CPSC Staff Statement on SEA, Ltd. Report "Yaw Rate Ratio Measurements of Recreational Off-Highway Vehicles"[1]
June 2016

The Recreational Off-Highway Vehicle Association (ROHVA) developed voluntary standard ANSI/ROHVA 1-2016, *American National Standard for Recreational Off-Highway Vehicles* for recreation-oriented ROVs, and the Outdoor Power Equipment Institute (OPEI) developed ANSI/B71.9, *American National Standard for Multipurpose Off-Highway Utility Vehicles* for utility-oriented ROVs. The latest editions of both standards include vehicle handling requirements for ROVs that use constant steer angle tests to compute a metric generally referred to as "yaw rate ratio." The ROHVA and OPEI standards have a performance requirement that is based on the values of the yaw rate ratios.

This report titled, "Yaw Rate Ratio Measurements of Recreational Off-Highway Vehicles," presents results from constant steer angle tests conducted by SEA, Ltd. ("SEA") on 11 recreational off-highway vehicles (ROVs) and presents the computed yaw rate ratios of each vehicle. Staff will use this report to assist in evaluating the ROHVA and OPEI voluntary standards. SEA tested 10 model-year 2014 to 2015 ROVs and one-model year 2009 ROV, under contract CPSC-D-11-0003, Task Orders 007 and 009. SEA conducted laboratory and dynamic tests on these 11 ROVs under past contract task orders, and the test results are contained in the following reports:

- Vehicle Characteristics Measurements of Recreational Off-Highway Vehicles – Results on Thirteen 2014-2015 Model Year Vehicles (available at: http://www.cpsc.gov//Global/Research-and-Statistics/Injury-Statistics/Sports-and-Recreation/ATVs/SEAreportVehicleCharacteristicsMeasurementsROVResultsTests%20Thirteen20142015ModelYearVehicles.pdf).
- Vehicle Characteristics Measurements of Recreational Off-Highway Vehicles. (available at: http://www.cpsc.gov/PageFiles/96037/rov.pdf).

The vehicle code notations used in this report are the same as previous reports. The constant steer angle tests conducted were consistent with the tests described in the SAE J266-1996, SAE Surface Vehicle Recommended Practice – Steady-State Directional Control Test Procedures for Passenger Cars and Light Trucks.

This report contains three main sections: Overview, Dynamic Testing, and Test Results. In addition, this report contains six appendices (Appendix A through Appendix F), providing graphical results from all of the tests conducted; and one appendix (Appendix G) compares SEA protocols with OPEI and ROHVA protocols for determining yaw rate ratios.

[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.

Yaw Rate Ratio Measurements Of Recreational Off-Highway Vehicles

Results from Constant Steer Angle Tests Conducted on 11 Vehicles

for:
Consumer Product Safety Commission

June 2016

Vehicle Dynamics Division
7001 Buffalo Parkway
Columbus, Ohio 43229

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1. OVERVIEW

This report contains results from constant steer angle tests made by SEA on ten 2014-2015 model year and one 2009 model year Recreational Off-Highway Vehicles (ROVs) for the Consumer Product Safety Commission (CPSC) under contract CPSC-D-11-0003. SEA previously performed numerous laboratory and dynamic (test track) tests on these vehicles, and the results from these other tests are contained in previous reports to CPSC.[1,2]

The constant steer angle tests conducted were consistent with constant steer angle tests described in SAE J266.[3] As part of their voluntary standards development, industry groups ROHVA (Recreational Off-Highway Vehicle Association) and OPEI (Outdoor Power Equipment Institute) have proposed doing constant steer angle tests to compute a metric generally referred to as "yaw rate ratio." The proposed industry standards have a performance requirement that is based on the values of the yaw rate ratios.

CPSC staff selected all of the vehicles for testing. The 2009 model year vehicle tested is Vehicle A, and results of previous laboratory and dynamic tests conducted on this vehicle are contained in a previous report to CPSC.[2] The ten 2004-2015 model year vehicles tested are Vehicle A15, B15, C15, D15, E15, I15, J15, K15, L15 and M15, and results of previous laboratory and dynamic tests conducted on these vehicles are also contained in a previous report to CPSC.[1]

Vehicle D15 is a four-passenger vehicle, and all of the other vehicles tested have side-by-side front seating for either two or three passengers.

Vehicles that exhibit understeer behavior up to 0.5 g of lateral acceleration during constant radius circle tests are generally considered vehicles that will pass the proposed industry standard yaw rate ratio performance requirement.[4] Tested in their most open driveline configuration, vehicles B15, F15, H15, J15, L15 and M15 exhibited understeer up to 0.5 g. of lateral acceleration during 100 ft constant radius circle tests.[1] CPSC Staff did not select Vehicles F15 and H15 for additional constant steer angle tests to measure yaw rate ratios.

This report contains three main sections: Overview, Dynamic Testing, and Test Results. This report also contains six appendices (Appendix A through Appendix F) containing graphical results from all of the tests conducted, and one appendix (Appendix G) containing comments regarding proposed OPEI and ROHVA protocols for determining yaw rate ratios.

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[1] *Vehicle Characteristics Measurements of Recreational Off-Highway Vehicles – Results from Tests on Thirteen 2014-2015 Model Year Vehicles*, CPSC Contract CPSC-D-11-0003, SEA, Ltd. Report to CPSC, September 2015. **http://www.cpsc.gov//Global/Research-and-Statistics/Injury-Statistics/Sports-and-Recreation/ATVs/SEAreportVehicleCharacteristicsMeasurementsROVResultsTests%20Thirteen20142015ModelYearVehicles.pdf**

[2] *Vehicle Characteristics Measurements of Recreational Off-Highway Vehicles*, CPSC Contract CPSC-S-10-0014, SEA, Ltd. Report to CPSC, April 2011. **http://www.cpsc.gov/library/foia/foia11/os/rov.pdf**.

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

[4] Lateral acceleration is expressed as a multiple of standard gravitational acceleration, defined as 9.8 m/s^2 or 32.2 ft/s^2.

2. DYNAMIC TESTING

All of the tests were conducted between May 20, 2015 and December 3, 2015. To establish baseline measurements for all 11 vehicles, they were all tested on the Transportation Research Center's (TRC's) Vehicle Dynamics Area (VDA), which is asphalt. All of the vehicles were tested in their most open driveline configurations. Vehicle L15 was also tested with its rear differential locked.

Repeat measurements were made on five of the vehicles (Vehicles A15, B15, E15, I15 and J15). Some of the repeat tests were conducted on the TRC VDA and some were conducted at three other sites. The three other sites are the TRC Crash Pad, the North Carolina Center for Automotive Research (NCCAR), and SEA. The surface on the TRC Crash Pad is chipseal (also called chip seal), and based on friction measurements conducted by TRC, this surface is somewhat less aggressive (i.e. has somewhat lower peak friction properties) than the TRC VDA. The test pad surface at NCCAR is asphalt, and based on previous tests conducted there and on the TRC VDA, the NCCAR surface is likely somewhat more aggressive (i.e. has somewhat higher peak friction properties) than the TRC VDA. The test pad surface at SEA is asphalt, and based on previous tests conducted there and on the TRC VDA, the SEA surface is similar to the surface on the TRC VDA. All of the test surface were dry and flat, sloping 1.0 degree (1.7% grade) or less.

The "Operator, Instrumentation, and Outriggers" loading condition was used for all tests, and this is the same loading condition used in previous tests of these vehicles.[5,6] This loading condition was specified to be the vehicle curb condition plus the weight of the actual test driver, test instrumentation (including measurement transducers, data acquisition computer, SEA's Automated Steering Controller (ASC), ASC controller box, and ASC battery box), and safety outriggers. This is the loading condition designed to represent the Operator (213 lb) and Passenger (213 lb) loading condition. Also, the instrumentation used during testing was the same instrumentation used in previous tests of these vehicles.[5,6]

2.1 Yaw Rate Ratio Tests – Test Procedure

Constant steer angle tests starting on a 50 foot radius circle were conducted in order to compute the yaw rate ratios. Table 1 lists the tests conducted on each vehicle as well as the test dates and test locations. For eight of the vehicles tested (Vehicle A15, C15, D15, E15, I15, J15, K15 and L15), tests conducted on the dates of the baseline tests on the TRC VDA were conducted with tires that were broken in by previous testing that included numerous J-turn tests (in each turn direction) that resulted in two-wheel lift events and at least two 100 ft radius circle tests (in each turn direction). For the other three vehicles tested (Vehicle A, B15 and M15), tests conducted on

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[5] *Vehicle Characteristics Measurements of Recreational Off-Highway Vehicles – Results from Tests on Thirteen 2014-2015 Model Year Vehicles*, CPSC Contract CPSC-D-11-0003, SEA, Ltd. Report to CPSC, September 2015. **http://www.cpsc.gov//Global/Research-and-Statistics/Injury-Statistics/Sports-and-Recreation/ATVs/SEAreportVehicleCharacteristicsMeasurementsROVResultsTests%20Thirteen20142015ModelYearVehicles.pdf**

[6] *Vehicle Characteristics Measurements of Recreational Off-Highway Vehicles*, CPSC Contract CPSC-S-10-0014, SEA, Ltd. Report to CPSC, April 2011. **http://www.cpsc.gov/library/foia/foia11/os/rov.pdf**.

the dates of the baseline tests on the TRC VDA were conducted using new tires. The tires used for previous testing on these vehicles were significantly worn so new tires were used. The tire break-in procedure for these sets of tires included at least four J-turns (in each turn direction) that resulted in two-wheel lift and two 100 ft radius circle test (in each turn direction).

For all repeat tests (except the set of tests conducted on Vehicle I15 at SEA on December 3, 2015) that were not conducted on the same day as the baseline tests, new tires were used. The tire break-in procedure used for these sets of tires included at least two constant radius circle tests (in each turn direction) up to the limits of the test (either two-wheel lift or loss of circle holding capability). The same tires were used on Vehicle I15 for the five set of tests conducted on TRC VDA on October 1, 2015 and for the single set of tests conducted at SEA on December 3, 2015.

Table 1: Summary of Tests Conducted, Test Dates and Test Locations

Vehicle	Original Baseline Tests 0n TRC VDA	Repeat Tests			Number Of Tests
A	June 11, 2015				1
A15	July 21, 2015	July 21, 2015 at TRC VDA 1. 30-60 sec 2. 30-60 sec – 110% Steering 3. 30-60 sec – 90% Steering 4. 30-60 sec – w/New Initial Steer	September 3, 2015 at NCCAR 1. Baseline 2. 30-60 sec 3. 30-60 sec – 110% Steering 4. 30-60 sec – Repeat #1 5. 30-60 sec – Repeat #2 – w/New Initial Steer		10
B15	July 21, 2015	July 21, 2015 at TRC VDA 1. 30-60 sec			2
C15	June 18, 2015				1
D15	June 18, 2015				1
E15	July 11, 2015	September 28, 2015 at TRC VDA 1. Baseline 2. 30-60 sec 3. 30-60 sec – 110% Steering 4. 30-60 sec – Repeat #1 5. 30-60 sec – Repeat #2 – w/New Initial Steer			6
I15	May 20, 2015	July 24, 2015 at TRC Crash Pad 1. Baseline 2. 30-60 sec 3. 30-60 sec – 110% Steering 4. 30-60 sec – w/Same Initial Steer	October 1, 2015 at TRC VDA 1. Baseline 2. 30-60 sec 3. 30-60 sec – 110% Steering 4. 30-60 sec – Repeat #1 5. 30-60 sec – Repeat #2 – w/New Initial Steer	December 3, 2015 at SEA 1. 30-60 sec	11
J15	May 21, 2015	September 4, 2015 at NCCAR 1. Baseline 2. 30-60 sec 3. 30-60 sec – 110% Steering 4. 30-60 sec – Repeat #1 5. 30-60 sec – Repeat #2 – w/New Initial Steer			6
K15	June 2, 2015				1
L15	June 2, 2015	June 2, 2015 at TRC VDA 1. Additional Baseline Test with Rear Differential Locked			2
M15	July 1, 2015				1
				Total Number Of Tests	**42**

All vehicles were tested in their most open driveline configurations. A repeat set of yaw rate ratio tests was also conducted on Vehicle L15 with its rear differential locked.

The following test procedure was used:

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). Once the initial steer angle has been determined, bring the vehicle to a stop.
2. The SEA Automated Steering Controller (ASC) was then used to steer the steering wheel 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 1mph/second. For all of the tests listed as "Baseline" tests, the total time for one test run was generally between 90 to 120 seconds. For all other tests (listed as 30-60 sec), the total time for one test run was generally between 30 to 60 seconds.
4. The tests were ended when a lateral acceleration of at least 0.5 g was achieved.
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.

With one exception, a total of 10 runs, five in the right turn direction and five in the left turn direction were conducted for each set of yaw rate ratio tests. The one exception is the additional baseline test conducted on Vehicle L15 with its rear differential unlocked. In this case, only two tests were run in each turn direction.

2.2 Yaw Rate Ratio Tests – Procedure to Compute Yaw Rate Ratios

The following steps were taken to compute the yaw rate ratios contained in this report:

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 2 Hz.[7] Then the estimated lateral acceleration in units of "g's" was computed using the following equation[8]:

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

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

[7] Original data processing protocols submitted to CPSC by industry representatives suggested the use of a 2 Hz low-pass filter, but the current protocols in the OPEI and ROHVA draft voluntary standards call for a 1 Hz low-pass filter.

[8] The equations in the current OPEI and ROHVA draft voluntary standards used to compute *Estimated* A_y 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.

2. The estimated lateral acceleration, *Estimated* A_y, was used to determine the start and stop points for the following regions[9]:

    a. The Initial Region is from 0.1 to 0.2 g.
    b. The Final Region is from 0.4 to 0.5 g.

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[10]. 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:

$$Yaw\ Rate\ Ratio\ (R) = \frac{\left(\frac{Y2}{V2}\right)}{\left(\frac{Y1}{V1}\right)}$$

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 Divergence Ratio = Average of the 5 right turn test runs[11]
    b. Left Turn Yaw Rate Divergence Ratio = Average of the 5 left turn test runs[10]
    c. Average Yaw Rate Divergence Ratio = Average of the Right Turn and Left Turn Yaw Rate Divergence Ratios

For some yaw rate ratio tests that exhibit significant yaw rate divergence at the end of the test, the measured forward vehicle speed actually decreases as yaw rate increases. The second counterclockwise (left turn) run shown on Page 1 of Appendix A – with initial and final slopes indicated by the BLUE lines – shows an example of this. For these cases, the individual final slope has the opposite sign as the individual initial slope, the individual slope ratio (individual yaw rate ratio, *R*) is negative, and the magnitude of the individual slope ratio might be large. In these cases, the absolute values of *R* are used in the calculations of final yaw rate ratio.

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[9] The region selection method used for the data presented in this report takes the first instance of *Estimated* A_y crossing 0.1 g to the first instance of it crossing 0.2 g, and the first instance of *Estimated* A_y crossing 0.4 g to the first instance of it crossing 0.5 g. Current protocols in the OPEI and ROHVA draft voluntary standards call for using contiguous regions of *Estimated* A_y between 0.4 g and 0.5 g.

[10] Current protocols in the OPEI and ROHVA draft voluntary standards call for 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.

[11] Current protocols in the OPEI and ROHVA draft voluntary standards call for computing Final Slope Ratio Right and Final Slope Ratio Left by averaging the absolute values of the slope ratios for the five runs in each direction.

3. TEST RESULTS

Table 2 contains a listing of the summary yaw rate ratio figures (bar charts) and graphical results (contained in appendices) for the Baseline tests configurations of all 11 vehicles as well as for all of the repeat runs conducted on five of the vehicles (Vehicles A15, B15, E15, I15 and J15).

Table 2: Summary of Test Results Charts and Graphs		
	Summary Yaw Rate Ratios	**Graphical Results**
Results from Baseline Tests on All 11 Vehicles	Figure 1	Appendix A
Results from All Tests on Vehicle A15	Figure 2	Appendix B
Results from All Tests on Vehicle B15	Figure 3	Appendix C
Results from All Tests on Vehicle E15	Figure 4	Appendix D
Results from All Tests on Vehicle I15	Figure 5	Appendix E
Results from All Tests on Vehicle J15	Figure 6	Appendix F

3.1 Baseline Tests on All 11 Vehicles

Figures 1-6 are bar charts containing Right Turn, Left Turn, and Average Yaw Rate Divergence Ratios (for all of the test conditions listed on Table 1). The appendices contain graphical results from all of the tests, and the last page of each appendix contains the bar chart summary for the results in the appendix. There are three graphs for each suite of vehicle test conditions listed on Table 1. The first graph for each test condition plots yaw rate versus speed, as well as the initial slope, final slope, and average slope values. The second and third graphs for each test condition contain magnified sections of the final slope regions for the right turn (clockwise) and left turn (counterclockwise) runs, respectively. All of the graphs also contain black lines indicating where combinations of yaw rate and speed equal 0.5 g of lateral acceleration.

Figure 1 is a bar chart containing results from all of the original Baseline runs for all 11 vehicles. The vehicles are organized from lowest to highest Average Yaw Rate Divergence Ratio. With one exception, the results on Figure 1 are the same as the results contained in the August 21, 2015 CPSC staff letter to OPEI.[12] The exception is that the yaw rate ratios for Vehicle B15 are negative on Figure 1, meaning that the right turn ratio and left turn ratio values are not based on the absolute values of *R* for five runs in each direction. Negative yaw rate ratios occur when the final yaw rate has the opposite slope as the initial yaw rate, and this phenomena can be seen on

[12] CPSC Staff Letter with Test Data and Comments to OPEI, August 21, 2015. **http://www.cpsc.gov/Global/Regulations-Laws-and-Standards/Voluntary-Standards/ROHVA/082115CPSClettertoOPEIsuggestedlinefitmethodandlatestyawratedata.pdf**

the test plots for Vehicle B15 contained on Page 7 of Appendix A. In this situation, the yaw rate is decreasing as vehicle speed increases, as the vehicle travels on a path of significantly increasing radius.

As mentioned, when tested in their most open driveline configuration, vehicles B15, J15, L15 and M15 exhibited understeer up to 0.5 g of lateral acceleration during 100 ft constant radius circle tests. These are the four vehicles with lowest yaw rate ratios (Figure 1), and Vehicle B15 (the vehicle with negative yaw rate ratio values) exhibited the highest degree of understeer in the circle tests.

For one vehicle, Vehicle L15, Baseline tests were also conducted with its rear differential locked (i.e. not is most open driveline configuration). As shown on Figure 1, the yaw rate ratio values increased when the rear differential was locked on Vehicle L15. With the rear differential locked, Vehicle L15 did exhibit a transition to oversteer prior to 0.5 g of lateral acceleration during 100 ft constant radius circle tests.

Based on this data from the baseline tests, vehicles with sets of tests that have lower final yaw rate ratios typically have less variation in their individual final yaw rate slopes. That is, vehicles that exhibit greater understeer have less variation in their individual yaw trate ratios, and therefore they are prone to providing repeatable final yaw rate ratio results. Conversely, vehicles that exhibit greater oversteer and are close to exhibiting divergent yaw rate responses at the end of the tests have greater variations in their individual slope ratios, and therefore they are likely less prone to providing repeatable final yaw rate ratio results.

3.2 Repeat Tests on Vehicles A15, B15, E15, I15 and J15

Vehicle A15

Figure 2 is a bar chart containing summary results from all tests on Vehicle A15, and Appendix B contains graphical results from all tests on Vehicle A15. For Vehicle A15 five sets of tests were conducted on the TRC VDA and five sets of tests were conducted at NCCAR. As mentioned, the total test time for the Baseline runs was generally between 90 to 120 seconds, and for all other runs the total test time was generally between 30 to 60 seconds. For tests using 110% steering, the steering wheel input used was 10% greater than the initial steer angle (the steering angle measured during initial driving on the 50 ft radius circle at less than 10 mph). For tests using 90% steering, the steering wheel input used was 10% less than the initial steer. For tests using new initial steer, the initial steer angle was re-measured prior to the tests (by again driving on the 50 ft radius circle at less than 10 mph). For all of the repeat tests that included new initial steer, the new initial steer angles were within one degree of the original initial steer angles.

All of the Right Turn and Left Turn Ratio values listed on the Figure 2 bar chart are comprised of the average of five individual runs in each direction. The variation in the values of individual ratios computed from the individual runs can be seen by examination of the graphical results listed in Appendix B. For instance, Page 7 of Appendix B shows that individual ratios for the right turn (clockwise) tests ranged from 2.02 to 2.86 (with a standard deviation of 0.356); while the left turn (counterclockwise) tests ranged from 2.22 to 6.89 (with a standard deviation of 2.14). Given that the final ratio values are dependent on the individual ratio values that contain

some level of inherent variation, it is difficult to conclude that any of the final ratio values are dependent on the particular test condition. That is, based on this data for Vehicle A15, it appears that test duration (90-120 sec. versus 30-60 sec.), steering magnitude (90%, 100% or 110% initial steer), or test surface (TRC VDA versus NCCAR) do not have any discernible effect on the final yaw rate ratios.

Vehicle B15

Results from all tests on Vehicle B15 are contained on Figure 3 and in Appendix C. The results from the two sets of tests on this vehicle are similar, in that all of the final right turn and left turn yaw rate ratios are within 0.28 of one another.

Vehicle E15

Results from all tests on Vehicle E15 are contained on Figure 4 and in Appendix D. The results from the six sets of tests on this vehicle, all conducted on the TRC VDA, are similar based on the fact that the final right turn yaw rate ratios are within 0.53 of one another and the final left turn yaw rate ratios are within 0.99 of one another.

Vehicle I15

Figure 5 is a bar chart containing summary results from all tests on Vehicle I15, and Appendix E contains graphical results from all tests on Vehicle I15. For Vehicle I15: one set of tests was conducted on the TRV VDA on May 20, 2015, four sets of tests were conducted on the TRC Crash Pad on July 24, 2015, five sets of tests were conducted on the TRC VDA on October 1, 2015, and one set of tests were conducted at SEA on December 3, 2015.

The results from the May 20 tests on the TRC VDA are similar to the first three sets of tests conducted on the TRC Crash Pad on July 24. Higher final yaw rate ratios were determined for the fourth set of tests conducted on the TRC Crash Pad, and Page 13 of Appendix E shows that there was more variation in the individual yaw rate ratios for this set of tests.

For Vehicle I15, the first two sets of tests conducted on the TRC VDA on October 1 had particularly large variations in their individual test yaw rate ratios (see Pages 16 and 19 of Appendix E). These tests included some individual yaw rate ratios in the range of the previous tests on this vehicle, but they also included some individual yaw rate ratios with large magnitudes, which resulted in higher-than-previous final yaw rate ratios (see Pages 17-18 and Pages 20-21 of Appendix E). The last three sets of tests conducted on this vehicle on October 1 had less variation in their individual slope ratios, and this resulted in final yaw rate ratios that were closer to the results from the previous tests. The tire break-in procedure for the new tests used on October 1 was the same as that used to break-in the new tires on July 24. Nothing was found regarding the test vehicle, the test vehicle loading, the test instrumentation, or the test protocol (which were all intended to be the same for all test dates and locations) that can explain the individual slope ratio variation that led to the higher yaw rate ratios measured on the TRC VDA on October 1 for this vehicle. However, for some sets of tests, this vehicle had some individual runs that exhibited divergent yaw rate behavior between 0.4 and 0.5 g, resulting in higher final yaw rate ratio values for these sets of tests.

The set of tests conducted at SEA on December 3 resulted in final yaw rate ratios similar to previous tests conducted on Vehicle I15 on the TRC VDA on May 20 and on the TRC Crash Pad on July 24.

Vehicle J15

Results from all tests on Vehicle J15 are contained on Figure 6 and in Appendix F. The final yaw rate ratios for the five sets of tests conducted at NCCAR are generally lower than the final yaw rate ratios for the single set of tests conducted at TRC. However, the results from all six tests are similar based on the fact that the final right turn yaw rate ratios are within 1.18 of one another and the final left turn yaw rate ratios are within 0.59 of one another.

3.3 Summary

The results from the repeat testing reinforce the findings from the baseline tests. Vehicles with sets of tests that have lower final yaw rate ratios typically have less variation in their individual final yaw rate slopes. That is, vehicles that exhibit greater understeer have less variation in their individual yaw rate ratios, and therefore they are prone to providing repeatable final yaw rate ratio results. Conversely, vehicles that exhibit greater oversteer and are close to exhibiting divergent yaw rate responses at the end of the tests have greater variations in their individual slope ratios, and therefore they are likely less prone to providing repeatable final yaw rate ratio results. For instance, the results from repeat tests on Vehicle I15 revealed that final yaw rate ratio values can vary significantly, because yaw rate divergences during several of the individual test runs resulted in high individual yaw rate ratios for theses runs.

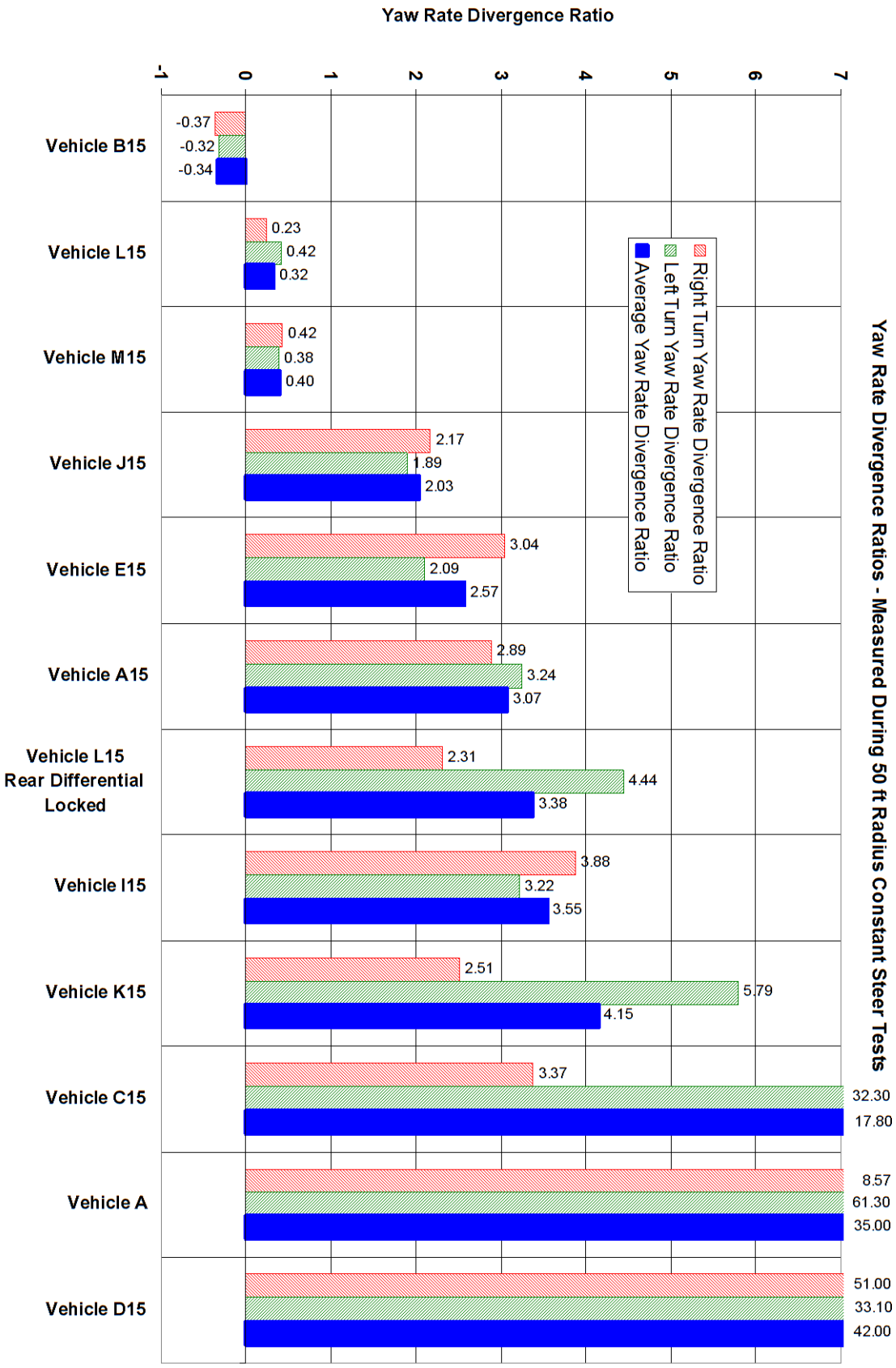


Figure 1: Results from Baseline Tests on all 11 Vehicles

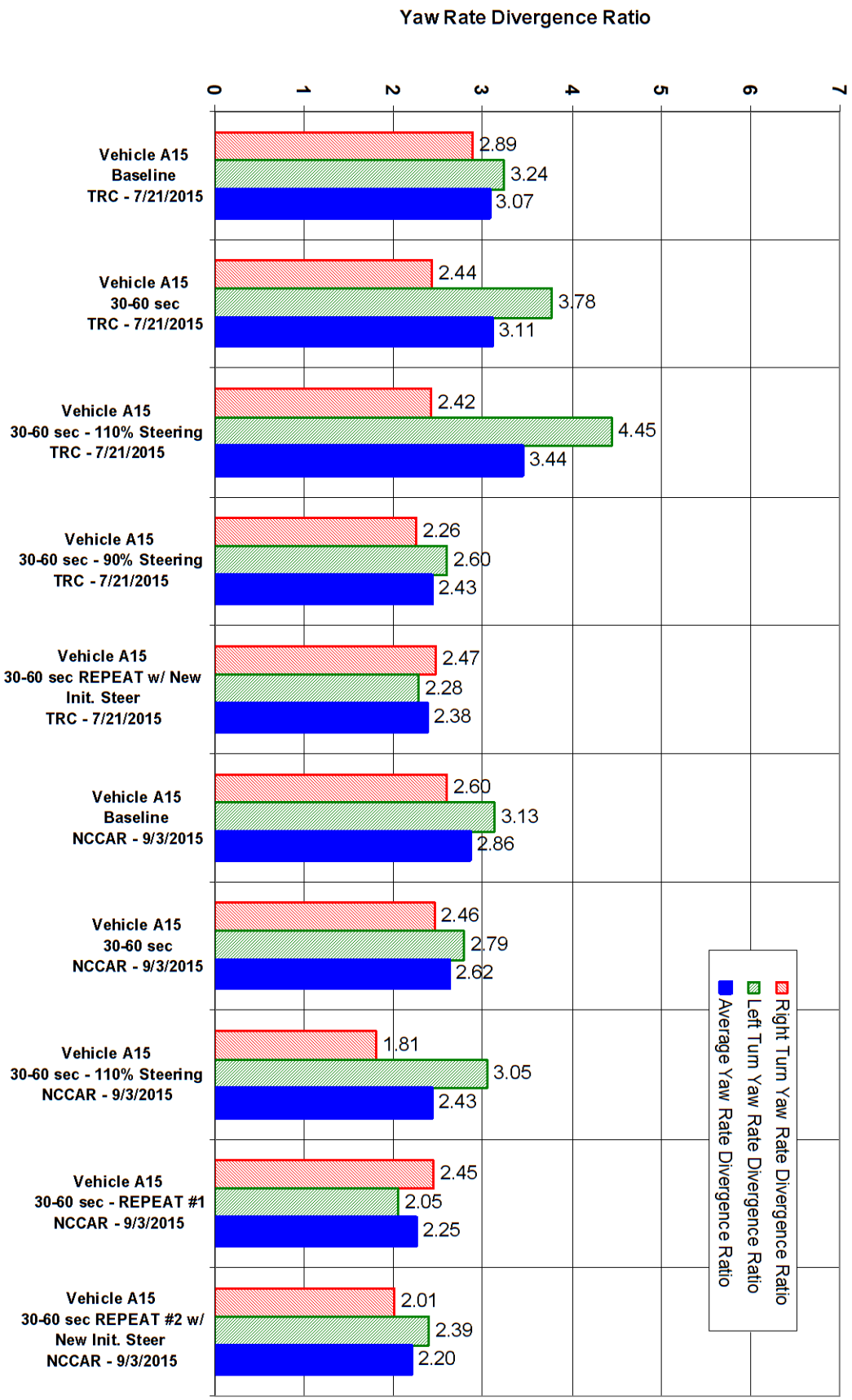


Figure 2: Results from All Tests On Vehicle A15

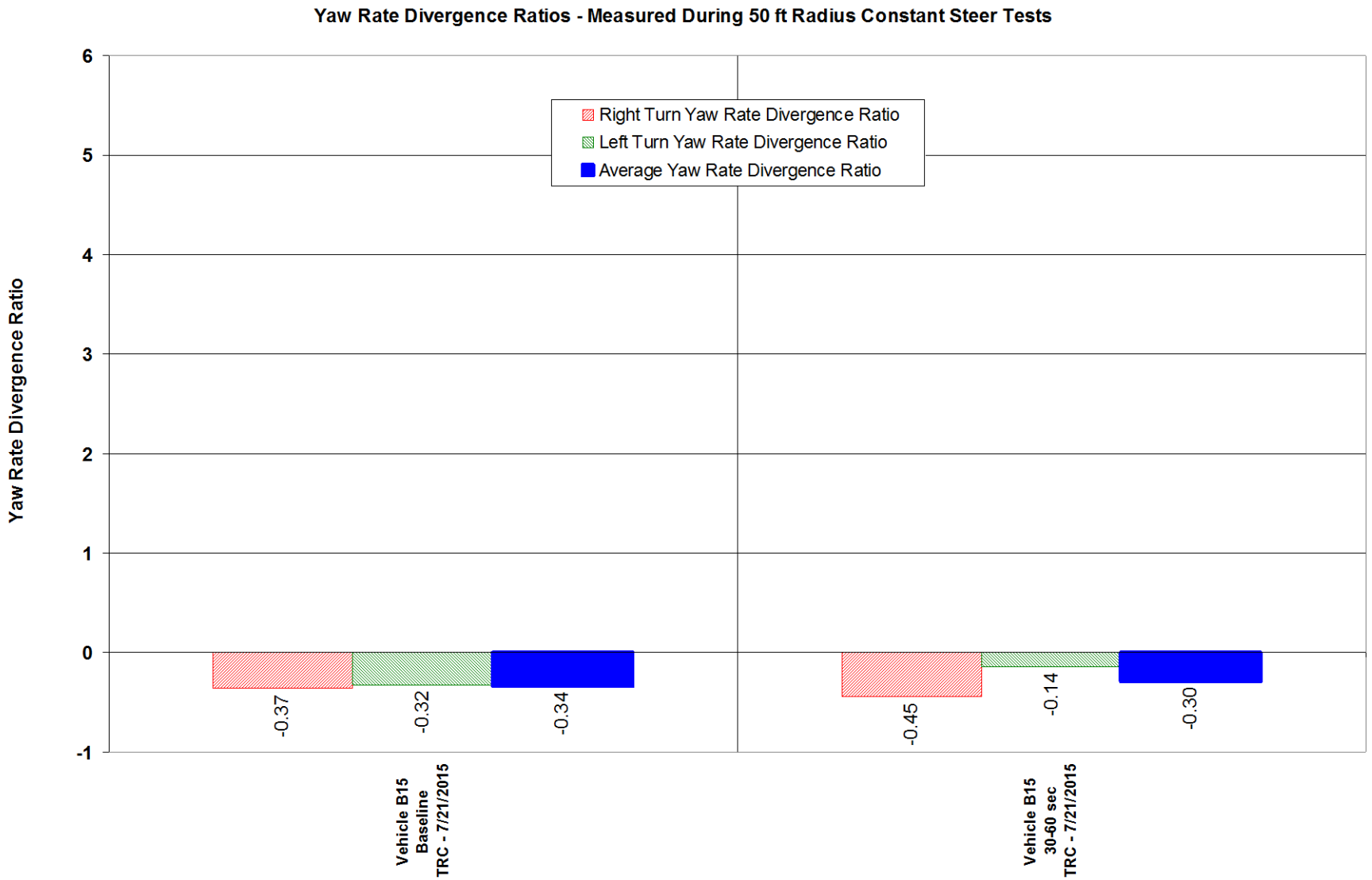


Figure 3: Results from All Tests On Vehicle B15

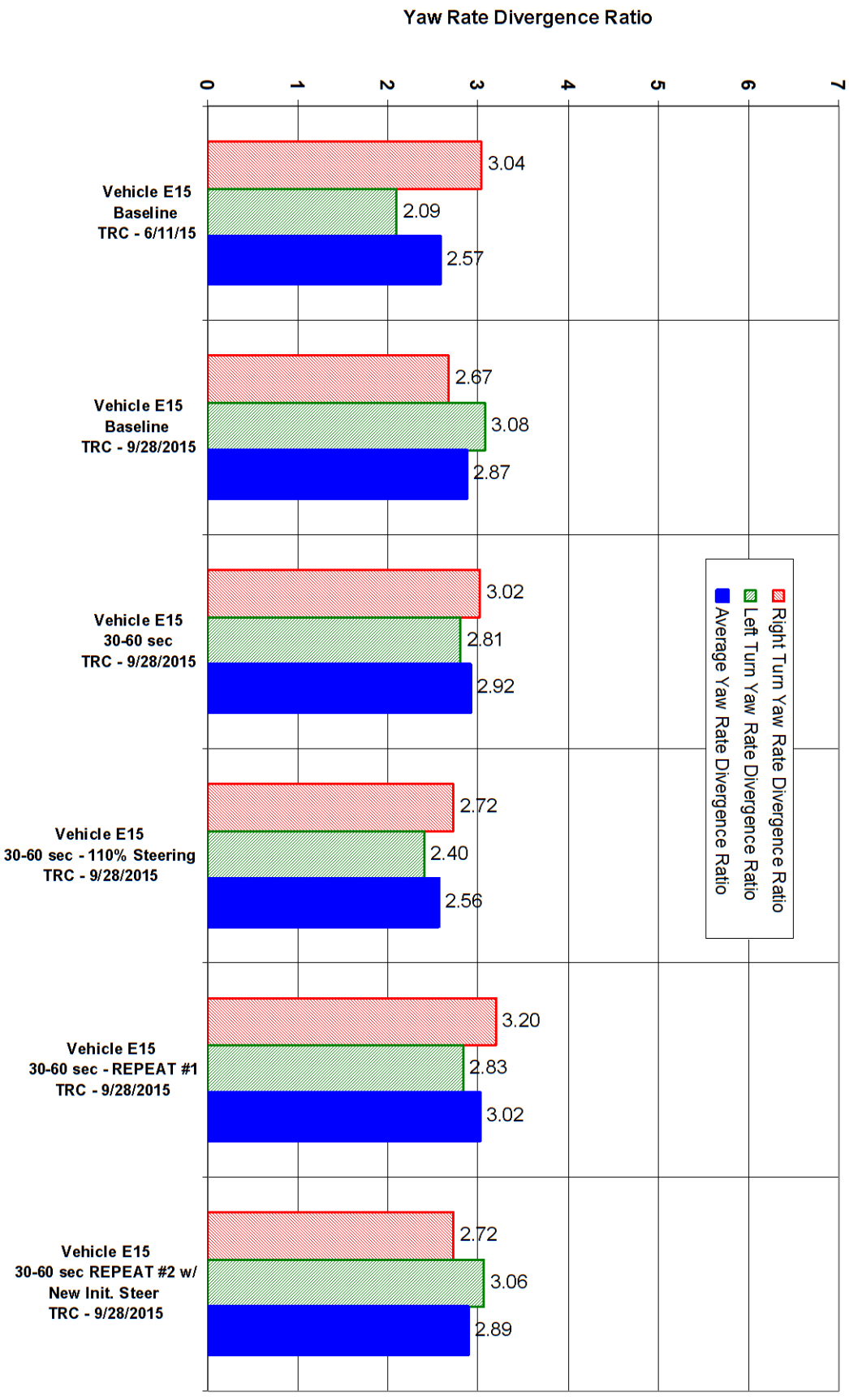


Figure 4: Results from All Tests On Vehicle E15

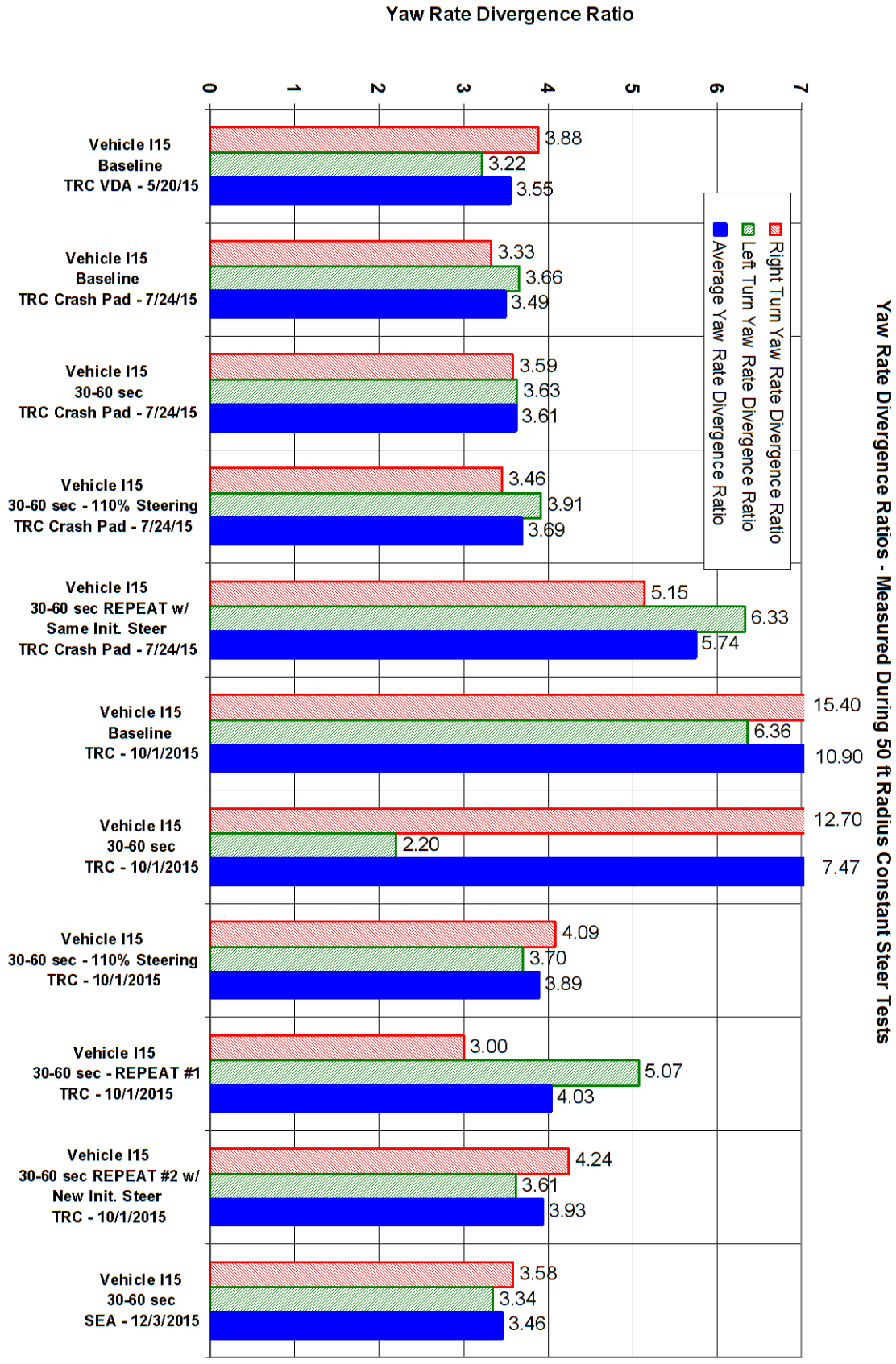


Figure 5: Results from All Tests On Vehicle I15

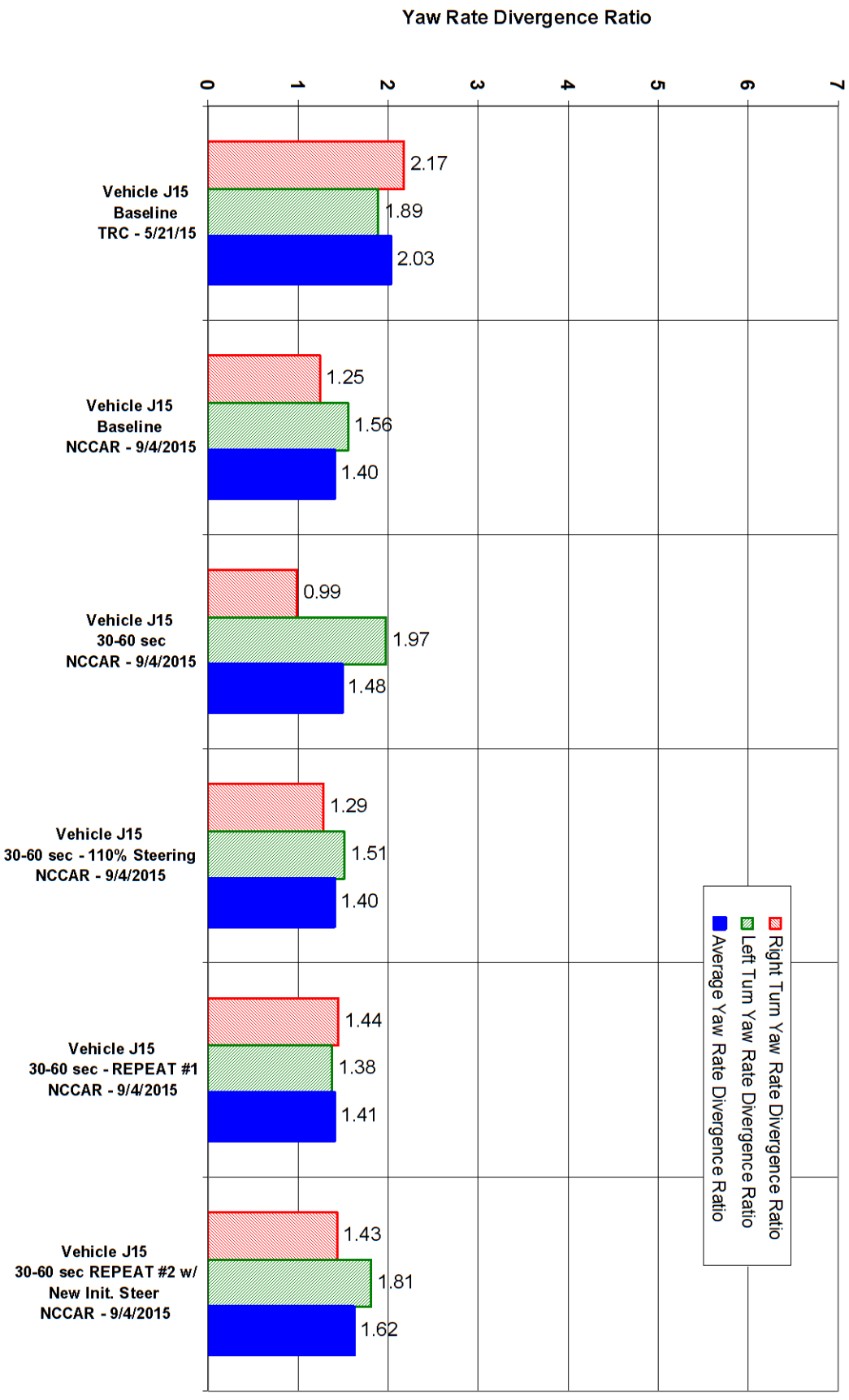
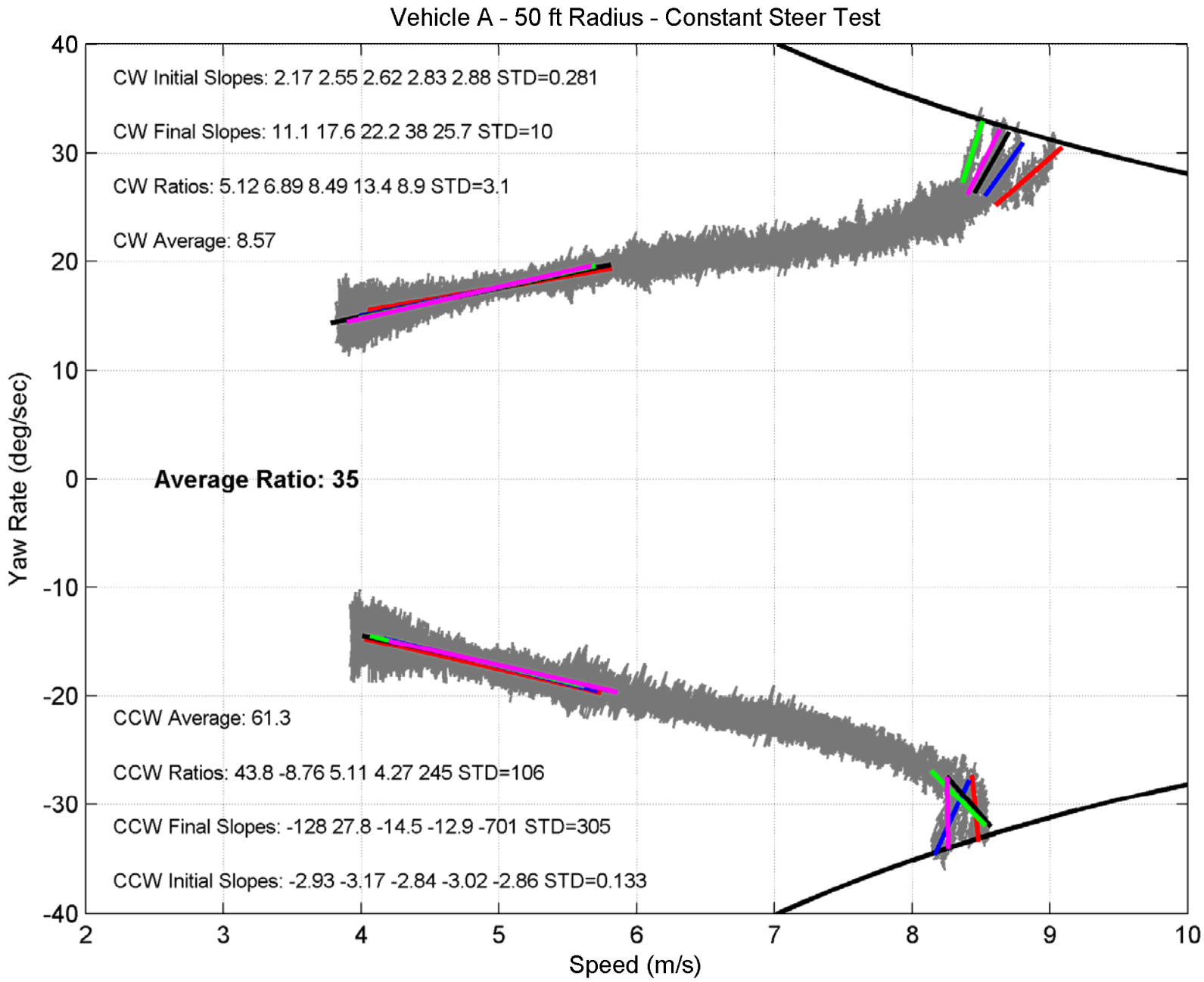
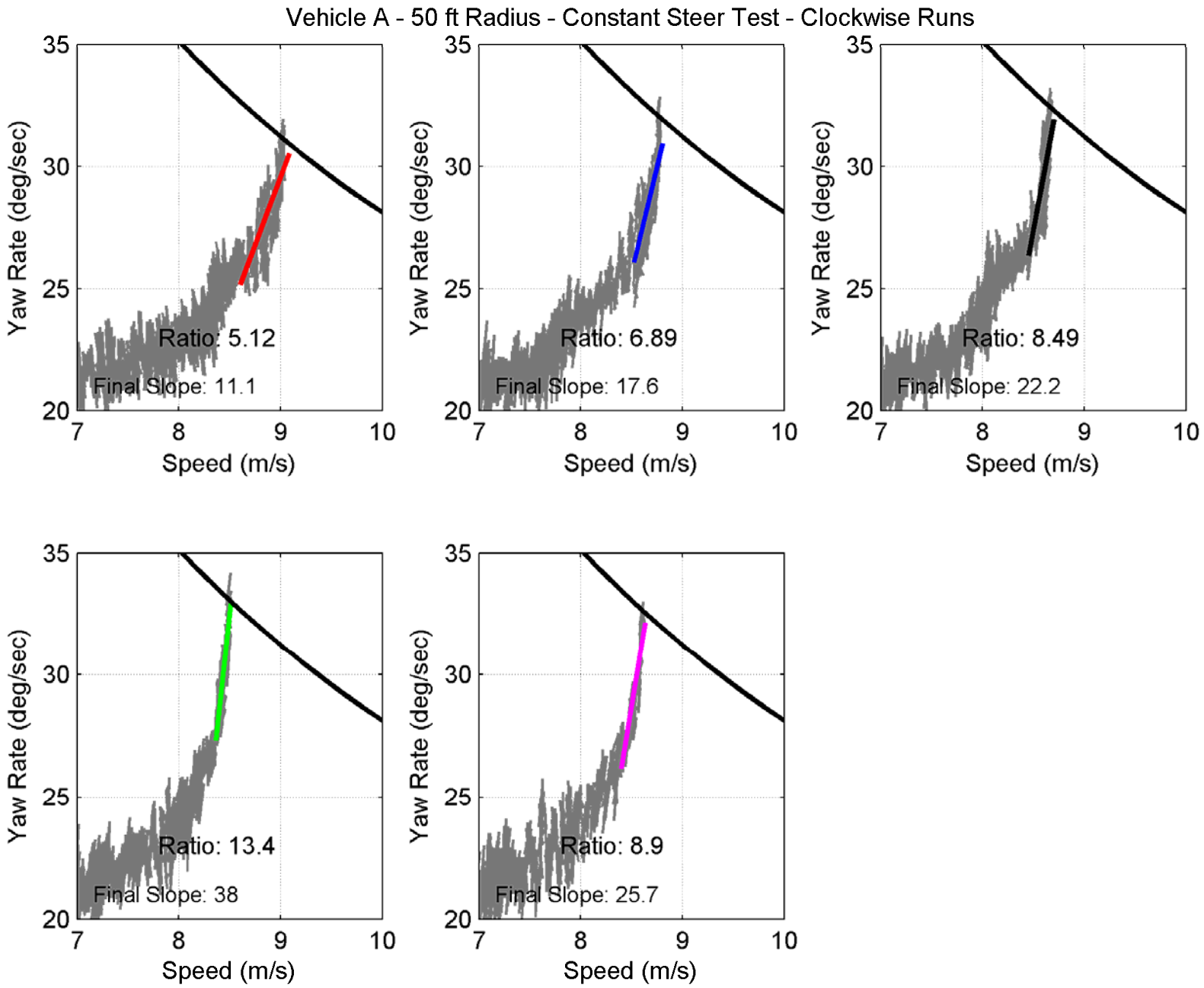
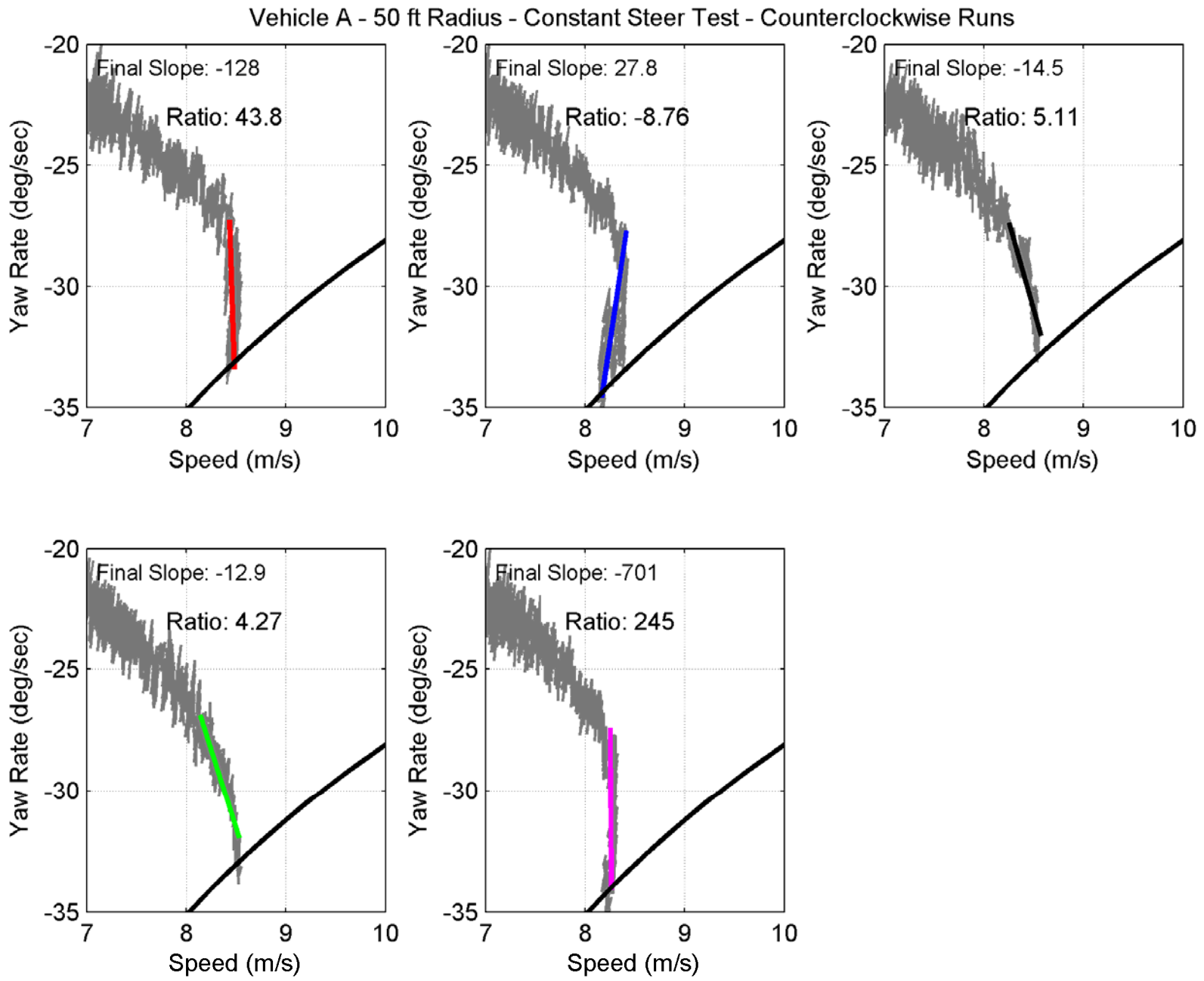
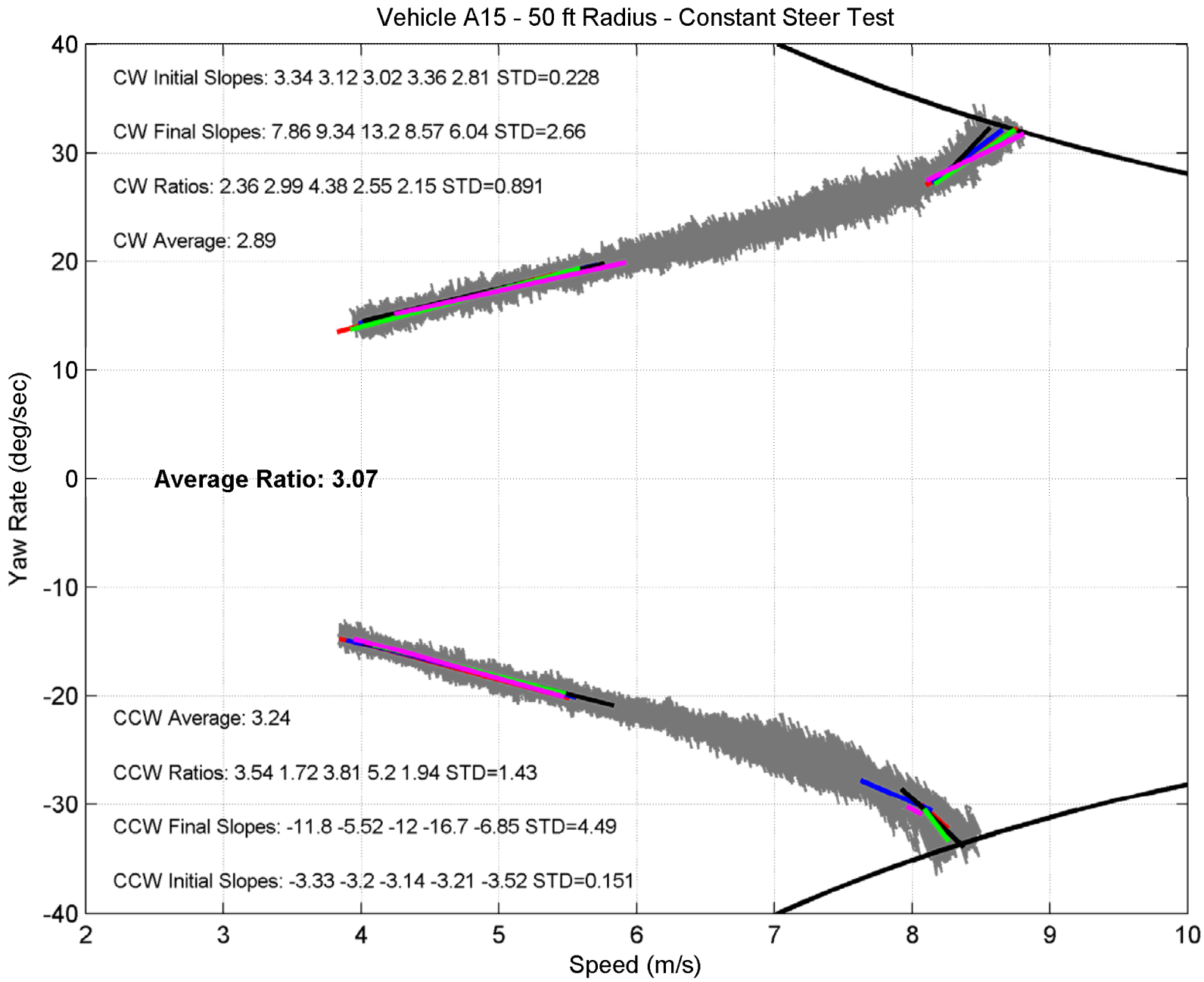


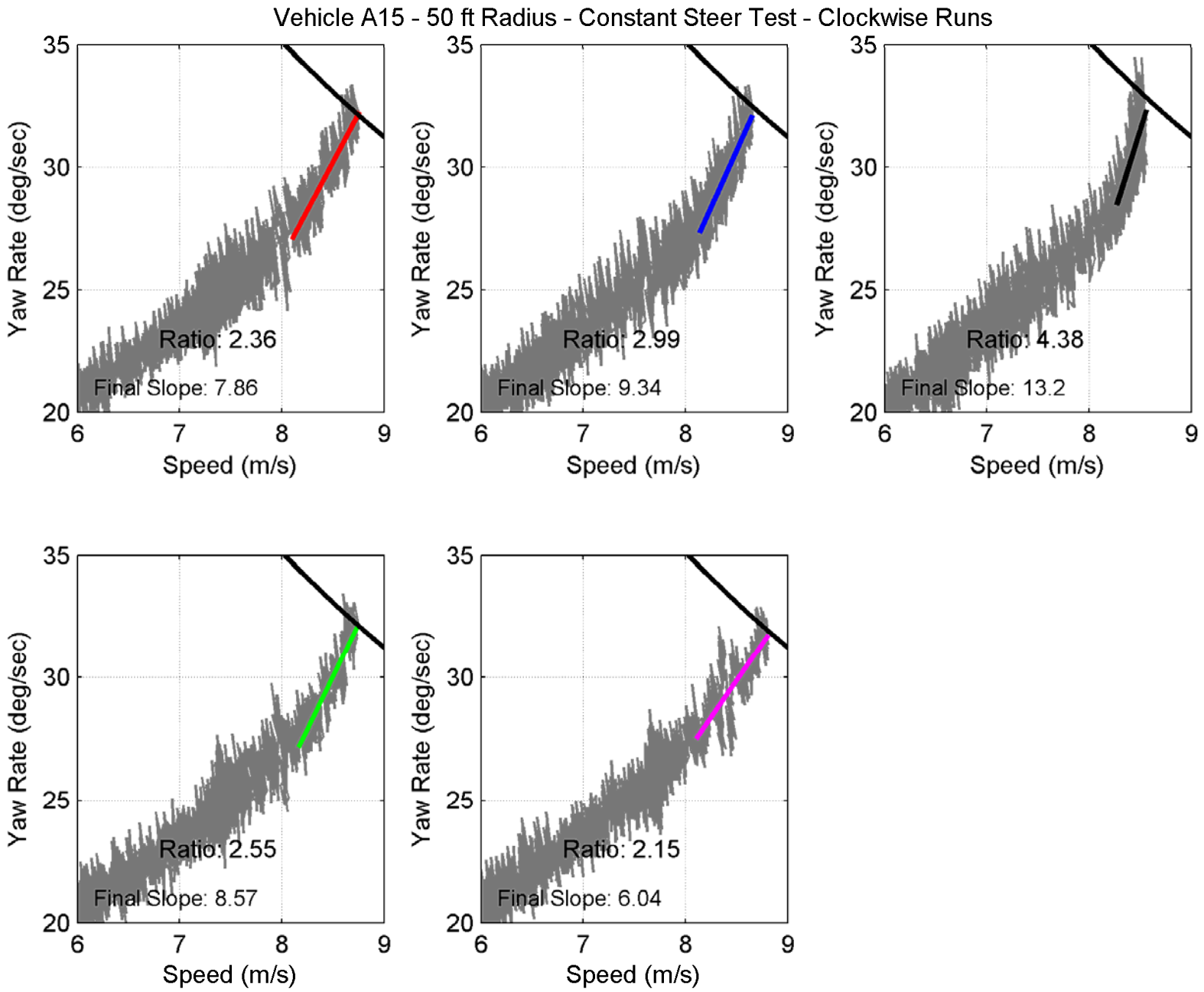
Figure 6: Results from All Tests On Vehicle J15

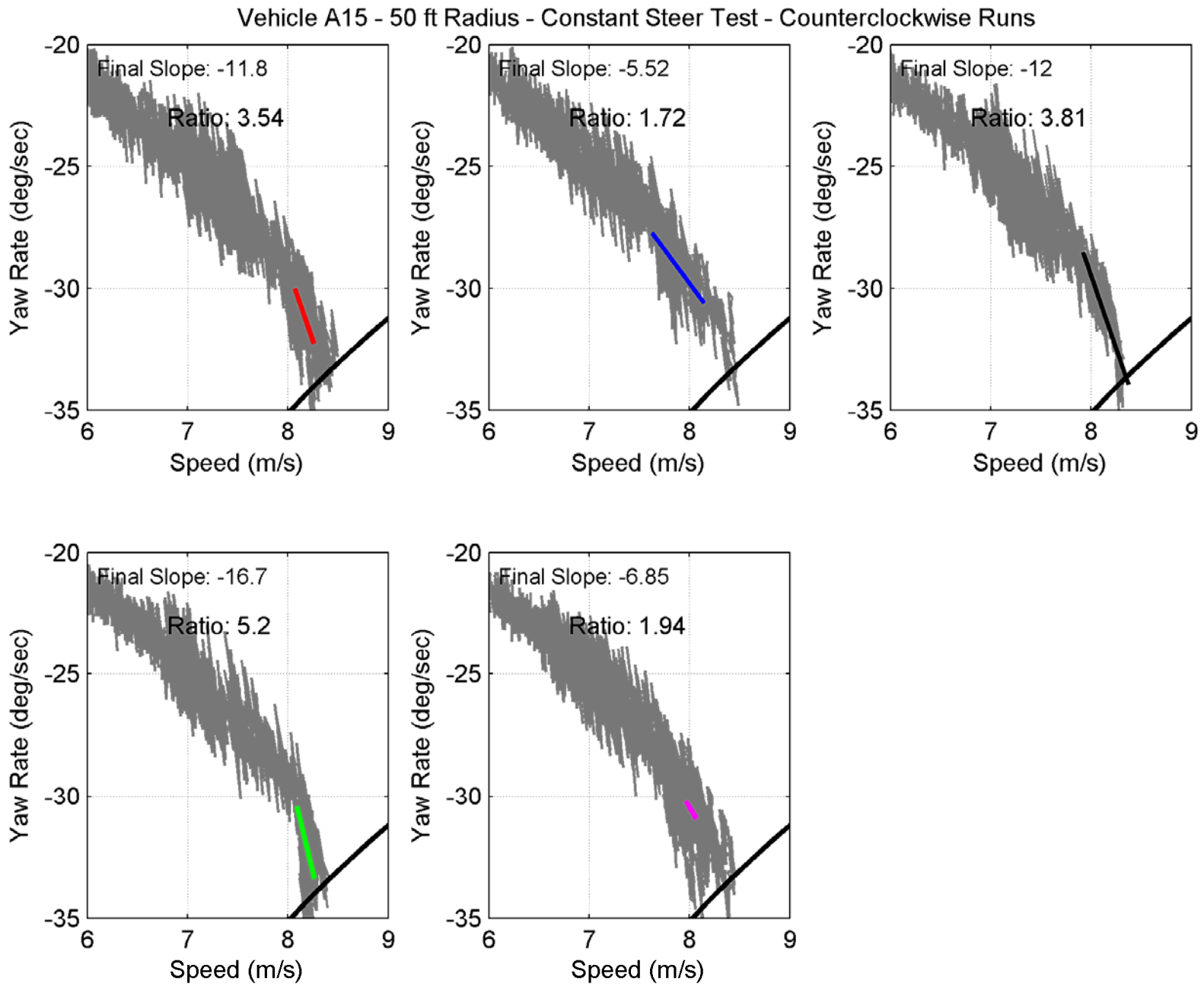

Vehicle A - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.17 2.55 2.62 2.83 2.88 STD=0.281
CW Final Slopes: 11.1 17.6 22.2 38 25.7 STD=10
CW Ratios: 5.12 6.89 8.49 13.4 8.9 STD=3.1
CW Average: 8.57
Average Ratio: 35
CCW Average: 61.3
CCW Ratios: 43.8 -8.76 5.11 4.27 245 STD=106
CCW Final Slopes: -128 27.8 -14.5 -12.9 -701 STD=305
CCW Initial Slopes: -2.93 -3.17 -2.84 -3.02 -2.86 STD=0.133
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

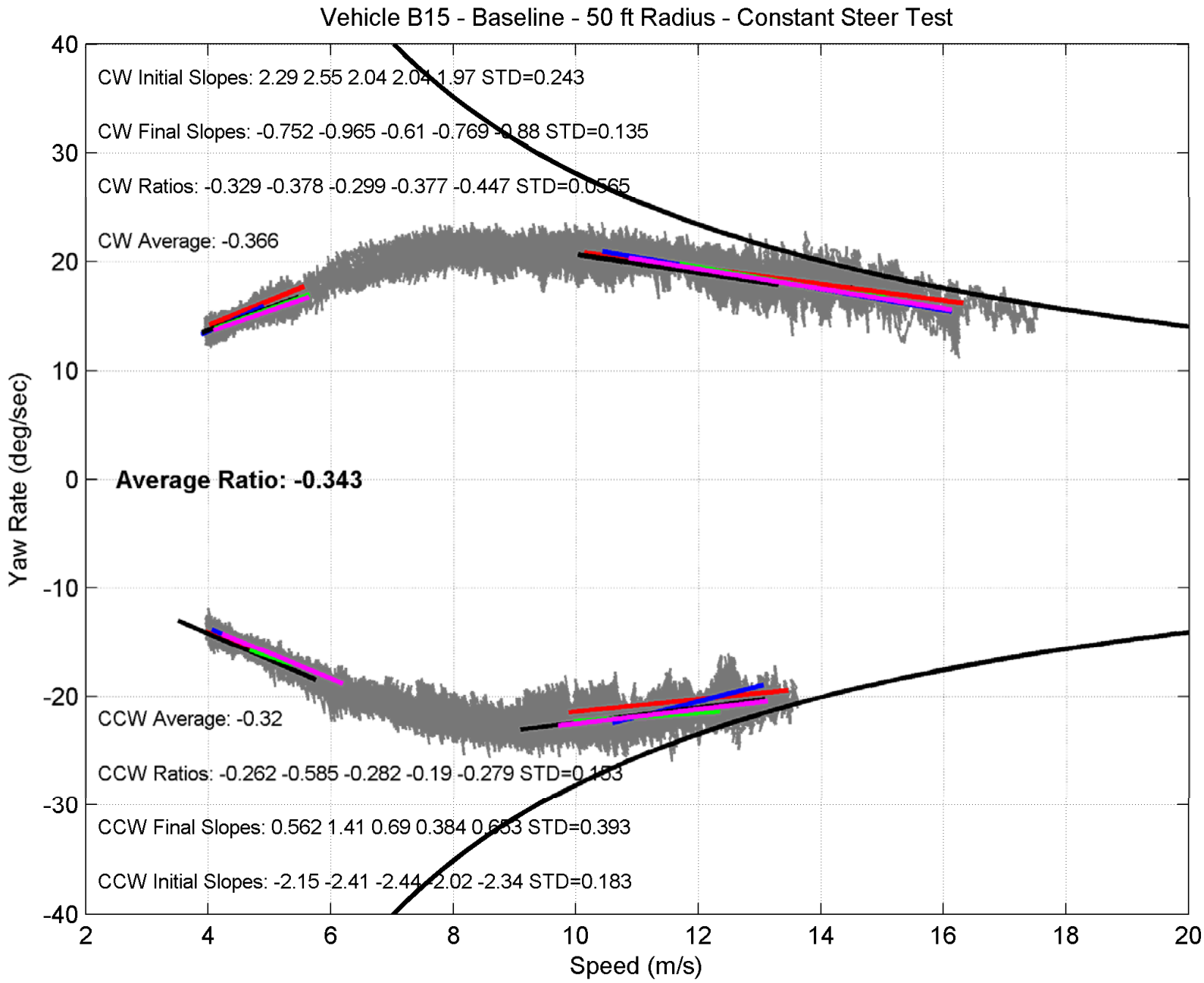

Vehicle A - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 5.12
Final Slope: 11.1
Ratio: 6.89
Final Slope: 17.6
Ratio: 8.49
Final Slope: 22.2
Ratio: 13.4
Final Slope: 38
Ratio: 8.9
Final Slope: 25.7

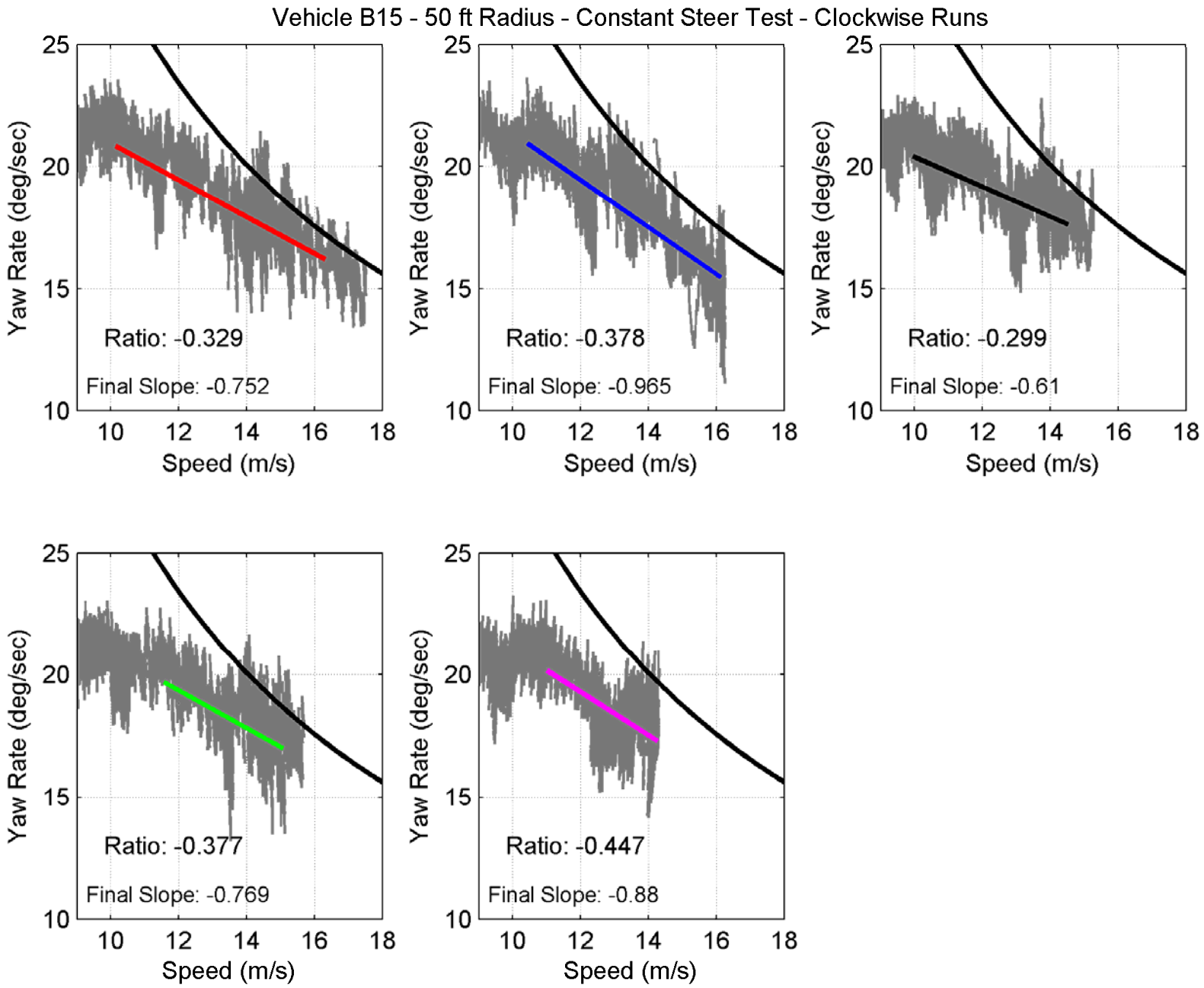

Vehicle A - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -128
Ratio: 43.8
Final Slope: 27.8
Ratio: -8.76
Final Slope: -14.5
Ratio: 5.11
Final Slope: -12.9
Ratio: 4.27
Final Slope: -701
Ratio: 245
Yaw Rate (deg/sec)
Speed (m/s)
-20
-25
-30
-35
7
8
9
10

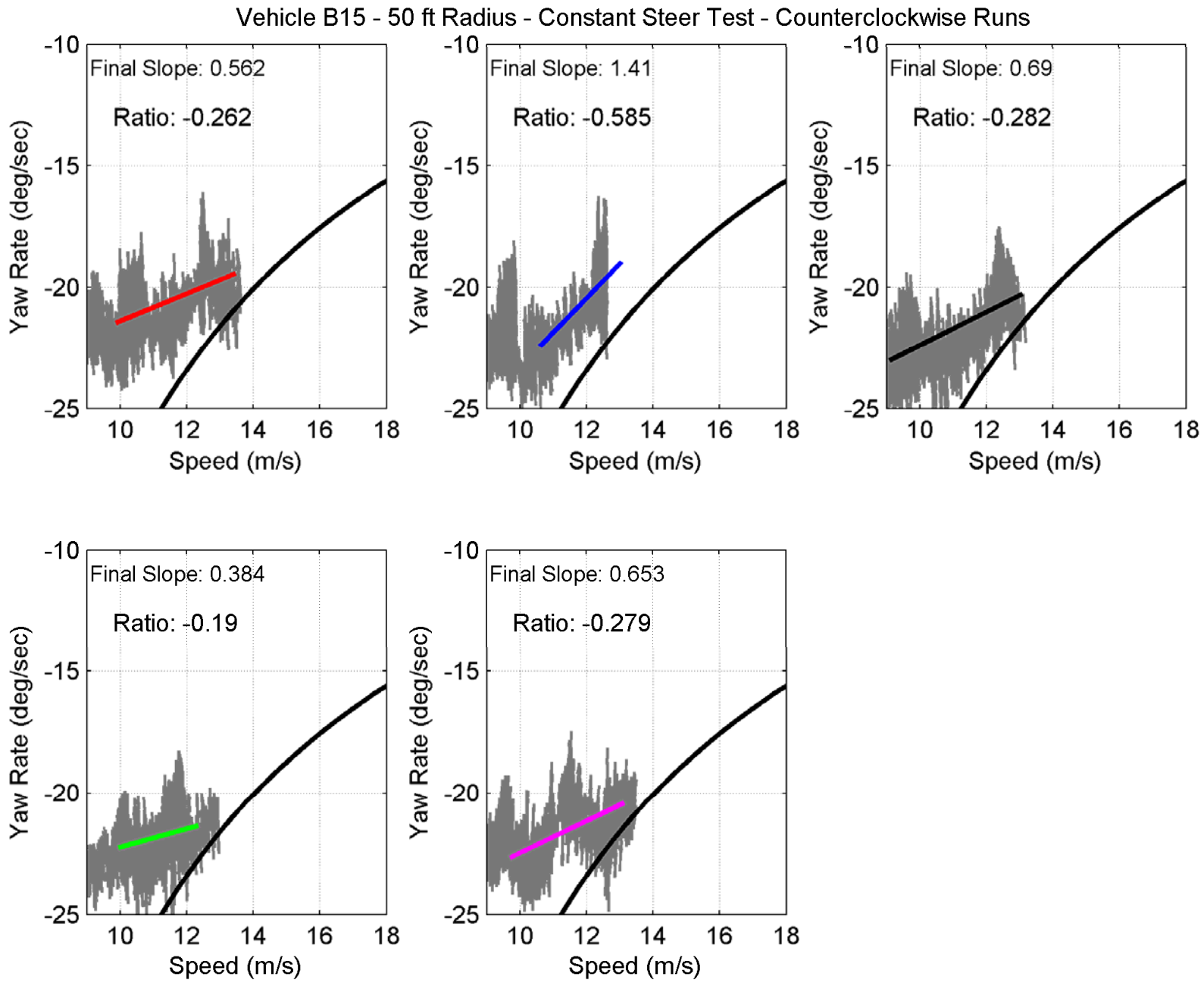

Vehicle A15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.34 3.12 3.02 3.36 2.81 STD=0.228
CW Final Slopes: 7.86 9.34 13.2 8.57 6.04 STD=2.66
CW Ratios: 2.36 2.99 4.38 2.55 2.15 STD=0.891
CW Average: 2.89
Average Ratio: 3.07
CCW Average: 3.24
CCW Ratios: 3.54 1.72 3.81 5.2 1.94 STD=1.43
CCW Final Slopes: -11.8 -5.52 -12 -16.7 -6.85 STD=4.49
CCW Initial Slopes: -3.33 -3.2 -3.14 -3.21 -3.52 STD=0.151
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

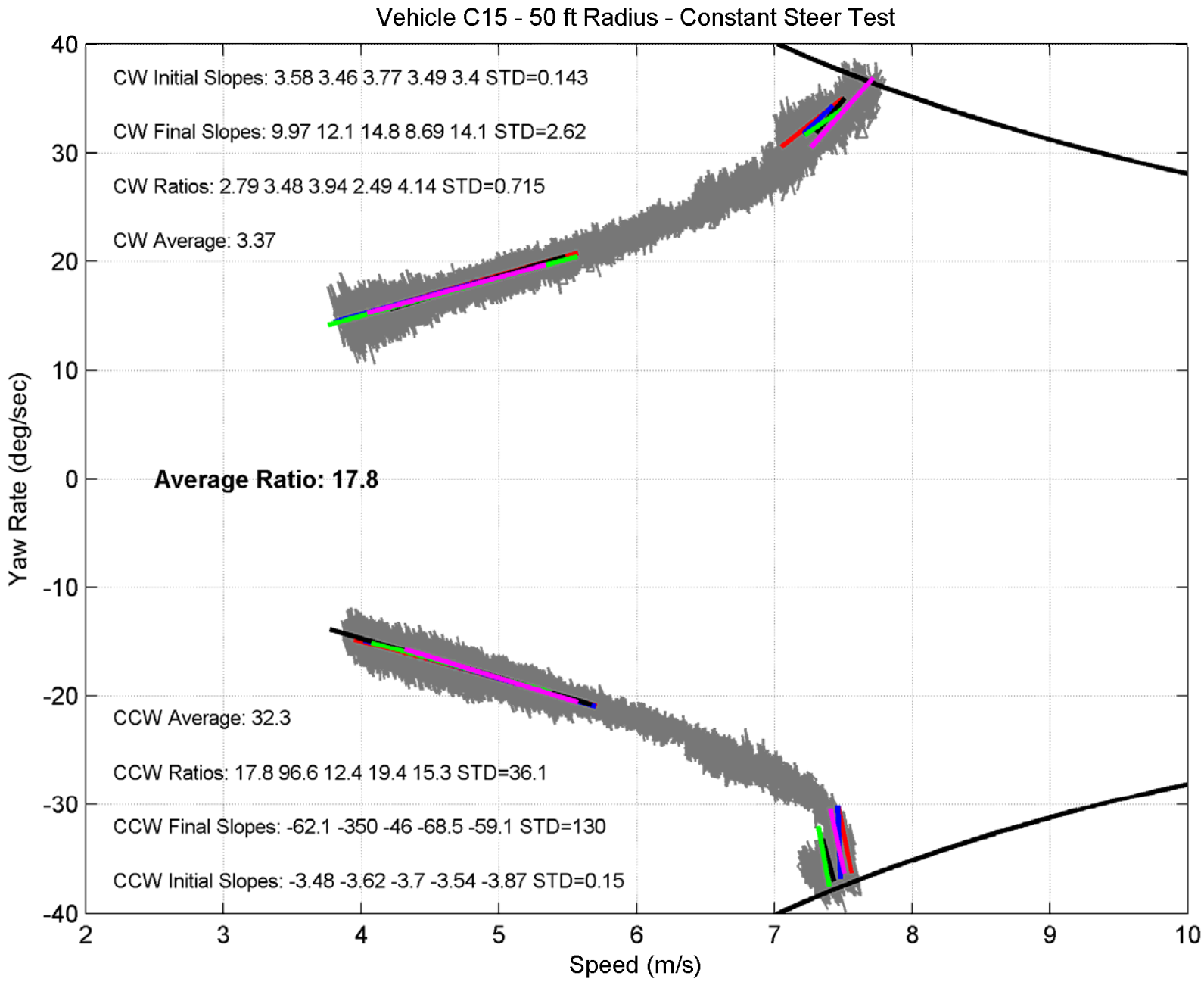

Vehicle A15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 2.36
Final Slope: 7.86
Ratio: 2.99
Final Slope: 9.34
Ratio: 4.38
Final Slope: 13.2
Ratio: 2.55
Final Slope: 8.57
Ratio: 2.15
Final Slope: 6.04

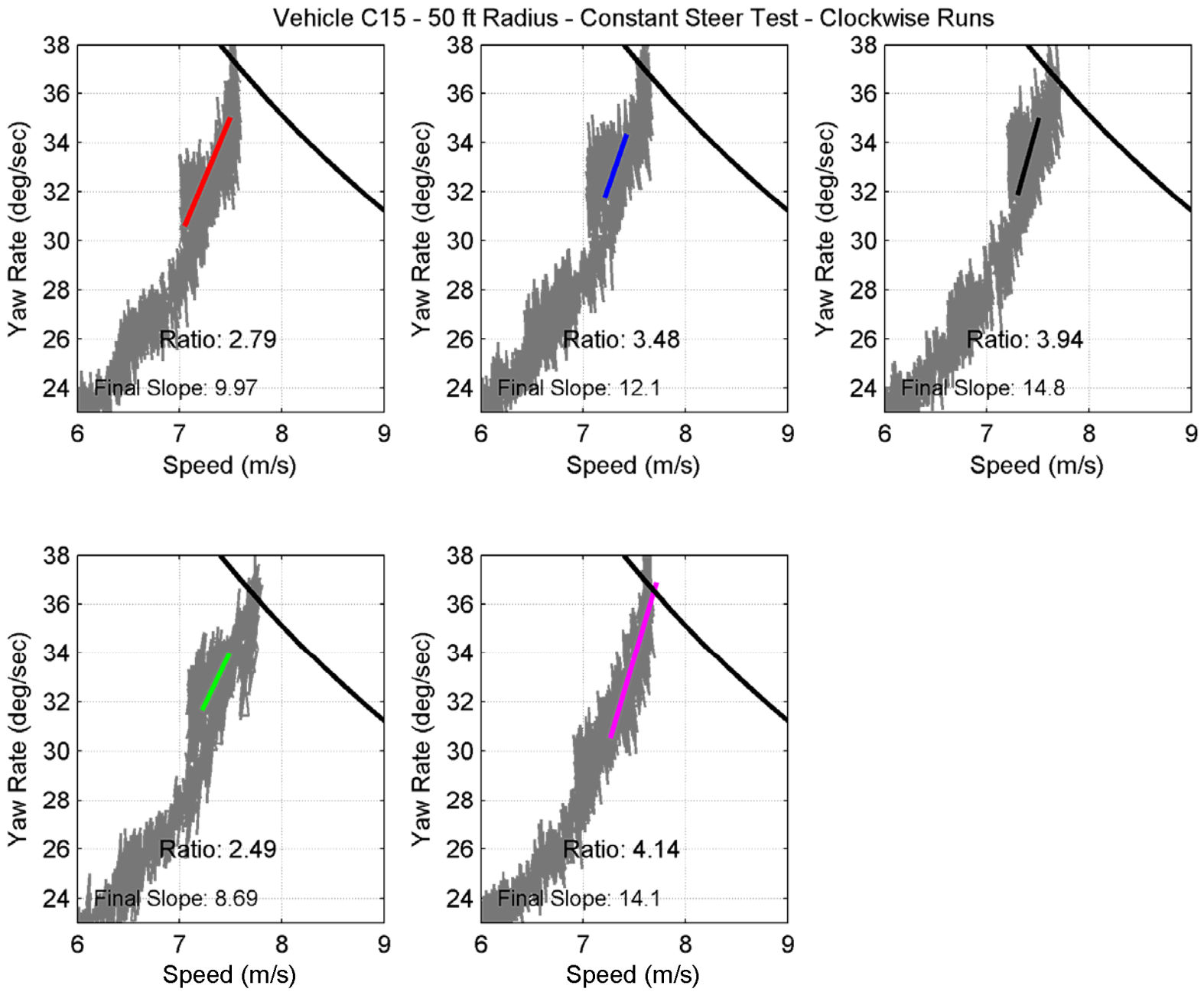

Vehicle A15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -11.8
Ratio: 3.54
Final Slope: -5.52
Ratio: 1.72
Final Slope: -12
Ratio: 3.81
Final Slope: -16.7
Ratio: 5.2
Final Slope: -6.85
Ratio: 1.94
Yaw Rate (deg/sec)
Speed (m/s)
-20
-25
-30
-35
6
7
8
9

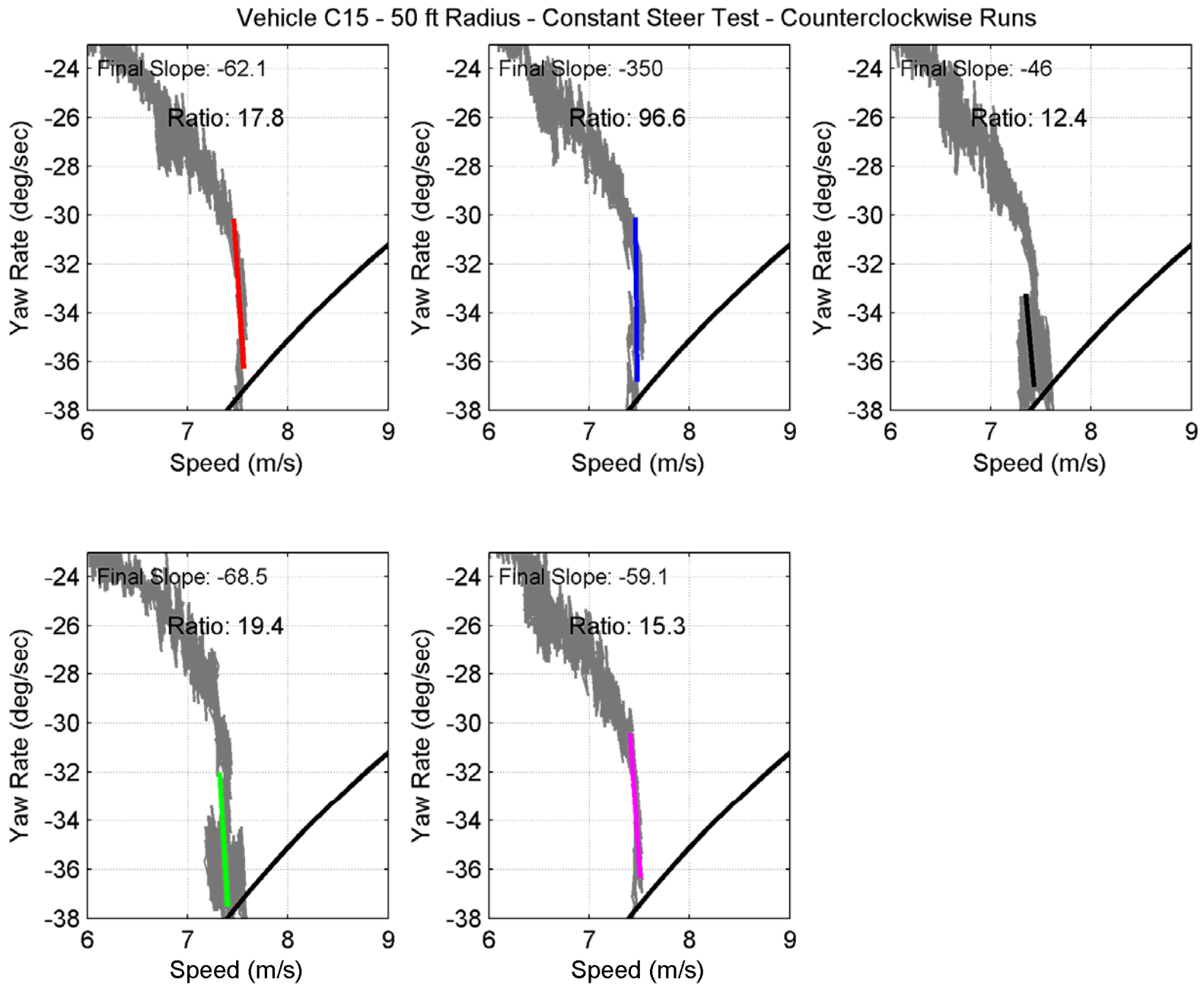

Vehicle B15 - Baseline - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.29 2.55 2.04 2.04 1.97 STD=0.243
CW Final Slopes: -0.752 -0.965 -0.61 -0.769 -0.88 STD=0.135
CW Ratios: -0.329 -0.378 -0.299 -0.377 -0.447 STD=0.0565
CW Average: -0.366
Average Ratio: -0.343
CCW Average: -0.32
CCW Ratios: -0.262 -0.585 -0.282 -0.19 -0.279 STD=0.153
CCW Final Slopes: 0.562 1.41 0.69 0.384 0.683 STD=0.393
CCW Initial Slopes: -2.15 -2.41 -2.44 -2.02 -2.34 STD=0.183
Yaw Rate (deg/sec)
Speed (m/s)
40
30
20
10
0
-10
-20
-30
-40
2
4
6
8
10
12
14
16
18
20

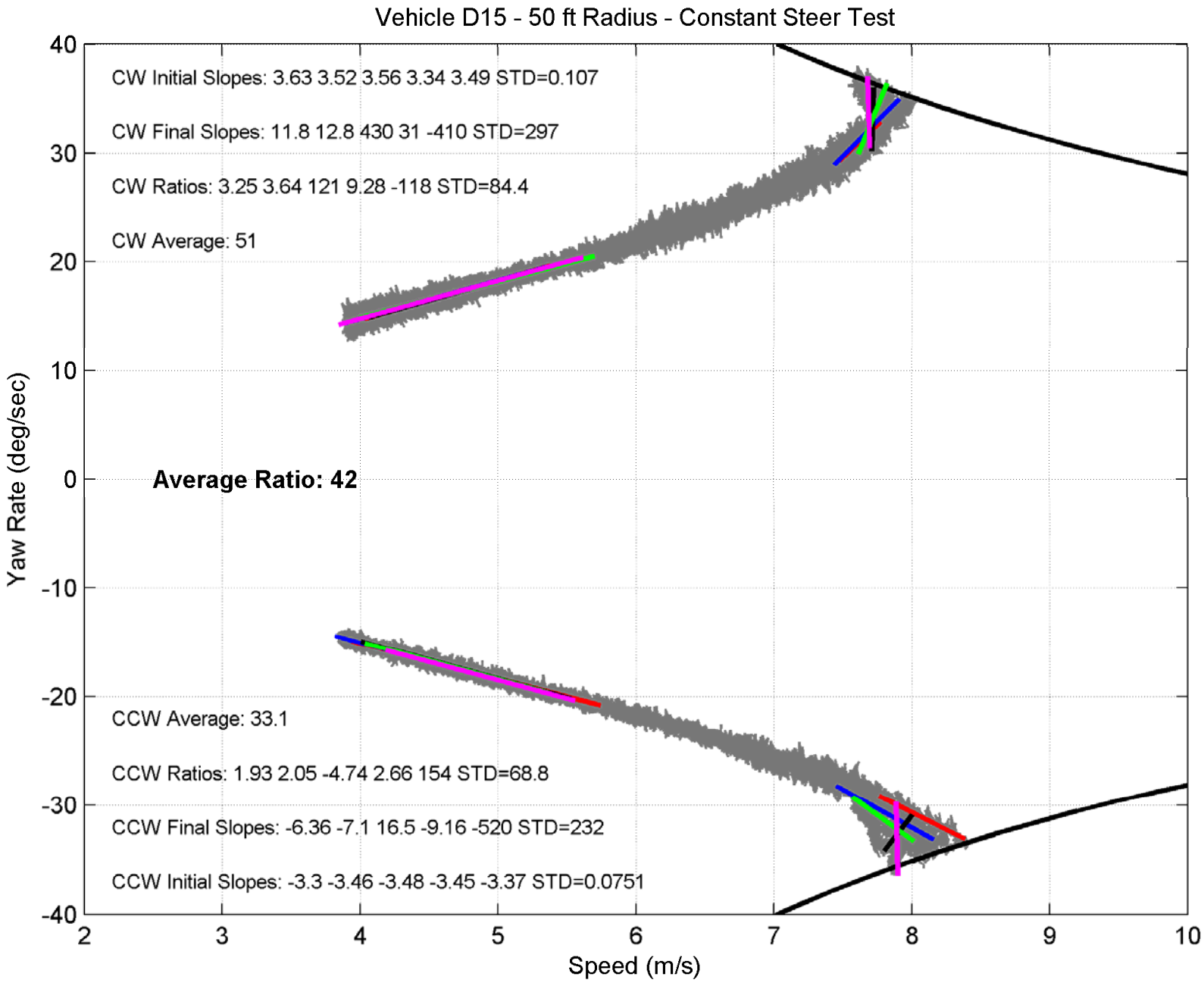

Vehicle B15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: -0.329
Final Slope: -0.752
Ratio: -0.378
Final Slope: -0.965
Ratio: -0.299
Final Slope: -0.61
Ratio: -0.377
Final Slope: -0.769
Ratio: -0.447
Final Slope: -0.88

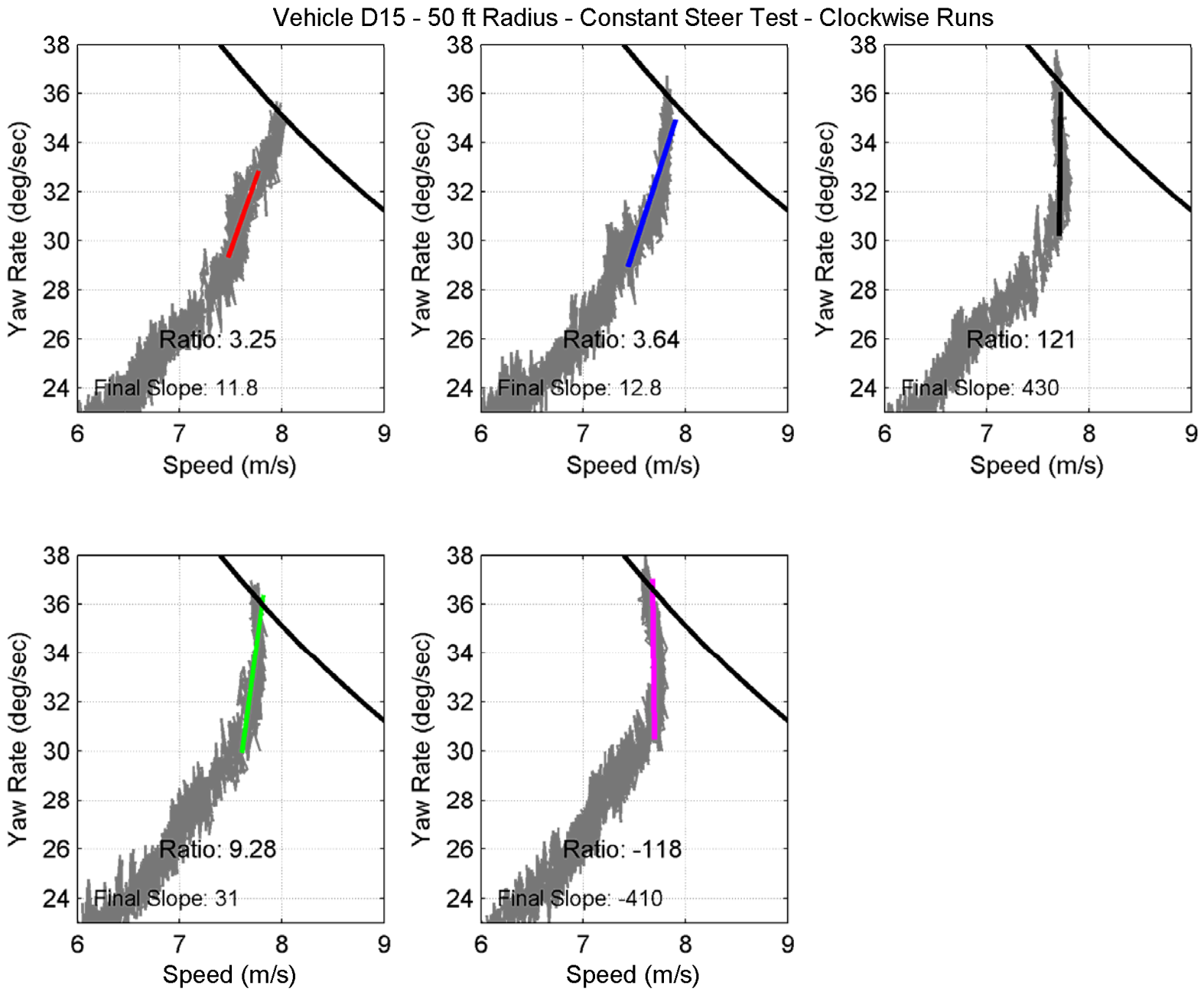

Vehicle B15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: 0.562
Ratio: -0.262
Final Slope: 1.41
Ratio: -0.585
Final Slope: 0.69
Ratio: -0.282
Final Slope: 0.384
Ratio: -0.19
Final Slope: 0.653
Ratio: -0.279
Yaw Rate (deg/sec)
Speed (m/s)
-10
-15
-20
-25
10
12
14
16
18

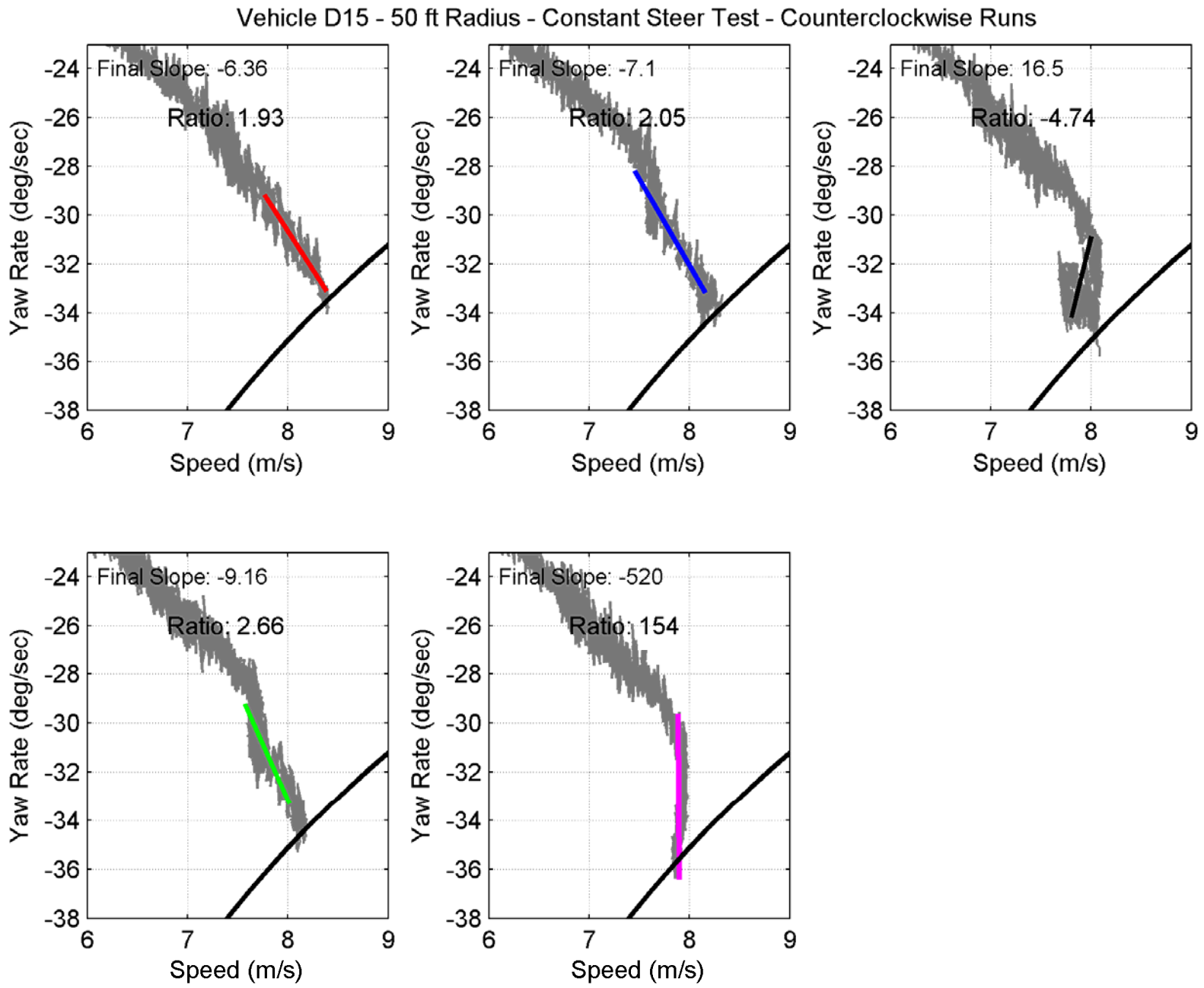

Vehicle C15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.58 3.46 3.77 3.49 3.4 STD=0.143
CW Final Slopes: 9.97 12.1 14.8 8.69 14.1 STD=2.62
CW Ratios: 2.79 3.48 3.94 2.49 4.14 STD=0.715
CW Average: 3.37
Average Ratio: 17.8
CCW Average: 32.3
CCW Ratios: 17.8 96.6 12.4 19.4 15.3 STD=36.1
CCW Final Slopes: -62.1 -350 -46 -68.5 -59.1 STD=130
CCW Initial Slopes: -3.48 -3.62 -3.7 -3.54 -3.87 STD=0.15
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

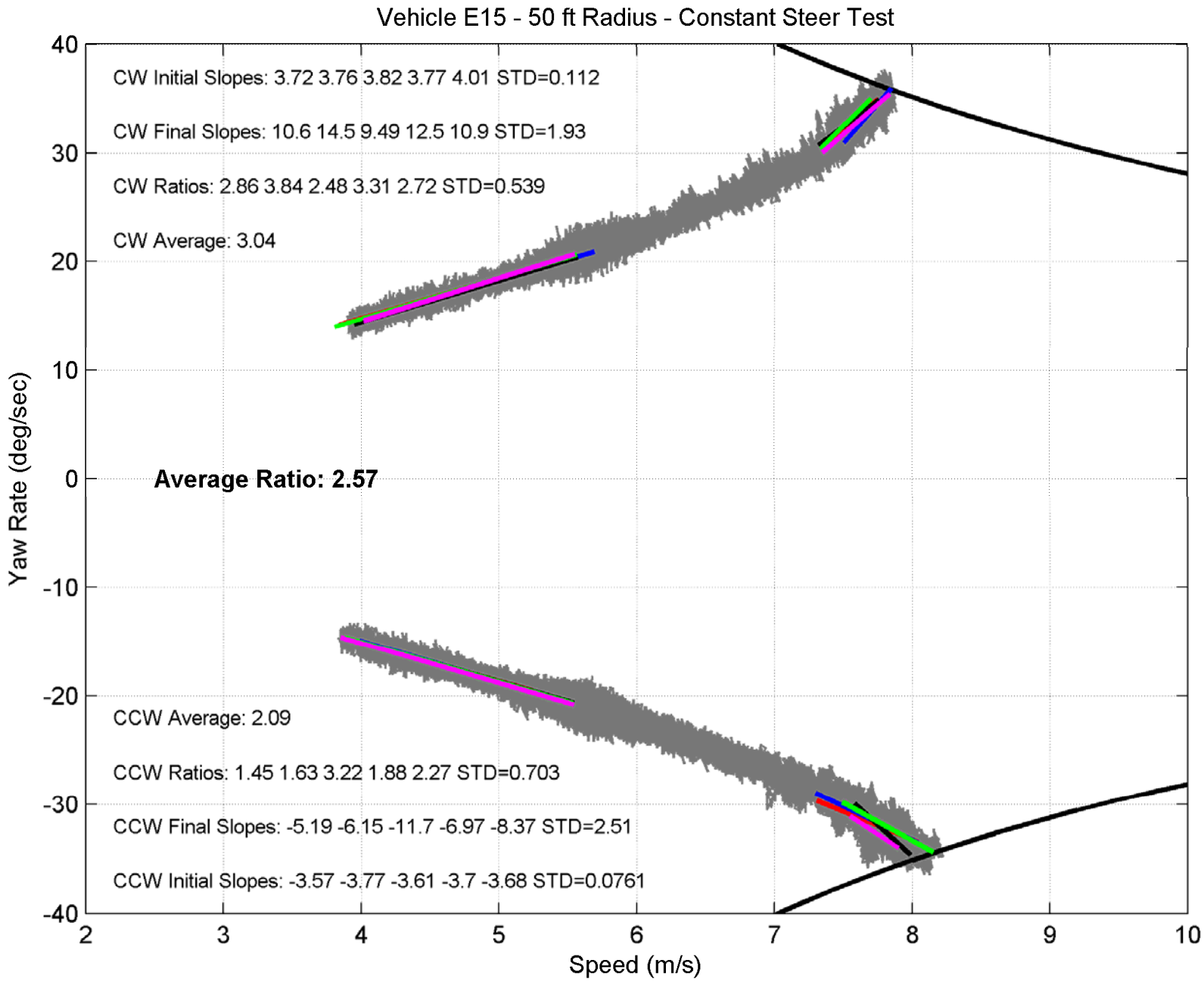

Vehicle C15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 2.79
Final Slope: 9.97
Ratio: 3.48
Final Slope: 12.1
Ratio: 3.94
Final Slope: 14.8
Ratio: 2.49
Final Slope: 8.69
Ratio: 4.14
Final Slope: 14.1

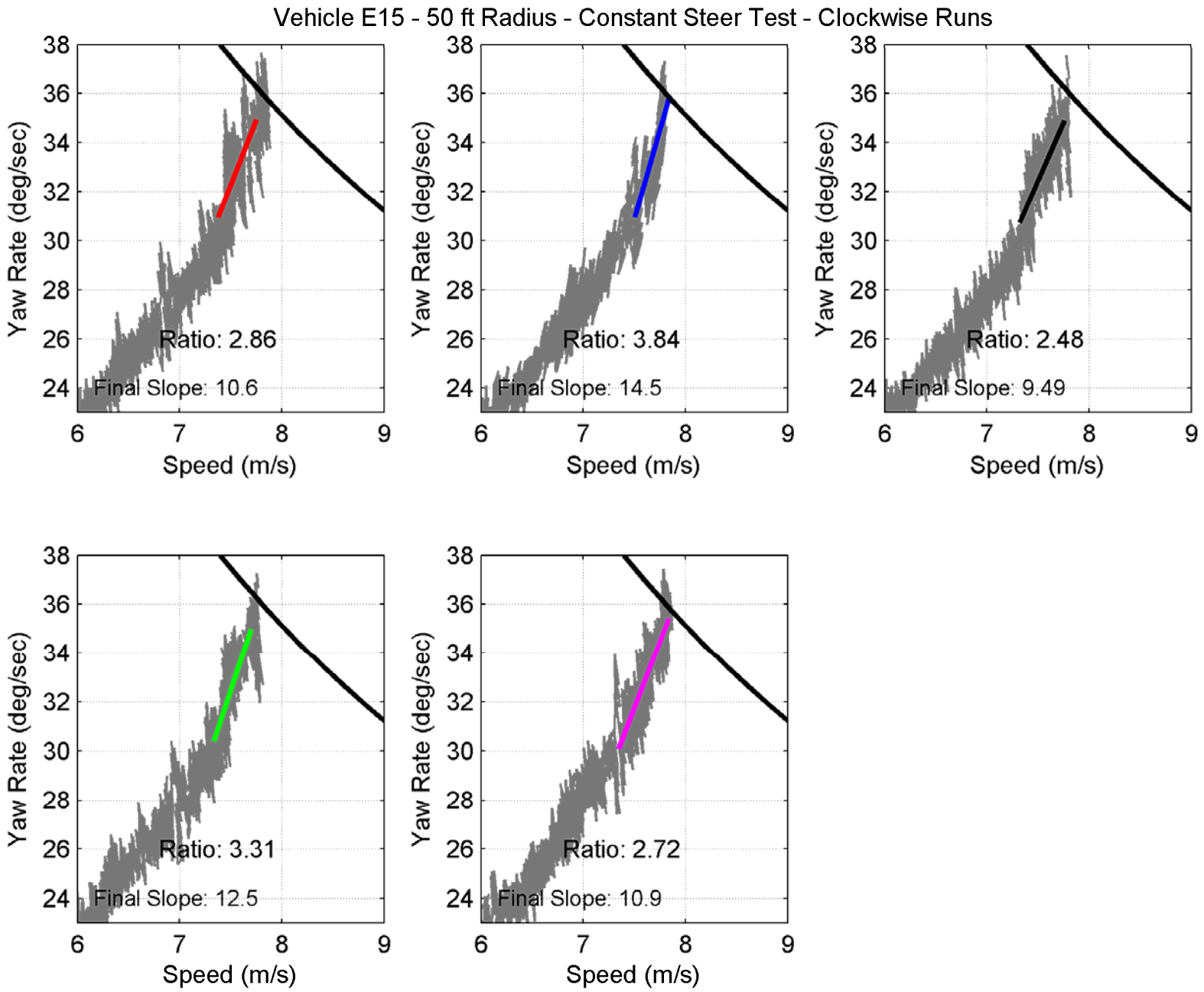

Vehicle C15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -62.1
Ratio: 17.8
Final Slope: -350
Ratio: 96.6
Final Slope: -46
Ratio: 12.4
Final Slope: -68.5
Ratio: 19.4
Final Slope: -59.1
Ratio: 15.3
Yaw Rate (deg/sec)
Speed (m/s)
-24
-26
-28
-30
-32
-34
-36
-38
6
7
8
9

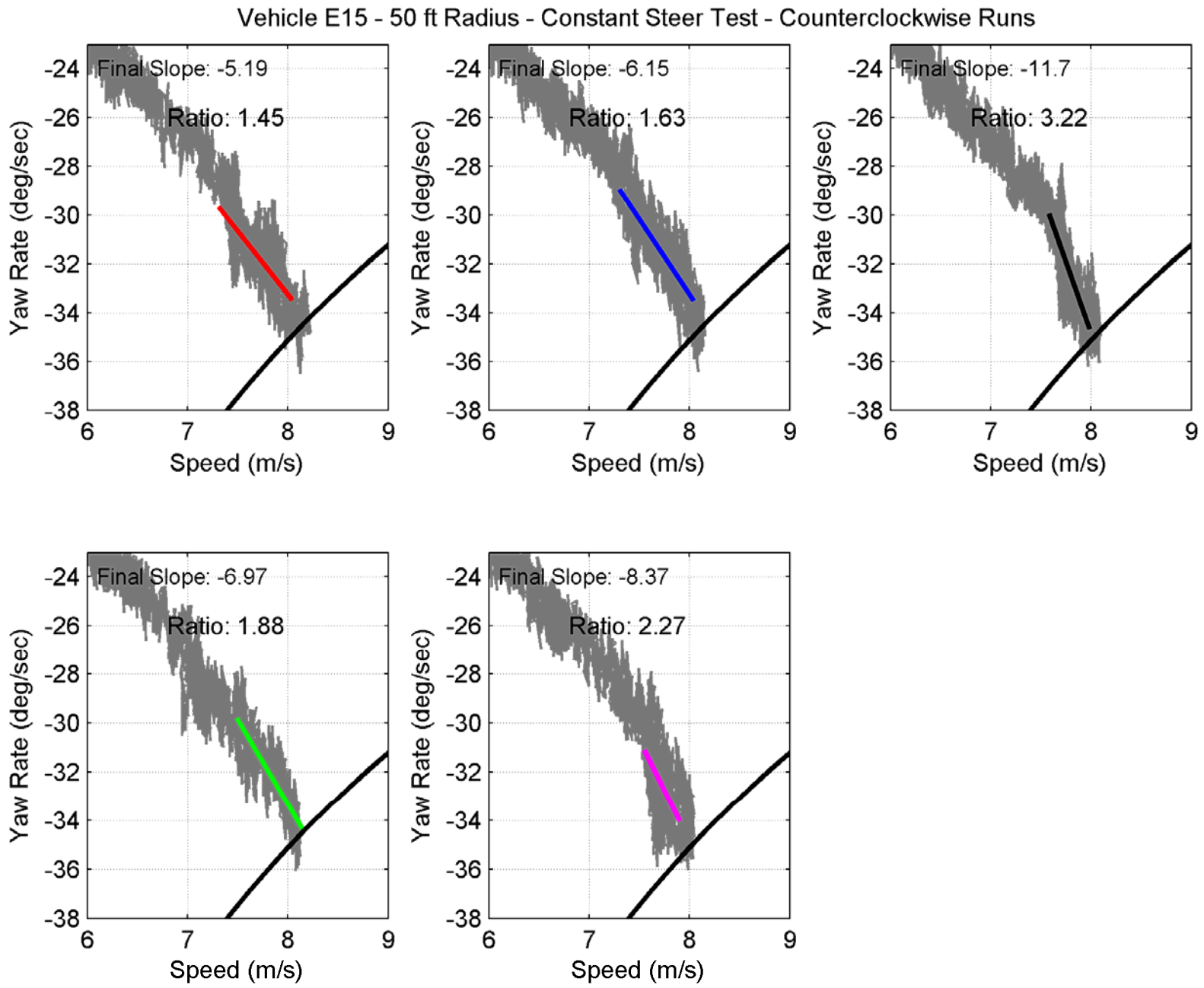

Vehicle D15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.63 3.52 3.56 3.34 3.49 STD=0.107
CW Final Slopes: 11.8 12.8 430 31 -410 STD=297
CW Ratios: 3.25 3.64 121 9.28 -118 STD=84.4
CW Average: 51
Average Ratio: 42
CCW Average: 33.1
CCW Ratios: 1.93 2.05 -4.74 2.66 154 STD=68.8
CCW Final Slopes: -6.36 -7.1 16.5 -9.16 -520 STD=232
CCW Initial Slopes: -3.3 -3.46 -3.48 -3.45 -3.37 STD=0.0751
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

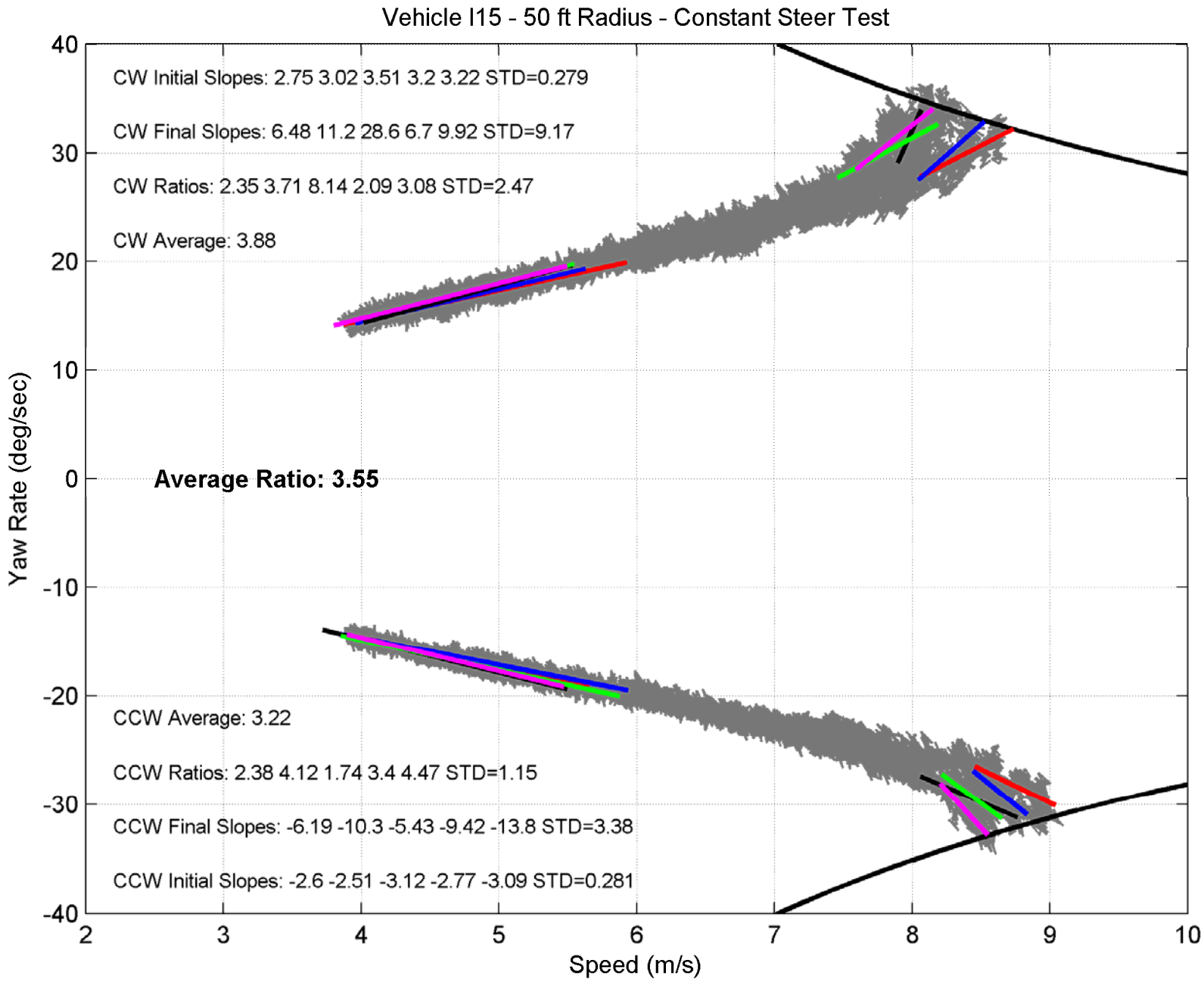

Vehicle D15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 3.25
Final Slope: 11.8
Ratio: 3.64
Final Slope: 12.8
Ratio: 121
Final Slope: 430
Ratio: 9.28
Final Slope: 31
Ratio: -118
Final Slope: -410

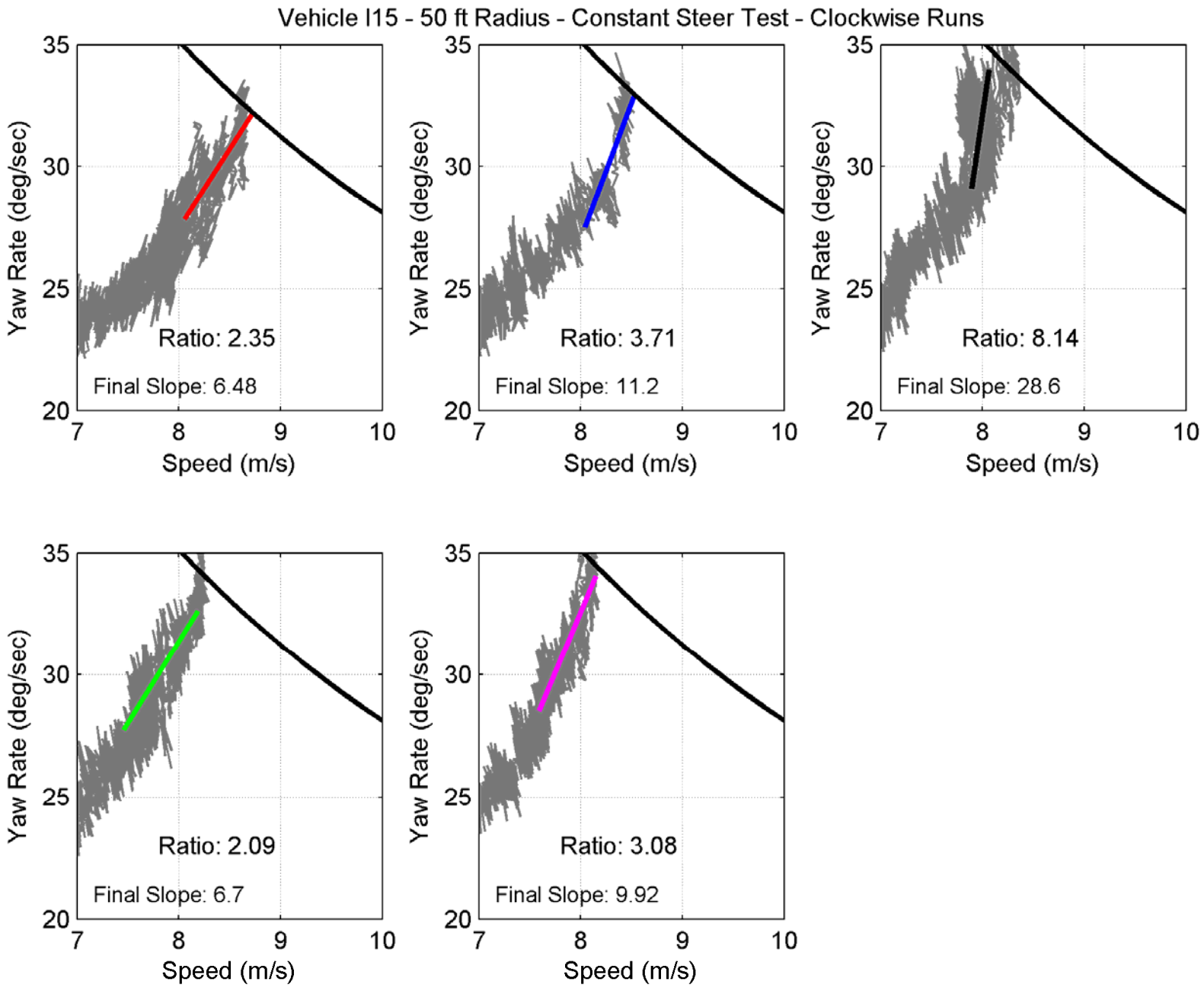

Vehicle D15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -6.36
Ratio: 1.93
Final Slope: -7.1
Ratio: 2.05
Final Slope: 16.5
Ratio: -4.74
Final Slope: -9.16
Ratio: 2.66
Final Slope: -520
Ratio: 154
Yaw Rate (deg/sec)
Speed (m/s)
-24
-26
-28
-30
-32
-34
-36
-38
6
7
8
9

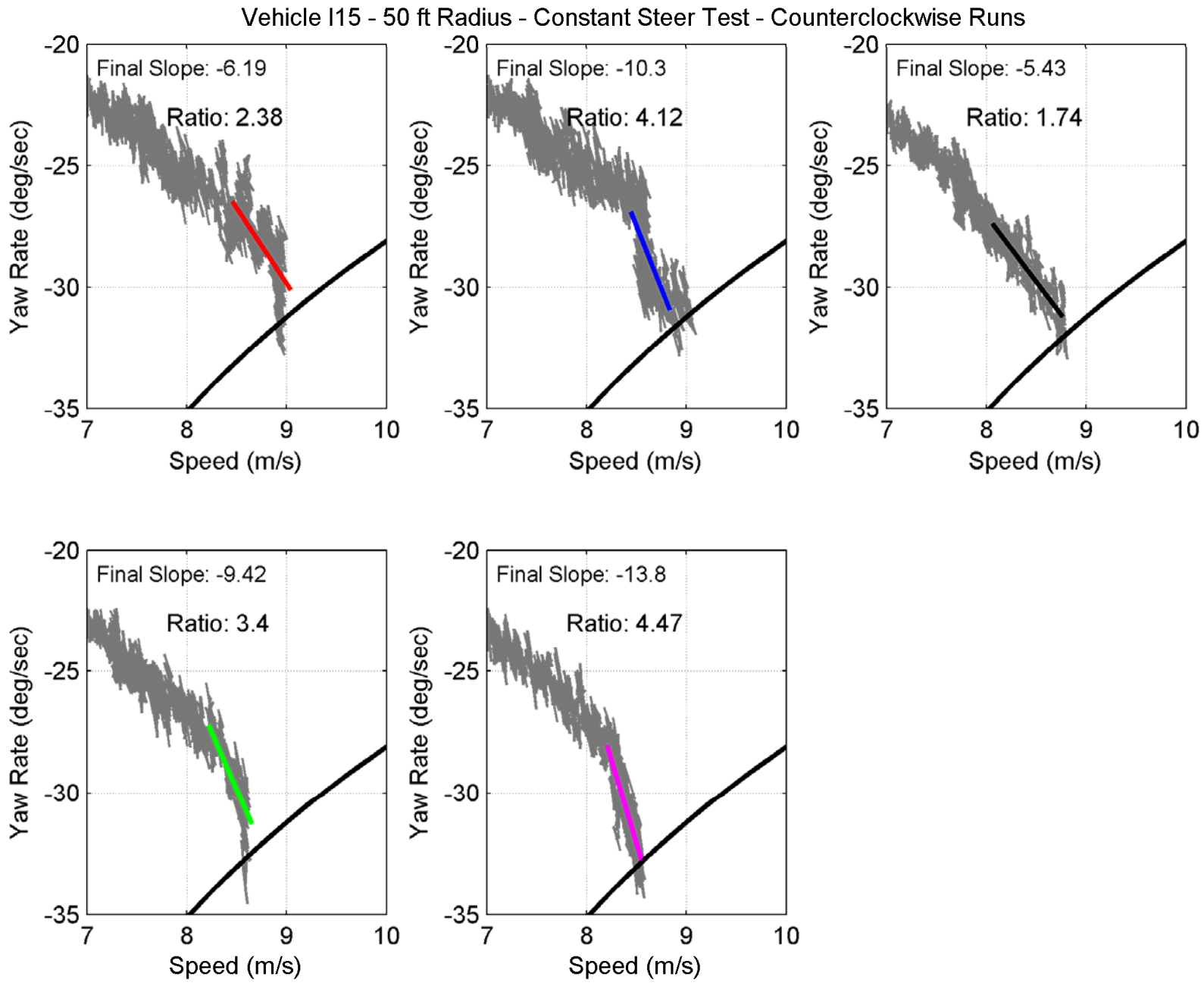

Vehicle E15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.72 3.76 3.82 3.77 4.01 STD=0.112
CW Final Slopes: 10.6 14.5 9.49 12.5 10.9 STD=1.93
CW Ratios: 2.86 3.84 2.48 3.31 2.72 STD=0.539
CW Average: 3.04
Average Ratio: 2.57
CCW Average: 2.09
CCW Ratios: 1.45 1.63 3.22 1.88 2.27 STD=0.703
CCW Final Slopes: -5.19 -6.15 -11.7 -6.97 -8.37 STD=2.51
CCW Initial Slopes: -3.57 -3.77 -3.61 -3.7 -3.68 STD=0.0761
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

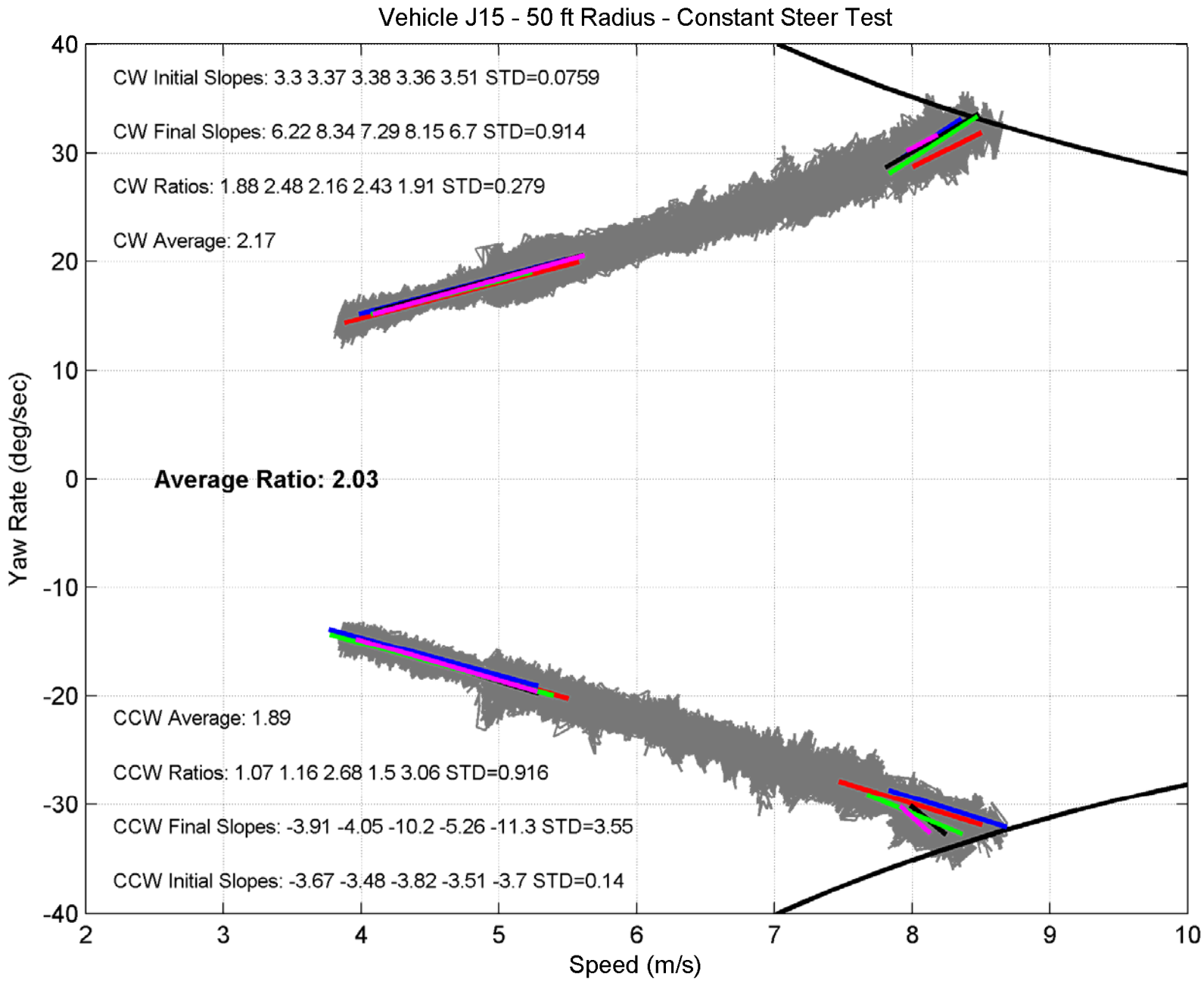

Vehicle E15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 2.86
Final Slope: 10.6
Ratio: 3.84
Final Slope: 14.5
Ratio: 2.48
Final Slope: 9.49
Ratio: 3.31
Final Slope: 12.5
Ratio: 2.72
Final Slope: 10.9

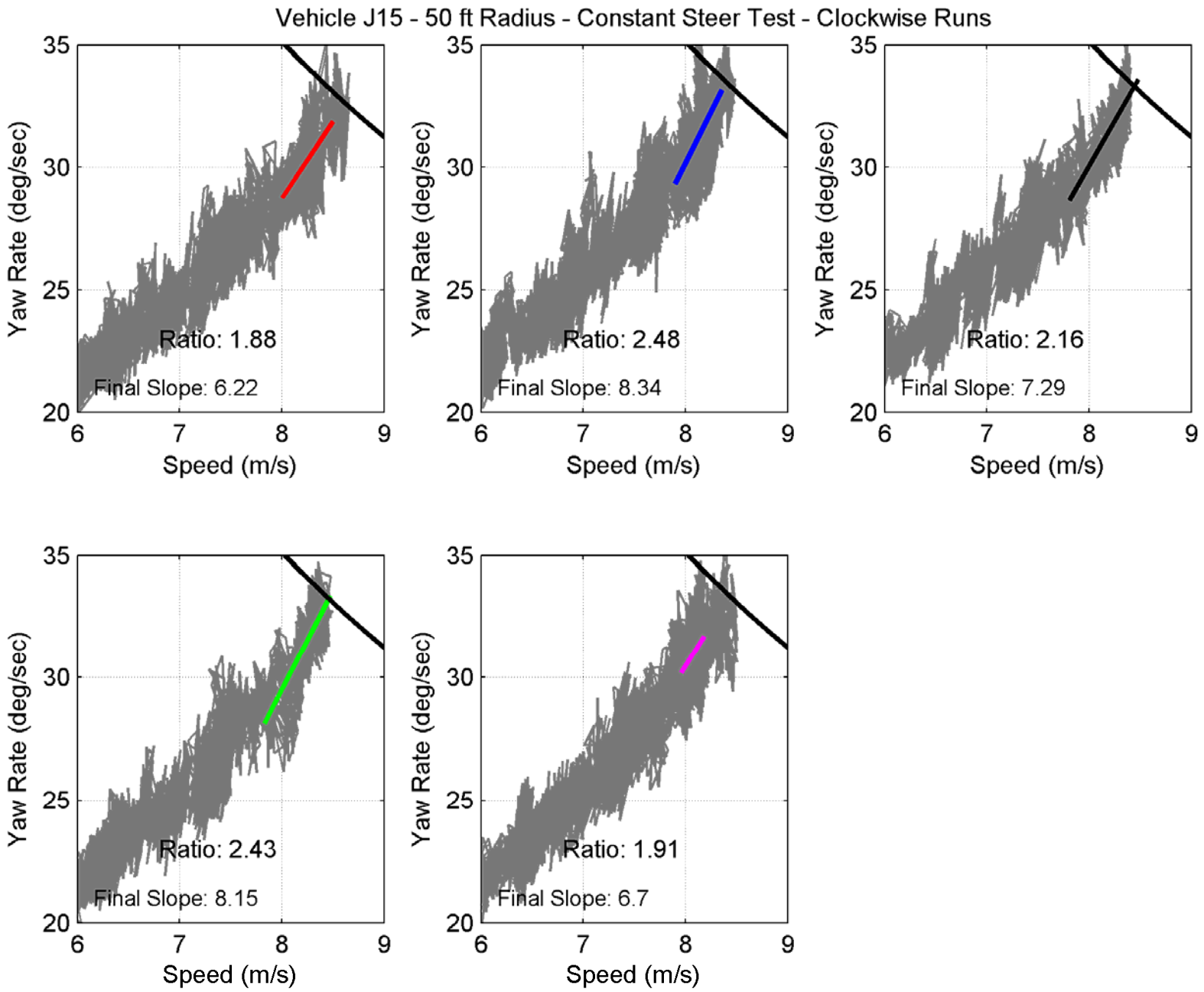

Vehicle E15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -5.19
Ratio: 1.45
Final Slope: -6.15
Ratio: 1.63
Final Slope: -11.7
Ratio: 3.22
Final Slope: -6.97
Ratio: 1.88
Final Slope: -8.37
Ratio: 2.27
Yaw Rate (deg/sec)
Speed (m/s)
-24
-26
-28
-30
-32
-34
-36
-38
6
7
8
9

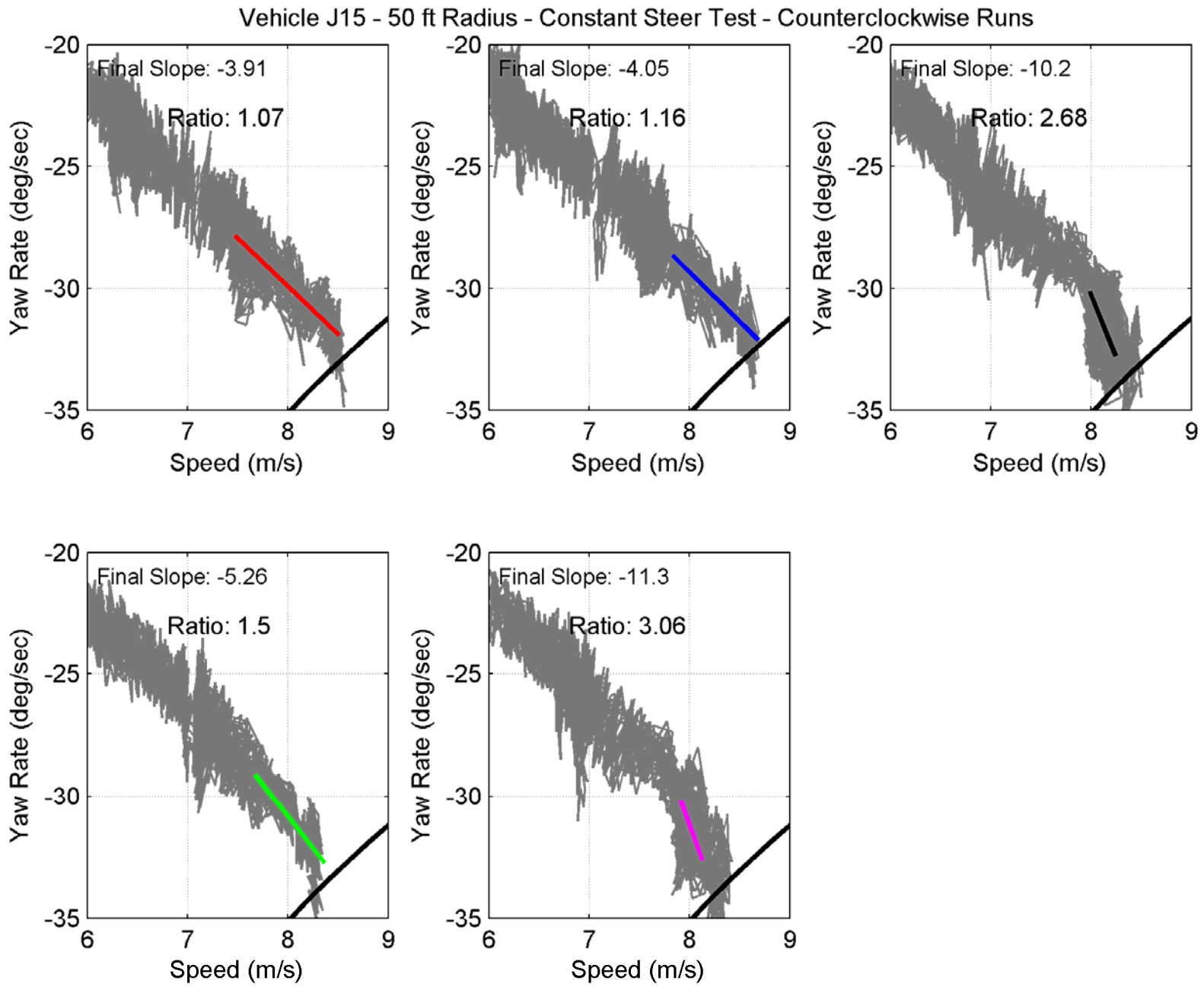

Vehicle I15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.75 3.02 3.51 3.2 3.22 STD=0.279
CW Final Slopes: 6.48 11.2 28.6 6.7 9.92 STD=9.17
CW Ratios: 2.35 3.71 8.14 2.09 3.08 STD=2.47
CW Average: 3.88
Average Ratio: 3.55
CCW Average: 3.22
CCW Ratios: 2.38 4.12 1.74 3.4 4.47 STD=1.15
CCW Final Slopes: -6.19 -10.3 -5.43 -9.42 -13.8 STD=3.38
CCW Initial Slopes: -2.6 -2.51 -3.12 -2.77 -3.09 STD=0.281
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

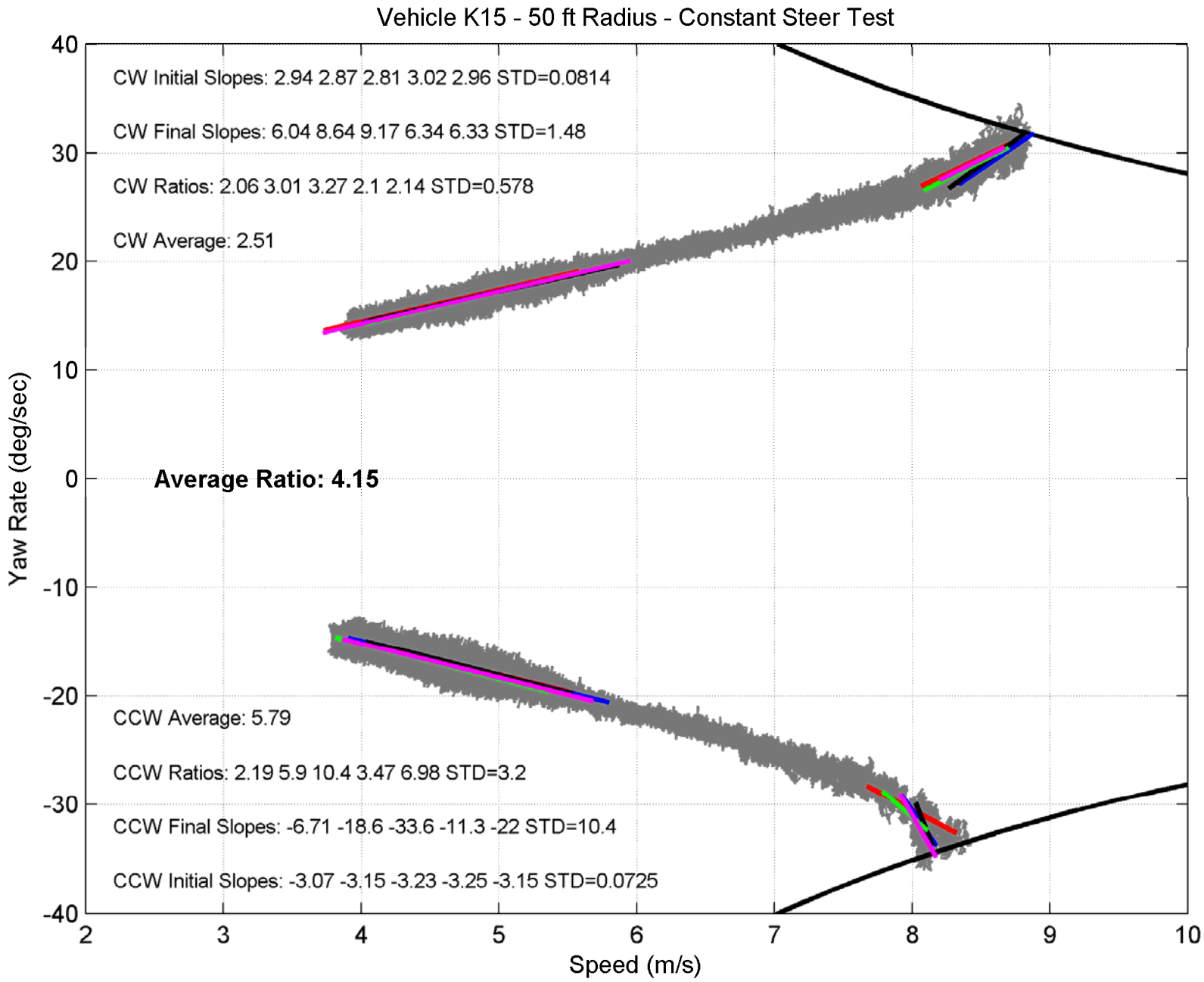

Vehicle I15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 2.35
Final Slope: 6.48
Ratio: 3.71
Final Slope: 11.2
Ratio: 8.14
Final Slope: 28.6
Ratio: 2.09
Final Slope: 6.7
Ratio: 3.08
Final Slope: 9.92

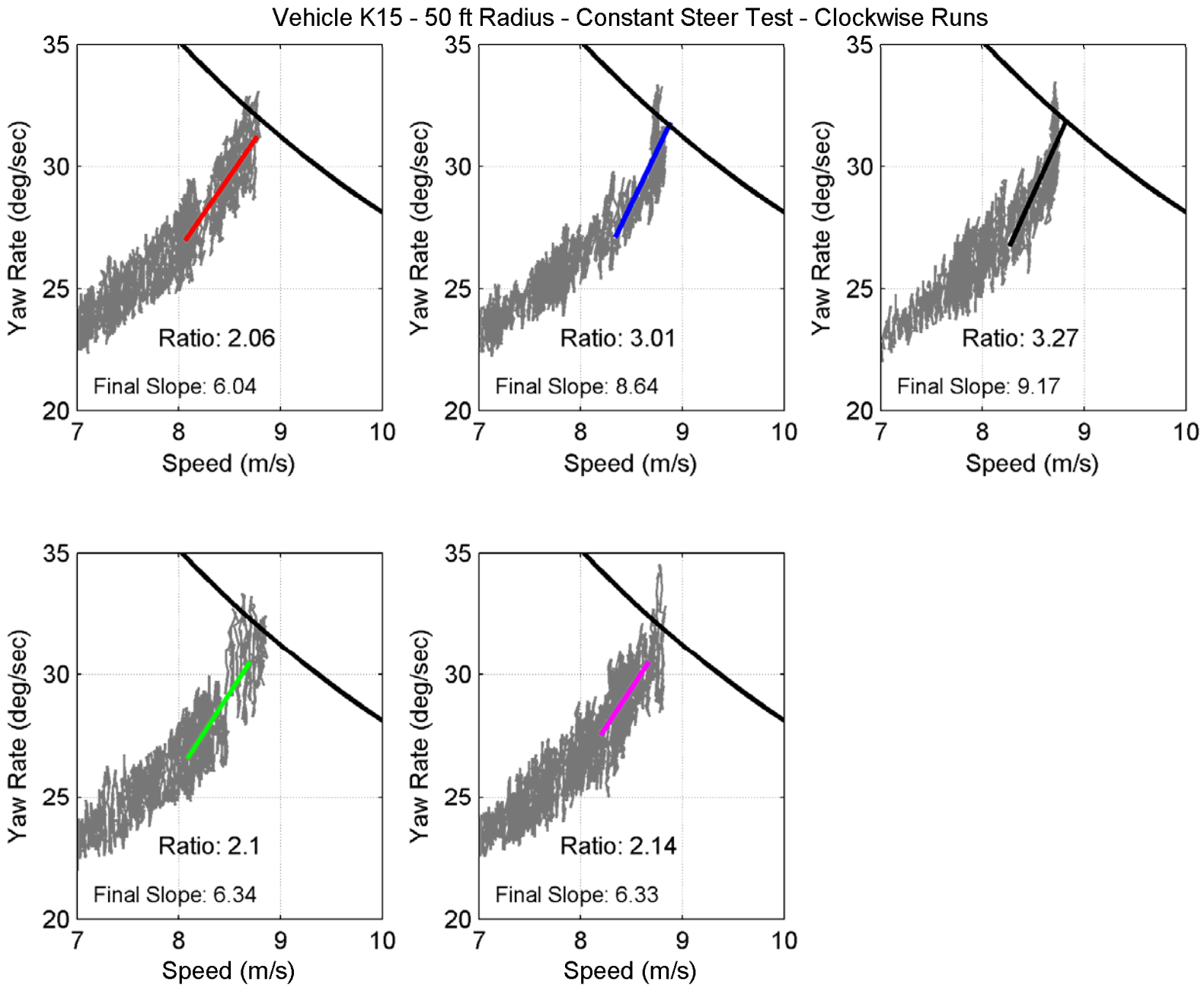

Vehicle I15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -6.19
Ratio: 2.38
Final Slope: -10.3
Ratio: 4.12
Final Slope: -5.43
Ratio: 1.74
Final Slope: -9.42
Ratio: 3.4
Final Slope: -13.8
Ratio: 4.47
Yaw Rate (deg/sec)
Speed (m/s)
-20
-25
-30
-35
7
8
9
10

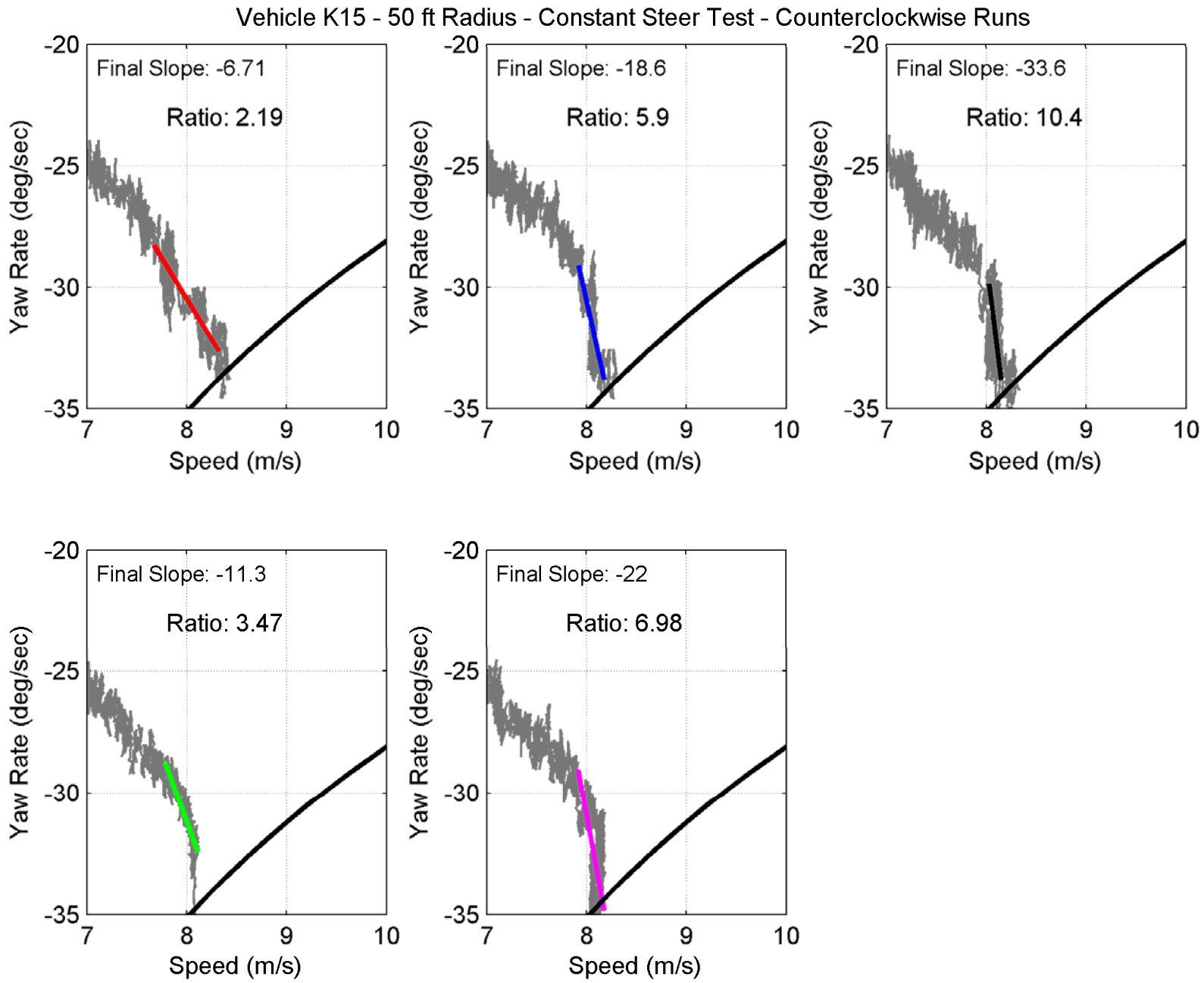

Vehicle J15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.3 3.37 3.38 3.36 3.51 STD=0.0759
CW Final Slopes: 6.22 8.34 7.29 8.15 6.7 STD=0.914
CW Ratios: 1.88 2.48 2.16 2.43 1.91 STD=0.279
CW Average: 2.17
Average Ratio: 2.03
CCW Average: 1.89
CCW Ratios: 1.07 1.16 2.68 1.5 3.06 STD=0.916
CCW Final Slopes: -3.91 -4.05 -10.2 -5.26 -11.3 STD=3.55
CCW Initial Slopes: -3.67 -3.48 -3.82 -3.51 -3.7 STD=0.14
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

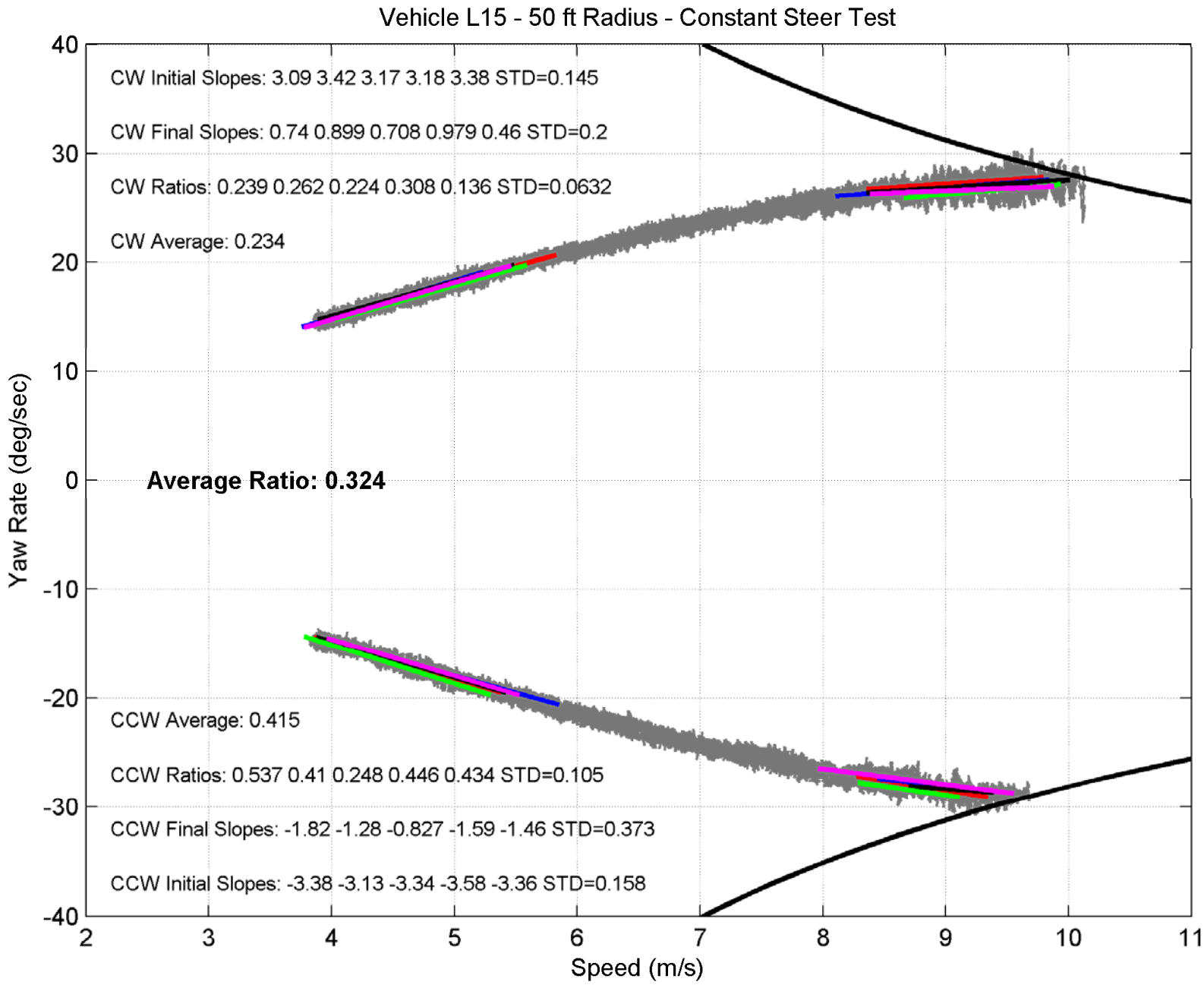

Vehicle J15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 1.88
Final Slope: 6.22
Ratio: 2.48
Final Slope: 8.34
Ratio: 2.16
Final Slope: 7.29
Ratio: 2.43
Final Slope: 8.15
Ratio: 1.91
Final Slope: 6.7

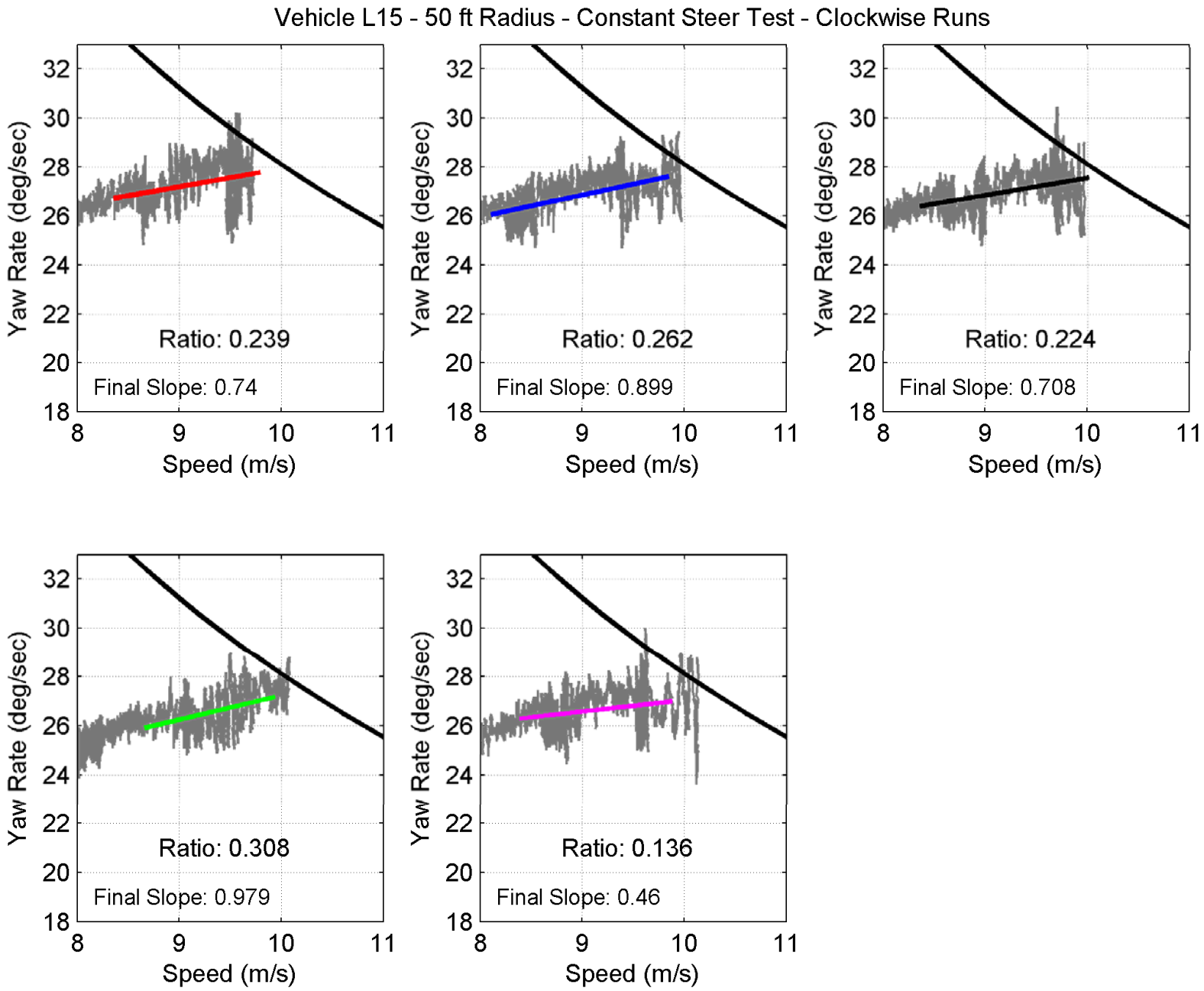

Vehicle J15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -3.91
Ratio: 1.07
Final Slope: -4.05
Ratio: 1.16
Final Slope: -10.2
Ratio: 2.68
Final Slope: -5.26
Ratio: 1.5
Final Slope: -11.3
Ratio: 3.06
Yaw Rate (deg/sec)
Speed (m/s)
-20
-25
-30
-35
6
7
8
9

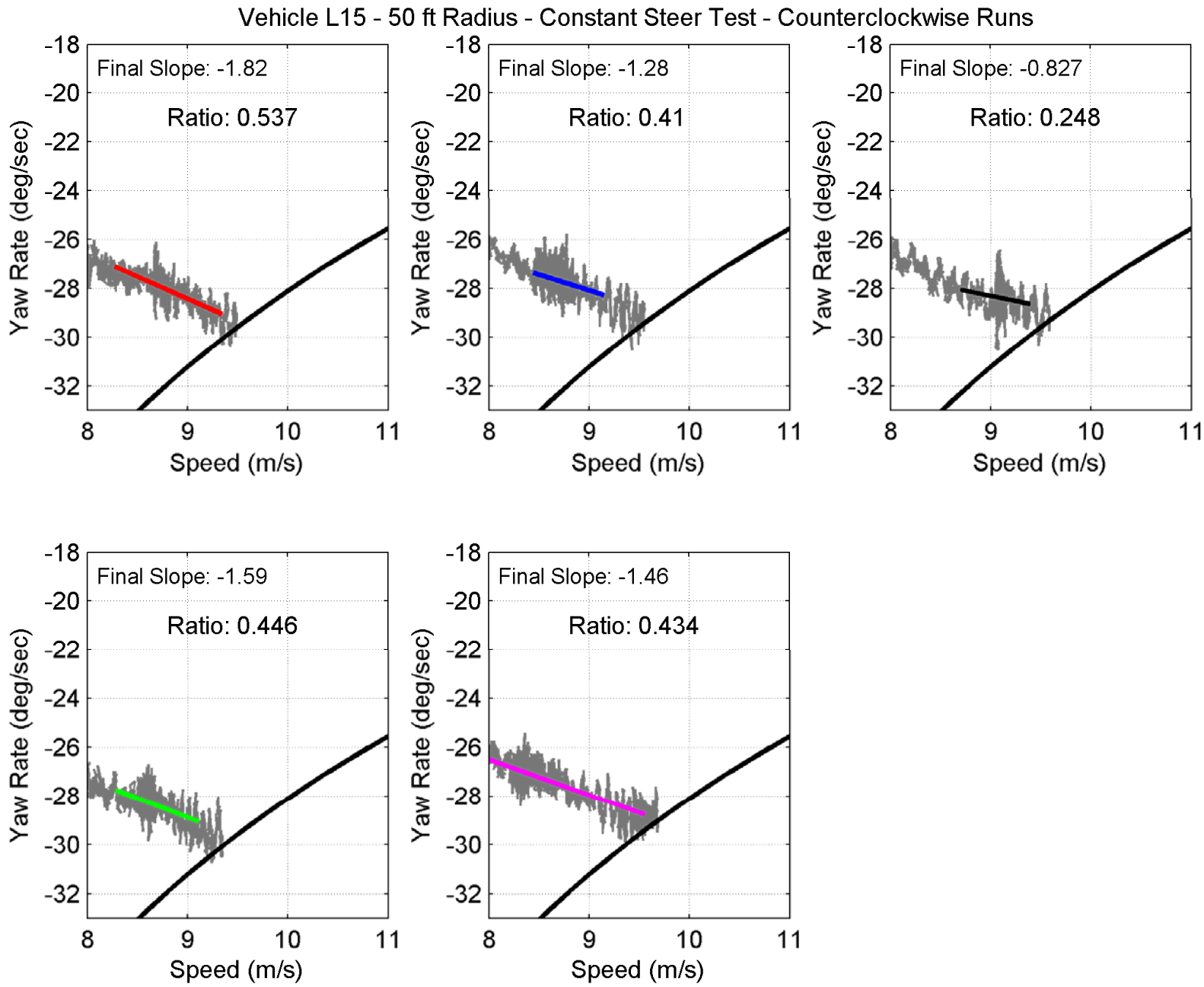

Vehicle K15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.94 2.87 2.81 3.02 2.96 STD=0.0814
CW Final Slopes: 6.04 8.64 9.17 6.34 6.33 STD=1.48
CW Ratios: 2.06 3.01 3.27 2.1 2.14 STD=0.578
CW Average: 2.51
Average Ratio: 4.15
CCW Average: 5.79
CCW Ratios: 2.19 5.9 10.4 3.47 6.98 STD=3.2
CCW Final Slopes: -6.71 -18.6 -33.6 -11.3 -22 STD=10.4
CCW Initial Slopes: -3.07 -3.15 -3.23 -3.25 -3.15 STD=0.0725
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

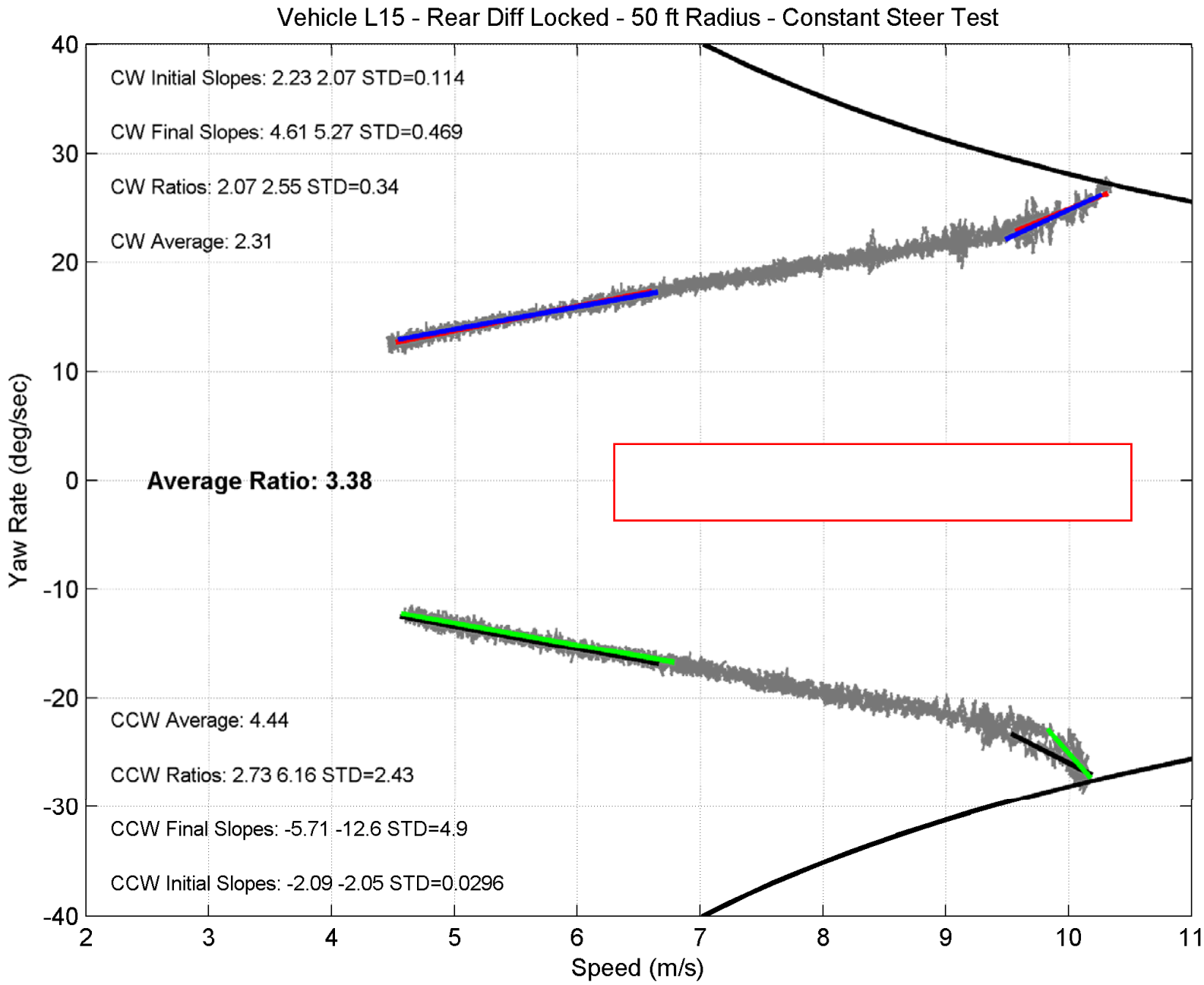

Vehicle K15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 2.06
Final Slope: 6.04
Ratio: 3.01
Final Slope: 8.64
Ratio: 3.27
Final Slope: 9.17
Ratio: 2.1
Final Slope: 6.34
Ratio: 2.14
Final Slope: 6.33


Vehicle K15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -6.71
Ratio: 2.19
Final Slope: -18.6
Ratio: 5.9
Final Slope: -33.6
Ratio: 10.4
Final Slope: -11.3
Ratio: 3.47
Final Slope: -22
Ratio: 6.98
Yaw Rate (deg/sec)
Speed (m/s)
-20
-25
-30
-35
7
8
9
10

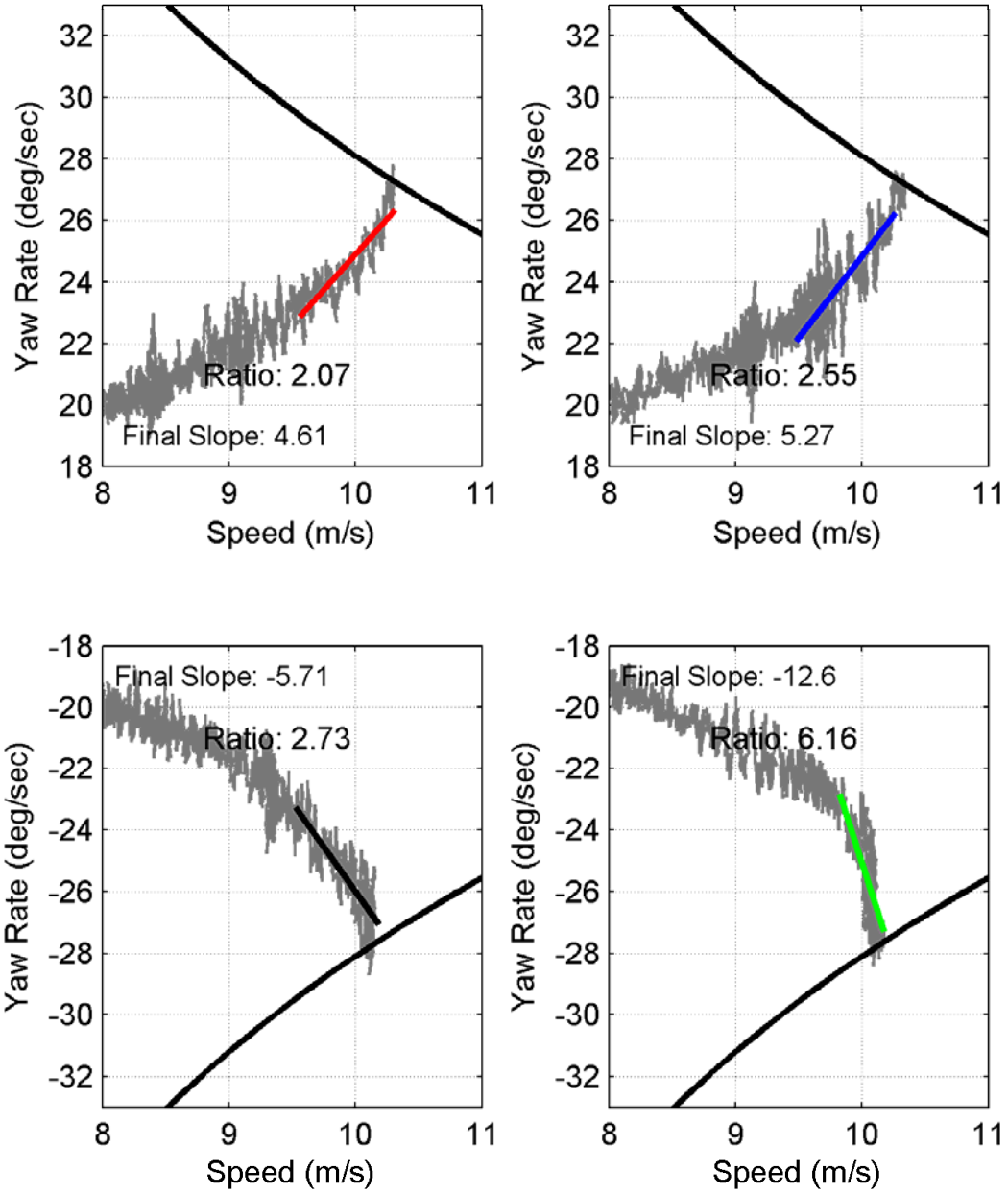

Vehicle L15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.09 3.42 3.17 3.18 3.38 STD=0.145
CW Final Slopes: 0.74 0.899 0.708 0.979 0.46 STD=0.2
CW Ratios: 0.239 0.262 0.224 0.308 0.136 STD=0.0632
CW Average: 0.234
Average Ratio: 0.324
CCW Average: 0.415
CCW Ratios: 0.537 0.41 0.248 0.446 0.434 STD=0.105
CCW Final Slopes: -1.82 -1.28 -0.827 -1.59 -1.46 STD=0.373
CCW Initial Slopes: -3.38 -3.13 -3.34 -3.58 -3.36 STD=0.158
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
11


Vehicle L15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 0.239
Final Slope: 0.74
Ratio: 0.262
Final Slope: 0.899
Ratio: 0.224
Final Slope: 0.708
Ratio: 0.308
Final Slope: 0.979
Ratio: 0.136
Final Slope: 0.46

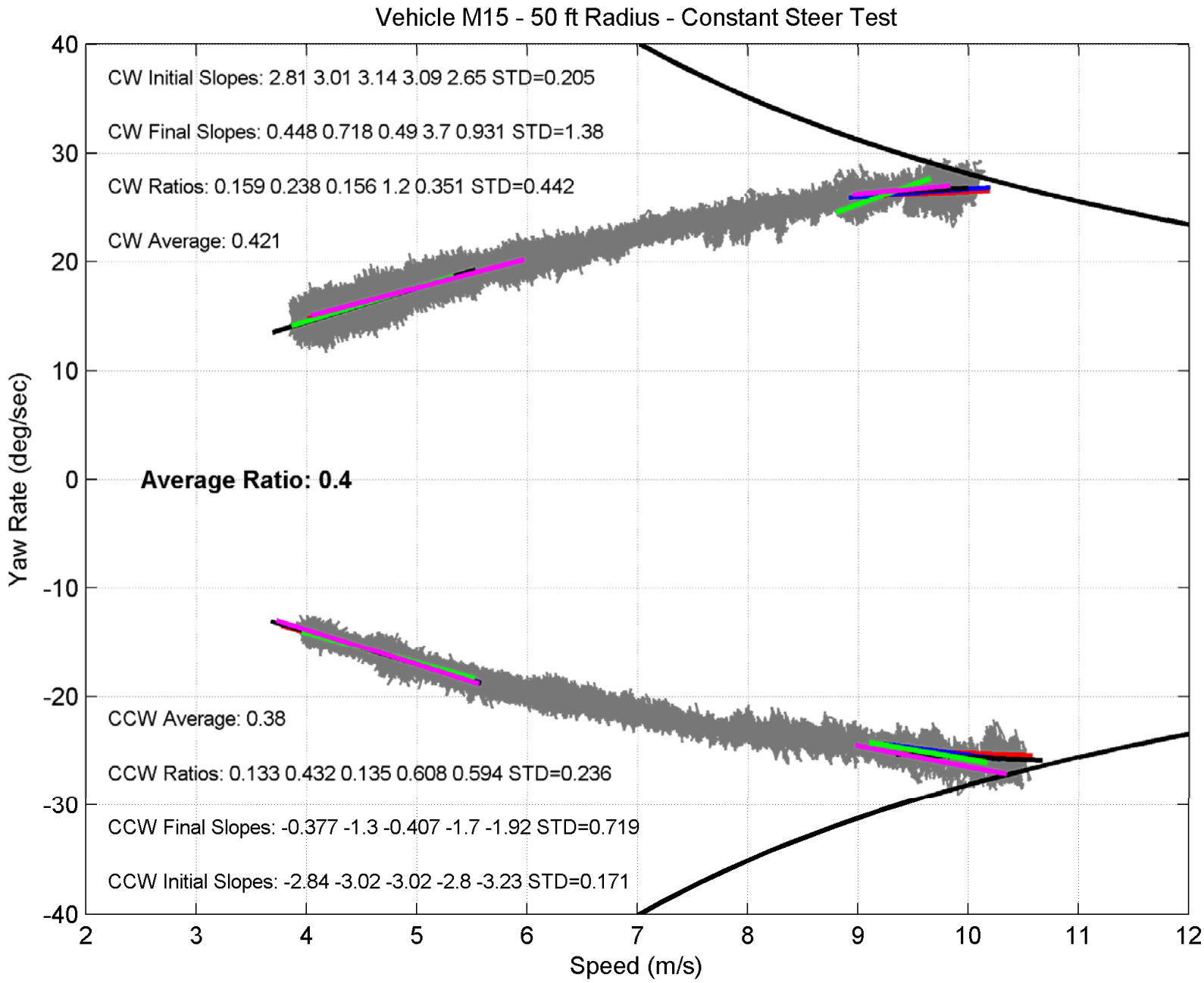

Vehicle L15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -1.82
Ratio: 0.537
Final Slope: -1.28
Ratio: 0.41
Final Slope: -0.827
Ratio: 0.248
Final Slope: -1.59
Ratio: 0.446
Final Slope: -1.46
Ratio: 0.434
Yaw Rate (deg/sec)
Speed (m/s)
-18
-20
-22
-24
-26
-28
-30
-32
8
9
10
11

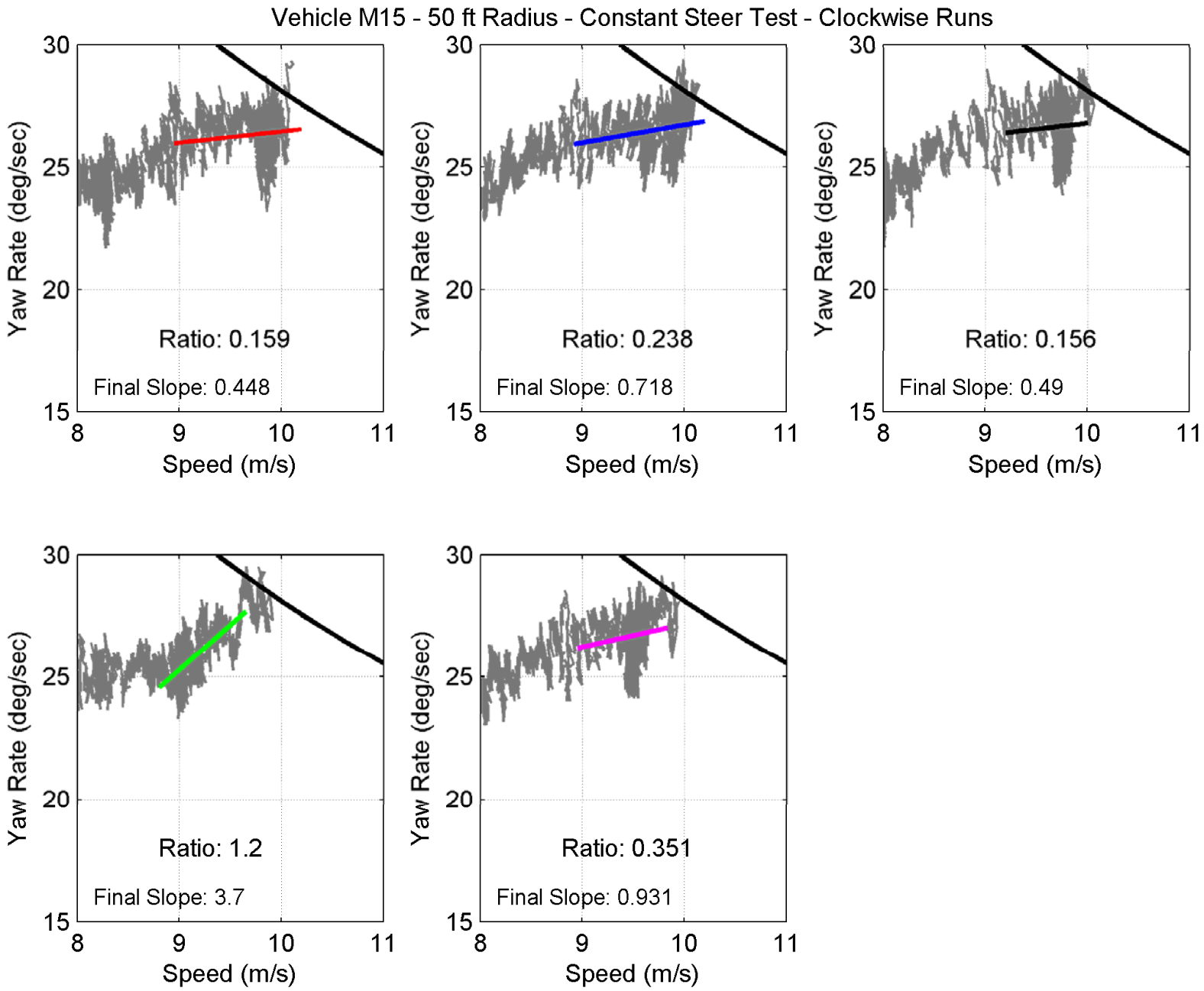

Vehicle L15 - Rear Diff Locked - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.23 2.07 STD=0.114
CW Final Slopes: 4.61 5.27 STD=0.469
CW Ratios: 2.07 2.55 STD=0.34
CW Average: 2.31
Average Ratio: 3.38
CCW Average: 4.44
CCW Ratios: 2.73 6.16 STD=2.43
CCW Final Slopes: -5.71 -12.6 STD=4.9
CCW Initial Slopes: -2.09 -2.05 STD=0.0296
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
11

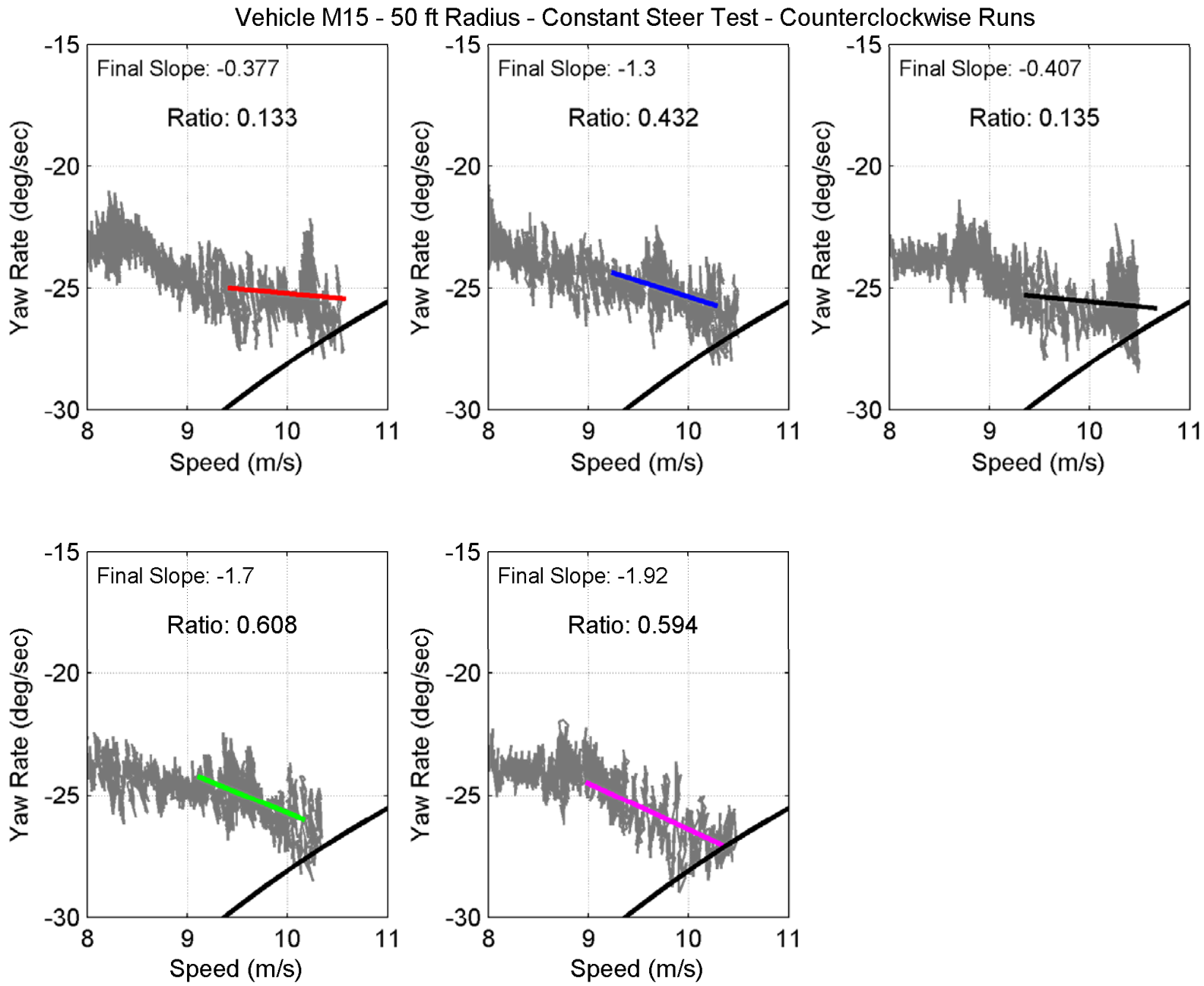
Vehicle L15 - Rear Diff Locked - 50 ft Radius - Constant Steer Test - CW & CCW Runs

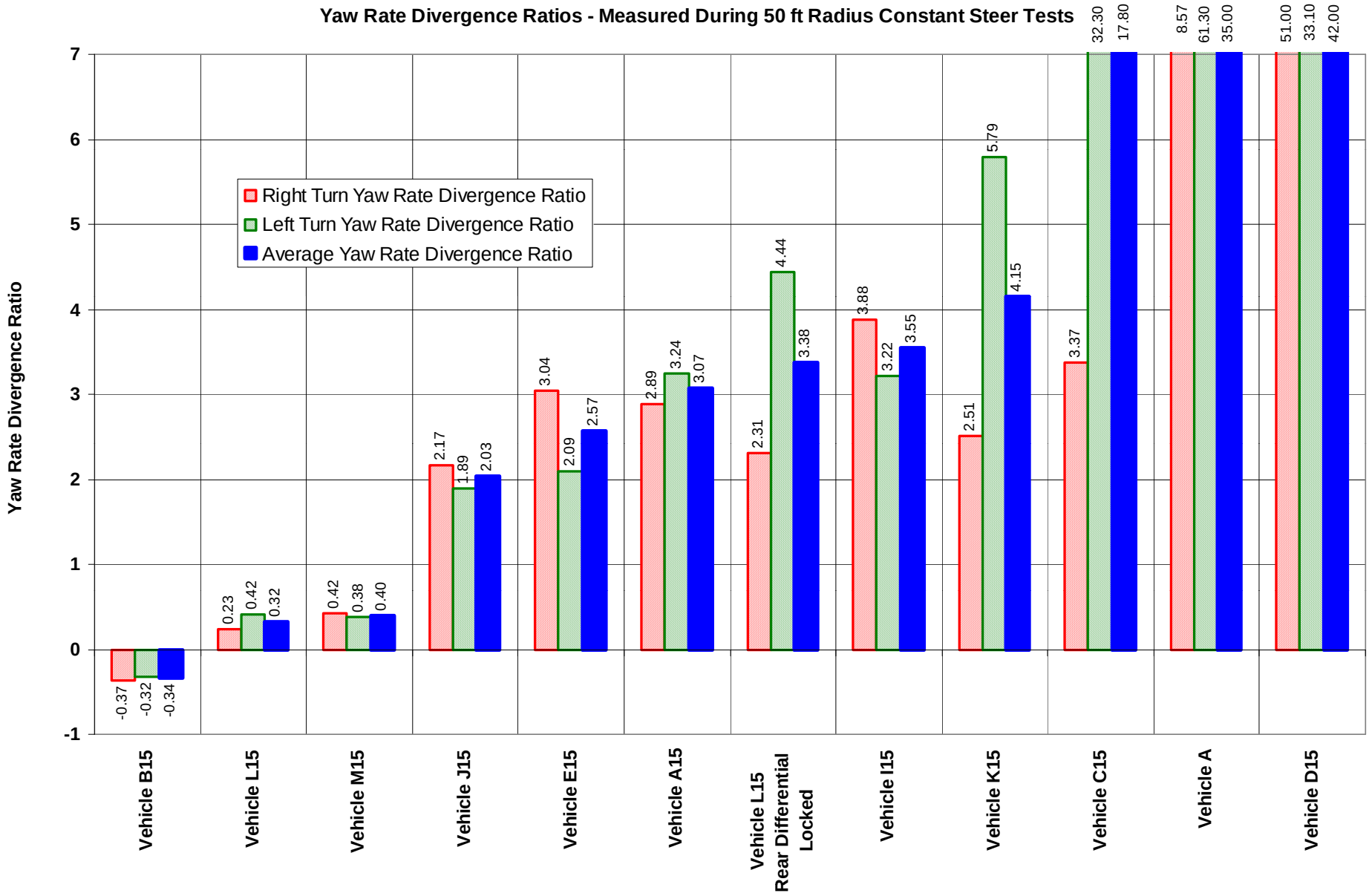


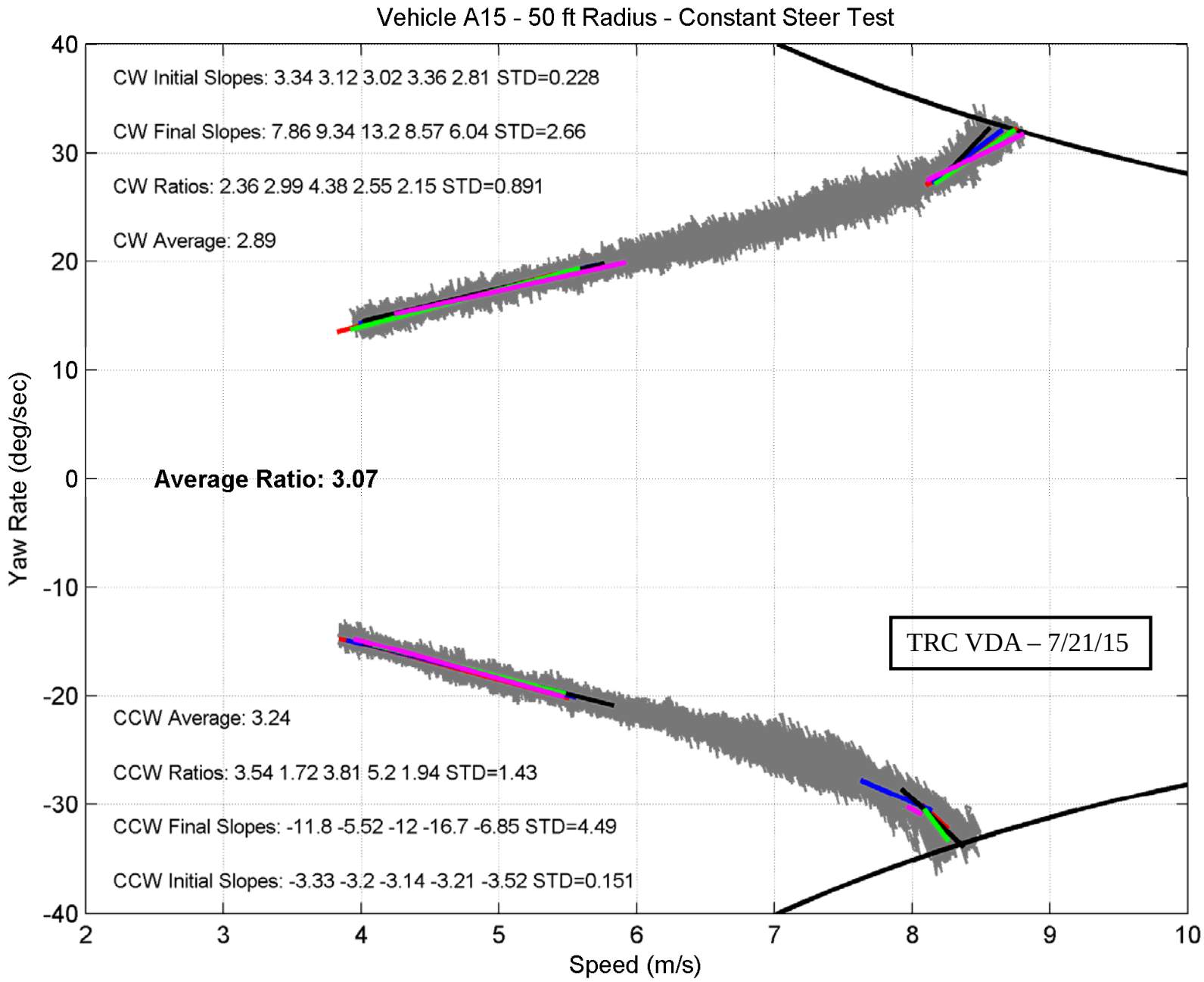
Rear Differential Locked

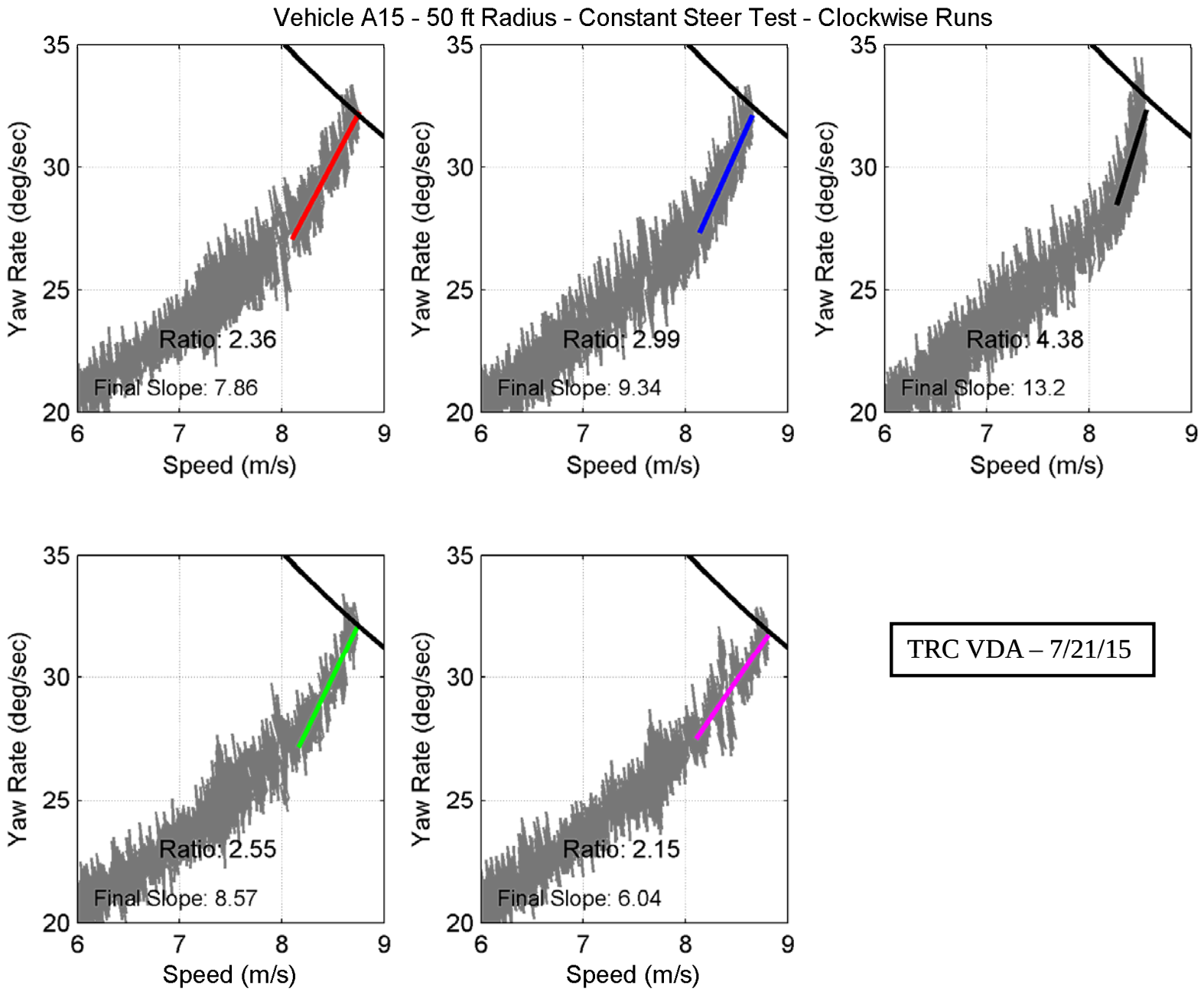

Vehicle M15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.81 3.01 3.14 3.09 2.65 STD=0.205
CW Final Slopes: 0.448 0.718 0.49 3.7 0.931 STD=1.38
CW Ratios: 0.159 0.238 0.156 1.2 0.351 STD=0.442
CW Average: 0.421
Average Ratio: 0.4
CCW Average: 0.38
CCW Ratios: 0.133 0.432 0.135 0.608 0.594 STD=0.236
CCW Final Slopes: -0.377 -1.3 -0.407 -1.7 -1.92 STD=0.719
CCW Initial Slopes: -2.84 -3.02 -3.02 -2.8 -3.23 STD=0.171
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
11
12


Vehicle M15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 0.159
Final Slope: 0.448
Ratio: 0.238
Final Slope: 0.718
Ratio: 0.156
Final Slope: 0.49
Ratio: 1.2
Final Slope: 3.7
Ratio: 0.351
Final Slope: 0.931

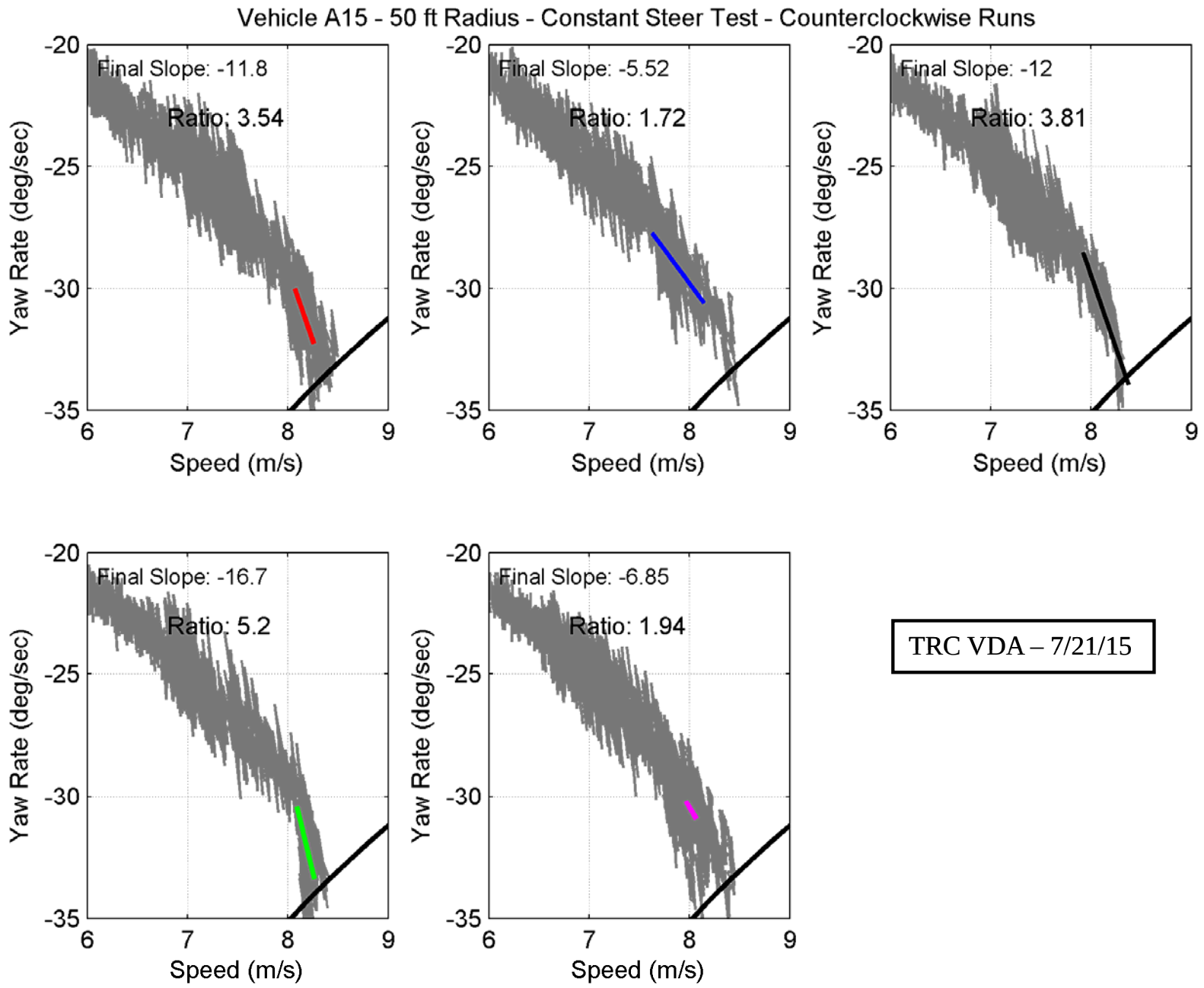

Vehicle M15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -0.377
Ratio: 0.133
Final Slope: -1.3
Ratio: 0.432
Final Slope: -0.407
Ratio: 0.135
Final Slope: -1.7
Ratio: 0.608
Final Slope: -1.92
Ratio: 0.594
Yaw Rate (deg/sec)
Speed (m/s)
-15
-20
-25
-30
8
9
10
11


Yaw Rate Divergence Ratios - Measured During 50 ft Radius Constant Steer Tests
Yaw Rate Divergence Ratio
Right Turn Yaw Rate Divergence Ratio
Left Turn Yaw Rate Divergence Ratio
Average Yaw Rate Divergence Ratio
7
6
5
4
3
2
1
0
-1
-0.37
-0.32
-0.34
0.23
0.42
0.32
0.42
0.38
0.40
2.17
1.89
2.03
3.04
2.09
2.57
2.89
3.24
3.07
2.31
4.44
3.38
3.88
3.22
3.55
2.51
5.79
4.15
3.37
32.30
17.80
8.57
61.30
35.00
51.00
33.10
42.00
Vehicle B15
Vehicle L15
Vehicle M15
Vehicle J15
Vehicle E15
Vehicle A15
Vehicle L15 Rear Differential Locked
Vehicle I15
Vehicle K15
Vehicle C15
Vehicle A
Vehicle D15

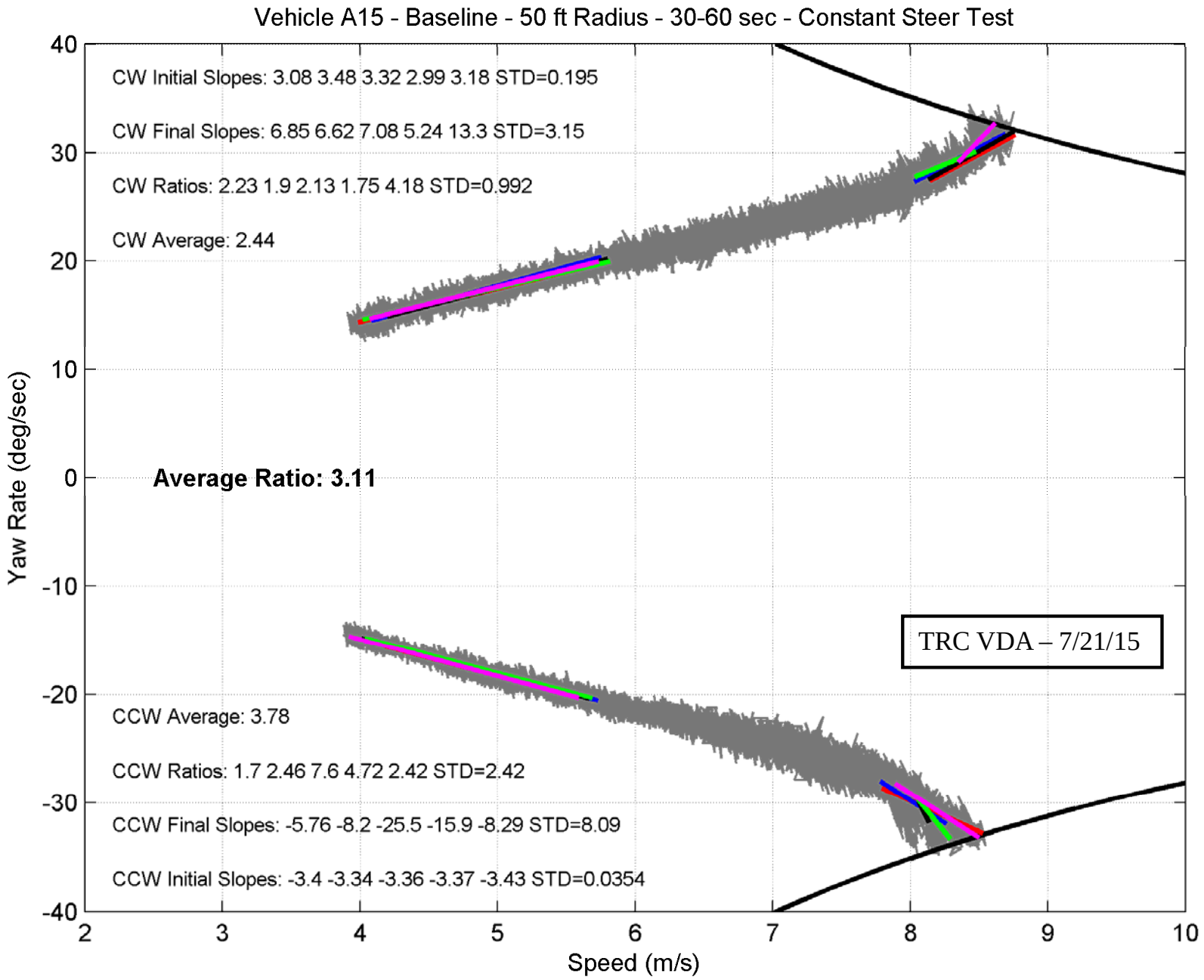

Vehicle A15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.34 3.12 3.02 3.36 2.81 STD=0.228
CW Final Slopes: 7.86 9.34 13.2 8.57 6.04 STD=2.66
CW Ratios: 2.36 2.99 4.38 2.55 2.15 STD=0.891
CW Average: 2.89
Average Ratio: 3.07
TRC VDA – 7/21/15
CCW Average: 3.24
CCW Ratios: 3.54 1.72 3.81 5.2 1.94 STD=1.43
CCW Final Slopes: -11.8 -5.52 -12 -16.7 -6.85 STD=4.49
CCW Initial Slopes: -3.33 -3.2 -3.14 -3.21 -3.52 STD=0.151
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

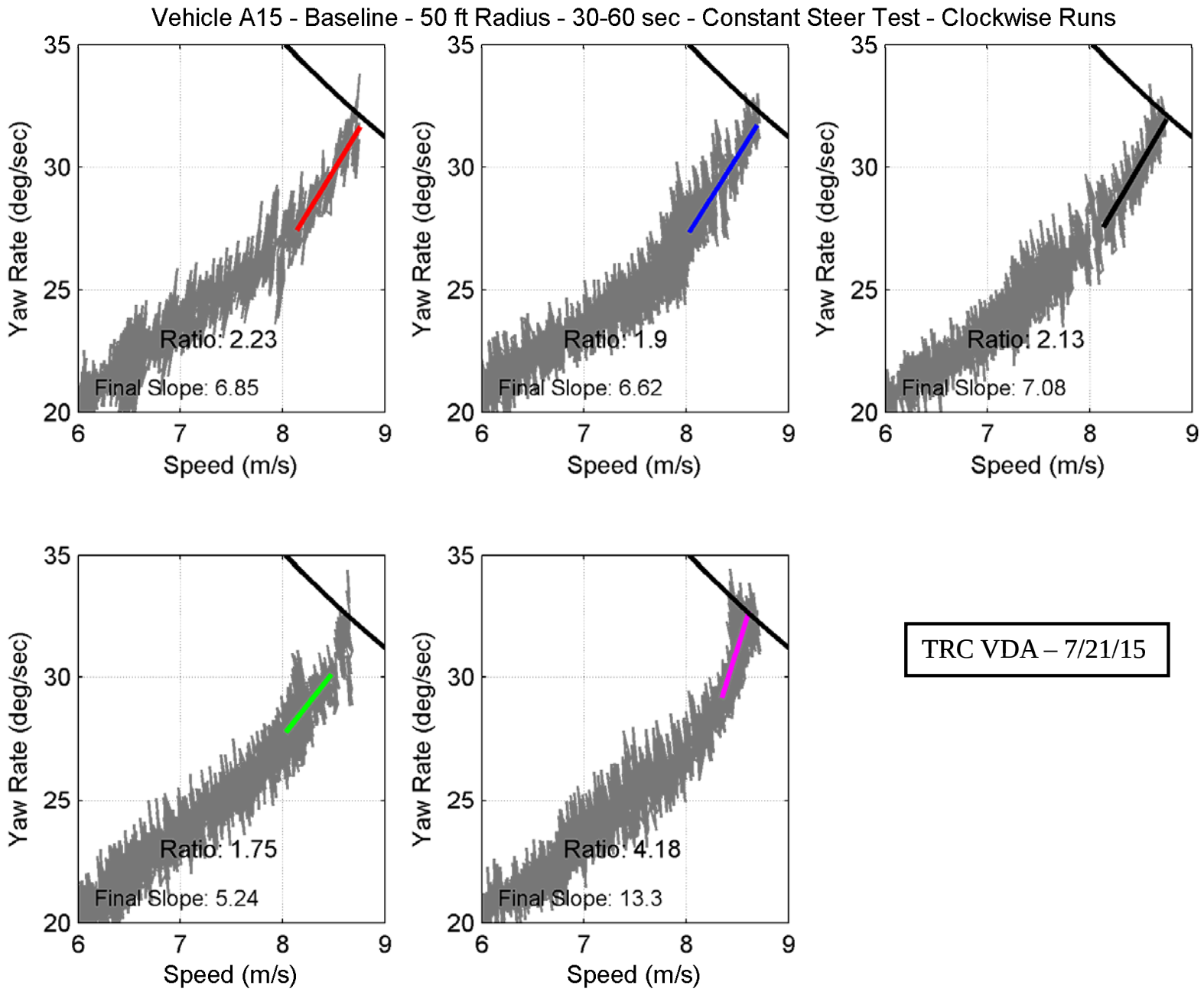


TRC VDA – 7/21/15

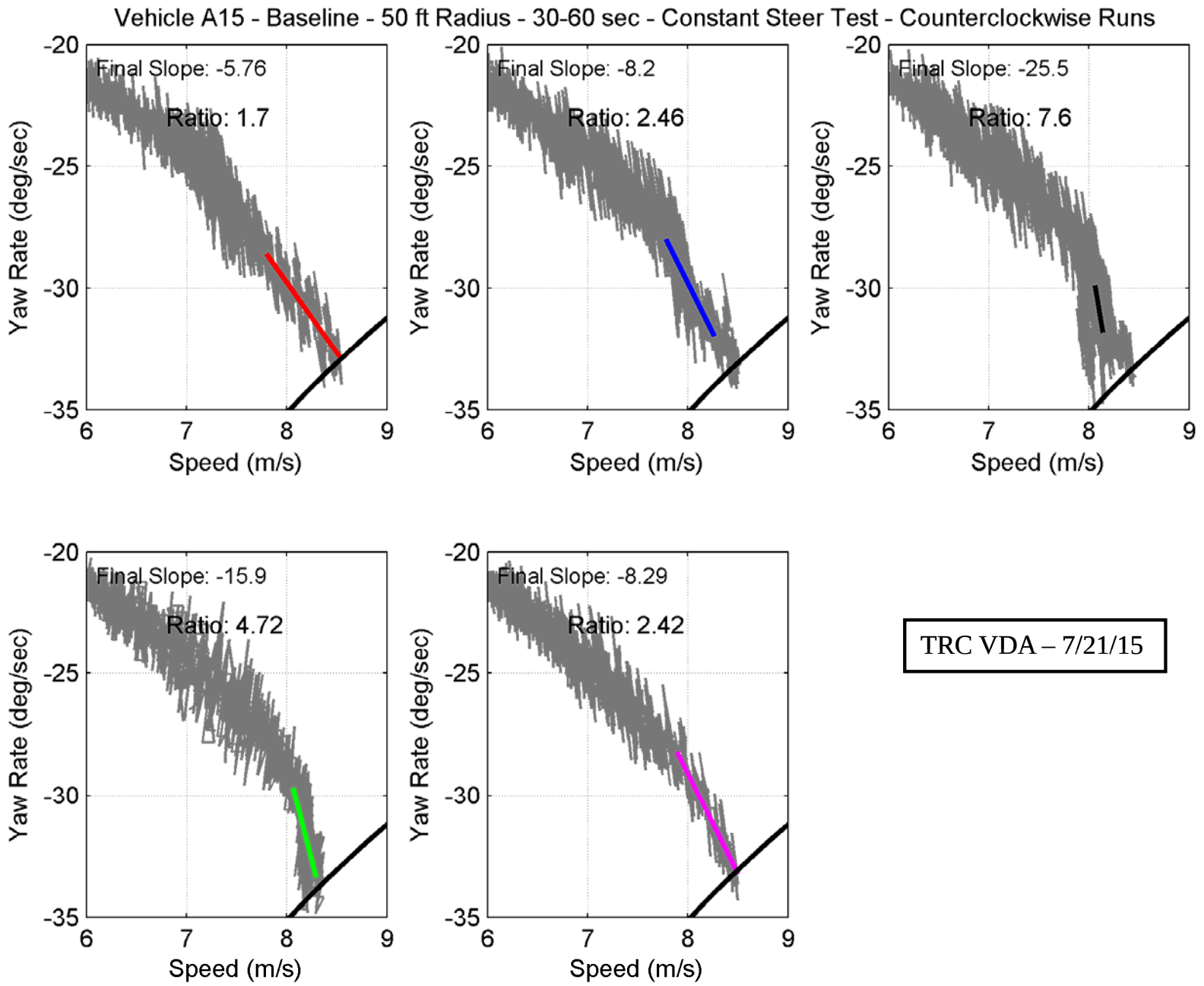


TRC VDA – 7/21/15

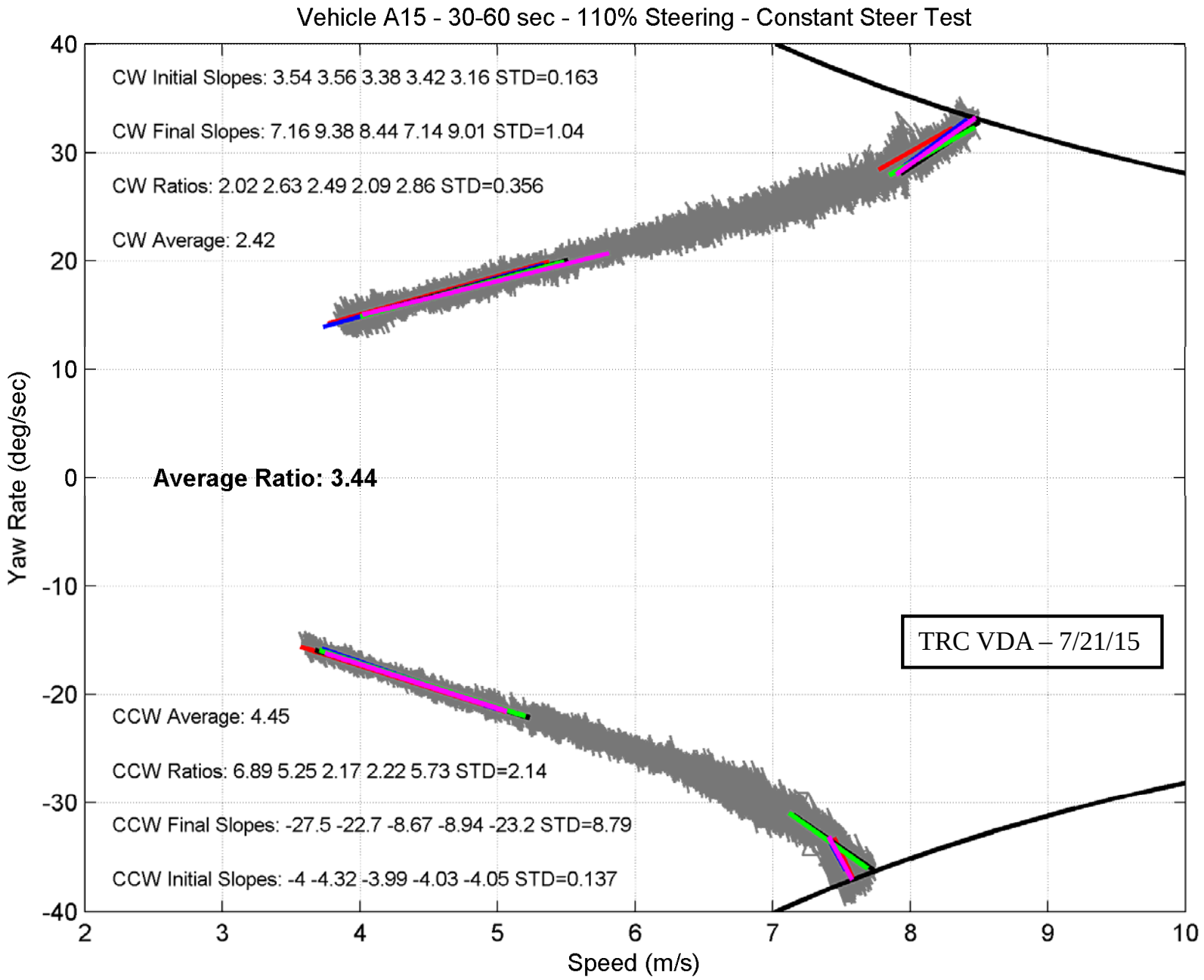

Vehicle A15 - Baseline - 50 ft Radius - 30-60 sec - Constant Steer Test
CW Initial Slopes: 3.08 3.48 3.32 2.99 3.18 STD=0.195
CW Final Slopes: 6.85 6.62 7.08 5.24 13.3 STD=3.15
CW Ratios: 2.23 1.9 2.13 1.75 4.18 STD=0.992
CW Average: 2.44
Average Ratio: 3.11
TRC VDA – 7/21/15
CCW Average: 3.78
CCW Ratios: 1.7 2.46 7.6 4.72 2.42 STD=2.42
CCW Final Slopes: -5.76 -8.2 -25.5 -15.9 -8.29 STD=8.09
CCW Initial Slopes: -3.4 -3.34 -3.36 -3.37 -3.43 STD=0.0354
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

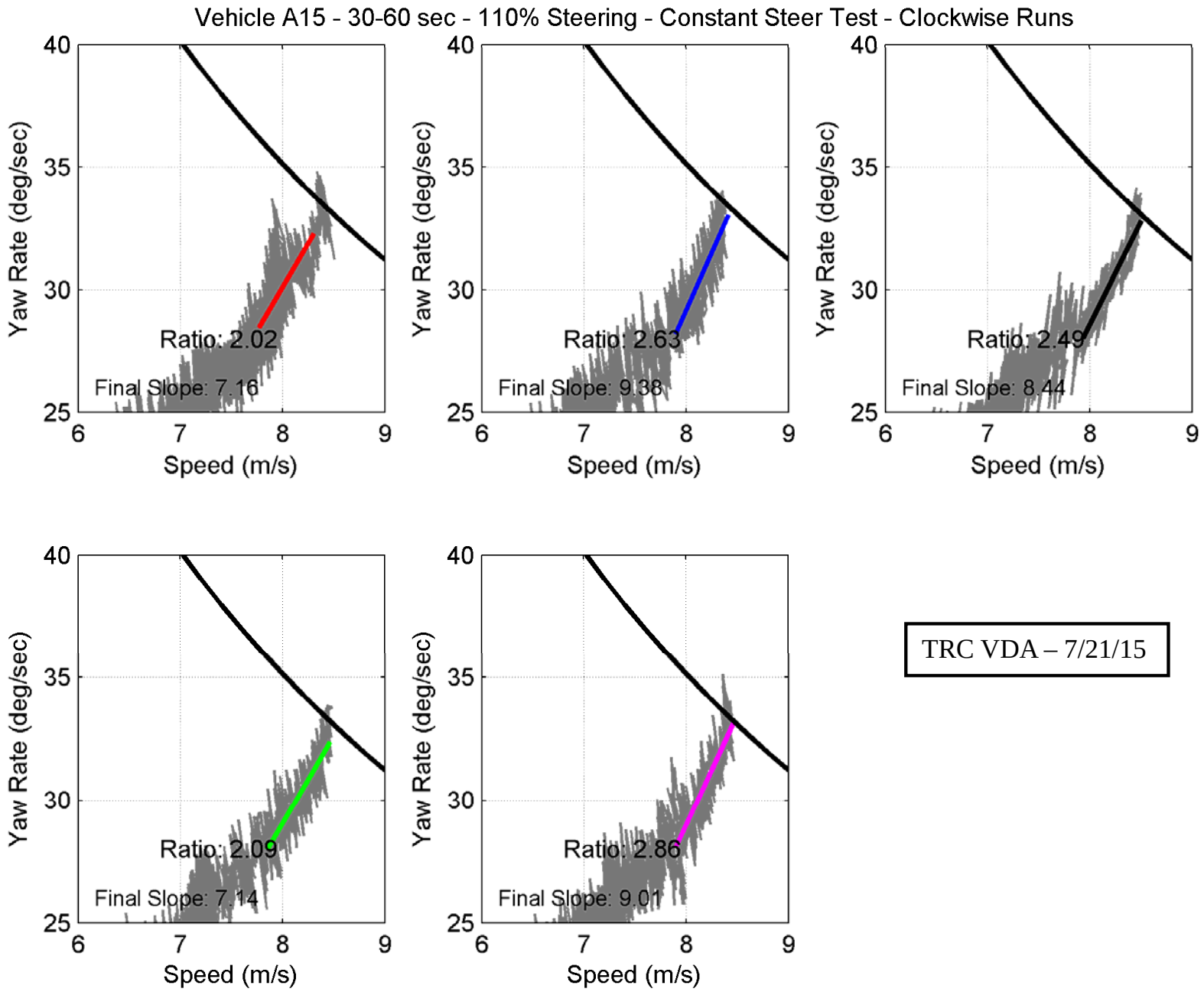


TRC VDA – 7/21/15

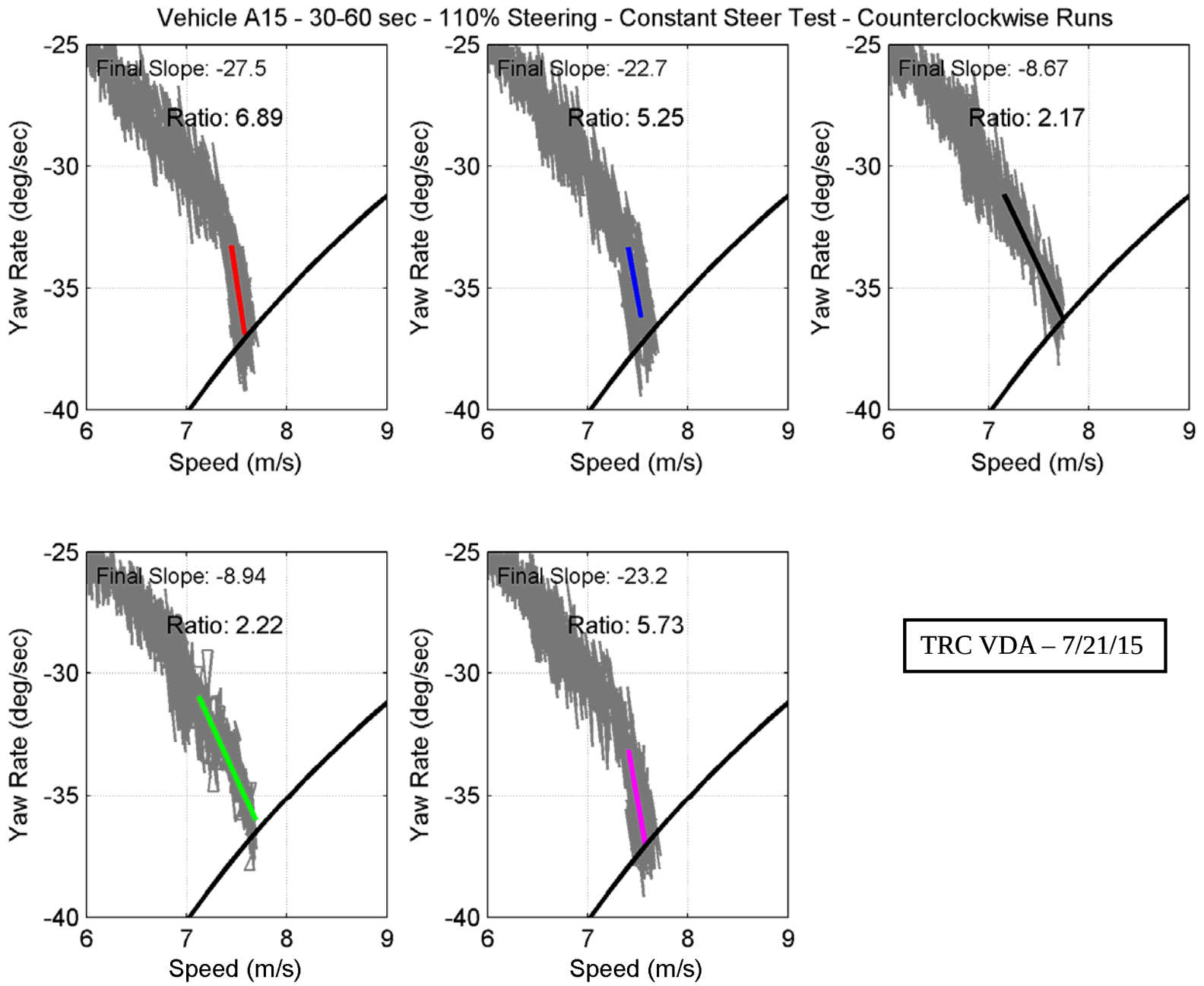


TRC VDA – 7/21/15

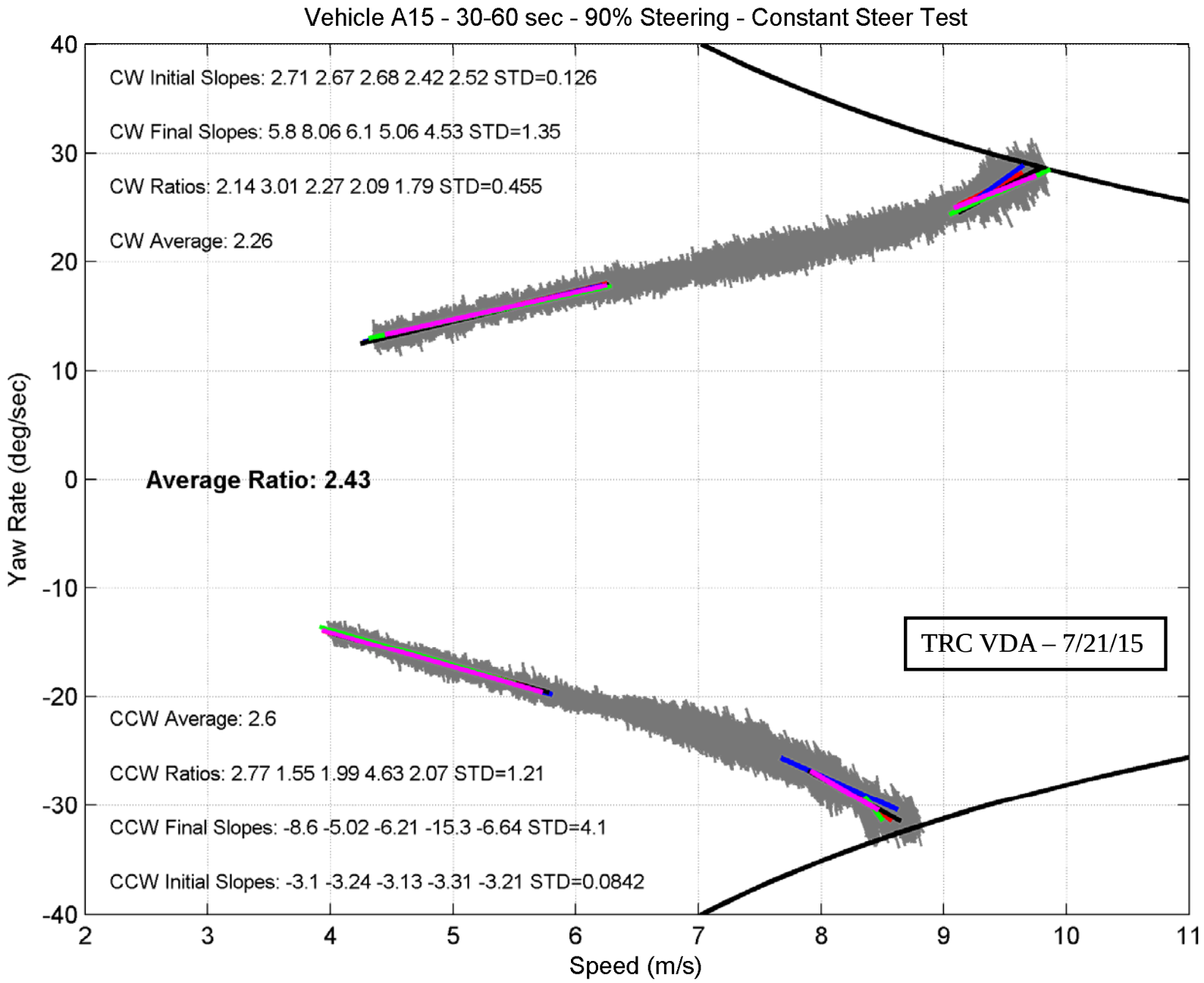

Vehicle A15 - 30-60 sec - 110% Steering - Constant Steer Test
CW Initial Slopes: 3.54 3.56 3.38 3.42 3.16 STD=0.163
CW Final Slopes: 7.16 9.38 8.44 7.14 9.01 STD=1.04
CW Ratios: 2.02 2.63 2.49 2.09 2.86 STD=0.356
CW Average: 2.42
Average Ratio: 3.44
CCW Average: 4.45
CCW Ratios: 6.89 5.25 2.17 2.22 5.73 STD=2.14
CCW Final Slopes: -27.5 -22.7 -8.67 -8.94 -23.2 STD=8.79
CCW Initial Slopes: -4 -4.32 -3.99 -4.03 -4.05 STD=0.137
TRC VDA – 7/21/15
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

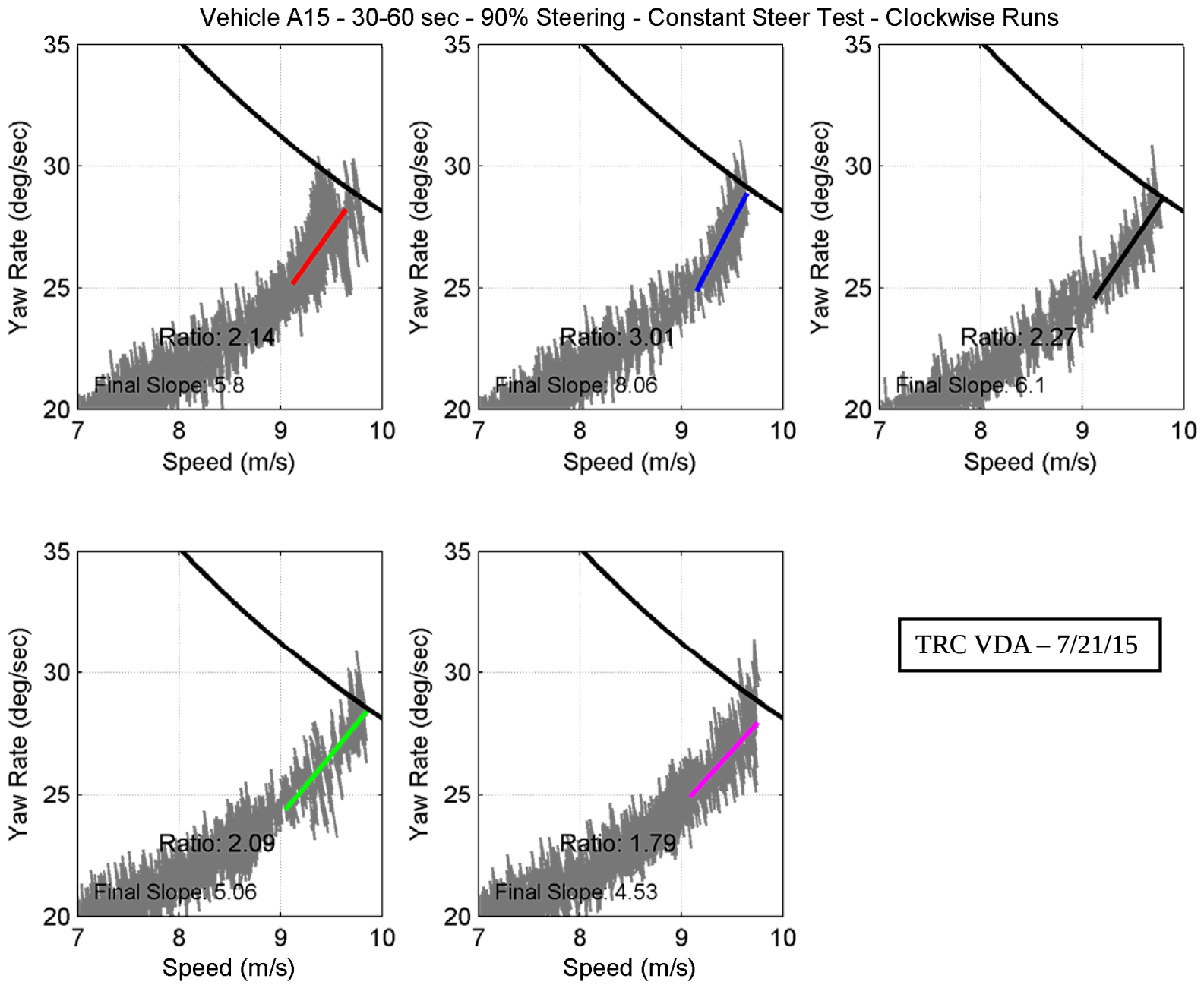


TRC VDA – 7/21/15

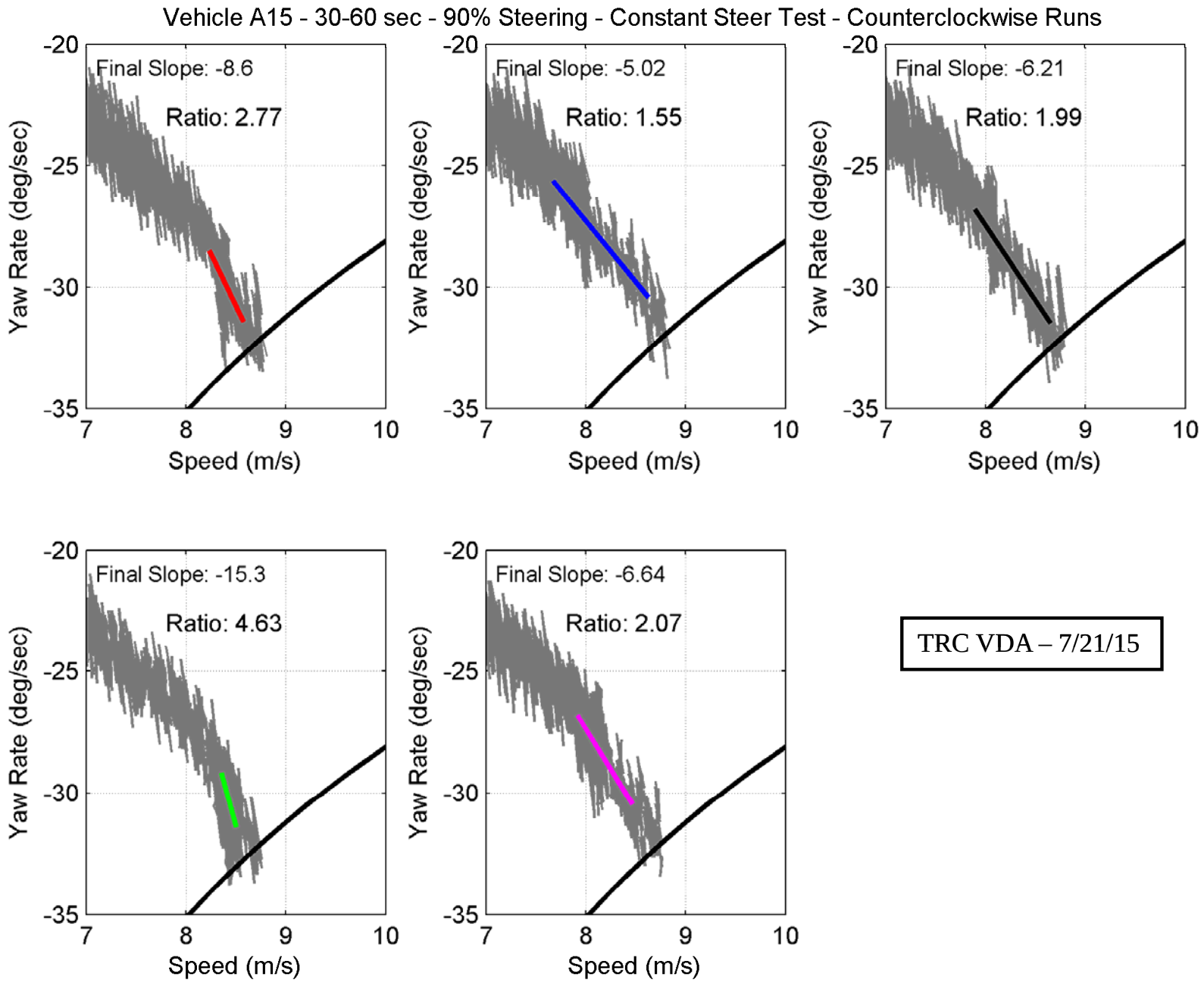


TRC VDA – 7/21/15

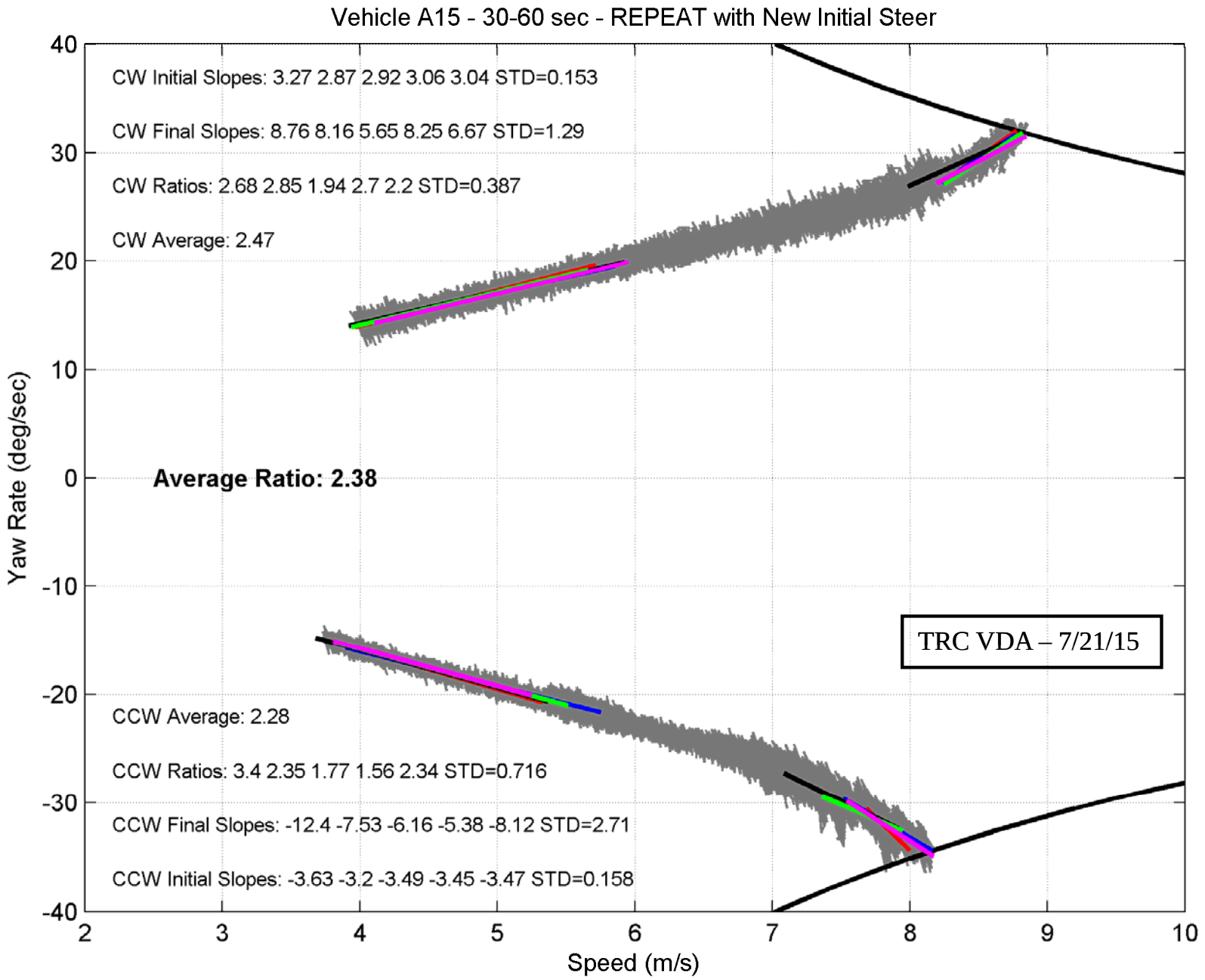

Vehicle A15 - 30-60 sec - 90% Steering - Constant Steer Test
CW Initial Slopes: 2.71 2.67 2.68 2.42 2.52 STD=0.126
CW Final Slopes: 5.8 8.06 6.1 5.06 4.53 STD=1.35
CW Ratios: 2.14 3.01 2.27 2.09 1.79 STD=0.455
CW Average: 2.26
Average Ratio: 2.43
TRC VDA – 7/21/15
CCW Average: 2.6
CCW Ratios: 2.77 1.55 1.99 4.63 2.07 STD=1.21
CCW Final Slopes: -8.6 -5.02 -6.21 -15.3 -6.64 STD=4.1
CCW Initial Slopes: -3.1 -3.24 -3.13 -3.31 -3.21 STD=0.0842
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
11

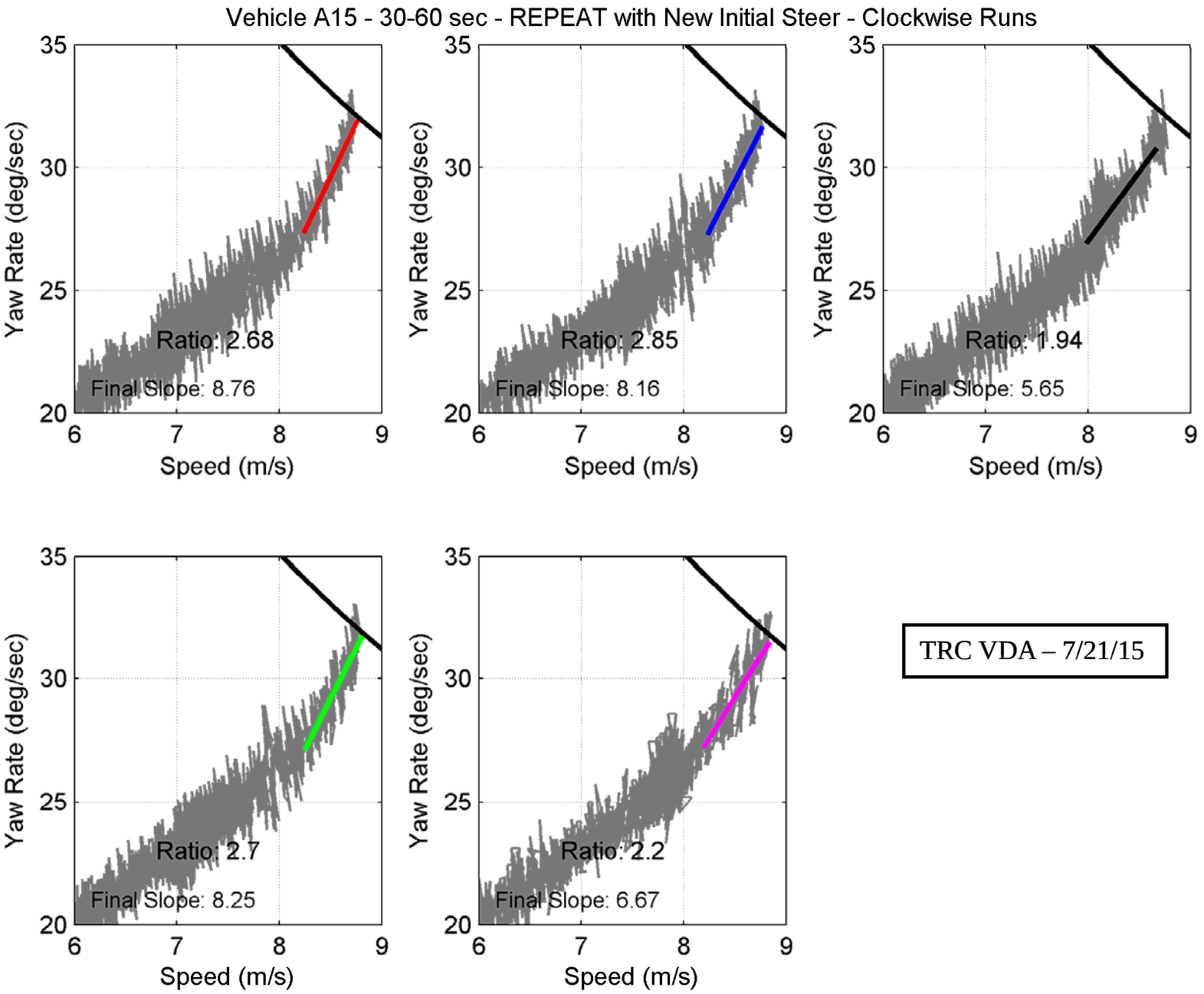


TRC VDA – 7/21/15

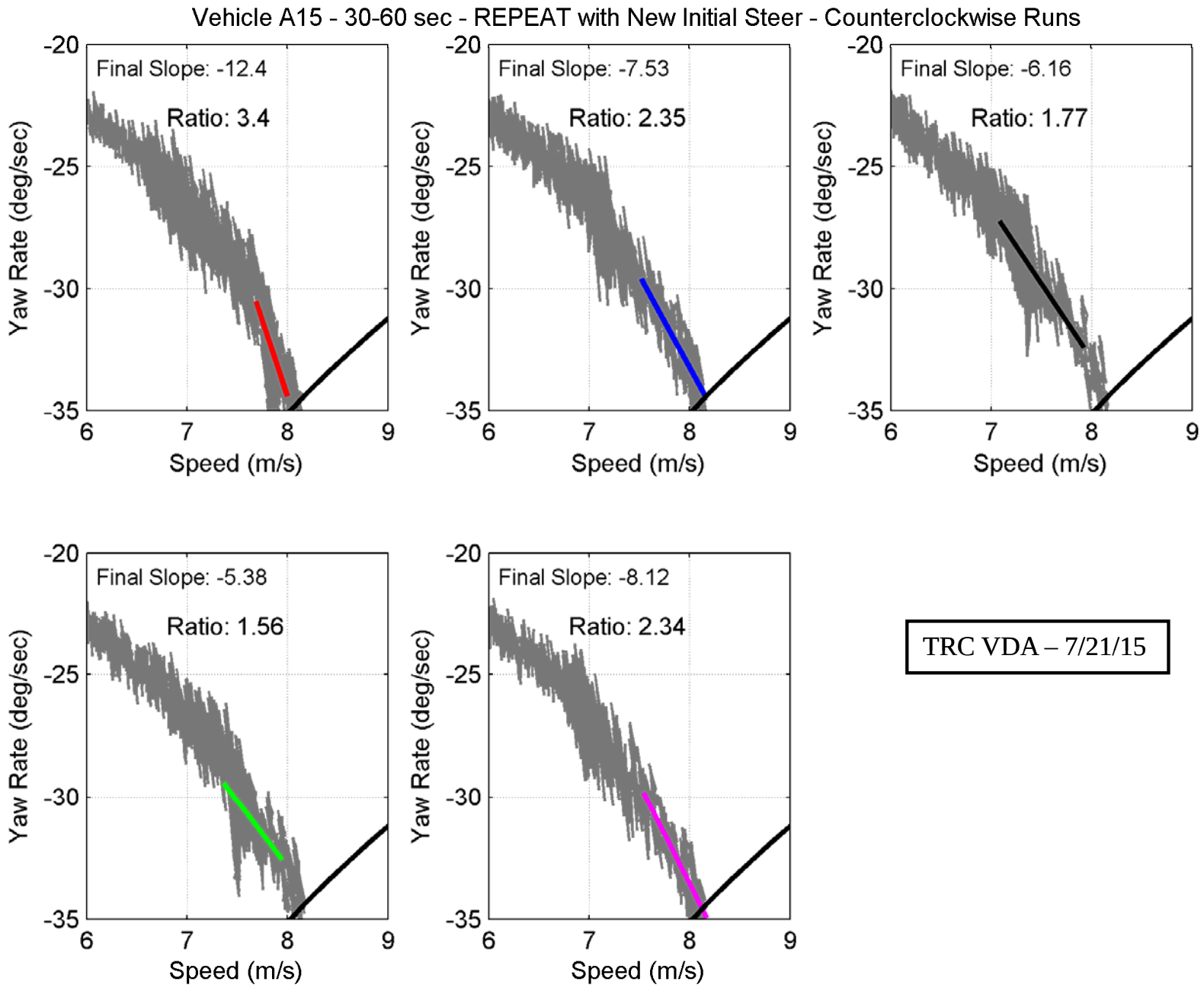


TRC VDA – 7/21/15

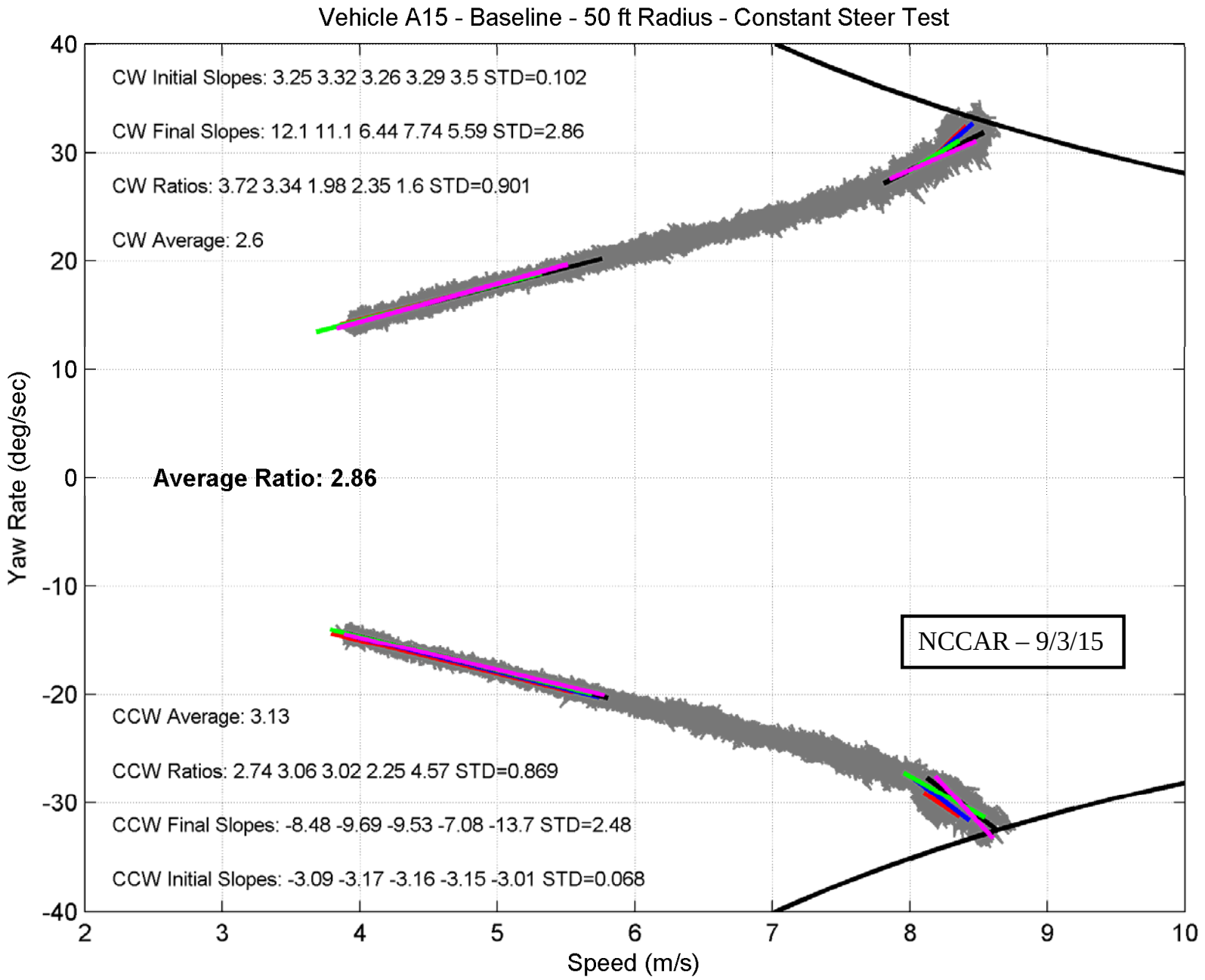

Vehicle A15 - 30-60 sec - REPEAT with New Initial Steer
CW Initial Slopes: 3.27 2.87 2.92 3.06 3.04 STD=0.153
CW Final Slopes: 8.76 8.16 5.65 8.25 6.67 STD=1.29
CW Ratios: 2.68 2.85 1.94 2.7 2.2 STD=0.387
CW Average: 2.47
Average Ratio: 2.38
TRC VDA – 7/21/15
CCW Average: 2.28
CCW Ratios: 3.4 2.35 1.77 1.56 2.34 STD=0.716
CCW Final Slopes: -12.4 -7.53 -6.16 -5.38 -8.12 STD=2.71
CCW Initial Slopes: -3.63 -3.2 -3.49 -3.45 -3.47 STD=0.158
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

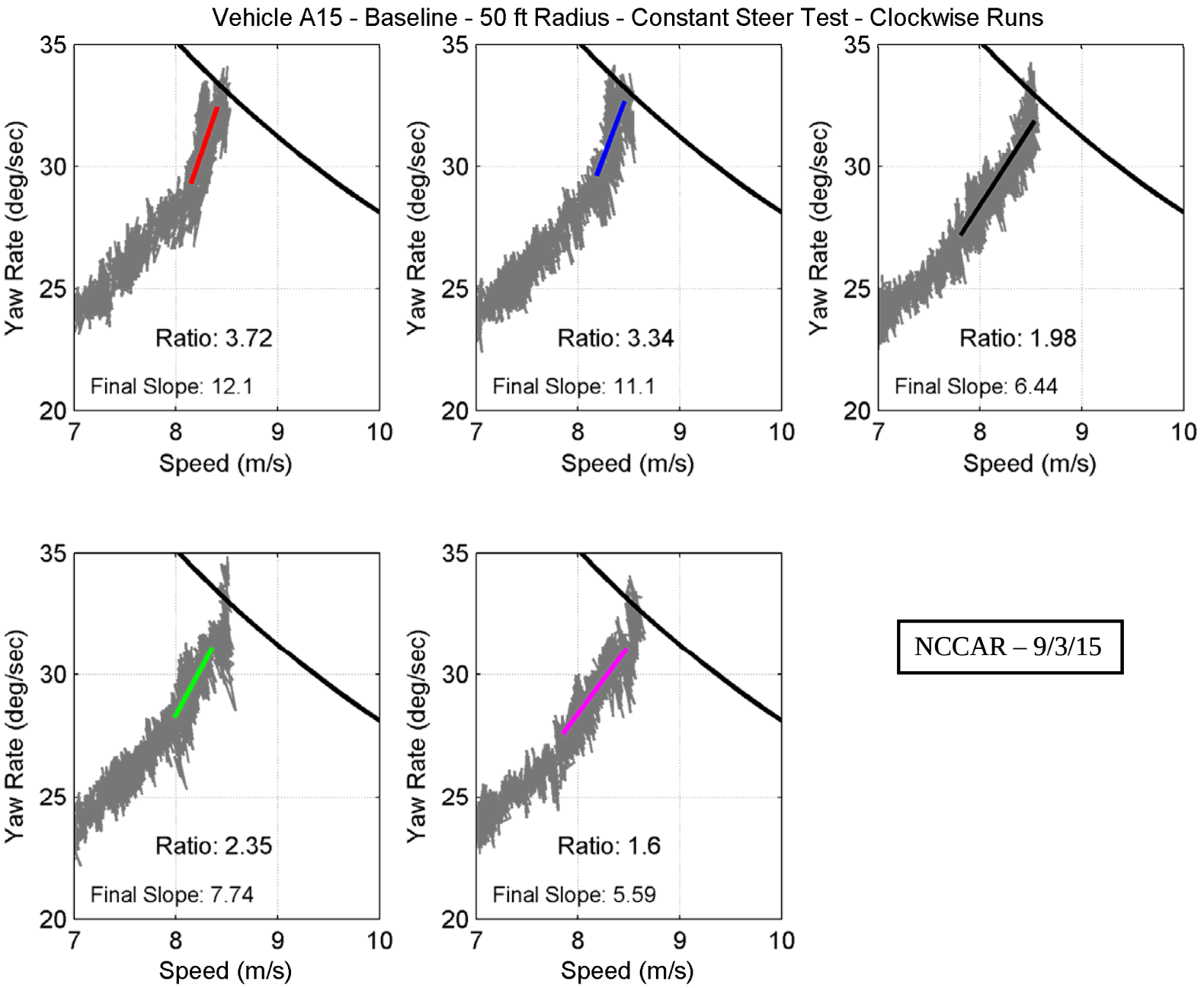


TRC VDA – 7/21/15

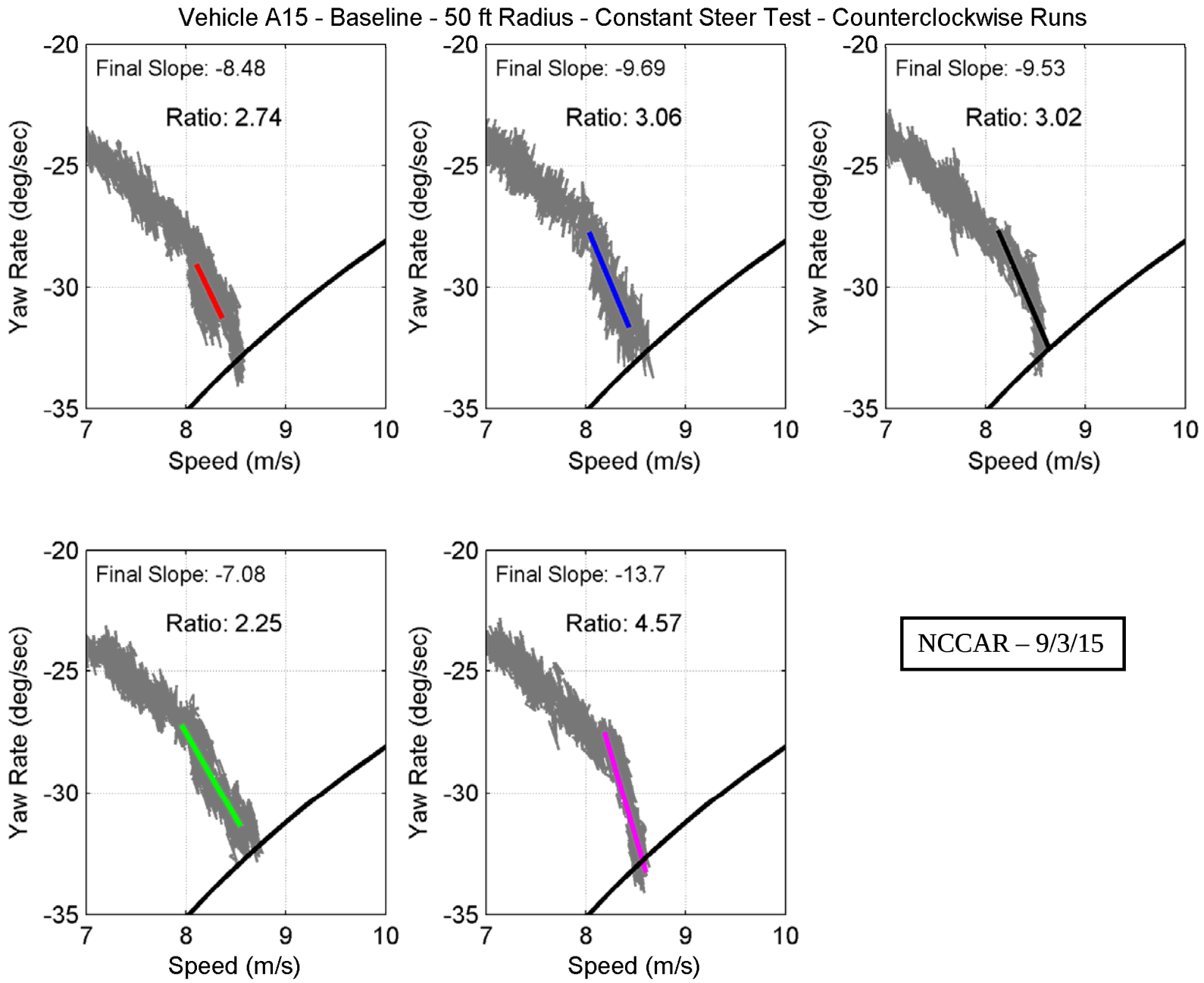


TRC VDA – 7/21/15

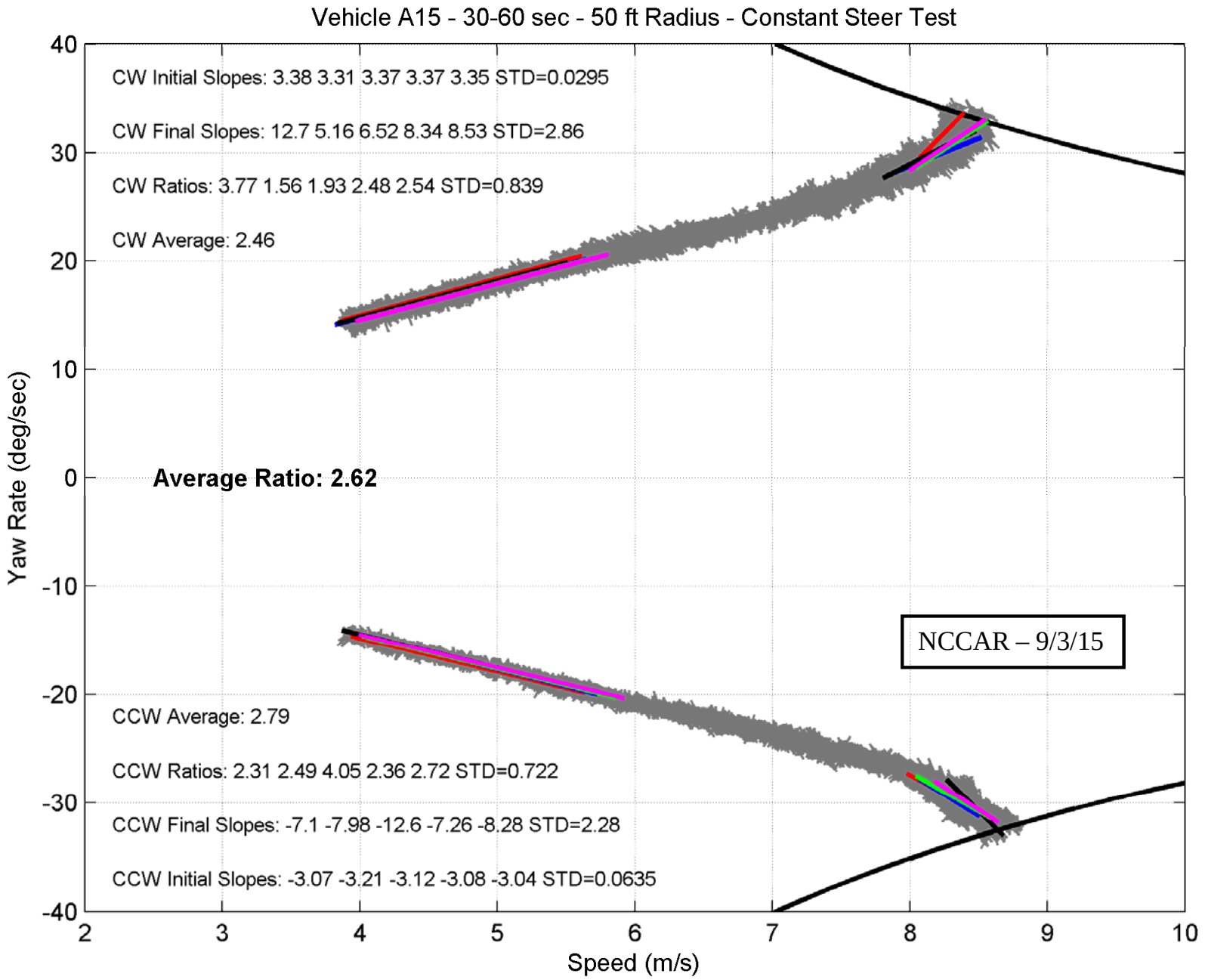

Vehicle A15 - Baseline - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.25 3.32 3.26 3.29 3.5 STD=0.102
CW Final Slopes: 12.1 11.1 6.44 7.74 5.59 STD=2.86
CW Ratios: 3.72 3.34 1.98 2.35 1.6 STD=0.901
CW Average: 2.6
Average Ratio: 2.86
NCCAR – 9/3/15
CCW Average: 3.13
CCW Ratios: 2.74 3.06 3.02 2.25 4.57 STD=0.869
CCW Final Slopes: -8.48 -9.69 -9.53 -7.08 -13.7 STD=2.48
CCW Initial Slopes: -3.09 -3.17 -3.16 -3.15 -3.01 STD=0.068
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

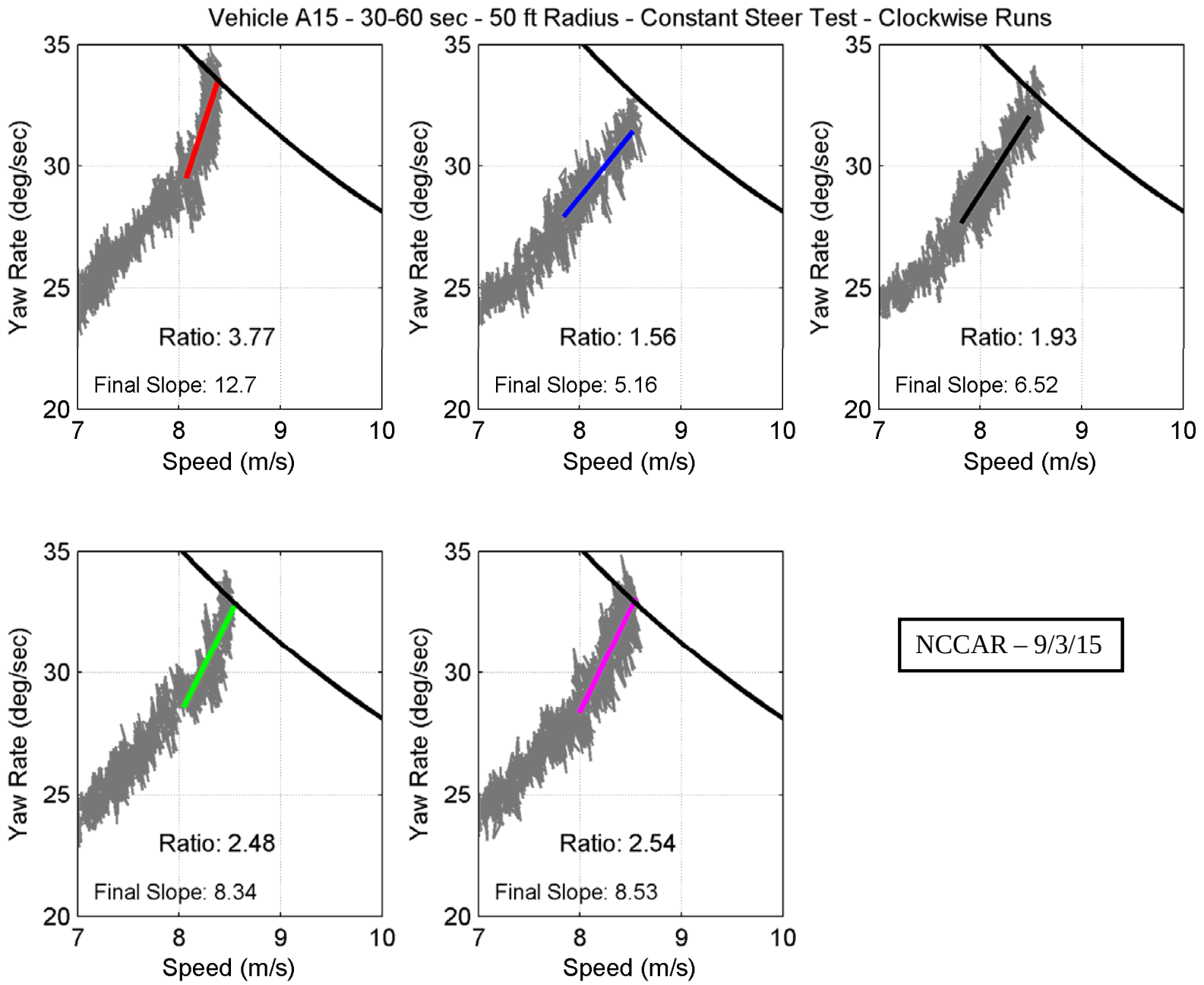

Vehicle A15 - Baseline - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 3.72
Final Slope: 12.1
Ratio: 3.34
Final Slope: 11.1
Ratio: 1.98
Final Slope: 6.44
Ratio: 2.35
Final Slope: 7.74
Ratio: 1.6
Final Slope: 5.59

NCCAR – 9/3/15

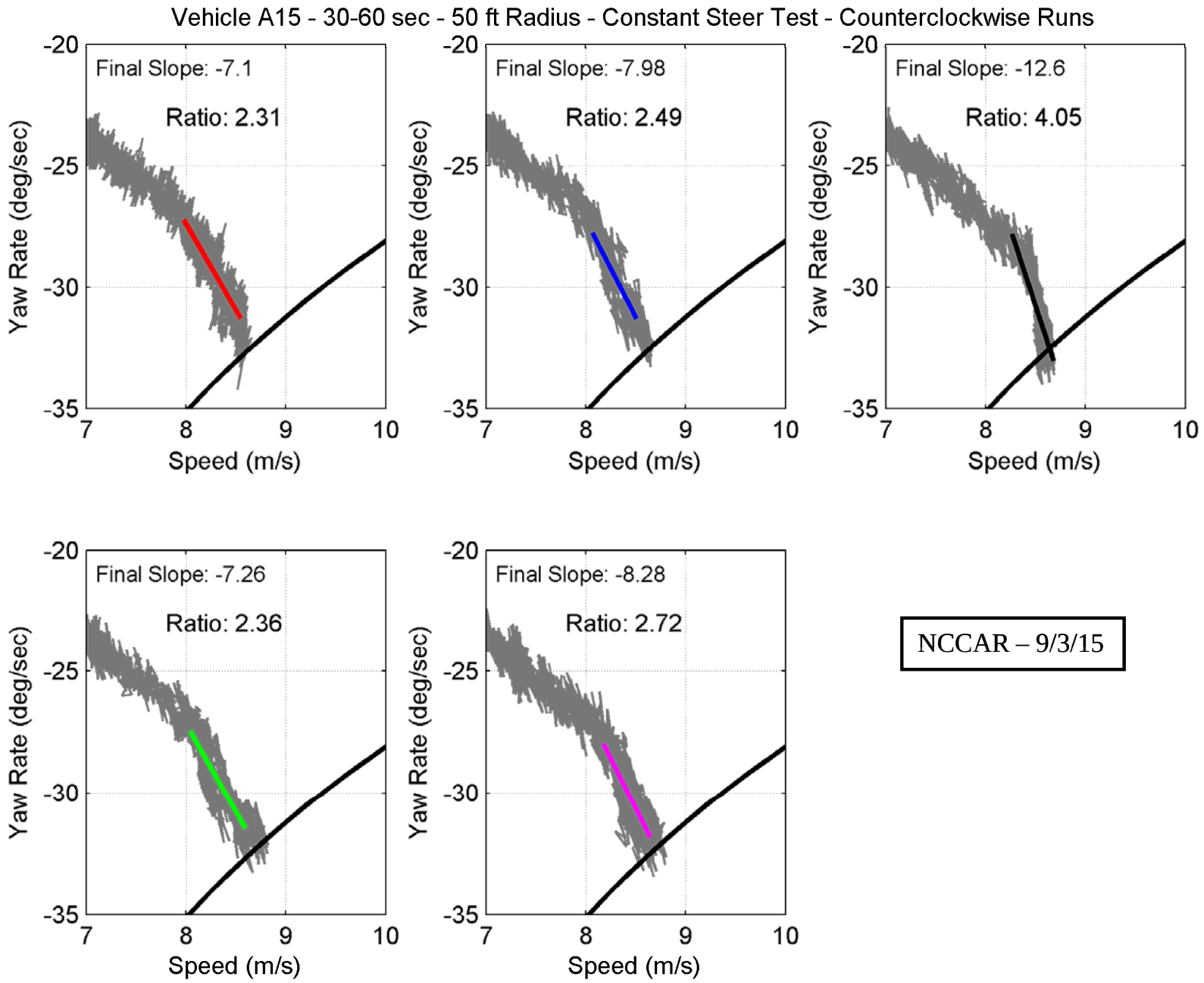

Vehicle A15 - Baseline - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -8.48
Ratio: 2.74
Final Slope: -9.69
Ratio: 3.06
Final Slope: -9.53
Ratio: 3.02
Final Slope: -7.08
Ratio: 2.25
Final Slope: -13.7
Ratio: 4.57
Yaw Rate (deg/sec)
Speed (m/s)
-20
-25
-30
-35
7
8
9
10

NCCAR – 9/3/15

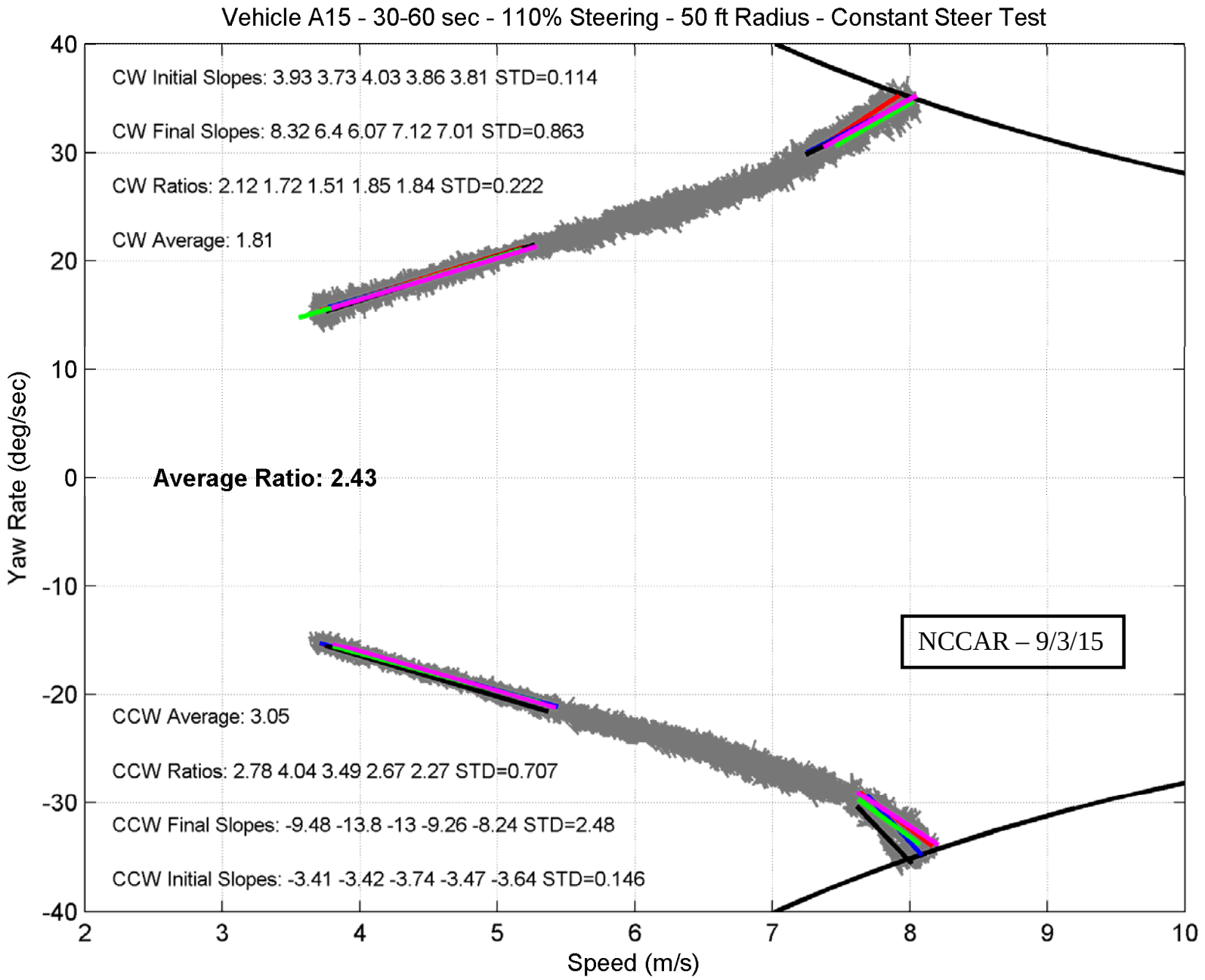

Vehicle A15 - 30-60 sec - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.38 3.31 3.37 3.37 3.35 STD=0.0295
CW Final Slopes: 12.7 5.16 6.52 8.34 8.53 STD=2.86
CW Ratios: 3.77 1.56 1.93 2.48 2.54 STD=0.839
CW Average: 2.46
Average Ratio: 2.62
NCCAR – 9/3/15
CCW Average: 2.79
CCW Ratios: 2.31 2.49 4.05 2.36 2.72 STD=0.722
CCW Final Slopes: -7.1 -7.98 -12.6 -7.26 -8.28 STD=2.28
CCW Initial Slopes: -3.07 -3.21 -3.12 -3.08 -3.04 STD=0.0635
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

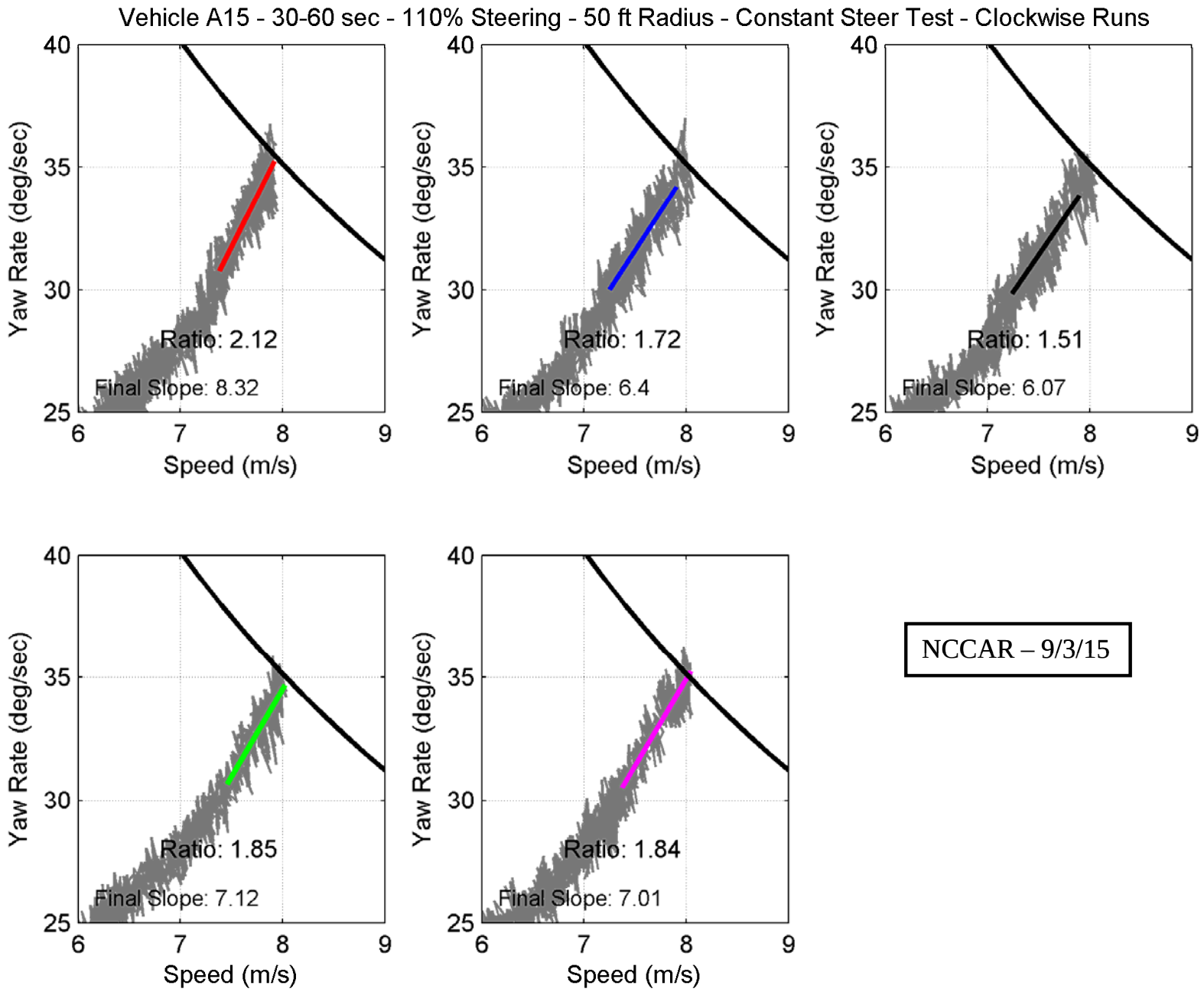

Vehicle A15 - 30-60 sec - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 3.77
Final Slope: 12.7
Ratio: 1.56
Final Slope: 5.16
Ratio: 1.93
Final Slope: 6.52
Ratio: 2.48
Final Slope: 8.34
Ratio: 2.54
Final Slope: 8.53

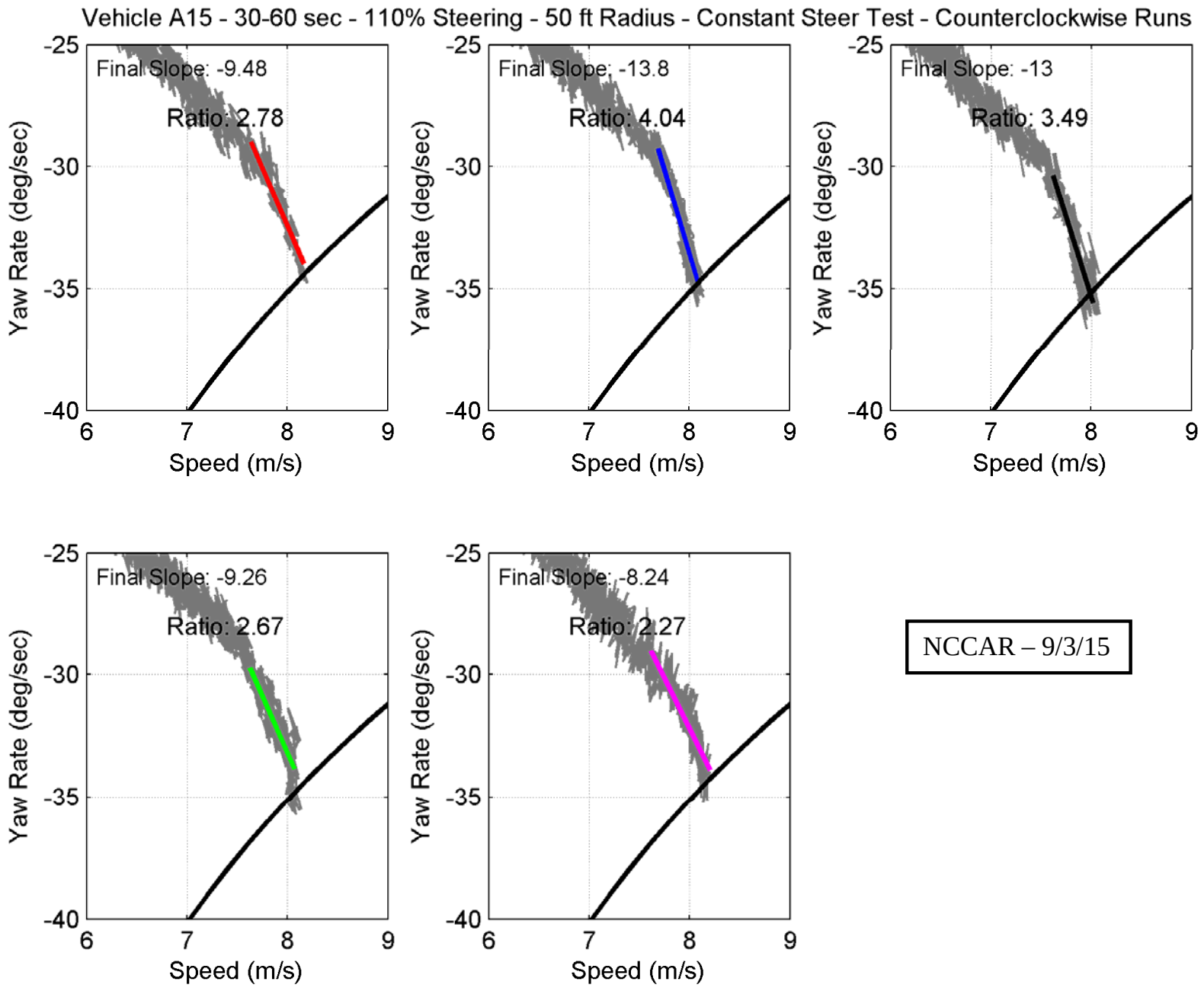
NCCAR – 9/3/15


Vehicle A15 - 30-60 sec - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -7.1
Ratio: 2.31
Final Slope: -7.98
Ratio: 2.49
Final Slope: -12.6
Ratio: 4.05
Final Slope: -7.26
Ratio: 2.36
Final Slope: -8.28
Ratio: 2.72
Yaw Rate (deg/sec)
Speed (m/s)
-20
-25
-30
-35
7
8
9
10

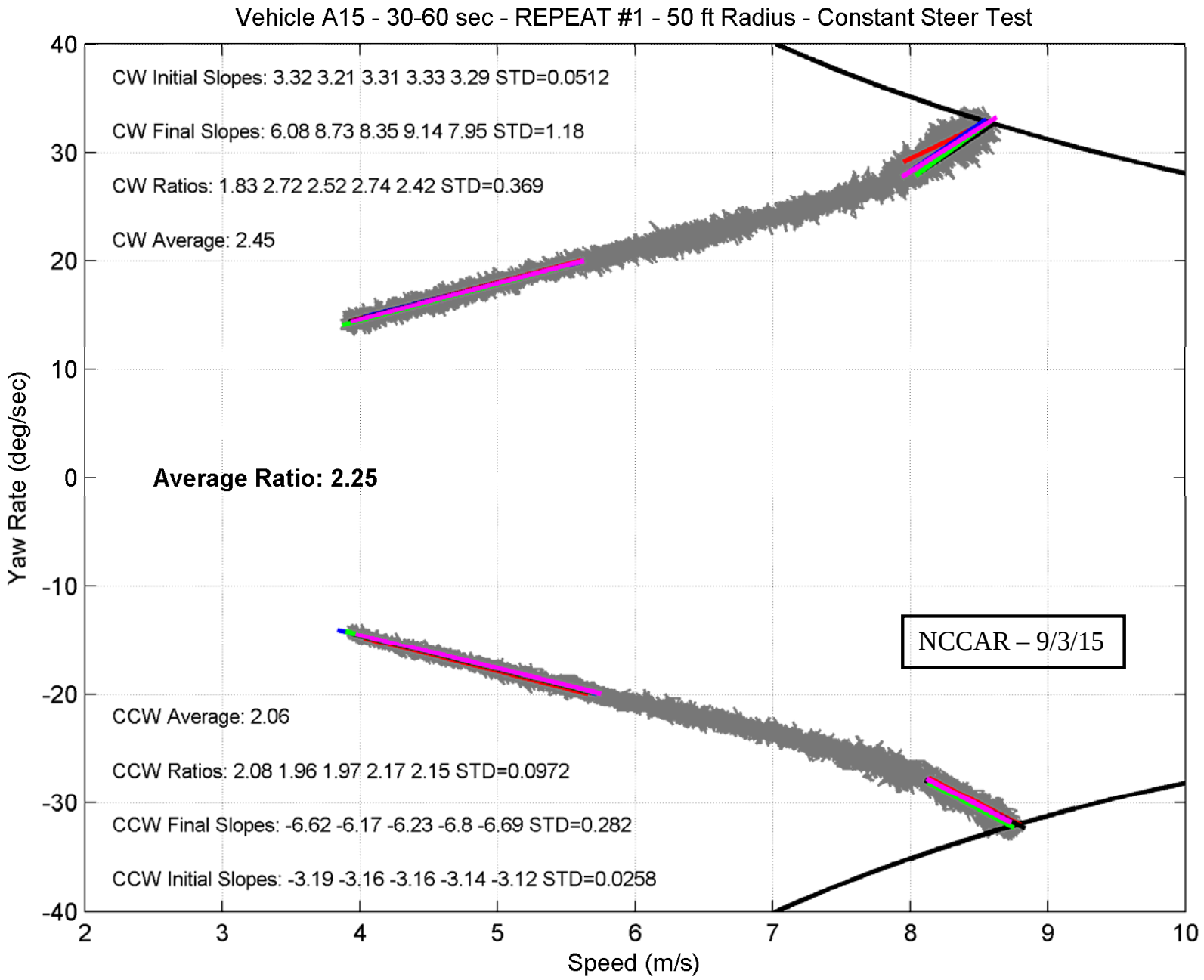
NCCAR – 9/3/15

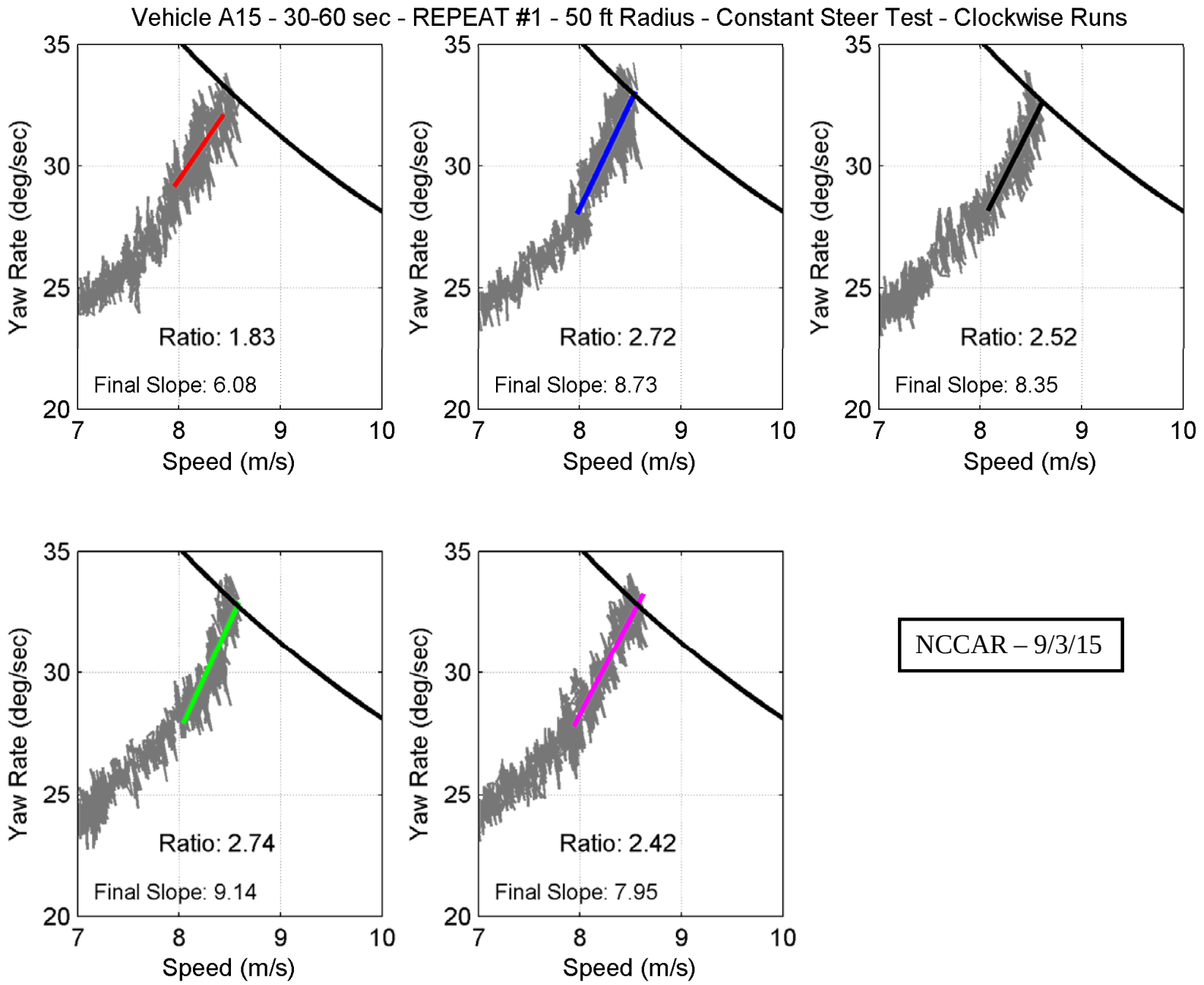

Vehicle A15 - 30-60 sec - 110% Steering - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.93 3.73 4.03 3.86 3.81 STD=0.114
CW Final Slopes: 8.32 6.4 6.07 7.12 7.01 STD=0.863
CW Ratios: 2.12 1.72 1.51 1.85 1.84 STD=0.222
CW Average: 1.81
Average Ratio: 2.43
NCCAR – 9/3/15
CCW Average: 3.05
CCW Ratios: 2.78 4.04 3.49 2.67 2.27 STD=0.707
CCW Final Slopes: -9.48 -13.8 -13 -9.26 -8.24 STD=2.48
CCW Initial Slopes: -3.41 -3.42 -3.74 -3.47 -3.64 STD=0.146
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


Vehicle A15 - 30-60 sec - 110% Steering - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 2.12
Final Slope: 8.32
Ratio: 1.72
Final Slope: 6.4
Ratio: 1.51
Final Slope: 6.07
Ratio: 1.85
Final Slope: 7.12
Ratio: 1.84
Final Slope: 7.01
NCCAR – 9/3/15

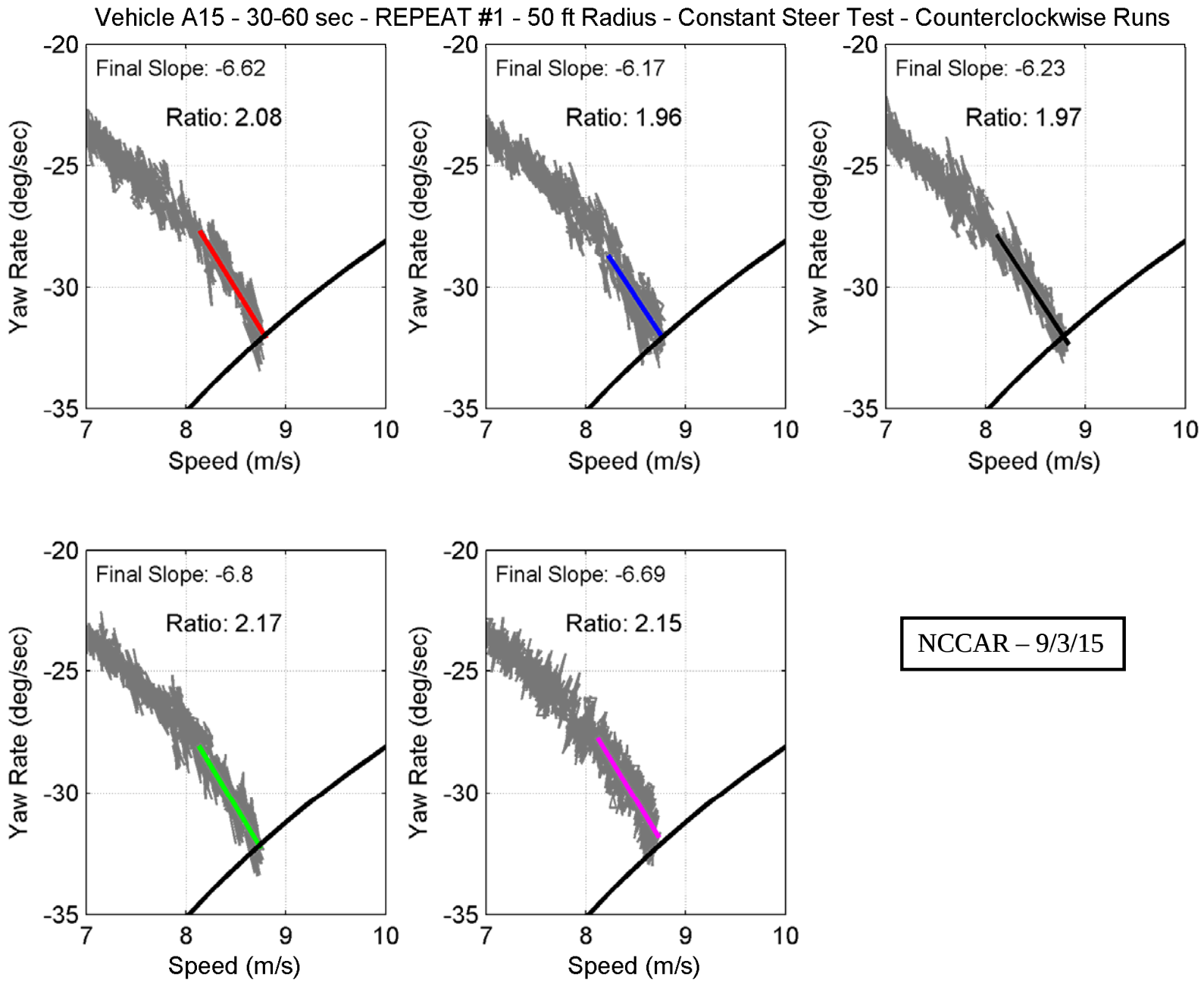

Vehicle A15 - 30-60 sec - 110% Steering - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -9.48
Ratio: 2.78
Final Slope: -13.8
Ratio: 4.04
Final Slope: -13
Ratio: 3.49
Final Slope: -9.26
Ratio: 2.67
Final Slope: -8.24
Ratio: 2.27
Yaw Rate (deg/sec)
Speed (m/s)
-25
-30
-35
-40
6
7
8
9

NCCAR – 9/3/15

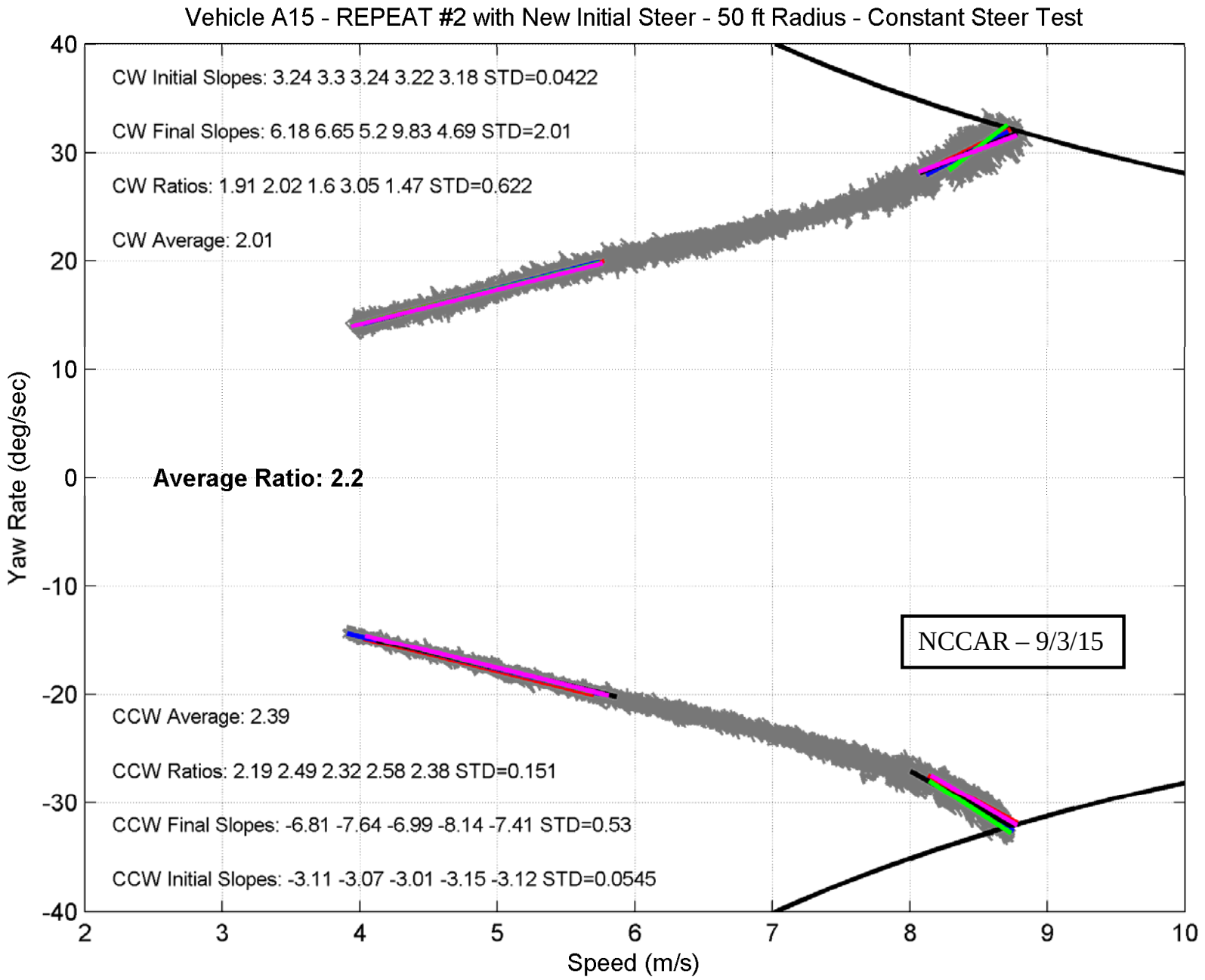

Vehicle A15 - 30-60 sec - REPEAT #1 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.32 3.21 3.31 3.33 3.29 STD=0.0512
CW Final Slopes: 6.08 8.73 8.35 9.14 7.95 STD=1.18
CW Ratios: 1.83 2.72 2.52 2.74 2.42 STD=0.369
CW Average: 2.45
Average Ratio: 2.25
NCCAR – 9/3/15
CCW Average: 2.06
CCW Ratios: 2.08 1.96 1.97 2.17 2.15 STD=0.0972
CCW Final Slopes: -6.62 -6.17 -6.23 -6.8 -6.69 STD=0.282
CCW Initial Slopes: -3.19 -3.16 -3.16 -3.14 -3.12 STD=0.0258
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

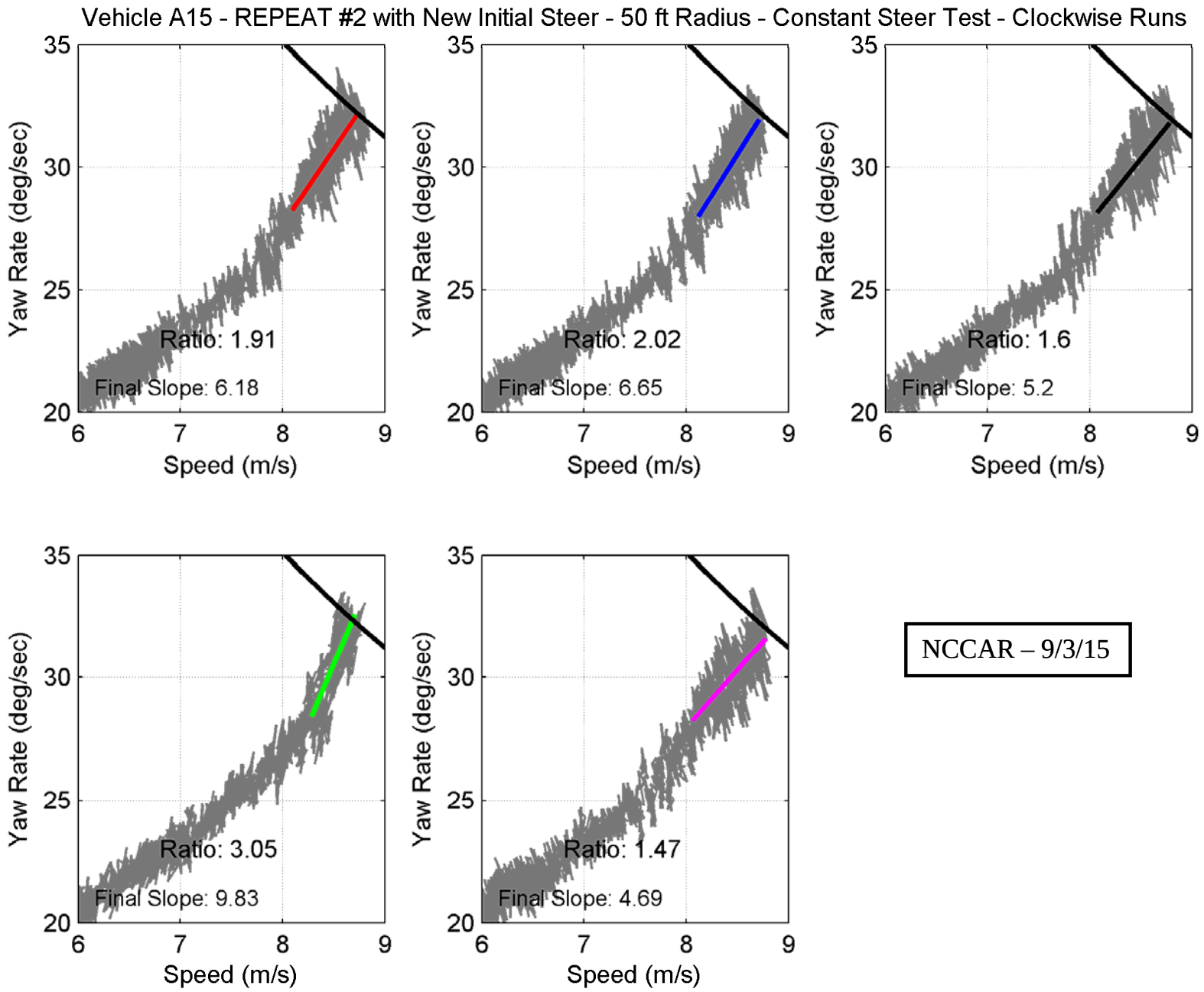

Vehicle A15 - 30-60 sec - REPEAT #1 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 1.83
Final Slope: 6.08
Ratio: 2.72
Final Slope: 8.73
Ratio: 2.52
Final Slope: 8.35
Ratio: 2.74
Final Slope: 9.14
Ratio: 2.42
Final Slope: 7.95

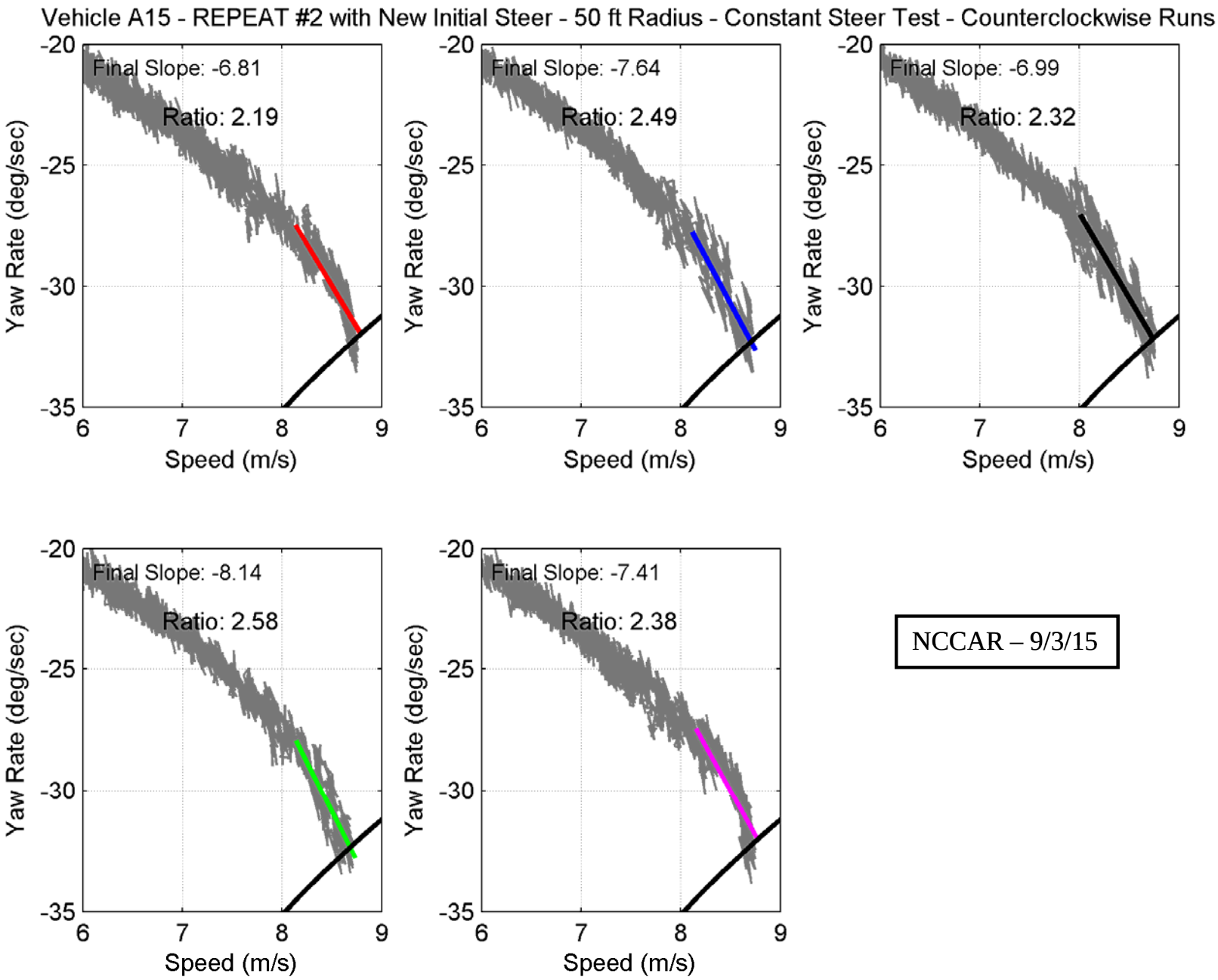
NCCAR – 9/3/15


Vehicle A15 - 30-60 sec - REPEAT #1 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -6.62
Ratio: 2.08
Final Slope: -6.17
Ratio: 1.96
Final Slope: -6.23
Ratio: 1.97
Final Slope: -6.8
Ratio: 2.17
Final Slope: -6.69
Ratio: 2.15
Yaw Rate (deg/sec)
Speed (m/s)
-20
-25
-30
-35
7
8
9
10

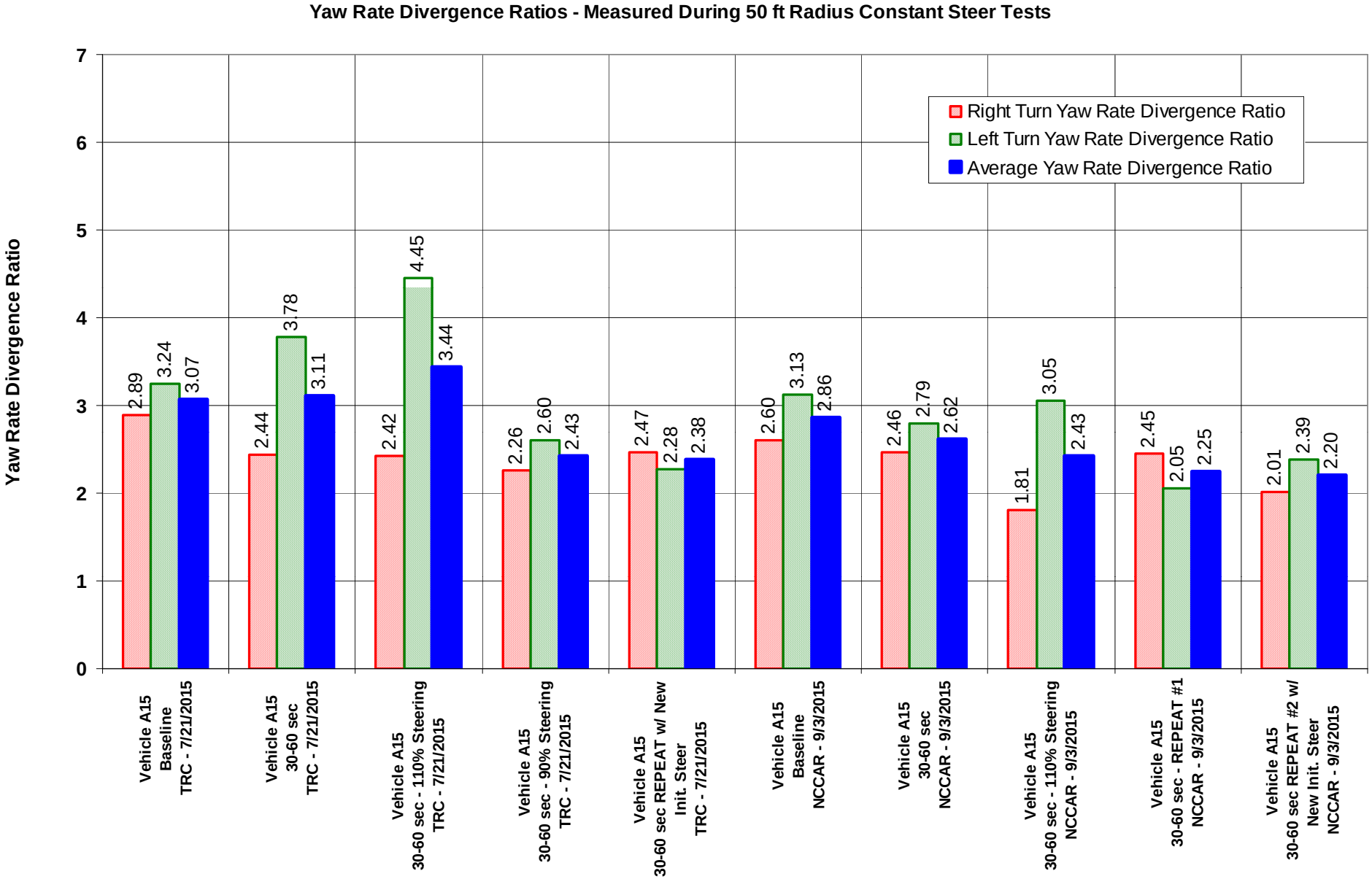
NCCAR – 9/3/15

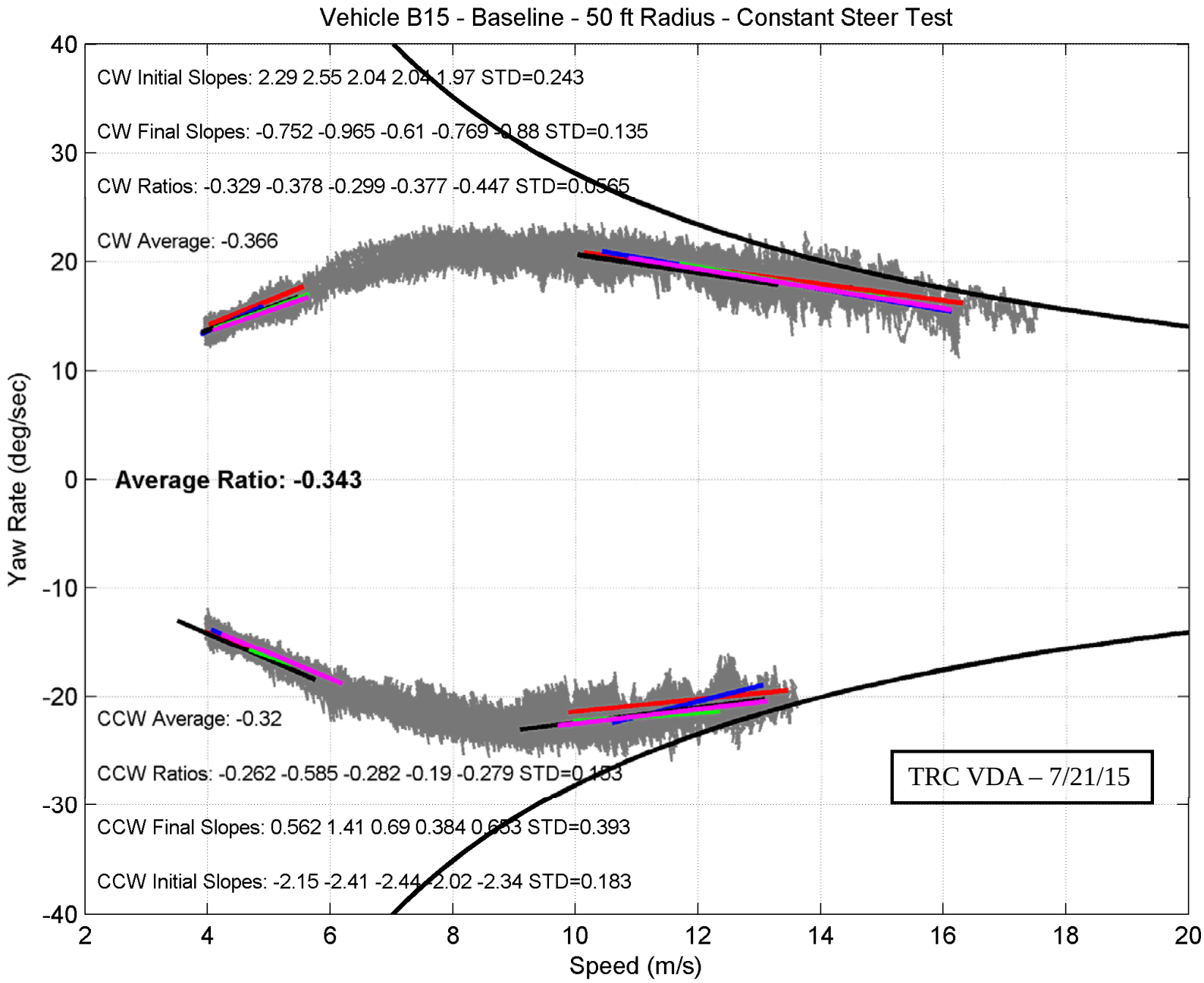

Vehicle A15 - REPEAT #2 with New Initial Steer - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.24 3.3 3.24 3.22 3.18 STD=0.0422
CW Final Slopes: 6.18 6.65 5.2 9.83 4.69 STD=2.01
CW Ratios: 1.91 2.02 1.6 3.05 1.47 STD=0.622
CW Average: 2.01
Average Ratio: 2.2
NCCAR – 9/3/15
CCW Average: 2.39
CCW Ratios: 2.19 2.49 2.32 2.58 2.38 STD=0.151
CCW Final Slopes: -6.81 -7.64 -6.99 -8.14 -7.41 STD=0.53
CCW Initial Slopes: -3.11 -3.07 -3.01 -3.15 -3.12 STD=0.0545
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

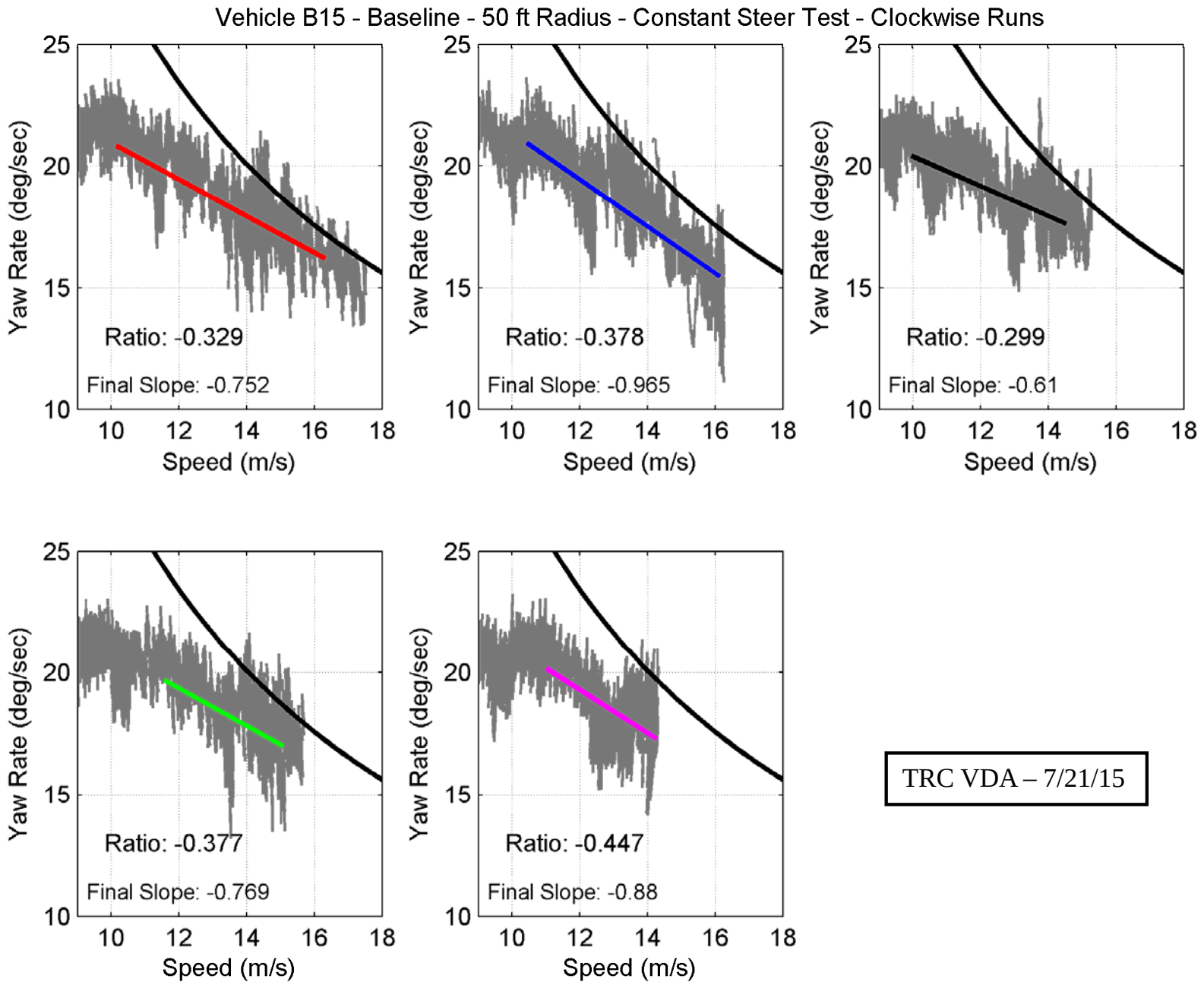

Vehicle A15 - REPEAT #2 with New Initial Steer - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 1.91
Final Slope: 6.18
Ratio: 2.02
Final Slope: 6.65
Ratio: 1.6
Final Slope: 5.2
Ratio: 3.05
Final Slope: 9.83
Ratio: 1.47
Final Slope: 4.69
NCCAR – 9/3/15


Vehicle A15 - REPEAT #2 with New Initial Steer - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -6.81
Ratio: 2.19
Final Slope: -7.64
Ratio: 2.49
Final Slope: -6.99
Ratio: 2.32
Final Slope: -8.14
Ratio: 2.58
Final Slope: -7.41
Ratio: 2.38
Yaw Rate (deg/sec)
Speed (m/s)
-20
-25
-30
-35
6
7
8
9

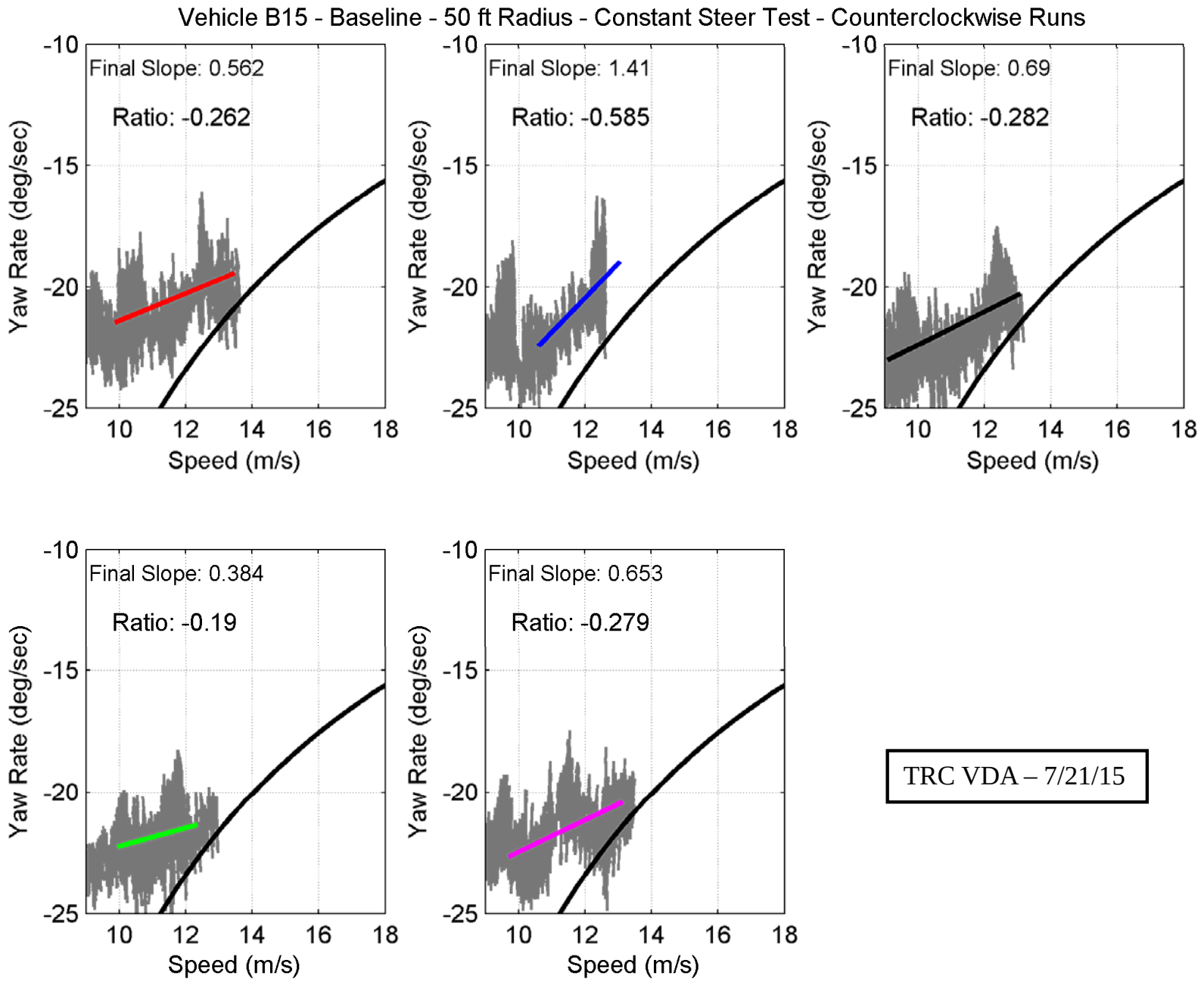
NCCAR – 9/3/15


Yaw Rate Divergence Ratios - Measured During 50 ft Radius Constant Steer Tests
Yaw Rate Divergence Ratio
Right Turn Yaw Rate Divergence Ratio
Left Turn Yaw Rate Divergence Ratio
Average Yaw Rate Divergence Ratio
0
1
2
3
4
5
6
7
2.89
3.24
3.07
2.44
3.78
3.11
2.42
4.45
3.44
2.26
2.60
2.43
2.47
2.28
2.38
2.60
3.13
2.86
2.46
2.79
2.62
1.81
3.05
2.43
2.45
2.05
2.25
2.01
2.39
2.20
Vehicle A15 Baseline TRC - 7/21/2015
Vehicle A15 30-60 sec TRC - 7/21/2015
Vehicle A15 30-60 sec - 110% Steering TRC - 7/21/2015
Vehicle A15 30-60 sec - 90% Steering TRC - 7/21/2015
Vehicle A15 30-60 sec REPEAT w/ New Init. Steer TRC - 7/21/2015
Vehicle A15 Baseline NCCAR - 9/3/2015
Vehicle A15 30-60 sec NCCAR - 9/3/2015
Vehicle A15 30-60 sec - 110% Steering NCCAR - 9/3/2015
Vehicle A15 30-60 sec - REPEAT #1 NCCAR - 9/3/2015
Vehicle A15 30-60 sec REPEAT #2 w/ New Init. Steer NCCAR - 9/3/2015

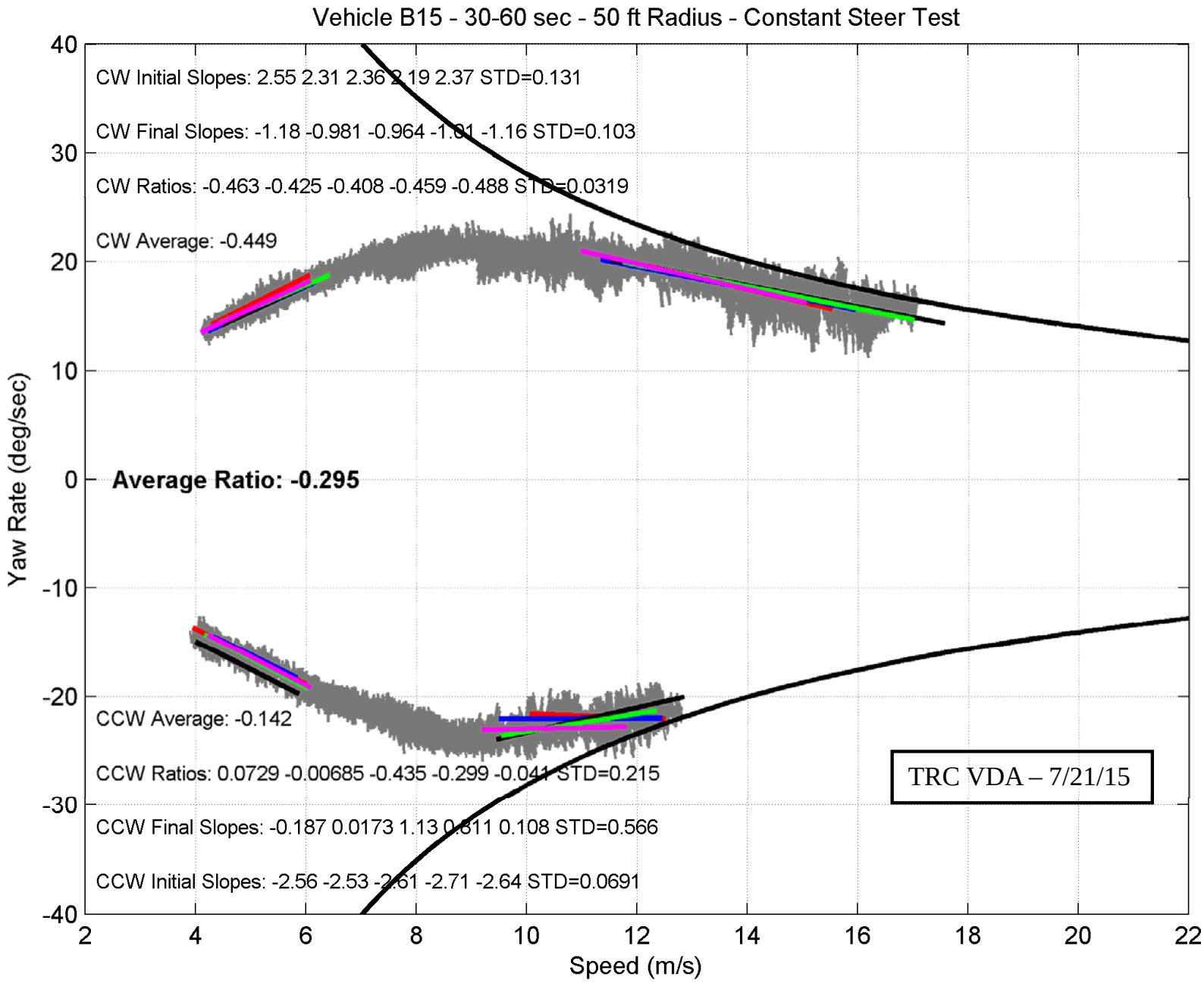

Vehicle B15 - Baseline - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.29 2.55 2.04 2.04 1.97 STD=0.243
CW Final Slopes: -0.752 -0.965 -0.61 -0.769 -0.88 STD=0.135
CW Ratios: -0.329 -0.378 -0.299 -0.377 -0.447 STD=0.0565
CW Average: -0.366
Average Ratio: -0.343
CCW Average: -0.32
CCW Ratios: -0.262 -0.585 -0.282 -0.19 -0.279 STD=0.153
CCW Final Slopes: 0.562 1.41 0.69 0.384 0.683 STD=0.393
CCW Initial Slopes: -2.15 -2.41 -2.44 -2.02 -2.34 STD=0.183
TRC VDA – 7/21/15
Yaw Rate (deg/sec)
Speed (m/s)
40
30
20
10
0
-10
-20
-30
-40
2
4
6
8
10
12
14
16
18
20

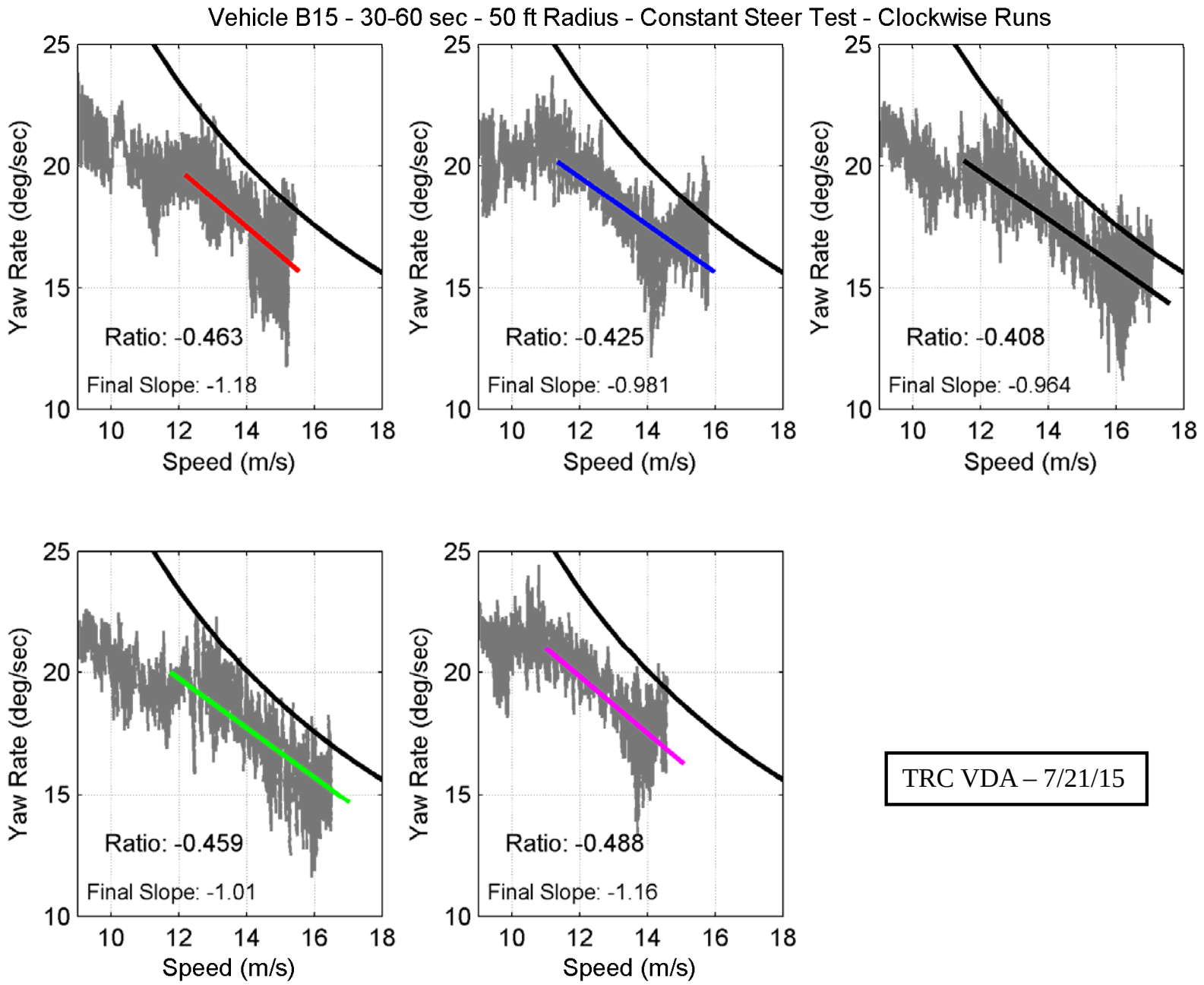


TRC VDA – 7/21/15

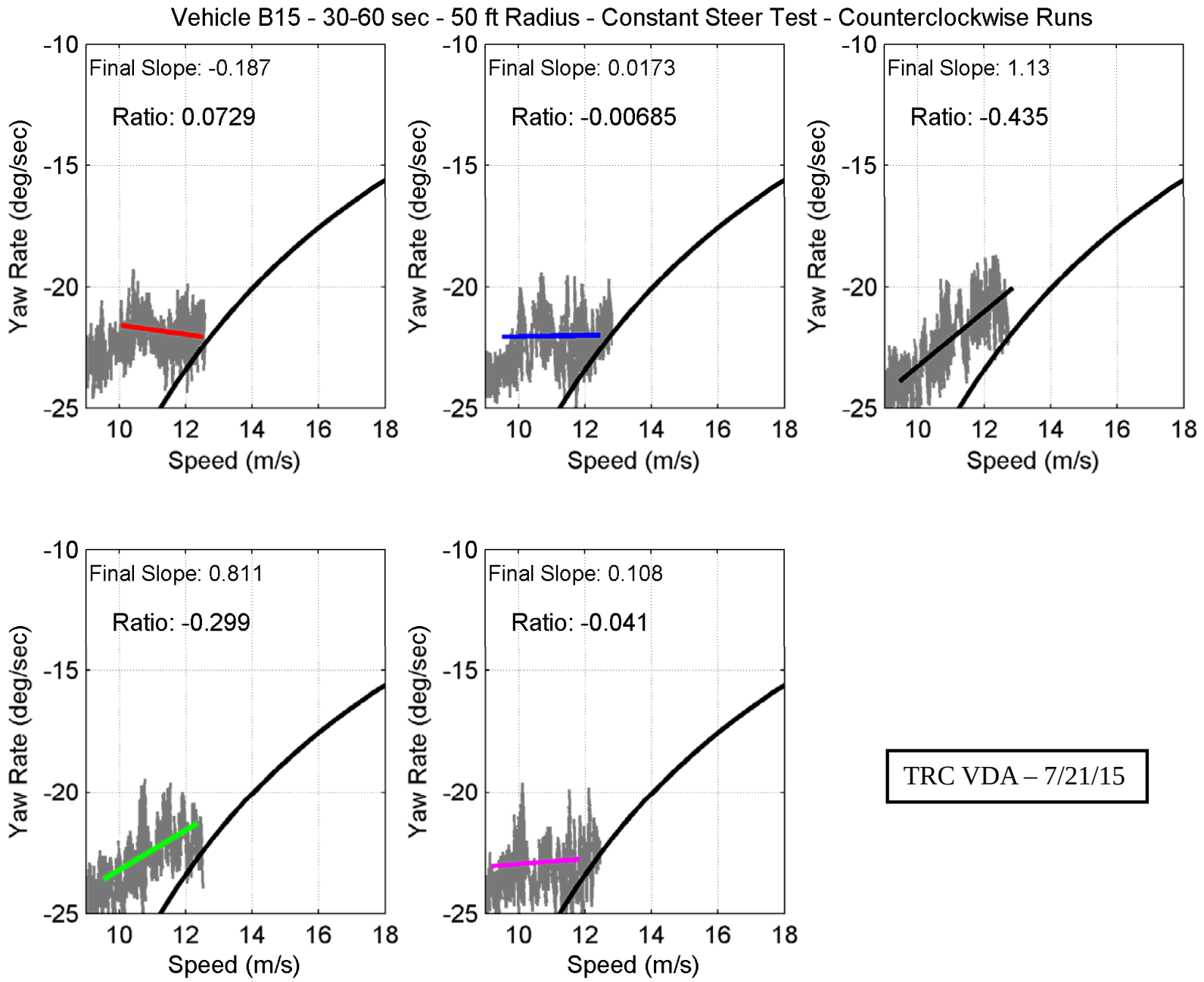


TRC VDA – 7/21/15

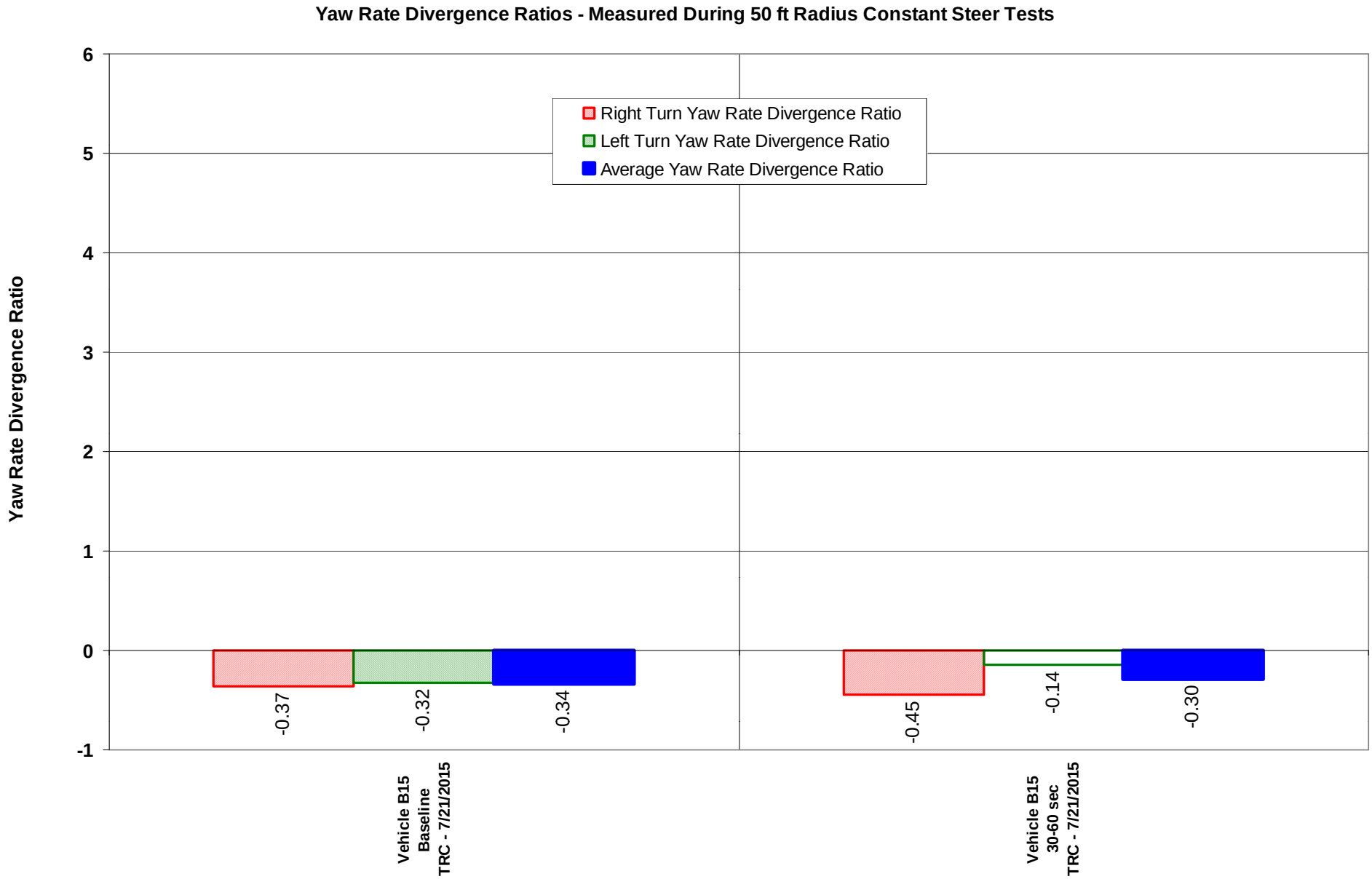

Vehicle B15 - 30-60 sec - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.55 2.31 2.36 2.19 2.37 STD=0.131
CW Final Slopes: -1.18 -0.981 -0.964 -1.01 -1.16 STD=0.103
CW Ratios: -0.463 -0.425 -0.408 -0.459 -0.488 STD=0.0319
CW Average: -0.449
Average Ratio: -0.295
CCW Average: -0.142
CCW Ratios: 0.0729 -0.00685 -0.435 -0.299 -0.041 STD=0.215
CCW Final Slopes: -0.187 0.0173 1.13 0.811 0.108 STD=0.566
CCW Initial Slopes: -2.56 -2.53 -2.61 -2.71 -2.64 STD=0.0691
TRC VDA – 7/21/15
Yaw Rate (deg/sec)
Speed (m/s)
40
30
20
10
0
-10
-20
-30
-40
2
4
6
8
10
12
14
16
18
20
22

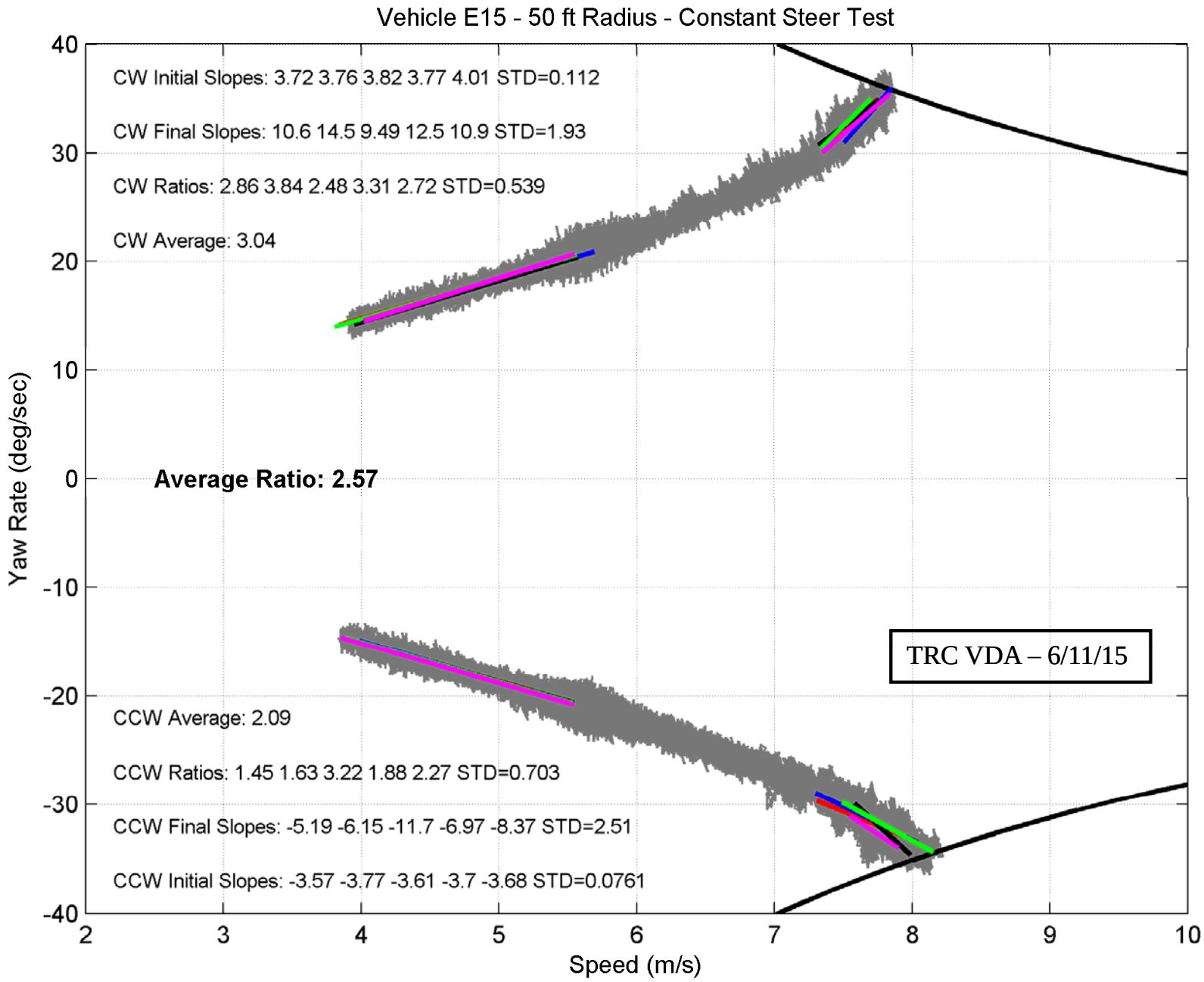


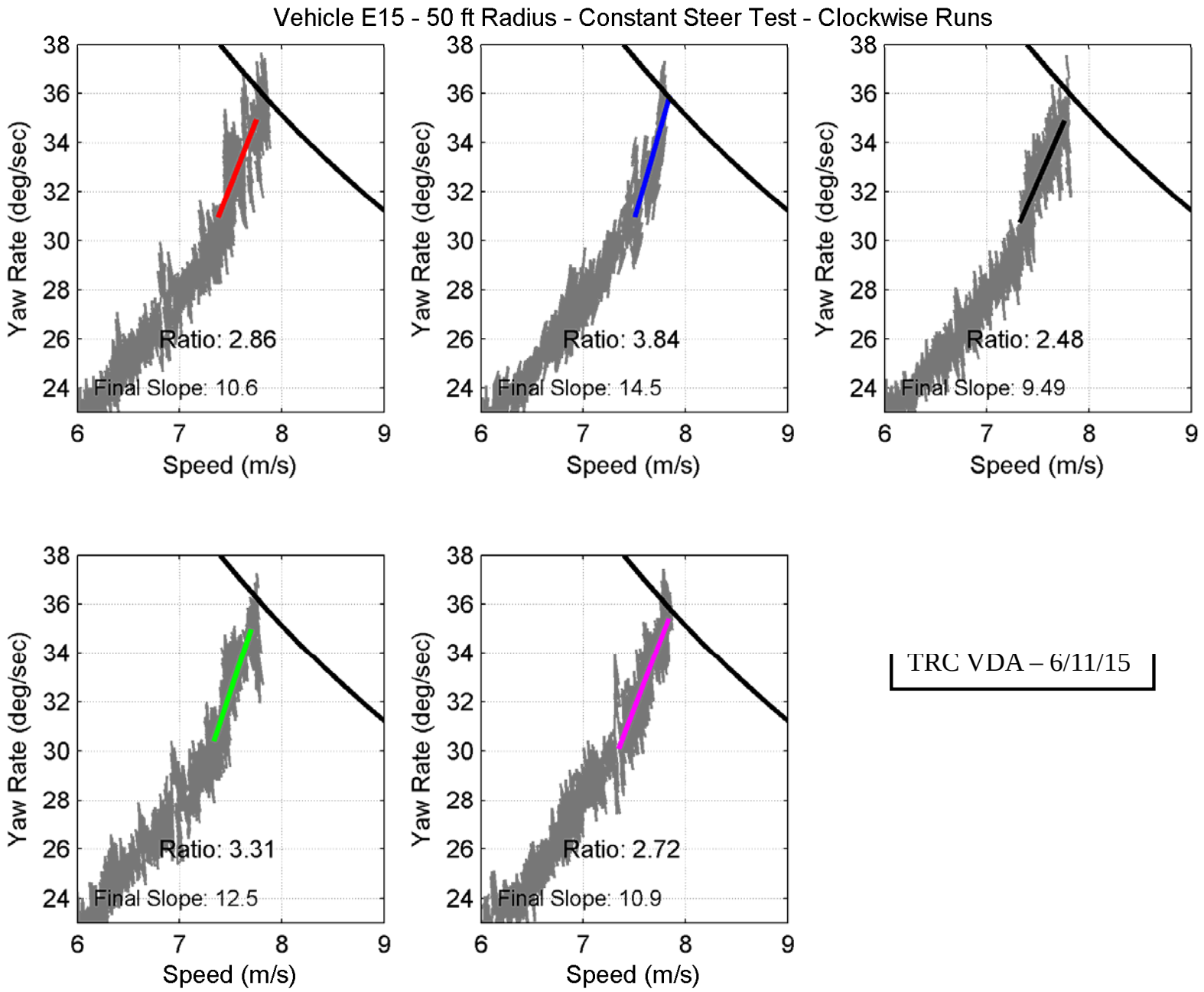
TRC VDA – 7/21/15



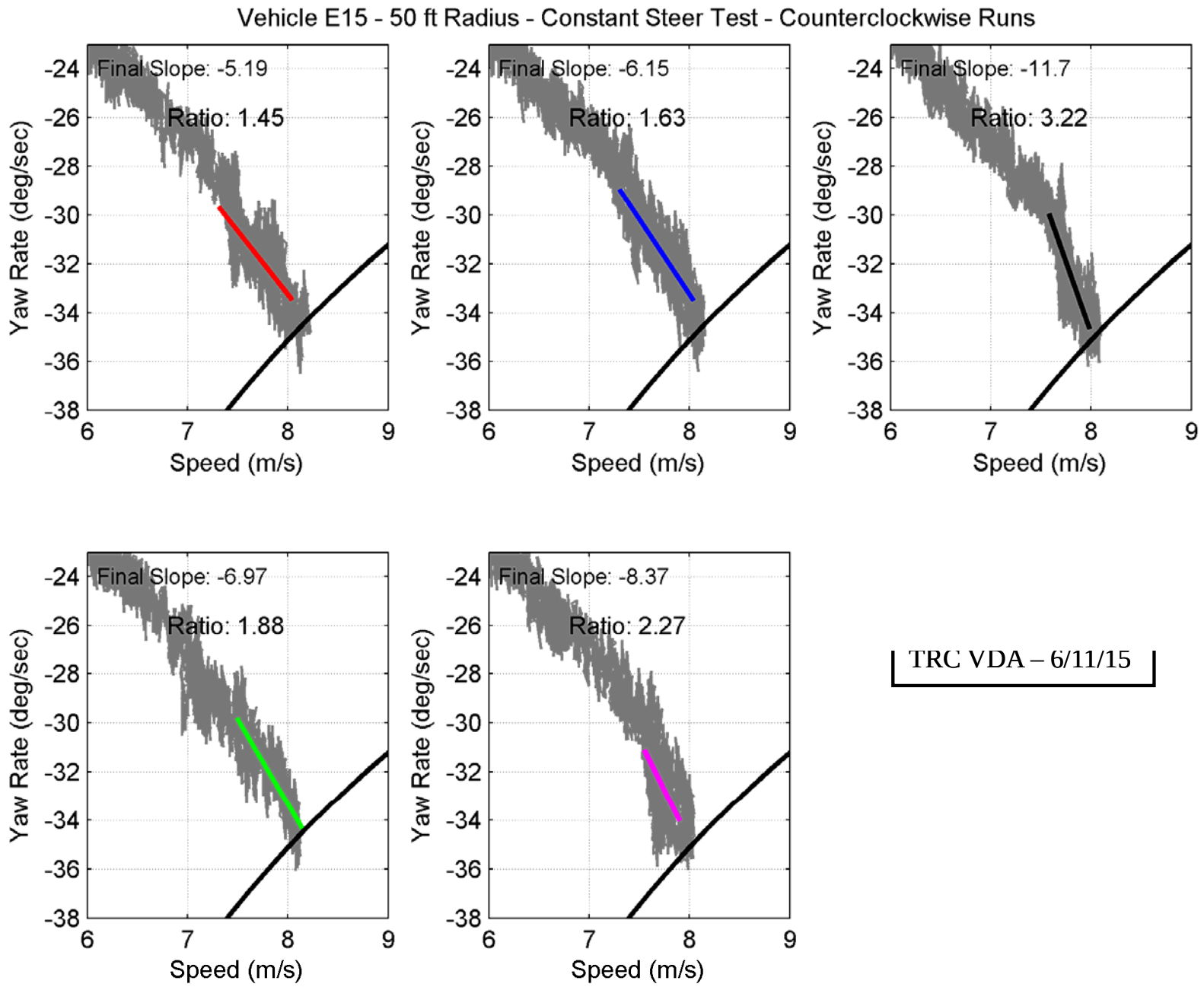
TRC VDA – 7/21/15


Yaw Rate Divergence Ratios - Measured During 50 ft Radius Constant Steer Tests
Yaw Rate Divergence Ratio
6
5
4
3
2
1
0
-1
Right Turn Yaw Rate Divergence Ratio
Left Turn Yaw Rate Divergence Ratio
Average Yaw Rate Divergence Ratio
-0.37
-0.32
-0.34
-0.45
-0.14
-0.30
Vehicle B15 Baseline TRC - 7/21/2015
Vehicle B15 30-60 sec TRC - 7/21/2015

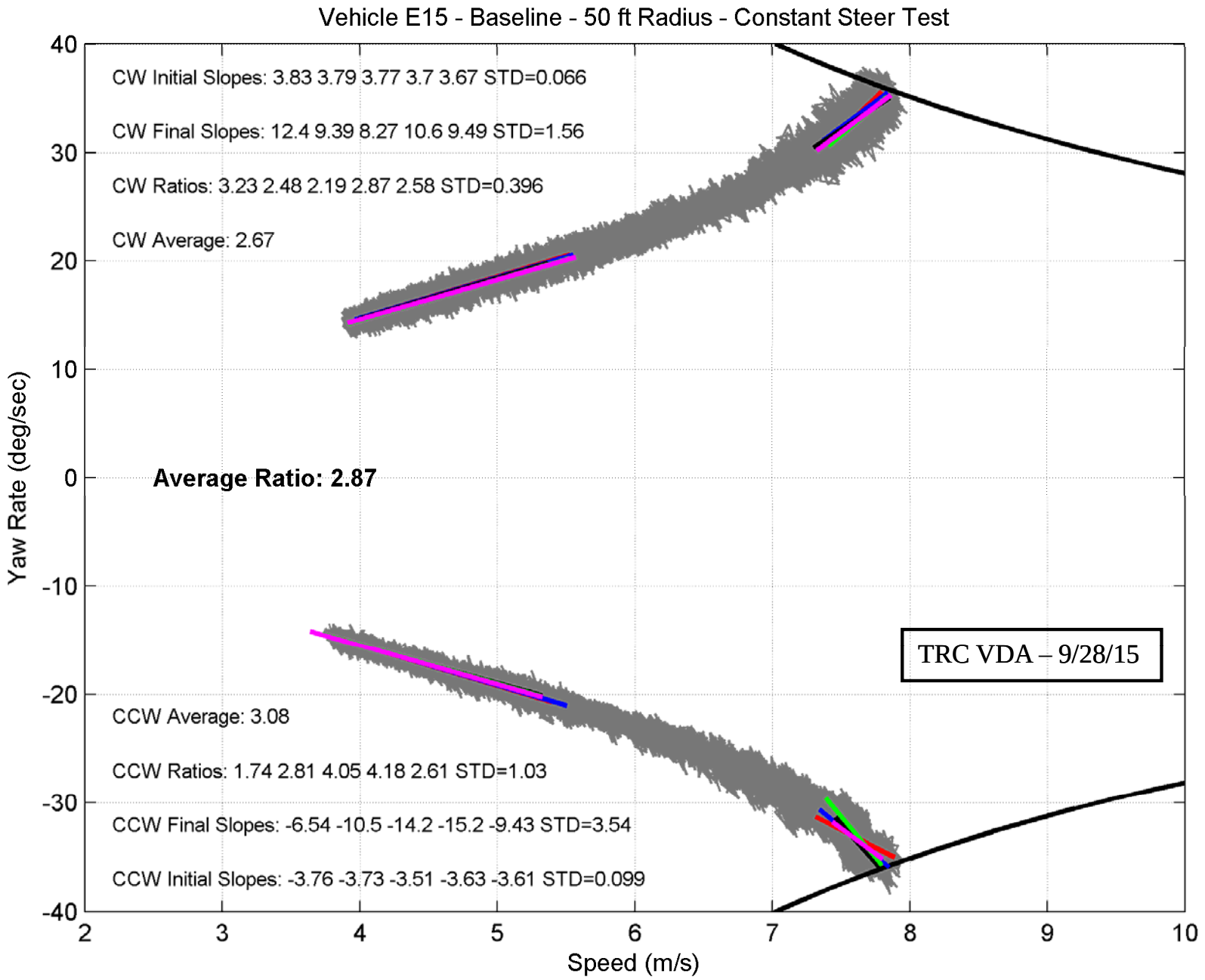

Vehicle E15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.72 3.76 3.82 3.77 4.01 STD=0.112
CW Final Slopes: 10.6 14.5 9.49 12.5 10.9 STD=1.93
CW Ratios: 2.86 3.84 2.48 3.31 2.72 STD=0.539
CW Average: 3.04
Average Ratio: 2.57
TRC VDA – 6/11/15
CCW Average: 2.09
CCW Ratios: 1.45 1.63 3.22 1.88 2.27 STD=0.703
CCW Final Slopes: -5.19 -6.15 -11.7 -6.97 -8.37 STD=2.51
CCW Initial Slopes: -3.57 -3.77 -3.61 -3.7 -3.68 STD=0.0761
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

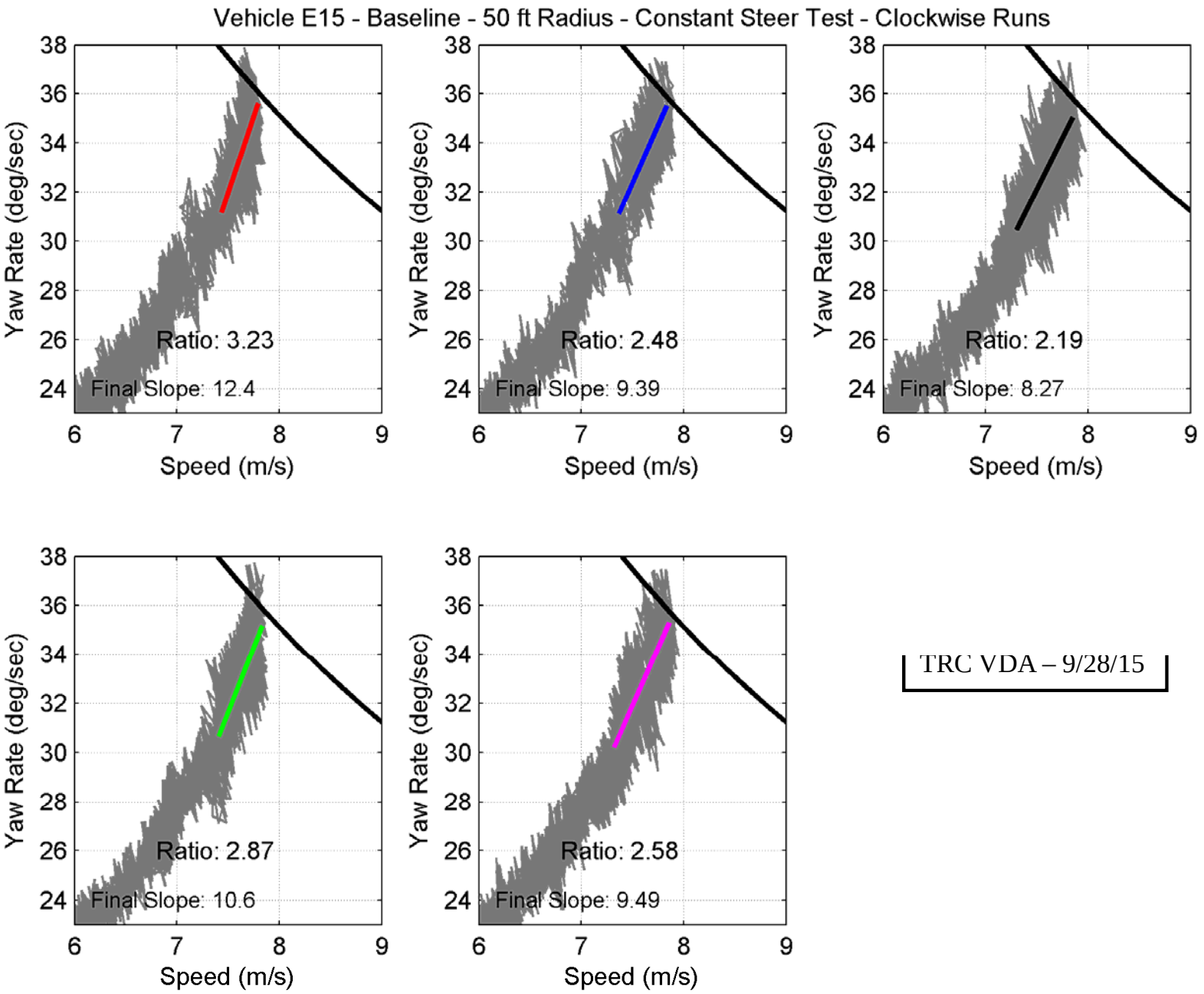


TRC VDA – 6/11/15

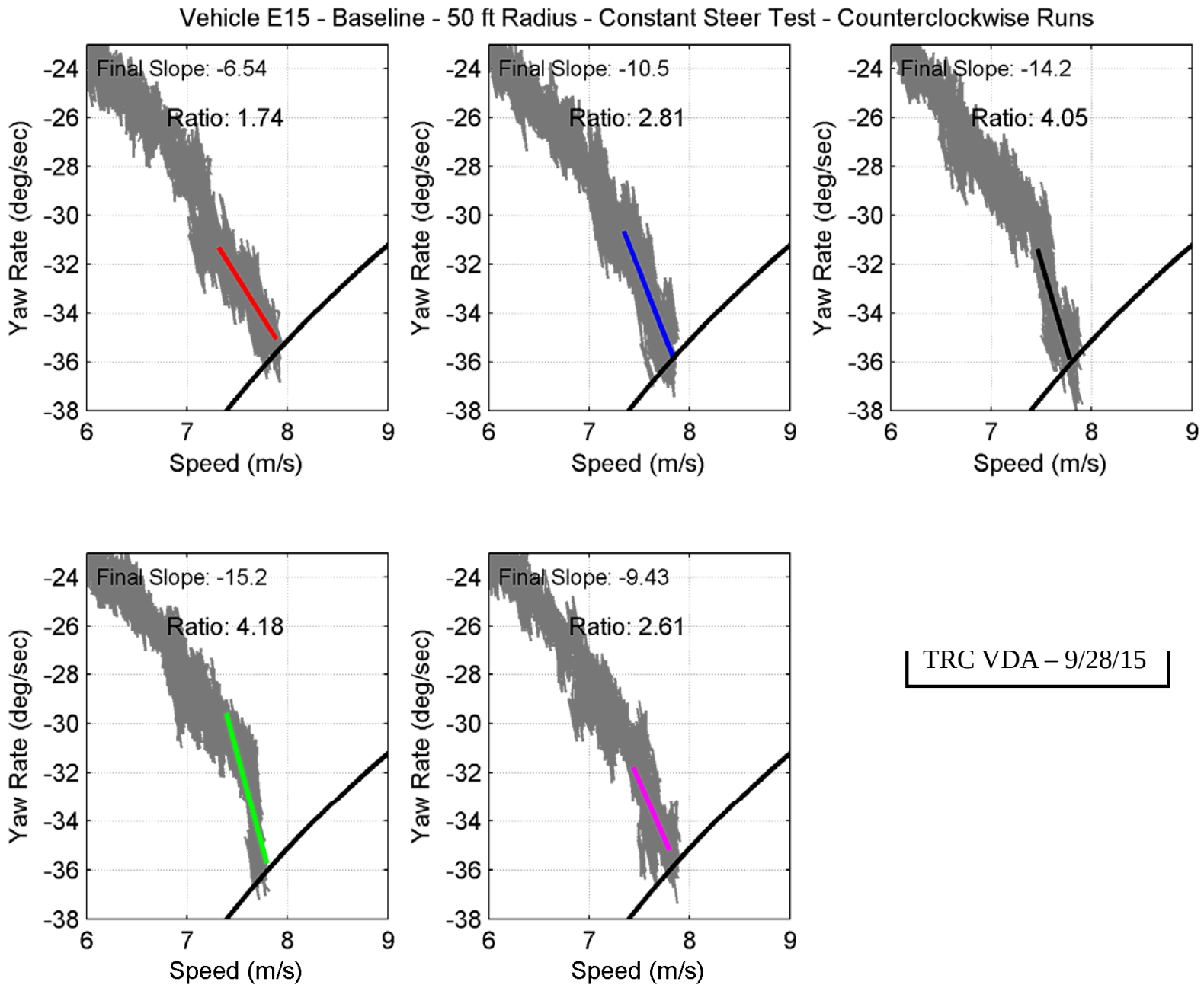


TRC VDA – 6/11/15

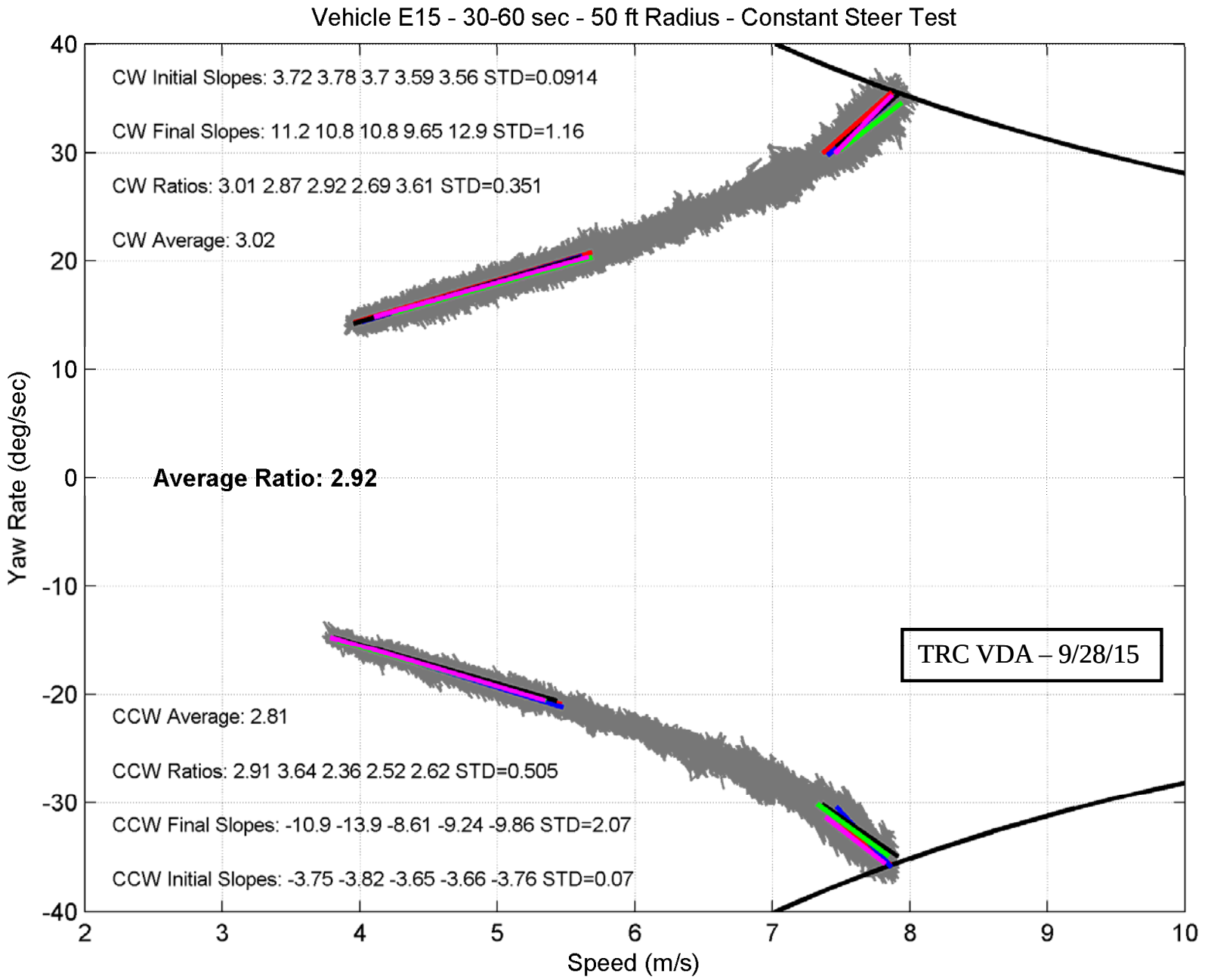

Vehicle E15 - Baseline - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.83 3.79 3.77 3.7 3.67 STD=0.066
CW Final Slopes: 12.4 9.39 8.27 10.6 9.49 STD=1.56
CW Ratios: 3.23 2.48 2.19 2.87 2.58 STD=0.396
CW Average: 2.67
Average Ratio: 2.87
TRC VDA – 9/28/15
CCW Average: 3.08
CCW Ratios: 1.74 2.81 4.05 4.18 2.61 STD=1.03
CCW Final Slopes: -6.54 -10.5 -14.2 -15.2 -9.43 STD=3.54
CCW Initial Slopes: -3.76 -3.73 -3.51 -3.63 -3.61 STD=0.099
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

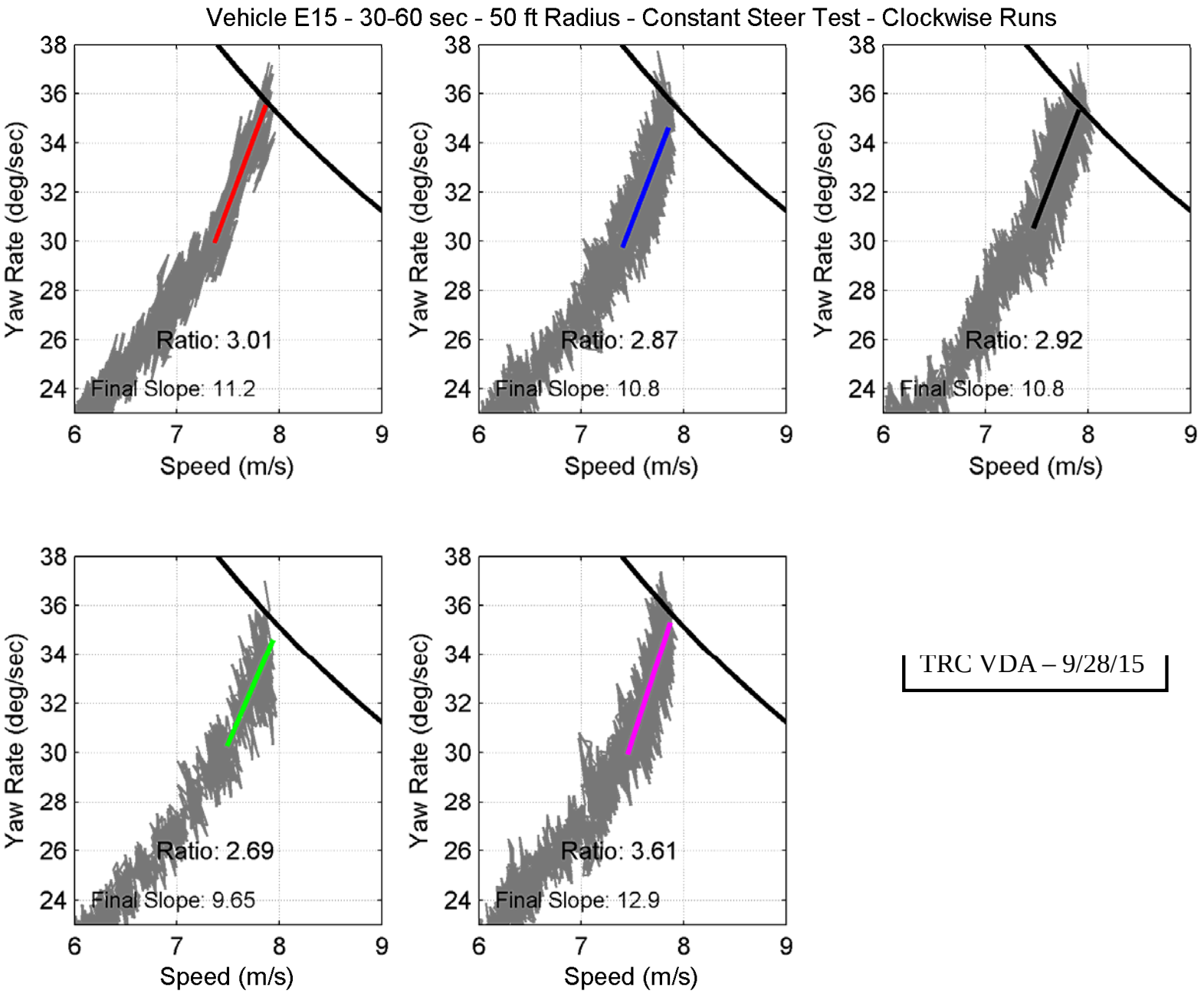


TRC VDA – 9/28/15

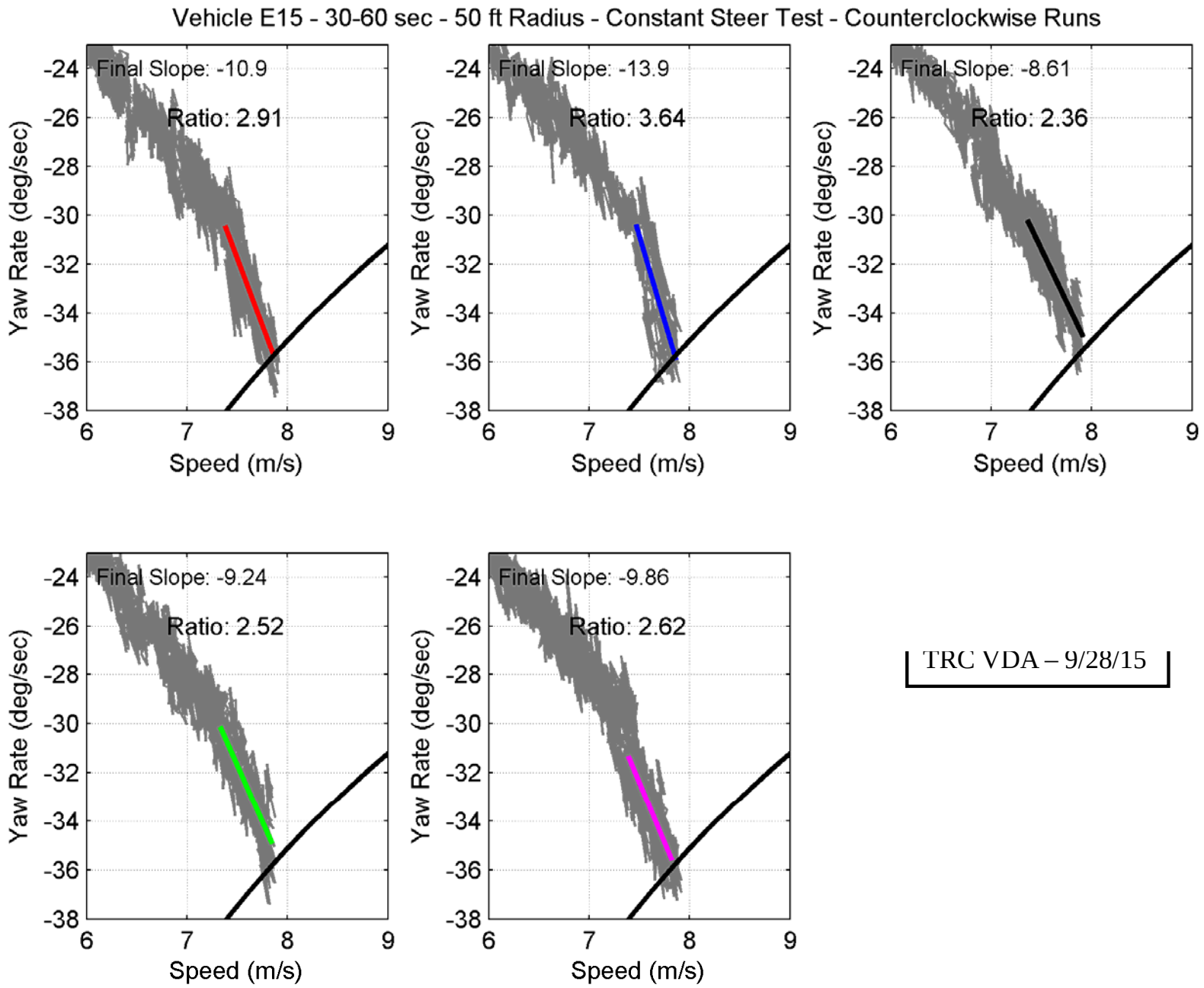


TRC VDA – 9/28/15

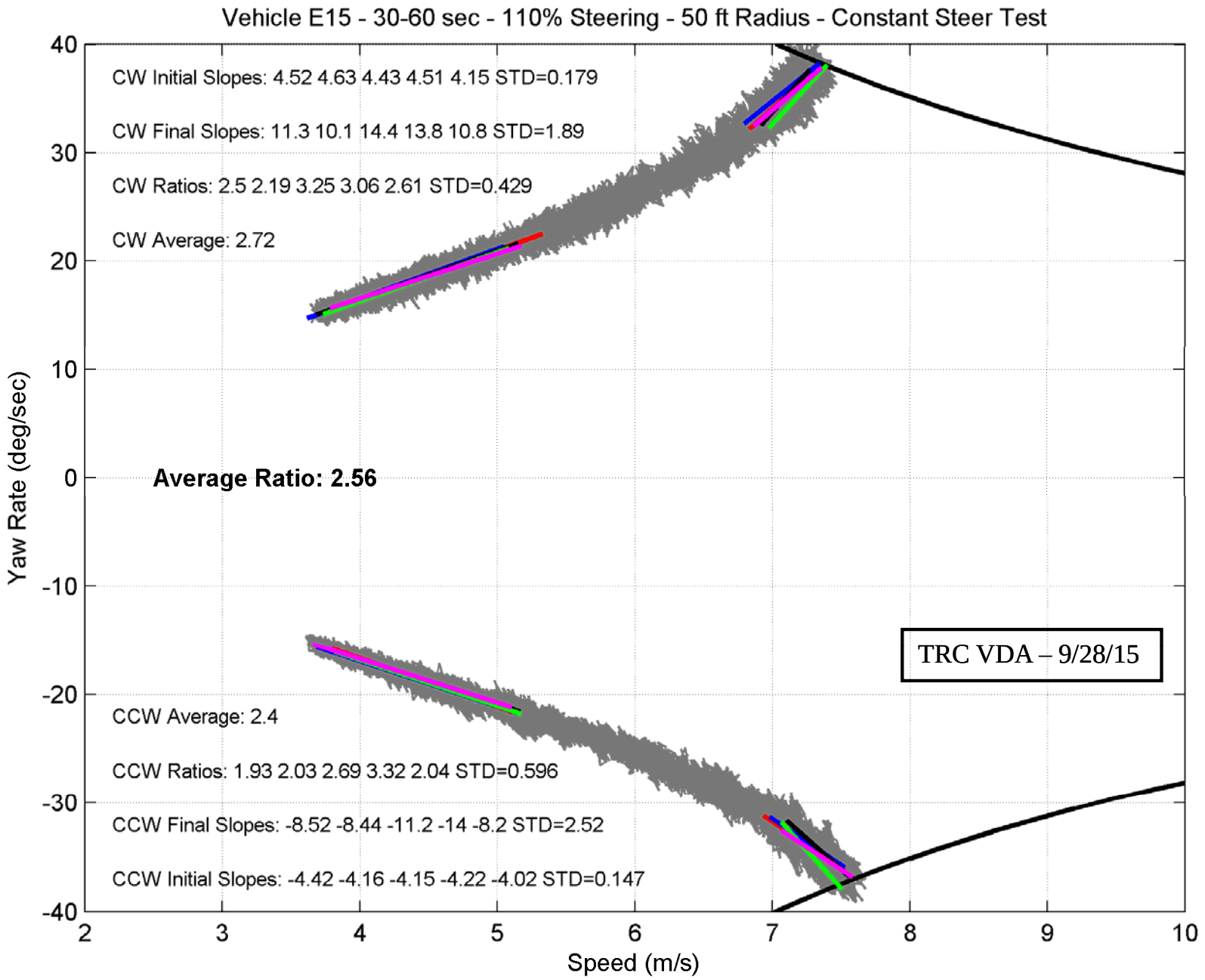

Vehicle E15 - 30-60 sec - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.72 3.78 3.7 3.59 3.56 STD=0.0914
CW Final Slopes: 11.2 10.8 10.8 9.65 12.9 STD=1.16
CW Ratios: 3.01 2.87 2.92 2.69 3.61 STD=0.351
CW Average: 3.02
Average Ratio: 2.92
TRC VDA – 9/28/15
CCW Average: 2.81
CCW Ratios: 2.91 3.64 2.36 2.52 2.62 STD=0.505
CCW Final Slopes: -10.9 -13.9 -8.61 -9.24 -9.86 STD=2.07
CCW Initial Slopes: -3.75 -3.82 -3.65 -3.66 -3.76 STD=0.07
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

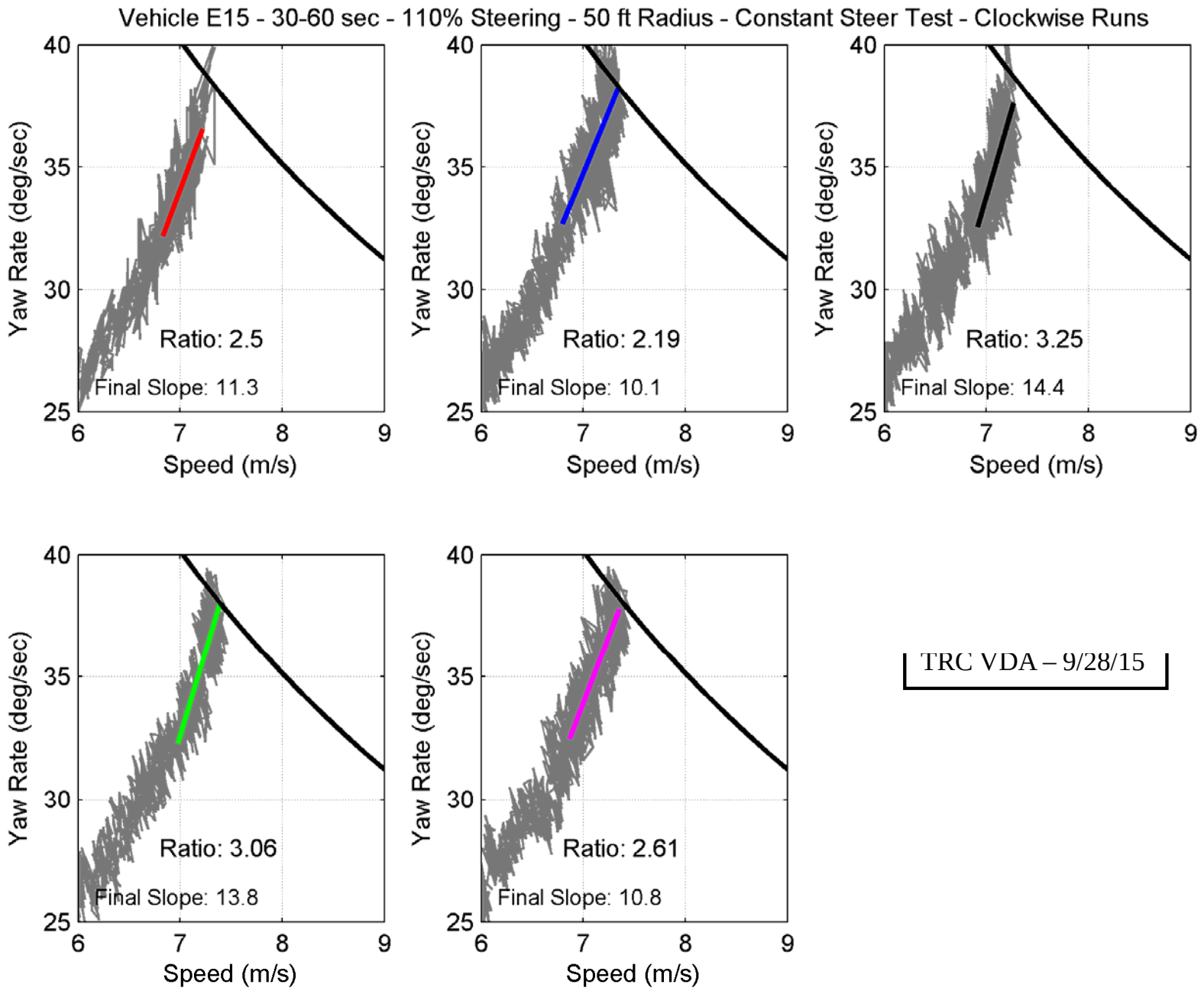


TRC VDA – 9/28/15

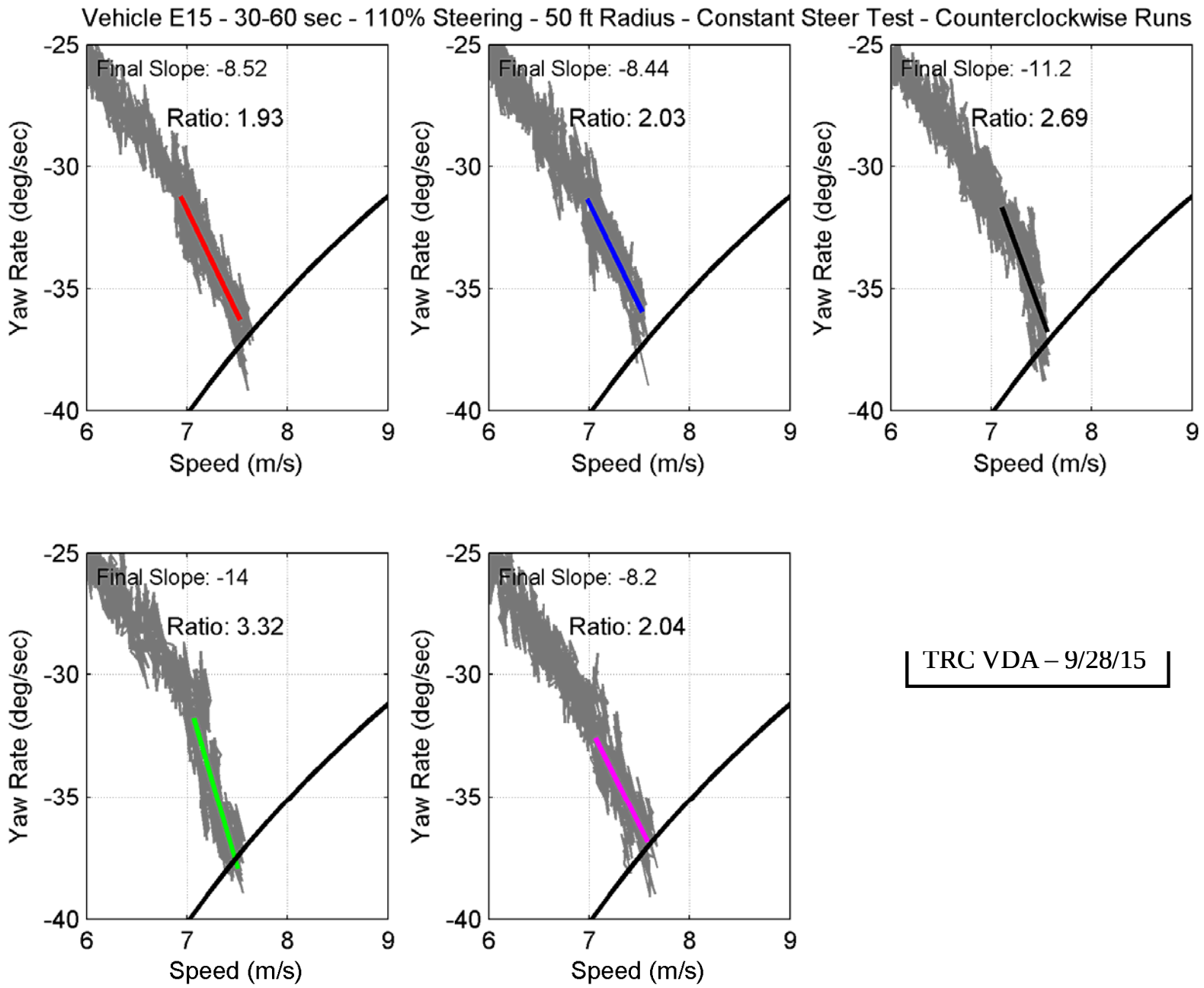


TRC VDA – 9/28/15

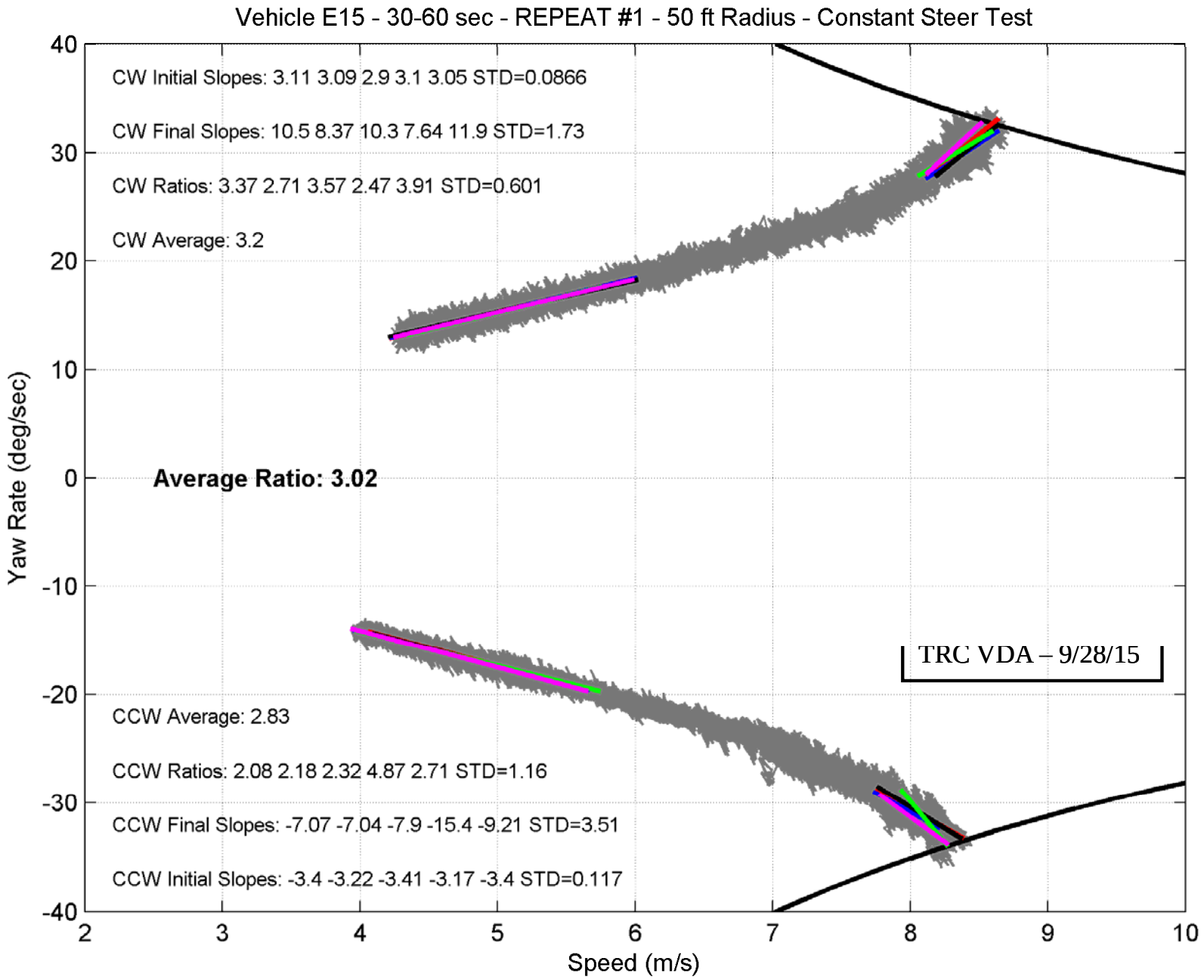

Vehicle E15 - 30-60 sec - 110% Steering - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 4.52 4.63 4.43 4.51 4.15 STD=0.179
CW Final Slopes: 11.3 10.1 14.4 13.8 10.8 STD=1.89
CW Ratios: 2.5 2.19 3.25 3.06 2.61 STD=0.429
CW Average: 2.72
Average Ratio: 2.56
CCW Average: 2.4
CCW Ratios: 1.93 2.03 2.69 3.32 2.04 STD=0.596
CCW Final Slopes: -8.52 -8.44 -11.2 -14 -8.2 STD=2.52
CCW Initial Slopes: -4.42 -4.16 -4.15 -4.22 -4.02 STD=0.147
TRC VDA – 9/28/15
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

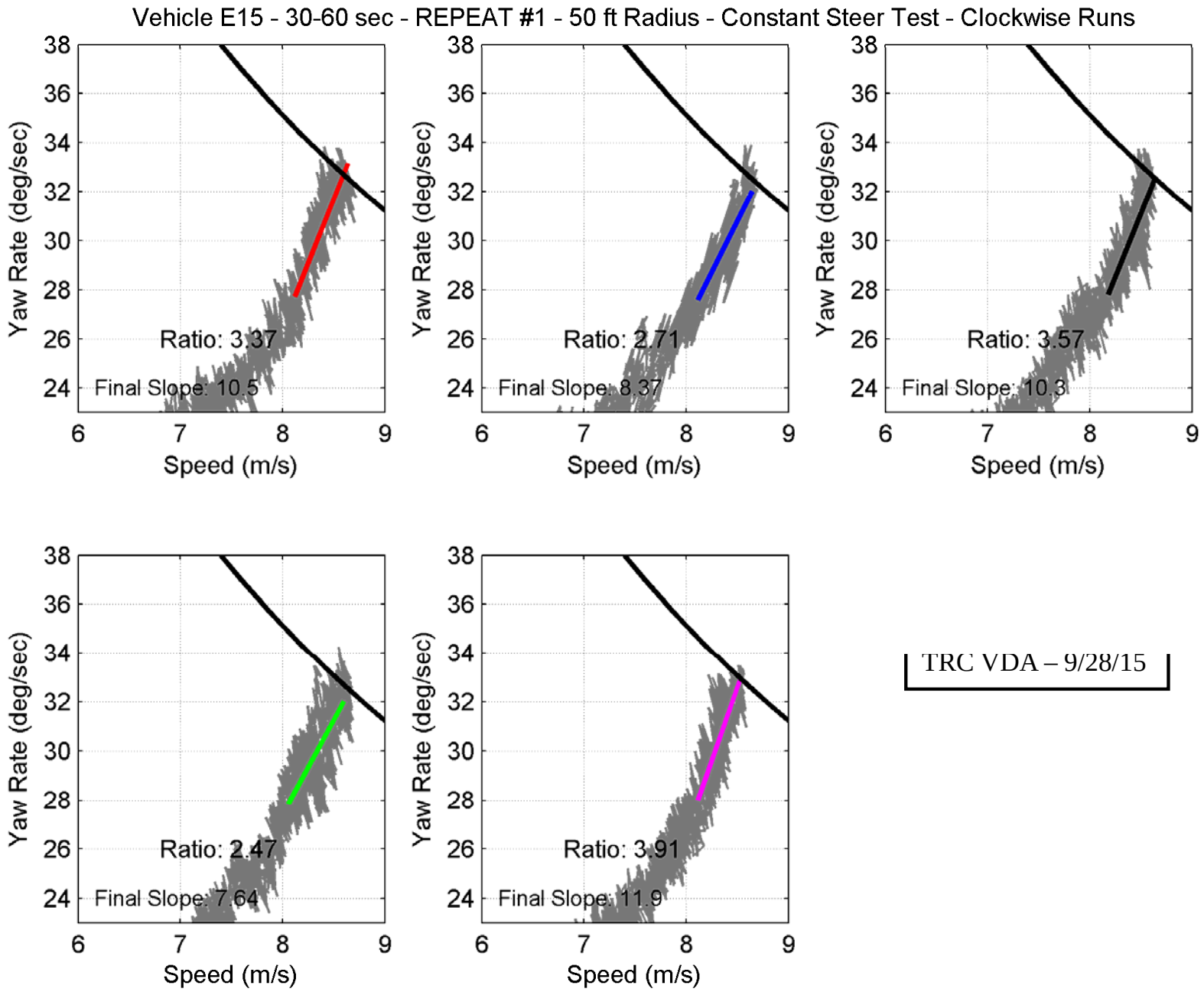


TRC VDA – 9/28/15

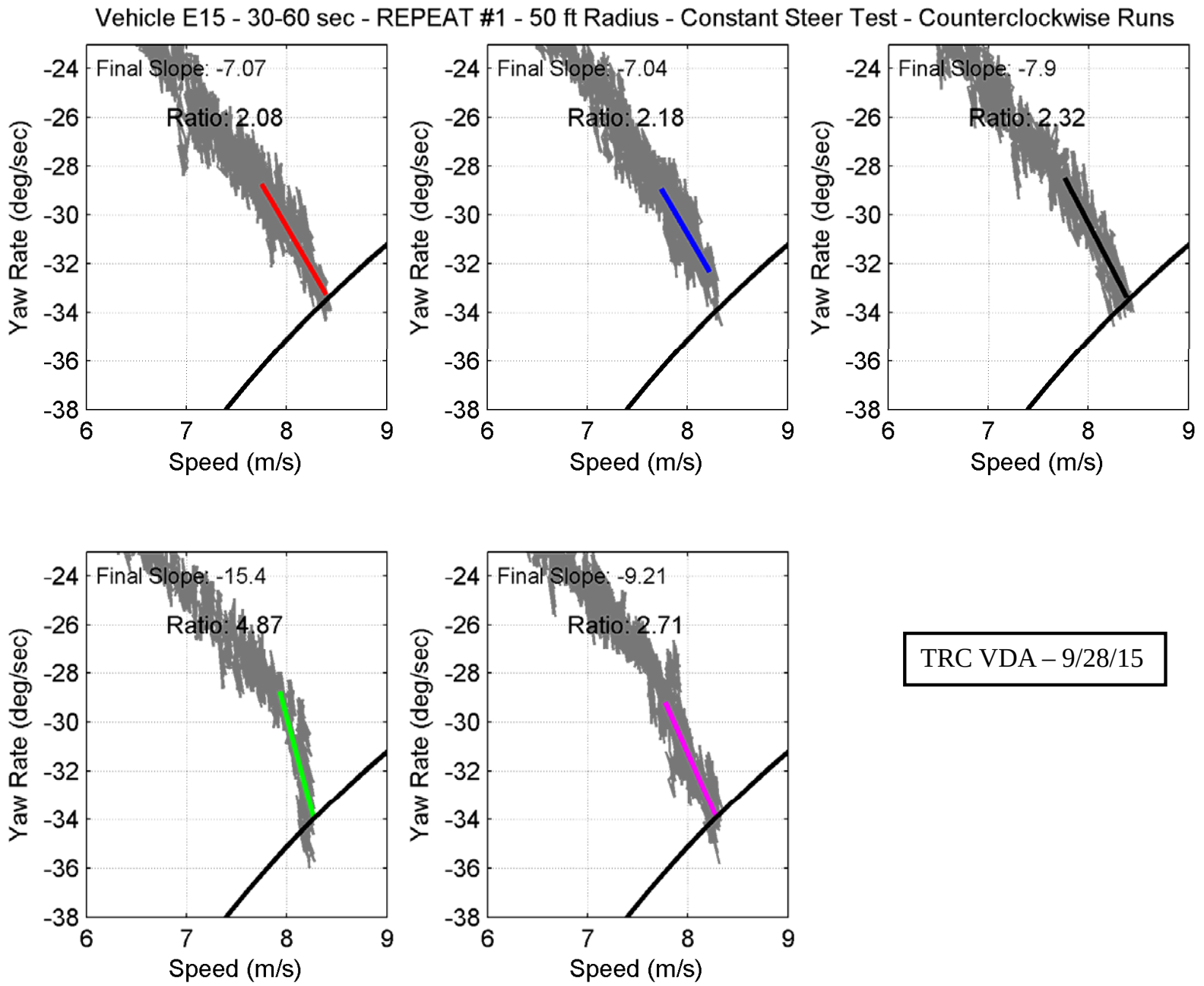


TRC VDA – 9/28/15

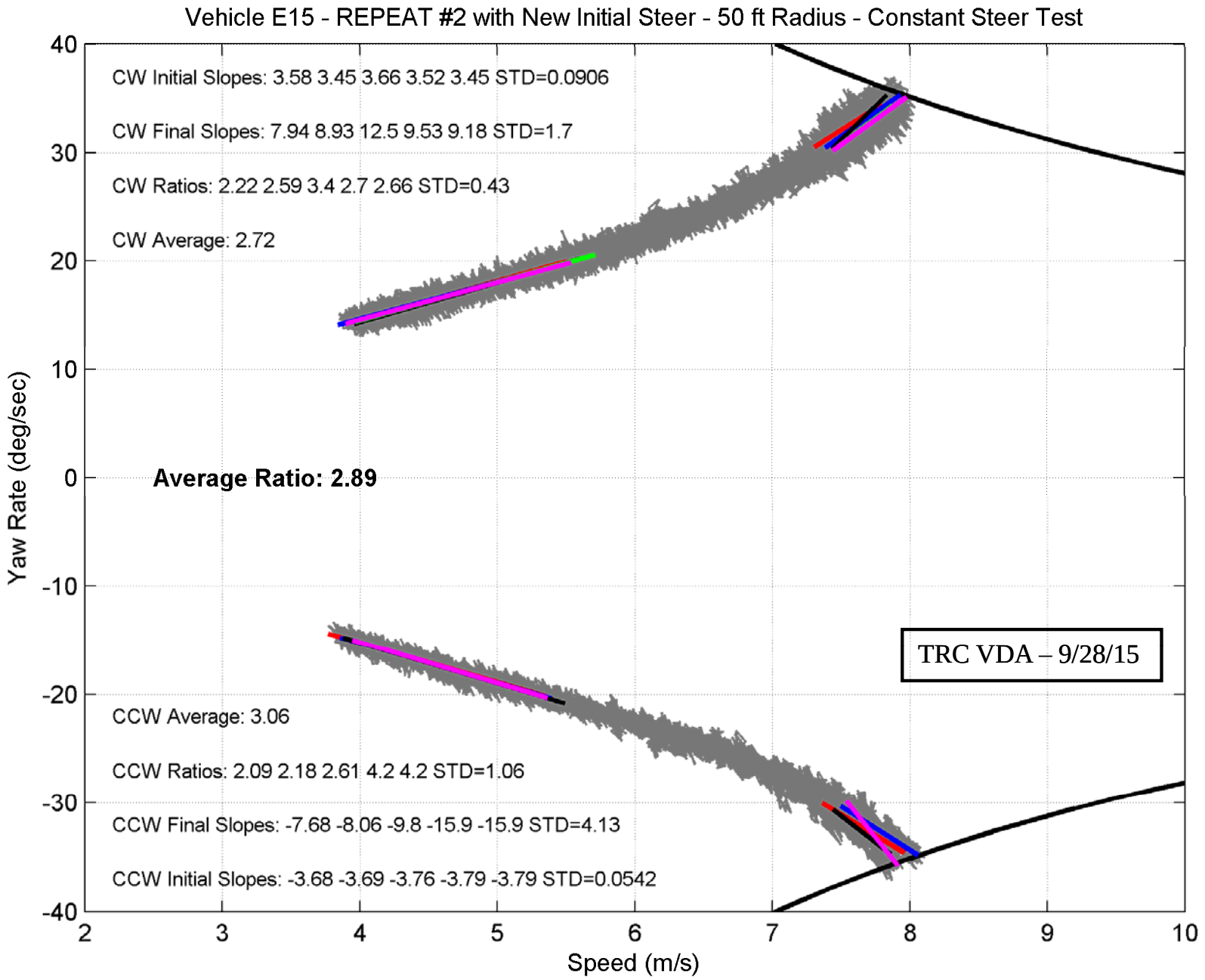

Vehicle E15 - 30-60 sec - REPEAT #1 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.11 3.09 2.9 3.1 3.05 STD=0.0866
CW Final Slopes: 10.5 8.37 10.3 7.64 11.9 STD=1.73
CW Ratios: 3.37 2.71 3.57 2.47 3.91 STD=0.601
CW Average: 3.2
Average Ratio: 3.02
TRC VDA – 9/28/15
CCW Average: 2.83
CCW Ratios: 2.08 2.18 2.32 4.87 2.71 STD=1.16
CCW Final Slopes: -7.07 -7.04 -7.9 -15.4 -9.21 STD=3.51
CCW Initial Slopes: -3.4 -3.22 -3.41 -3.17 -3.4 STD=0.117
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

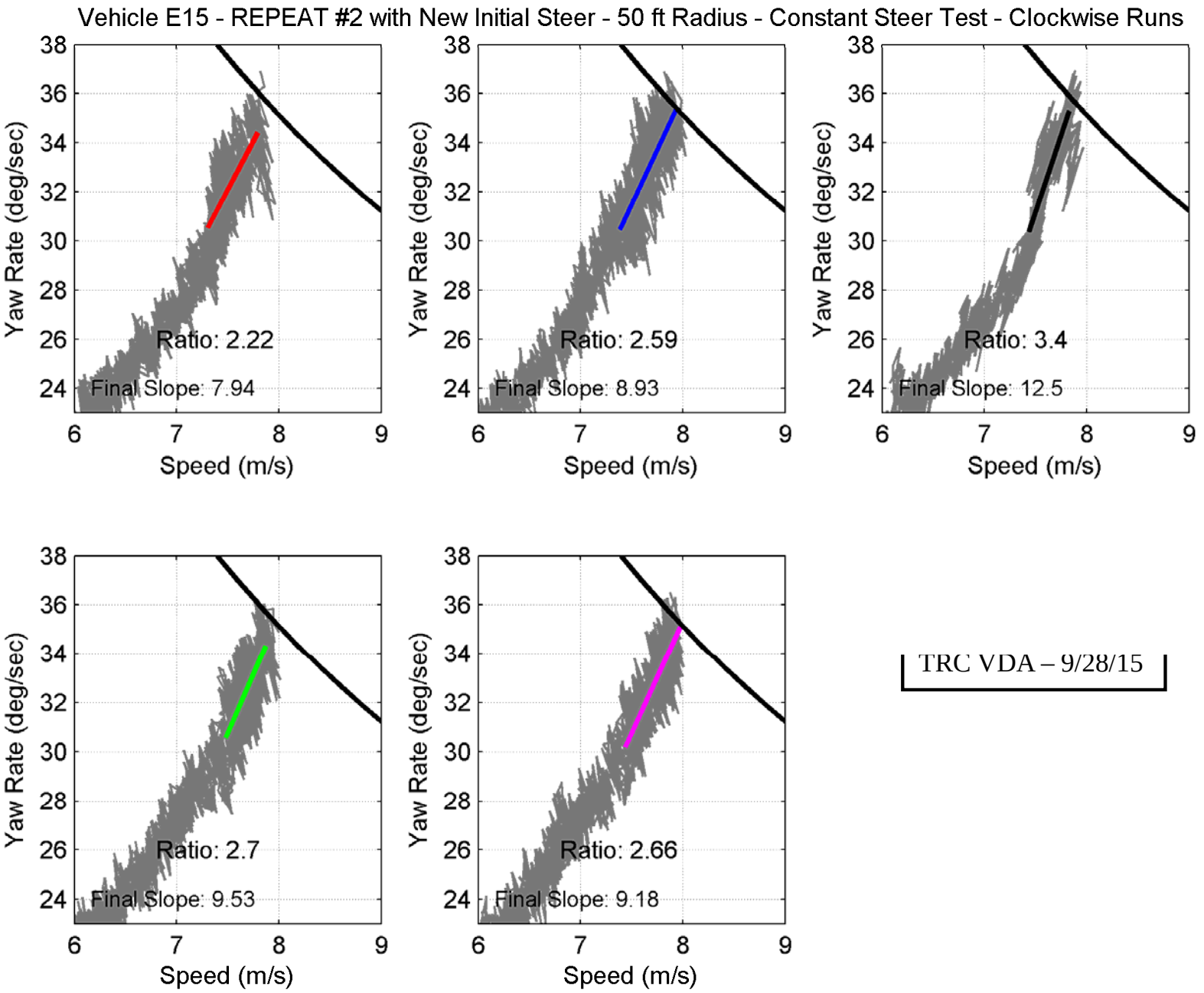


TRC VDA – 9/28/15

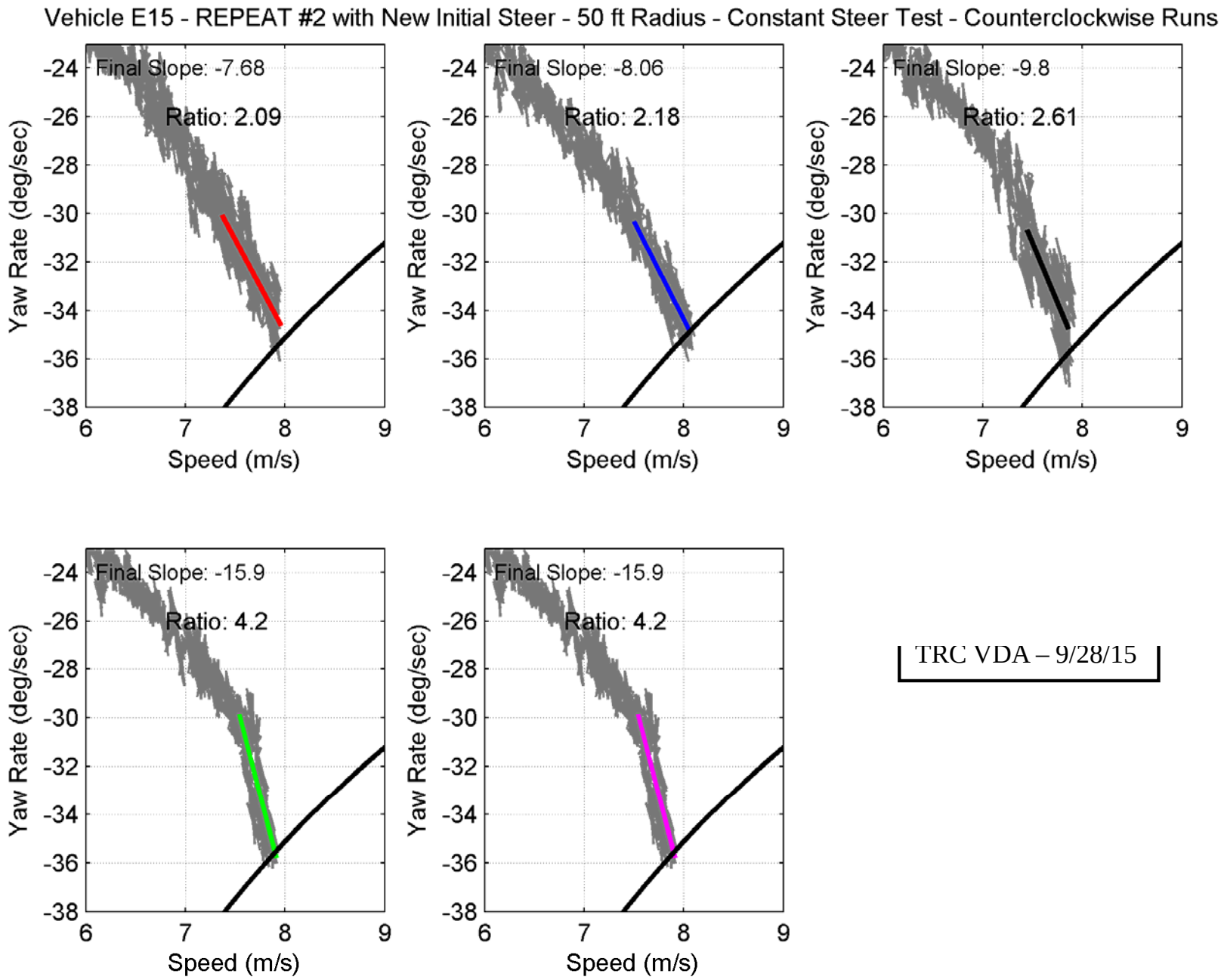


TRC VDA – 9/28/15

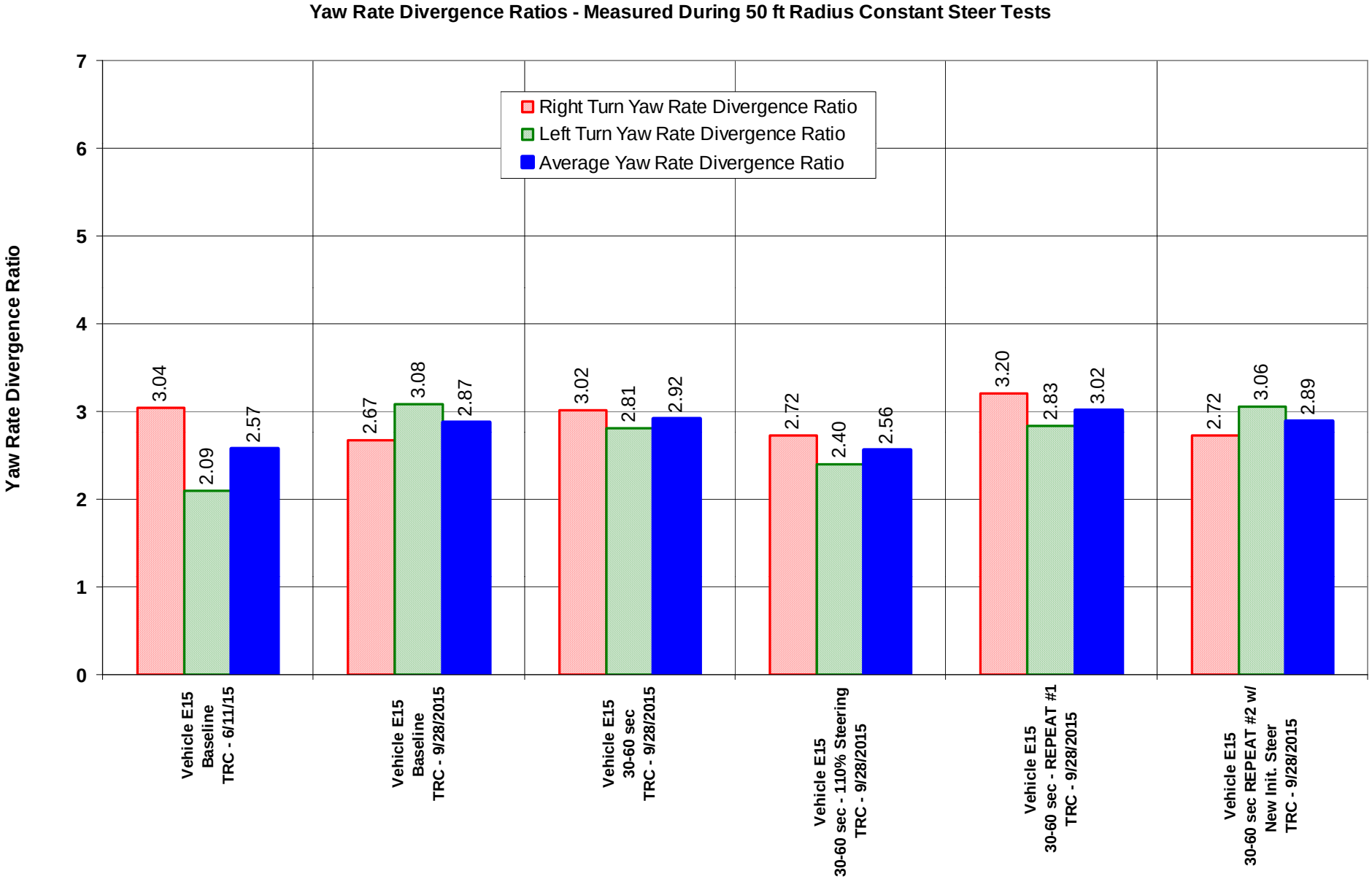

Vehicle E15 - REPEAT #2 with New Initial Steer - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.58 3.45 3.66 3.52 3.45 STD=0.0906
CW Final Slopes: 7.94 8.93 12.5 9.53 9.18 STD=1.7
CW Ratios: 2.22 2.59 3.4 2.7 2.66 STD=0.43
CW Average: 2.72
Average Ratio: 2.89
TRC VDA – 9/28/15
CCW Average: 3.06
CCW Ratios: 2.09 2.18 2.61 4.2 4.2 STD=1.06
CCW Final Slopes: -7.68 -8.06 -9.8 -15.9 -15.9 STD=4.13
CCW Initial Slopes: -3.68 -3.69 -3.76 -3.79 -3.79 STD=0.0542
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

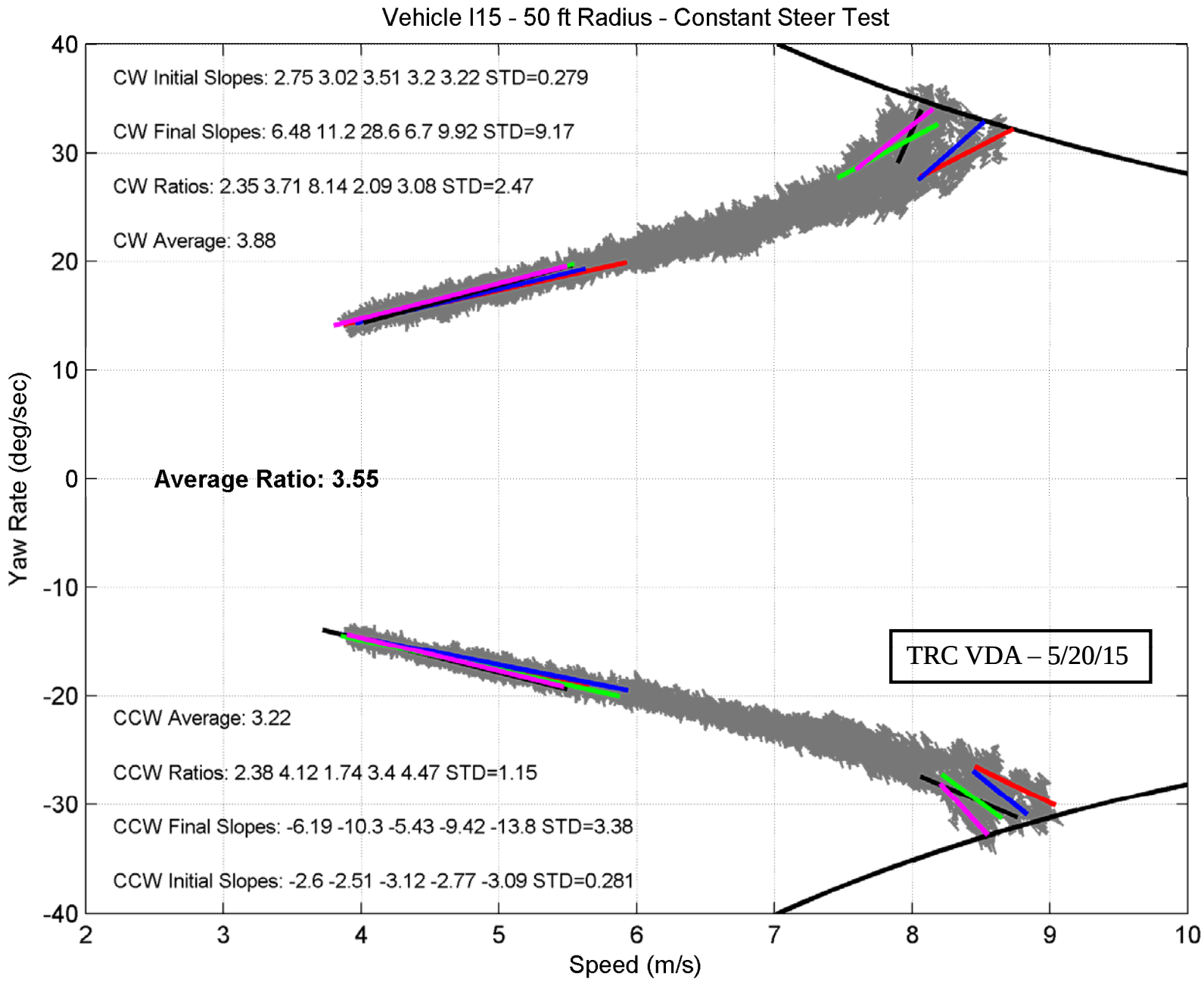


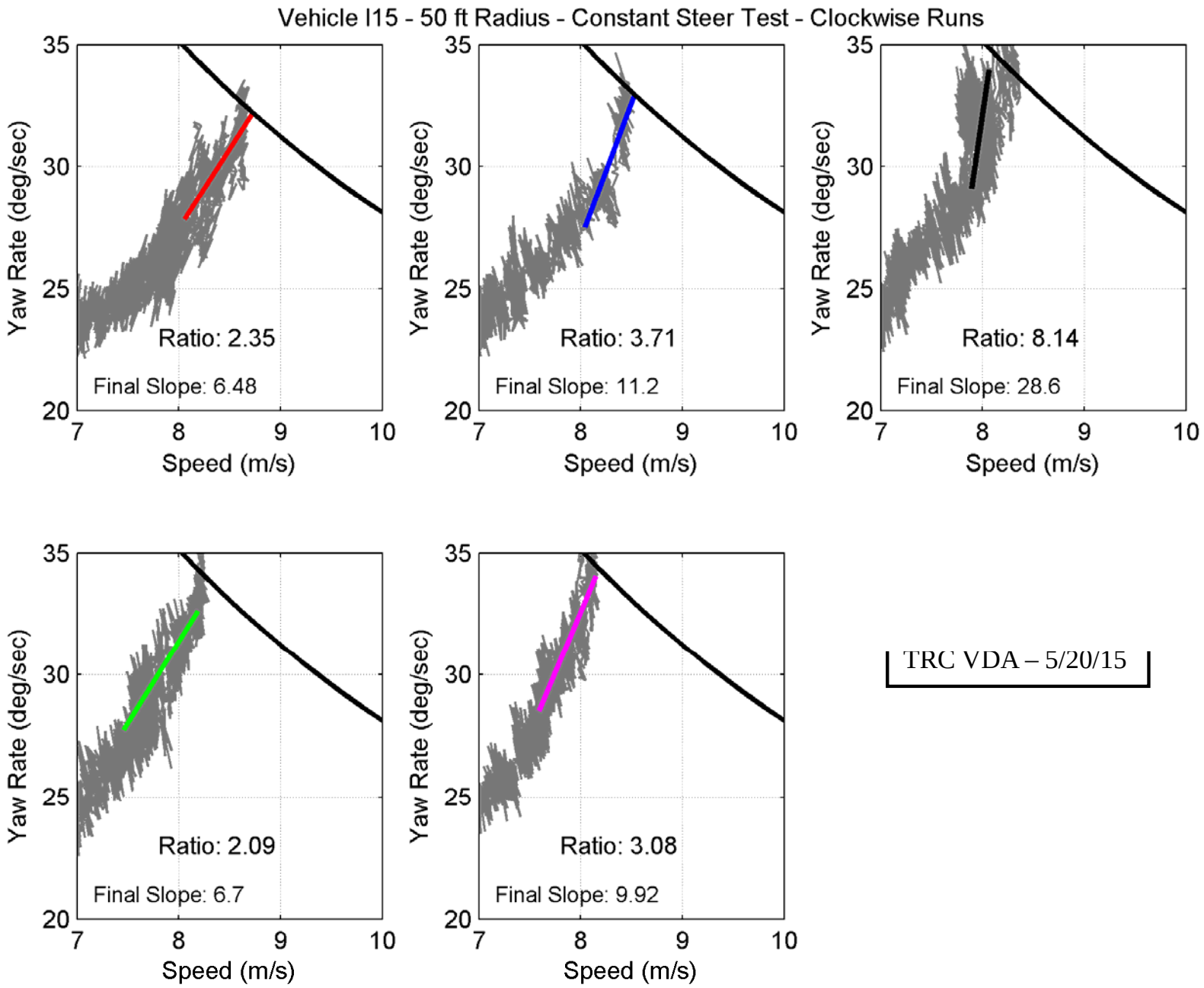
TRC VDA – 9/28/15



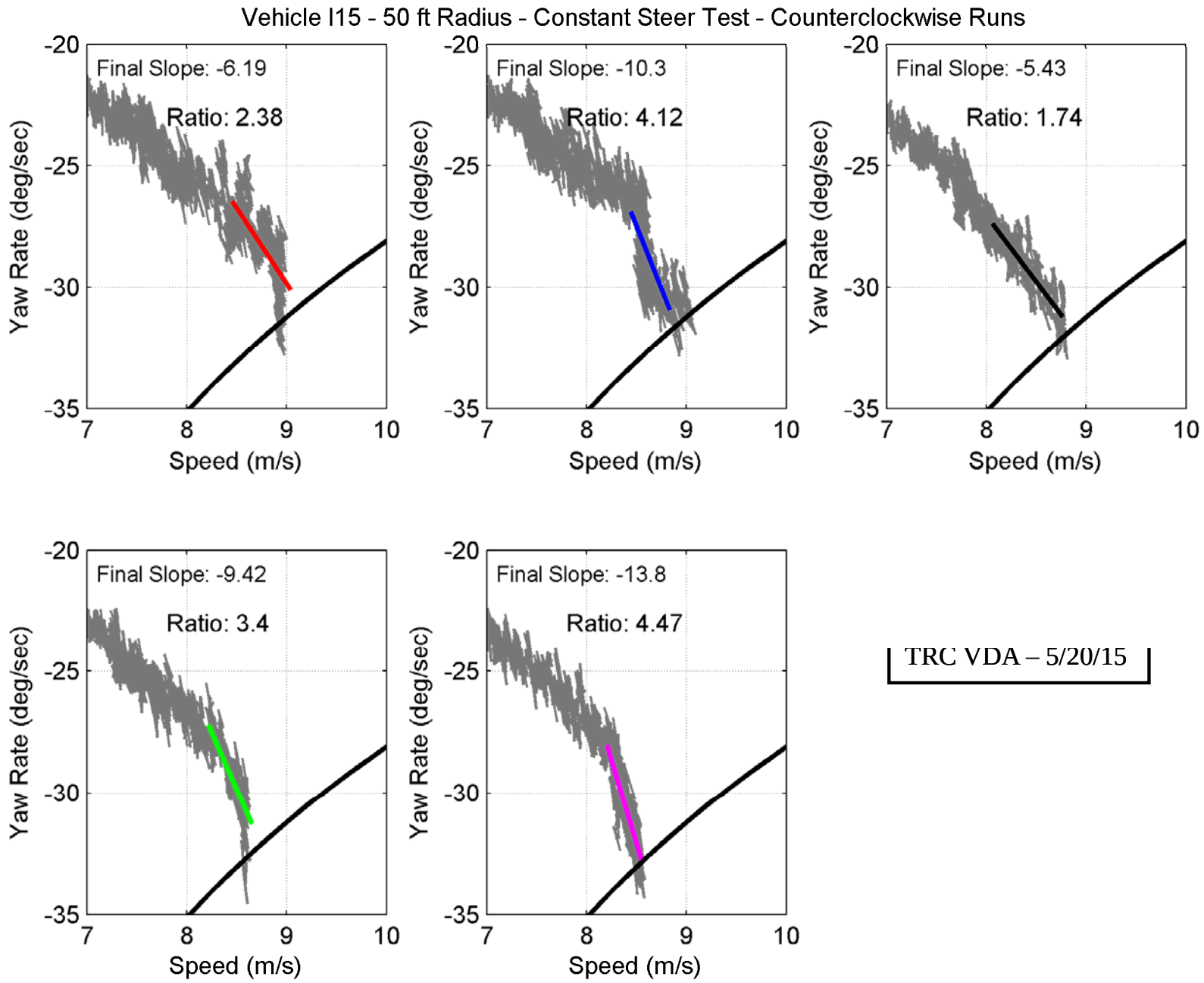
TRC VDA – 9/28/15


Yaw Rate Divergence Ratios - Measured During 50 ft Radius Constant Steer Tests
Yaw Rate Divergence Ratio
Right Turn Yaw Rate Divergence Ratio
Left Turn Yaw Rate Divergence Ratio
Average Yaw Rate Divergence Ratio
0
1
2
3
4
5
6
7
3.04
2.09
2.57
2.67
3.08
2.87
3.02
2.81
2.92
2.72
2.40
2.56
3.20
2.83
3.02
2.72
3.06
2.89
Vehicle E15 Baseline TRC - 6/11/15
Vehicle E15 Baseline TRC - 9/28/2015
Vehicle E15 30-60 sec TRC - 9/28/2015
Vehicle E15 30-60 sec - 110% Steering TRC - 9/28/2015
Vehicle E15 30-60 sec - REPEAT #1 TRC - 9/28/2015
Vehicle E15 30-60 sec REPEAT #2 w/ New Init. Steer TRC - 9/28/2015

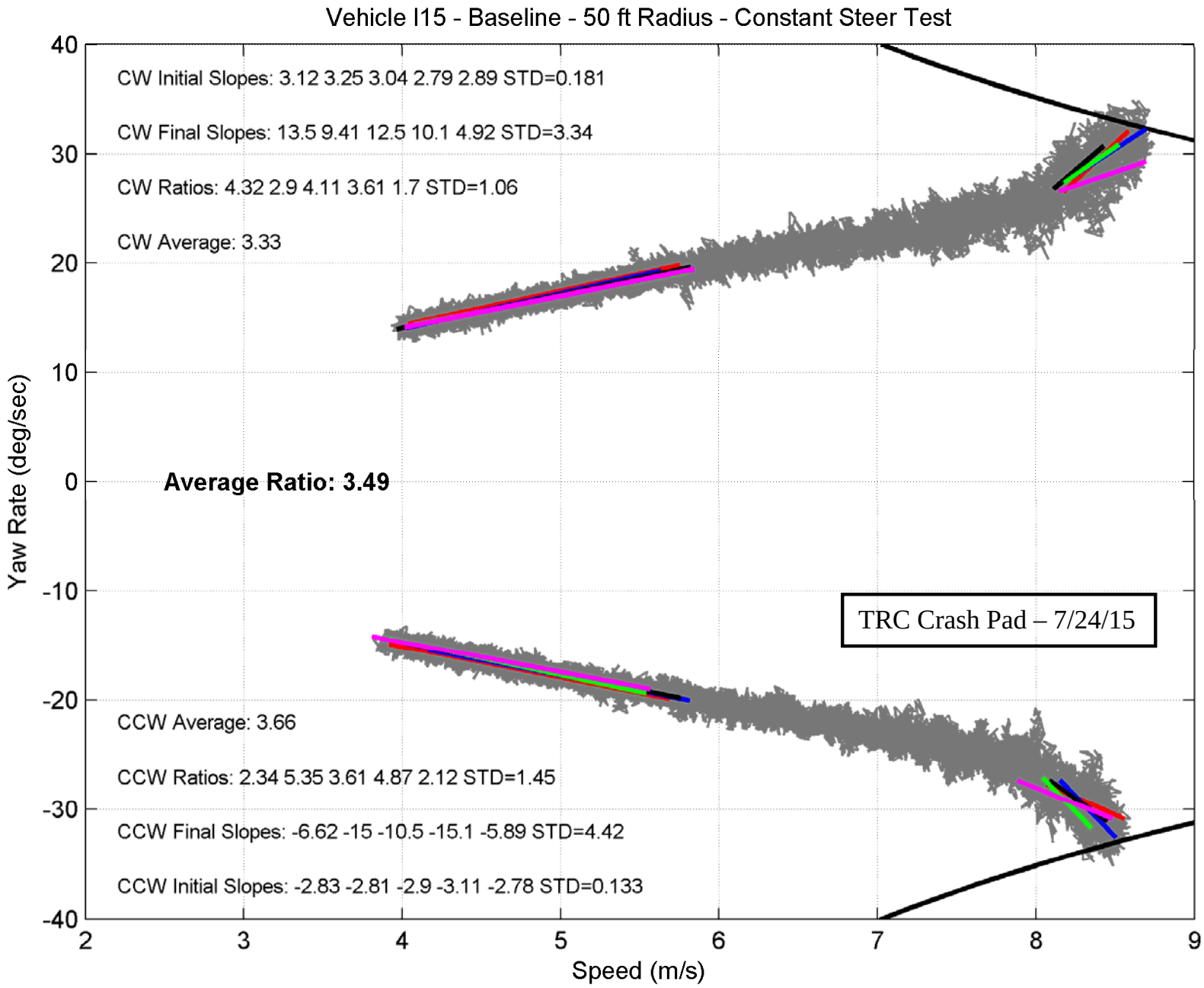

Vehicle I15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.75 3.02 3.51 3.2 3.22 STD=0.279
CW Final Slopes: 6.48 11.2 28.6 6.7 9.92 STD=9.17
CW Ratios: 2.35 3.71 8.14 2.09 3.08 STD=2.47
CW Average: 3.88
Average Ratio: 3.55
TRC VDA – 5/20/15
CCW Average: 3.22
CCW Ratios: 2.38 4.12 1.74 3.4 4.47 STD=1.15
CCW Final Slopes: -6.19 -10.3 -5.43 -9.42 -13.8 STD=3.38
CCW Initial Slopes: -2.6 -2.51 -3.12 -2.77 -3.09 STD=0.281
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

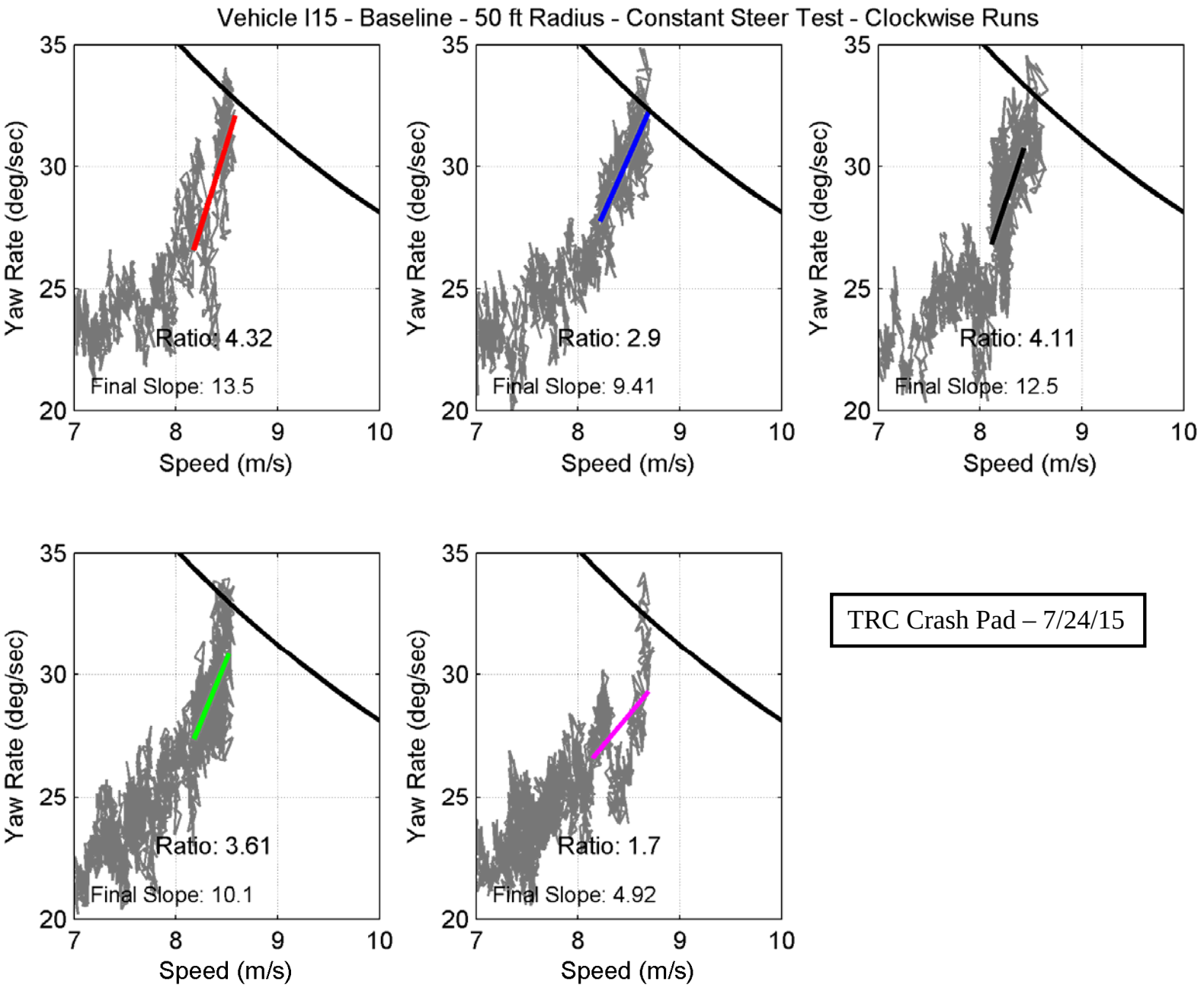


TRC VDA – 5/20/15

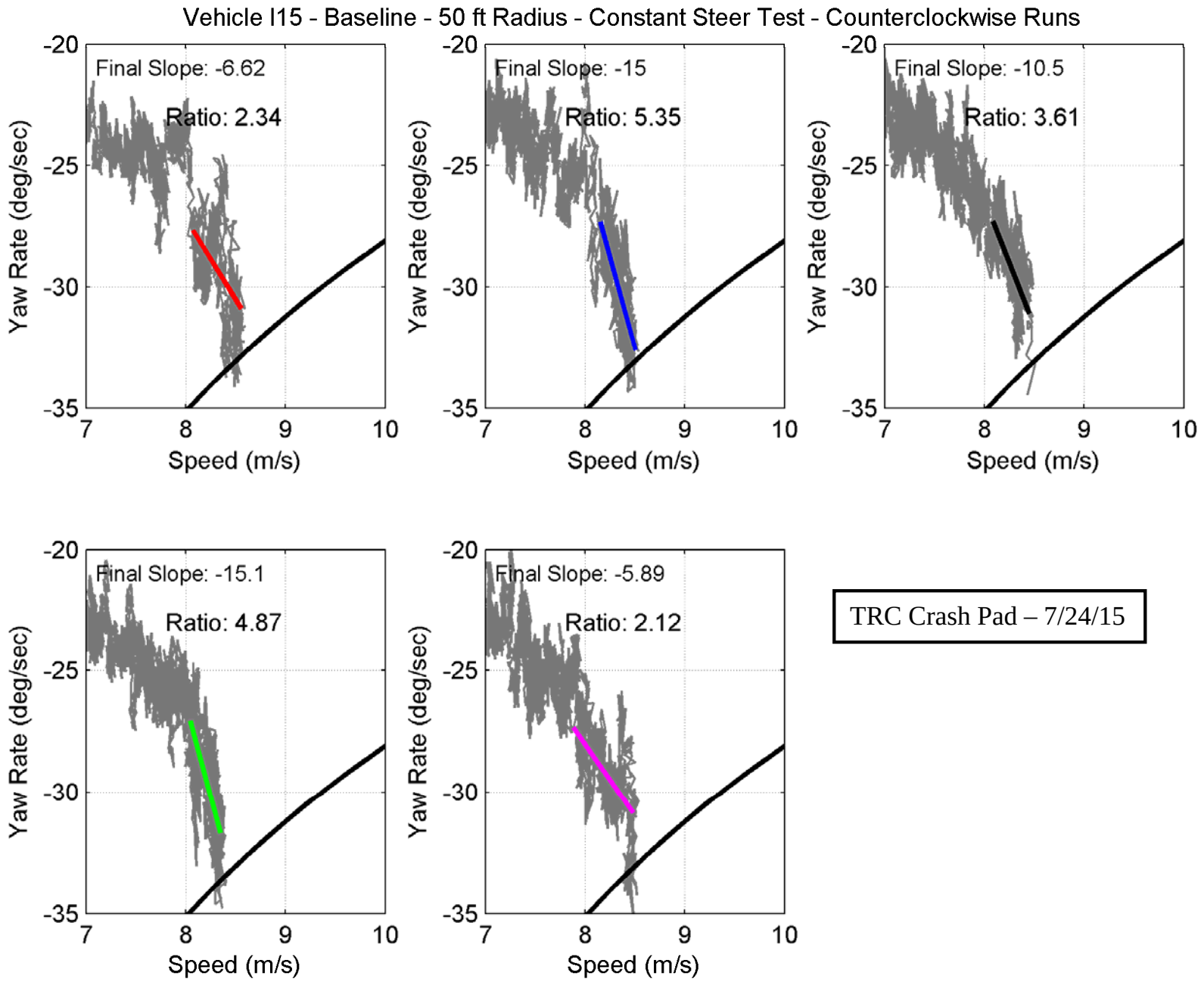


TRC VDA – 5/20/15

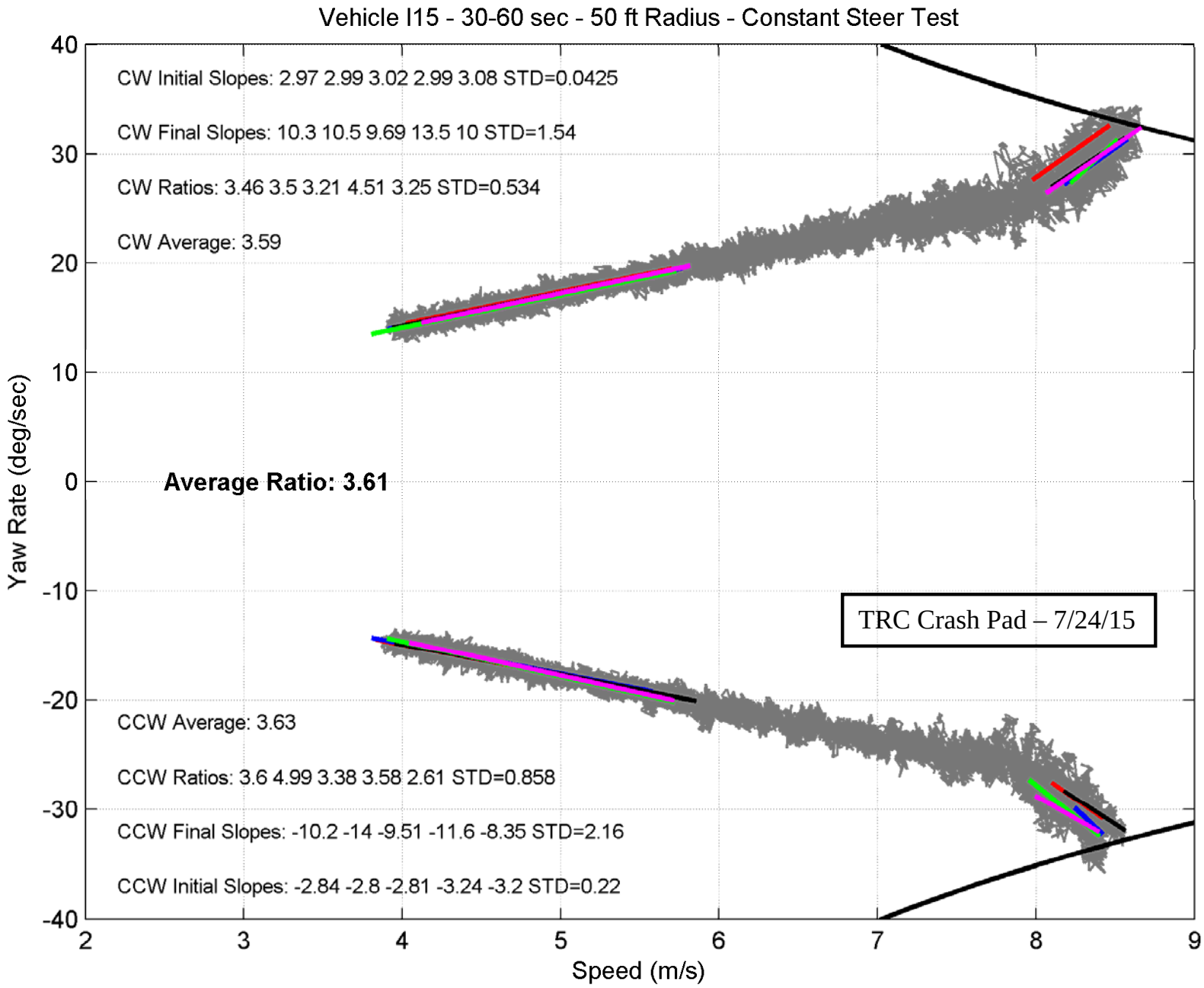

Vehicle I15 - Baseline - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.12 3.25 3.04 2.79 2.89 STD=0.181
CW Final Slopes: 13.5 9.41 12.5 10.1 4.92 STD=3.34
CW Ratios: 4.32 2.9 4.11 3.61 1.7 STD=1.06
CW Average: 3.33
Average Ratio: 3.49
TRC Crash Pad – 7/24/15
CCW Average: 3.66
CCW Ratios: 2.34 5.35 3.61 4.87 2.12 STD=1.45
CCW Final Slopes: -6.62 -15 -10.5 -15.1 -5.89 STD=4.42
CCW Initial Slopes: -2.83 -2.81 -2.9 -3.11 -2.78 STD=0.133
Yaw Rate (deg/sec)
Speed (m/s)
40
30
20
10
0
-10
-20
-30
-40
2
3
4
5
6
7
8
9

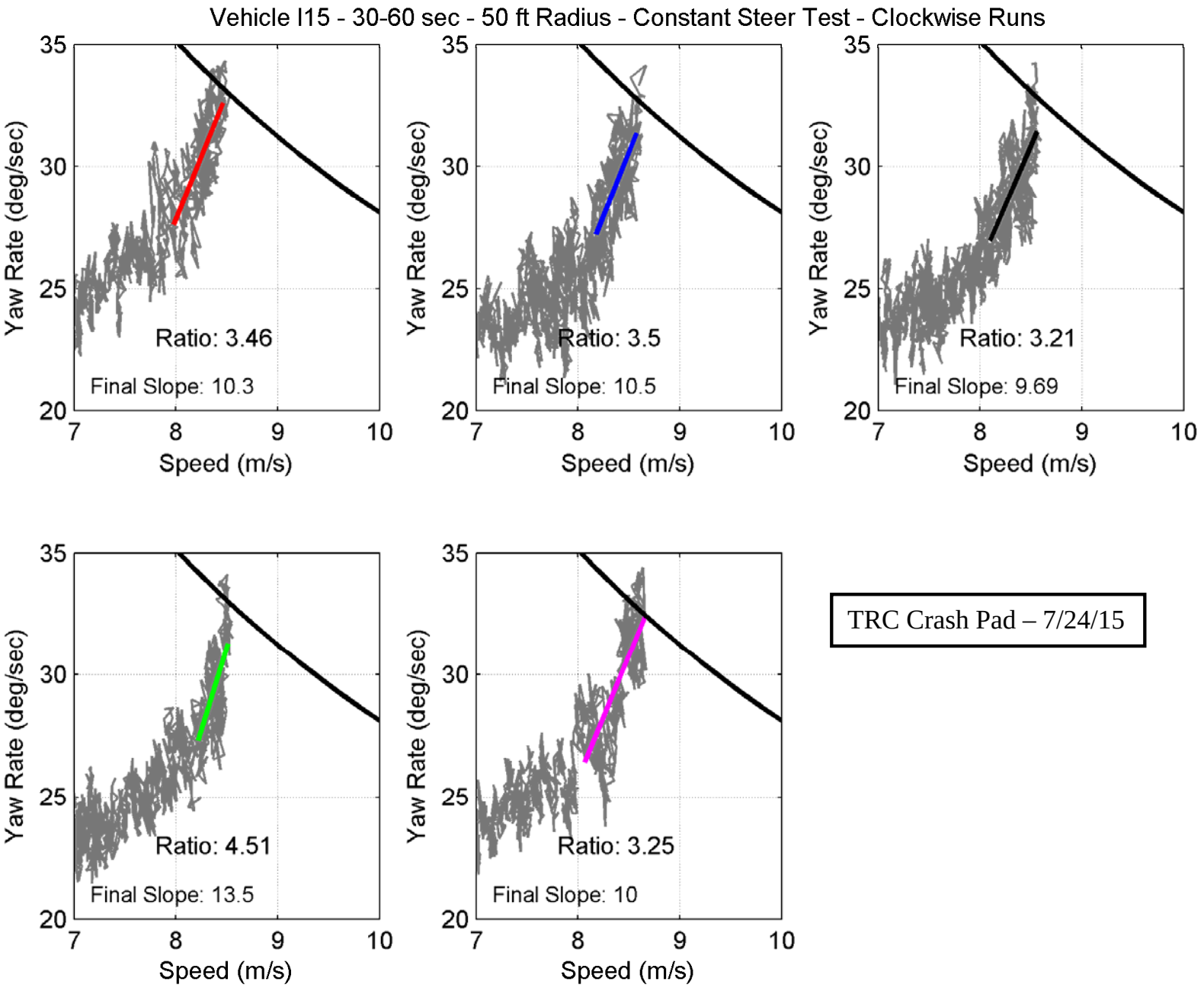


TRC Crash Pad – 7/24/15

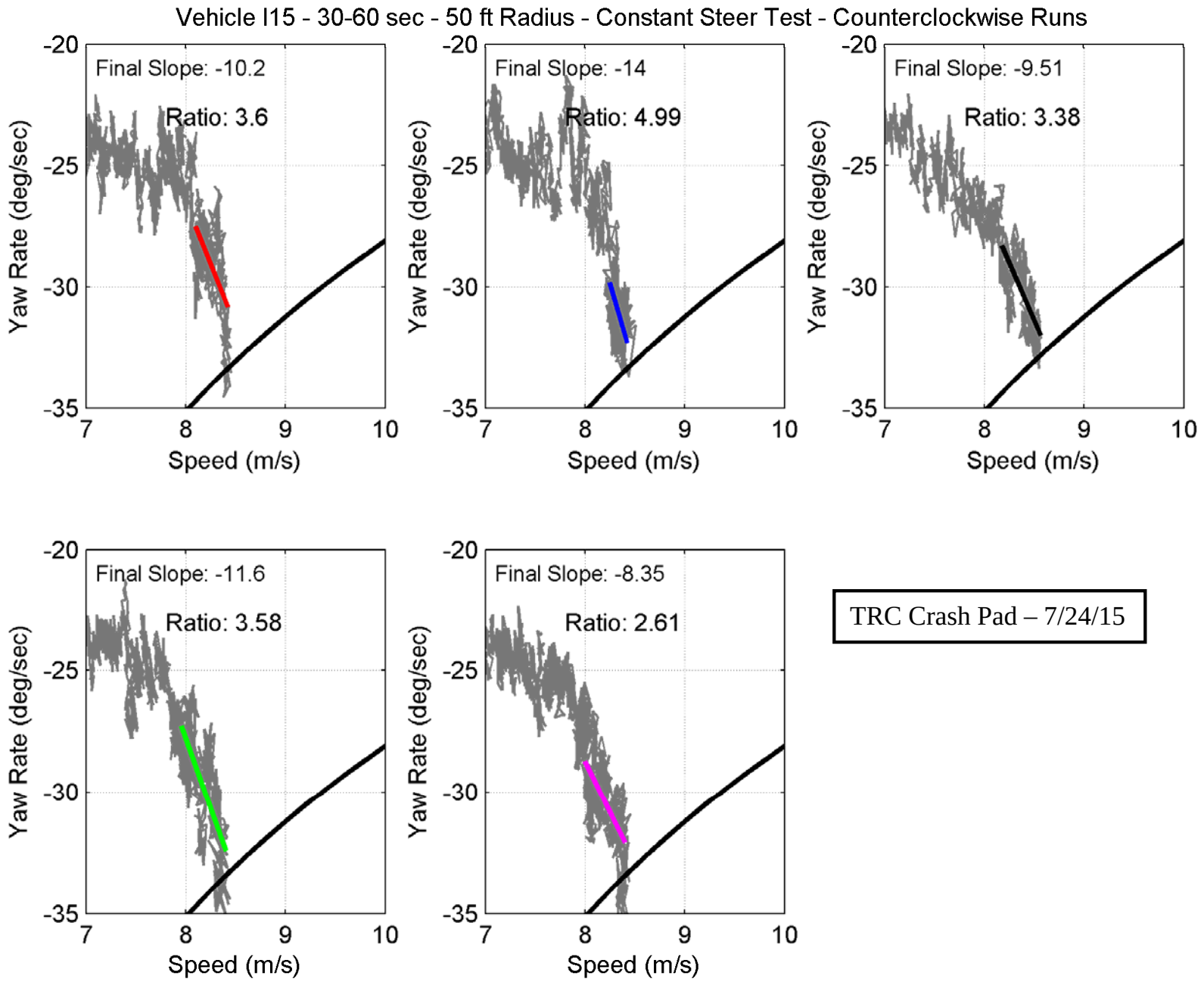


TRC Crash Pad – 7/24/15

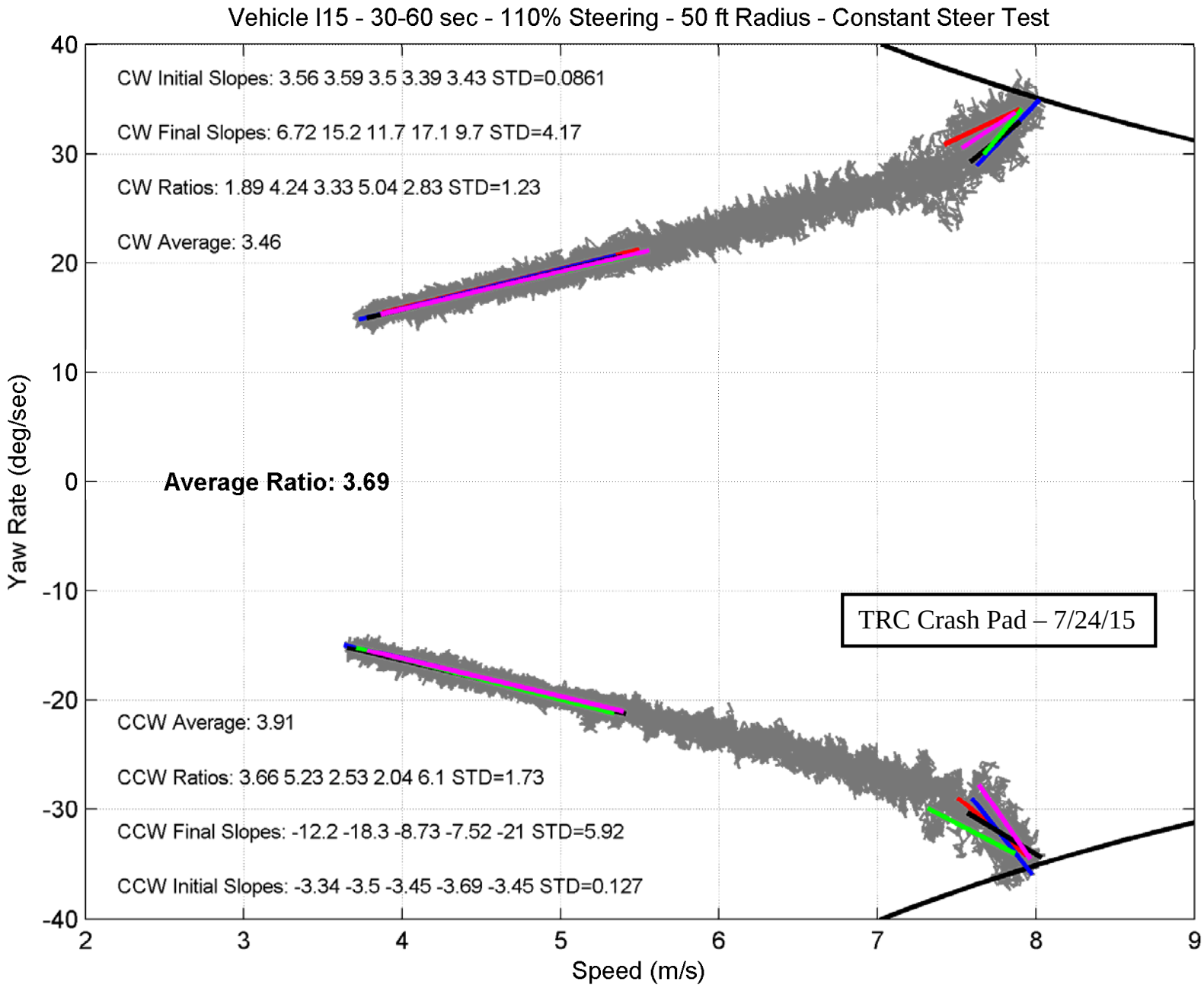

Vehicle I15 - 30-60 sec - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.97 2.99 3.02 2.99 3.08 STD=0.0425
CW Final Slopes: 10.3 10.5 9.69 13.5 10 STD=1.54
CW Ratios: 3.46 3.5 3.21 4.51 3.25 STD=0.534
CW Average: 3.59
Average Ratio: 3.61
TRC Crash Pad – 7/24/15
CCW Average: 3.63
CCW Ratios: 3.6 4.99 3.38 3.58 2.61 STD=0.858
CCW Final Slopes: -10.2 -14 -9.51 -11.6 -8.35 STD=2.16
CCW Initial Slopes: -2.84 -2.8 -2.81 -3.24 -3.2 STD=0.22
Yaw Rate (deg/sec)
Speed (m/s)
40
30
20
10
0
-10
-20
-30
-40
2
3
4
5
6
7
8
9

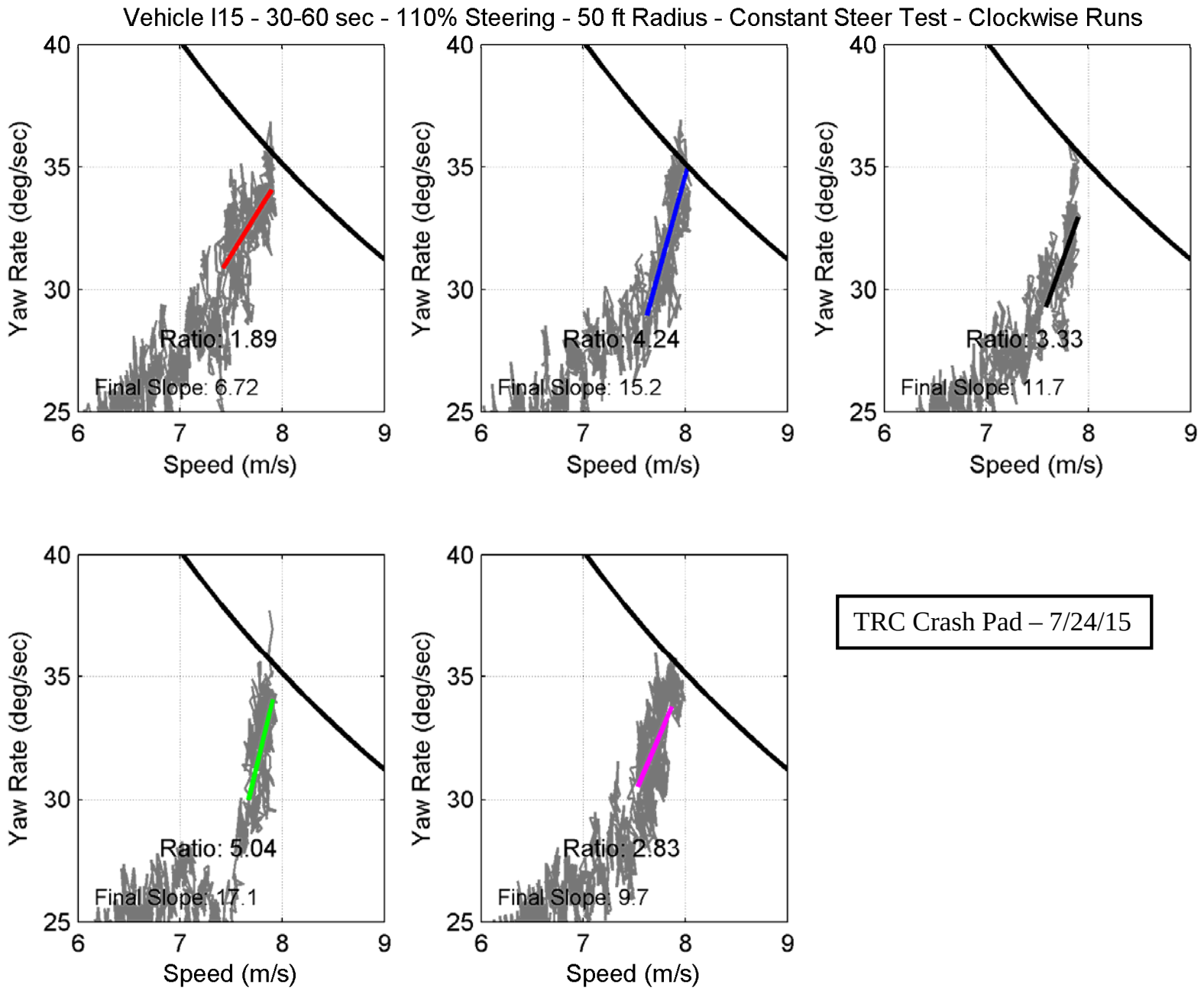


TRC Crash Pad – 7/24/15

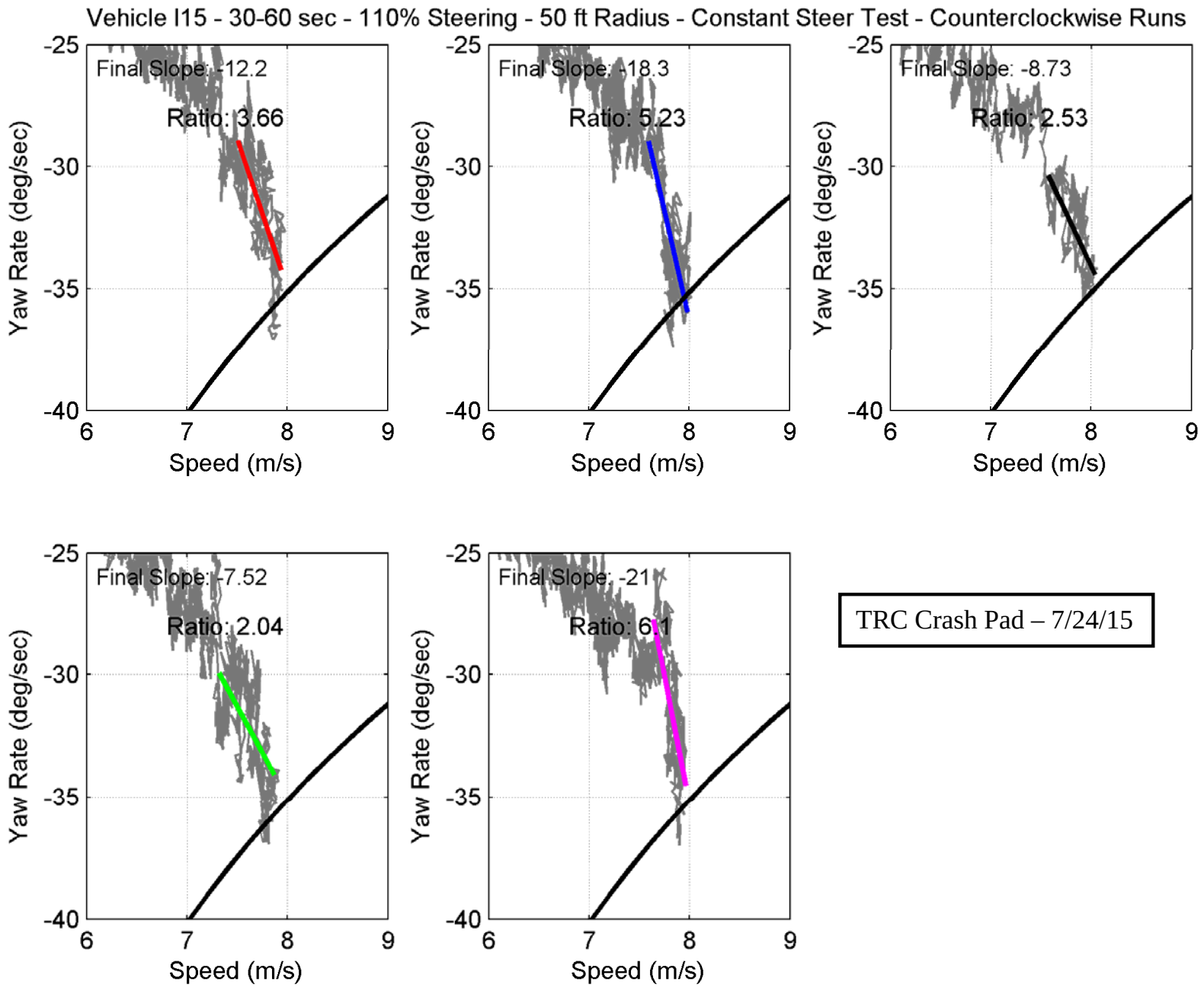


TRC Crash Pad – 7/24/15

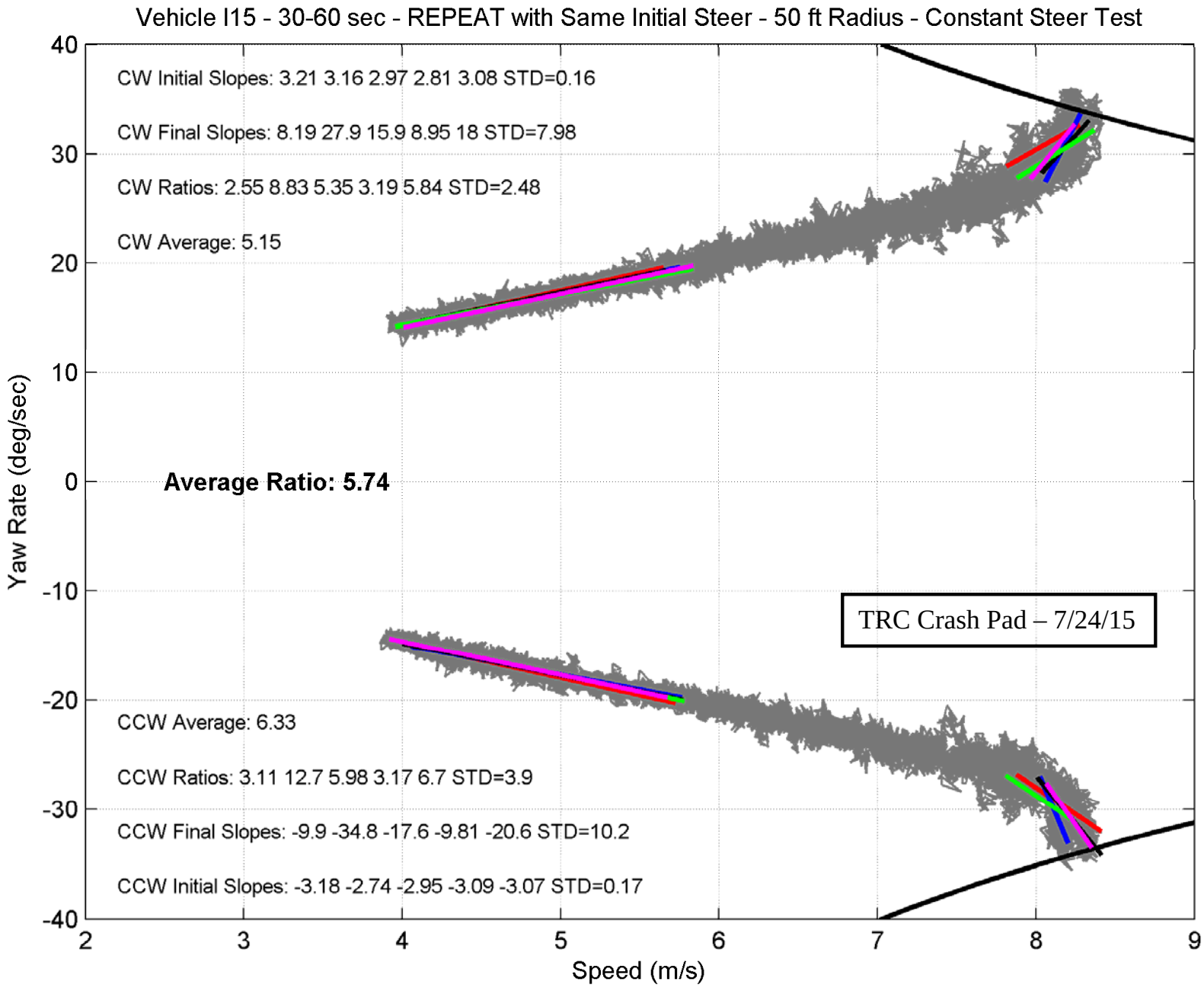

Vehicle I15 - 30-60 sec - 110% Steering - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.56 3.59 3.5 3.39 3.43 STD=0.0861
CW Final Slopes: 6.72 15.2 11.7 17.1 9.7 STD=4.17
CW Ratios: 1.89 4.24 3.33 5.04 2.83 STD=1.23
CW Average: 3.46
Average Ratio: 3.69
TRC Crash Pad – 7/24/15
CCW Average: 3.91
CCW Ratios: 3.66 5.23 2.53 2.04 6.1 STD=1.73
CCW Final Slopes: -12.2 -18.3 -8.73 -7.52 -21 STD=5.92
CCW Initial Slopes: -3.34 -3.5 -3.45 -3.69 -3.45 STD=0.127
Yaw Rate (deg/sec)
Speed (m/s)
40
30
20
10
0
-10
-20
-30
-40
2
3
4
5
6
7
8
9

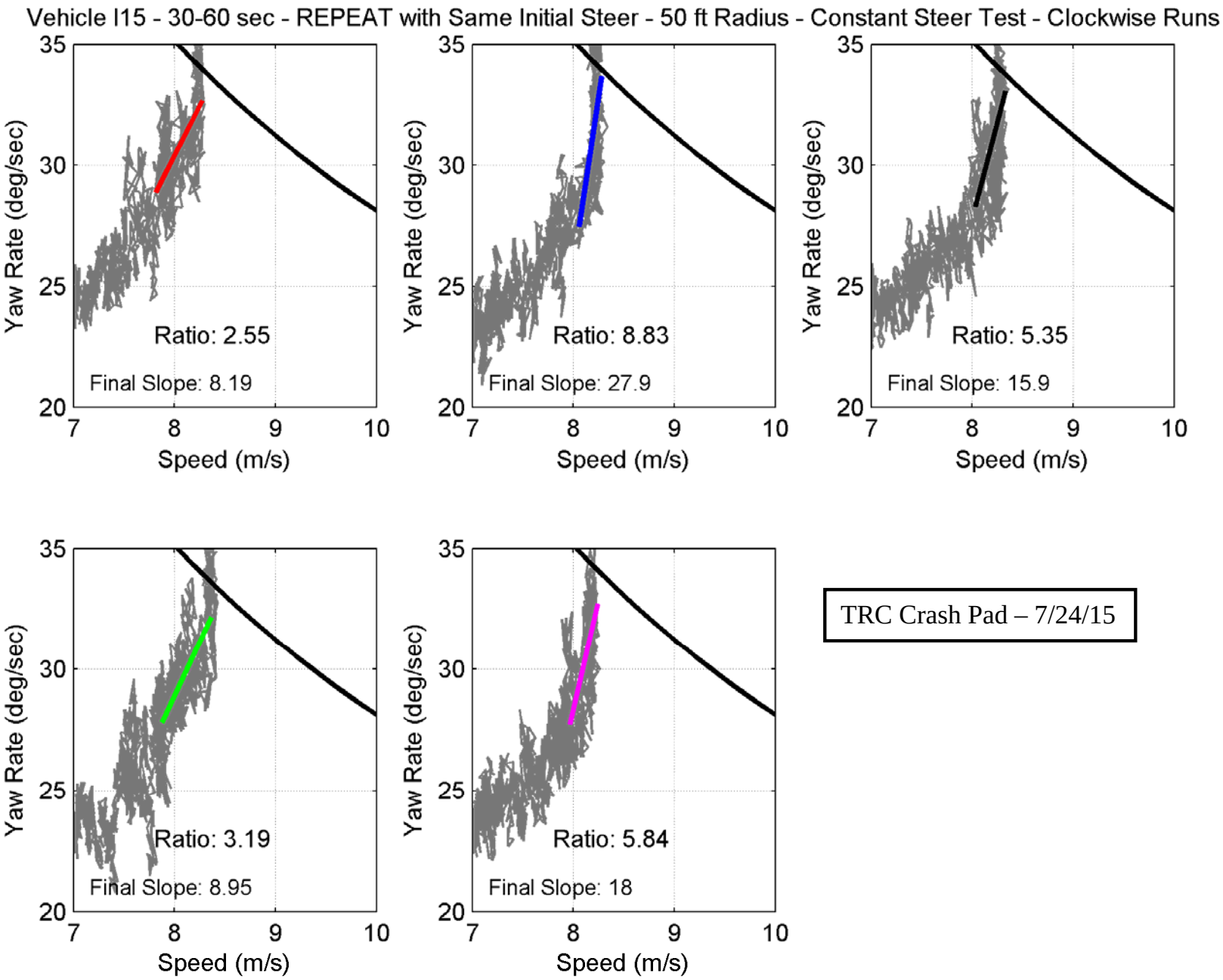


TRC Crash Pad – 7/24/15



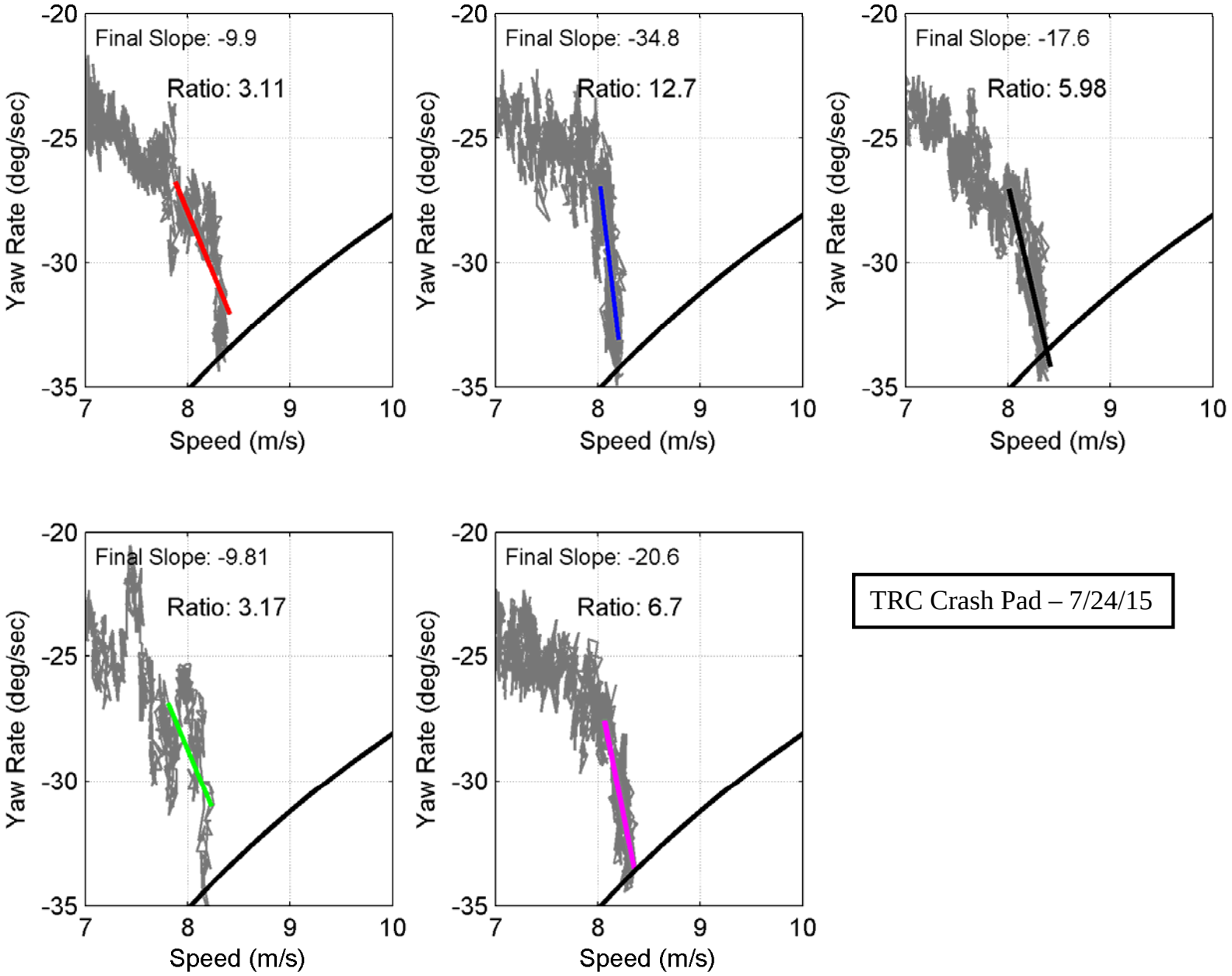
TRC Crash Pad – 7/24/15


Vehicle I15 - 30-60 sec - REPEAT with Same Initial Steer - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.21 3.16 2.97 2.81 3.08 STD=0.16
CW Final Slopes: 8.19 27.9 15.9 8.95 18 STD=7.98
CW Ratios: 2.55 8.83 5.35 3.19 5.84 STD=2.48
CW Average: 5.15
Average Ratio: 5.74
TRC Crash Pad – 7/24/15
CCW Average: 6.33
CCW Ratios: 3.11 12.7 5.98 3.17 6.7 STD=3.9
CCW Final Slopes: -9.9 -34.8 -17.6 -9.81 -20.6 STD=10.2
CCW Initial Slopes: -3.18 -2.74 -2.95 -3.09 -3.07 STD=0.17
Yaw Rate (deg/sec)
Speed (m/s)
40
30
20
10
0
-10
-20
-30
-40
2
3
4
5
6
7
8
9

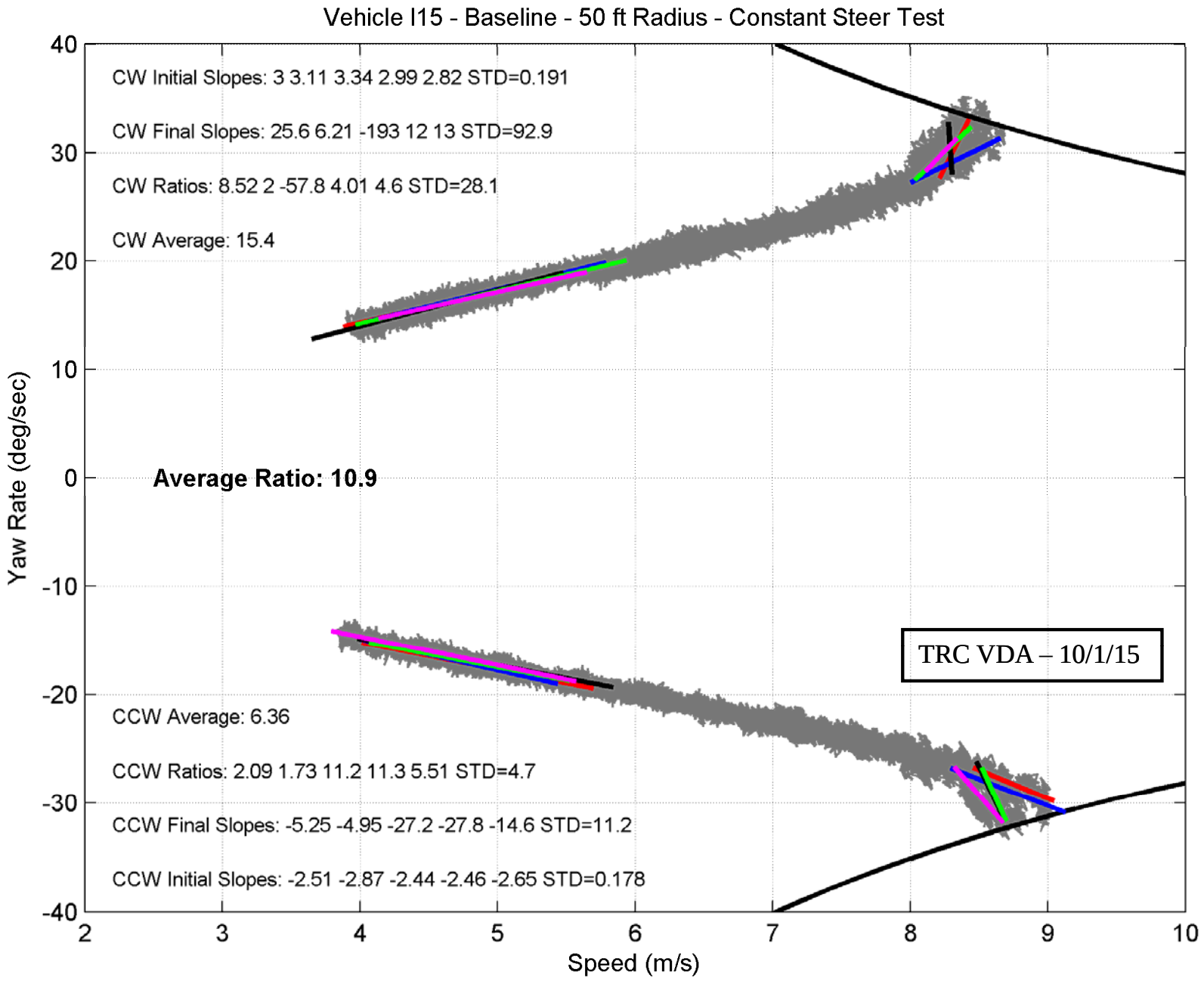


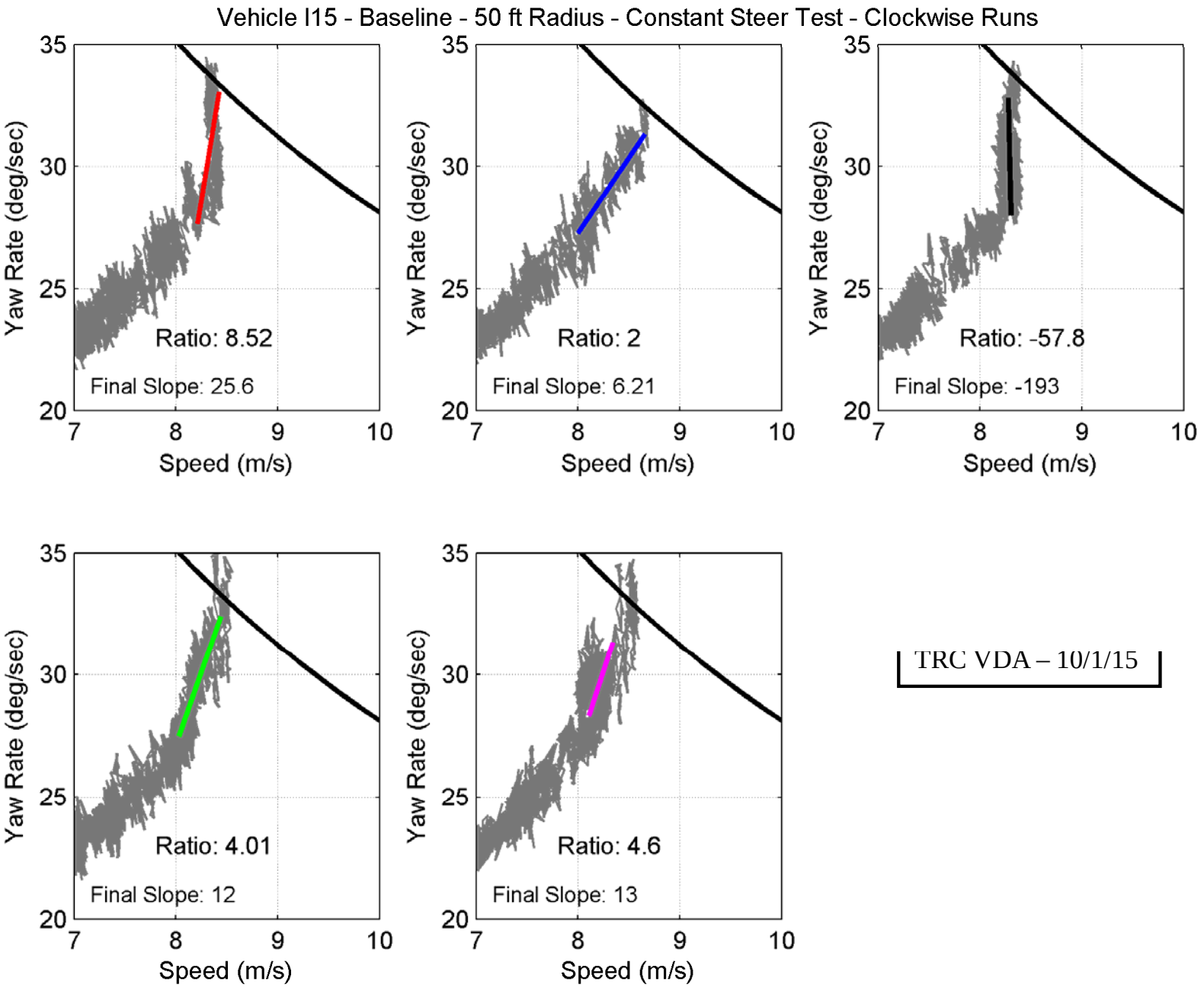
TRC Crash Pad – 7/24/15

Vehicle I15 - 30-60 sec - REPEAT with Same Initial Steer - 50 ft Radius - Constant Steer Test - Counterclockwise Runs

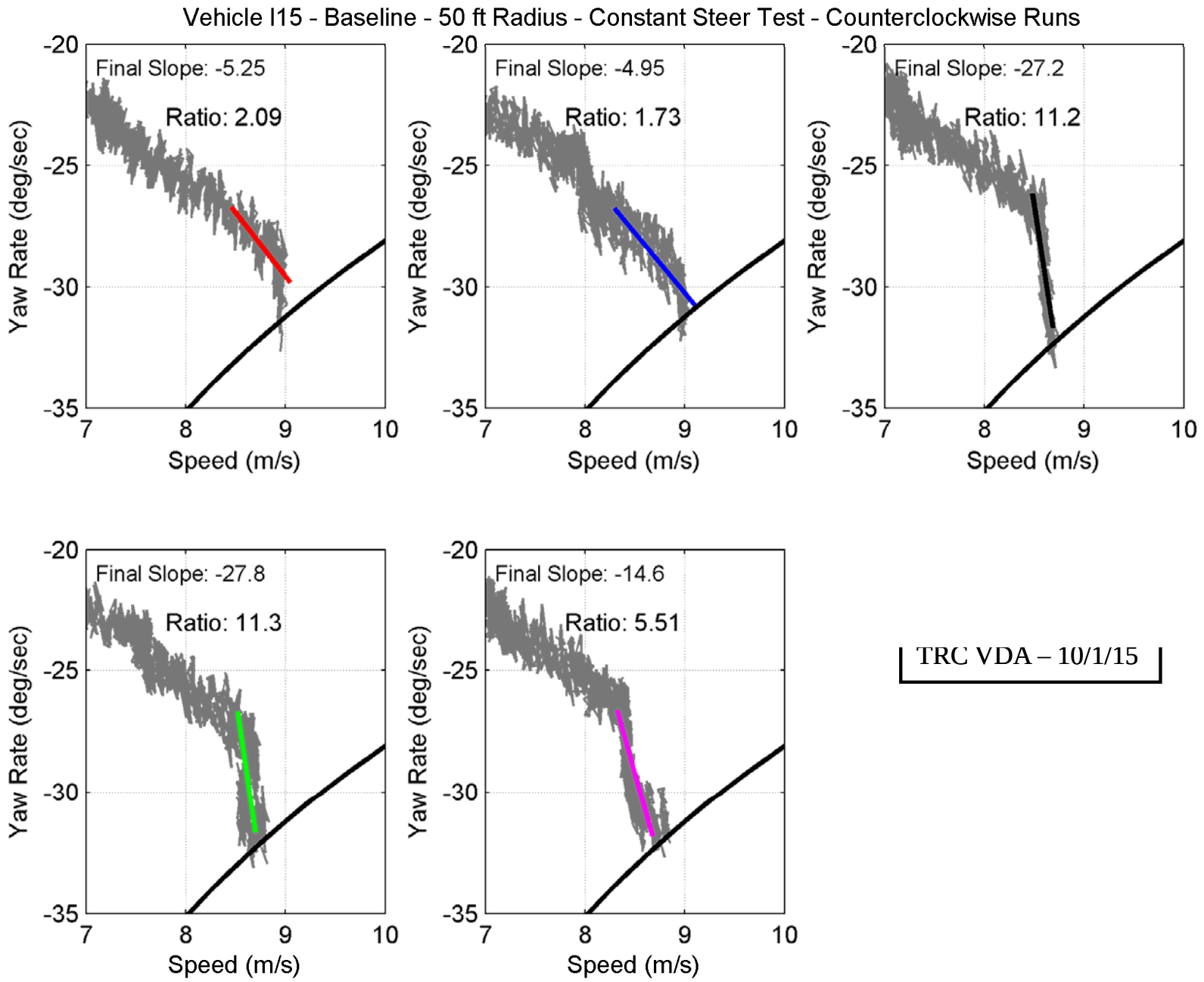


TRC Crash Pad – 7/24/15

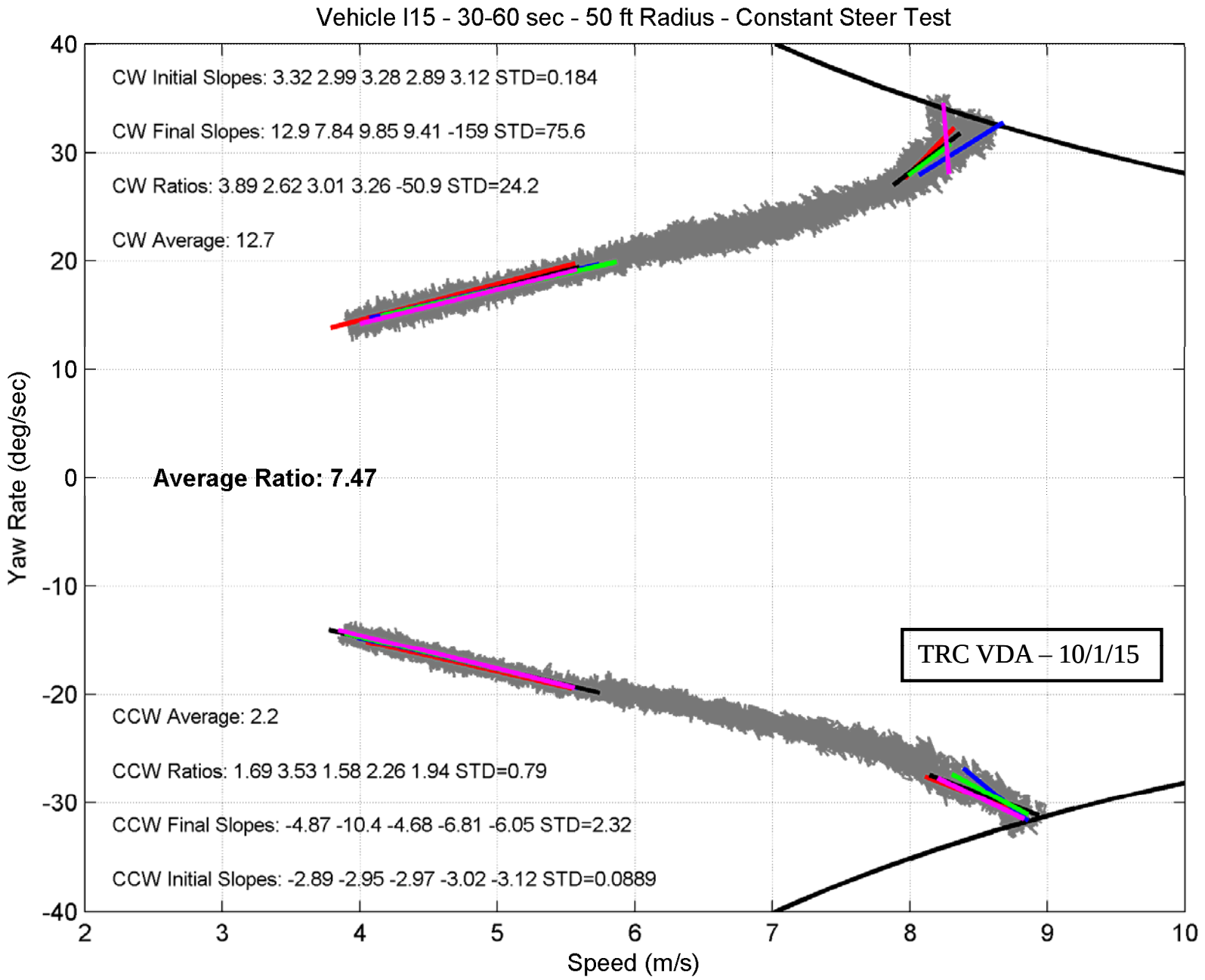

Vehicle I15 - Baseline - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3 3.11 3.34 2.99 2.82 STD=0.191
CW Final Slopes: 25.6 6.21 -193 12 13 STD=92.9
CW Ratios: 8.52 2 -57.8 4.01 4.6 STD=28.1
CW Average: 15.4
Average Ratio: 10.9
TRC VDA – 10/1/15
CCW Average: 6.36
CCW Ratios: 2.09 1.73 11.2 11.3 5.51 STD=4.7
CCW Final Slopes: -5.25 -4.95 -27.2 -27.8 -14.6 STD=11.2
CCW Initial Slopes: -2.51 -2.87 -2.44 -2.46 -2.65 STD=0.178
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

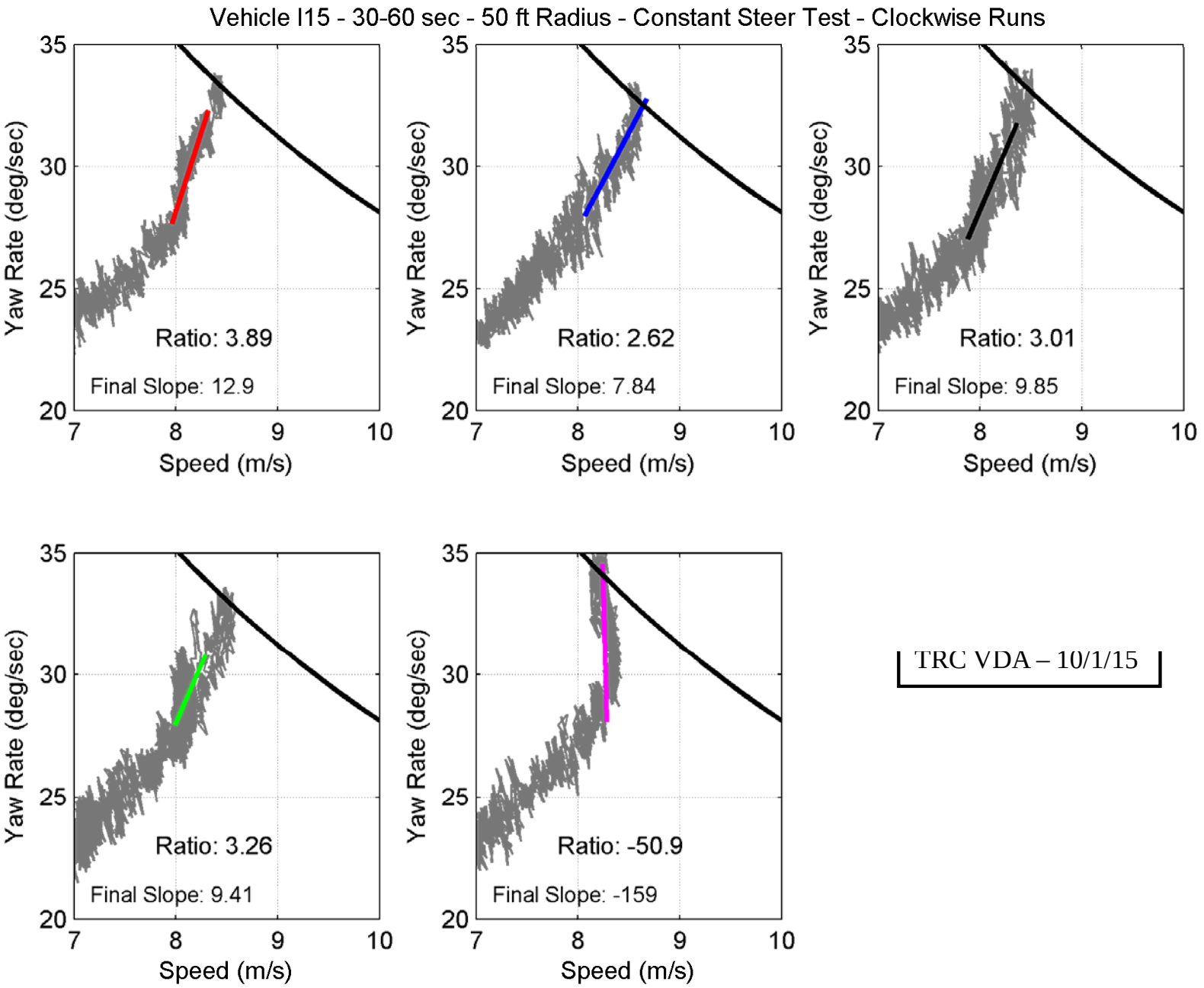


TRC VDA – 10/1/15

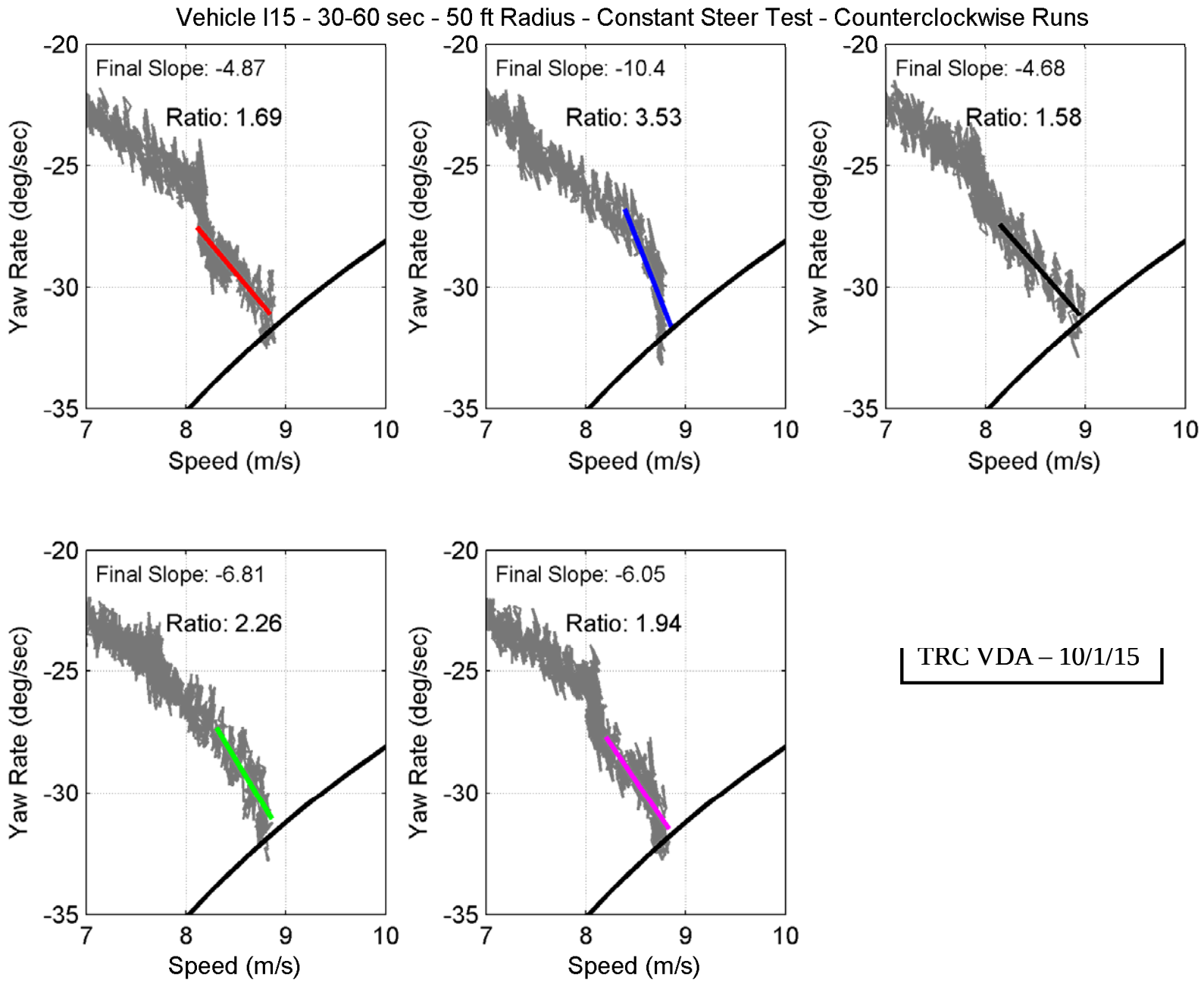


TRC VDA – 10/1/15

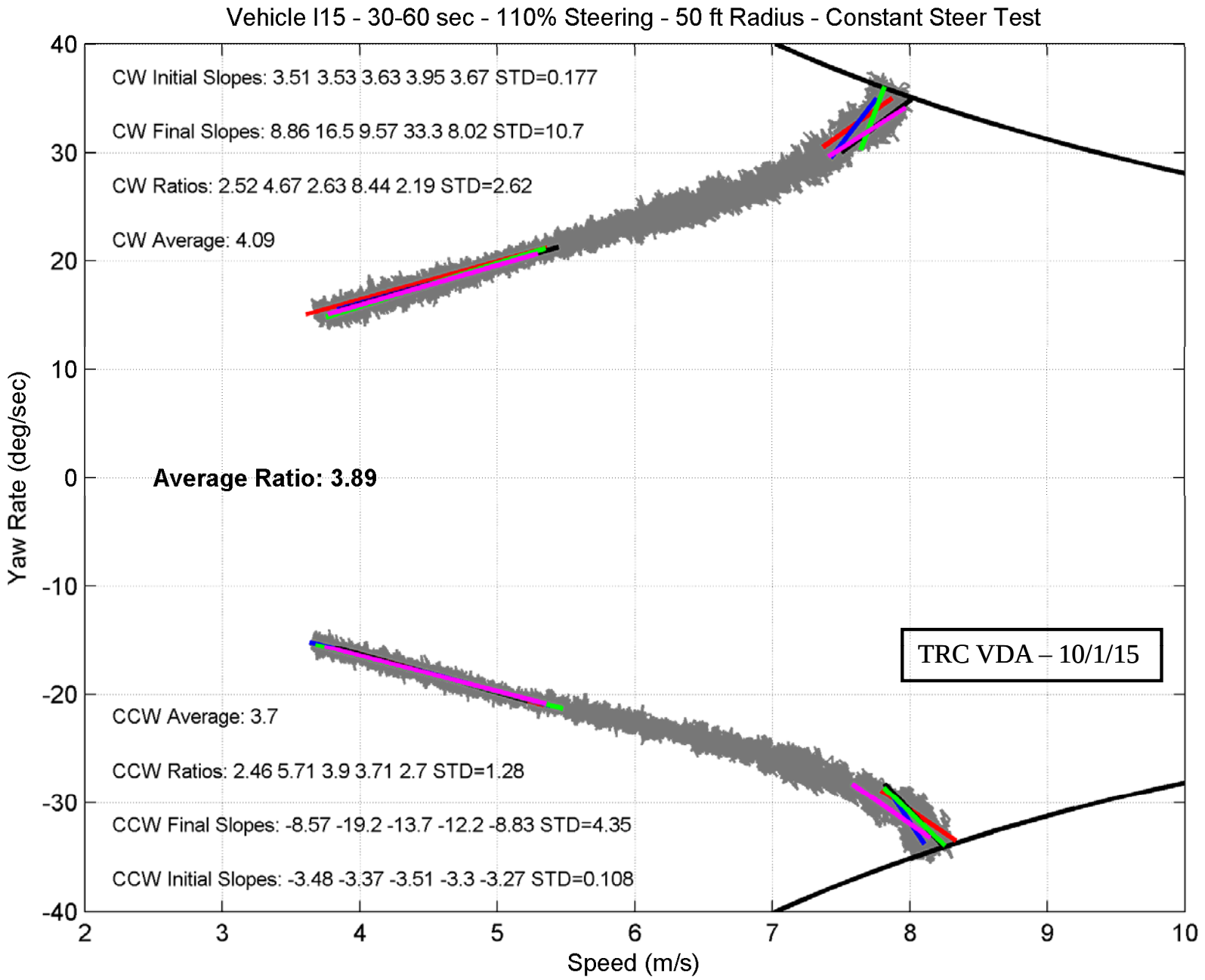

Vehicle I15 - 30-60 sec - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.32 2.99 3.28 2.89 3.12 STD=0.184
CW Final Slopes: 12.9 7.84 9.85 9.41 -159 STD=75.6
CW Ratios: 3.89 2.62 3.01 3.26 -50.9 STD=24.2
CW Average: 12.7
Average Ratio: 7.47
TRC VDA – 10/1/15
CCW Average: 2.2
CCW Ratios: 1.69 3.53 1.58 2.26 1.94 STD=0.79
CCW Final Slopes: -4.87 -10.4 -4.68 -6.81 -6.05 STD=2.32
CCW Initial Slopes: -2.89 -2.95 -2.97 -3.02 -3.12 STD=0.0889
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

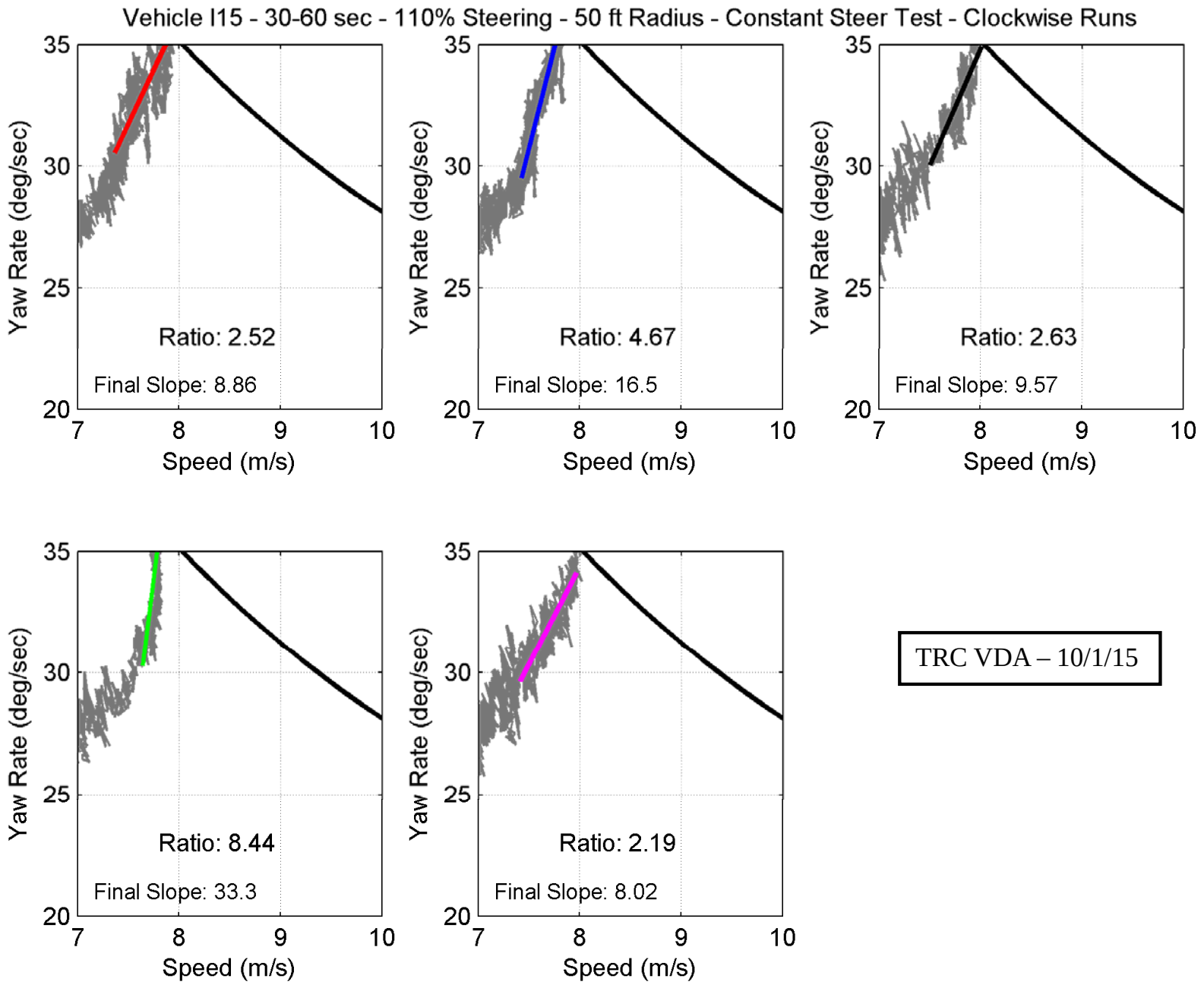


TRC VDA – 10/1/15

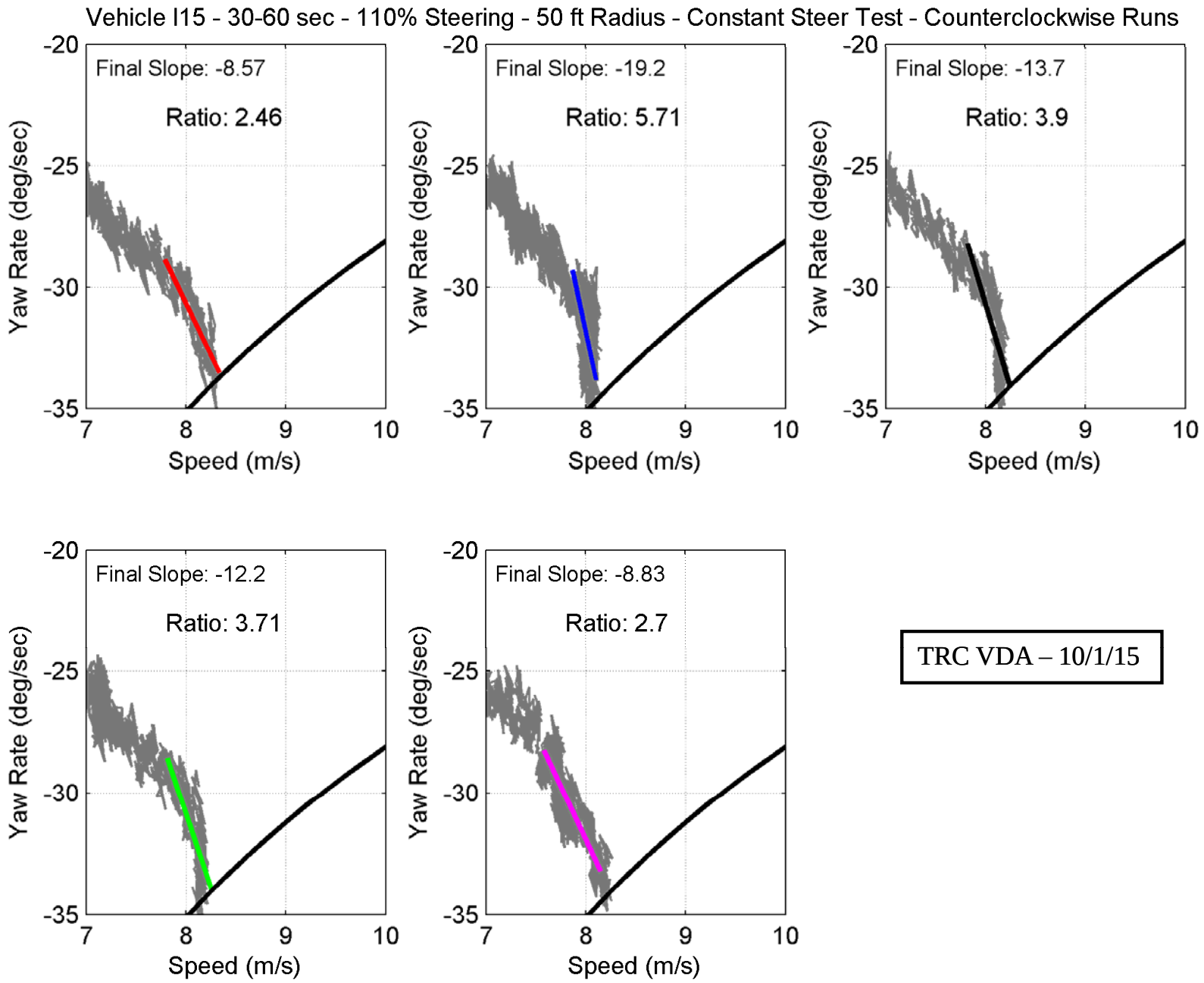


TRC VDA – 10/1/15

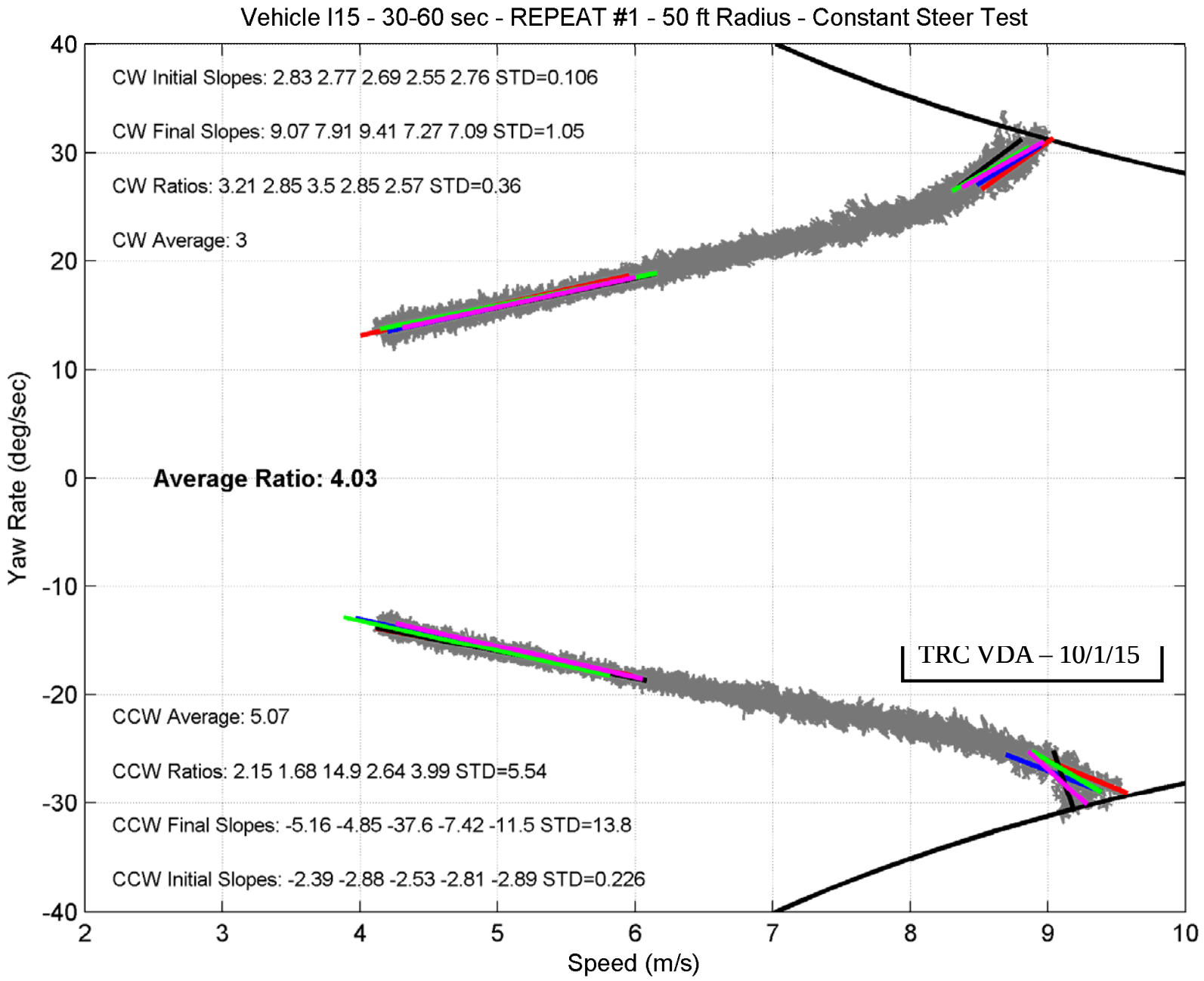

Vehicle I15 - 30-60 sec - 110% Steering - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.51 3.53 3.63 3.95 3.67 STD=0.177
CW Final Slopes: 8.86 16.5 9.57 33.3 8.02 STD=10.7
CW Ratios: 2.52 4.67 2.63 8.44 2.19 STD=2.62
CW Average: 4.09
Average Ratio: 3.89
TRC VDA – 10/1/15
CCW Average: 3.7
CCW Ratios: 2.46 5.71 3.9 3.71 2.7 STD=1.28
CCW Final Slopes: -8.57 -19.2 -13.7 -12.2 -8.83 STD=4.35
CCW Initial Slopes: -3.48 -3.37 -3.51 -3.3 -3.27 STD=0.108
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

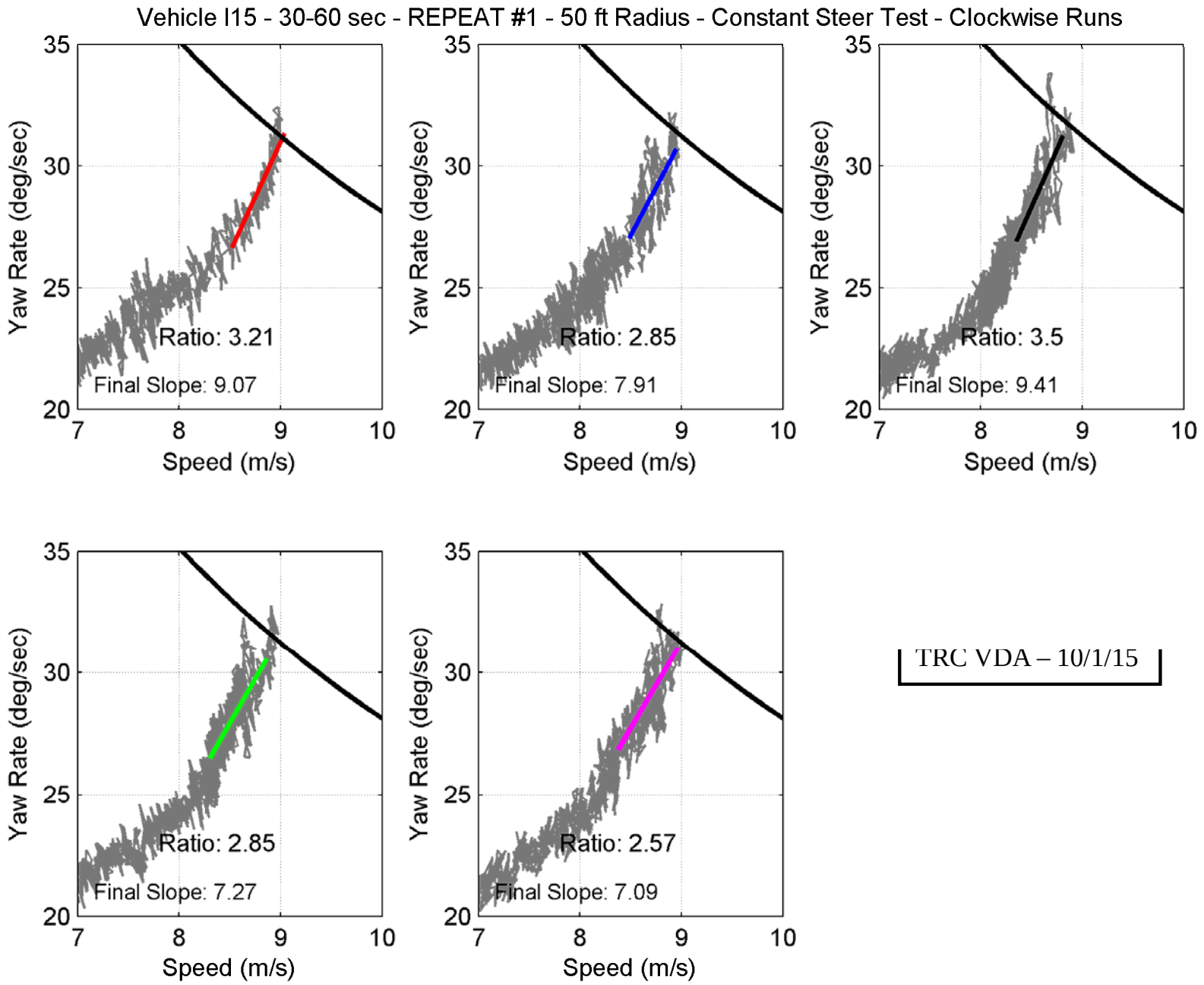


TRC VDA – 10/1/15

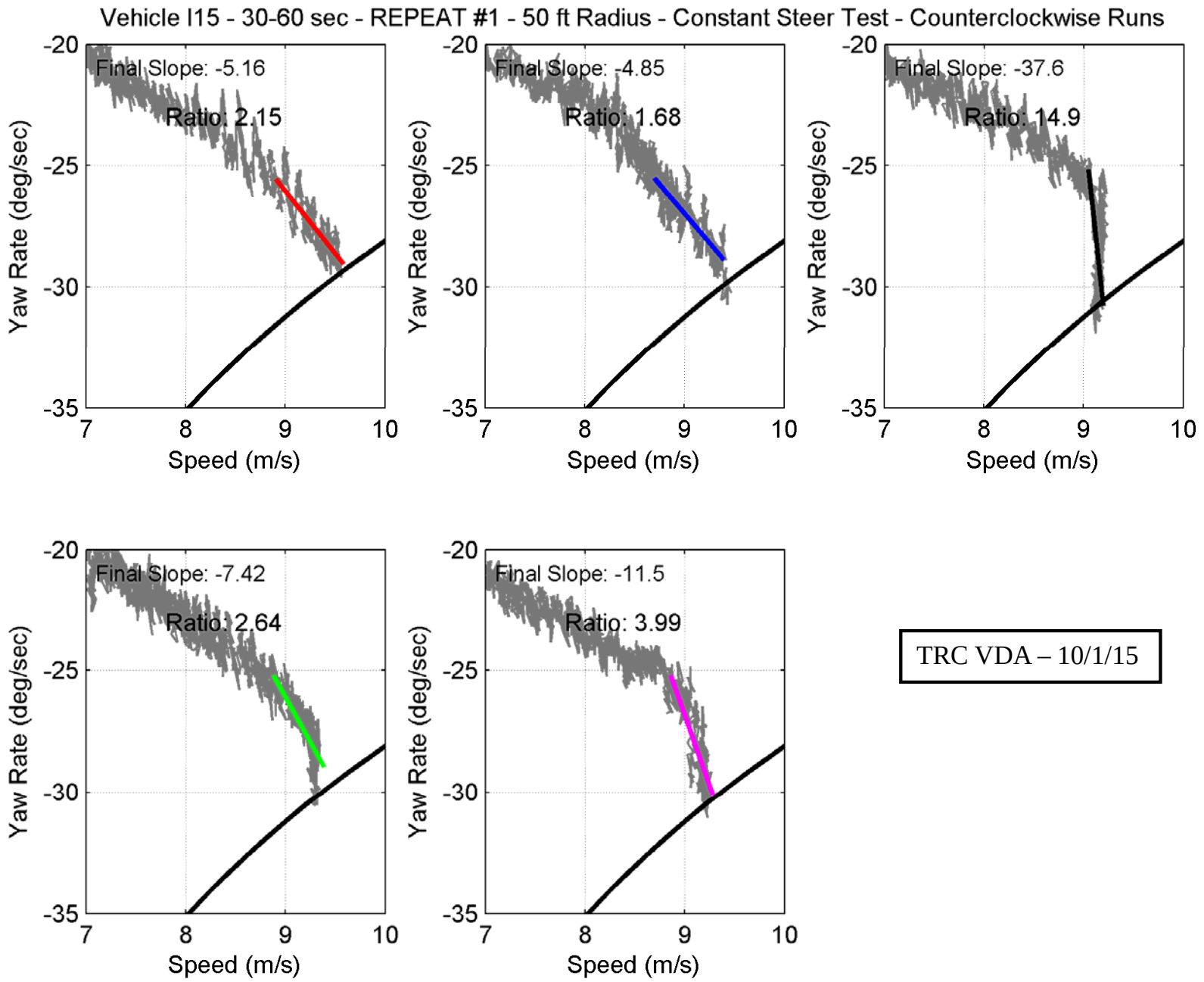


TRC VDA – 10/1/15

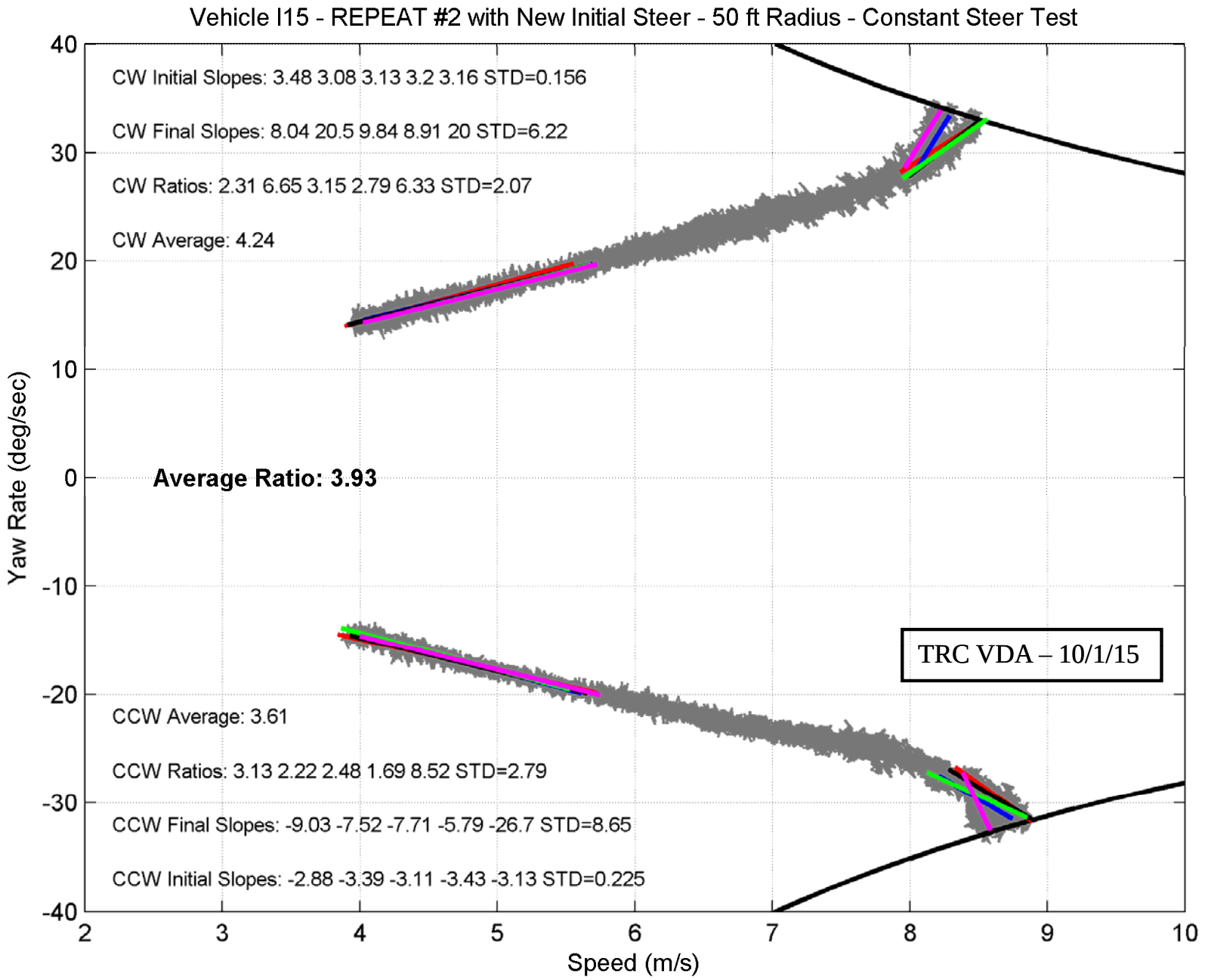

Vehicle I15 - 30-60 sec - REPEAT #1 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.83 2.77 2.69 2.55 2.76 STD=0.106
CW Final Slopes: 9.07 7.91 9.41 7.27 7.09 STD=1.05
CW Ratios: 3.21 2.85 3.5 2.85 2.57 STD=0.36
CW Average: 3
Average Ratio: 4.03
TRC VDA – 10/1/15
CCW Average: 5.07
CCW Ratios: 2.15 1.68 14.9 2.64 3.99 STD=5.54
CCW Final Slopes: -5.16 -4.85 -37.6 -7.42 -11.5 STD=13.8
CCW Initial Slopes: -2.39 -2.88 -2.53 -2.81 -2.89 STD=0.226
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

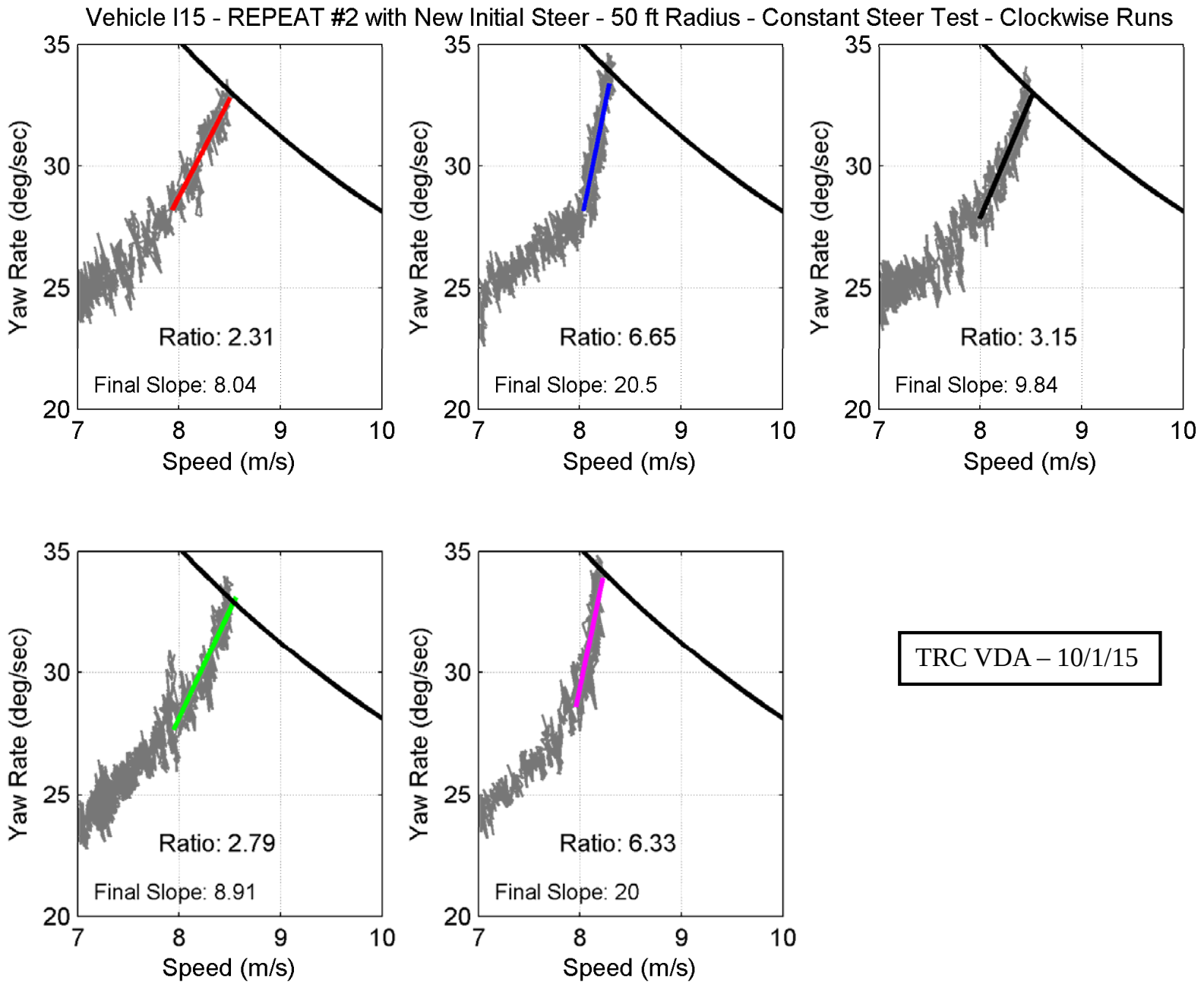


TRC VDA – 10/1/15

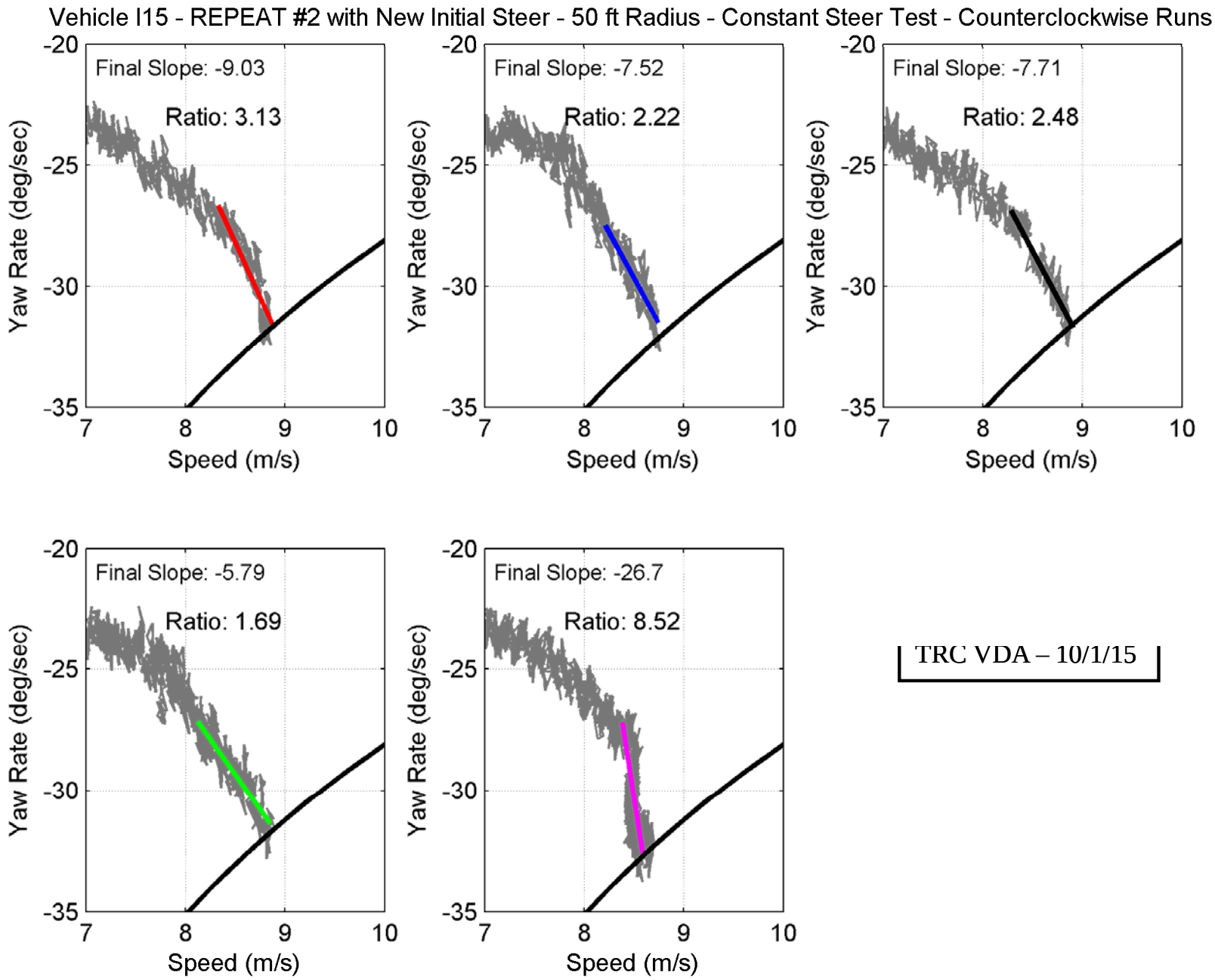


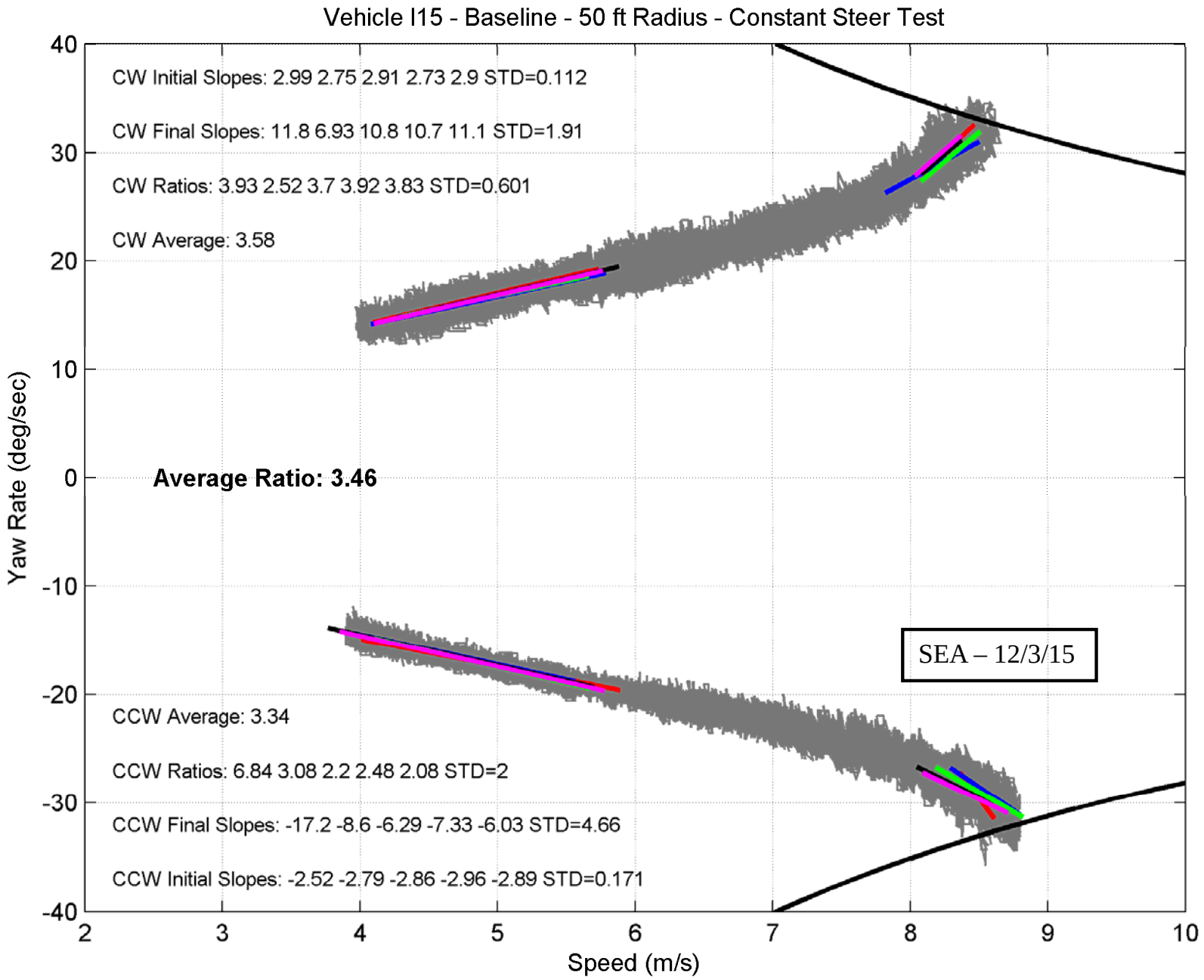
TRC VDA – 10/1/15

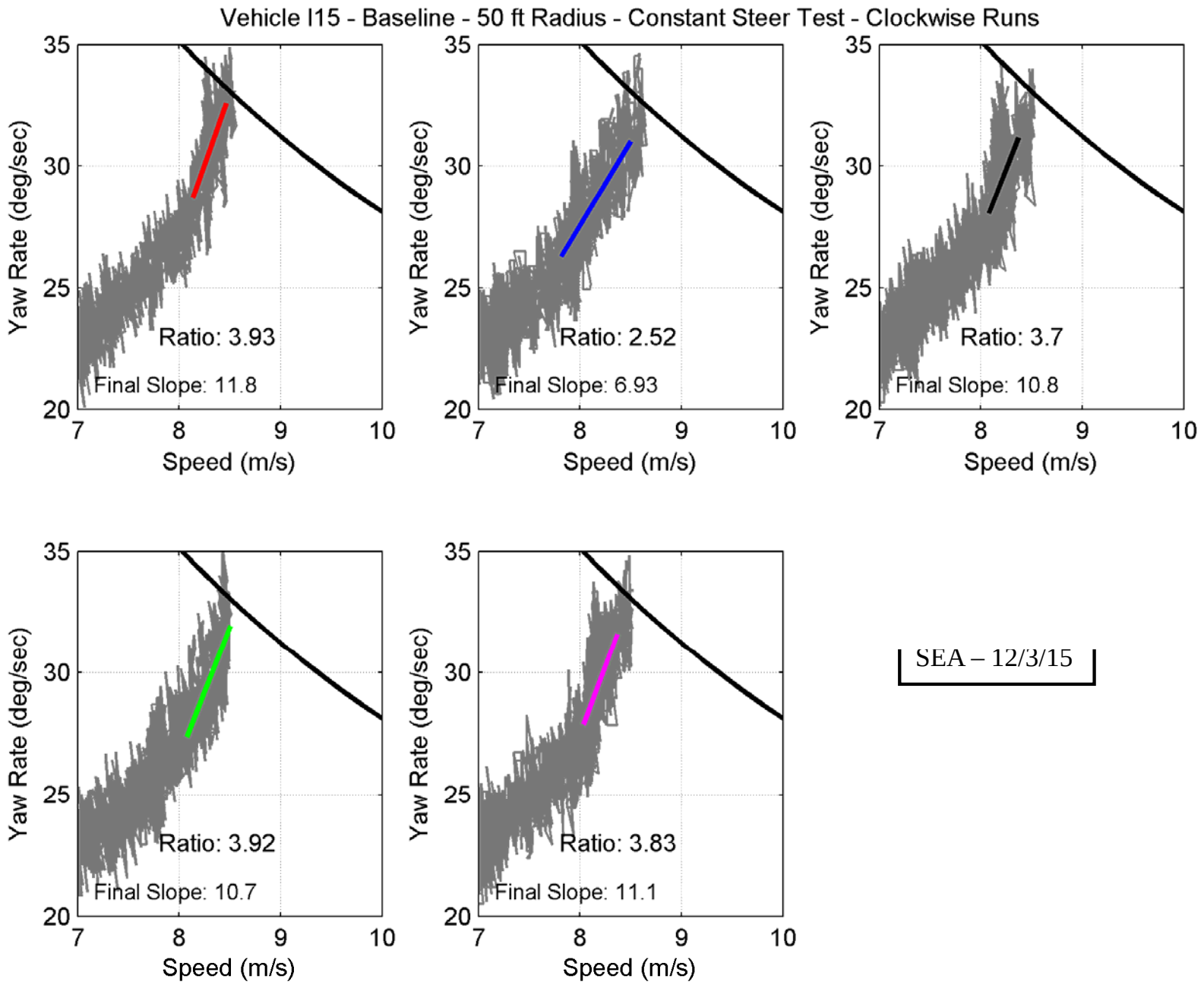

Vehicle I15 - REPEAT #2 with New Initial Steer - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.48 3.08 3.13 3.2 3.16 STD=0.156
CW Final Slopes: 8.04 20.5 9.84 8.91 20 STD=6.22
CW Ratios: 2.31 6.65 3.15 2.79 6.33 STD=2.07
CW Average: 4.24
Average Ratio: 3.93
TRC VDA – 10/1/15
CCW Average: 3.61
CCW Ratios: 3.13 2.22 2.48 1.69 8.52 STD=2.79
CCW Final Slopes: -9.03 -7.52 -7.71 -5.79 -26.7 STD=8.65
CCW Initial Slopes: -2.88 -3.39 -3.11 -3.43 -3.13 STD=0.225
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



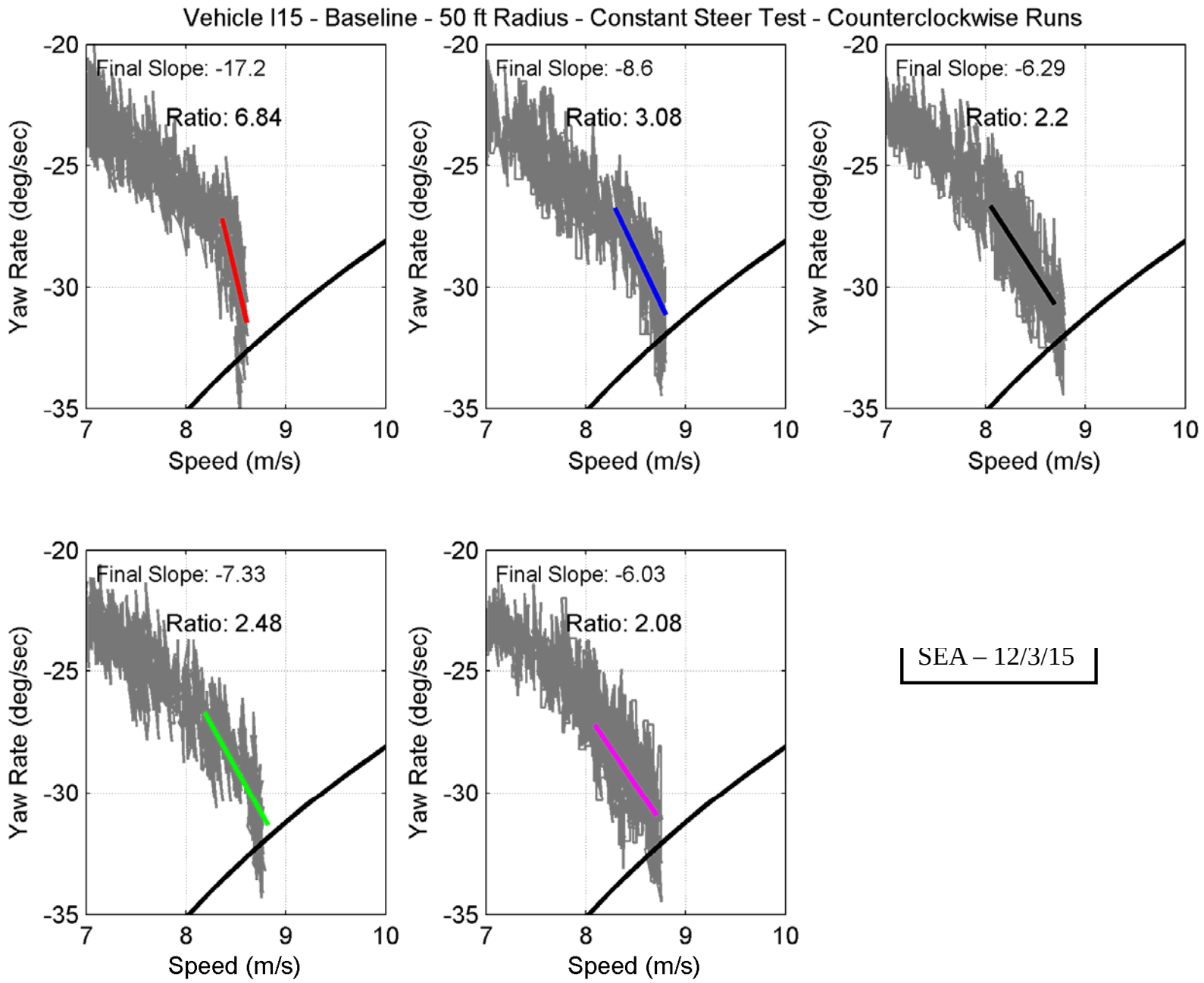
TRC VDA – 10/1/15


Vehicle I15 - REPEAT #2 with New Initial Steer - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -9.03
Ratio: 3.13
Final Slope: -7.52
Ratio: 2.22
Final Slope: -7.71
Ratio: 2.48
Final Slope: -5.79
Ratio: 1.69
Final Slope: -26.7
Ratio: 8.52
Yaw Rate (deg/sec)
Speed (m/s)
-20
-25
-30
-35
7
8
9
10
TRC VDA – 10/1/15

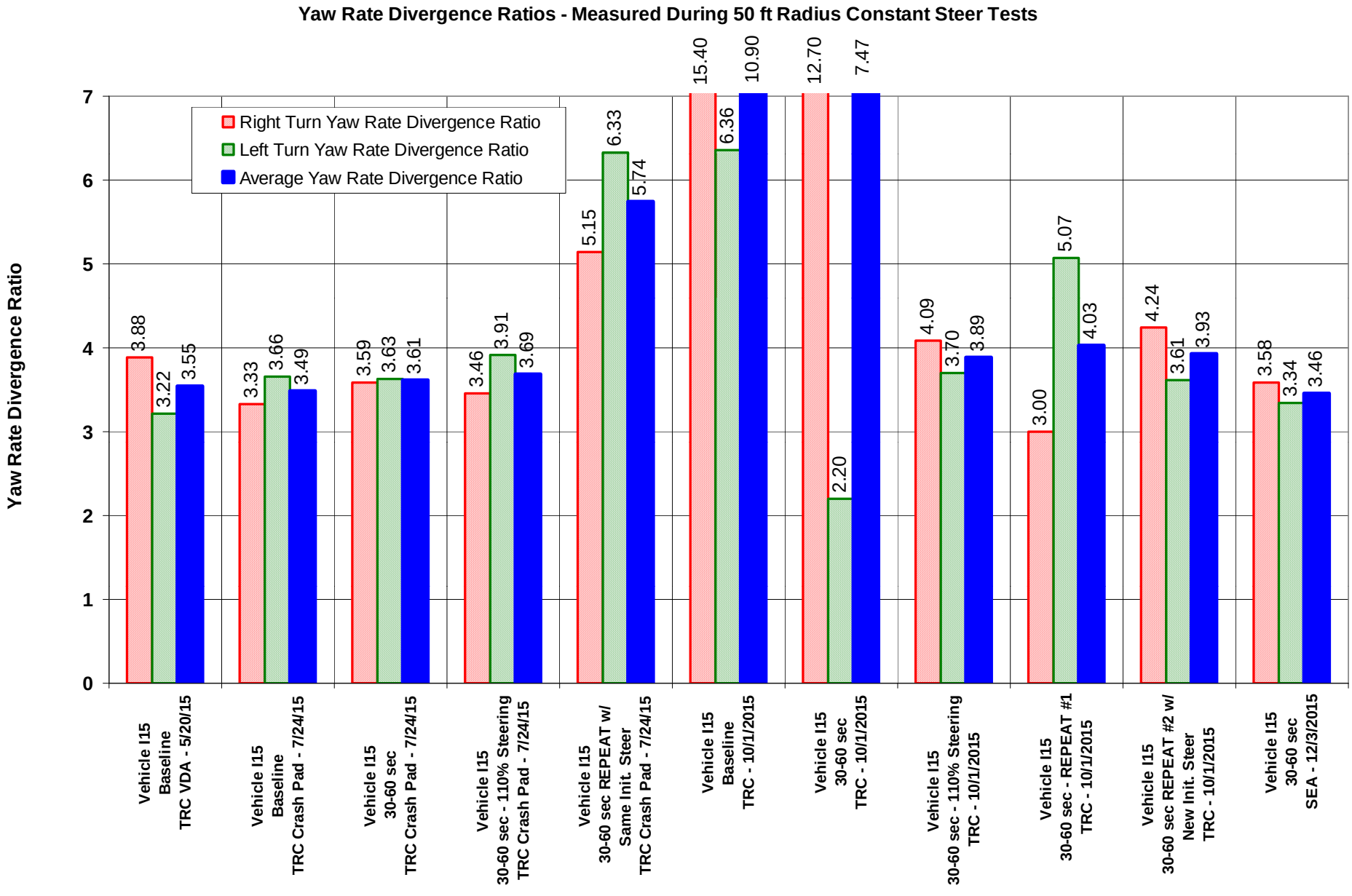

Vehicle I15 - Baseline - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.99 2.75 2.91 2.73 2.9 STD=0.112
CW Final Slopes: 11.8 6.93 10.8 10.7 11.1 STD=1.91
CW Ratios: 3.93 2.52 3.7 3.92 3.83 STD=0.601
CW Average: 3.58
Average Ratio: 3.46
SEA – 12/3/15
CCW Average: 3.34
CCW Ratios: 6.84 3.08 2.2 2.48 2.08 STD=2
CCW Final Slopes: -17.2 -8.6 -6.29 -7.33 -6.03 STD=4.66
CCW Initial Slopes: -2.52 -2.79 -2.86 -2.96 -2.89 STD=0.171
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

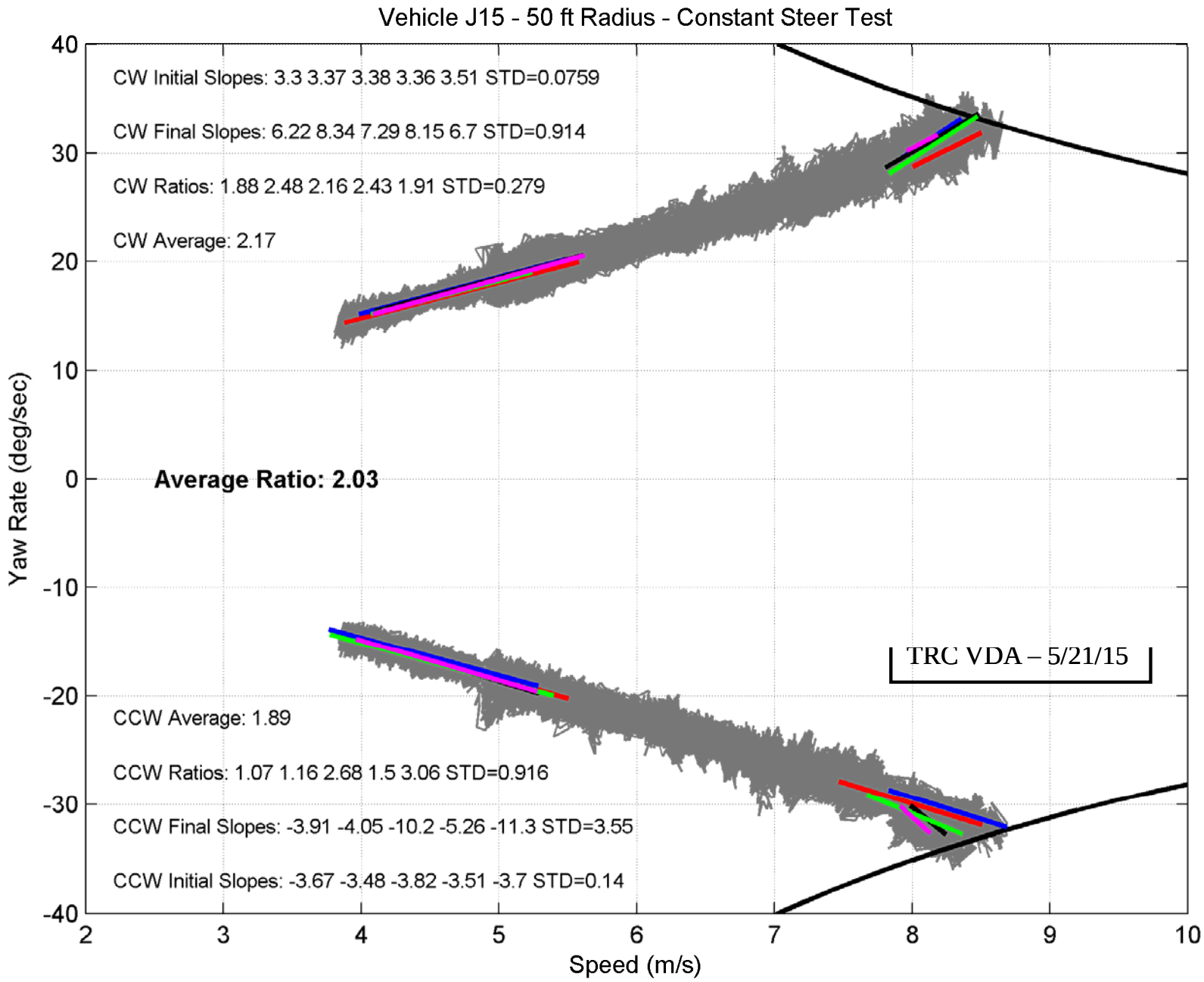

Vehicle I15 - Baseline - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 3.93
Final Slope: 11.8
Ratio: 2.52
Final Slope: 6.93
Ratio: 3.7
Final Slope: 10.8
Ratio: 3.92
Final Slope: 10.7
Ratio: 3.83
Final Slope: 11.1

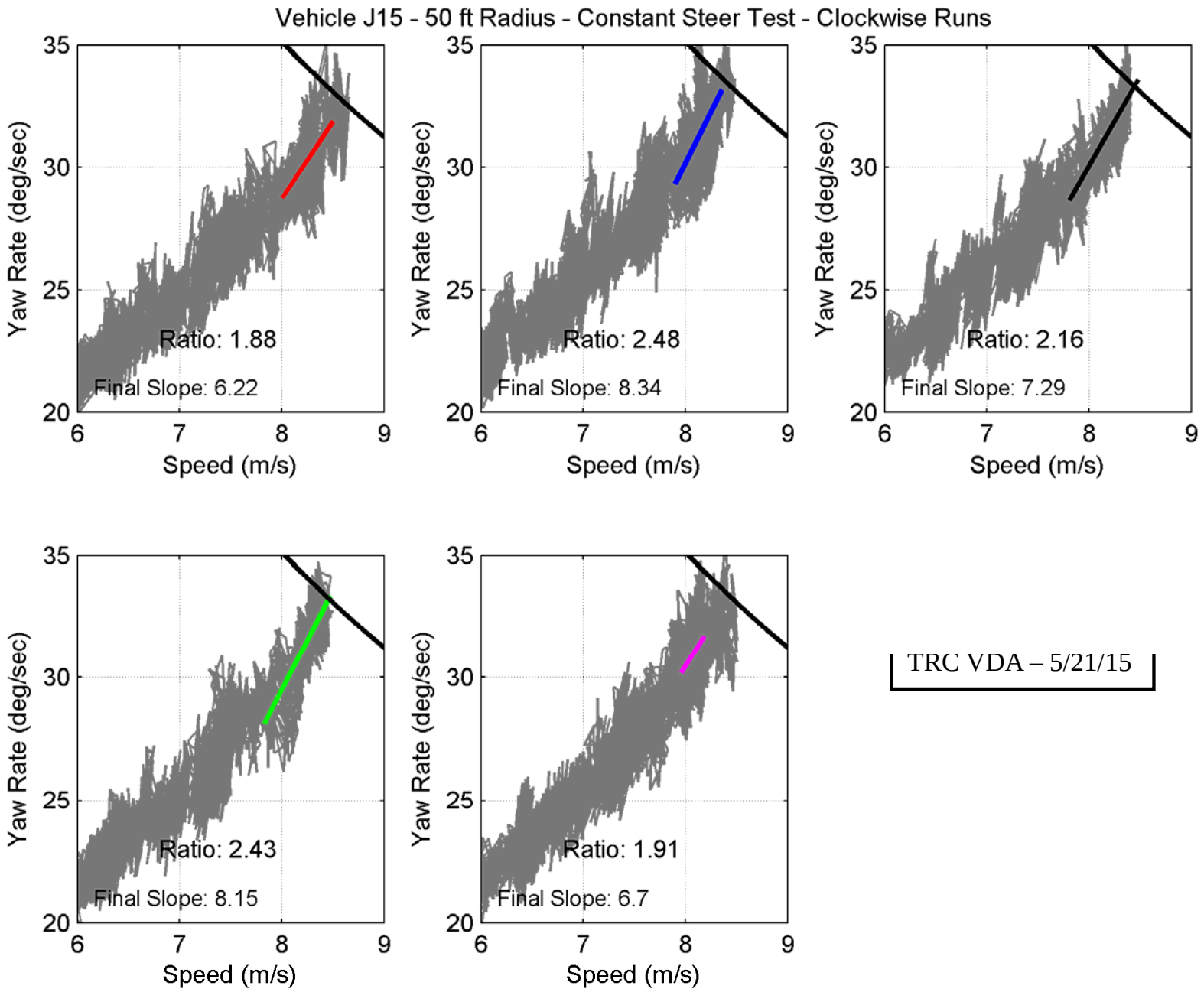
SEA – 12/3/15


Vehicle I15 - Baseline - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -17.2
Ratio: 6.84
Final Slope: -8.6
Ratio: 3.08
Final Slope: -6.29
Ratio: 2.2
Final Slope: -7.33
Ratio: 2.48
Final Slope: -6.03
Ratio: 2.08
Yaw Rate (deg/sec)
Speed (m/s)
-20
-25
-30
-35
7
8
9
10

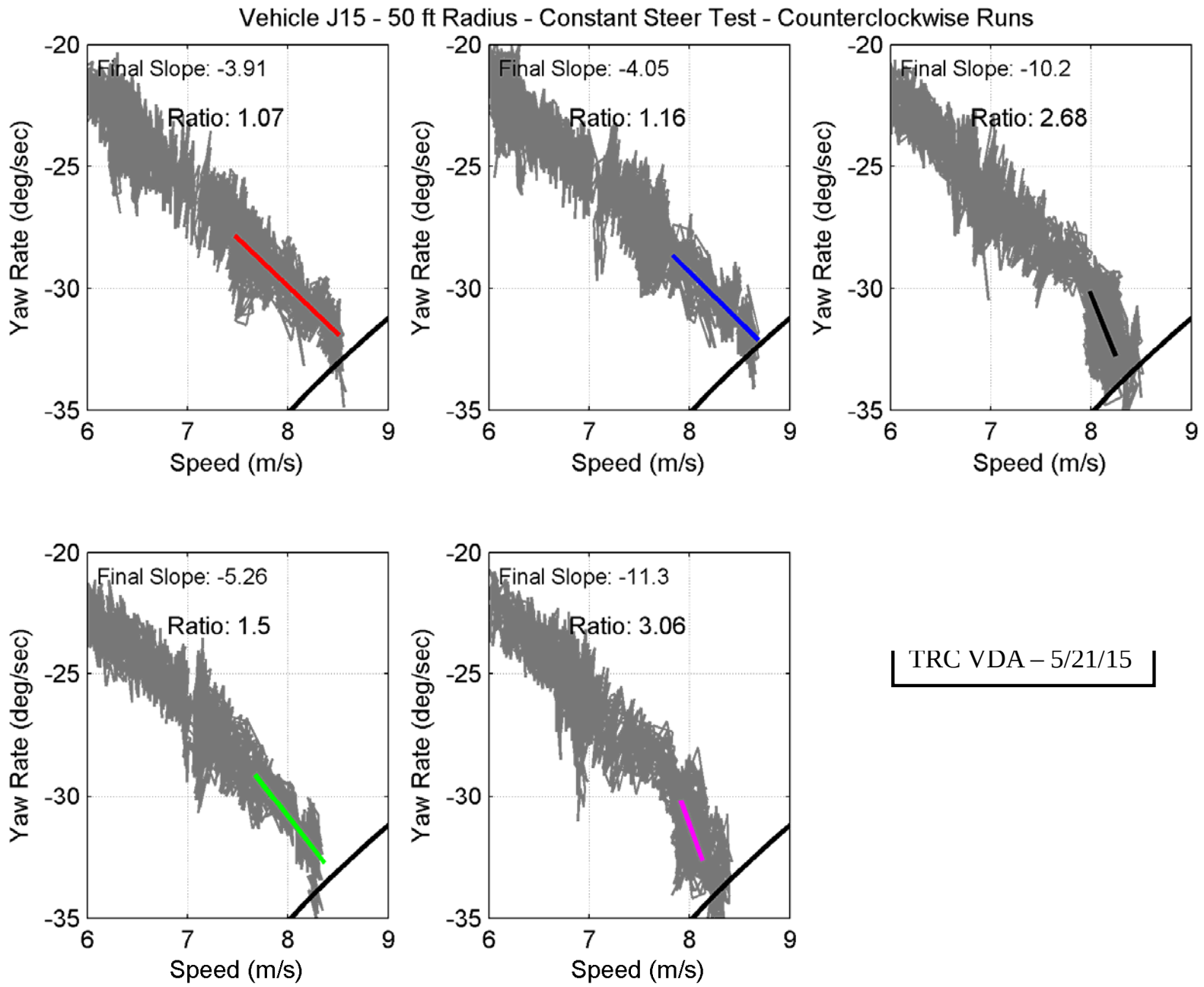
SEA – 12/3/15


Yaw Rate Divergence Ratios - Measured During 50 ft Radius Constant Steer Tests
Yaw Rate Divergence Ratio
Right Turn Yaw Rate Divergence Ratio
Left Turn Yaw Rate Divergence Ratio
Average Yaw Rate Divergence Ratio
0
1
2
3
4
5
6
7
3.88
3.22
3.55
3.33
3.66
3.49
3.59
3.63
3.61
3.46
3.91
3.69
5.15
6.33
5.74
15.40
6.36
10.90
12.70
2.20
7.47
4.09
3.70
3.89
3.00
5.07
4.03
4.24
3.61
3.93
3.58
3.34
3.46
Vehicle I15 Baseline TRC VDA - 5/20/15
Vehicle I15 Baseline TRC Crash Pad - 7/24/15
Vehicle I15 30-60 sec TRC Crash Pad - 7/24/15
Vehicle I15 30-60 sec - 110% Steering TRC Crash Pad - 7/24/15
Vehicle I15 30-60 sec REPEAT w/ Same Init. Steer TRC Crash Pad - 7/24/15
Vehicle I15 Baseline TRC - 10/1/2015
Vehicle I15 30-60 sec TRC - 10/1/2015
Vehicle I15 30-60 sec - 110% Steering TRC - 10/1/2015
Vehicle I15 30-60 sec - REPEAT #1 TRC - 10/1/2015
Vehicle I15 30-60 sec REPEAT #2 w/ New Init. Steer TRC - 10/1/2015
Vehicle I15 30-60 sec SEA - 12/3/2015

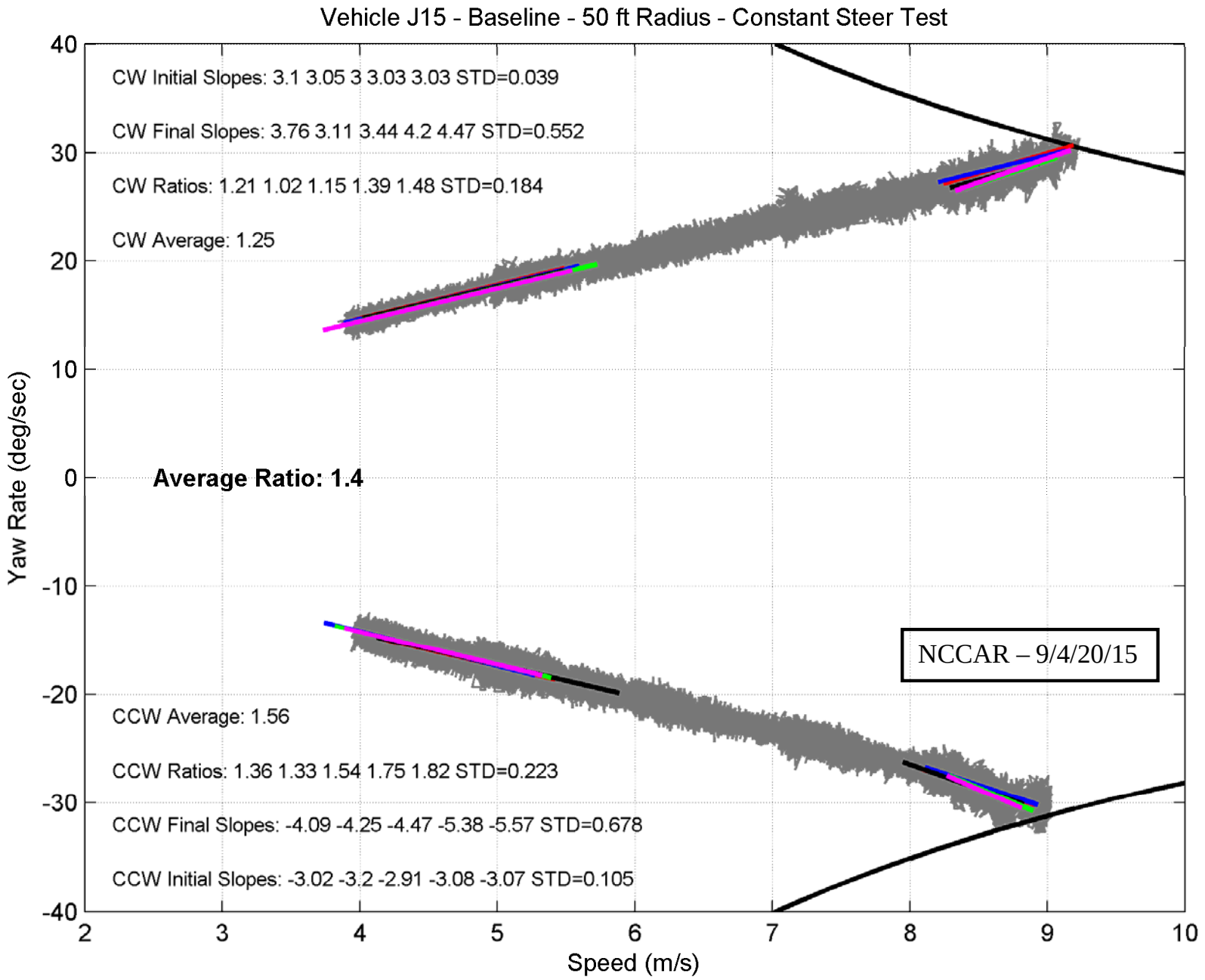

Vehicle J15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.3 3.37 3.38 3.36 3.51 STD=0.0759
CW Final Slopes: 6.22 8.34 7.29 8.15 6.7 STD=0.914
CW Ratios: 1.88 2.48 2.16 2.43 1.91 STD=0.279
CW Average: 2.17
Average Ratio: 2.03
TRC VDA – 5/21/15
CCW Average: 1.89
CCW Ratios: 1.07 1.16 2.68 1.5 3.06 STD=0.916
CCW Final Slopes: -3.91 -4.05 -10.2 -5.26 -11.3 STD=3.55
CCW Initial Slopes: -3.67 -3.48 -3.82 -3.51 -3.7 STD=0.14
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

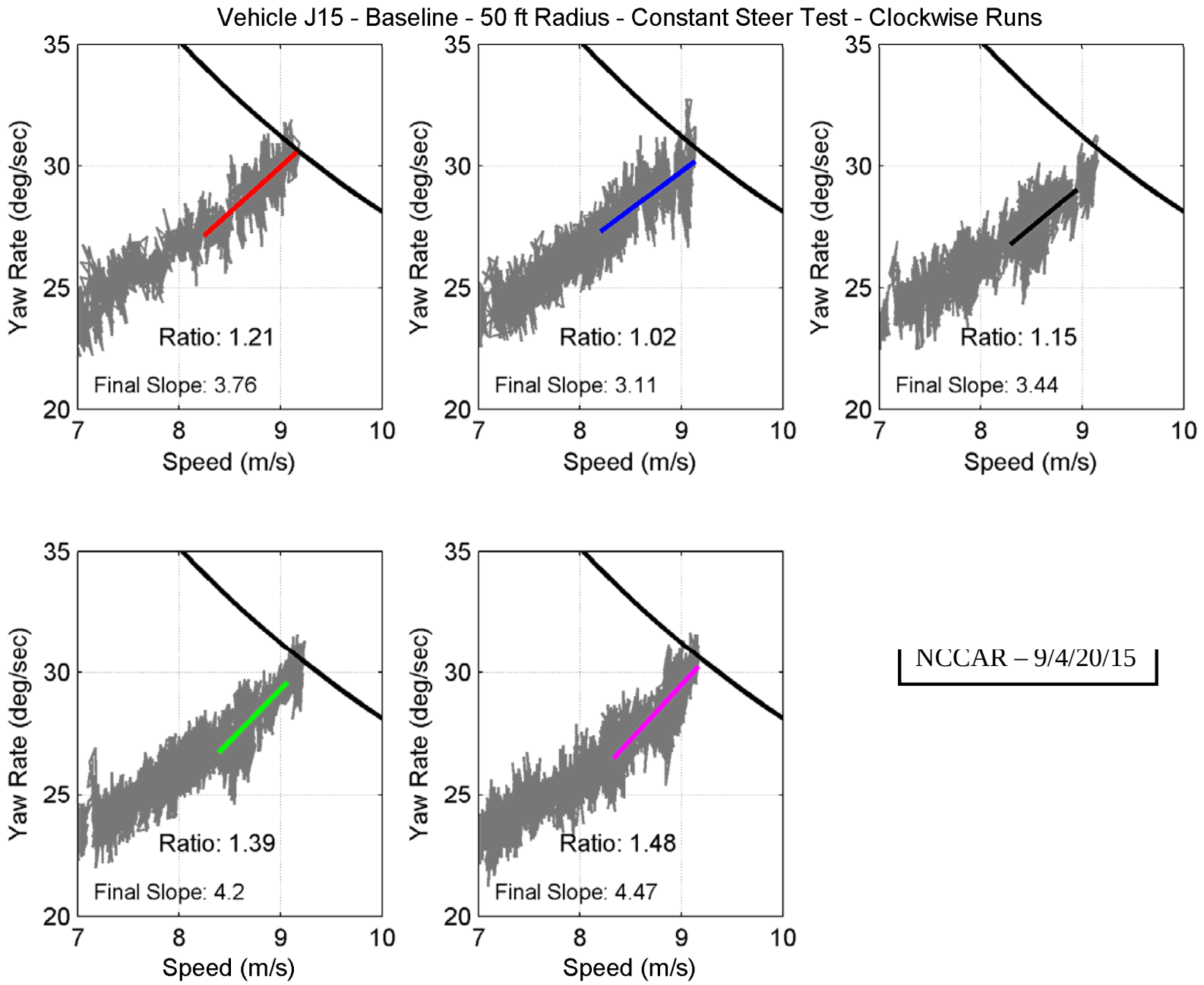


TRC VDA – 5/21/15

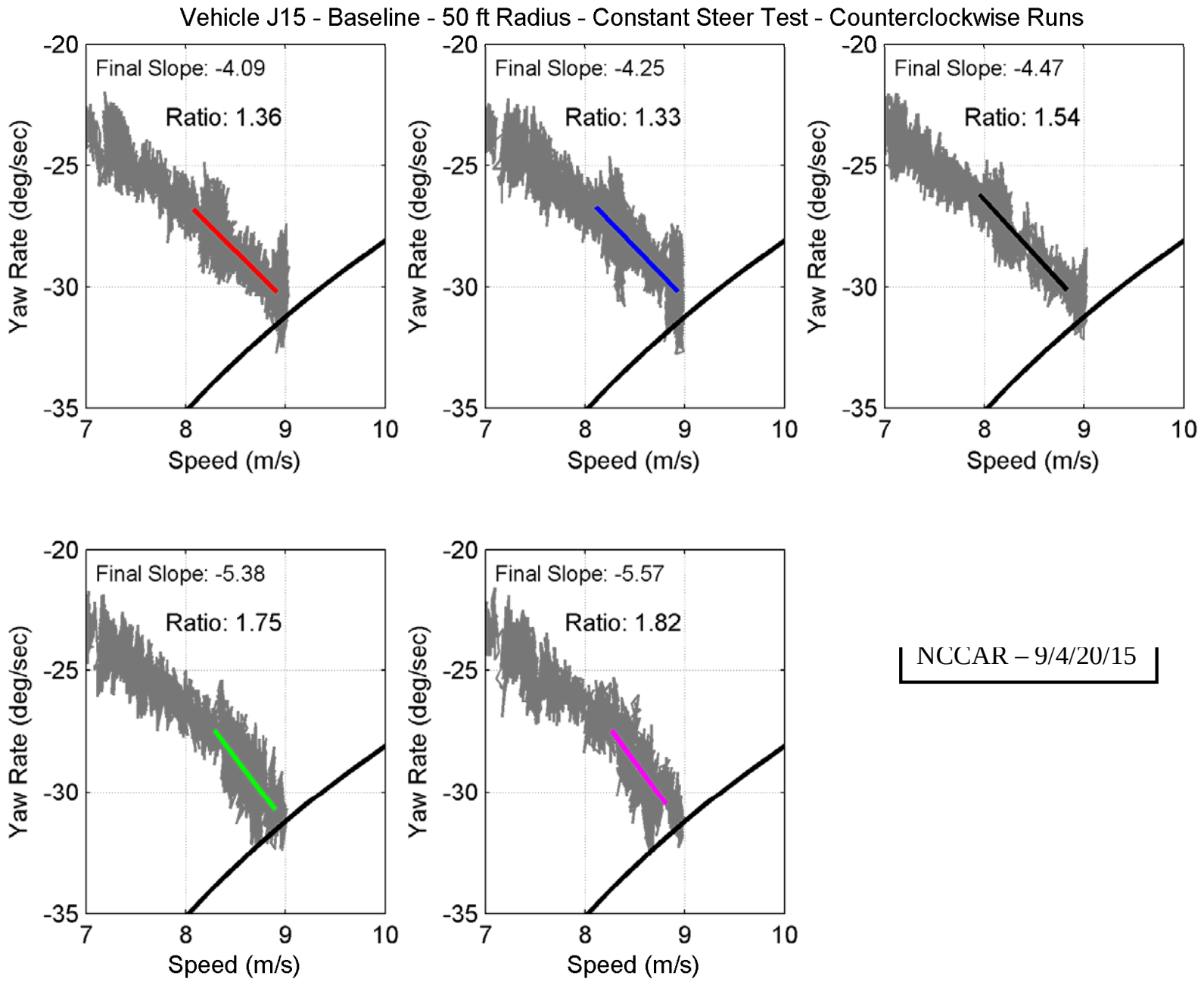


TRC VDA – 5/21/15

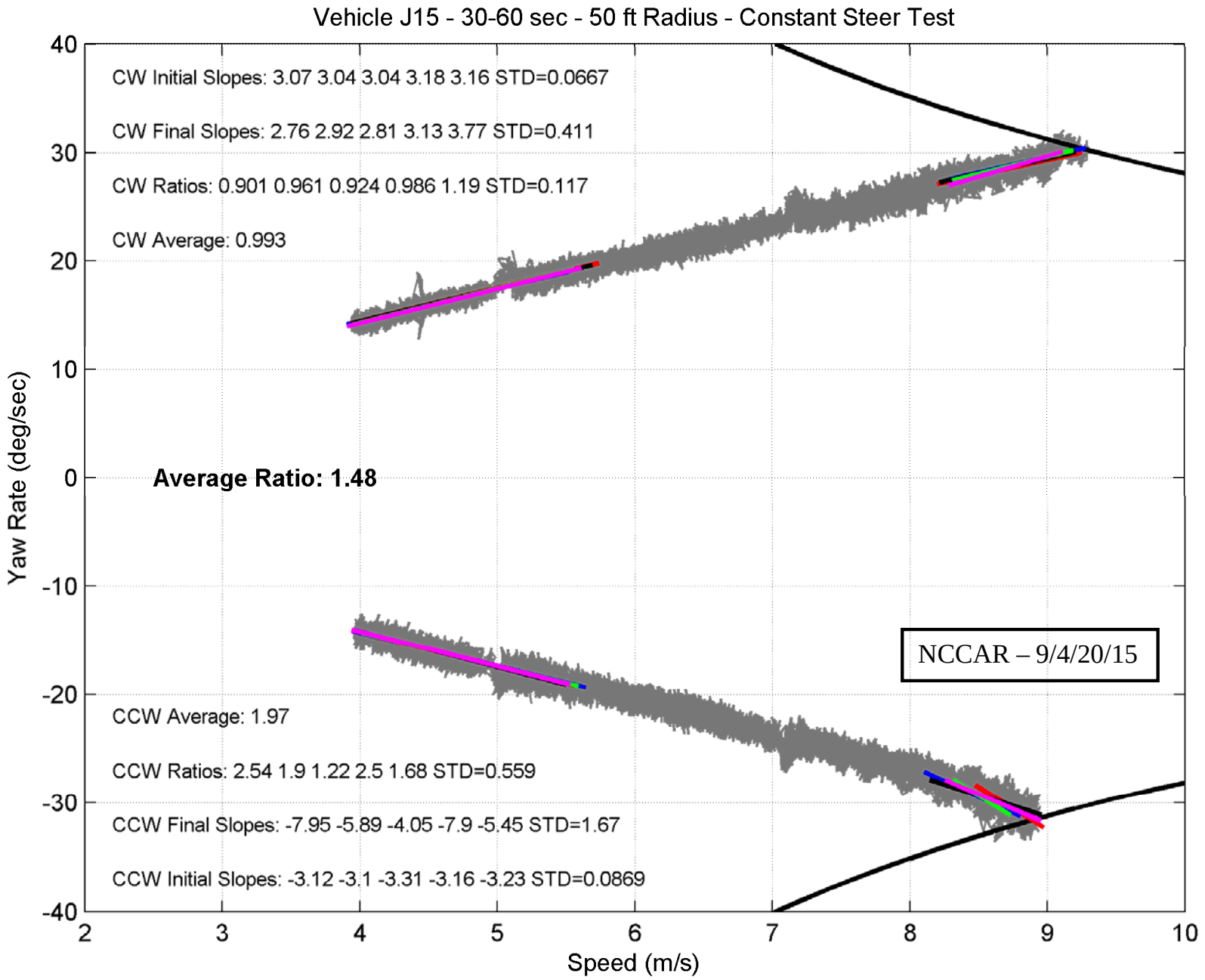

Vehicle J15 - Baseline - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.1 3.05 3 3.03 3.03 STD=0.039
CW Final Slopes: 3.76 3.11 3.44 4.2 4.47 STD=0.552
CW Ratios: 1.21 1.02 1.15 1.39 1.48 STD=0.184
CW Average: 1.25
Average Ratio: 1.4
NCCAR – 9/4/20/15
CCW Average: 1.56
CCW Ratios: 1.36 1.33 1.54 1.75 1.82 STD=0.223
CCW Final Slopes: -4.09 -4.25 -4.47 -5.38 -5.57 STD=0.678
CCW Initial Slopes: -3.02 -3.2 -2.91 -3.08 -3.07 STD=0.105
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

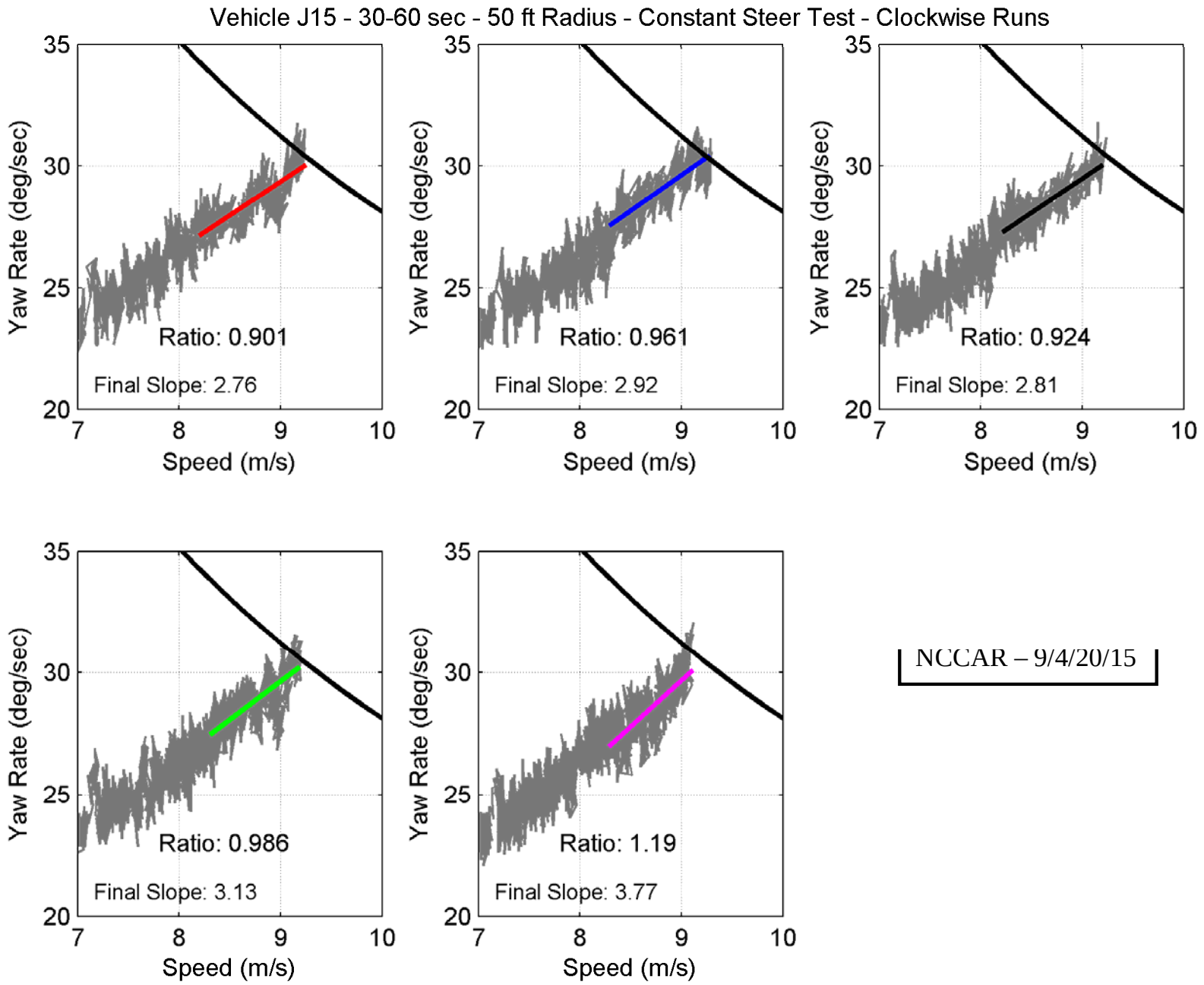


NCCAR – 9/4/20/15

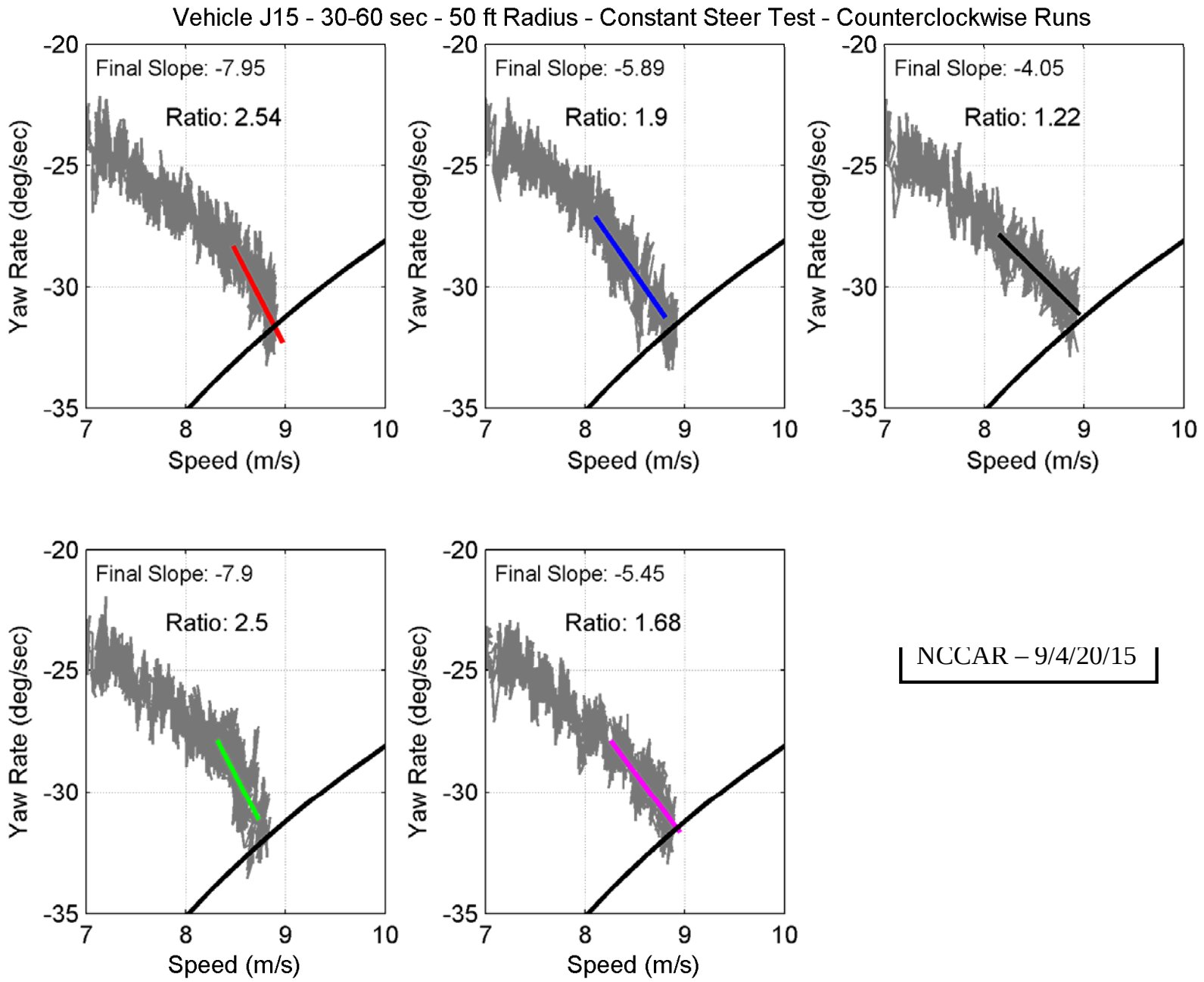


NCCAR – 9/4/20/15

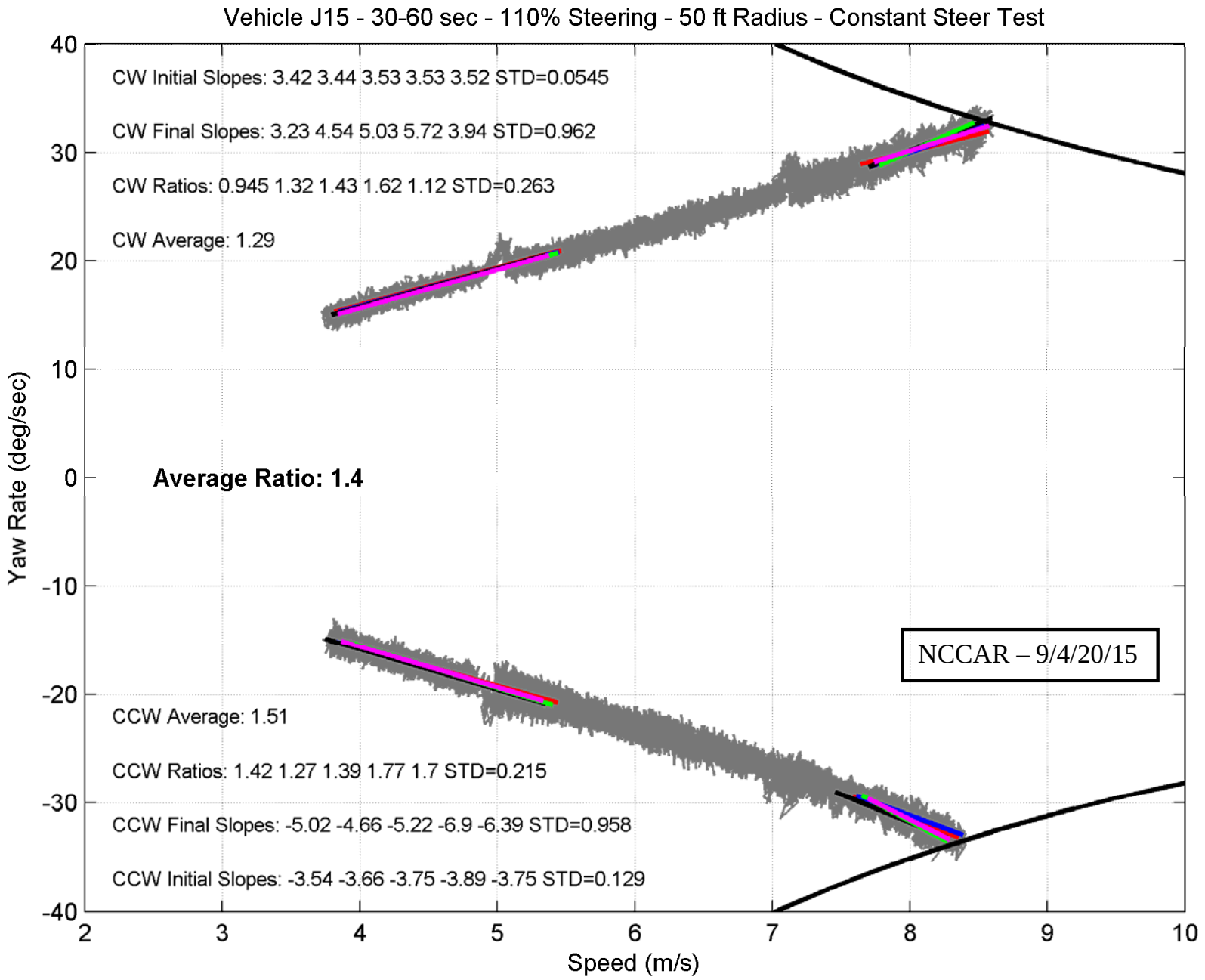

Vehicle J15 - 30-60 sec - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.07 3.04 3.04 3.18 3.16 STD=0.0667
CW Final Slopes: 2.76 2.92 2.81 3.13 3.77 STD=0.411
CW Ratios: 0.901 0.961 0.924 0.986 1.19 STD=0.117
CW Average: 0.993
Average Ratio: 1.48
NCCAR – 9/4/20/15
CCW Average: 1.97
CCW Ratios: 2.54 1.9 1.22 2.5 1.68 STD=0.559
CCW Final Slopes: -7.95 -5.89 -4.05 -7.9 -5.45 STD=1.67
CCW Initial Slopes: -3.12 -3.1 -3.31 -3.16 -3.23 STD=0.0869
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

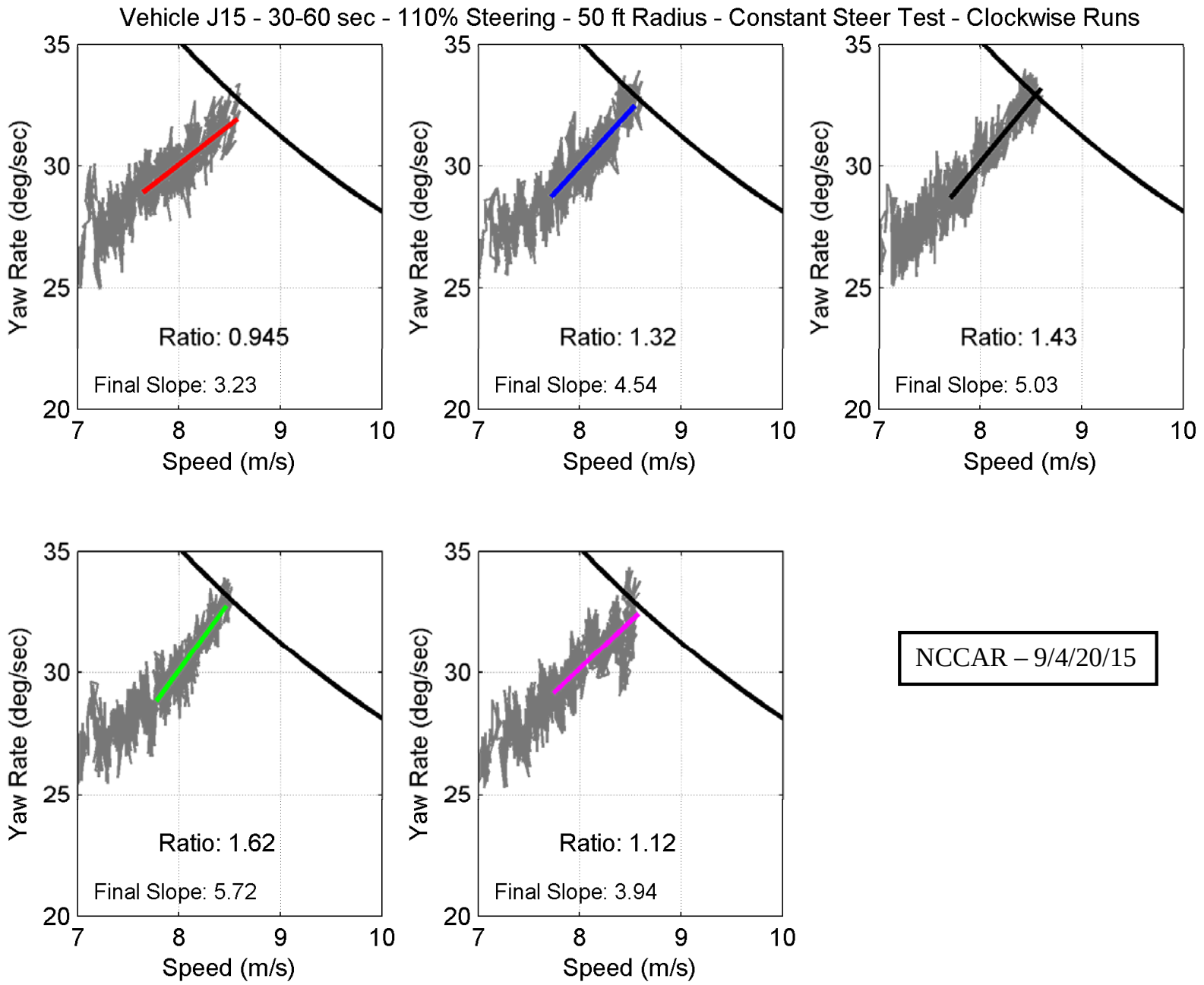


NCCAR – 9/4/20/15

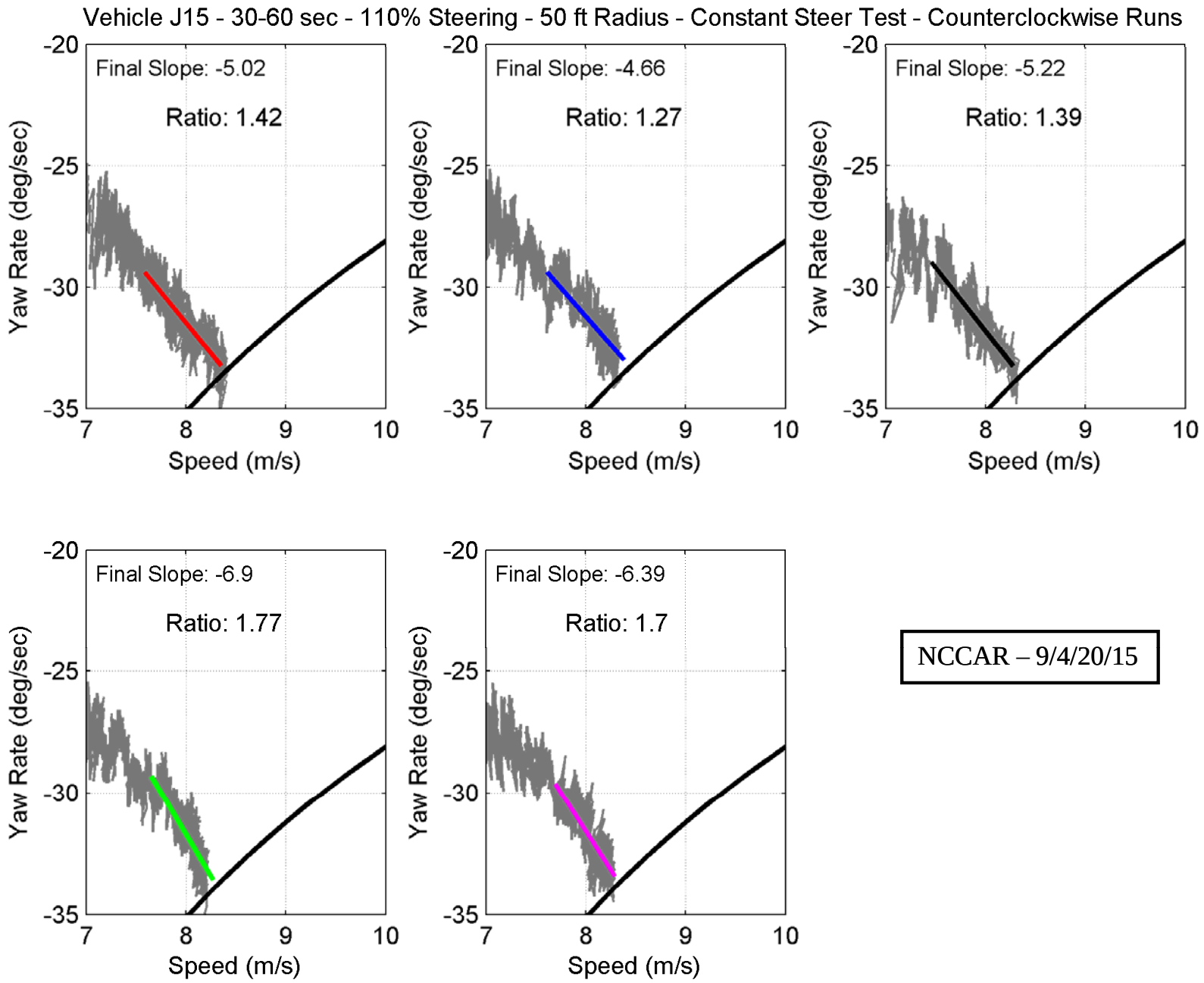


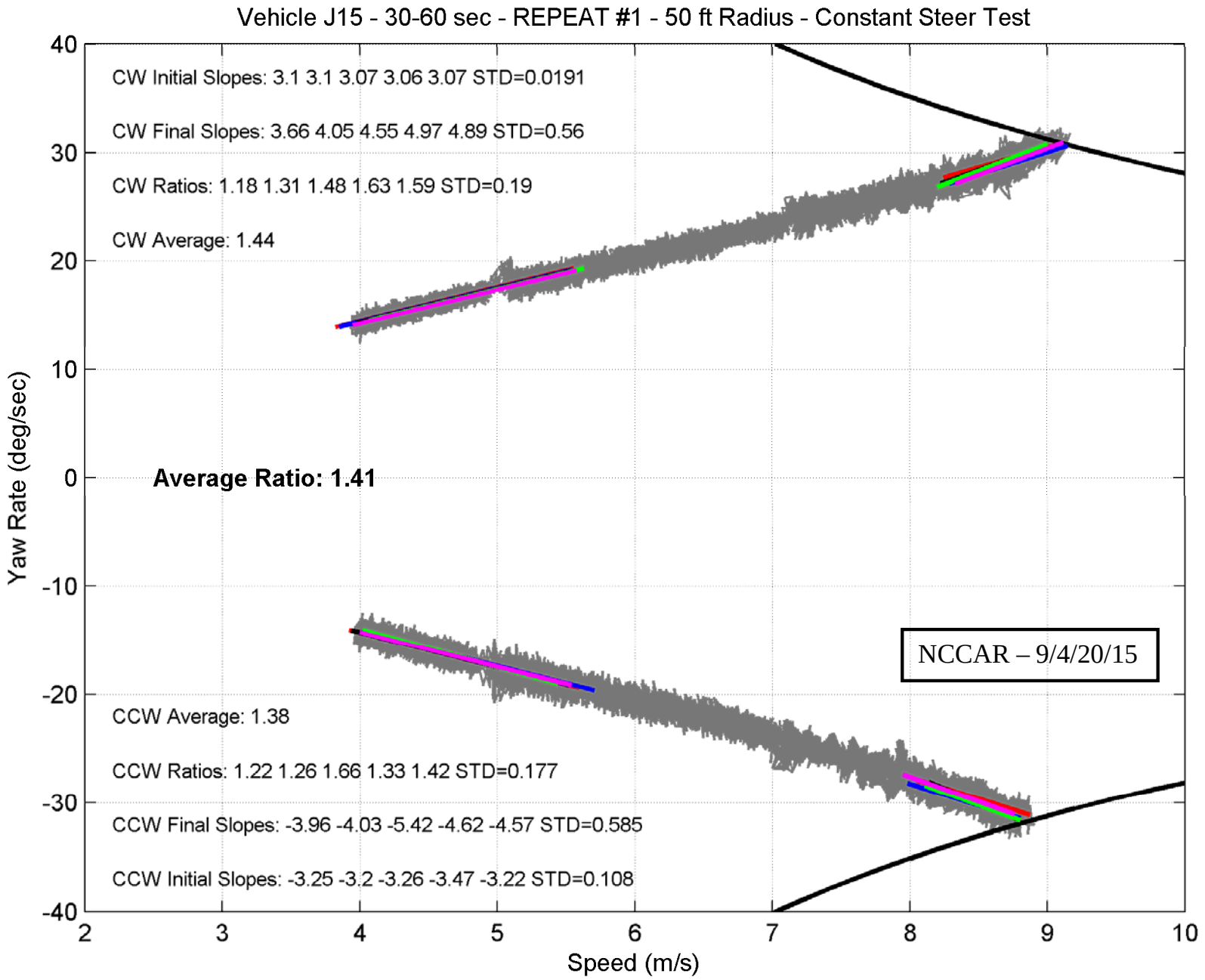
NCCAR – 9/4/20/15

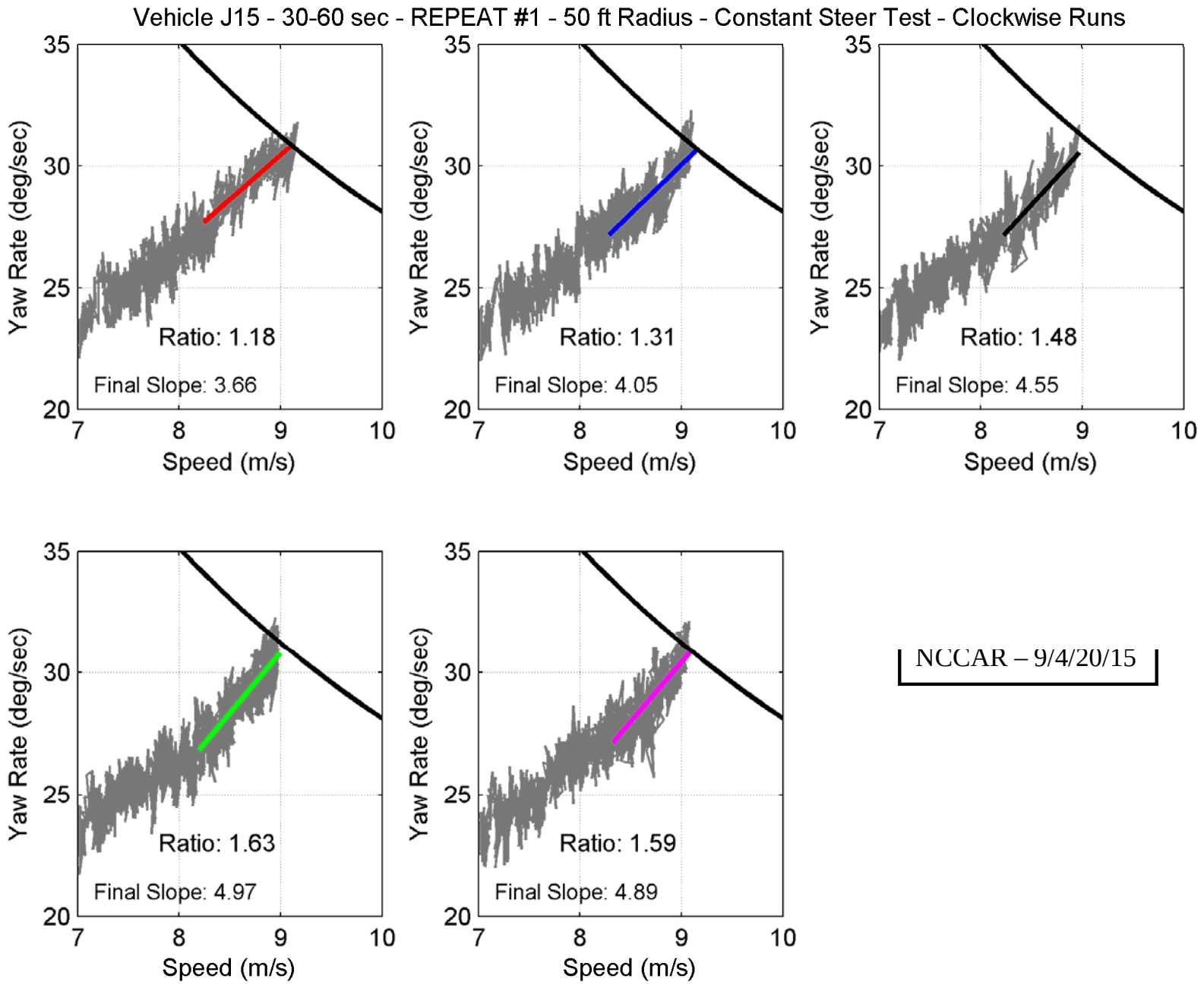

Vehicle J15 - 30-60 sec - 110% Steering - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.42 3.44 3.53 3.53 3.52 STD=0.0545
CW Final Slopes: 3.23 4.54 5.03 5.72 3.94 STD=0.962
CW Ratios: 0.945 1.32 1.43 1.62 1.12 STD=0.263
CW Average: 1.29
Average Ratio: 1.4
NCCAR – 9/4/20/15
CCW Average: 1.51
CCW Ratios: 1.42 1.27 1.39 1.77 1.7 STD=0.215
CCW Final Slopes: -5.02 -4.66 -5.22 -6.9 -6.39 STD=0.958
CCW Initial Slopes: -3.54 -3.66 -3.75 -3.89 -3.75 STD=0.129
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

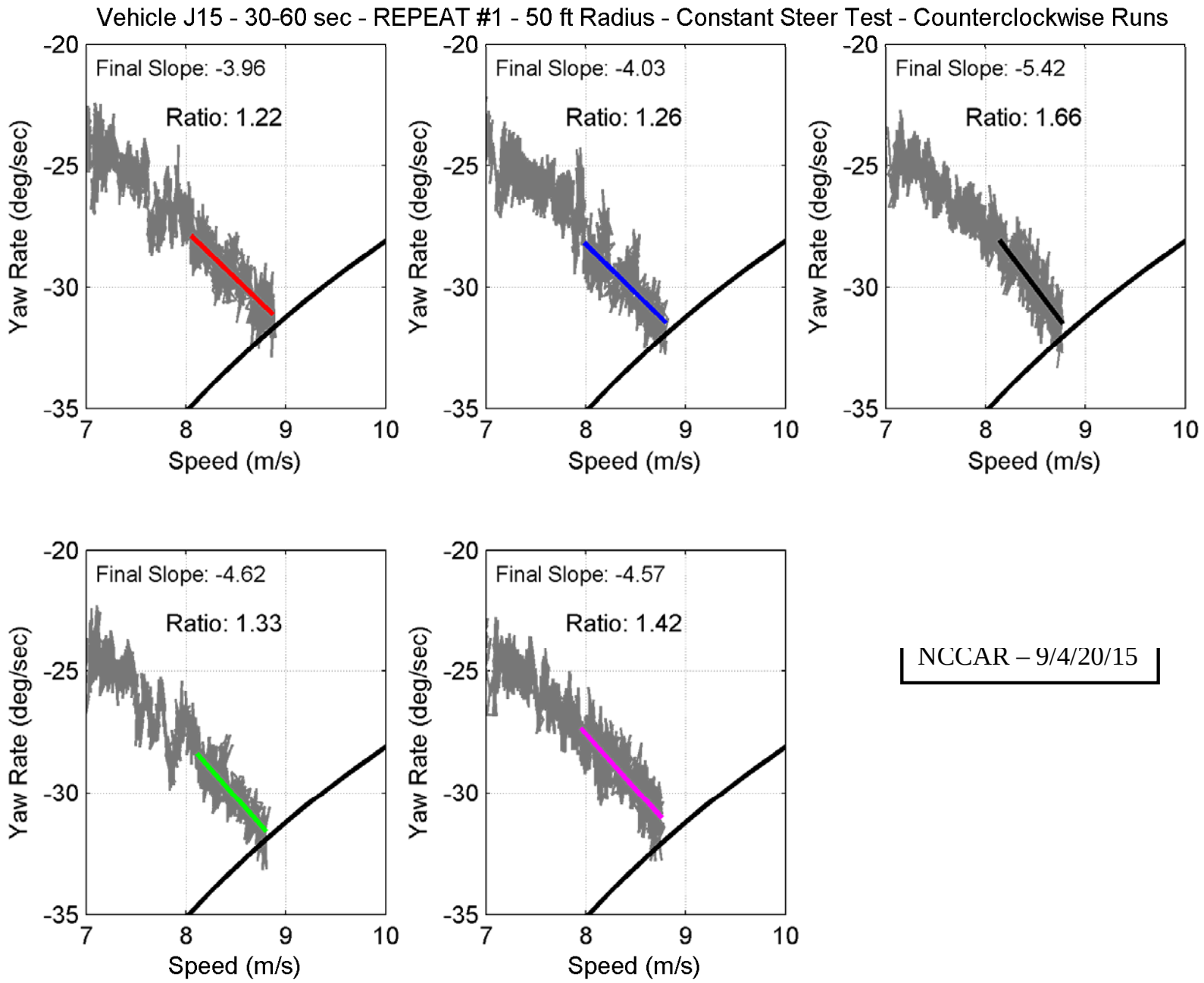


NCCAR – 9/4/20/15

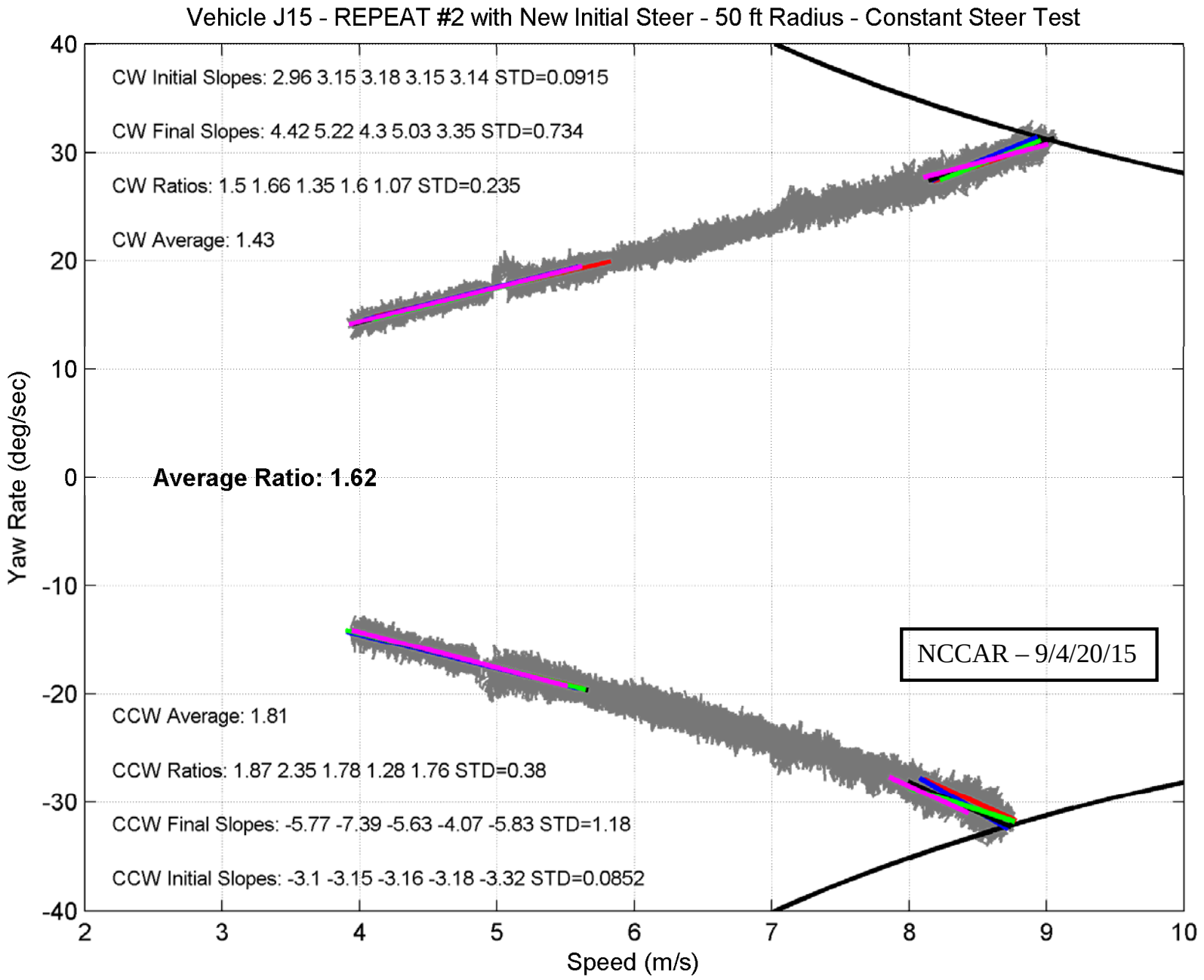

Vehicle J15 - 30-60 sec - 110% Steering - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -5.02
Ratio: 1.42
Final Slope: -4.66
Ratio: 1.27
Final Slope: -5.22
Ratio: 1.39
Final Slope: -6.9
Ratio: 1.77
Final Slope: -6.39
Ratio: 1.7
Yaw Rate (deg/sec)
Speed (m/s)
-20
-25
-30
-35
7
8
9
10
NCCAR – 9/4/20/15

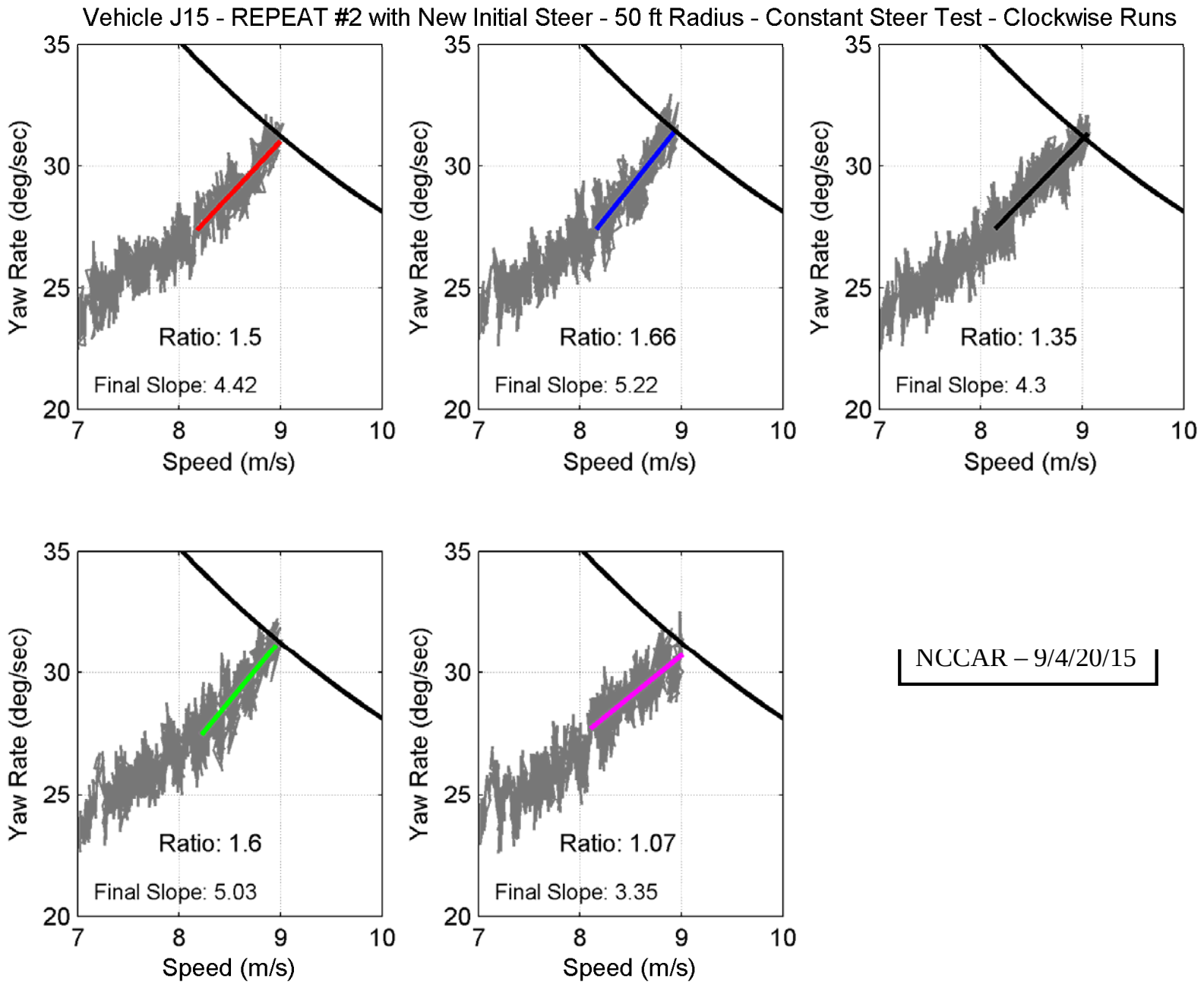

Vehicle J15 - 30-60 sec - REPEAT #1 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.1 3.1 3.07 3.06 3.07 STD=0.0191
CW Final Slopes: 3.66 4.05 4.55 4.97 4.89 STD=0.56
CW Ratios: 1.18 1.31 1.48 1.63 1.59 STD=0.19
CW Average: 1.44
Average Ratio: 1.41
NCCAR – 9/4/20/15
CCW Average: 1.38
CCW Ratios: 1.22 1.26 1.66 1.33 1.42 STD=0.177
CCW Final Slopes: -3.96 -4.03 -5.42 -4.62 -4.57 STD=0.585
CCW Initial Slopes: -3.25 -3.2 -3.26 -3.47 -3.22 STD=0.108
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

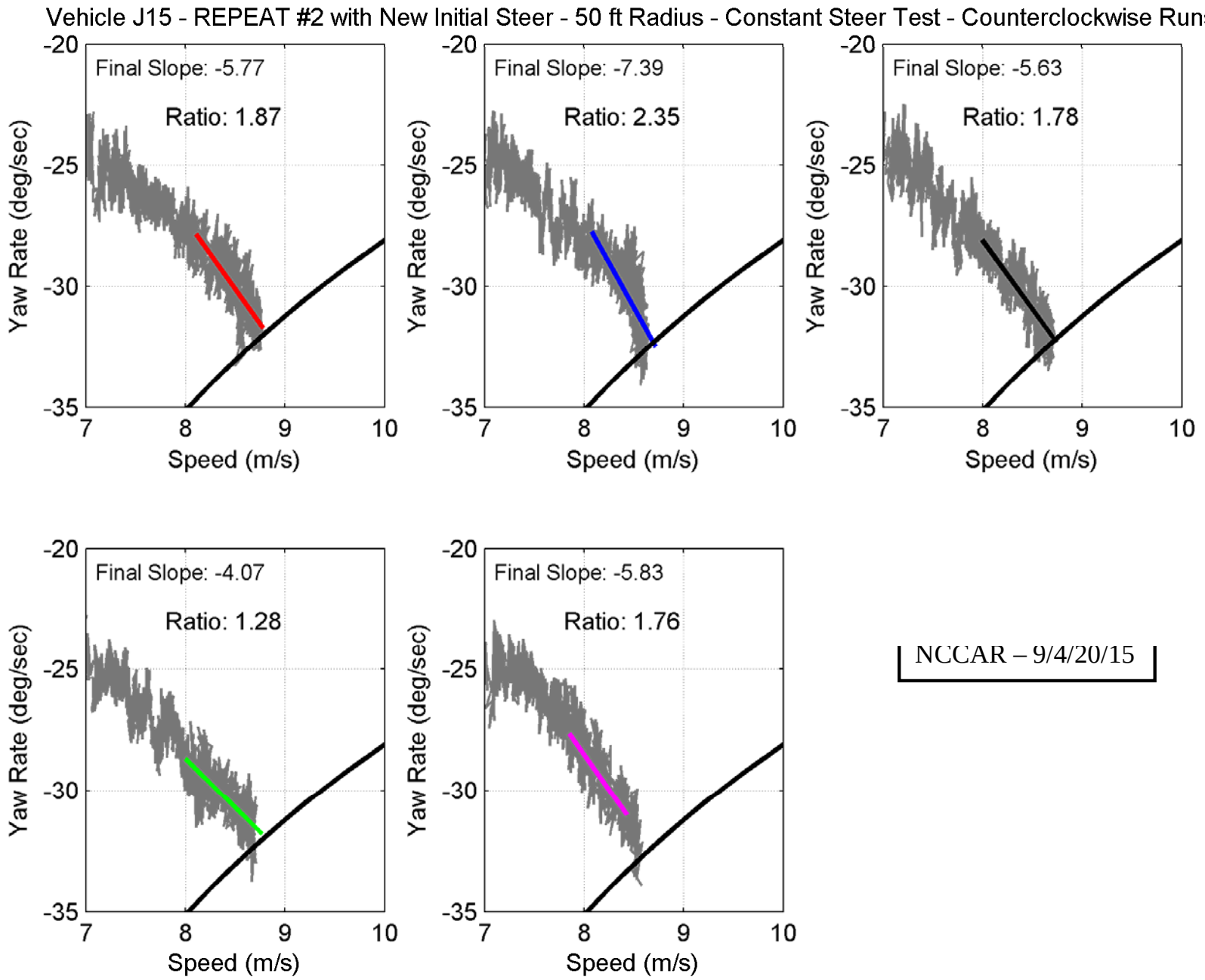

Vehicle J15 - 30-60 sec - REPEAT #1 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 1.18
Final Slope: 3.66
Ratio: 1.31
Final Slope: 4.05
Ratio: 1.48
Final Slope: 4.55
Ratio: 1.63
Final Slope: 4.97
Ratio: 1.59
Final Slope: 4.89
NCCAR – 9/4/20/15



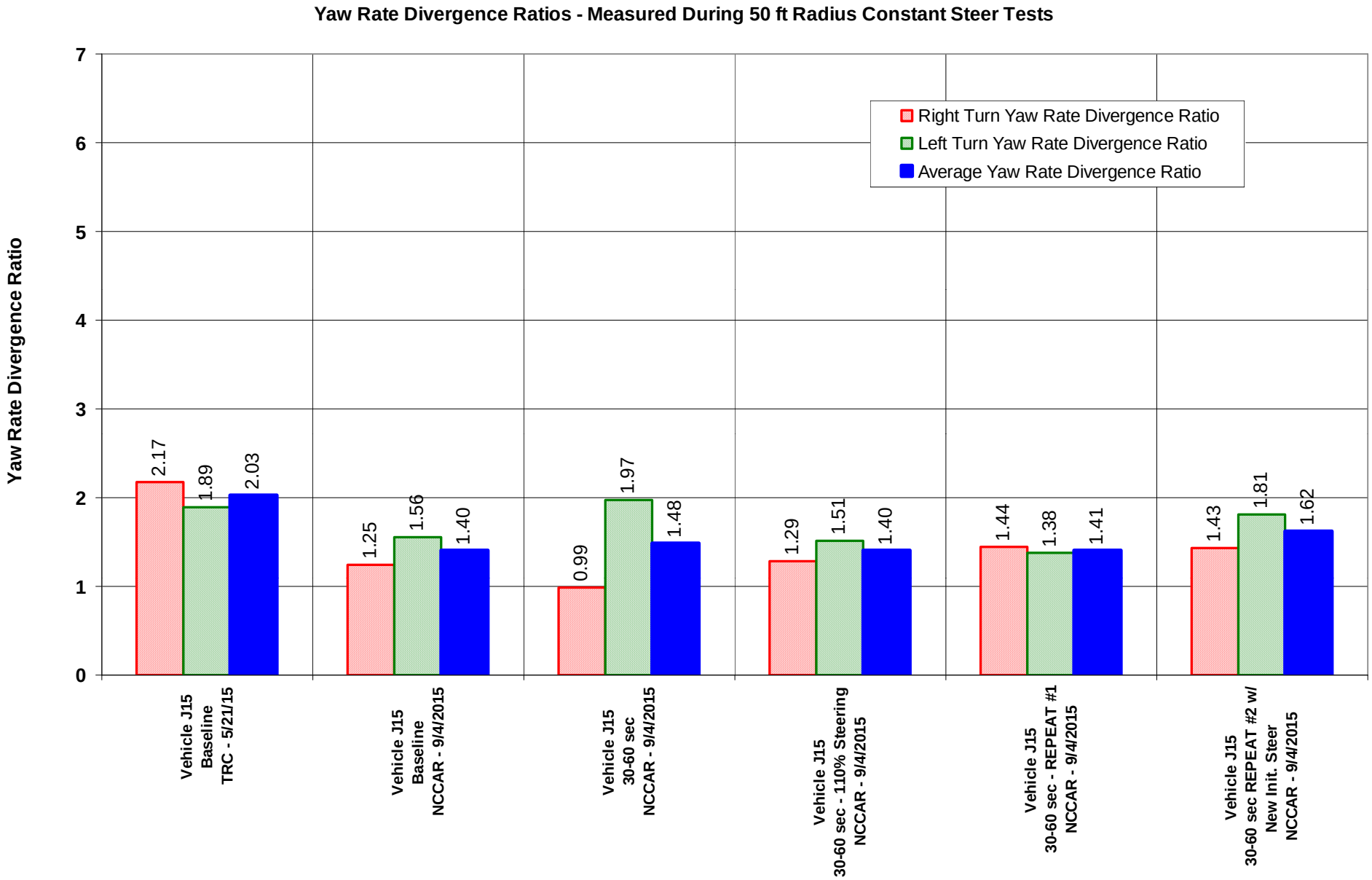
NCCAR – 9/4/20/15


Vehicle J15 - REPEAT #2 with New Initial Steer - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.96 3.15 3.18 3.15 3.14 STD=0.0915
CW Final Slopes: 4.42 5.22 4.3 5.03 3.35 STD=0.734
CW Ratios: 1.5 1.66 1.35 1.6 1.07 STD=0.235
CW Average: 1.43
Average Ratio: 1.62
NCCAR – 9/4/20/15
CCW Average: 1.81
CCW Ratios: 1.87 2.35 1.78 1.28 1.76 STD=0.38
CCW Final Slopes: -5.77 -7.39 -5.63 -4.07 -5.83 STD=1.18
CCW Initial Slopes: -3.1 -3.15 -3.16 -3.18 -3.32 STD=0.0852
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


Vehicle J15 - REPEAT #2 with New Initial Steer - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 1.5
Final Slope: 4.42
Ratio: 1.66
Final Slope: 5.22
Ratio: 1.35
Final Slope: 4.3
Ratio: 1.6
Final Slope: 5.03
Ratio: 1.07
Final Slope: 3.35
NCCAR – 9/4/20/15



NCCAR – 9/4/20/15


Yaw Rate Divergence Ratios - Measured During 50 ft Radius Constant Steer Tests
Yaw Rate Divergence Ratio
0
1
2
3
4
5
6
7
Right Turn Yaw Rate Divergence Ratio
Left Turn Yaw Rate Divergence Ratio
Average Yaw Rate Divergence Ratio
2.17
1.89
2.03
1.25
1.56
1.40
0.99
1.97
1.48
1.29
1.51
1.40
1.44
1.38
1.41
1.43
1.81
1.62
Vehicle J15 Baseline TRC - 5/21/15
Vehicle J15 Baseline NCCAR - 9/4/2015
Vehicle J15 30-60 sec NCCAR - 9/4/2015
Vehicle J15 30-60 sec - 110% Steering NCCAR - 9/4/2015
Vehicle J15 30-60 sec - REPEAT #1 NCCAR - 9/4/2015
Vehicle J15 30-60 sec REPEAT #2 w/ New Init. Steer NCCAR - 9/4/2015

Appendix G: Comments Regarding Proposed OPEI and ROHVA Protocols

Since spring 2015, CPSC staff and the CPSC contractor that conducted the yaw rate ratio testing (SEA) have been in communication with industry organizations OPEI and ROHVA regarding yaw rate ratio test protocols and protocols for computing final yaw rate ratios. This appendix provides comments regarding the current proposed OPEI and ROHVA protocols (contained in their February 2016 voluntary standards drafts), and addresses how any differences between the proposed voluntary standard protocols and the protocols used in this report generally affect the final yaw rate ratios. Currently, the test procedures (except for the tire break-in procedure) and data processing protocols in the OPEI draft voluntary standard are the same as those contained in the ROHVA draft voluntary standard.

The comments below are based in part on CPSC staff and contractor analyses of their data and test procedures using the protocols contained in the draft voluntary standards.

1. Regarding using a test duration of 90-120 seconds or 30-60 seconds (OPEI and ROHVA protocol):

   Test results contained in this report suggest that there is no discernable difference between tests conducted using a test duration of 90-120 seconds or a test duration 30-60 seconds. One OPEI member said that their testing indicated that conducting the yaw rate ratio tests in 30-60 seconds was generally easier for their test drivers to achieve smoother speed profiles than conducting the tests using longer duration. Given this, using a test duration of 30-60 seconds is appropriate.

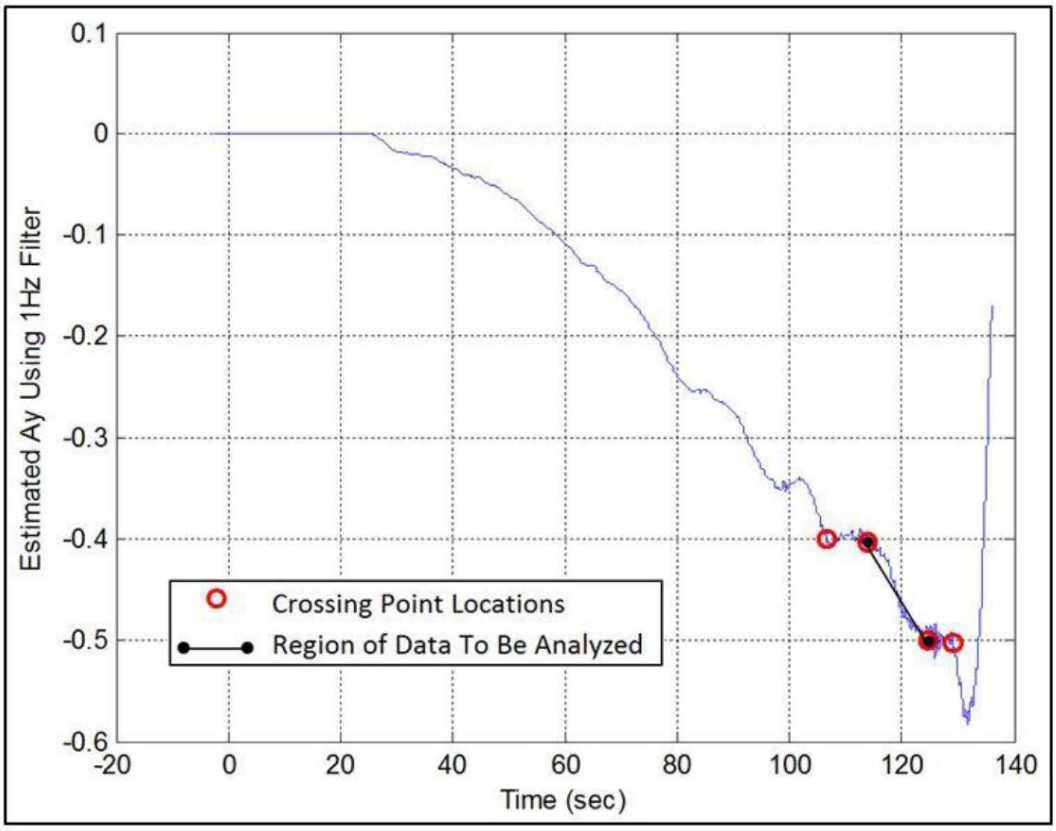
2. Regarding the use of 1 Hz versus 2 Hz low-pass filters for yaw rate and speed used to compute *Estimated Ay*:

   Using a 1 Hz low-pass filter, the filter used in the OPEI and ROHVA protocols, better smoothes the yaw rate and speed channels and thus provides a smoother *Estimated Ay*. Using 1 Hz filtered data generally expands the initial and final data regions, and it also helps mitigate selecting shorter regions based on spurious (noisy) data. Using data from a number of sets of yaw rate ratio tests, checks were made to compute final yaw rate ratio results using both 1 Hz and 2 Hz low-pass filters. Results from these checks indicated that the differences between using a 1 Hz filter or a 2 Hz filter are minimal, but the yaw rate ratios were generally somewhat greater using a 1 Hz filter. For the reasons stated above, using a 1 Hz low-pass filter is appropriate.

3. Regarding the use of continuous data to select the 0.4-0.5 g regions:

   The region selection method used for the data presented in this report takes the first instance of *Estimated* A_y crossing 0.4 g to the first instance of it crossing 0.5 g. Current protocols in the OPEI and ROHVA draft voluntary standards call for using continuous regions of *Estimated* A_y between 0.4 g and 0.5 g. The following text box and figure (from the draft voluntary standards) illustrate the OPEI and ROHVA protocol for selecting continuous regions of data.

Note: Select the first continuous zone of data where the value increases from 0.4 to 0.5g (indicated by the black line in the figure 7 below) as opposed to any momentary value that crosses the 0.4g or 0.5g line.



Using data from a number of sets of yaw rate ratio tests, checks were made to compute final yaw rate ratio results using both the first-crossing (method used for results presented in this report) and continuous (OPEI and ROHVA protocol) data regions. Results from these checks indicated that there is no difference in the regions selected in many cases, when *Estimated Ay* does not cross back-and-forth the ends of the regions. However, in cases when *Estimated Ay* does cross back-and-forth at the ends of the regions (as shown in the figure above) the continuous method for region selection generally results in steeper (greater) yaw rate slopes, and this results in somewhat higher yaw rate ratios. Using the continuous method for region selection mitigates the potential for having the *Estimated Ay* channel momentarily cross the region start threshold then drop down below the threshold (possibly as a result of a momentary drop in the vehicle speed) and re-cross the threshold as the test progresses. Based on the checks done on a number of sets of yaw rate ratio tests, and the above reasoning, using a continuous method for region selection is appropriate.

Figure G.1 is a bar chart containing results from all of the original Baseline runs re-processed using the OPEI and ROHVA protocols of using a 1.0 Hz low-pass for yaw rate

and speed to compute *Estimated Ay*, and for using continuous data to select the 0.4-0.5 g regions. The vehicles are organized from lowest to highest Average Yaw Rate Divergence Ratio, and the order of the vehicles is the same as that on Figure 1 in the body of this report. As mentioned, using the OPEI and ROHVA protocols for data reduction generally increases the yaw rate ratios beyond those shown in Figure 1 (which used a 2.0 Hz low-pass filter and a first-crossing method for determining *Estimated Ay* in the range of 0.4-0.5 g).

Variations between the use of the two different data reduction protocols was greater for the vehicles that had the highest yaw rate ratios. These vehicles with the highest yaw rate ratios exhibit divergent yaw rate responses at the ends of the tests and they have greater variations in their individual final slope ratios, and therefore they are likely less prone to providing repeatable final yaw rate ratio results.

4. Regarding the use of absolute value of *R* for the average slope ratio calculations:

   Current protocols in the OPEI and ROHVA draft voluntary standards call for computing Final Slope Ratio Right and Final Slope Ratio Left by averaging the absolute values of the individual slope ratios (*R* values) for the five runs in each direction. This is the same procedure used for results generated in this report for cases that had mixed positive and negative values individual slope ratios (i.e. both positive and negative individual *R* values during a set of yaw rate tests in the one direction).

   For some yaw rate ratio tests that exhibit significant yaw rate divergence at the end of the test, negative *R* values will arise when the measured forward vehicle speed actually decreases as yaw rate increases. (The second counterclockwise (left turn) run shown on Page 1 of Appendix A – with initial and final slopes indicated by the BLUE lines – shows an example of this.) In these cases, it is appropriate to use the absolute values of *R* in the final yaw rate ratio calculations.

   For the majority of the sets of tests presented in this report, the vehicles exhibited yaw rate divergences at the ends of the tests such that all of the individual *R* values were positive. For these cases, using the absolute values for *R* or not has no impact on the final yaw rate ratios computed.

   However, for one of the vehicles tested (Vehicle B15), all of the individual *R* values were negative. These negative *R* values occurred because the yaw rate in the final region had the opposite slope as the yaw rate in the initial region, and this phenomena can be seen on the test plots for Vehicle B15 contained on Page 7 of Appendix A. This is the vehicle that exhibited the highest degree of understeer among the vehicles tested, and its final yaw rate divergence ratios should be negative. In cases like this, it is more appropriate to not use absolute values of *R* in the final yaw rate ratio calculations.

5. Regarding the tire break-in procedures:

   The current OPEI draft voluntary standard states that the tires should be broken-in and warmed up by conducting at least five (5) J-turns in each turning direction at a speed and steering angle sufficient of achieving two-wheel lift.

   The current ROHVA draft voluntary standard states that the tires should be warmed up by conducting at least five (5) J-turns in each turning direction at a speed of 48 km/h (30 mph) using a steering input of 110 degrees.

   For all of the vehicles tested in this report: if worn tires were used, they were warmed up during instruction initialization and confirmation runs; if new tires were used on the dates the baseline tests were conducted, the tire break-in procedure included at least four (4) J-turns (in each turn direction) that resulted in two-wheel lift and two 100 ft constant radius circle test (in each turn direction); and if new tires were used on dates of repeat tests, the tire break-in procedure included at least two circle tests (in each turn direction) up to the limits of the test (either two-wheel lift or loss of circle holding capability).

   Using any of the tire break-in procedures listed above should be sufficient to wear off any tire sheen typically found on new tires and scrub off the outside corners of the tire treads. A single circle test generally wears a tire more than a single J-turn test, because the duration of the test at moderate to high lateral acceleration levels is longer. Likewise, the yaw rate ratio tests themselves generally cause a fair amount of tire wear. Based on the results of the tests included in this report, it is difficult to make any definitive comments on a new tire break-in procedure needed prior to running yaw rate ratio tests, or to make any definitive comments on how tire wear affects the final yaw rate ratios after numerous sets of tests are conducted using the same tires.

6. Regarding the center-of-gravity (CG) height of the test load representing the weight of two occupants:

   For the yaw rate ratio tests (on vehicles with more than one seating position), the test load is the weight of the test driver, test instrumentation and safety outriggers; and it is specified to be 195 (kg) (430 lb), representing the weight of two 97.5 kg (215 lb) occupants. Current protocols in the OPEI and ROHVA draft voluntary standards call for distributing the test load to simulate the CG location of two occupants. Both the OPEI and ROHVA draft standards call for distributing the test load such that the CG height of the test load is 6 inches above the lowest point of the occupant-supporting surface. Using a test load with a CG height of 6 inches above the lowest seating position is specified in numerous existing off-road industry standards.

   For the tests conducted for CPSC by SEA, the test load was located at a CG height close to 10 inches. SEA has historically used this value based on literature containing measurements of CG heights for seated humans.

The yaw rate ratio test is a steady-state directional control test, and at steady-state conditions, the ground plane lateral acceleration is equal to yaw rate times vehicle speed. This is generally not true during typical driving or during any dynamic tests that are not at a steady-state condition. During dynamic, non-steady-state conditions, center-of-gravity height and other vehicle properties that influence roll dynamics have a significant effect on the lateral acceleration of a vehicle. However, for the yaw rate ratio tests, which evaluate only the yaw plane handling dynamics of a vehicle, the differences between using 6 inches or 10 inches for the CG height of the test load are thought to have an insignificant effect on the measured yaw rate ratios. For this reason, using a test load CG height of 6 inches above the lowest occupant-support surface is appropriate.

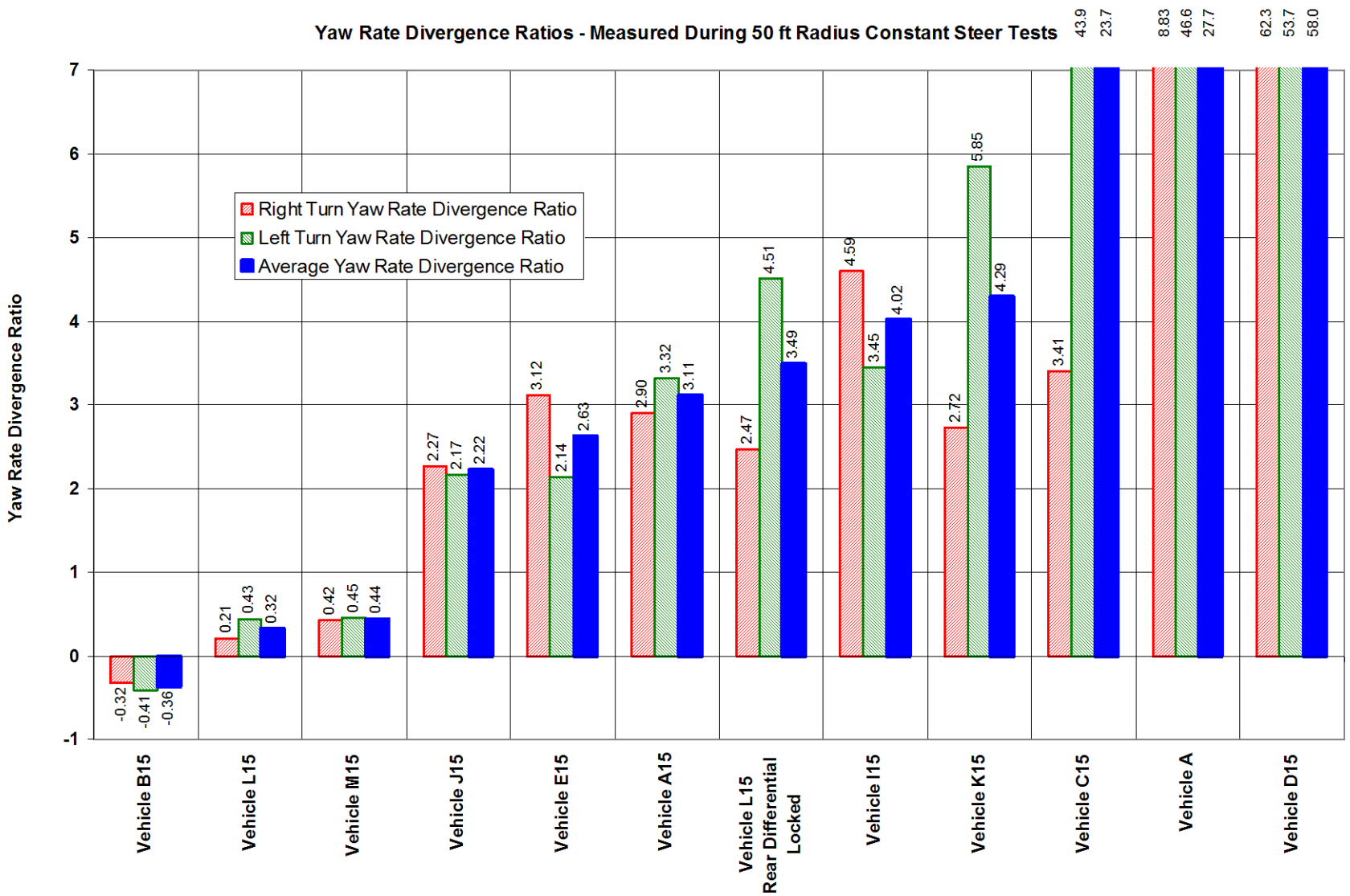


Figure G.1: Results from Baseline Tests on all 11 Vehicles – Using OPEI and ROHVA Data Processing, Including: Using 1.0 Hz Low-Pass Filters for Yaw Rate and Speed used to Compute *Estimated Ay*, and Using Continuous Data to Select the 0.4-0.5 g Regions