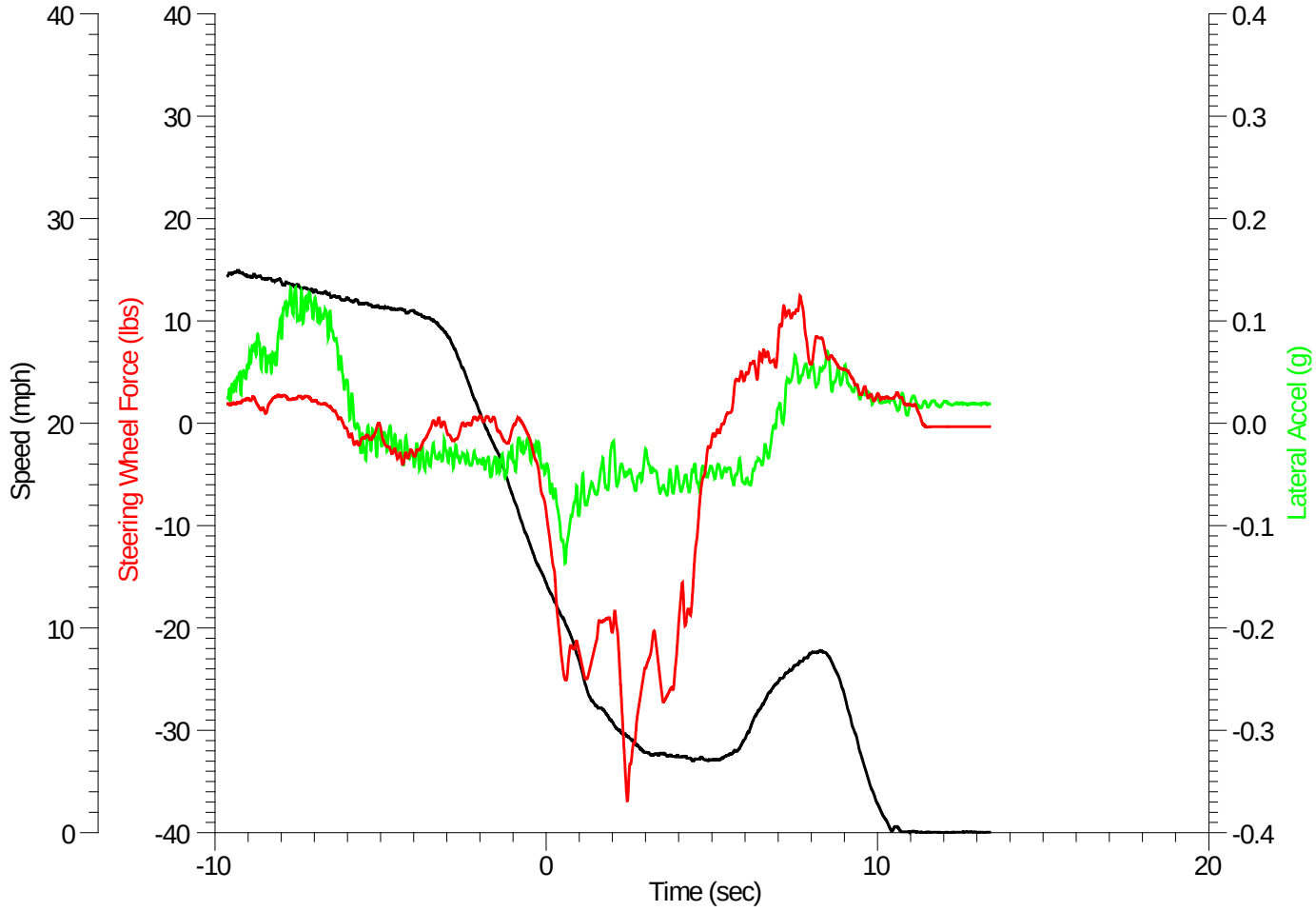
-0.2
-0.3
-0.4
-10
0
10
20

Driver No. 4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Steering Wheel Force (lbs)
Lateral Accel (g)
Time (sec)
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10
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-10
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-40
0.4
0.3
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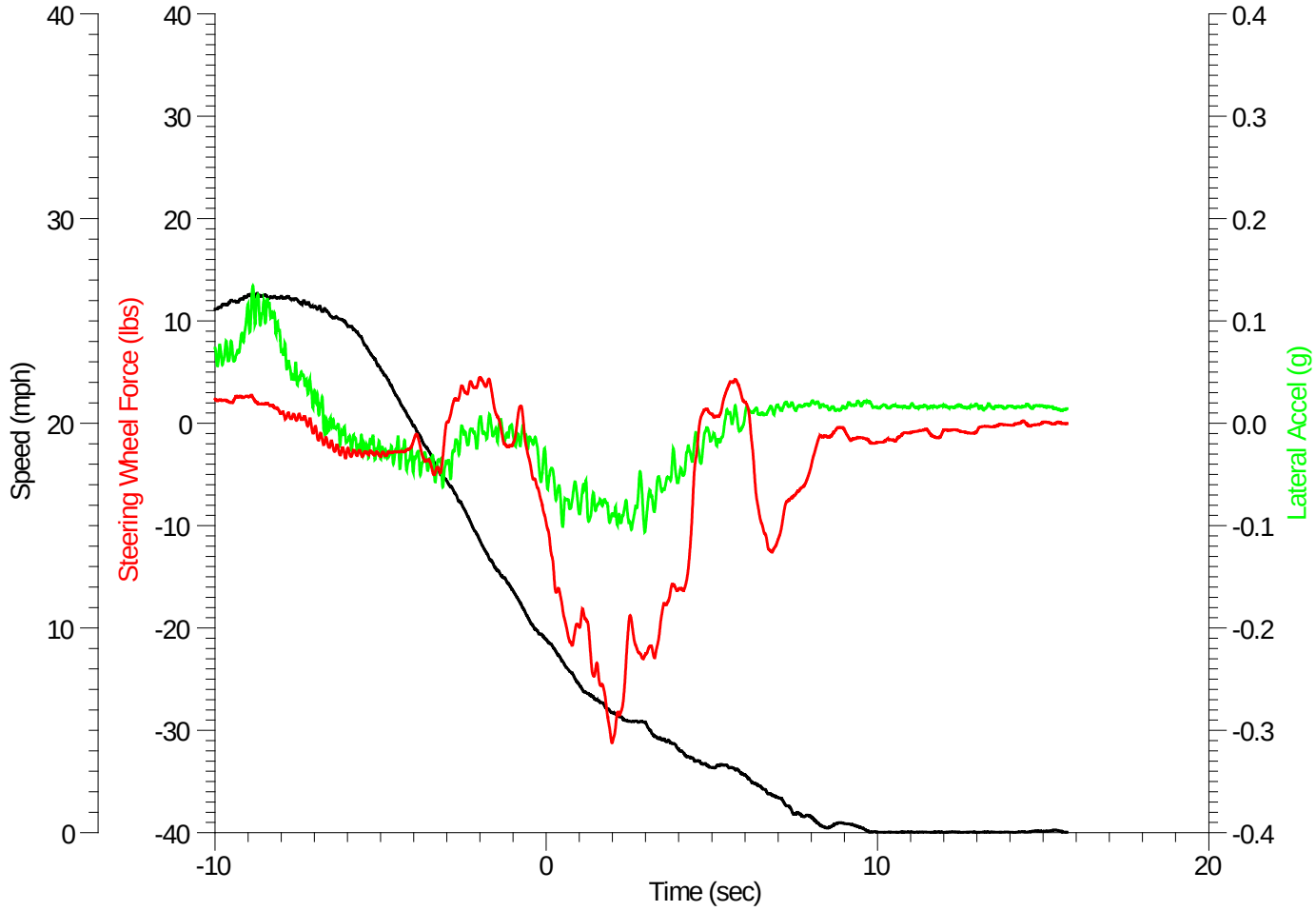
-0.2
-0.3
-0.4
-10
0
10
20

Driver No. 5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Steering Wheel Force (lbs)
Lateral Accel (g)
Time (sec)
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-40
0.4
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-0.4
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0
10
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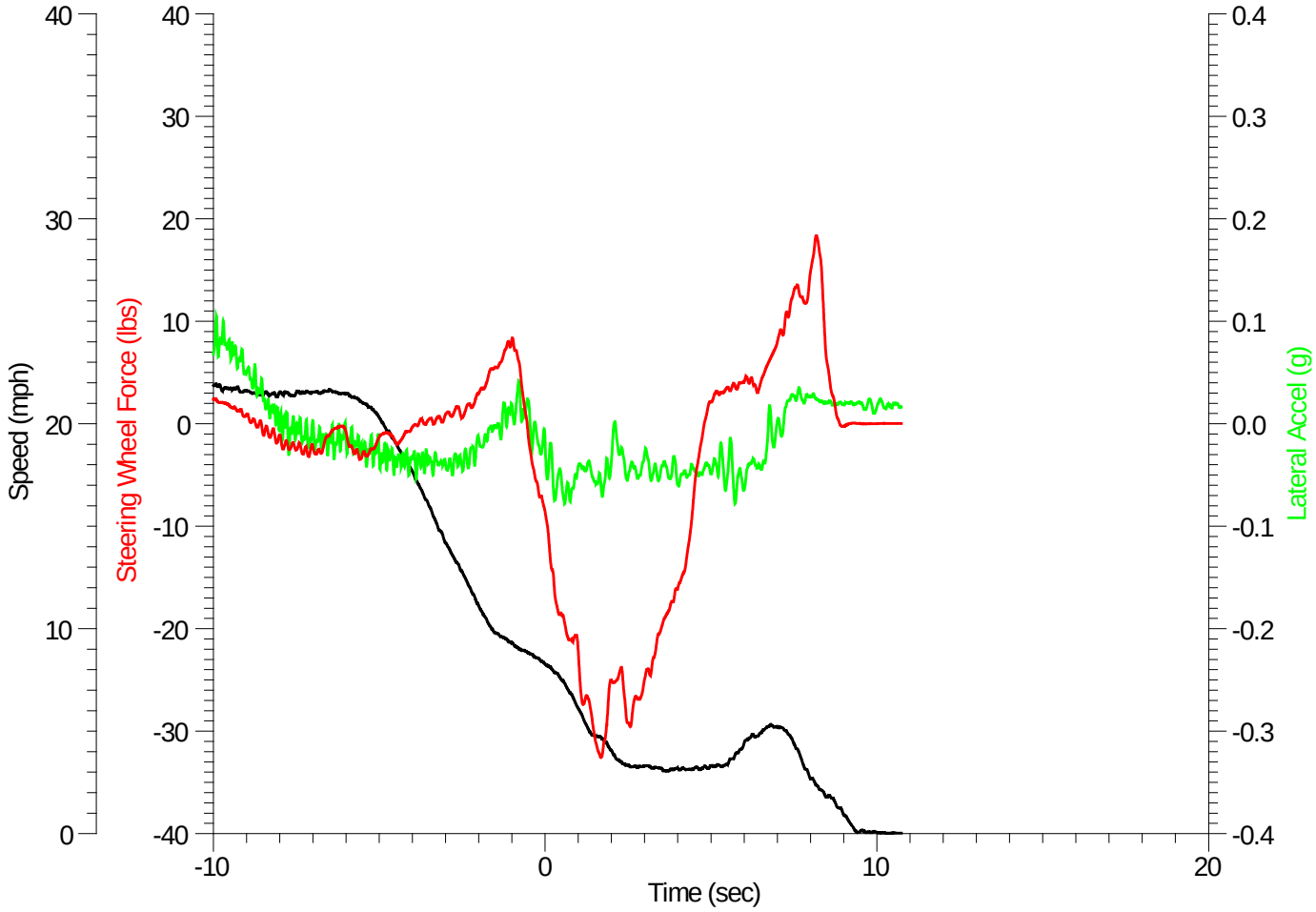
Driver No. 6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Steering Wheel Force (lbs)
Lateral Accel (g)
Time (sec)
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20
10
0
-10
-20
-30
-40
0.4
0.3
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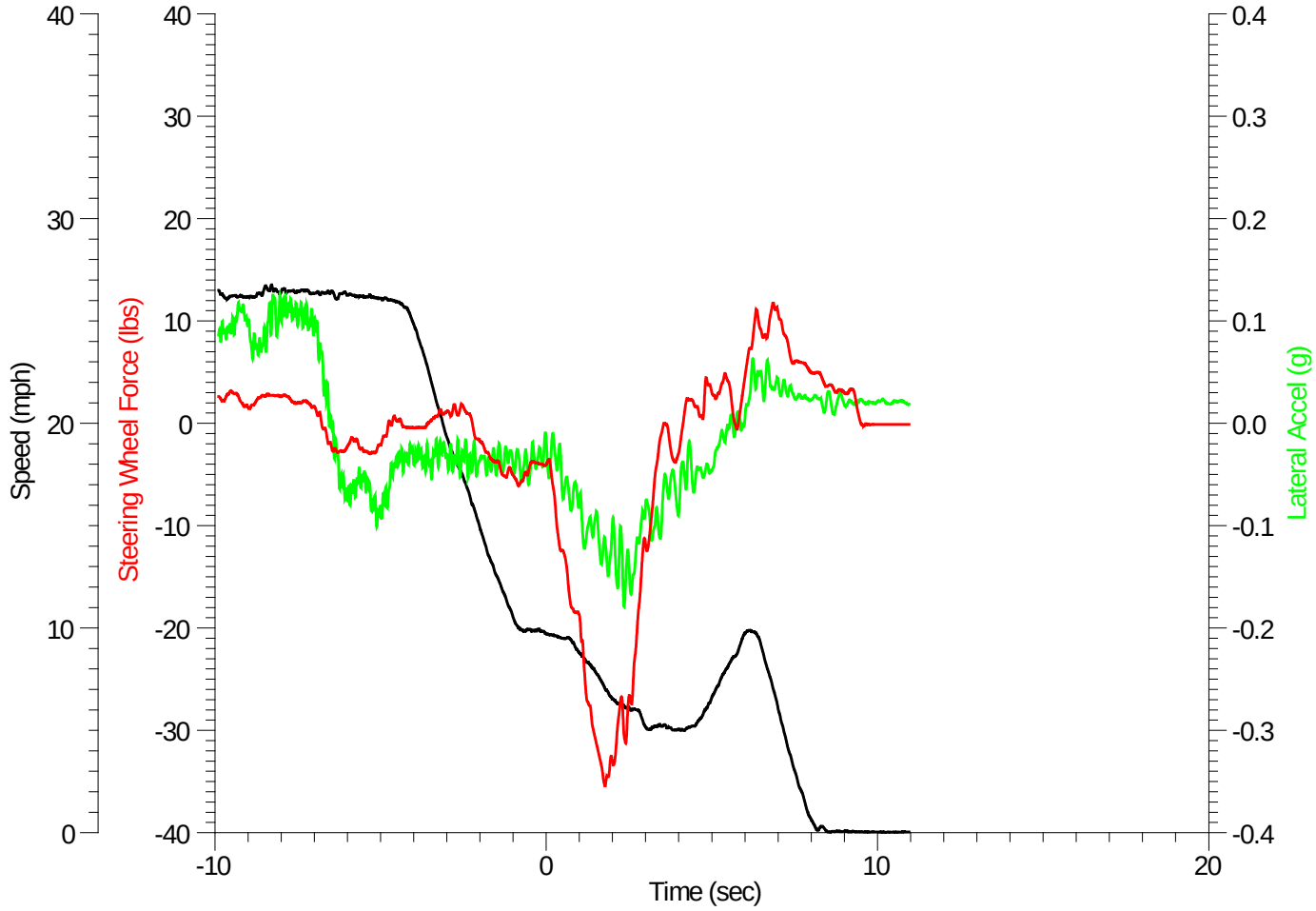
-0.2
-0.3
-0.4
-10
0
10
20

Driver No. 7


Speed (mph)
Steering Wheel Force (lbs)
Lateral Accel (g)
Time (sec)
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-10
-20
-30
-40
0.4
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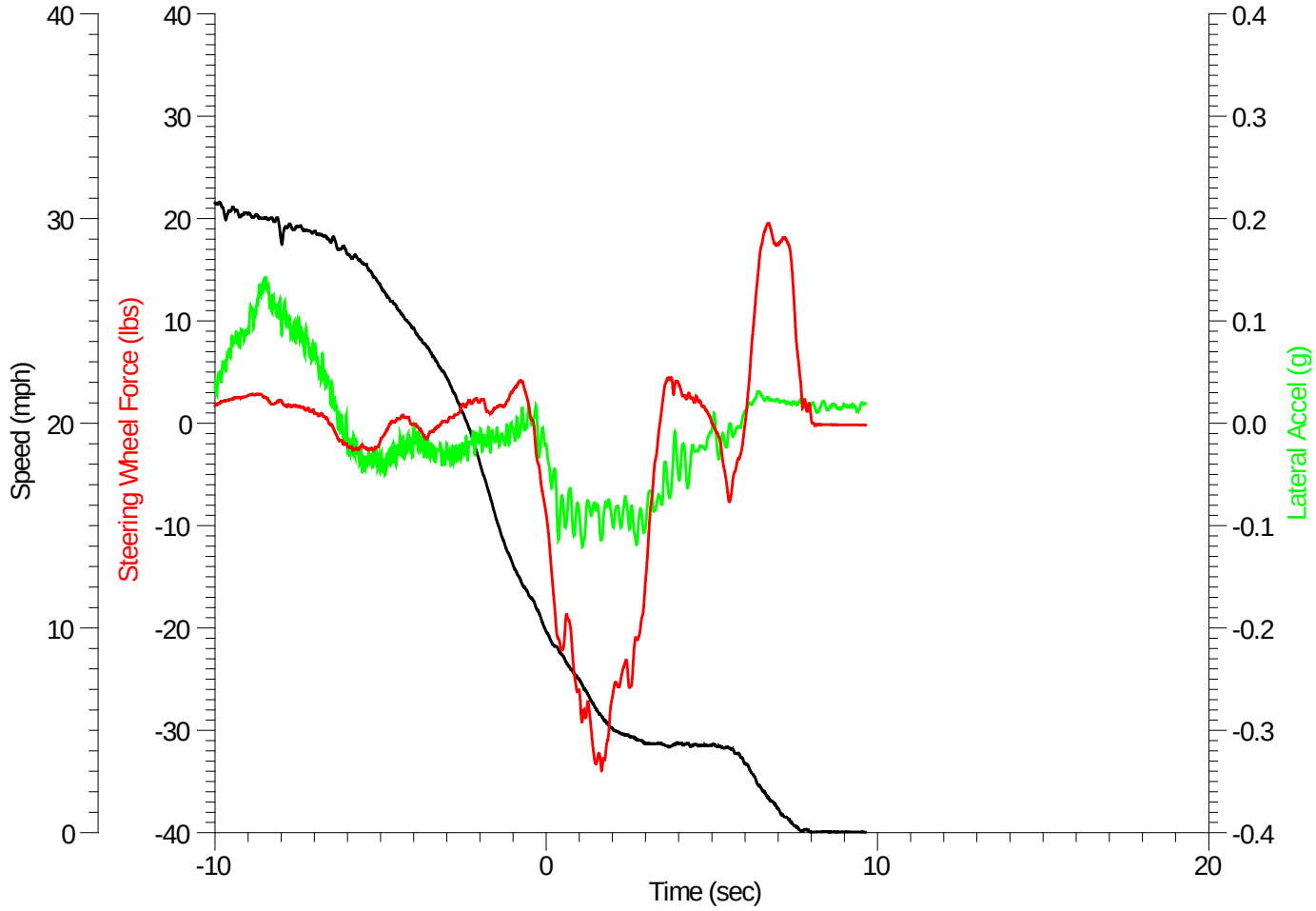
-0.2
-0.3
-0.4
-10
0
10
20

Driver No. 8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Steering Wheel Force (lbs)
Lateral Accel (g)
Time (sec)
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-10
-20
-30
-40
0.4
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-0.2
-0.3
-0.4
-10
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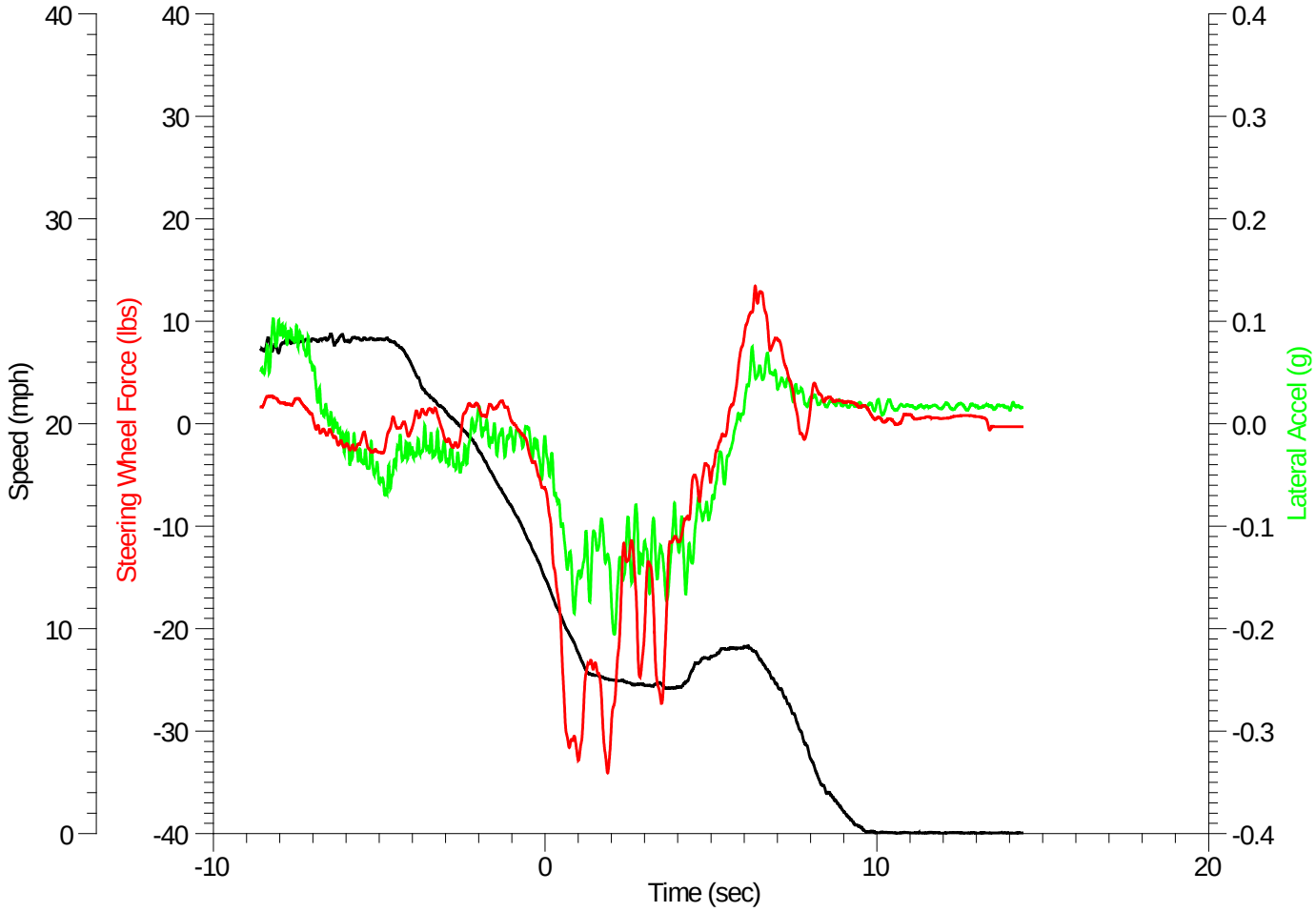
Driver No. 9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Steering Wheel Force (lbs)
Lateral Accel (g)
Time (sec)
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-10
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-40
0.4
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-0.2
-0.3
-0.4
-10
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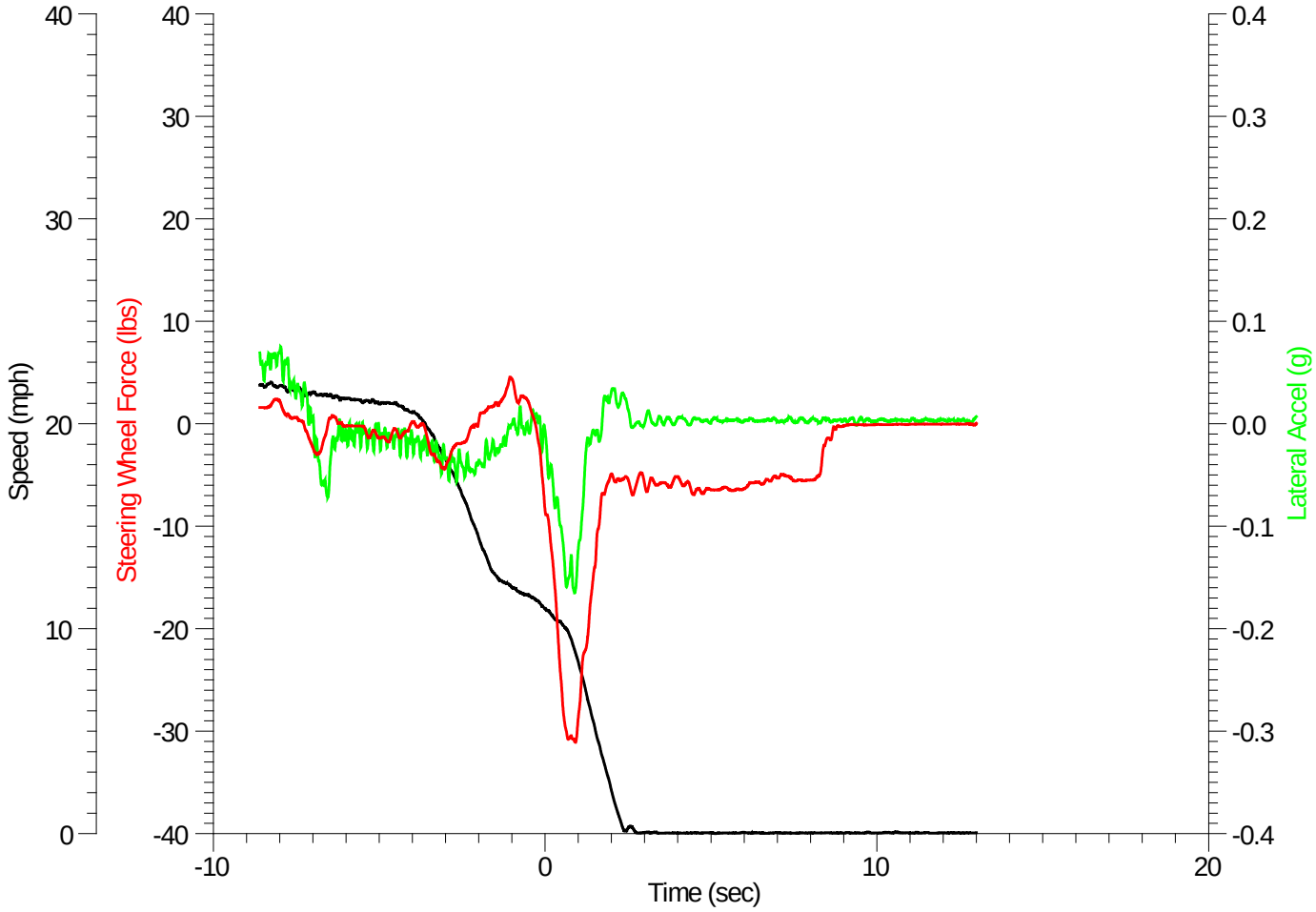
Driver No. 10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Steering Wheel Force (lbs)
Lateral Accel (g)
Time (sec)
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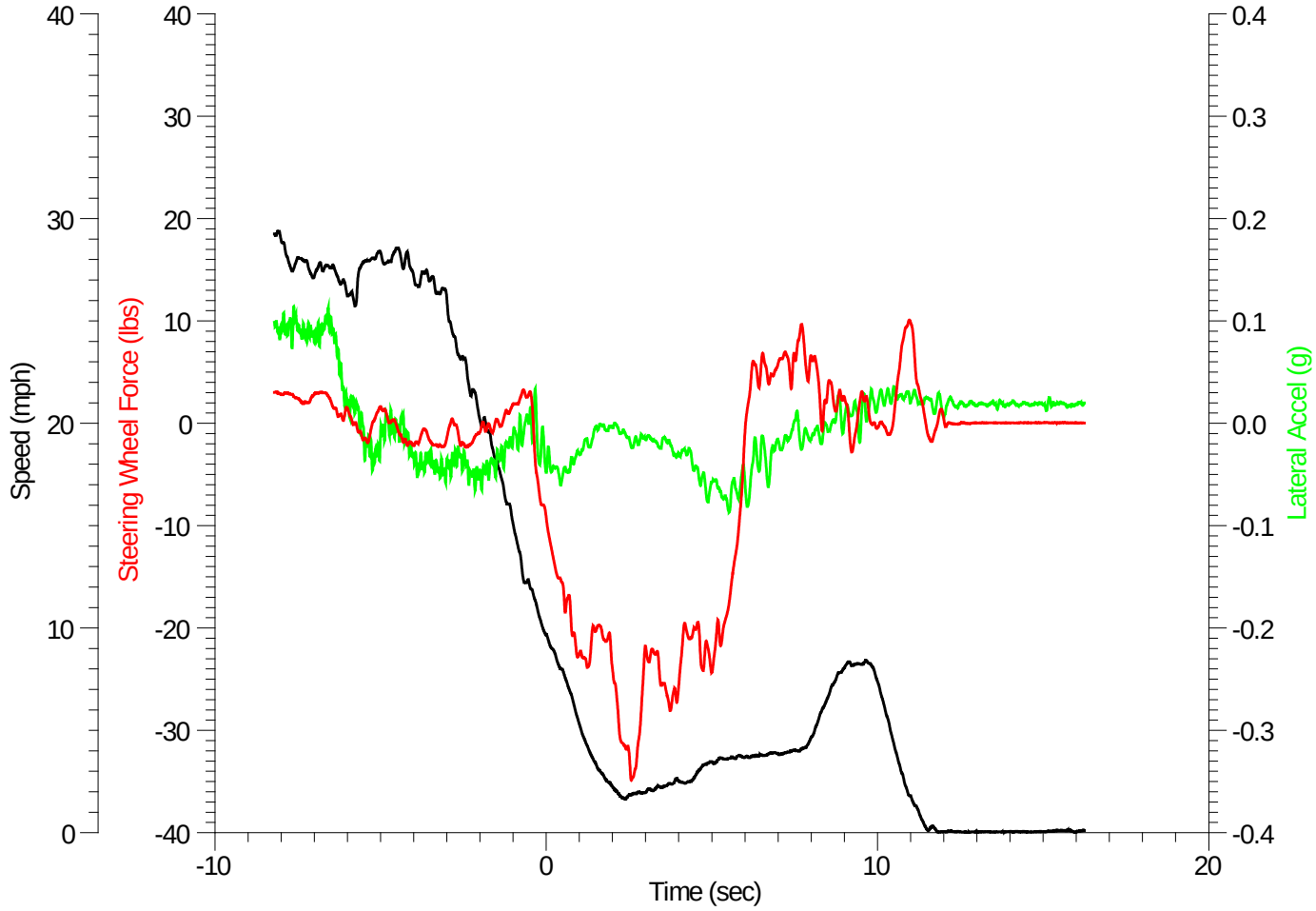
Driver No. 11


Speed (mph)
Steering Wheel Force (lbs)
Lateral Accel (g)
Time (sec)
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-10
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0.4
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-10
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10
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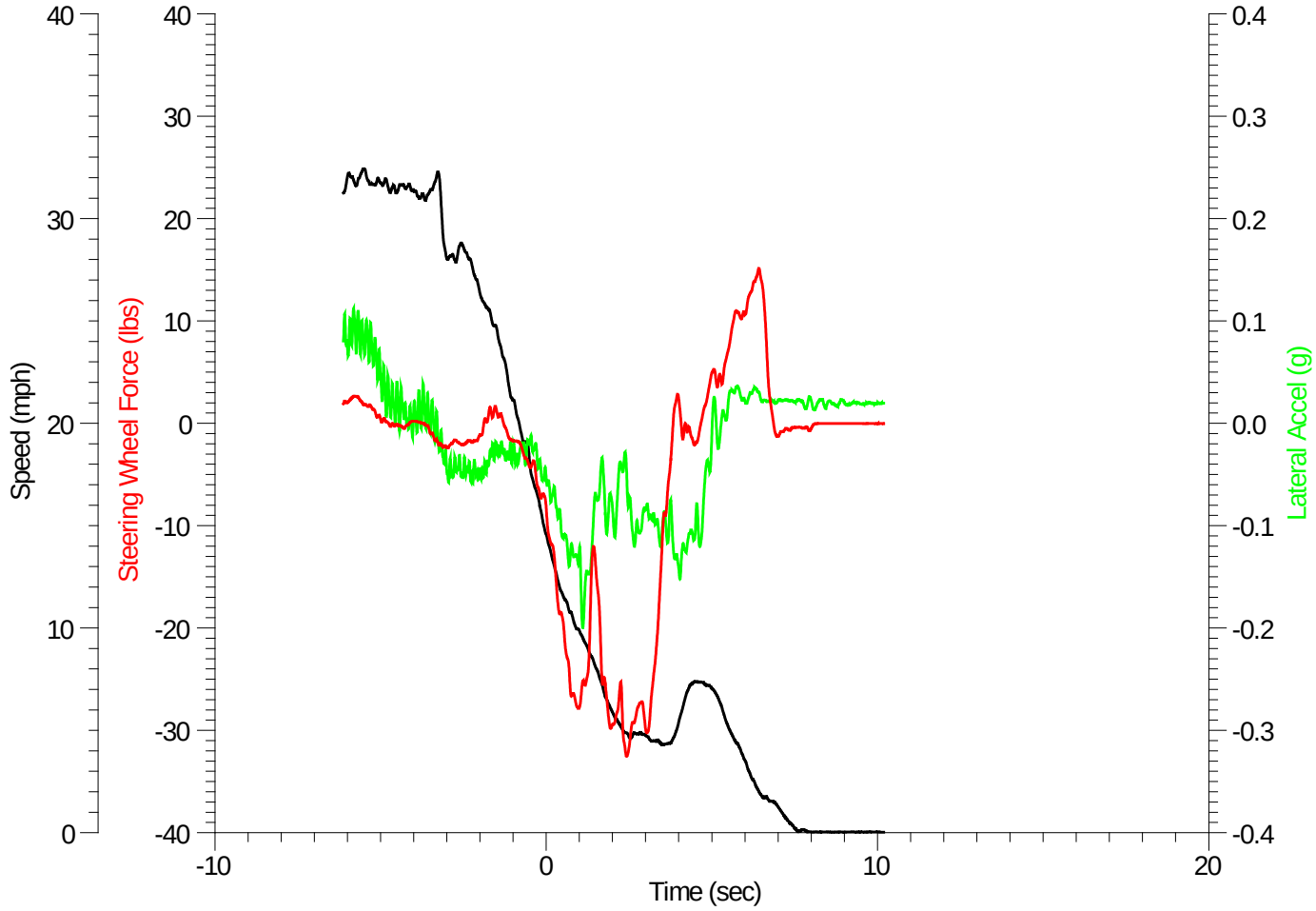
Driver No. 12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Lateral Accel (g)
Time (sec)
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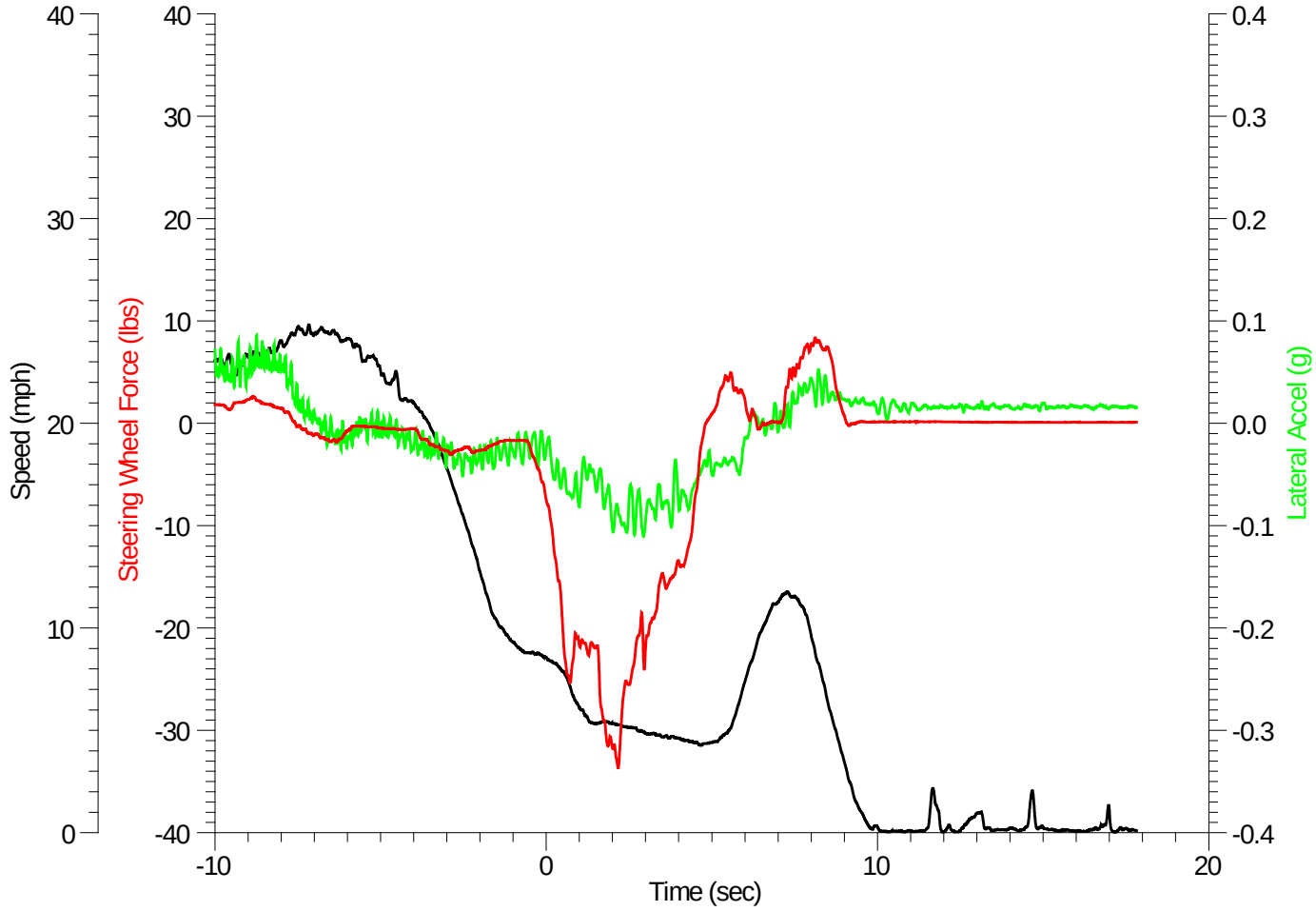
Driver No. 13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Lateral Accel (g)
Time (sec)
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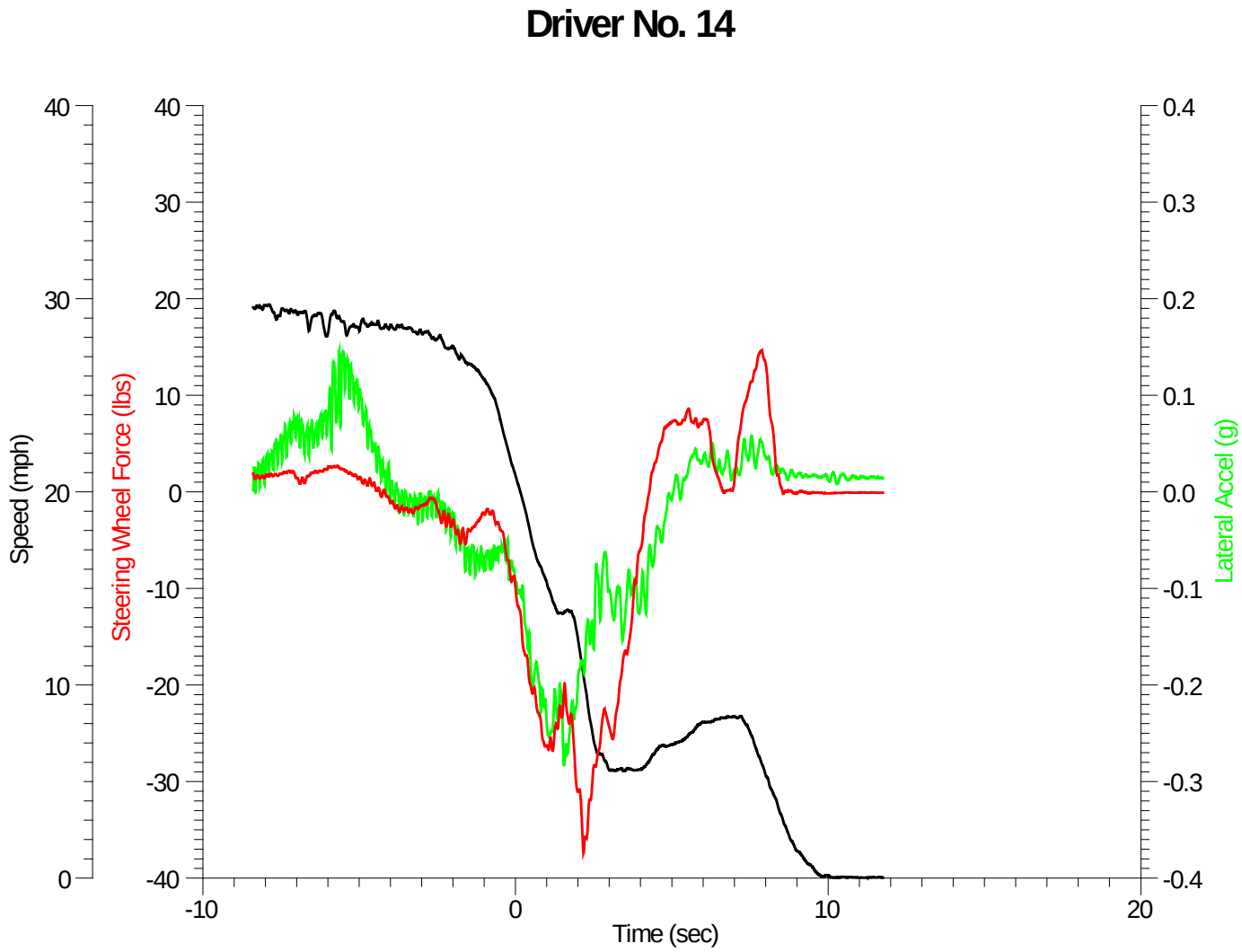
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Lateral Accel (g)
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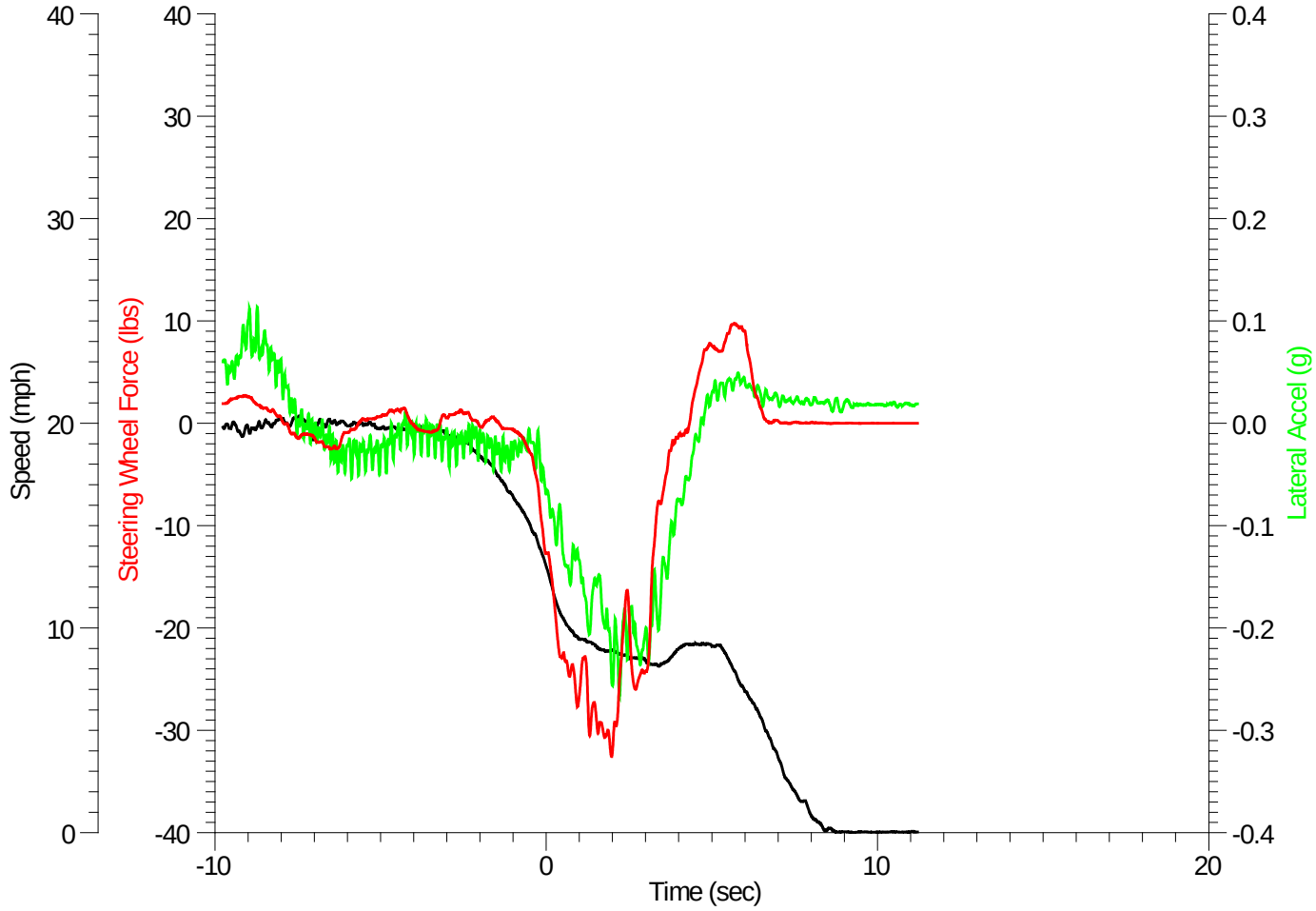
0
10
20

Driver No. 15


Speed (mph)
Steering Wheel Force (lbs)
Lateral Accel (g)
Time (sec)
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-40
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0.0
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-0.2
-0.3
-0.4
-10
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