CPSC Staff Statement on SEA, Ltd. Report "Effects on Vehicle Characteristics of Two Persons Riding ATVs"[1]
September 2017

The report titled, "Effects on Vehicle Characteristics of Two Persons Riding ATVs," presents the results of autonomous dynamic vehicle testing conducted by SEA, Limited (SEA) on 12 model year 2014-2015 adult single-rider all-terrain vehicles (ATVs) to study the effects of two riders on a single-rider ATV. The same 12 vehicles were previously tested under a separate task order to establish baseline performance of the vehicles with a single rider, and the results were published in a report titled, "Vehicle Characteristics Measurements of All-Terrain Vehicles."[2] All task orders were conducted under contract HHSP233201400030I. This contract is funded by CPSC and is administered under an interagency agreement with the U.S. Department of Health and Human Services. The work represented by this report is part of a larger effort by CPSC staff to develop test methods, collect static and dynamic data, and identify opportunities for improvement regarding ATV performance characteristics related to vehicle stability and safety. Follow-on work is underway to measure characteristics for the same 12 vehicles in the following special circumstances to determine the effects on vehicle dynamics: rider active weight shift and operation on a groomed dirt surface. Follow-on work will also include testing of three selected vehicles with characteristics that have been modified to study effects on steering and stability. Additionally, staff has previously identified a need for future testing, when resources are available, to include autonomous rollover testing and rollover simulation testing, with a goal to discover opportunities to reduce the likelihood and severity of injury.

[1] This statement was prepared by the CPSC staff, and the attached report was produced by SEA for CPSC staff. The statement and report have not been reviewed or approved by, and do not necessarily represent the views of, the Commission.

[2] Report titled, "Vehicle Characteristics Measurements of All-Terrain Vehicles," retrieved from: https://www.cpsc.gov/s3fs-public/SEA_Report_to_CPSC_Vehicle_Characteristics_Measurements_of_All_Terrain_Vehicles.pdf.

Effects on Vehicle Characteristics of Two Persons Riding ATVs

Results from Tests on Twelve 2014-2015 Model Year Vehicles

for:
U.S. Consumer Product Safety Commission

September 2017

Vehicle Dynamics Division
7001 Buffalo Parkway
Columbus, Ohio 43229

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"These comments are those of SEA, Ltd. staff, and they have not been reviewed or approved by, and may not necessarily reflect the views of, the Commission."

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1. OVERVIEW

This report contains results from measurements made by SEA, Ltd. (SEA) for the U.S. Consumer Product Safety Commission (CPSC) under U.S. Department of Health and Human Services (HHS) contract HHSP233201400030I.

This report covers work completed on Task Order 2 of the multi-task contract:

- Evaluate effects on characteristics of two persons riding ATVs for 12 vehicles.

This report contains test results for measurements made on twelve 2014-2015 model year vehicles. The vehicles are designated Vehicle A through Vehicle L. Vehicles A-J are model year 2014 vehicles, and Vehicles K and L are model year 2015 vehicles. Task Order 1 on this contract was to make characteristics measurements on these same 12 vehicles in the Driver Plus Instrumentation (DPI) loading condition (representing a nominal 215 lb driver) and in the Gross Vehicle Weight (GVW) loading condition. The SEA report to CPSC on these measurements is titled *Vehicle Characteristics Measurements of All-Terrain Vehicles – Results from Tests on Twelve 2014-2015 Model Year Vehicles*[1], and it contains results from laboratory and dynamic test track measurements made on all 12 vehicles. For the previous Task 1 testing, all 12 of the vehicles were tested in DPI loading condition and nine of them were tested in the GVW loading condition. Vehicles B, H and I, were tested only in the DPI loading condition; because for these vehicles the added weight of the test driver and instrumentation brought the total test weight up to near their manufacturer-specified maximum weight ratings. Vehicles B, H and I are the only three manual transmission vehicles and they are the three lightest vehicles. All of the dynamic testing for the Task 1 measurements was conducted with a human test driver.

Task 2 involved doing only dynamic tests, and all of the testing was conducted using SEA's ATV Robotic Test Driver (ATV RTD). The ATV RTD is a system of automated steering, throttle, brake, and clutch controllers along with differential GPS that was used to conduct the tests in a fully autonomous mode, without a human test driver. Conducting the testing autonomously eliminated the need to have a human driver and a human (or surrogate ballast) passenger. Conducting the tests autonomously was deemed to be safer than having a human driver conduct the tests with a human or surrogate ballast rider. Also, conducting the tests autonomously mitigated the potential for having the test results influenced by the driver and rider shifting their weight in order to secure themselves to the vehicles during the tests.

All of the vehicles were selected by CPSC. All of the vehicles have straddle seating and their intended use is for a single occupant, the driver. All of the vehicles have clear warning labels stating "Never Carry a Passenger" or "Never Carry Passengers." All of the vehicles have handlebar (tiller) steering, thumb activated throttles, and hand and foot activated brakes.

The measured curb weights (weights with full fluids and no drivers or cargo) of the vehicles ranged from 395.5 lb to 832.0 lb. The measured average maximum speeds of the vehicles ranged

[1] *Vehicle Characteristics Measurements of All-Terrain Vehicles – Results from Tests on Twelve 2014-2015 Model Year Vehicles*, HHS Contract HHSP233201400030I, SEA, Ltd. Report to CPSC, November 2016. https://www.cpsc.gov/s3fs-public/SEA_Report_to_CPSC_Vehicle_Characteristics_Measurements_of_All_Terrain_Vehicles.pdf

from 45.7 mph to 74.0 mph in a loading condition representing driver-only loading.

Table 1 contains a list of assorted vehicle information and tire specifications for the 12 vehicles. The measured curb weights and maximum speeds are listed.

Also listed in Table 1 is information on the transmission types (Automatic or Manual) and whether the vehicle has a Solid Rear Axle or Independent Rear Suspension. All of the vehicles with solid rear axles are two-wheel drive (2WD) only vehicles. All of the vehicles with independent rear suspensions are equipped with selectable four-wheel drive (4WD) or all-wheel drive (AWD). Table 1 contains the manufacturers' specified driveline setting options for each of the vehicles. All vehicles were tested in two-wheel drive mode, and in their most open driveline configurations (which was locked rear differential for all 12 vehicles tested).

Table 1 also lists the front and rear tire make, tire size, and tire pressure for each vehicle.

The dynamic tests were performed by SEA on numerous dates between July 25, 2016 and December 21, 2016. All of the vehicles were tested at SEA in Columbus, Ohio. The following suite of dynamic tests was performed in the 2-Rider loading condition for each vehicle:

- **Constant Radius (50 ft) (Circle) Tests**
- **Dropped Throttle J-Turn (Step Steer) Tests (Initial Speed of 20 mph)**
- **Constant Steer Tests (Yaw Rate Ratio Tests)**

This report contains four main sections: Overview, Dynamic Testing, Discussion of Test Results, and Comparison of 2-Rider Results to Single Driver Results. There are also three appendices containing test results, and one appendix containing photographs of test equipment.

Table 1: Test Vehicle Information and Tire Specifications		
Vehicle A **Curb Weight: 523.9 lb** **Maximum Speed: 47.0 mph**	**Automatic Transmission** **Solid Rear Axle** **2WD**	
	Front Tires	Rear Tires
Tire Make	Maxxis MU13	Maxxis MU13
Tire Size	AT25X8-12 4 Ply	AT25X10-12 4 Ply
Tire Pressure (psi)	3.6	3.6
Vehicle B **Curb Weight: 432.8 lb** **Maximum Speed: 70.0 mph**	**Manual Transmission** **Solid Rear Axle** **2WD**	
	Front Tires	Rear Tires
Tire Make	Maxxis M976Y	Maxxis M976Y
Tire Size	AT21X7-10	AT20X10-9
Tire Pressure (psi)	4	4
Vehicle C **Curb Weight: 650.8 lb** **Maximum Speed: 66.0 mph**	**Automatic Transmission** **Independent Rear Suspension** **2WD, 4WD, or 4WD Lock**	
	Front Tires	Rear Tires
Tire Make	Maxxis MU19A	Maxxis MU19A
Tire Size	AT25X8-12 4 Ply	AT25X10-12 4 Ply
Tire Pressure (psi)	5	4.4
Vehicle D **Curb Weight: 714.0 lb** **Maximum Speed: 45.8 mph**	**Automatic Transmission** **Independent Rear Suspension** **2WD, 4WD, or 4WD Lock**	
	Front Tires	Rear Tires
Tire Make	Kaden Duro 45J	Kaden Duro 52J
Tire Size	AT25X8-12 6 Ply	AT25X10-12 6 Ply
Tire Pressure (psi)	5	5
Vehicle E **Curb Weight: 734.1 lb** **Maximum Speed: 45.7 mph**	**Automatic Transmission** **Independent Rear Suspension** **2WD, 4WD, or 4WD Lock**	
	Front Tires	Rear Tires
Tire Make	Kaden Duro 45J	Kaden Duro 52J
Tire Size	AT25X8-12 6 Ply	AT25X10-12 6 Ply
Tire Pressure (psi)	5	5
Vehicle F **Curb Weight: 526.2 lb** **Maximum Speed: 53.5 mph**	**Automatic Transmission** **Solid Rear Axle** **2WD**	
	Front Tires	Rear Tires
Tire Make	Kenda Pathfinder	Kenda Pathfinder
Tire Size	AT22X7-10 4 Ply	AT22X10-10 4 Ply
Tire Pressure (psi)	4	3.5

Table 1 (Continued): Test Vehicle Information and Tire Specifications		
Vehicle G **Curb Weight: 694.0 lb** **Maximum Speed: 69.0 mph**	**Automatic Transmission** **Independent Rear Suspension** **2WD or 4WD**	
	Front Tires	Rear Tires
Tire Make	Duro DI-K911	Duro DI-K911
Tire Size	AT25X8-12 4 Ply	AT25X10-12 4 Ply
Tire Pressure (psi)	5	5
Vehicle H **Curb Weight: 395.5 lb** **Maximum Speed: 71.5 mph**	**Manual Transmission** **Solid Rear Axle** **2WD**	
	Front Tires	Rear Tires
Tire Make	Dunlop KT391	Dunlop KT396
Tire Size	AT21X7R10 ☆☆	AT20X10R9 ☆☆
Tire Pressure (psi)	4.4	3.9
Vehicle I **Curb Weight: 408.4 lb** **Maximum Speed: 63.0 mph**	**Manual Transmission** **Solid Rear Axle** **2WD**	
	Front Tires	Rear Tires
Tire Make	Ohtsu Radial HTRAK M/R101	Ohtsu Radial HTRAK M/R101
Tire Size	AT22X7-10 4 Ply	AT22X10-9 4 Ply
Tire Pressure (psi)	4	4
Vehicle J **Curb Weight: 649.8 lb** **Maximum Speed: 60.5 mph**	**Automatic Transmission** **Independent Rear Suspension** **2WD or AWD**	
	Front Tires	Rear Tires
Tire Make	Dunlop KT511	Dunlop KT515
Tire Size	AT25X8 R12	AT25X10 R12
Tire Pressure (psi)	4.4	3.6
Vehicle K **Curb Weight: 832.0 lb** **Maximum Speed: 74.0 mph**	**Automatic Transmission** **Independent Rear Suspension** **2x4, 4x4, or 4x4 Lock**	
	Front Tires	Rear Tires
Tire Make	Carlisle AT489 II	Carlisle AT489 II
Tire Size	AT 26X8-14 6 Ply	AT 26X10-14 6 Ply
Tire Pressure (psi)	7	7
Vehicle L **Curb Weight: 716.4 lb** **Maximum Speed: 52.7 mph**	**Automatic Transmission** **Independent Rear Suspension** **2x4 or AWD**	
	Front Tires	Rear Tires
Tire Make	Wanda NS388	Wanda NS388
Tire Size	AT24X8-12 6 Ply	AT24X10-12 6 Ply
Tire Pressure (psi)	5	5

2. DYNAMIC TESTING

This section describes the dynamic tests conducted on numerous dates between July 25, 2016 and December 21, 2016. All of the vehicles were tested at SEA in Columbus, Ohio, on their flat dry asphalt vehicle dynamics test pad. All of the vehicles with automatic transmissions were tested in two-wheel drive mode, and in their most-open driveline configurations. The vehicles with manual transmissions were tested in second gear (as they were when they were tested previously using human test drivers).

2.1 Vehicle Loading Condition

The loading condition used for all of the testing was the representative 2-Rider loading condition. Page 1 of Appendix D contains photographs of one of the test vehicles in the 2-Rider loading condition. For these autonomous tests, a weight frame constructed of 80/20 T-slot aluminum bars was used to rigidly hold enough steel weights to bring the total test weight up to nominally 430 lb (representing two 215 riders) above the curb weight for each vehicle. The frame was designed so the steel weights could be adjusted vertically so that the center-of-gravity (CG) height of the added ballast would represent the CG height of two 215 lb riders (with their nominal CG heights 10 inches above the lowest point of their position on the seat).

The two-person loading condition was specified to be the vehicle curb condition plus the weight (nominally 430 lb) of the test instrumentation and equipment that included: measurement transducers, SEA's ATV RTD,[2] SEA's ATV safety outriggers,[3] an auxiliary 24V battery, and the ballast weight frame described above. Table 2 lists the nominal weights of the components that comprise the 2-Rider loading condition.

The right-most columns in the tables contained in Appendix A contain the test weight, corner weights, track widths, wheelbase, and CG longitudinal and lateral positions for all 12 vehicles in the 2-Rider loading condition (loading conditions used for CPSC tests are also included in these tables). Vehicles B, H and I are the smallest, manual transmission ATVs with manufacturer-specified maximum loading of 220 lb, 250 lb and 243 lb, respectively. For these three vehicles the 2-Rider loading weight exceeded the manufacturer-specified maximum loading. Also, for Vehicle F, the 2-Rider weight slightly exceeded the manufacturer-specified maximum loading.

[2] As part of this project, SEA designed the ATV RTD. The ATV RTD consists of a computer-controlled 24V electric motor that mounts to the front rack of an ATV for steering control. A four bar linkage arrangement is used to connect the motor drive gear to an aluminum rod that is connected to the ATV steering column beneath the ATV handlebars. The ATV RTD also includes up to three other computer-controlled 24V electric motors that mount to the aluminum rod inserted beneath the ATV handlebars. One motor is used to control the throttle, one is used to apply the right hand brake, and in the case of the manual transmission vehicles, one is used to control the clutch on the left side of the handlebar. The ATV RTD also includes a GPS/IMU (OxTS RT3002), an electronics box (with a National Instruments (NI) cRIO, the on-vehicle computer with the motor controllers and data acquisition software), and antennas for wireless communication. Pages 2-4 of Appendix D contain photographs of the ATV RTD.

[3] SEA designed ATV-specific safety outriggers consisting of a single aluminum tubular beam structure that mounts to the underside of the ATVs. Adjustable height nylon pads are mounted to the ends of the outrigger beam, and these interact with the test surface to prevent the vehicles from tipping over. Page 5 of Appendix D contains photographs of these standard ATV safety outriggers. These standard ATV outriggers could not be used on the three lightest ATVs tested, the manual transmission vehicles, because their frames were too close to the ground when they were loaded in the 2-Rider loading condition. For these three vehicles, SEA designed, built and used the light-vehicle ATV outriggers shown on Page 6 of Appendix D. These outriggers attached to the foot pegs of the vehicles and were further supported by an aluminum brace to the frame.

Table 2: 2-Rider Loading		
Component	**Automatic Transmission Vehicles** — **Nominal Weight (lb)**	**Manual Transmission Vehicles** — **Nominal Weight (lb)**
Components Mounted at Front of Each Vehicle Base Plate, Steer Motor, Throttle Motor, Brake Motor, Clutch Motor (for Manual Transmission Vehicles), Steering Column Transducer, and Associated Linkages	37.2	47.7
Components Mounted at Rear of Each Vehicle Base Frame, Electronics Box, GPS/IMU (RT3002), 24V Battery, and Antennas	57.6	57.6
Standard ATV Outriggers	29.0	NA
Light-Vehicle ATV Outriggers	NA	23.5
Ballast Frame without 215 lb Steel Weights (Includes 45 lb Laterally-Adjustable Steel Weights Used for Rider-Active Study)	91.2	91.2
2nd Rider Weight Steel Weights in Center Portion of Ballast Frame	215.0	210.0
Total Nominal 2-Rider Weight	**430.0**	**430.0**

2.2 Test Instrumentation

The instrumentation used during the testing is listed in Table 3. The GPS/IMU (RT3002) was mounted on the rear base frame of each vehicle. The base frames were constructed using 80/20 T-slot aluminum bars and aluminum plates. For each vehicle, the longitudinal, lateral, and vertical offsets from the center of the RT3002 to the actual vehicle CG location were measured and entered into the RT3002 system software. This information was used to translate the measured quantities to those at the CG of the vehicle. The lateral accelerations measured and reported herein are accelerations parallel to the road plane, as opposed to vehicle body-fixed accelerations.

Steering column angle (handlebar steering angle) was measured using either a digital rotary encoder or an analog string potentiometer. For several of the test vehicles, electronic noise was present in the digital encoder signal. This noise is presumably related to the vehicle's electronic output and the ATV RTD electronic sensing configuration or grounding. After this problem was identified, all subsequent vehicles were tested using the analog string potentiometer to measure steering column angle. Page 7 of Appendix D contains photographs of the arrangement used to measure steering column angle using both instruments. A split sheave, with an inner (bore) diameter sized to fit securely around the steering column shaft was fixed around each steering column. In all cases, the steering ratios between the steering column sensor and roadwheel

angles were measured, and these were used to determine the Roadwheel Steer Angles (shown on the graphical results in Appendix C).

Table 3: Instrumentation Used During Dynamic Testing			
Transducer	**Measurement**	**Range**	**Accuracy**
Oxford Technical Solutions (OxTS) RT3002 Inertial and GPS Navigation System	Longitudinal, Lateral, and Vertical Accelerations	± 100 m/s^2 (± 10 g)	0.01 m/s^2 (0.001 g)
	Roll, Pitch, and Yaw Rates	± 100 deg/s	0.01 deg/s
	Speed	No Limit Specified	0.05 km/h (0.03 mph)
	Roll and Pitch Angles	-180 to +180 deg	0.03 deg
	Vehicle Heading	0 to 360 deg	0.1 deg
Steering Column Encoder or Potentiometer	Steering Column Angle (Handlebar Angle)	No Limit Specified	± 0.25 deg

2.3 Constant Radius (50 ft) (Circle) Tests

Constant Radius or Circle tests were used to evaluate the vehicles' understeer characteristics.[4] A Constant Radius test involves driving a vehicle on a circular path of constant radius (50 ft in this case). The test vehicles were autonomously driven in both the clockwise and counterclockwise directions. The ATV RTD was used to steer the vehicles and control the vehicle throttle (speed) during these tests.

A circular path was generated in GPS coordinates to match the physical location of the 50 ft radius circle on the SEA test pad. The "path-following" feature of the RTD was used to control the steering input during these tests. The path-following algorithm has a collection of parameters used to model driver look-ahead distance, vehicle steering properties, and other steering-related control gains that were adjusted to provide good path following behavior for each vehicle tested.

For the vehicles with automatic transmissions, the throttle input was increased in piecewise linear steps to generate speed profiles from a very low speed up to a speed where the lateral acceleration reached 0.4 g, or in some cases, to a speed where the test was stopped before the lateral acceleration reached 0.4 g. For some of the vehicles, the tests were stopped at the speed at which the vehicle tipped up (two-wheel lift) or the occurrence of one-wheel lift resulted in the need for significant steering corrections (oscillations) to maintain the circular path. The test

[4] SAE Surface Vehicle Recommended Practice - Steady-State Directional Control Test Procedures For Passenger Cars and Light Trucks, SAE J266, 1996.

engineers stopped the autonomous tests using the RTD program.

For vehicles with manual transmissions, the vehicles were tested in second gear. For these vehicles, the RTD was programmed to rev the throttle and slowly engage the clutch. The throttle and clutch positions were synchronized and tuned for each vehicle to provide smooth take offs. Once the vehicles started moving, the throttles were backed off so the vehicle could achieve a low speed at the start of the circle tests. The throttle inputs were then increased in piecewise linear steps to generate speed profiles up to a speed where the lateral acceleration reached 0.4 g.

Constant Radius tests were used to determine if the vehicles transitioned from understeer to oversteer during the tests. Roll gradients, vehicle roll angle response as a function of lateral acceleration, were also computed from these tests. Detailed results from the Constant Radius tests are contained in Appendix C.

2.4 Dropped Throttle J-Turn (Step Steer) Tests (Initial Speed of 20 mph)

J-Turn tests, often referred to as step steer tests, involve imparting a rapid steering input up to a fixed magnitude while the vehicle is traveling along a straight path. For the dropped throttle J-Turn tests, the RTD drove each vehicle along a straight-line path (defined by GPS coordinates) from low speed up to a speed of 21 mph. The RTD throttle inputs were programmed to generate the appropriate speed profiles so that the J-Turn maneuvers would take place near the center of the test pad. Once 21 mph was achieved, the RTD then dropped the throttle and triggered the steering input precisely when the vehicle speed reached 20 mph. For the manual transmission vehicles, the clutch was left engaged when the throttle was dropped. The handlebar (motor) steering input rates used were 40 deg/sec, and the steering dwell or hold time used was 10.0 seconds, at which time the steering angle was programmed to return to 0 deg. The test engineer typically stopped the RTD program once the vehicle came to a stop at the end of each test, before 10 seconds of steering hold time. This eliminated the need to return the steering angle to zero while the vehicle was stopped, which helped preserve RTD 24V battery life by eliminating the need to use relatively high steering torques to steer the vehicle while it was not moving.

The J-Turn test procedure involved initially running tests with steering magnitudes less than the steering required to produce tip-up events, events that have visual two-wheel lift outcomes. The handlebar steering input magnitude was gradually increased in 1.0 degree increments to the point where a test run resulted in a two-wheel lift event. Then another test run using 0.5 degrees less steering input was used to refine the steering required for two-wheel lift. Once the steering input magnitude required for visual two-wheel lift was determined, repeat test runs using this steering input were conducted. Enough tests using this steering magnitude were conducted until three visual two-wheels lifts were achieved in each direction.

These tests provided a measure of the minimum peak lateral acceleration (Threshold Ay) required to cause visual two-wheel lifts during the tests. Detailed results from the Dropped Throttle J-Turn tests are contained in Appendix C.

2.5 Constant Steer Tests (Yaw Rate Ratio Tests)

Constant Steer tests are yet another well established method used to evaluate a vehicle's understeer characteristics.[5] The ROV industry groups ROHVA and OPEI, as well as CPSC, have used Constant Steer tests to evaluate vehicle yaw rate divergence. The industry groups have developed protocols for computing the ratio of yaw rate gain at a high lateral acceleration range (0.4-0.5 g) divided by the yaw rate gain at a low lateral acceleration range (0.1-0.2 g), and this ratio is referred to here as Yaw Rate Ratio. At the time of this report, both ROHVA[6] and OPEI[7] have industry voluntary standards that describe similar test and data reduction protocols for computing Yaw Rate Ratio for ROVs. The same test and data reduction protocols were used for the current ATV testing. The only significant difference is that for the ATV testing, the high range of lateral accelerations was reduced to a range at or below 0.4 g.

The test procedure used for the Yaw Rate Ratio tests was:

1. Follow a 100 ft diameter (50 ft radius) circle at a speed less than 10 mph until the mean steer angle required to maintain the circular path is established (this is referred to as "initial steer" in this report). *Test Note: For the autonomous tests conducted using steering based on a 50 ft radius path, the initial steer was determined from the 50 ft radius circle tests. For tests conducted using steering based on a 25 ft radius path, a test driver drove the loaded test vehicles slowly around a 25 ft radius circular path to determine the initial steer.*
2. The ATV RTD was then used to steer the steering column (handlebars) to the initial steer angle and hold it there for the duration of the test.
3. The vehicle was then steadily accelerated at a rate not to exceed 1 mph/second. Efforts were made to program the RTD throttle to complete each test run in about 60 seconds, and the tests for many of the vehicles are close to 60 seconds in duration. *Test Note: However, some of these autonomous tests were in the range of 30 seconds in duration and some were close to 120 seconds in duration. The speed control improved as the test engineers gained experience with the nuances of RTD throttle control as additional vehicles were tested.*
4. The tests were ended by the test engineer when a lateral acceleration of at least 0.4 g was achieved, or when tip-up was imminent.
5. Items 2-4 were repeated until at least five runs in the first steer direction were completed.
6. Item 1 was repeated in the opposite steer direction, and then Items 2-4 were repeated until at least five runs in the opposite steer direction were completed.

If a vehicle understeers during portions of a Yaw Rate Ratio test, its path radius could increase significantly, based on the amount of its understeer. If the path of a vehicle became large enough to run off of the available test surface, the test starting on a 100 ft diameter was terminated and the testing was conducted using a starting diameter of 50 ft.

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[5] Ibid

[6] American National Standard for Recreational Off-Highway Vehicles, ANSI/ROHVA 1-2016, May 2016.

[7] American National Standard for Multipurpose Off-Highway Utility Vehicles, ANSI/OPEI B71.9-2016, August 2016.

3. DISCUSSION OF TEST RESULTS

Appendix B contains a collection of tables and bar charts summarizing selected results from the dynamic testing. Detailed graphical results from all of the dynamic testing conducted are contained in Appendix C. This section of the report contains discussions of the results in Appendices B and C.

3.1 Discussion of Appendix B: Summary Tables and Bar Charts

Page 1 of Appendix B contains a summary table of the CW, CCW, and Average lateral acceleration levels at which the vehicles that transitioned from understeer to oversteer did so during the autonomous 2-Rider Circle tests. "NA" in the table indicates that no transition to oversteer occurred. Page 2 of Appendix B contains a bar chart showing the Roll Gradients, the amount of roll angle in degrees per "g" of lateral acceleration measured during the Circle tests.

Page 3 contains a table and Page 4 a bar chart of the Threshold Lateral Acceleration (Threshold Ay) determined from the dynamic 20 mph Dropped Throttle J-Turn tests. Threshold Ay is the minimum peak lateral acceleration required to cause visual two-wheel lift during the J-Turn tests, and it is a metric that is used to categorize a vehicle's tip-up or rollover resistance.

Page 5 of Appendix B contains a table listing the Right Turn, Left Turn, and Average values for the final Yaw Rate Ratios determined from the Constant Steer (Yaw Rate Ratio) tests. This table also contains a column listing the maximum lateral acceleration (Ay) used during the post-processing of the test results for each vehicle, and a column listing the initial path radius used for each vehicle. Page 6 is a bar chart of the Yaw Rate Ratio results.

3.2 Discussion of Appendix C: Results from Dynamic Tests

Appendix C contains the graphical test results for all 12 vehicles tested, in the following order:

- Constant Radius (50 ft) (Circle) Tests
- Dropped Throttle J-Turn (Step Steer) Tests (Initial Speed of 20 mph)
- Constant Steer Tests (Yaw Rate Ratio Tests)

Table 4 contains a table of contents for Appendix C, listing the pages containing results for each of the 12 vehicles.

Table 4: Appendix C Table of Contents			
Vehicle	**Page Numbers**	**Vehicle**	**Page Numbers**
A	1-16	G	97-112
B	17-32	H	113-128
C	33-48	I	129-144
D	49-64	J	145-160
E	65-80	K	161-176
F	81-96	L	177-192

The discussion in this section will cover each test in the order listed above. A couple of general comments regarding the graphs presented for all test types are:

- The lateral accelerations shown on the graphs are the lateral accelerations parallel to the road plane, not the vehicle body-fixed lateral accelerations.
- The steering angles shown on the graphs are generally roadwheel steer angles, which are the measured steering column angles divided by the measured steering ratios (The measured steering ratios between the steering columns and roadwheels ranged from 1.21:1 to 1.62:1.). However, in the case of all of tests conducted on Vehicle B and the Yaw Rate Ratio tests conducted on Vehicle J, the steering column angle sensor was not functioning. In these cases, the steering angles shown on the graphs are Steer Motor/Ratio (where Ratio is the measured steering ratio between the handlebar angle, the ATV RTD input angle, and the roadwheels).
- The ATV RTD was used for all of the Circle, J-Turn, and Yaw Rate Ratio tests. For tests using the ATV RTD, the commanded steering input is the input to the ATV RTD steering motor. The ATV RTD steering angle and the steering column angle are not exactly one-to-one, due to compliance in the ATV RTD four-bar linkage arrangement, its motor base mounting to the vehicles, and the handlebars.

3.2.1 Constant Radius (50 ft) (Circle) Tests

For each vehicle there are four pages showing results from both the clockwise (CW) and counterclockwise (CCW) Circle tests. The first page shows time domain plots of Roadwheel Steer Angle, Lateral Acceleration, Speed, Roll Angle, and Yaw Rate. All of the dynamic test data is sampled at 100 Hz. For the Circle test results, the data shown was digitally low-pass filtered to 1.0 Hz using a phaseless, eighth-order, Butterworth filter. The circle tests are quasi-steady state tests, and it is common to use a low pass filter on data from these tests. The time domain data shown for each vehicle contains all of the data from the time the test engineer started the ATV RTD data acquisition (prior to starting to move on the circle) to the time the test engineer ended the ATV RTD program to end the test. The test engineers intended to drive the vehicles to a lateral acceleration level of at least 0.4 g, but in some cases the tests were stopped

before the lateral acceleration reached 0.4 g. For some of the vehicles, the tests were stopped at the speed at which the vehicle tipped up (two-wheel lift) or the occurrence of one-wheel lift resulted in the need for significant steering corrections (oscillations) to maintain the circular path. The test engineers stopped the autonomous tests using the RTD program.

On the first page of Circle test graphs for each vehicle, the thin black lines for the CW and CCW tests show the full range of data collected. The thicker lines (red for CW and blue for CCW) indicate the range of data used to fit the subsequent understeer and roll gradient characteristic curves. These ranges typically start from the time the vehicle attained a speed of 5.5 mph, which is a lateral acceleration of 0.04 g on a 50 ft radius circle. By the time most of the vehicles reached 5.5 mph, the RTD steering had settled to a steady state. However, in a few cases, a speed somewhat greater than 5.5 mph was needed before the RTD steering settled to steady state. The range of data used for the curve fits was ended when the vehicle attained a lateral acceleration of 0.40 g or the maximum vehicle speed during the test. The speed plots show that the Circle tests were conducted using a very slow rate of increase in speed during the circle tests. Regarding conducting circle tests for passenger vehicles, SAE J266[8] states: "If speed is steadily increased, the rate of increase shall not exceed 1.5 km/h per second (0.93 mph per second), and data shall be recorded continuously, so long as the vehicle remains on radius." The overall rates of speed increase during the Circle tests conducted are less than the J266 recommended maximum allowable rate.

The second page for each vehicle shows graphs of Roadwheel Steer Angle versus Ay (lateral acceleration). The CW test results are in the upper right quadrants of the graphs and the CCW test results are in the lower left quadrants of the graphs. The thin red and blue lines show data in the selected ranges, as described above. For both the CW and CCW data, there is a thicker blue line indicating second-order polynomial curve fits to the range of data selected. The red circles on these graphs are the geometric Ackermann steer angles, a function of the steering ratio (K) times the wheelbase (L) divided by the circle radius (R), given by:

$$\delta_{SW\ (\text{Geometric Ac ker mann})} = \frac{(180/\pi)\times K\times L}{R}$$

The geometric Ackermann steer angles are not the same as the actual roadwheel steer angles required to negotiate the circles at very low speed, with Ay close to zero. The actual roadwheel steer angles, which can be referred to as the measured Ackermann steer angles, are generally greater than the geometric Ackermann steer angles due primarily to compliance and lash in the steering system, and compliance in the suspension systems and tires.

The third page for each vehicle contains a graph of Roadwheel Steer Angle minus (measured) Ackermann Angle versus Ay (lateral acceleration). For these graphs, the signs of the CCW data are reversed so that the CW and CCW results can be directly compared. The thin lines show data in the range of data selected for each vehicle as described above, and the thick lines are the second-order polynomial curve fits to the data. Notice that the measured Ackermann steer angles are the abscissae of the curve fits taken at Ay equal to zero, so the curve fits tend to zero as Ay goes to zero. For a circle test: understeer can be defined as the condition when the steering input

[8] SAE Surface Vehicle Recommended Practice - Steady-State Directional Control Test Procedures For Passenger Cars and Light Trucks, SAE J266, 1996.

required to maintain the circular path increases as the vehicle speed increases, neutral steer can be defined as the condition when the steering input required to maintain the circular path does not change as the vehicle speed increases, and oversteer can be defined as the condition when the steering input required to maintain the circular path decreases as the vehicle speed increases. The second-order polynomial curve fits do a good job of representing the underlying data whether the particular test vehicle exhibits understeer, neutral steer, or oversteer characteristics during the Circle tests.

All of the vehicles tested exhibit understeer at low levels of lateral acceleration and then all of the vehicles except Vehicles C, D and E transition to oversteer at higher levels of lateral acceleration. The points of transition from understeer to oversteer are indicated on the graphs by black circles, and they are mathematically the points where the slopes of the curve fits change from being positive to negative. For circle tests where the vehicles exhibited a transition from understeer to oversteer, the values of the lateral acceleration at the points of transition are indicated on the graphs.

The fourth page for each vehicle contains a graph of Roll Angle versus Ay (lateral acceleration). The CW test results are in the lower right quadrants of the graphs and the CCW test results are in the upper left quadrants of the graphs. The thin lines show data in the range of vehicle speeds selected for each test. The thick lines are linear curve fits to the CW and CCW data over the selected ranges. The average of the CW and CCW curve fit slopes are listed on the graphs as the Roll Gradient.

3.2.2 Dropped Throttle J-Turn (Step Steer) Tests (Initial Speed of 20 mph)

For each vehicle there are five pages of results for the Dropped Throttle J-Turn tests. The first four pages show time domain plots for the tests. The first and third pages for each vehicle show plots of Roadwheel Steer Angle, Lateral Acceleration, Speed, Roll Angle, and Yaw Rate; for the six Northwest and the six Southeast runs, respectively. The second and forth pages for each vehicle show larger plots of Lateral Acceleration; for the six Northwest and six Southeast runs, respectively. For the J-Turn test results, the data shown was digitally low-pass filtered to 2.0 Hz using a phaseless, eighth-order, Butterworth filter. For tests conducted by SEA for CPSC on Recreational Off-Highway Vehicles (ROVs), the same 2.0 Hz. filter was used to filter all J-Turn test data used to select peak lateral acceleration values (Threshold Ay values) during J-Turn tests that resulted in two-wheel lift outcomes. Justification for using a 2.0 Hz low pass filter for selecting peak lateral accelerations is presented in the SEA report to CPSC titled *Repeatability of J-Turn Testing of Four Recreational Off-Highway Vehicles*.[9] The time domain data shown for each vehicle contains data from 0.5 seconds before the ATV RTD steering input was applied until 5.0 seconds after it was applied.

For each vehicle, the plots contain results from three Northwest right steer J-Turns, three Northwest left steer J-Turns, three Southeast right steer J-Turns, and three Southeast left steer J-Turns. In all cases, the plots contain results for tests that resulted in visually determined two-

[9] *Repeatability of J-Turn Testing of Four Recreational Off-Highway Vehicles*, CPSC Contract CPSC-D-11-0003, SEA, Ltd. Report to CPSC, September 2013. **https://www.cpsc.gov/s3fs-public/SEAReporttoCPSCRepeatabilityTestingSeptember%202013.pdf**

wheel lift. An SAE standard sign convention is used, with Roadwheel Steer Angle, Lateral Acceleration, and Yaw Rate being positive for right turns and Roll Angle being negative for right turns.

The fifth page shown for each vehicle contains a summary of the peak lateral accelerations measured in each test. These values are the maximum values of lateral acceleration shown on the plots, which contain data that has been filtered to 2.0 Hz.

The summary pages show the peak lateral accelerations for the three runs conducted in the Northwest right steer direction, Northwest left steer direction, Southeast right steer direction, and Southeast left steer direction. The mean values and standard deviations from each of the three sample runs are shown on the summary pages. Also, the average values of the six Northwest and six Southeast runs are shown, as is the average of all 12 runs, which is the Threshold Ay value. Page 3 of Appendix B contains a table listing the Threshold Ay values for each vehicle.

3.2.3 Constant Steer Tests (Yaw Rate Ratio Tests)

There are seven pages of Constant Steer test results for each vehicle. The first page shows time domain plots of Roadwheel Steer Angle, Estimated Ay (Estimated Lateral Acceleration), Speed, Roll Angle, and Yaw Rate. There are plots for the five right direction steer tests (CW tests) and for the five left direction steer tests (CCW tests). For all of the graphs from the Constant Steer tests, the Roadwheel Steer Angle, Speed, Roll Angle and Yaw Rate data shown is unfiltered. Per the OPEI and ROHVA ANSI protocols, the Estimated Ay data shown is computed by multiplying the Yaw Rate (filtered using a low-pass Butterworth filter with a cut-off frequency of 1.0 Hz) and Speed (filtered using a low-pass Butterworth filter with a cut-off frequency of 1.0 Hz). The thin black lines show all of the data collected for each run, and the colored lines show the data from the start of each test to the end point of the data range that was selected for post processing. The end points are nominally where the lateral acceleration reached 0.4 g. However, in many cases the end points are at the maximum lateral acceleration levels achieved prior to the time when the test engineer stopped the test, and just prior to when the vehicle began to slow down. In these latter cases, the tests were stopped by the test engineer at the speed at which vehicle tip-up was deemed to be imminent. For understeering Vehicles D and E the tests were ended prior to 0.4 g because their paths were continuing to get larger and they would have likely run off of the available test surface if they were left to continue. All of the maximum Estimated Ay values used are given in the table on Page 5 of Appendix B.

The second page of results from the Constant Steer tests contains the plots of Estimated Ay versus Speed for all ten tests. Notice that in some cases, the Estimated Ay levels shown on these graphs are greater than the selected end point lateral acceleration levels. This is because the lateral accelerations increase as soon as the throttle (and vehicle speed) is dropped. When the vehicle speed drops, weight is shifted to the front axle and the vehicles tend to turn in, generally increasing lateral acceleration, roll angle and yaw rate. Data after the speed was dropped at the ends of the tests was not used in the analyses to compute yaw rate ratios.

The third page of results contains the plot of Yaw Rate versus Speed for all ten tests, and this is the graph that also shows the slope values for the individual test run initial and final ranges (and their standard deviations), the individual test run CW and CCW slope ratios (and their standard

deviations), the average CW and CCW slope ratios (the Yaw Rate Ratios), and the final average of the CW and CCW slope ratios (the Average Ratio). All of the linear curve fits in the initial and final ranges are shown, and the thick black lines indicate where combinations of yaw rate and speed equal 0.4 g of lateral acceleration or the maximum lateral acceleration achevied for the vehicle, as described above.

The following steps were taken to compute the slopes and Yaw Rate Ratios contained on the third page graphs:

1. For each test run, to determine the data regions for analysis, the yaw rate and speed channels were filtered using a low-pass Butterworth filter with a cut-off frequency of 1 Hz. Then the estimated lateral acceleration in units of "g's" was computed using the following equation:

$$\text{Estimated } A_y = \frac{\pi}{180} \times \frac{\text{Yaw Rate} \times \text{Speed}}{32.2}$$

   where Yaw Rate is in deg/sec and Speed is in ft/sec.

   The protocol used to compute Estimated Ay is the same as the protocols contained in ANSI/ROHVA 1-2016 and ANSI/OPEI B71.9-2016.[10]

2. The estimated lateral acceleration, Estimated Ay, was used to determine the start and stop points for the following regions:
   a. The Initial Region is from 0.1 to 0.2 g.
   b. The Final Region is from 0.3 to 0.4 g or from 0.1 g less than the maximum Ay acheived to the maximum Ay acheived.

3. For each test run, in both the initial and final regions, linear slopes of unfiltered yaw rate versus data index and linear slopes of unfiltered speed versus data index were computed.[11] The slopes can be classified as:
   a. Y1 = linear slope of the yaw rate versus index plot for Initial Region
   b. Y2 = linear slope of the yaw rate versus index plot for Final Region
   c. V1 = linear slope of the vehicle speed versus index plot for Initial Region
   d. V2 = linear slope of the vehicle speed versus index plot for Final Region

4. The Yaw Rate Ratio (R) for each run was then computed using the following equation:

[10] The equations given in ANSI/ROHVA 1-2016 and ANSI/OPEI B71.9-2016 to compute Estimated Ay differ from the equation listed above because metric dimensions are used in the voluntary standards. However, all of the equations compute Estimated Ay in units of "g's", by dividing by the gravitational constant defined as 9.8 m/s^2 or 32.2 ft/s^2.

[11] The ANSI/ROHVA 1-2016 and ANSI/OPEI B71.9-2016 protocols specify computing slopes as versus *time*. Given the form of the final computation for Yaw Rate Ratio, computing the slopes versus *time* or versus *data index* result in the same answer for Yaw Rate Ratio.

$$\text{Yaw Rate Ratio (R)} = \frac{\left(\frac{Y2}{V2}\right)}{\left(\frac{Y1}{V1}\right)}$$ Note: This value may be negative or positive.

5. Steps 1 through 4 were then repeated for all ten test runs.

6. The following final slope ratios were then computed:
   a. Right Turn Yaw Rate Ratio (CW Average) = Average of the absolute values of the 5 right turn test runs
   b. Left Turn Yaw Rate Ratio (CCW Average) = Average of the absolute values of the 5 left turn test runs
   c. Average Yaw Rate Ratio (Average Ratio) = Average of the Right Turn and Left Turn Yaw Rate Ratios

The fourth and fifth pages for each test condition contain magnified sections of the individual final slope regions for the right turn (CW) and left turn (CCW) runs, respectively. These graphs also contain black lines indicating where combinations of yaw rate and speed equal 0.4 g of lateral acceleration or the maximum lateral acceleration selected for the vehicle. A vehicle with severe oversteer in the final slope region will have a steep slope (high Final Slope value), and this will produce a high Yaw Rate Ratio. Steep final slopes are indicative of divergent vehicle behavior, a condition when the yaw rate and lateral acceleration gains are high and the vehicle is prone to yaw and/or tip-up instability.

The sixth and seventh pages show individual path plots for the right turn (CW) and left turn (CCW) runs, respectively. As speed is increased during a Constant Steer test, an understeering vehicle will travel on a path of increasing radius, and an oversteering vehicle will travel on a path of decreasing radius. The path plot graphs have green, red, and black line portions, indicating ranges of lateral acceleration during the runs. The initial regions are shown with the green lines and the final regions are shown with the red lines.

Vehicles D and E are the most understeering vehicles tested; and these two vehicles have Yaw Rate Ratios less than one and they did not transition to oversteer during any of the Circle tests conducted. During these autonomous 2-Rider loading condition tests, Vehicle C also has Yaw Rate Ratios less than one and it did not transition to oversteer during any of the Circle tests. However, the Circle and Yaw Rate Ratio tests for this vehicle were stopped by the test engineer at relatively low lateral acceleration levels (because there was some apprehension about the vehicle pitching/rolling over when the ATV RTD program was stopped).

Page 5 in Appendix B contains a summary table of the Right Turn (CW), Left Turn (CCW), and Average Yaw Rate Ratios computed from the Constant Steer tests. Page 6 in Appendix B is a bar chart of the Yaw Rate Ratio results.

The ANSI/ROHVA 1-2016 and ANSI/OPEI B71.9-2016 criteria for passing their constant steer handling test using an ROV is that neither the right turn Yaw Rate Ratio nor the left turn Yaw Rate Ratio exceeds 4.5.

4. COMPARISON OF 2-RIDER RESULTS TO DPI AND GVW RESULTS

As mentioned, for the previous Task Order 1 testing[12], all 12 of the vehicles were tested using a human driver in the representative driver-only (DPI) loading condition and nine of them were tested in the the Gross Vehicle Weight (GVW) loading condition. Vehicles B, H and I, were tested only in the DPI loading condition; because for these vehicles the added weight of the test driver and instrumentation brought the total test weight up to near their maximum weight ratings. Vehicles B, H and I are the only three manual transmission vehicles and they are the three lightest vehicles. All of the dynamic testing for the Task 1 measurements was conducted with a human test driver. This section contains a comparison of the results from the autonomous 2-Rider tests with those from some of the human driver DPI and GVW tests conducted previously.

4.1 Comparison of Circle Test Results

Table 5 is a summary table of the average CW and CCW lateral acceleration levels at which the vehicles that transitioned from understeer to oversteer did so during the autonomous 2-Rider and human driver DPI and GVW tests. "NA" in the table indicates that no transition to oversteer occurred.

Two of the vehicles, Vehicles D and E, remained understeering through the entire range of lateral accelerations tested in all three loading conditions (i.e. they did not transitions to oversteer). For these two vehicles, the general shapes of their characteristics curves are similar between all three loading conditions.

For eight of the vehicles (Vehicles A, B, F, G, H, I, J and K) the transition acceleration values are relatively close for all three loading conditions (and in these cases the general shapes of the characteristics curves are also similar). For these eight vehicles, all of the transition acceleration values are slightly lower for the 2-Rider tests than they are for the DPI tests. For these vehicles, the 2-Rider transition acceleration values are the same as, slightly lower or slightly higher than the GVW values.

Vehicle C did not exhibit a transition to oversteer during the autonomous 2-Rider tests, but it did during the human driver DPI and GVW tests. Vehicle L transitioned to oversteer at a higher acceleration value in the 2-Rider tests than it did in the DPI and GVW tests.

Figure 1 is a bar chart showing the Roll Gradients, the amount of roll angle in degrees per "g" of lateral acceleration measured during the 2-Rider, DPI and GVW Circle tests. For all of the vehicles, the roll gradients are greater for the autonomous 2-Rider tests than they are for the human driver DPI tests. The roll gradients are relative close between the autonomous 2-Rider and human driver GVW tests.

[12] *Vehicle Characteristics Measurements of All-Terrain Vehicles – Results from Tests on Twelve 2014-2015 Model Year Vehicles*, HHS Contract HHSP233201400030I, SEA, Ltd. Report to CPSC, November 2016. https://www.cpsc.gov/s3fs-public/SEA_Report_to_CPSC_Vehicle_Characteristics_Measurements_of_All_Terrain_Vehicles.pdf

4.2 Comparison of J-Turn Test Results

A summary of the Threshold Lateral Acceleration (Threshold Ay) values determined from the 20 mph Dropped Throttle J-Turn tests for all three loading conditions is given in Table 6. A bar chart with the same information is provided in Figure 2. The bar chart also shows each of the vehicle curb weights.

For all of the vehicles, except for the three lightest (the three manual transmission vehicles, Vehicles B, H and I), the Threshold Ay values are less for the autonomous 2-Rider tests than they are for the human driver DPI tests. For the nine automatic transmission vehicles for which GVW tests were conducted, the Threshold Ay values during the human driver GVW tests are equal to or less than they are for the autonomous 2-Rider tests.

For Vehicles B and H the Threshold Ay values measured during the autonomous 2-Rider tests are the same as those measured during the human driver DPI tests. For Vehicle I, the Threshold Ay value measured during the 2-Rider tests is slightly greater than (by 0.01 g) the value measured during the DPI tests.

4.3 Comparison of Yaw Rate Ratio Test Results

Table 7 contains results comparing the Average Yaw Rate Ratios determined from the Constant Steer tests for the autonomous 2-Rider tests and human driver DPI tests (Constant Steer tests were not conducted in the GVW loading condition).

As mentioned, Vehicles D and E are the most understeering vehicles tested, and these two vehicles have Yaw Rate Ratios less than one in both loading conditions tested.

Vehicles B and L have similar Average Yaw Rate Ratios during the autonomous 2-Rider and human driver DPI loading condition tests.

Seven of the vehicles, Vehicles A, F, G, H, I, J and K, have greater Average Yaw Rate Ratios in the 2-Rider loading condition than they do in the DPI loading condition; and for six of the seven (Vehicles A, F, G, H, I and J) the values are significantly greater. In the human driver DPI loading condition, Vehicles A and F exhibited the phenomenon of going from understeer to oversteer and then back to understeer, all at lateral acceleration levels less than 0.4 g.[13] The yaw rate ratio values for these two vehicles in the human driver DPI loading condition were computed using final lateral accelerations ranges up to the point of transition from oversteer to understeer (0.27-0.32 g for Vehicle A and 0.26-0.31 g for Vehicle F).

During the autonomous 2-Rider tests, Vehicle C also has an Average Yaw Rate Ratio less than one; but during the human driver DPI tests, Vehicle C had an Average Yaw Rate Ratio of 3.44. This result is consistent with the Circle test results for this vehicle, in that it did not transition to oversteer in the autonomous 2-Rider loading condition tests but it did in the human driver DPI (and GVW) loading condition tests.

[13] Ibid

4.4 Summary

These comparisons indicated that using the autonomous two-rider loading condition generally degrades stability and handling characteristics compared to using the human driver-only loading condition.

The Circle test results indicate that the majority of vehicles that transition to oversteer do so in the autonomous 2-Rider tests at a lower lateral acceleration value then they do during the human driver DPI tests.

The J-Turn test results showed that the 2-Rider loading condition generally provides less roll stabilty than the DPI loading condition except for the three lightest, manual transmission vehicles. The Threshold Ay values for the nine automatic transmission vehicles are all lower in the autonomous 2-Rider tests than they are in the human driver DPI tests. The Threshold Ay values for the three manual transmission vehicles are essentially the same in the autonomous 2-Rider tests as they are they are in the human driver DPI tests. Also, the roll gradients (measured during the Circle tests) were greater for all 12 vehicles tested in the 2-Rider loading condition than they were in the DPI loading condition. Higher roll gradients somewhat also reduce tip-up resistance.

The Yaw Rate Ratio test results indicate that the majority of vehicles with high Average Yaw Rate Ratio values during the human driver DPI tests have even higher Average Yaw Rate Ratio values during the autonomous 2-Rider tests.

The longitudinal center-of-gravity (CG) locations used during the autonomous 2-Rider tests were more rearward than they were during the DPI and GVW tests (see Appendix A). During the human driver DPI and GVW tests, most of the test equipment was mounted to the front of the vehicles. For the autonomous 2-Rider tests, some of the test equipment was moved to the rear of the vehicles, to offset the weight of the additional brake, throttle and clutch motors mounted on the front of the vehicles. Further, although the human test drivers attempted to remain “upright” during the DPI and GVW tests, they did lean during these tests to maintain their posture on the vehicles. Task Order 3 of this overall project involves using autonomous tests to study the effects of active drivers on the vehicle characteristics, and the vehicle test weights used for these tests are representative of a driver-only loading condition (close to the human driver DPI weight). Pending results from the Task Order 3 testing will include comparisons of autonomous tests conducted in both the 2-Rider and representative driver-only loading conditions, as well as comparisons of both autonomous and human-driver tests conducted in the representative driver-only loading condition. These pending test results will provide additional insight into the effects of longitudinal CG position and driver lean attitude on the test results.

Table 5: Comparison of US to OS Transitions Points

Constant Radius (50 ft) Circle Tests Lateral Acceleration Level at Point of Transition from Understeer to Oversteer Average of CW and CCW Values			
	Autonomous 2-Riders (g)	Human Driver DPI (g)	Human Driver GVW (g)
Vehicle A	0.15	0.16	0.15
Vehicle B	0.16	0.18	Not Tested
Vehicle C	NA	0.21	0.19
Vehicle D	NA	NA	NA
Vehicle E	NA	NA	NA
Vehicle F	0.12	0.13	0.11
Vehicle G	0.16	0.18	0.14
Vehicle H	0.11	0.13	Not Tested
Vehicle I	0.11	0.13	Not Tested
Vehicle J	0.10	0.15	0.13
Vehicle K	0.23	0.24	0.23
Vehicle L	0.36	0.24	0.28

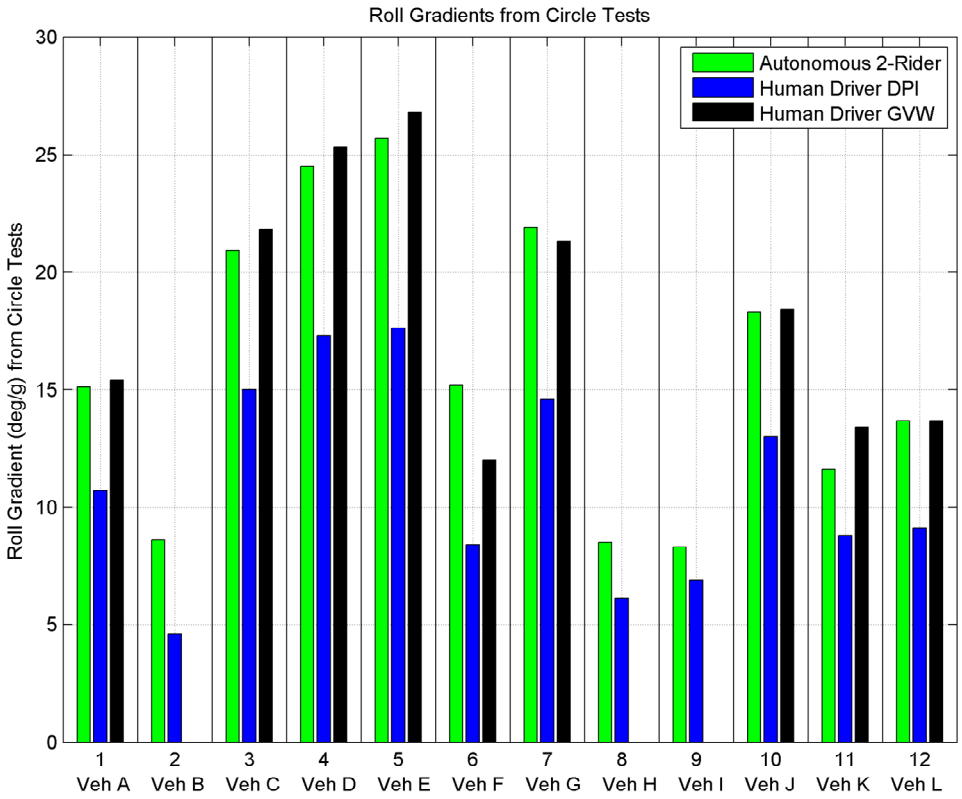


Figure 1: Comparison of Roll Gradients

Table 6: Comparison of Threshold Ay Values

20 mph Dropped Throttle J-Turn Tests Threshold Lateral Acceleration Average of Right and Left Turn Values			
	Autonomous 2-Riders (g)	Human Driver DPI (g)	Human Driver GVW (g)
Vehicle A	0.364	0.385	0.350
Vehicle B	0.548	0.548	Not Tested
Vehicle C	0.448	0.495	0.428
Vehicle D	0.489	0.553	0.485
Vehicle E	0.493	0.548	0.466
Vehicle F	0.371	0.411	0.367
Vehicle G	0.399	0.425	0.353
Vehicle H	0.546	0.548	Not Tested
Vehicle I	0.513	0.502	Not Tested
Vehicle J	0.431	0.493	0.421
Vehicle K	0.494	0.538	0.477
Vehicle L	0.519	0.565	0.521

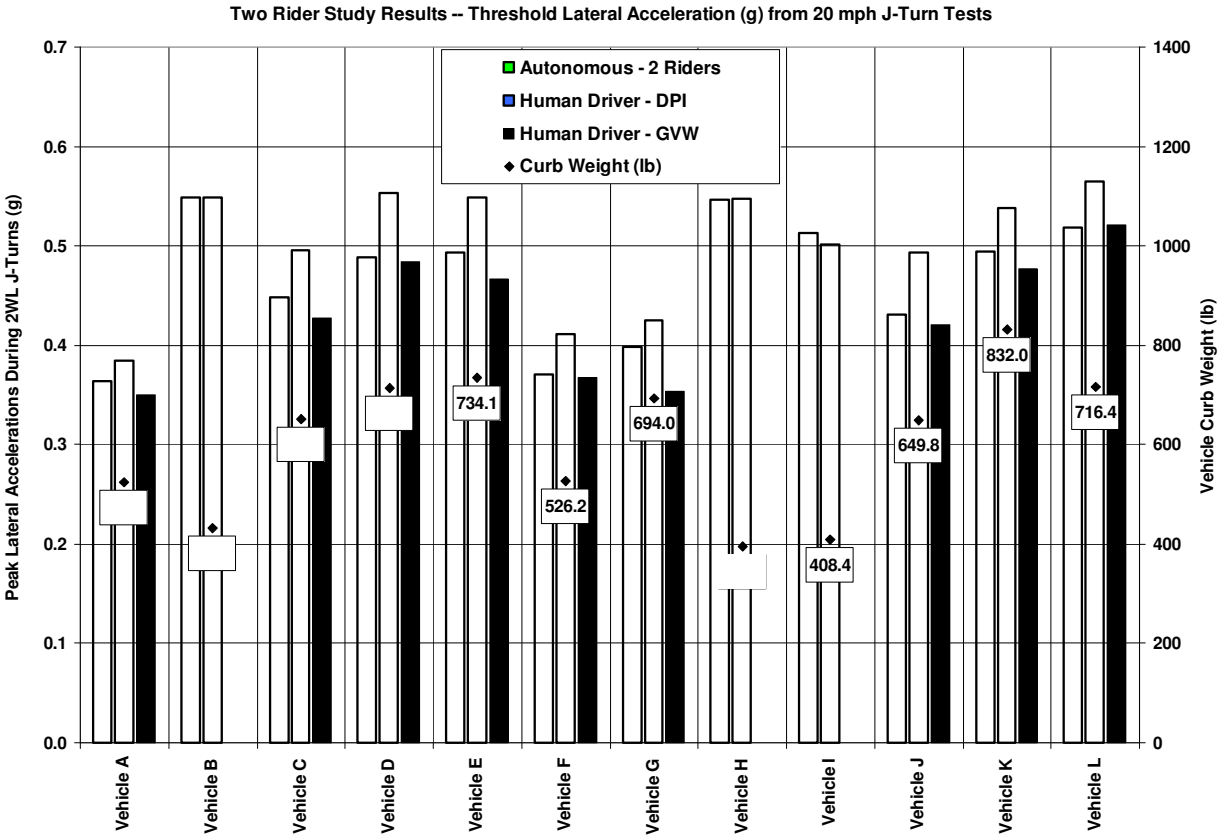


Figure 2: Comparison of Threshold Ay Values

Table 7: Comparison of Yaw Rate Ratio Values

Constant Steer Tests Yaw Rate Ratios Average of Right and Left Turn Values		
	Autonomous 2-Riders	Human Driver DPI
Vehicle A	49.0	2.11
Vehicle B	2.35	2.70
Vehicle C	0.19	3.44
Vehicle D	0.21	0.17
Vehicle E	0.38	0.20
Vehicle F	17.1	3.32
Vehicle G	68.0	5.49
Vehicle H	79.4	40.2
Vehicle I	101	3.52
Vehicle J	48.9	20.8
Vehicle K	4.54	2.51
Vehicle L	1.12	2.65

Vehicle A

	Curb	Driver	Driver Plus Instrumentation (DPI)	Gross Vehicle Weight (GVW)	Autonomous Ballast to Driver Loading	Autonomous Ballast to 2 Riders
VIMF Test Number		5765	5766	5842		
Total Vehicle Weight (lb)	523.9	737.1	759.6	989.7	741.1	954.4
Left Front Weight (lb)	151.5	177.3	198.3	232.2	168.4	187.6
Right Front Weight (lb)	118.4	161.0	176.8	212.1	160.4	176.3
Left Rear Weight (lb)	132.0	206.1	204.4	293.5	211.6	300.2
Right Rear Weight (lb)	122.0	192.7	180.1	251.9	200.7	290.3
Front Track Width (in)	33.20	33.50	33.66	33.93	33.50	33.93
Rear Track Width (in)	32.25	32.30	32.28	32.35	32.30	32.35
Average Track Width (in)	32.73	32.90	32.97	33.14	32.90	33.14
Wheelbase (in)	48.40	48.35	48.30	48.25	48.35	48.25
CG Longitudinal (in)	23.47	26.16	24.45	26.59	26.90	29.85
CG Lateral (in)	-1.36	-0.66	-0.99	-1.02	-0.42	-0.37
CG Height (in)		23.61	22.65	25.00		
Roll Inertia - I_{XX} (ft-lb-s^2)		55	66	86		
Pitch Inertia - I_{YY} (ft-lb-s^2)		73	80	141		
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		54	63	115		
Roll/Yaw - I_{XZ} (ft-lb-s^2)		4	3	8		
SSF		0.697	0.728	0.663		
KST		0.698	0.728	0.664		
Steering Ratio (deg/deg)			1.42			

Vehicle B

	Curb	Driver	Driver Plus Instrumentation (DPI)	Gross Vehicle Weight (GVW)	Autonomous Ballast to Driver Loading	Autonomous Ballast to 2 Riders
VIMF Test Number		5768	5769			
Total Vehicle Weight (lb)	432.8	644.9	689.6		660.8	859.6
Left Front Weight (lb)	117.8	144.0	174.5		143.8	164.2
Right Front Weight (lb)	101.4	130.9	156.6		140.9	158.4
Left Rear Weight (lb)	107.7	181.7	172.0		185.1	258.1
Right Rear Weight (lb)	105.9	188.3	186.5		191.0	278.9
Front Track Width (in)	37.78	38.13	38.45		38.13	38.58
Rear Track Width (in)	35.58	35.50	35.40		35.50	35.50
Average Track Width (in)	36.68	36.81	36.93		36.81	37.04
Wheelbase (in)	50.30	50.85	50.85		50.85	51.50
CG Longitudinal (in)	24.82	29.17	26.44		28.94	32.17
CG Lateral (in)	-0.79	-0.21	-0.13		0.07	0.30
CG Height (in)		22.77	22.34			
Roll Inertia - I_{XX} (ft-lb-s^2)		48	48			
Pitch Inertia - I_{YY} (ft-lb-s^2)		61	71			
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		42	56			
Roll/Yaw - I_{XZ} (ft-lb-s^2)		4	4			
SSF		0.808	0.826			
KST		0.813	0.828			
Steering Ratio (deg/deg)			1.34			

Vehicle C

	Curb	Driver	Driver Plus Instrumentation (DPI)	Gross Vehicle Weight (GVW)	Autonomous Ballast to Driver Loading	Autonomous Ballast to 2 Riders
VIMF Test Number		5771	5772	5844		
Total Vehicle Weight (lb)	650.8	863.6	885.0	1135.1	864.0	1080.2
Left Front Weight (lb)	175.1	208.3	224.7	251.5	195.0	212.7
Right Front Weight (lb)	163.9	199.5	221.9	245.1	194.0	210.3
Left Rear Weight (lb)	155.9	231.6	225.7	317.5	236.7	324.6
Right Rear Weight (lb)	155.9	224.2	212.7	321.0	238.3	332.6
Front Track Width (in)	39.71	39.95	39.95	40.10	39.95	40.10
Rear Track Width (in)	37.66	38.40	38.45	38.85	38.40	38.85
Average Track Width (in)	38.69	39.18	39.20	39.48	39.18	39.48
Wheelbase (in)	49.33	49.30	49.30	49.30	49.30	49.30
CG Longitudinal (in)	23.63	26.02	24.42	27.73	27.10	29.99
CG Lateral (in)	-0.34	-0.37	-0.35	-0.05	0.01	0.10
CG Height (in)		23.74	22.97	25.50		
Roll Inertia - I_{XX} (ft-lb-s^2)		75	78	109		
Pitch Inertia - I_{YY} (ft-lb-s^2)		92	101	174		
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		72	83	147		
Roll/Yaw - I_{XZ} (ft-lb-s^2)		7	5	18		
SSF		0.825	0.853	0.774		
KST		0.826	0.853	0.776		
Steering Ratio (deg/deg)			1.62			

Vehicle D

	Curb	Driver	Driver Plus Instrumentation (DPI)	Gross Vehicle Weight (GVW)	Autonomous Ballast to Driver Loading	Autonomous Ballast to 2 Riders
VIMF Test Number		5774	5775	5845		
Total Vehicle Weight (lb)	714.0	927.4	948.8	1227.9	929.7	1143.8
Left Front Weight (lb)	179.9	216.3	234.7	268.9	206.6	229.5
Right Front Weight (lb)	169.7	205.7	223.9	269.9	203.7	225.5
Left Rear Weight (lb)	181.7	254.2	246.6	352.7	254.2	338.6
Right Rear Weight (lb)	182.7	251.2	243.6	336.4	265.2	350.2
Front Track Width (in)	39.46	39.90	39.99	40.40	39.90	40.40
Rear Track Width (in)	38.08	38.88	38.85	39.64	38.88	39.64
Average Track Width (in)	38.77	39.39	39.42	40.02	39.39	40.02
Wheelbase (in)	50.05	49.88	49.90	50.00	49.88	50.00
CG Longitudinal (in)	25.54	27.18	25.78	28.06	27.87	30.11
CG Lateral (in)	-0.26	-0.29	-0.29	-0.25	0.17	0.13
CG Height (in)		24.14	23.54	26.27		
Roll Inertia - I_{XX} (ft-lb-s^2)		75	74	119		
Pitch Inertia - I_{YY} (ft-lb-s^2)		108	114	200		
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		88	99	170		
Roll/Yaw - I_{XZ} (ft-lb-s^2)		9	6	16		
SSF		0.816	0.837	0.762		
KST		0.817	0.838	0.763		
Steering Ratio (deg/deg)			1.22			

Vehicle E

	Curb	Driver	Driver Plus Instrumentation (DPI)	Gross Vehicle Weight (GVW)	Autonomous Ballast to Driver Loading	Autonomous Ballast to 2 Riders
VIMF Test Number		5777	5778	5846		
Total Vehicle Weight (lb)	734.1	947.6	968.9	1248.5	948.5	1160.7
Left Front Weight (lb)	190.3	221.1	245.4	277.0	208.9	231.9
Right Front Weight (lb)	168.5	210.1	220.9	260.1	209.1	230.7
Left Rear Weight (lb)	186.9	260.3	251.7	357.8	257.0	346.4
Right Rear Weight (lb)	188.4	256.1	250.9	353.6	273.5	351.7
Front Track Width (in)	39.48	39.80	40.05	40.50	39.80	40.50
Rear Track Width (in)	38.13	39.05	39.20	39.80	39.05	39.80
Average Track Width (in)	38.80	39.43	39.63	40.15	39.43	40.15
Wheelbase (in)	49.95	49.95	49.95	49.95	49.95	49.95
CG Longitudinal (in)	25.54	27.22	25.91	28.46	27.94	30.04
CG Lateral (in)	-0.55	-0.32	-0.52	-0.34	0.34	0.07
CG Height (in)		23.70	23.12	26.24		
Roll Inertia - I_{XX} (ft-lb-s^2)		72	76	125		
Pitch Inertia - I_{YY} (ft-lb-s^2)		108	116	201		
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		95	100	169		
Roll/Yaw - I_{XZ} (ft-lb-s^2)		5	6	20		
SSF		0.832	0.857	0.765		
KST		0.832	0.857	0.766		
Steering Ratio (deg/deg)			1.21			

Vehicle F

	Curb	Driver	Driver Plus Instrumentation (DPI)	Gross Vehicle Weight (GVW)	Autonomous Ballast to Driver Loading	Autonomous Ballast to 2 Riders
VIMF Test Number		5780	5781	5847		
Total Vehicle Weight (lb)	526.2	739.8	761.4	924.0	741.5	954.5
Left Front Weight (lb)	149.1	166.1	190.7	211.9	162.4	188.7
Right Front Weight (lb)	122.7	172.1	179.2	198.3	159.4	184.3
Left Rear Weight (lb)	151.6	213.1	208.6	270.9	220.8	300.9
Right Rear Weight (lb)	102.8	188.5	182.9	242.9	198.9	280.6
Front Track Width (in)	32.14	32.55	32.45	32.76	32.55	32.76
Rear Track Width (in)	30.71	30.95	30.89	30.98	30.95	30.98
Average Track Width (in)	31.43	31.75	31.67	31.87	31.75	31.87
Wheelbase (in)	46.20	46.20	46.20	46.20	46.20	46.20
CG Longitudinal (in)	22.34	25.08	23.76	25.69	26.15	28.15
CG Lateral (in)	-2.23	-0.38	-0.77	-0.71	-0.52	-0.40
CG Height (in)		23.45	22.38	24.04		
Roll Inertia - I_{XX} (ft-lb-s^2)		53	60	74		
Pitch Inertia - I_{YY} (ft-lb-s^2)		74	78	114		
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		52	60	93		
Roll/Yaw - I_{XZ} (ft-lb-s^2)		6	4	11		
SSF		0.677	0.708	0.663		
KST		0.678	0.708	0.665		
Steering Ratio (deg/deg)			1.29			

Vehicle G

	Curb	Driver	Driver Plus Instrumentation (DPI)	Gross Vehicle Weight (GVW)	Autonomous Ballast to Driver Loading	Autonomous Ballast to 2 Riders
VIMF Test Number		5783	5784	5848		
Total Vehicle Weight (lb)	694.0	909.4	928.6	1168.7	913.5	1127.7
Left Front Weight (lb)	174.2	215.4	223.9	253.3	198.2	220.2
Right Front Weight (lb)	168.1	199.1	219.4	251.0	198.7	222.5
Left Rear Weight (lb)	175.9	246.6	242.5	332.9	253.8	337.6
Right Rear Weight (lb)	175.8	248.3	242.8	331.5	262.8	347.4
Front Track Width (in)	36.35	36.45	36.50	36.45	36.45	36.45
Rear Track Width (in)	35.60	36.10	36.06	36.60	36.10	36.60
Average Track Width (in)	35.98	36.28	36.28	36.53	36.28	36.53
Wheelbase (in)	50.55	50.65	50.60	50.60	50.65	50.60
CG Longitudinal (in)	25.62	27.56	26.44	28.77	28.64	30.74
CG Lateral (in)	-0.16	-0.29	-0.08	-0.06	0.19	0.20
CG Height (in)		24.07	23.34	26.13		
Roll Inertia - I_{XX} (ft-lb-s^2)		79	75	109		
Pitch Inertia - I_{YY} (ft-lb-s^2)		110	117	198		
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		88	96	163		
Roll/Yaw - I_{XZ} (ft-lb-s^2)		5	5	17		
SSF		0.753	0.777	0.699		
KST		0.754	0.777	0.699		
Steering Ratio (deg/deg)			1.41			

Vehicle H

	Curb	Driver	Driver Plus Instrumentation (DPI)	Gross Vehicle Weight (GVW)	Autonomous Ballast to Driver Loading	Autonomous Ballast to 2 Riders
VIMF Test Number		5789	5790			
Total Vehicle Weight (lb)	395.5	608.7	654.6		621.6	821.2
Left Front Weight (lb)	103.2	130.8	160.0		123.8	138.0
Right Front Weight (lb)	93.4	121.8	161.2		126.9	148.0
Left Rear Weight (lb)	99.6	178.8	163.7		186.9	269.7
Right Rear Weight (lb)	99.3	177.3	169.7		184.0	265.5
Front Track Width (in)	38.75	39.00	39.35		39.00	38.85
Rear Track Width (in)	35.30	35.35	35.33		35.35	35.60
Average Track Width (in)	37.03	37.18	37.34		37.18	37.23
Wheelbase (in)	49.25	49.60	49.30		49.60	50.13
CG Longitudinal (in)	24.77	29.02	25.11		29.60	32.67
CG Lateral (in)	-0.49	-0.33	0.20		0.01	0.15
CG Height (in)		22.08	21.45			
Roll Inertia - I_{XX} (ft-lb-s^2)		48	46			
Pitch Inertia - I_{YY} (ft-lb-s^2)		59	69			
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		43	52			
Roll/Yaw - I_{XZ} (ft-lb-s^2)		3	4			
SSF		0.842	0.870			
KST		0.849	0.871			
Steering Ratio (deg/deg)			1.41			

Vehicle I

	Curb	Driver	Driver Plus Instrumentation (DPI)	Gross Vehicle Weight (GVW)	Autonomous Ballast to Driver Loading	Autonomous Ballast to 2 Riders
VIMF Test Number		5786	5787			
Total Vehicle Weight (lb)	408.4	621.6	656.8		633.2	837.5
Left Front Weight (lb)	100.9	131.8	157.7		123.2	142.4
Right Front Weight (lb)	95.9	132.1	147.1		125.3	140.4
Left Rear Weight (lb)	113.6	187.3	186.3		198.1	284.9
Right Rear Weight (lb)	98.0	170.4	165.7		186.6	269.8
Front Track Width (in)	35.85	36.40	36.50		36.40	36.30
Rear Track Width (in)	35.55	35.63	35.63		35.63	35.63
Average Track Width (in)	35.70	36.01	36.06		36.01	35.97
Wheelbase (in)	47.95	48.35	48.40		48.35	49.35
CG Longitudinal (in)	24.84	27.82	25.94		29.37	32.69
CG Lateral (in)	-0.90	-0.48	-0.85		-0.26	-0.36
CG Height (in)		23.29	22.71			
Roll Inertia - I_{XX} (ft-lb-s^2)		51	49			
Pitch Inertia - I_{YY} (ft-lb-s^2)		56	68			
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		51	53			
Roll/Yaw - I_{XZ} (ft-lb-s^2)		2	3			
SSF		0.773	0.794			
KST		0.774	0.795			
Steering Ratio (deg/deg)			1.33			

Vehicle J

	Curb	Driver	Driver Plus Instrumentation (DPI)	Gross Vehicle Weight (GVW)	Autonomous Ballast to Driver Loading	Autonomous Ballast to 2 Riders
VIMF Test Number		5792	5793	5851		
Total Vehicle Weight (lb)	649.8	862.4	885.2	1135.3	869.1	1086.3
Left Front Weight (lb)	172.3	202.7	216.1	255.7	195.7	218.1
Right Front Weight (lb)	160.9	195.8	208.8	248.6	195.9	220.9
Left Rear Weight (lb)	151.2	230.4	228.1	313.0	232.7	321.3
Right Rear Weight (lb)	165.4	233.5	232.2	318.0	244.8	326
Front Track Width (in)	36.05	36.73	36.79	36.96	36.73	36.96
Rear Track Width (in)	37.13	38.01	38.00	38.38	38.01	38.38
Average Track Width (in)	36.59	37.37	37.39	37.67	37.37	37.67
Wheelbase (in)	50.50	50.45	50.35	50.25	50.45	50.25
CG Longitudinal (in)	24.60	27.14	26.18	27.93	27.72	29.94
CG Lateral (in)	0.09	-0.08	-0.06	-0.03	0.27	0.13
CG Height (in)		23.76	23.08	25.40		
Roll Inertia - I_{XX} (ft-lb-s^2)		69	68	87		
Pitch Inertia - I_{YY} (ft-lb-s^2)		98	103	176		
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		69	89	154		
Roll/Yaw - I_{XZ} (ft-lb-s^2)		8	8	14		
SSF		0.786	0.810	0.742		
KST		0.785	0.810	0.740		
Steering Ratio (deg/deg)			1.42			

Vehicle K

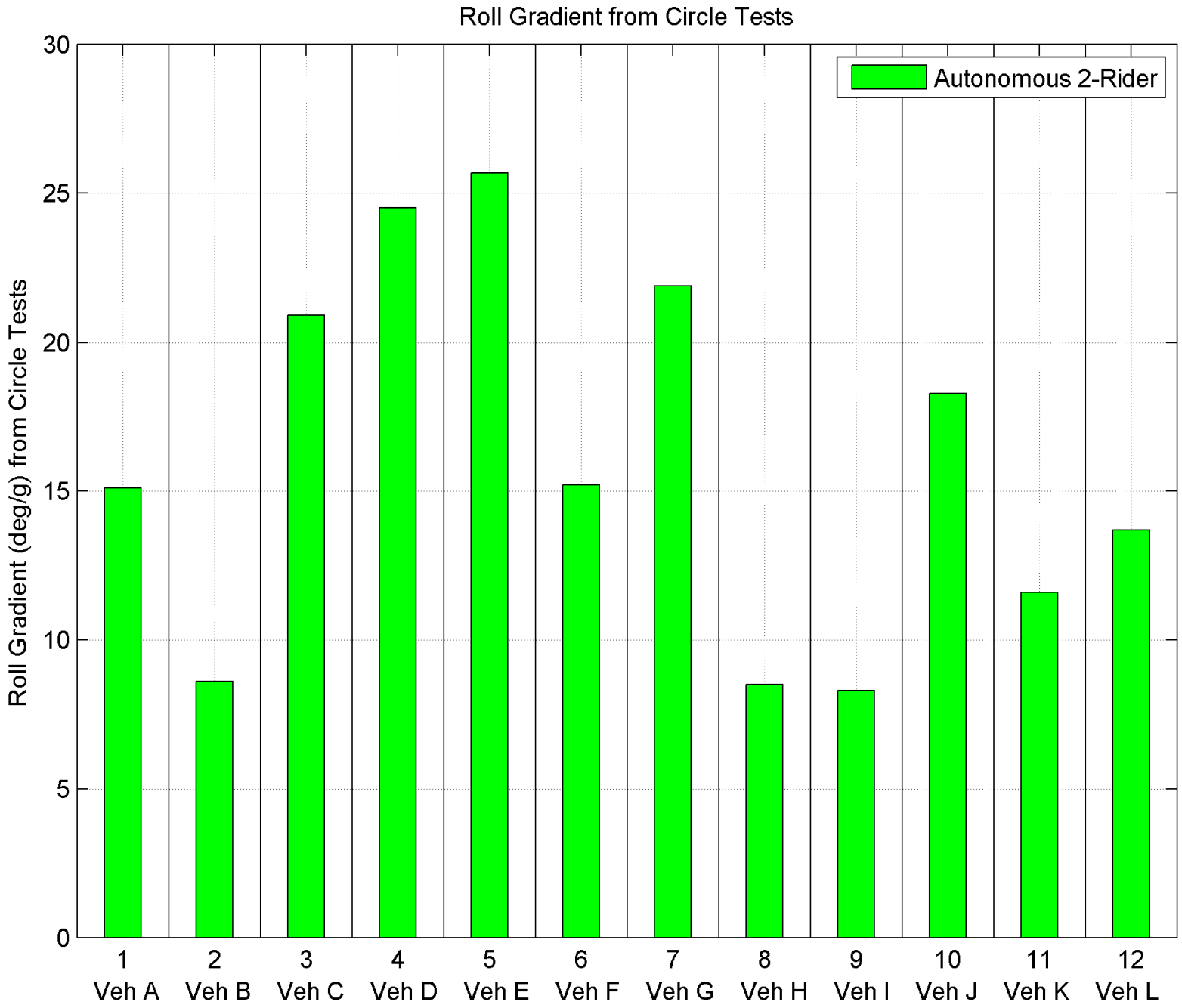
	Curb	Driver	Driver Plus Instrumentation (DPI)	Gross Vehicle Weight (GVW)	Autonomous Ballast to Driver Loading	Autonomous Ballast to 2 Riders
VIMF Test Number		5795	5796	5852		
Total Vehicle Weight (lb)	832.0	1044.8	1070.7	1412.1	1045.6	1258.7
Left Front Weight (lb)	206.7	239.9	241.8	283.8	227.0	253.4
Right Front Weight (lb)	192.0	220.6	224.7	268.3	217.7	246.7
Left Rear Weight (lb)	227.2	295.8	303.9	435.4	294.9	372.6
Right Rear Weight (lb)	206.1	288.5	300.3	424.6	306.0	386.0
Front Track Width (in)	39.96	40.83	40.83	41.30	40.83	41.30
Rear Track Width (in)	38.20	39.24	39.16	40.13	39.24	40.13
Average Track Width (in)	39.08	40.03	39.99	40.71	40.03	40.71
Wheelbase (in)	53.15	53.15	53.20	53.20	53.15	53.20
CG Longitudinal (in)	27.68	29.72	30.02	32.40	30.54	32.06
CG Lateral (in)	-0.84	-0.51	-0.39	-0.38	0.03	0.10
CG Height (in)		23.44	22.92	25.51		
Roll Inertia - I_{XX} (ft-lb-s^2)		73	79	110		
Pitch Inertia - I_{YY} (ft-lb-s^2)		130	138	234		
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		116	126	208		
Roll/Yaw - I_{XZ} (ft-lb-s^2)		4	5	17		
SSF		0.854	0.873	0.798		
KST		0.856	0.875	0.800		
Steering Ratio (deg/deg)			1.43			

Vehicle L

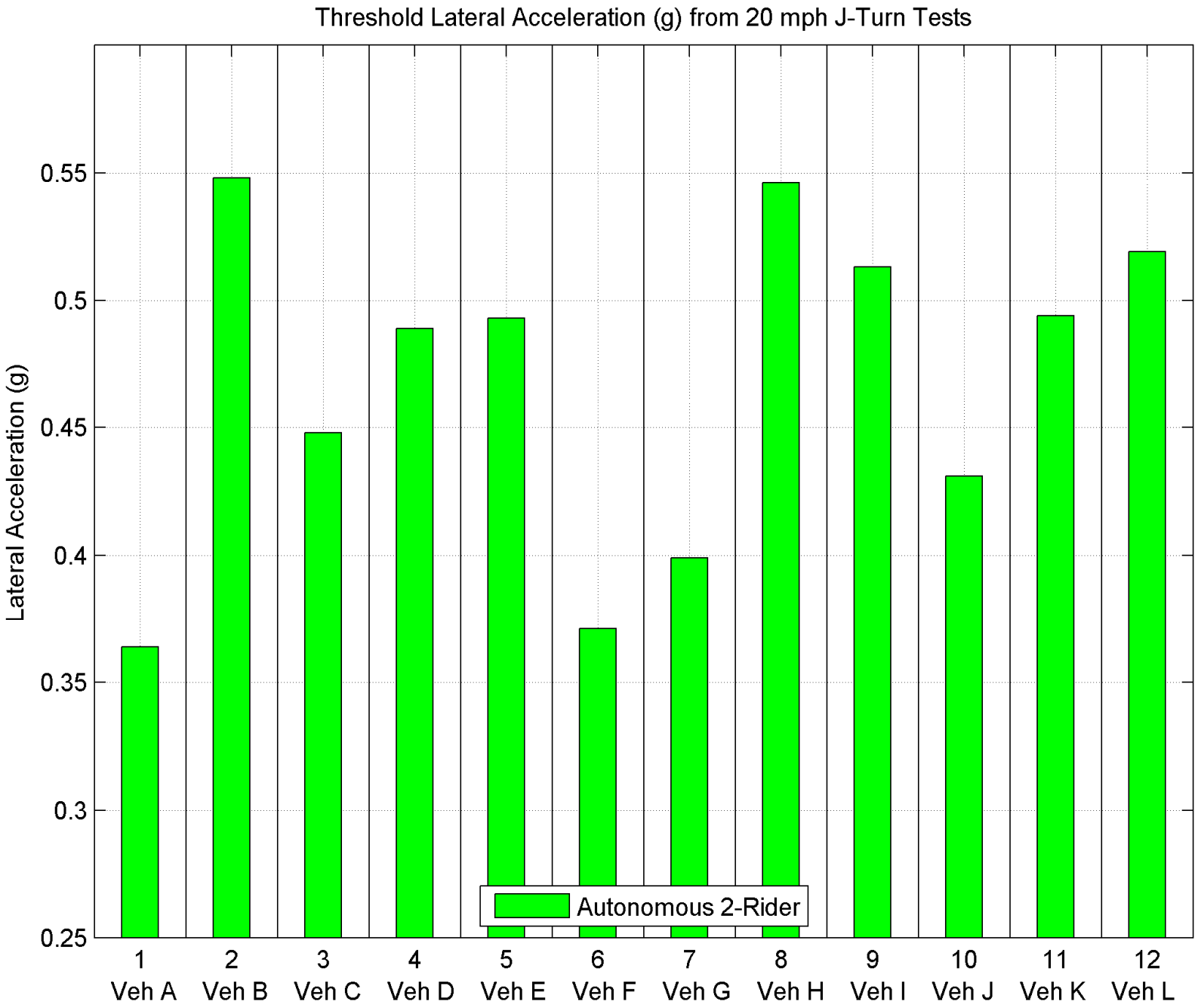
	Curb	Driver	Driver Plus Instrumentation (DPI)	Gross Vehicle Weight (GVW)	Autonomous Ballast to Driver Loading	Autonomous Ballast to 2 Riders
VIMF Test Number		5798	5799	5853		
Total Vehicle Weight (lb)	716.4	929.1	951.1	1201.3	932.4	1142.1
Left Front Weight (lb)	185.8	216.9	235.3	261.4	205.6	231.1
Right Front Weight (lb)	159.6	202.4	217.1	250.3	197.4	221.0
Left Rear Weight (lb)	189.5	253.1	246.8	342.1	253.1	334.7
Right Rear Weight (lb)	181.5	256.7	251.9	347.5	276.3	355.3
Front Track Width (in)	39.59	39.76	39.80	39.40	39.76	39.40
Rear Track Width (in)	37.00	37.50	37.50	36.90	37.50	36.90
Average Track Width (in)	38.29	38.63	38.65	38.15	38.63	38.15
Wheelbase (in)	50.50	50.60	50.60	50.45	50.60	50.45
CG Longitudinal (in)	26.15	27.76	26.53	28.96	28.73	30.48
CG Lateral (in)	-0.93	-0.24	-0.28	-0.10	0.29	0.16
CG Height (in)		22.96	22.53	25.02		
Roll Inertia - I_{XX} (ft-lb-s^2)		78	84	132		
Pitch Inertia - I_{YY} (ft-lb-s^2)		115	120	185		
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		98	101	157		
Roll/Yaw - I_{XZ} (ft-lb-s^2)		5	7	18		
SSF		0.841	0.858	0.762		
KST		0.844	0.859	0.766		
Steering Ratio (deg/deg)			1.60			

Constant Radius (50 ft) Circle Tests
Lateral Acceleration Level at Point of Transition from Understeer to Oversteer (Autonomous 2-Rider Loading)

	CW (g)	CCW (g)	Average (g)
Vehicle A	0.15	0.14	0.15
Vehicle B	0.16	0.16	0.16
Vehicle C	NA	NA	NA
Vehicle D	NA	NA	NA
Vehicle E	NA	NA	NA
Vehicle F	0.14	0.11	0.12
Vehicle G	0.17	0.14	0.16
Vehicle H	0.12	0.11	0.11
Vehicle I	0.11	0.13	0.11
Vehicle J	0.10	0.10	0.10
Vehicle K	0.22	0.24	0.23
Vehicle L	0.37	0.35	0.36

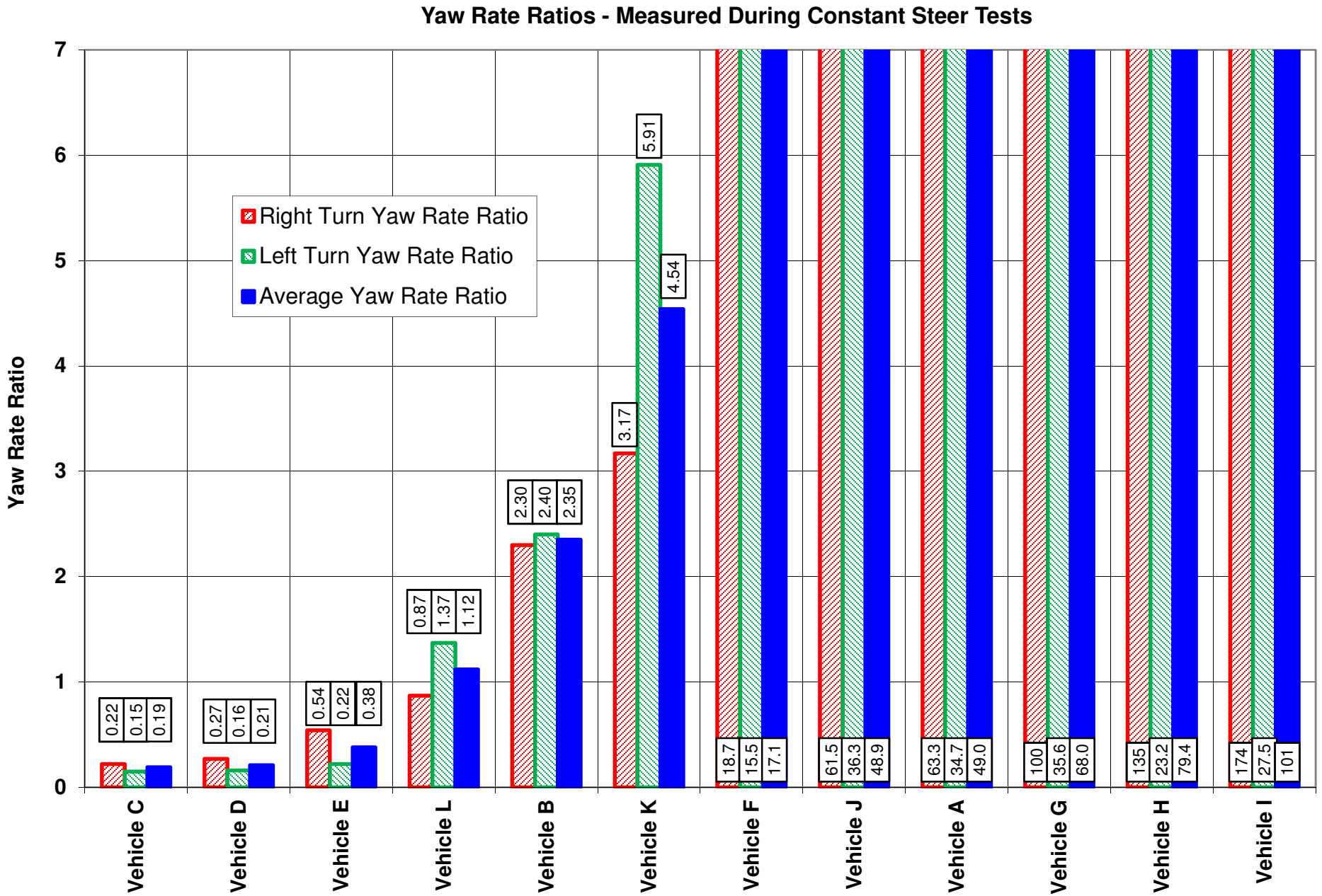

Roll Gradient from Circle Tests
Autonomous 2-Rider
Roll Gradient (deg/g) from Circle Tests
0
5
10
15
20
25
30
1 Veh A
2 Veh B
3 Veh C
4 Veh D
5 Veh E
6 Veh F
7 Veh G
8 Veh H
9 Veh I
10 Veh J
11 Veh K
12 Veh L

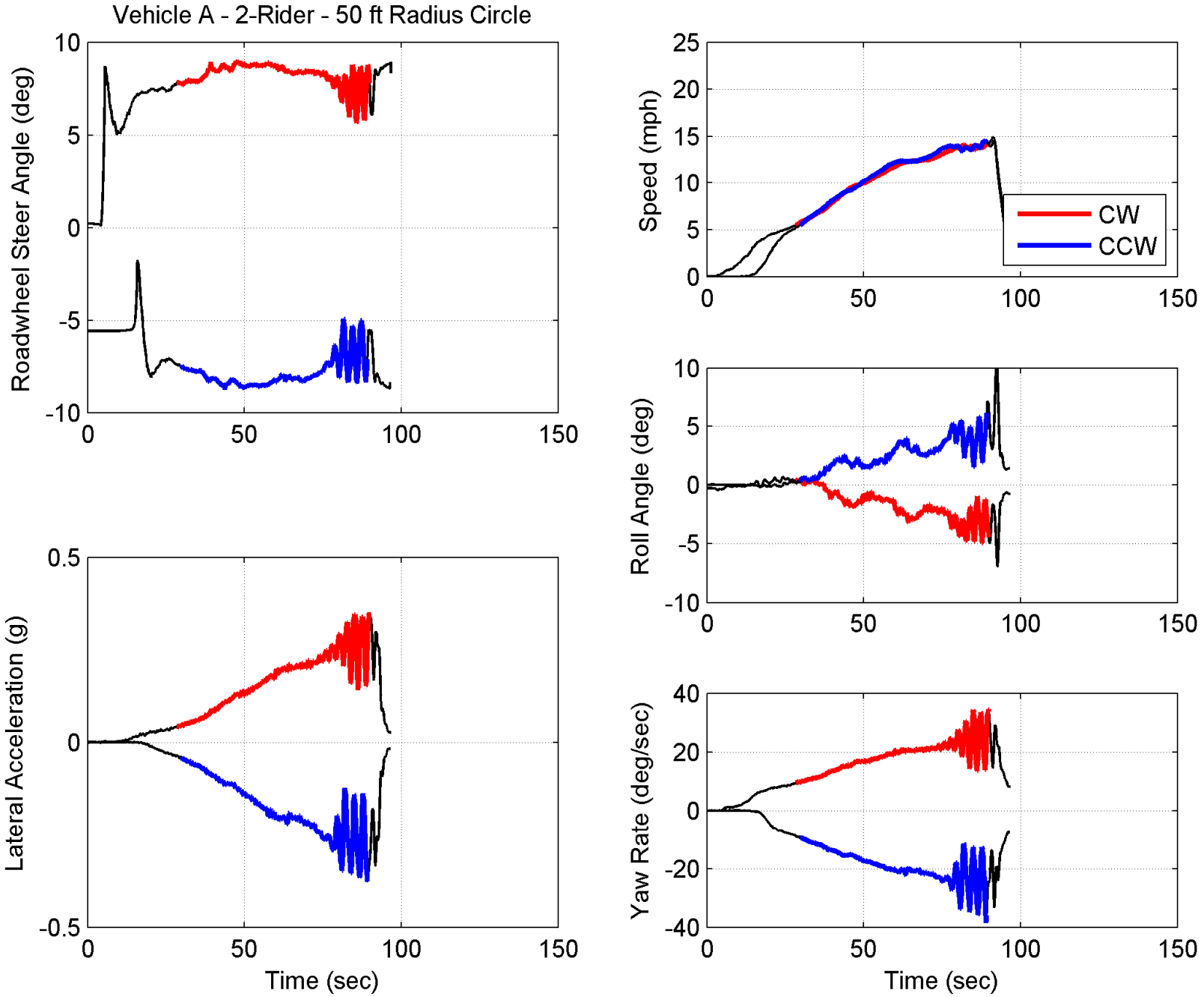
20 mph Dropped Throttle J-Turn Tests Threshold Lateral Acceleration (Autonomous 2-Rider Loading)	
	Threshold Lateral Acceleration (g)
Vehicle A	0.364
Vehicle B	0.548
Vehicle C	0.448
Vehicle D	0.489
Vehicle E	0.493
Vehicle F	0.371
Vehicle G	0.399
Vehicle H	0.546
Vehicle I	0.513
Vehicle J	0.431
Vehicle K	0.494
Vehicle L	0.519

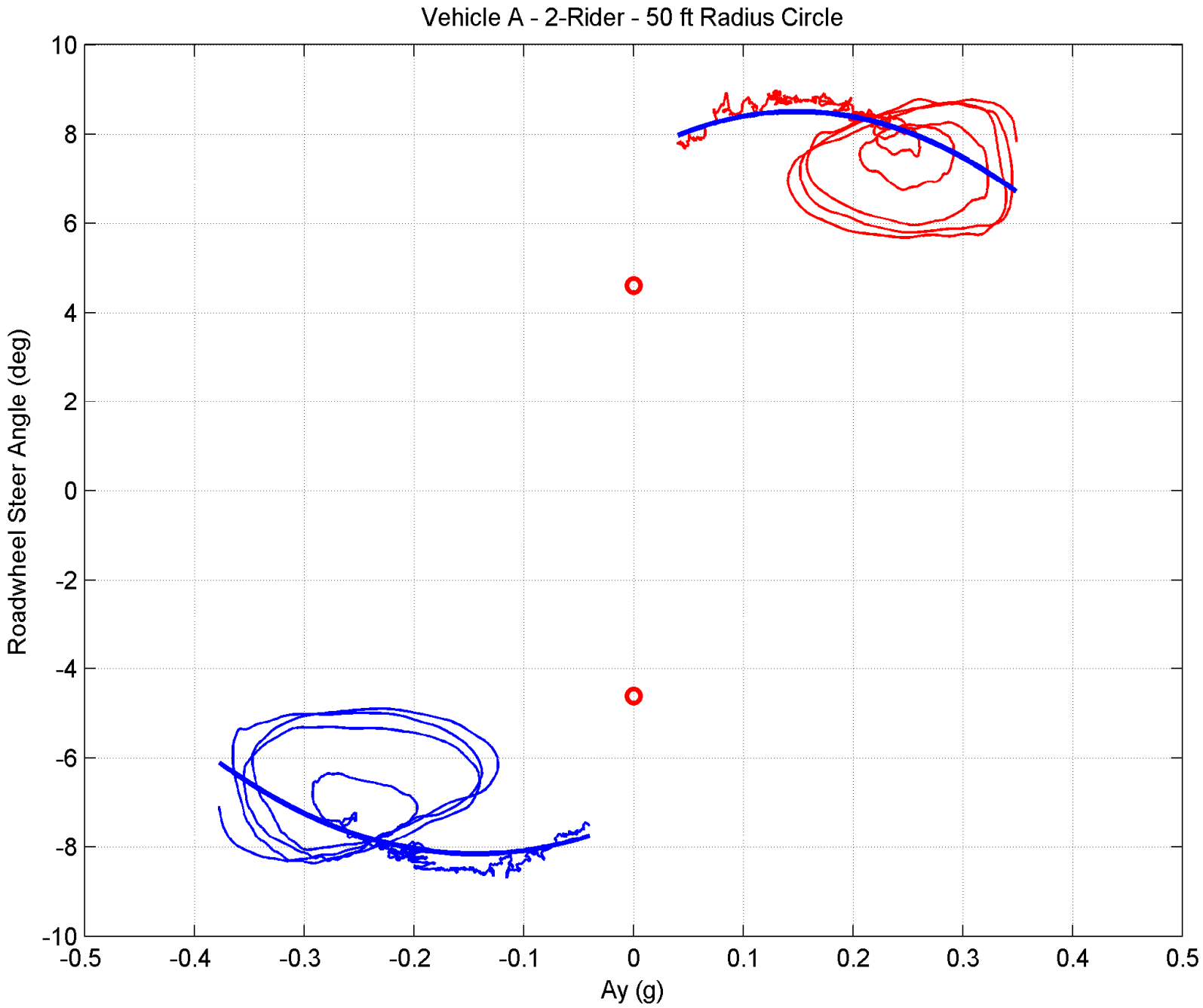

Threshold Lateral Acceleration (g) from 20 mph J-Turn Tests
Lateral Acceleration (g)
0.55
0.5
0.45
0.4
0.35
0.3
0.25
Autonomous 2-Rider
1
Veh A
2
Veh B
3
Veh C
4
Veh D
5
Veh E
6
Veh F
7
Veh G
8
Veh H
9
Veh I
10
Veh J
11
Veh K
12
Veh L

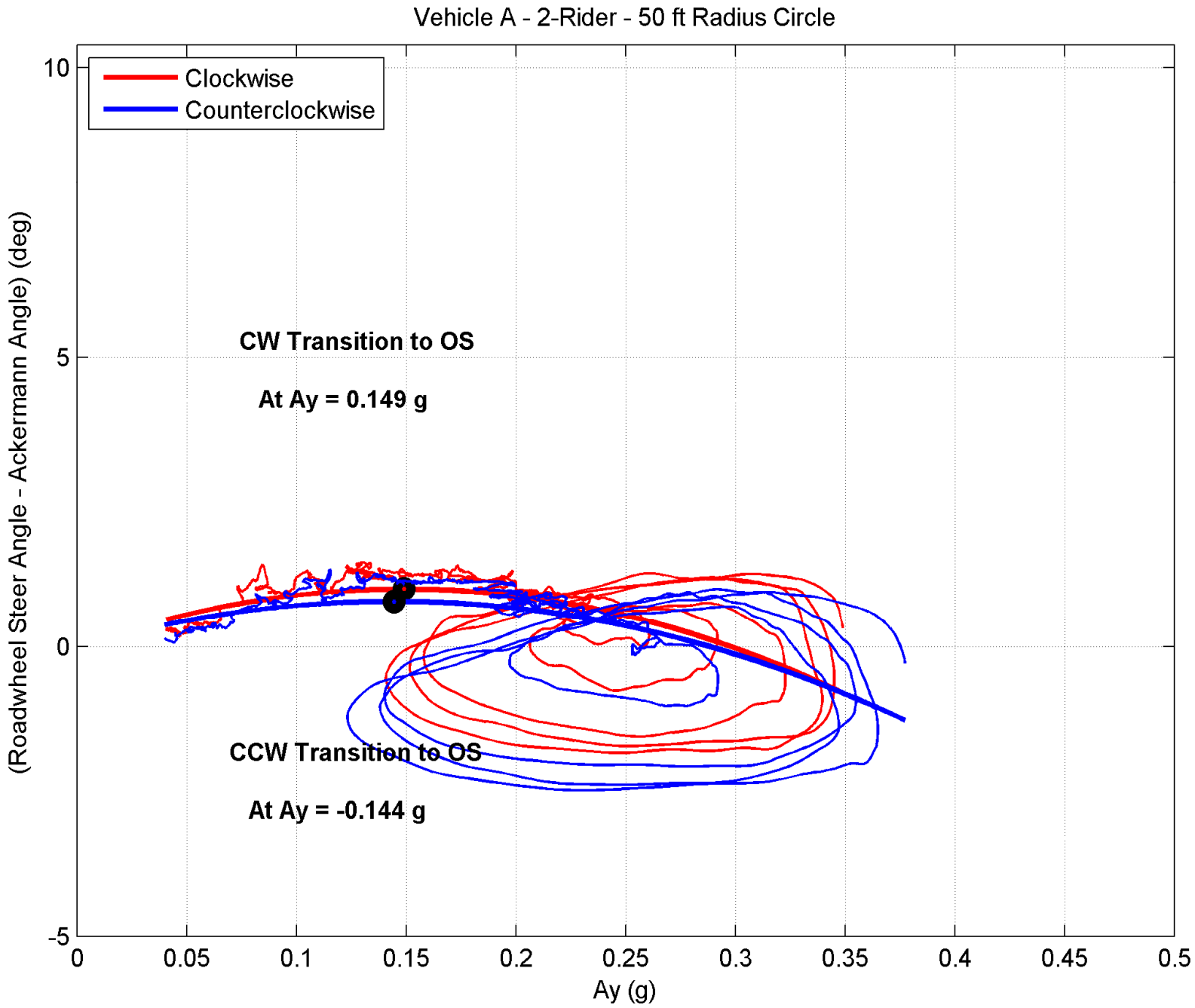
Constant Steer Tests
Yaw Rate Ratios
(Autonomous 2-Rider Loading)

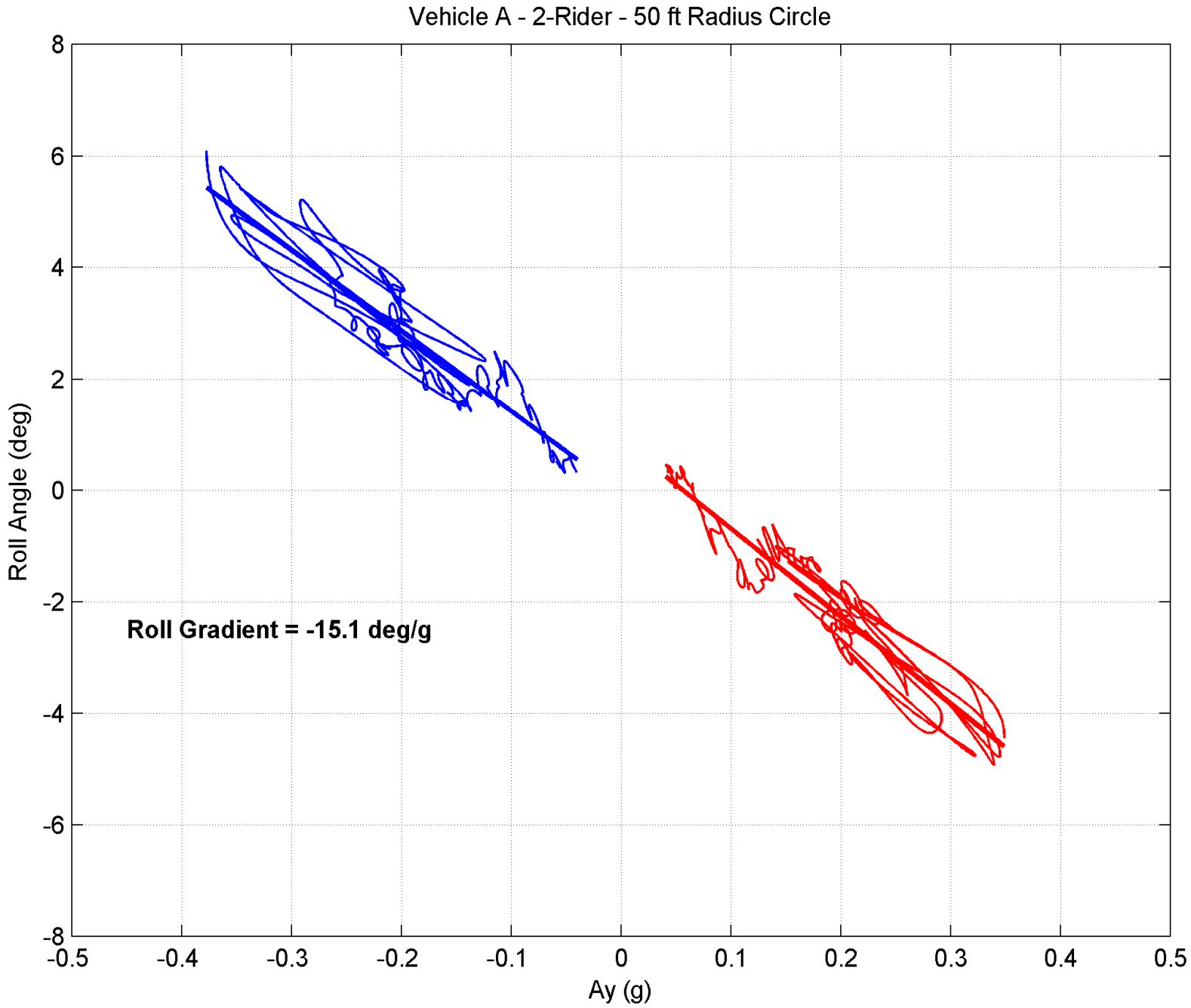
	Maximum Ay Used (g)	Initial Path Radius (ft)	Right Turn Ratio	Left Turn Ratio	Average Ratio
Vehicle A	0.34	50	63.3	34.7	49.0
Vehicle B	0.35	25	2.30	2.40	2.35
Vehicle C	0.30	50	0.22	0.15	0.19
Vehicle D	0.32	25	0.27	0.16	0.21
Vehicle E	0.28	25	0.54	0.22	0.38
Vehicle F	0.31	50	18.7	15.5	17.1
Vehicle G	0.40	50	100	35.6	68.0
Vehicle H	0.40	50	135	23.2	79.4
Vehicle I	0.40	50	174	27.5	101
Vehicle J	0.40	50	61.5	36.3	48.9
Vehicle K	0.40	25	3.17	5.91	4.54
Vehicle L	0.40	25	0.87	1.37	1.12

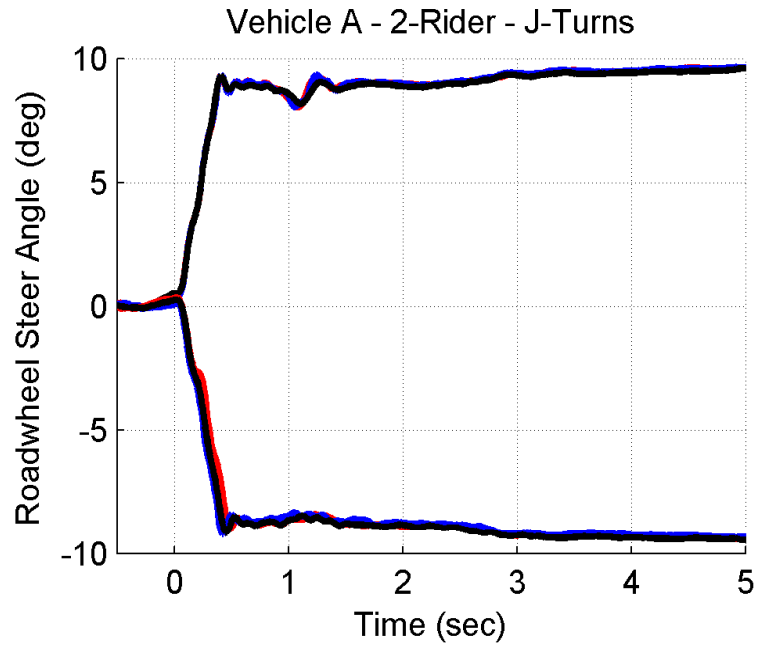

Yaw Rate Ratios - Measured During Constant Steer Tests
Yaw Rate Ratio
Right Turn Yaw Rate Ratio
Left Turn Yaw Rate Ratio
Average Yaw Rate Ratio
0
1
2
3
4
5
6
7
Vehicle C
0.22
0.15
0.19
Vehicle D
0.27
0.16
0.21
Vehicle E
0.54
0.22
0.38
Vehicle L
0.87
1.37
1.12
Vehicle B
2.30
2.40
2.35
Vehicle K
3.17
5.91
4.54
Vehicle F
18.7
15.5
17.1
Vehicle J
61.5
36.3
48.9
Vehicle A
63.3
34.7
49.0
Vehicle G
100
35.6
68.0
Vehicle H
135
23.2
79.4
Vehicle I
174
27.5
101

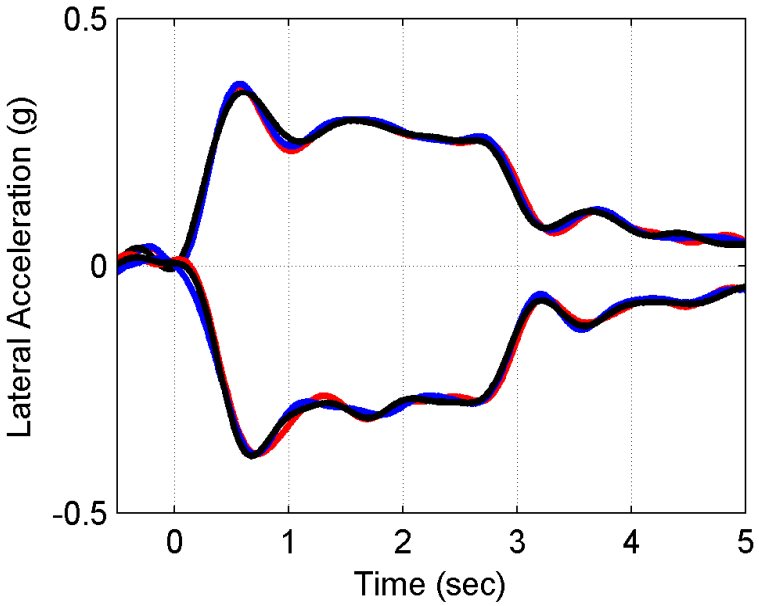

Vehicle A - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
Speed (mph)
CW
CCW
Roll Angle (deg)
Lateral Acceleration (g)
Yaw Rate (deg/sec)
Time (sec)
Time (sec)

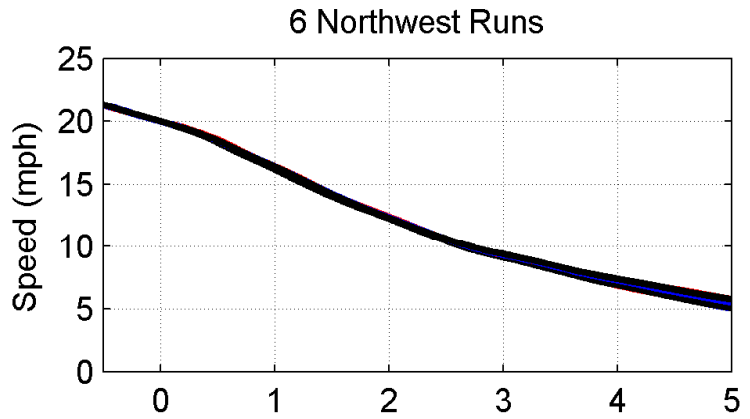

Vehicle A - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
Ay (g)
10
8
6
4
2
0
-2
-4
-6
-8
-10
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

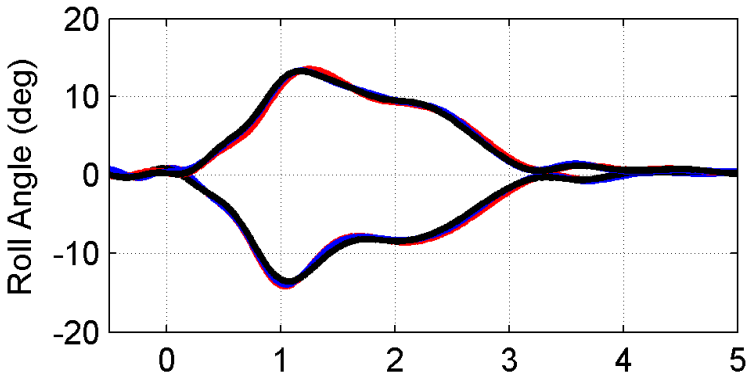

Vehicle A - 2-Rider - 50 ft Radius Circle
Clockwise
Counterclockwise
CW Transition to OS
At Ay = 0.149 g
CCW Transition to OS
At Ay = -0.144 g
(Roadwheel Steer Angle - Ackermann Angle) (deg)
Ay (g)
10
5
0
-5
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5

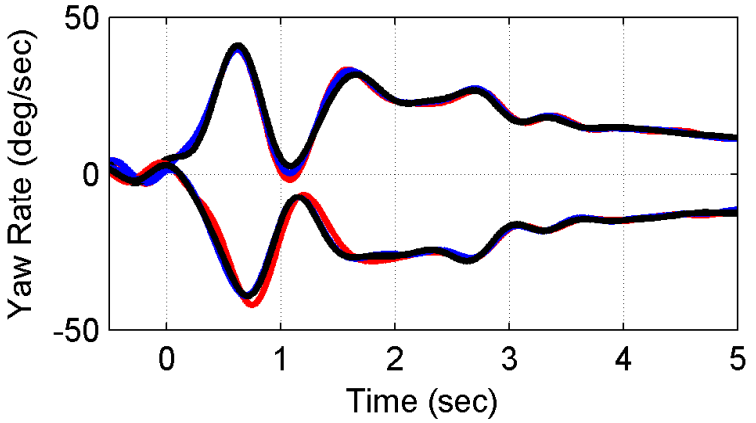

Vehicle A - 2-Rider - 50 ft Radius Circle
Roll Angle (deg)
Ay (g)
Roll Gradient = -15.1 deg/g
8
6
4
2
0
-2
-4
-6
-8
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

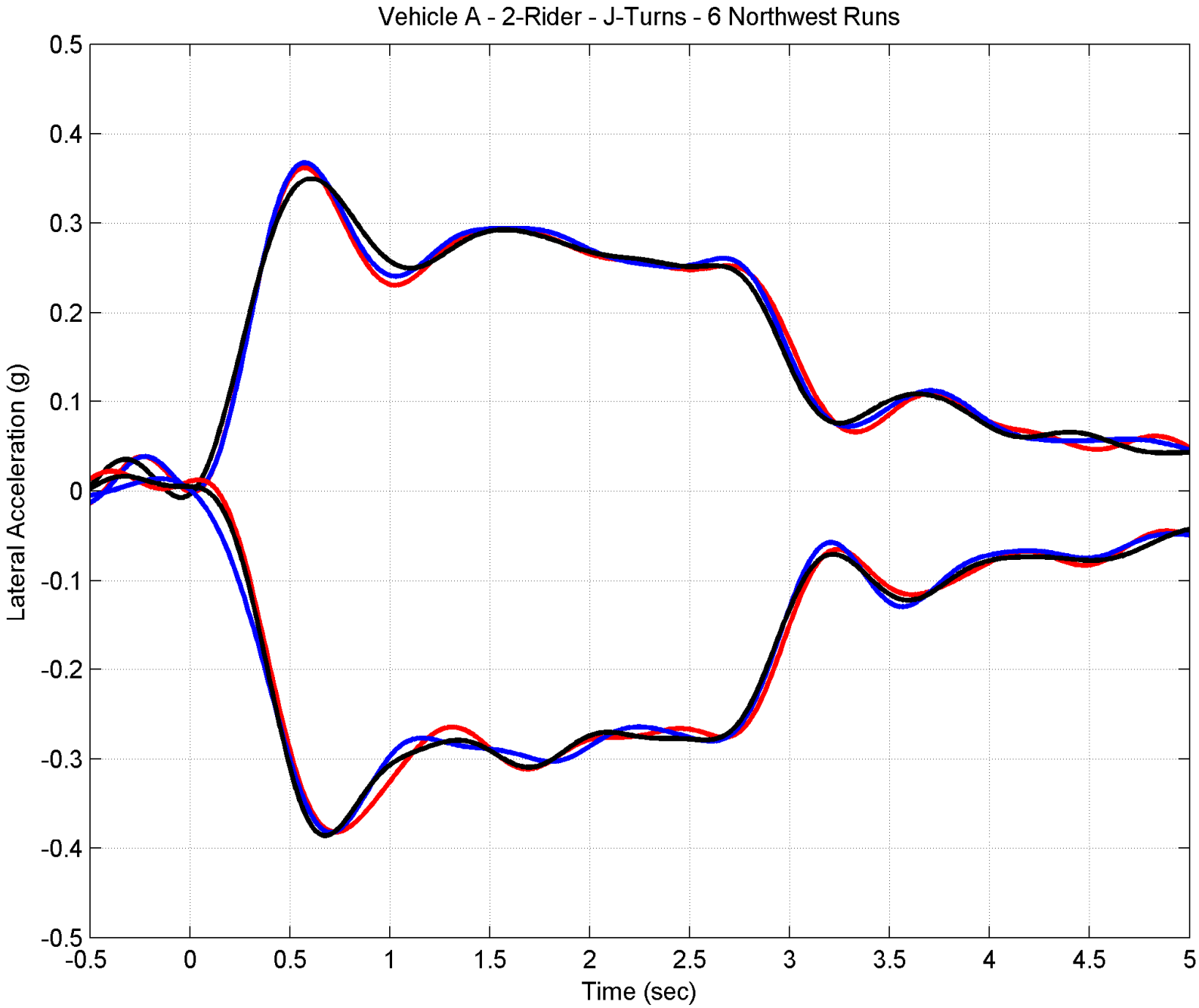

Vehicle A - 2-Rider - J-Turns
Roadwheel Steer Angle (deg)
10
5
0
-5
-10
0
1
2
3
4
5
Time (sec)

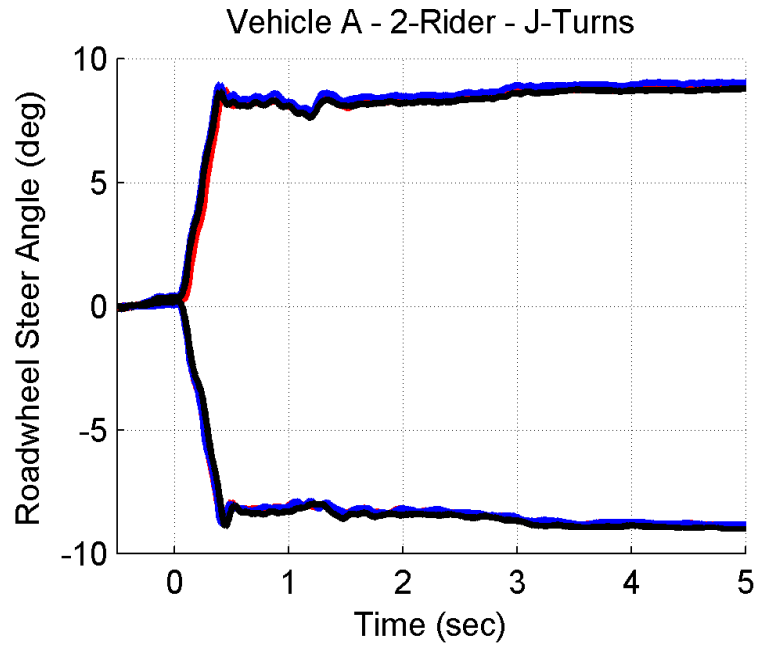

Lateral Acceleration (g)
0.5
0
-0.5
0
1
2
3
4
5
Time (sec)

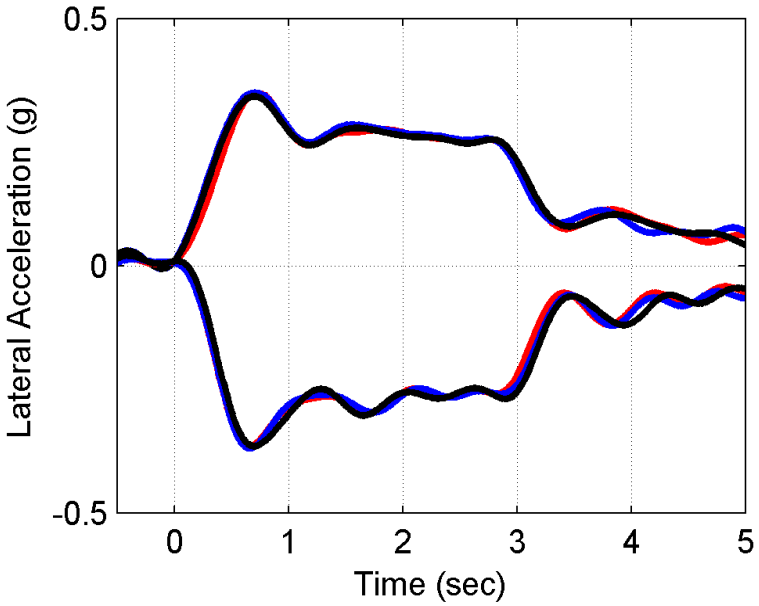

6 Northwest Runs
Speed (mph)
25
20
15
10
5
0
0
1
2
3
4
5

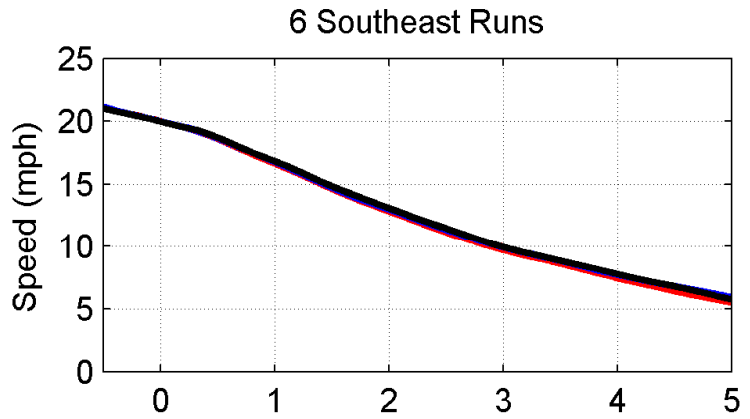

Roll Angle (deg)
20
10
0
-10
-20
0
1
2
3
4
5

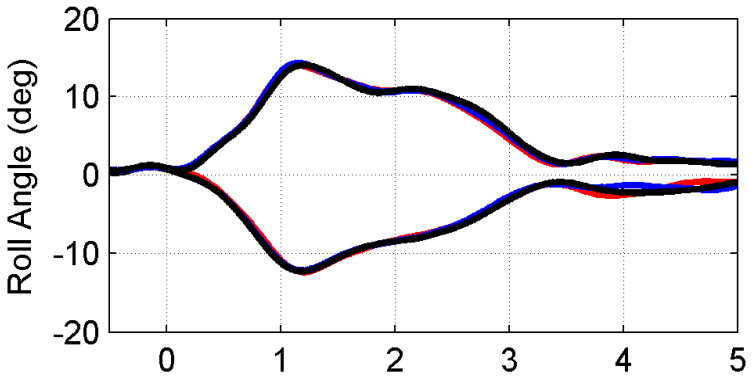

Yaw Rate (deg/sec)
50
0
-50
0
1
2
3
4
5
Time (sec)

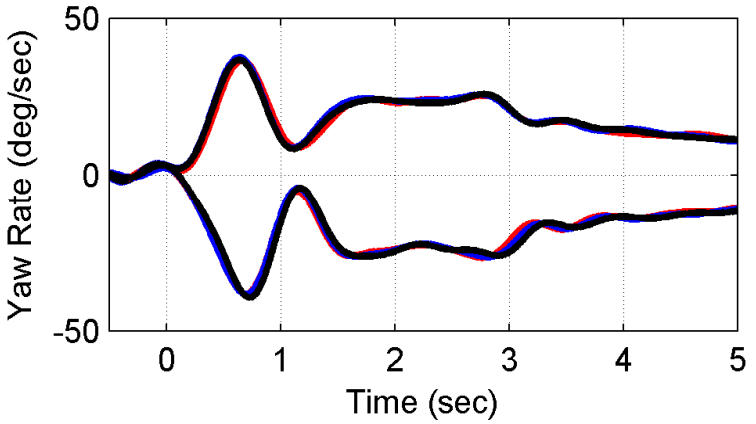

Vehicle A - 2-Rider - J-Turns - 6 Northwest Runs
Lateral Acceleration (g)
Time (sec)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

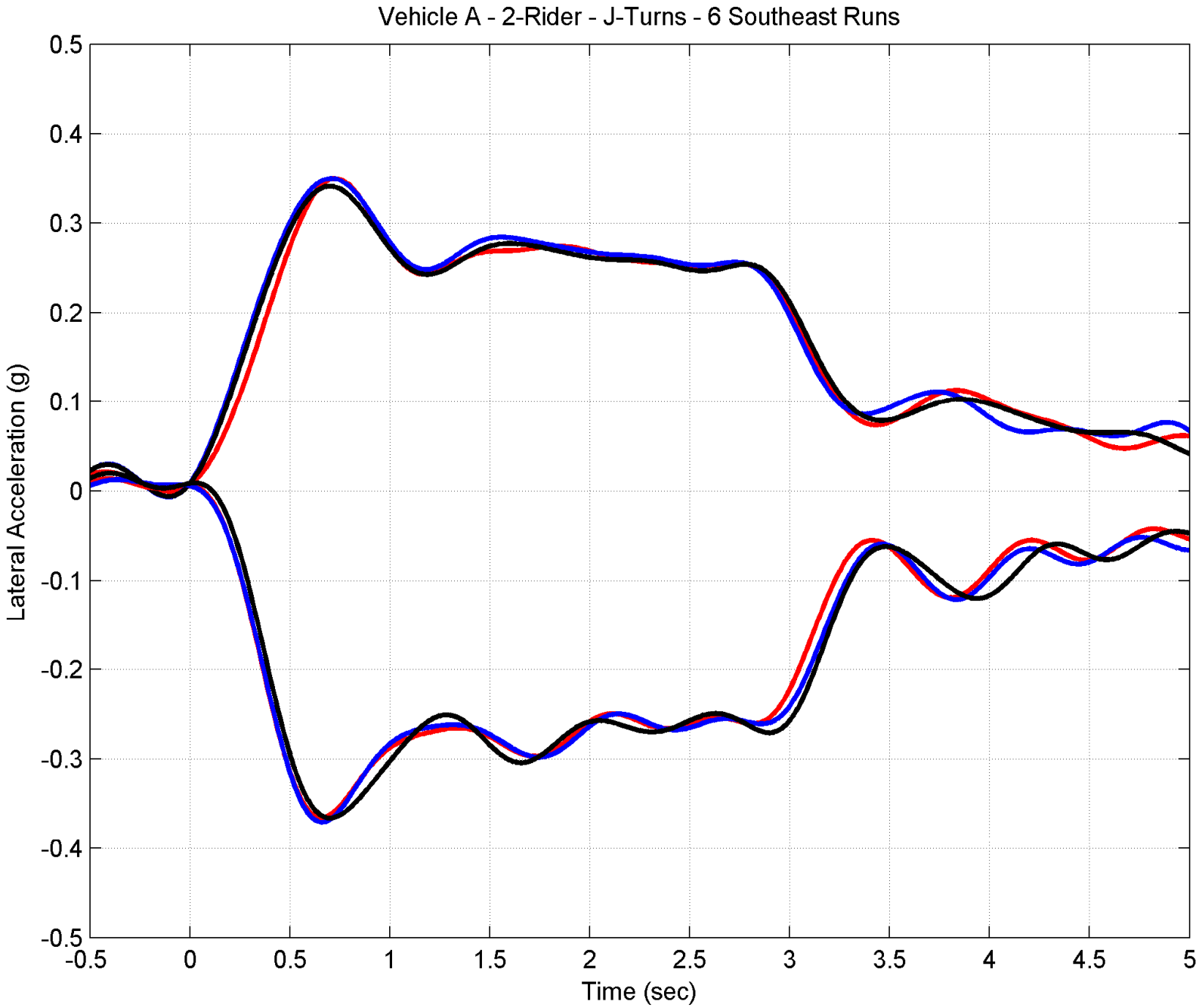

Vehicle A - 2-Rider - J-Turns
Roadwheel Steer Angle (deg)
10
5
0
-5
-10
0
1
2
3
4
5
Time (sec)


Lateral Acceleration (g)
0.5
0
-0.5
0
1
2
3
4
5
Time (sec)


6 Southeast Runs
Speed (mph)
25
20
15
10
5
0
0
1
2
3
4
5


Roll Angle (deg)
20
10
0
-10
-20
0
1
2
3
4
5


Yaw Rate (deg/sec)
50
0
-50
0
1
2
3
4
5
Time (sec)


Vehicle A - 2-Rider - J-Turns - 6 Southeast Runs
Lateral Acceleration (g)
Time (sec)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

Vehicle A - 2-Rider Results

Peak Lateral Accelerations During 2WL J-Turns - All Values in "g's"

Run Number	Northwest Right Turns	Northwest Left Turns
1	0.363	-0.382
2	0.368	-0.382
3	0.350	-0.385
Mean Value of 3 Runs	0.360	-0.383
Standard Deviation of 3 Runs	0.009	0.002

Average of 6 Northwest Runs

0.372

Run Number	Southeast Right Turns	Southeast Left Turns
1	0.350	-0.365
2	0.350	-0.371
3	0.341	-0.366
Mean Value of 3 Runs	0.347	-0.367
Standard Deviation of 3 Runs	0.005	0.003

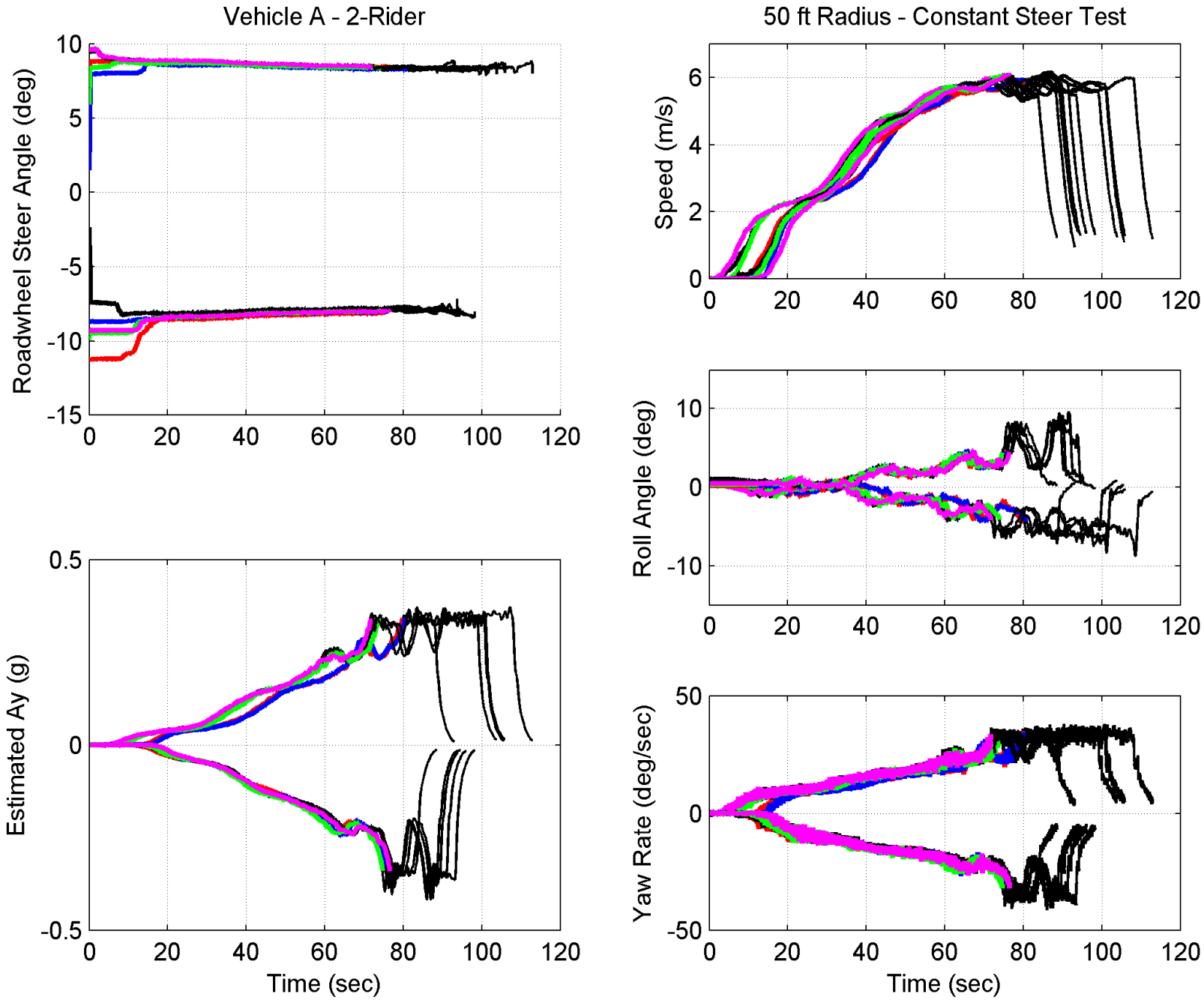
Average of 6 Southeast Runs

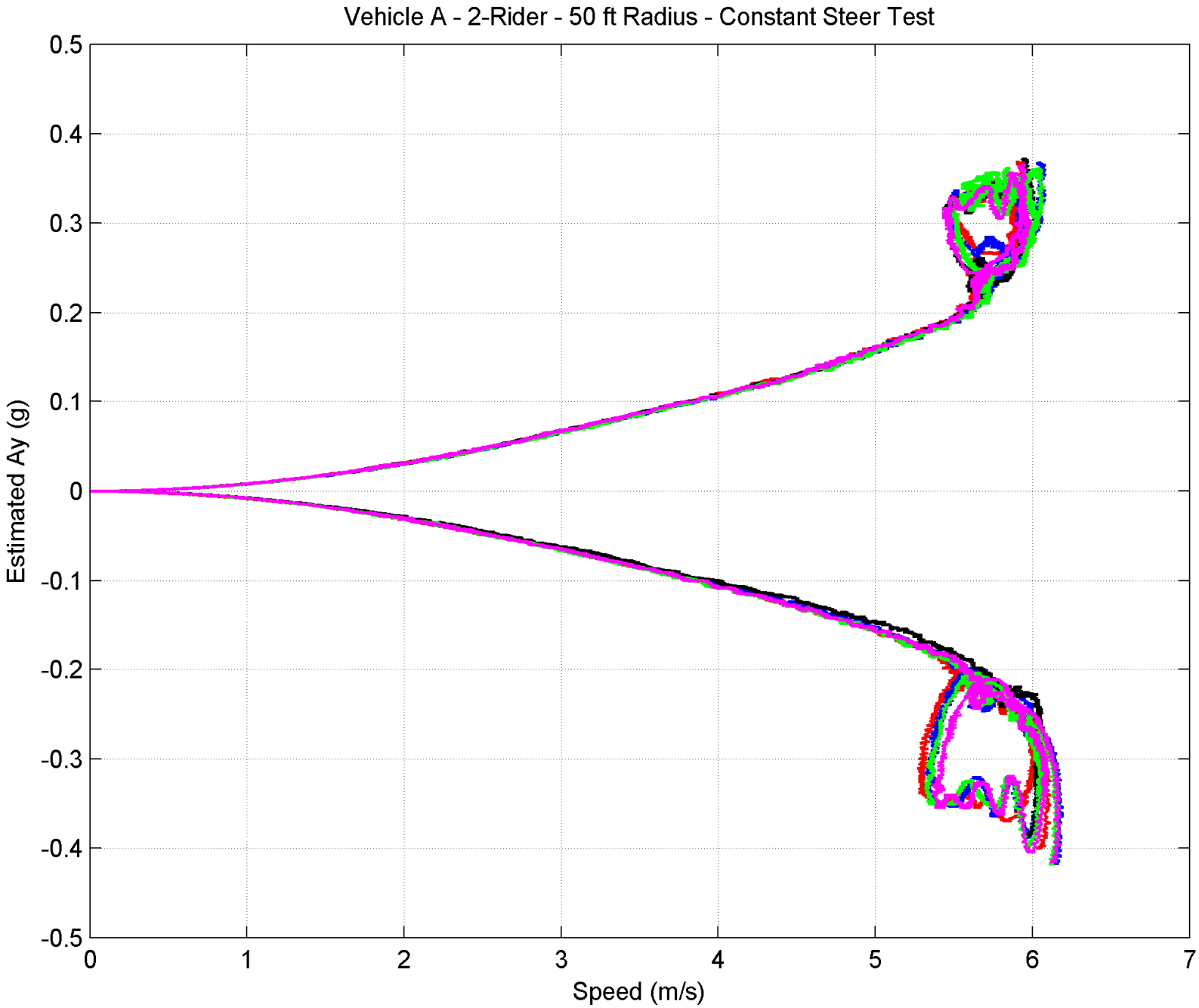
0.357

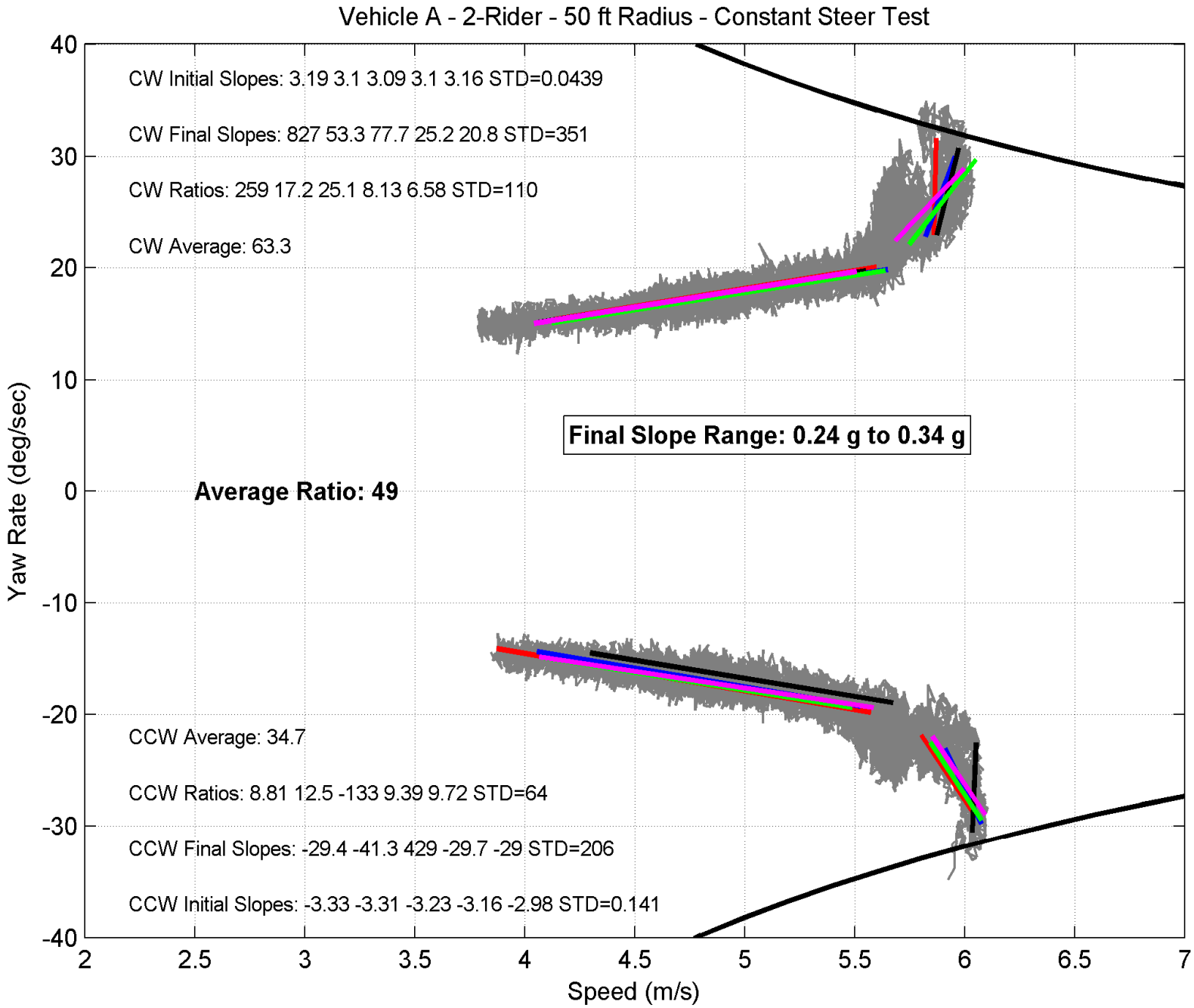
Average of All 12 Runs

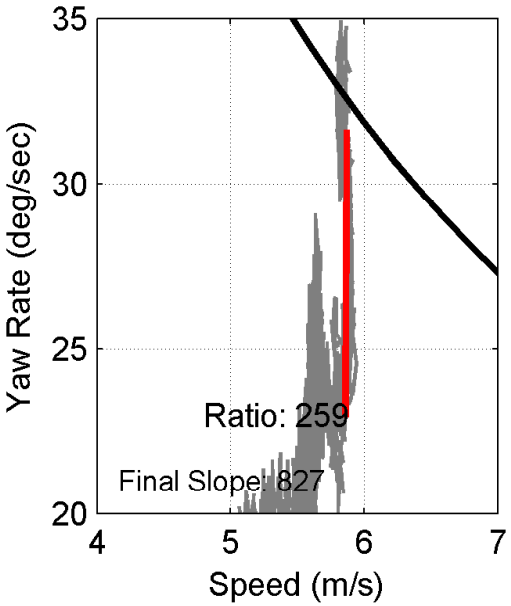
0.364

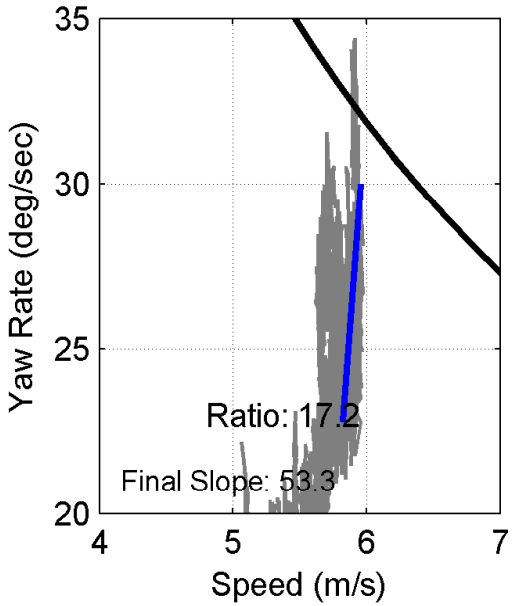
Threshold Ay

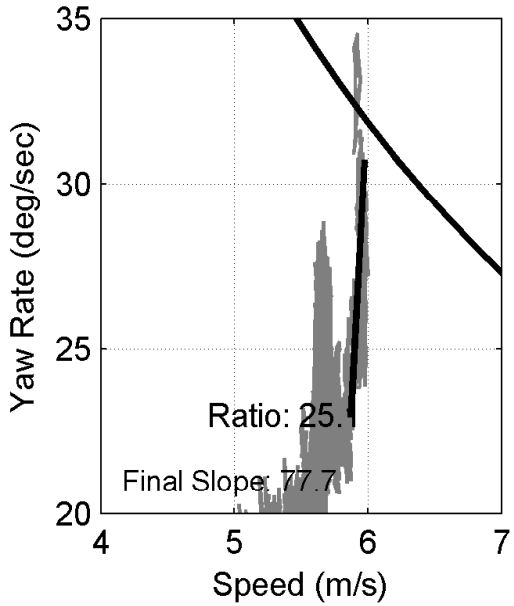

Vehicle A - 2-Rider
50 ft Radius - Constant Steer Test
Roadwheel Steer Angle (deg)
Speed (m/s)
Roll Angle (deg)
Estimated Ay (g)
Yaw Rate (deg/sec)
Time (sec)
Time (sec)

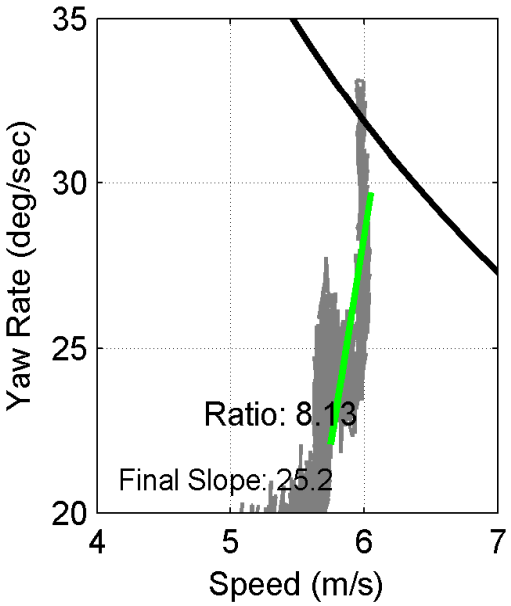

Vehicle A - 2-Rider - 50 ft Radius - Constant Steer Test
Estimated Ay (g)
Speed (m/s)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
1
2
3
4
5
6
7

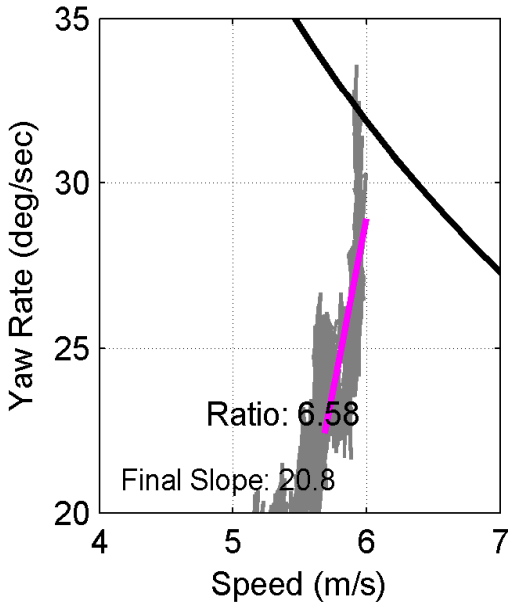

Vehicle A - 2-Rider - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.19 3.1 3.09 3.1 3.16 STD=0.0439
CW Final Slopes: 827 53.3 77.7 25.2 20.8 STD=351
CW Ratios: 259 17.2 25.1 8.13 6.58 STD=110
CW Average: 63.3
Final Slope Range: 0.24 g to 0.34 g
Average Ratio: 49
CCW Average: 34.7
CCW Ratios: 8.81 12.5 -133 9.39 9.72 STD=64
CCW Final Slopes: -29.4 -41.3 429 -29.7 -29 STD=206
CCW Initial Slopes: -3.33 -3.31 -3.23 -3.16 -2.98 STD=0.141
Yaw Rate (deg/sec)
Speed (m/s)
40
30
20
10
0
-10
-20
-30
-40
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7





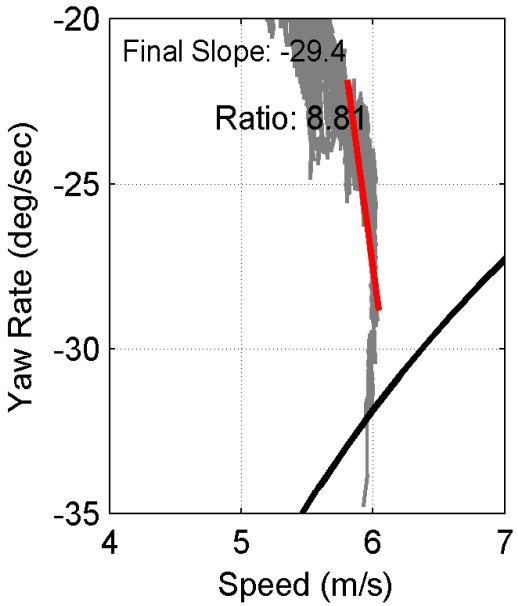


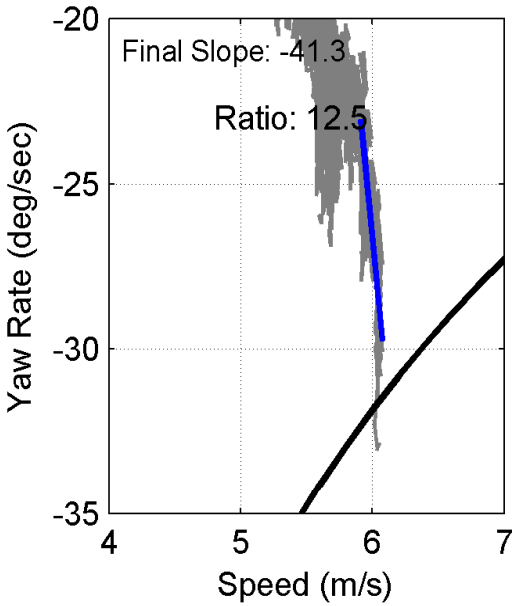


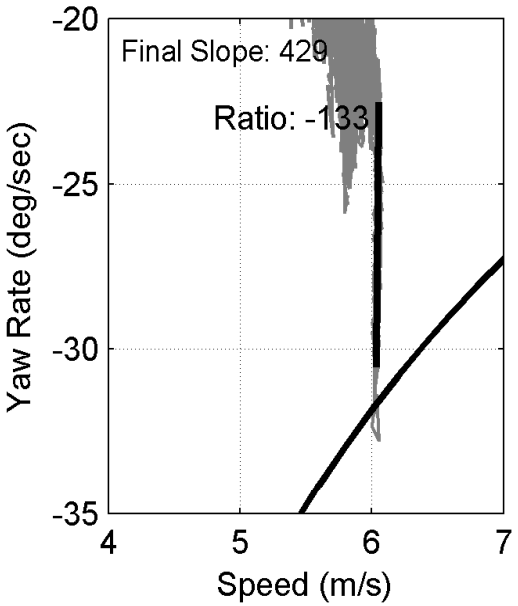


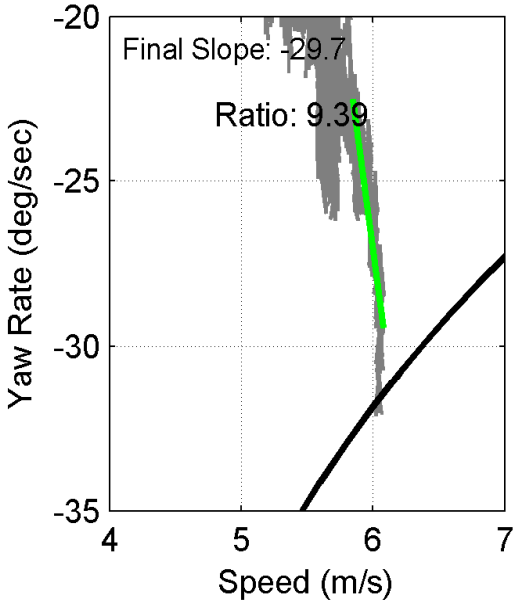
Final Slope Range:

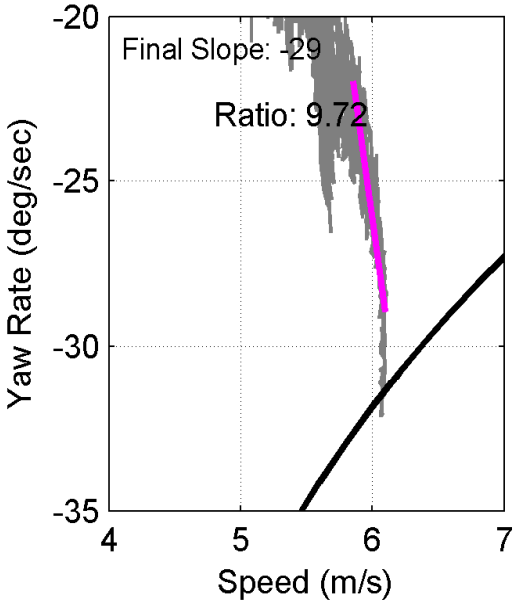
0.24 g to 0.34 g





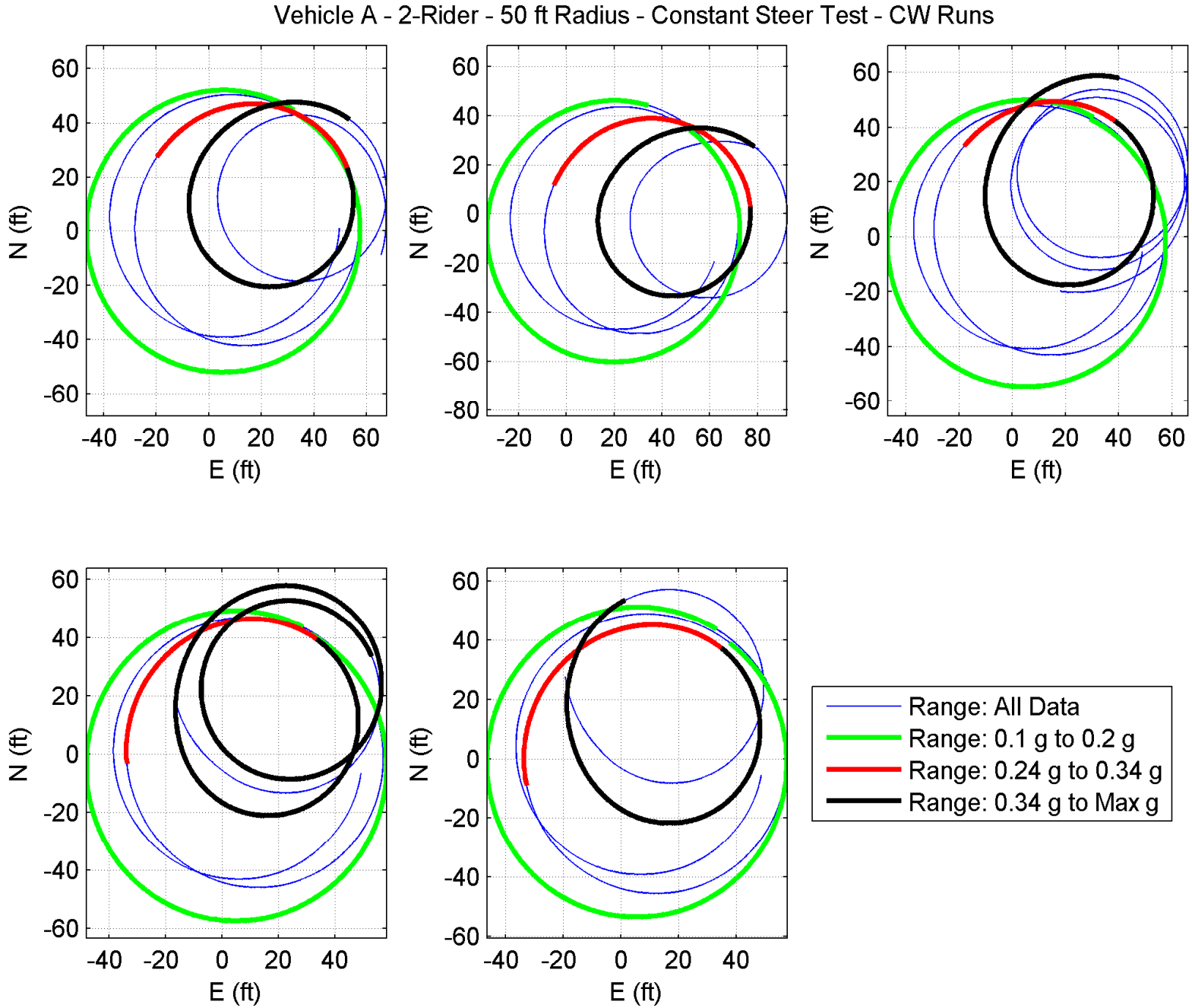


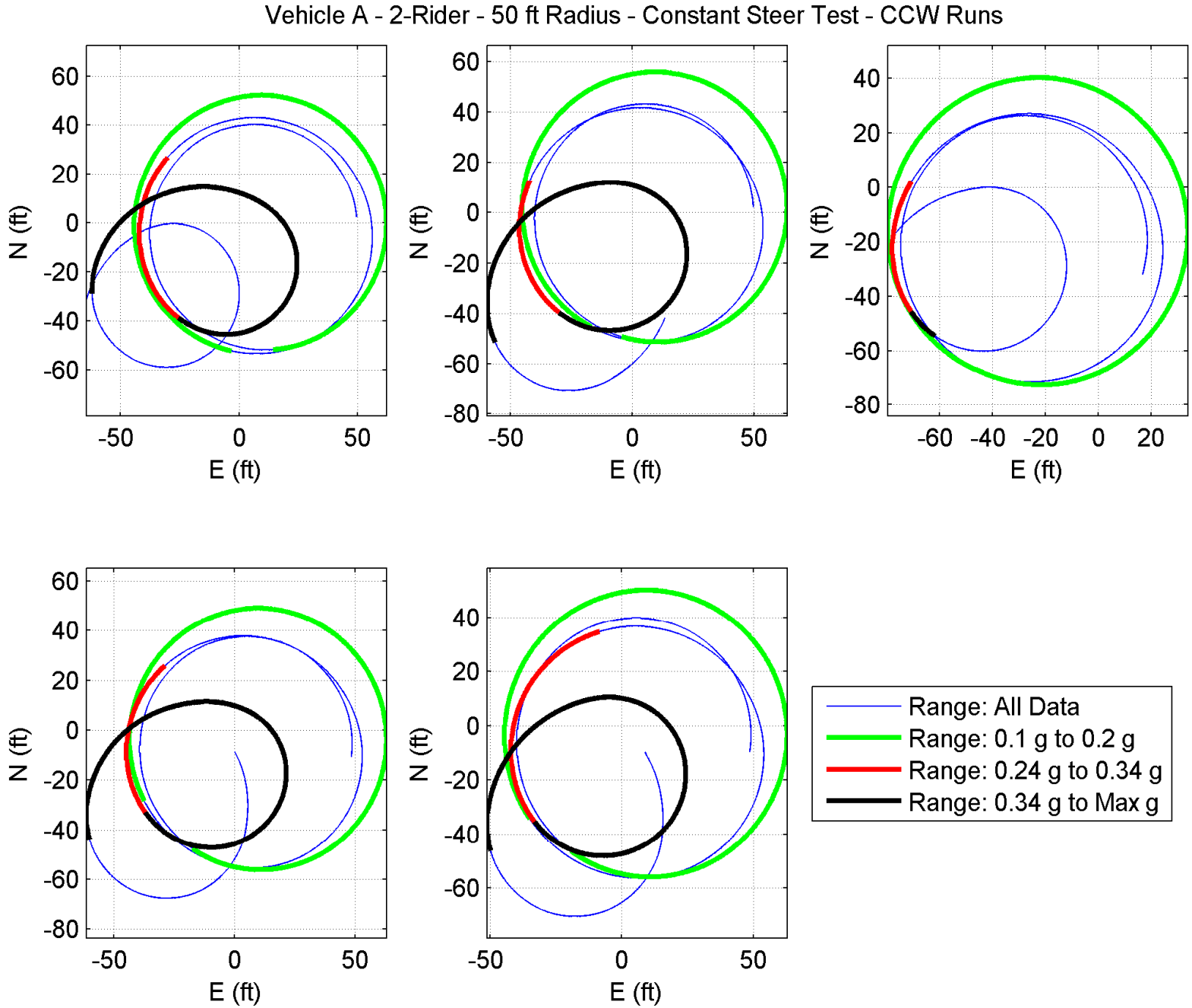


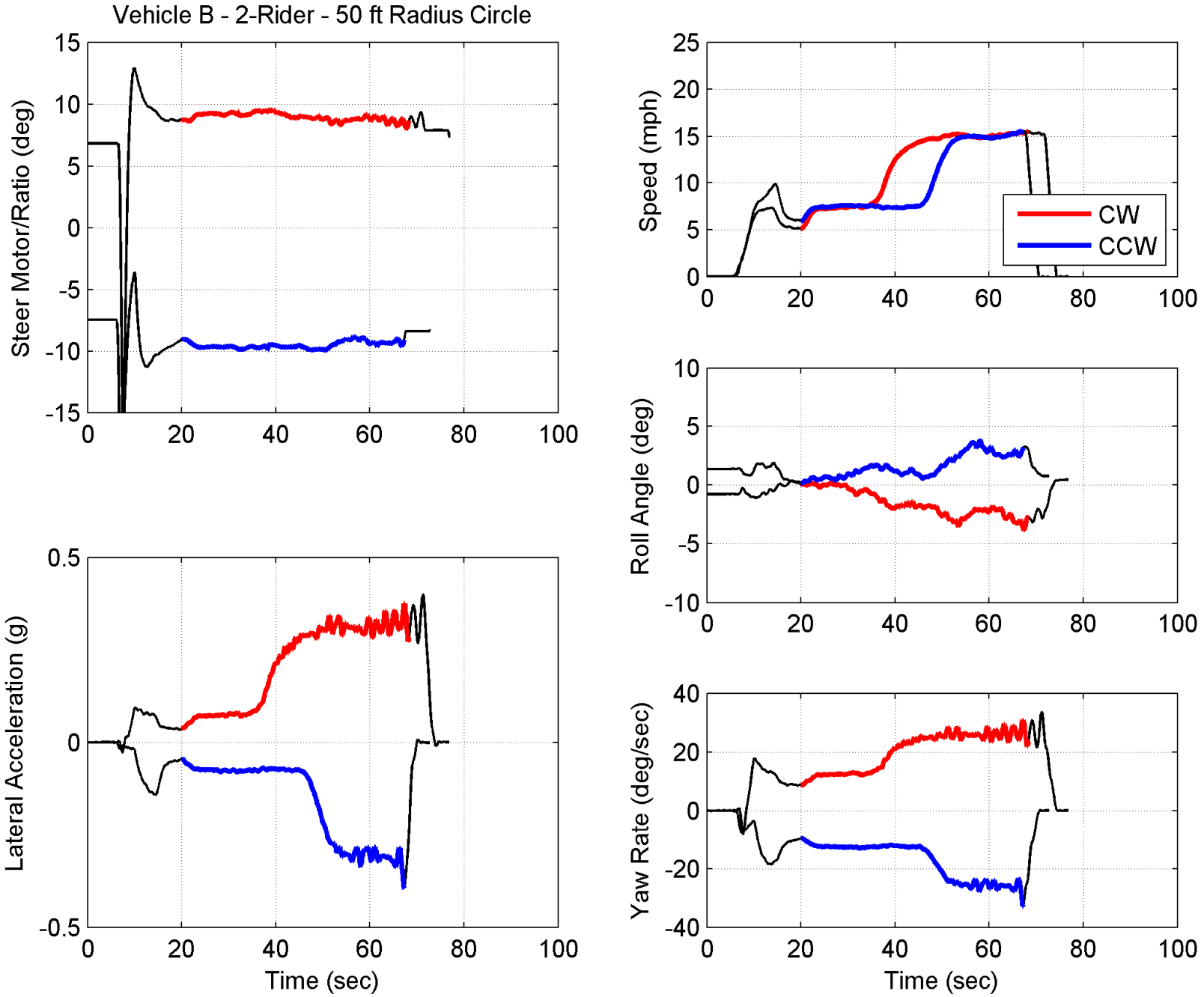


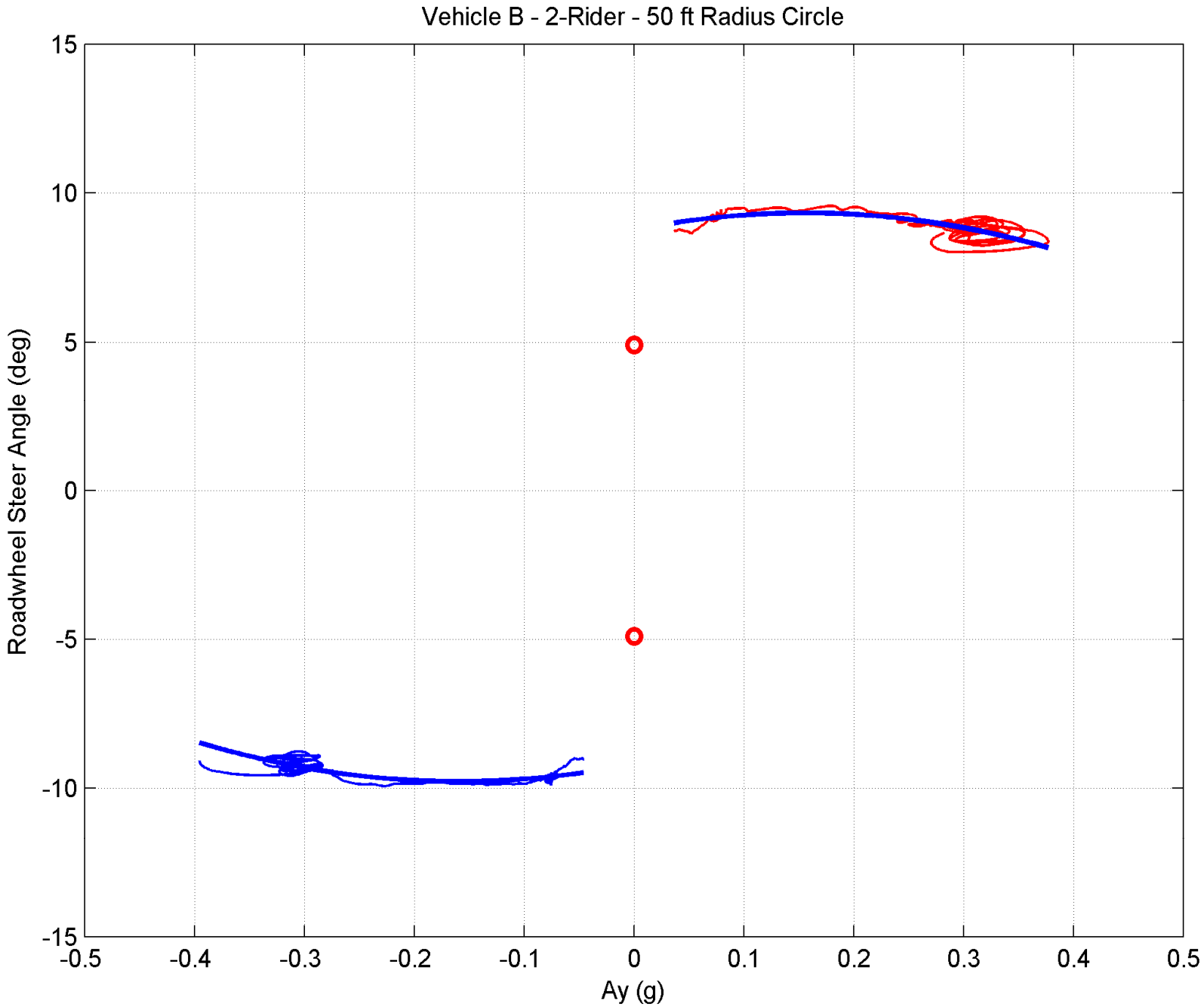
Final Slope Range:

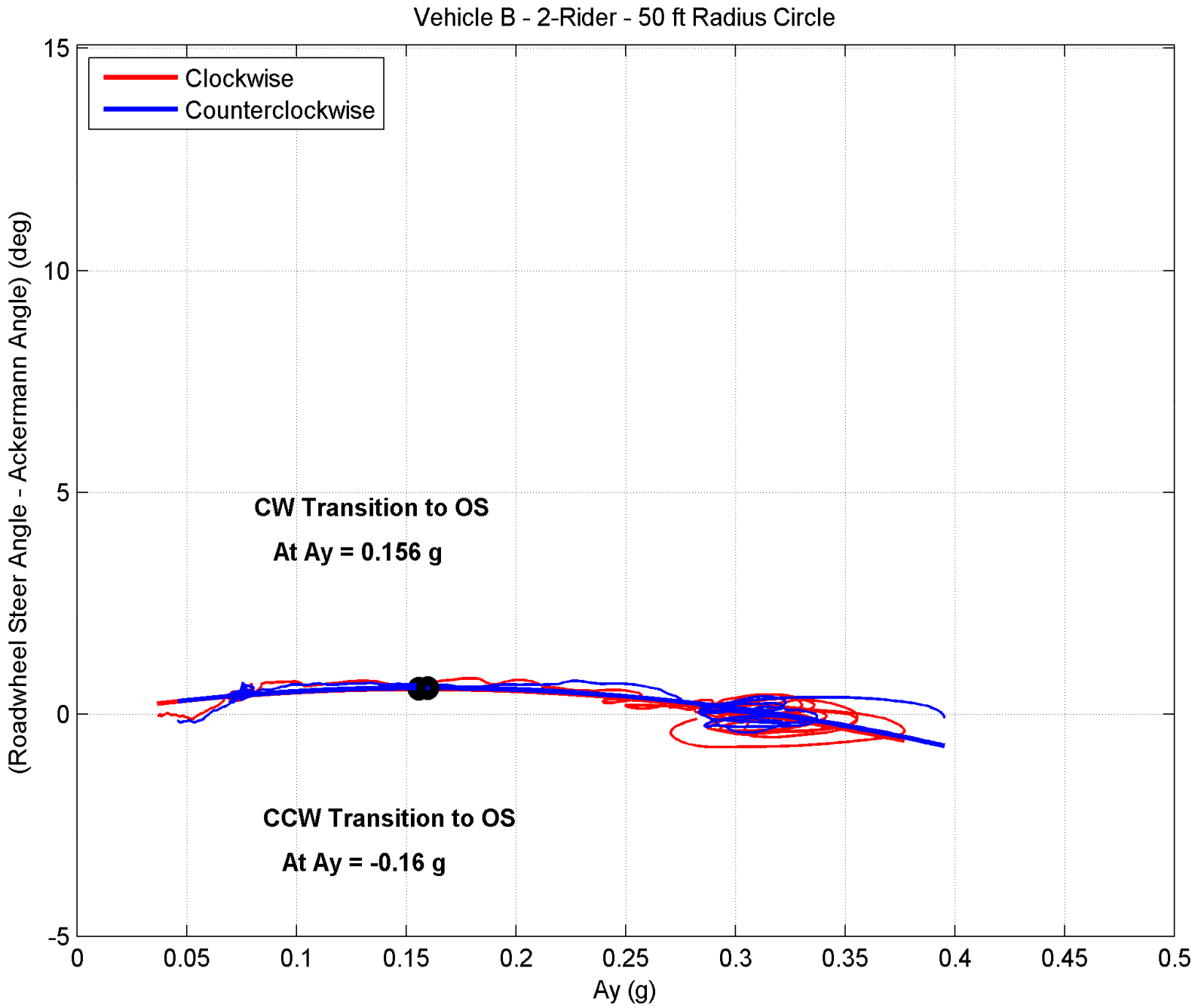
0.24 g to 0.34 g

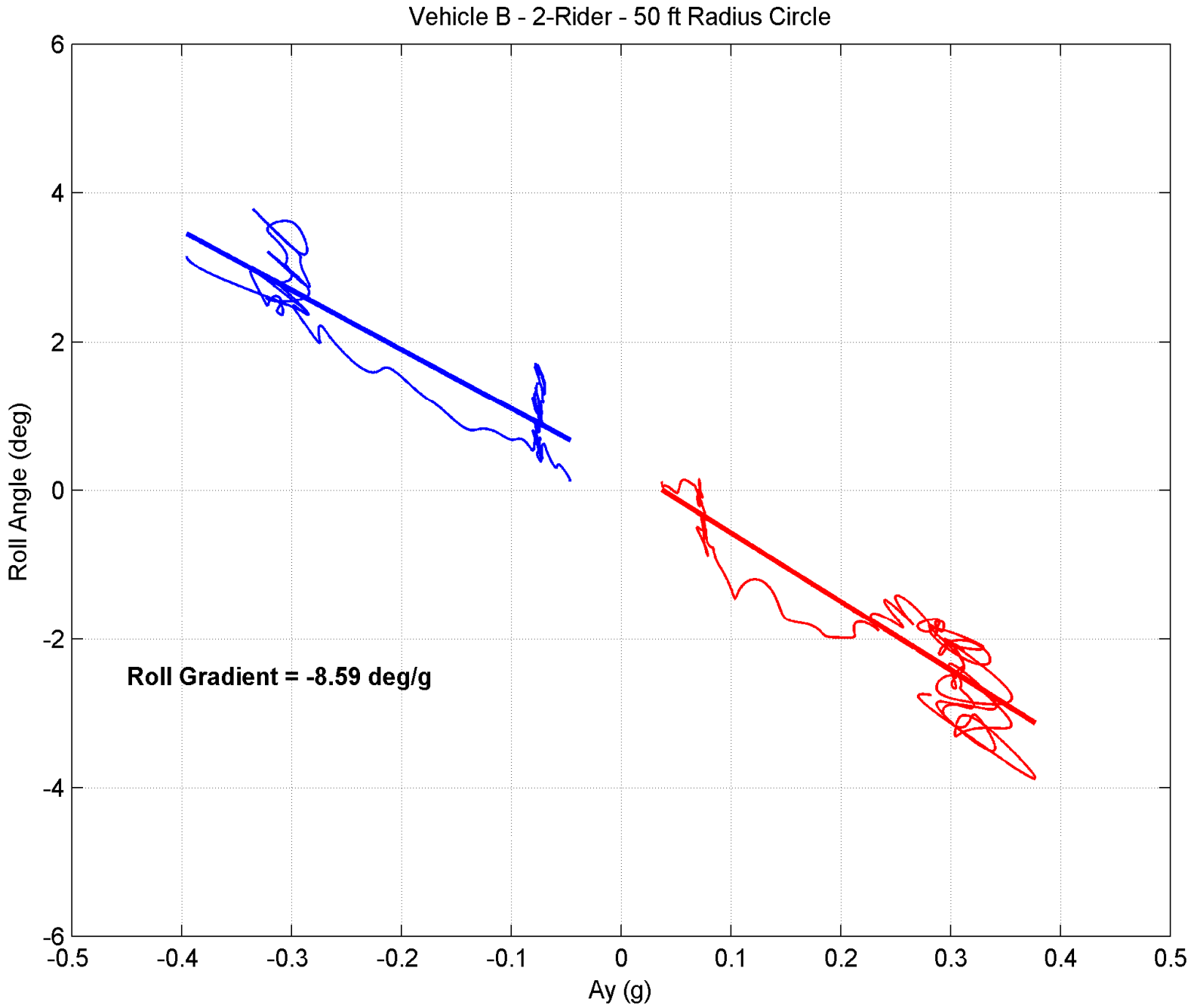

Vehicle A - 2-Rider - 50 ft Radius - Constant Steer Test - CW Runs
N (ft)
E (ft)
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.24 g to 0.34 g
Range: 0.34 g to Max g

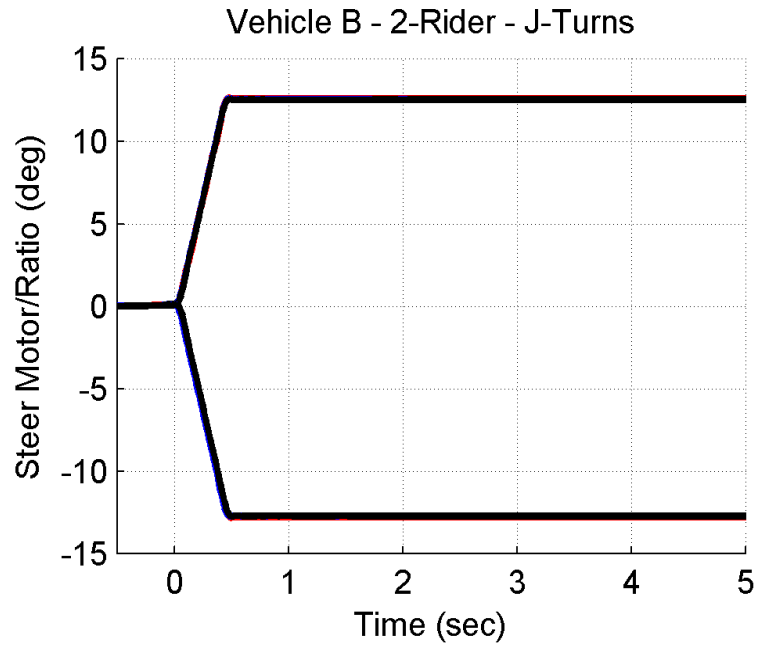

Vehicle A - 2-Rider - 50 ft Radius - Constant Steer Test - CCW Runs
N (ft)
E (ft)
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.24 g to 0.34 g
Range: 0.34 g to Max g

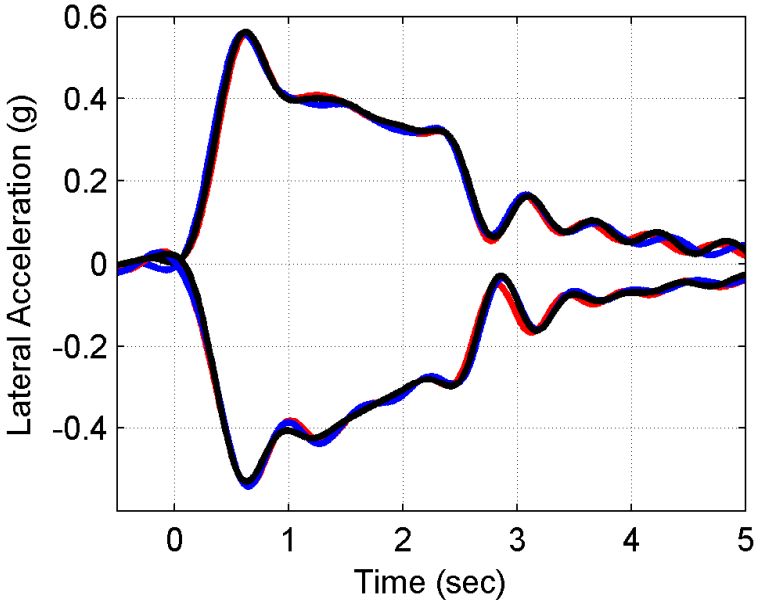

Vehicle B - 2-Rider - 50 ft Radius Circle
Steer Motor/Ratio (deg)
Speed (mph)
CW
CCW
Roll Angle (deg)
Lateral Acceleration (g)
Yaw Rate (deg/sec)
Time (sec)
Time (sec)

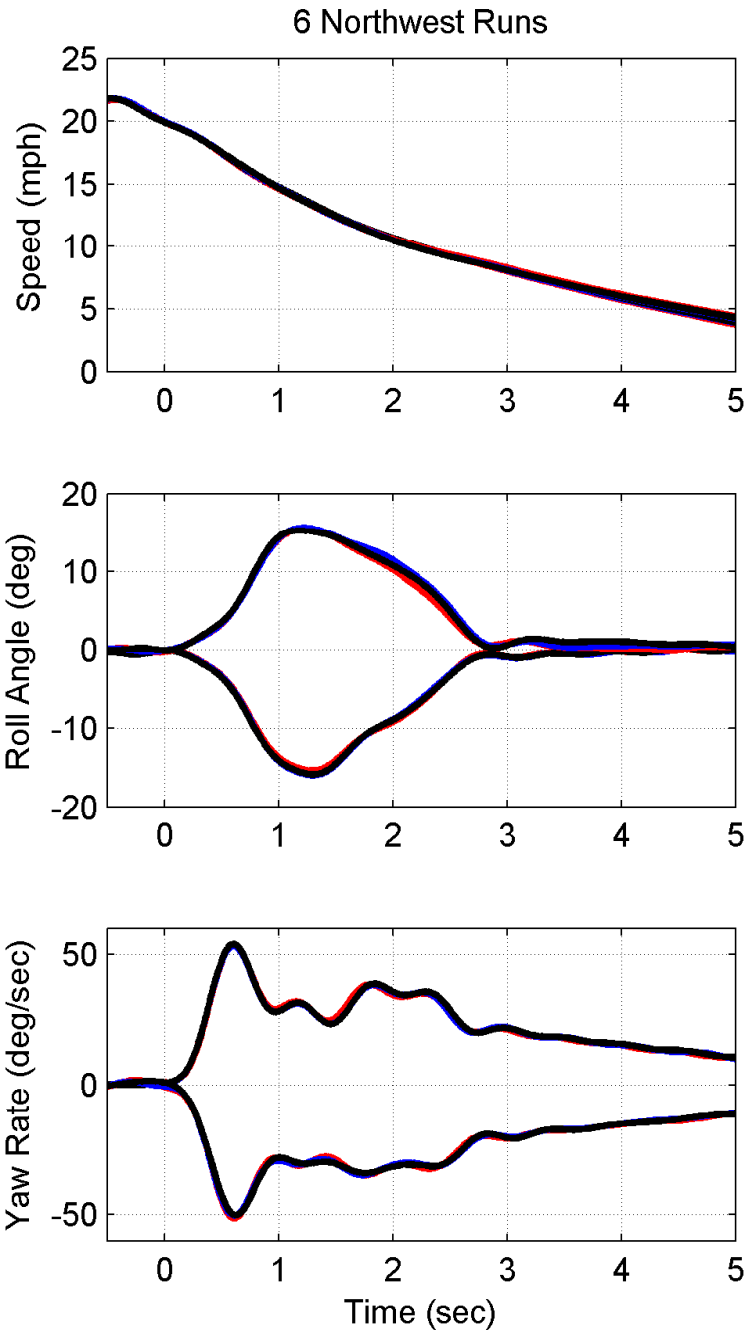

Vehicle B - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
Ay (g)
15
10
5
0
-5
-10
-15
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

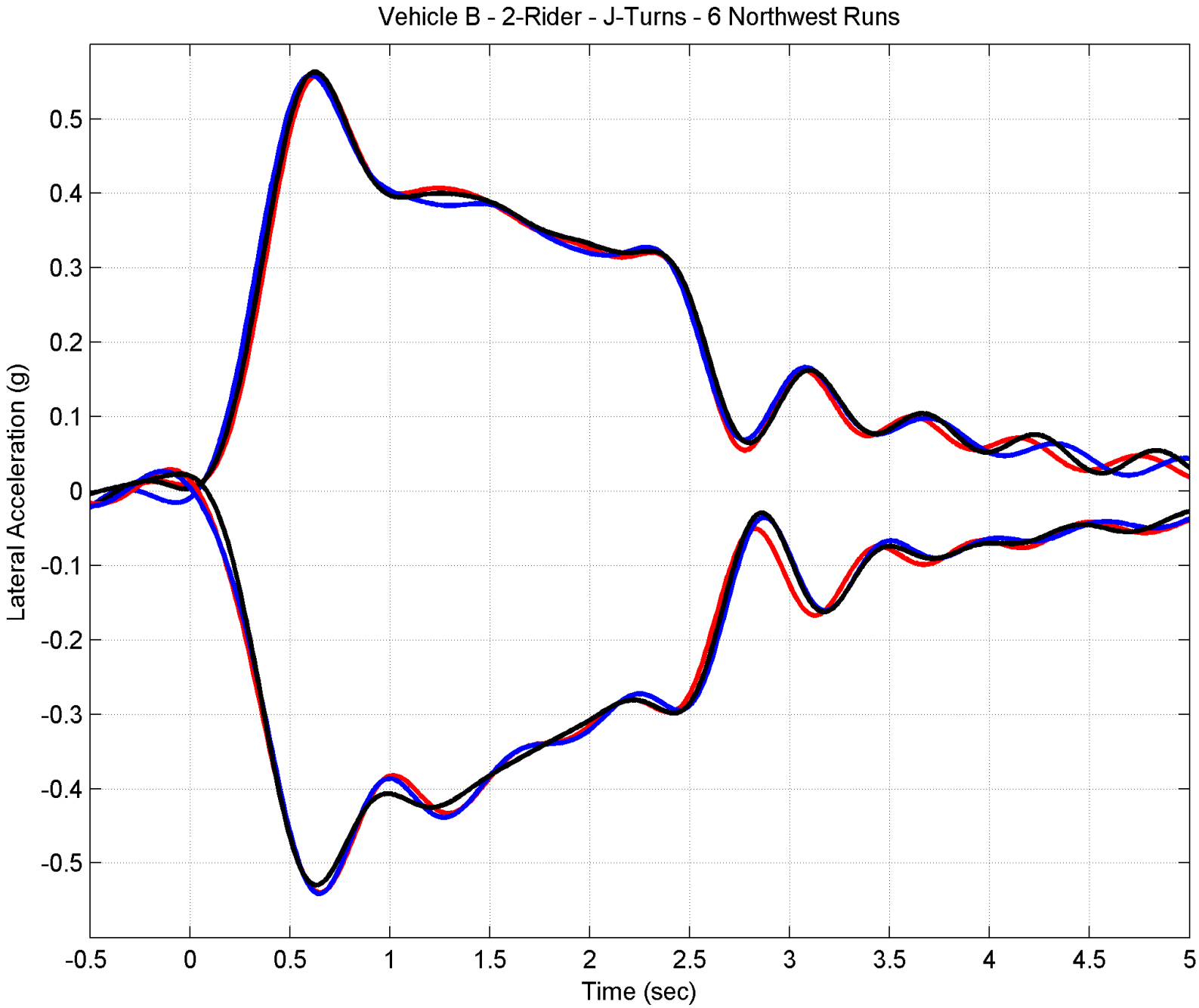

Vehicle B - 2-Rider - 50 ft Radius Circle
Clockwise
Counterclockwise
CW Transition to OS
At Ay = 0.156 g
CCW Transition to OS
At Ay = -0.16 g
(Roadwheel Steer Angle - Ackermann Angle) (deg)
Ay (g)
15
10
5
0
-5
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5

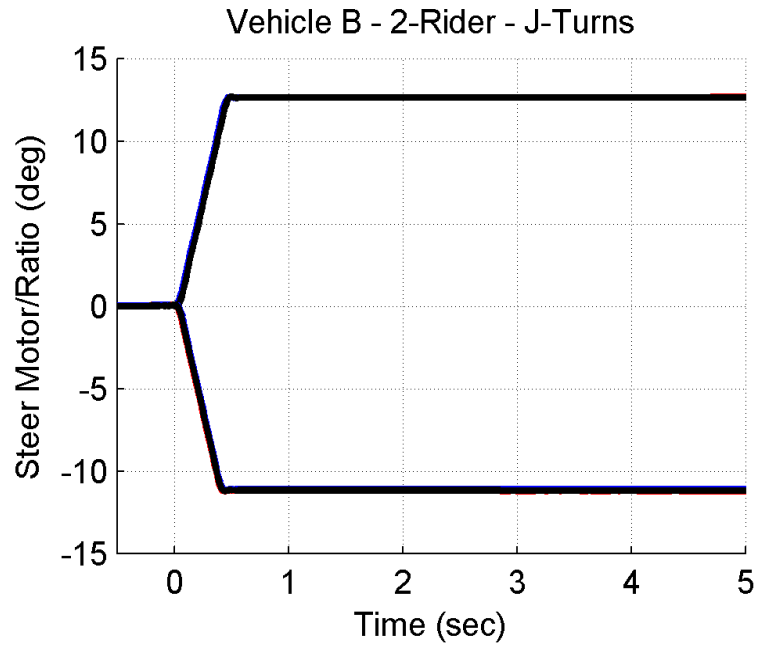

Vehicle B - 2-Rider - 50 ft Radius Circle
Roll Angle (deg)
Ay (g)
Roll Gradient = -8.59 deg/g
6
4
2
0
-2
-4
-6
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

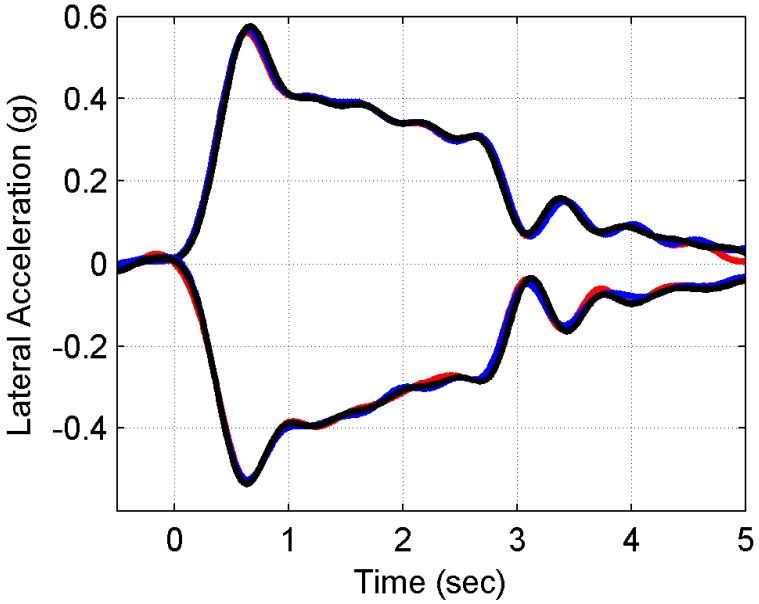

Vehicle B - 2-Rider - J-Turns
Steer Motor/Ratio (deg)
15
10
5
0
-5
-10
-15
0
1
2
3
4
5
Time (sec)

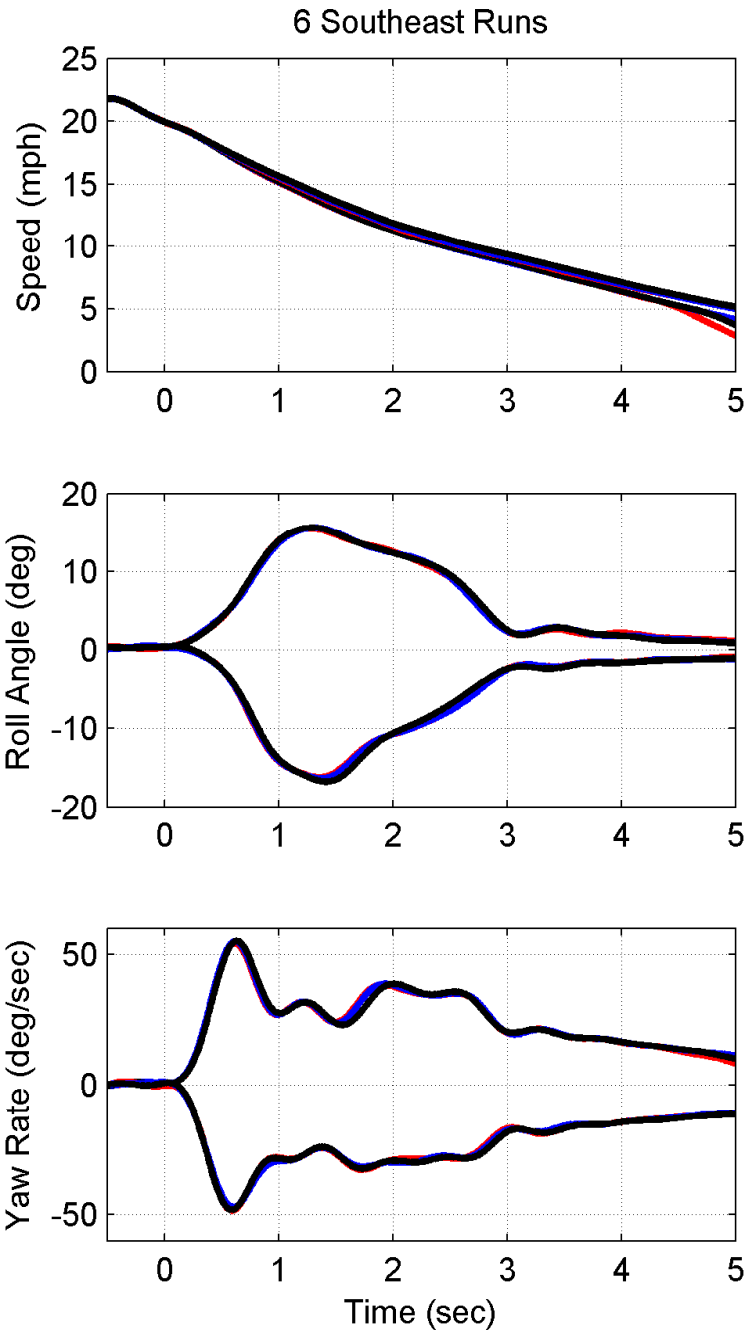

Lateral Acceleration (g)
0.6
0.4
0.2
0
-0.2
-0.4
0
1
2
3
4
5
Time (sec)

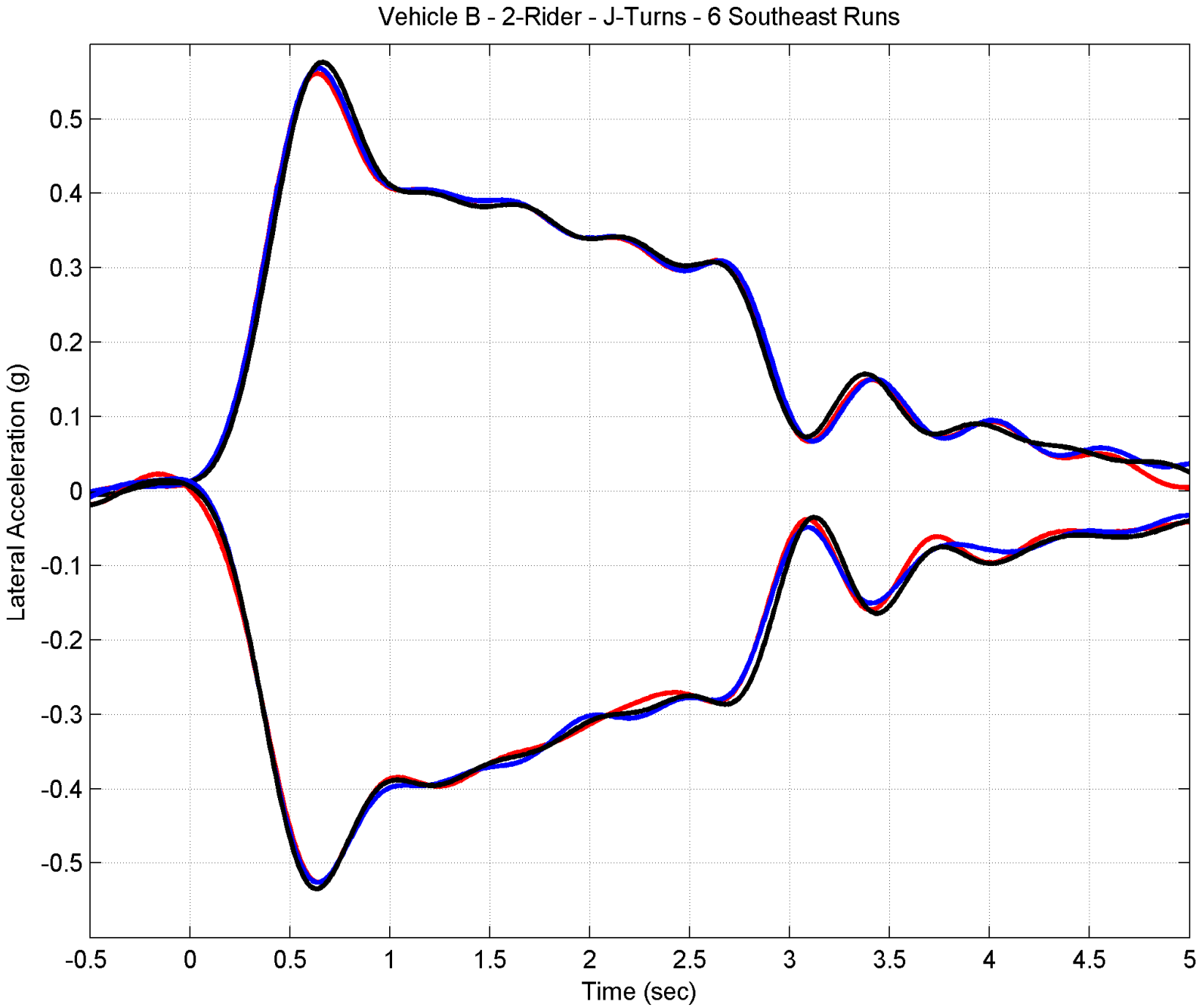

6 Northwest Runs
Speed (mph)
25
20
15
10
5
0
0
1
2
3
4
5
Roll Angle (deg)
20
10
0
-10
-20
0
1
2
3
4
5
Yaw Rate (deg/sec)
50
0
-50
0
1
2
3
4
5
Time (sec)


Vehicle B - 2-Rider - J-Turns - 6 Northwest Runs
Lateral Acceleration (g)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (sec)


Vehicle B - 2-Rider - J-Turns
Steer Motor/Ratio (deg)
15
10
5
0
-5
-10
-15
0
1
2
3
4
5
Time (sec)


Lateral Acceleration (g)
0.6
0.4
0.2
0
-0.2
-0.4
0
1
2
3
4
5
Time (sec)


6 Southeast Runs
Speed (mph)
25
20
15
10
5
0
Roll Angle (deg)
20
10
0
-10
-20
Yaw Rate (deg/sec)
50
0
-50
0
1
2
3
4
5
Time (sec)


Vehicle B - 2-Rider - J-Turns - 6 Southeast Runs
Lateral Acceleration (g)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (sec)

Vehicle B - 2-Rider Results

Peak Lateral Accelerations During 2WL J-Turns - All Values in "g's"

Run Number	Northwest Right Turns	Northwest Left Turns
1	0.558	-0.540
2	0.559	-0.541
3	0.563	-0.530
Mean Value of 3 Runs	0.560	-0.537
Standard Deviation of 3 Runs	0.003	0.006

Average of 6 Northwest Runs

0.548

Run Number	Southeast Right Turns	Southeast Left Turns
1	0.561	-0.526
2	0.568	-0.526
3	0.576	-0.535
Mean Value of 3 Runs	0.568	-0.529
Standard Deviation of 3 Runs	0.007	0.005

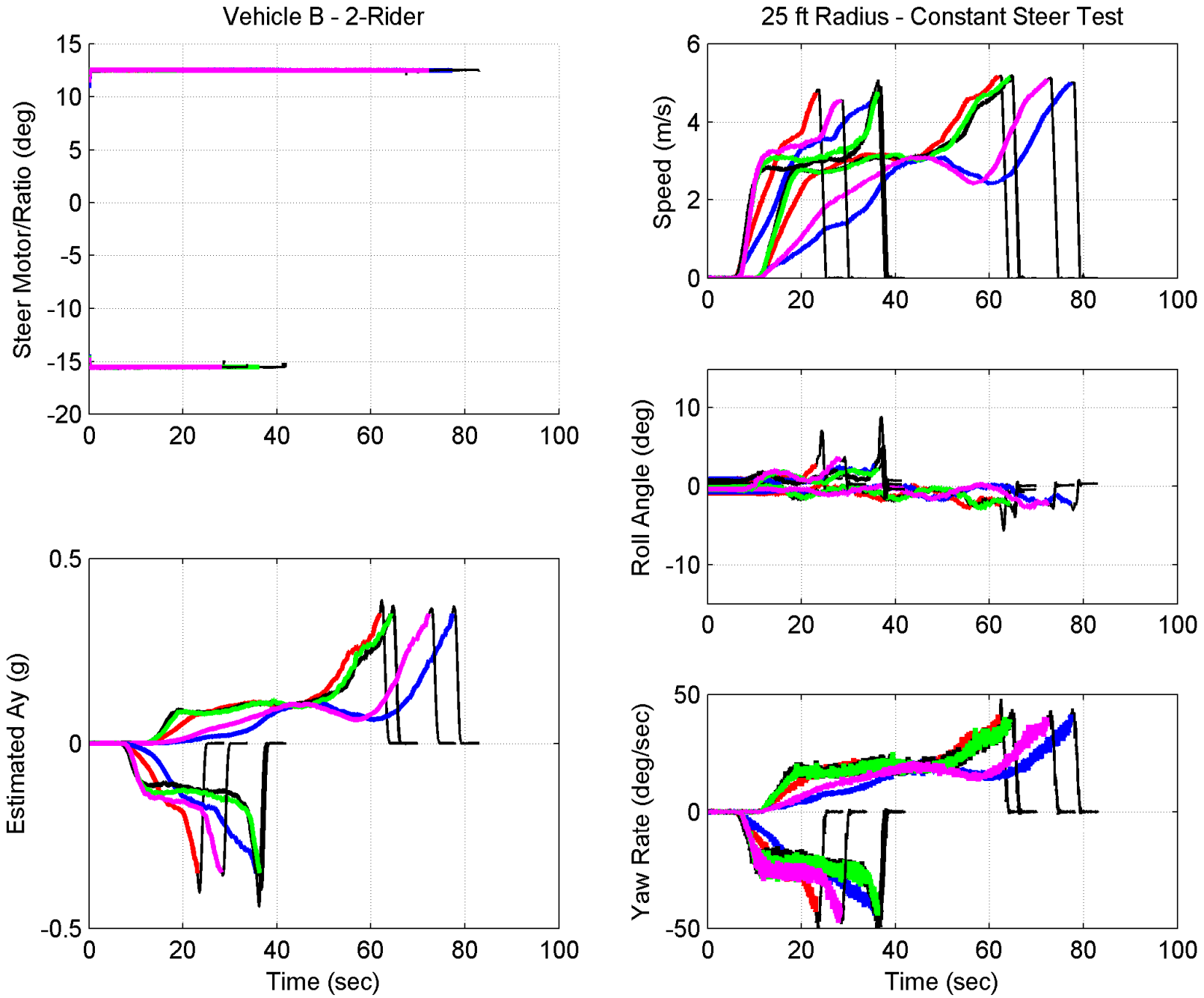
Average of 6 Southeast Runs

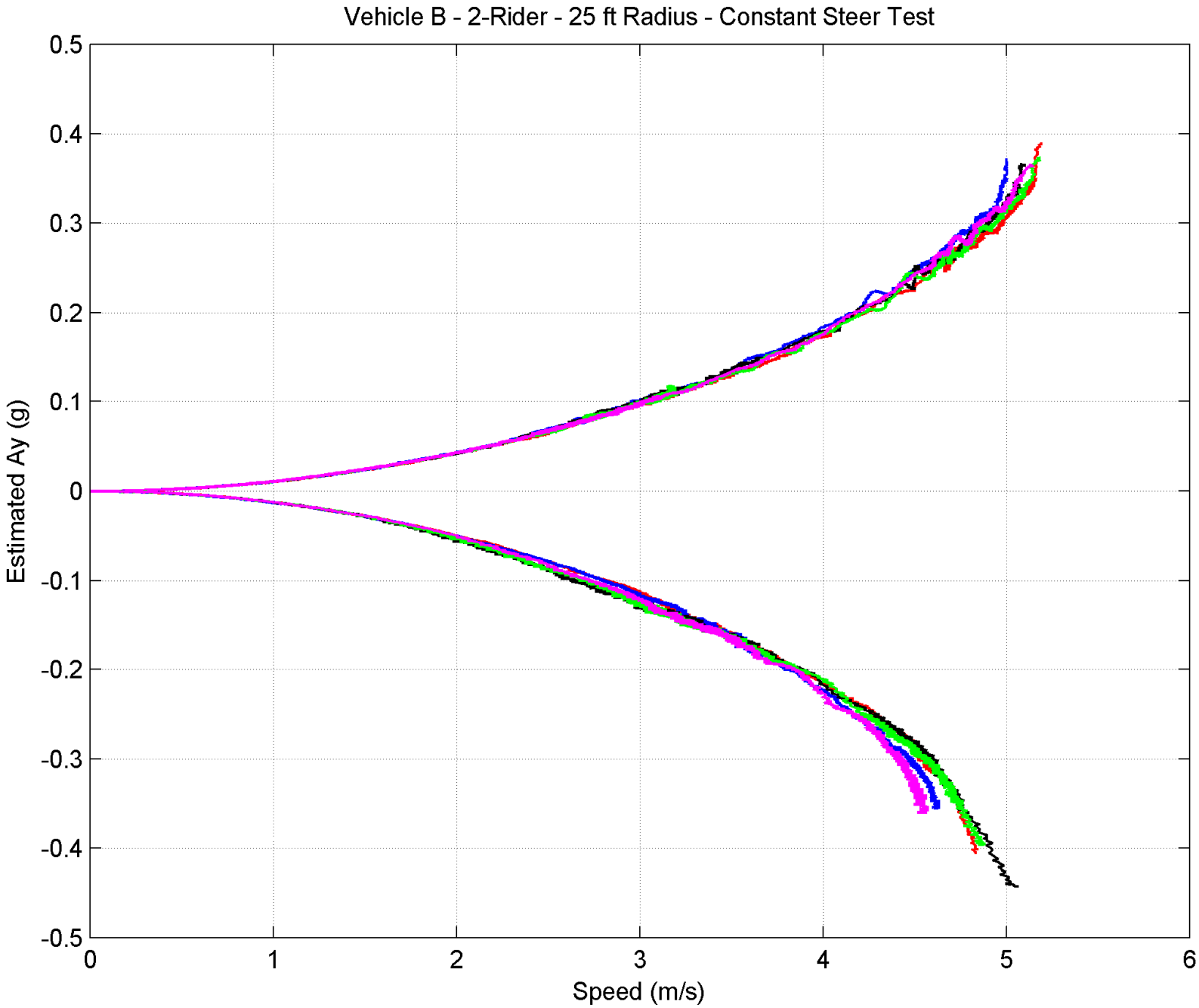
0.549

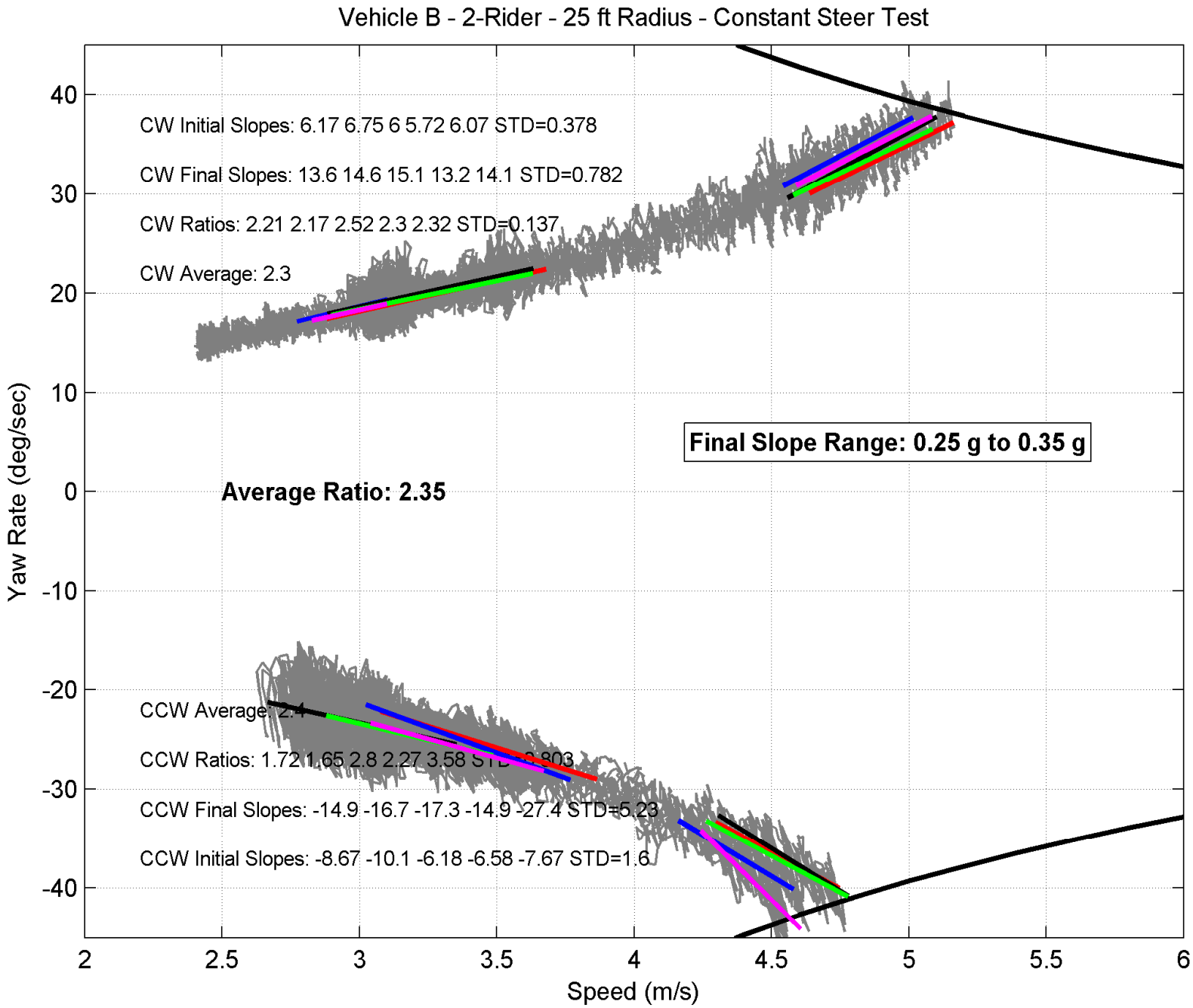
Average of All 12 Runs

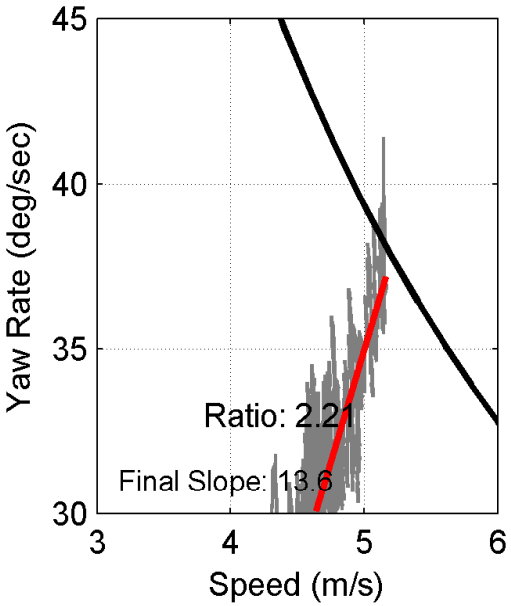
0.548

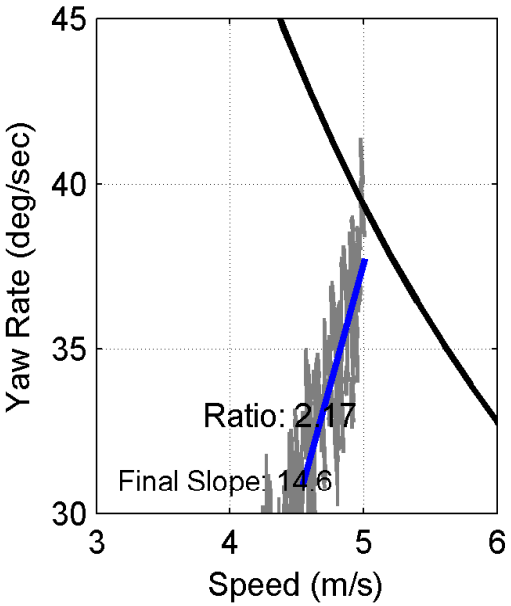
Threshold Ay

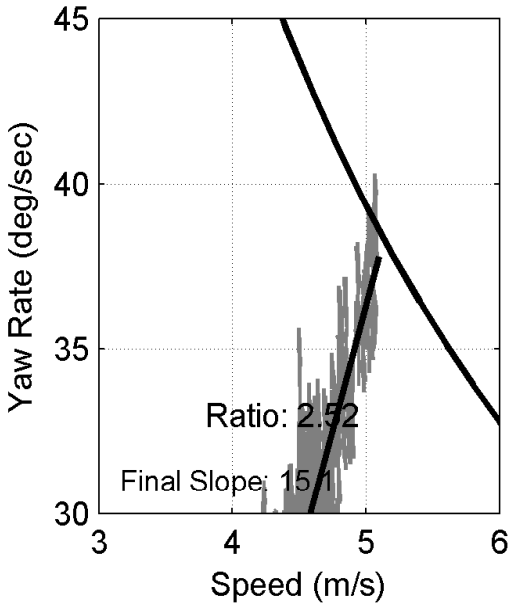

Vehicle B - 2-Rider
25 ft Radius - Constant Steer Test
Steer Motor/Ratio (deg)
Speed (m/s)
Roll Angle (deg)
Estimated Ay (g)
Yaw Rate (deg/sec)
Time (sec)
Time (sec)

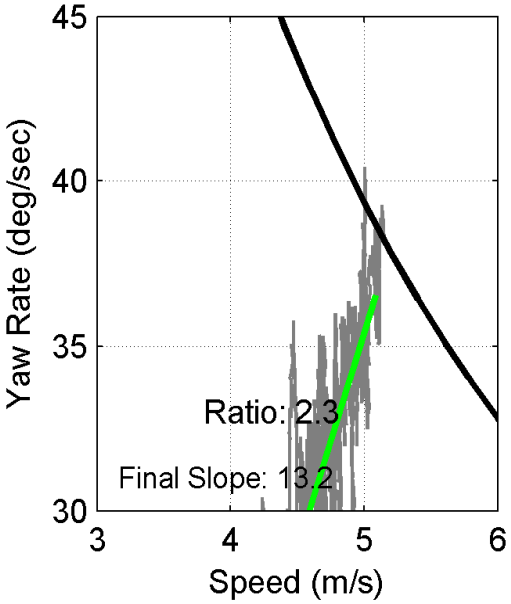

Vehicle B - 2-Rider - 25 ft Radius - Constant Steer Test
Estimated Ay (g)
Speed (m/s)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
1
2
3
4
5
6

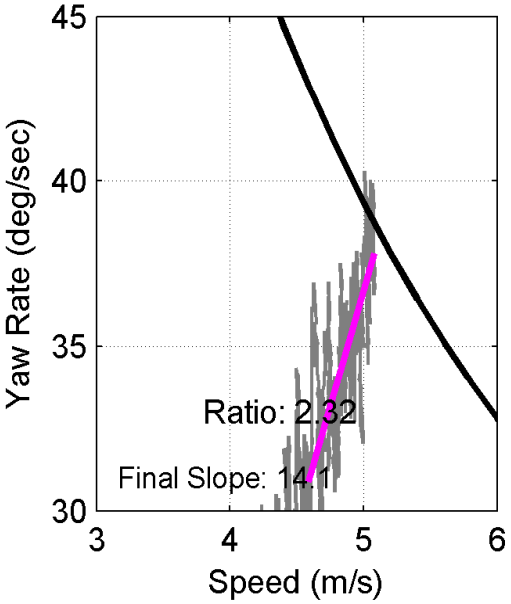

Vehicle B - 2-Rider - 25 ft Radius - Constant Steer Test
CW Initial Slopes: 6.17 6.75 6 5.72 6.07 STD=0.378
CW Final Slopes: 13.6 14.6 15.1 13.2 14.1 STD=0.782
CW Ratios: 2.21 2.17 2.52 2.3 2.32 STD=0.137
CW Average: 2.3
Final Slope Range: 0.25 g to 0.35 g
Average Ratio: 2.35
CCW Average: 2.4
CCW Ratios: 1.72 1.65 2.8 2.27 3.58 STD=0.803
CCW Final Slopes: -14.9 -16.7 -17.3 -14.9 -27.4 STD=5.23
CCW Initial Slopes: -8.67 -10.1 -6.18 -6.58 -7.67 STD=1.6
Yaw Rate (deg/sec)
Speed (m/s)
40
30
20
10
0
-10
-20
-30
-40
2
2.5
3
3.5
4
4.5
5
5.5
6





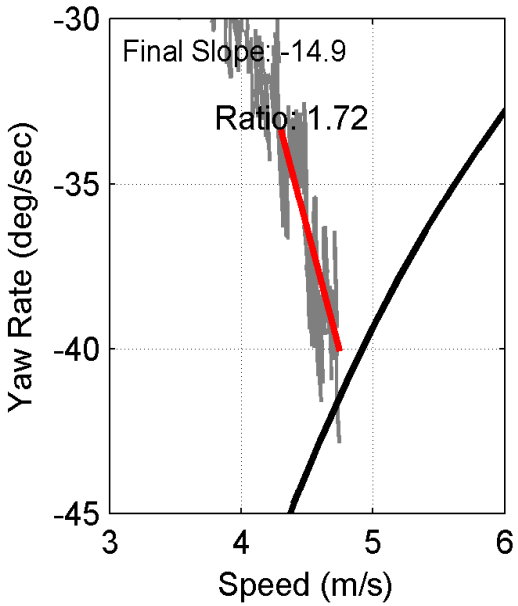


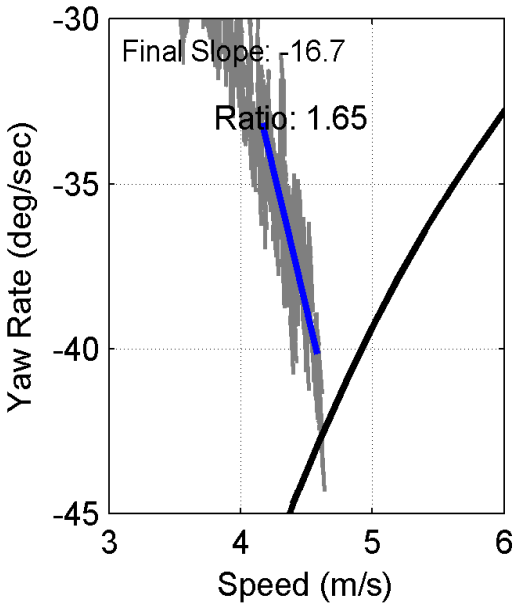


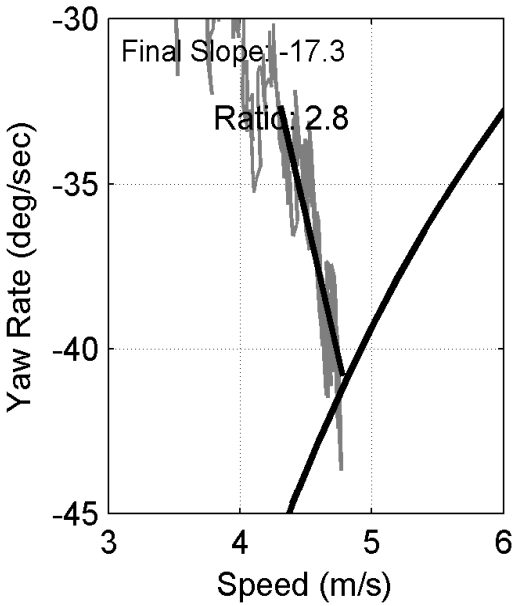


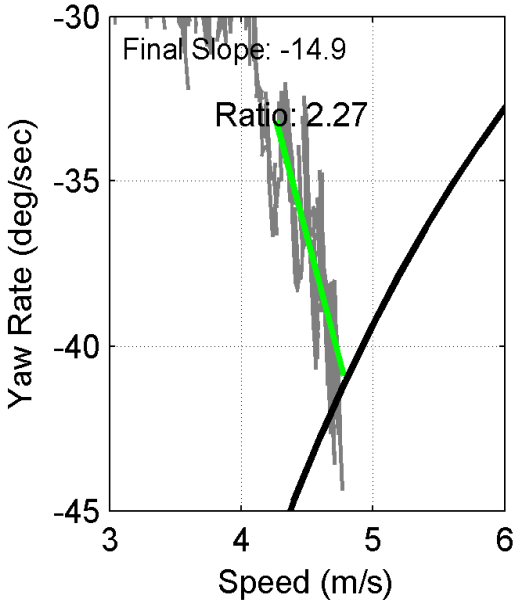
Final Slope Range:

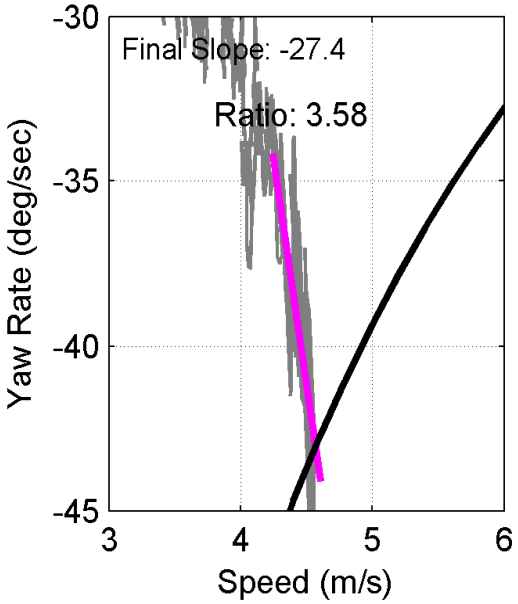
0.25 g to 0.35 g





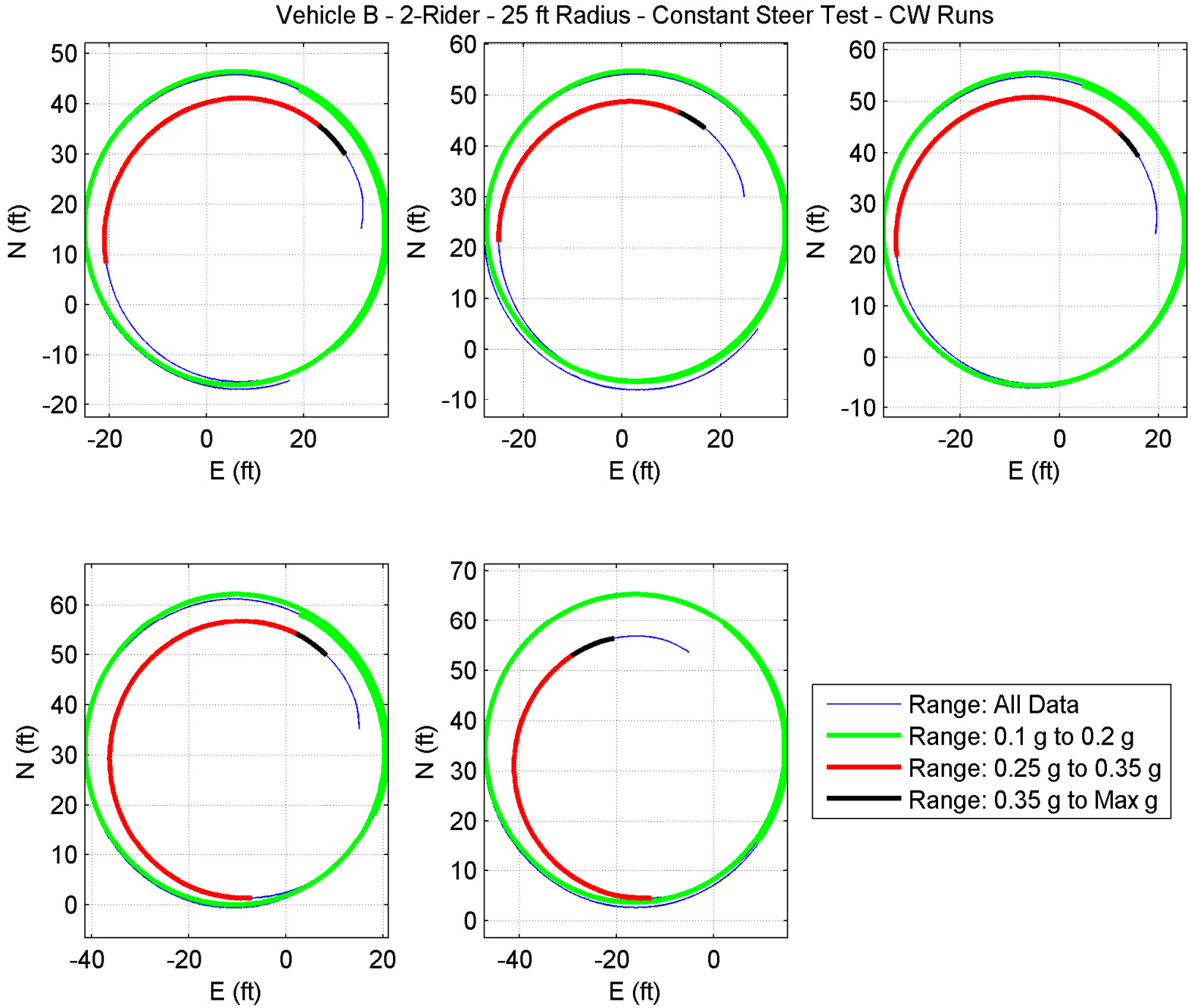


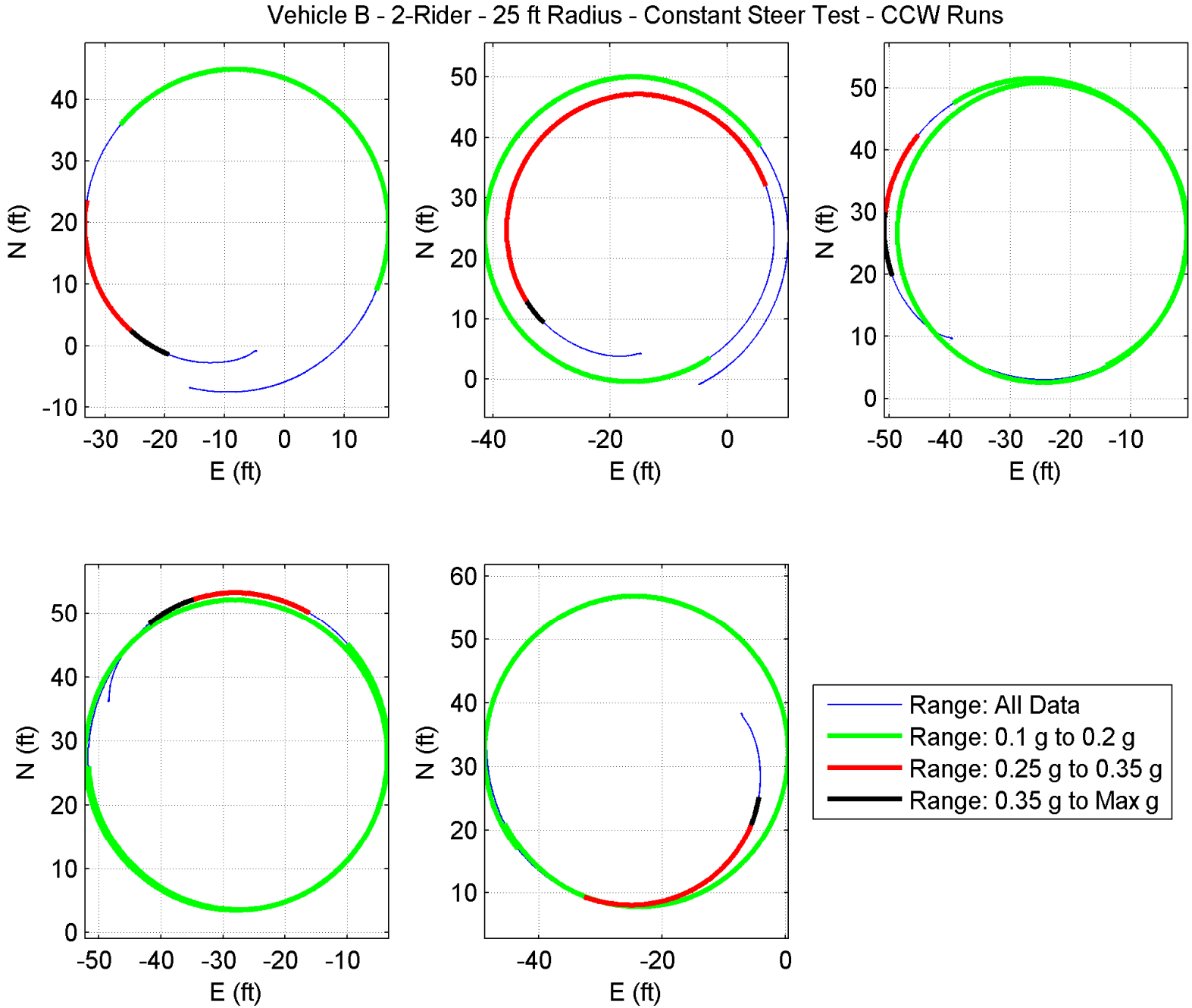


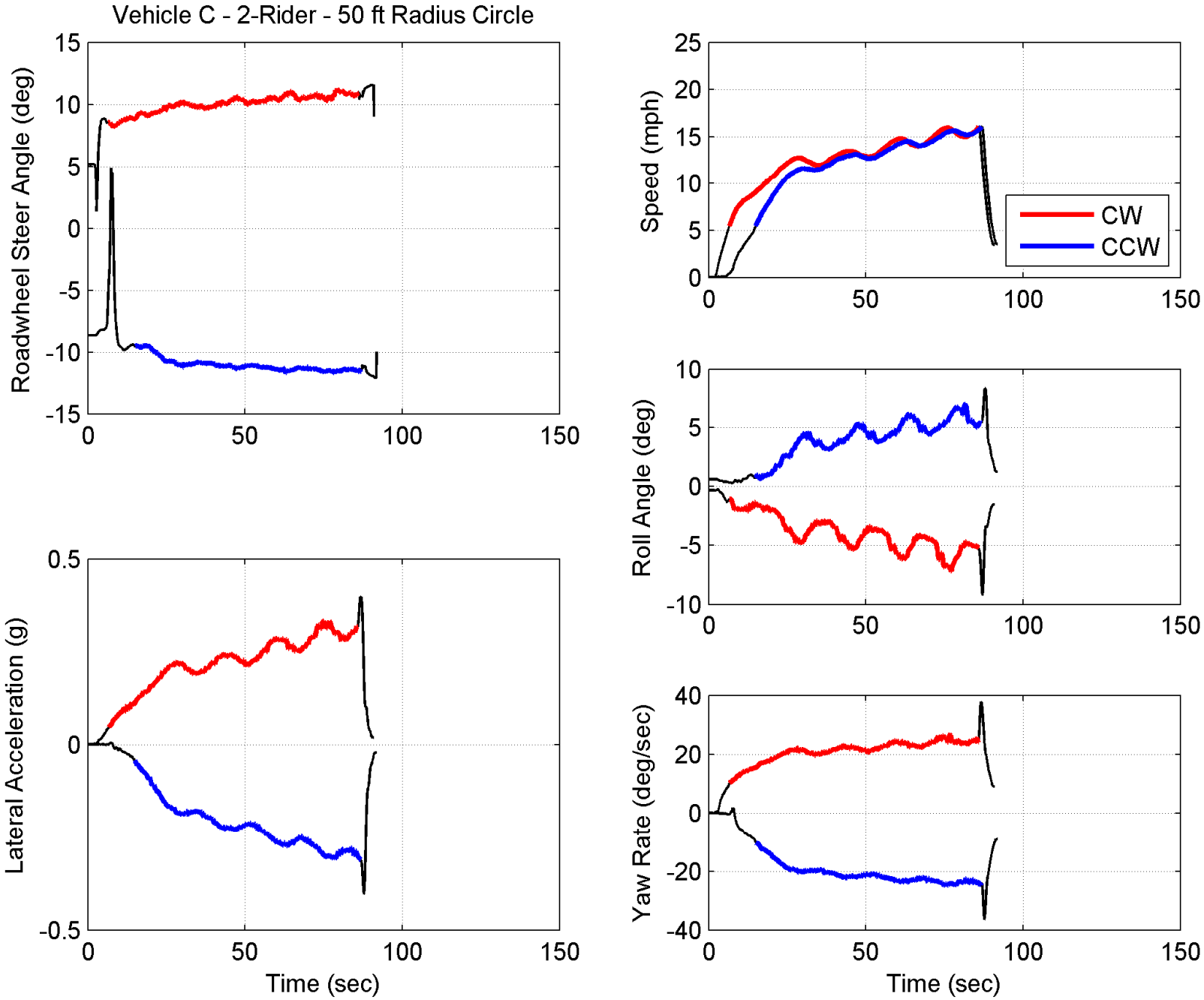


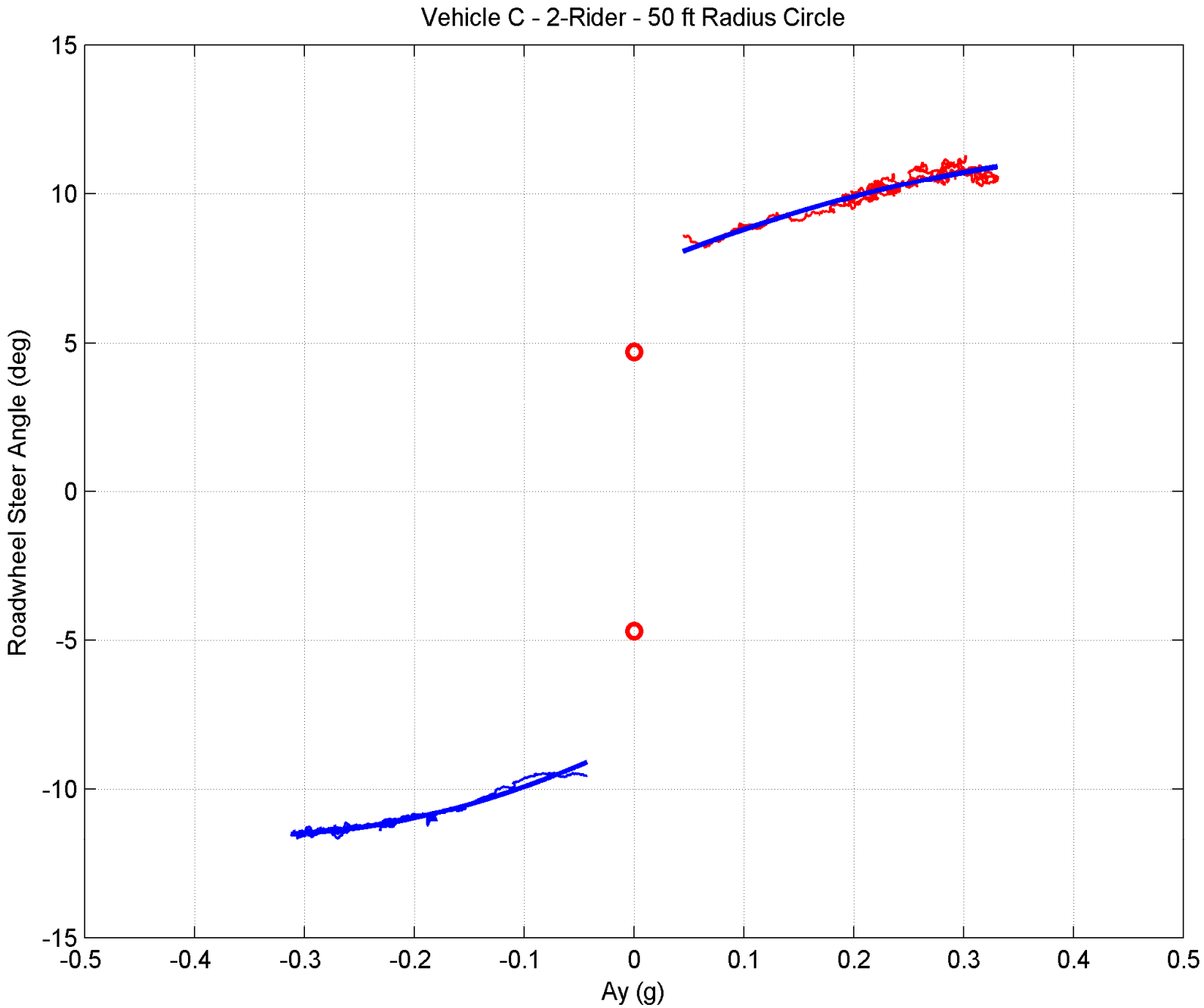
Final Slope Range:

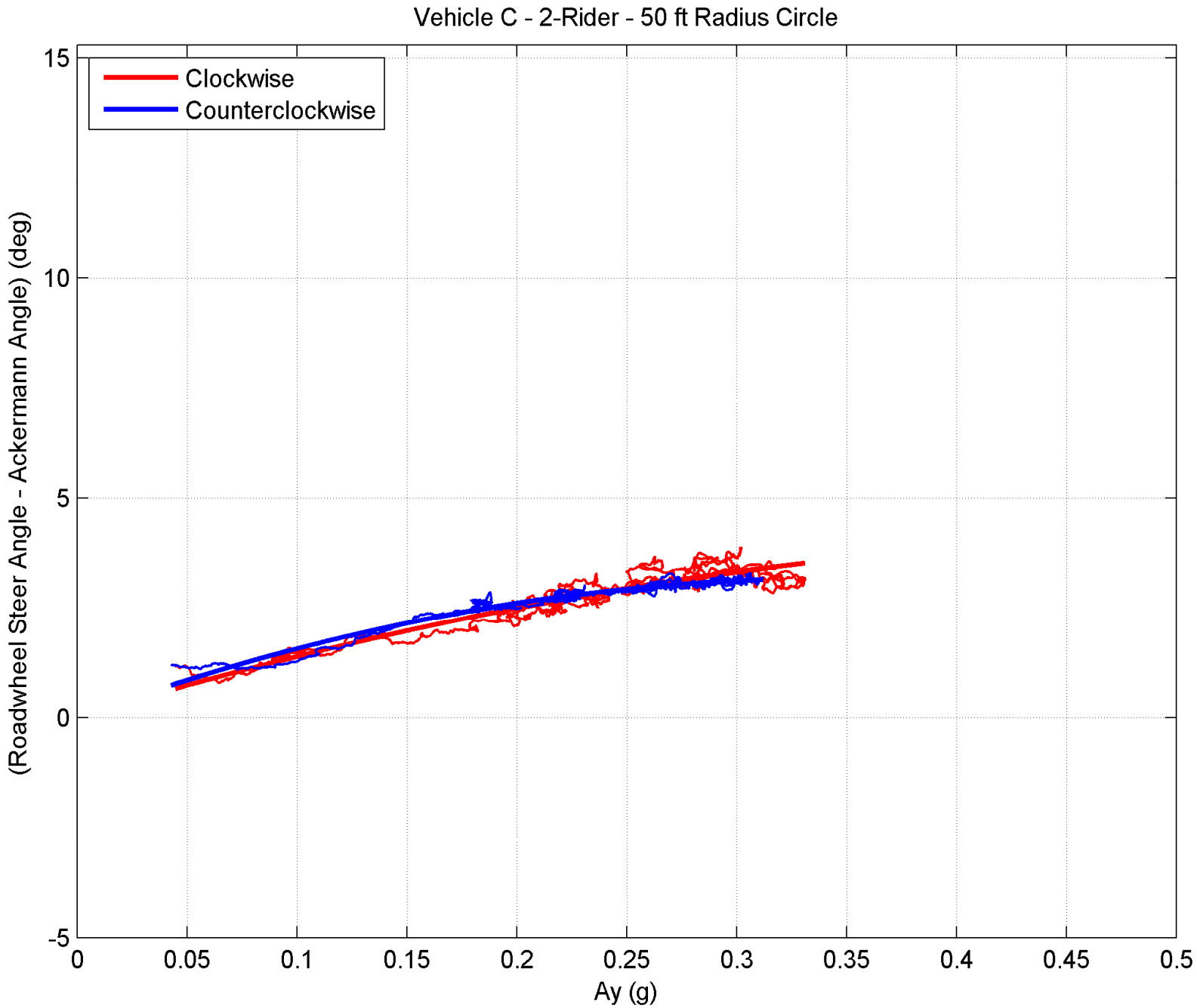
0.25 g to 0.35 g

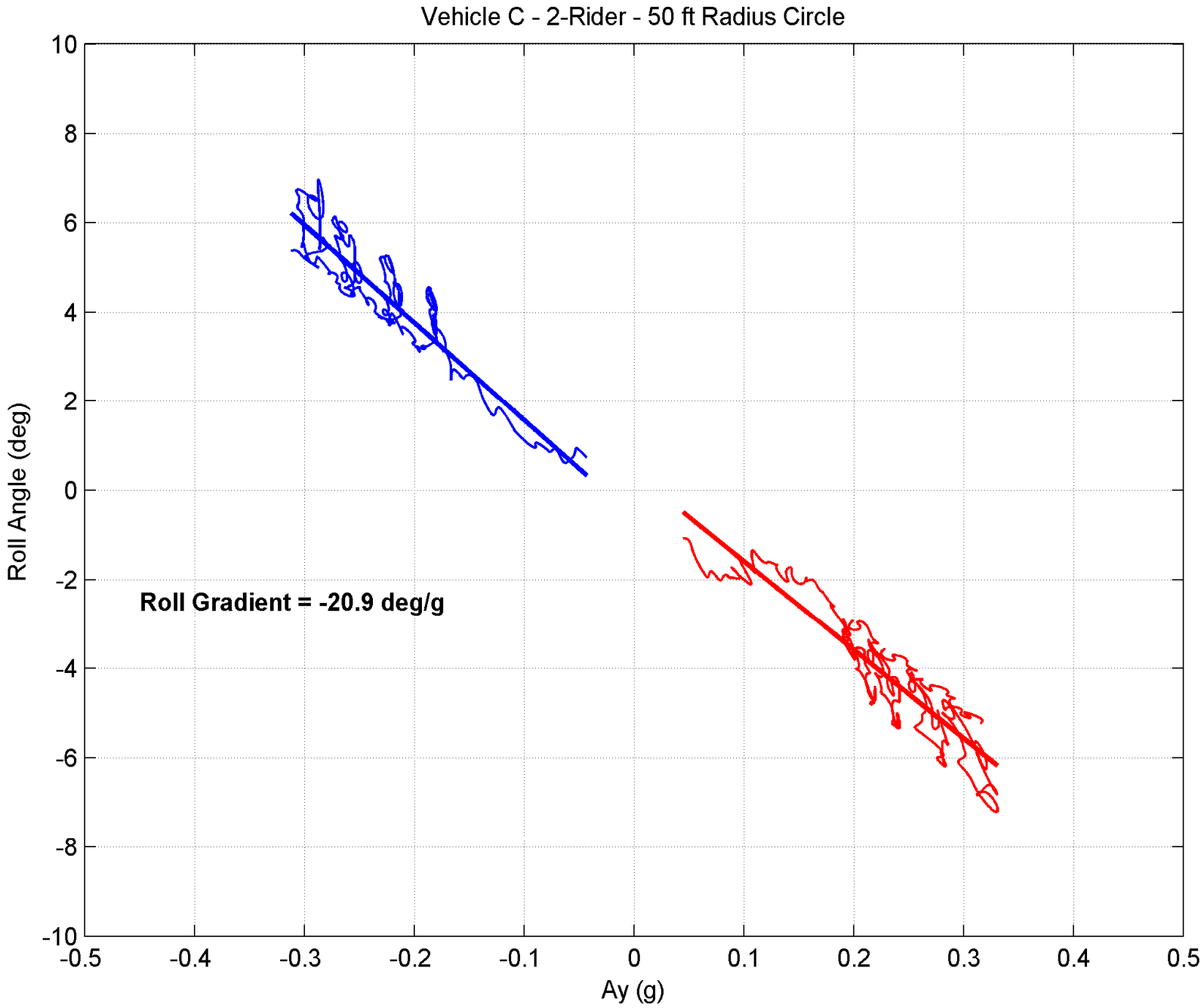

Vehicle B - 2-Rider - 25 ft Radius - Constant Steer Test - CW Runs
N (ft)
E (ft)
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.25 g to 0.35 g
Range: 0.35 g to Max g

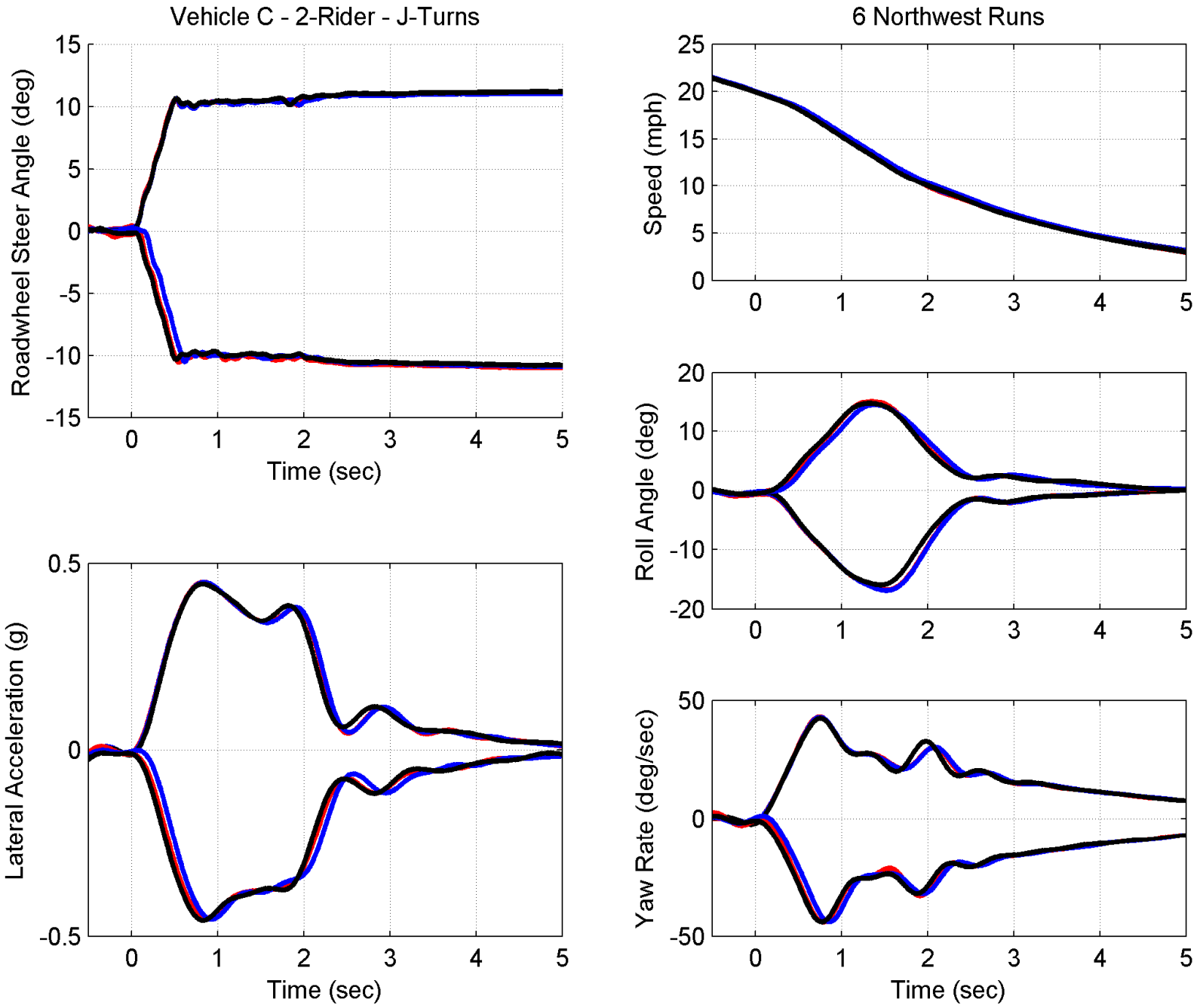

Vehicle B - 2-Rider - 25 ft Radius - Constant Steer Test - CCW Runs
N (ft)
E (ft)
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.25 g to 0.35 g
Range: 0.35 g to Max g

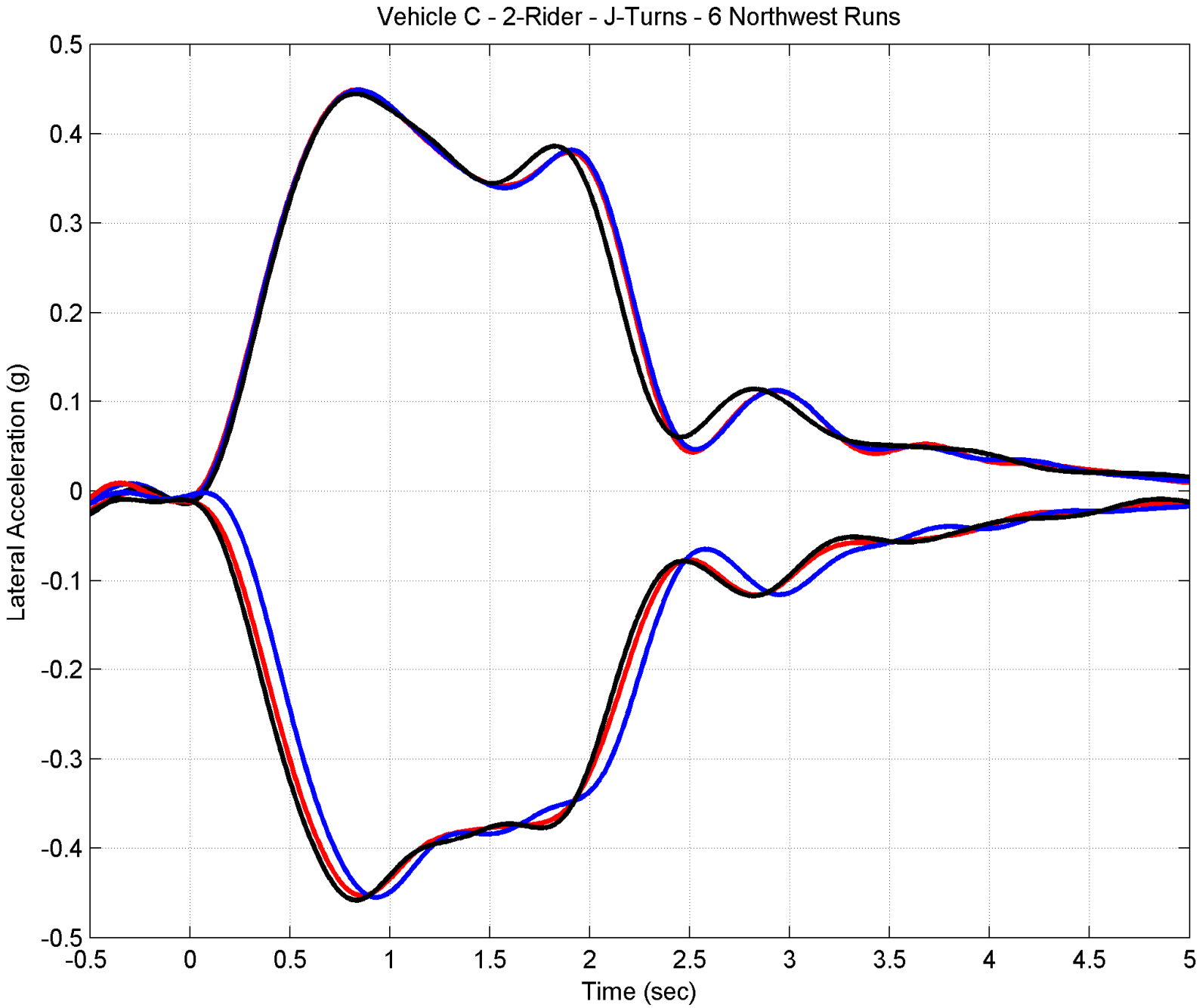

Vehicle C - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
15
10
5
0
-5
-10
-15
0
50
100
150
Speed (mph)
25
20
15
10
5
0
CW
CCW
Roll Angle (deg)
10
5
0
-5
-10
Lateral Acceleration (g)
0.5
0
-0.5
Yaw Rate (deg/sec)
40
20
0
-20
-40
Time (sec)
Time (sec)

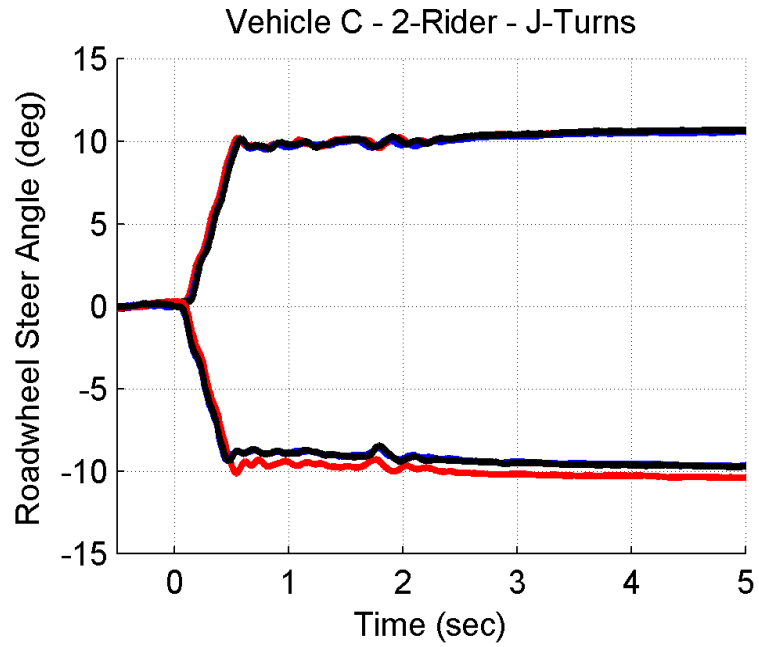

Vehicle C - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
Ay (g)
15
10
5
0
-5
-10
-15
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

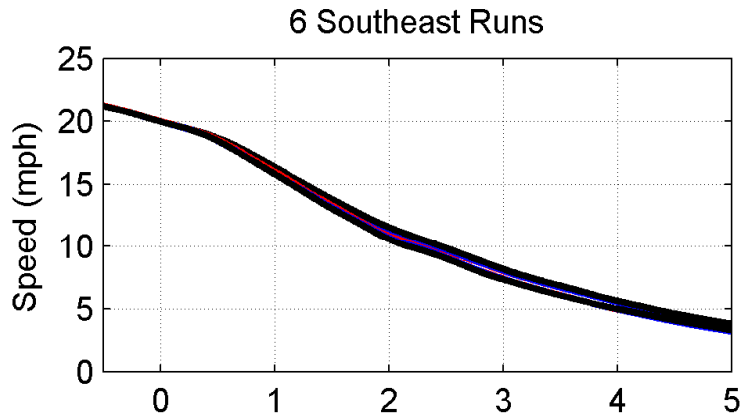

Vehicle C - 2-Rider - 50 ft Radius Circle
Clockwise
Counterclockwise
(Roadwheel Steer Angle - Ackermann Angle) (deg)
15
10
5
0
-5
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Ay (g)

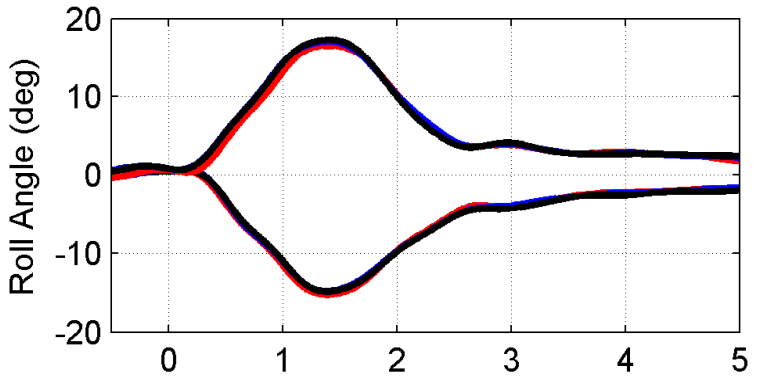

Vehicle C - 2-Rider - 50 ft Radius Circle
Roll Angle (deg)
Ay (g)
Roll Gradient = -20.9 deg/g
10
8
6
4
2
0
-2
-4
-6
-8
-10
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

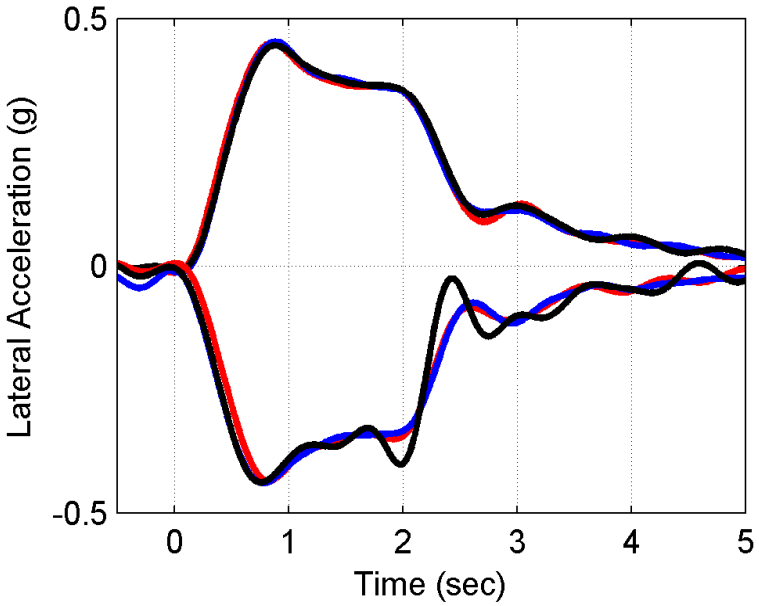

Vehicle C - 2-Rider - J-Turns
Roadwheel Steer Angle (deg)
Time (sec)
Lateral Acceleration (g)
Time (sec)
6 Northwest Runs
Speed (mph)
Roll Angle (deg)
Yaw Rate (deg/sec)
Time (sec)

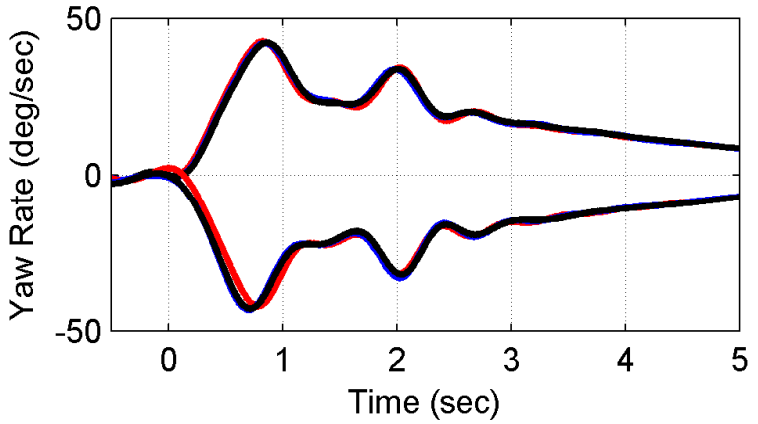

Vehicle C - 2-Rider - J-Turns - 6 Northwest Runs
Lateral Acceleration (g)
Time (sec)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

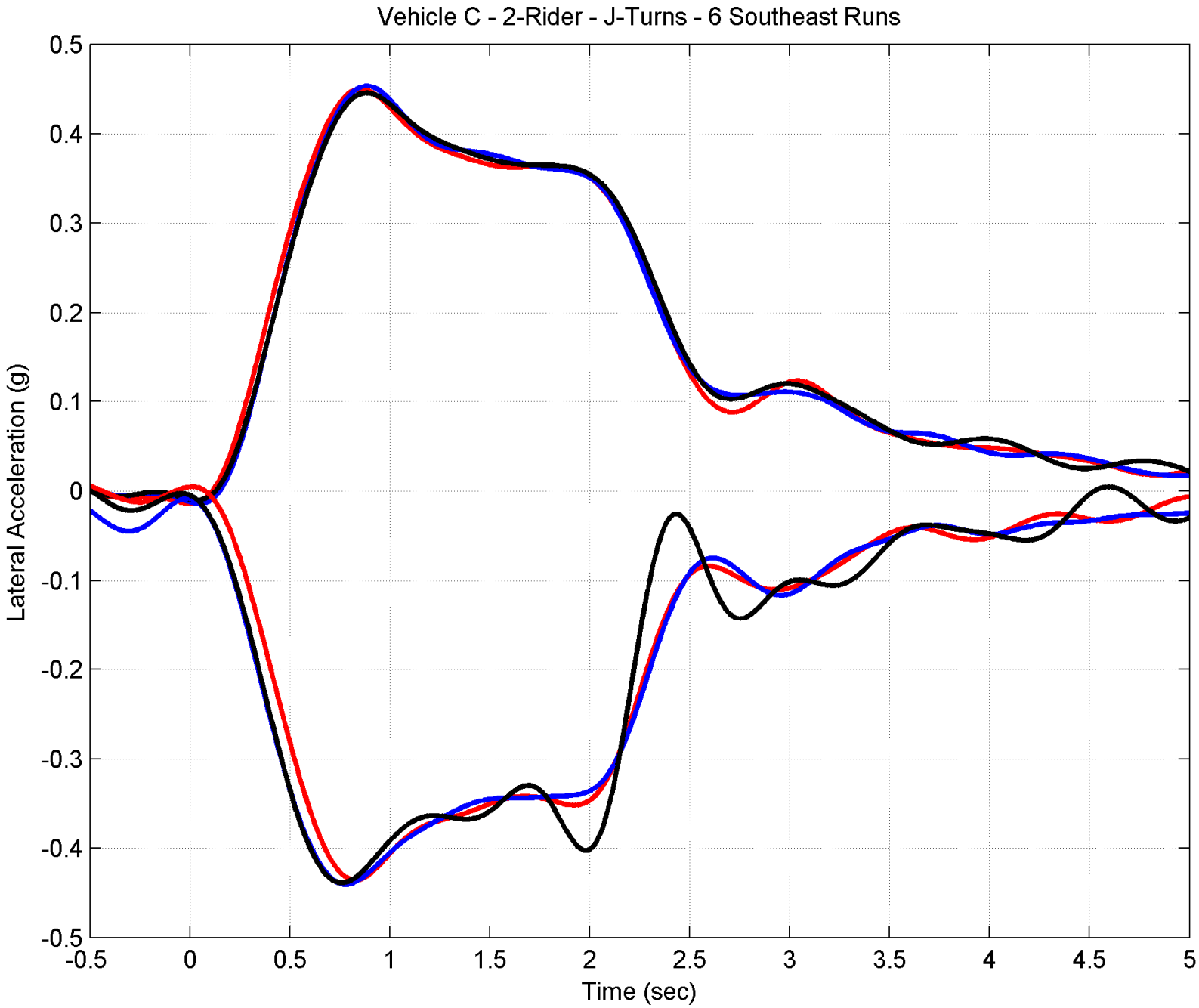

Vehicle C - 2-Rider - J-Turns
Roadwheel Steer Angle (deg)
15
10
5
0
-5
-10
-15
0
1
2
3
4
5
Time (sec)


6 Southeast Runs
Speed (mph)
25
20
15
10
5
0
0
1
2
3
4
5


Roll Angle (deg)
20
10
0
-10
-20
0
1
2
3
4
5


Lateral Acceleration (g)
0.5
0
-0.5
0
1
2
3
4
5
Time (sec)


Yaw Rate (deg/sec)
50
0
-50
0
1
2
3
4
5
Time (sec)


Vehicle C - 2-Rider - J-Turns - 6 Southeast Runs
Lateral Acceleration (g)
Time (sec)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

Vehicle C - 2-Rider Results

Peak Lateral Accelerations During 2WL J-Turns - All Values in "g's"

Run Number	Northwest Right Turns	Northwest Left Turns
1	0.449	-0.453
2	0.449	-0.455
3	0.445	-0.458
Mean Value of 3 Runs	0.447	-0.456
Standard Deviation of 3 Runs	0.003	0.002

Average of 6 Northwest Runs

0.452

Run Number	Southeast Right Turns	Southeast Left Turns
1	0.450	-0.436
2	0.453	-0.441
3	0.446	-0.439
Mean Value of 3 Runs	0.450	-0.439
Standard Deviation of 3 Runs	0.004	0.002

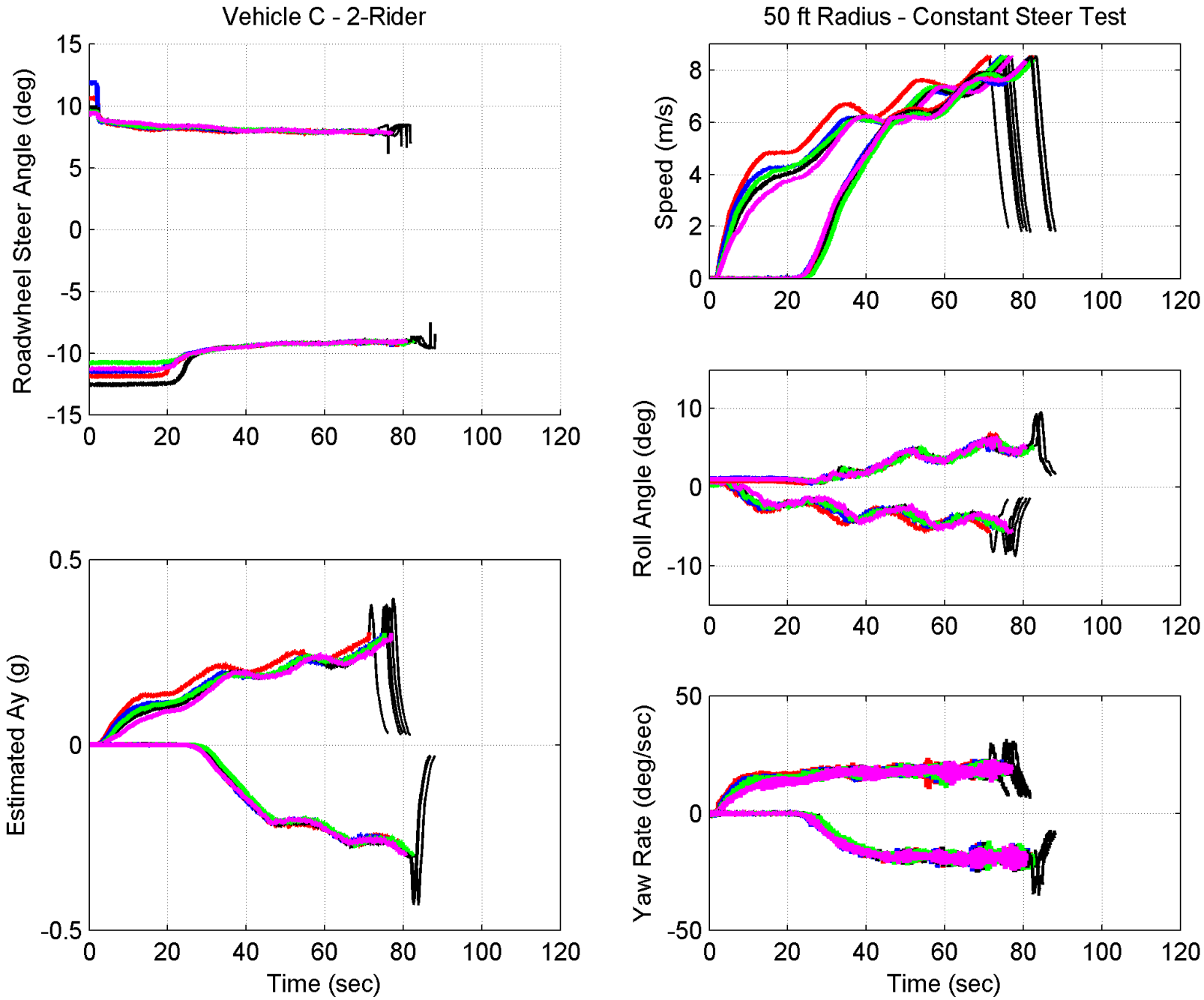
Average of 6 Southeast Runs

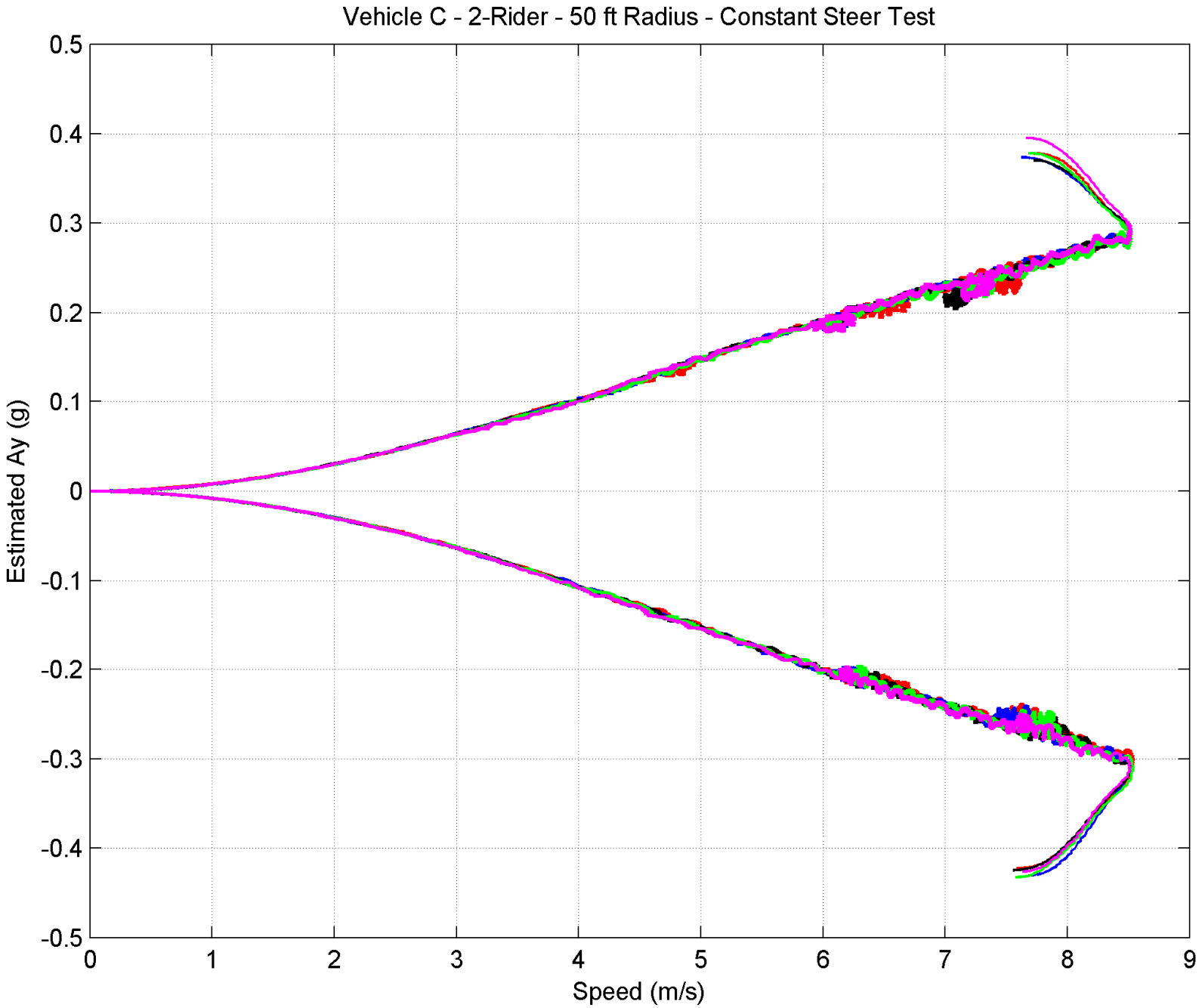
0.444

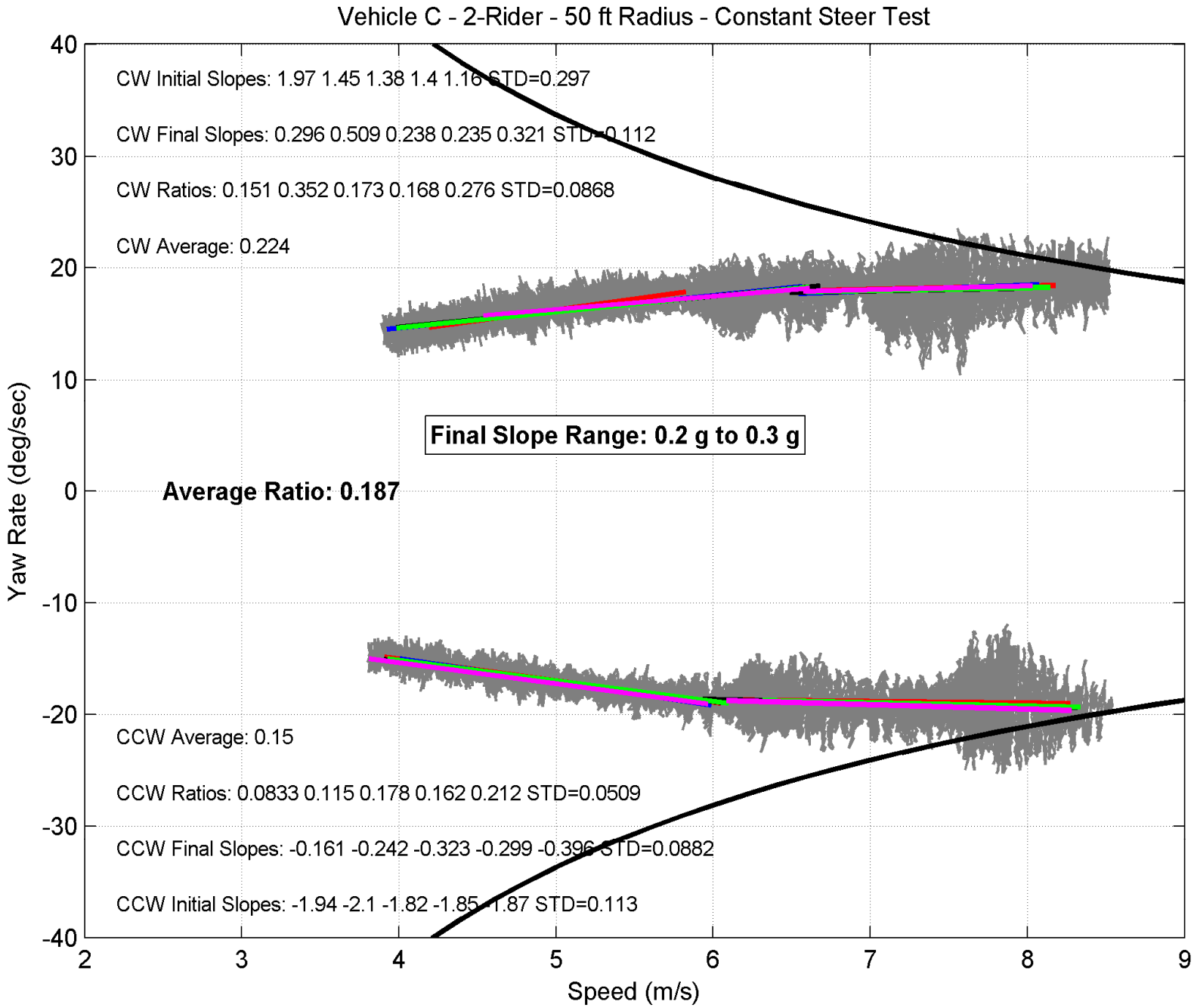
Average of All 12 Runs

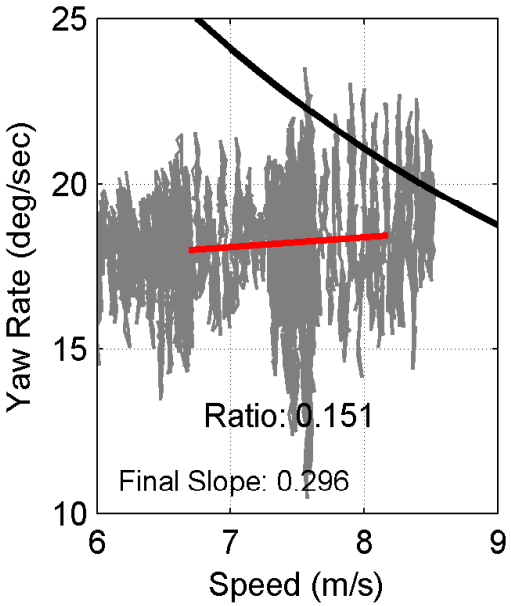
0.448

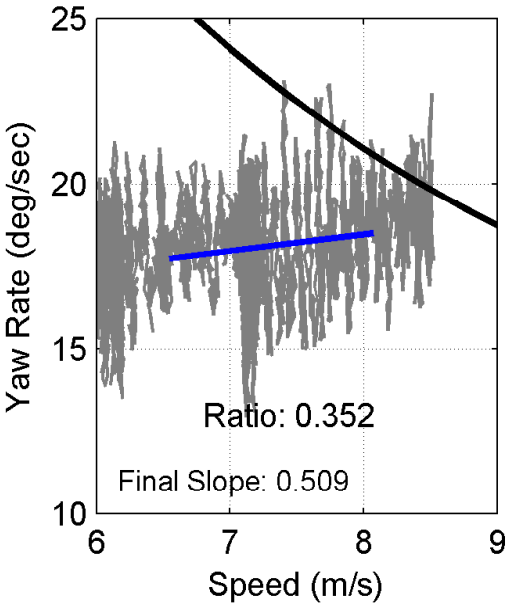
Threshold Ay

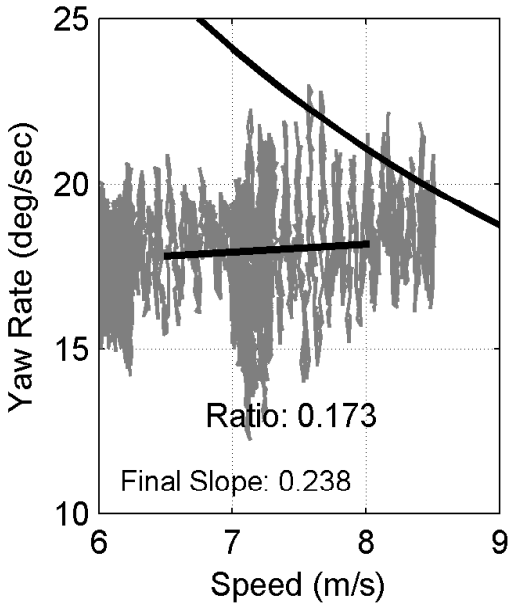

Vehicle C - 2-Rider
50 ft Radius - Constant Steer Test
Roadwheel Steer Angle (deg)
Speed (m/s)
Roll Angle (deg)
Estimated Ay (g)
Yaw Rate (deg/sec)
Time (sec)
Time (sec)

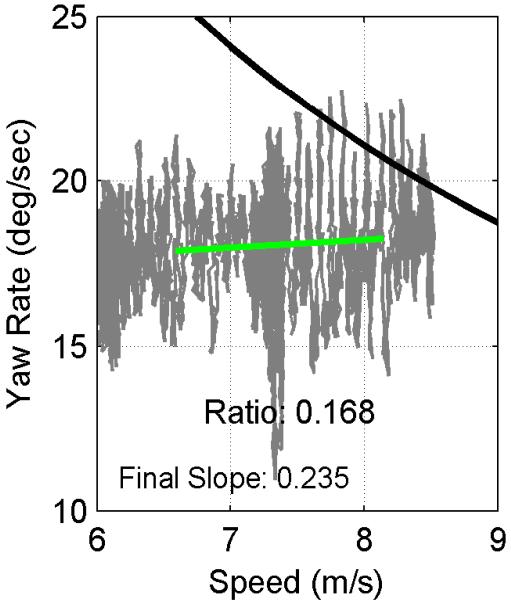

Vehicle C - 2-Rider - 50 ft Radius - Constant Steer Test
Estimated Ay (g)
Speed (m/s)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
1
2
3
4
5
6
7
8
9

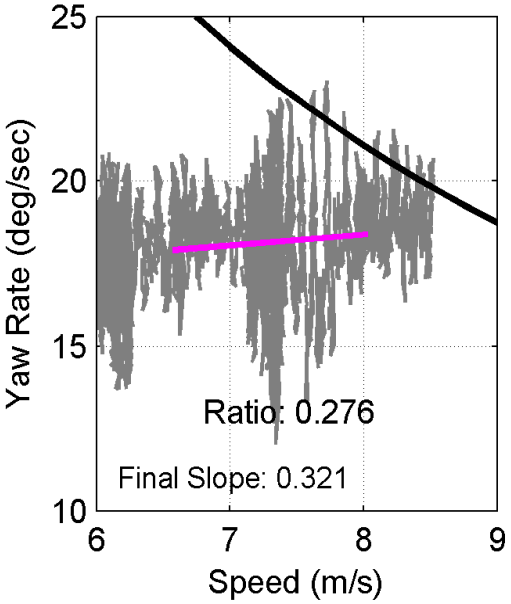

Vehicle C - 2-Rider - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 1.97 1.45 1.38 1.4 1.16 STD=0.297
CW Final Slopes: 0.296 0.509 0.238 0.235 0.321 STD=0.112
CW Ratios: 0.151 0.352 0.173 0.168 0.276 STD=0.0868
CW Average: 0.224
Final Slope Range: 0.2 g to 0.3 g
Average Ratio: 0.187
CCW Average: 0.15
CCW Ratios: 0.0833 0.115 0.178 0.162 0.212 STD=0.0509
CCW Final Slopes: -0.161 -0.242 -0.323 -0.299 -0.396 STD=0.0882
CCW Initial Slopes: -1.94 -2.1 -1.82 -1.85 -1.87 STD=0.113
Yaw Rate (deg/sec)
Speed (m/s)
40
30
20
10
0
-10
-20
-30
-40
2
3
4
5
6
7
8
9





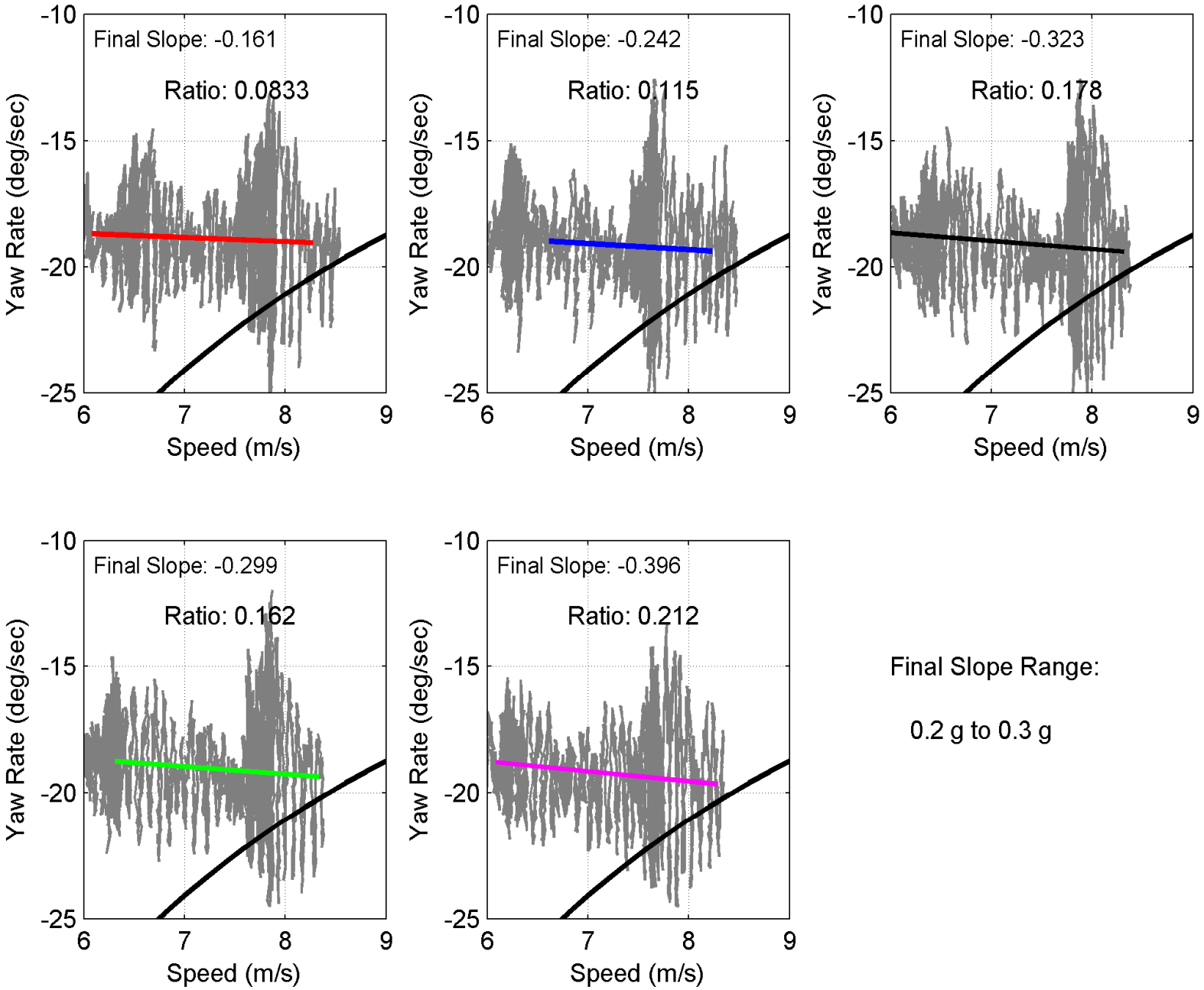






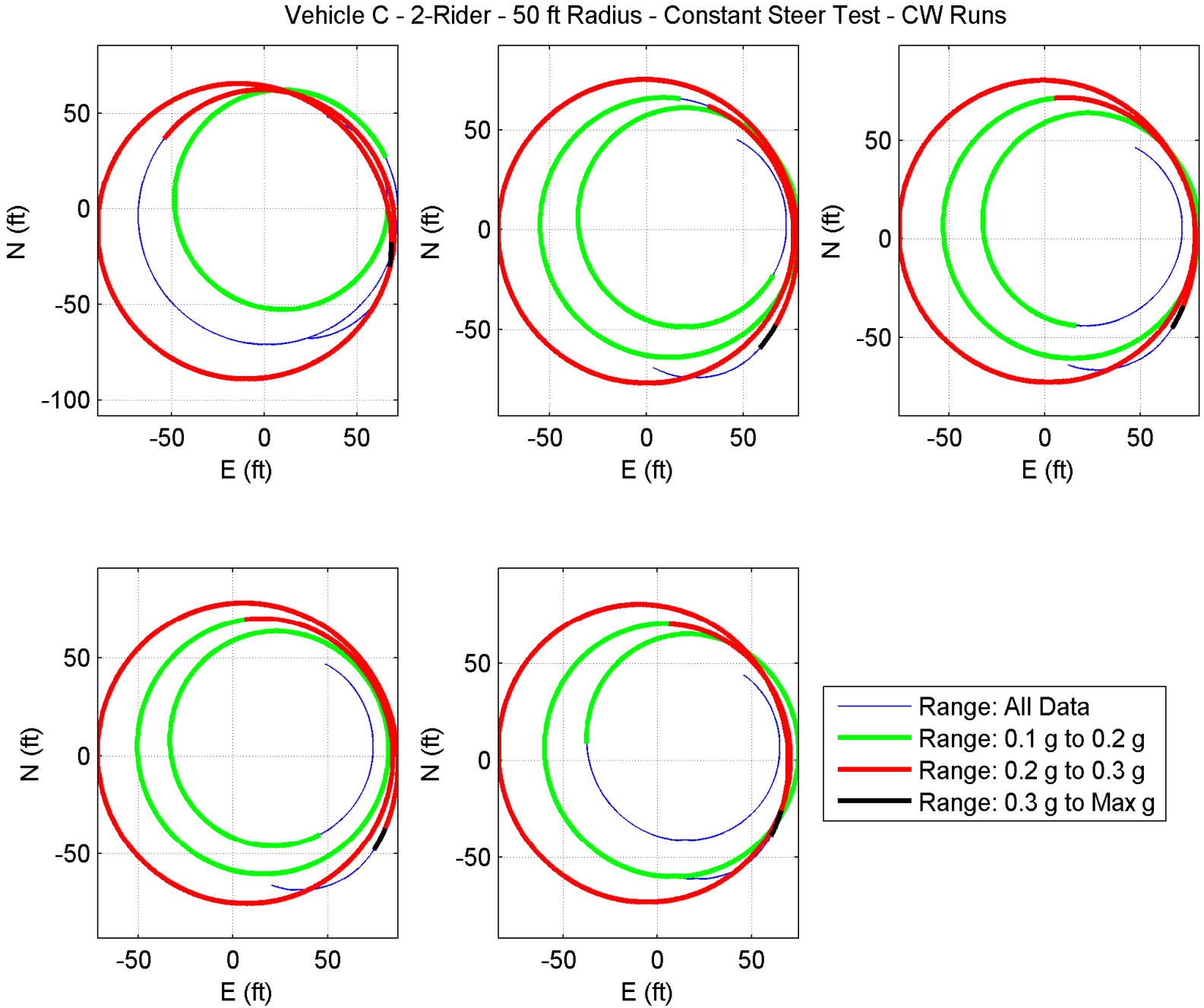
Final Slope Range:

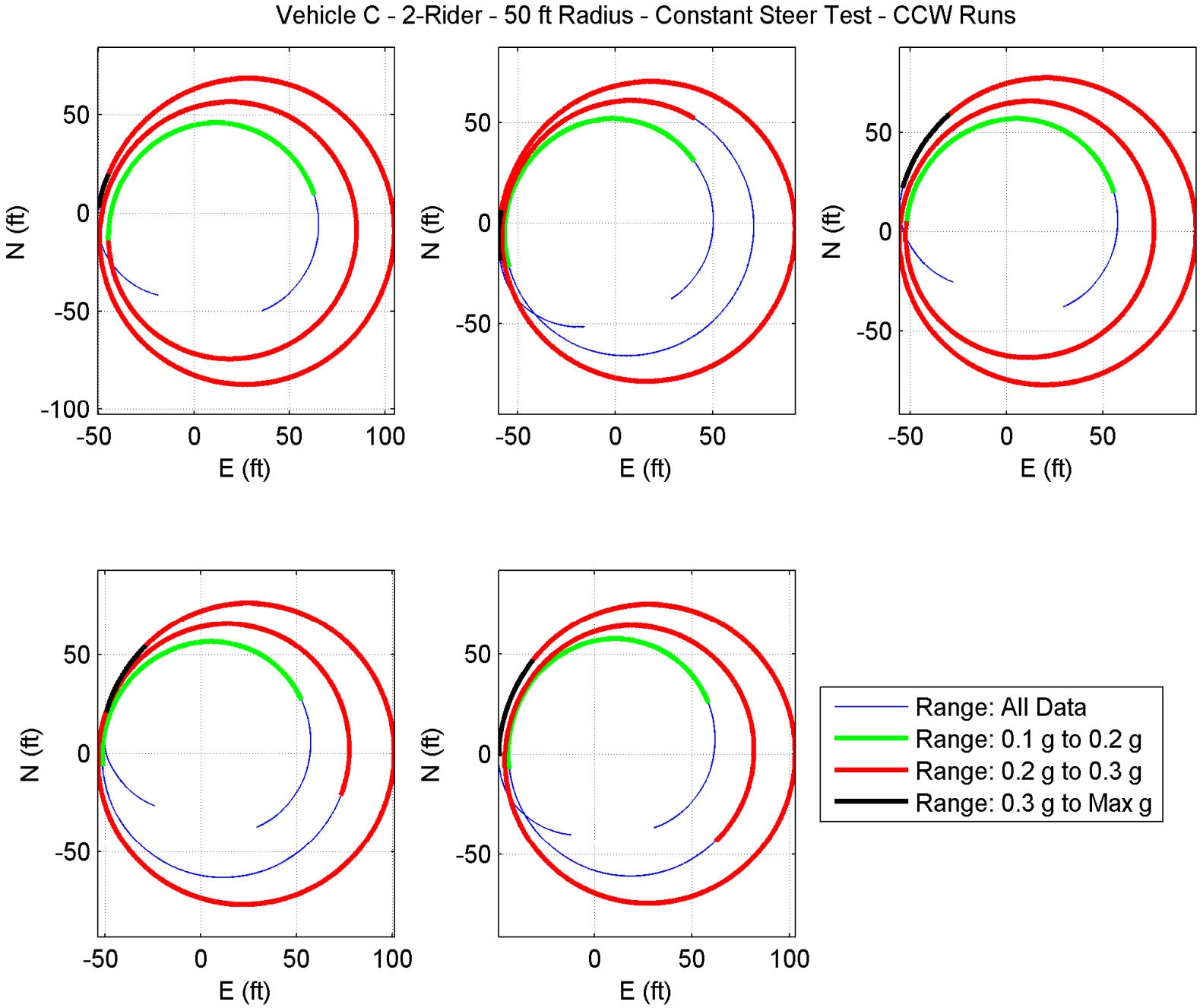
0.2 g to 0.3 g

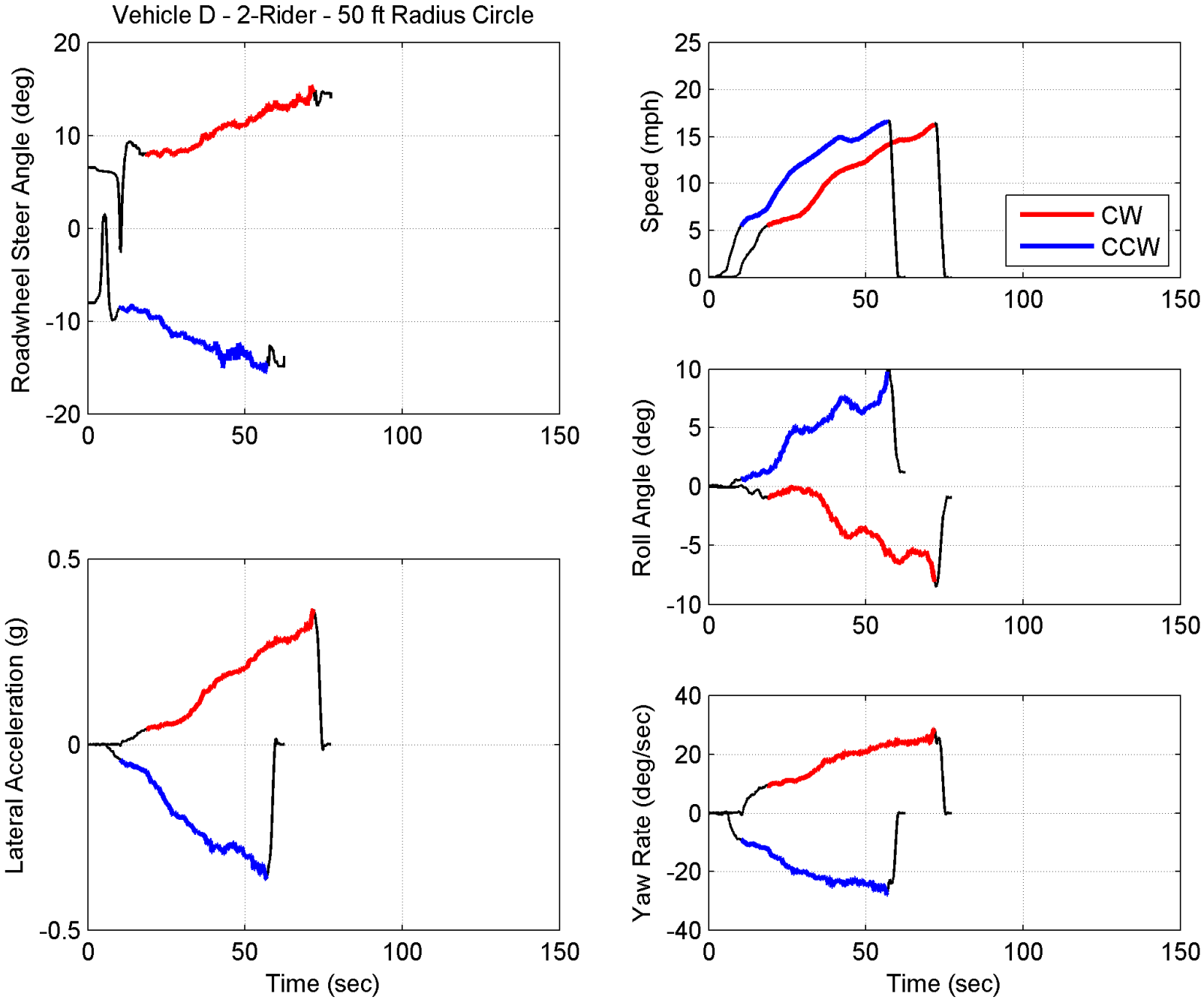


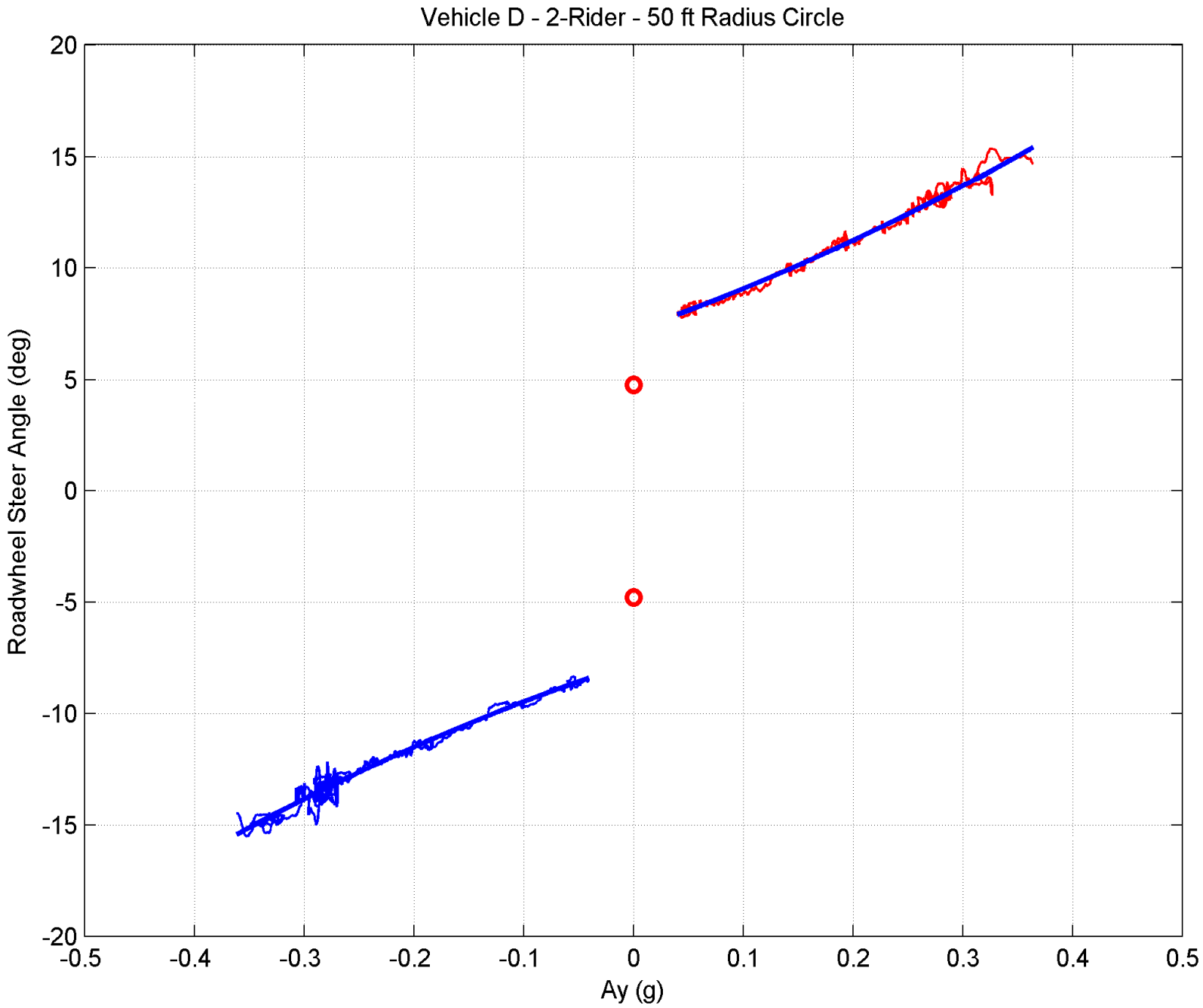
Final Slope Range:

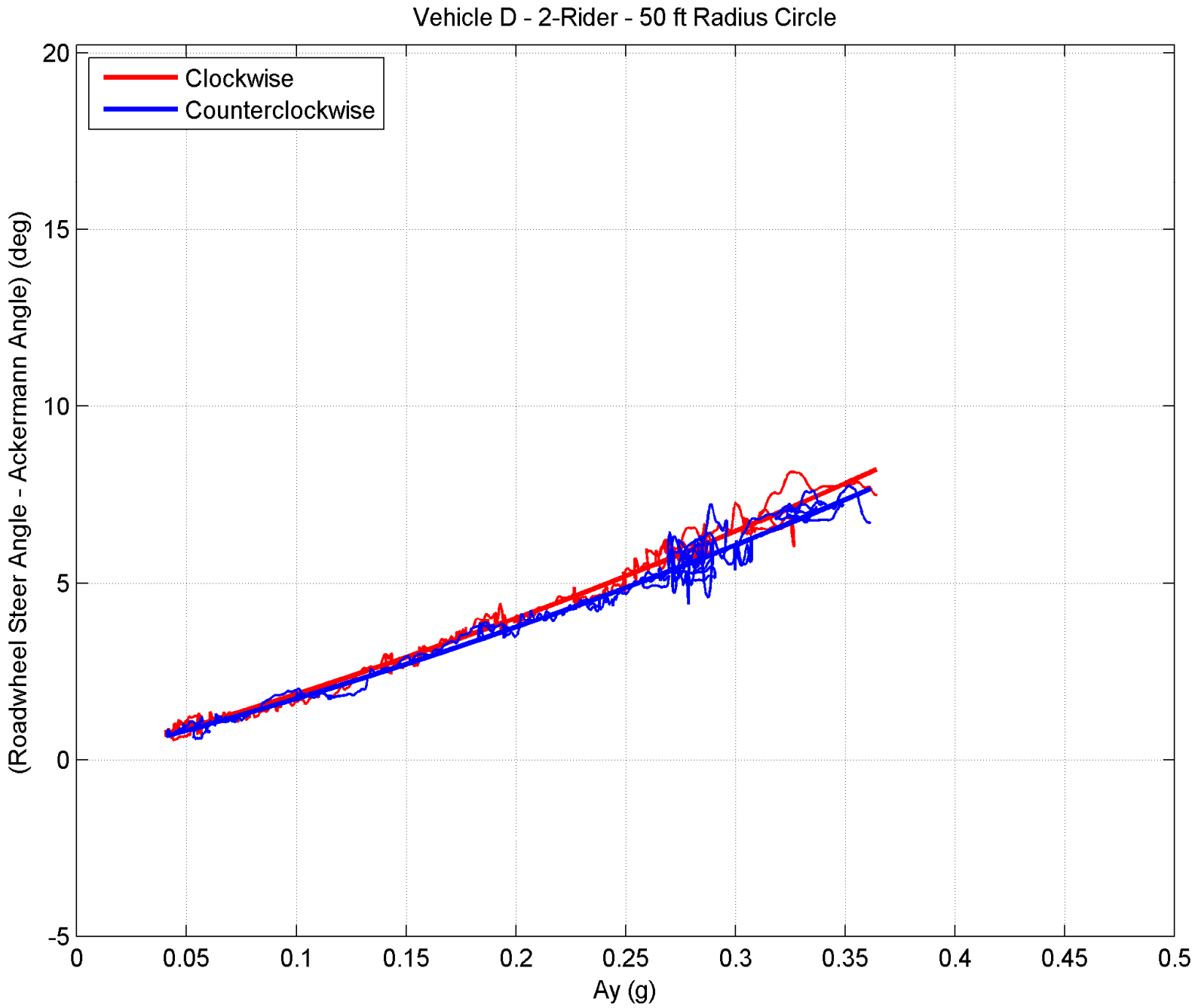
0.2 g to 0.3 g

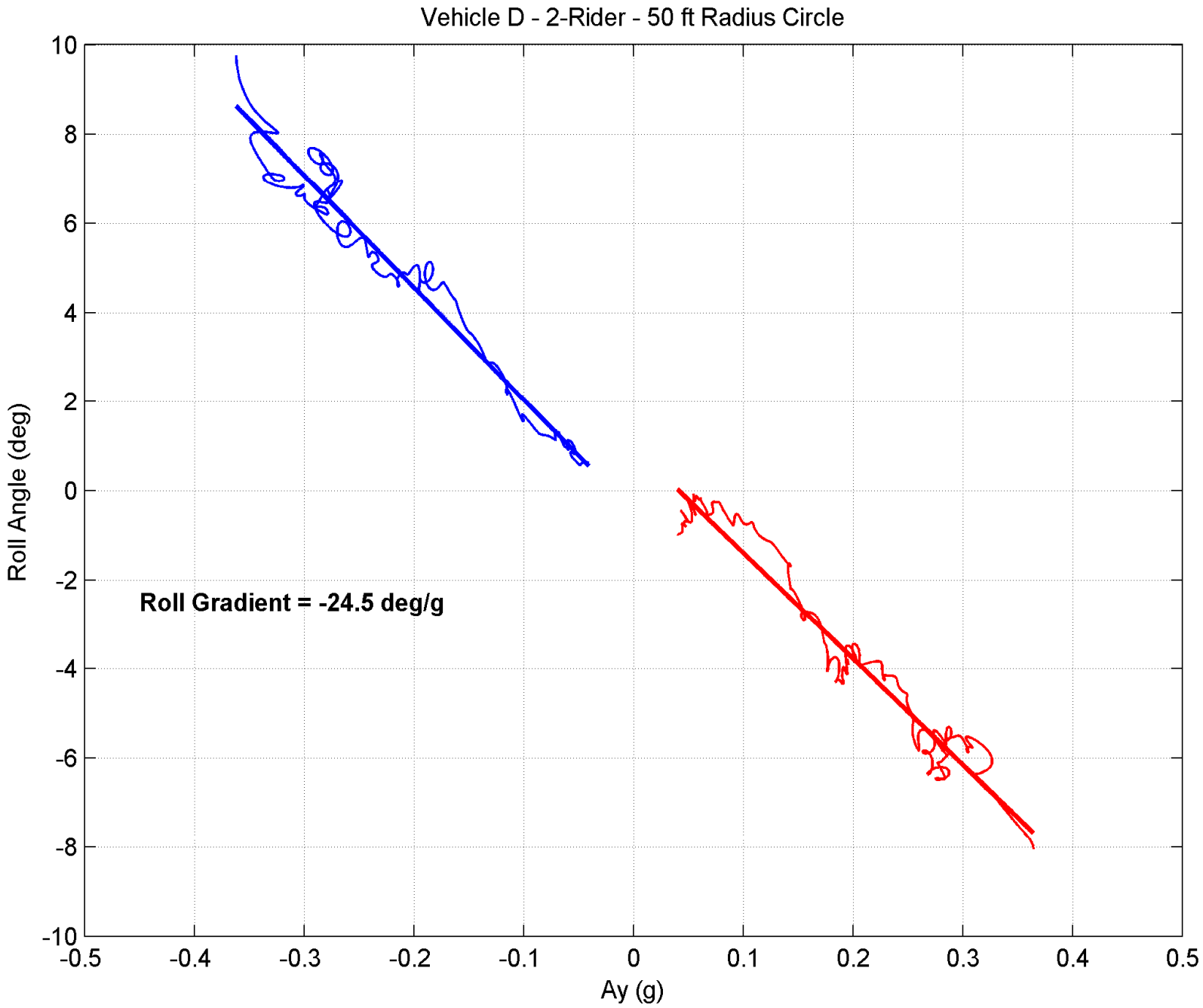

Vehicle C - 2-Rider - 50 ft Radius - Constant Steer Test - CW Runs
N (ft)
E (ft)
50
0
-50
-100
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.2 g to 0.3 g
Range: 0.3 g to Max g

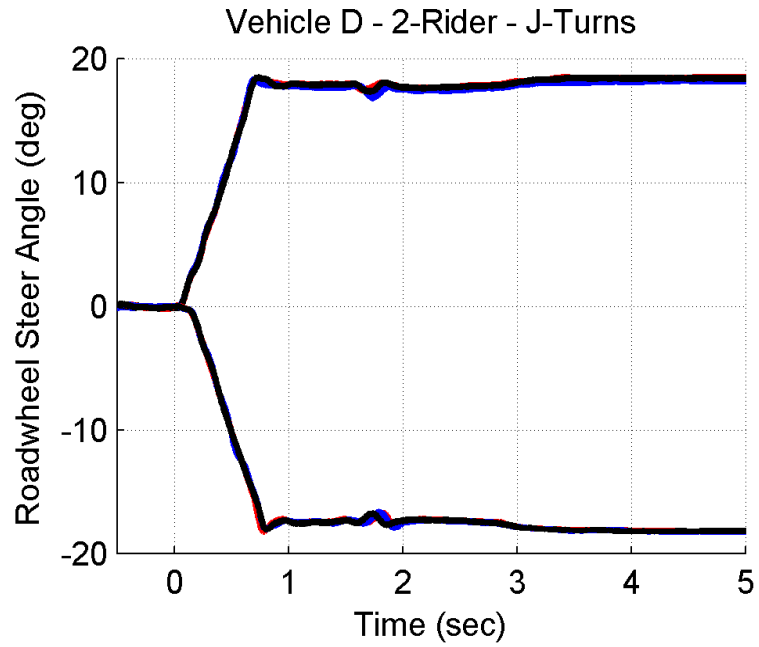

Vehicle C - 2-Rider - 50 ft Radius - Constant Steer Test - CCW Runs
N (ft)
E (ft)
50
0
-50
-100
-50
0
50
100
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.2 g to 0.3 g
Range: 0.3 g to Max g

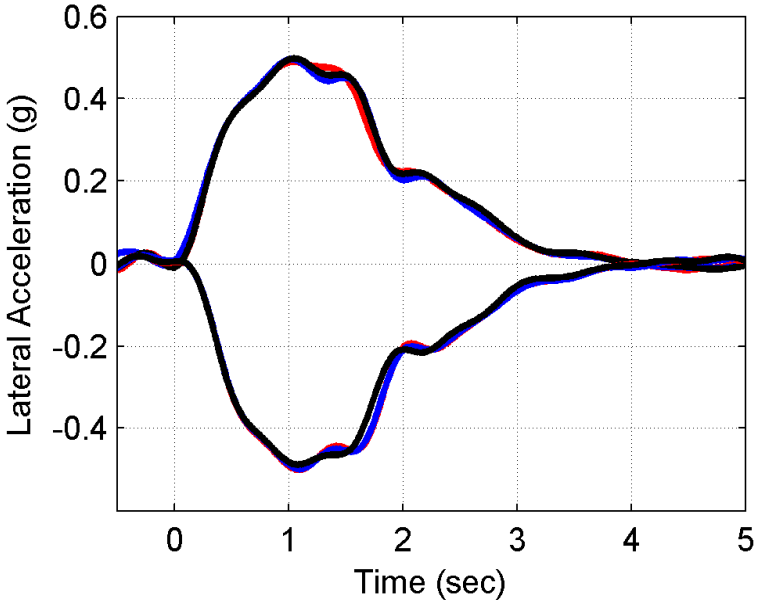

Vehicle D - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
20
10
0
-10
-20
0
50
100
150
Speed (mph)
25
20
15
10
5
0
CW
CCW
Roll Angle (deg)
10
5
0
-5
-10
Lateral Acceleration (g)
0.5
0
-0.5
Yaw Rate (deg/sec)
40
20
0
-20
-40
Time (sec)
Time (sec)

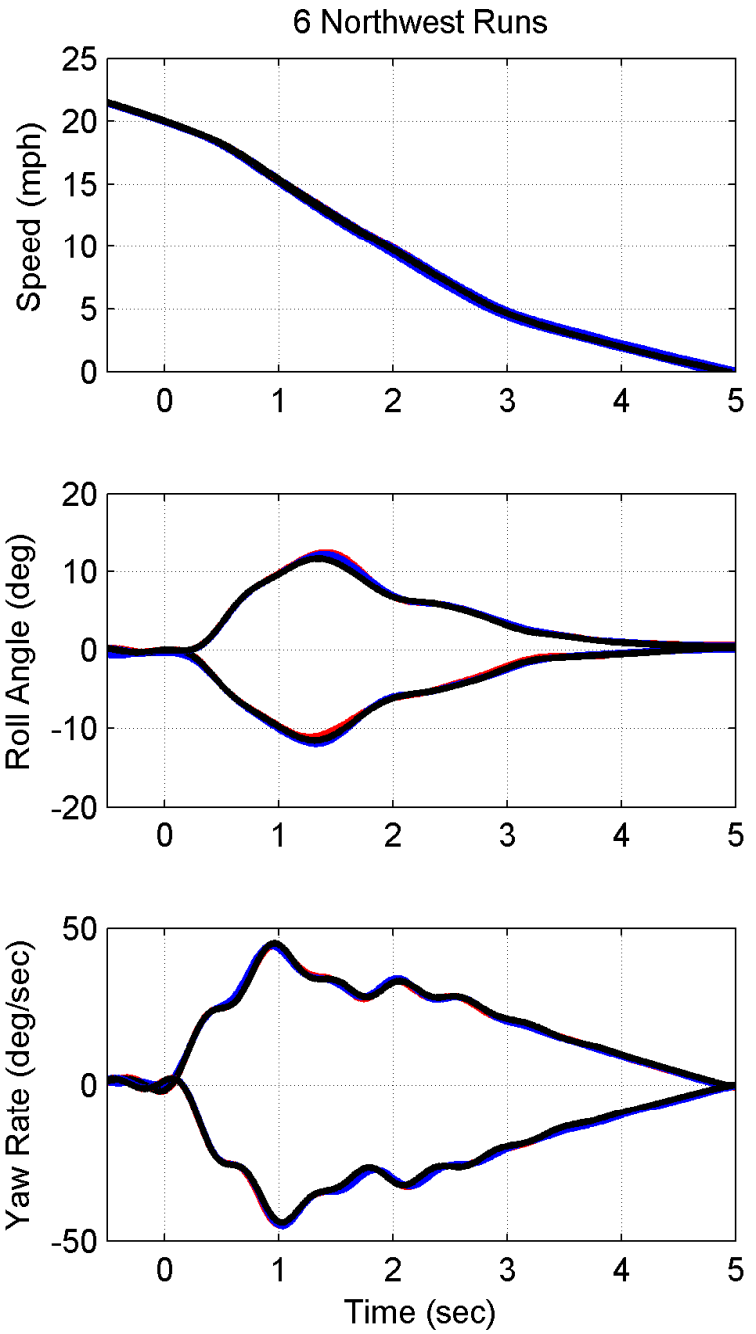

Vehicle D - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
Ay (g)
20
15
10
5
0
-5
-10
-15
-20
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

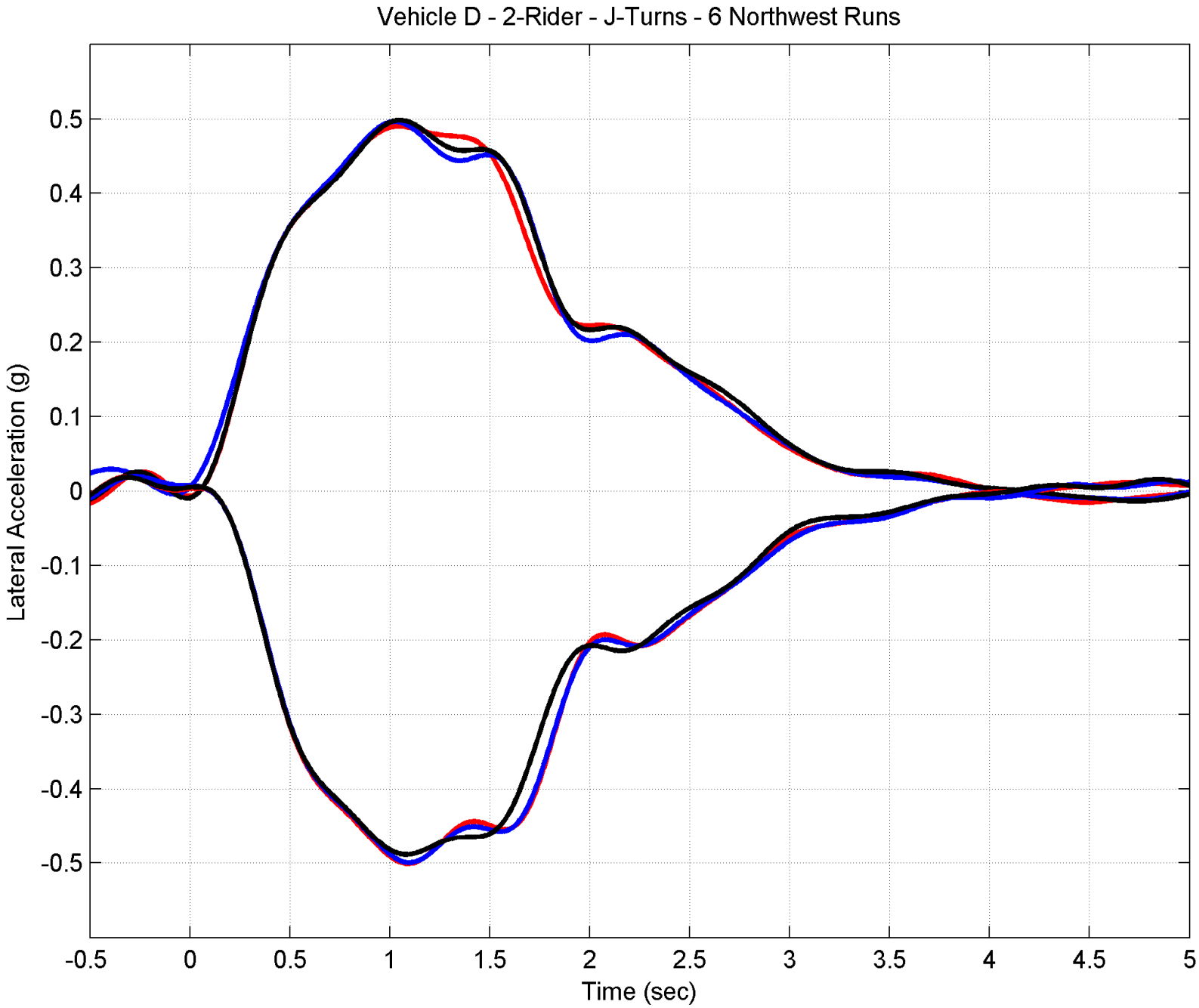

Vehicle D - 2-Rider - 50 ft Radius Circle
Clockwise
Counterclockwise
(Roadwheel Steer Angle - Ackermann Angle) (deg)
20
15
10
5
0
-5
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Ay (g)

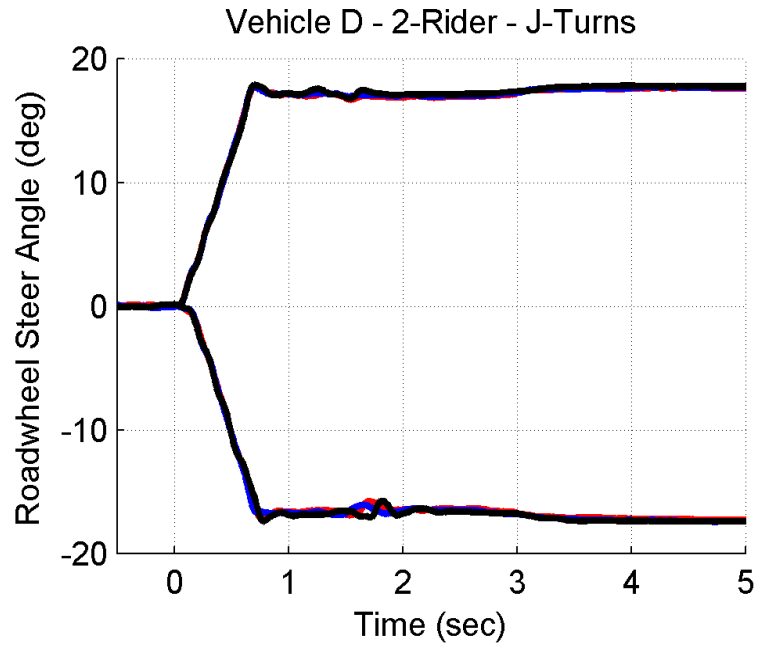

Vehicle D - 2-Rider - 50 ft Radius Circle
Roll Angle (deg)
Ay (g)
Roll Gradient = -24.5 deg/g
10
8
6
4
2
0
-2
-4
-6
-8
-10
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

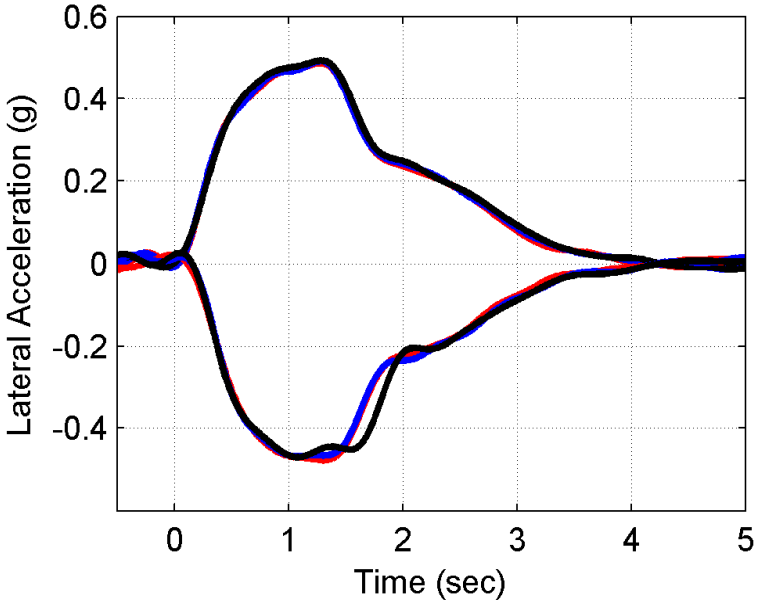

Vehicle D - 2-Rider - J-Turns
Roadwheel Steer Angle (deg)
20
10
0
-10
-20
0
1
2
3
4
5
Time (sec)

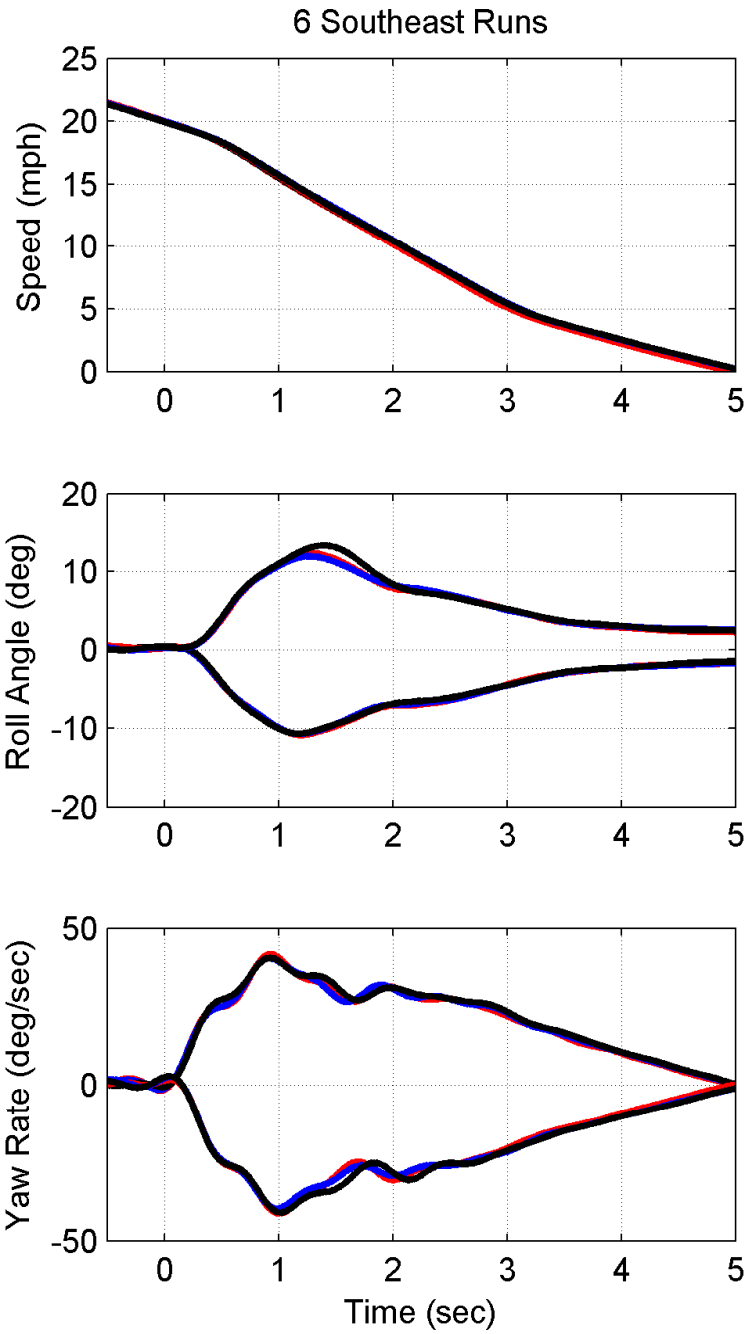

Lateral Acceleration (g)
0.6
0.4
0.2
0
-0.2
-0.4
0
1
2
3
4
5
Time (sec)

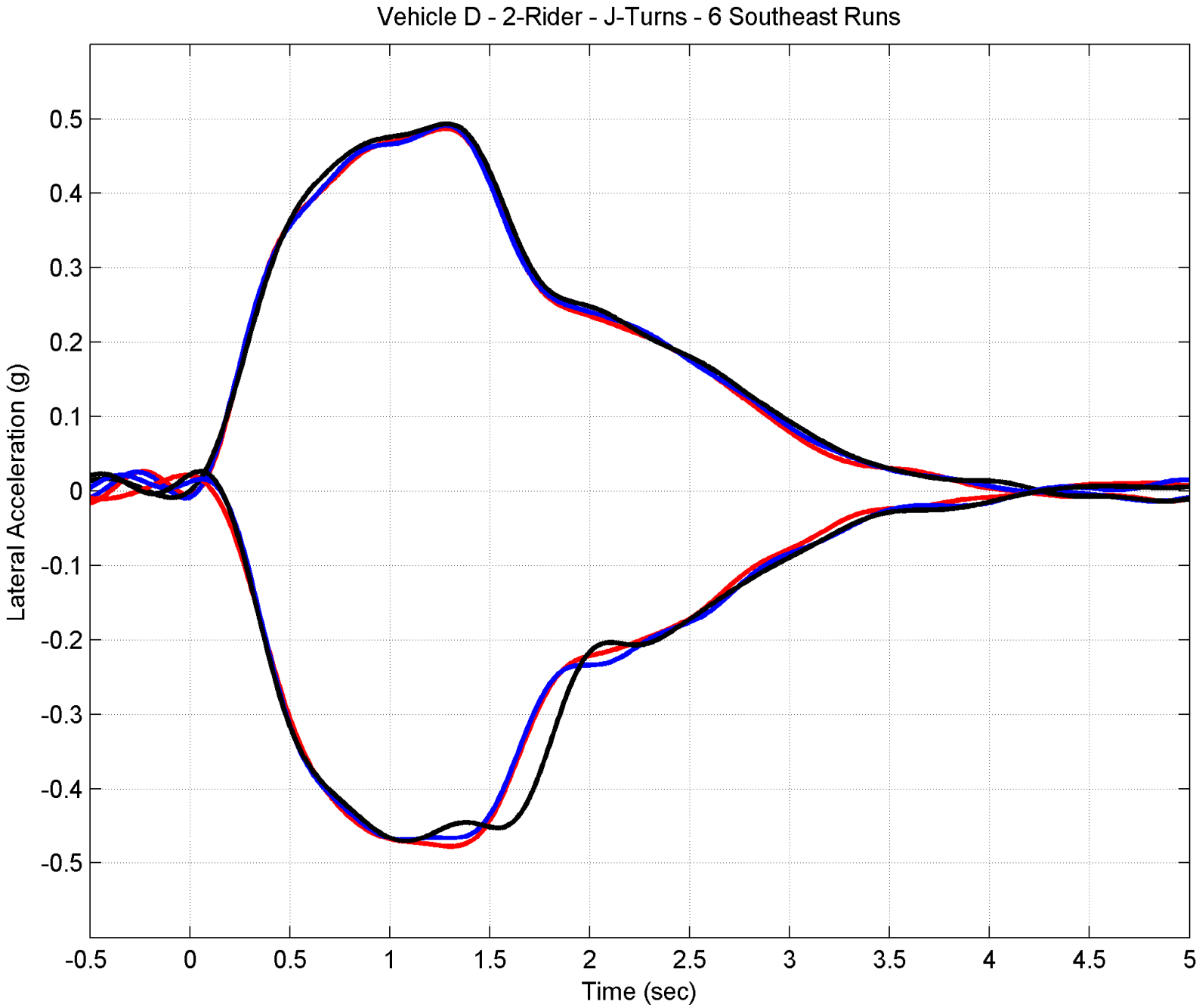

6 Northwest Runs
Speed (mph)
25
20
15
10
5
0
0
1
2
3
4
5
Roll Angle (deg)
20
10
0
-10
-20
Yaw Rate (deg/sec)
50
0
-50
Time (sec)


Vehicle D - 2-Rider - J-Turns - 6 Northwest Runs
Lateral Acceleration (g)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (sec)


Vehicle D - 2-Rider - J-Turns
Roadwheel Steer Angle (deg)
20
10
0
-10
-20
0
1
2
3
4
5
Time (sec)


Lateral Acceleration (g)
0.6
0.4
0.2
0
-0.2
-0.4
0
1
2
3
4
5
Time (sec)


6 Southeast Runs
Speed (mph)
25
20
15
10
5
0
Roll Angle (deg)
20
10
0
-10
-20
Yaw Rate (deg/sec)
50
0
-50
0
1
2
3
4
5
Time (sec)


Vehicle D - 2-Rider - J-Turns - 6 Southeast Runs
Lateral Acceleration (g)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (sec)

Vehicle D - 2-Rider Results

Peak Lateral Accelerations During 2WL J-Turns - All Values in "g's"

Run Number	Northwest Right Turns	Northwest Left Turns
1	0.490	-0.501
2	0.497	-0.499
3	0.498	-0.489
Mean Value of 3 Runs	0.495	-0.496
Standard Deviation of 3 Runs	0.004	0.007

Average of 6 Northwest Runs

0.496

Run Number	Southeast Right Turns	Southeast Left Turns
1	0.487	-0.478
2	0.492	-0.468
3	0.493	-0.470
Mean Value of 3 Runs	0.491	-0.472
Standard Deviation of 3 Runs	0.003	0.005

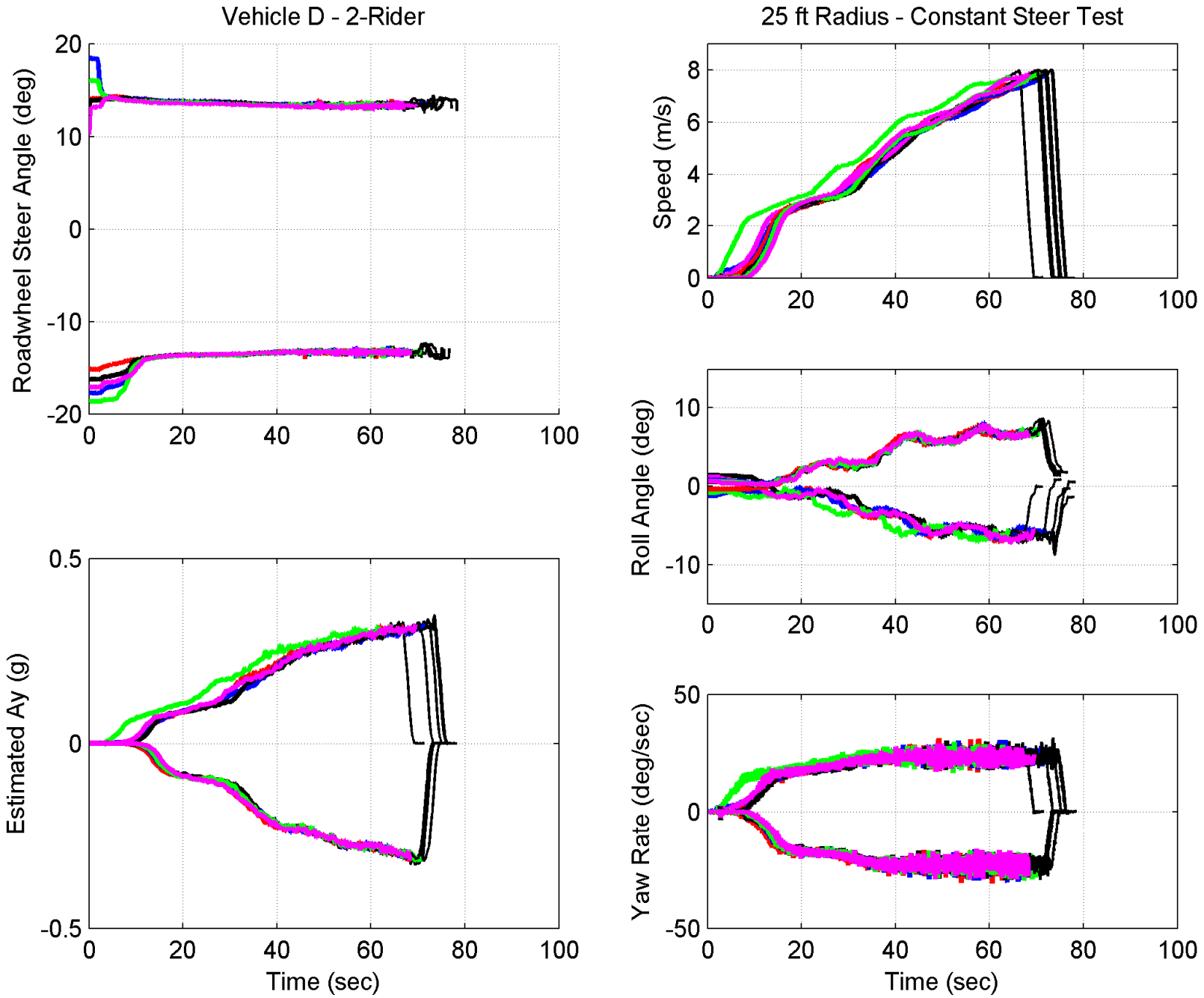
Average of 6 Southeast Runs

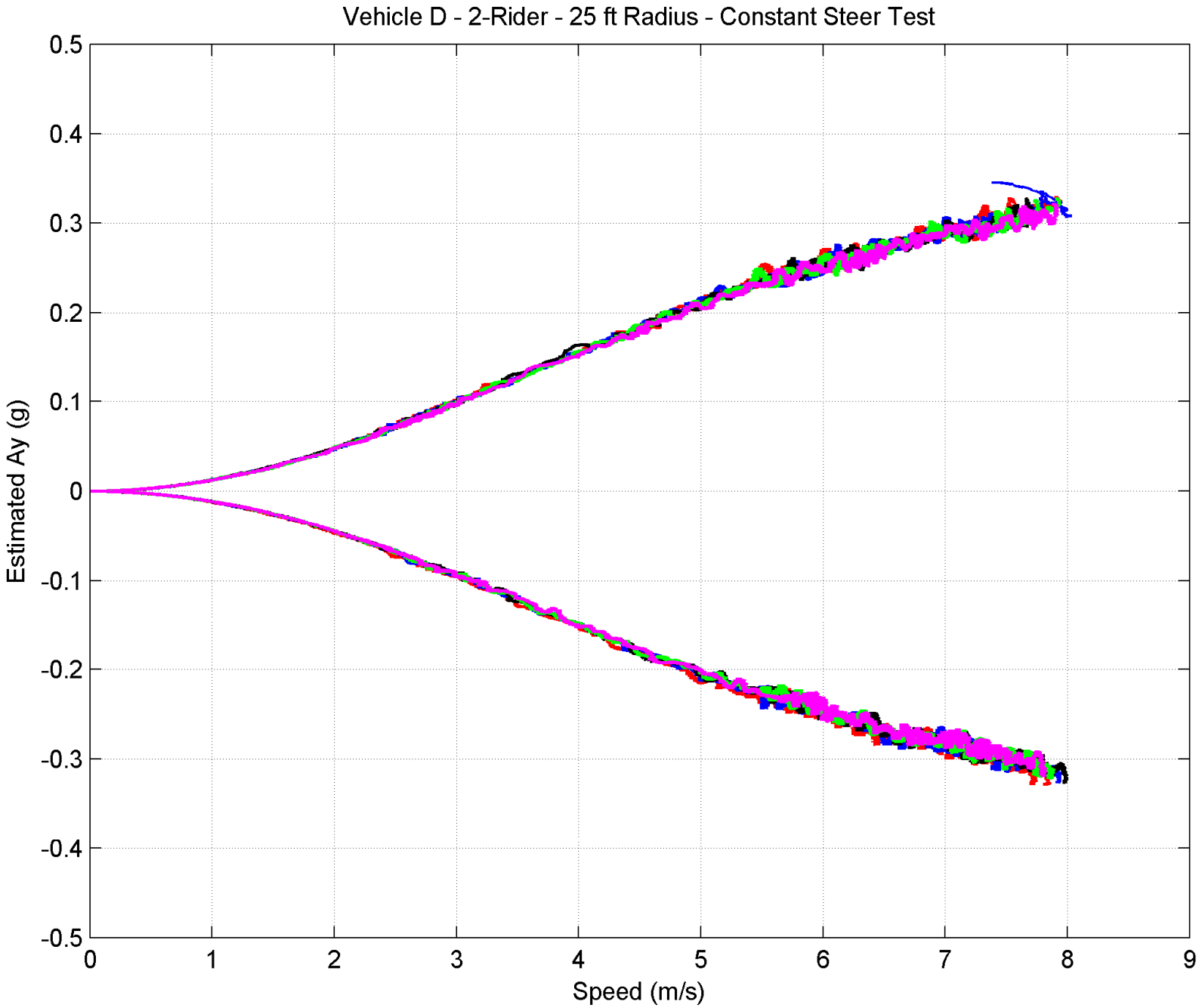
0.481

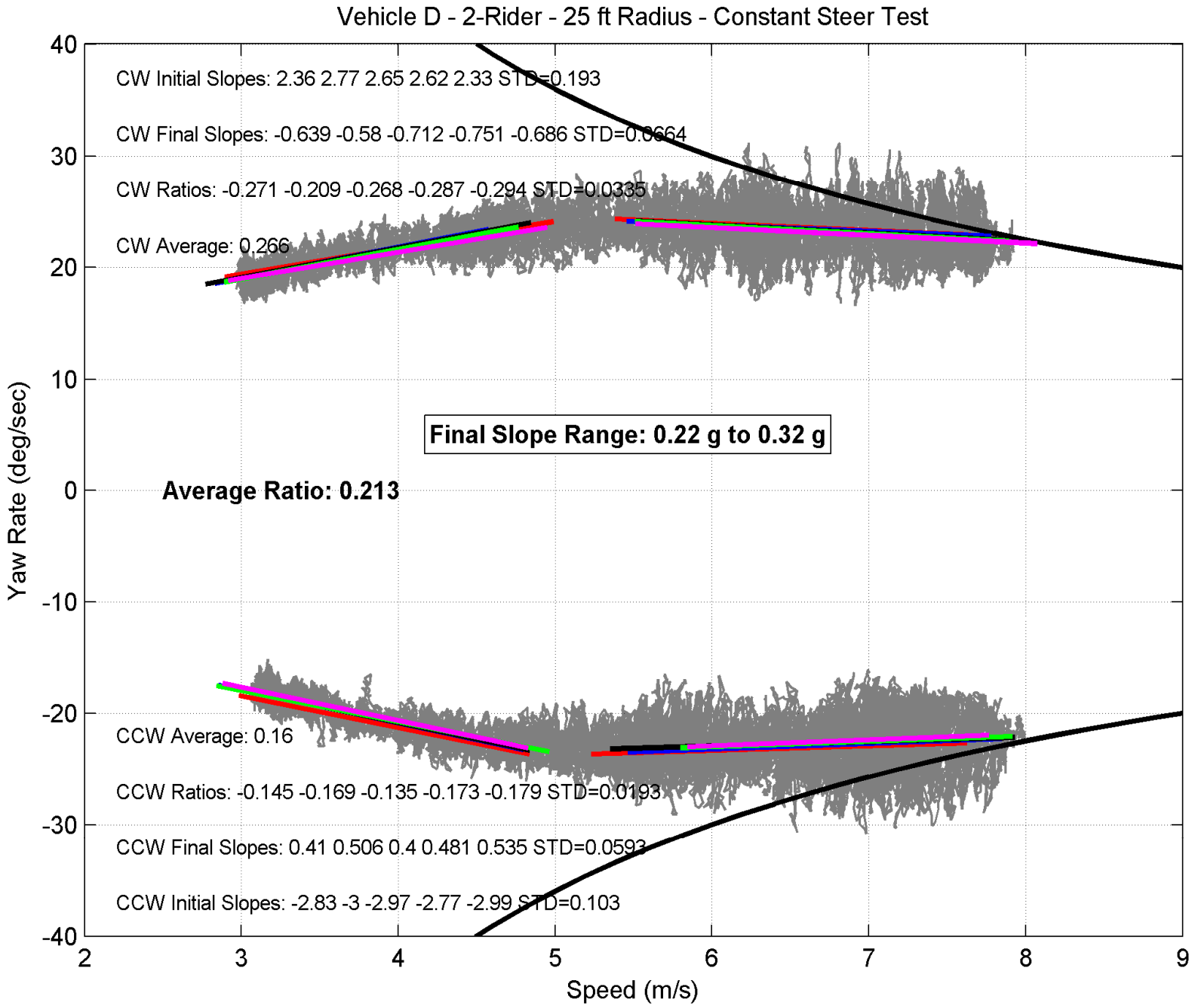
Average of All 12 Runs

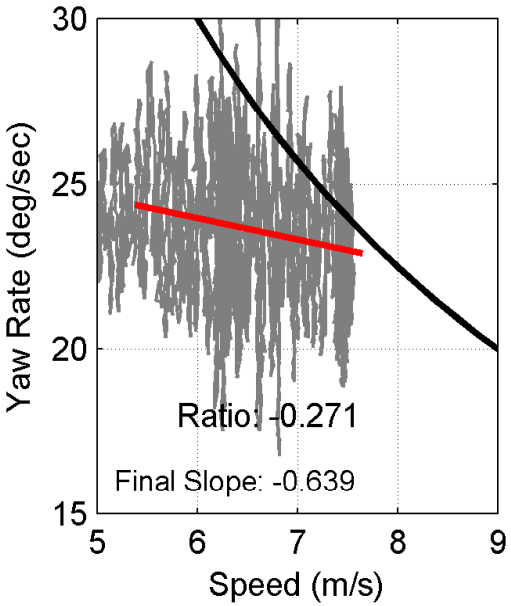
0.489

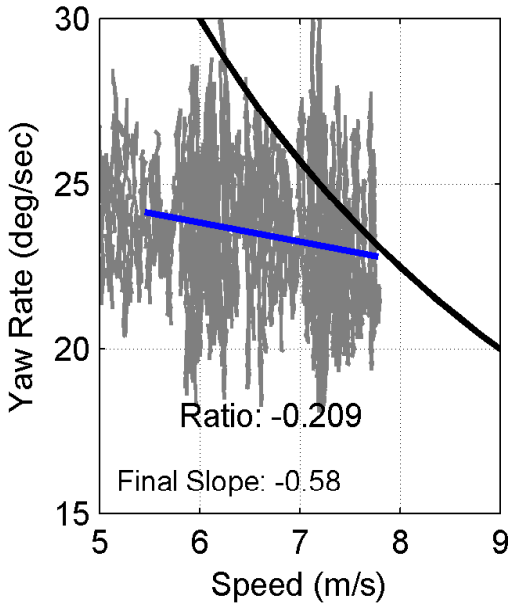
Threshold Ay

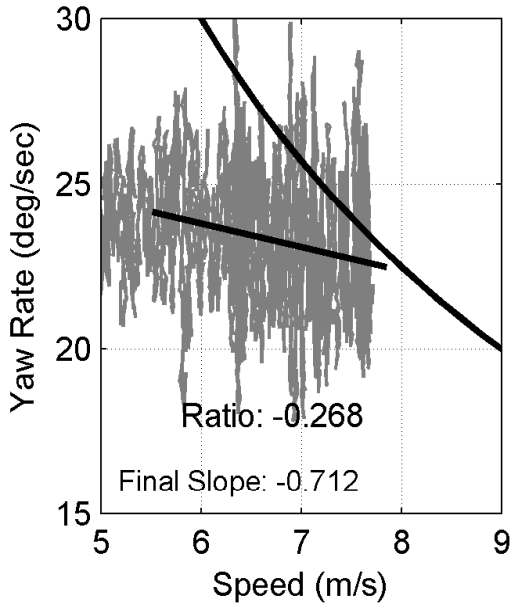

Vehicle D - 2-Rider
25 ft Radius - Constant Steer Test
Roadwheel Steer Angle (deg)
Speed (m/s)
Roll Angle (deg)
Estimated Ay (g)
Yaw Rate (deg/sec)
Time (sec)
Time (sec)

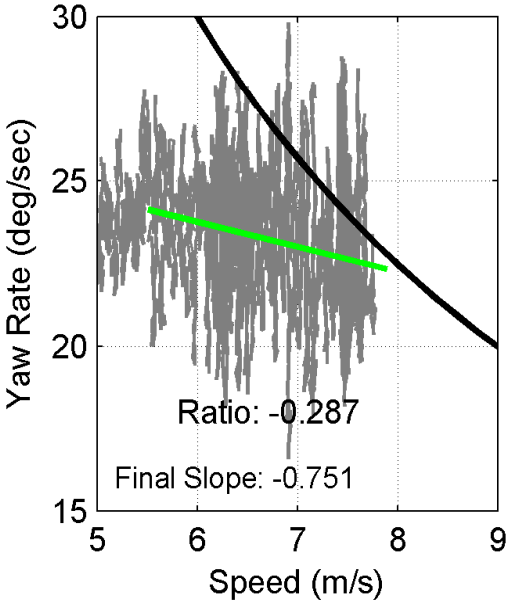

Vehicle D - 2-Rider - 25 ft Radius - Constant Steer Test
Estimated Ay (g)
Speed (m/s)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
1
2
3
4
5
6
7
8
9

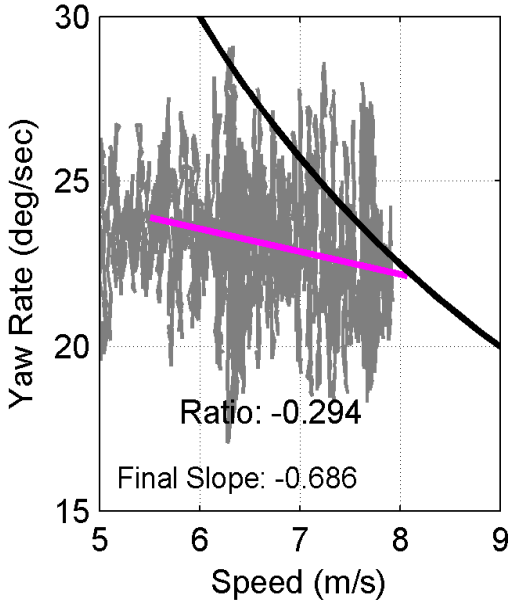

Vehicle D - 2-Rider - 25 ft Radius - Constant Steer Test
CW Initial Slopes: 2.36 2.77 2.65 2.62 2.33 STD=0.193
CW Final Slopes: -0.639 -0.58 -0.712 -0.751 -0.686 STD=0.0664
CW Ratios: -0.271 -0.209 -0.268 -0.287 -0.294 STD=0.0335
CW Average: 0.266
Final Slope Range: 0.22 g to 0.32 g
Average Ratio: 0.213
CCW Average: 0.16
CCW Ratios: -0.145 -0.169 -0.135 -0.173 -0.179 STD=0.0193
CCW Final Slopes: 0.41 0.506 0.4 0.481 0.535 STD=0.0593
CCW Initial Slopes: -2.83 -3 -2.97 -2.77 -2.99 STD=0.103
Yaw Rate (deg/sec)
Speed (m/s)
40
30
20
10
0
-10
-20
-30
-40
2
3
4
5
6
7
8
9





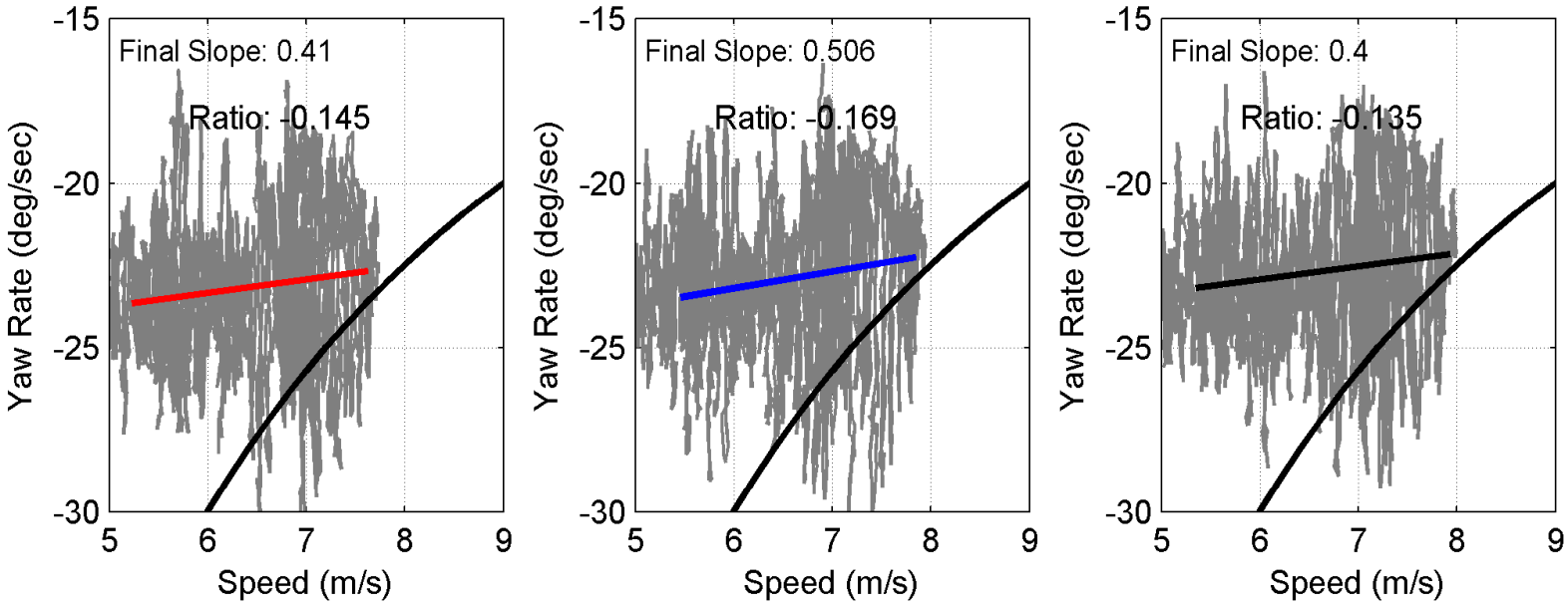


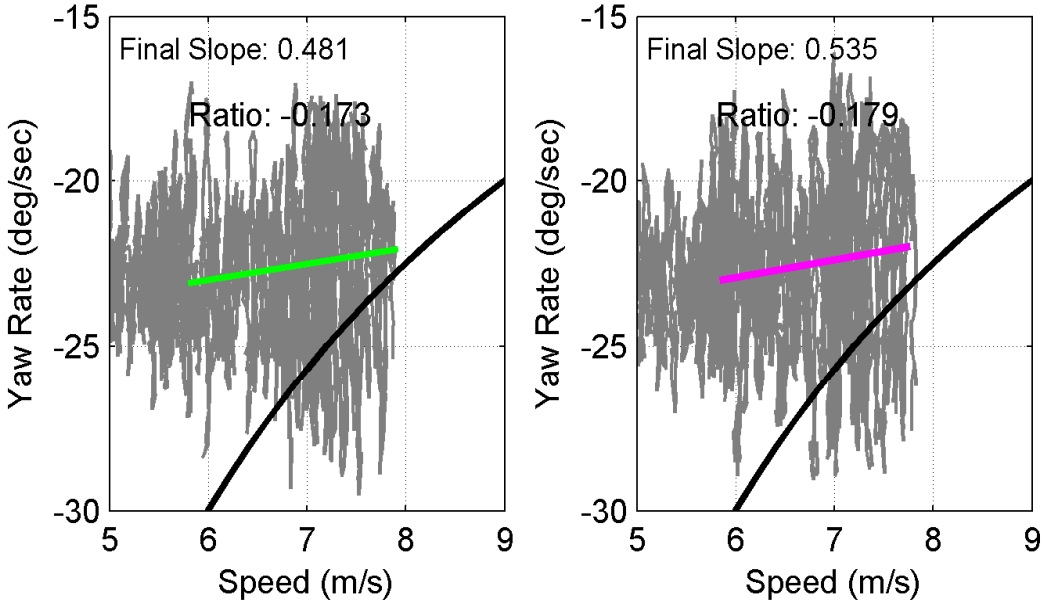




Final Slope Range:

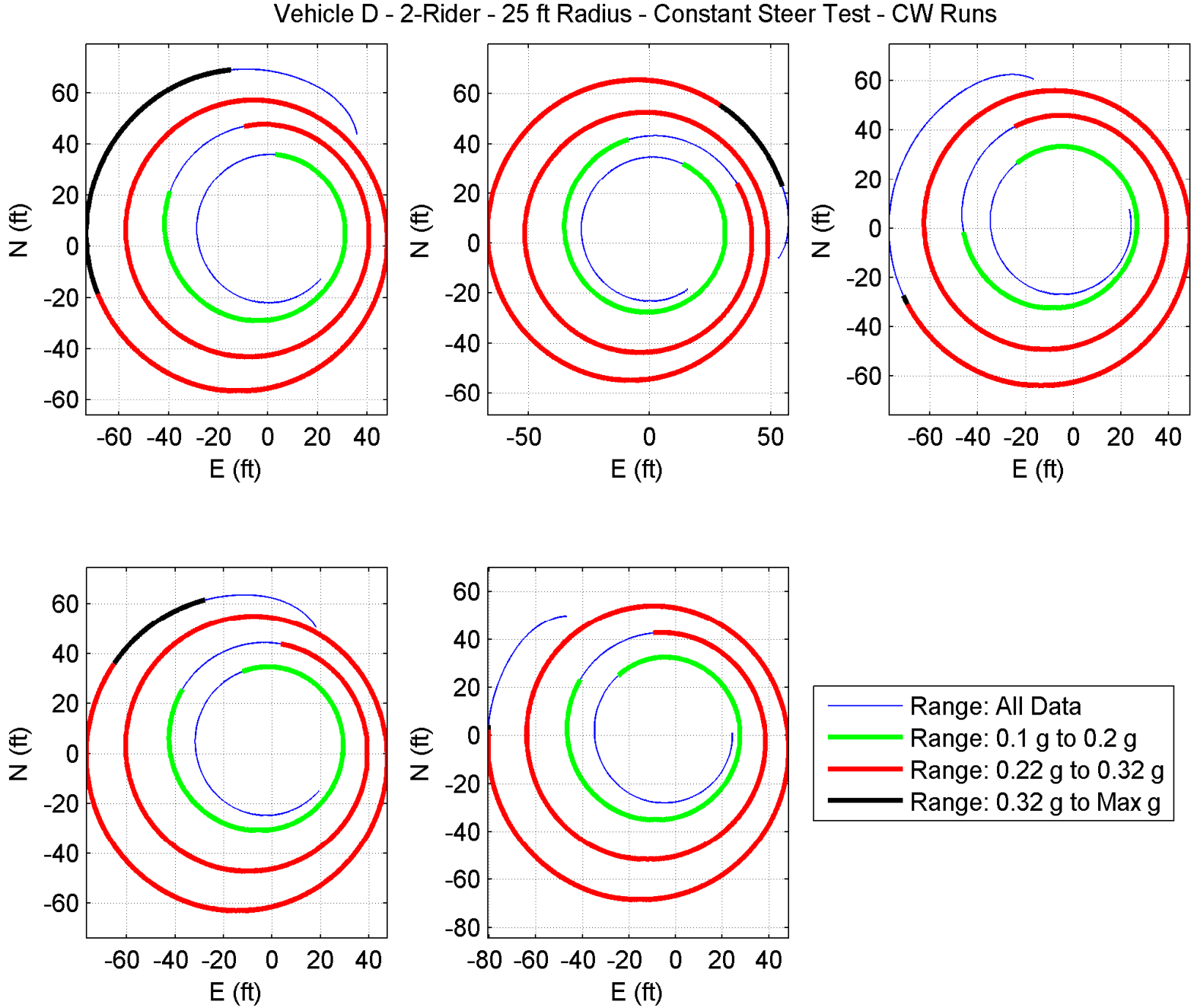
0.22 g to 0.32 g

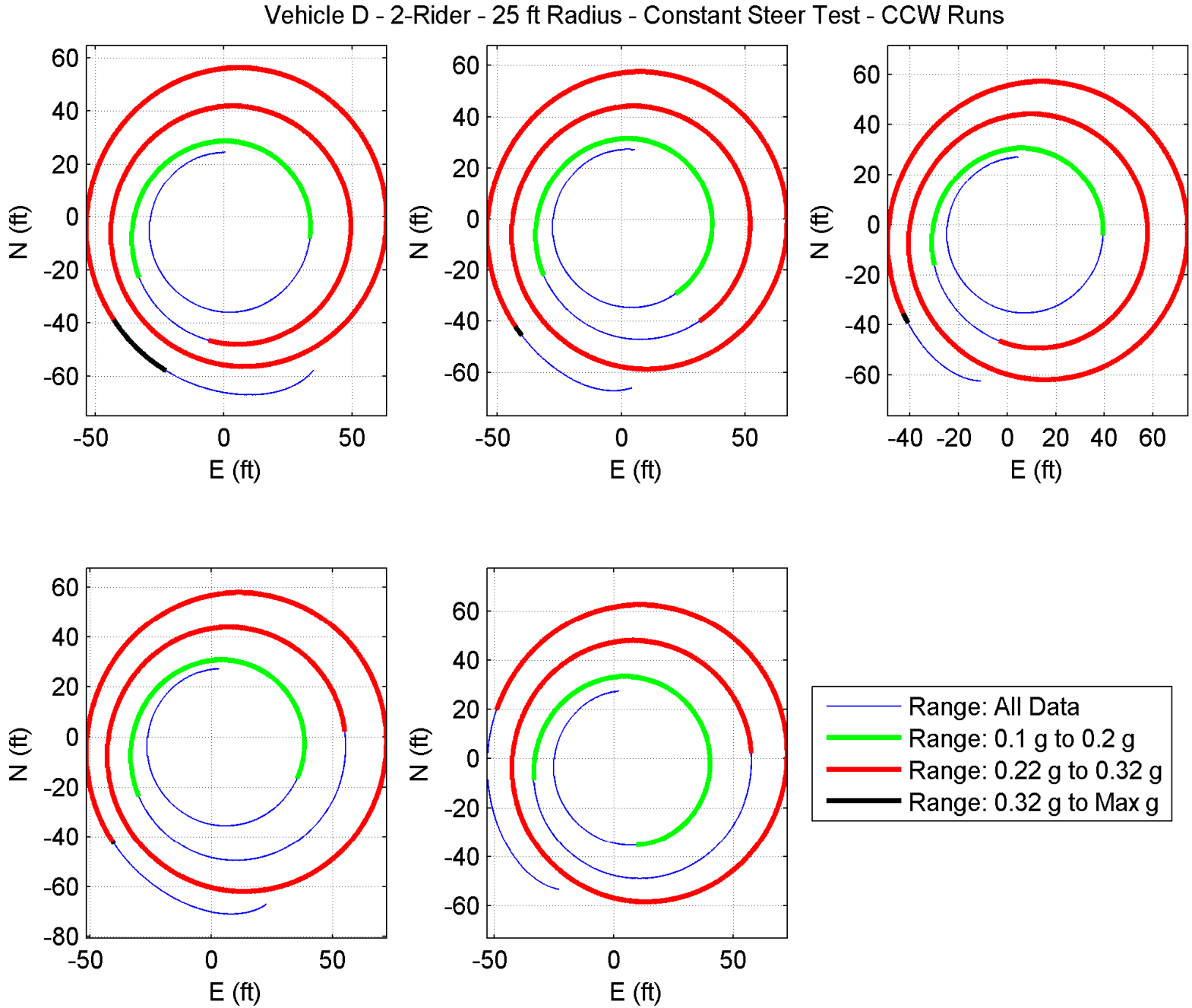


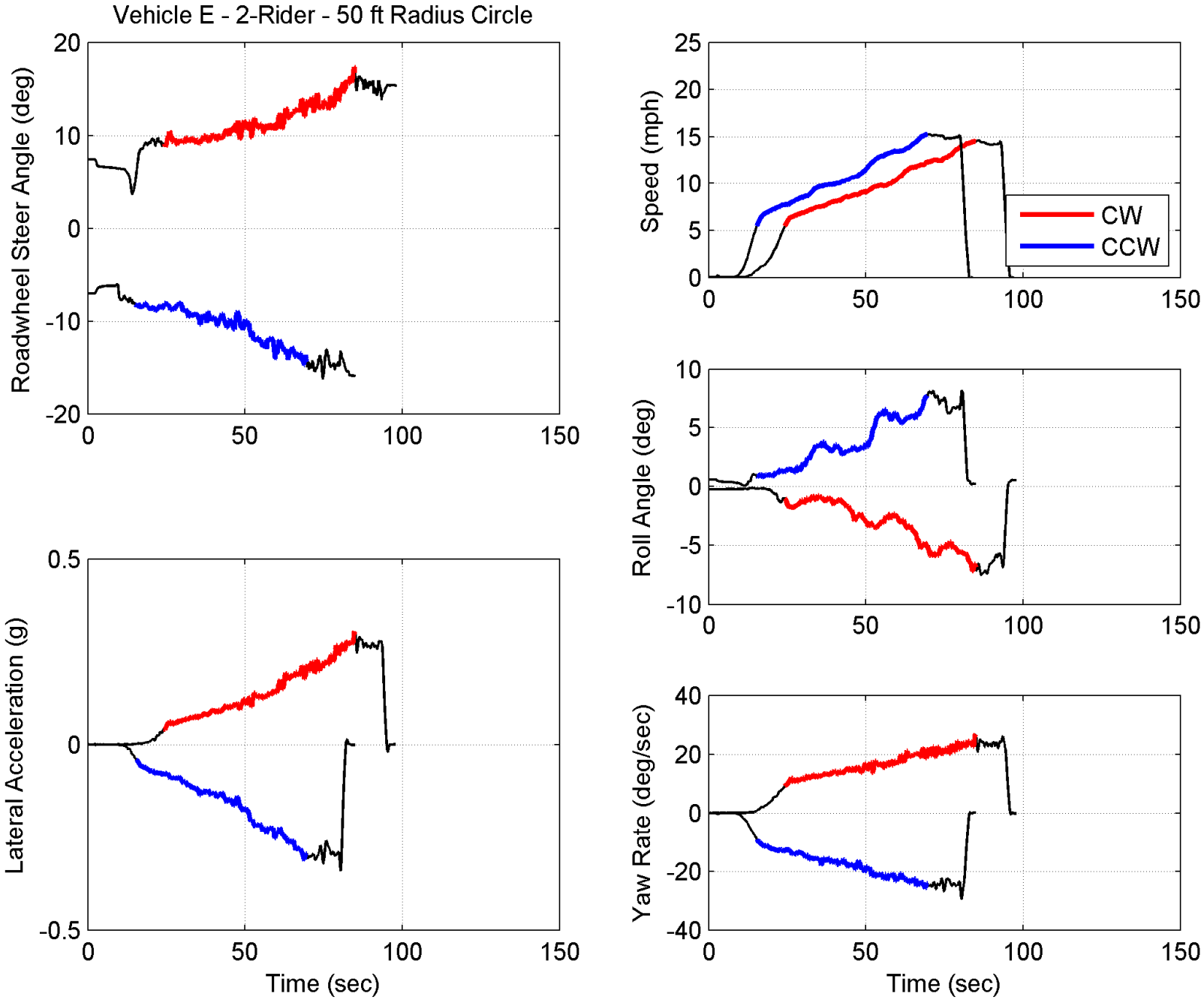


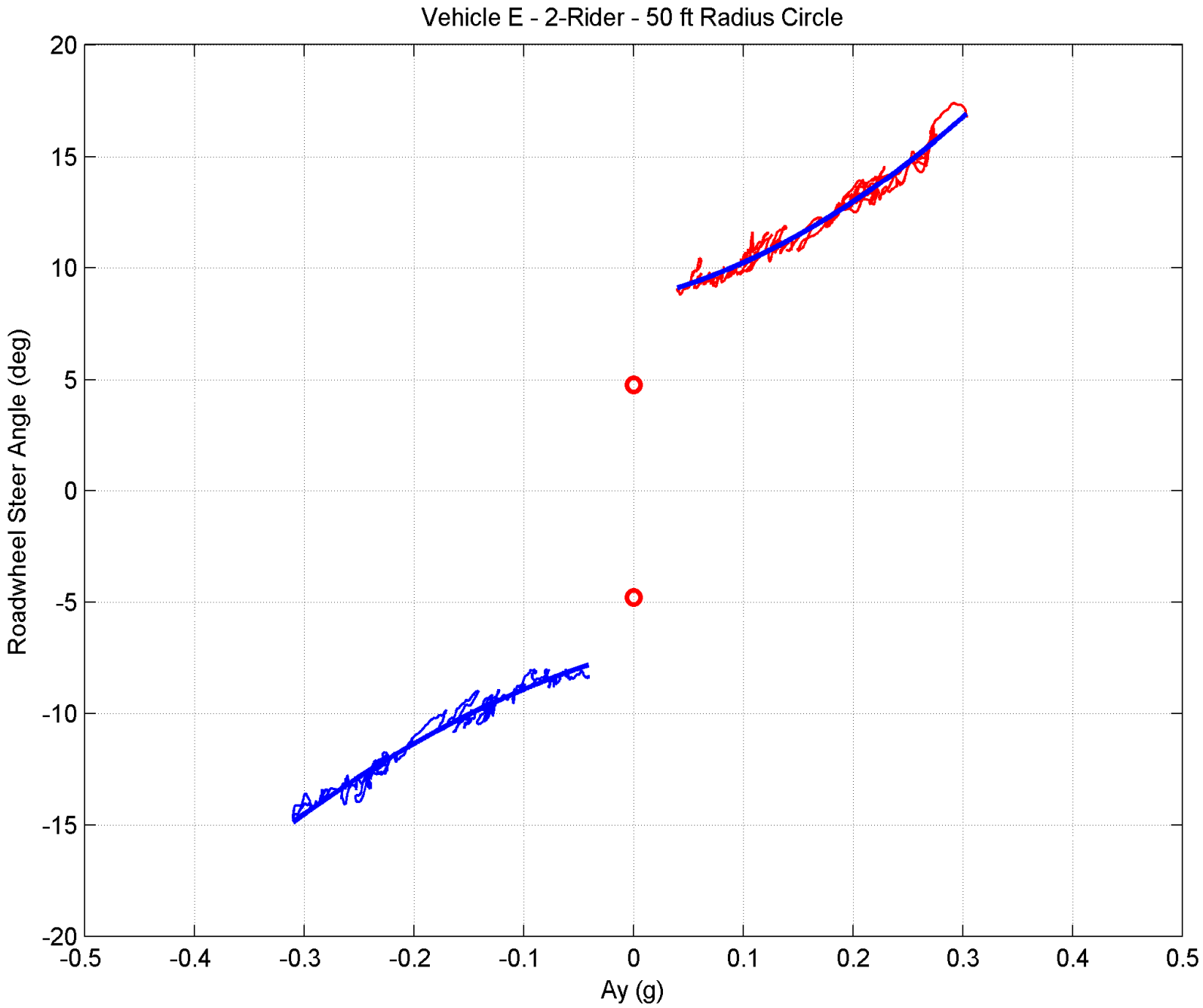
Final Slope Range:

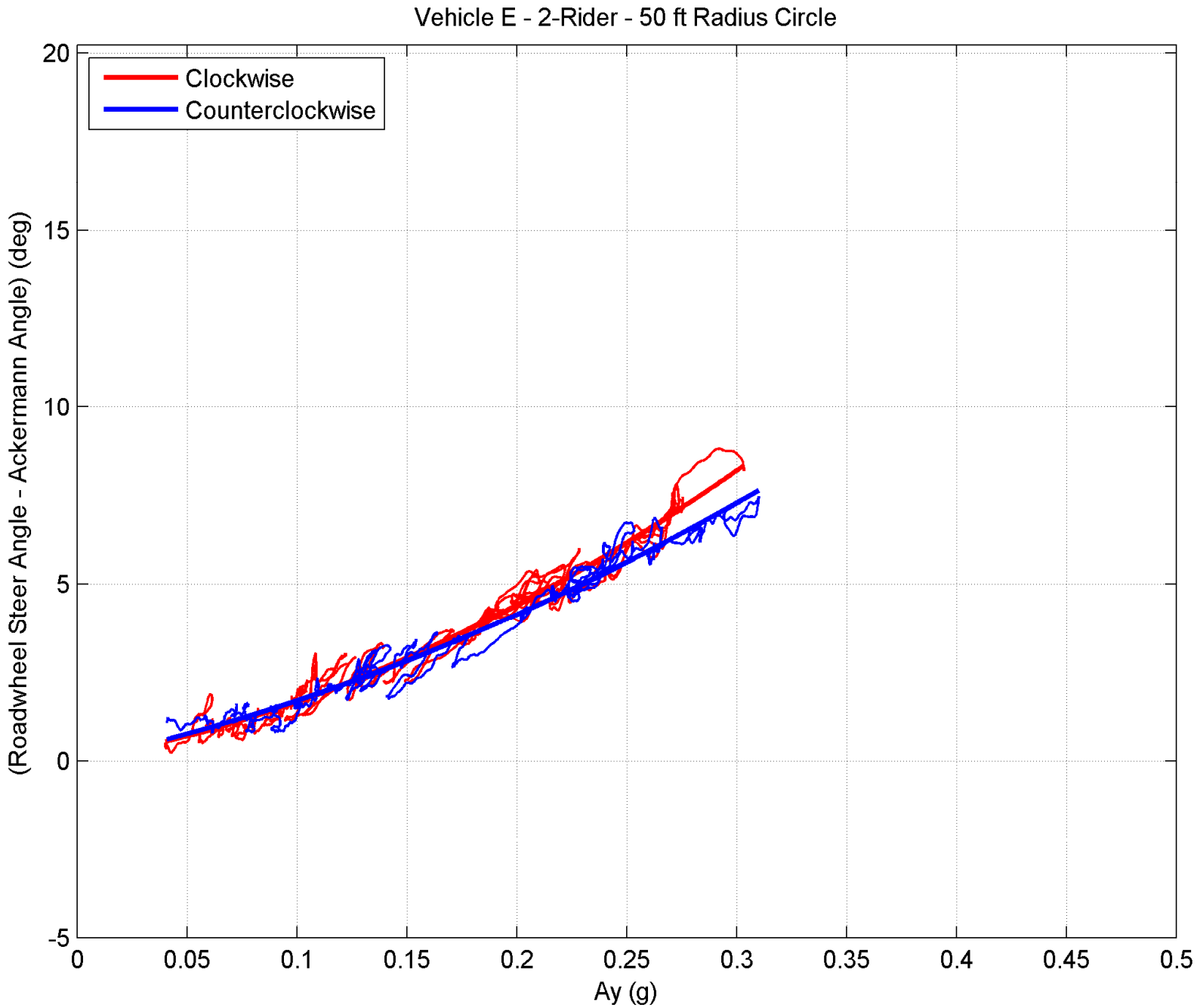
0.22 g to 0.32 g

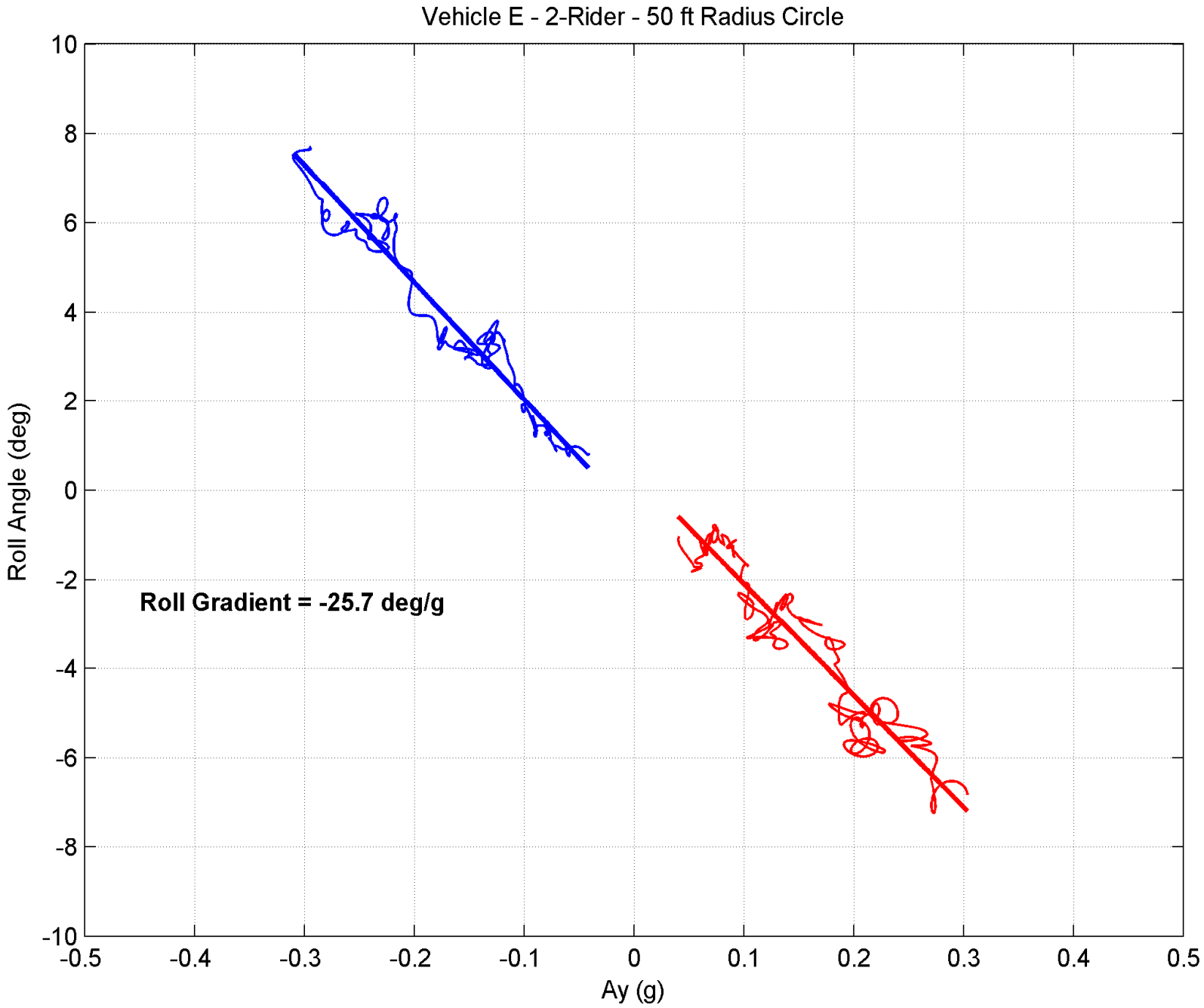

Vehicle D - 2-Rider - 25 ft Radius - Constant Steer Test - CW Runs
N (ft)
E (ft)
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.22 g to 0.32 g
Range: 0.32 g to Max g

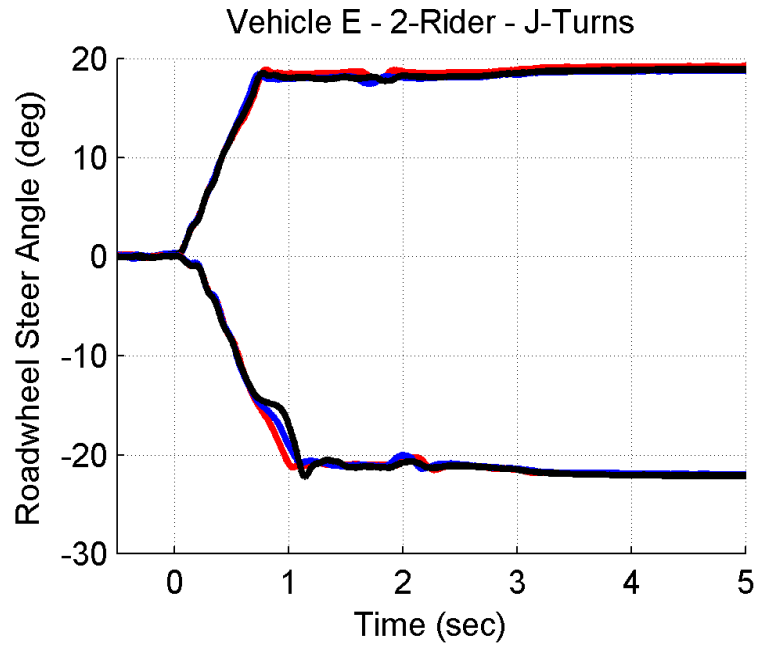

Vehicle D - 2-Rider - 25 ft Radius - Constant Steer Test - CCW Runs
N (ft)
E (ft)
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.22 g to 0.32 g
Range: 0.32 g to Max g

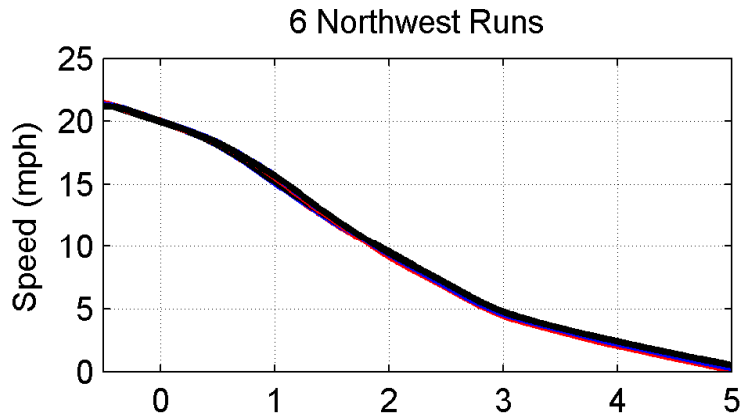

Vehicle E - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
Speed (mph)
CW
CCW
Roll Angle (deg)
Lateral Acceleration (g)
Yaw Rate (deg/sec)
Time (sec)
Time (sec)

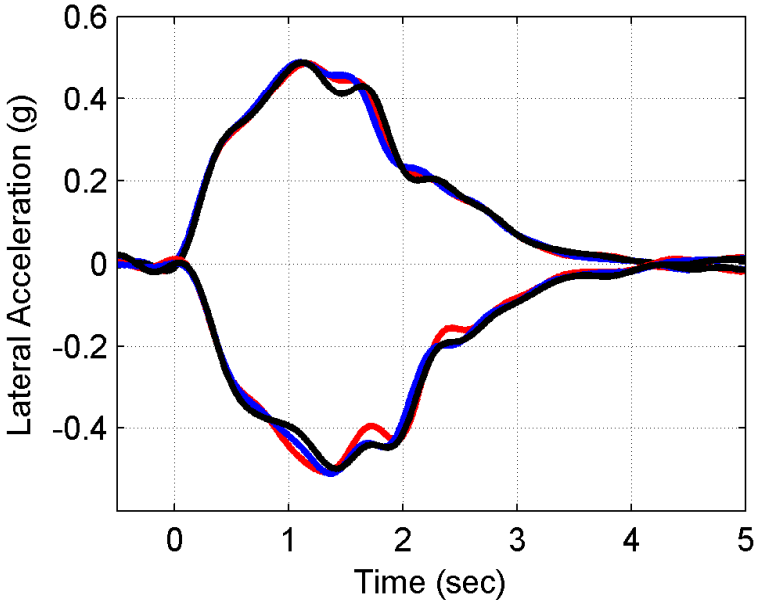

Vehicle E - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
Ay (g)
20
15
10
5
0
-5
-10
-15
-20
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

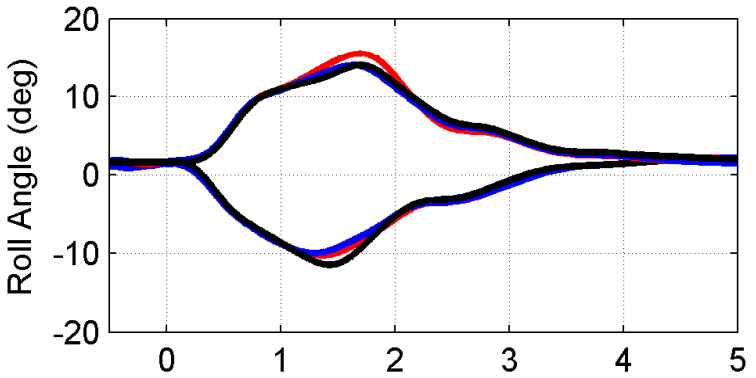

Vehicle E - 2-Rider - 50 ft Radius Circle
Clockwise
Counterclockwise
(Roadwheel Steer Angle - Ackermann Angle) (deg)
20
15
10
5
0
-5
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Ay (g)

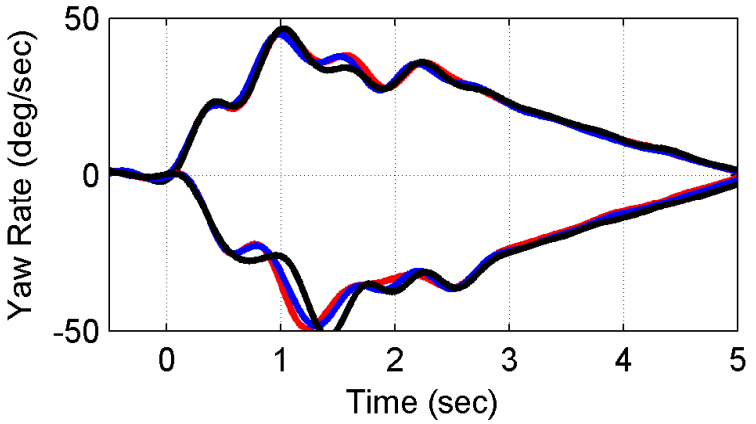

Vehicle E - 2-Rider - 50 ft Radius Circle
Roll Angle (deg)
Ay (g)
Roll Gradient = -25.7 deg/g
10
8
6
4
2
0
-2
-4
-6
-8
-10
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

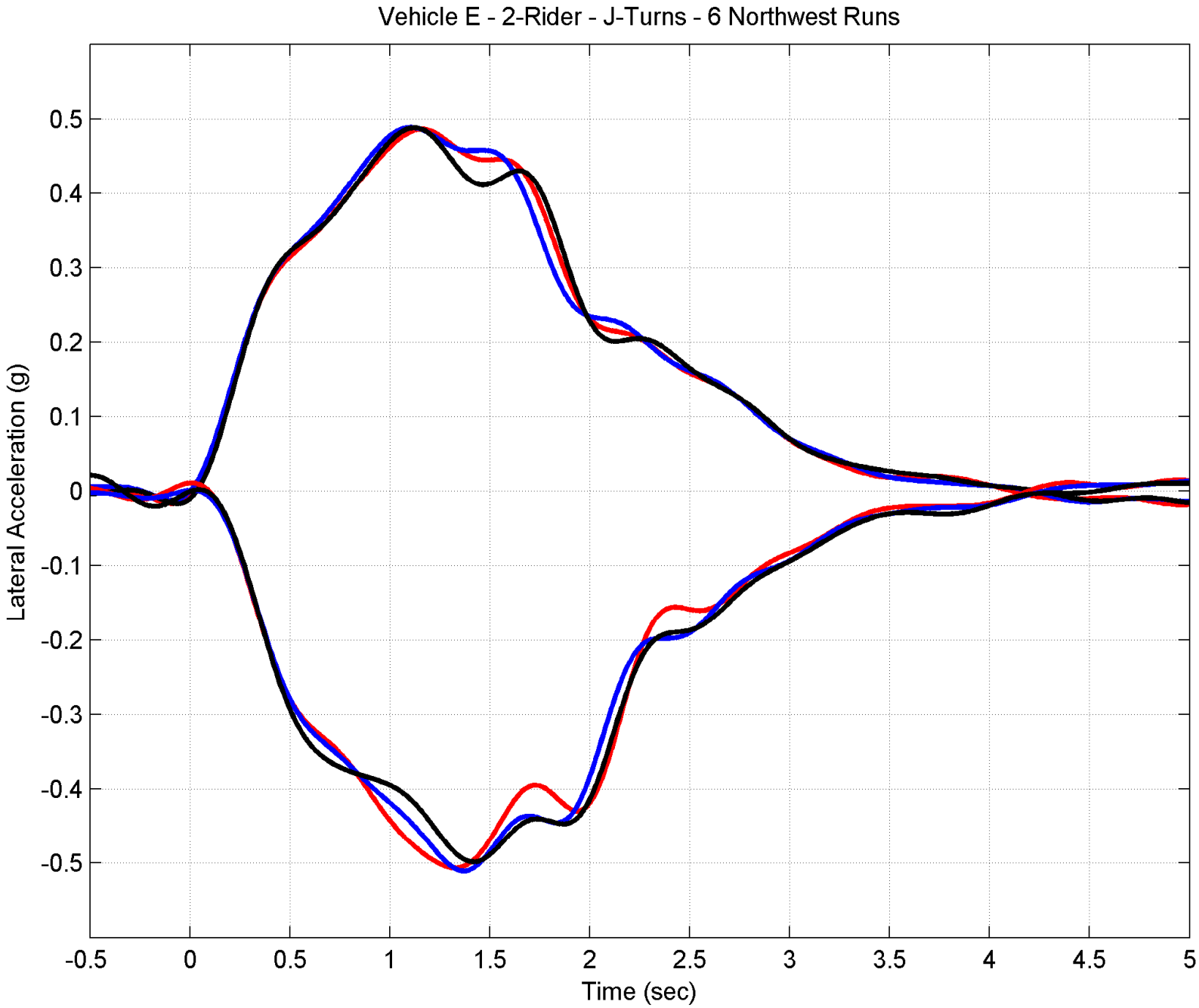

Vehicle E - 2-Rider - J-Turns
Roadwheel Steer Angle (deg)
20
10
0
-10
-20
-30
0
1
2
3
4
5
Time (sec)

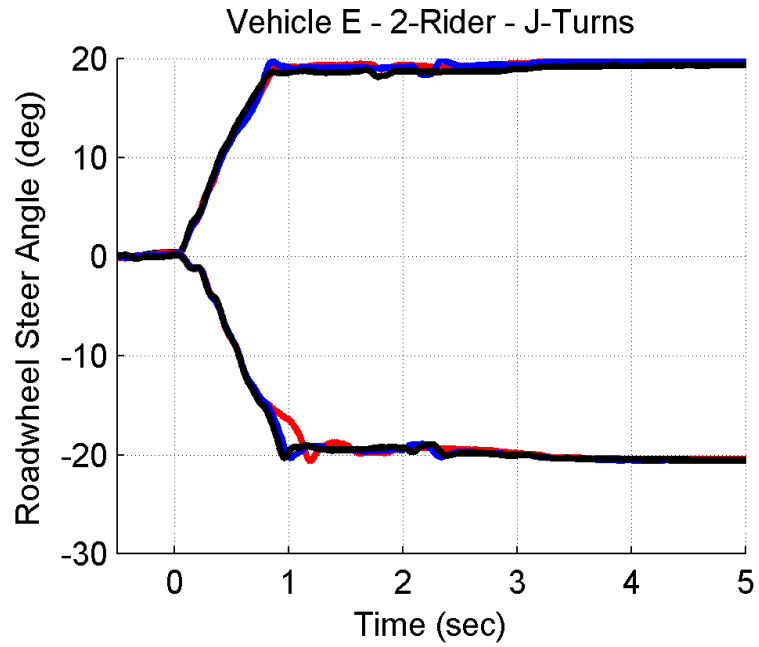

6 Northwest Runs
Speed (mph)
25
20
15
10
5
0
0
1
2
3
4
5

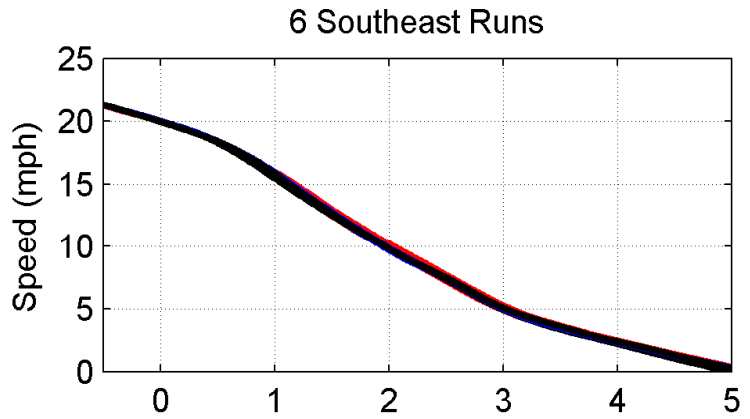

Lateral Acceleration (g)
0.6
0.4
0.2
0
-0.2
-0.4
0
1
2
3
4
5
Time (sec)

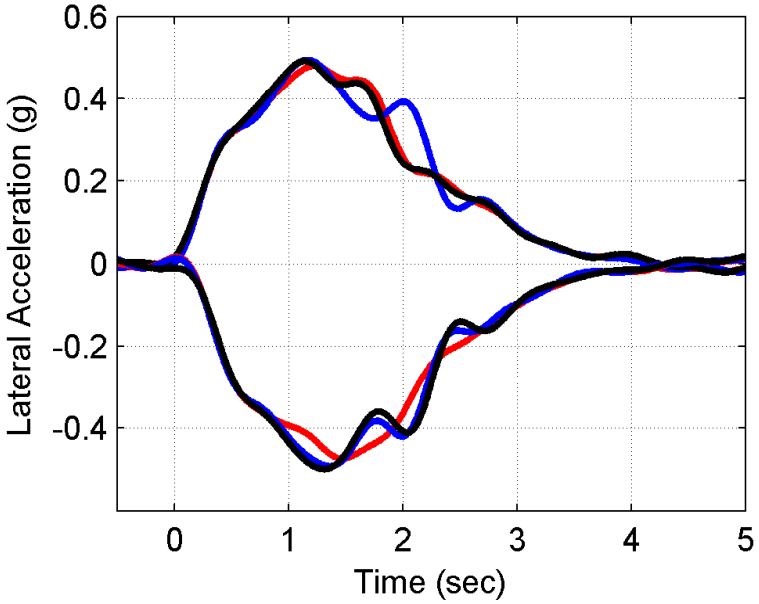

Roll Angle (deg)
20
10
0
-10
-20
0
1
2
3
4
5

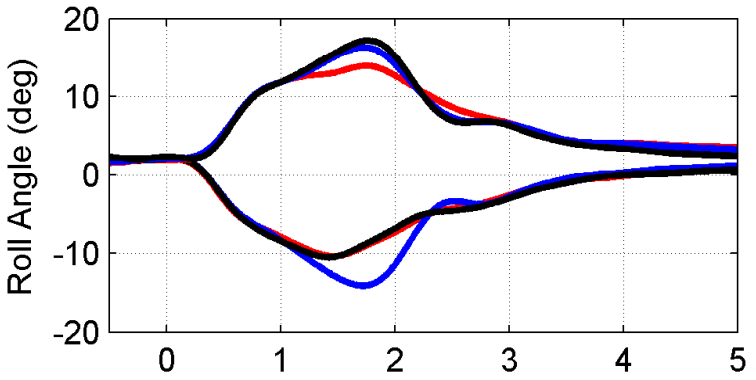

Yaw Rate (deg/sec)
50
0
-50
0
1
2
3
4
5
Time (sec)

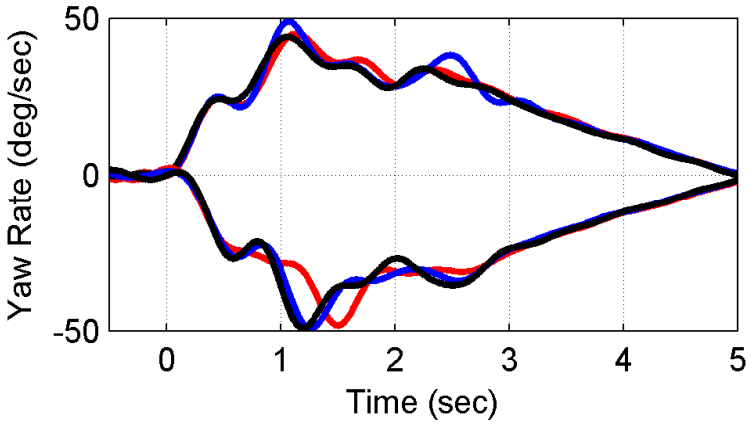

Vehicle E - 2-Rider - J-Turns - 6 Northwest Runs
Lateral Acceleration (g)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (sec)

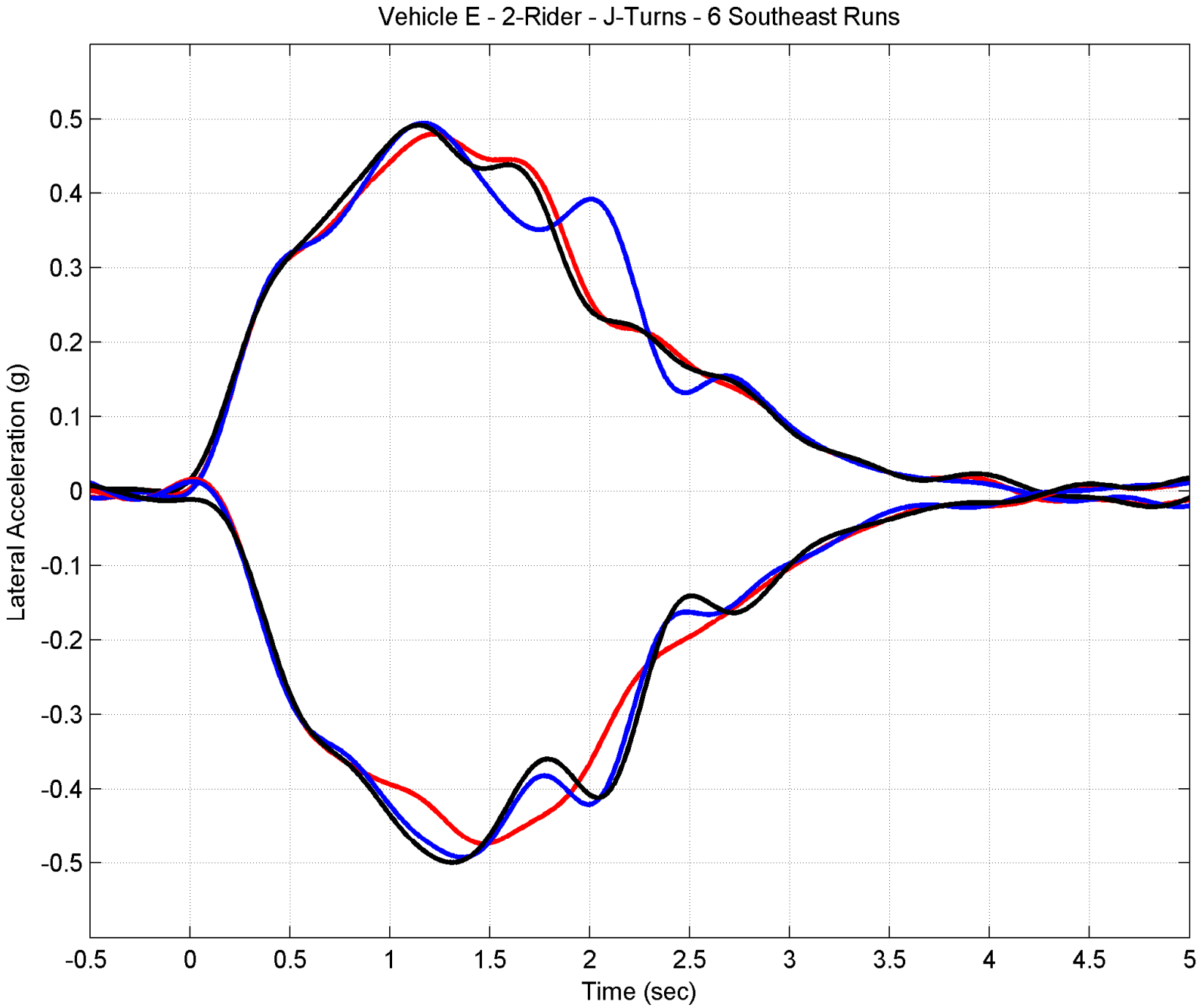

Vehicle E - 2-Rider - J-Turns
Roadwheel Steer Angle (deg)
20
10
0
-10
-20
-30
0
1
2
3
4
5
Time (sec)


6 Southeast Runs
Speed (mph)
25
20
15
10
5
0
0
1
2
3
4
5


Lateral Acceleration (g)
0.6
0.4
0.2
0
-0.2
-0.4
0
1
2
3
4
5
Time (sec)


Roll Angle (deg)
20
10
0
-10
-20
0
1
2
3
4
5


Yaw Rate (deg/sec)
50
0
-50
0
1
2
3
4
5
Time (sec)


Vehicle E - 2-Rider - J-Turns - 6 Southeast Runs
Lateral Acceleration (g)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (sec)

Vehicle E - 2-Rider Results

Peak Lateral Accelerations During 2WL J-Turns - All Values in "g's"

Run Number	Northwest Right Turns	Northwest Left Turns
1	0.486	-0.507
2	0.489	-0.511
3	0.488	-0.499
Mean Value of 3 Runs	0.488	-0.505
Standard Deviation of 3 Runs	0.001	0.006

Average of 6 Northwest Runs

0.497

Run Number	Southeast Right Turns	Southeast Left Turns
1	0.480	-0.474
2	0.494	-0.493
3	0.492	-0.499
Mean Value of 3 Runs	0.489	-0.489
Standard Deviation of 3 Runs	0.008	0.013

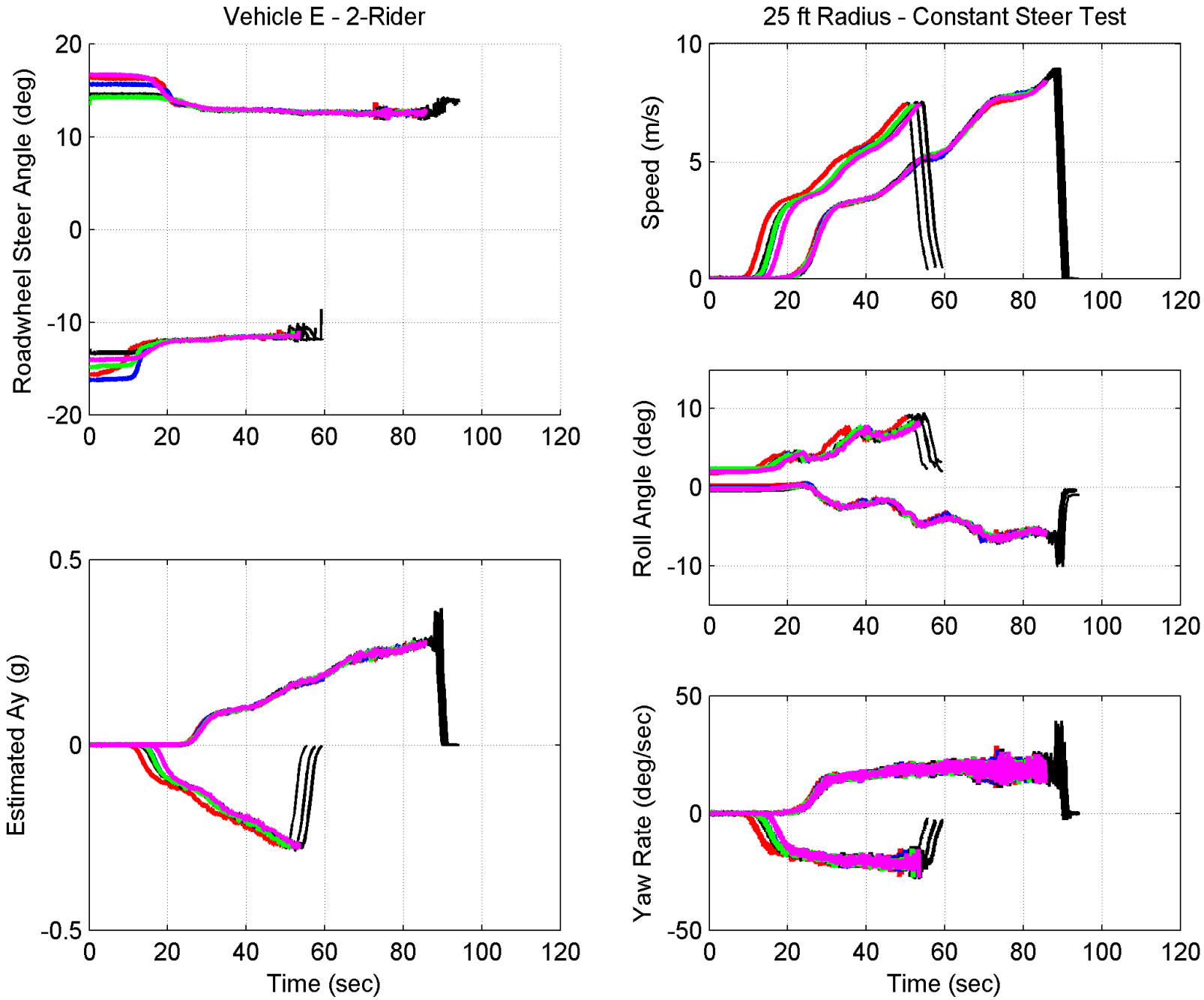
Average of 6 Southeast Runs

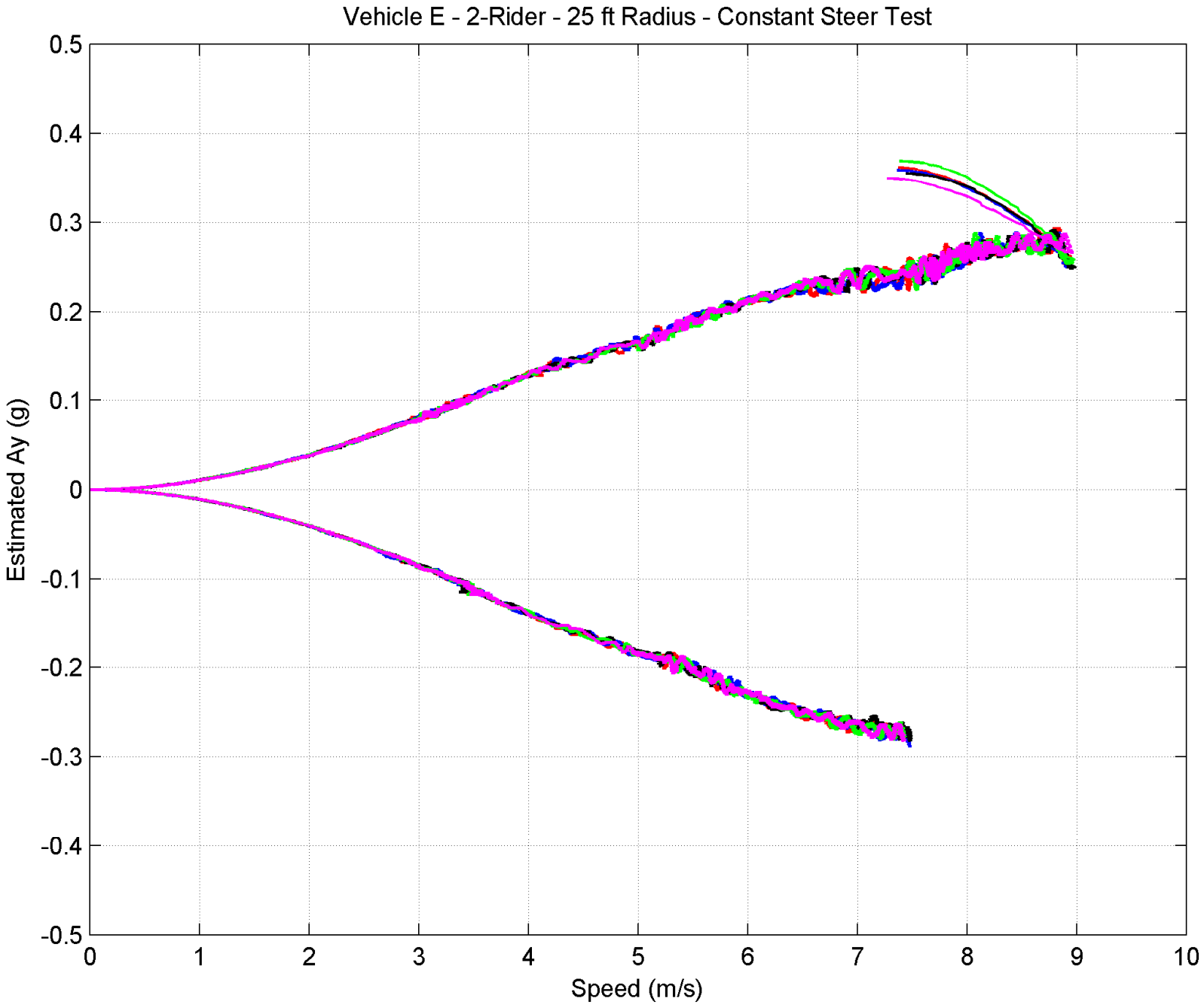
0.489

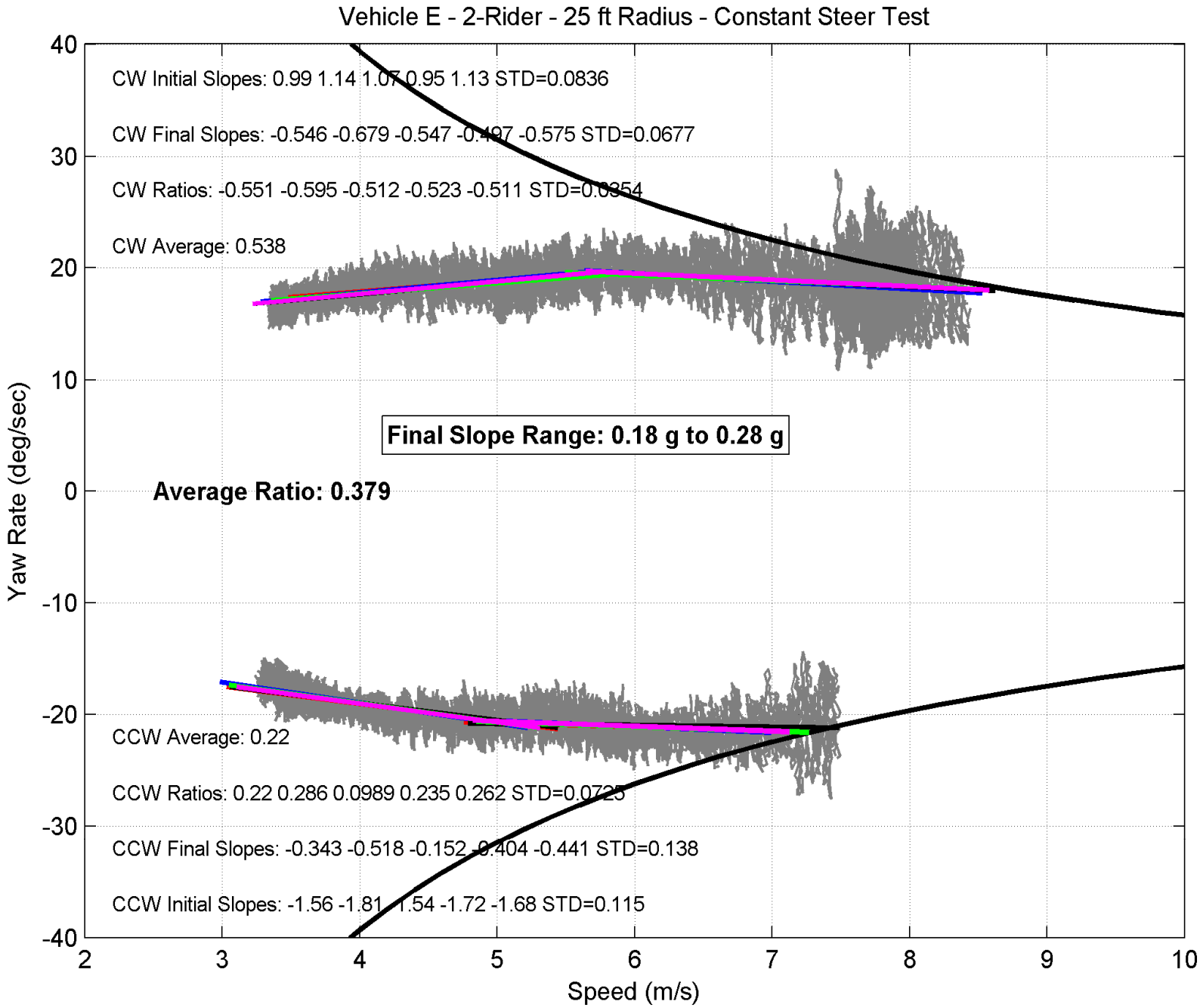
Average of All 12 Runs

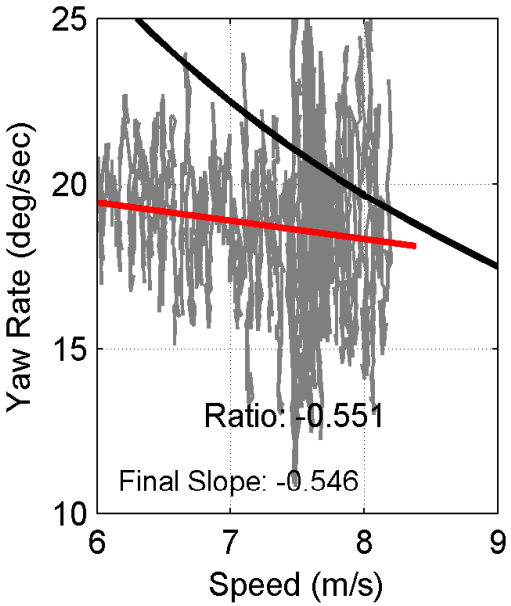
0.493

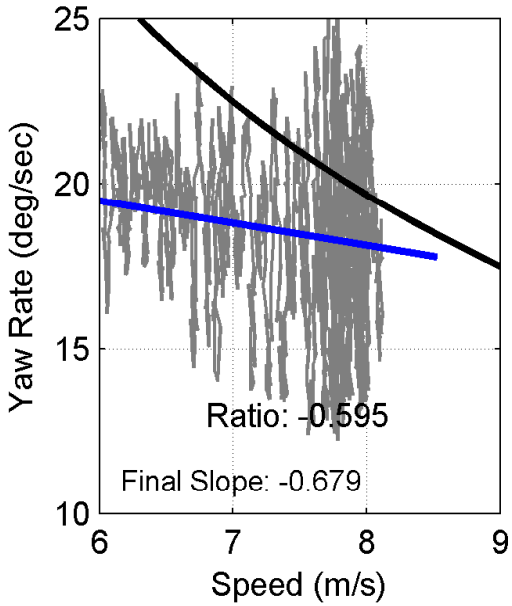
Threshold Ay

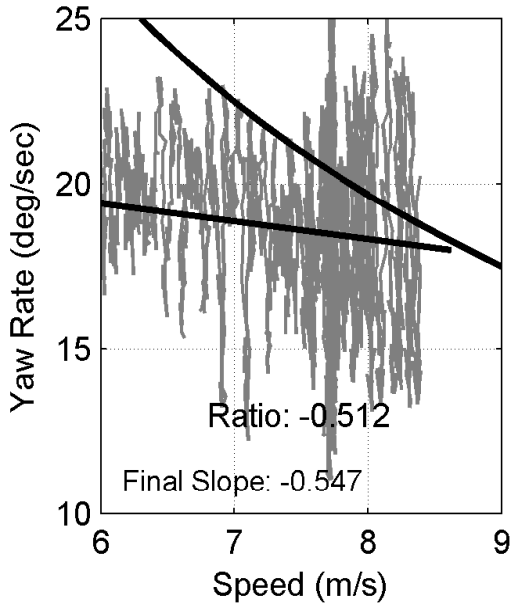

Vehicle E - 2-Rider
25 ft Radius - Constant Steer Test
Roadwheel Steer Angle (deg)
Speed (m/s)
Roll Angle (deg)
Estimated Ay (g)
Yaw Rate (deg/sec)
Time (sec)
Time (sec)

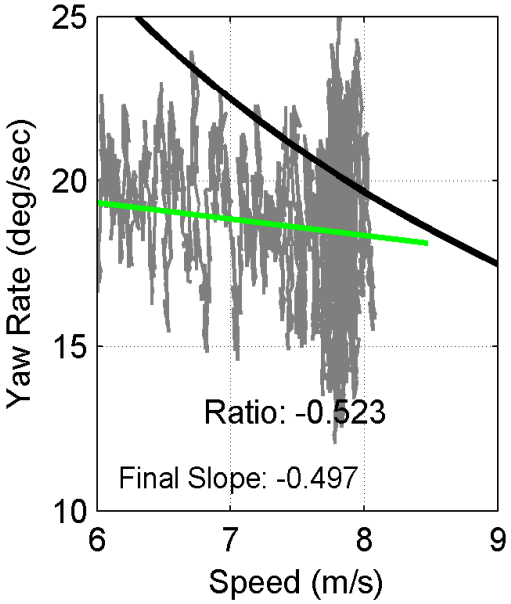

Vehicle E - 2-Rider - 25 ft Radius - Constant Steer Test
Estimated Ay (g)
Speed (m/s)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
1
2
3
4
5
6
7
8
9
10

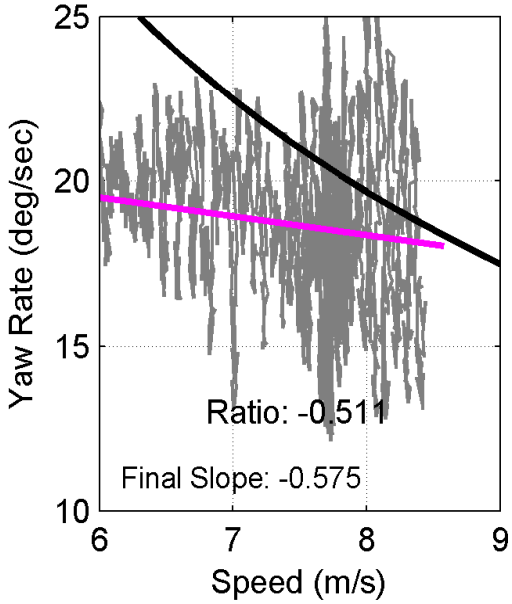

Vehicle E - 2-Rider - 25 ft Radius - Constant Steer Test
CW Initial Slopes: 0.99 1.14 1.07 0.95 1.13 STD=0.0836
CW Final Slopes: -0.546 -0.679 -0.547 -0.497 -0.575 STD=0.0677
CW Ratios: -0.551 -0.595 -0.512 -0.523 -0.511 STD=0.0354
CW Average: 0.538
Final Slope Range: 0.18 g to 0.28 g
Average Ratio: 0.379
CCW Average: 0.22
CCW Ratios: 0.22 0.286 0.0989 0.235 0.262 STD=0.0725
CCW Final Slopes: -0.343 -0.518 -0.152 -0.404 -0.441 STD=0.138
CCW Initial Slopes: -1.56 -1.81 -1.54 -1.72 -1.68 STD=0.115
Yaw Rate (deg/sec)
Speed (m/s)
40
30
20
10
0
-10
-20
-30
-40
2
3
4
5
6
7
8
9
10





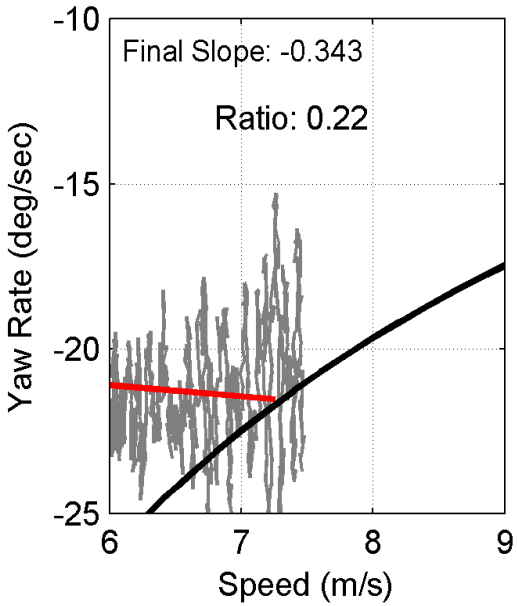


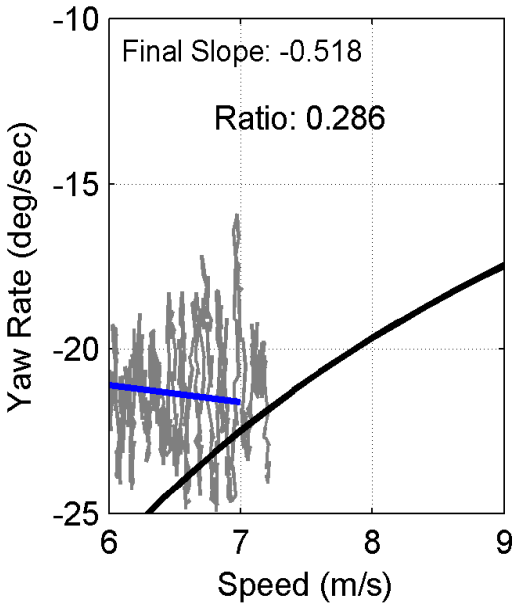


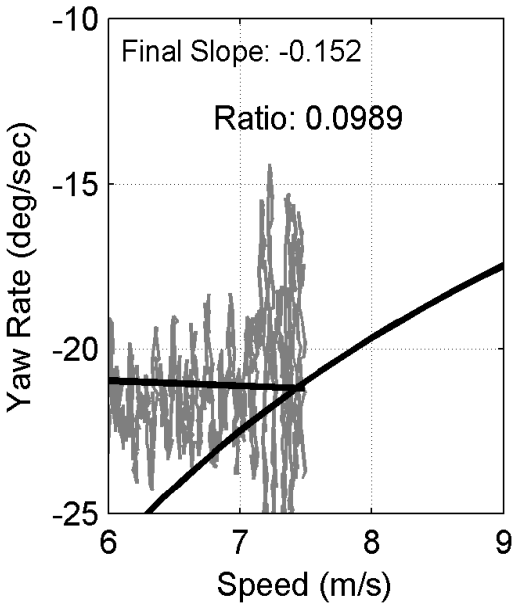


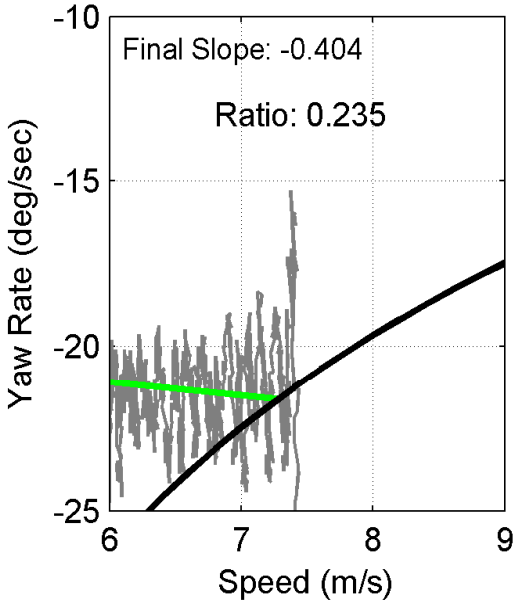
Final Slope Range:

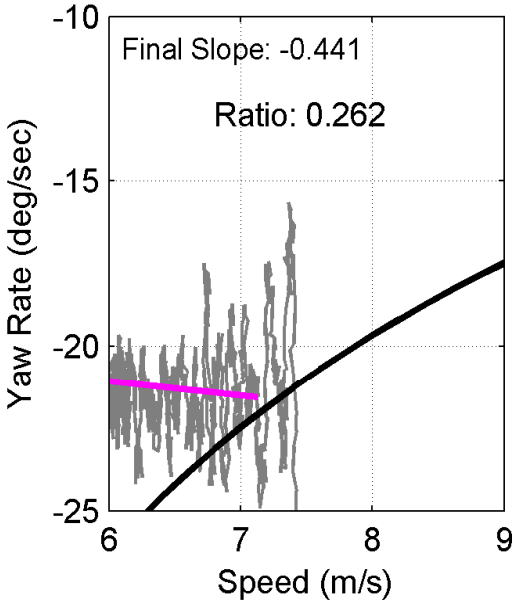
0.18 g to 0.28 g





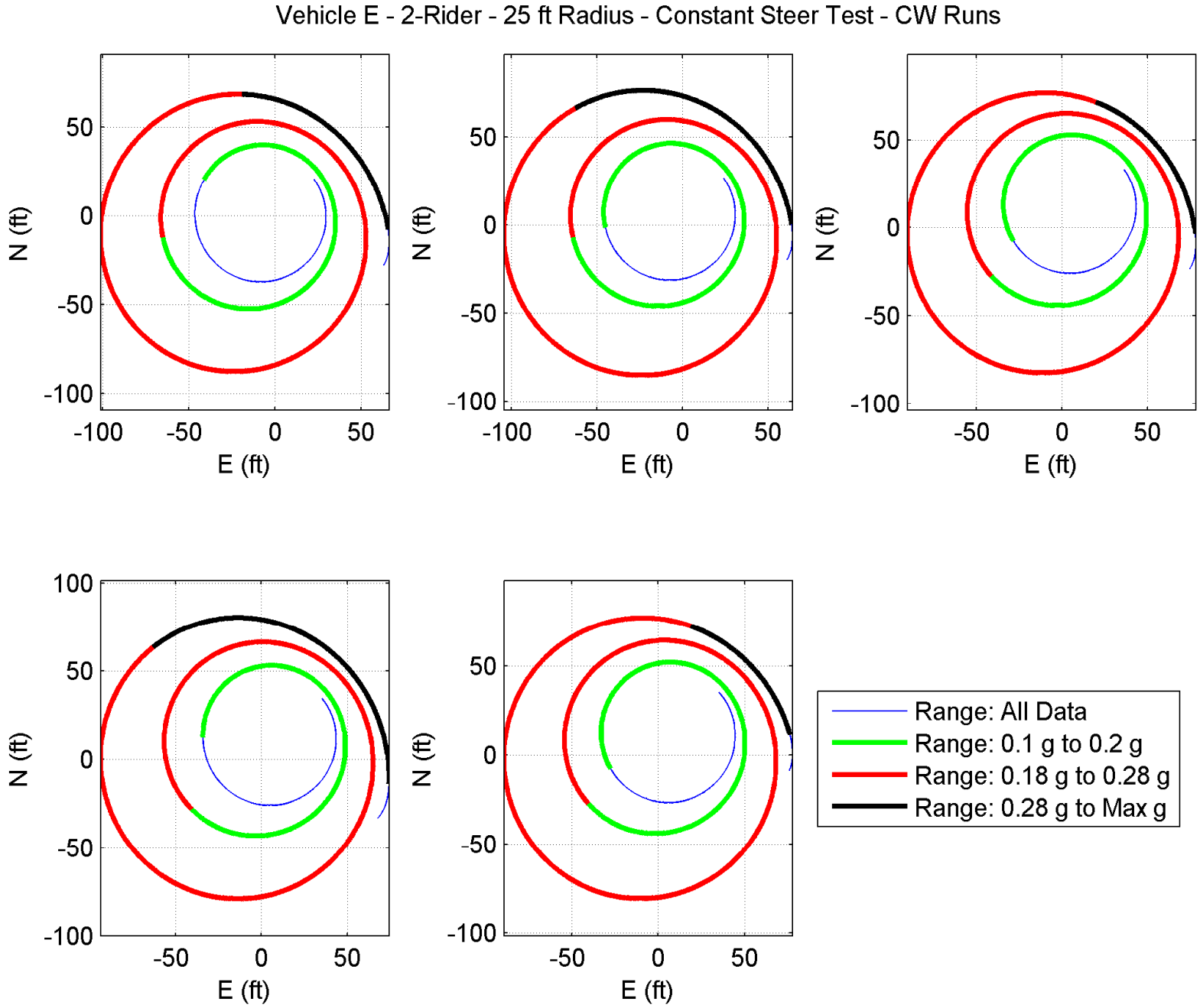


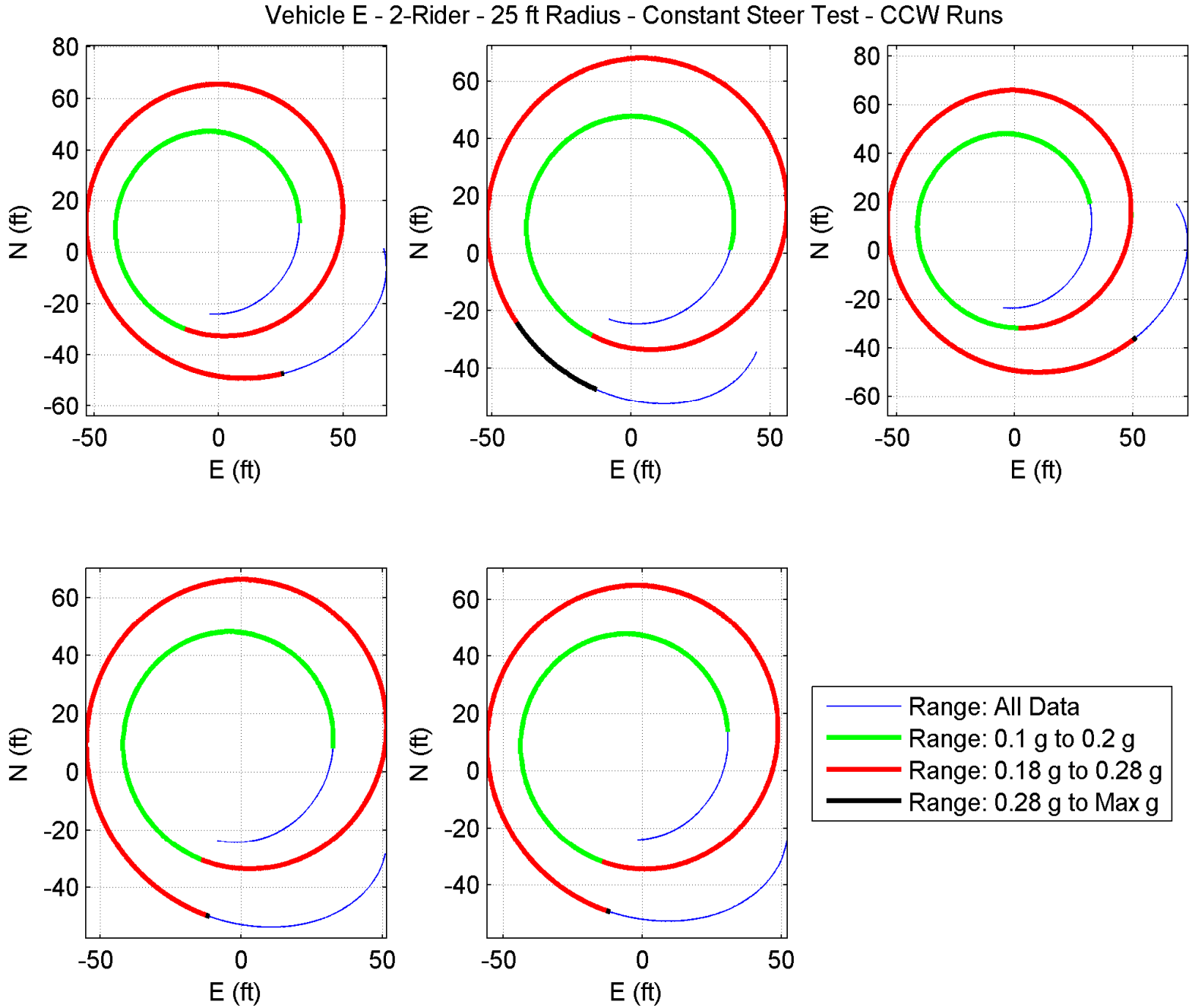


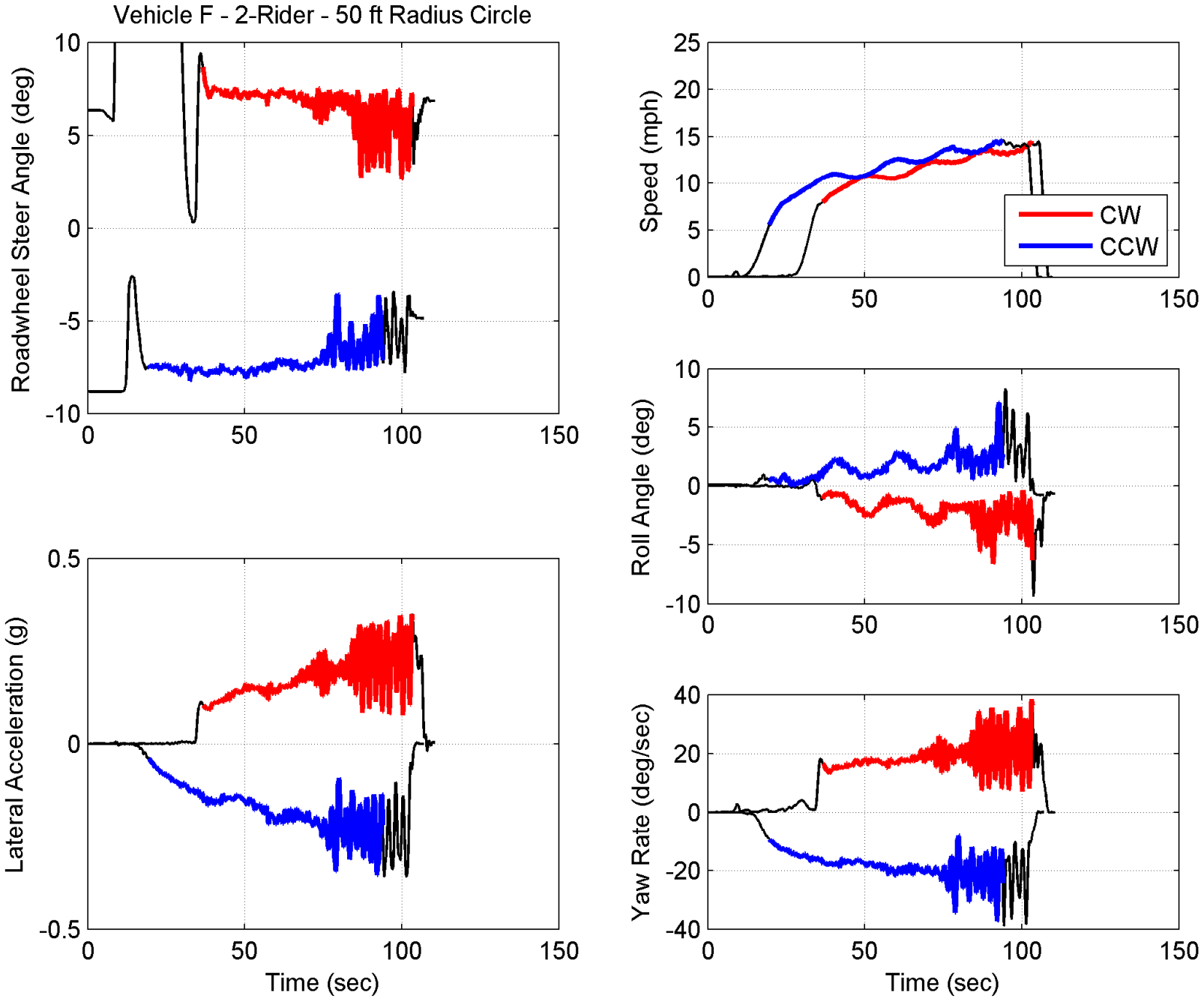


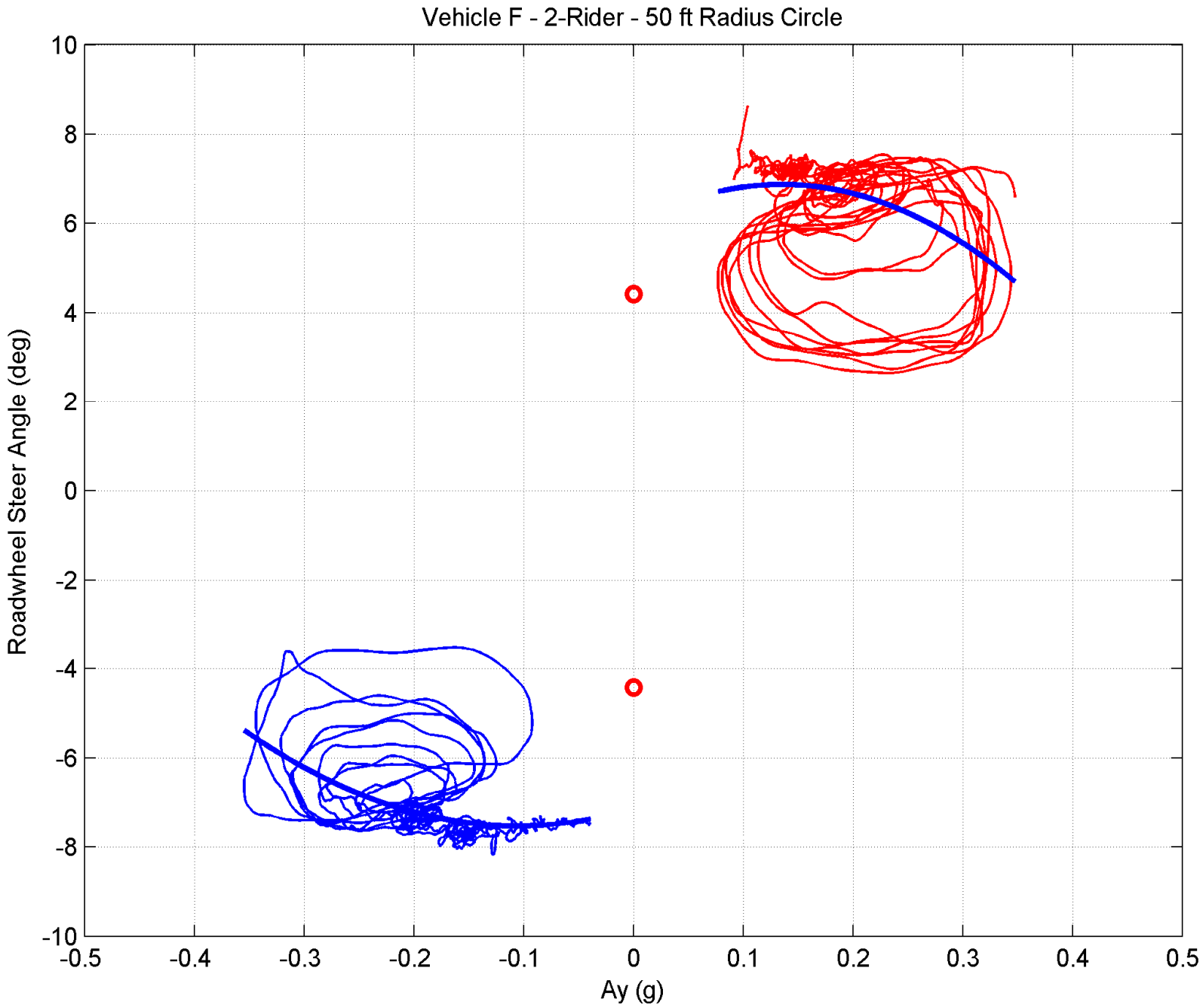
Final Slope Range:

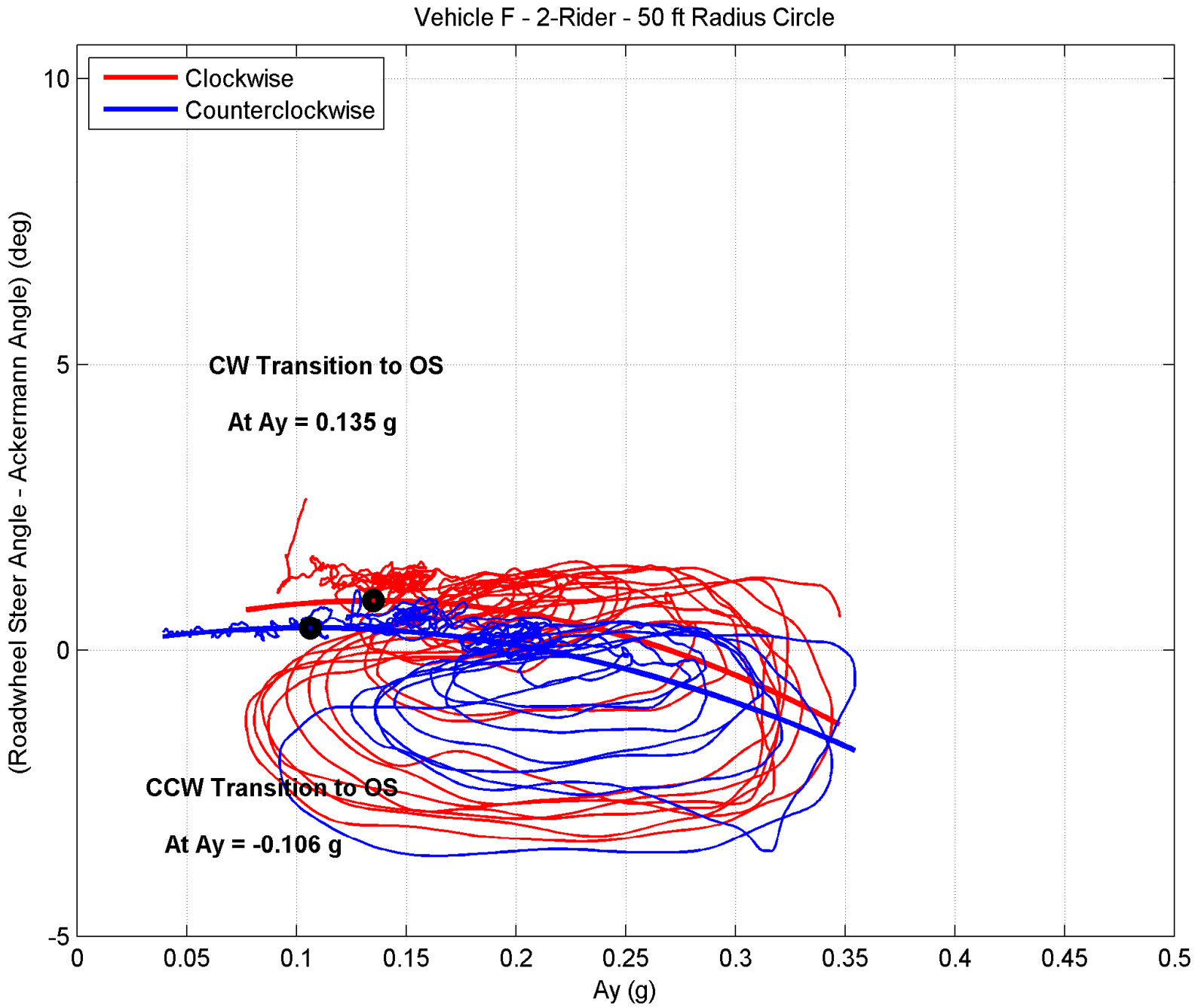
0.18 g to 0.28 g

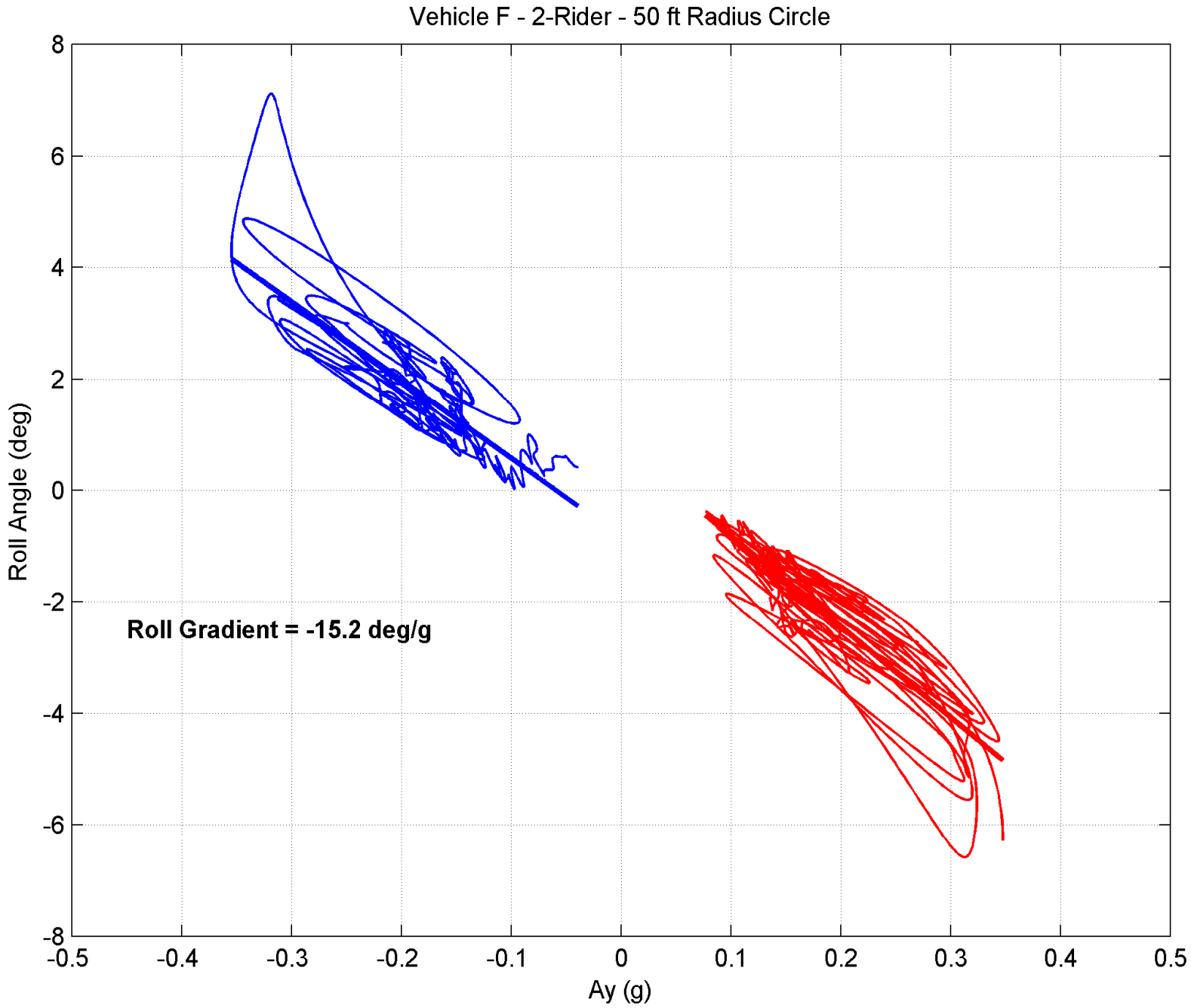

Vehicle E - 2-Rider - 25 ft Radius - Constant Steer Test - CW Runs
N (ft)
E (ft)
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.18 g to 0.28 g
Range: 0.28 g to Max g

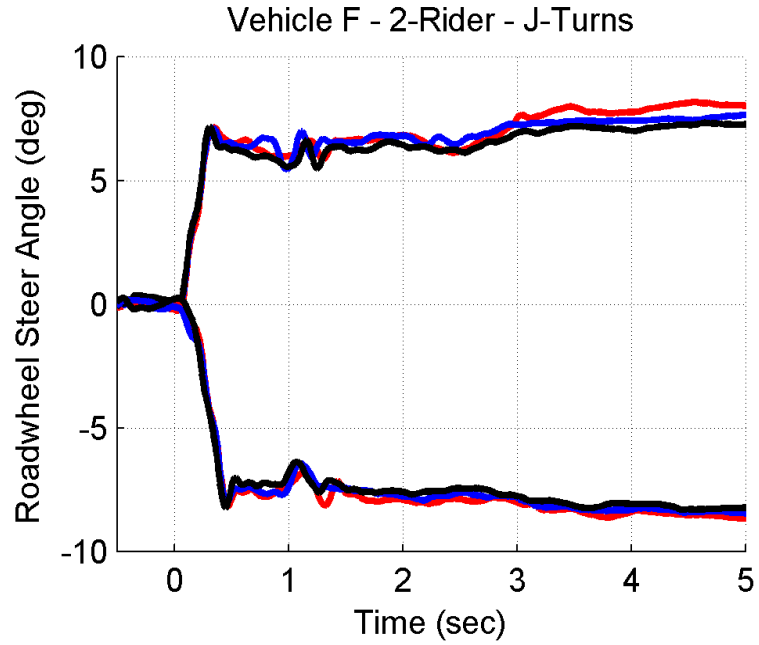

Vehicle E - 2-Rider - 25 ft Radius - Constant Steer Test - CCW Runs
N (ft)
E (ft)
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.18 g to 0.28 g
Range: 0.28 g to Max g

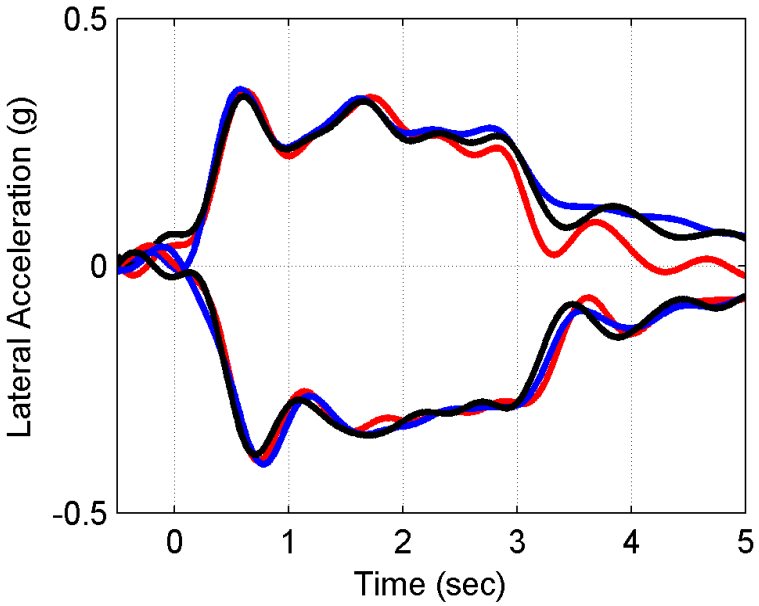

Vehicle F - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
Speed (mph)
CW
CCW
Roll Angle (deg)
Lateral Acceleration (g)
Yaw Rate (deg/sec)
Time (sec)
Time (sec)

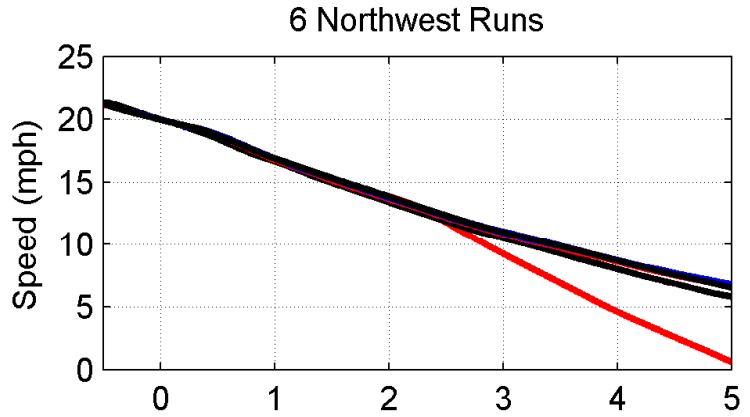

Vehicle F - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
Ay (g)
10
8
6
4
2
0
-2
-4
-6
-8
-10
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

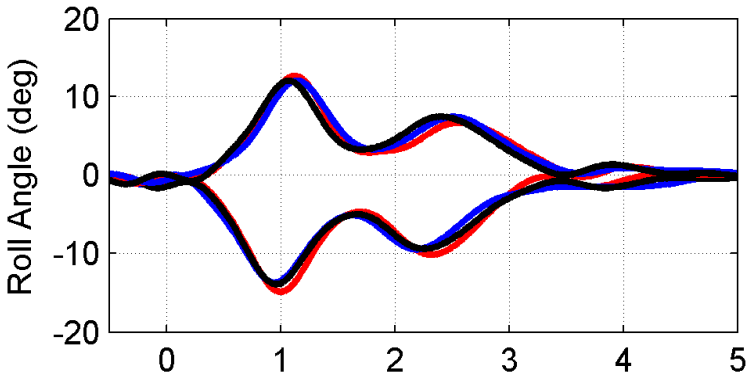

Vehicle F - 2-Rider - 50 ft Radius Circle
Clockwise
Counterclockwise
CW Transition to OS
At Ay = 0.135 g
CCW Transition to OS
At Ay = -0.106 g
(Roadwheel Steer Angle - Ackermann Angle) (deg)
Ay (g)
10
5
0
-5
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5

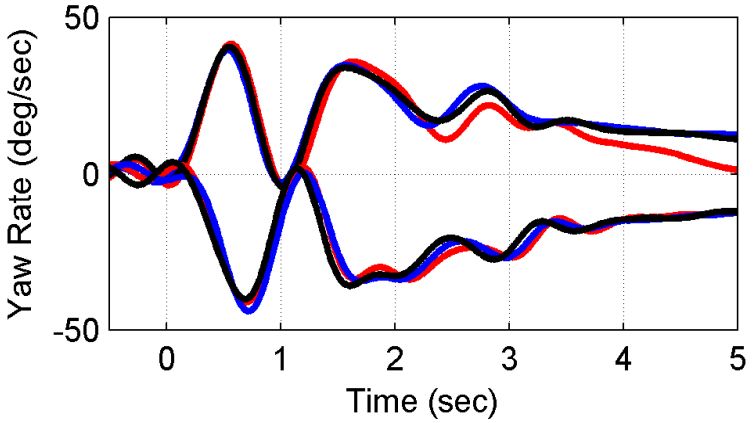

Vehicle F - 2-Rider - 50 ft Radius Circle
Roll Angle (deg)
Ay (g)
Roll Gradient = -15.2 deg/g
8
6
4
2
0
-2
-4
-6
-8
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

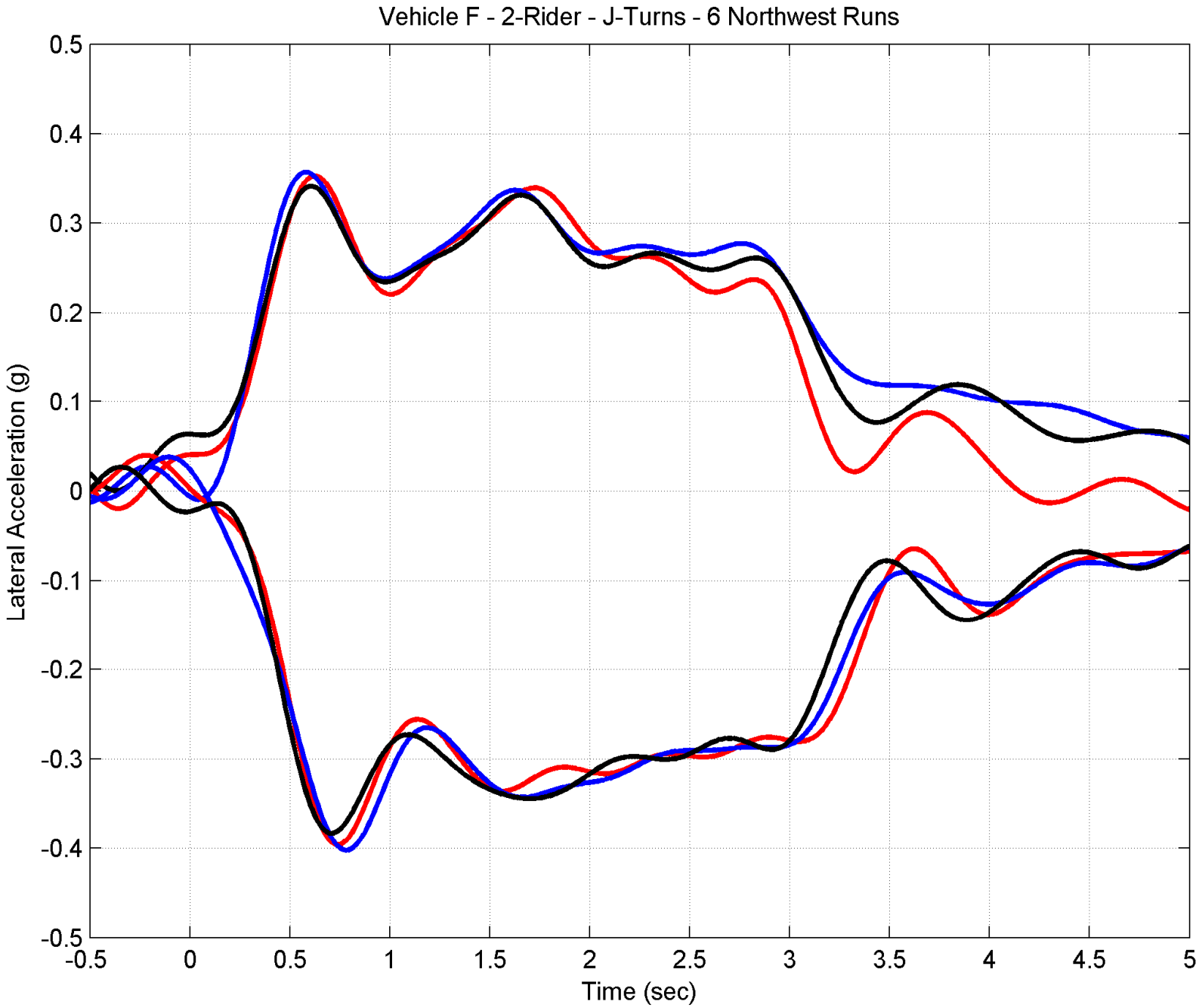

Vehicle F - 2-Rider - J-Turns
Roadwheel Steer Angle (deg)
10
5
0
-5
-10
0
1
2
3
4
5
Time (sec)

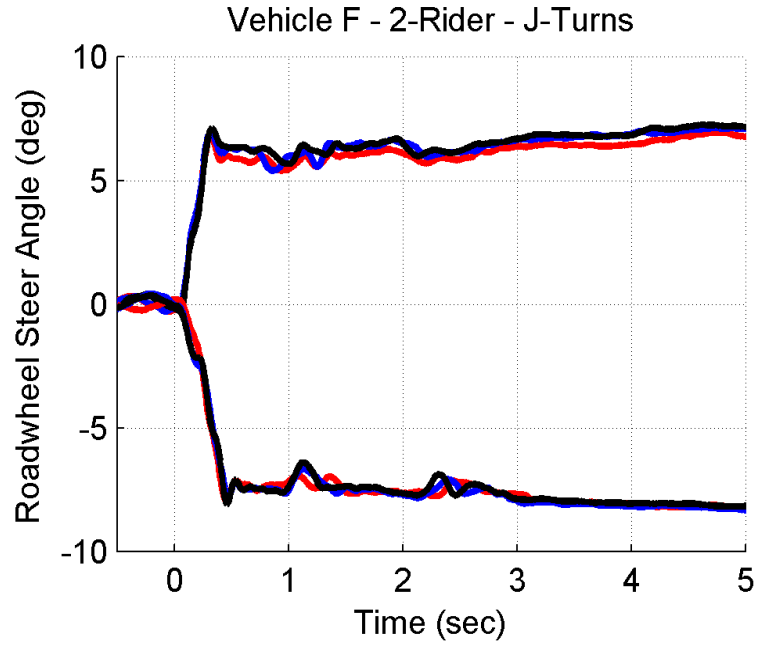

Lateral Acceleration (g)
0.5
0
-0.5
0
1
2
3
4
5
Time (sec)

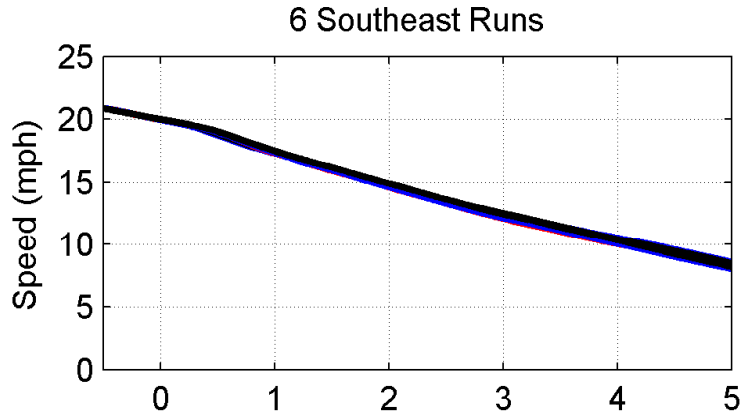

6 Northwest Runs
Speed (mph)
25
20
15
10
5
0
0
1
2
3
4
5

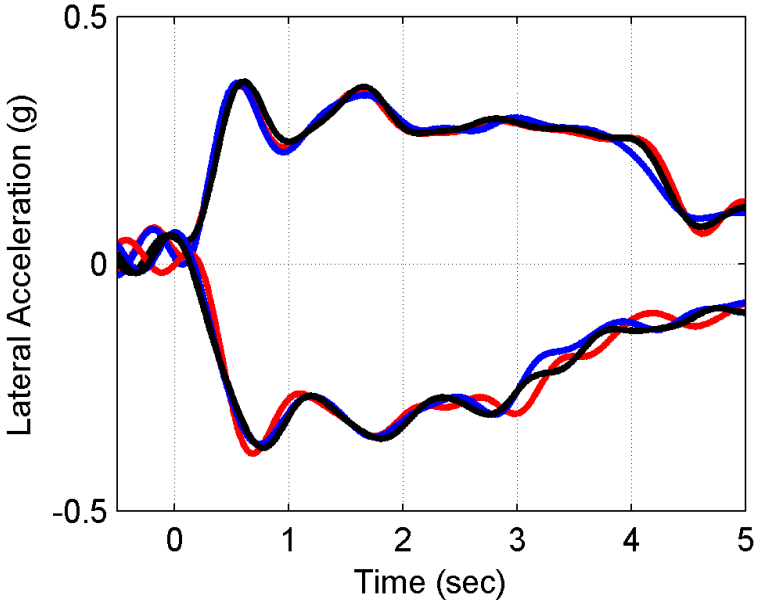

Roll Angle (deg)
20
10
0
-10
-20
0
1
2
3
4
5

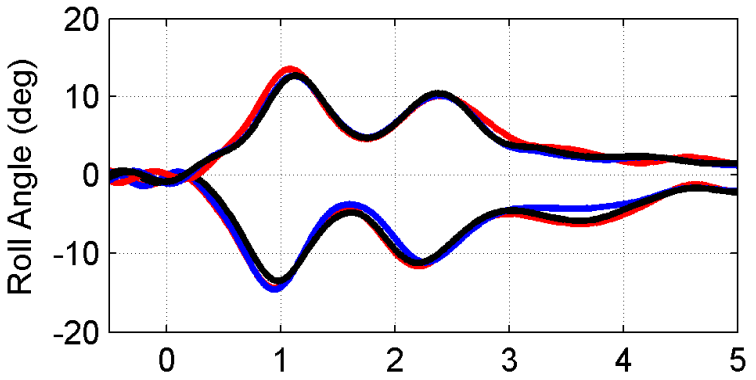

Yaw Rate (deg/sec)
50
0
-50
0
1
2
3
4
5
Time (sec)

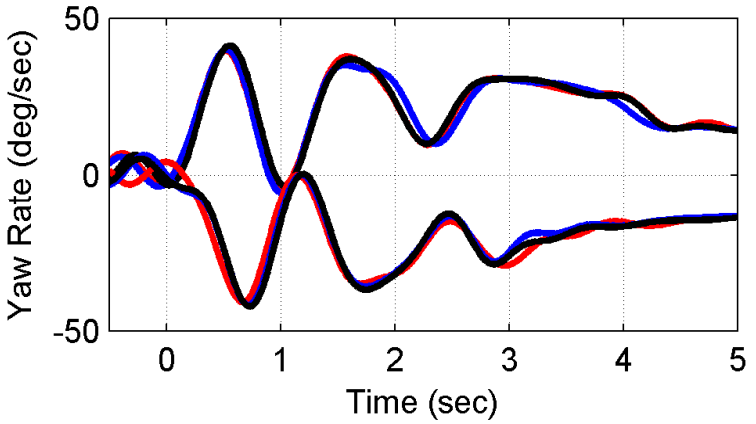

Vehicle F - 2-Rider - J-Turns - 6 Northwest Runs
Lateral Acceleration (g)
Time (sec)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

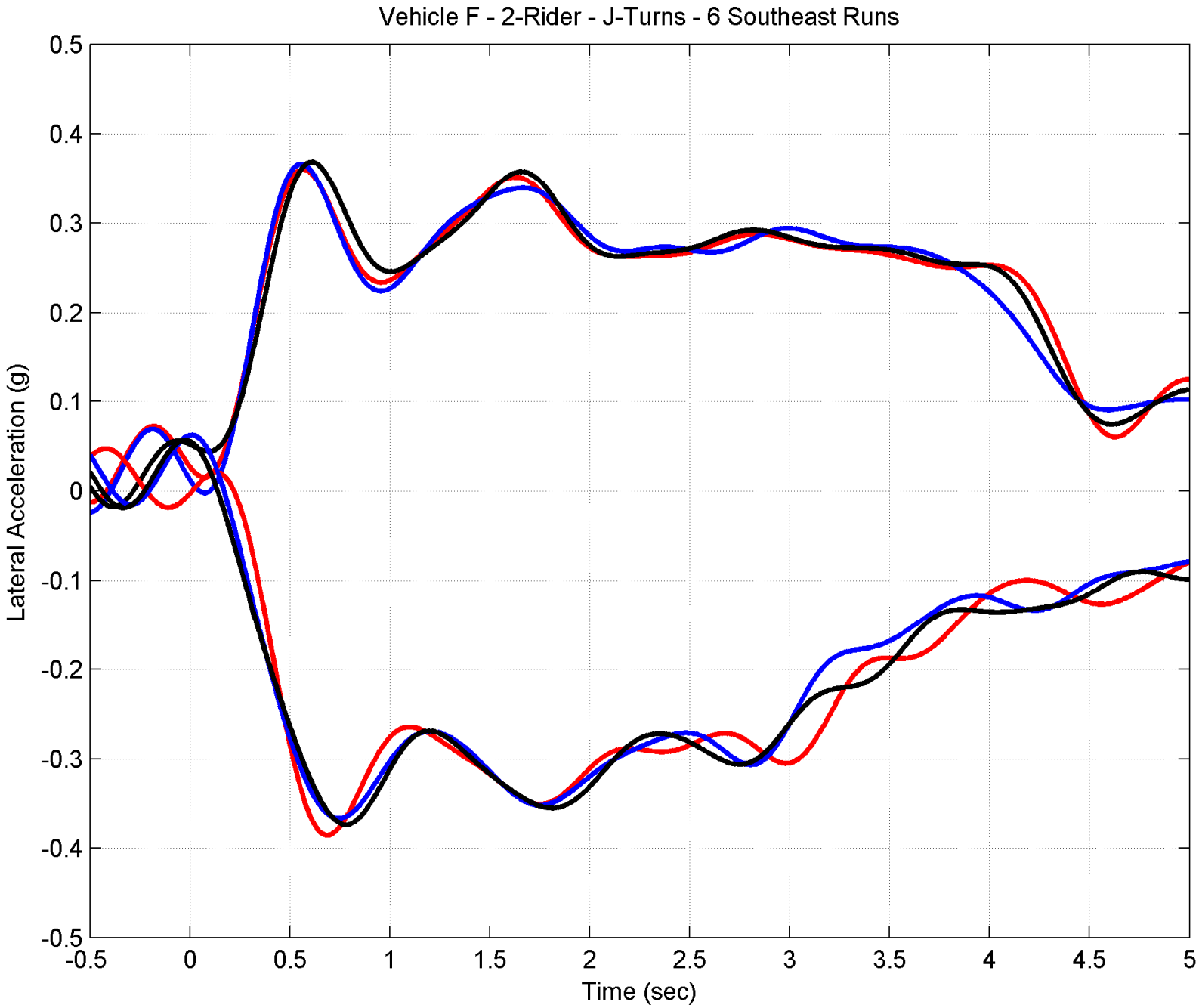

Vehicle F - 2-Rider - J-Turns
Roadwheel Steer Angle (deg)
10
5
0
-5
-10
0
1
2
3
4
5
Time (sec)


6 Southeast Runs
Speed (mph)
25
20
15
10
5
0
0
1
2
3
4
5


Lateral Acceleration (g)
0.5
0
-0.5
0
1
2
3
4
5
Time (sec)


Roll Angle (deg)
20
10
0
-10
-20
0
1
2
3
4
5


Yaw Rate (deg/sec)
50
0
-50
0
1
2
3
4
5
Time (sec)


Vehicle F - 2-Rider - J-Turns - 6 Southeast Runs
Lateral Acceleration (g)
Time (sec)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

Vehicle F - 2-Rider Results

Peak Lateral Accelerations During 2WL J-Turns - All Values in "g's"

Run Number	Northwest Right Turns	Northwest Left Turns
1	0.353	-0.396
2	0.358	-0.403
3	0.341	-0.383
Mean Value of 3 Runs	0.351	-0.394
Standard Deviation of 3 Runs	0.009	0.010

Average of 6 Northwest Runs

0.372

Run Number	Southeast Right Turns	Southeast Left Turns
1	0.360	-0.385
2	0.366	-0.366
3	0.369	-0.373
Mean Value of 3 Runs	0.365	-0.375
Standard Deviation of 3 Runs	0.004	0.009

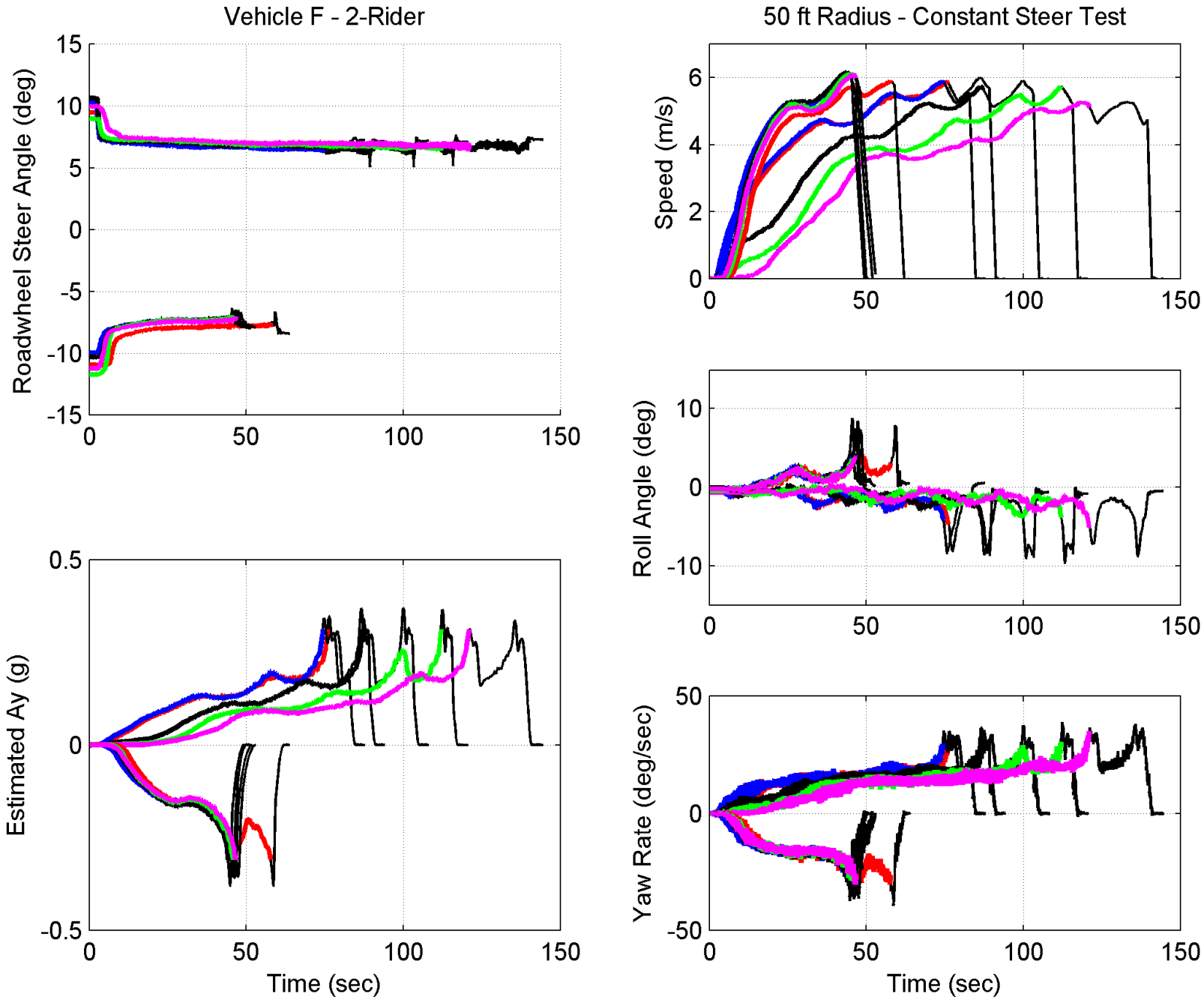
Average of 6 Southeast Runs

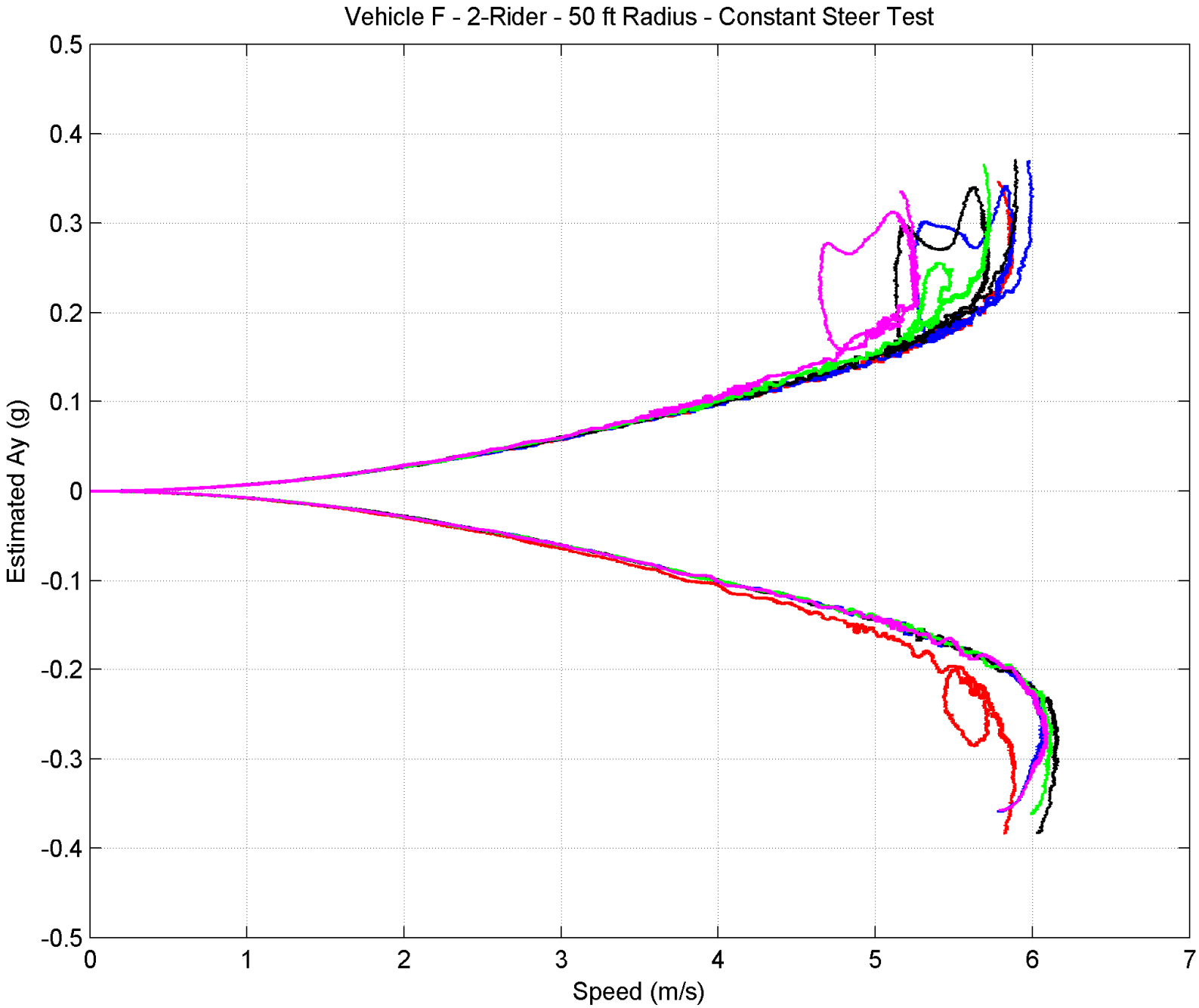
0.370

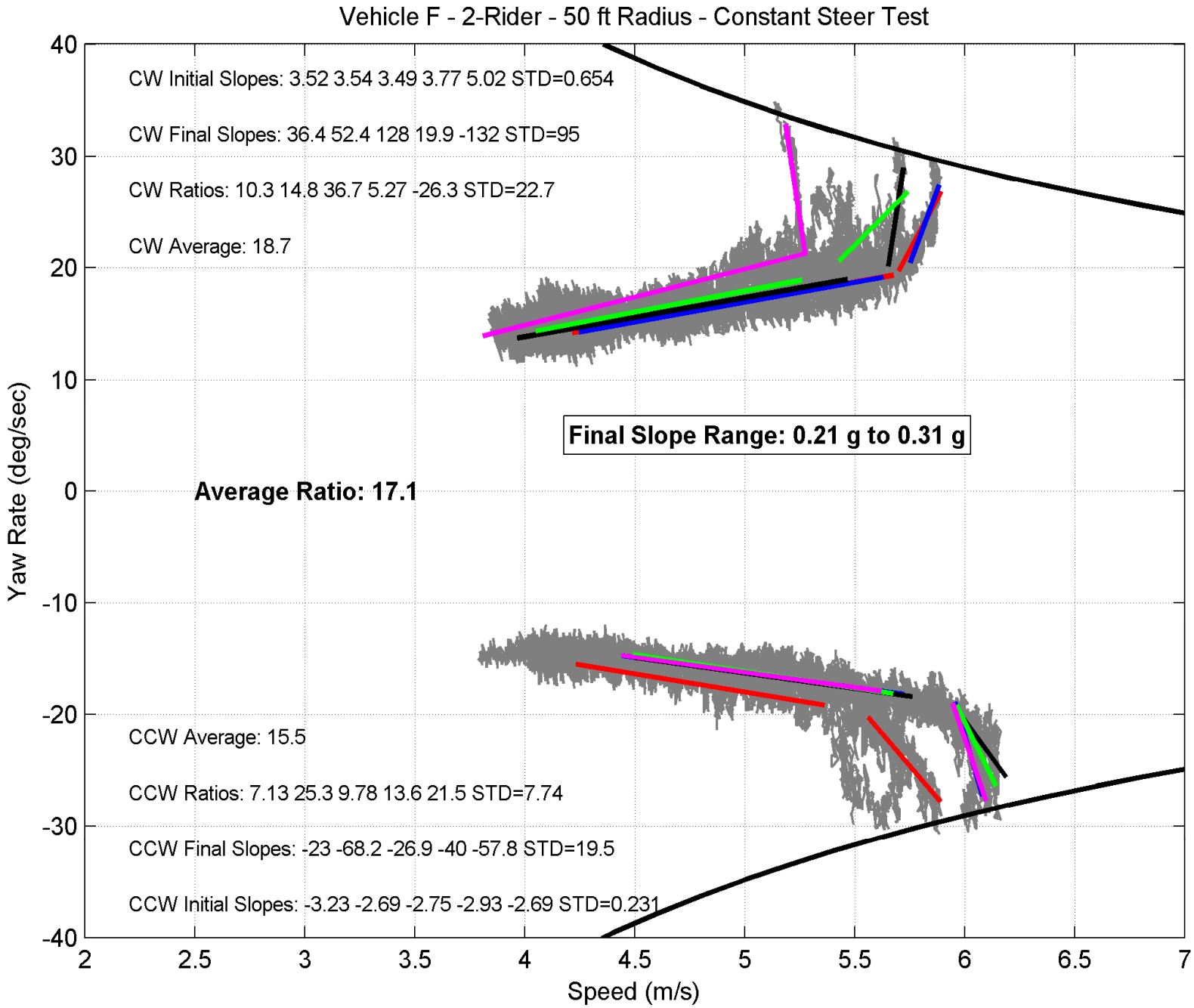
Average of All 12 Runs

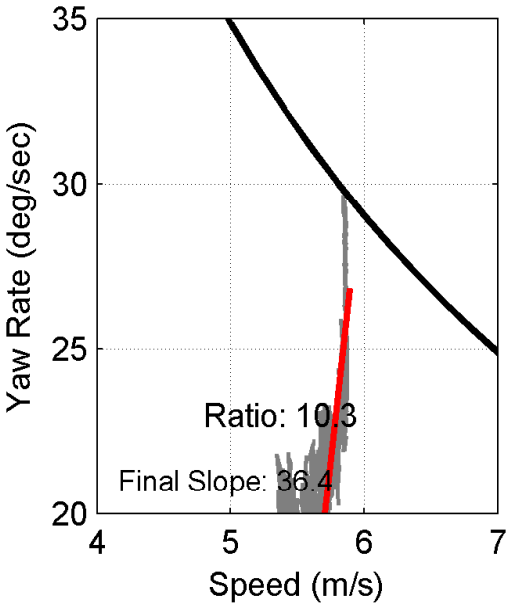
0.371

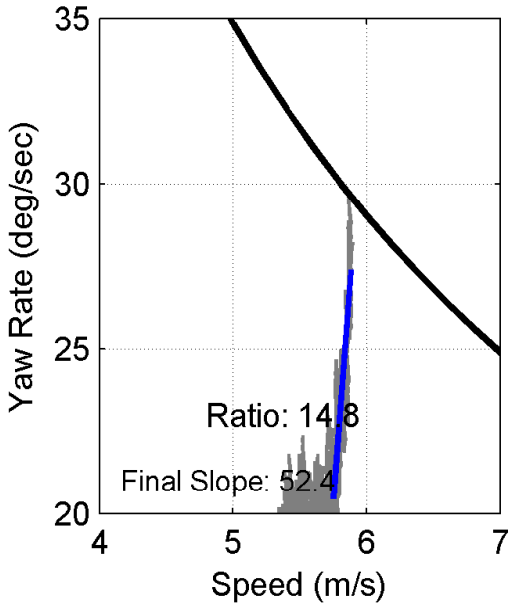
Threshold Ay

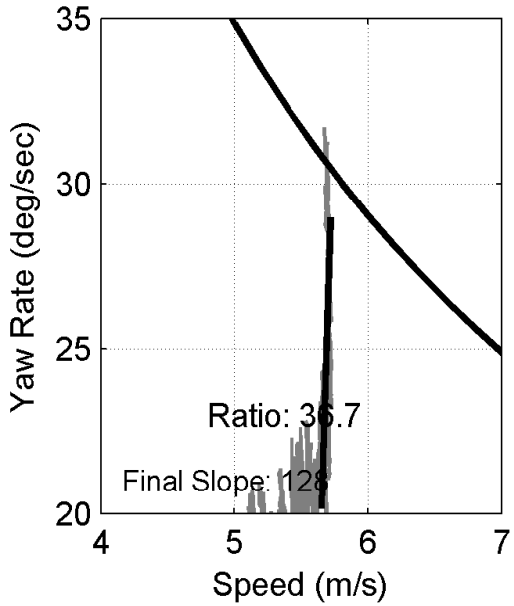

Vehicle F - 2-Rider
50 ft Radius - Constant Steer Test
Roadwheel Steer Angle (deg)
Speed (m/s)
Roll Angle (deg)
Estimated Ay (g)
Yaw Rate (deg/sec)
Time (sec)
Time (sec)

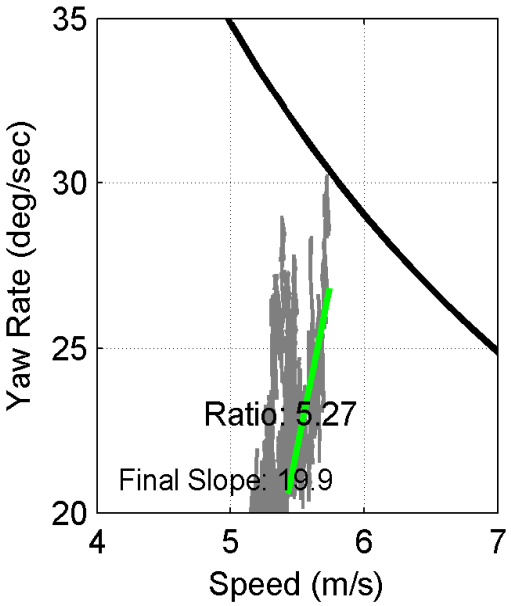

Vehicle F - 2-Rider - 50 ft Radius - Constant Steer Test
Estimated Ay (g)
Speed (m/s)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
1
2
3
4
5
6
7

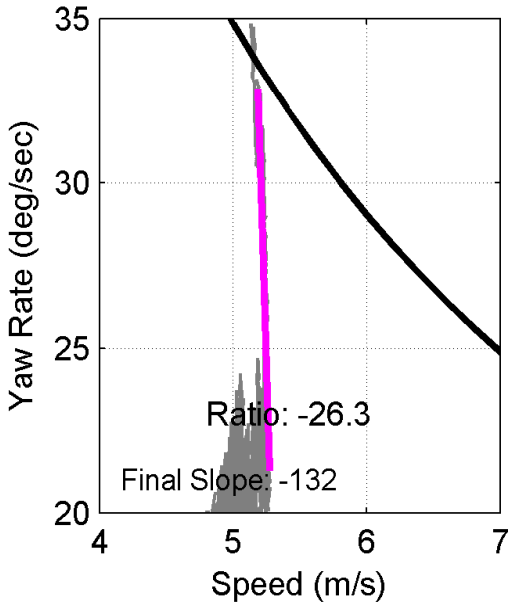

Vehicle F - 2-Rider - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.52 3.54 3.49 3.77 5.02 STD=0.654
CW Final Slopes: 36.4 52.4 128 19.9 -132 STD=95
CW Ratios: 10.3 14.8 36.7 5.27 -26.3 STD=22.7
CW Average: 18.7
Final Slope Range: 0.21 g to 0.31 g
Average Ratio: 17.1
CCW Average: 15.5
CCW Ratios: 7.13 25.3 9.78 13.6 21.5 STD=7.74
CCW Final Slopes: -23 -68.2 -26.9 -40 -57.8 STD=19.5
CCW Initial Slopes: -3.23 -2.69 -2.75 -2.93 -2.69 STD=0.231
Yaw Rate (deg/sec)
Speed (m/s)
40
30
20
10
0
-10
-20
-30
-40
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7





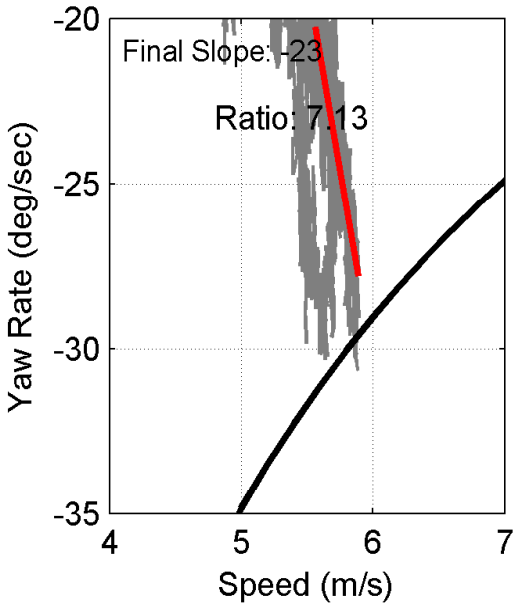


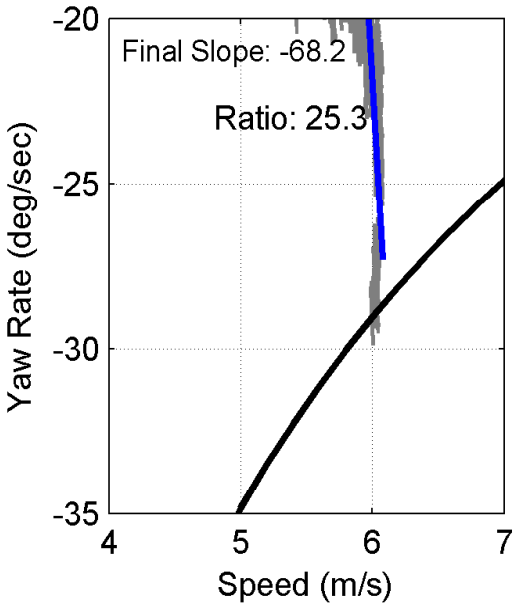


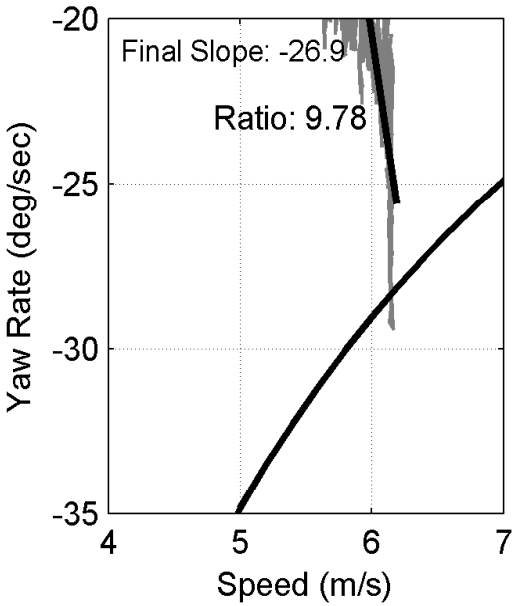


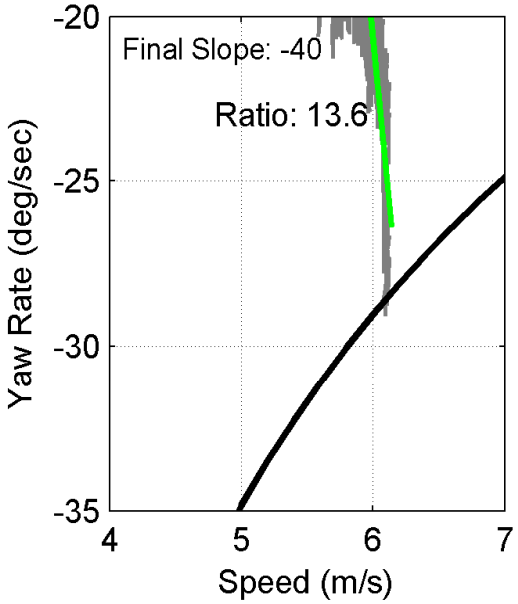
Final Slope Range:

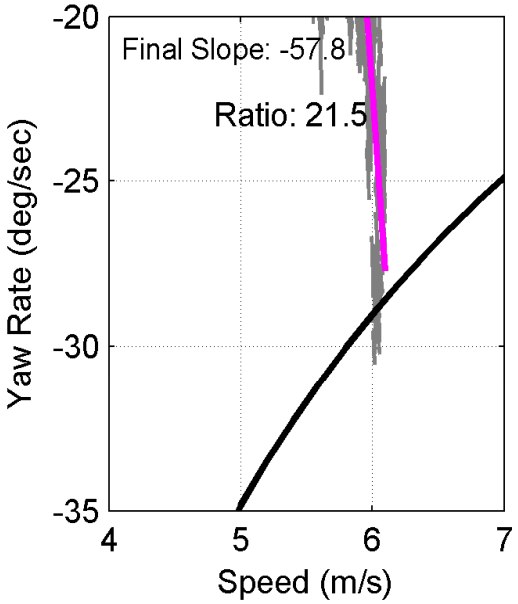
0.21 g to 0.31 g





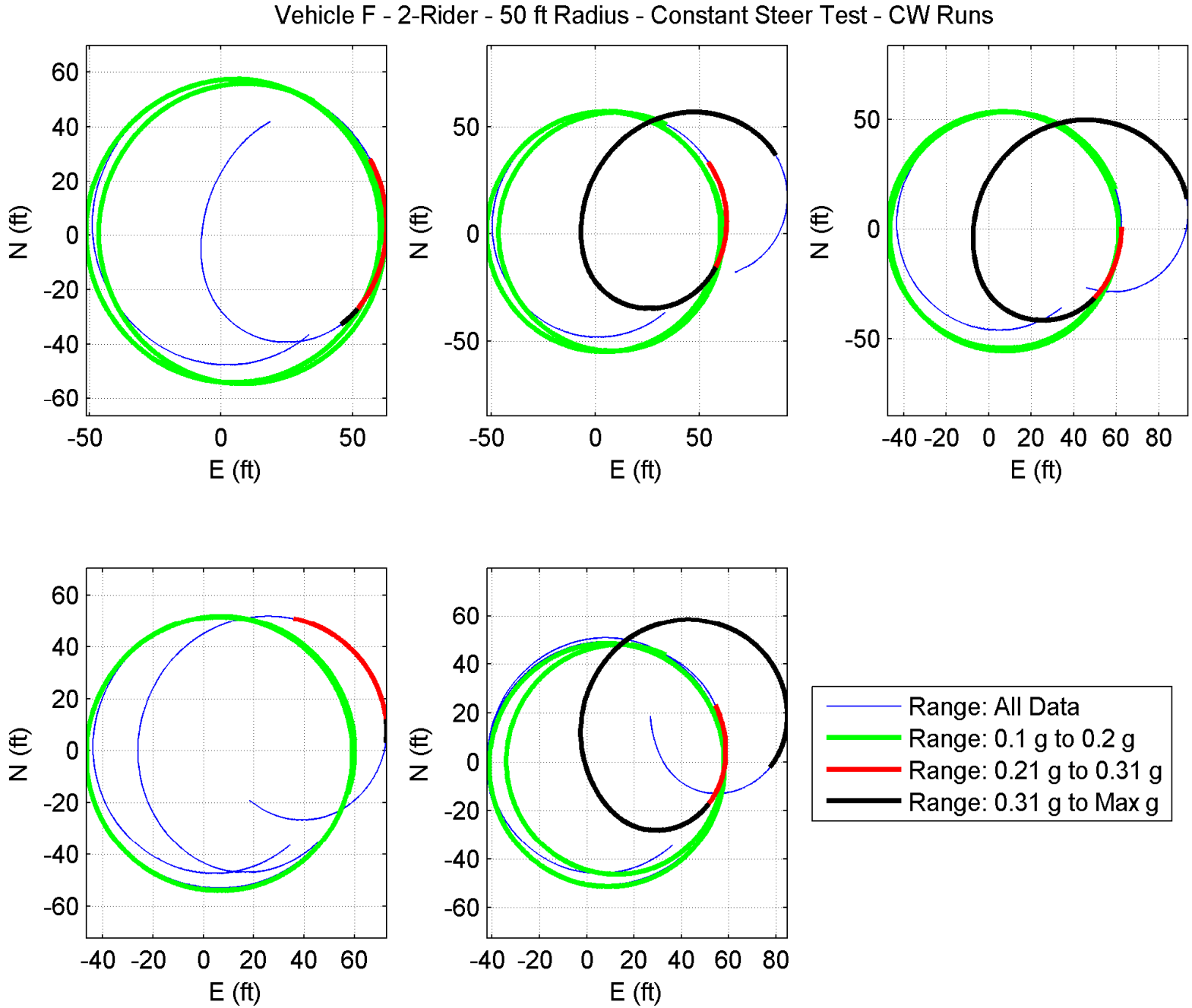


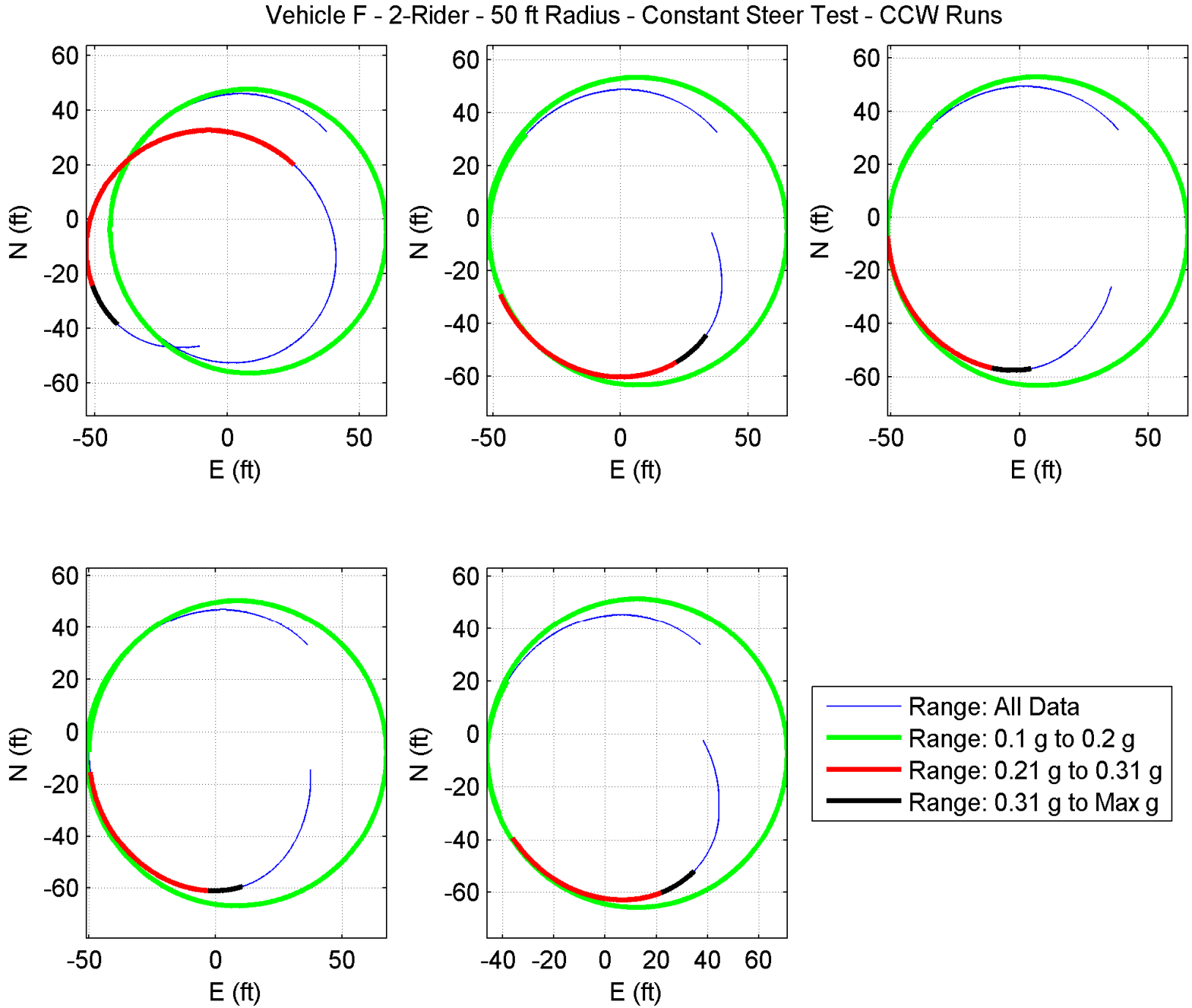


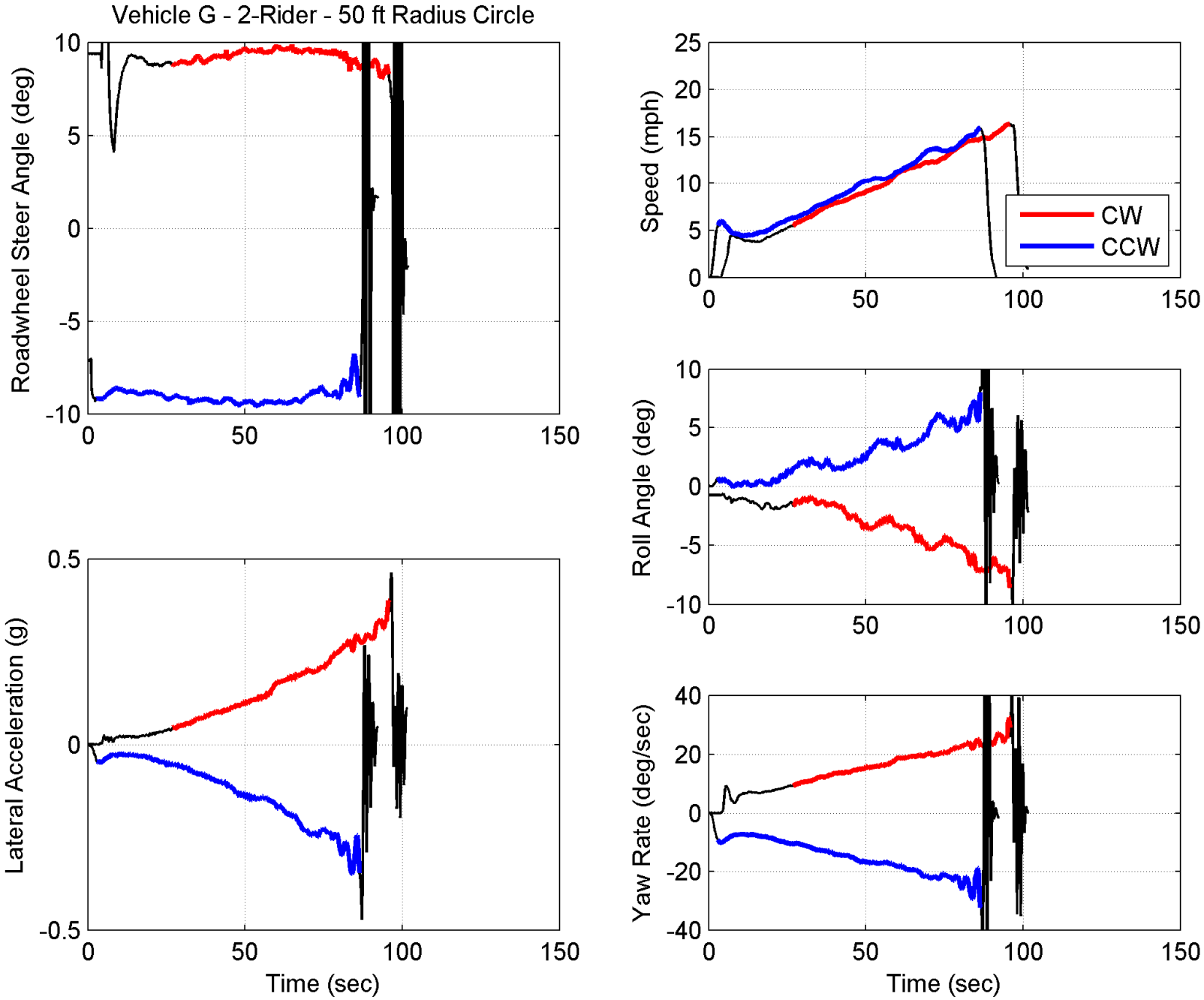


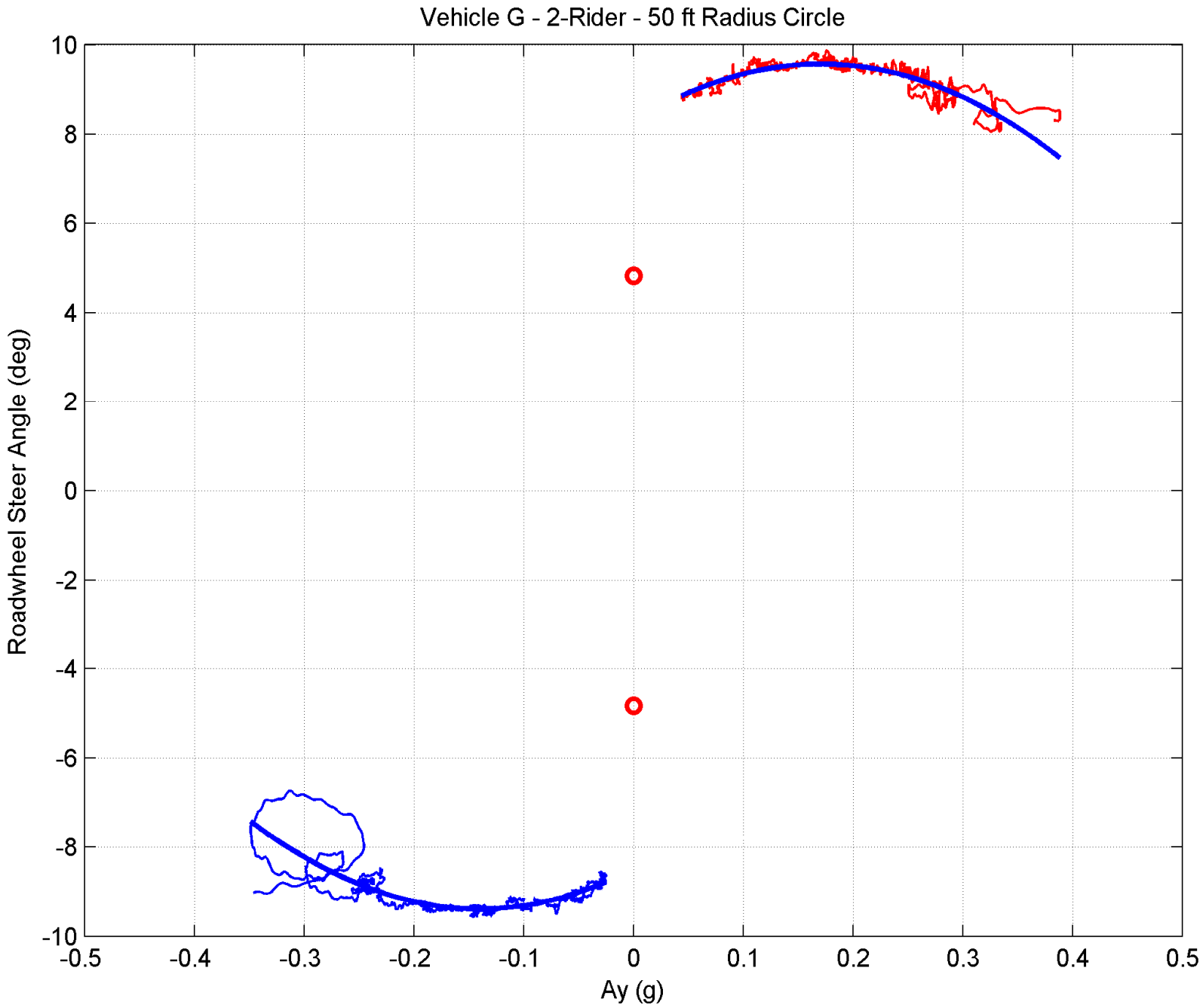
Final Slope Range:

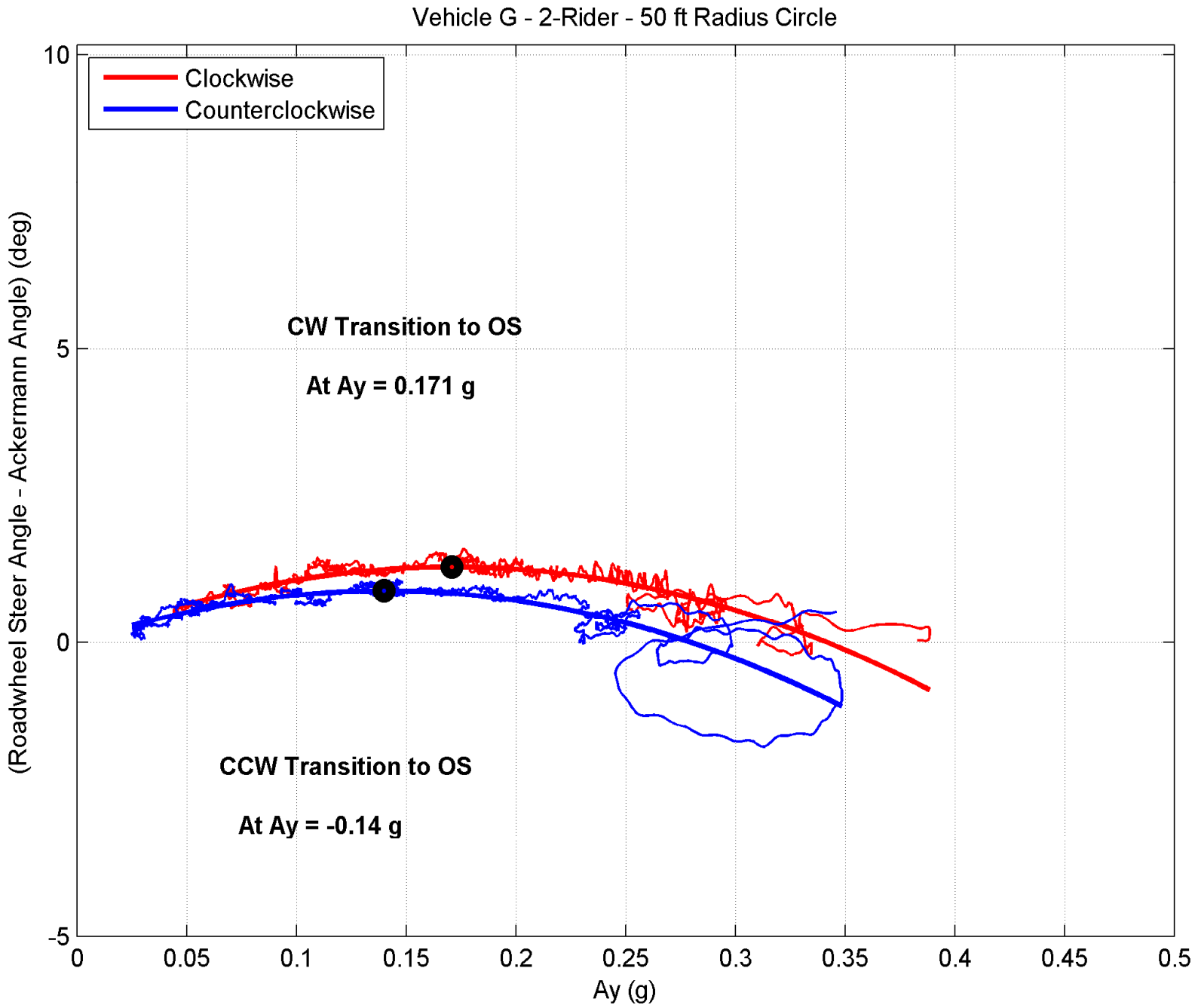
0.21 g to 0.31 g

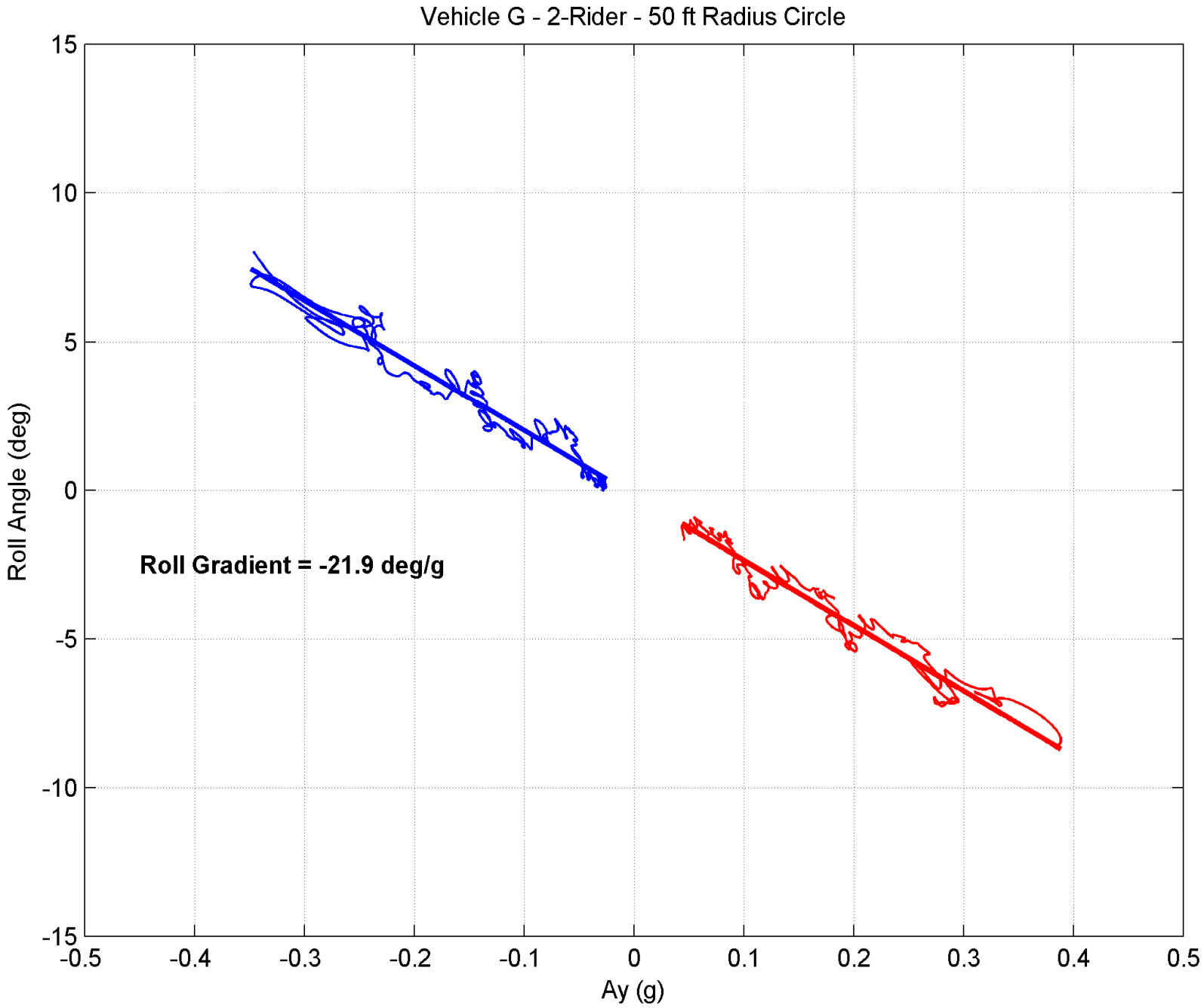

Vehicle F - 2-Rider - 50 ft Radius - Constant Steer Test - CW Runs
N (ft)
E (ft)
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.21 g to 0.31 g
Range: 0.31 g to Max g

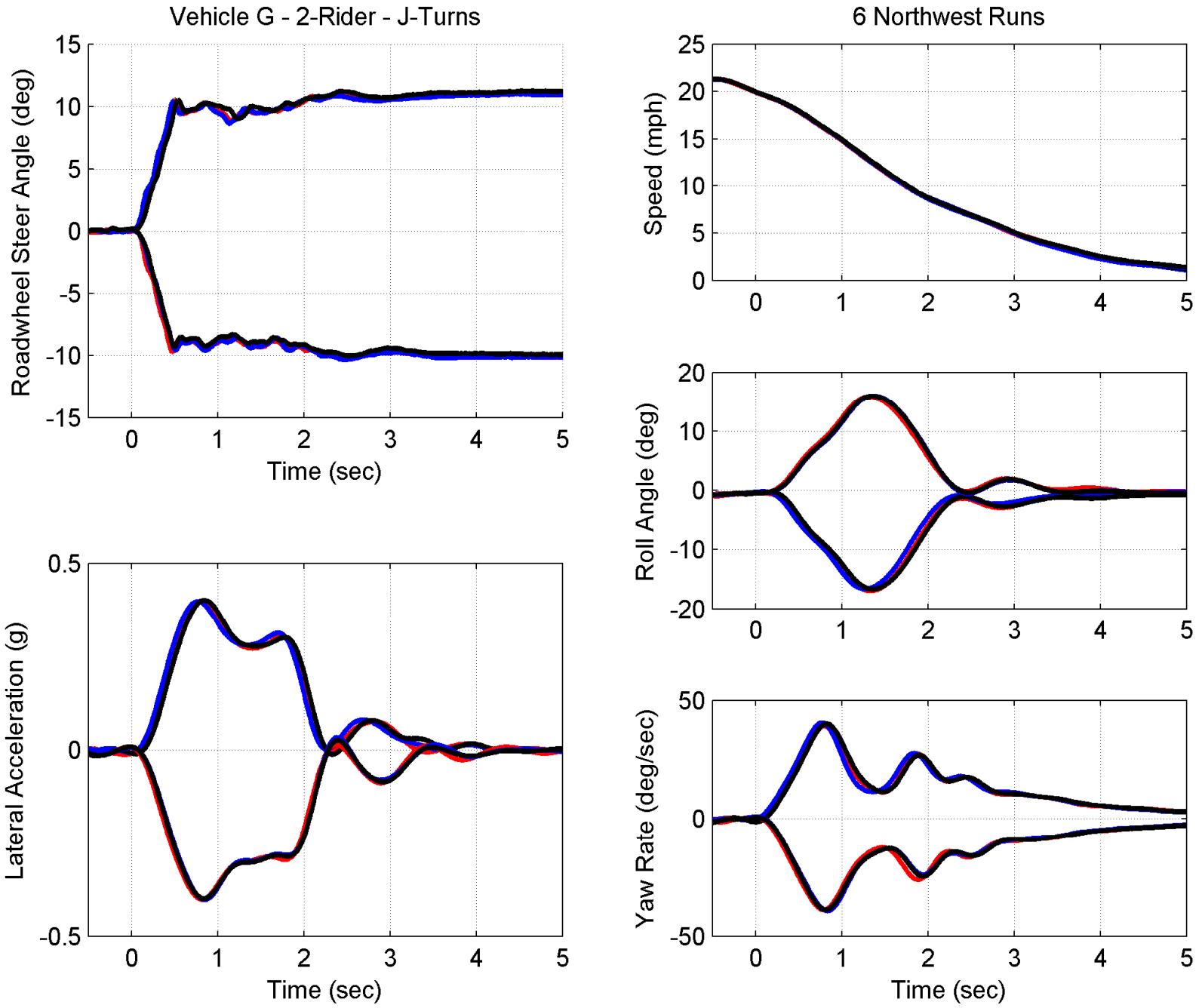

Vehicle F - 2-Rider - 50 ft Radius - Constant Steer Test - CCW Runs
N (ft)
E (ft)
60
40
20
0
-20
-40
-60
-50
0
50
-40
-20
0
20
40
60
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.21 g to 0.31 g
Range: 0.31 g to Max g

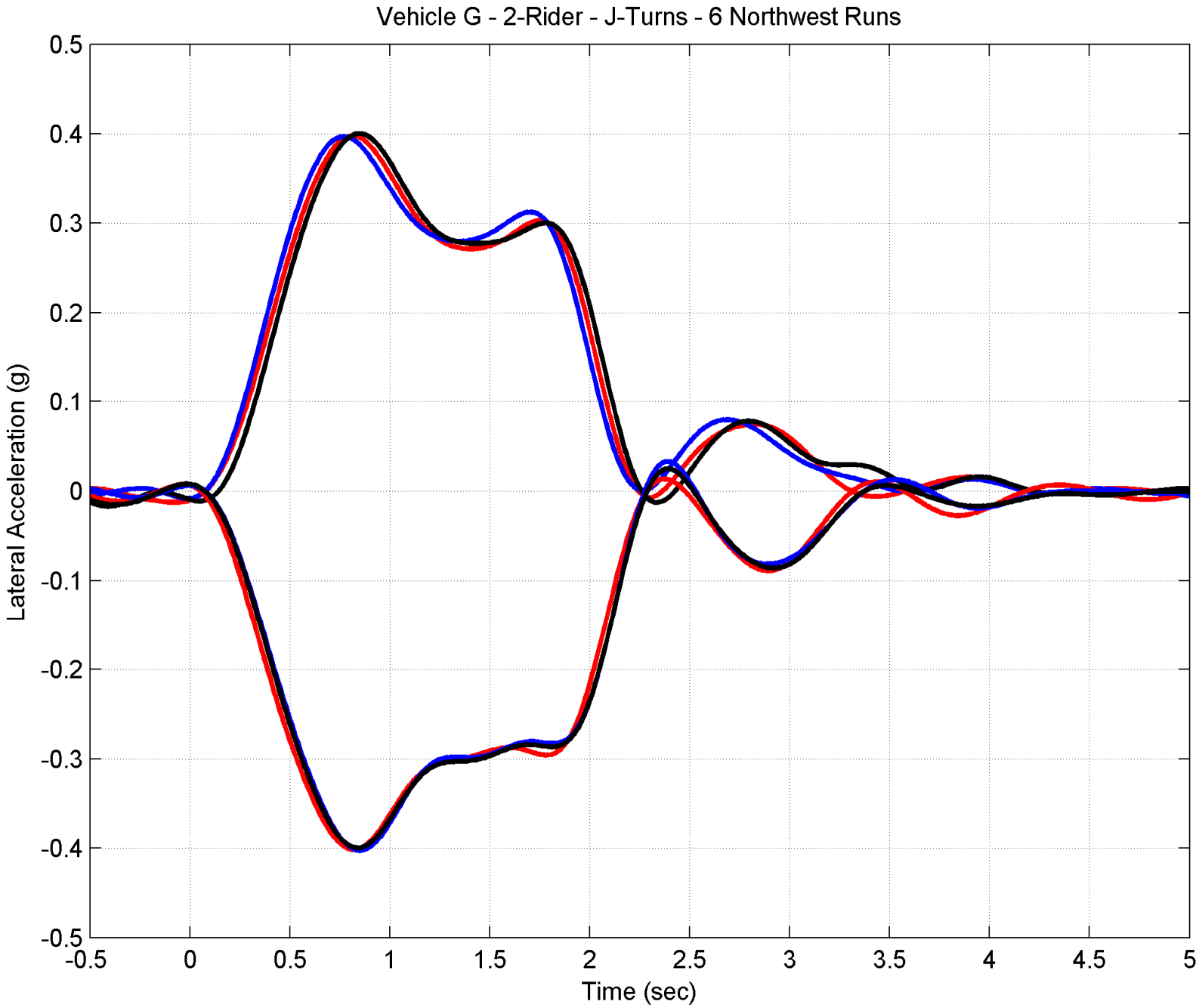

Vehicle G - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
10
5
0
-5
-10
0
50
100
150
Speed (mph)
25
20
15
10
5
0
CW
CCW
Roll Angle (deg)
10
5
0
-5
-10
Lateral Acceleration (g)
0.5
0
-0.5
Yaw Rate (deg/sec)
40
20
0
-20
-40
Time (sec)
Time (sec)

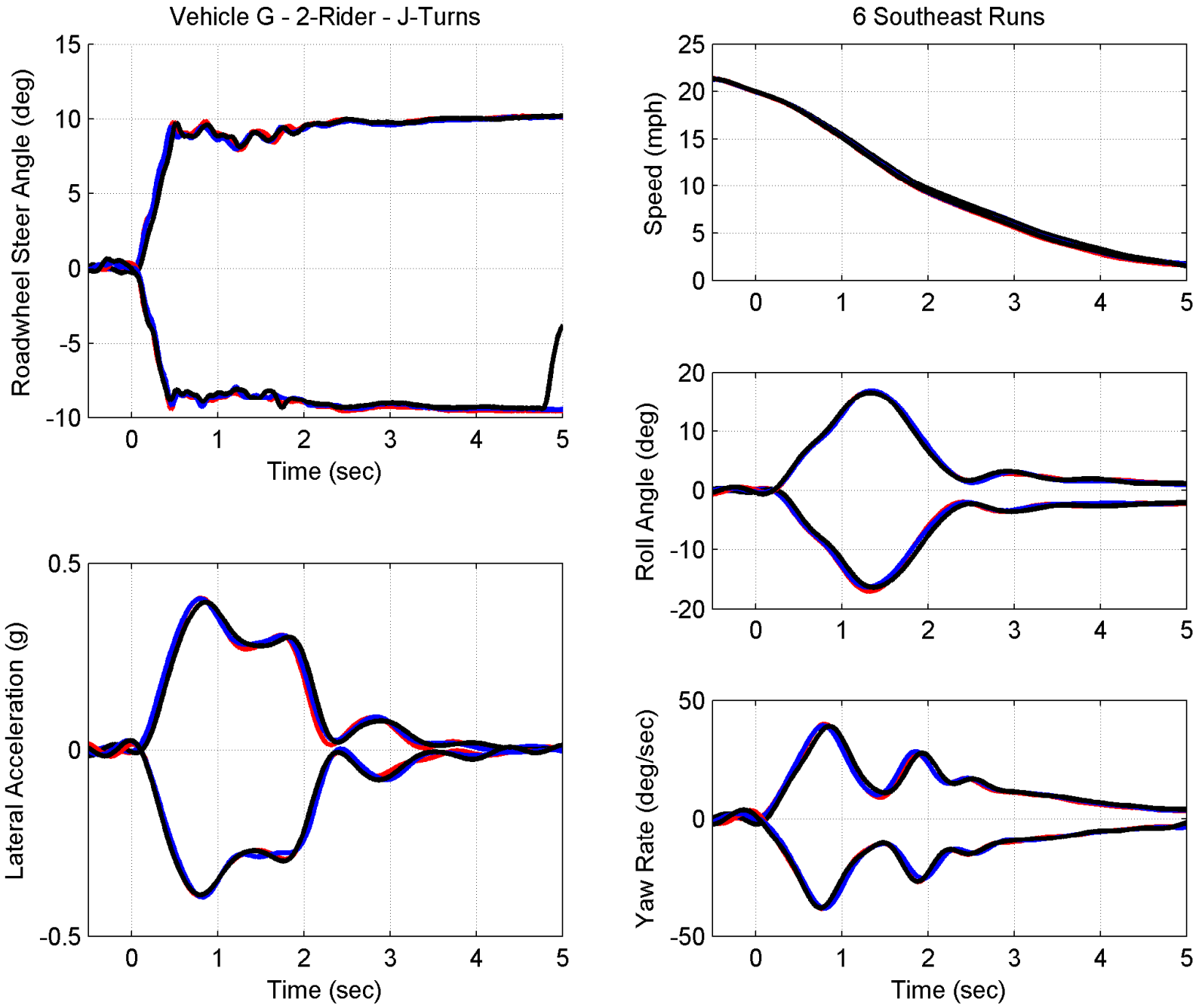

Vehicle G - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
Ay (g)
10
8
6
4
2
0
-2
-4
-6
-8
-10
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

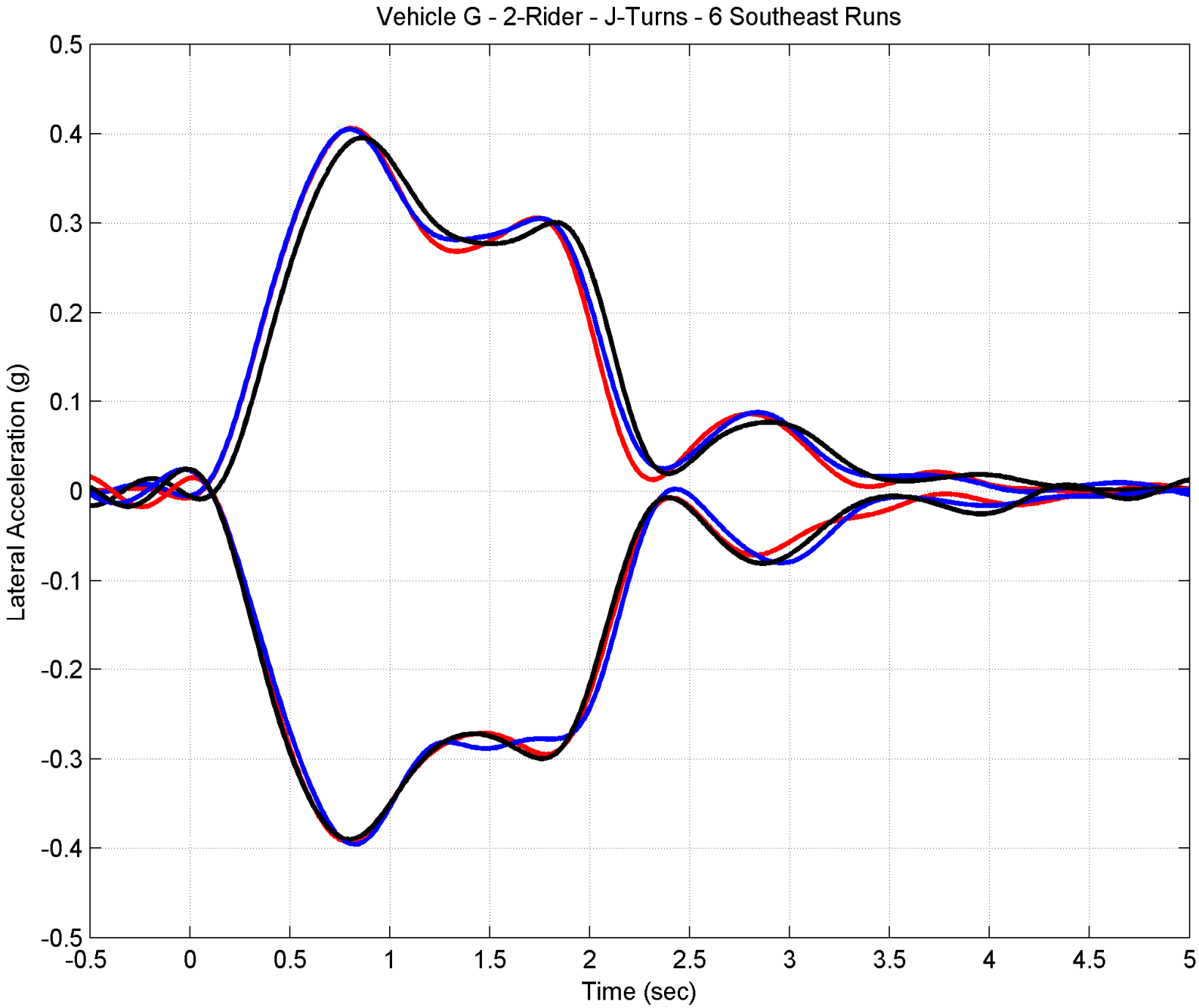

Vehicle G - 2-Rider - 50 ft Radius Circle
Clockwise
Counterclockwise
CW Transition to OS
At Ay = 0.171 g
CCW Transition to OS
At Ay = -0.14 g
(Roadwheel Steer Angle - Ackermann Angle) (deg)
Ay (g)
10
5
0
-5
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5


Vehicle G - 2-Rider - 50 ft Radius Circle
Roll Angle (deg)
Ay (g)
Roll Gradient = -21.9 deg/g
15
10
5
0
-5
-10
-15
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5


Vehicle G - 2-Rider - J-Turns
6 Northwest Runs
Roadwheel Steer Angle (deg)
Speed (mph)
Roll Angle (deg)
Lateral Acceleration (g)
Yaw Rate (deg/sec)
Time (sec)
Time (sec)


Vehicle G - 2-Rider - J-Turns - 6 Northwest Runs
Lateral Acceleration (g)
Time (sec)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


Vehicle G - 2-Rider - J-Turns
Roadwheel Steer Angle (deg)
Time (sec)
Lateral Acceleration (g)
Time (sec)
6 Southeast Runs
Speed (mph)
Roll Angle (deg)
Yaw Rate (deg/sec)
Time (sec)


Vehicle G - 2-Rider - J-Turns - 6 Southeast Runs
Lateral Acceleration (g)
Time (sec)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

Vehicle G - 2-Rider Results

Peak Lateral Accelerations During 2WL J-Turns - All Values in "g's"

Run Number	Northwest Right Turns	Northwest Left Turns
1	0.398	-0.402
2	0.397	-0.403
3	0.400	-0.400
Mean Value of 3 Runs	0.398	-0.402
Standard Deviation of 3 Runs	0.002	0.002

Average of 6 Northwest Runs

0.400

Run Number	Southeast Right Turns	Southeast Left Turns
1	0.406	-0.393
2	0.405	-0.396
3	0.396	-0.390
Mean Value of 3 Runs	0.402	-0.393
Standard Deviation of 3 Runs	0.006	0.003

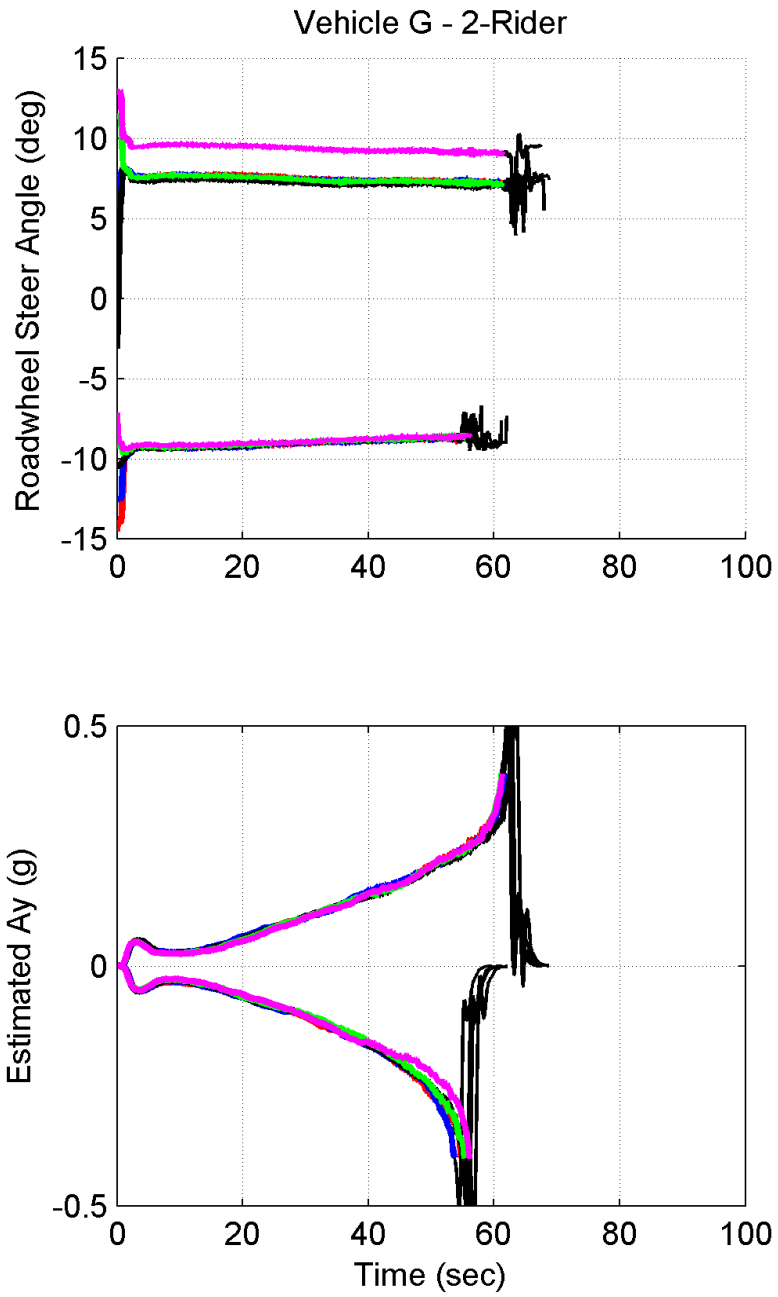
Average of 6 Southeast Runs

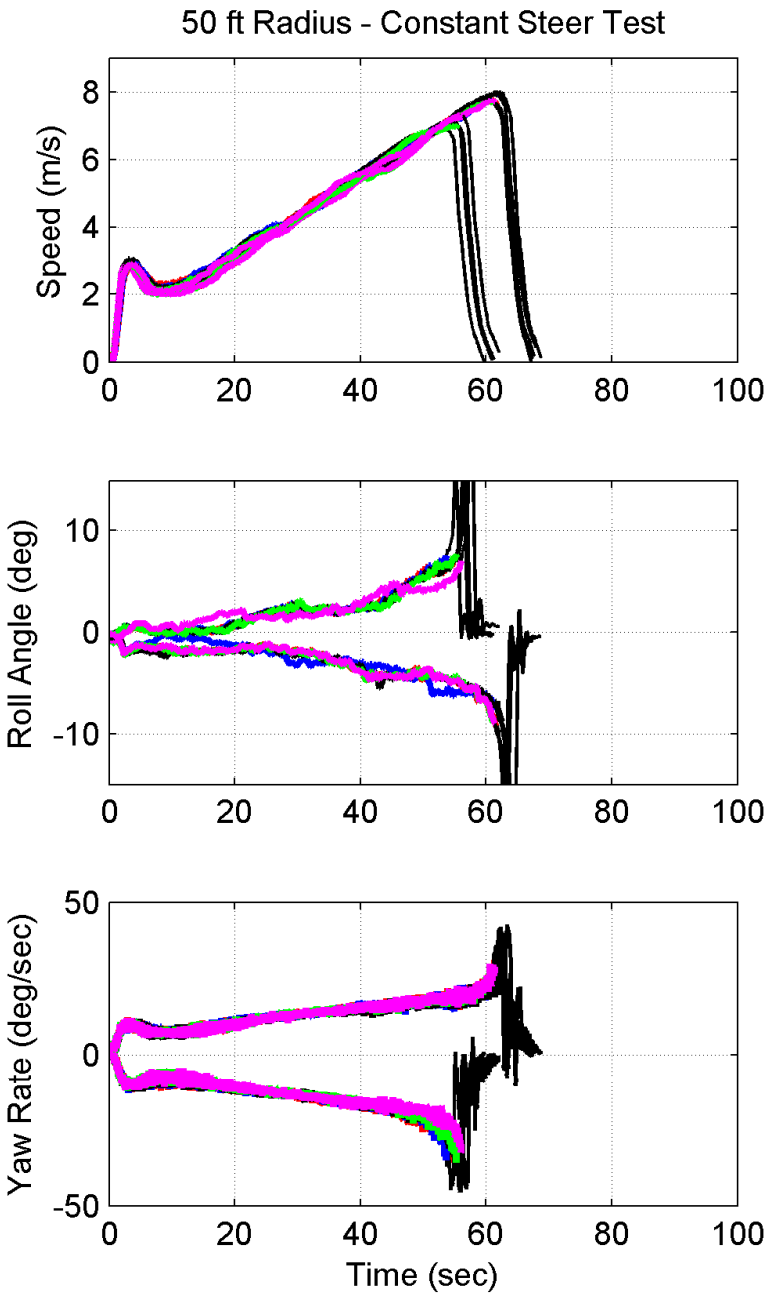
0.398

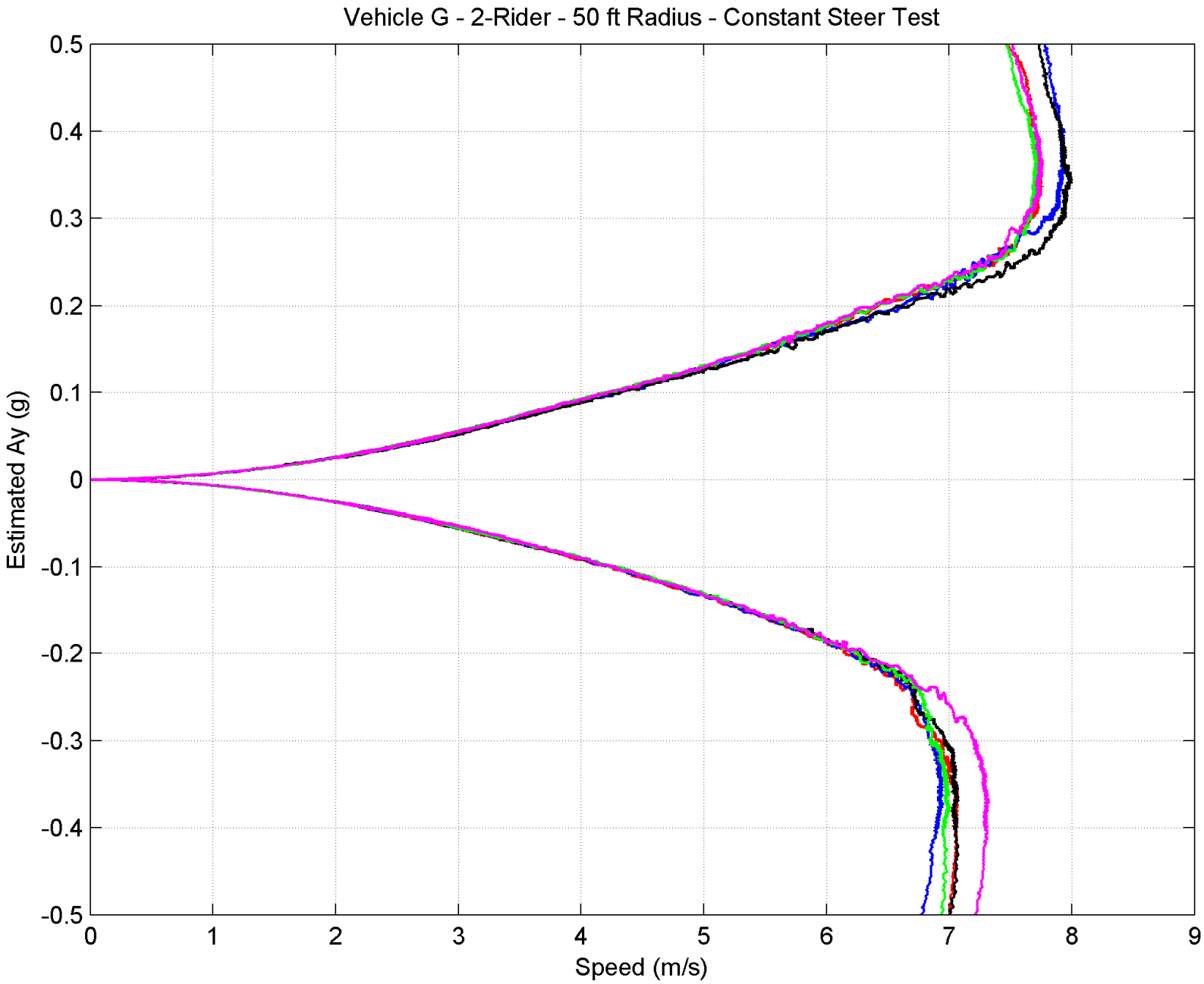
Average of All 12 Runs

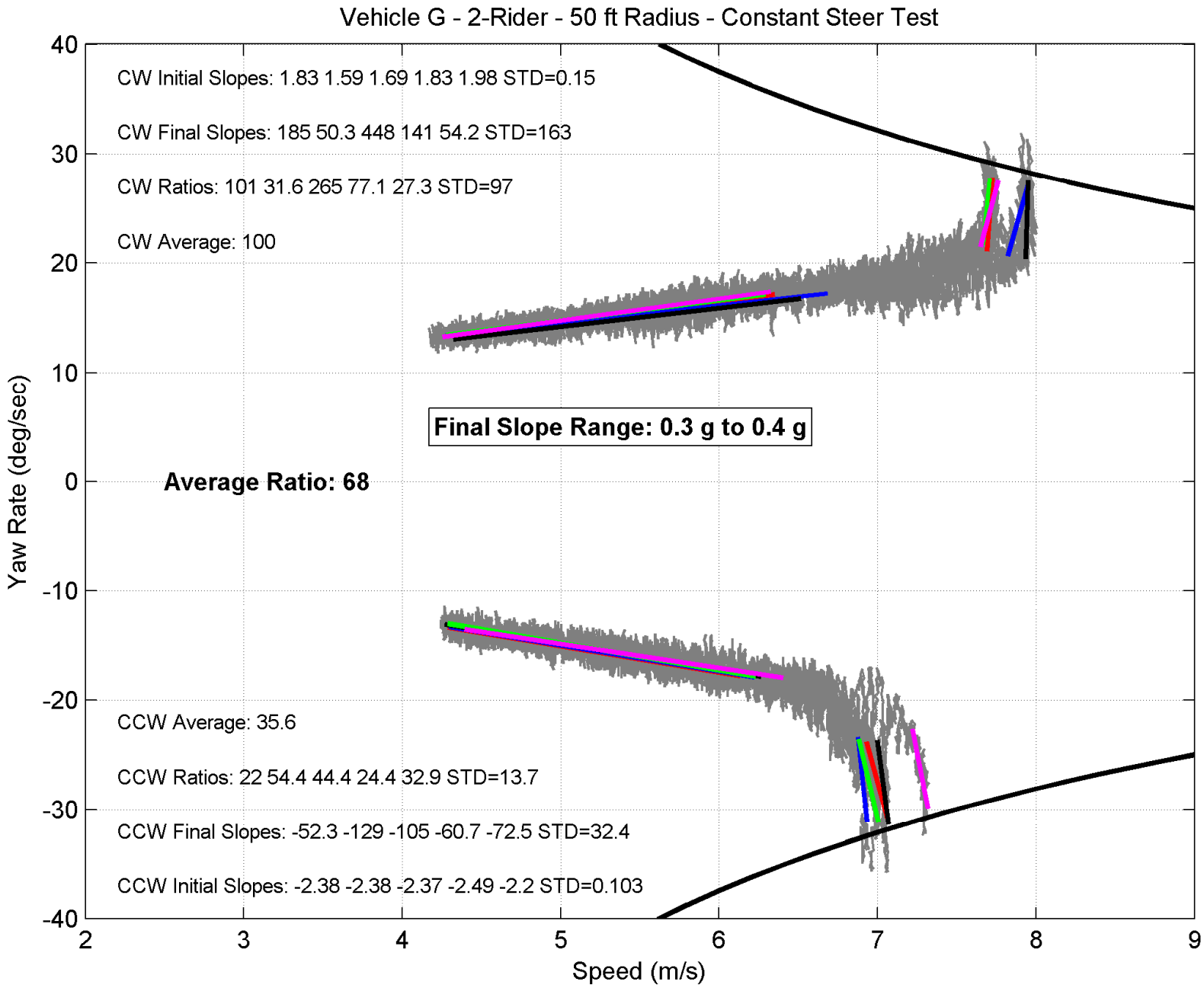
0.399

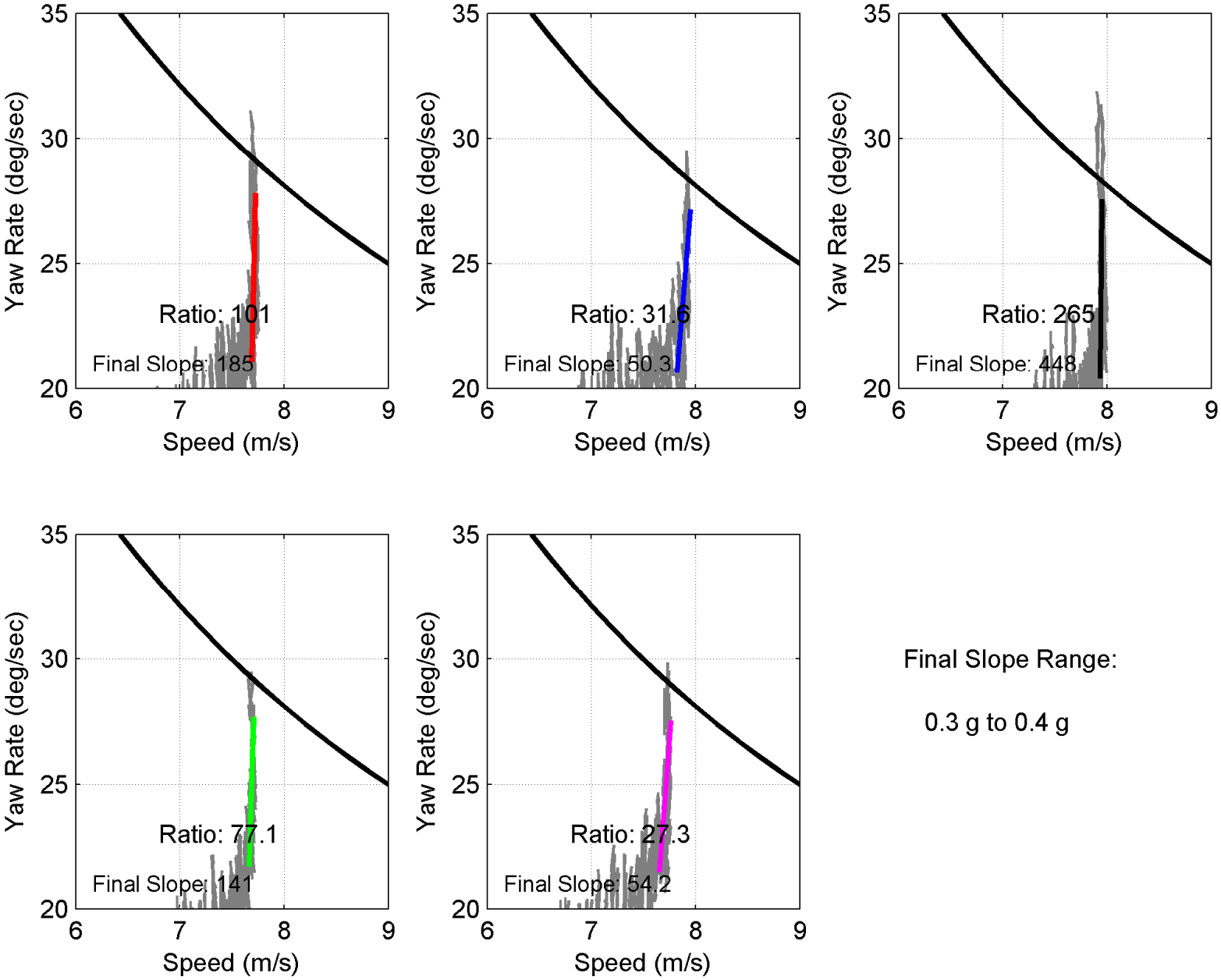
Threshold Ay


Vehicle G - 2-Rider
Roadwheel Steer Angle (deg)
15
10
5
0
-5
-10
-15
0
20
40
60
80
100
Estimated Ay (g)
0.5
0
-0.5
Time (sec)


50 ft Radius - Constant Steer Test
Speed (m/s)
8
6
4
2
0
Roll Angle (deg)
10
0
-10
Yaw Rate (deg/sec)
50
0
-50
0
20
40
60
80
100
Time (sec)

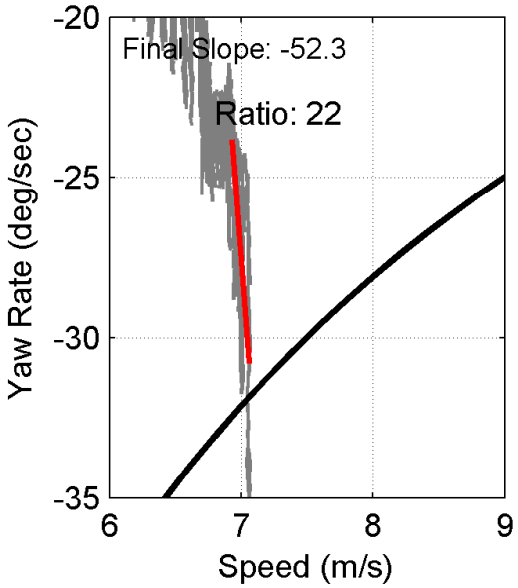

Vehicle G - 2-Rider - 50 ft Radius - Constant Steer Test
Estimated Ay (g)
Speed (m/s)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
1
2
3
4
5
6
7
8
9

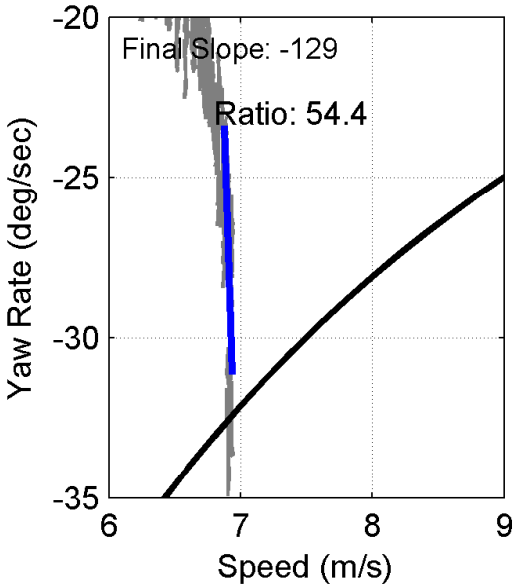

Vehicle G - 2-Rider - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 1.83 1.59 1.69 1.83 1.98 STD=0.15
CW Final Slopes: 185 50.3 448 141 54.2 STD=163
CW Ratios: 101 31.6 265 77.1 27.3 STD=97
CW Average: 100
Final Slope Range: 0.3 g to 0.4 g
Average Ratio: 68
CCW Average: 35.6
CCW Ratios: 22 54.4 44.4 24.4 32.9 STD=13.7
CCW Final Slopes: -52.3 -129 -105 -60.7 -72.5 STD=32.4
CCW Initial Slopes: -2.38 -2.38 -2.37 -2.49 -2.2 STD=0.103
Yaw Rate (deg/sec)
Speed (m/s)
40
30
20
10
0
-10
-20
-30
-40
2
3
4
5
6
7
8
9

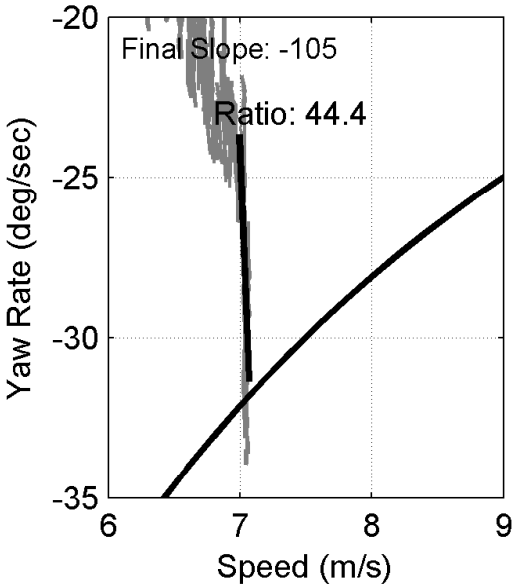


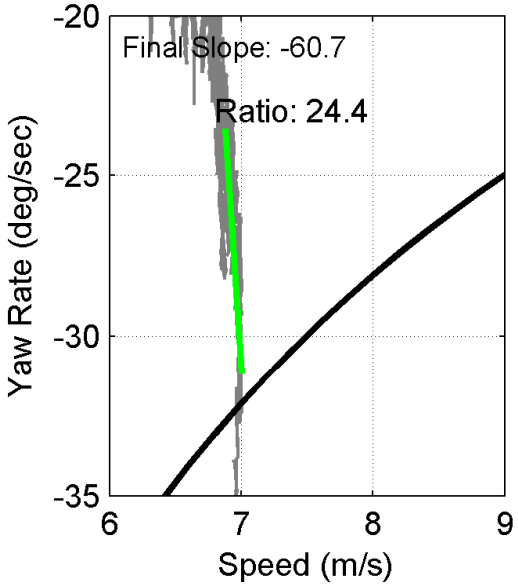
Final Slope Range:

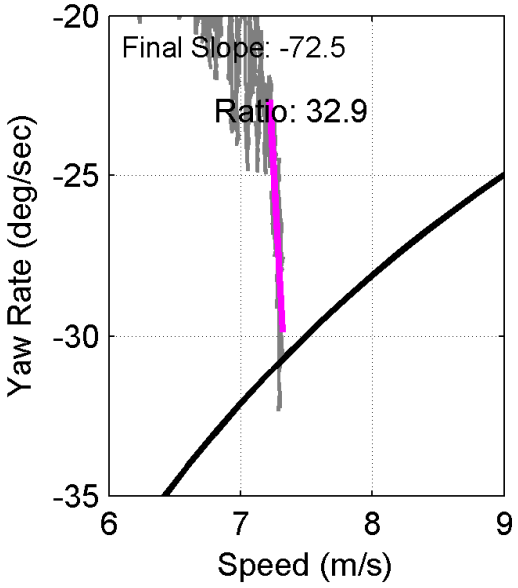
0.3 g to 0.4 g





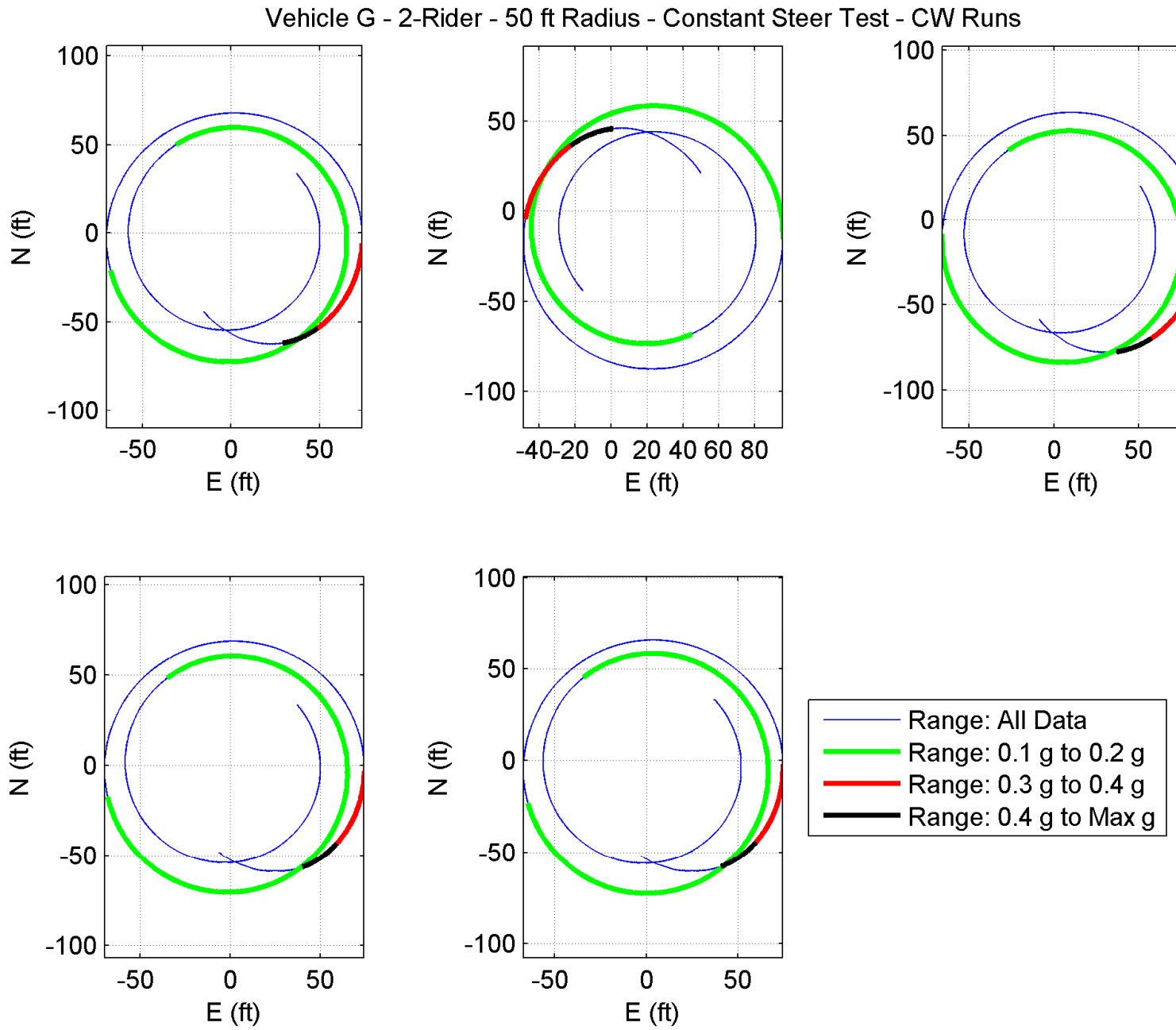


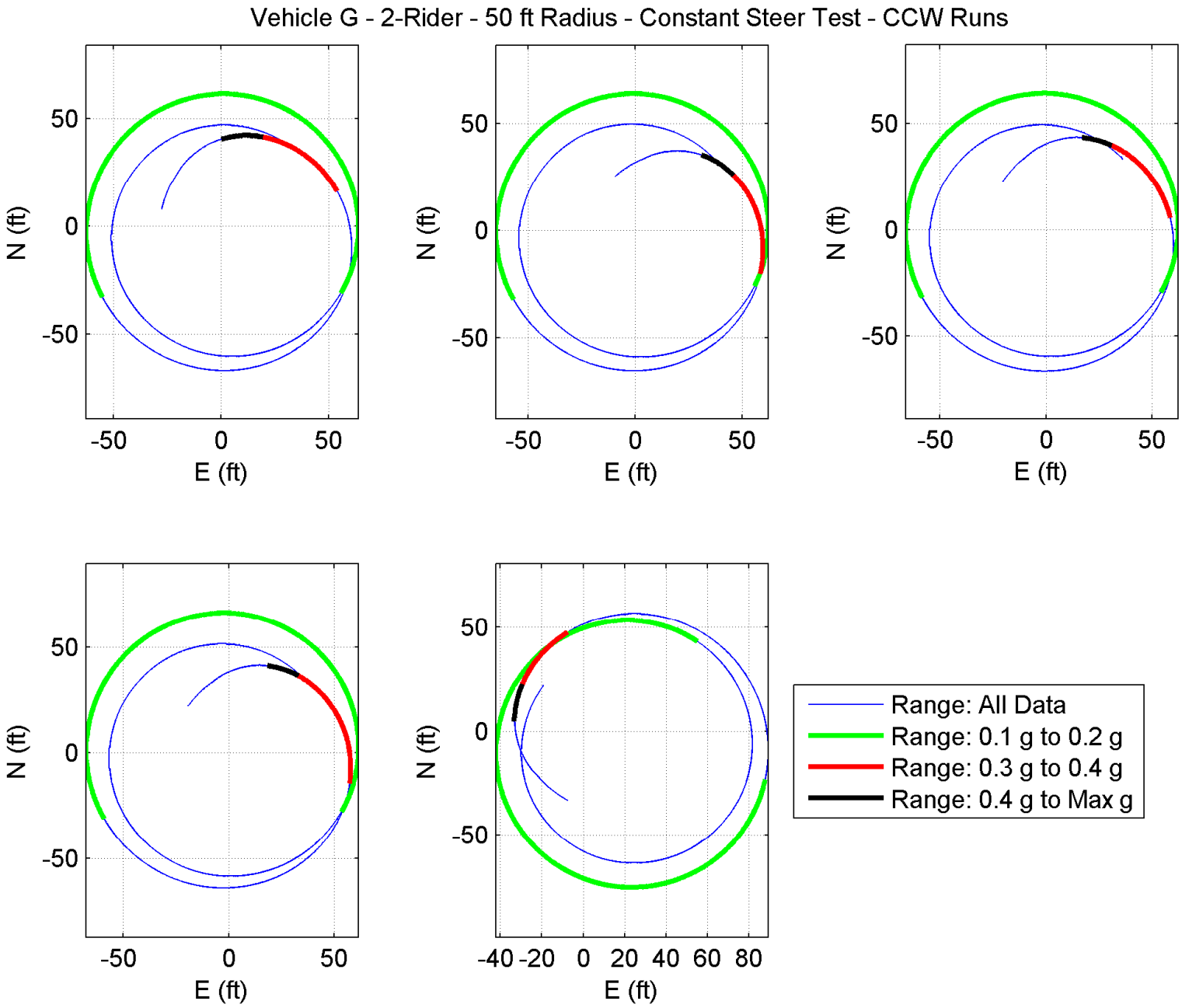


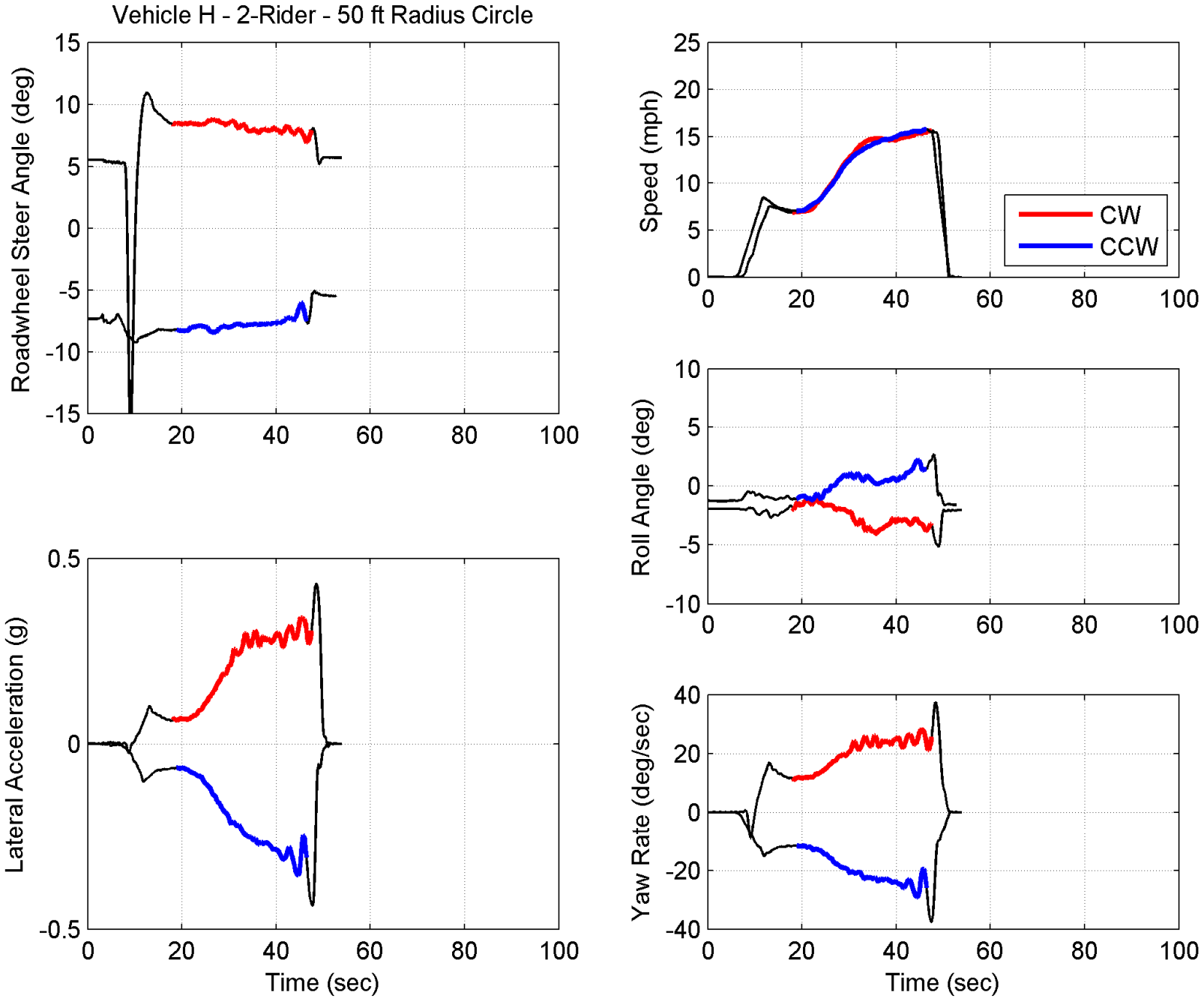


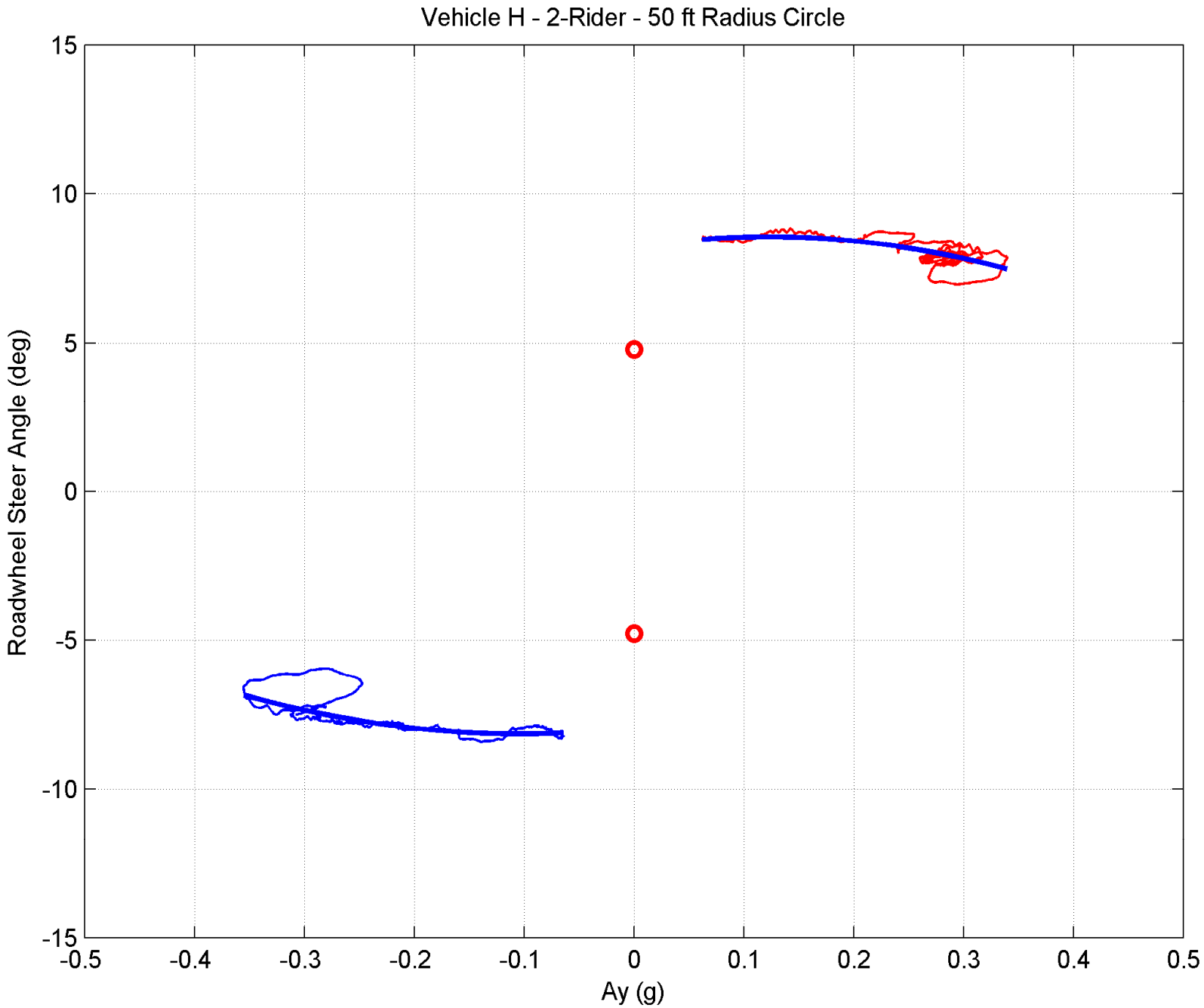
Final Slope Range:

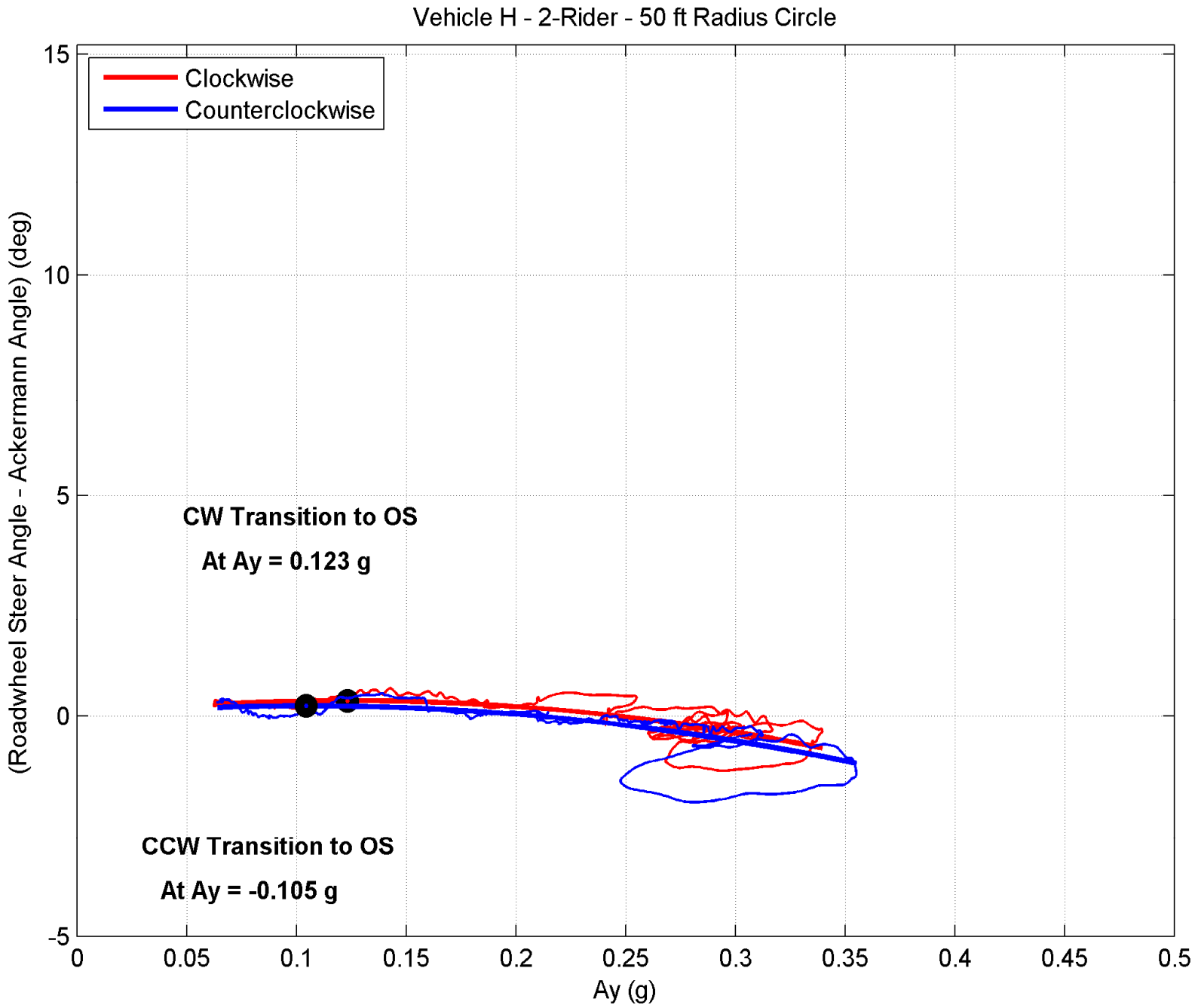
0.3 g to 0.4 g

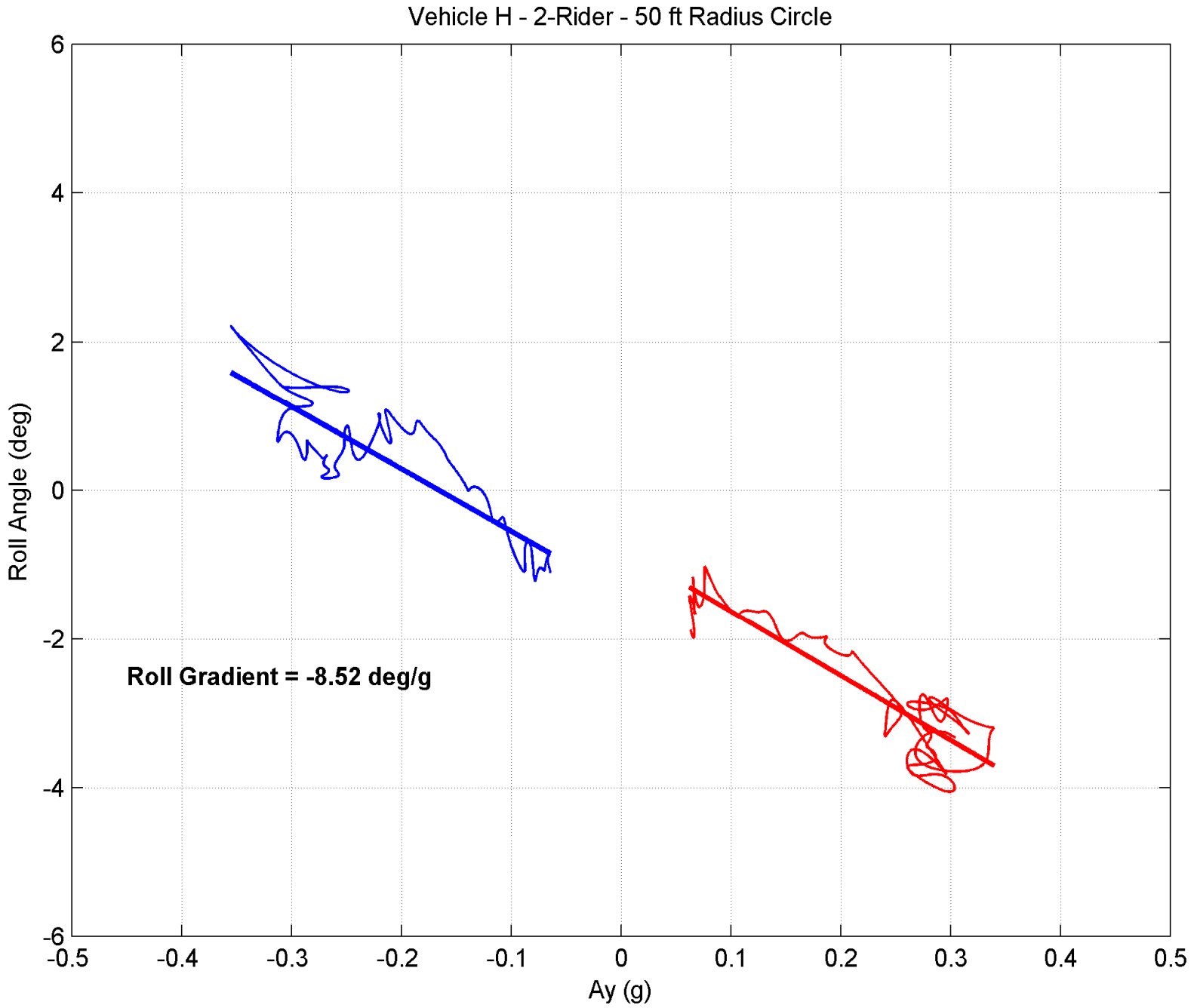

Vehicle G - 2-Rider - 50 ft Radius - Constant Steer Test - CW Runs
N (ft)
E (ft)
100
50
0
-50
-100
-50
0
50
-40
-20
0
20
40
60
80
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.3 g to 0.4 g
Range: 0.4 g to Max g

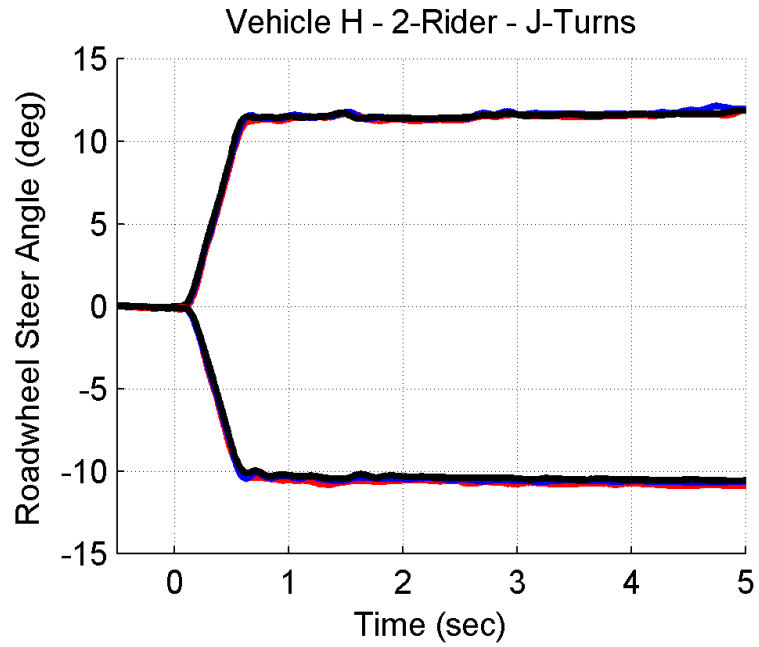

Vehicle G - 2-Rider - 50 ft Radius - Constant Steer Test - CCW Runs
N (ft)
E (ft)
50
0
-50
-40 -20 0 20 40 60 80
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.3 g to 0.4 g
Range: 0.4 g to Max g

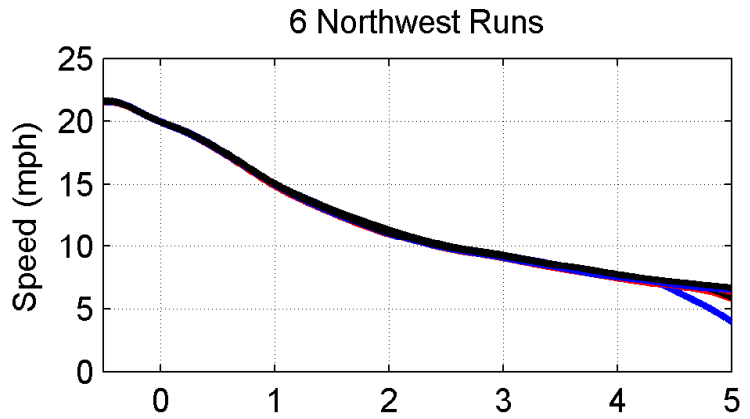

Vehicle H - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
Speed (mph)
CW
CCW
Roll Angle (deg)
Lateral Acceleration (g)
Yaw Rate (deg/sec)
Time (sec)
Time (sec)

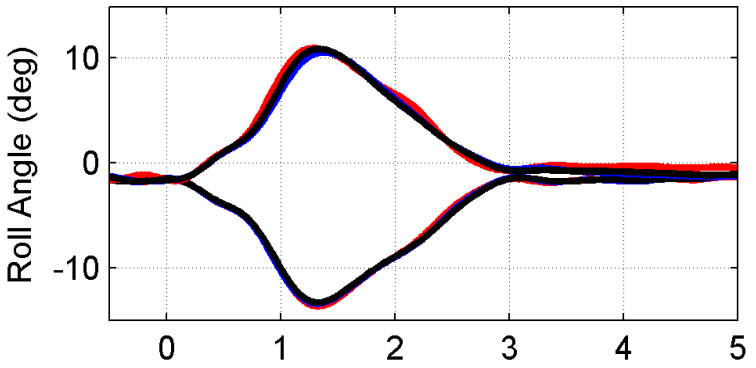

Vehicle H - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
Ay (g)
15
10
5
0
-5
-10
-15
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

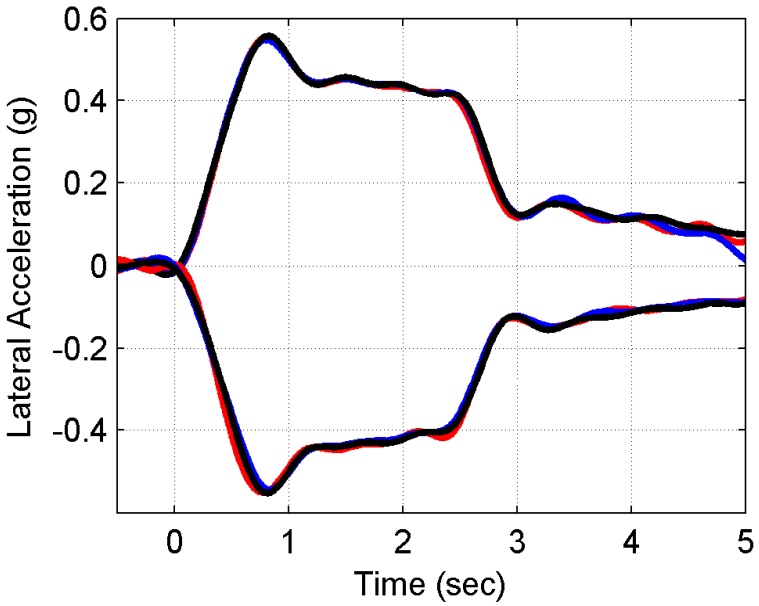

Vehicle H - 2-Rider - 50 ft Radius Circle
Clockwise
Counterclockwise
(Roadwheel Steer Angle - Ackermann Angle) (deg)
Ay (g)
CW Transition to OS
At Ay = 0.123 g
CCW Transition to OS
At Ay = -0.105 g
15
10
5
0
-5
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5

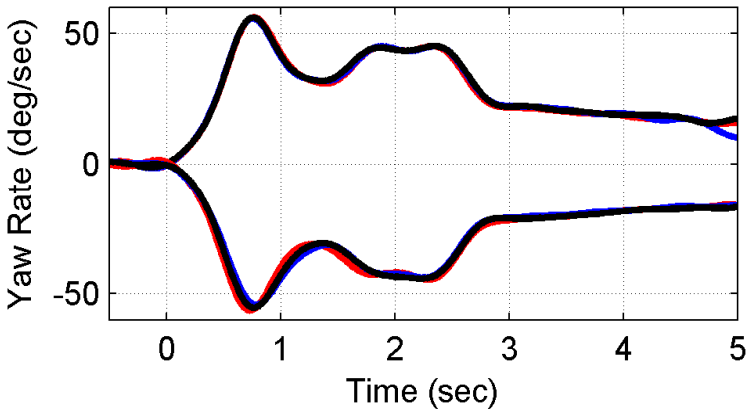

Vehicle H - 2-Rider - 50 ft Radius Circle
Roll Angle (deg)
Ay (g)
Roll Gradient = -8.52 deg/g
6
4
2
0
-2
-4
-6
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

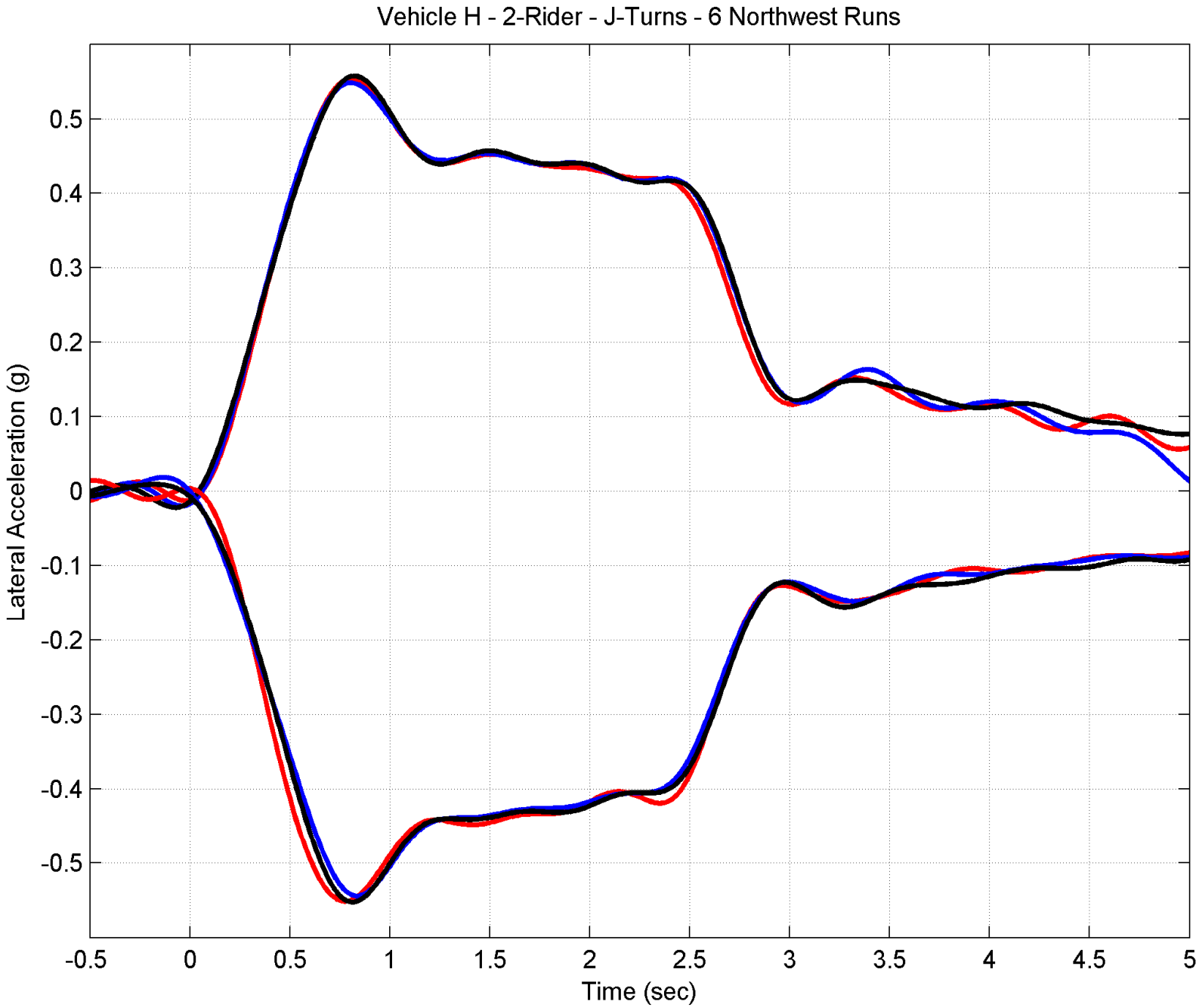

Vehicle H - 2-Rider - J-Turns
Roadwheel Steer Angle (deg)
15
10
5
0
-5
-10
-15
0
1
2
3
4
5
Time (sec)

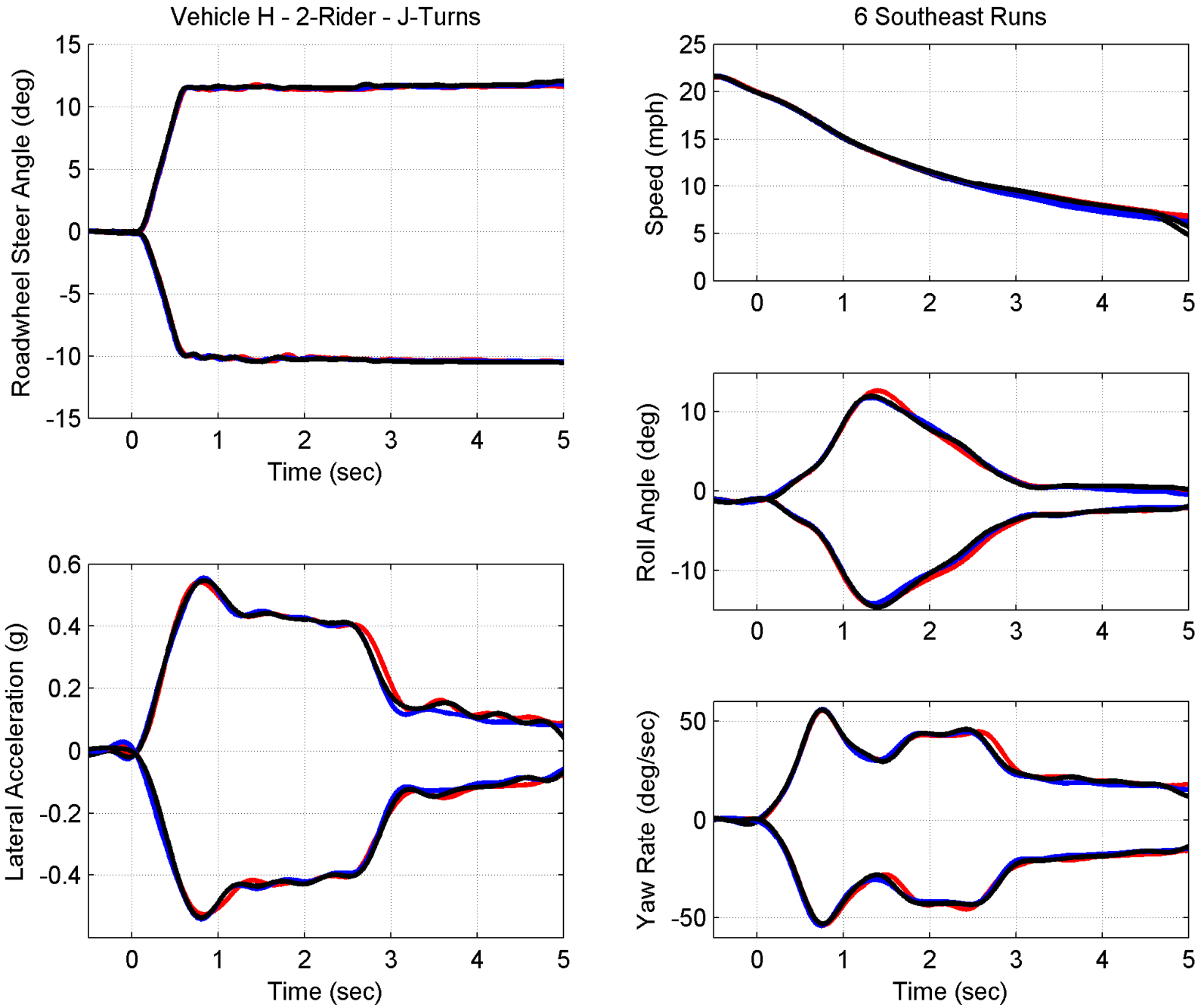

6 Northwest Runs
Speed (mph)
25
20
15
10
5
0
0
1
2
3
4
5

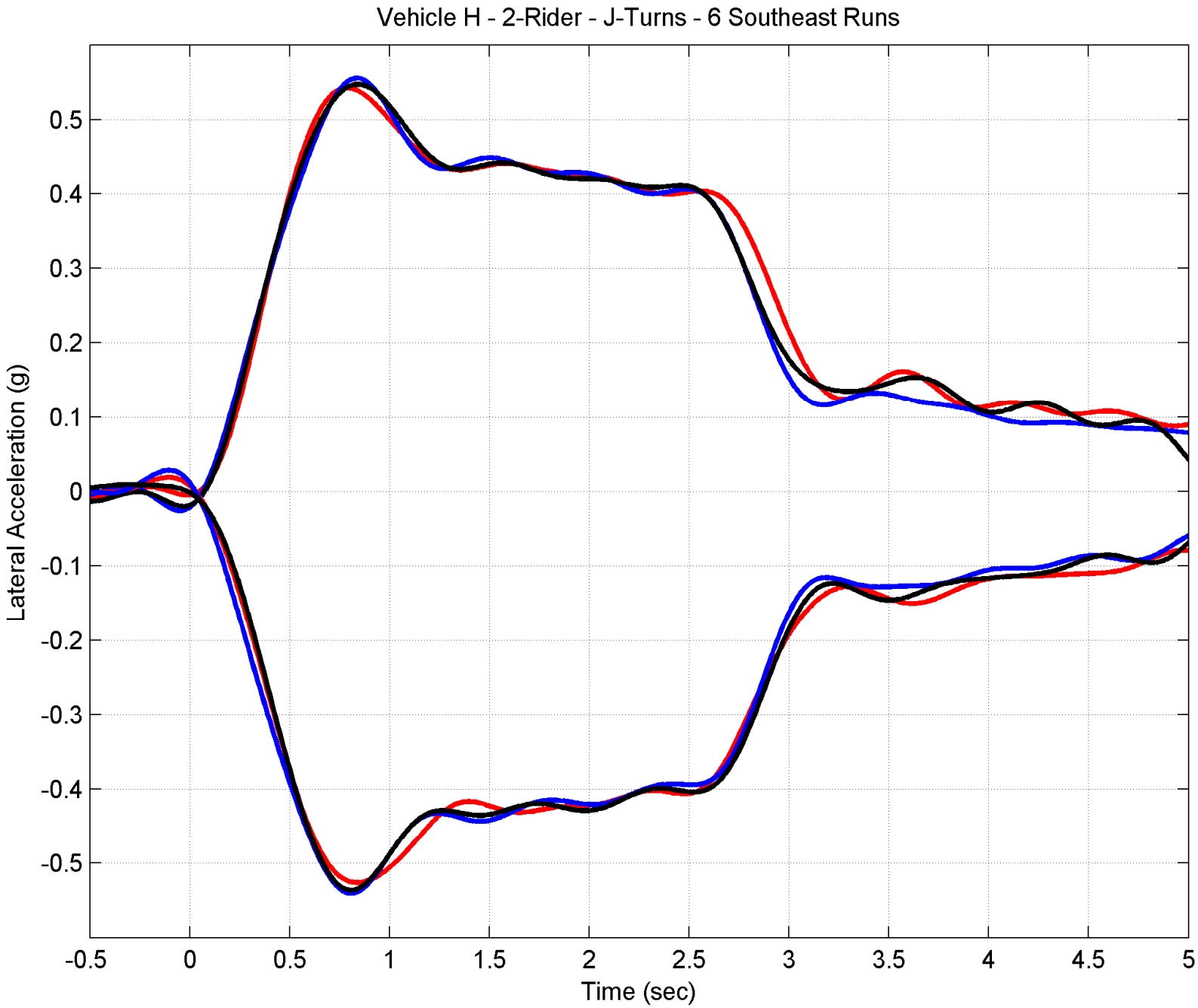

Roll Angle (deg)
10
0
-10
0
1
2
3
4
5


Lateral Acceleration (g)
0.6
0.4
0.2
0
-0.2
-0.4
0
1
2
3
4
5
Time (sec)


Yaw Rate (deg/sec)
50
0
-50
0
1
2
3
4
5
Time (sec)


Vehicle H - 2-Rider - J-Turns - 6 Northwest Runs
Lateral Acceleration (g)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (sec)


Vehicle H - 2-Rider - J-Turns
Roadwheel Steer Angle (deg)
15
10
5
0
-5
-10
-15
0
1
2
3
4
5
Time (sec)
6 Southeast Runs
Speed (mph)
25
20
15
10
5
0
Roll Angle (deg)
10
0
-10
Lateral Acceleration (g)
0.6
0.4
0.2
0
-0.2
-0.4
Yaw Rate (deg/sec)
50
0
-50
Time (sec)


Vehicle H - 2-Rider - J-Turns - 6 Southeast Runs
Lateral Acceleration (g)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (sec)

Vehicle H - 2-Rider Results

Peak Lateral Accelerations During 2WL J-Turns - All Values in "g's"

Run Number	Northwest Right Turns	Northwest Left Turns
1	0.554	-0.552
2	0.548	-0.544
3	0.557	-0.553
Mean Value of 3 Runs	0.553	-0.550
Standard Deviation of 3 Runs	0.005	0.004

Average of 6 Northwest Runs

0.551

Run Number	Southeast Right Turns	Southeast Left Turns
1	0.542	-0.526
2	0.555	-0.541
3	0.547	-0.537
Mean Value of 3 Runs	0.548	-0.534
Standard Deviation of 3 Runs	0.007	0.007

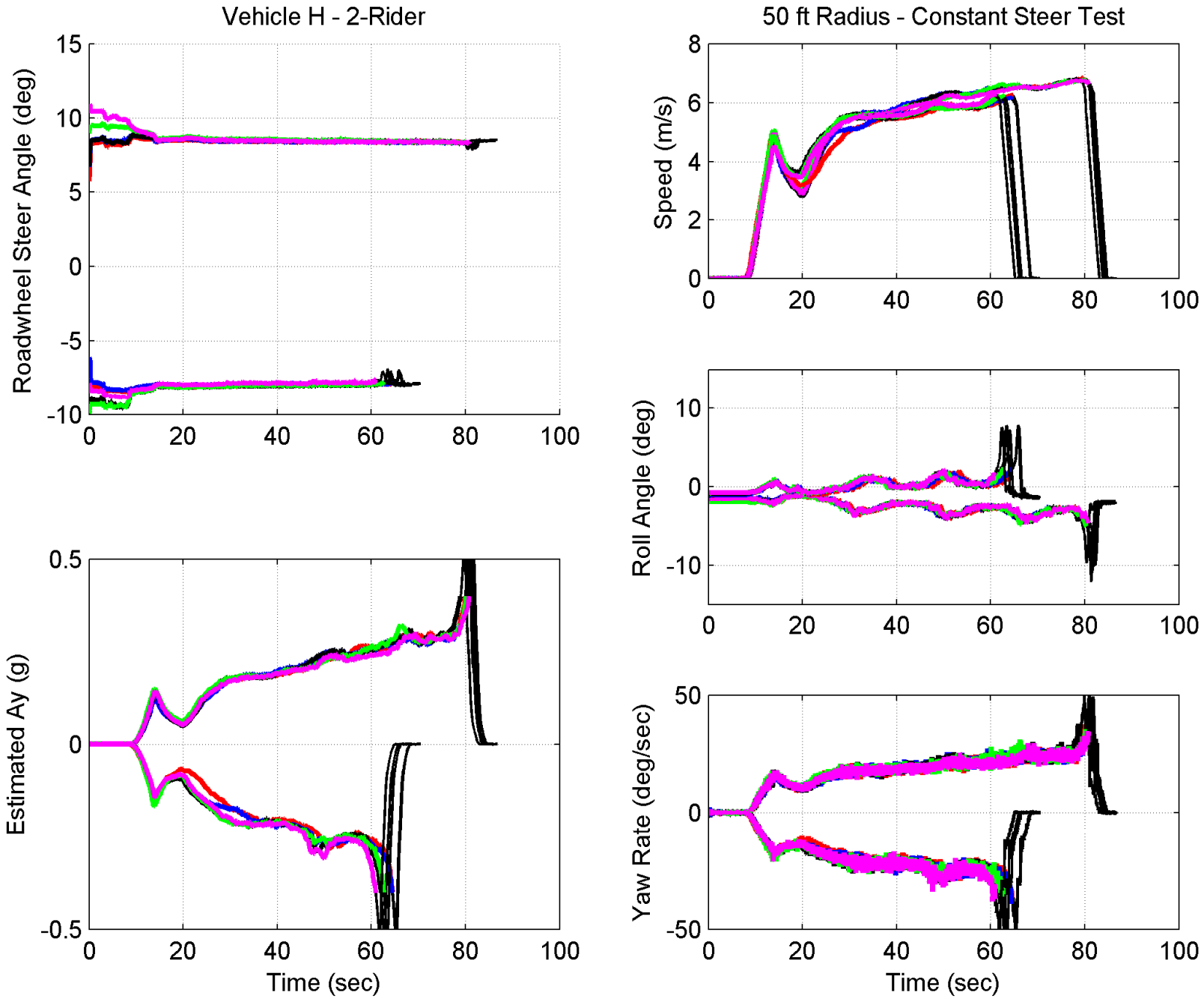
Average of 6 Southeast Runs

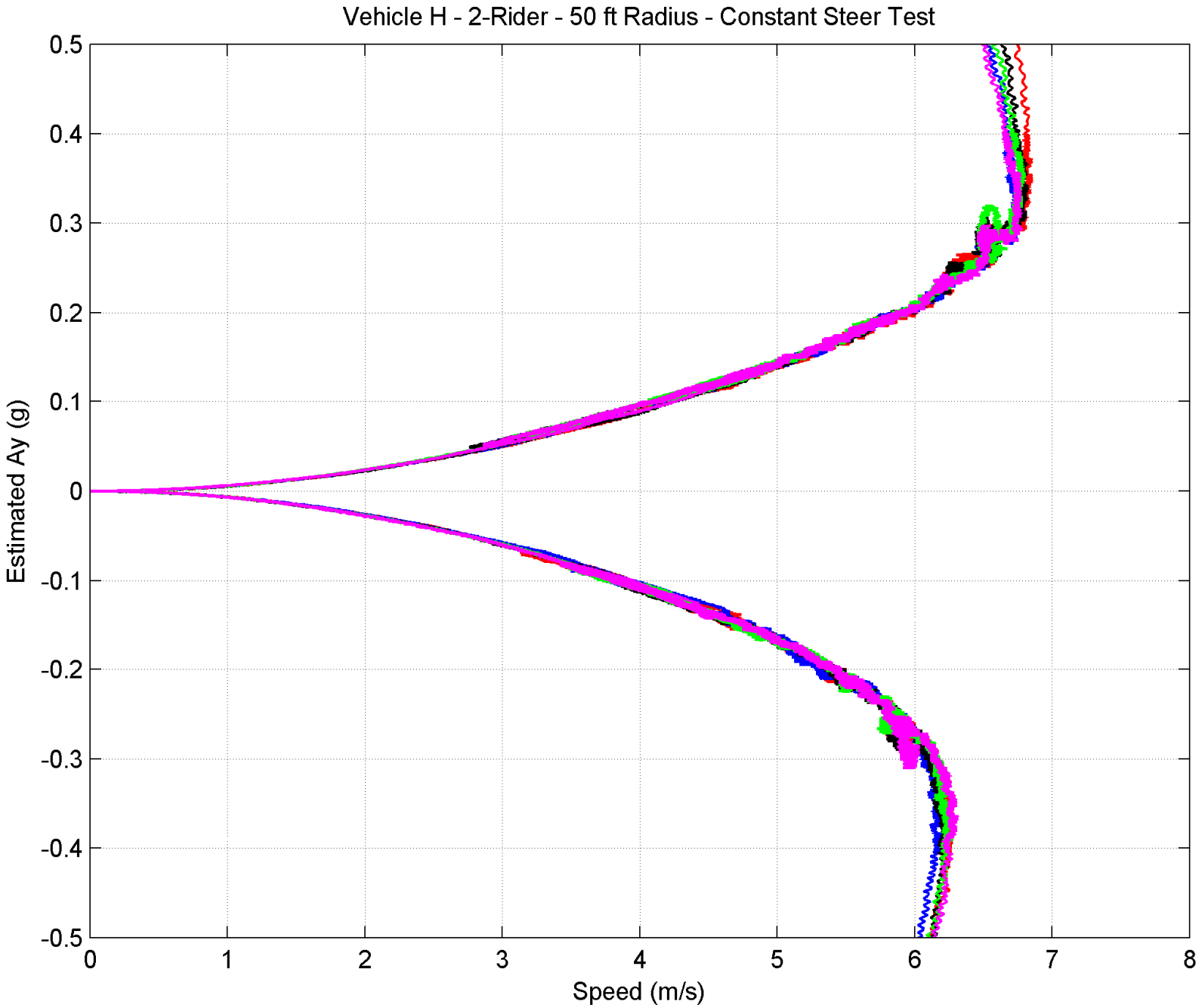
0.541

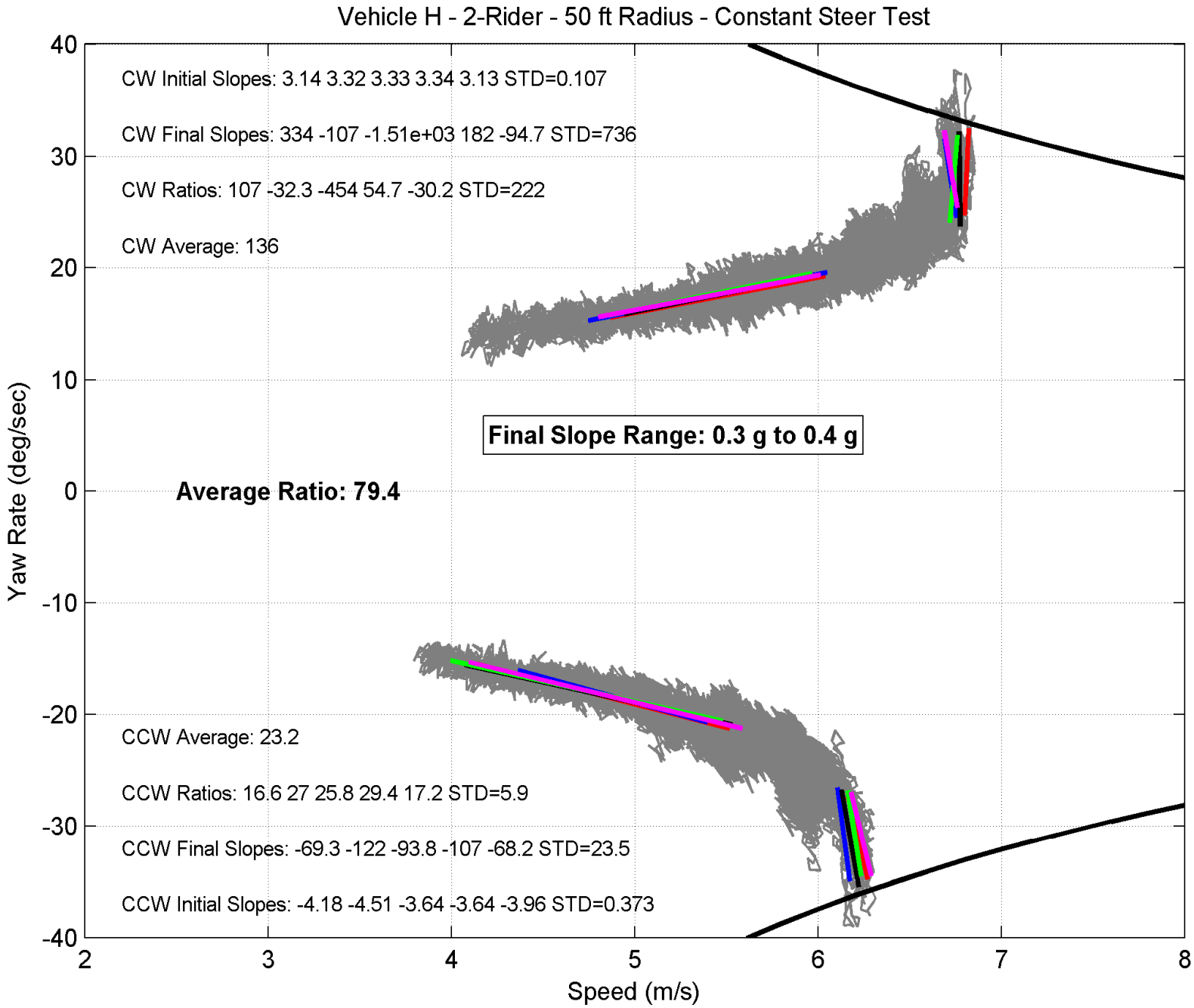
Average of All 12 Runs

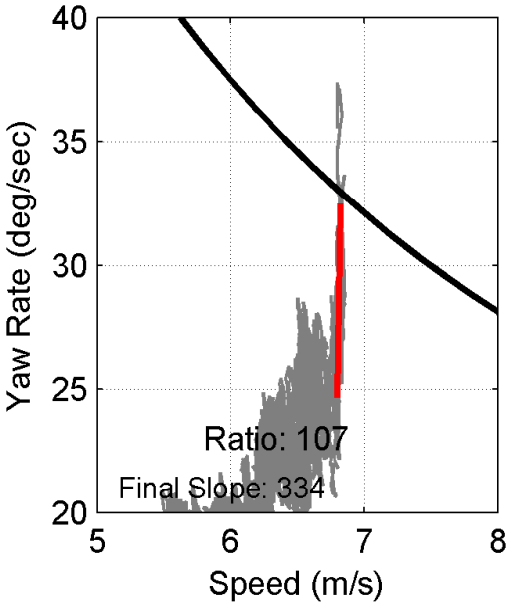
0.546

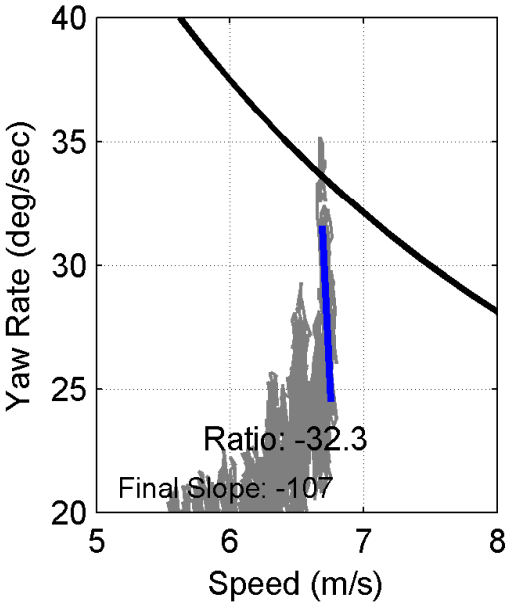
Threshold Ay

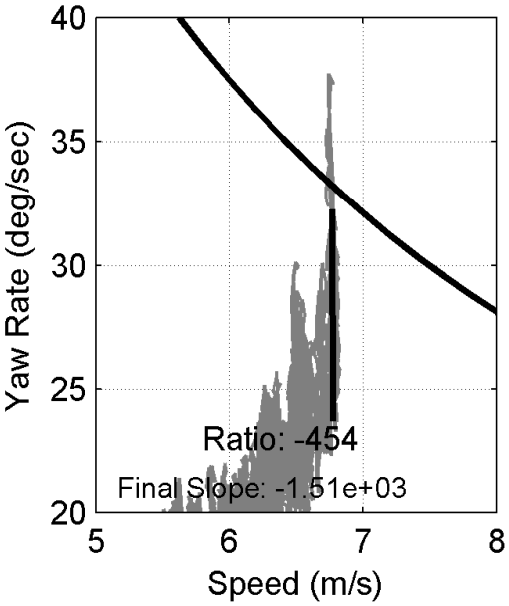

Vehicle H - 2-Rider
50 ft Radius - Constant Steer Test
Roadwheel Steer Angle (deg)
Speed (m/s)
Roll Angle (deg)
Estimated Ay (g)
Yaw Rate (deg/sec)
Time (sec)
Time (sec)

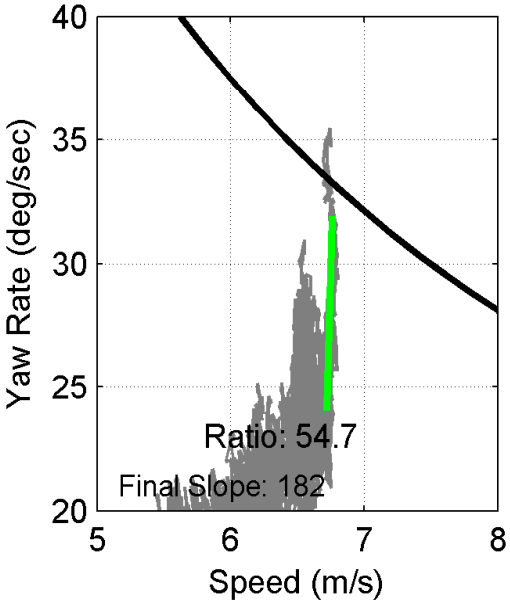

Vehicle H - 2-Rider - 50 ft Radius - Constant Steer Test
Estimated Ay (g)
Speed (m/s)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
1
2
3
4
5
6
7
8

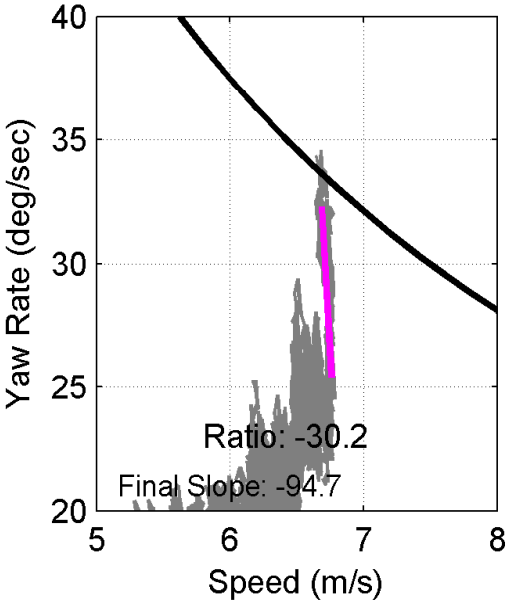

Vehicle H - 2-Rider - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.14 3.32 3.33 3.34 3.13 STD=0.107
CW Final Slopes: 334 -107 -1.51e+03 182 -94.7 STD=736
CW Ratios: 107 -32.3 -454 54.7 -30.2 STD=222
CW Average: 136
Final Slope Range: 0.3 g to 0.4 g
Average Ratio: 79.4
CCW Average: 23.2
CCW Ratios: 16.6 27 25.8 29.4 17.2 STD=5.9
CCW Final Slopes: -69.3 -122 -93.8 -107 -68.2 STD=23.5
CCW Initial Slopes: -4.18 -4.51 -3.64 -3.64 -3.96 STD=0.373
Yaw Rate (deg/sec)
Speed (m/s)
40
30
20
10
0
-10
-20
-30
-40
2
3
4
5
6
7
8





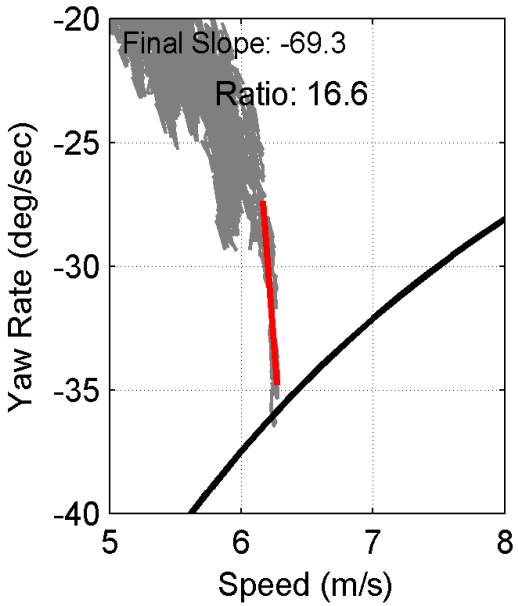


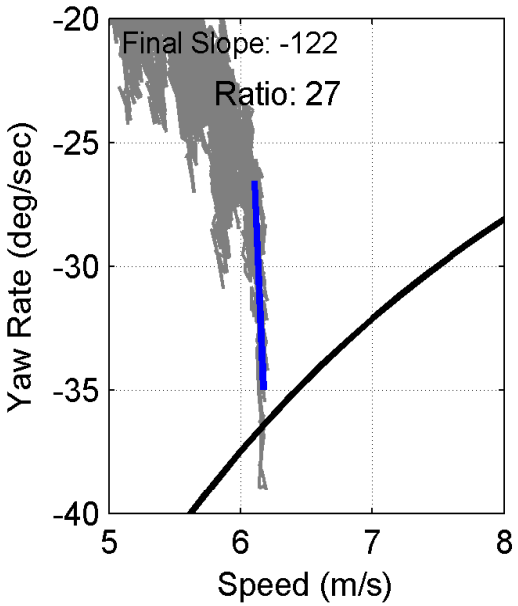


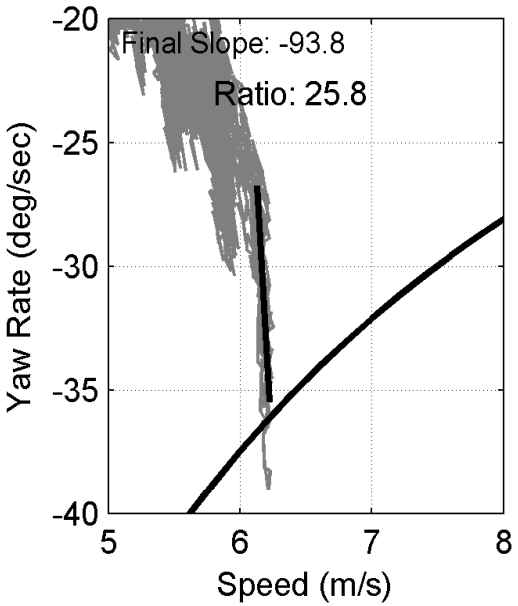


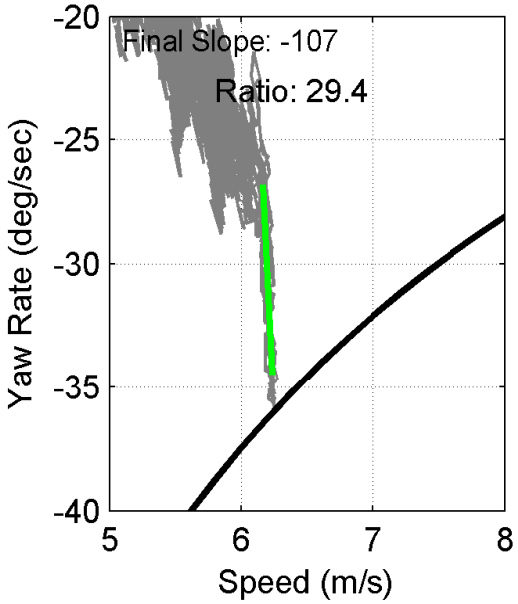
Final Slope Range:

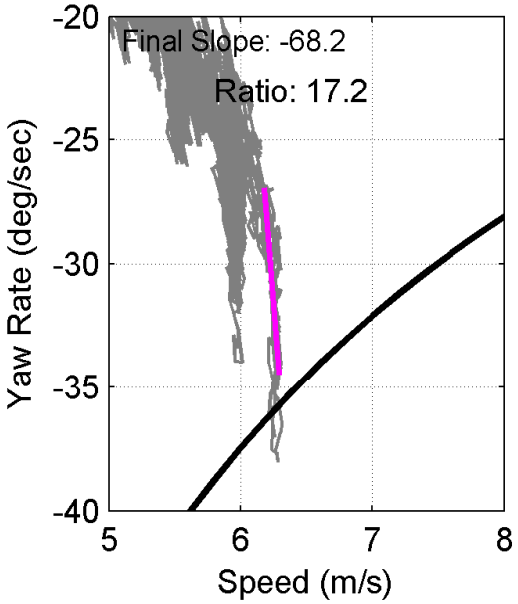
0.3 g to 0.4 g





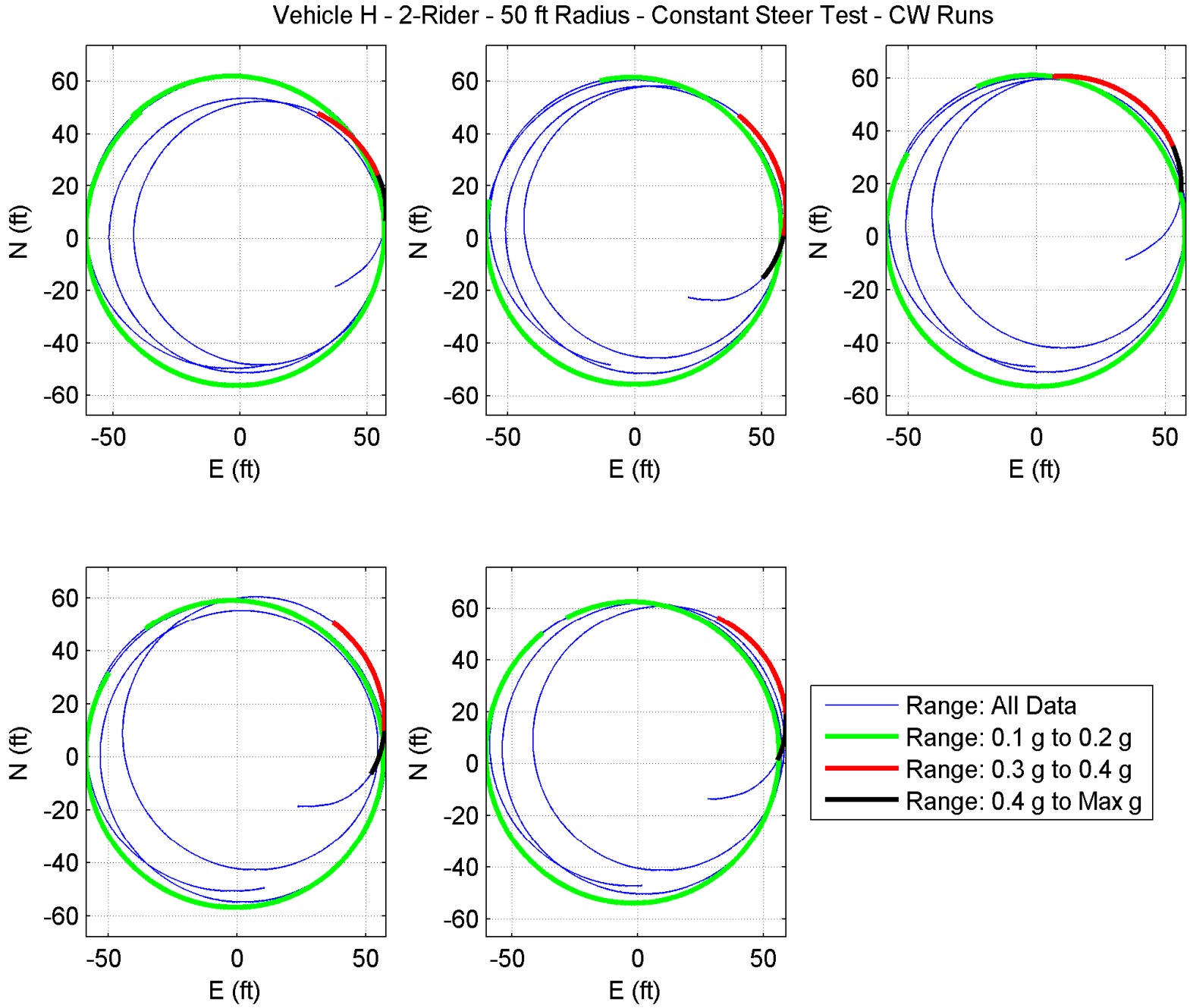


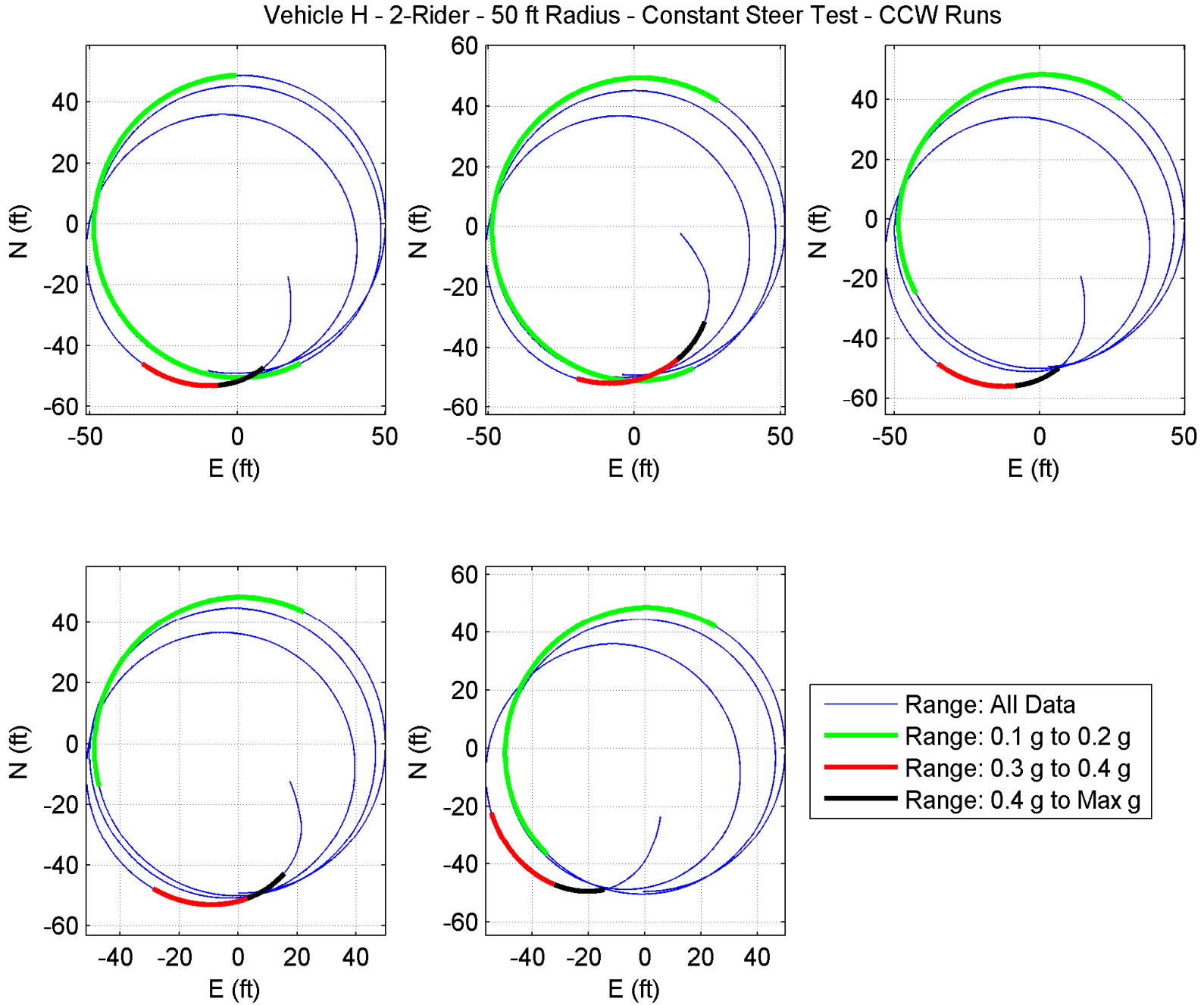


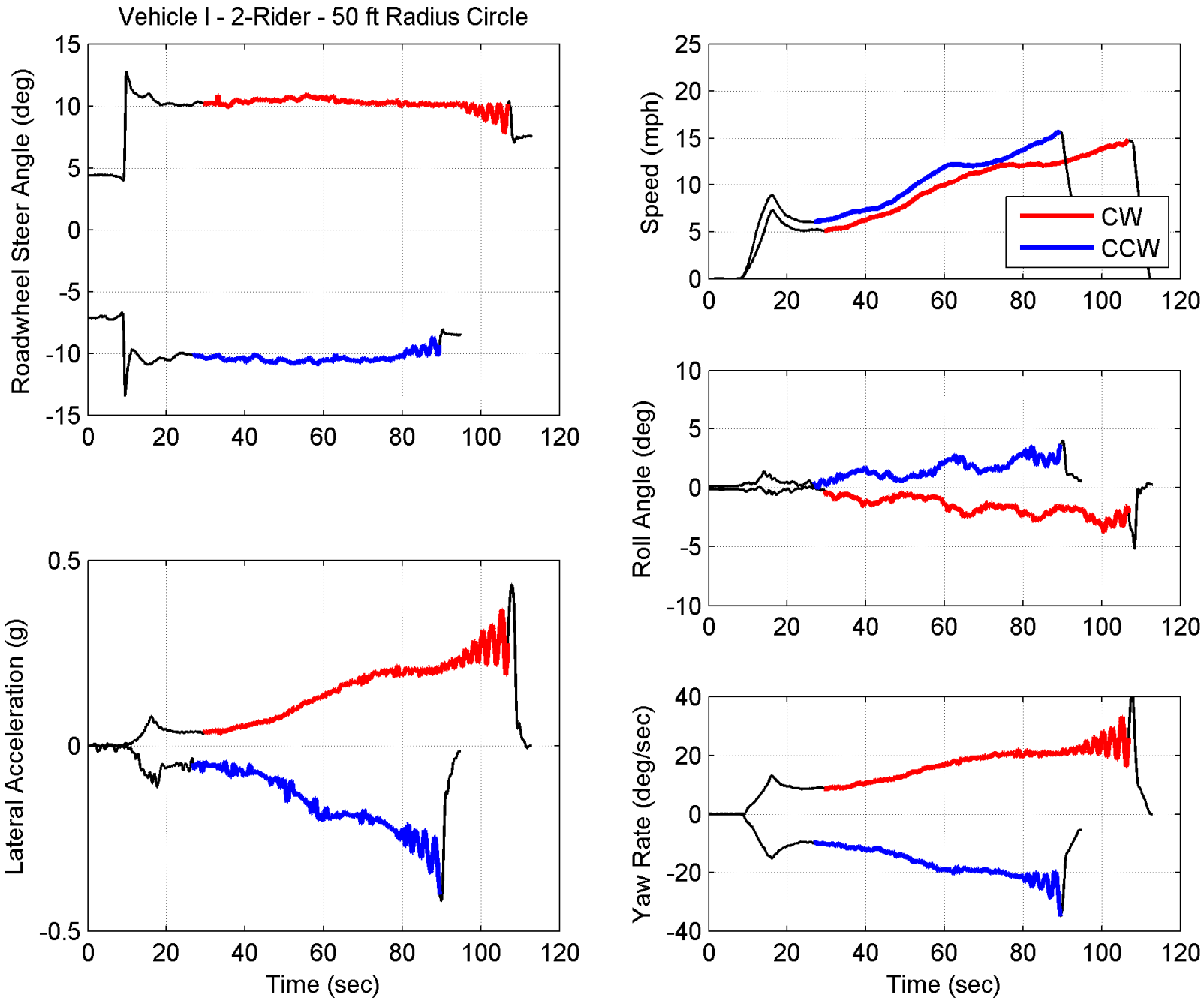


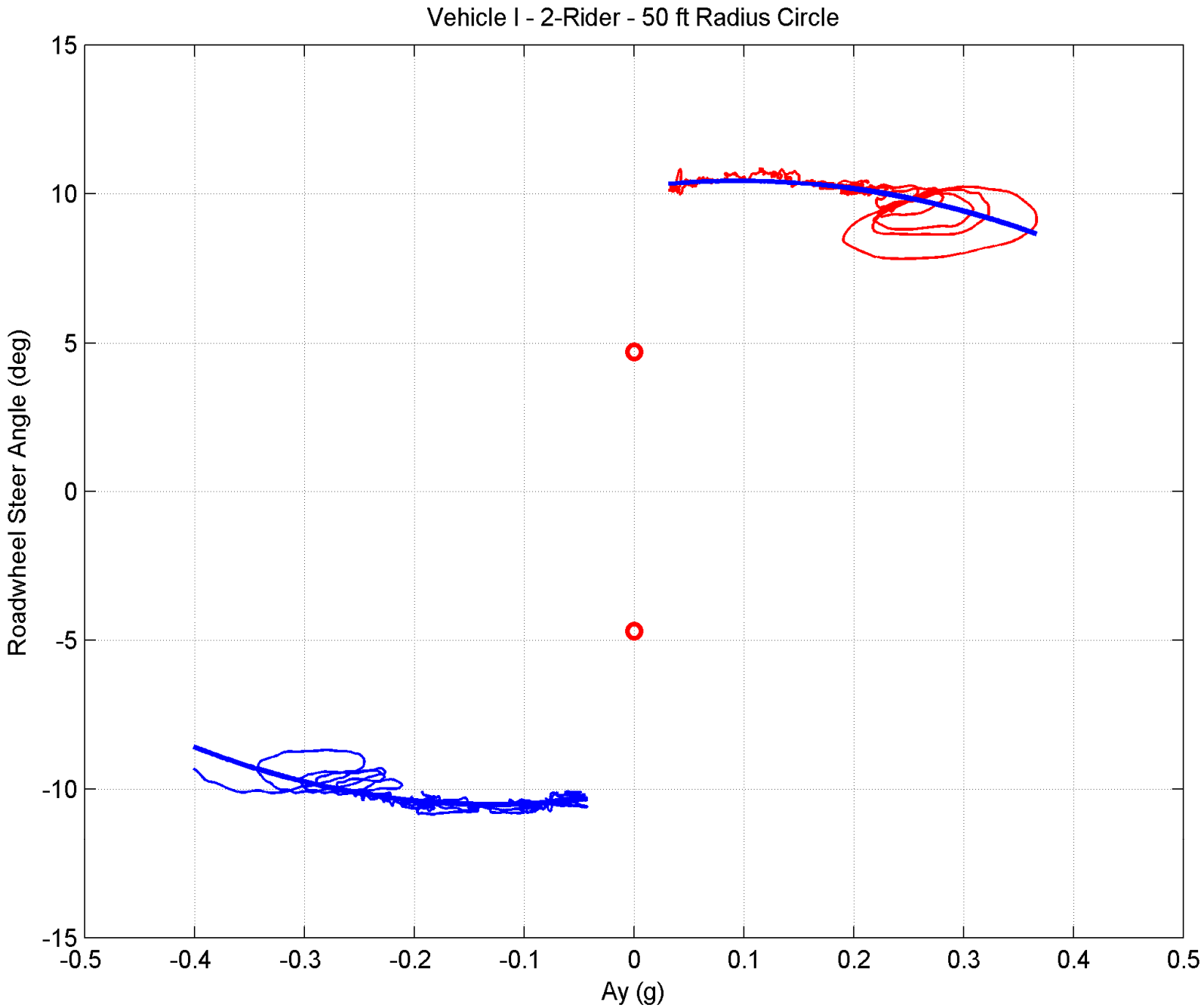
Final Slope Range:

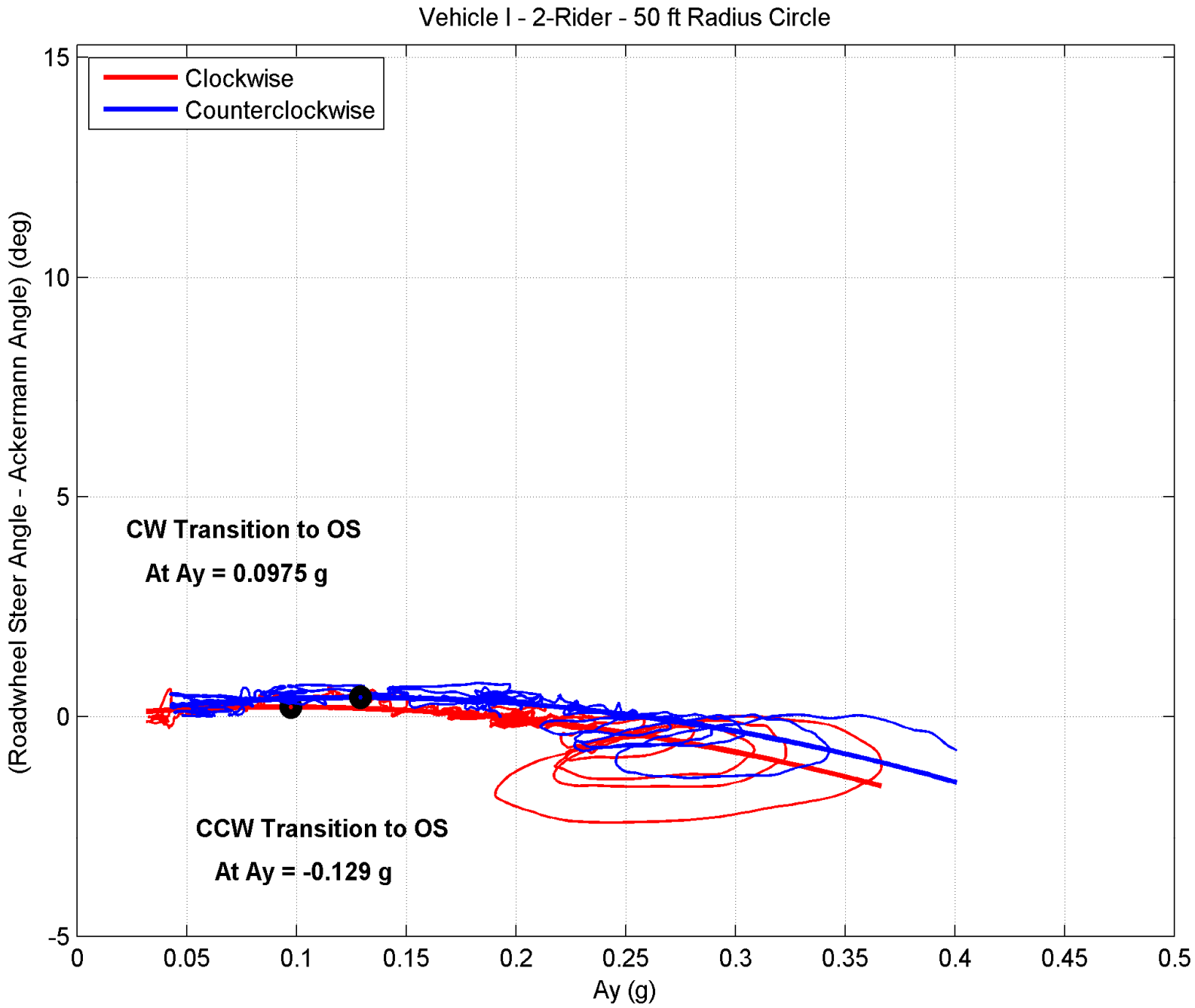
0.3 g to 0.4 g

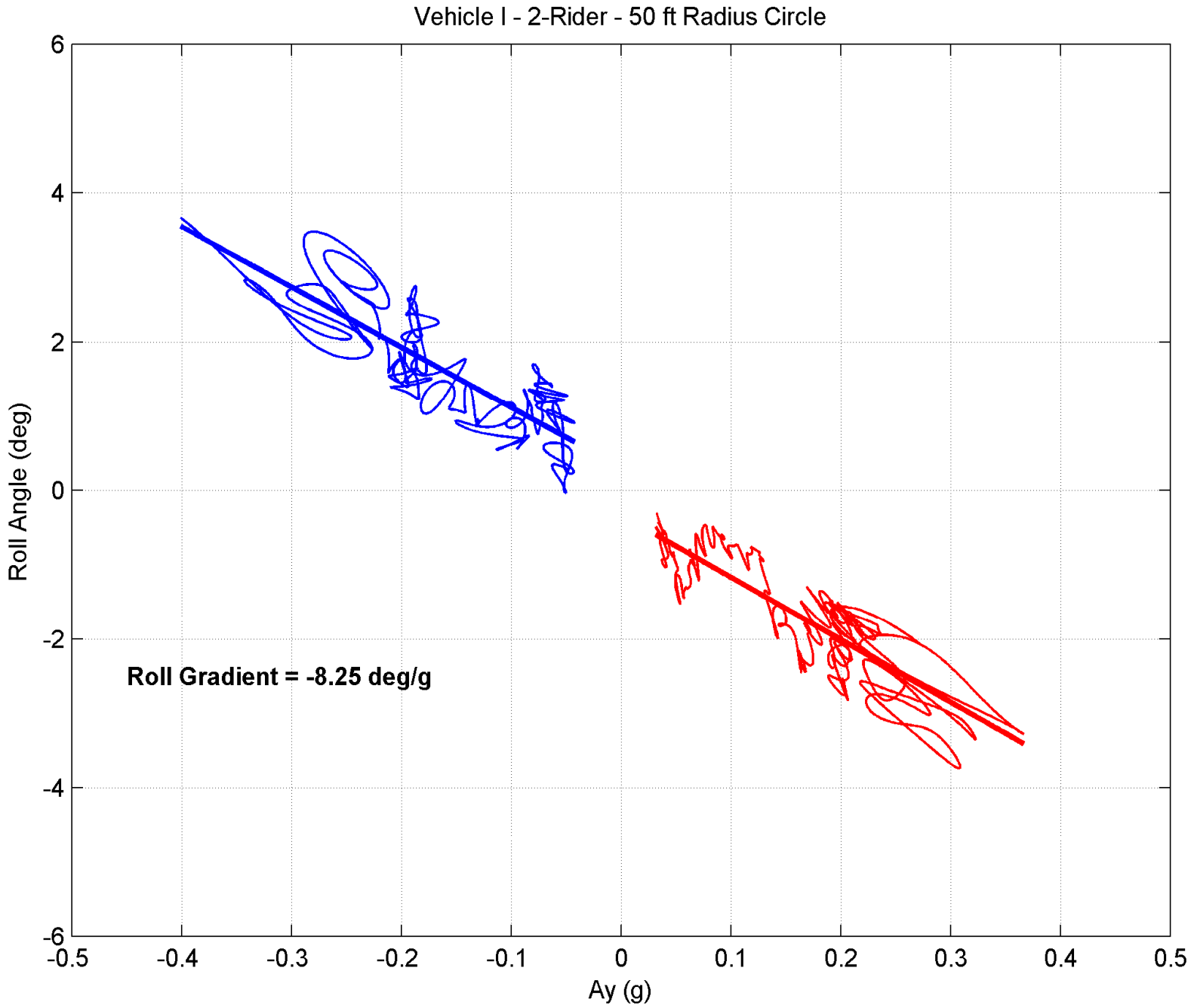

Vehicle H - 2-Rider - 50 ft Radius - Constant Steer Test - CW Runs
N (ft)
E (ft)
60
40
20
0
-20
-40
-60
-50
0
50
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.3 g to 0.4 g
Range: 0.4 g to Max g

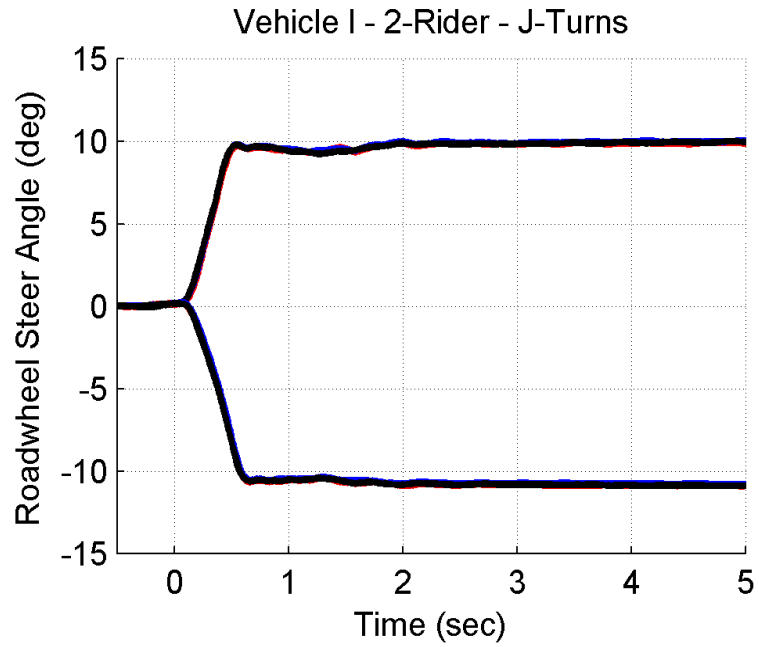

Vehicle H - 2-Rider - 50 ft Radius - Constant Steer Test - CCW Runs
N (ft)
E (ft)
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.3 g to 0.4 g
Range: 0.4 g to Max g

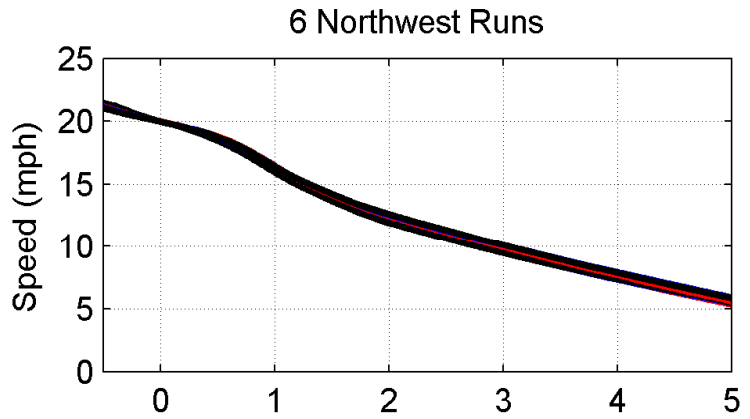

Vehicle I - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
Speed (mph)
CW
CCW
Roll Angle (deg)
Lateral Acceleration (g)
Yaw Rate (deg/sec)
Time (sec)
Time (sec)

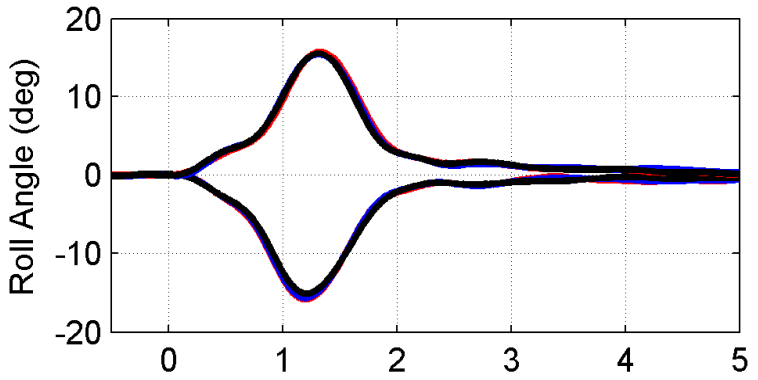

Vehicle I - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
Ay (g)
15
10
5
0
-5
-10
-15
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

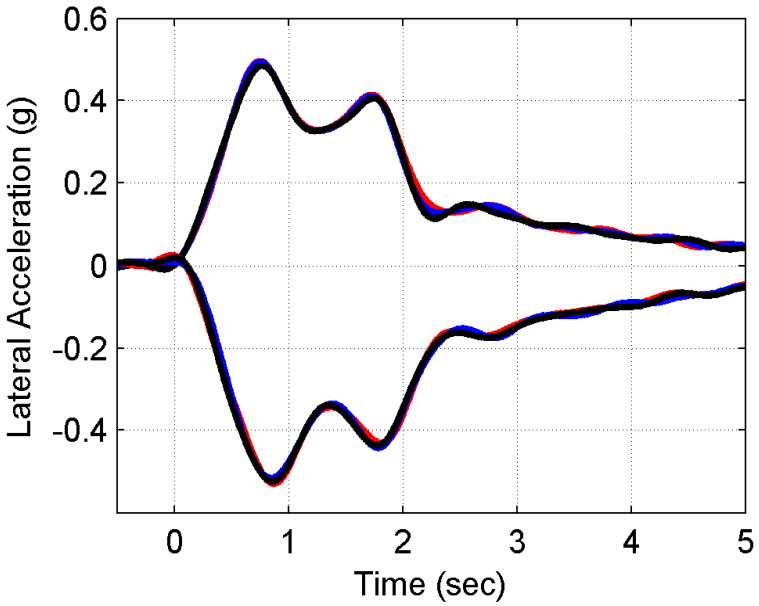

Vehicle I - 2-Rider - 50 ft Radius Circle
Clockwise
Counterclockwise
(Roadwheel Steer Angle - Ackermann Angle) (deg)
15
10
5
0
-5
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Ay (g)
CW Transition to OS
At Ay = 0.0975 g
CCW Transition to OS
At Ay = -0.129 g

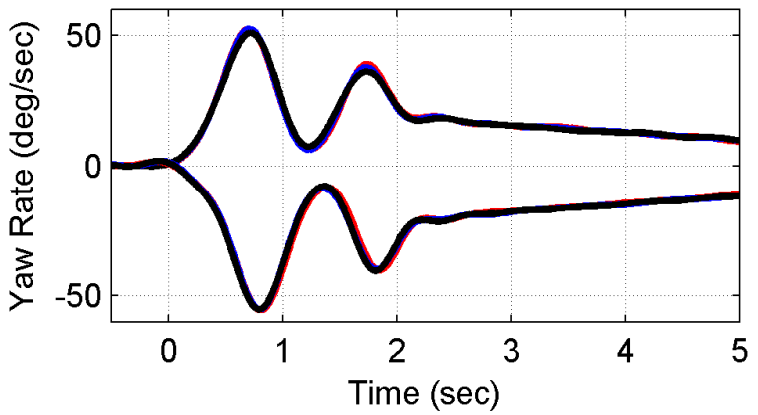

Vehicle I - 2-Rider - 50 ft Radius Circle
Roll Angle (deg)
Ay (g)
Roll Gradient = -8.25 deg/g
6
4
2
0
-2
-4
-6
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

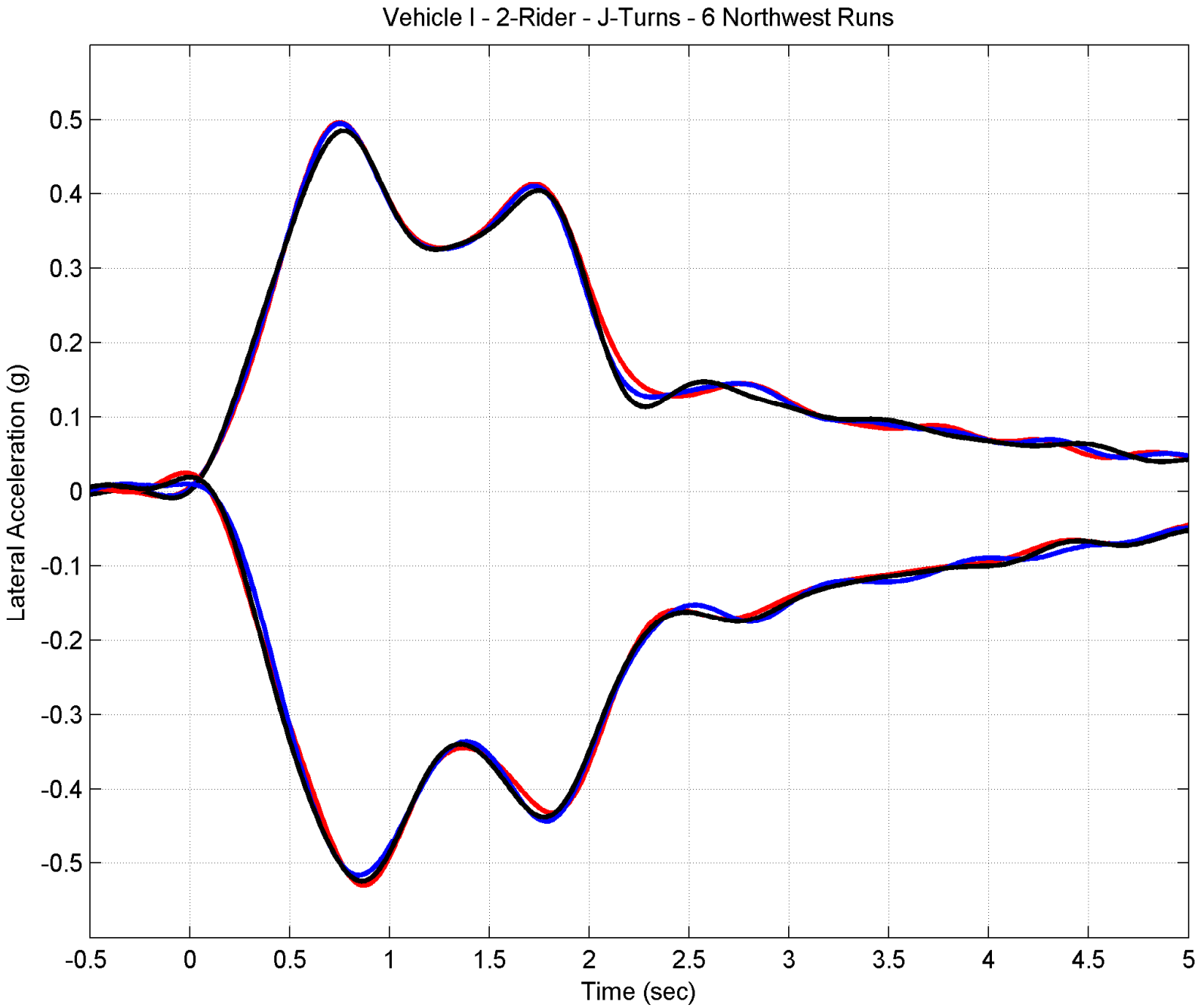

Vehicle I - 2-Rider - J-Turns
Roadwheel Steer Angle (deg)
15
10
5
0
-5
-10
-15
0
1
2
3
4
5
Time (sec)

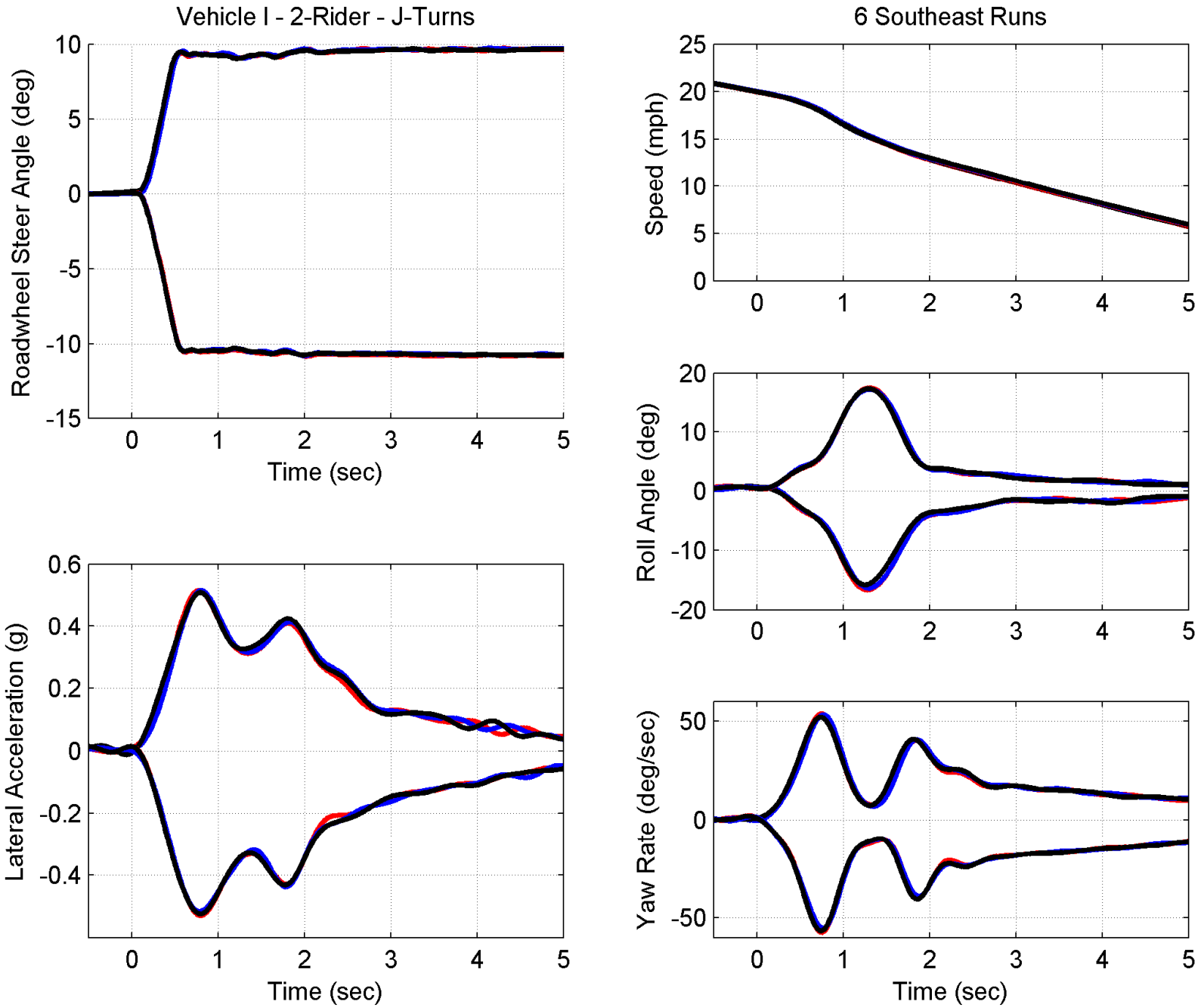

6 Northwest Runs
Speed (mph)
25
20
15
10
5
0
0
1
2
3
4
5

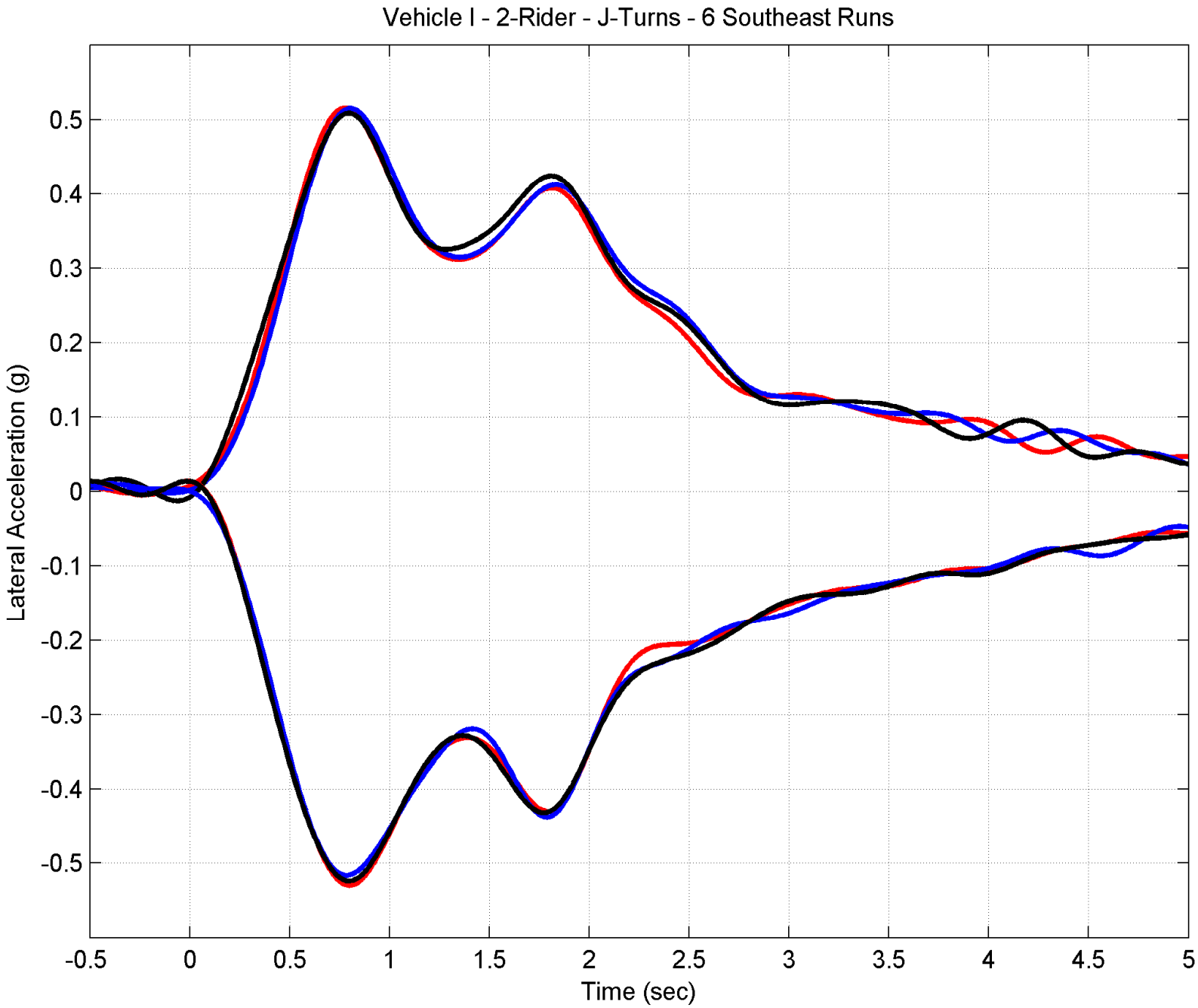

Roll Angle (deg)
20
10
0
-10
-20
0
1
2
3
4
5


Lateral Acceleration (g)
0.6
0.4
0.2
0
-0.2
-0.4
0
1
2
3
4
5
Time (sec)


Yaw Rate (deg/sec)
50
0
-50
0
1
2
3
4
5
Time (sec)


Vehicle I - 2-Rider - J-Turns - 6 Northwest Runs
Lateral Acceleration (g)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (sec)


Vehicle I - 2-Rider - J-Turns
Roadwheel Steer Angle (deg)
Time (sec)
Lateral Acceleration (g)
Time (sec)
6 Southeast Runs
Speed (mph)
Roll Angle (deg)
Yaw Rate (deg/sec)
Time (sec)


Vehicle I - 2-Rider - J-Turns - 6 Southeast Runs
Lateral Acceleration (g)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (sec)

Vehicle I - 2-Rider Results

Peak Lateral Accelerations During 2WL J-Turns - All Values in "g's"

Run Number	Northwest Right Turns	Northwest Left Turns
1	0.496	-0.530
2	0.495	-0.516
3	0.485	-0.524
Mean Value of 3 Runs	0.492	-0.524
Standard Deviation of 3 Runs	0.006	0.007

Average of 6 Northwest Runs

0.508

Run Number	Southeast Right Turns	Southeast Left Turns
1	0.516	-0.530
2	0.515	-0.517
3	0.509	-0.524
Mean Value of 3 Runs	0.513	-0.524
Standard Deviation of 3 Runs	0.004	0.007

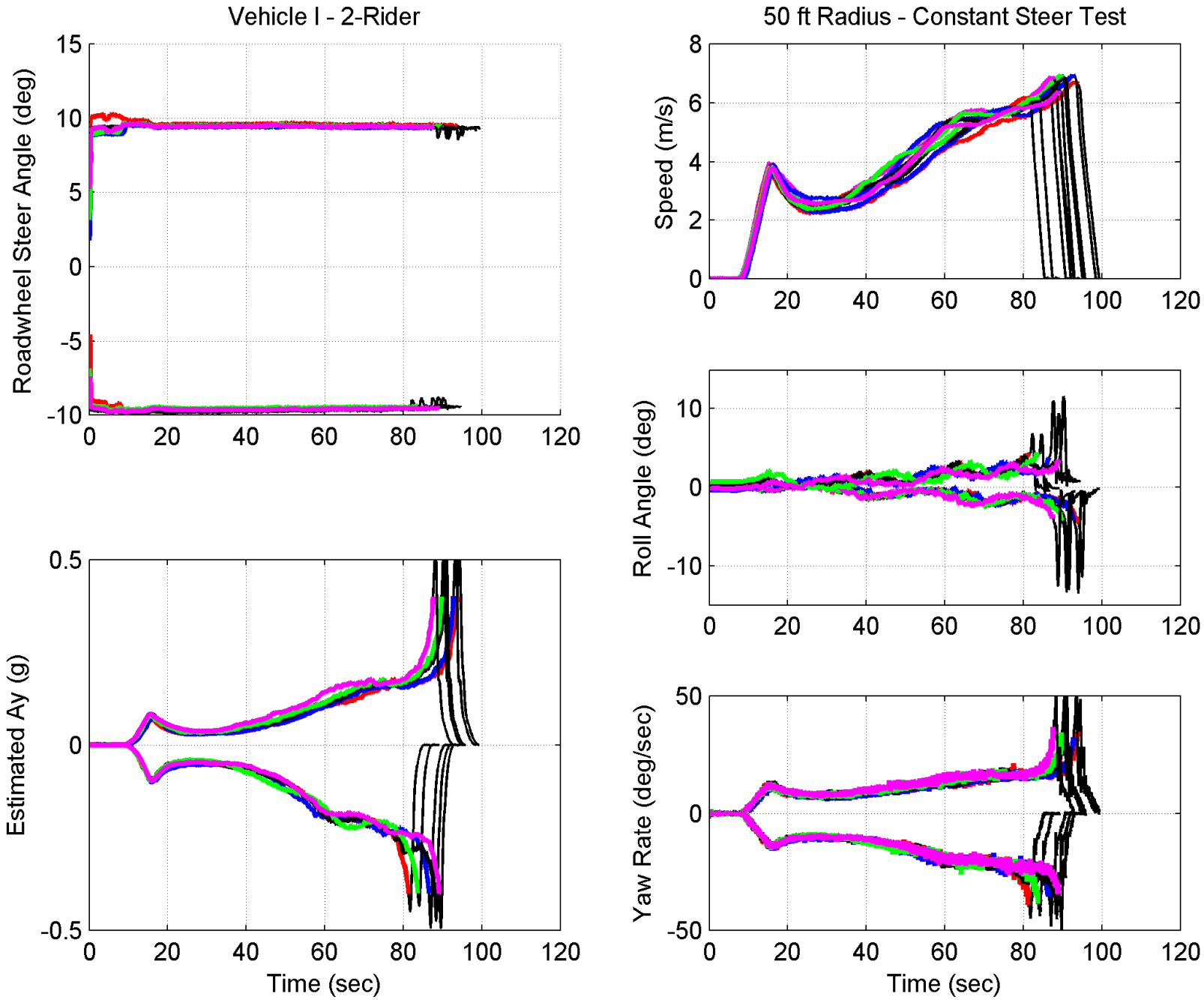
Average of 6 Southeast Runs

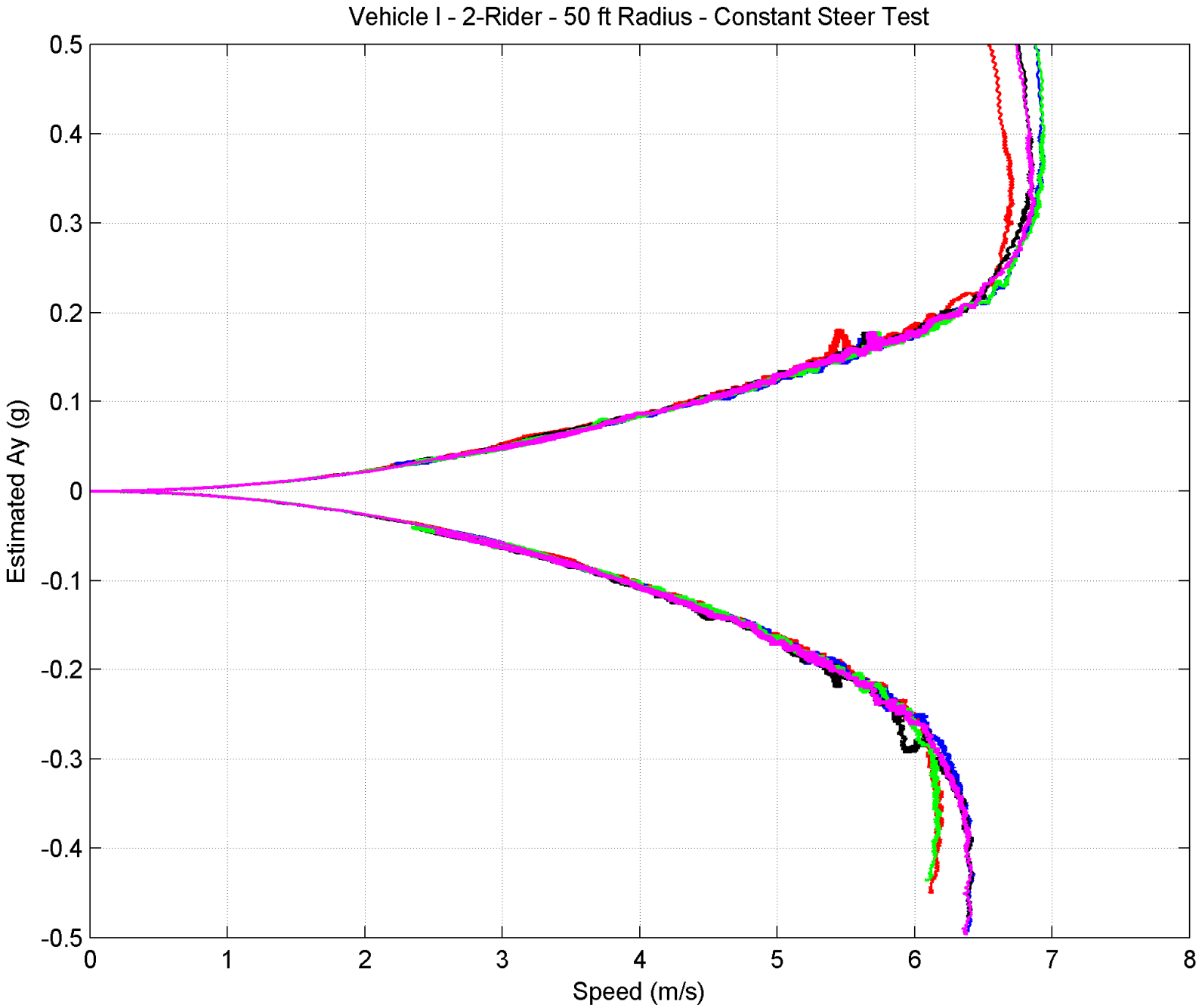
0.518

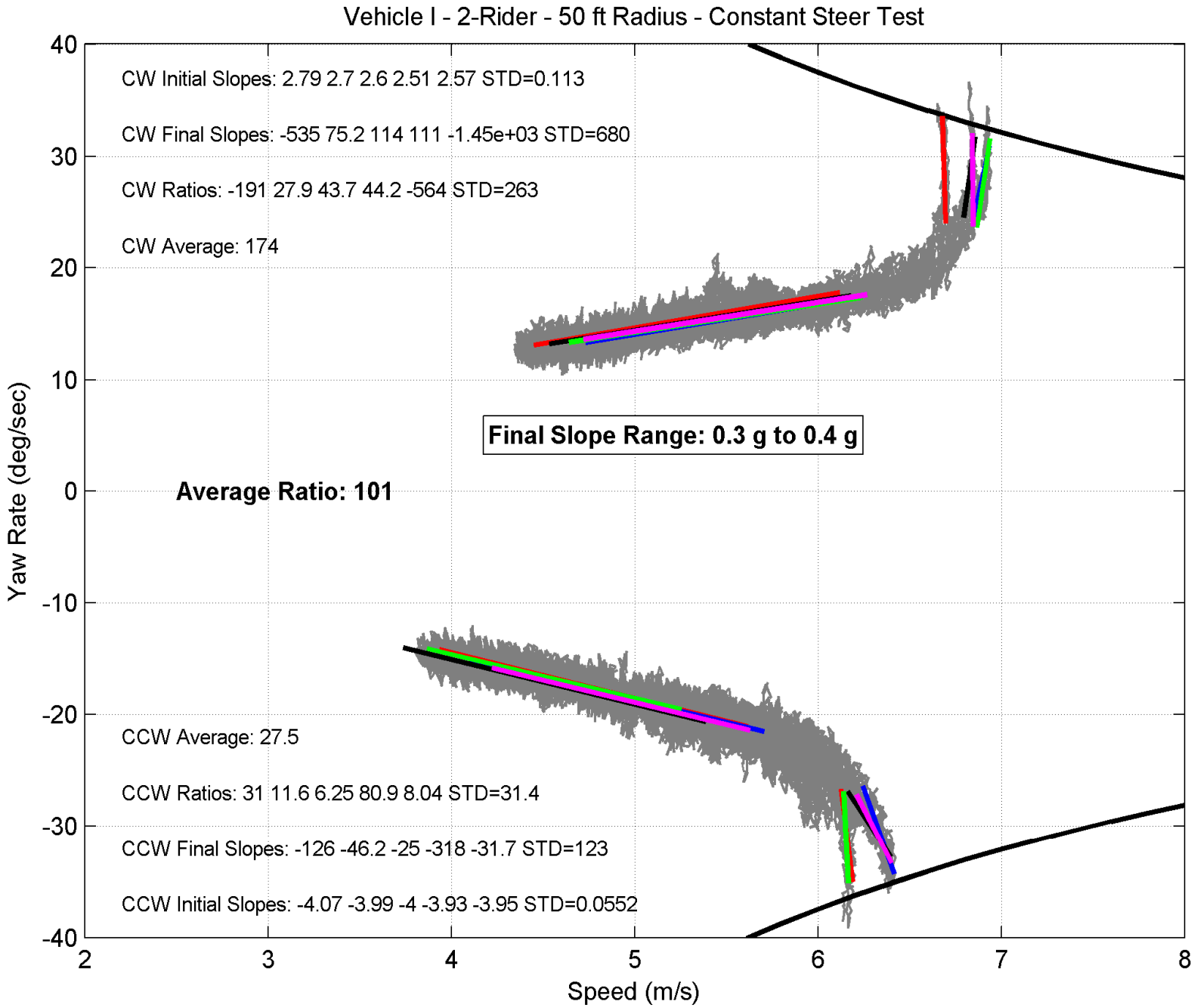
Average of All 12 Runs

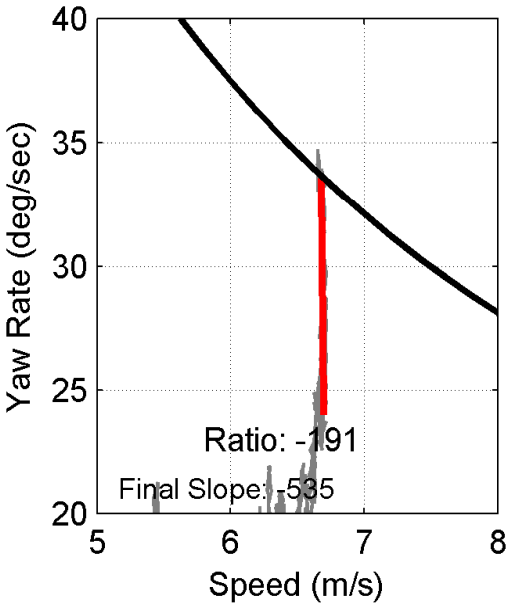
0.513

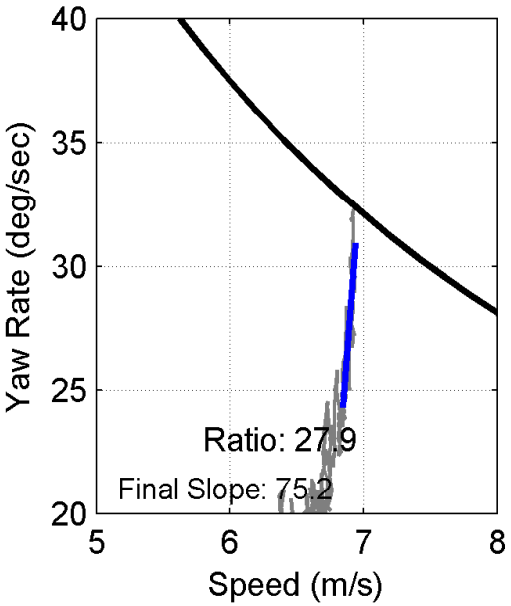
Threshold Ay

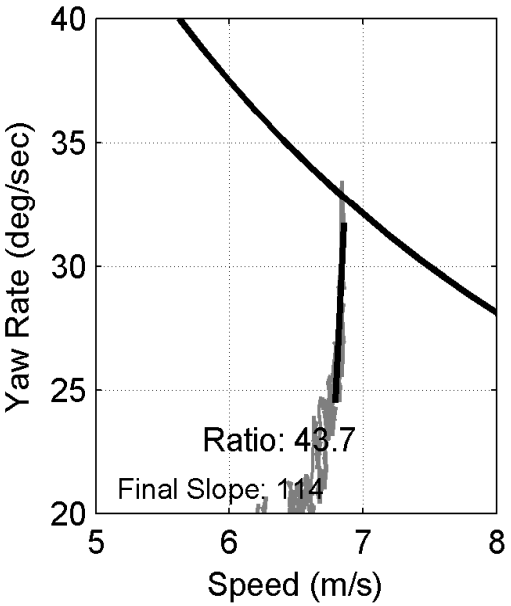

Vehicle I - 2-Rider
50 ft Radius - Constant Steer Test
Roadwheel Steer Angle (deg)
Speed (m/s)
Roll Angle (deg)
Estimated Ay (g)
Yaw Rate (deg/sec)
Time (sec)
Time (sec)

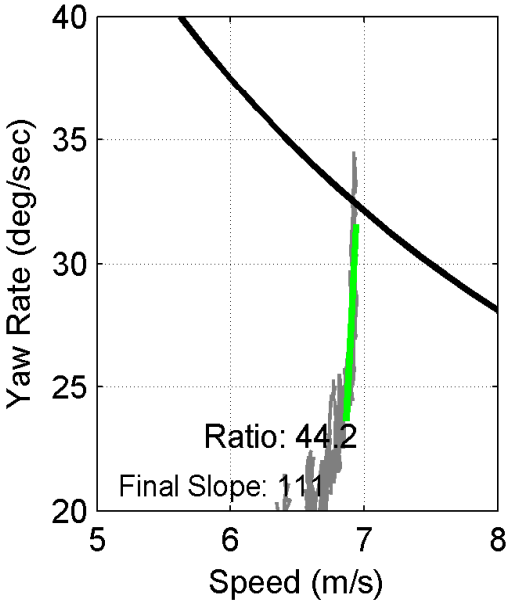

Vehicle I - 2-Rider - 50 ft Radius - Constant Steer Test
Estimated Ay (g)
Speed (m/s)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
1
2
3
4
5
6
7
8

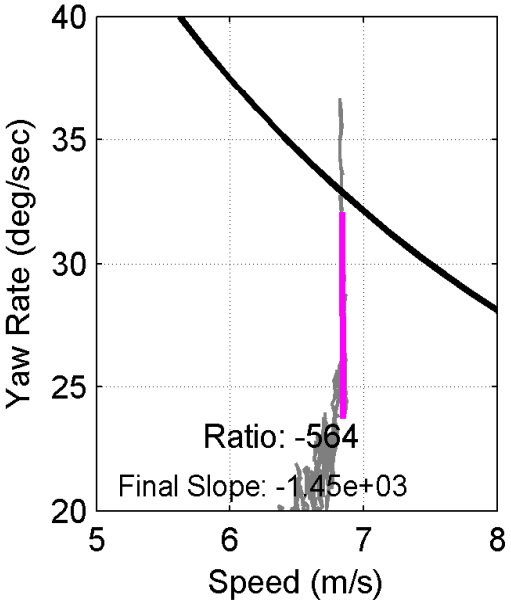

Vehicle I - 2-Rider - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.79 2.7 2.6 2.51 2.57 STD=0.113
CW Final Slopes: -535 75.2 114 111 -1.45e+03 STD=680
CW Ratios: -191 27.9 43.7 44.2 -564 STD=263
CW Average: 174
Final Slope Range: 0.3 g to 0.4 g
Average Ratio: 101
CCW Average: 27.5
CCW Ratios: 31 11.6 6.25 80.9 8.04 STD=31.4
CCW Final Slopes: -126 -46.2 -25 -318 -31.7 STD=123
CCW Initial Slopes: -4.07 -3.99 -4 -3.93 -3.95 STD=0.0552
Yaw Rate (deg/sec)
Speed (m/s)
40
30
20
10
0
-10
-20
-30
-40
2
3
4
5
6
7
8





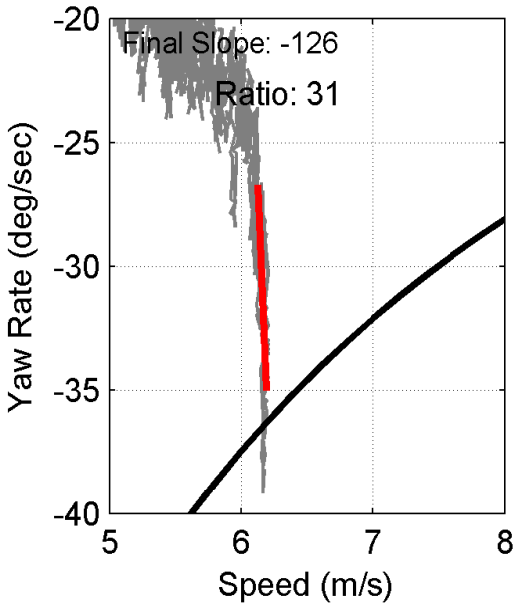


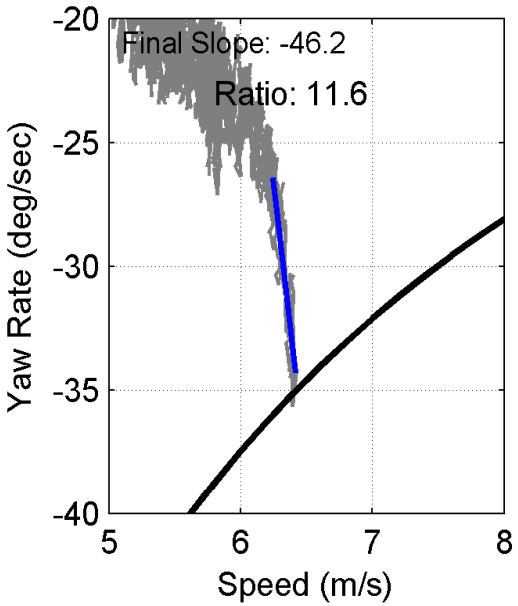


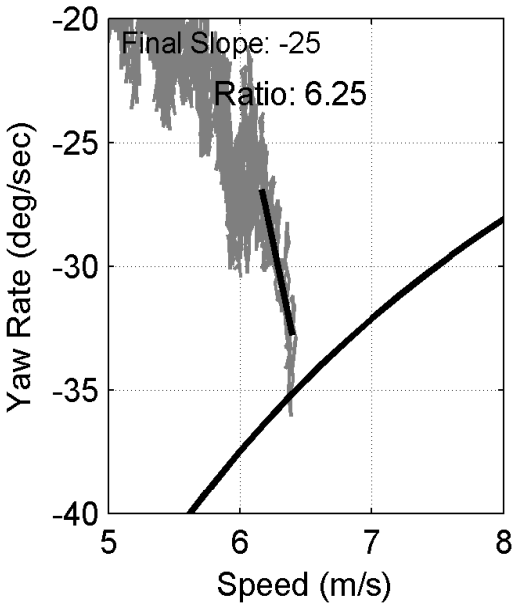


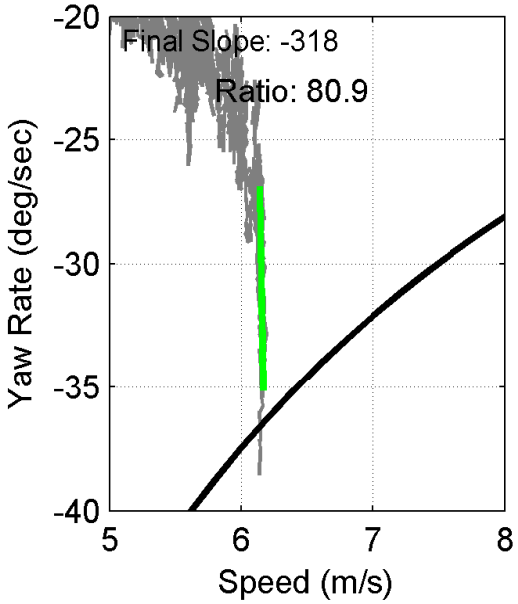
Final Slope Range:

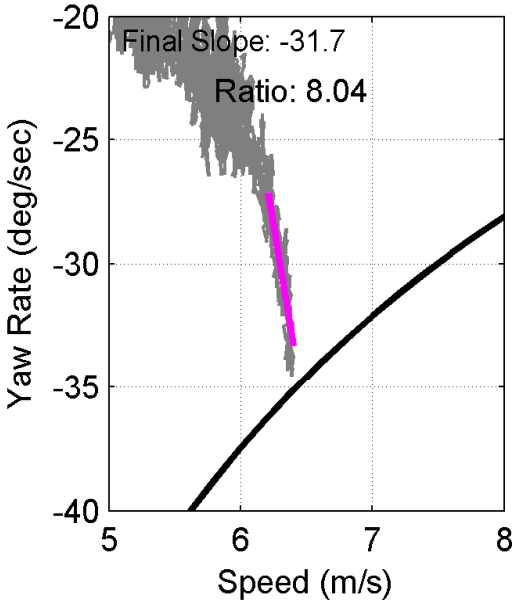
0.3 g to 0.4 g





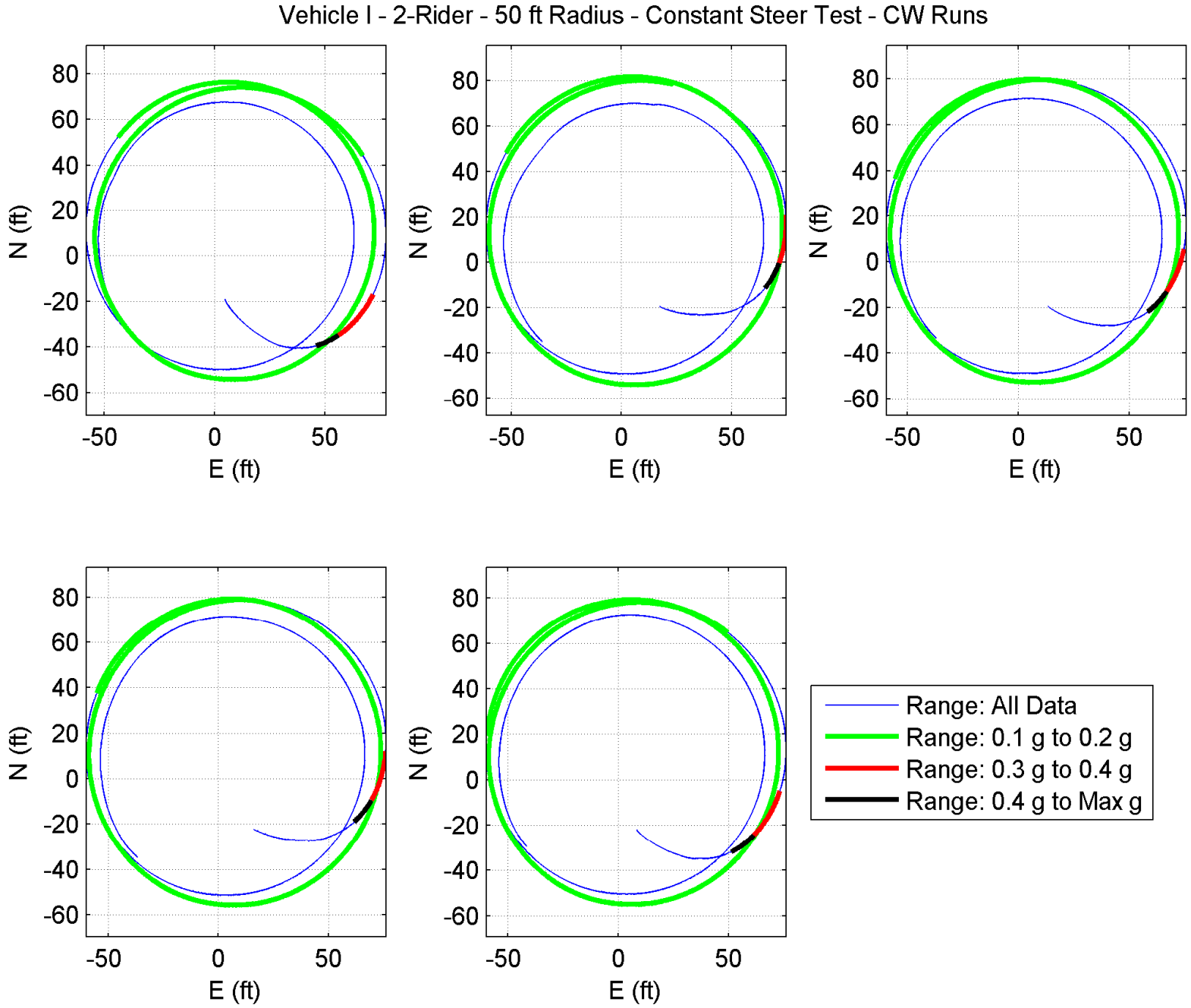


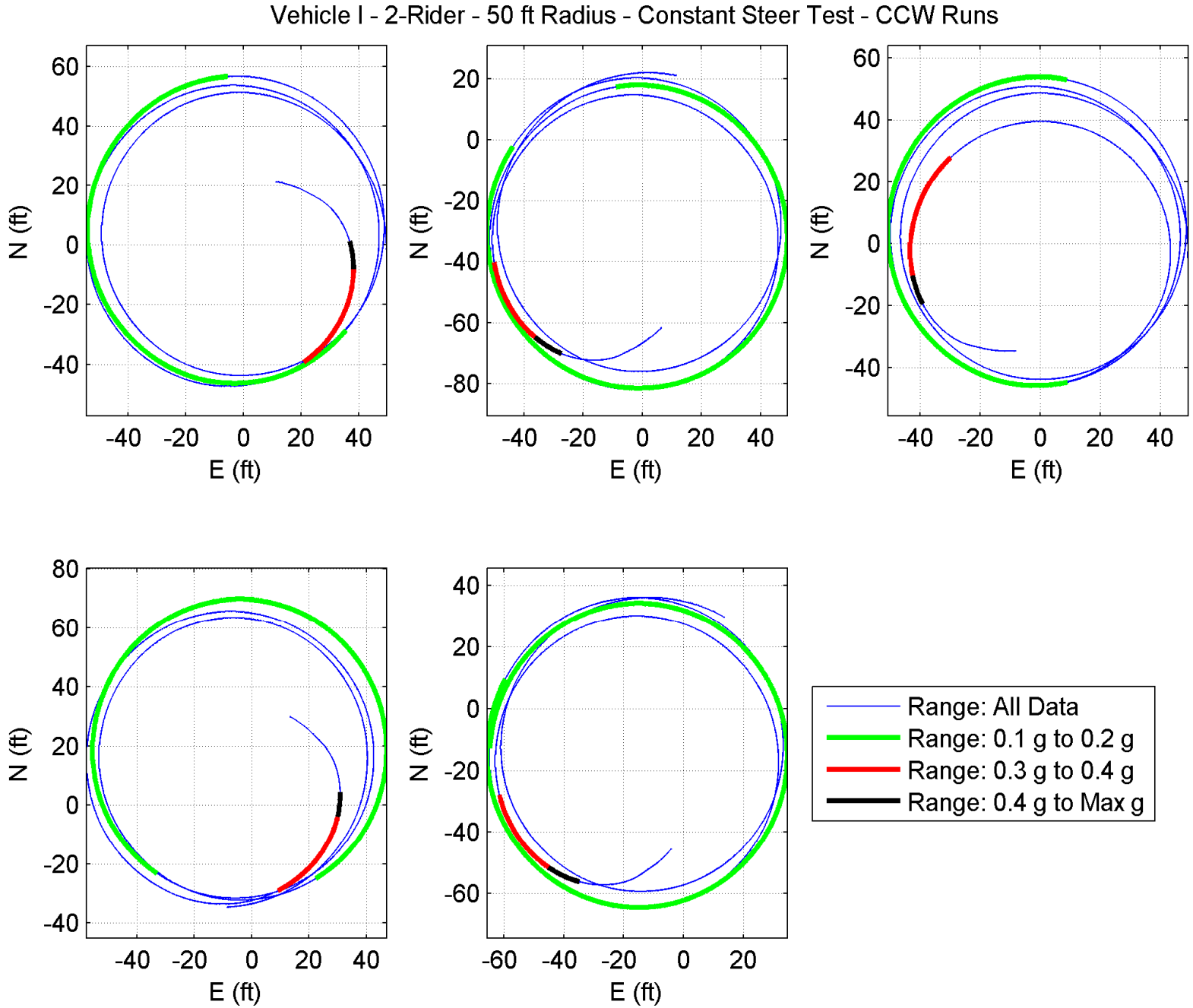


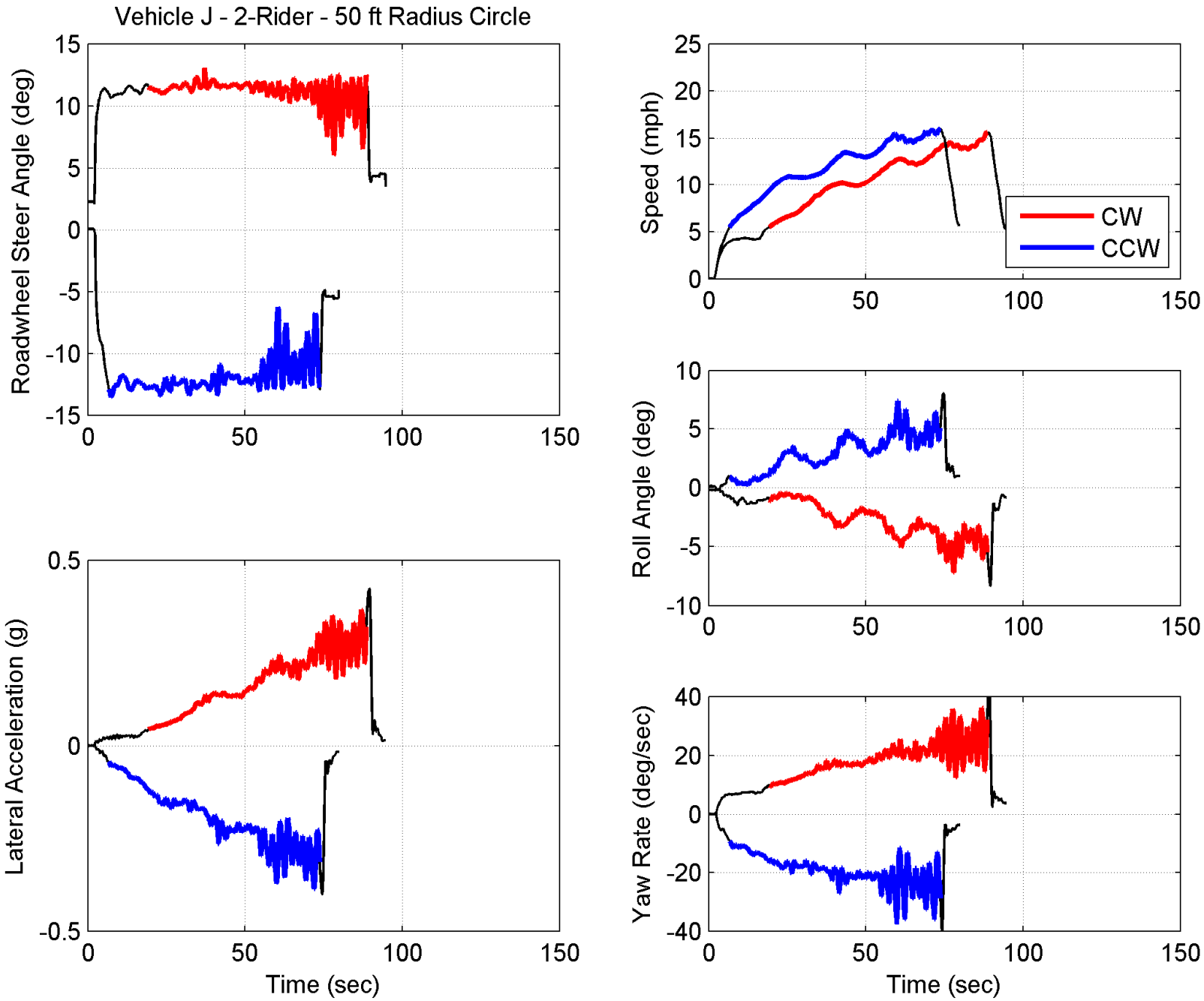


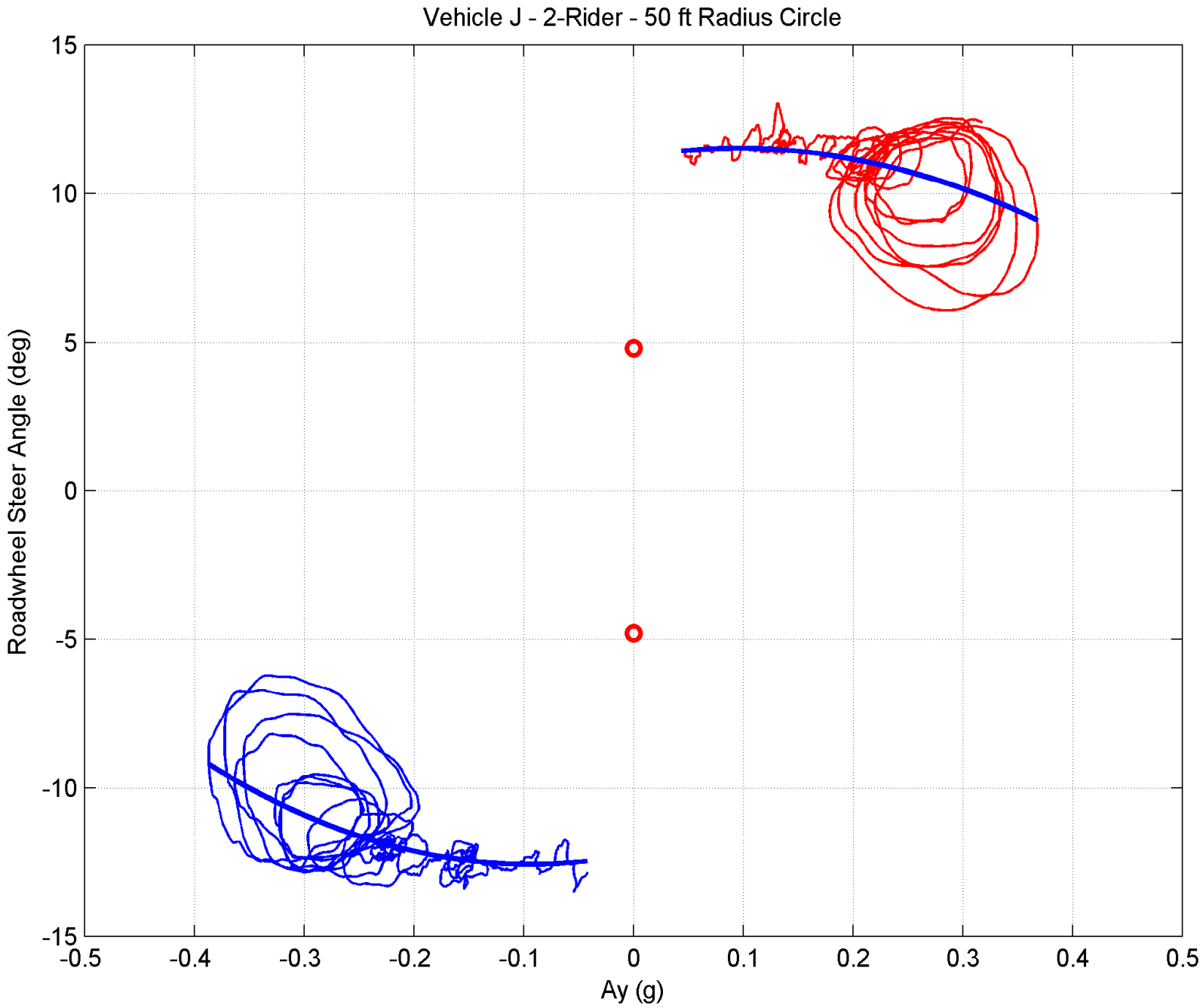
Final Slope Range:

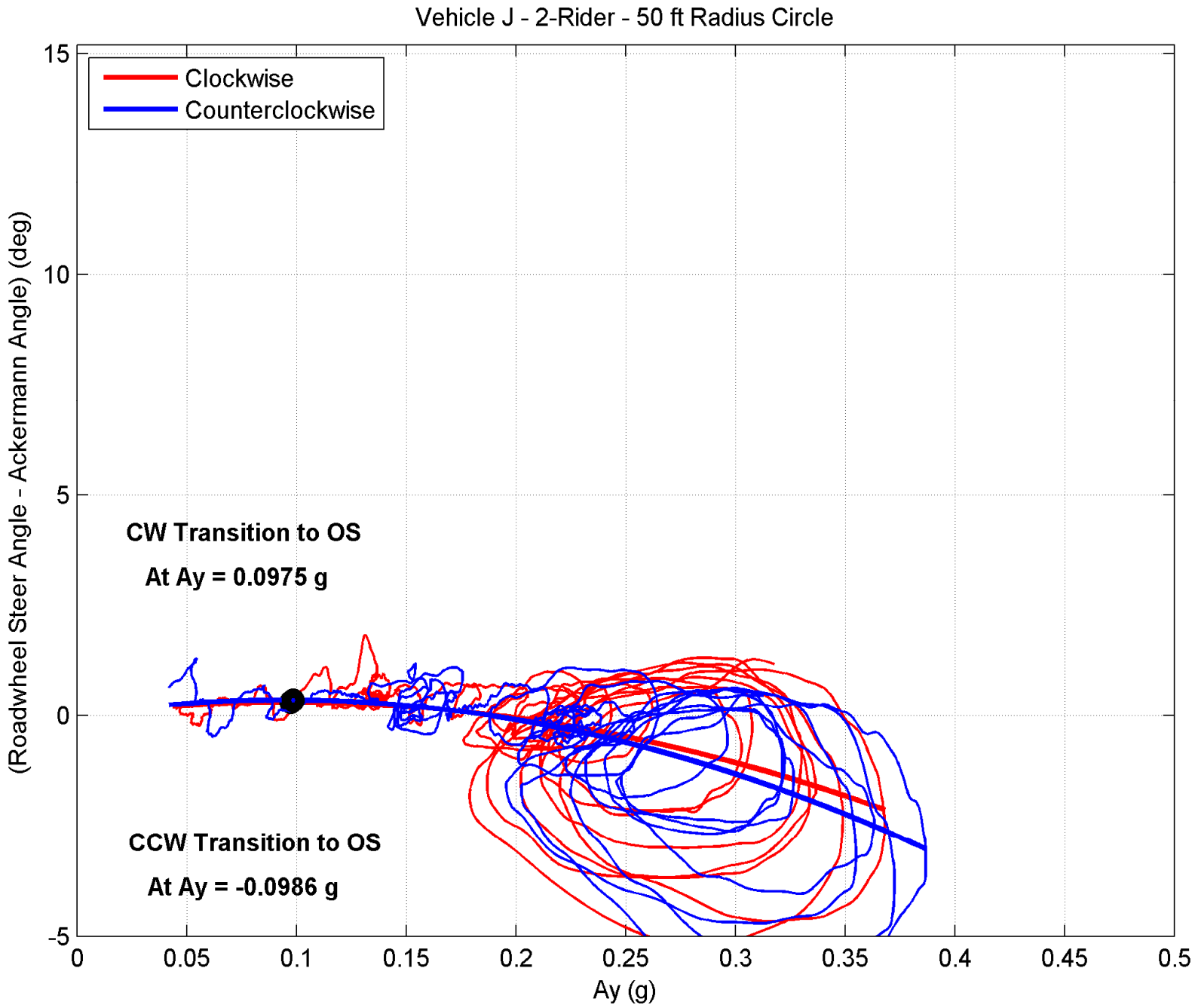
0.3 g to 0.4 g

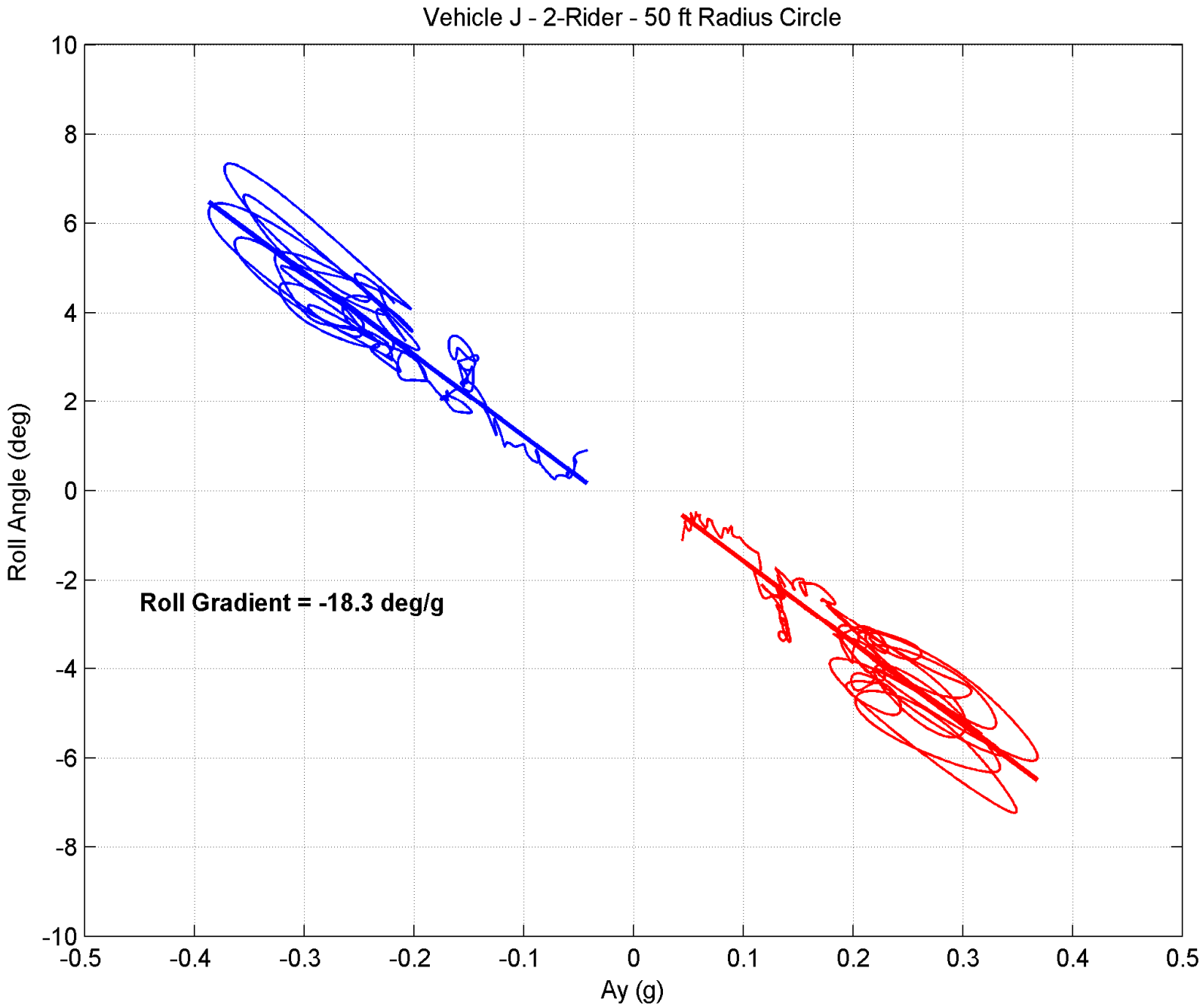

Vehicle I - 2-Rider - 50 ft Radius - Constant Steer Test - CW Runs
N (ft)
E (ft)
80
60
40
20
0
-20
-40
-60
-50
0
50
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.3 g to 0.4 g
Range: 0.4 g to Max g

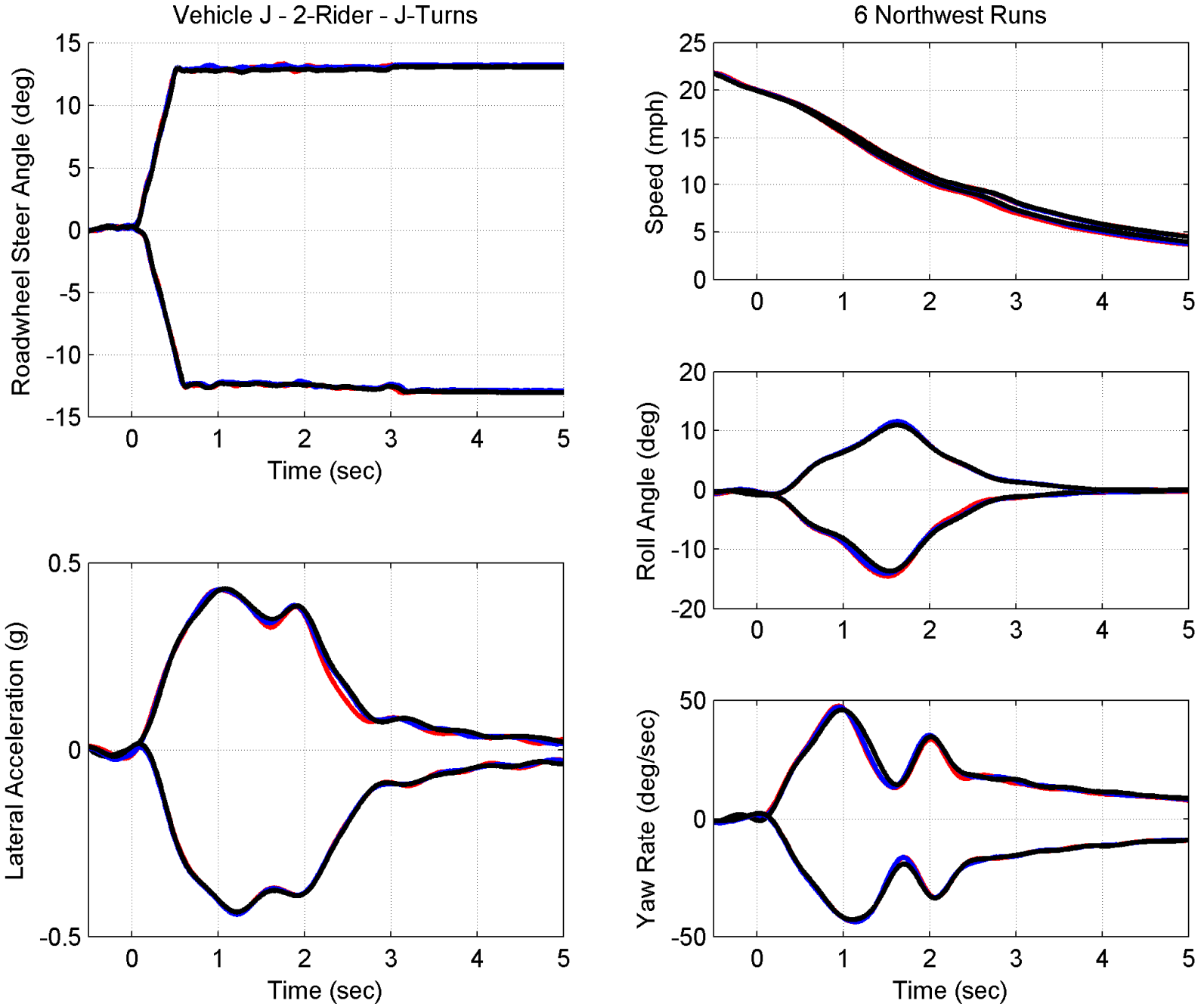

Vehicle I - 2-Rider - 50 ft Radius - Constant Steer Test - CCW Runs
N (ft)
E (ft)
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.3 g to 0.4 g
Range: 0.4 g to Max g

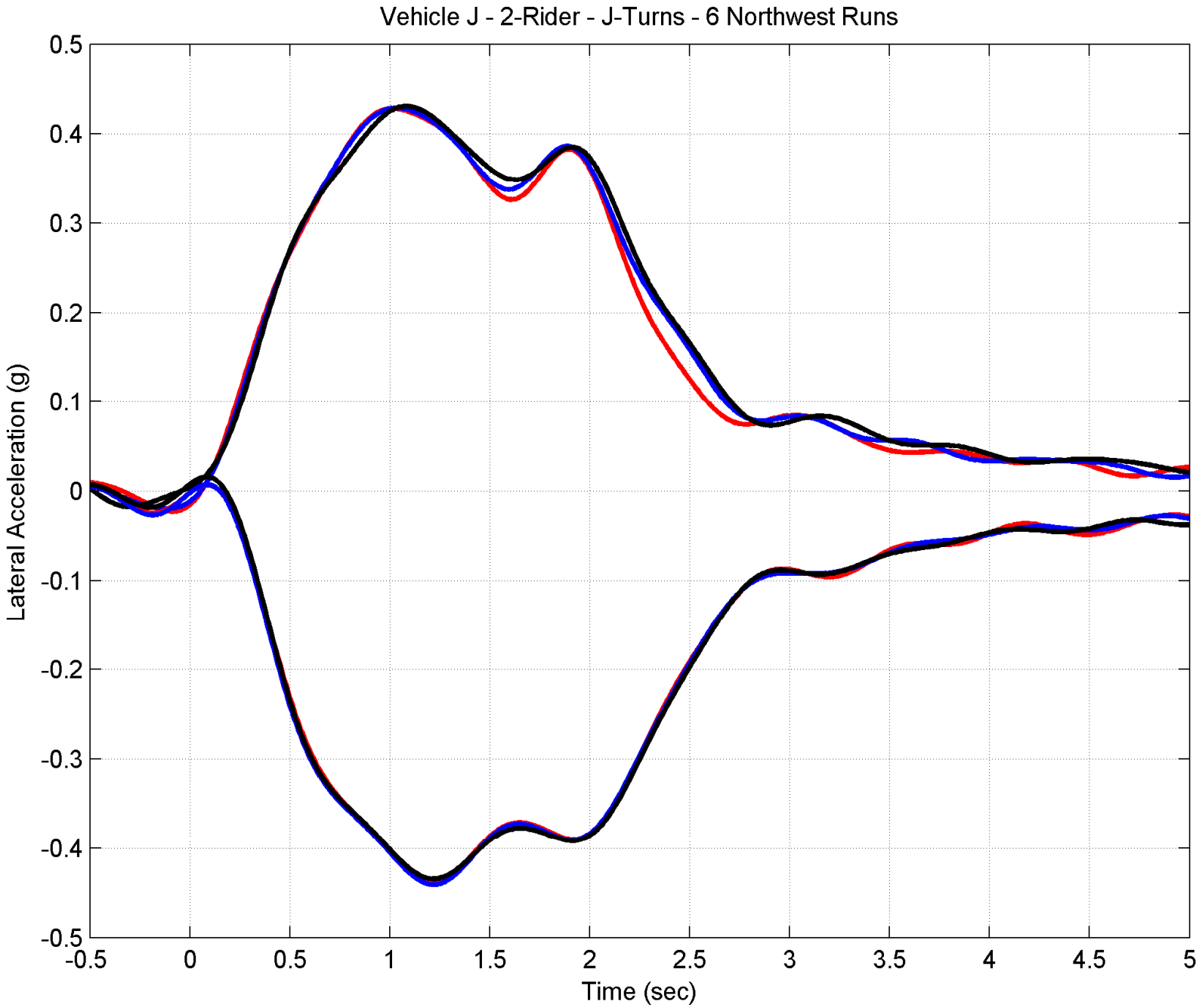

Vehicle J - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
Speed (mph)
CW
CCW
Roll Angle (deg)
Lateral Acceleration (g)
Yaw Rate (deg/sec)
Time (sec)
Time (sec)

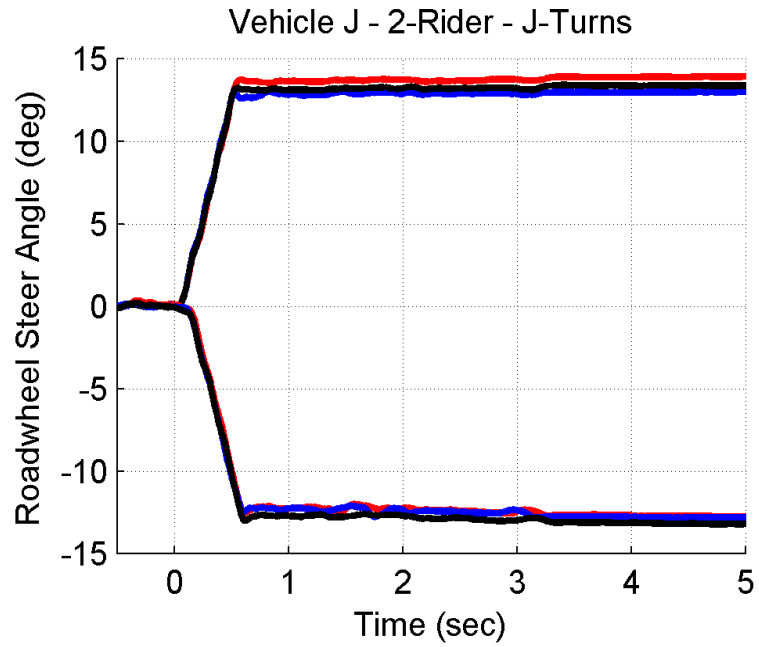

Vehicle J - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
Ay (g)
15
10
5
0
-5
-10
-15
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

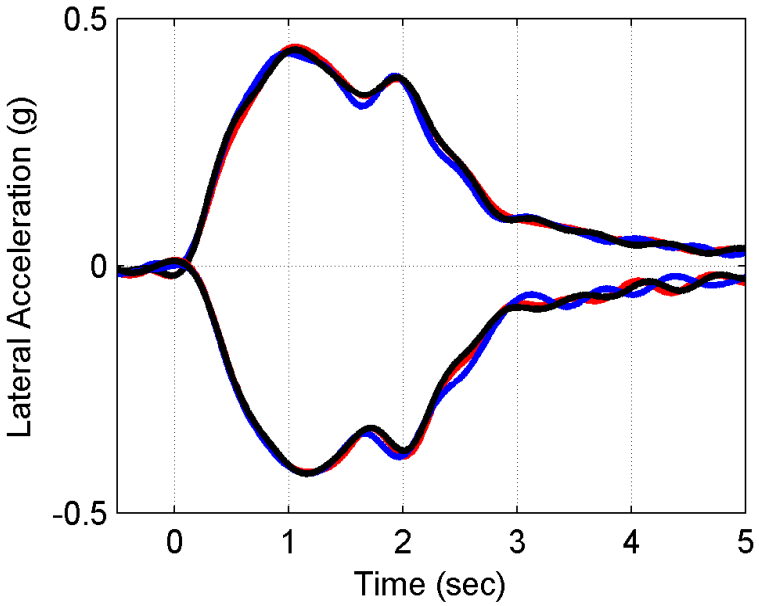

Vehicle J - 2-Rider - 50 ft Radius Circle
Clockwise
Counterclockwise
(Roadwheel Steer Angle - Ackermann Angle) (deg)
Ay (g)
CW Transition to OS
At Ay = 0.0975 g
CCW Transition to OS
At Ay = -0.0986 g
15
10
5
0
-5
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5

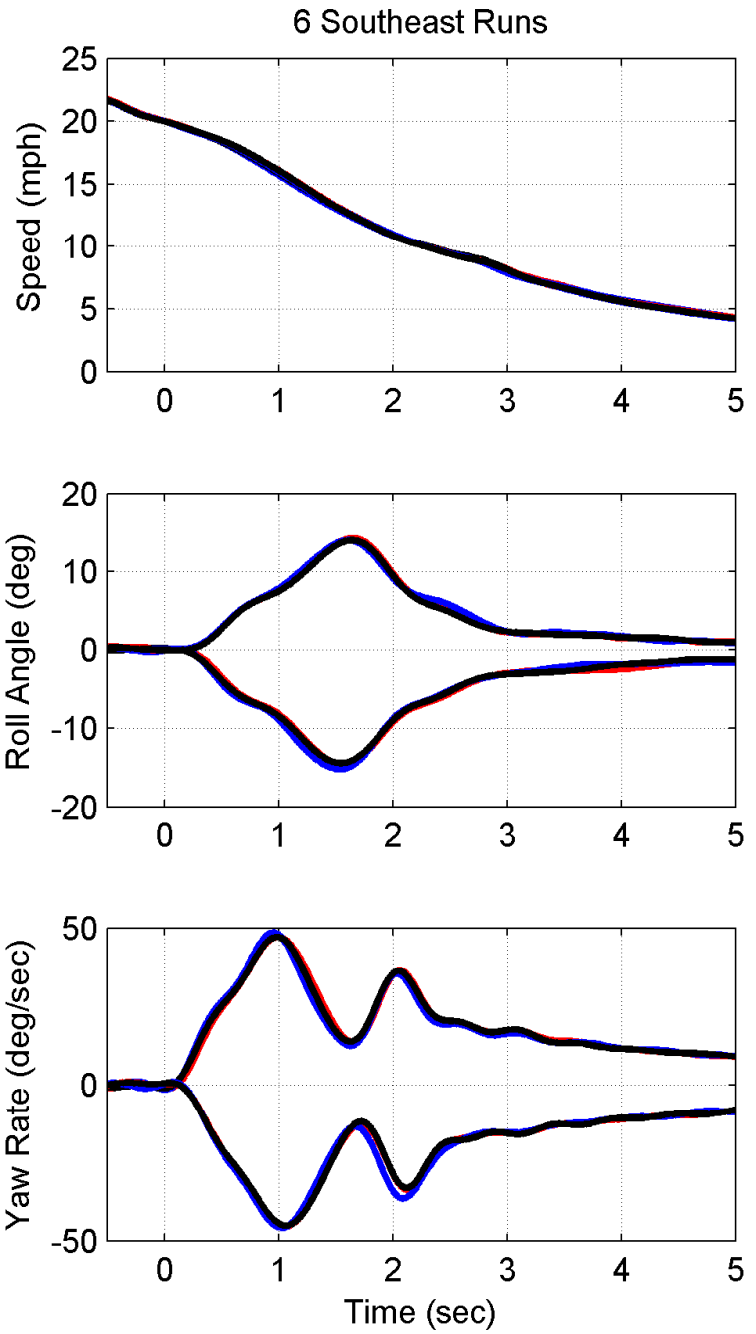

Vehicle J - 2-Rider - 50 ft Radius Circle
Roll Angle (deg)
Ay (g)
Roll Gradient = -18.3 deg/g
10
8
6
4
2
0
-2
-4
-6
-8
-10
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

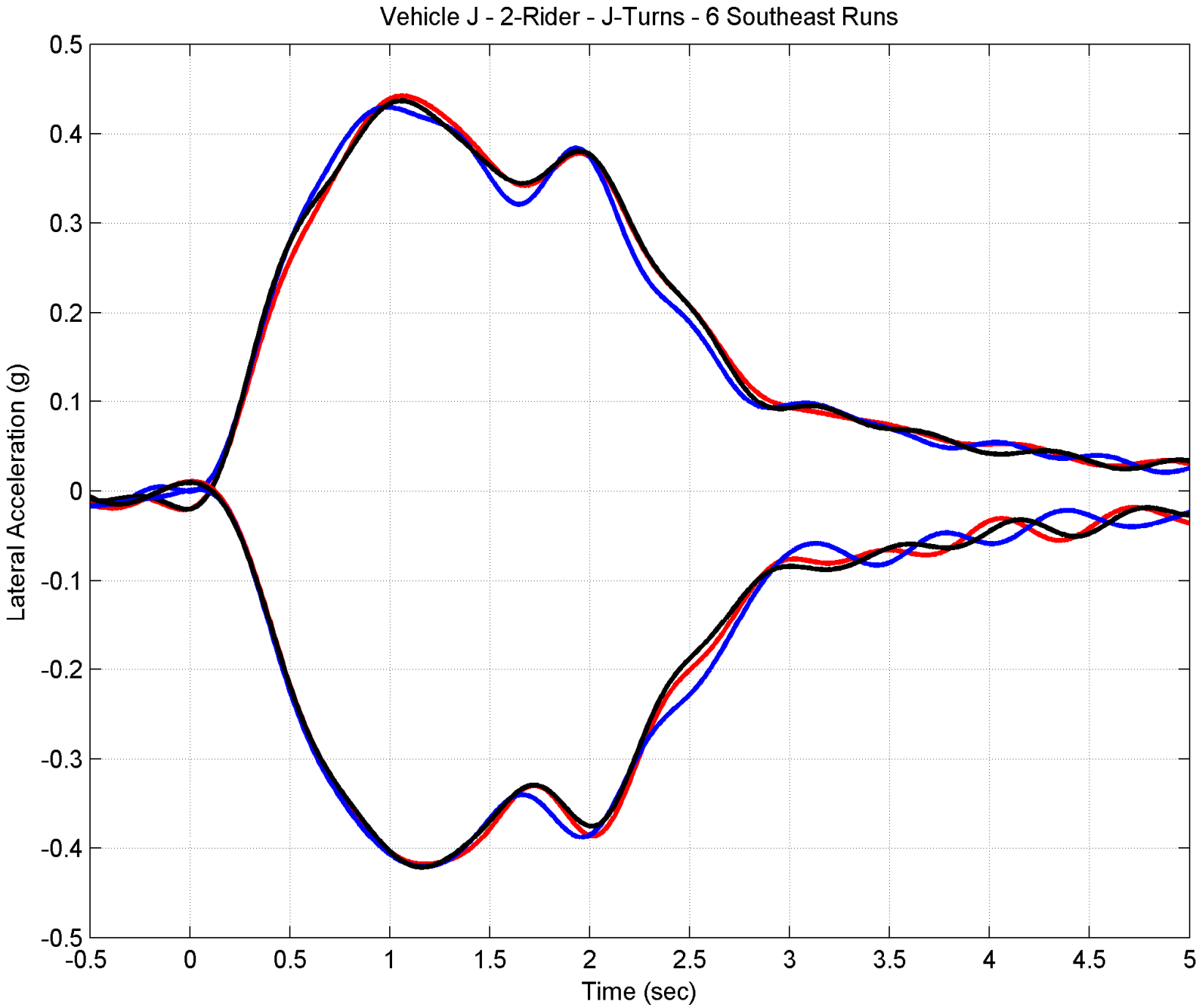

Vehicle J - 2-Rider - J-Turns
Roadwheel Steer Angle (deg)
Time (sec)
Lateral Acceleration (g)
Time (sec)
6 Northwest Runs
Speed (mph)
Roll Angle (deg)
Yaw Rate (deg/sec)
Time (sec)


Vehicle J - 2-Rider - J-Turns - 6 Northwest Runs
Lateral Acceleration (g)
Time (sec)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


Vehicle J - 2-Rider - J-Turns
Roadwheel Steer Angle (deg)
15
10
5
0
-5
-10
-15
0
1
2
3
4
5
Time (sec)


Lateral Acceleration (g)
0.5
0
-0.5
0
1
2
3
4
5
Time (sec)


6 Southeast Runs
Speed (mph)
25
20
15
10
5
0
0
1
2
3
4
5
Roll Angle (deg)
20
10
0
-10
-20
0
1
2
3
4
5
Yaw Rate (deg/sec)
50
0
-50
0
1
2
3
4
5
Time (sec)


Vehicle J - 2-Rider - J-Turns - 6 Southeast Runs
Lateral Acceleration (g)
Time (sec)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

Vehicle J - 2-Rider Results

Peak Lateral Accelerations During 2WL J-Turns - All Values in "g's"

Run Number	Northwest Right Turns	Northwest Left Turns
1	0.428	-0.438
2	0.429	-0.441
3	0.431	-0.435
Mean Value of 3 Runs	0.429	-0.438
Standard Deviation of 3 Runs	0.001	0.003

Average of 6 Northwest Runs

0.434

Average of All 12 Runs

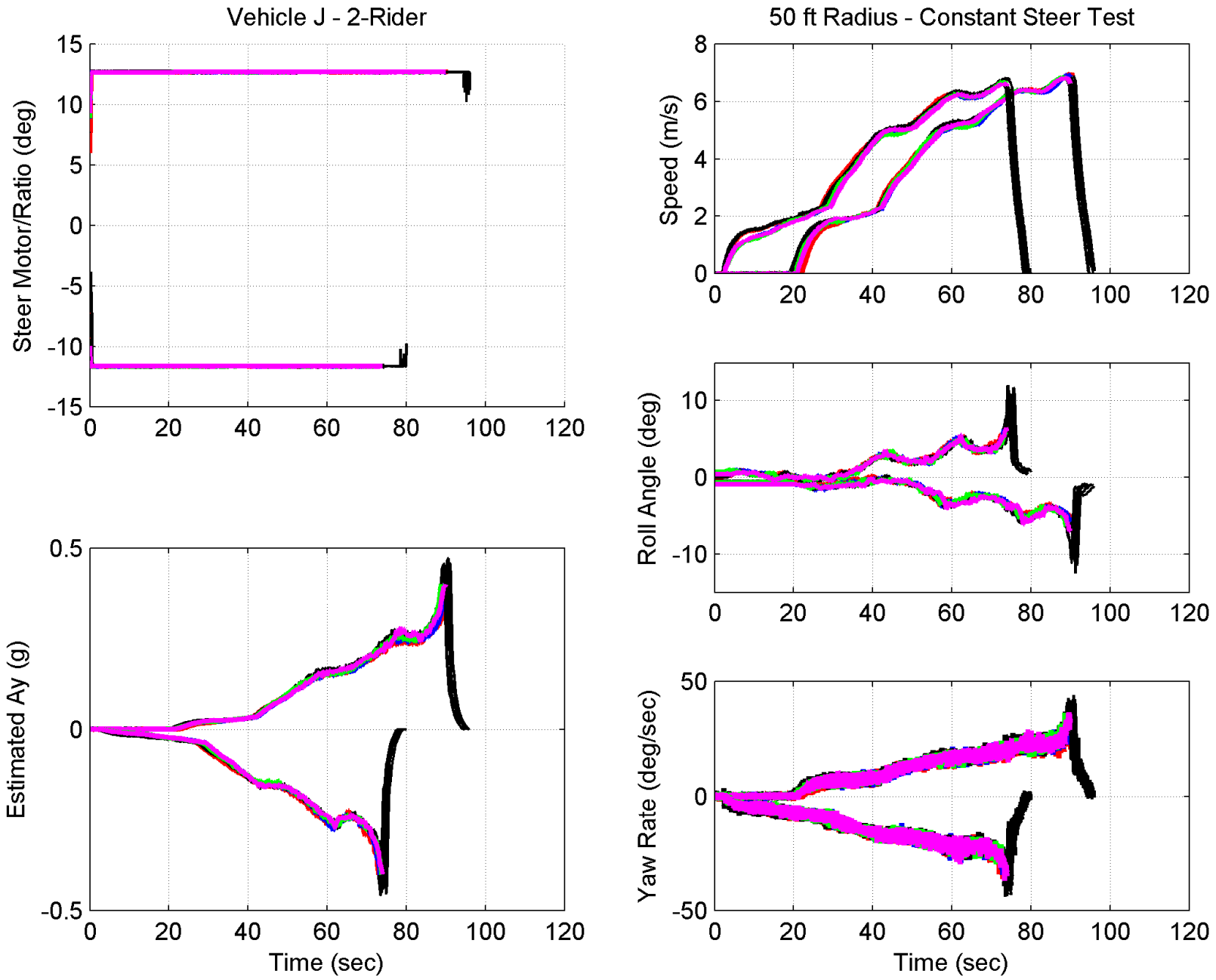
0.431

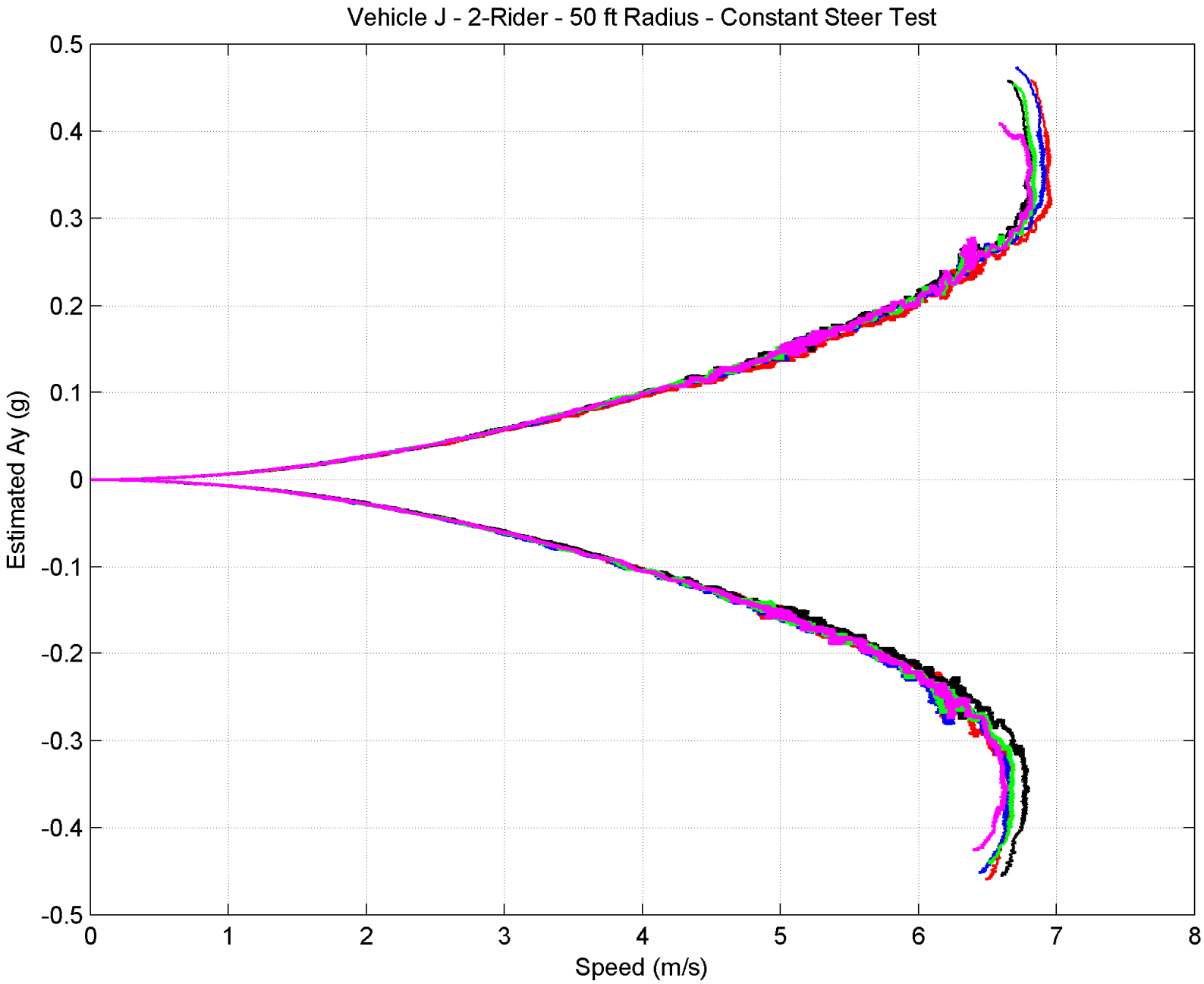
Threshold Ay

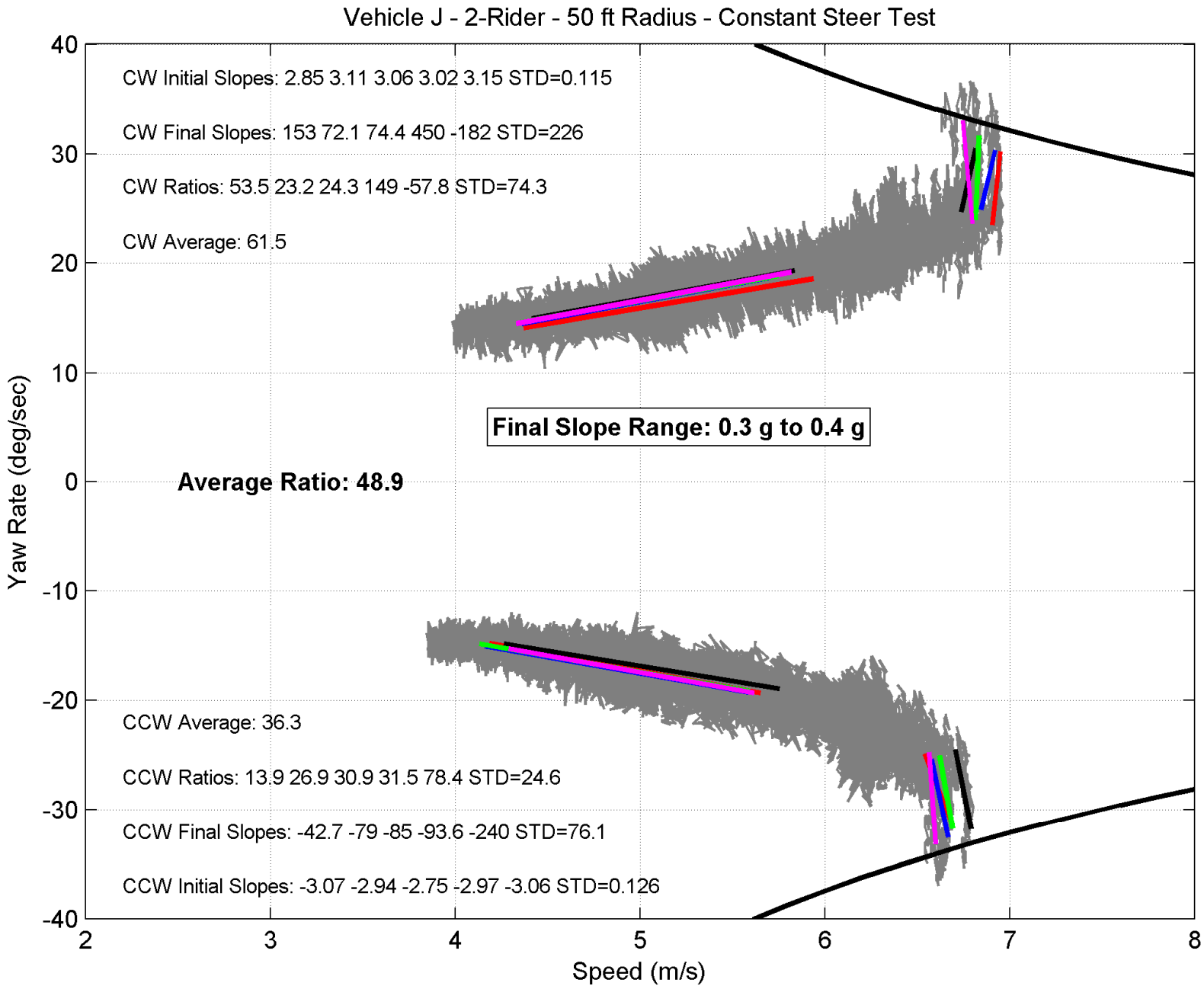
Run Number	Southeast Right Turns	Southeast Left Turns
1	0.442	-0.418
2	0.430	-0.421
3	0.437	-0.421
Mean Value of 3 Runs	0.436	-0.420
Standard Deviation of 3 Runs	0.006	0.002

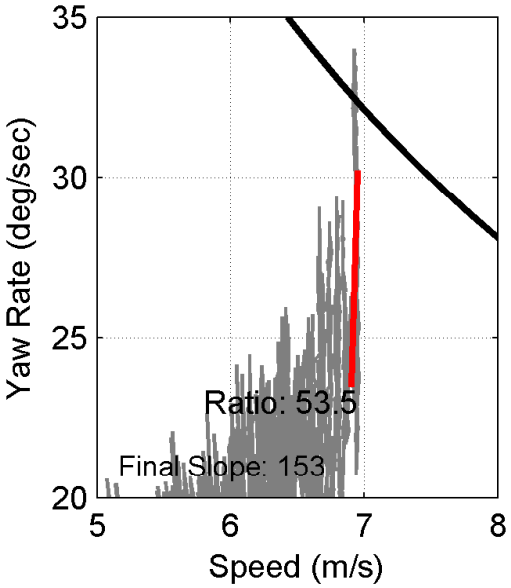
Average of 6 Southeast Runs

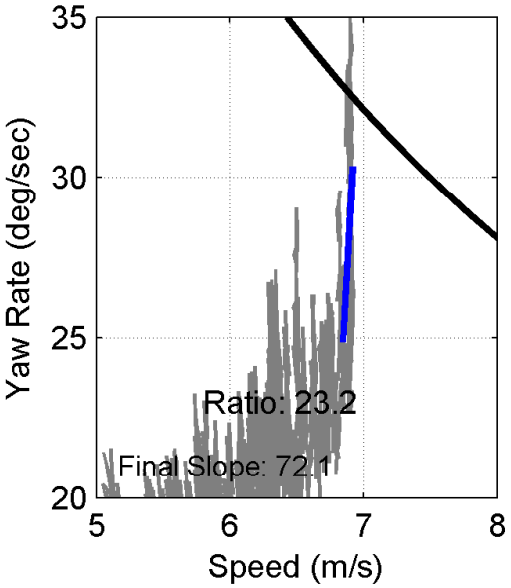
0.428

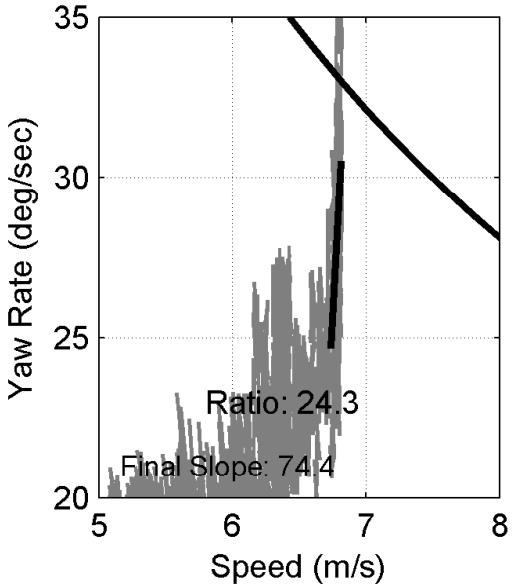

Vehicle J - 2-Rider
Steer Motor/Ratio (deg)
15
10
5
0
-5
-10
-15
0
20
40
60
80
100
120
50 ft Radius - Constant Steer Test
Speed (m/s)
8
6
4
2
0
Roll Angle (deg)
10
0
-10
Estimated Ay (g)
0.5
0
-0.5
Yaw Rate (deg/sec)
50
0
-50
Time (sec)
Time (sec)

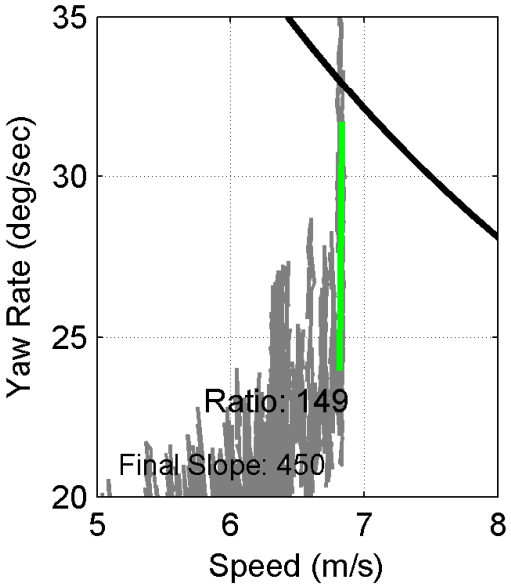

Vehicle J - 2-Rider - 50 ft Radius - Constant Steer Test
Estimated Ay (g)
Speed (m/s)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
1
2
3
4
5
6
7
8

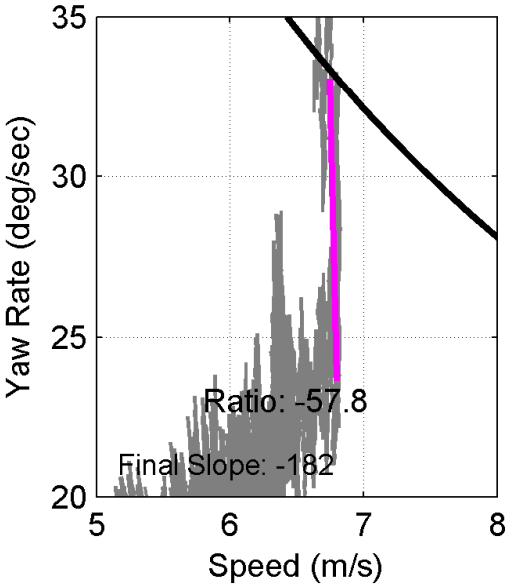

Vehicle J - 2-Rider - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.85 3.11 3.06 3.02 3.15 STD=0.115
CW Final Slopes: 153 72.1 74.4 450 -182 STD=226
CW Ratios: 53.5 23.2 24.3 149 -57.8 STD=74.3
CW Average: 61.5
Final Slope Range: 0.3 g to 0.4 g
Average Ratio: 48.9
CCW Average: 36.3
CCW Ratios: 13.9 26.9 30.9 31.5 78.4 STD=24.6
CCW Final Slopes: -42.7 -79 -85 -93.6 -240 STD=76.1
CCW Initial Slopes: -3.07 -2.94 -2.75 -2.97 -3.06 STD=0.126
Yaw Rate (deg/sec)
Speed (m/s)
40
30
20
10
0
-10
-20
-30
-40
2
3
4
5
6
7
8





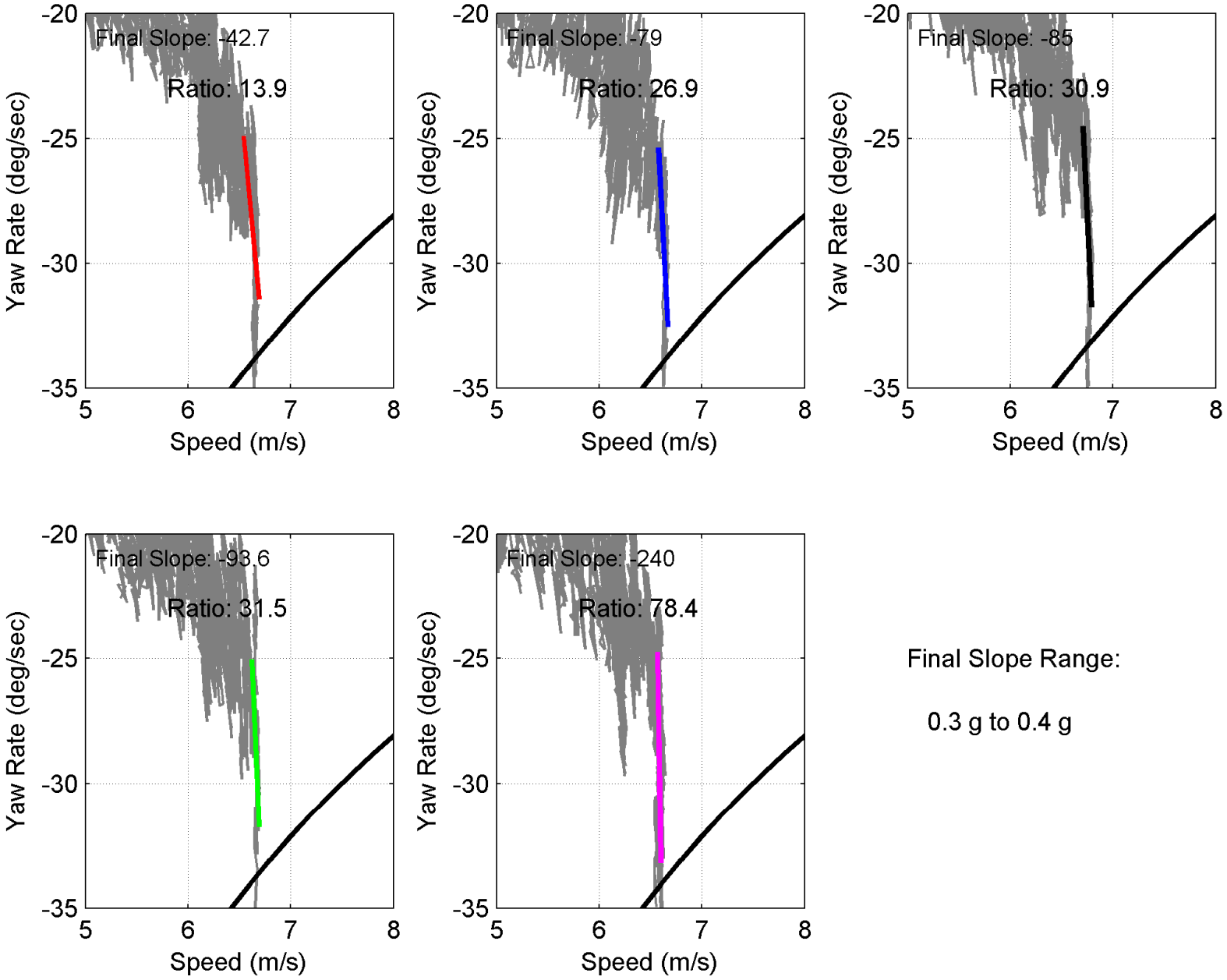






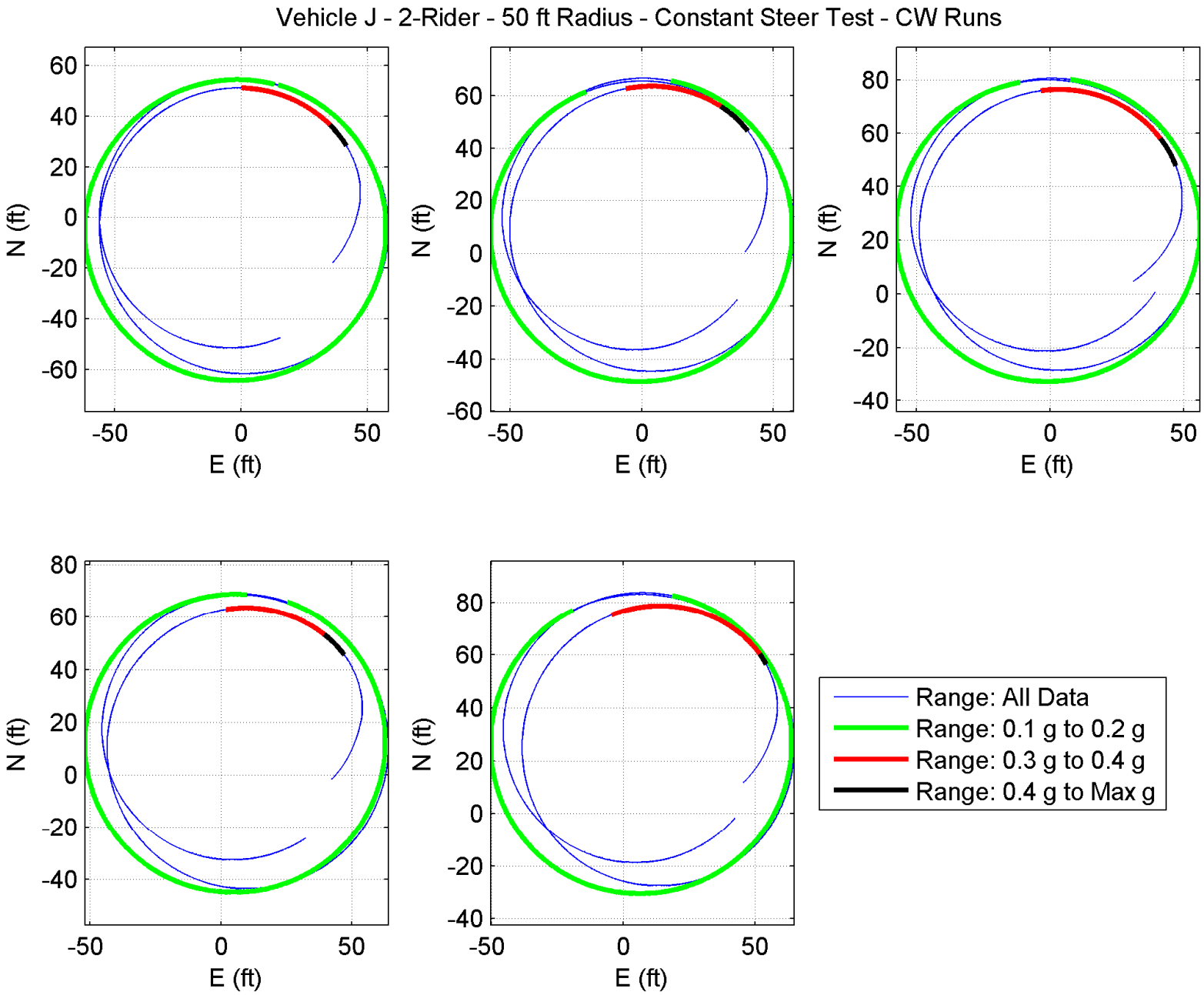
Final Slope Range:

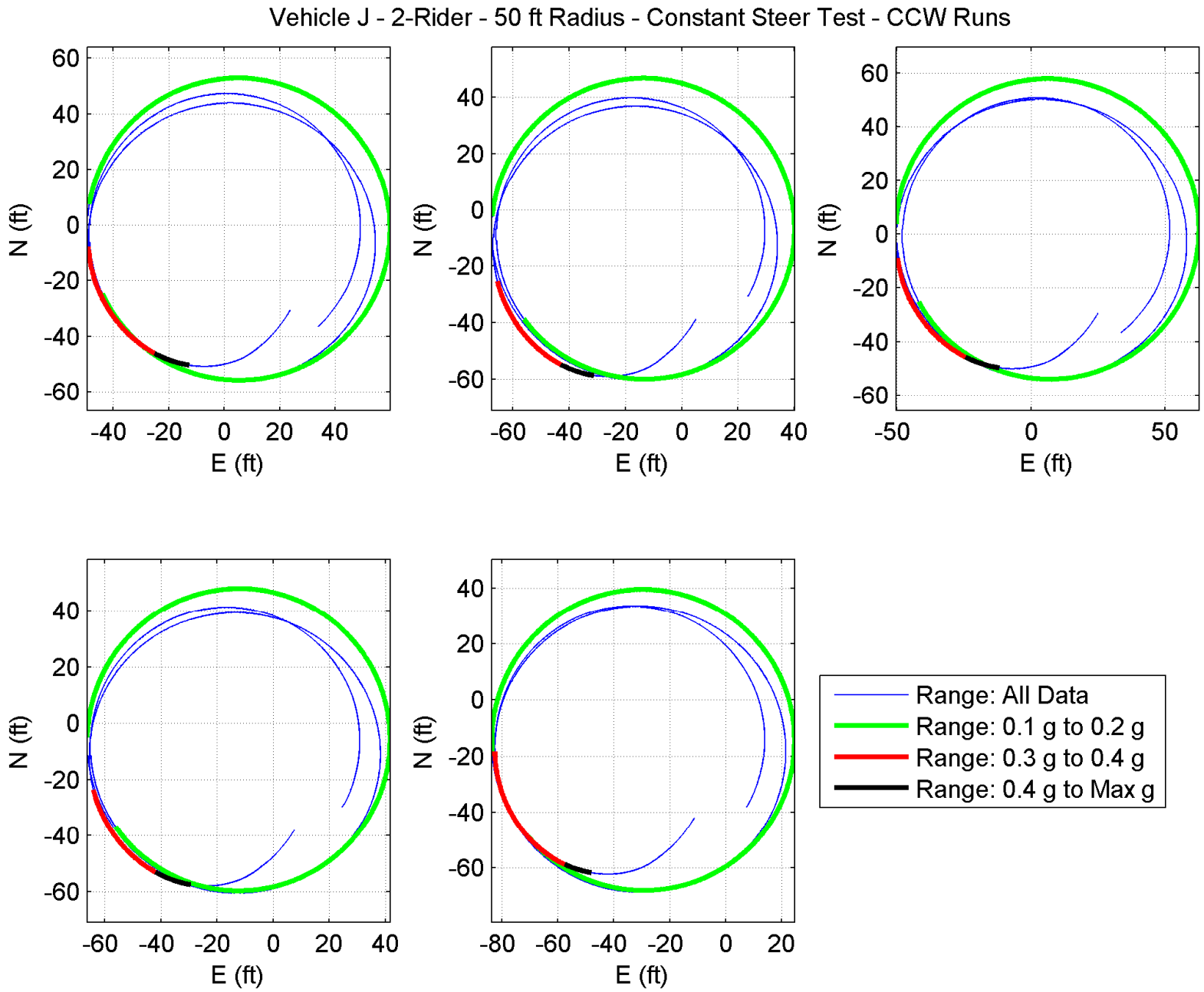
0.3 g to 0.4 g

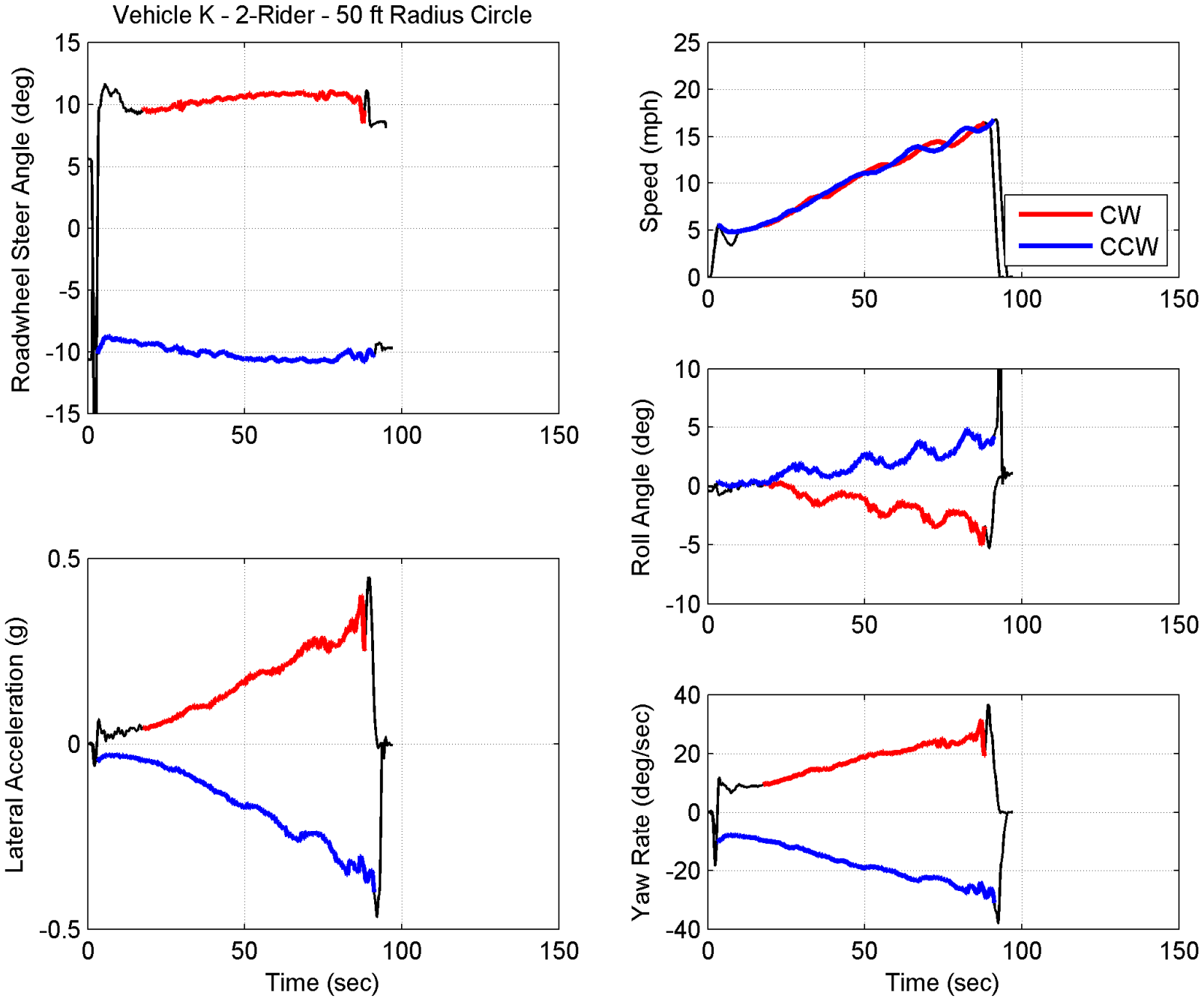


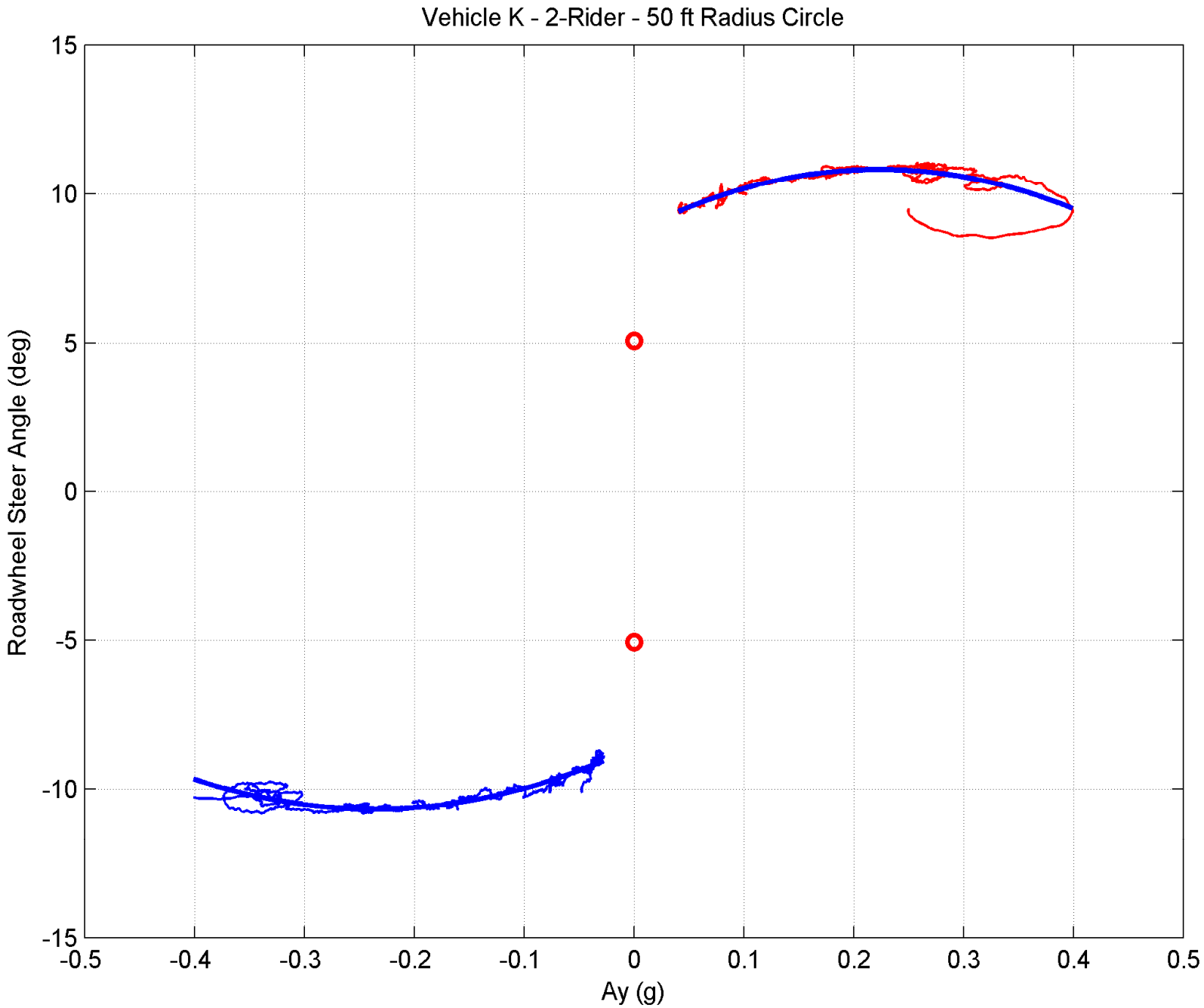
Final Slope Range:

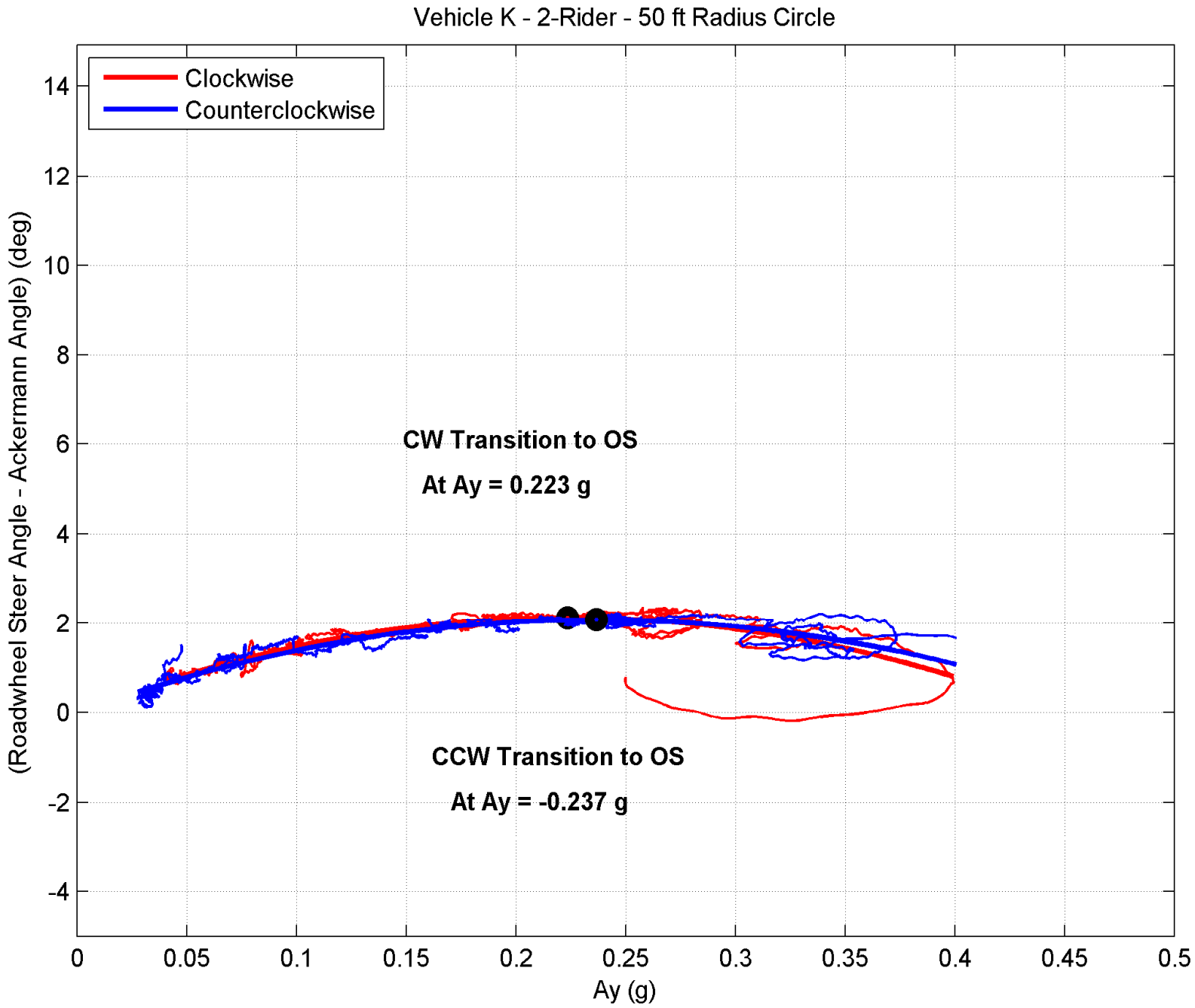
0.3 g to 0.4 g

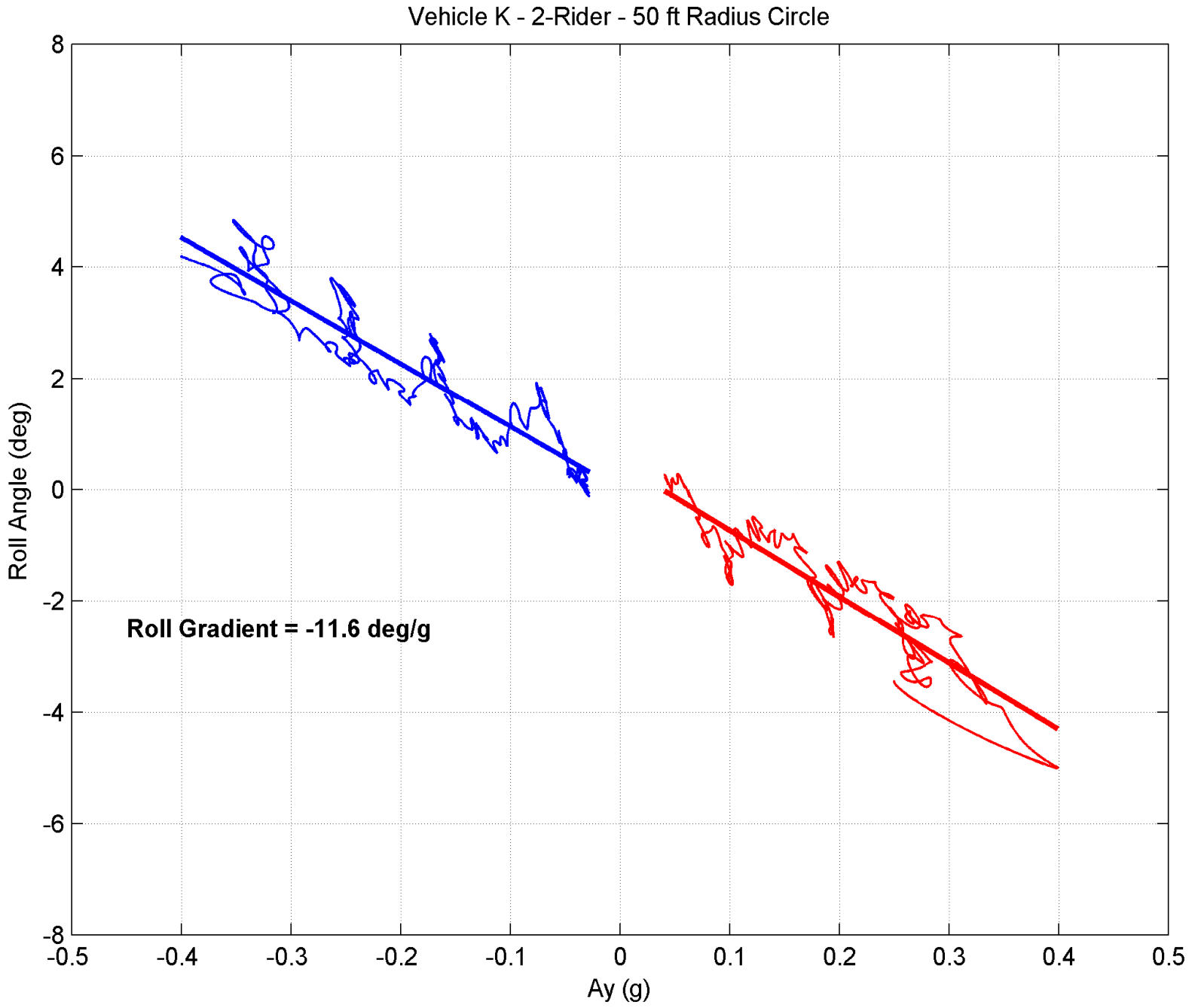

Vehicle J - 2-Rider - 50 ft Radius - Constant Steer Test - CW Runs
N (ft)
E (ft)
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.3 g to 0.4 g
Range: 0.4 g to Max g

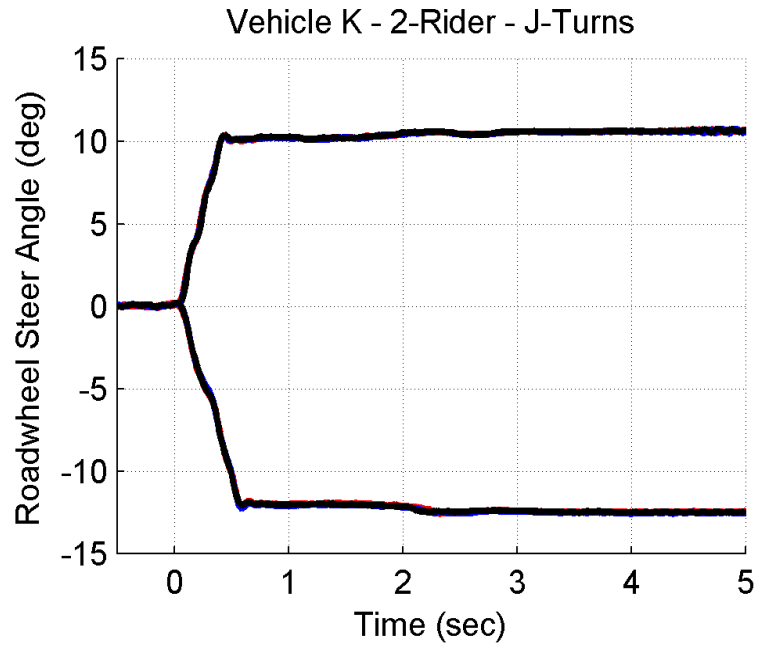

Vehicle J - 2-Rider - 50 ft Radius - Constant Steer Test - CCW Runs
N (ft)
E (ft)
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.3 g to 0.4 g
Range: 0.4 g to Max g

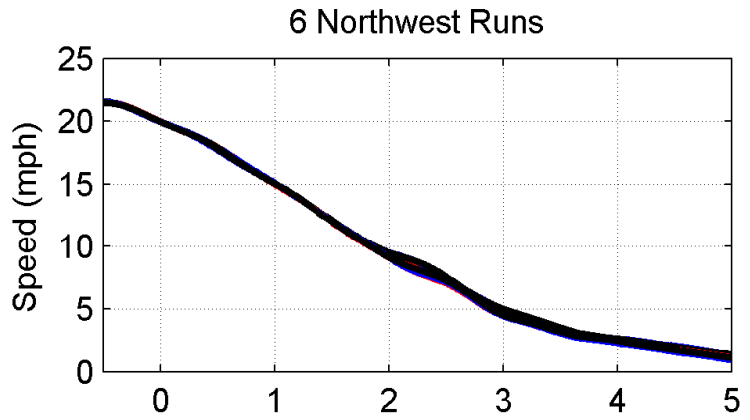

Vehicle K - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
15
10
5
0
-5
-10
-15
0
50
100
150
Speed (mph)
25
20
15
10
5
0
CW
CCW
Roll Angle (deg)
10
5
0
-5
-10
Lateral Acceleration (g)
0.5
0
-0.5
Yaw Rate (deg/sec)
40
20
0
-20
-40
Time (sec)
Time (sec)

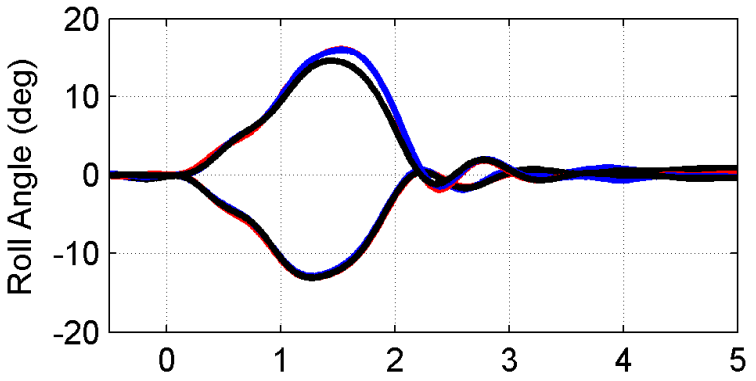

Vehicle K - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
Ay (g)
15
10
5
0
-5
-10
-15
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

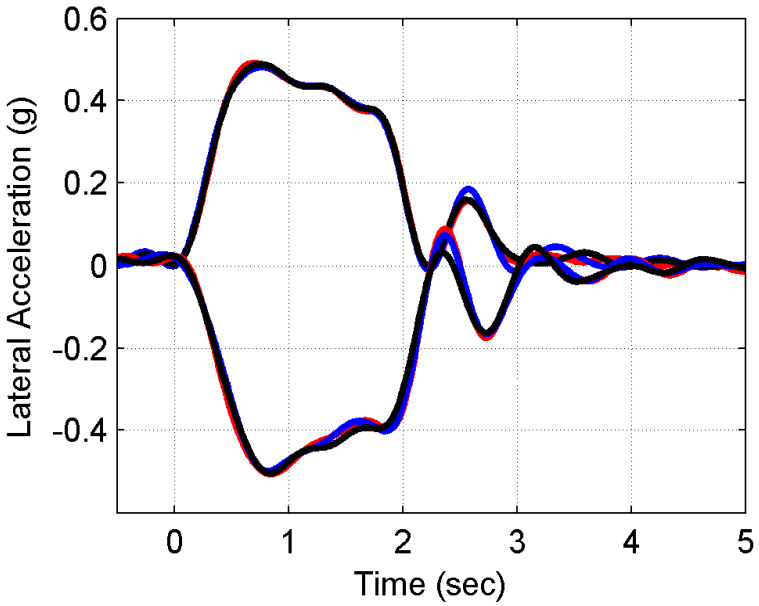

Vehicle K - 2-Rider - 50 ft Radius Circle
Clockwise
Counterclockwise
CW Transition to OS
At Ay = 0.223 g
CCW Transition to OS
At Ay = -0.237 g
(Roadwheel Steer Angle - Ackermann Angle) (deg)
Ay (g)
14
12
10
8
6
4
2
0
-2
-4
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5

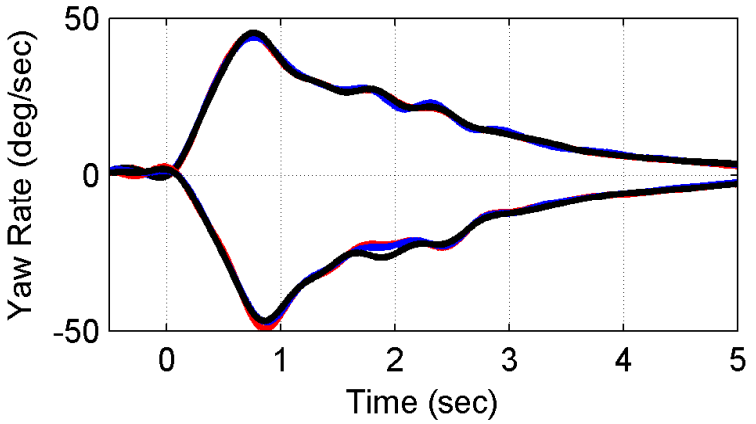

Vehicle K - 2-Rider - 50 ft Radius Circle
Roll Angle (deg)
Ay (g)
Roll Gradient = -11.6 deg/g
8
6
4
2
0
-2
-4
-6
-8
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

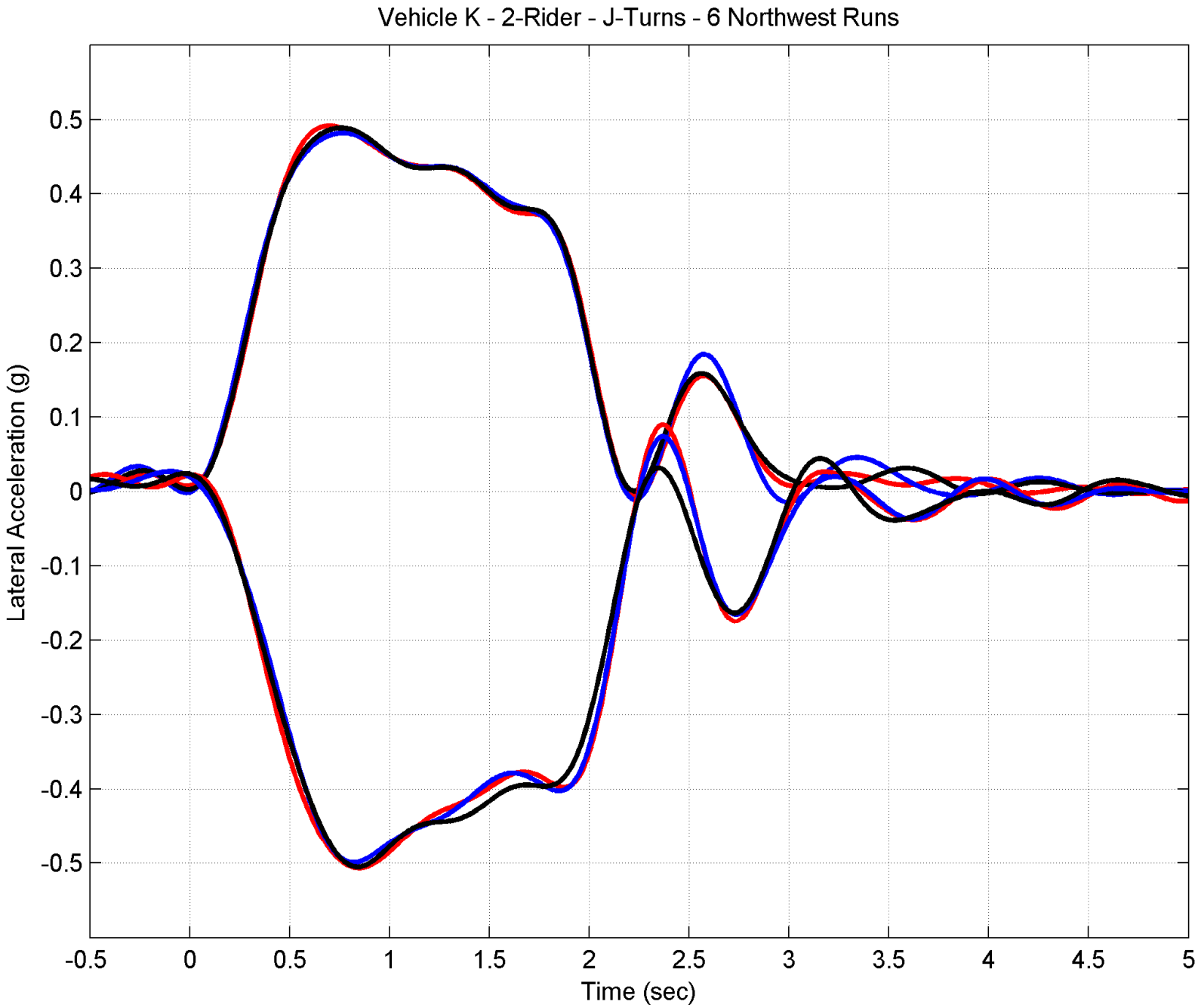

Vehicle K - 2-Rider - J-Turns
Roadwheel Steer Angle (deg)
15
10
5
0
-5
-10
-15
0
1
2
3
4
5
Time (sec)

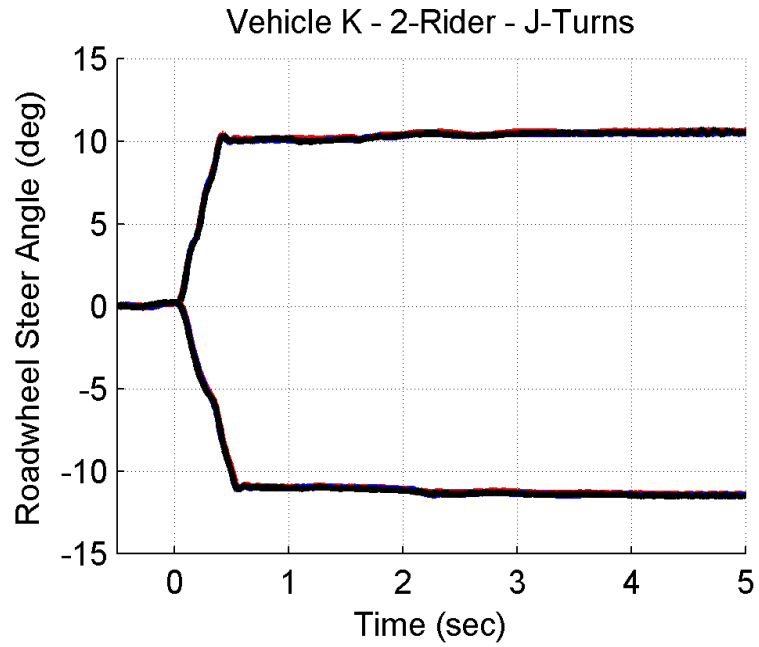

6 Northwest Runs
Speed (mph)
25
20
15
10
5
0
0
1
2
3
4
5

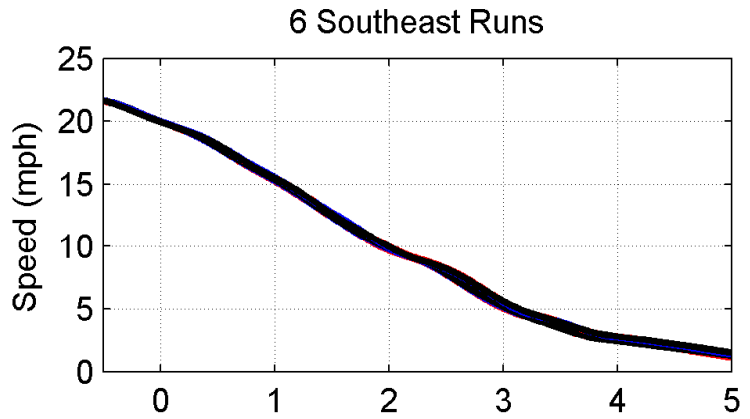

Roll Angle (deg)
20
10
0
-10
-20
0
1
2
3
4
5

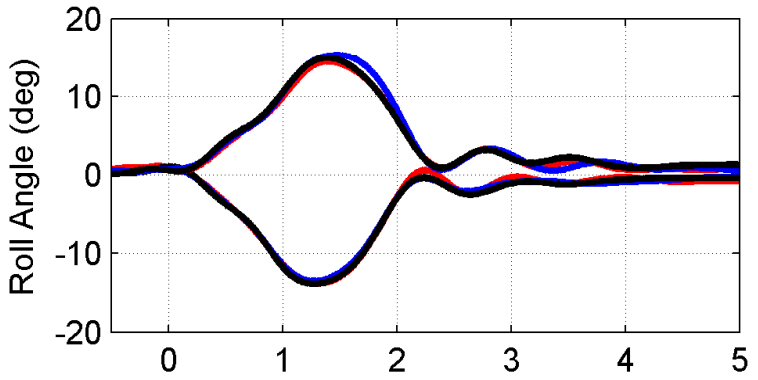

Lateral Acceleration (g)
0.6
0.4
0.2
0
-0.2
-0.4
0
1
2
3
4
5
Time (sec)

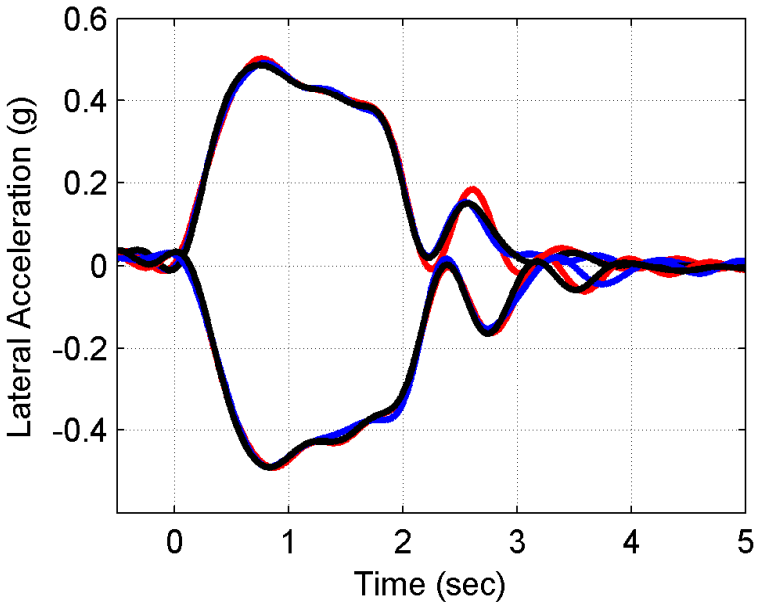

Yaw Rate (deg/sec)
50
0
-50
0
1
2
3
4
5
Time (sec)

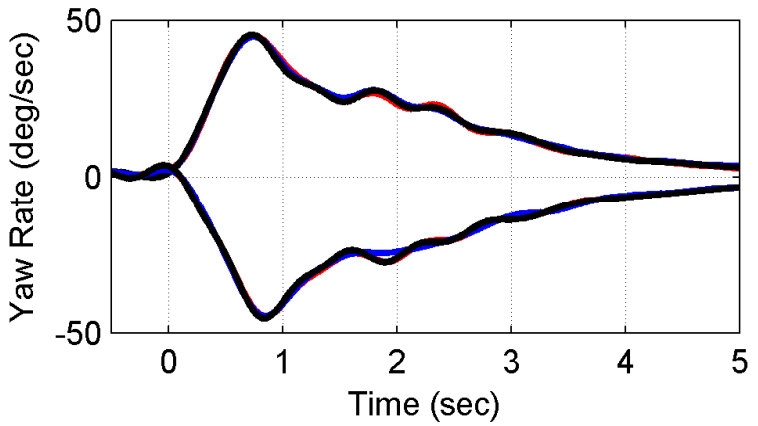

Vehicle K - 2-Rider - J-Turns - 6 Northwest Runs
Lateral Acceleration (g)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (sec)

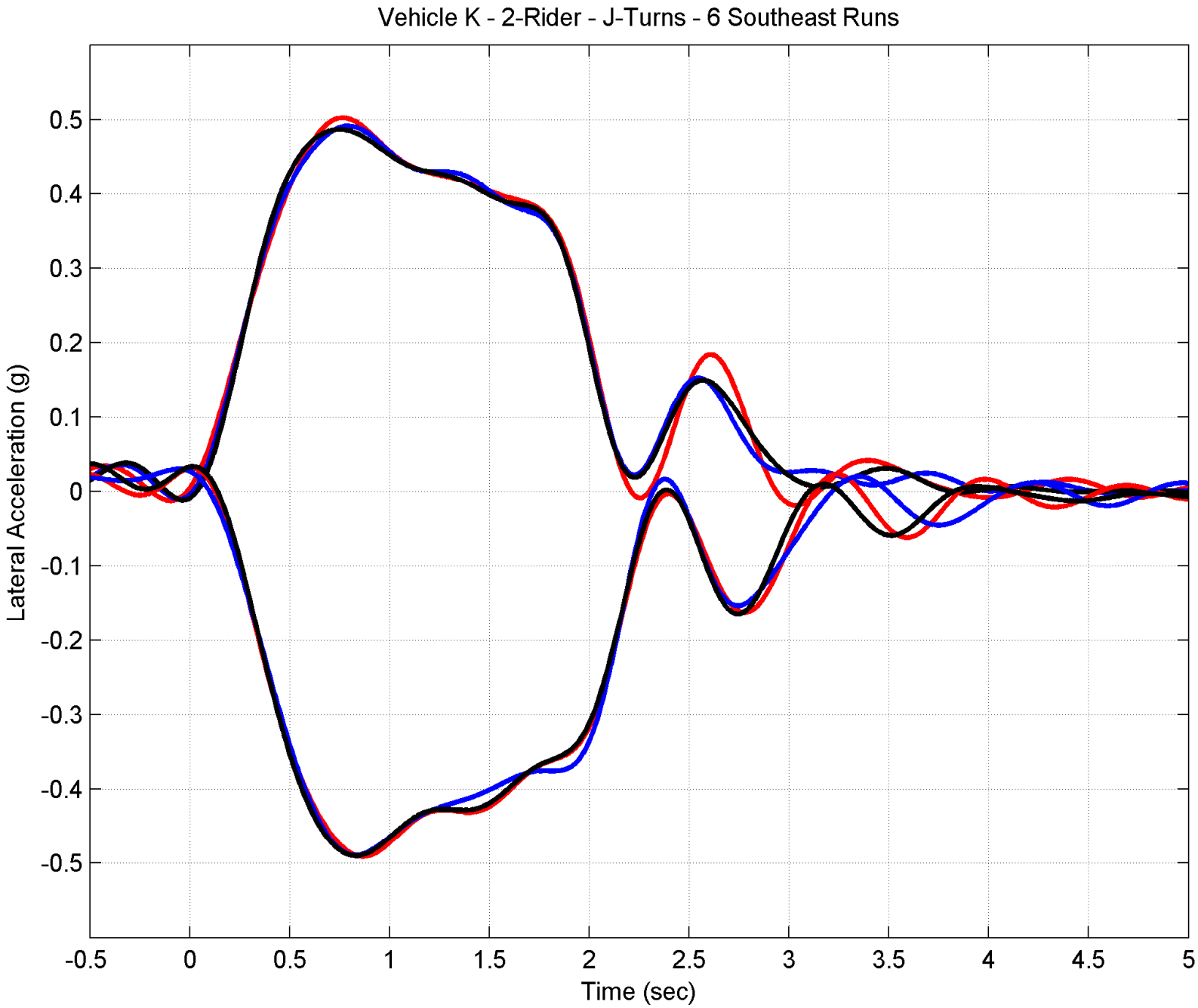

Vehicle K - 2-Rider - J-Turns
Roadwheel Steer Angle (deg)
15
10
5
0
-5
-10
-15
0
1
2
3
4
5
Time (sec)


6 Southeast Runs
Speed (mph)
25
20
15
10
5
0
0
1
2
3
4
5


Roll Angle (deg)
20
10
0
-10
-20
0
1
2
3
4
5


Lateral Acceleration (g)
0.6
0.4
0.2
0
-0.2
-0.4
0
1
2
3
4
5
Time (sec)


Yaw Rate (deg/sec)
50
0
-50
0
1
2
3
4
5
Time (sec)


Vehicle K - 2-Rider - J-Turns - 6 Southeast Runs
Lateral Acceleration (g)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (sec)

Vehicle K - 2-Rider Results

Peak Lateral Accelerations During 2WL J-Turns - All Values in "g's"

Run Number	Northwest Right Turns	Northwest Left Turns
1	0.492	-0.507
2	0.482	-0.499
3	0.489	-0.505
Mean Value of 3 Runs	0.488	-0.504
Standard Deviation of 3 Runs	0.005	0.004

Average of 6 Northwest Runs

0.496

Run Number	Southeast Right Turns	Southeast Left Turns
1	0.503	-0.491
2	0.491	-0.490
3	0.487	-0.490
Mean Value of 3 Runs	0.494	-0.490
Standard Deviation of 3 Runs	0.008	0.001

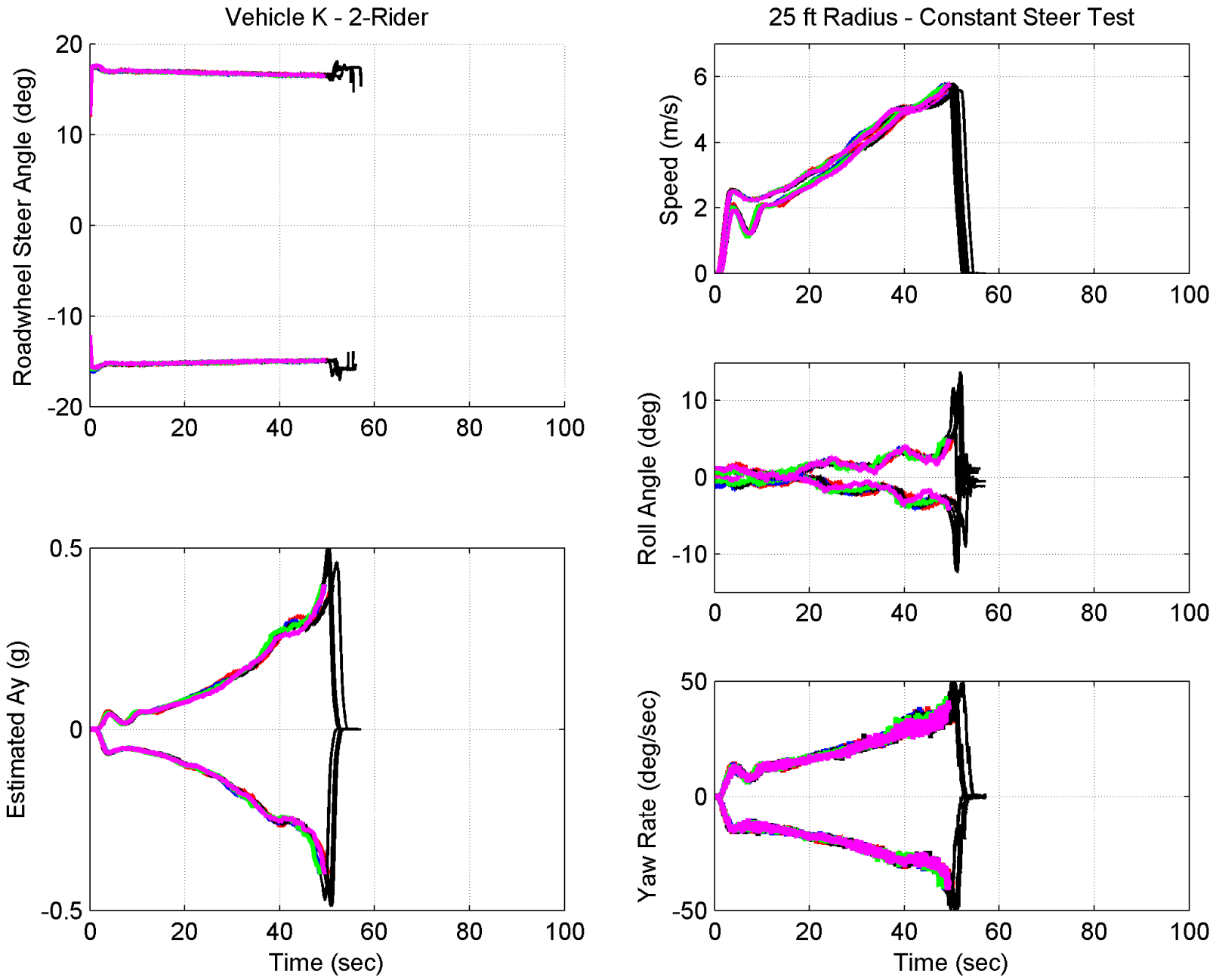
Average of 6 Southeast Runs

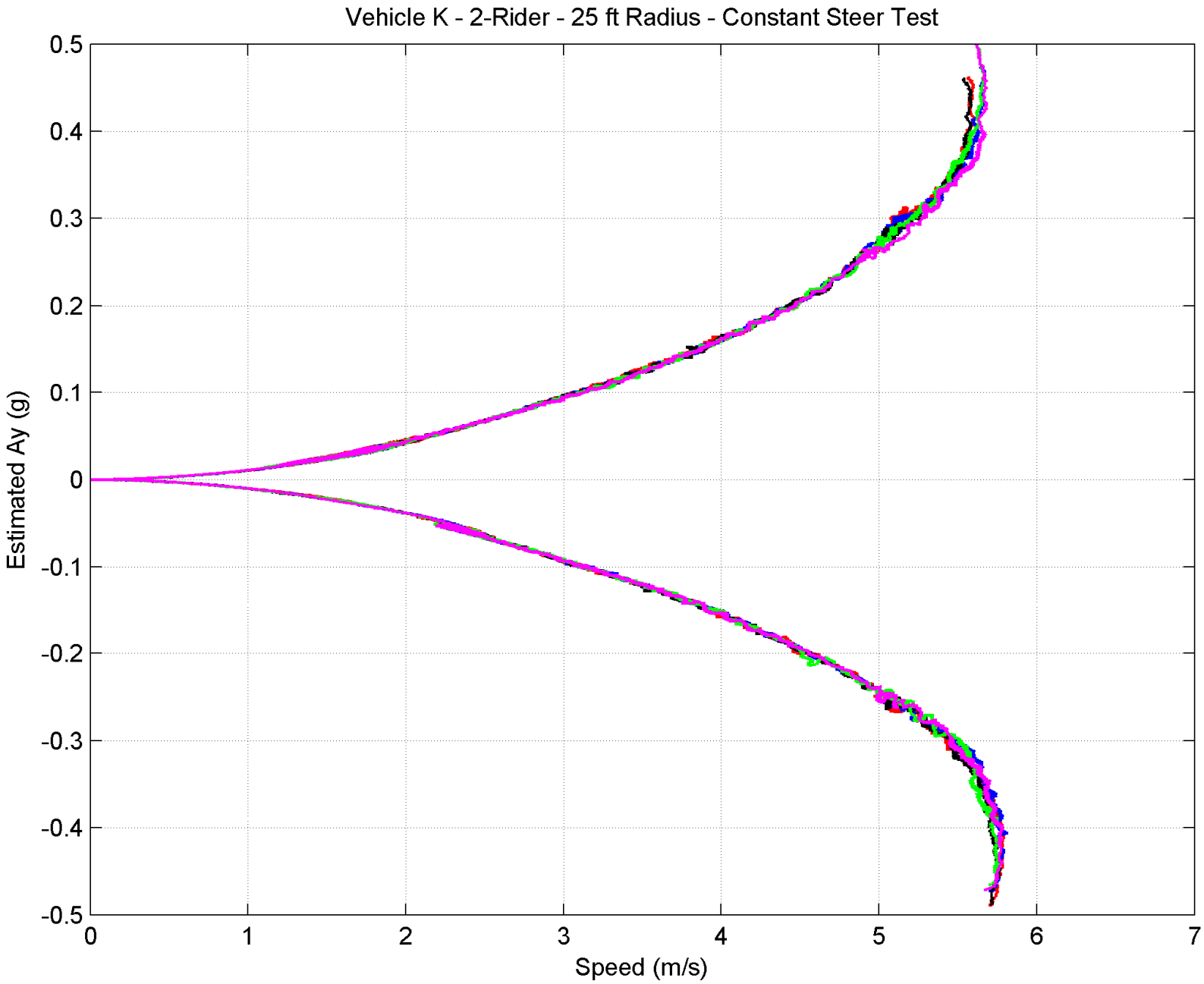
0.492

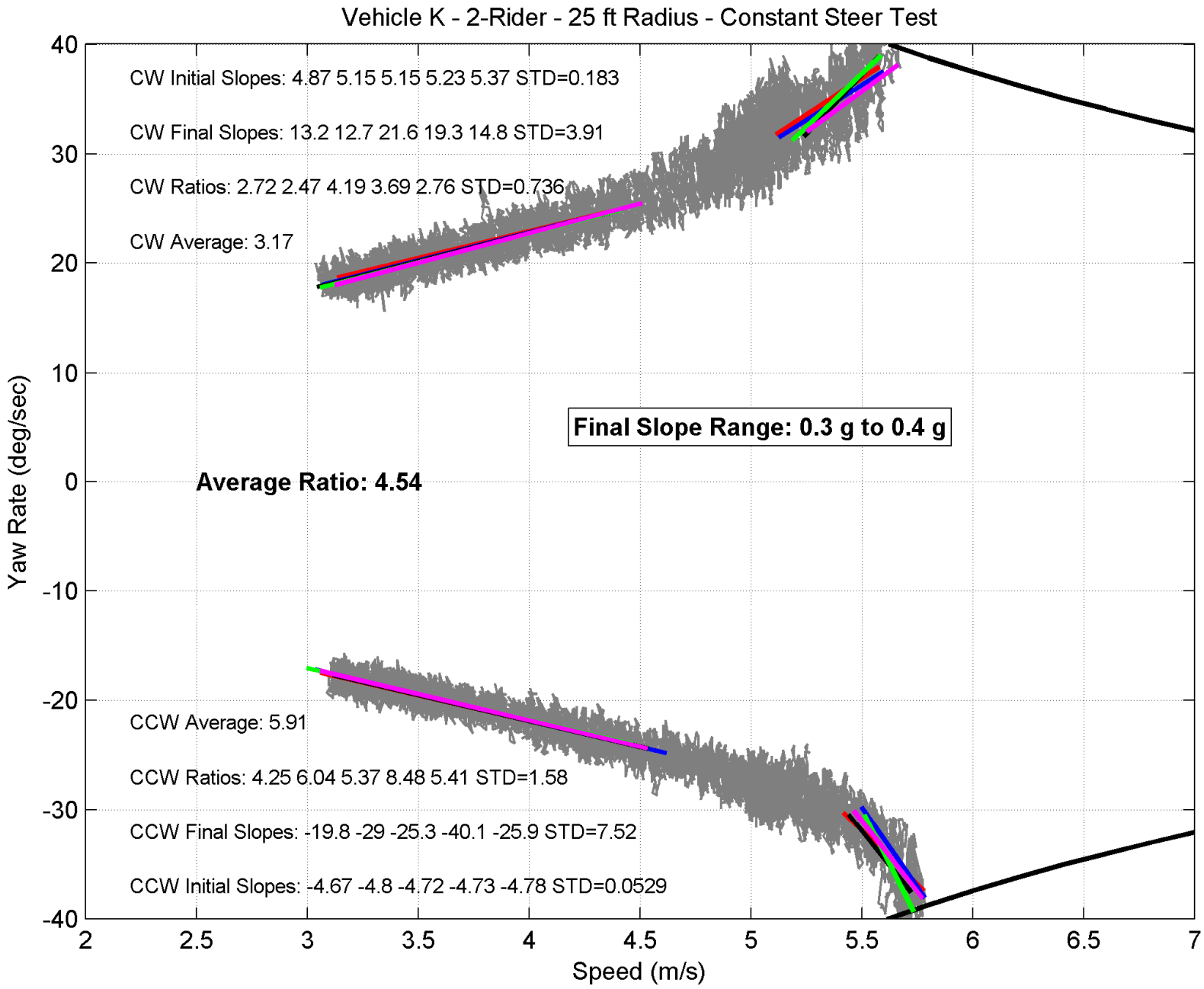
Average of All 12 Runs

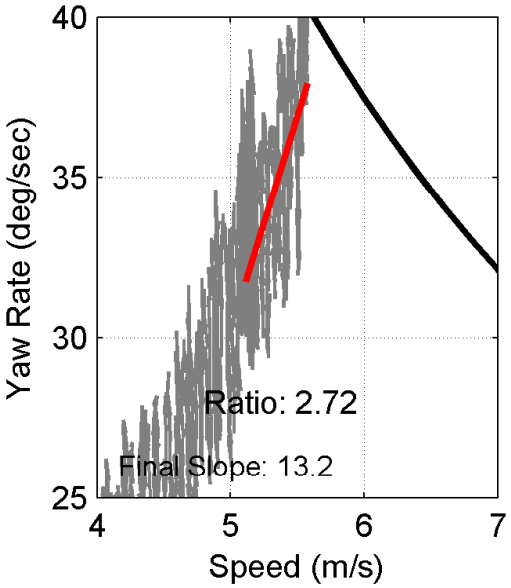
0.494

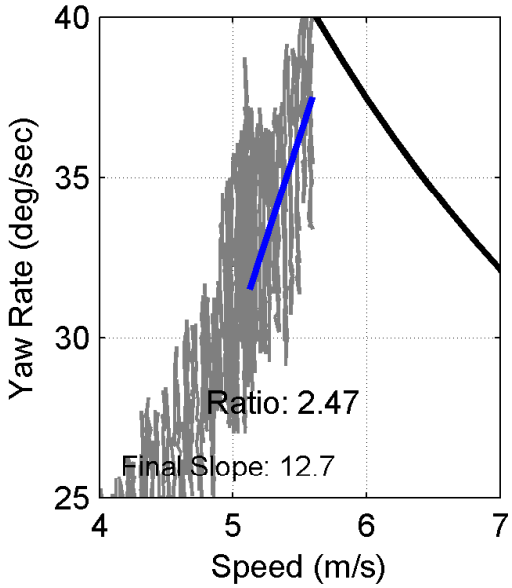
Threshold Ay

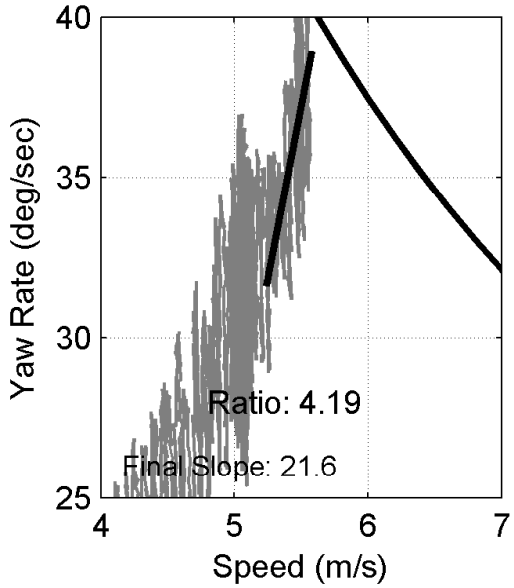

Vehicle K - 2-Rider
Roadwheel Steer Angle (deg)
Estimated Ay (g)
Time (sec)
25 ft Radius - Constant Steer Test
Speed (m/s)
Roll Angle (deg)
Yaw Rate (deg/sec)
Time (sec)

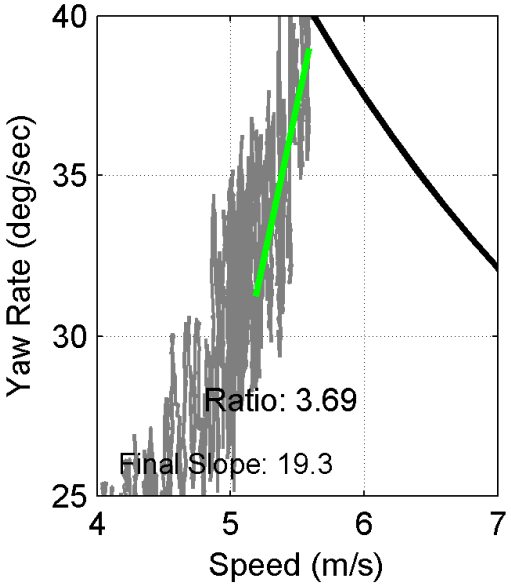

Vehicle K - 2-Rider - 25 ft Radius - Constant Steer Test
Estimated Ay (g)
Speed (m/s)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
1
2
3
4
5
6
7

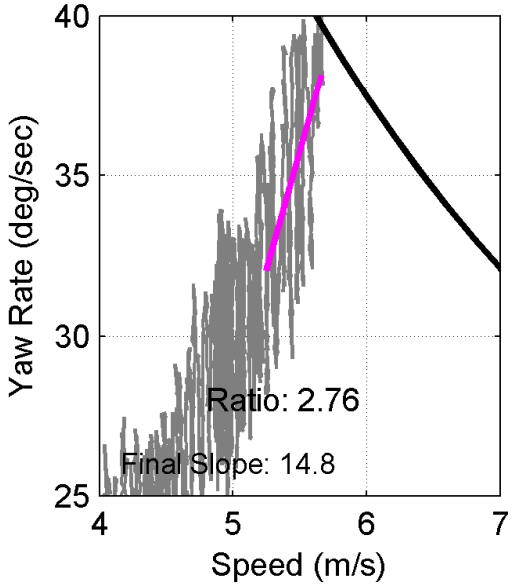

Vehicle K - 2-Rider - 25 ft Radius - Constant Steer Test
CW Initial Slopes: 4.87 5.15 5.15 5.23 5.37 STD=0.183
CW Final Slopes: 13.2 12.7 21.6 19.3 14.8 STD=3.91
CW Ratios: 2.72 2.47 4.19 3.69 2.76 STD=0.736
CW Average: 3.17
Final Slope Range: 0.3 g to 0.4 g
Average Ratio: 4.54
CCW Average: 5.91
CCW Ratios: 4.25 6.04 5.37 8.48 5.41 STD=1.58
CCW Final Slopes: -19.8 -29 -25.3 -40.1 -25.9 STD=7.52
CCW Initial Slopes: -4.67 -4.8 -4.72 -4.73 -4.78 STD=0.0529
Yaw Rate (deg/sec)
Speed (m/s)
40
30
20
10
0
-10
-20
-30
-40
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7





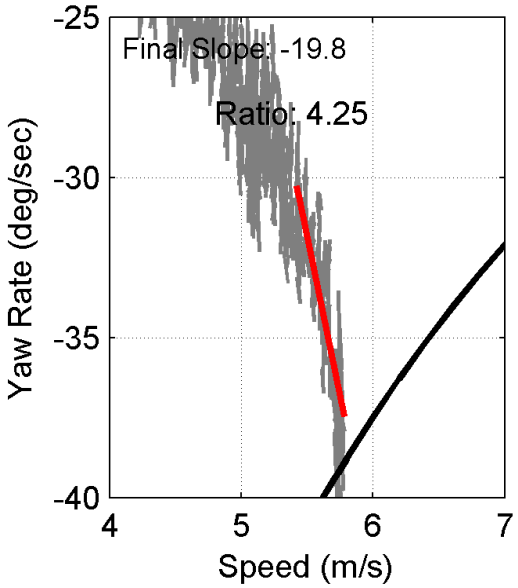


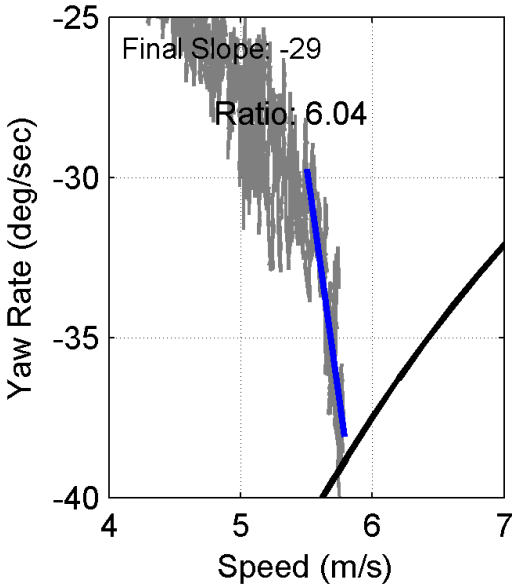


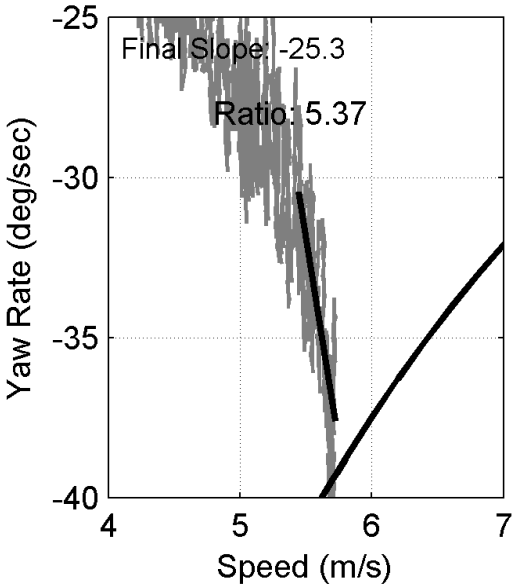


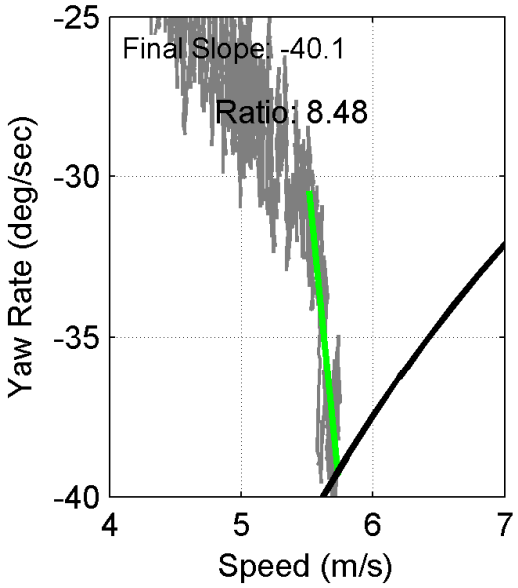
Final Slope Range:

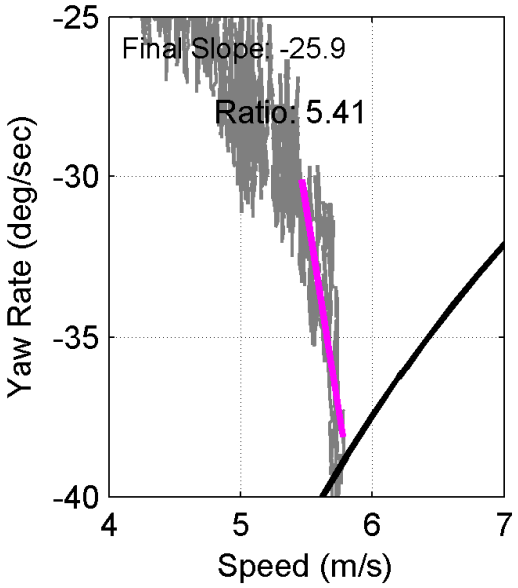
0.3 g to 0.4 g





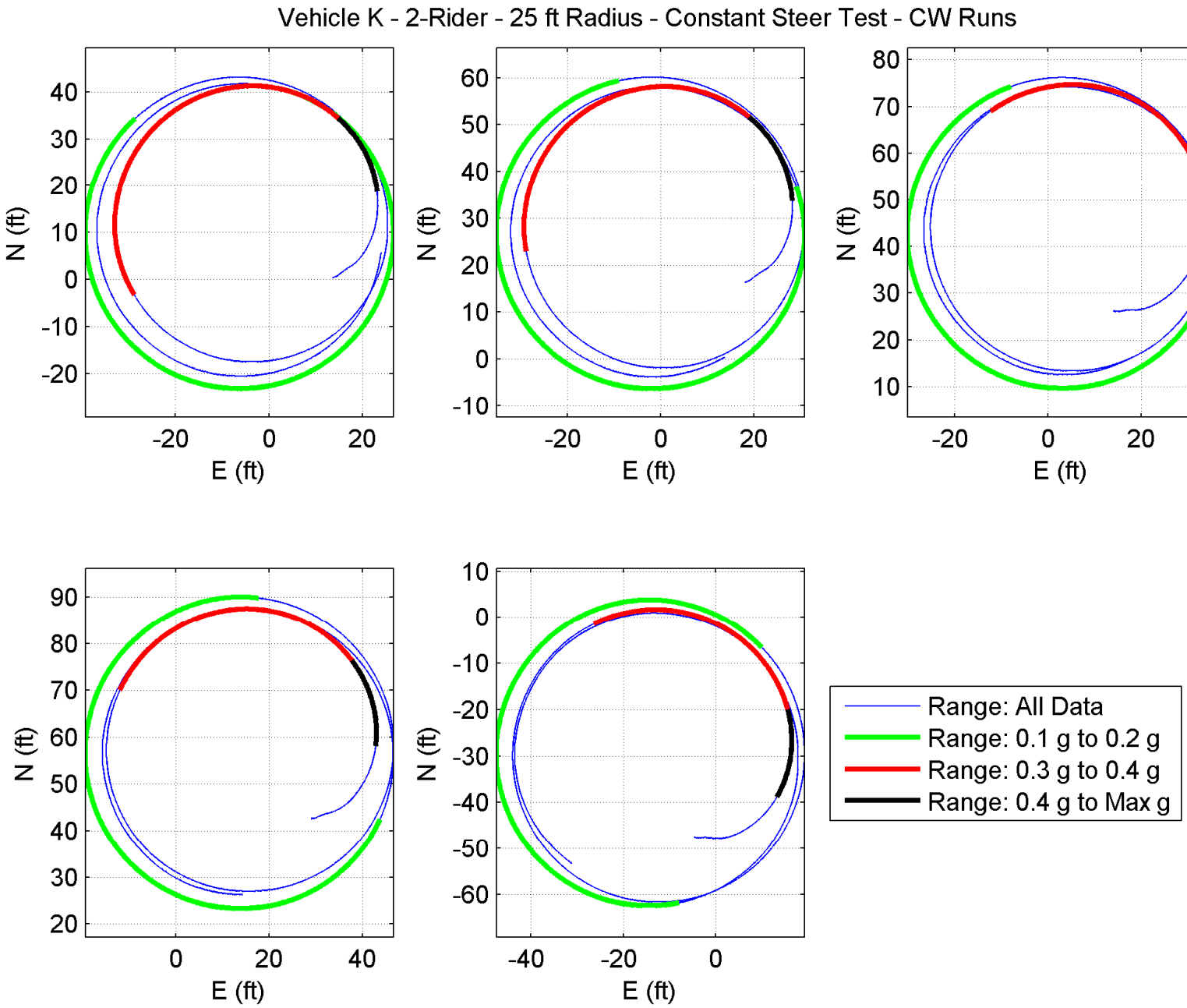


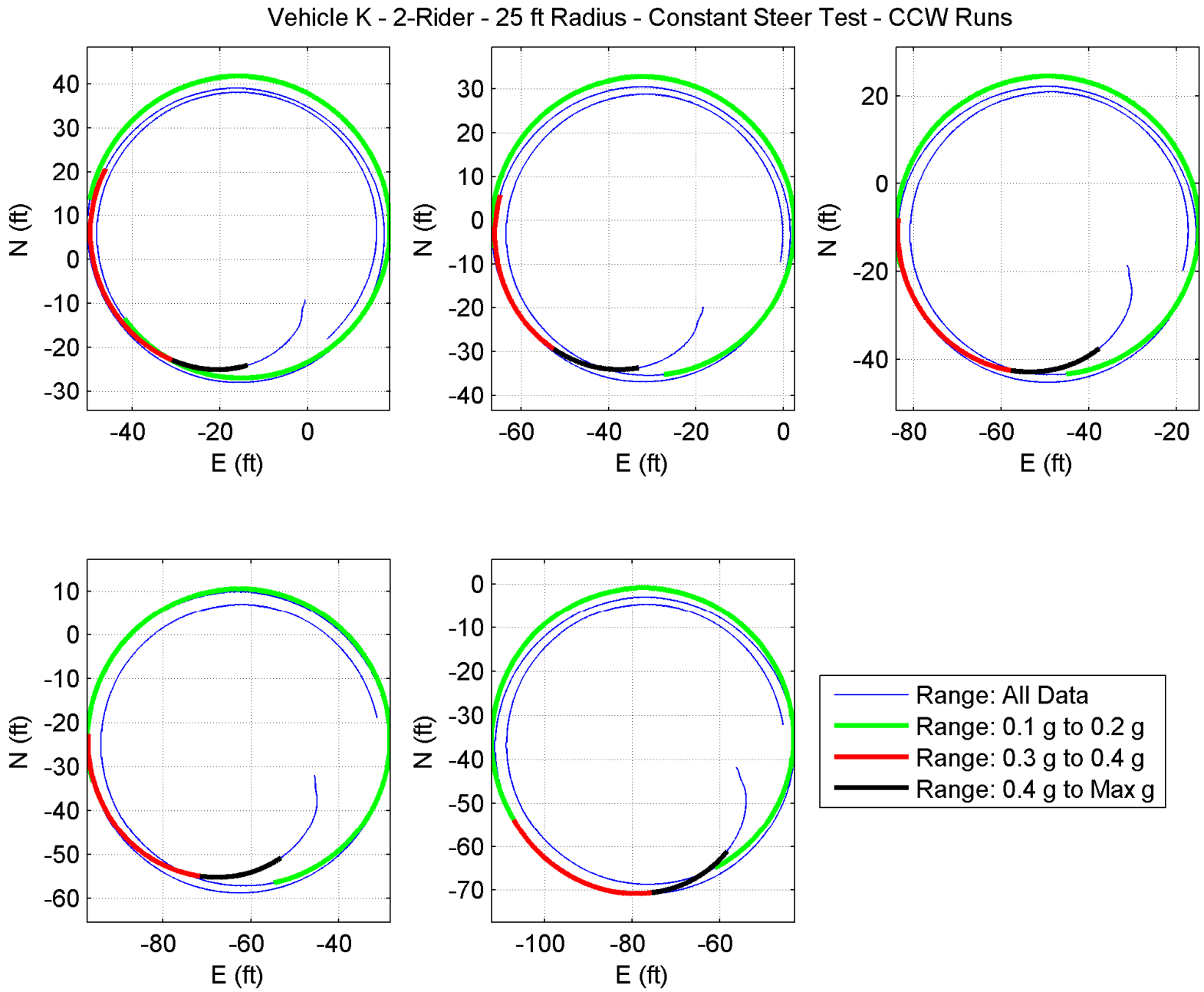


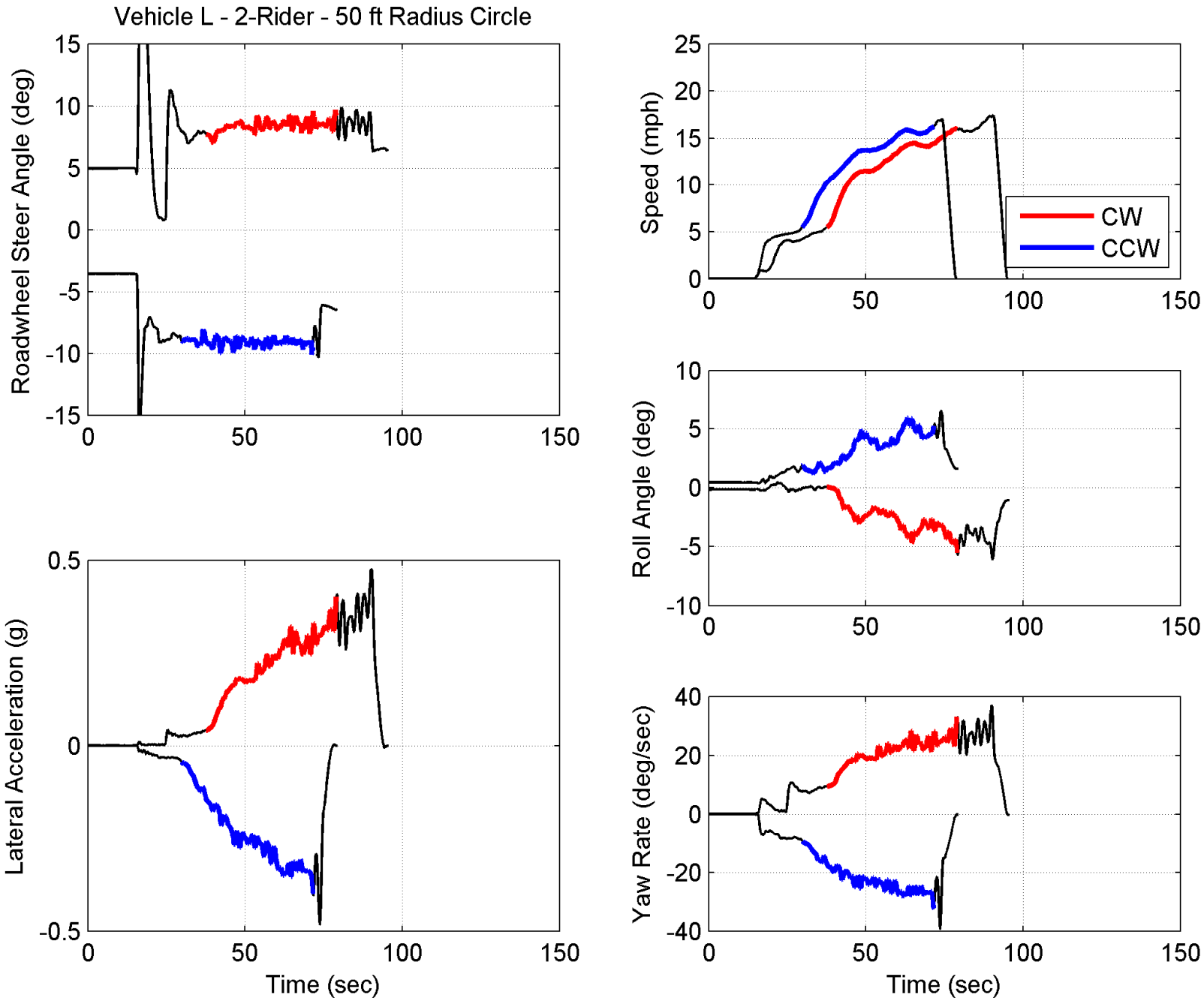


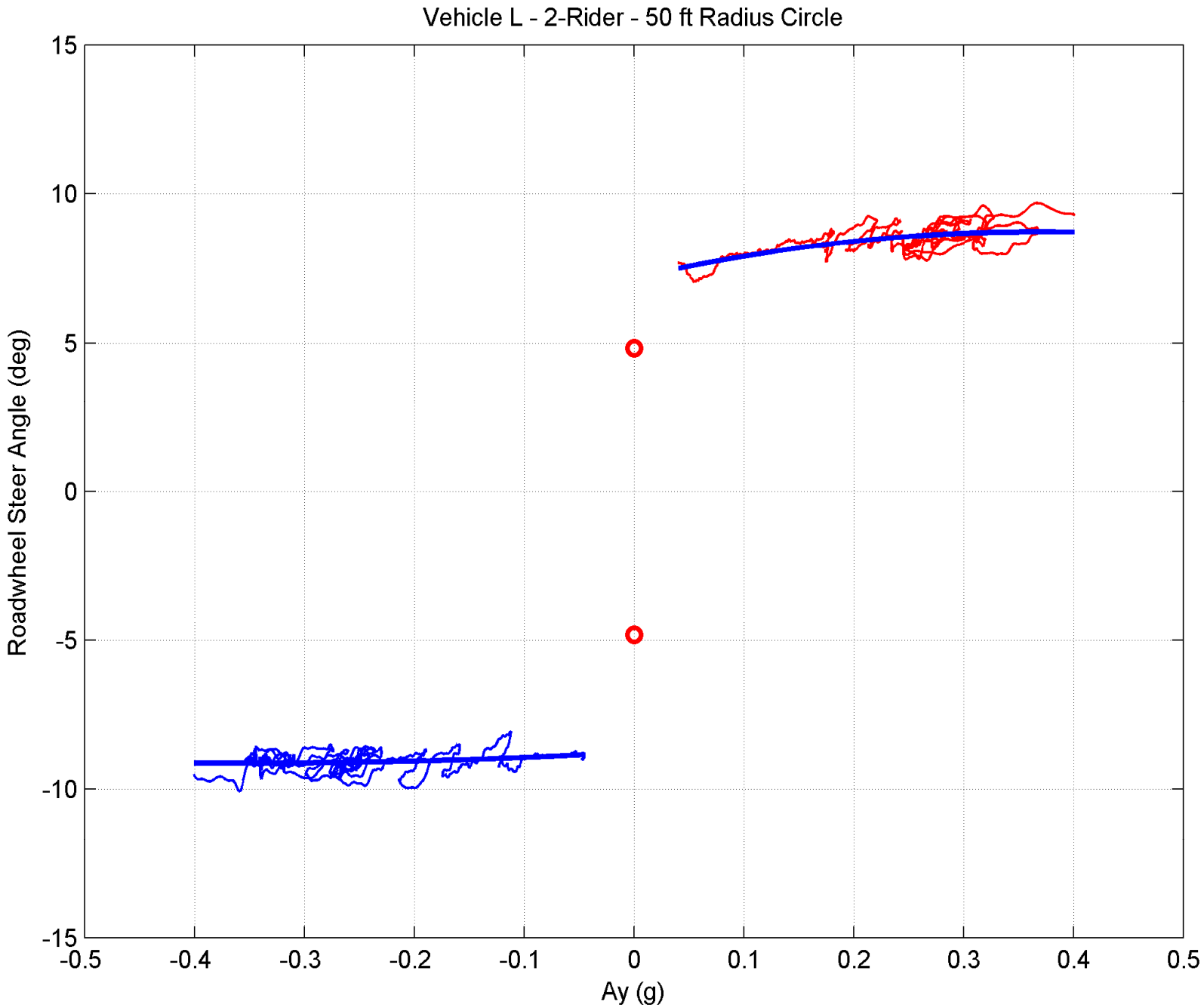
Final Slope Range:

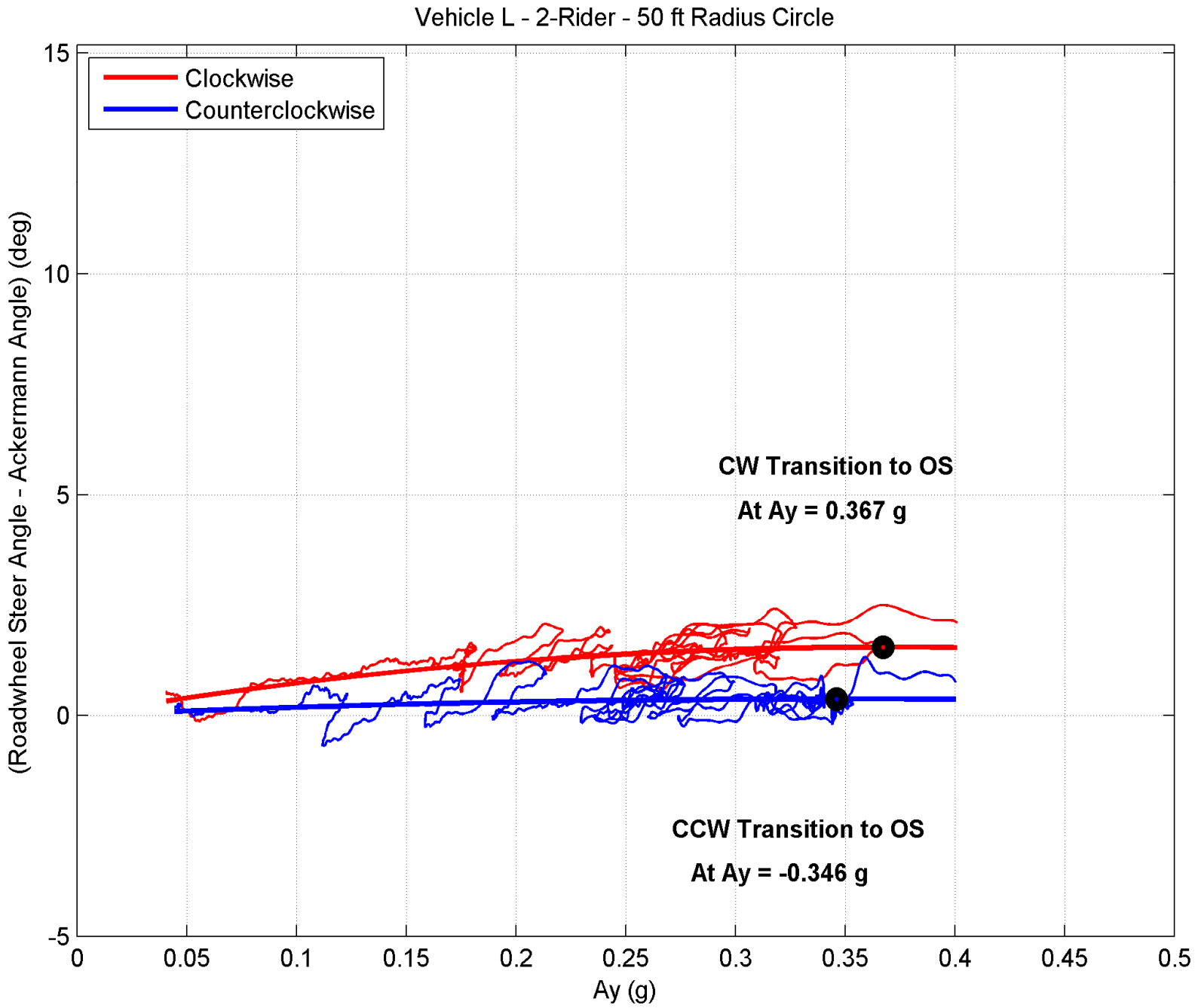
0.3 g to 0.4 g

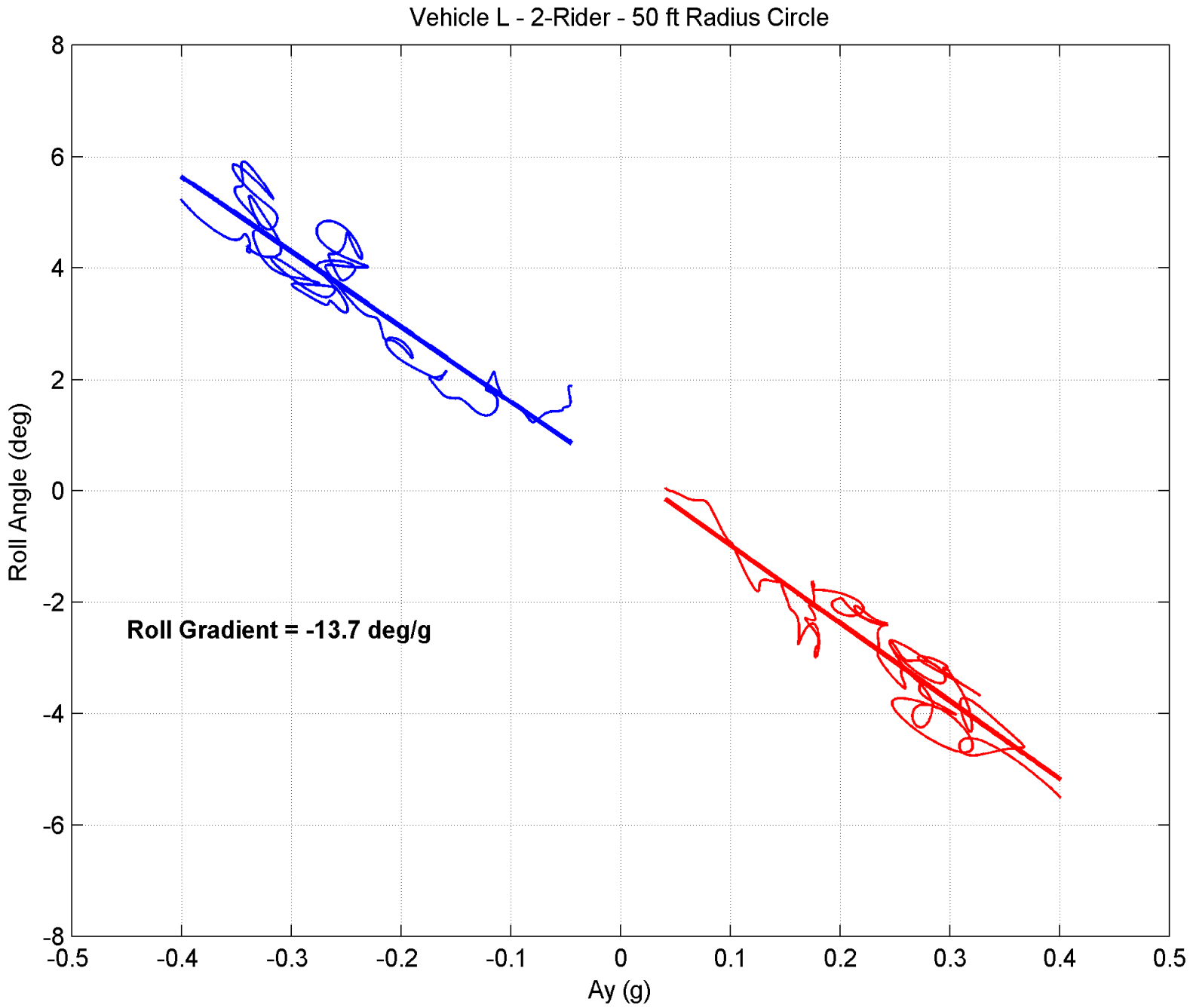

Vehicle K - 2-Rider - 25 ft Radius - Constant Steer Test - CW Runs
N (ft)
E (ft)
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.3 g to 0.4 g
Range: 0.4 g to Max g

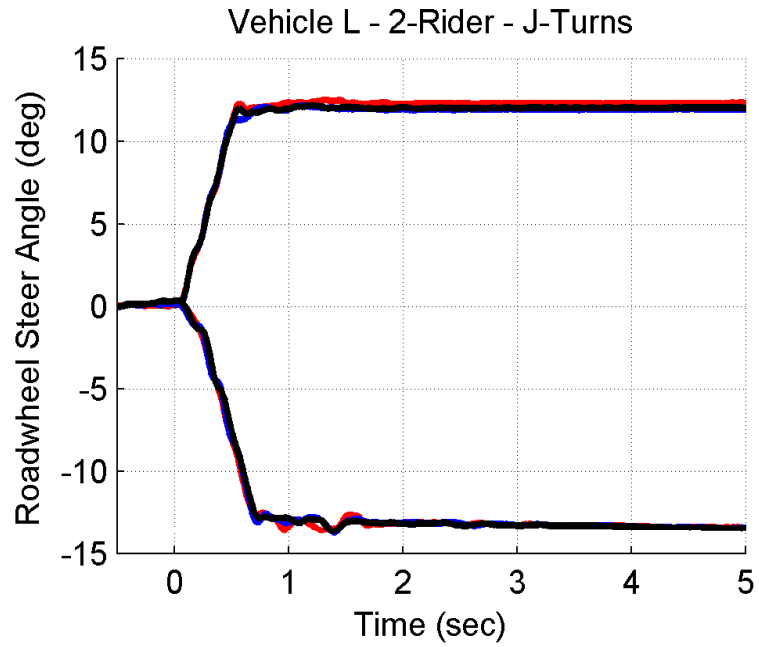

Vehicle K - 2-Rider - 25 ft Radius - Constant Steer Test - CCW Runs
N (ft)
E (ft)
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.3 g to 0.4 g
Range: 0.4 g to Max g

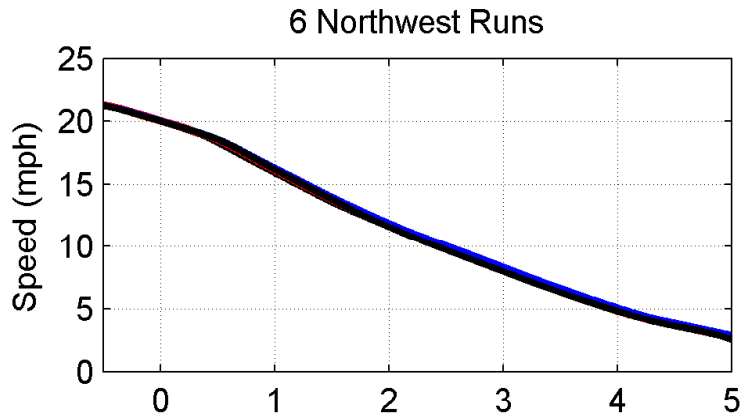

Vehicle L - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
Speed (mph)
CW
CCW
Roll Angle (deg)
Lateral Acceleration (g)
Yaw Rate (deg/sec)
Time (sec)
Time (sec)

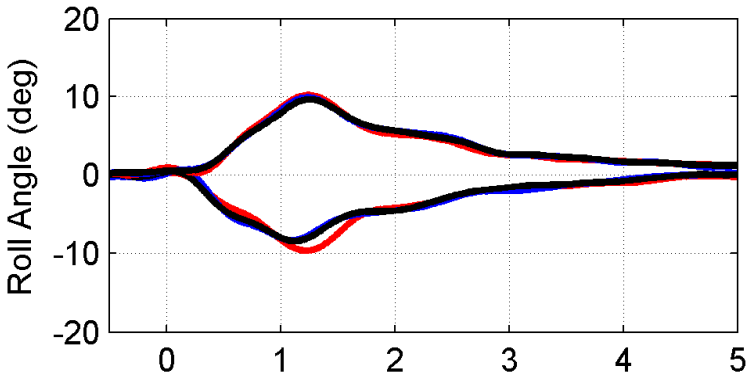

Vehicle L - 2-Rider - 50 ft Radius Circle
Roadwheel Steer Angle (deg)
Ay (g)
15
10
5
0
-5
-10
-15
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

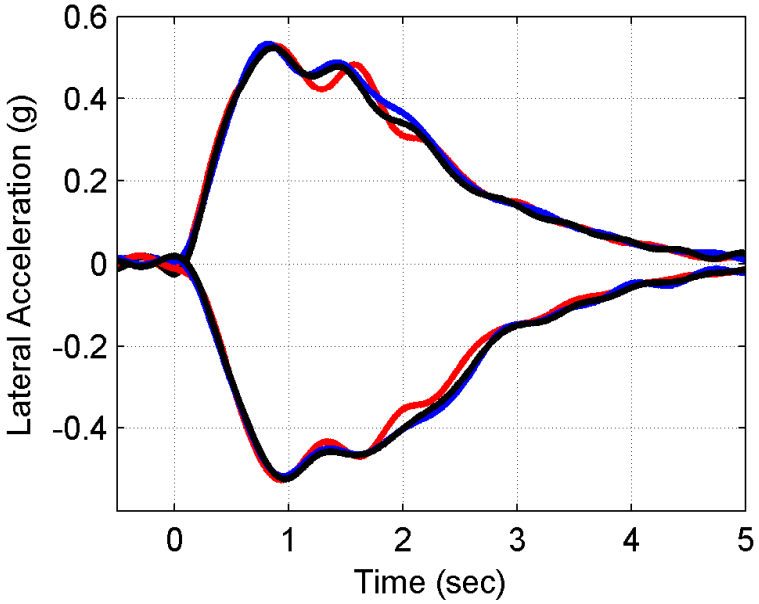

Vehicle L - 2-Rider - 50 ft Radius Circle
Clockwise
Counterclockwise
CW Transition to OS
At Ay = 0.367 g
CCW Transition to OS
At Ay = -0.346 g
(Roadwheel Steer Angle - Ackermann Angle) (deg)
Ay (g)
15
10
5
0
-5
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5

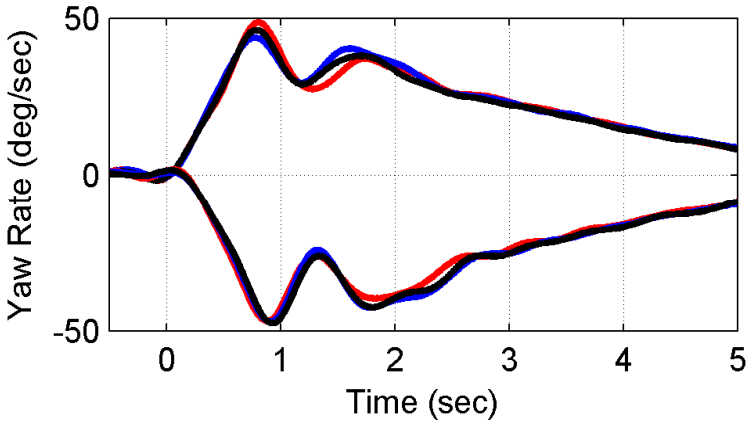

Vehicle L - 2-Rider - 50 ft Radius Circle
Roll Angle (deg)
Ay (g)
Roll Gradient = -13.7 deg/g
8
6
4
2
0
-2
-4
-6
-8
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

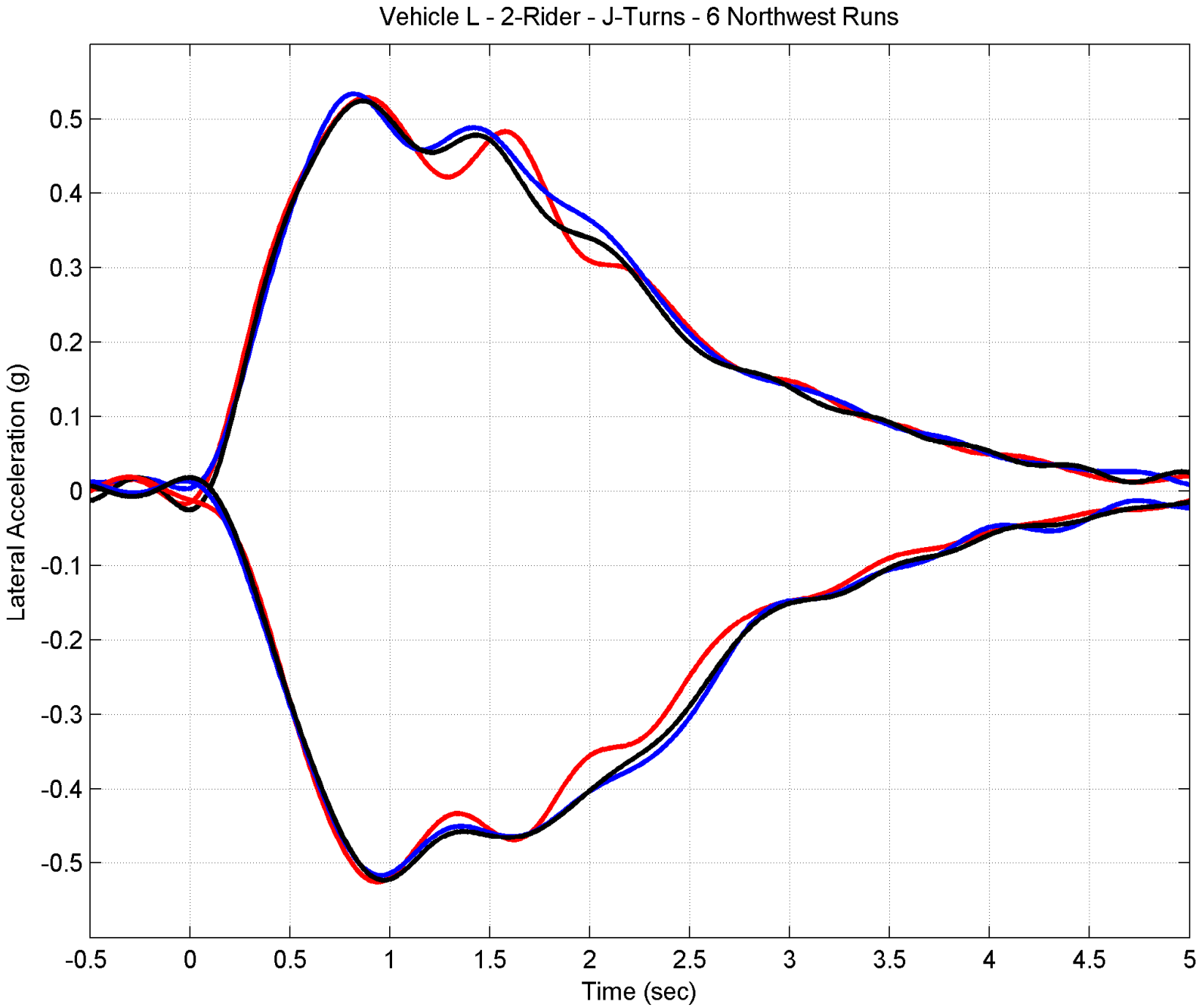

Vehicle L - 2-Rider - J-Turns
Roadwheel Steer Angle (deg)
15
10
5
0
-5
-10
-15
0
1
2
3
4
5
Time (sec)

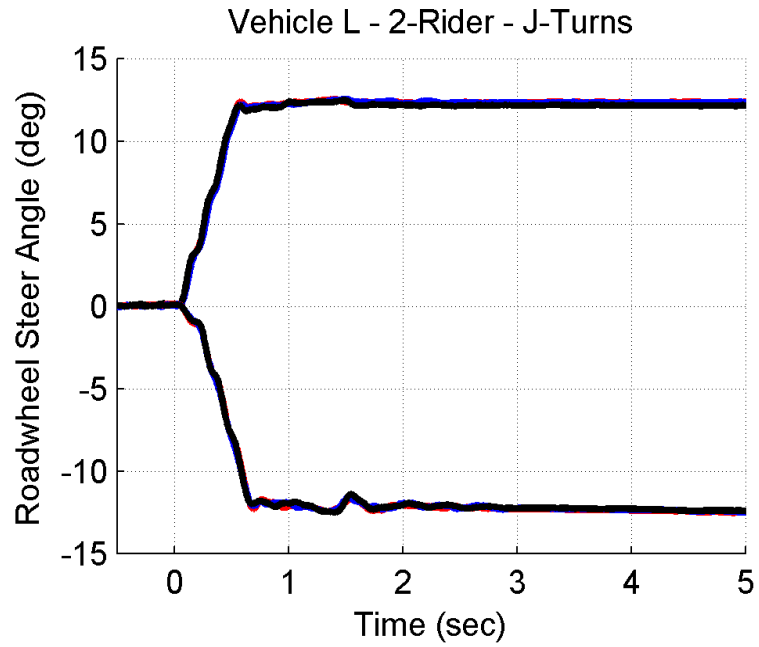

6 Northwest Runs
Speed (mph)
25
20
15
10
5
0
0
1
2
3
4
5

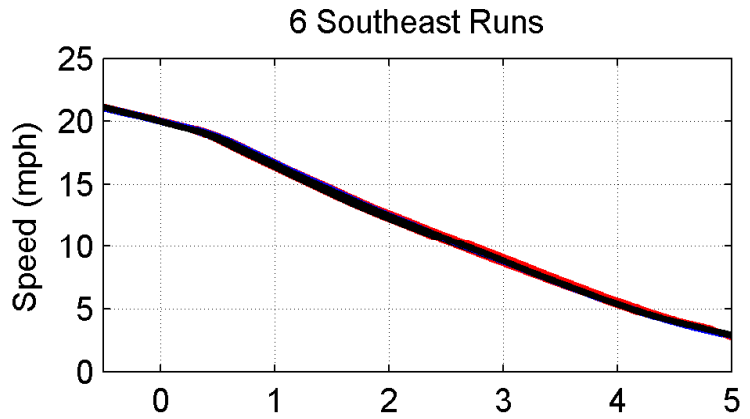

Roll Angle (deg)
20
10
0
-10
-20
0
1
2
3
4
5

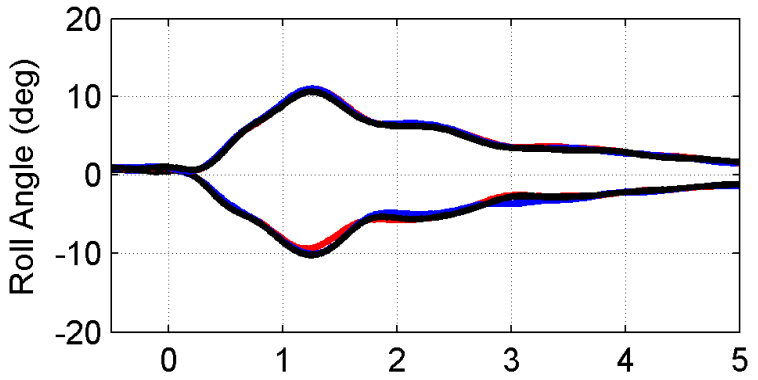

Lateral Acceleration (g)
0.6
0.4
0.2
0
-0.2
-0.4
0
1
2
3
4
5
Time (sec)

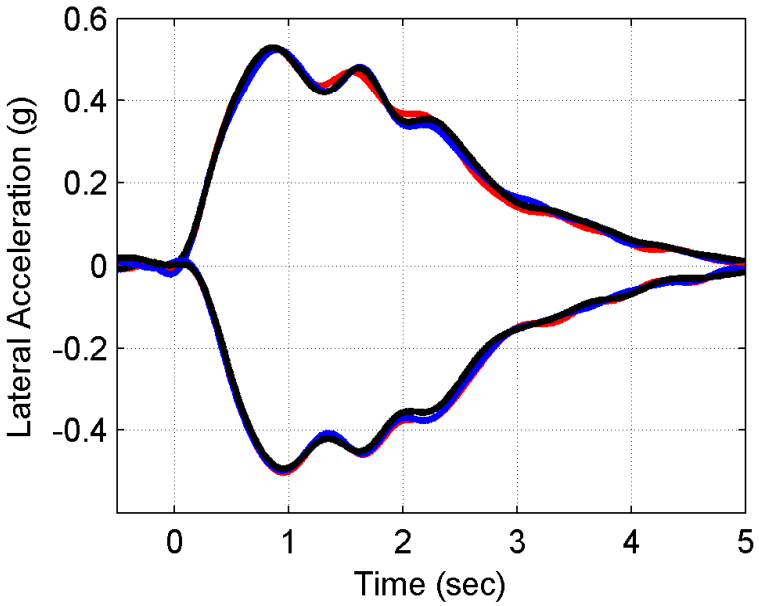

Yaw Rate (deg/sec)
50
0
-50
0
1
2
3
4
5
Time (sec)

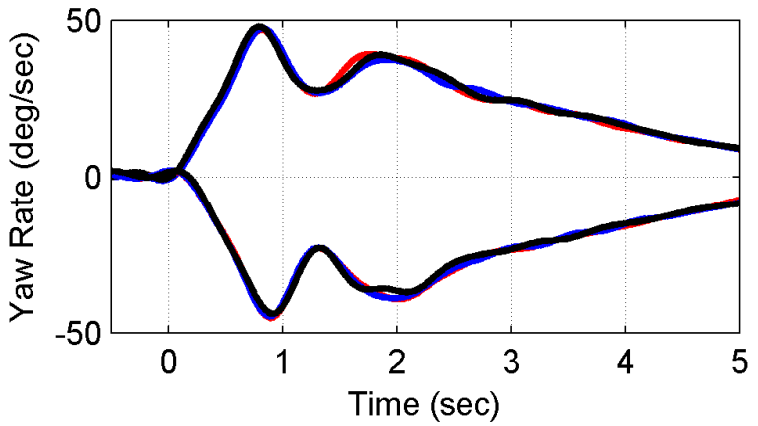

Vehicle L - 2-Rider - J-Turns - 6 Northwest Runs
Lateral Acceleration (g)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (sec)

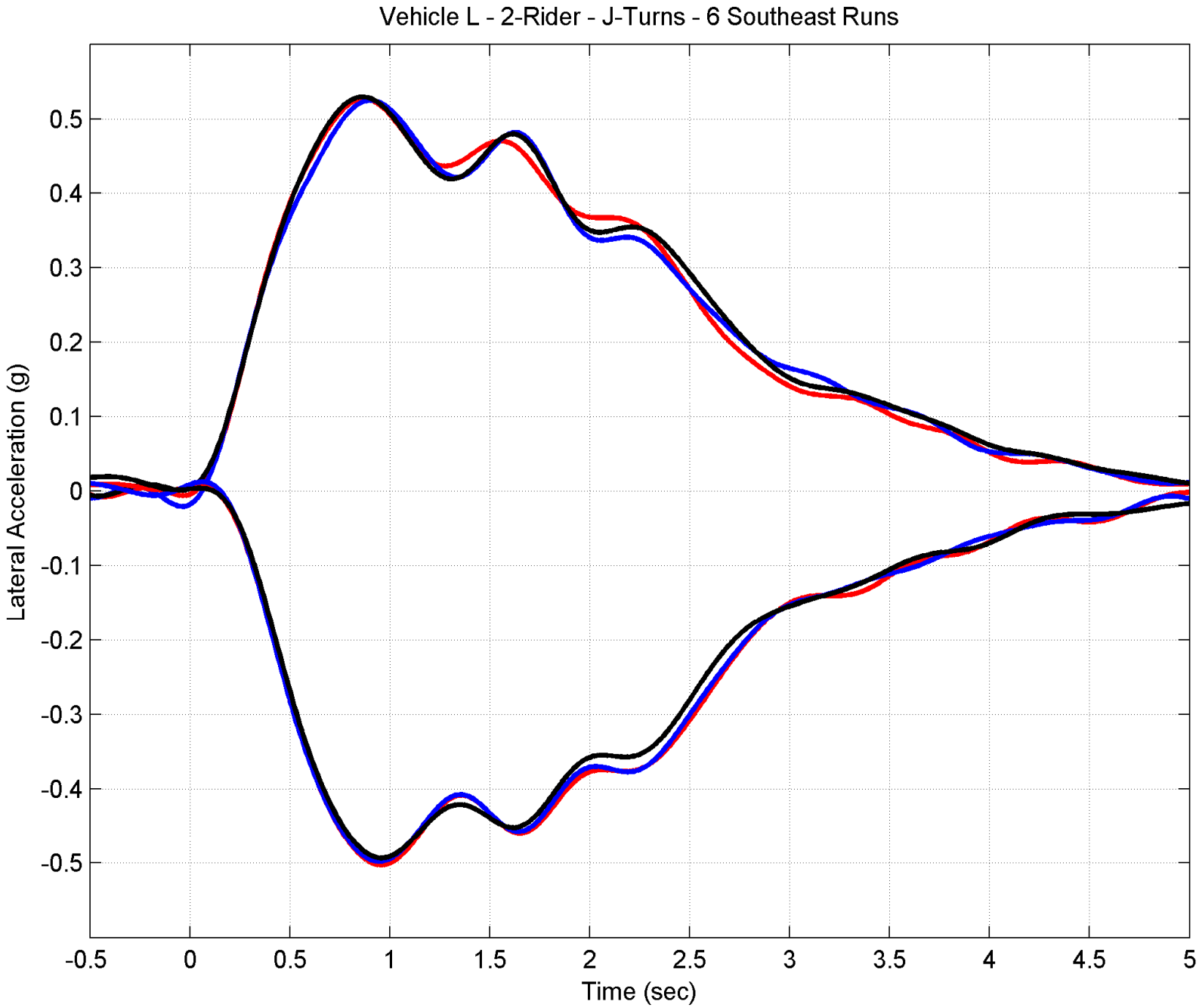

Vehicle L - 2-Rider - J-Turns
Roadwheel Steer Angle (deg)
15
10
5
0
-5
-10
-15
0
1
2
3
4
5
Time (sec)


6 Southeast Runs
Speed (mph)
25
20
15
10
5
0
0
1
2
3
4
5


Roll Angle (deg)
20
10
0
-10
-20
0
1
2
3
4
5


Lateral Acceleration (g)
0.6
0.4
0.2
0
-0.2
-0.4
0
1
2
3
4
5
Time (sec)


Yaw Rate (deg/sec)
50
0
-50
0
1
2
3
4
5
Time (sec)


Vehicle L - 2-Rider - J-Turns - 6 Southeast Runs
Lateral Acceleration (g)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (sec)

Vehicle L - 2-Rider Results

Peak Lateral Accelerations During 2WL J-Turns - All Values in "g's"

Run Number	Northwest Right Turns	Northwest Left Turns
1	0.529	-0.526
2	0.534	-0.517
3	0.524	-0.523
Mean Value of 3 Runs	0.529	-0.522
Standard Deviation of 3 Runs	0.005	0.005

Average of 6 Northwest Runs

0.525

Average of All 12 Runs

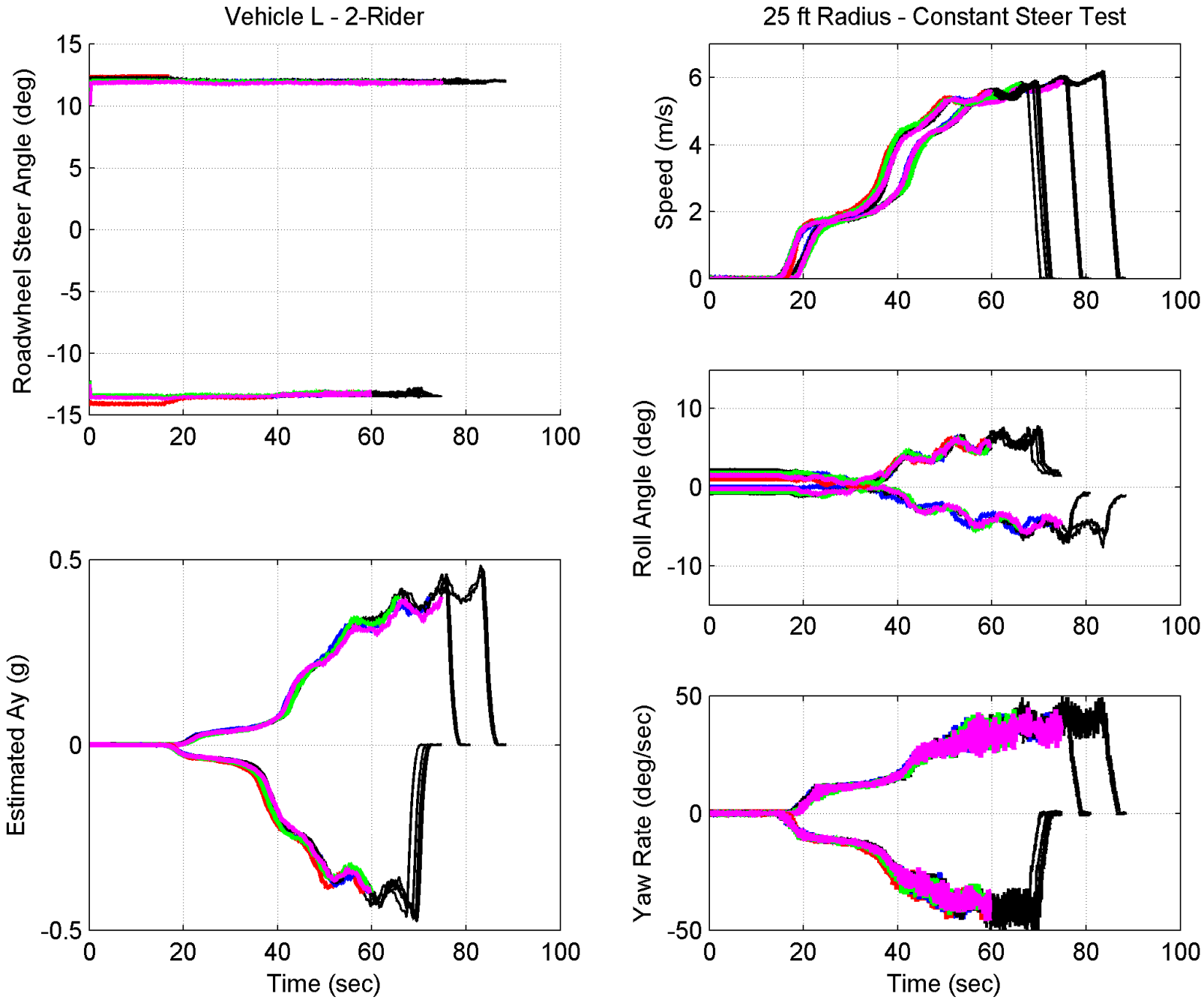
0.519

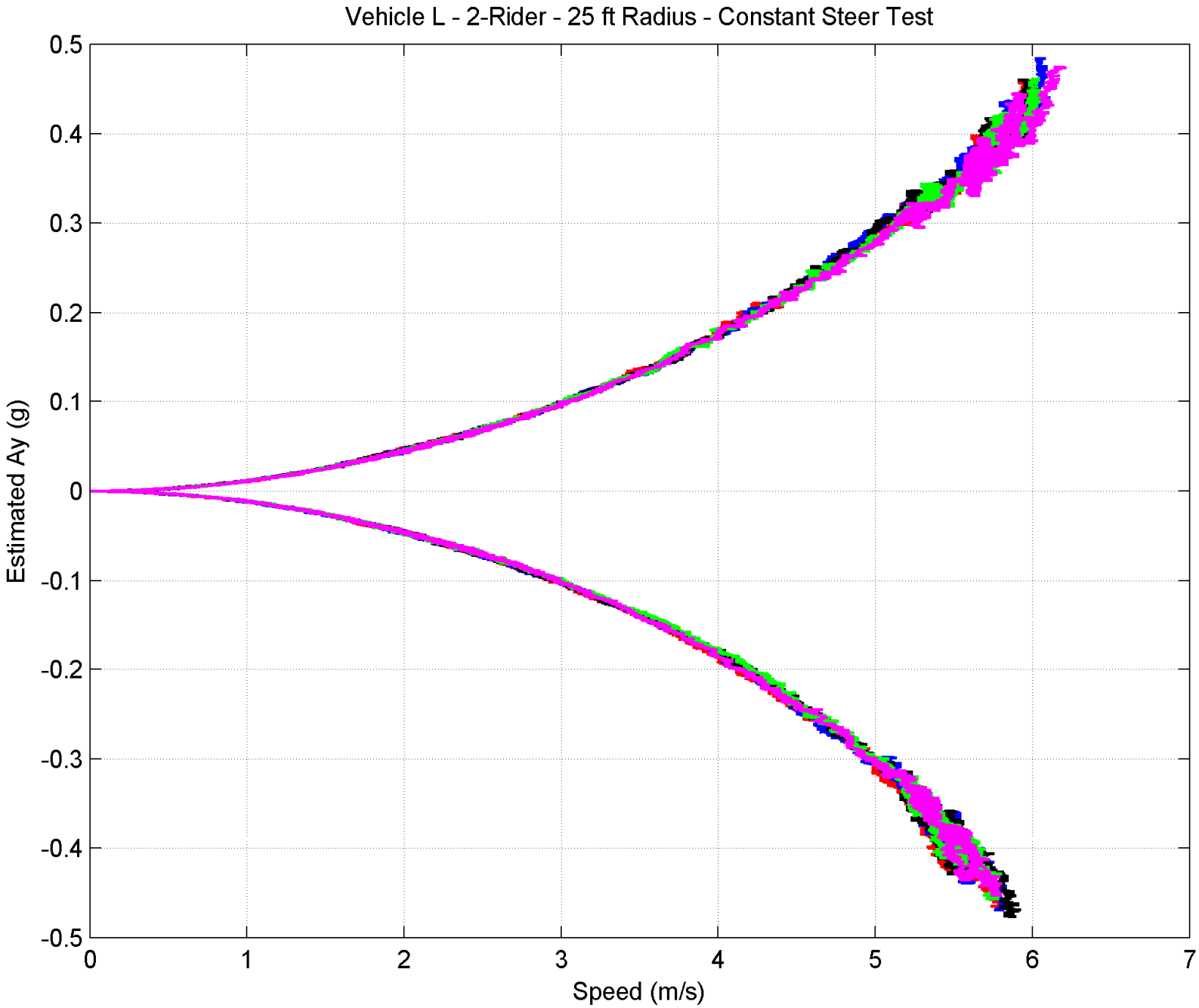
Threshold Ay

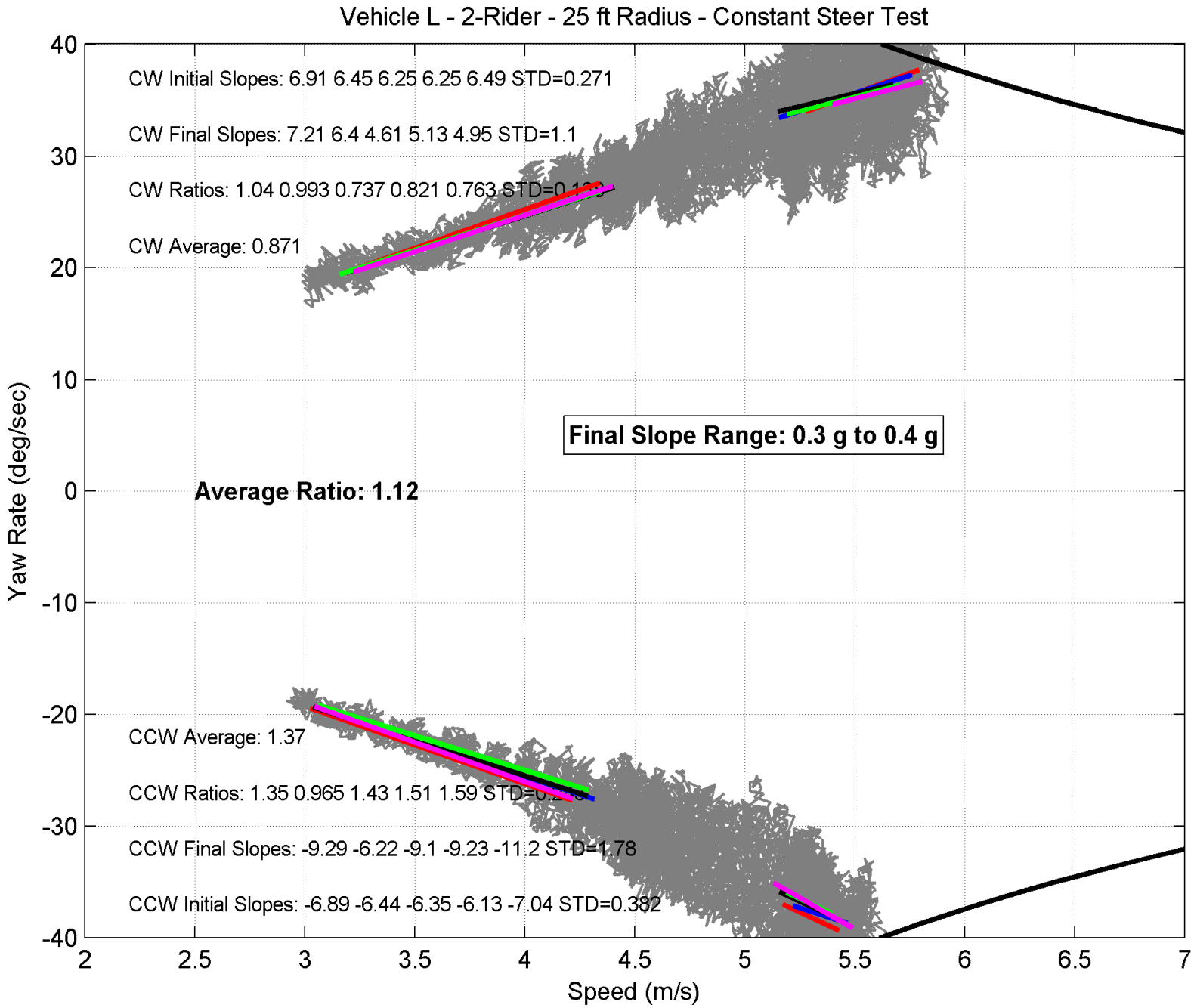
Run Number	Southeast Right Turns	Southeast Left Turns
1	0.527	-0.503
2	0.525	-0.498
3	0.530	-0.493
Mean Value of 3 Runs	0.527	-0.498
Standard Deviation of 3 Runs	0.002	0.005

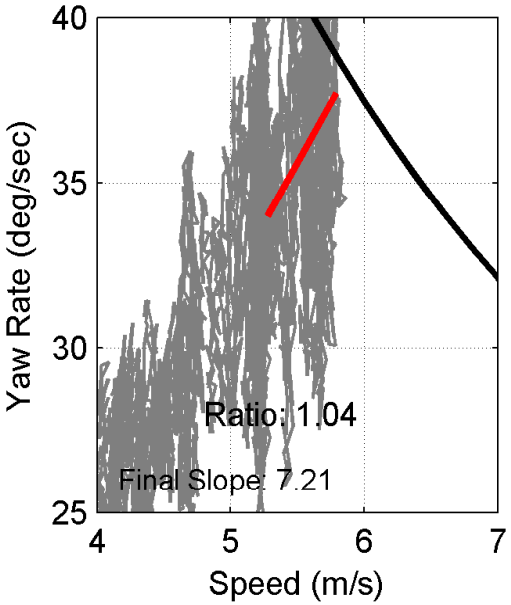
Average of 6 Southeast Runs

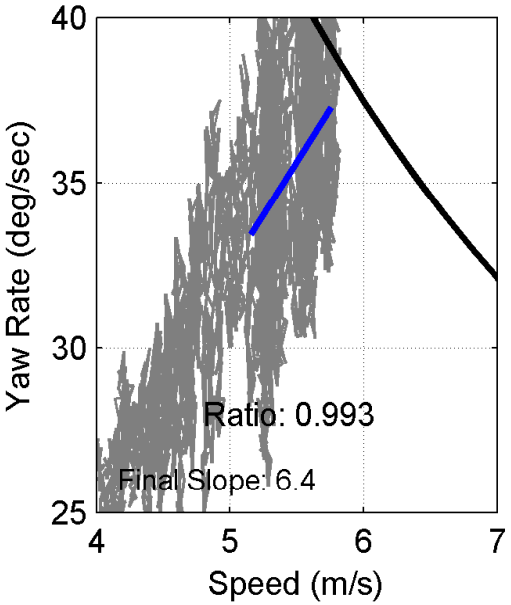
0.513

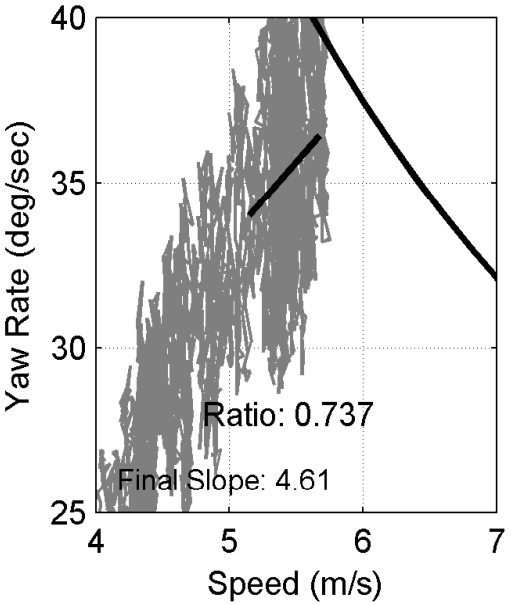

Vehicle L - 2-Rider
25 ft Radius - Constant Steer Test
Roadwheel Steer Angle (deg)
Speed (m/s)
Roll Angle (deg)
Estimated Ay (g)
Yaw Rate (deg/sec)
Time (sec)
Time (sec)

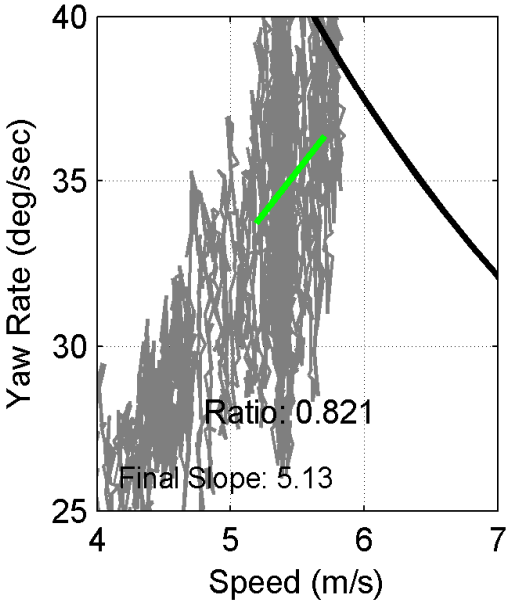

Vehicle L - 2-Rider - 25 ft Radius - Constant Steer Test
Estimated Ay (g)
Speed (m/s)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
1
2
3
4
5
6
7

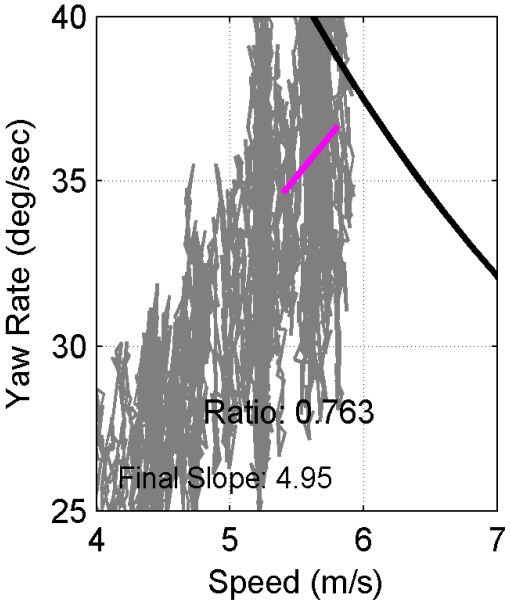

Vehicle L - 2-Rider - 25 ft Radius - Constant Steer Test
CW Initial Slopes: 6.91 6.45 6.25 6.25 6.49 STD=0.271
CW Final Slopes: 7.21 6.4 4.61 5.13 4.95 STD=1.1
CW Ratios: 1.04 0.993 0.737 0.821 0.763 STD=0.1
CW Average: 0.871
Final Slope Range: 0.3 g to 0.4 g
Average Ratio: 1.12
CCW Average: 1.37
CCW Ratios: 1.35 0.965 1.43 1.51 1.59 STD=0.2
CCW Final Slopes: -9.29 -6.22 -9.1 -9.23 -11.2 STD=1.78
CCW Initial Slopes: -6.89 -6.44 -6.35 -6.13 -7.04 STD=0.382
Yaw Rate (deg/sec)
Speed (m/s)
40
30
20
10
0
-10
-20
-30
-40
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7





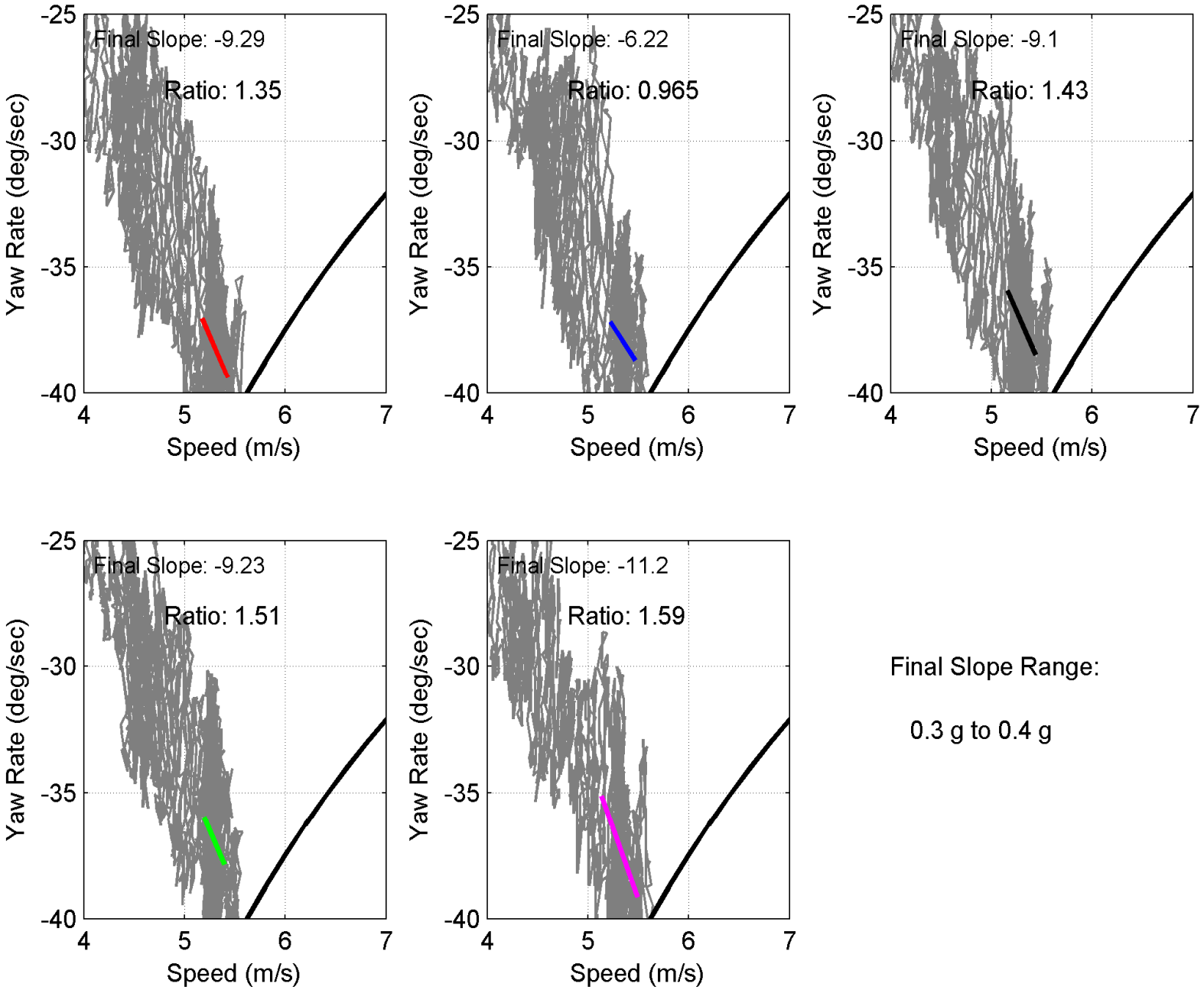






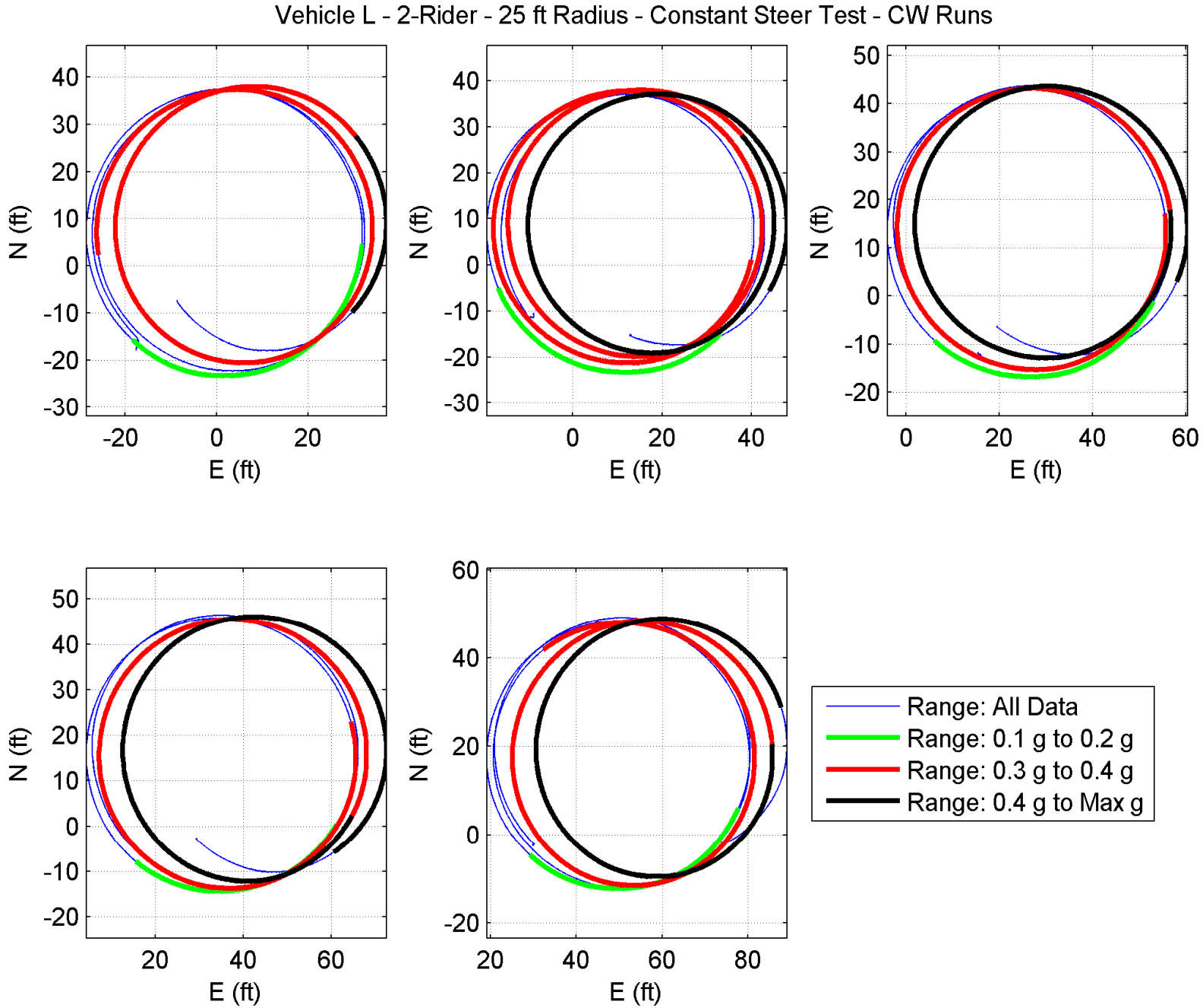
Final Slope Range:

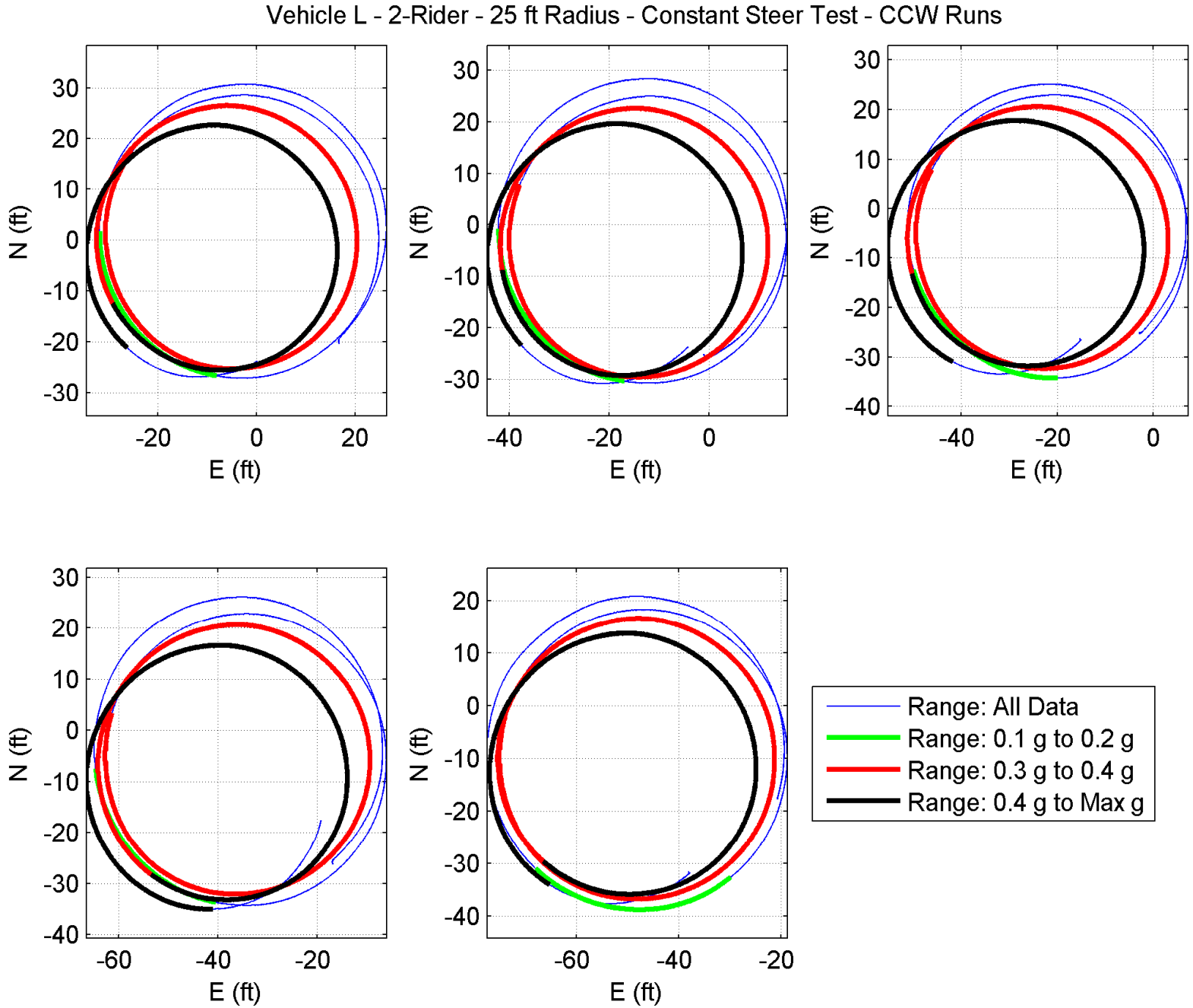
0.3 g to 0.4 g



Final Slope Range:

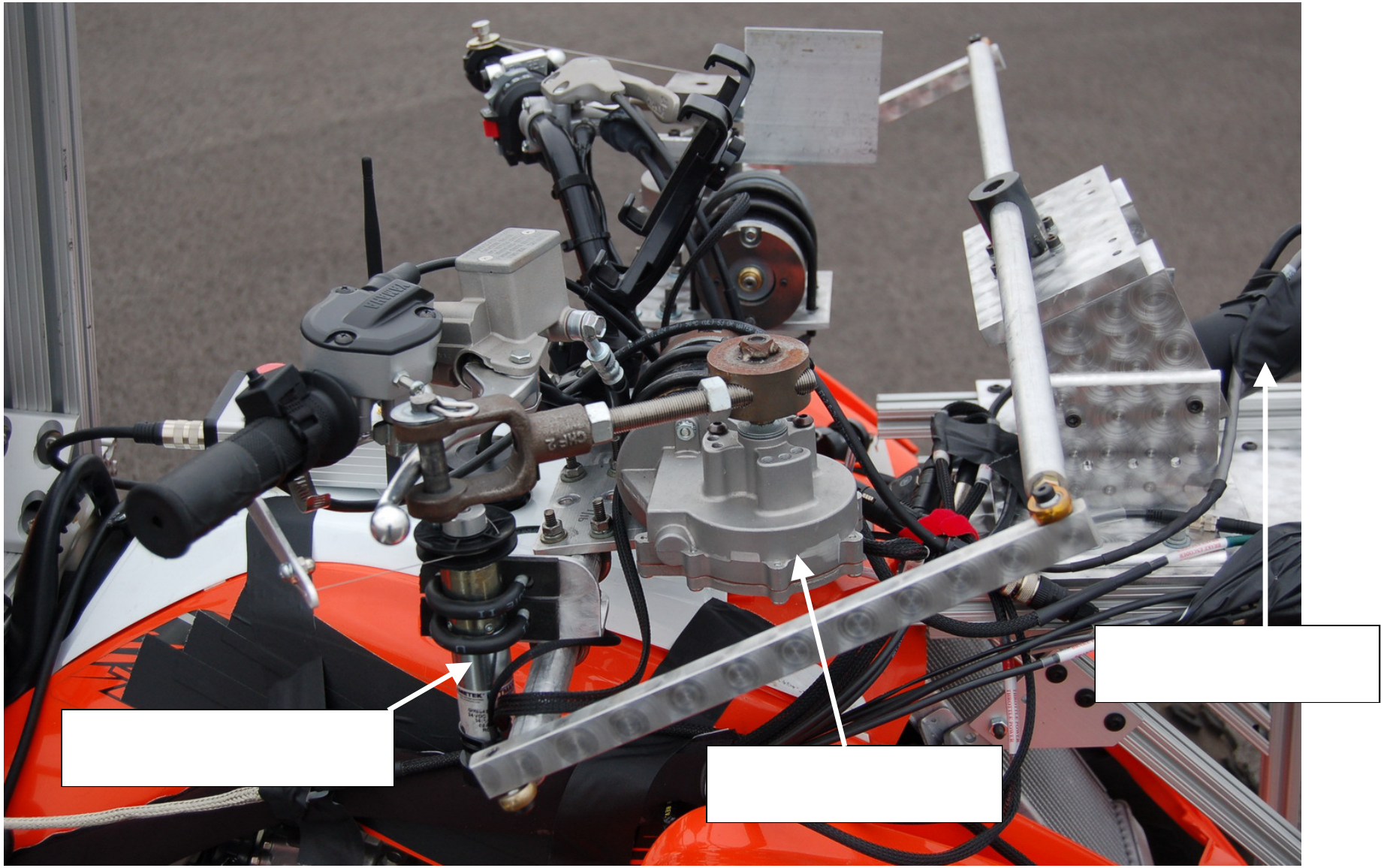
0.3 g to 0.4 g


Vehicle L - 2-Rider - 25 ft Radius - Constant Steer Test - CW Runs
N (ft)
E (ft)
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.3 g to 0.4 g
Range: 0.4 g to Max g


Vehicle L - 2-Rider - 25 ft Radius - Constant Steer Test - CCW Runs
N (ft)
E (ft)
Range: All Data
Range: 0.1 g to 0.2 g
Range: 0.3 g to 0.4 g
Range: 0.4 g to Max g

Photographs of 2-Rider Loading Condition

Photographs of SEA ATV Robotic Test Driver (RTD) Components (Throttle, Brake and Steer Motors)

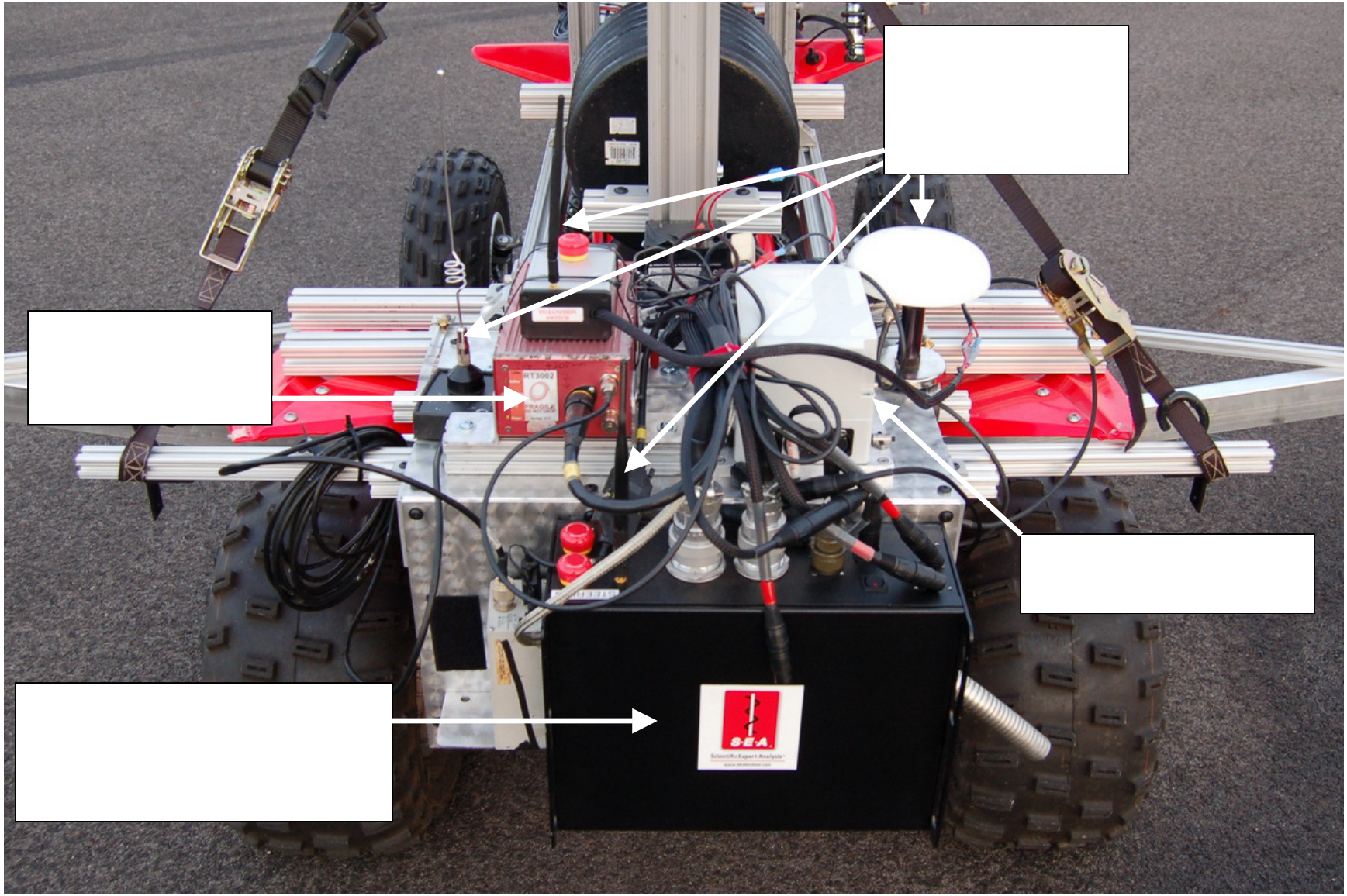


Photographs of SEA ATV Robotic Test Driver (RTD) Component (Clutch Motor)

Clutch Motor
Shown in Clutch
Engaged Position

Clutch Motor
Shown in Clutch
Disengaged Position

Photographs of SEA ATV Robotic Test Driver (RTD) Components (GPS/IMU, Control Box, and Antennas)



Photographs of SEA Standard ATV Safety Outriggers

Photographs of SEA Light-Vehicle ATV Safety Outriggers

Photographs of Steering Column Angle Encoder (Left) and Potentiometer (Right)