U.S. CONSUMER PRODUCT SAFETY COMMISSION
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August 21, 2015

Mr. Greg Knott
Vice President, Regulatory Affairs
Outdoor Power Equipment Institute
341 South Patrick Street
Alexandria, VA 22314

Dear Mr. Knott:

On July 7, 2015, U.S. Consumer Product Safety Commission ("CPSC") staff sent a comment letter to the Outdoor Power Equipment Institute ("OPEI") on the pre-canvass draft of ANSI/OPEI B71.9-201X, *American National Standard for Multipurpose Off-Highway Utility Vehicles*.[1] CSPC staff commented that OPEI's introduction of vehicle handling requirements to avoid divergent instability in recreational off-highway vehicles ("ROVs") was encouraging and that staff had contracted SEA Limited ("SEA") to conduct yaw rate ratio tests of several ROVs in accordance with the protocols described in the ANSI/OPEI B71.9-201X pre-canvass draft. Test results of yaw rate ratios for nine vehicles that had been tested by SEA were attached to staff's letter.

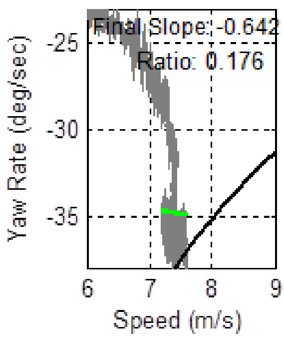
At a public meeting on July 8, 2015, CPSC staff and OPEI members discussed the comments in staff's letter and the test data.[2] Staff expressed concern that vehicles that exhibit divergent instability would pass the yaw rate ratio performance requirement in ANSI/OPEI B71.9-201X. At this meeting, CPSC staff committed to providing OPEI members with a magnified view of the yaw rate data between 0.4 g and 0.5 g of the estimated lateral acceleration for each vehicle tested. These enlarged plots are included in Appendix A-*Yaw Rate Ratio Test Result – OPEI Method for Slope Determinations* and Appendix B -*Yaw Rate Ratio Test Result – Slopes Normalized to Speed*.

Upon further review of the yaw rate data between 0.4 g and 0.5 g of estimated lateral acceleration in the test data in Appendix A, staff believes the OPEI proposed method for

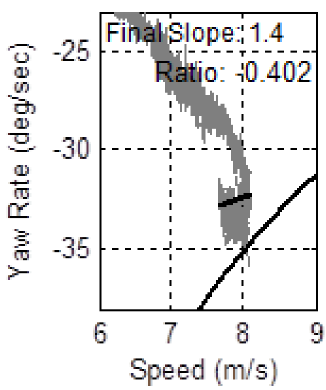
[1] The comments in this letter are those of the CPSC staff and have not been reviewed or approved by, and may not necessarily reflect the views of, the Commission.
[2]Meeting log dated July 8, 2015. Retrieved at: http://www.cpsc.gov//Global/Regulations-Laws-and-Standards/Voluntary-Standards/ROHVA/070715CPSClettertoOPEIcommenttoprecanvassdraft%20ANSIOPEIB719201X.pdf

determining slopes of the data may not always produce line slopes that accurately represent the underlying data. Staff has observed that for some vehicles, the line fitting algorithm will occasionally plot line fits that are clearly not representative of the final slope data. This line fitting anomaly has not been observed for initial slopes at the start of the test and only occurs when plotting linear fits in the 0.4 g to 0.5 g range of estimated lateral acceleration.

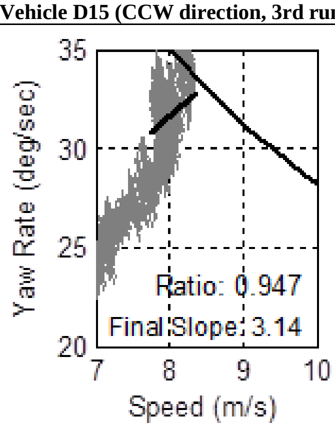
Line fit by OPEI proposed method



Vehicle C15 (CCW direction, 4th run)



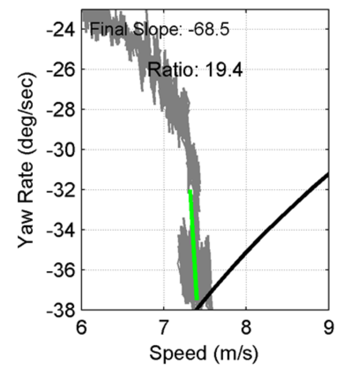
Vehicle D15 (CCW direction, 3rd run)



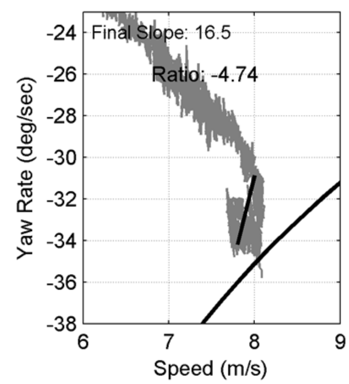
Vehicle I15 (CW direction, 3rd run)

Figure 1. Examples of linear fit lines that do not capture underlying yaw rate data from 0.4 g to 0.5 g of estimated lateral acceleration. (plots from pages 12, 15, and 20 of Appendix A)

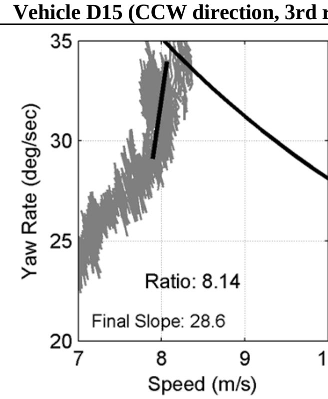
Line fit by suggested modified method



Vehicle C15 (CCW direction, 4th run)



Vehicle D15 (CCW direction, 3rd run)



Vehicle I15 (CW direction, 3rd run)

Figure 2. Examples of linear fit lines normalized for speed from 0.4 g to 0.5 g of estimated lateral acceleration. (plots from pages 12, 15, and 20 of Appendix B)

As shown in Figure 1, the method proposed in ANSI/OPEI B71.9-201X may result in line fits that do not represent the real data trend for vehicles exhibiting divergent instability (as evidenced by the asymptotic yaw rate gains shown in the plotted data). In addition, the slopes of the line fits in Figure 1 contribute to artificial reductions in average yaw rate ratio values that could incorrectly allow vehicles to pass the vehicle handling performance requirement in ANSI/OPEI B71.9-201X.

Staff believes the underlying data generated by the yaw rate ratio test provides an accurate picture of the vehicle's handling, and can be used to determine whether a vehicle exhibits divergent instability. However, CPSC staff, with information from SEA, has noticed that the ANSI/OPEI B71.9-201X line fit method is skewed by its sensitivity to variations in vehicle speed, which can cause the data to "bunch" at sections where the speed increase is relatively slow. This phenomenon causes the line fit to favor the "data dense" portions of the fit range (see Figure 1, above).

Yaw rate ratios based on slopes of lines that fit the yaw rate data well are more reliable predictors of how the vehicle handles and whether the vehicle will exhibit divergent instability. Therefore, CPSC staff suggests that OPEI explore other linear curve fit methods to ensure that the resultant lines accurately represent the real data. Staff also suggests that a more accurate line fit can be obtained by using a method developed by SEA, which normalized each final slope plot by dividing the slope of the yaw rate by the slope of the speed between 0.4 g and 0.5 g of estimated lateral acceleration for each run. As shown in Figure 2, this method uses the same underlying data and appears to provides a more accurate line fit of the yaw rate between 0.4 g and 0.5 g of estimated lateral acceleration. Appendix C provides a more in-depth explanation of the Matlab routine used to compute the least-squares linear fit of each slope and the method to normalize the yaw rate slope.

Staff supports OPEI's effort to base a vehicle handling requirement on the yaw rate ratio tests and is attaching test results for 11 vehicles tested by SEA in Appendix A and Appendix B. Appendix A - *Yaw Rate Ratio Test Result – OPEI Method for Slope Determinations,* includes magnified portions of the final slopes between 0.4 g and 0.5 g of estimated lateral acceleration for each test run. The final slopes were calculated using the protocol proposed in ANSI/B71.9-201X. Appendix B -*Yaw Rate Ratio Test Result – Slopes Normalized to Speed*, includes the same data of the 11 vehicles tested, but the magnified portions of the final slopes show the line fit using data that has been normalized for vehicle speed. Of interest is the difference in how well the line fits match the trend of the data and the associated final slope values that reflect the yaw rate gain. For example, in Appendix B (page 14) for Vehicle D15 in the clockwise runs, the slopes more clearly show the vertical yaw rate gain, indicating a spin-out prior to 0.5 g, than the slopes in Appendix A for the same vehicle (page 14 of Appendix A). At the OPEI meeting, there was general agreement that such a vertical end slope should constitute a failure, and staff believes that the new method for calculating slopes results in clarification of this behavior.

CPSC staff intends to continue conducting yaw rate ratio tests of ROVs on different test surfaces to study any potential effects of test surface friction on yaw rate slopes. Variability in yaw rate slopes is an important factor in determining an appropriate vehicle handling performance requirement to ensure that ROVs do not exhibit divergent instability. Staff believes it is important to validate and verify the test method and performance requirement. As part of the validation process, staff continues to believe that vehicle handling requirements should not allow obvious signs of divergent instability, such as negative, vertical, or near-vertical yaw rate end slopes, in either turn direction of the vehicle. Staff believes that with better line fitting of the data, as described in this letter, the proposed OPEI yaw rate test can better be used to distinguish this behavior, as shown in Appendix B.

Staff hopes that the data in Appendix A and Appendix B can be discussed at a public meeting in the near future, and we would be pleased to host the meeting at our facility in Rockville, MD. CPSC staff looks forward to continued communication with OPEI regarding the ANSI/OPEI B71.9-201X draft standard. If you have any questions or comments, please feel free to contact me.

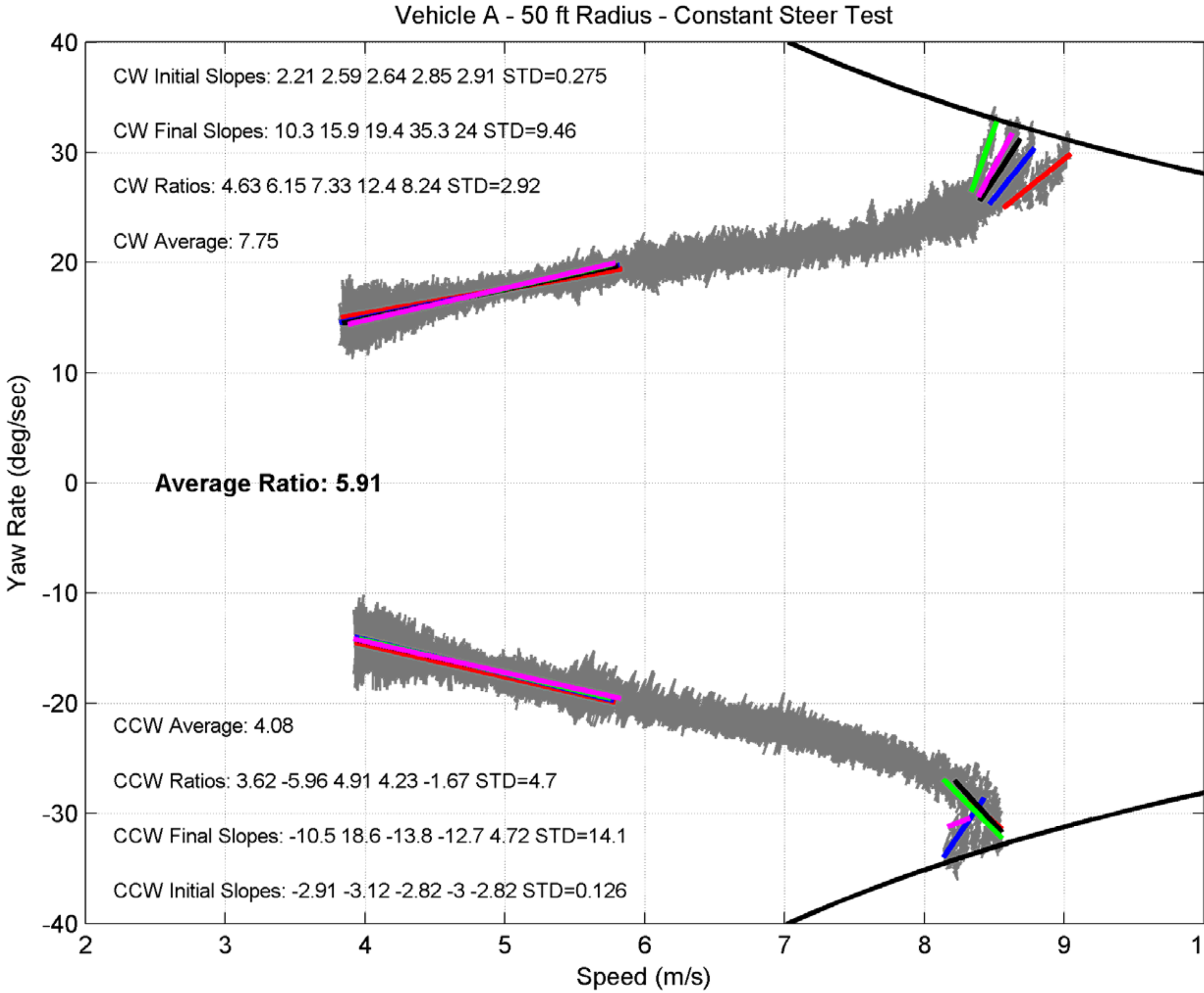
Sincerely,

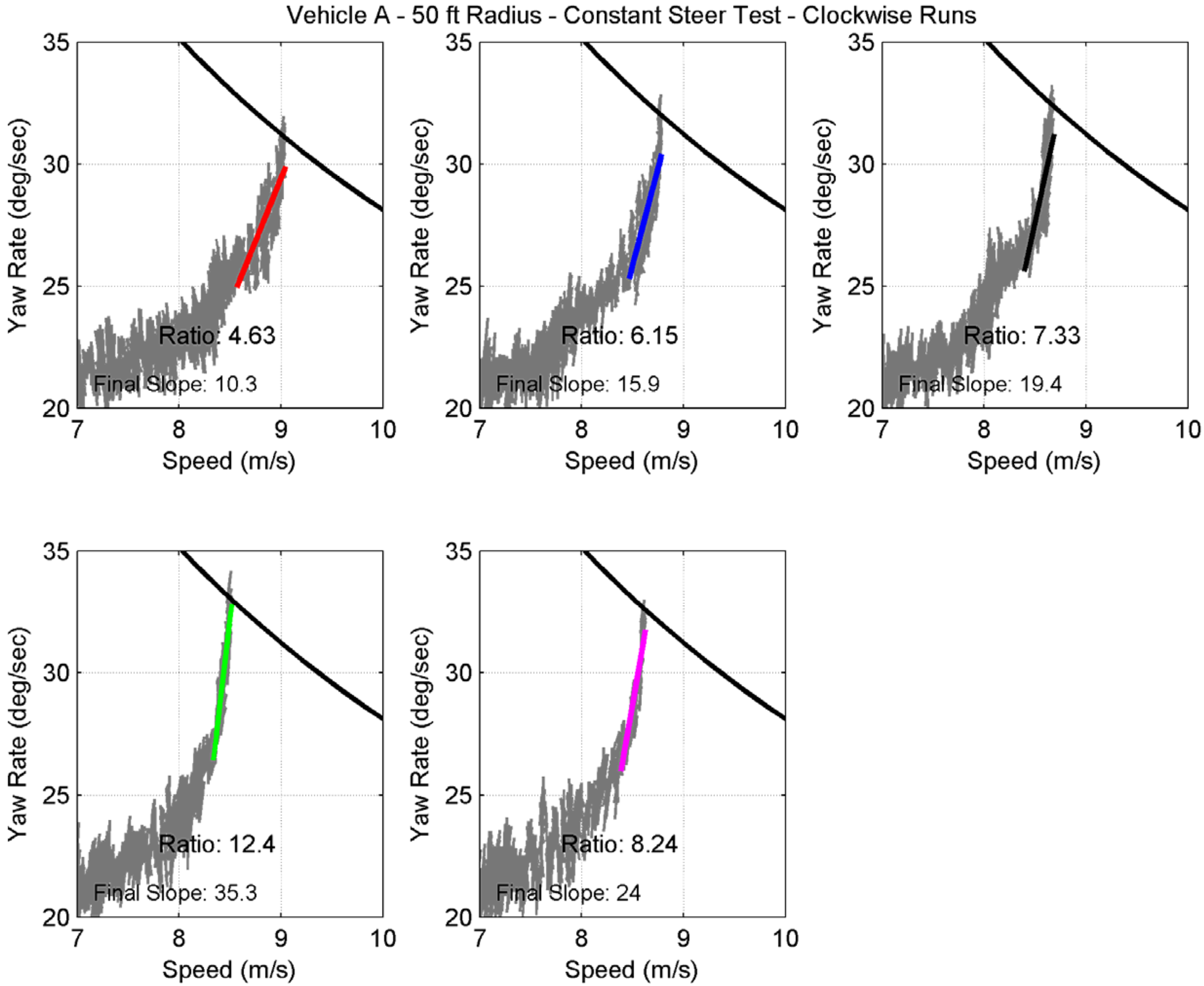
Caroleene Paul

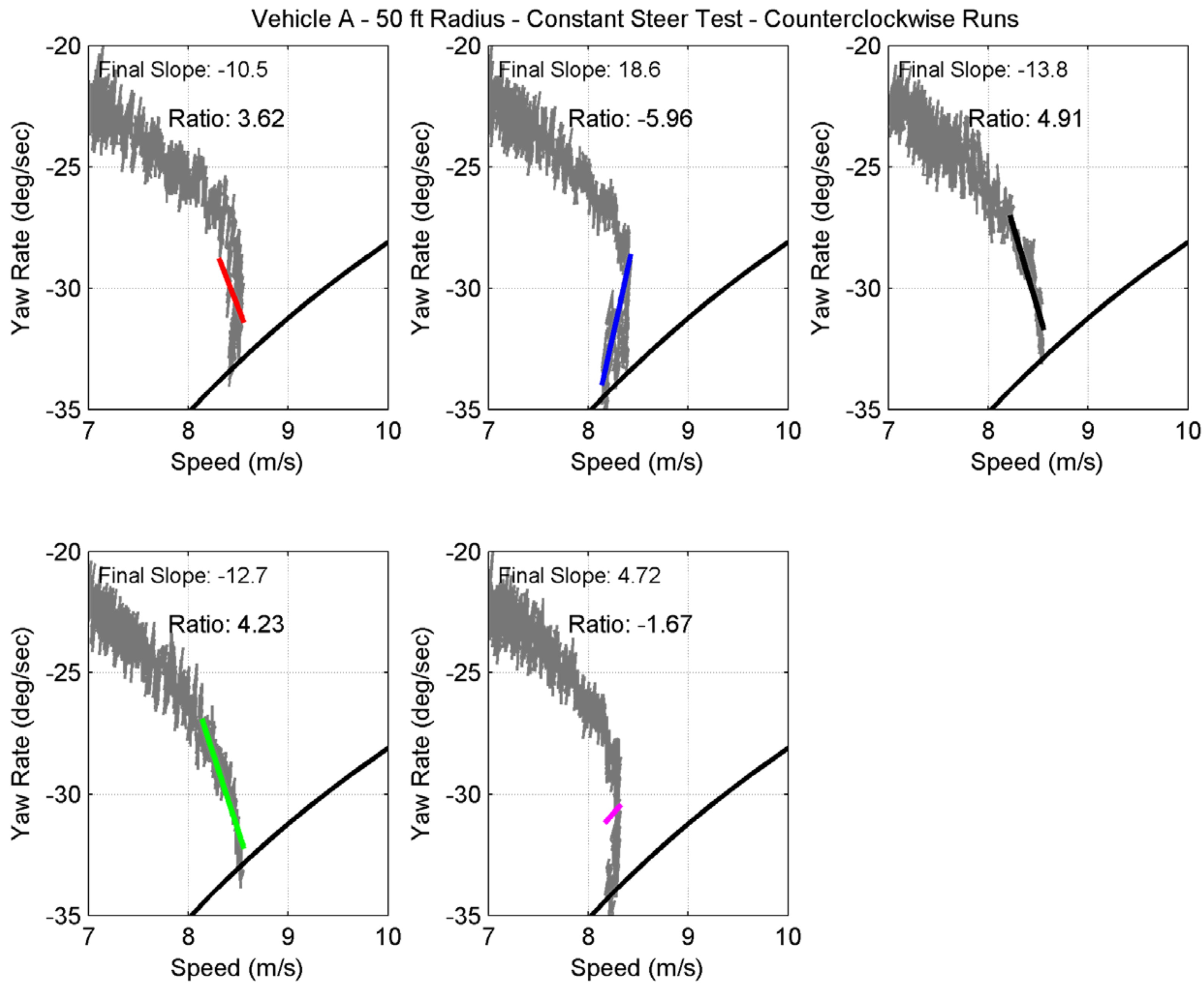
cc: Erik Pritchard, ROHVA
Colin Church, CPSC Voluntary Standards Coordinator

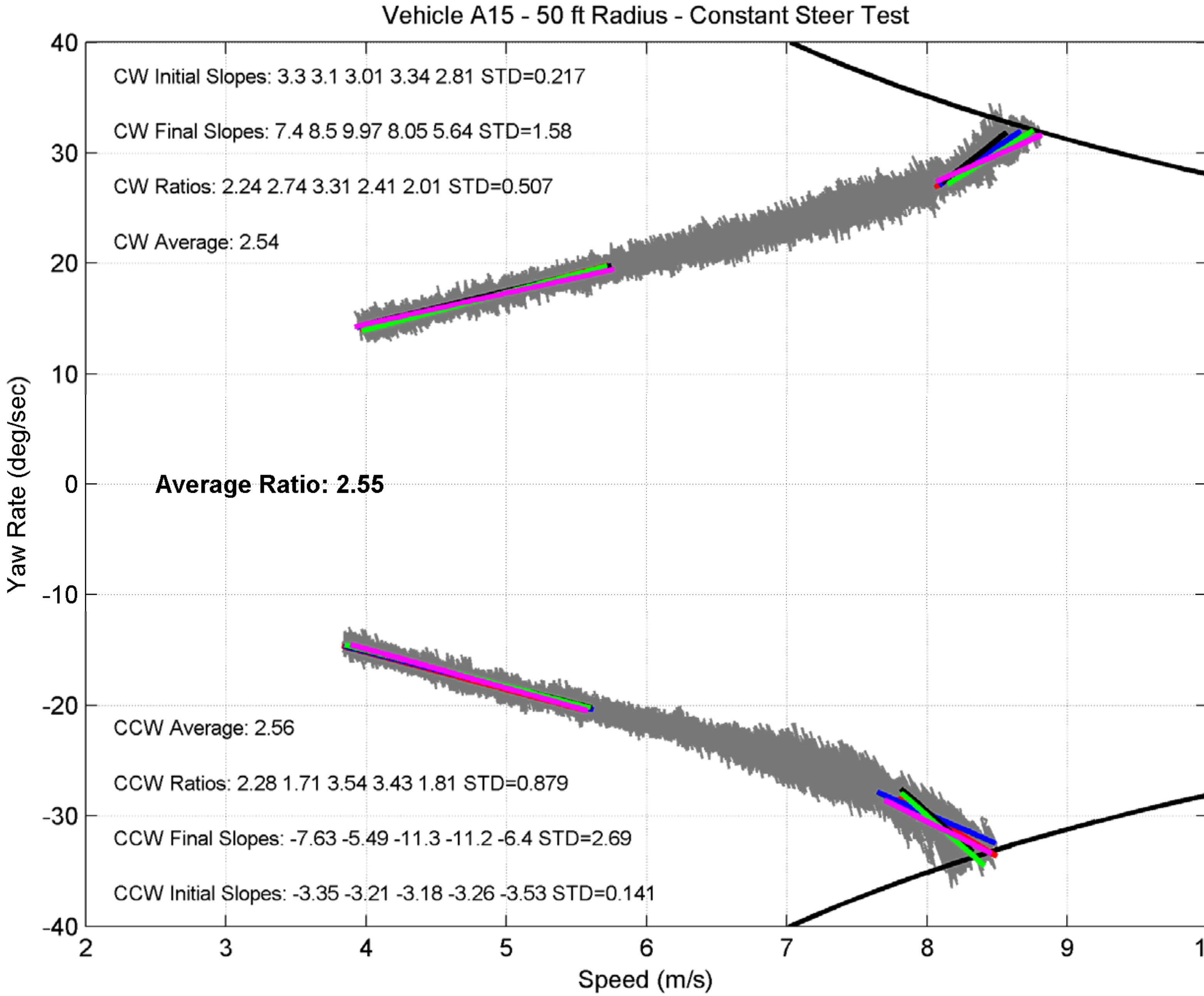
Appendix A

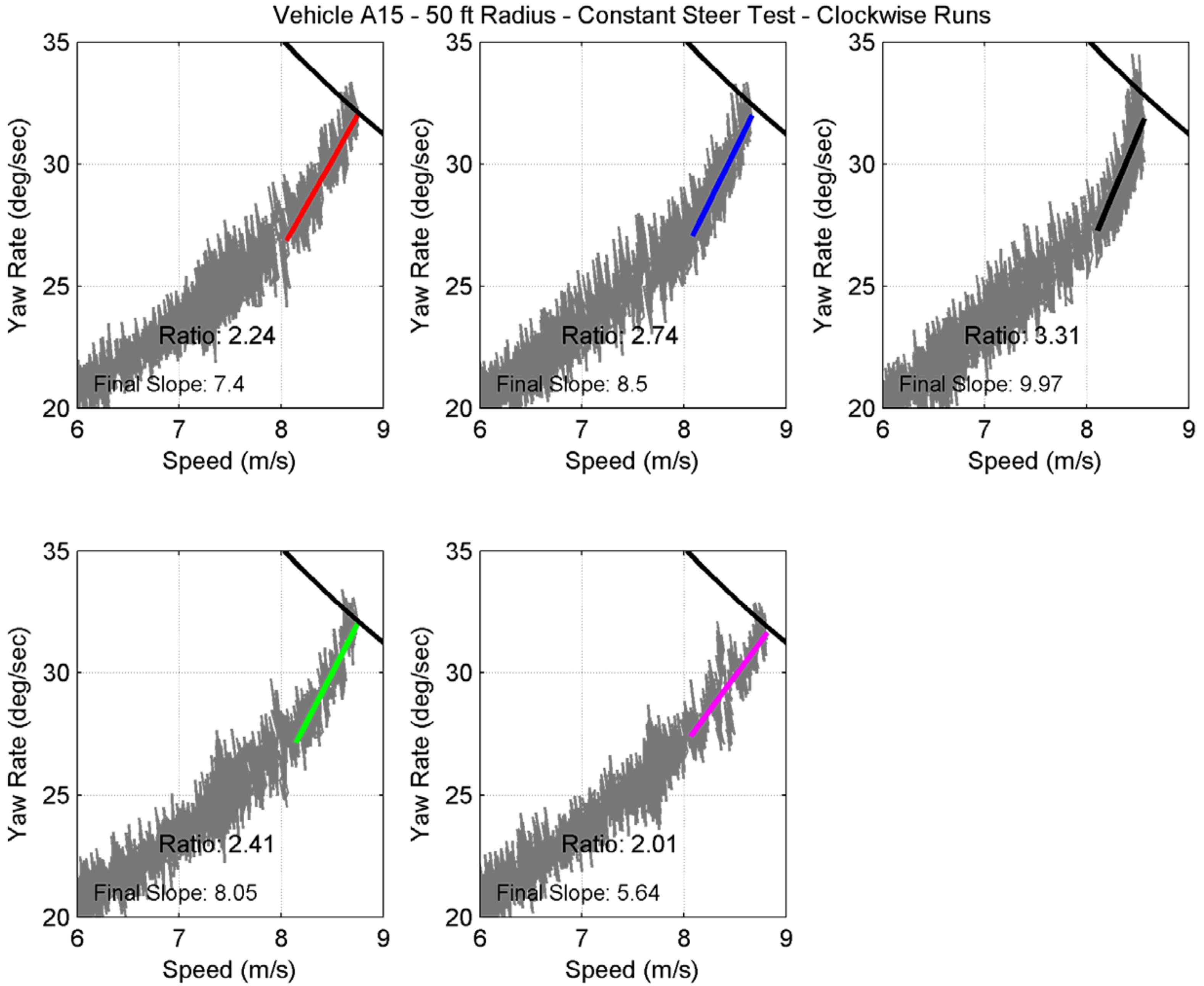
Yaw rate ratio test data of 11 ROVs using line fit formula specified in pre-canvass draft ANSI/OPEI B71.9-201X.


Vehicle A - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.21 2.59 2.64 2.85 2.91 STD=0.275
CW Final Slopes: 10.3 15.9 19.4 35.3 24 STD=9.46
CW Ratios: 4.63 6.15 7.33 12.4 8.24 STD=2.92
CW Average: 7.75
Average Ratio: 5.91
CCW Average: 4.08
CCW Ratios: 3.62 -5.96 4.91 4.23 -1.67 STD=4.7
CCW Final Slopes: -10.5 18.6 -13.8 -12.7 4.72 STD=14.1
CCW Initial Slopes: -2.91 -3.12 -2.82 -3 -2.82 STD=0.126
Yaw Rate (deg/sec)
Speed (m/s)
40
30
20
10
0
-10
-20
-30
-40
2
3
4
5
6
7
8
9
10

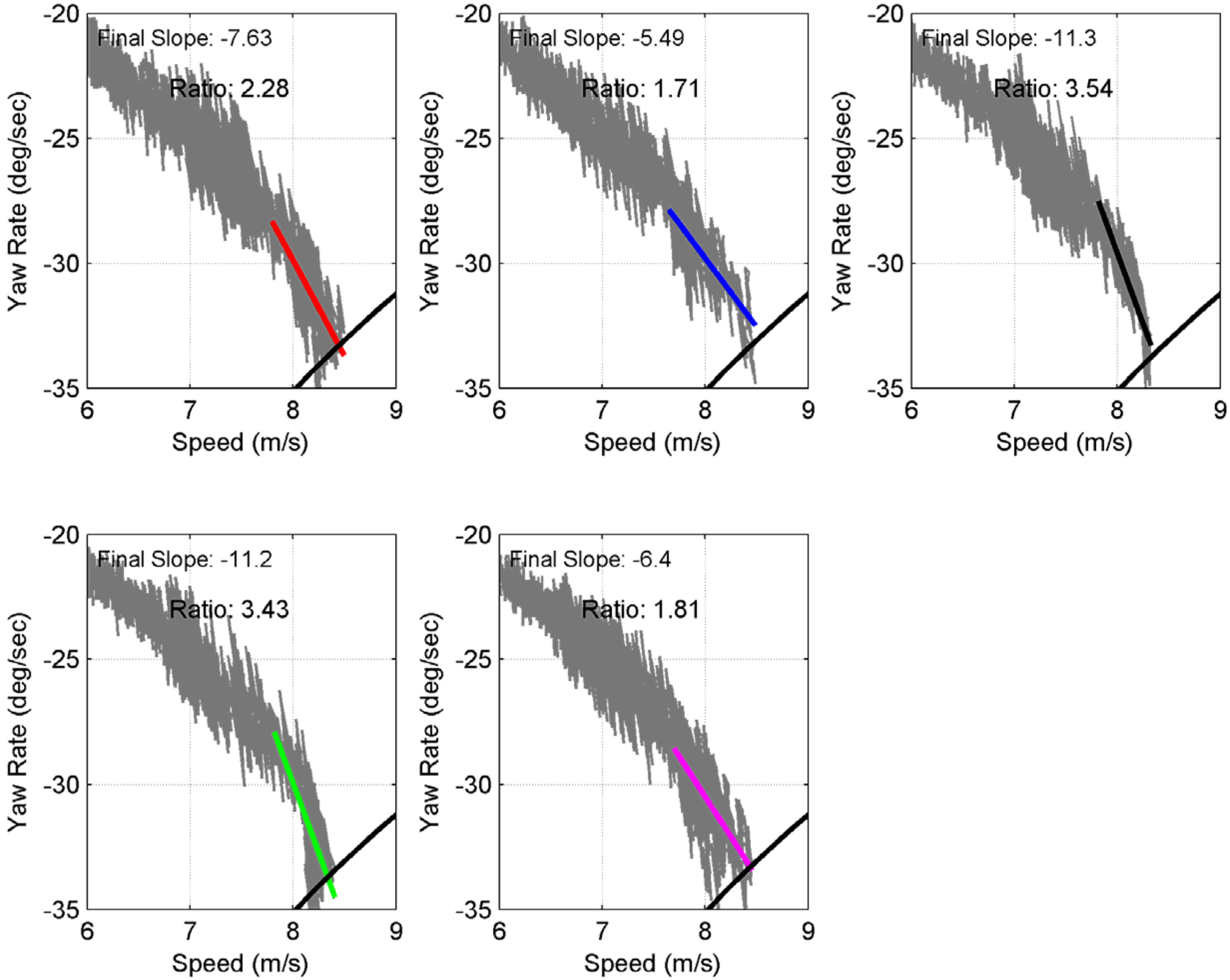

Vehicle A - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 4.63
Final Slope: 10.3
Ratio: 6.15
Final Slope: 15.9
Ratio: 7.33
Final Slope: 19.4
Ratio: 12.4
Final Slope: 35.3
Ratio: 8.24
Final Slope: 24

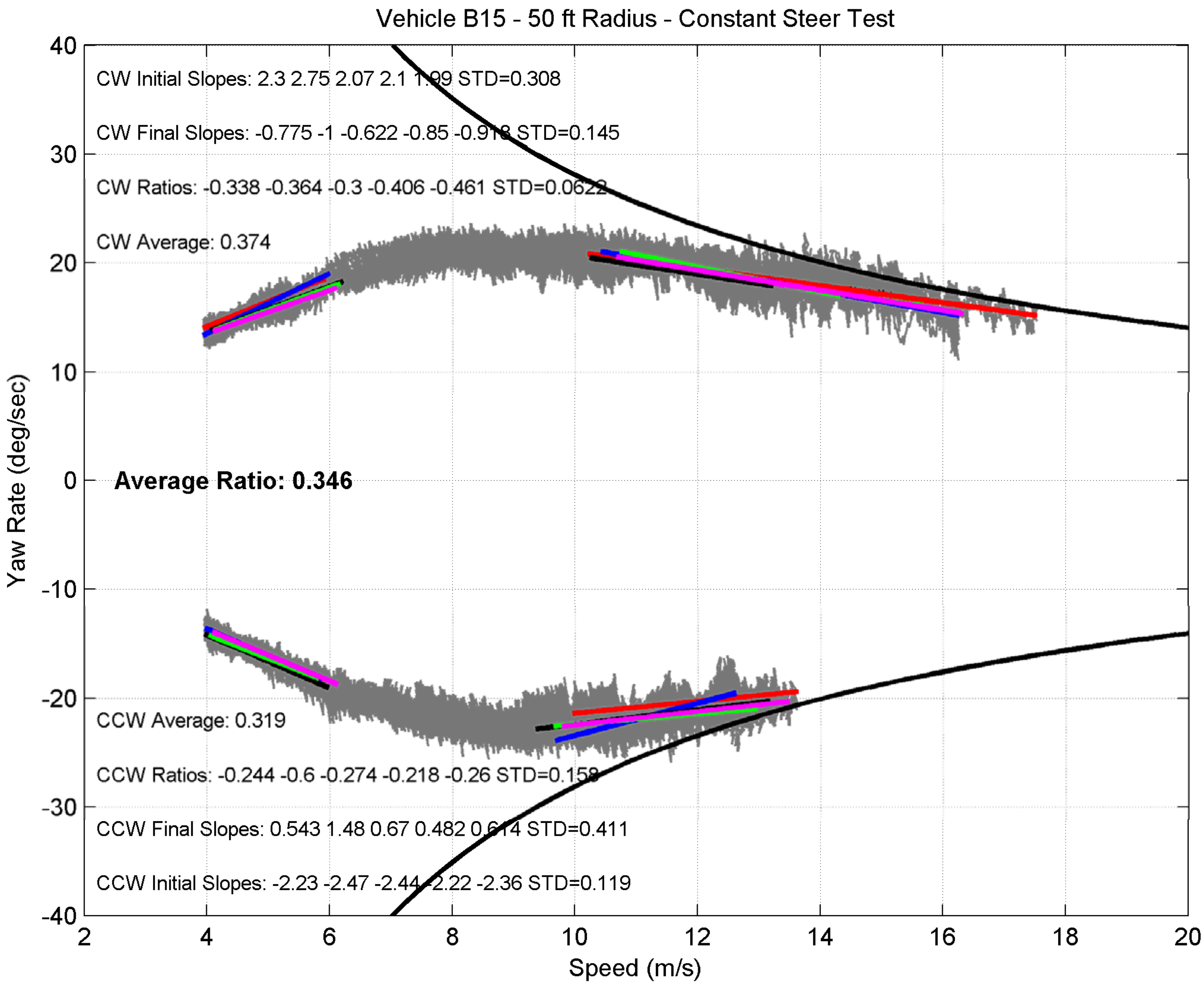

Vehicle A - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -10.5
Ratio: 3.62
Final Slope: 18.6
Ratio: -5.96
Final Slope: -13.8
Ratio: 4.91
Final Slope: -12.7
Ratio: 4.23
Final Slope: 4.72
Ratio: -1.67
Yaw Rate (deg/sec)
Speed (m/s)
-20
-25
-30
-35
7
8
9
10

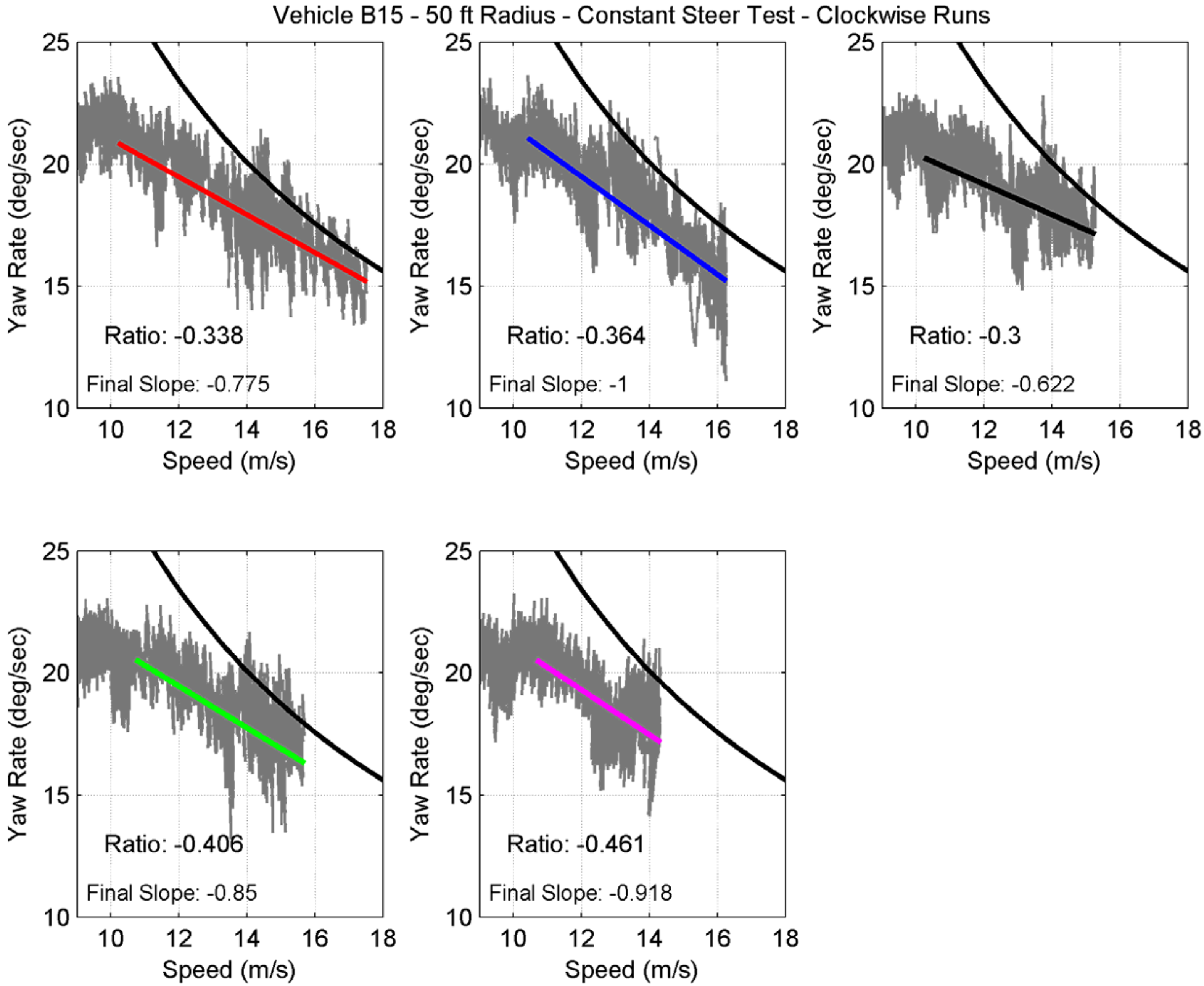

Vehicle A15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.3 3.1 3.01 3.34 2.81 STD=0.217
CW Final Slopes: 7.4 8.5 9.97 8.05 5.64 STD=1.58
CW Ratios: 2.24 2.74 3.31 2.41 2.01 STD=0.507
CW Average: 2.54
Average Ratio: 2.55
CCW Average: 2.56
CCW Ratios: 2.28 1.71 3.54 3.43 1.81 STD=0.879
CCW Final Slopes: -7.63 -5.49 -11.3 -11.2 -6.4 STD=2.69
CCW Initial Slopes: -3.35 -3.21 -3.18 -3.26 -3.53 STD=0.141
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

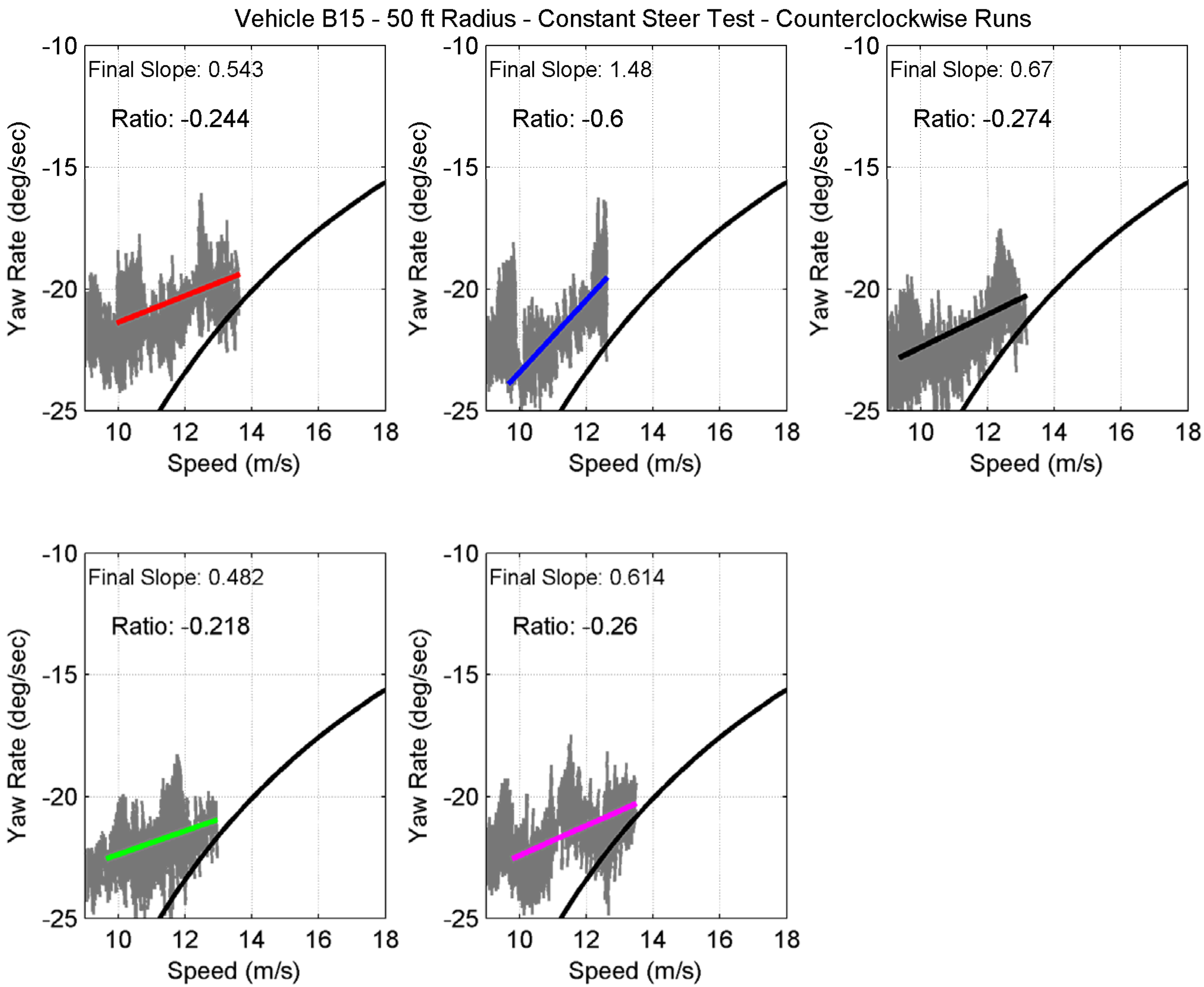

Vehicle A15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 2.24
Final Slope: 7.4
Ratio: 2.74
Final Slope: 8.5
Ratio: 3.31
Final Slope: 9.97
Ratio: 2.41
Final Slope: 8.05
Ratio: 2.01
Final Slope: 5.64

Vehicle A15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs

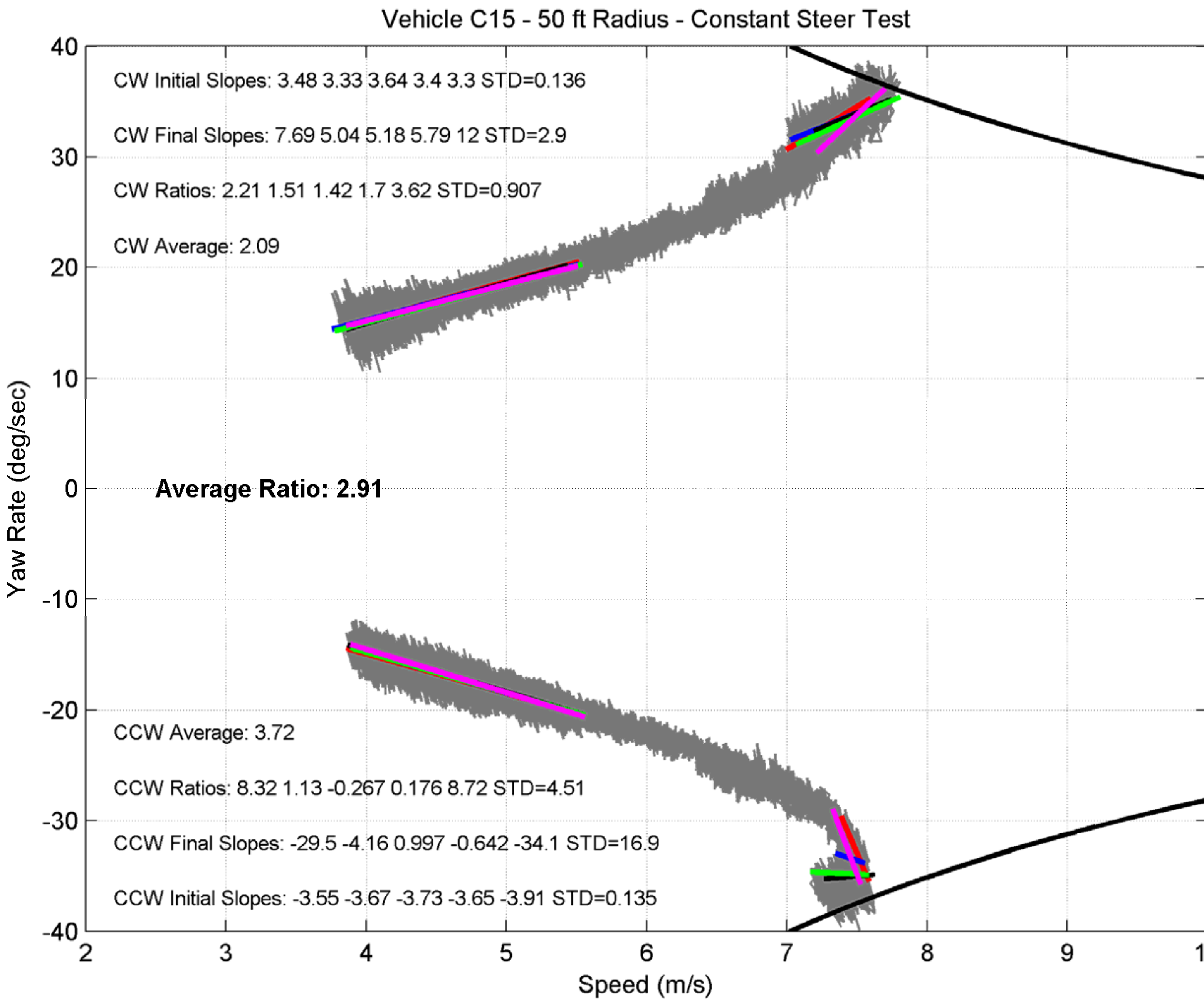


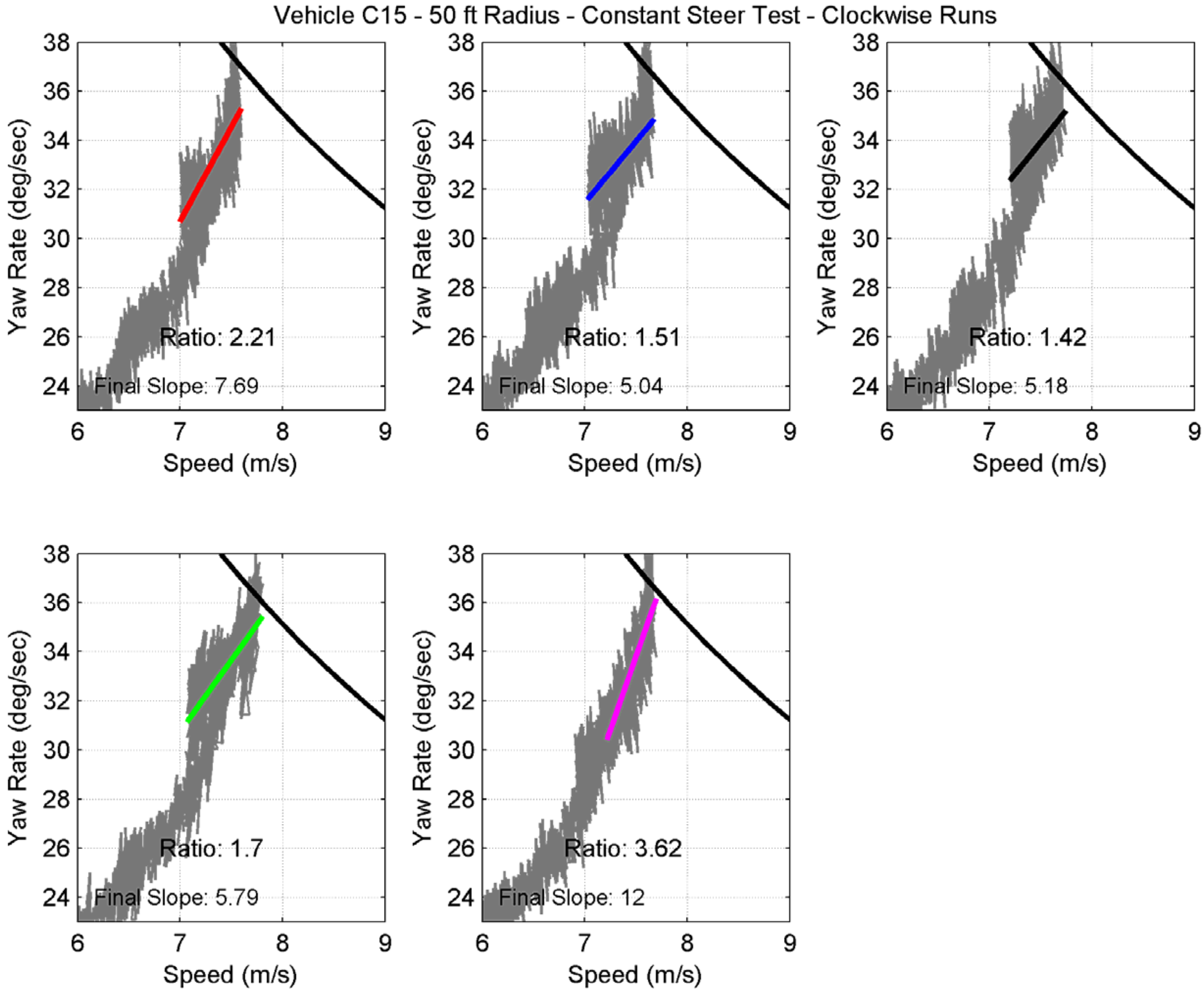

Vehicle B15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.3 2.75 2.07 2.1 1.99 STD=0.308
CW Final Slopes: -0.775 -1 -0.622 -0.85 -0.918 STD=0.145
CW Ratios: -0.338 -0.364 -0.3 -0.406 -0.461 STD=0.0622
CW Average: 0.374
Average Ratio: 0.346
CCW Average: 0.319
CCW Ratios: -0.244 -0.6 -0.274 -0.218 -0.26 STD=0.158
CCW Final Slopes: 0.543 1.48 0.67 0.482 0.614 STD=0.411
CCW Initial Slopes: -2.23 -2.47 -2.44 -2.22 -2.36 STD=0.119
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

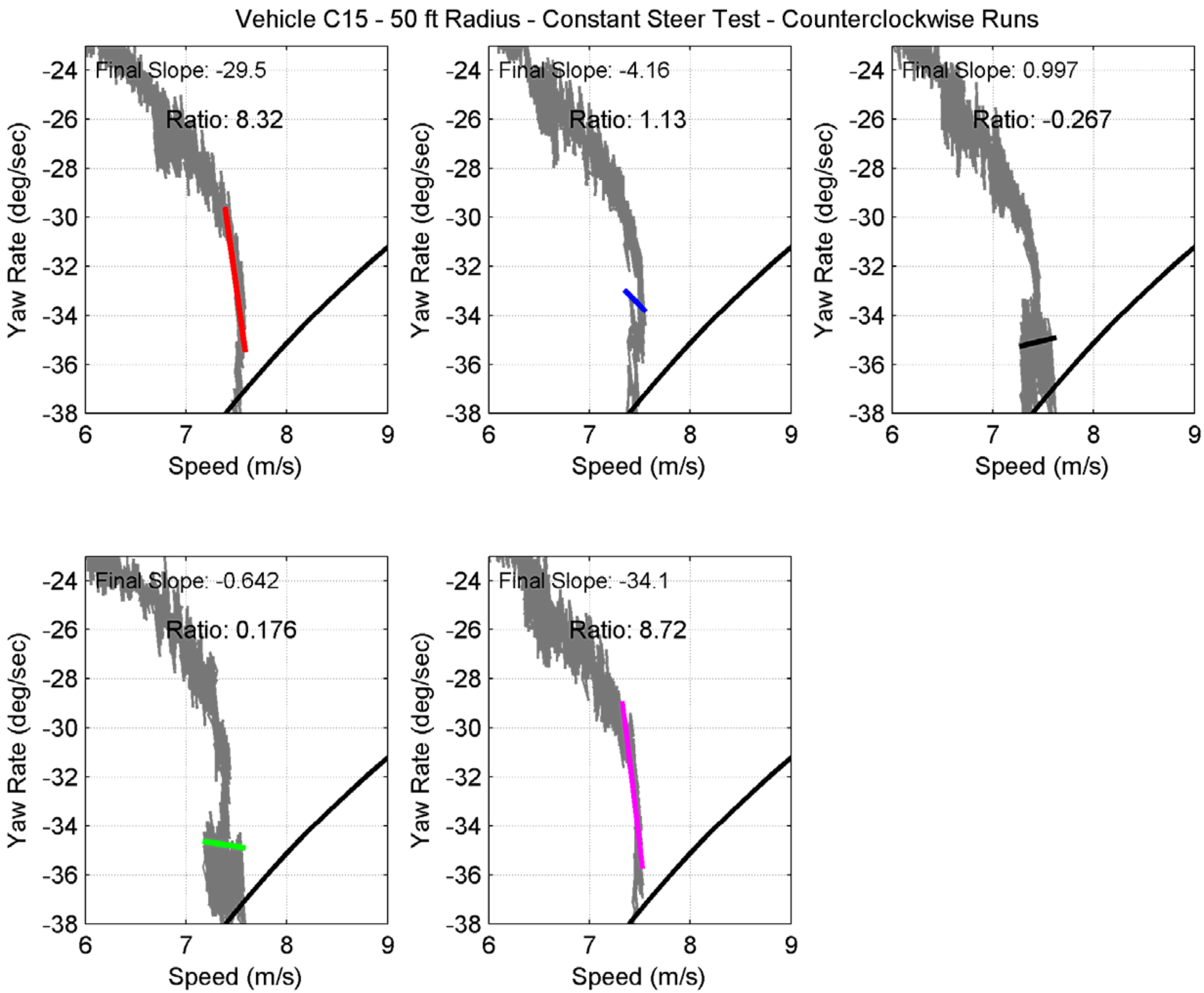

Vehicle B15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: -0.338
Final Slope: -0.775
Ratio: -0.364
Final Slope: -1
Ratio: -0.3
Final Slope: -0.622
Ratio: -0.406
Final Slope: -0.85
Ratio: -0.461
Final Slope: -0.918

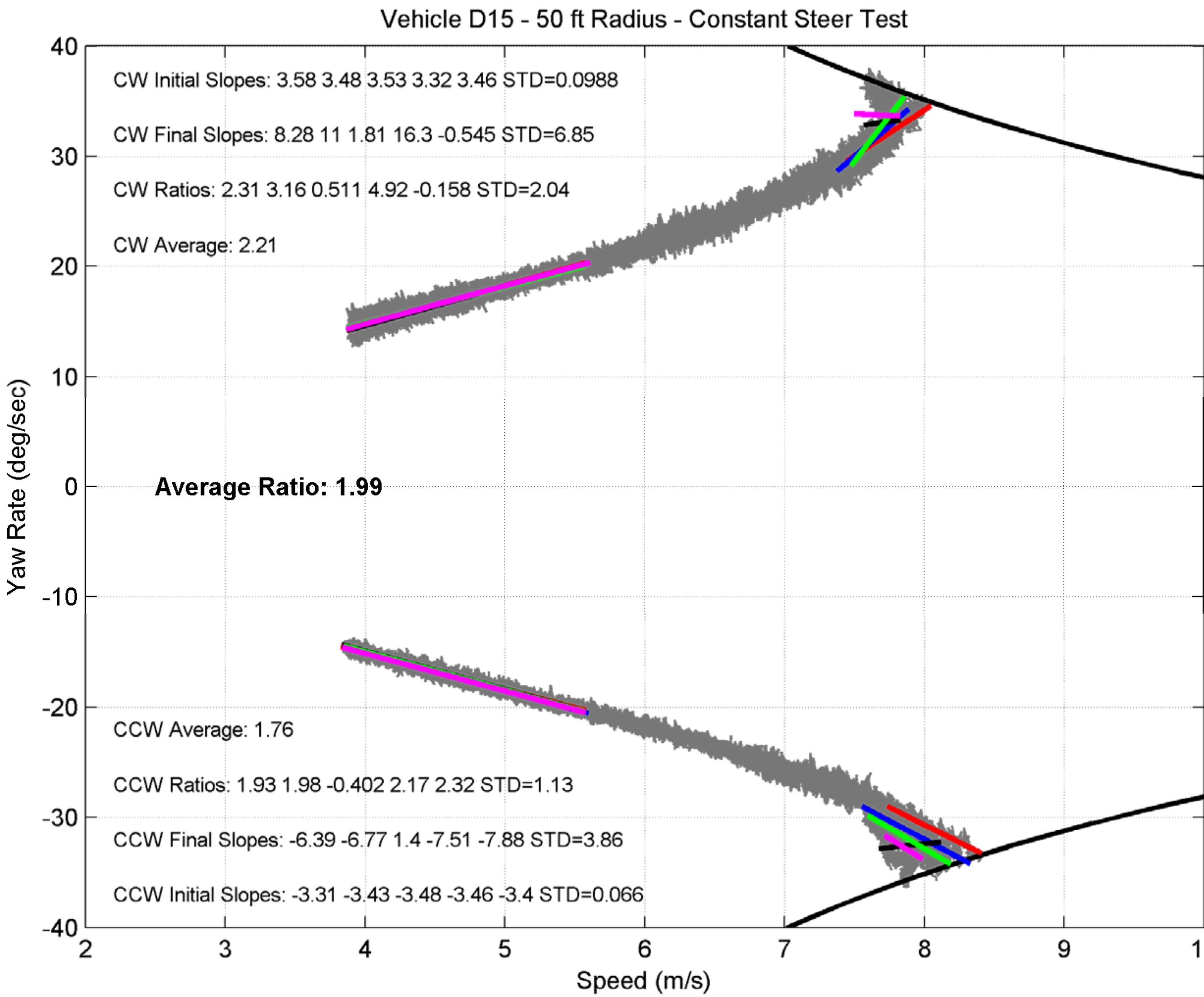


Vehicle B15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: 0.543
Ratio: -0.244
Final Slope: 1.48
Ratio: -0.6
Final Slope: 0.67
Ratio: -0.274
Final Slope: 0.482
Ratio: -0.218
Final Slope: 0.614
Ratio: -0.26
Yaw Rate (deg/sec)
Speed (m/s)
-10
-15
-20
-25
10
12
14
16
18


Vehicle C15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.48 3.33 3.64 3.4 3.3 STD=0.136
CW Final Slopes: 7.69 5.04 5.18 5.79 12 STD=2.9
CW Ratios: 2.21 1.51 1.42 1.7 3.62 STD=0.907
CW Average: 2.09
Average Ratio: 2.91
CCW Average: 3.72
CCW Ratios: 8.32 1.13 -0.267 0.176 8.72 STD=4.51
CCW Final Slopes: -29.5 -4.16 0.997 -0.642 -34.1 STD=16.9
CCW Initial Slopes: -3.55 -3.67 -3.73 -3.65 -3.91 STD=0.135
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: 2.21
Final Slope: 7.69
Ratio: 1.51
Final Slope: 5.04
Ratio: 1.42
Final Slope: 5.18
Ratio: 1.7
Final Slope: 5.79
Ratio: 3.62
Final Slope: 12


Vehicle C15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -29.5
Ratio: 8.32
Final Slope: -4.16
Ratio: 1.13
Final Slope: 0.997
Ratio: -0.267
Final Slope: -0.642
Ratio: 0.176
Final Slope: -34.1
Ratio: 8.72
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: 3.58 3.48 3.53 3.32 3.46 STD=0.0988
CW Final Slopes: 8.28 11 1.81 16.3 -0.545 STD=6.85
CW Ratios: 2.31 3.16 0.511 4.92 -0.158 STD=2.04
CW Average: 2.21
Average Ratio: 1.99
CCW Average: 1.76
CCW Ratios: 1.93 1.98 -0.402 2.17 2.32 STD=1.13
CCW Final Slopes: -6.39 -6.77 1.4 -7.51 -7.88 STD=3.86
CCW Initial Slopes: -3.31 -3.43 -3.48 -3.46 -3.4 STD=0.066
Yaw Rate (deg/sec)
Speed (m/s)
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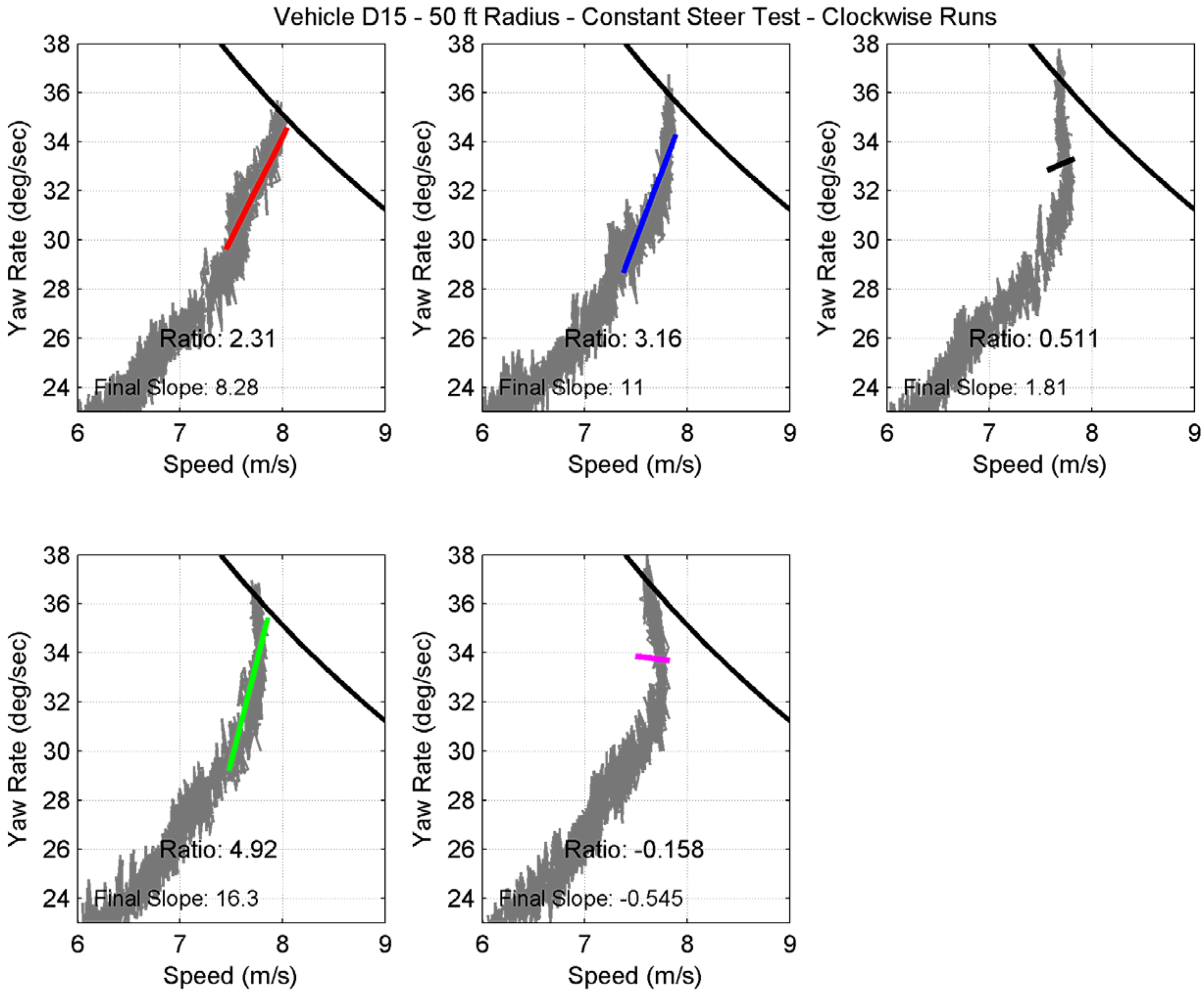
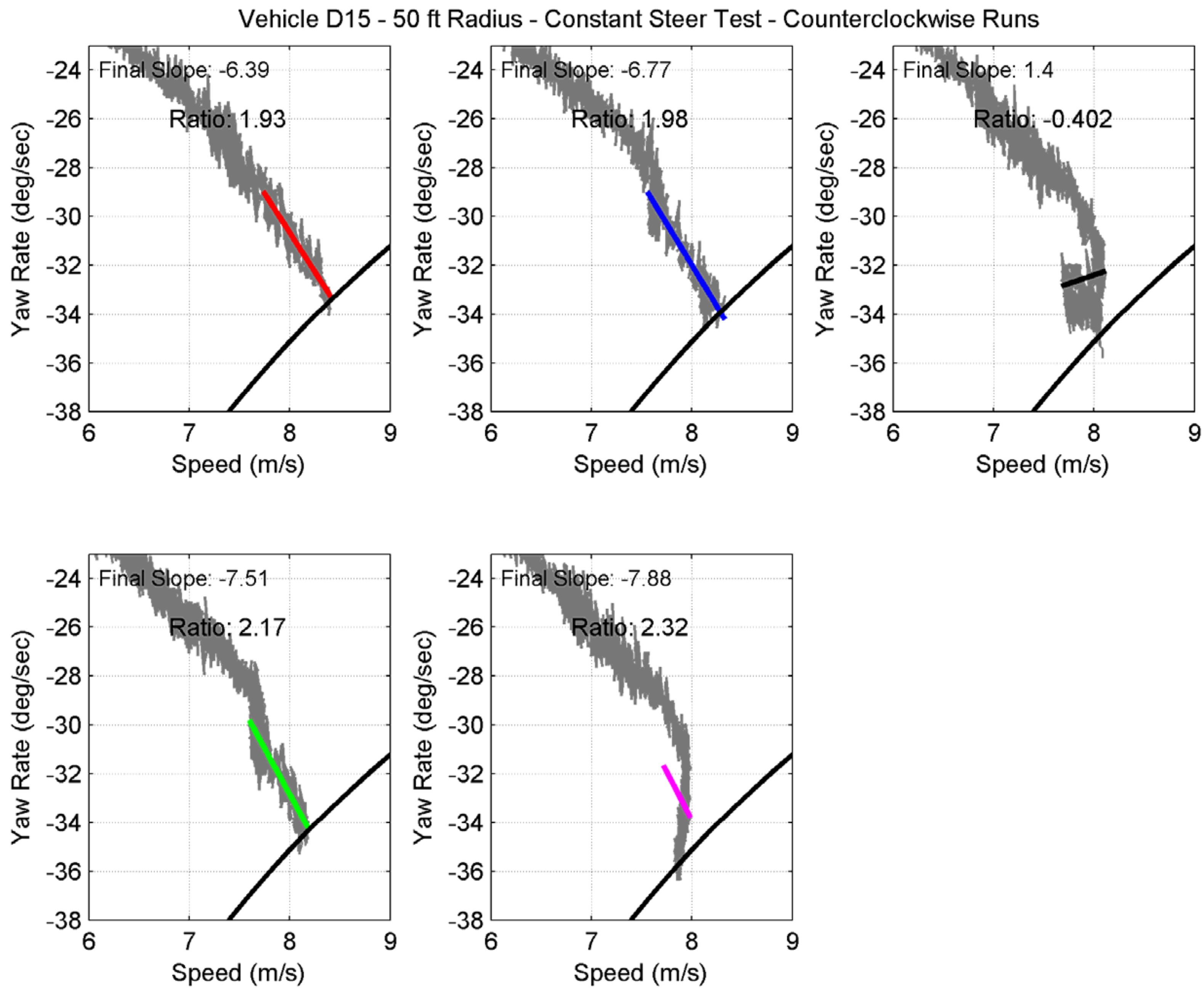
30
20
10
0
-10
-20
-30
-40
2
3
4
5
6
7
8
9
10


Vehicle D15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 2.31
Final Slope: 8.28
Ratio: 3.16
Final Slope: 11
Ratio: 0.511
Final Slope: 1.81
Ratio: 4.92
Final Slope: 16.3
Ratio: -0.158
Final Slope: -0.545


Vehicle D15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -6.39
Ratio: 1.93
Final Slope: -6.77
Ratio: 1.98
Final Slope: 1.4
Ratio: -0.402
Final Slope: -7.51
Ratio: 2.17
Final Slope: -7.88
Ratio: 2.32
Yaw Rate (deg/sec)
Speed (m/s)
-24
-26
-28
-30
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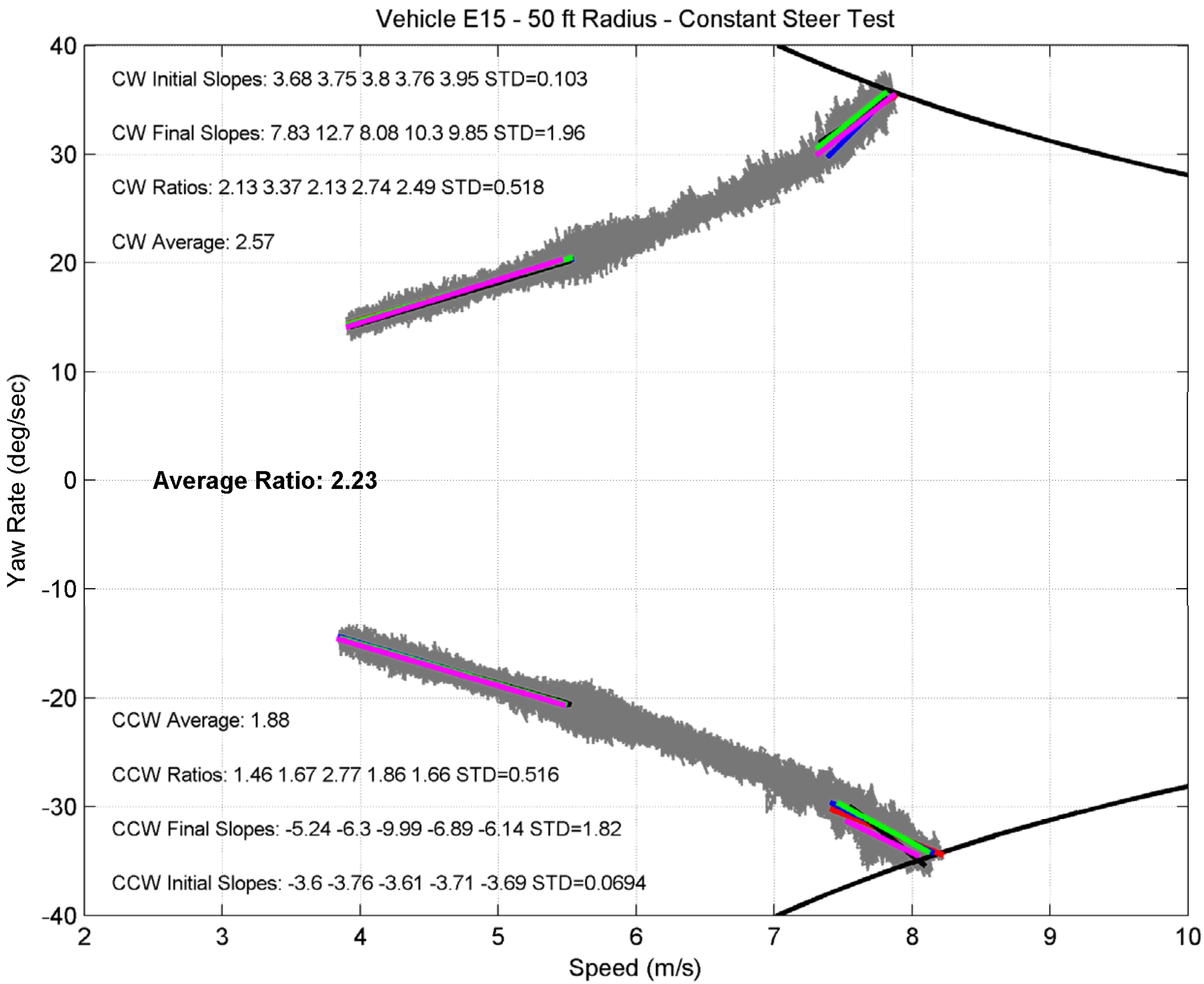
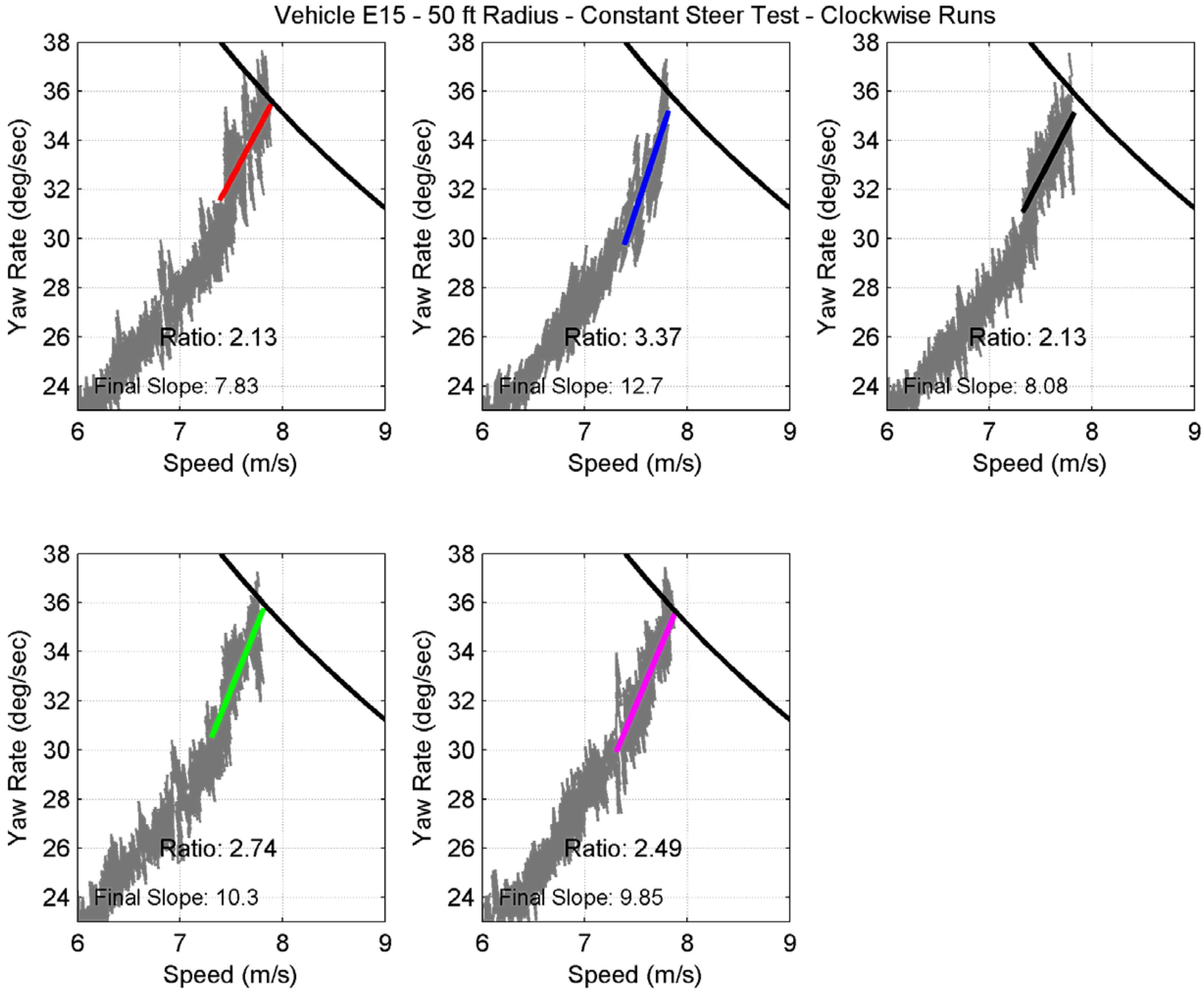
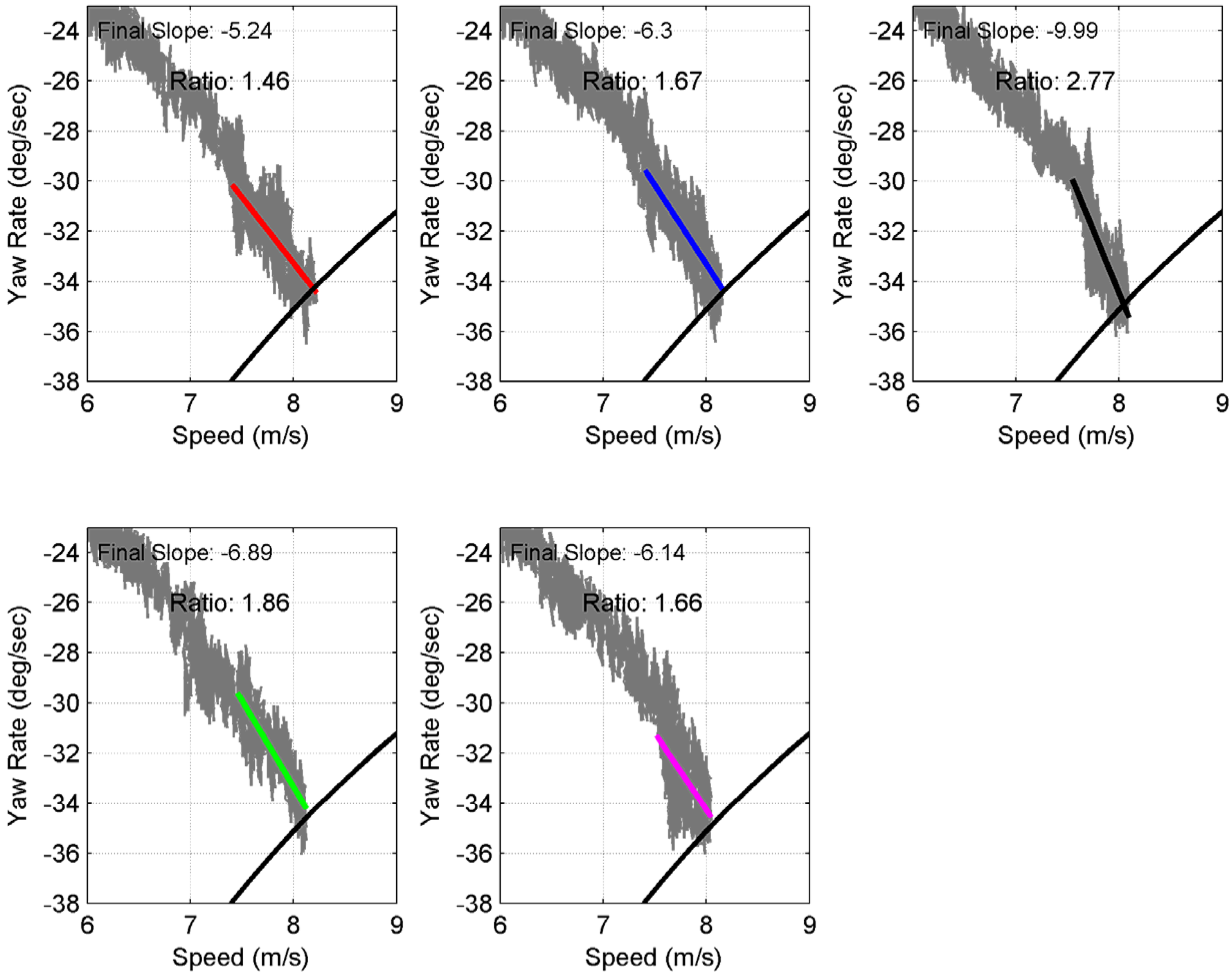
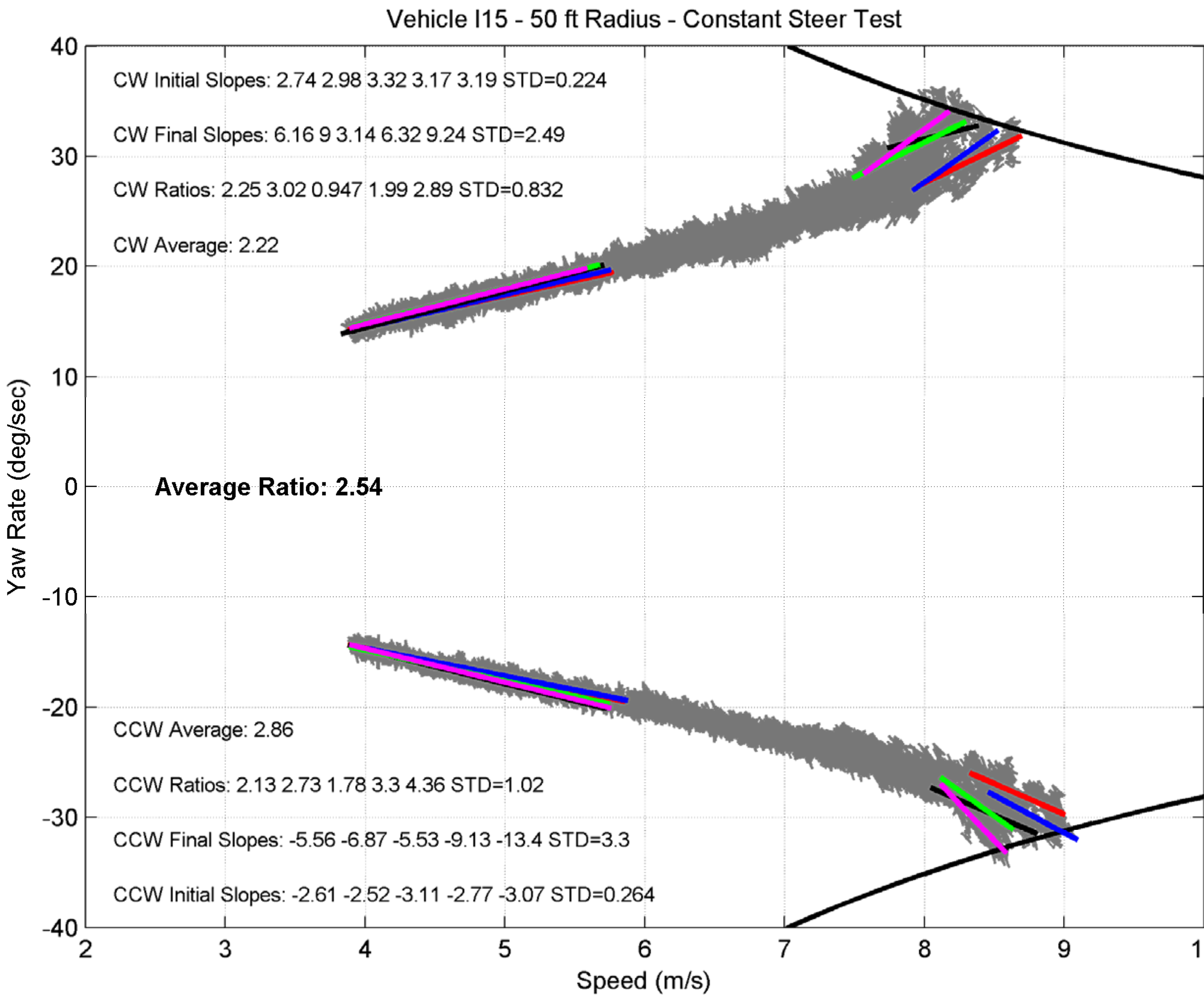
-36
-38
6
7
8
9


Vehicle E15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.68 3.75 3.8 3.76 3.95 STD=0.103
CW Final Slopes: 7.83 12.7 8.08 10.3 9.85 STD=1.96
CW Ratios: 2.13 3.37 2.13 2.74 2.49 STD=0.518
CW Average: 2.57
Average Ratio: 2.23
CCW Average: 1.88
CCW Ratios: 1.46 1.67 2.77 1.86 1.66 STD=0.516
CCW Final Slopes: -5.24 -6.3 -9.99 -6.89 -6.14 STD=1.82
CCW Initial Slopes: -3.6 -3.76 -3.61 -3.71 -3.69 STD=0.0694
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

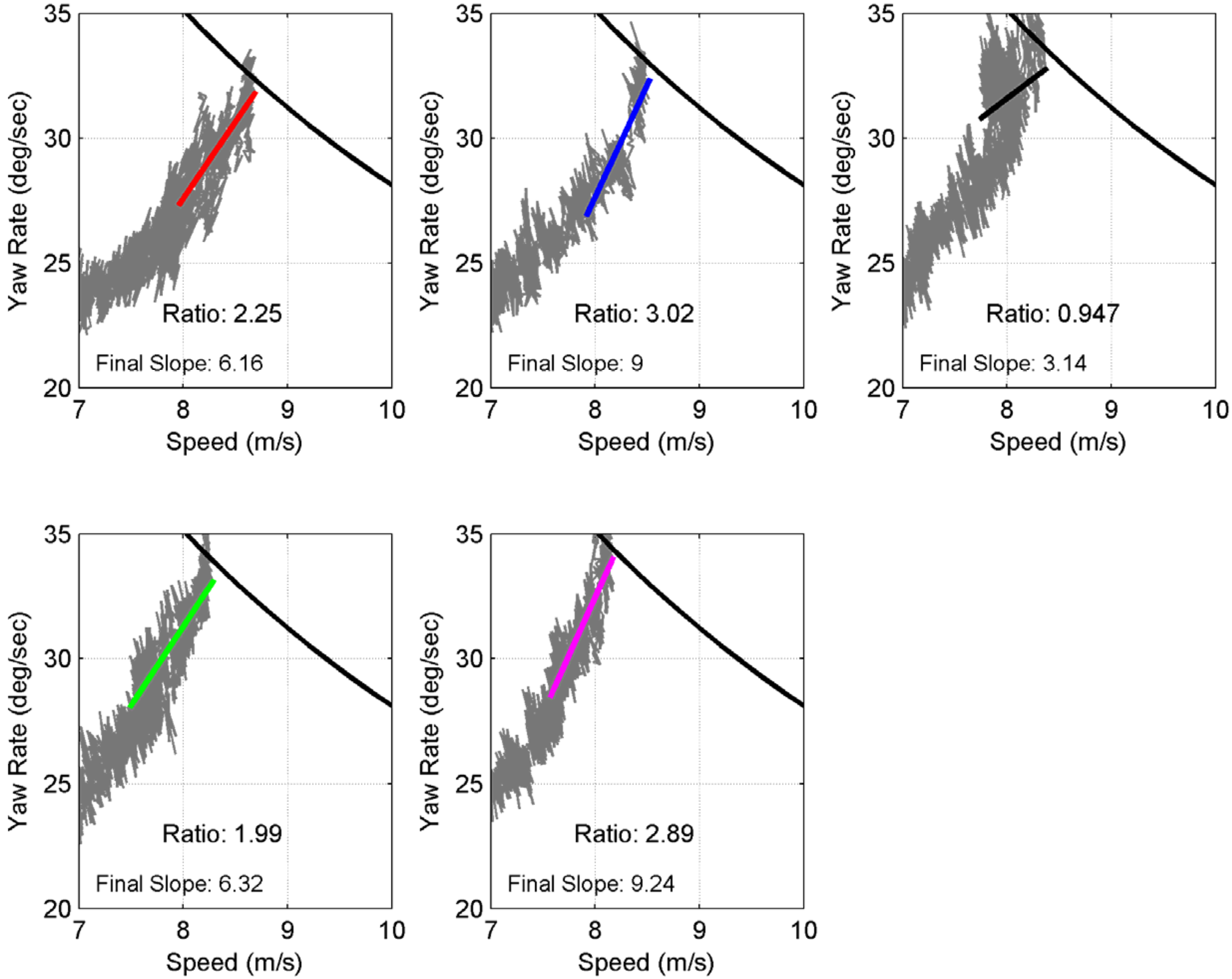

Vehicle E15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 2.13
Final Slope: 7.83
Ratio: 3.37
Final Slope: 12.7
Ratio: 2.13
Final Slope: 8.08
Ratio: 2.74
Final Slope: 10.3
Ratio: 2.49
Final Slope: 9.85

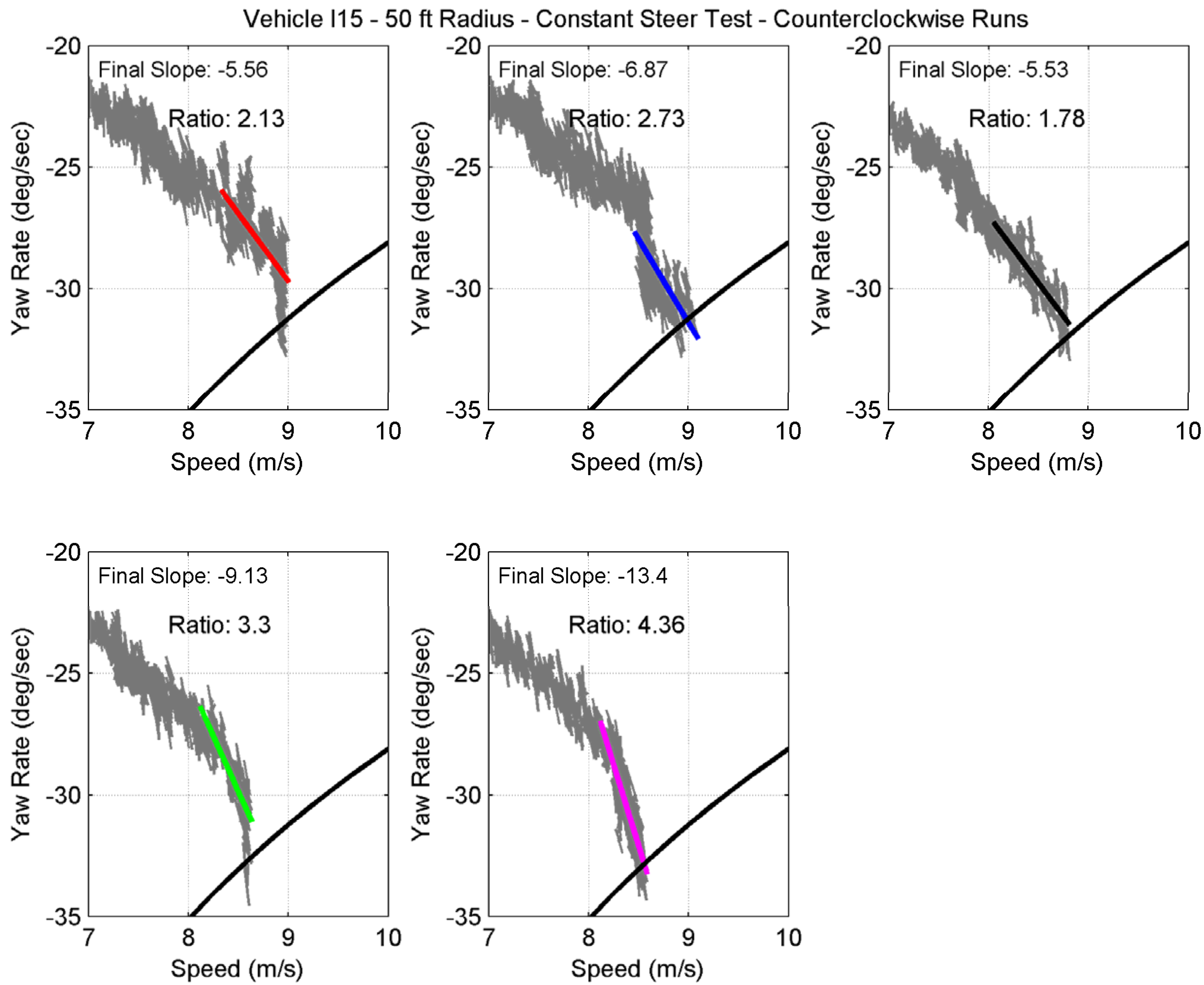
Vehicle E15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs

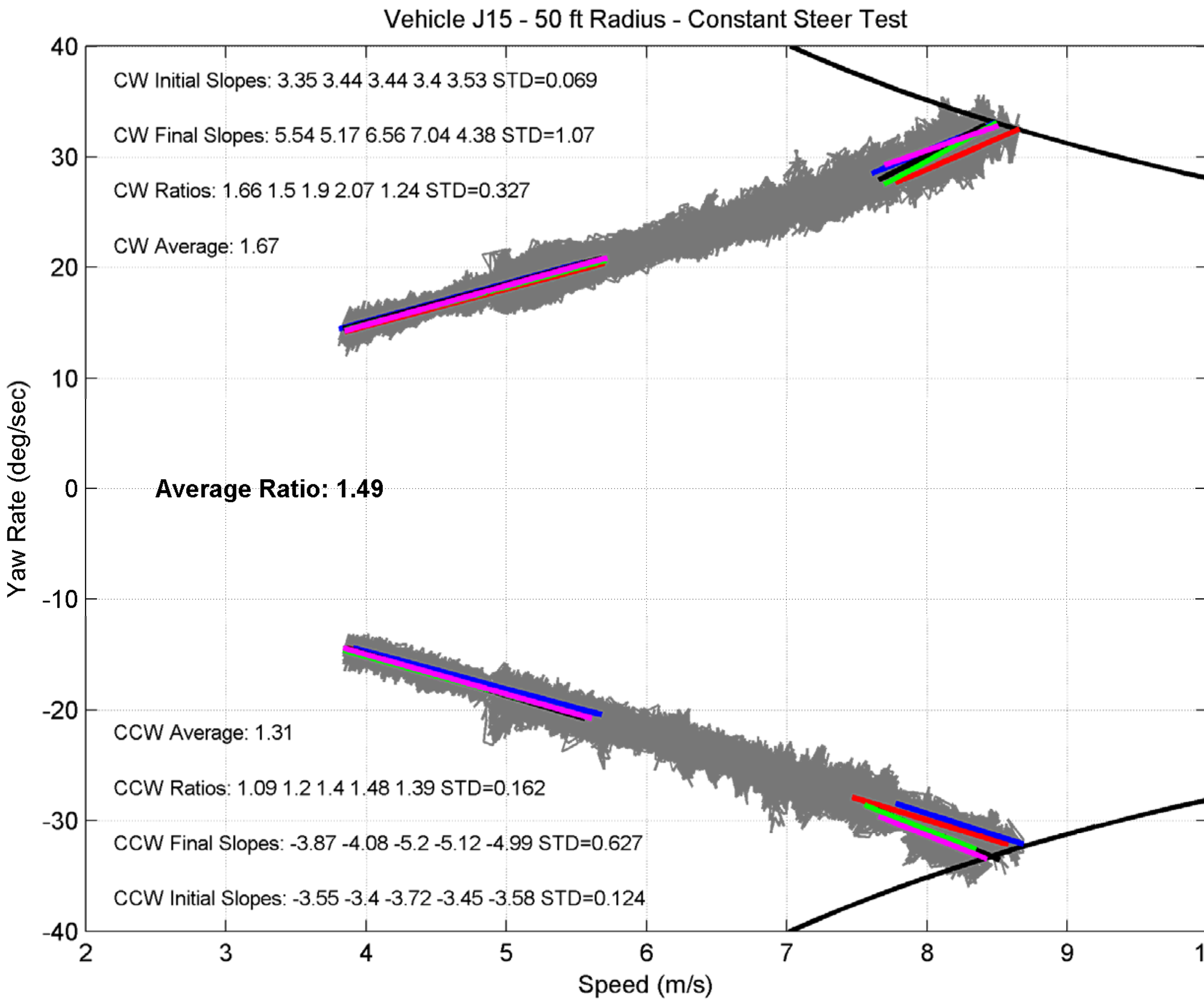


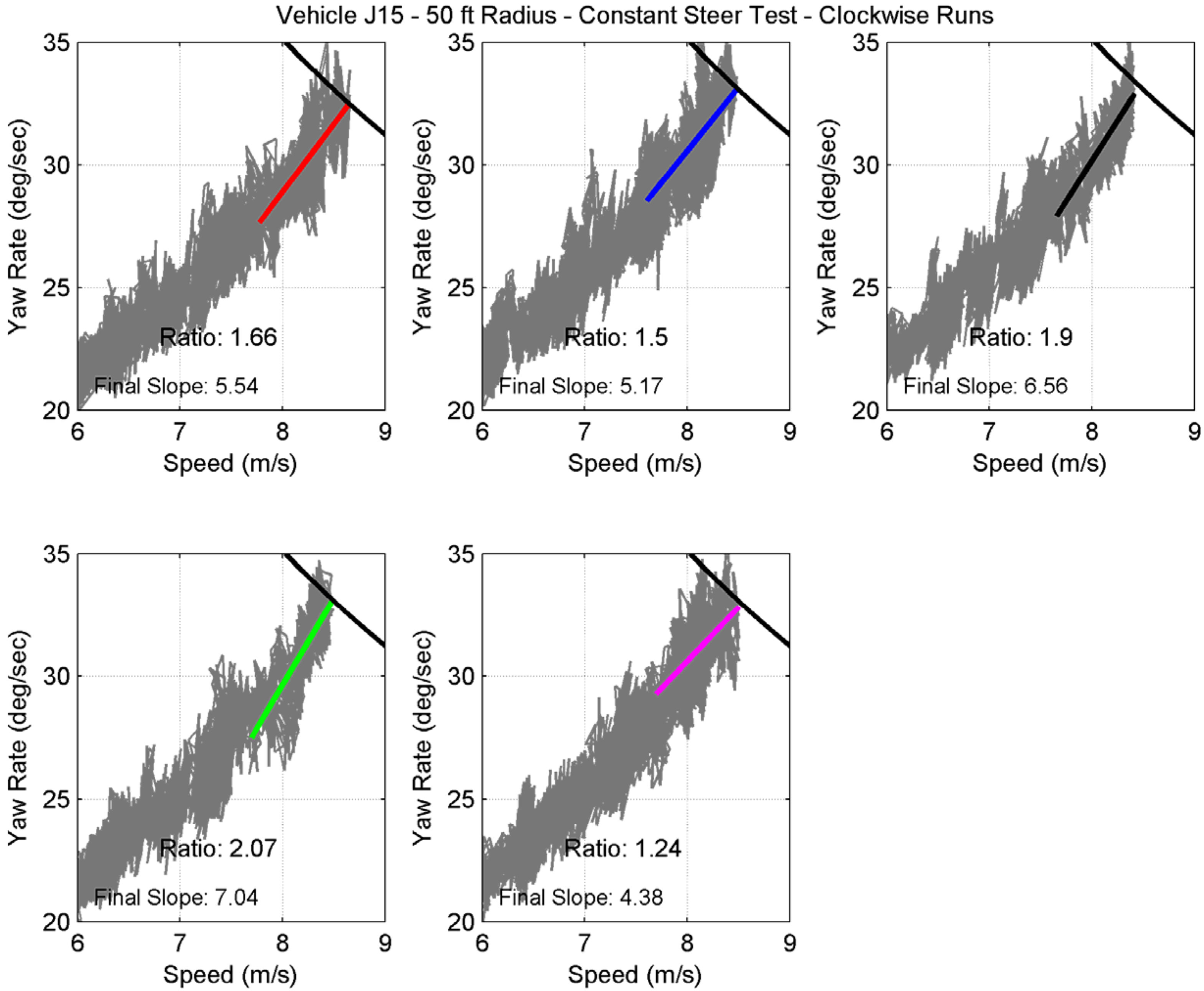

Vehicle I15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.74 2.98 3.32 3.17 3.19 STD=0.224
CW Final Slopes: 6.16 9 3.14 6.32 9.24 STD=2.49
CW Ratios: 2.25 3.02 0.947 1.99 2.89 STD=0.832
CW Average: 2.22
Average Ratio: 2.54
CCW Average: 2.86
CCW Ratios: 2.13 2.73 1.78 3.3 4.36 STD=1.02
CCW Final Slopes: -5.56 -6.87 -5.53 -9.13 -13.4 STD=3.3
CCW Initial Slopes: -2.61 -2.52 -3.11 -2.77 -3.07 STD=0.264
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

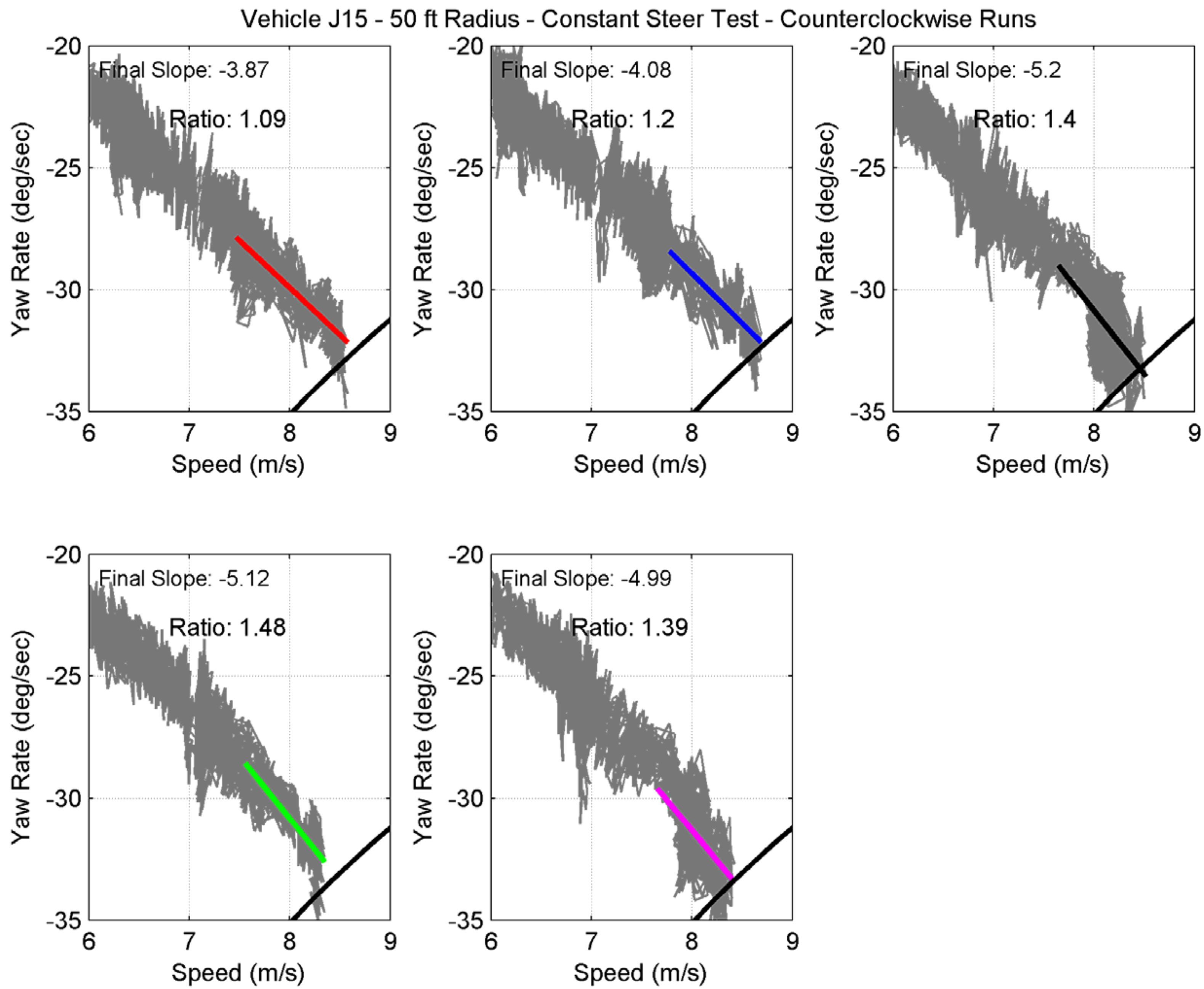
Vehicle I15 - 50 ft Radius - Constant Steer Test - Clockwise Runs



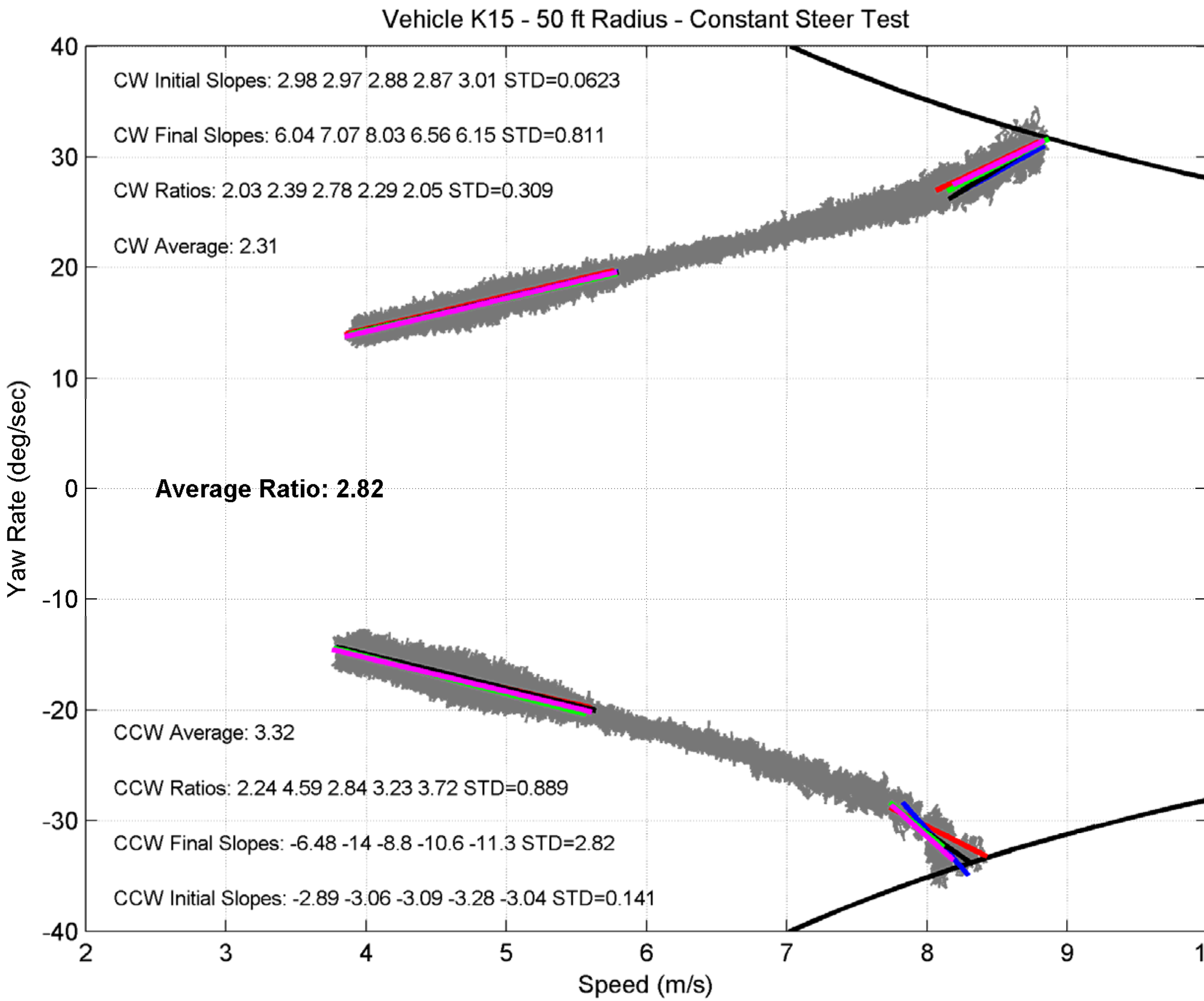

Vehicle I15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -5.56
Ratio: 2.13
Final Slope: -6.87
Ratio: 2.73
Final Slope: -5.53
Ratio: 1.78
Final Slope: -9.13
Ratio: 3.3
Final Slope: -13.4
Ratio: 4.36
Yaw Rate (deg/sec)
Speed (m/s)

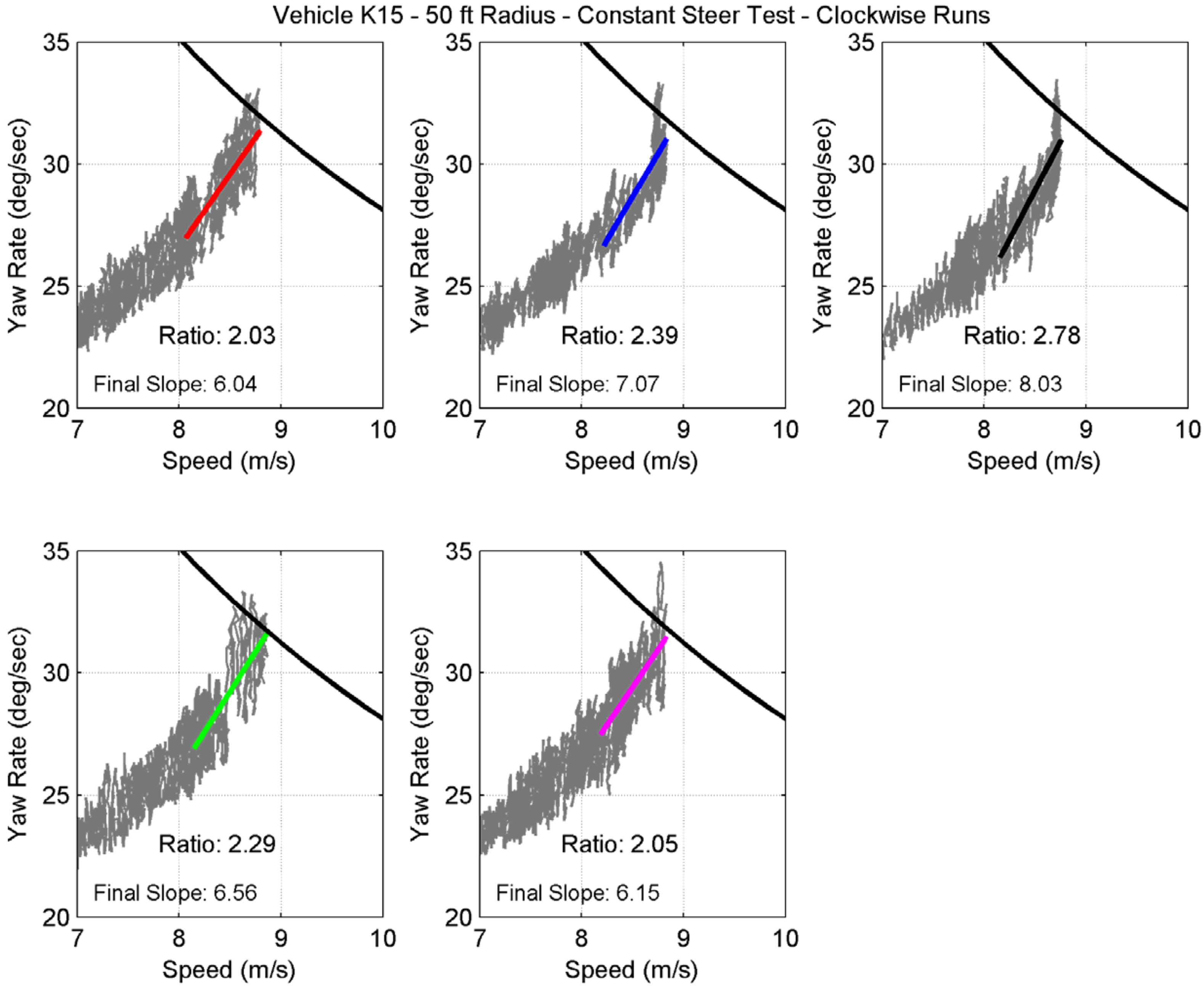

Vehicle J15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.35 3.44 3.44 3.4 3.53 STD=0.069
CW Final Slopes: 5.54 5.17 6.56 7.04 4.38 STD=1.07
CW Ratios: 1.66 1.5 1.9 2.07 1.24 STD=0.327
CW Average: 1.67
Average Ratio: 1.49
CCW Average: 1.31
CCW Ratios: 1.09 1.2 1.4 1.48 1.39 STD=0.162
CCW Final Slopes: -3.87 -4.08 -5.2 -5.12 -4.99 STD=0.627
CCW Initial Slopes: -3.55 -3.4 -3.72 -3.45 -3.58 STD=0.124
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

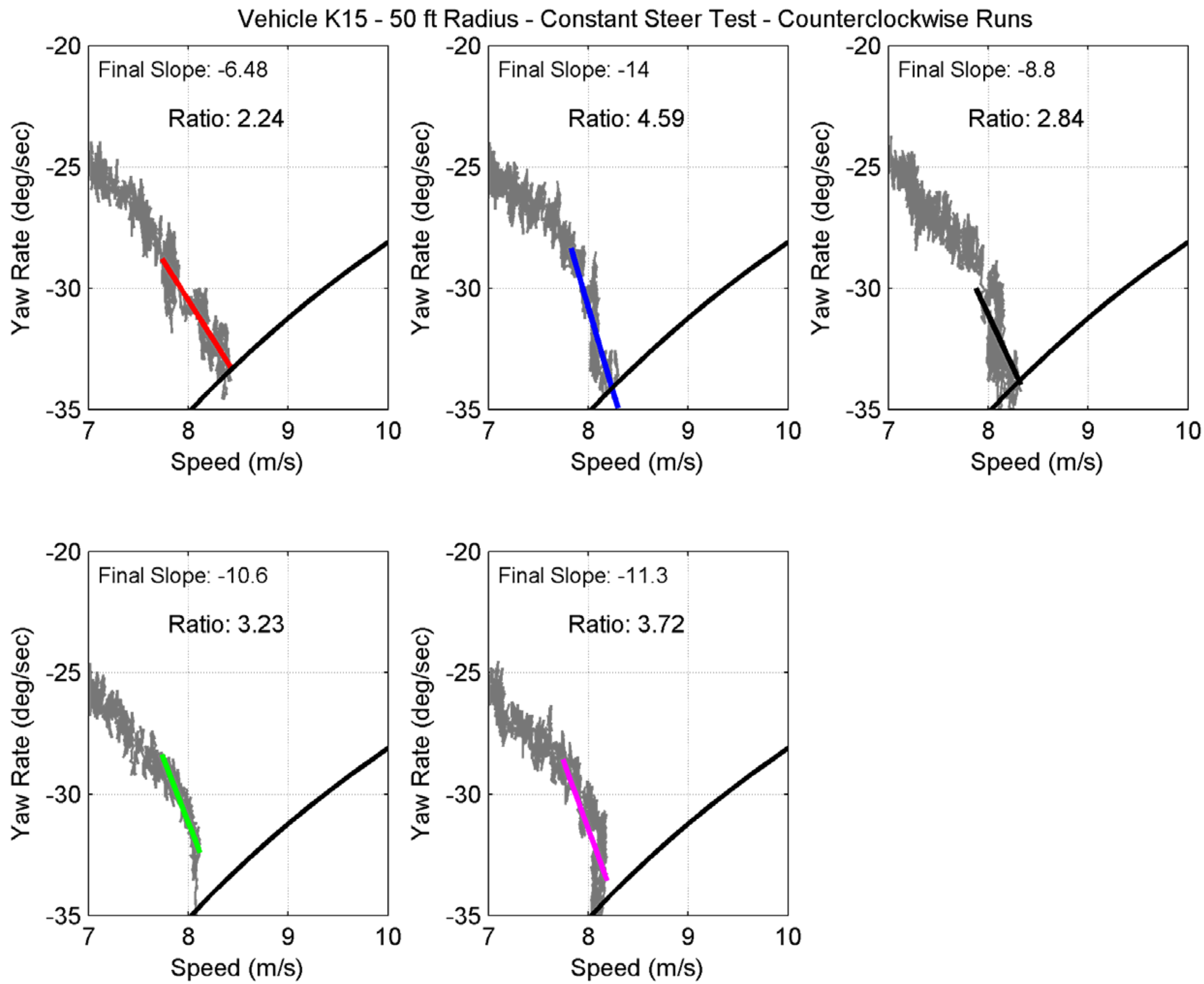

Vehicle J15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 1.66
Final Slope: 5.54
Ratio: 1.5
Final Slope: 5.17
Ratio: 1.9
Final Slope: 6.56
Ratio: 2.07
Final Slope: 7.04
Ratio: 1.24
Final Slope: 4.38
35
30
25
20
6
7
8
9

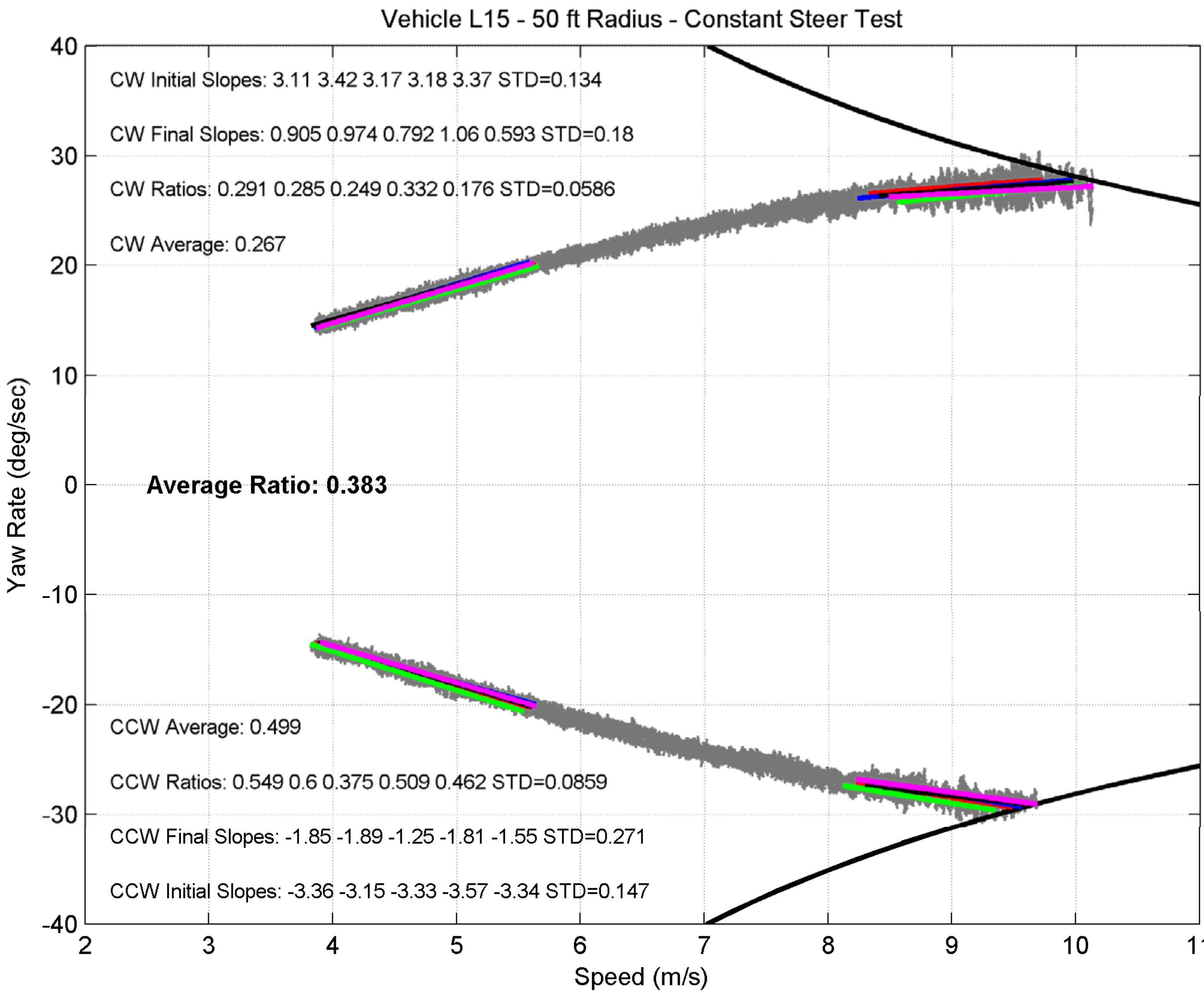


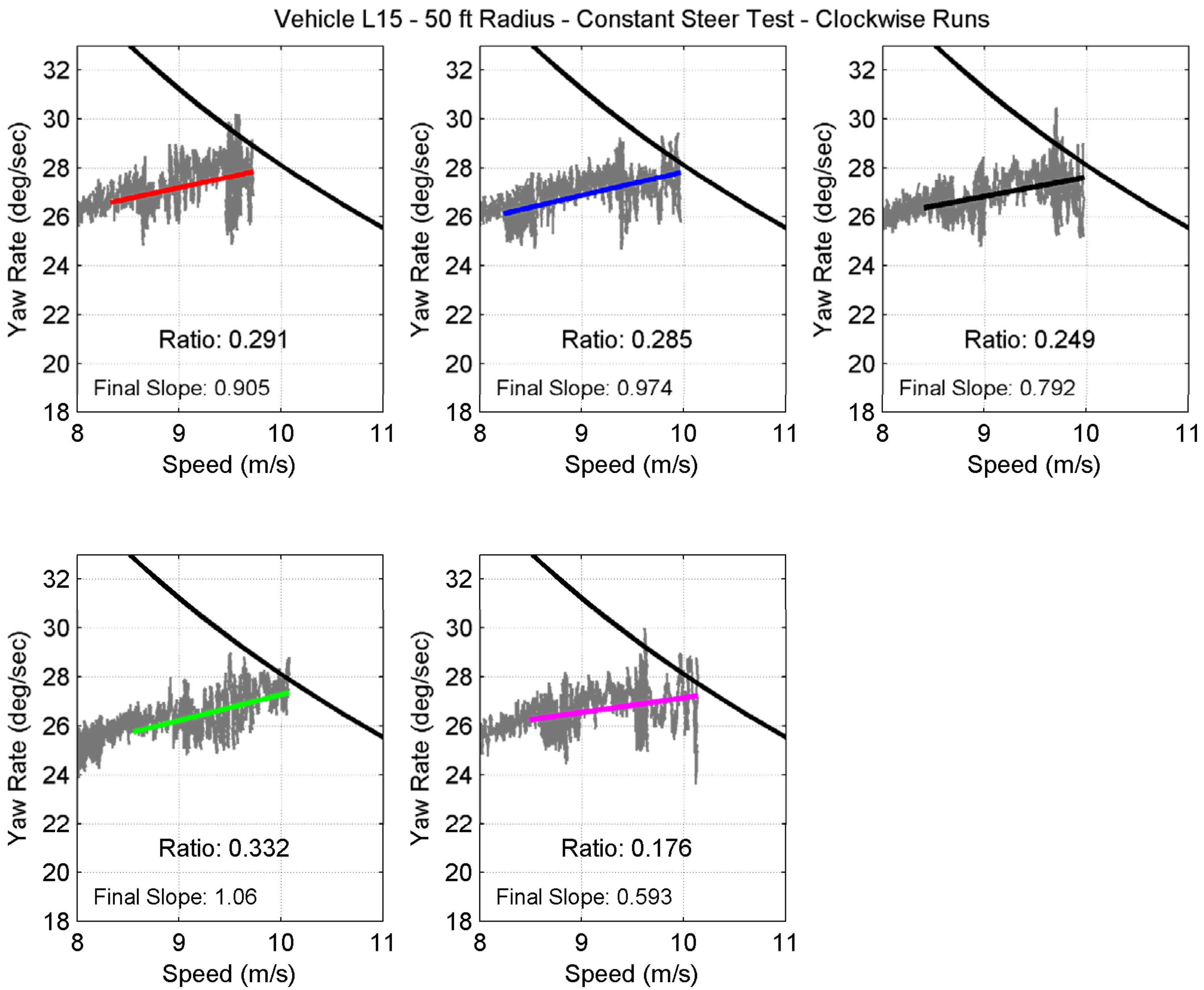
Vehicle J15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -3.87
Ratio: 1.09
Final Slope: -4.08
Ratio: 1.2
Final Slope: -5.2
Ratio: 1.4
Final Slope: -5.12
Ratio: 1.48
Final Slope: -4.99
Ratio: 1.39
Yaw Rate (deg/sec)
Speed (m/s)


Vehicle K15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.98 2.97 2.88 2.87 3.01 STD=0.0623
CW Final Slopes: 6.04 7.07 8.03 6.56 6.15 STD=0.811
CW Ratios: 2.03 2.39 2.78 2.29 2.05 STD=0.309
CW Average: 2.31
Average Ratio: 2.82
CCW Average: 3.32
CCW Ratios: 2.24 4.59 2.84 3.23 3.72 STD=0.889
CCW Final Slopes: -6.48 -14 -8.8 -10.6 -11.3 STD=2.82
CCW Initial Slopes: -2.89 -3.06 -3.09 -3.28 -3.04 STD=0.141
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

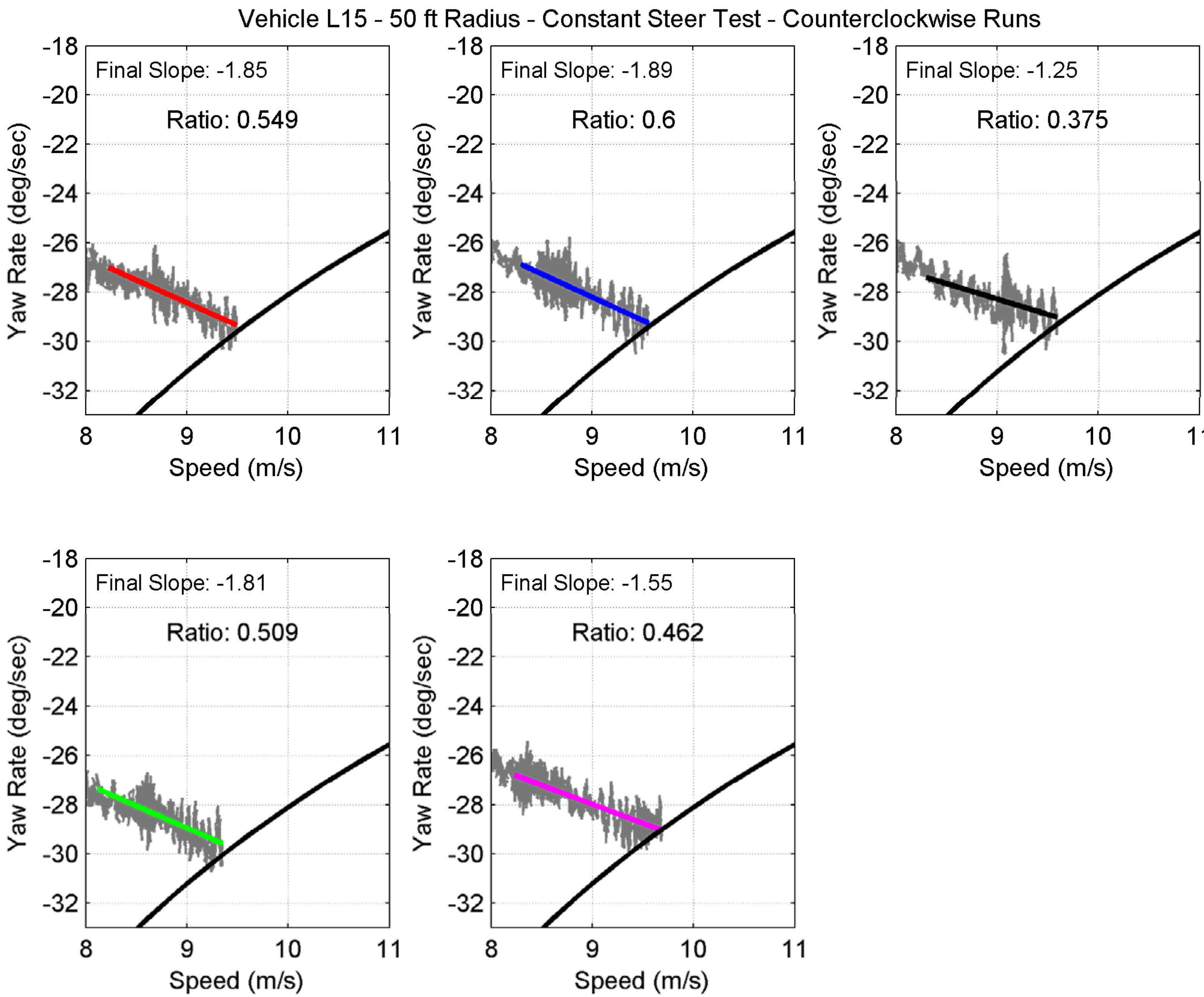

Vehicle K15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 2.03
Final Slope: 6.04
Ratio: 2.39
Final Slope: 7.07
Ratio: 2.78
Final Slope: 8.03
Ratio: 2.29
Final Slope: 6.56
Ratio: 2.05
Final Slope: 6.15

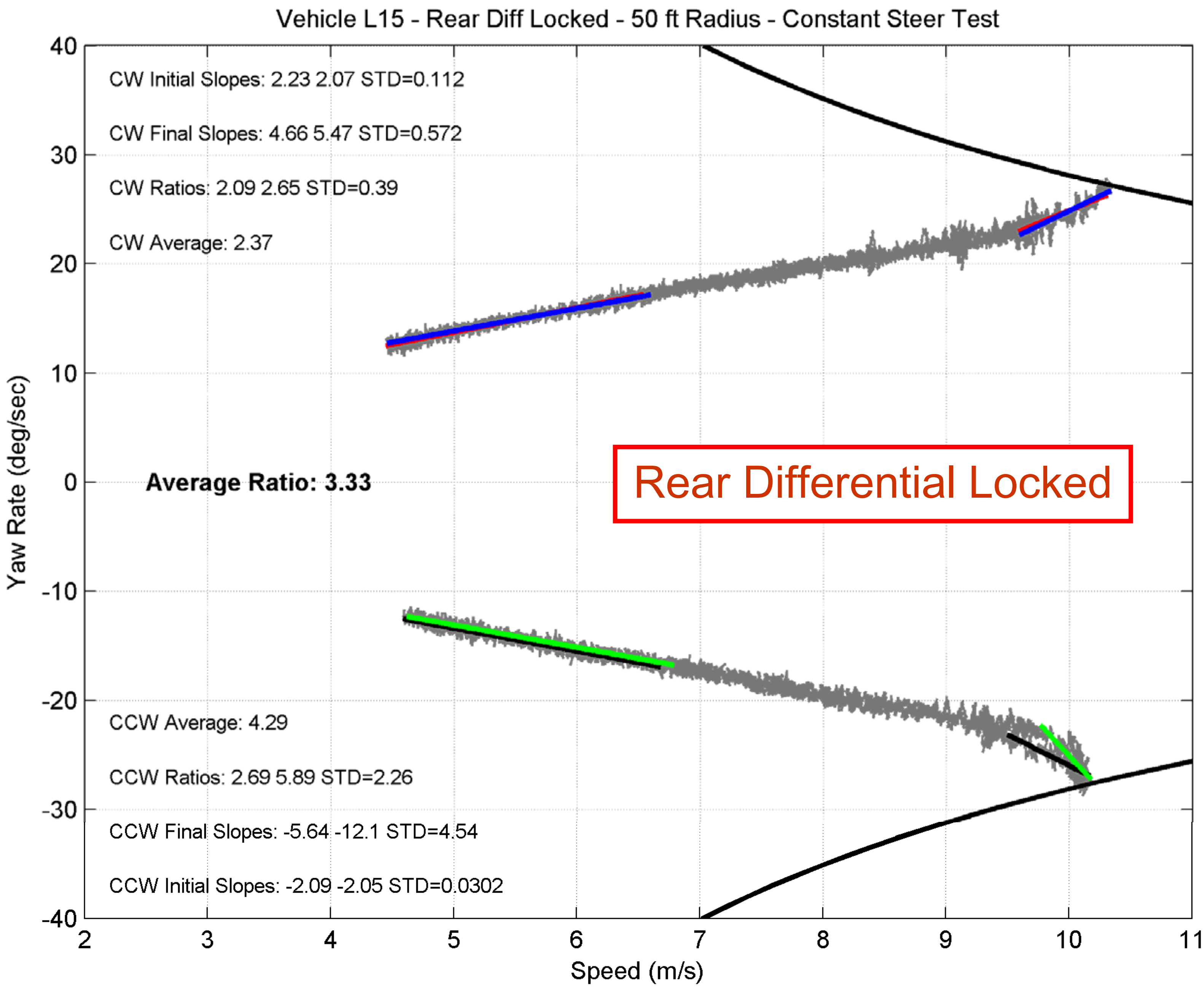

Vehicle K15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -6.48
Ratio: 2.24
Final Slope: -14
Ratio: 4.59
Final Slope: -8.8
Ratio: 2.84
Final Slope: -10.6
Ratio: 3.23
Final Slope: -11.3
Ratio: 3.72
Yaw Rate (deg/sec)
Speed (m/s)
-20
-25
-30
-35
7
8
9
10

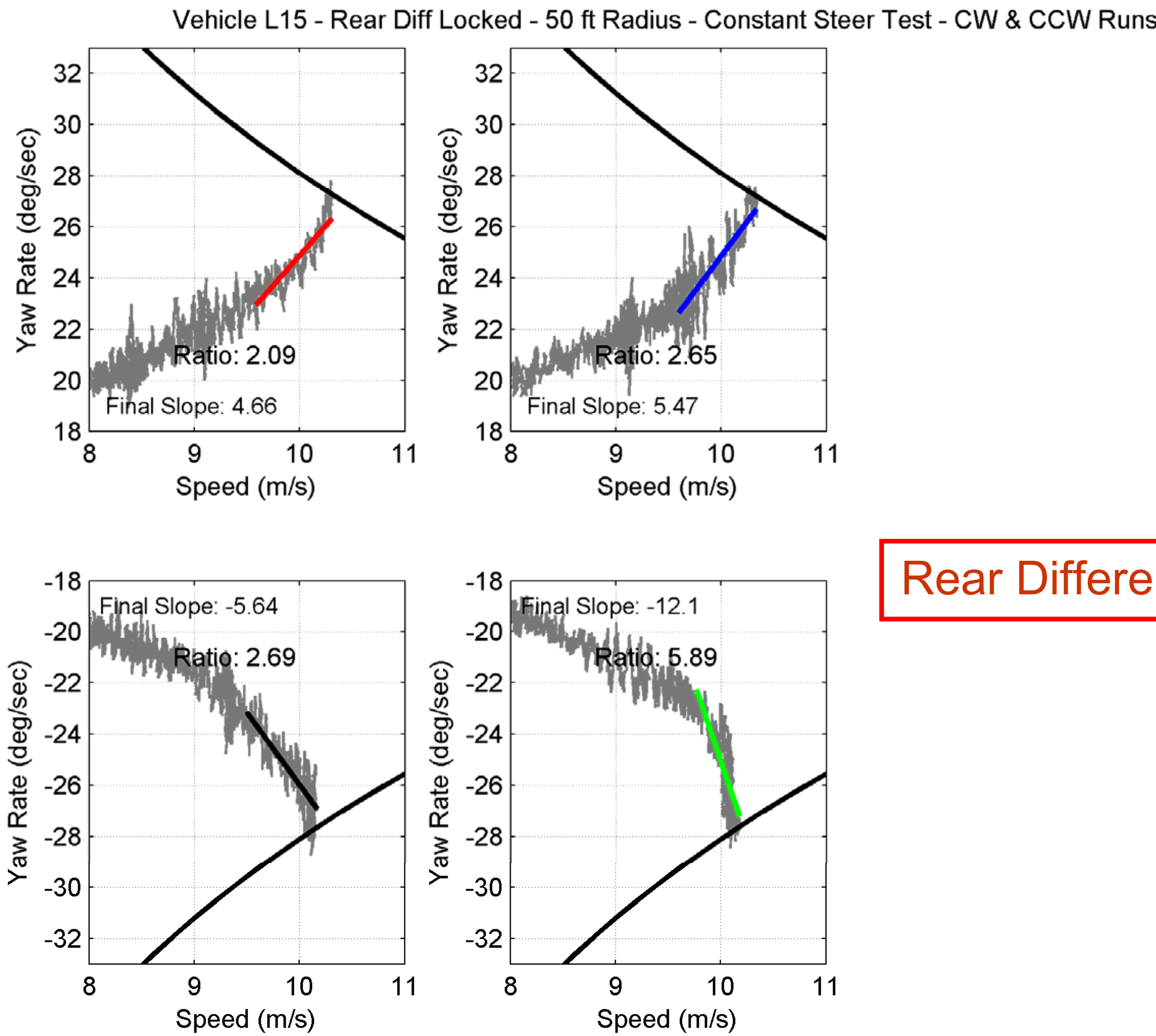

Vehicle L15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.11 3.42 3.17 3.18 3.37 STD=0.134
CW Final Slopes: 0.905 0.974 0.792 1.06 0.593 STD=0.18
CW Ratios: 0.291 0.285 0.249 0.332 0.176 STD=0.0586
CW Average: 0.267
Average Ratio: 0.383
CCW Average: 0.499
CCW Ratios: 0.549 0.6 0.375 0.509 0.462 STD=0.0859
CCW Final Slopes: -1.85 -1.89 -1.25 -1.81 -1.55 STD=0.271
CCW Initial Slopes: -3.36 -3.15 -3.33 -3.57 -3.34 STD=0.147
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



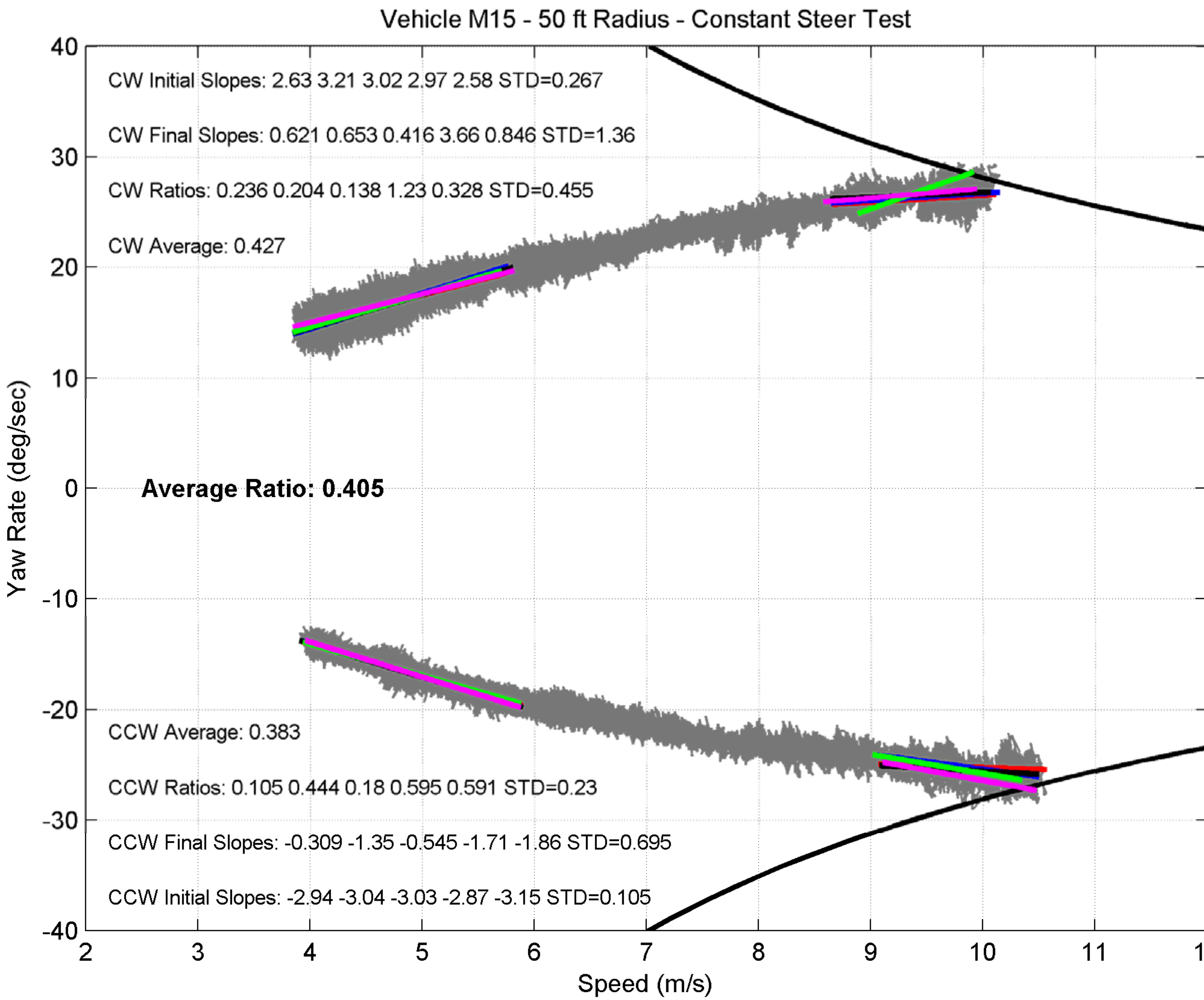
Vehicle L15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 0.291
Final Slope: 0.905
Ratio: 0.285
Final Slope: 0.974
Ratio: 0.249
Final Slope: 0.792
Ratio: 0.332
Final Slope: 1.06
Ratio: 0.176
Final Slope: 0.593

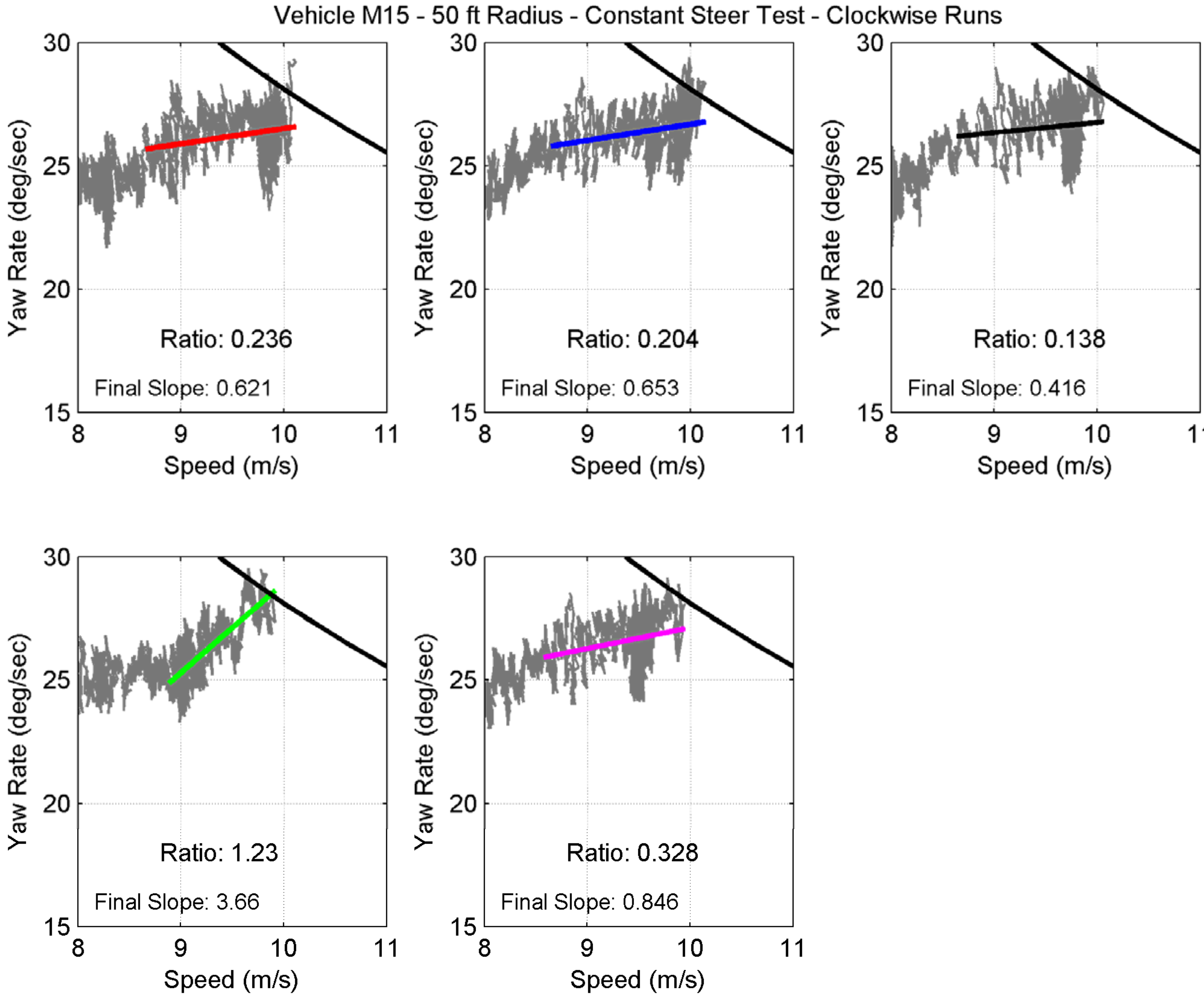

Vehicle L15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -1.85
Ratio: 0.549
Final Slope: -1.89
Ratio: 0.6
Final Slope: -1.25
Ratio: 0.375
Final Slope: -1.81
Ratio: 0.509
Final Slope: -1.55
Ratio: 0.462
Yaw Rate (deg/sec)
Speed (m/s)

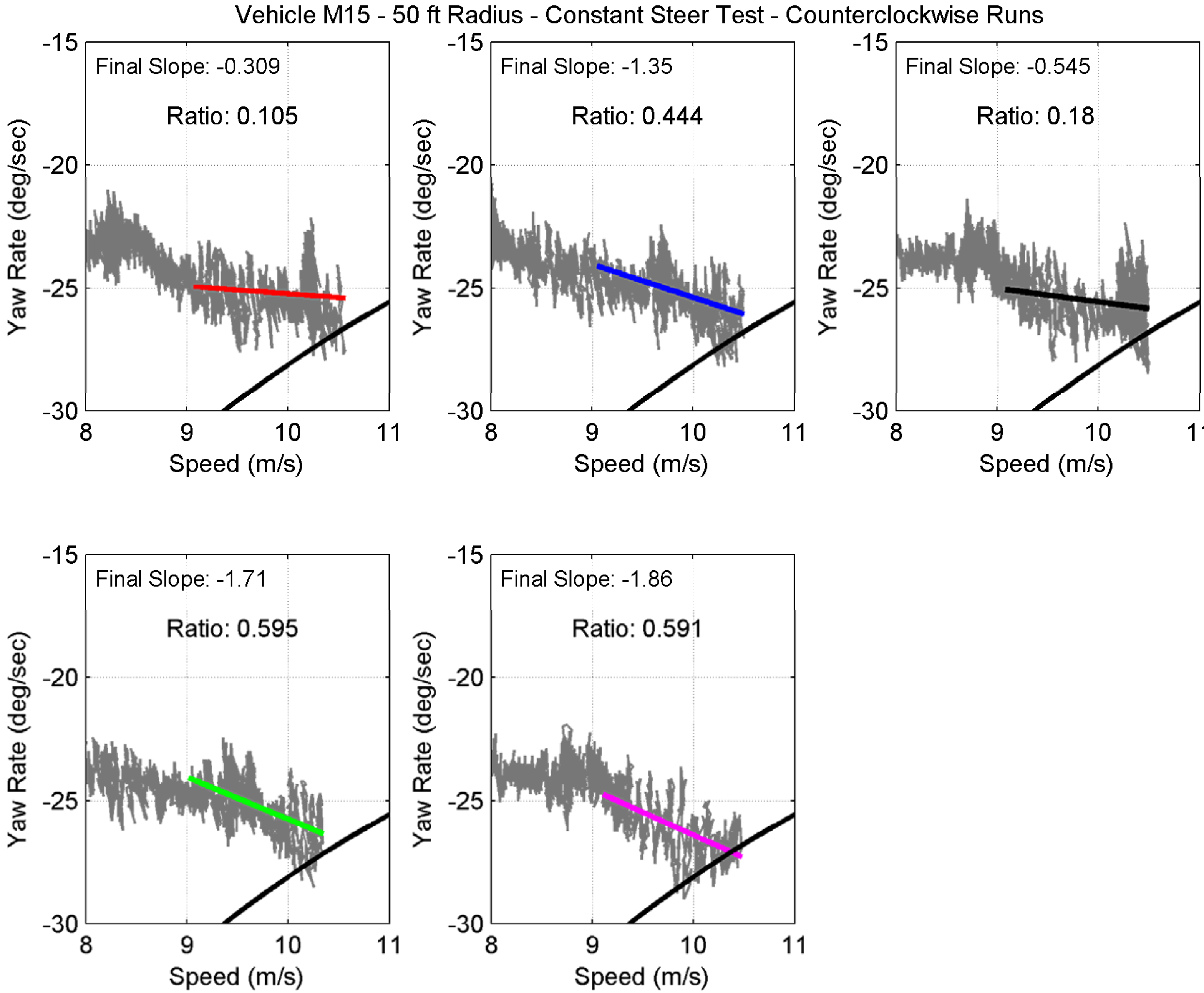

Vehicle L15 - Rear Diff Locked - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.23 2.07 STD=0.112
CW Final Slopes: 4.66 5.47 STD=0.572
CW Ratios: 2.09 2.65 STD=0.39
CW Average: 2.37
Average Ratio: 3.33
Rear Differential Locked
CCW Average: 4.29
CCW Ratios: 2.69 5.89 STD=2.26
CCW Final Slopes: -5.64 -12.1 STD=4.54
CCW Initial Slopes: -2.09 -2.05 STD=0.0302
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

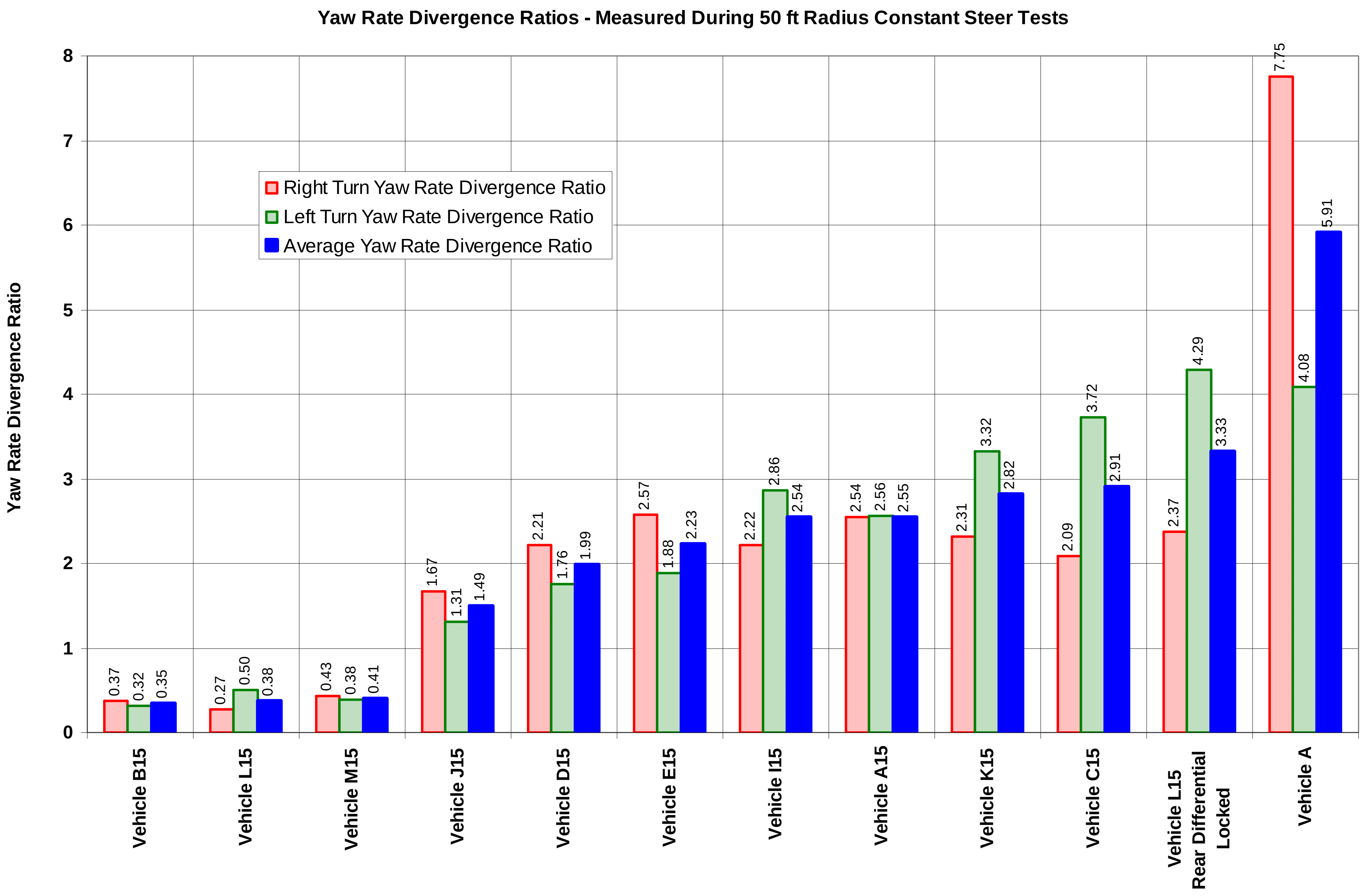


Rear Differential Locked


Vehicle M15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.63 3.21 3.02 2.97 2.58 STD=0.267
CW Final Slopes: 0.621 0.653 0.416 3.66 0.846 STD=1.36
CW Ratios: 0.236 0.204 0.138 1.23 0.328 STD=0.455
CW Average: 0.427
Average Ratio: 0.405
CCW Average: 0.383
CCW Ratios: 0.105 0.444 0.18 0.595 0.591 STD=0.23
CCW Final Slopes: -0.309 -1.35 -0.545 -1.71 -1.86 STD=0.695
CCW Initial Slopes: -2.94 -3.04 -3.03 -2.87 -3.15 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
11
12

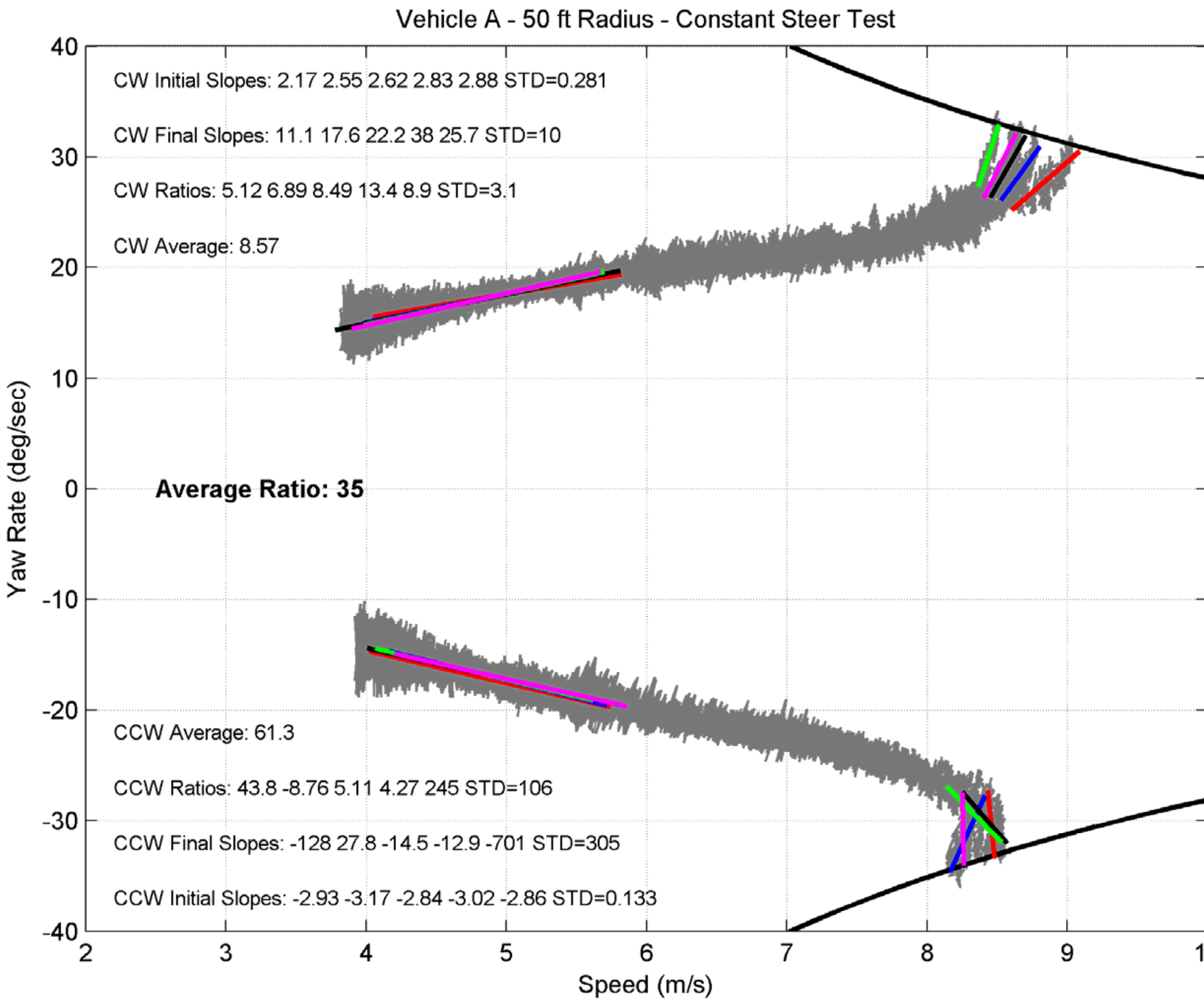

Vehicle M15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 0.236
Final Slope: 0.621
Ratio: 0.204
Final Slope: 0.653
Ratio: 0.138
Final Slope: 0.416
Ratio: 1.23
Final Slope: 3.66
Ratio: 0.328
Final Slope: 0.846

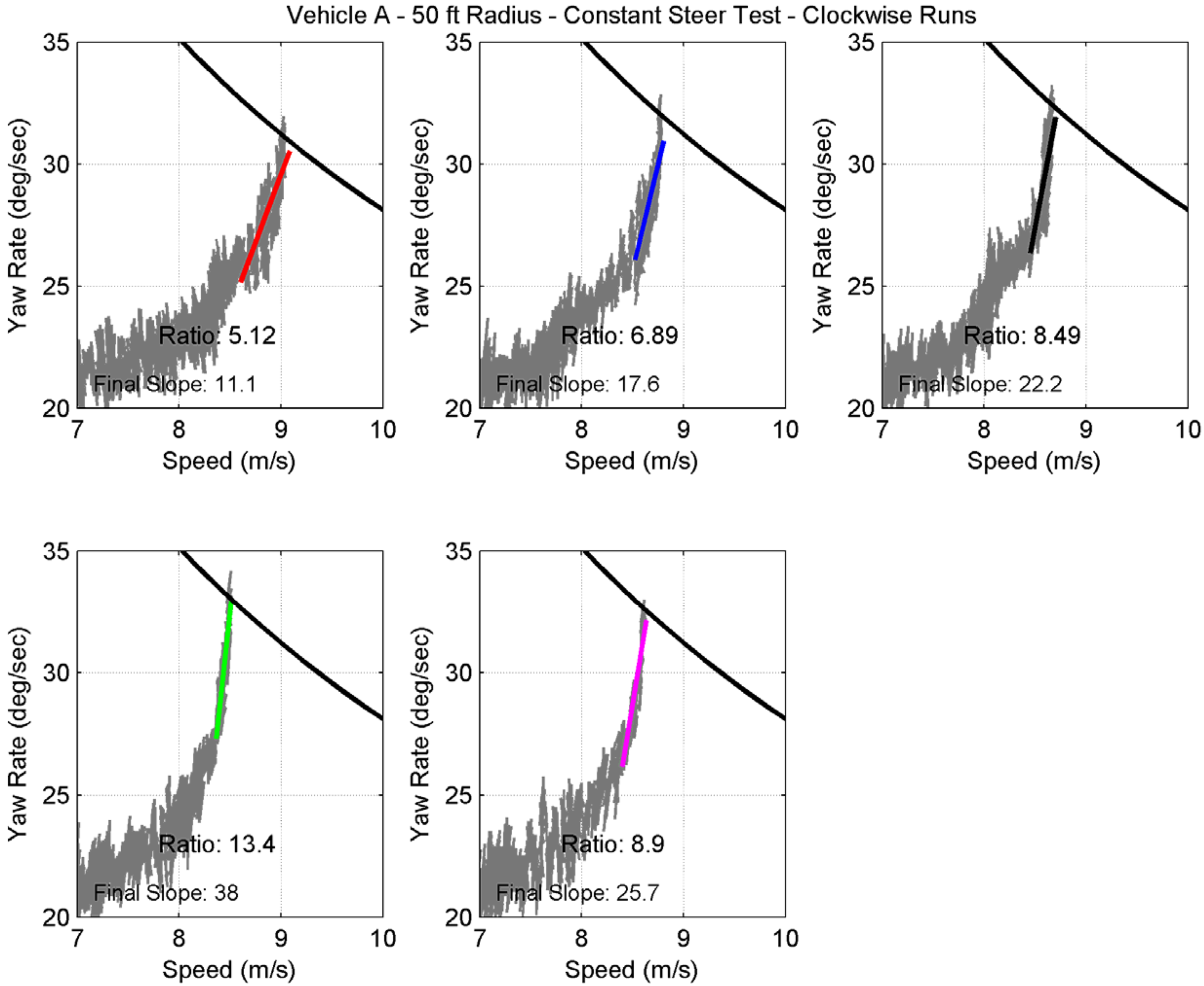

Vehicle M15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -0.309
Ratio: 0.105
Final Slope: -1.35
Ratio: 0.444
Final Slope: -0.545
Ratio: 0.18
Final Slope: -1.71
Ratio: 0.595
Final Slope: -1.86
Ratio: 0.591
Yaw Rate (deg/sec)
Speed (m/s)
-15
-20
-25
-30
8
9
10
11

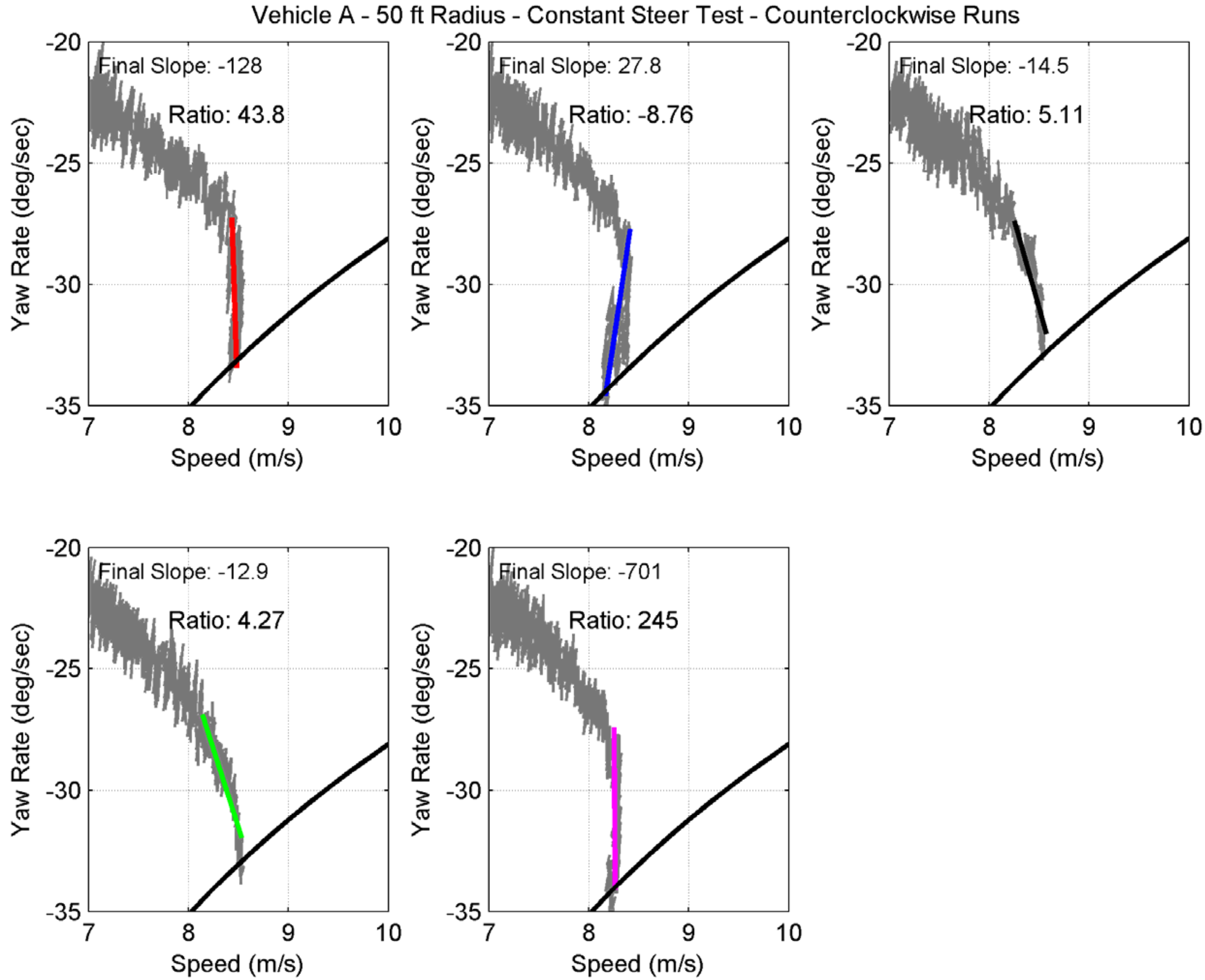

Yaw Rate Divergence Ratios - Measured During 50 ft Radius Constant Steer Tests
Yaw Rate Divergence Ratio
Right Turn Yaw Rate Divergence Ratio
Left Turn Yaw Rate Divergence Ratio
Average Yaw Rate Divergence Ratio
0
1
2
3
4
5
6
7
8
0.37
0.32
0.35
0.27
0.50
0.38
0.43
0.38
0.41
1.67
1.31
1.49
2.21
1.76
1.99
2.57
1.88
2.23
2.22
2.86
2.54
2.54
2.56
2.55
2.31
3.32
2.82
2.09
3.72
2.91
2.37
4.29
3.33
7.75
4.08
5.91
Vehicle B15
Vehicle L15
Vehicle M15
Vehicle J15
Vehicle D15
Vehicle E15
Vehicle I15
Vehicle A15
Vehicle K15
Vehicle C15
Vehicle L15
Rear Differential
Locked
Vehicle A

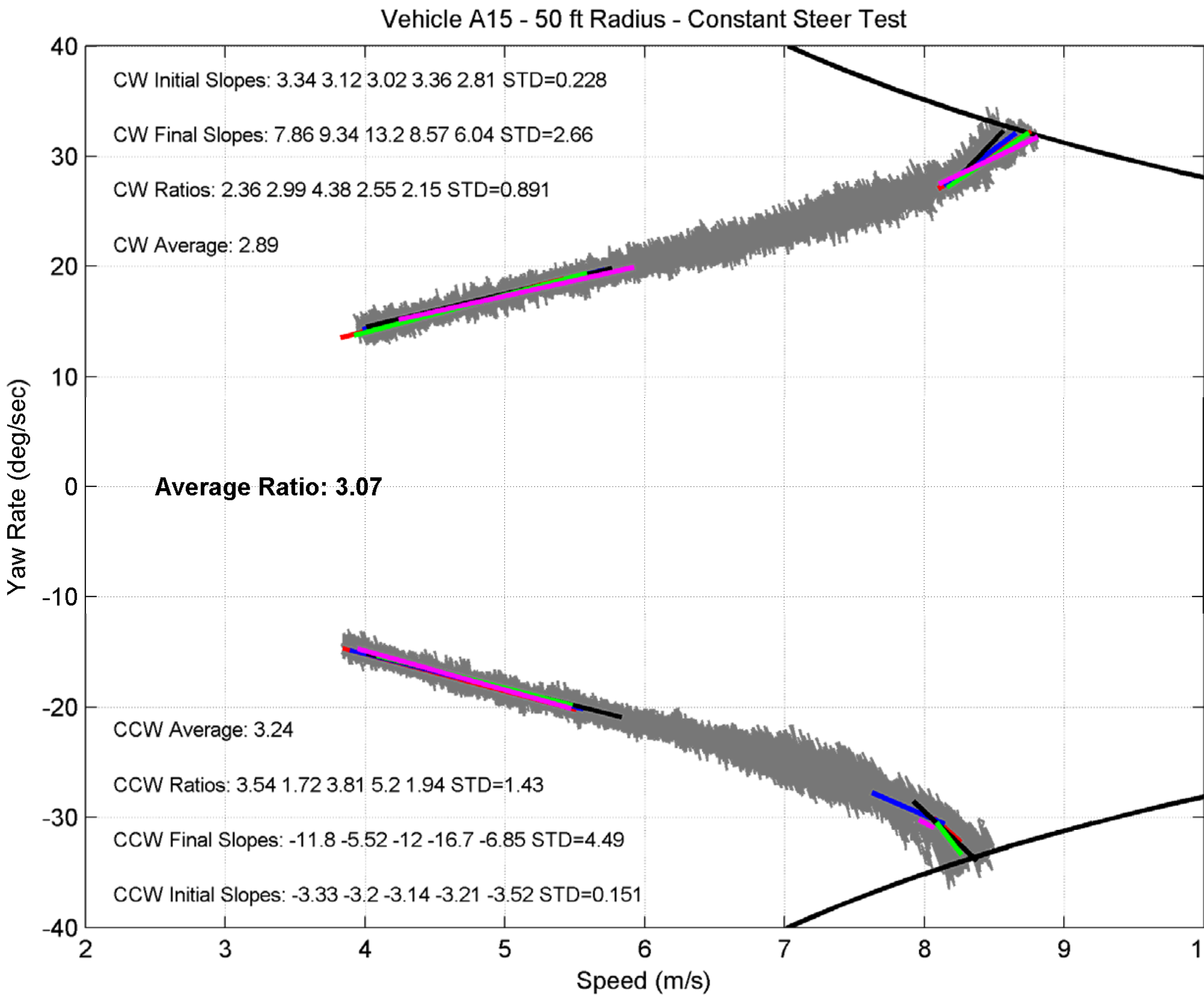
Appendix B

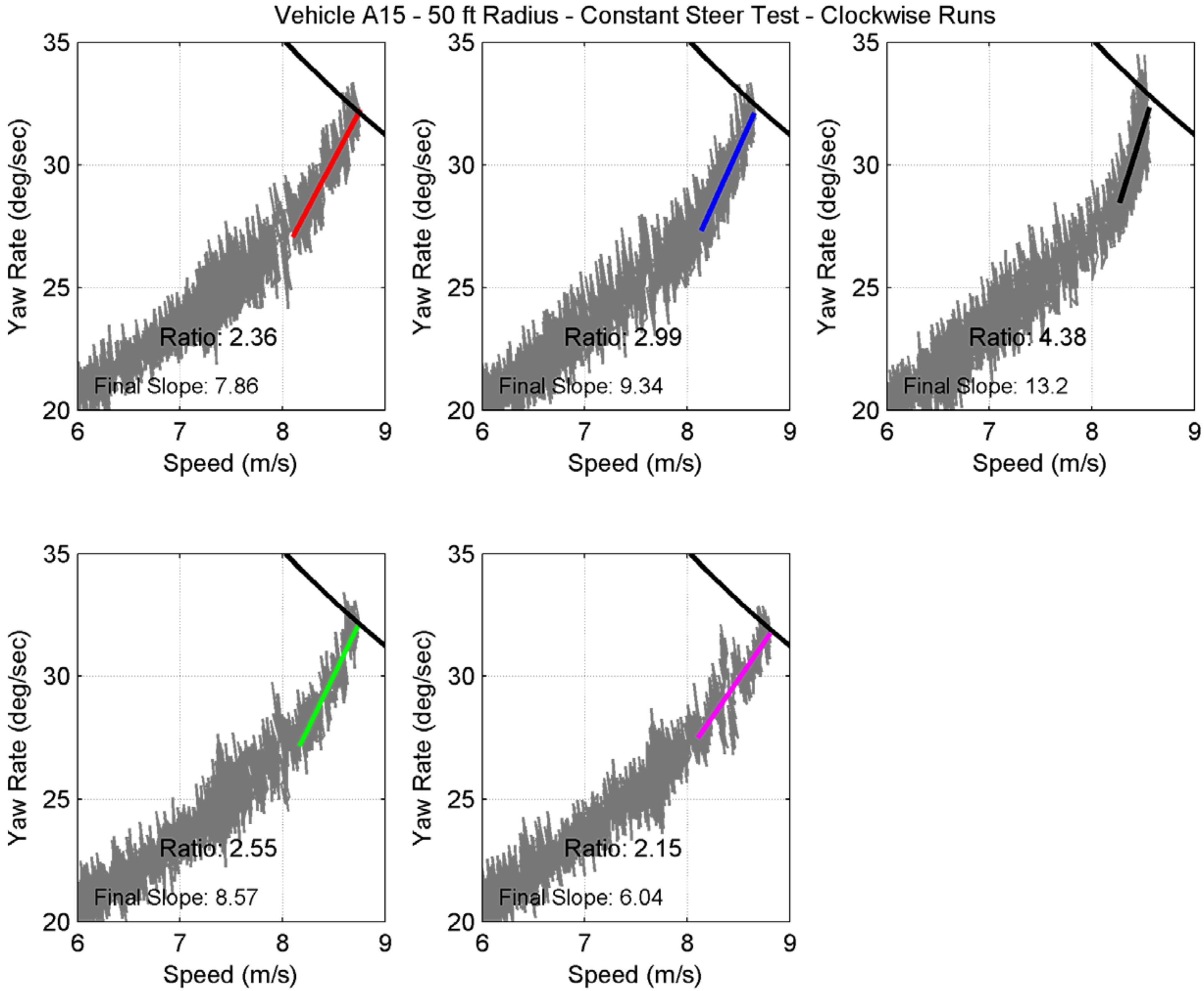
Yaw rate ratio test data of 11 ROVs using line fit formula normalized for speed.

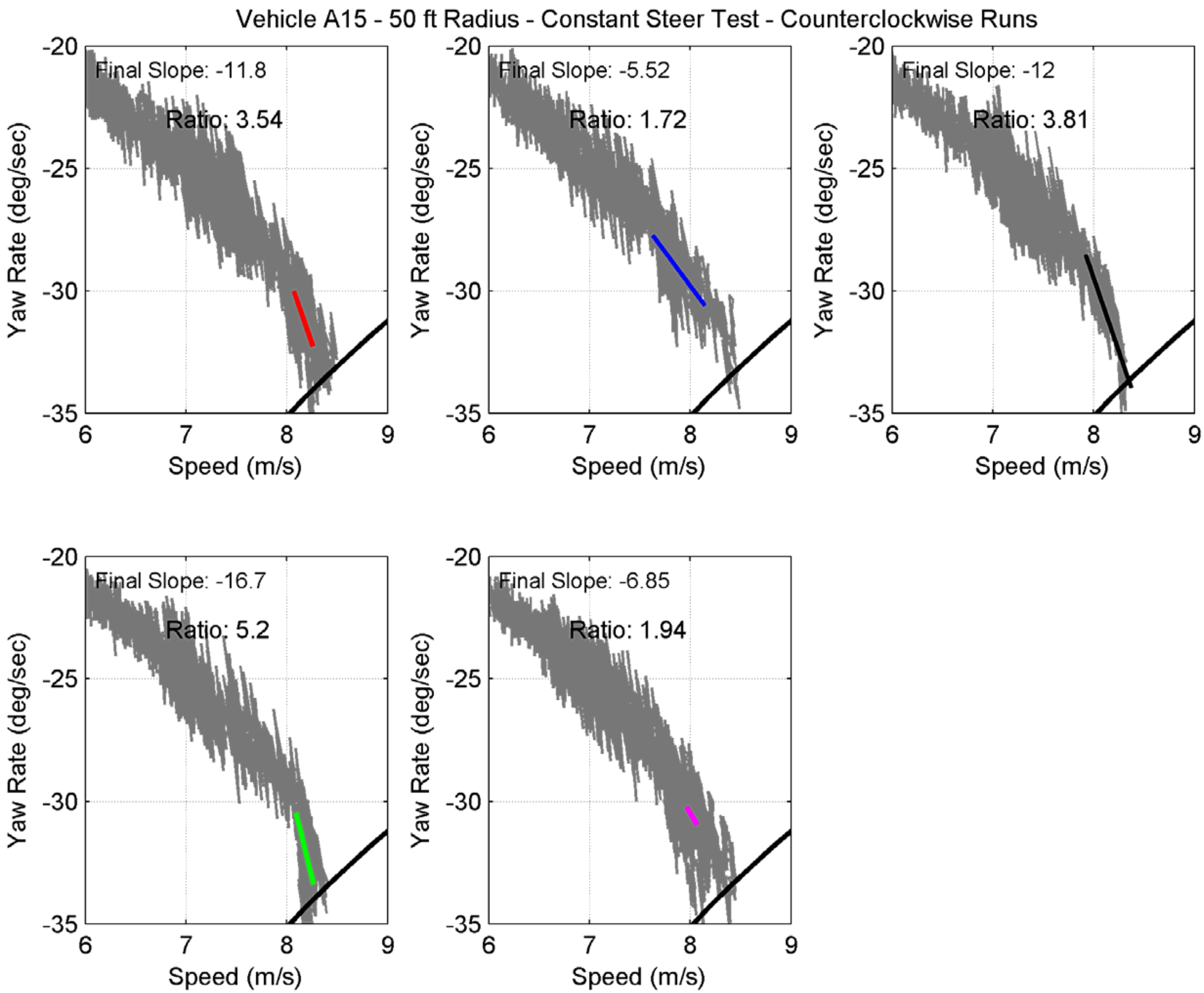

Vehicle A - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.17 2.55 2.62 2.83 2.88 STD=0.281
CW Final Slopes: 11.1 17.6 22.2 38 25.7 STD=10
CW Ratios: 5.12 6.89 8.49 13.4 8.9 STD=3.1
CW Average: 8.57
Average Ratio: 35
CCW Average: 61.3
CCW Ratios: 43.8 -8.76 5.11 4.27 245 STD=106
CCW Final Slopes: -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

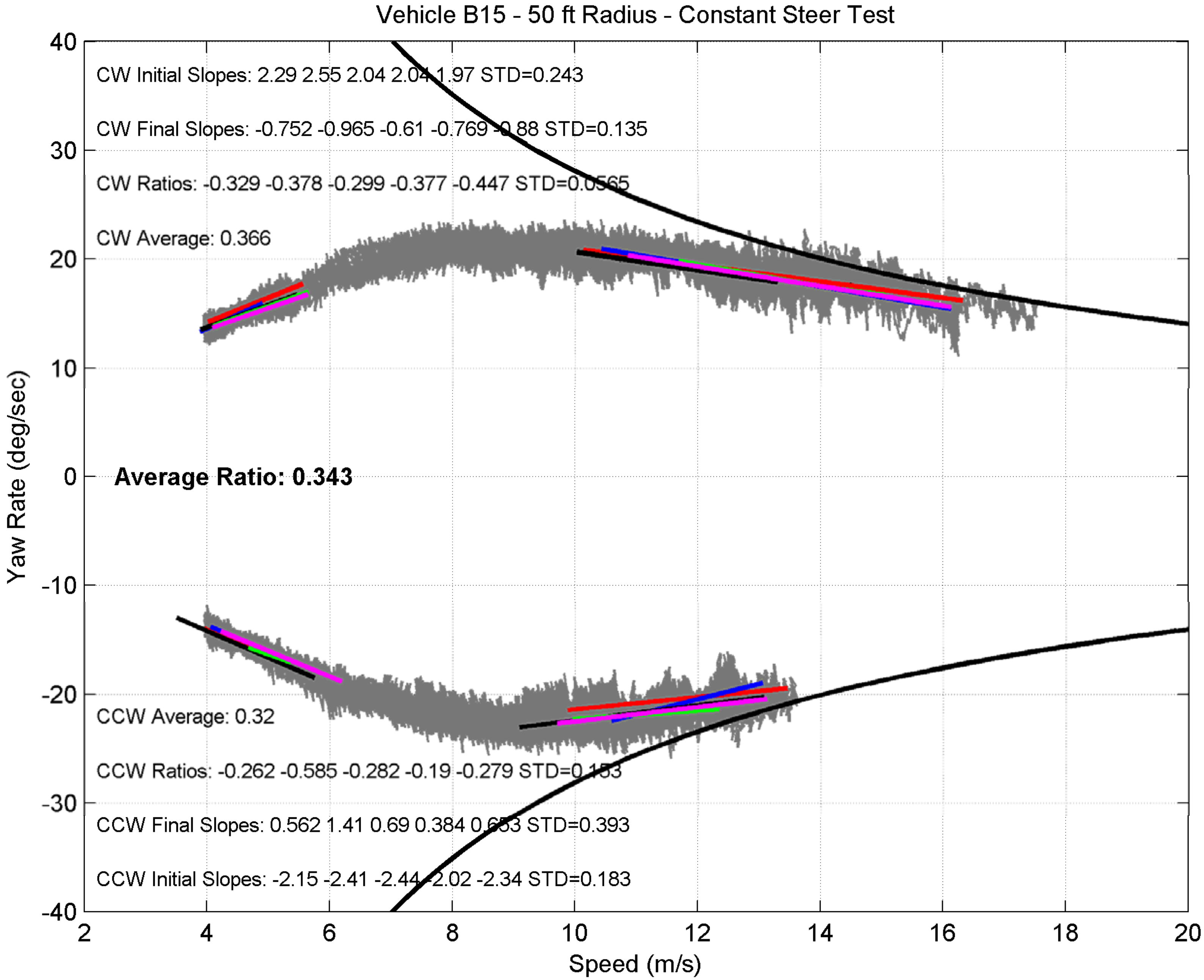

Vehicle A - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 5.12
Final Slope: 11.1
Ratio: 6.89
Final Slope: 17.6
Ratio: 8.49
Final Slope: 22.2
Ratio: 13.4
Final Slope: 38
Ratio: 8.9
Final Slope: 25.7


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

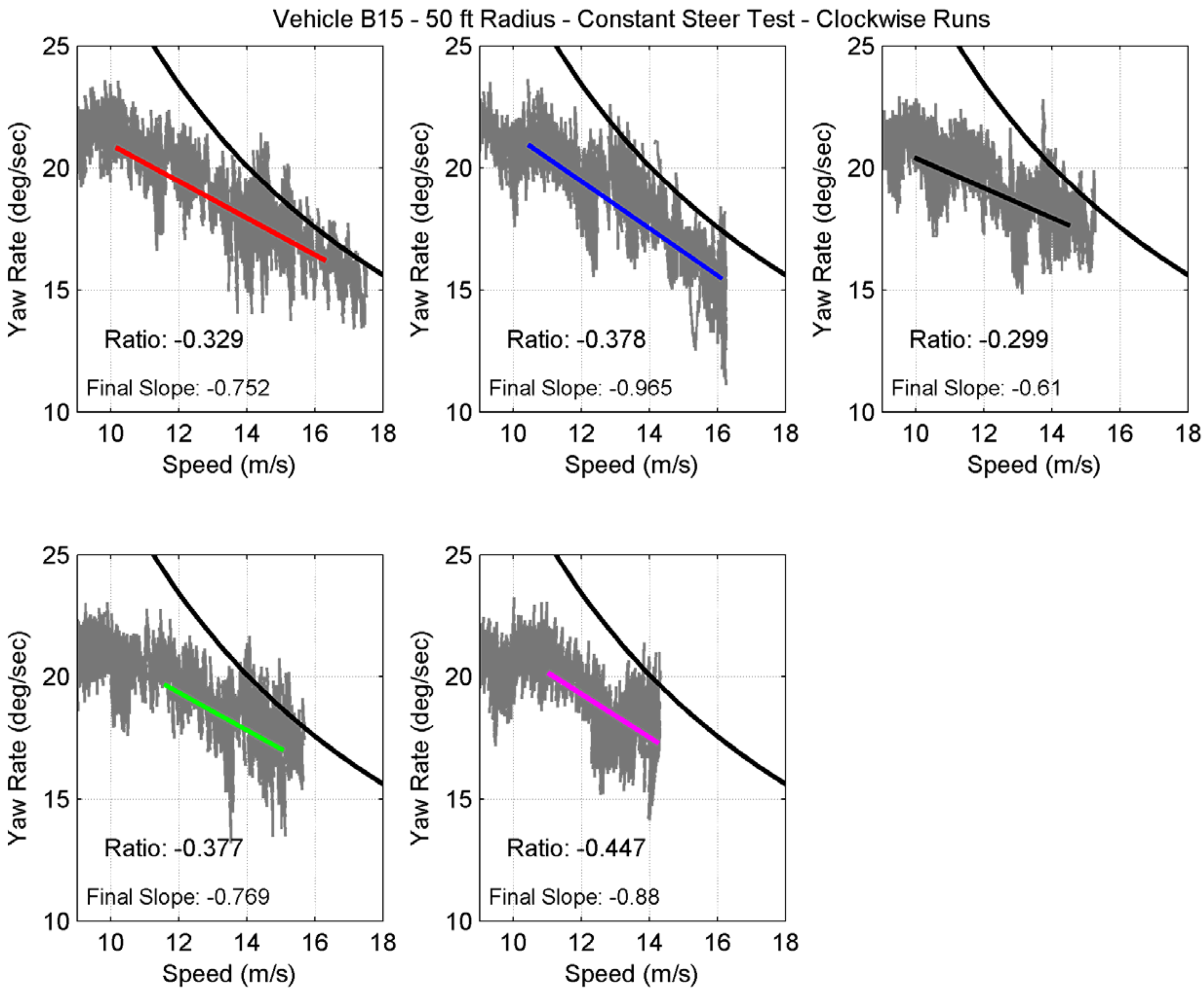

Vehicle A15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.34 3.12 3.02 3.36 2.81 STD=0.228
CW Final Slopes: 7.86 9.34 13.2 8.57 6.04 STD=2.66
CW Ratios: 2.36 2.99 4.38 2.55 2.15 STD=0.891
CW Average: 2.89
Average Ratio: 3.07
CCW Average: 3.24
CCW Ratios: 3.54 1.72 3.81 5.2 1.94 STD=1.43
CCW 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
35
30
25
20
6
7
8
9

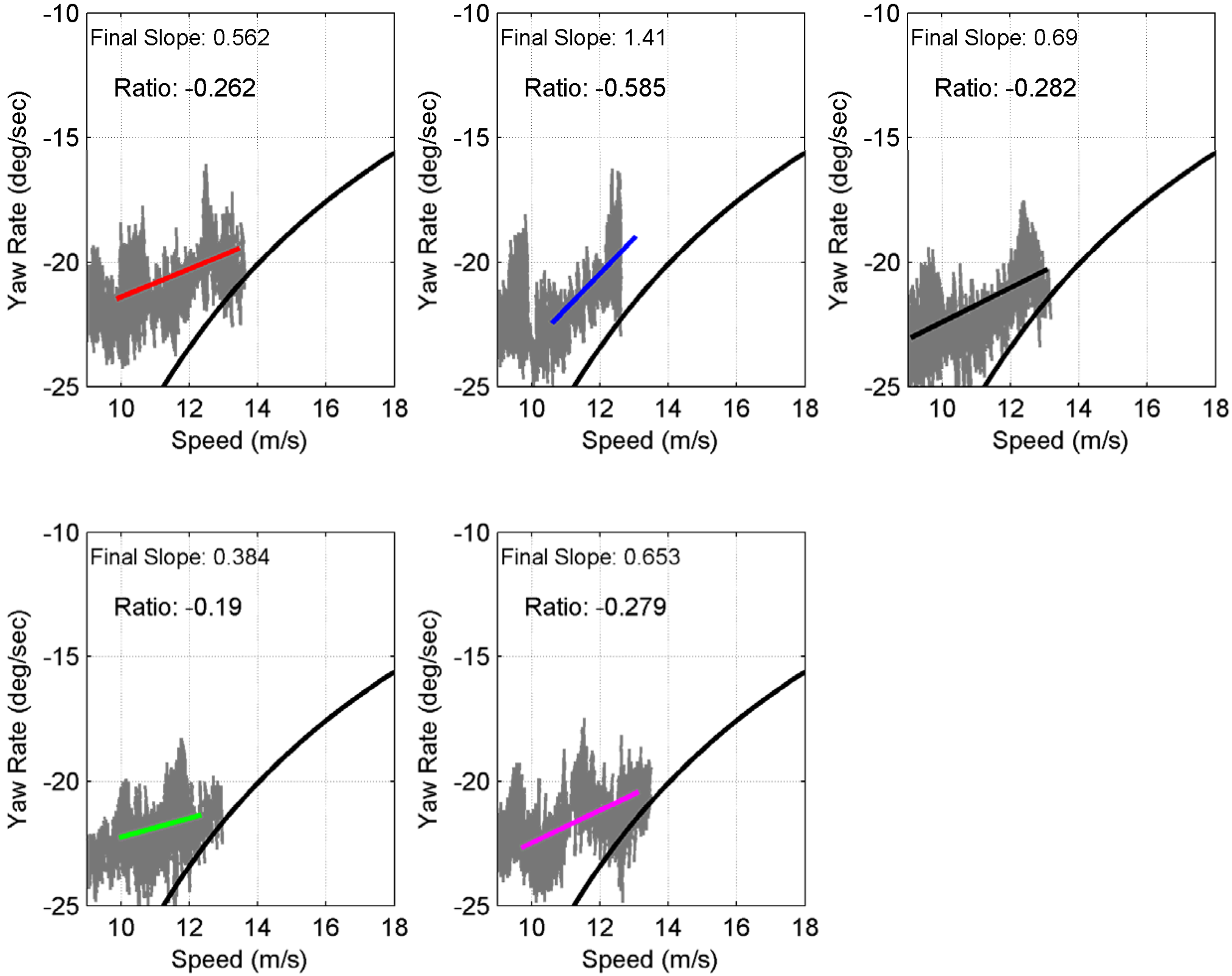

Vehicle A15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -11.8
Ratio: 3.54
Final Slope: -5.52
Ratio: 1.72
Final Slope: -12
Ratio: 3.81
Final Slope: -16.7
Ratio: 5.2
Final Slope: -6.85
Ratio: 1.94
Yaw Rate (deg/sec)
Speed (m/s)
-20
-25
-30
-35
6
7
8
9

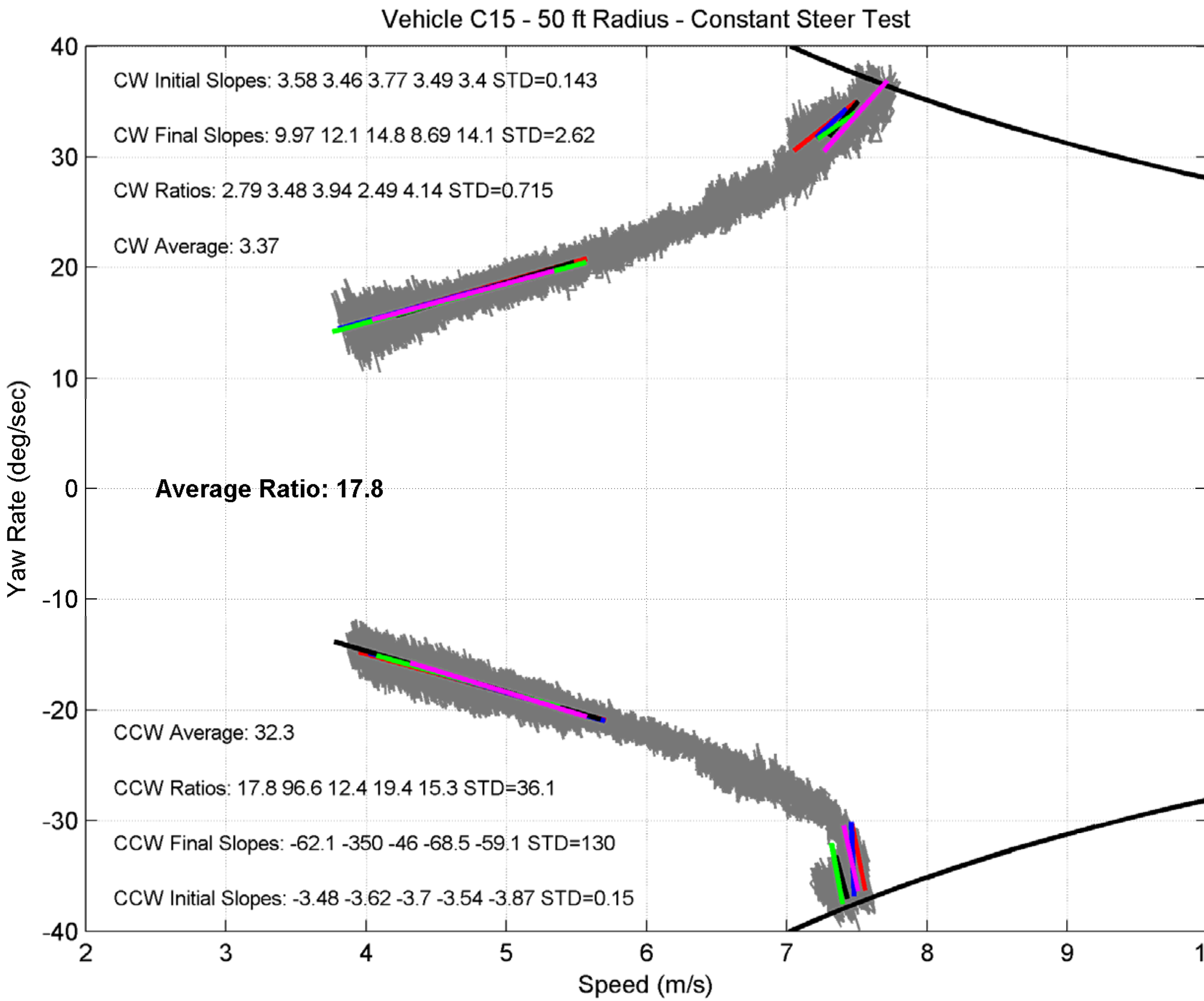


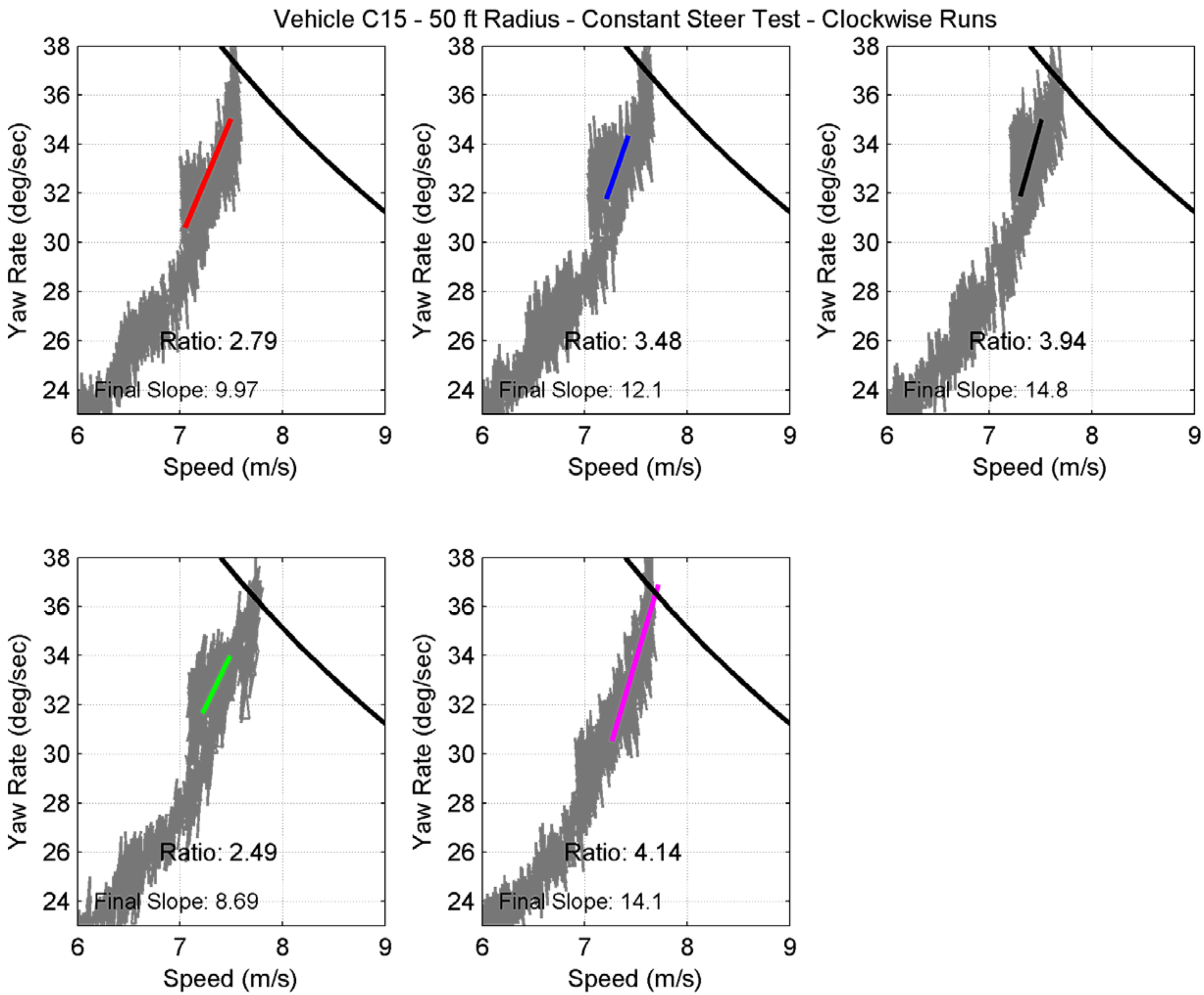
Vehicle B15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.29 2.55 2.04 2.04 1.97 STD=0.243
CW Final Slopes: -0.752 -0.965 -0.61 -0.769 -0.88 STD=0.135
CW Ratios: -0.329 -0.378 -0.299 -0.377 -0.447 STD=0.0565
CW Average: 0.366
Average Ratio: 0.343
CCW Average: 0.32
CCW Ratios: -0.262 -0.585 -0.282 -0.19 -0.279 STD=0.153
CCW Final Slopes: 0.562 1.41 0.69 0.384 0.653 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

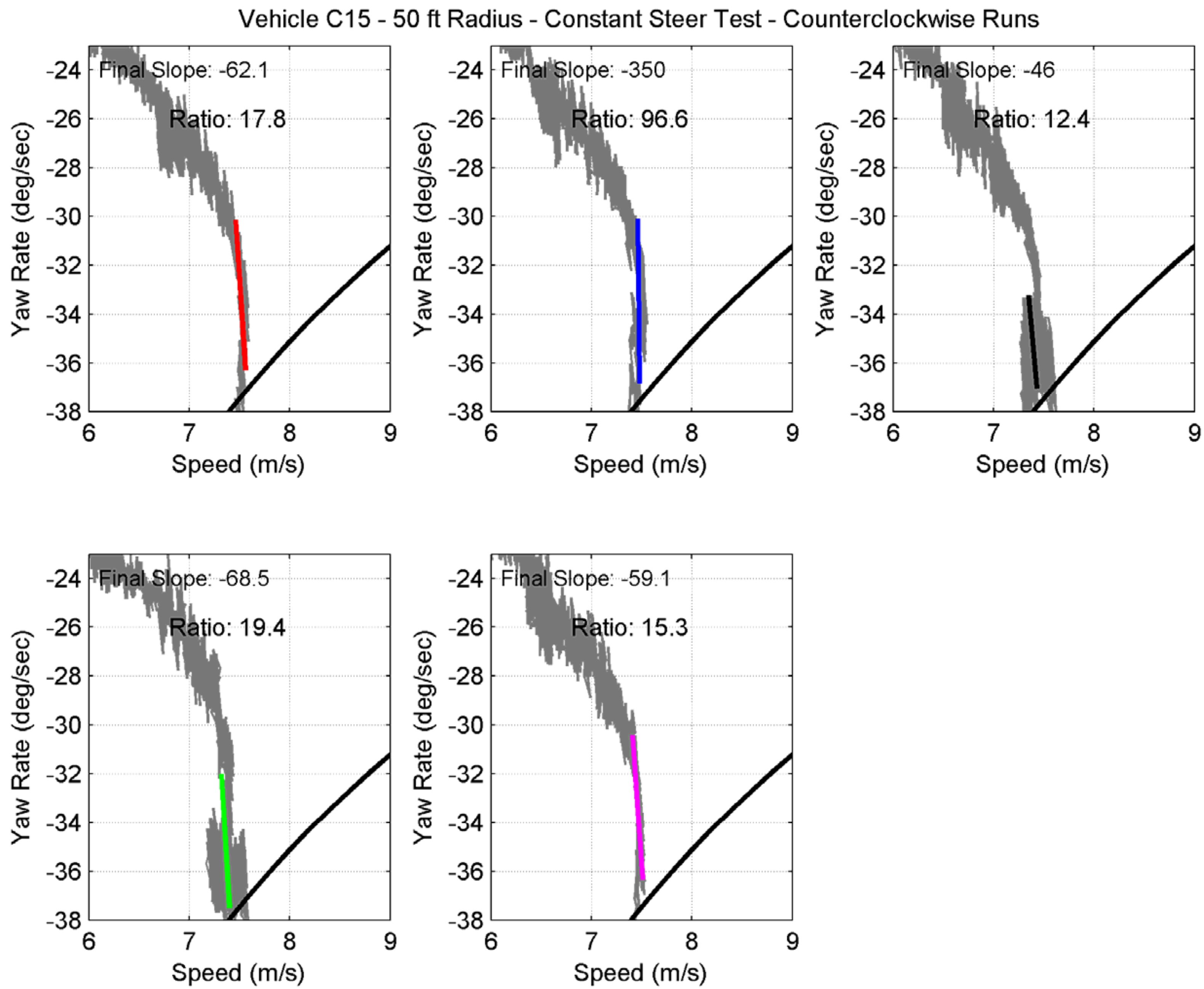

Vehicle B15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Ratio: -0.329
Final Slope: -0.752
Ratio: -0.378
Final Slope: -0.965
Ratio: -0.299
Final Slope: -0.61
Ratio: -0.377
Final Slope: -0.769
Ratio: -0.447
Final Slope: -0.88
Yaw Rate (deg/sec)
Speed (m/s)

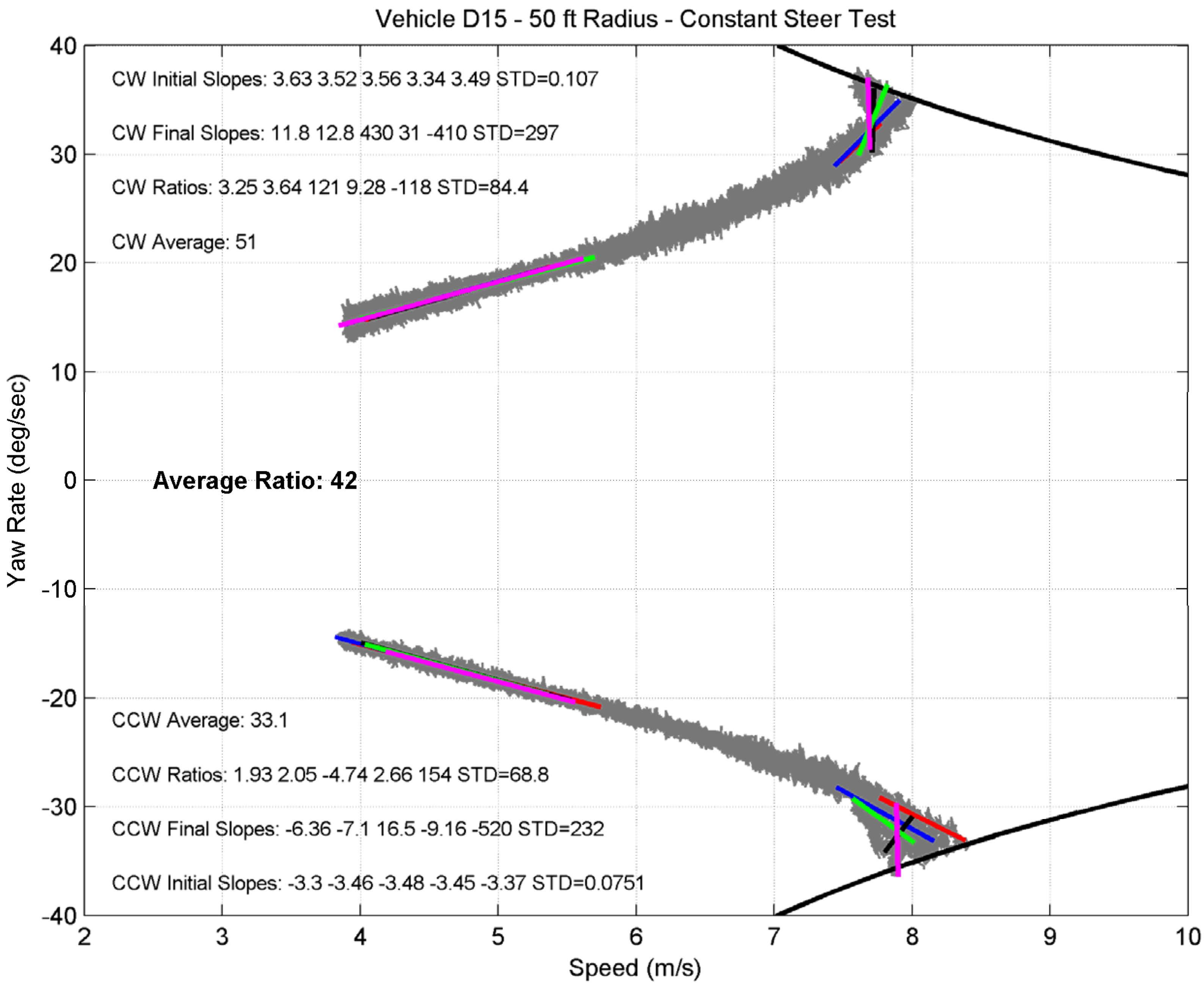
Vehicle B15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs

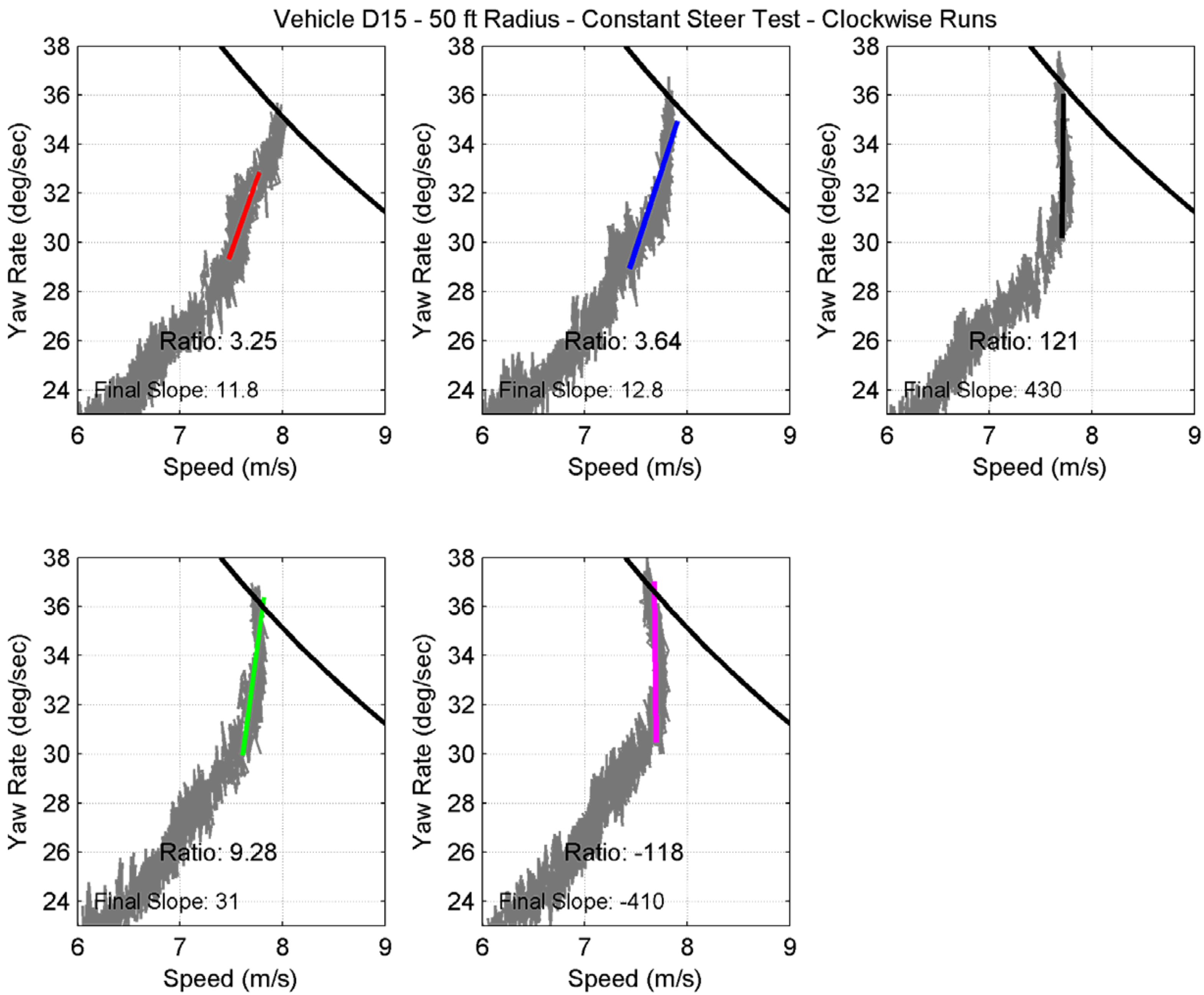


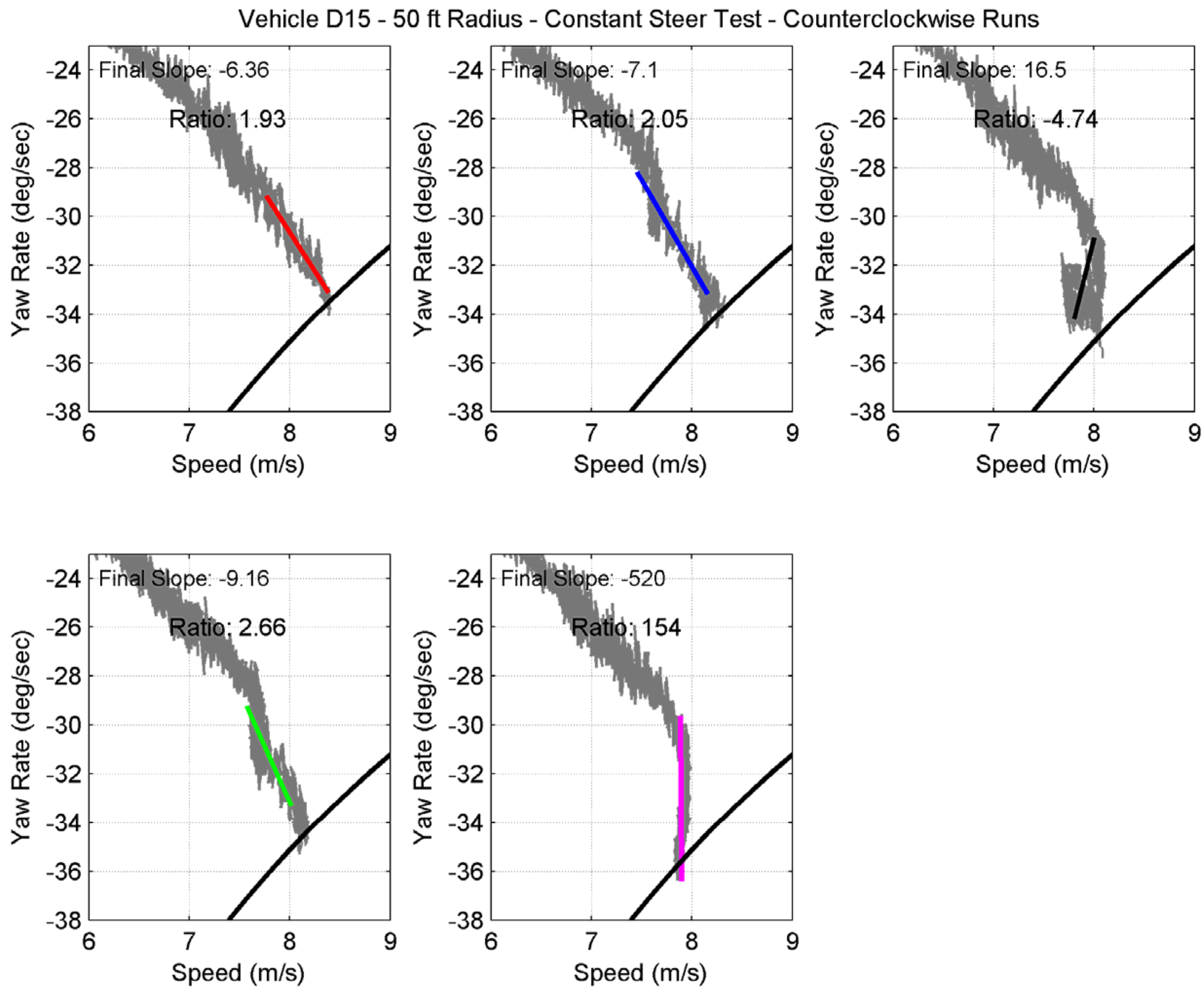

Vehicle C15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.58 3.46 3.77 3.49 3.4 STD=0.143
CW Final Slopes: 9.97 12.1 14.8 8.69 14.1 STD=2.62
CW Ratios: 2.79 3.48 3.94 2.49 4.14 STD=0.715
CW Average: 3.37
Average Ratio: 17.8
CCW Average: 32.3
CCW Ratios: 17.8 96.6 12.4 19.4 15.3 STD=36.1
CCW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

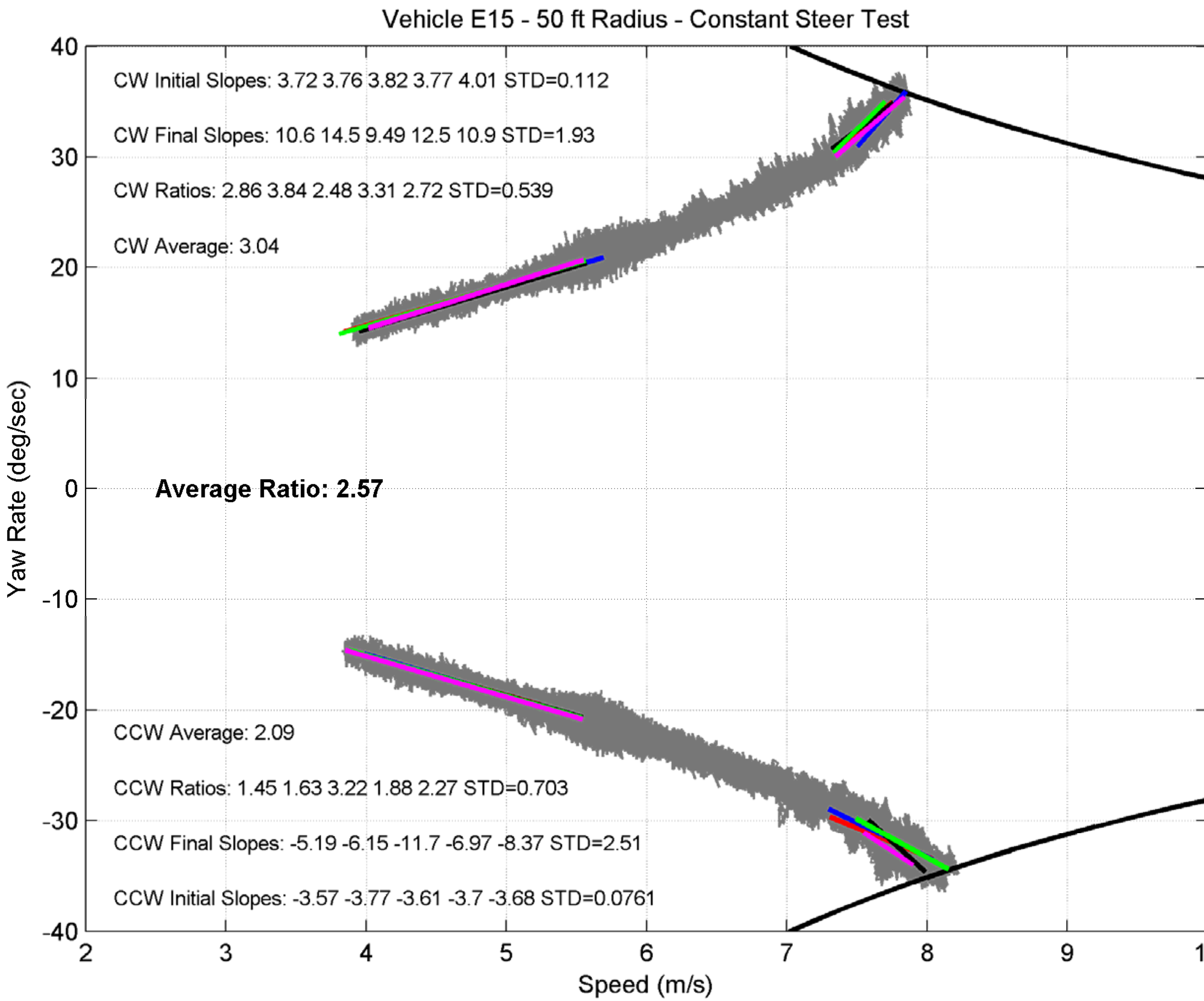

Vehicle C15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 2.79
Final Slope: 9.97
Ratio: 3.48
Final Slope: 12.1
Ratio: 3.94
Final Slope: 14.8
Ratio: 2.49
Final Slope: 8.69
Ratio: 4.14
Final Slope: 14.1


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)

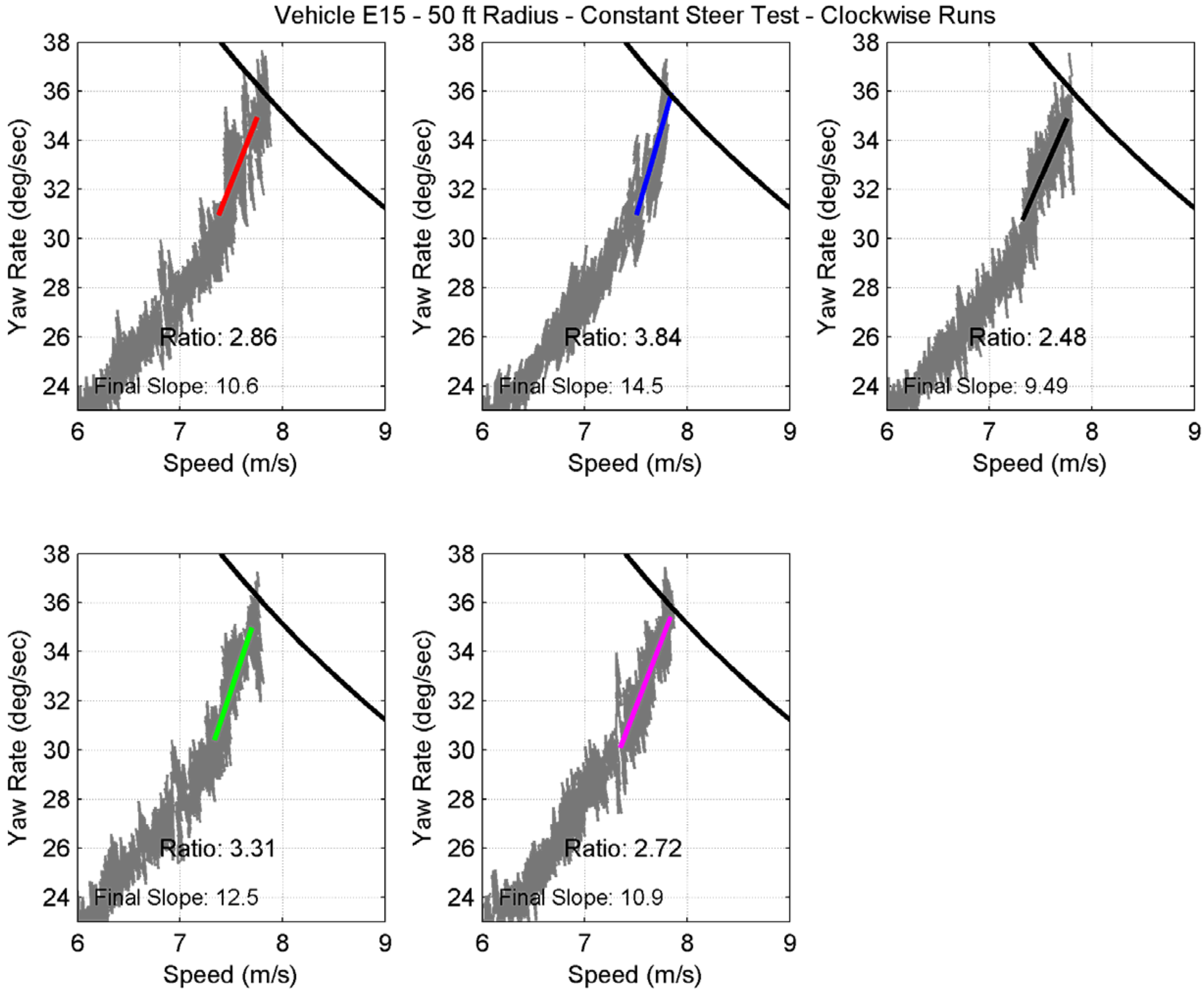

Vehicle D15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.63 3.52 3.56 3.34 3.49 STD=0.107
CW Final Slopes: 11.8 12.8 430 31 -410 STD=297
CW Ratios: 3.25 3.64 121 9.28 -118 STD=84.4
CW Average: 51
Average Ratio: 42
CCW Average: 33.1
CCW Ratios: 1.93 2.05 -4.74 2.66 154 STD=68.8
CCW Final 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

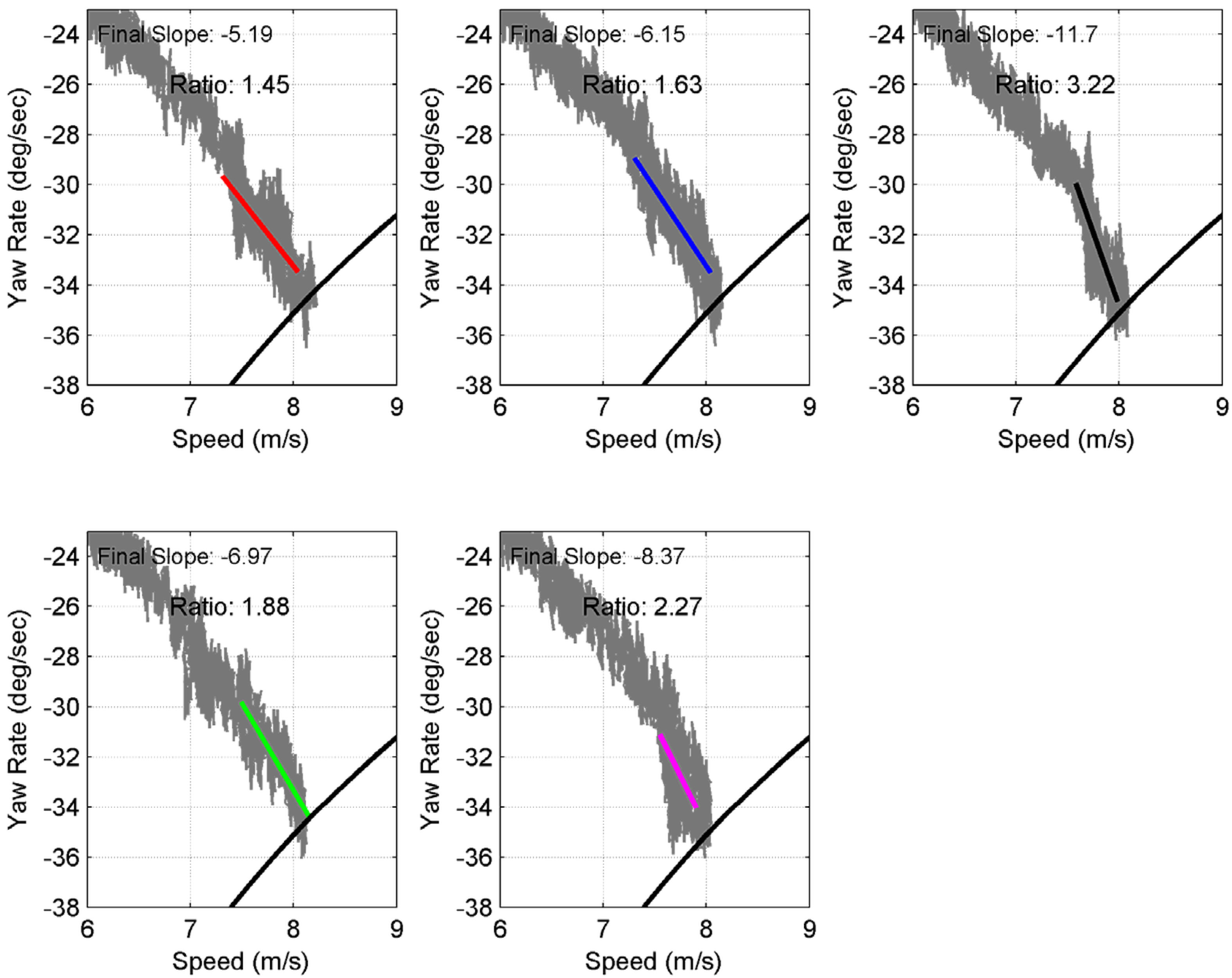


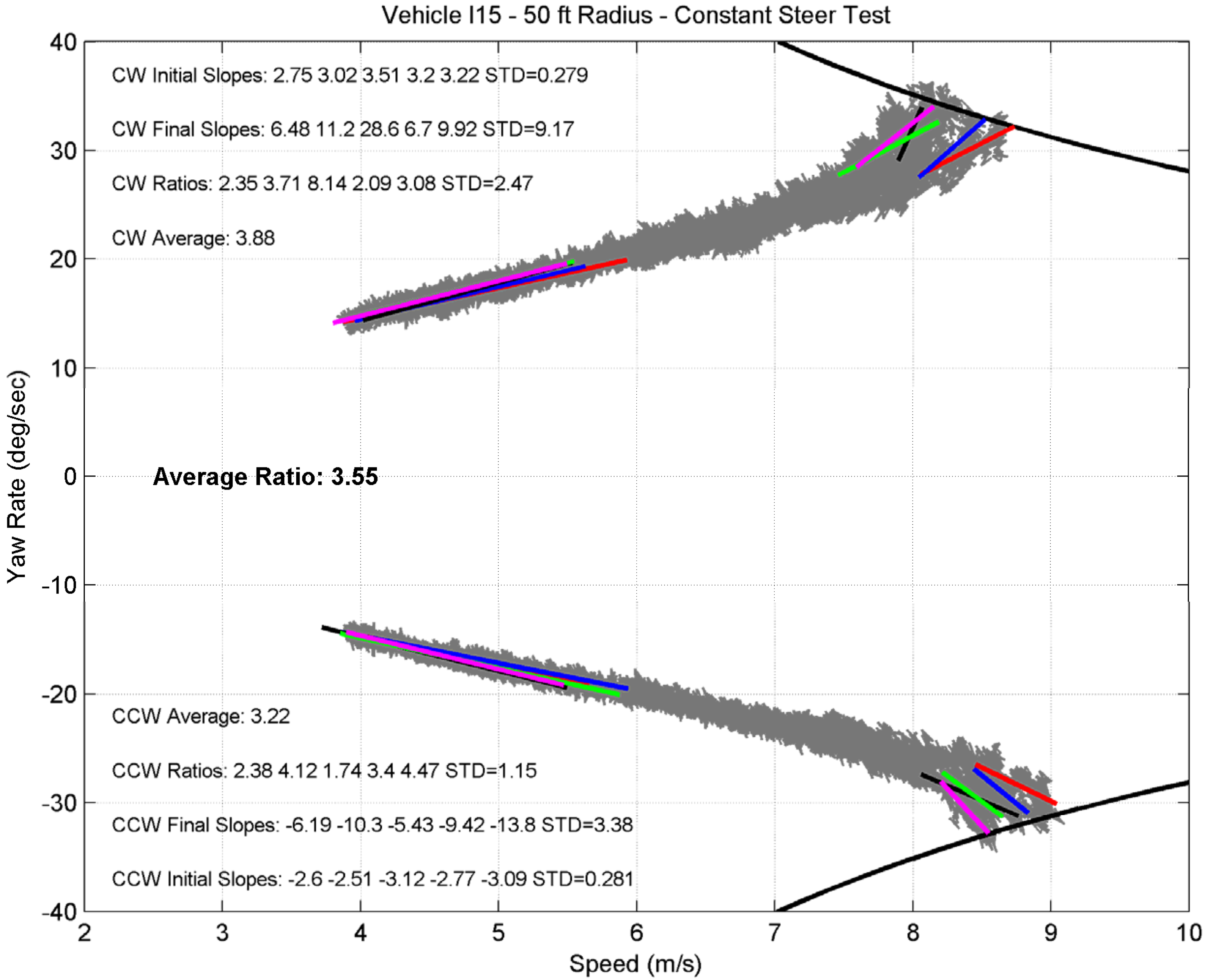
Vehicle E15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.72 3.76 3.82 3.77 4.01 STD=0.112
CW Final Slopes: 10.6 14.5 9.49 12.5 10.9 STD=1.93
CW Ratios: 2.86 3.84 2.48 3.31 2.72 STD=0.539
CW Average: 3.04
Average Ratio: 2.57
CCW Average: 2.09
CCW Ratios: 1.45 1.63 3.22 1.88 2.27 STD=0.703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

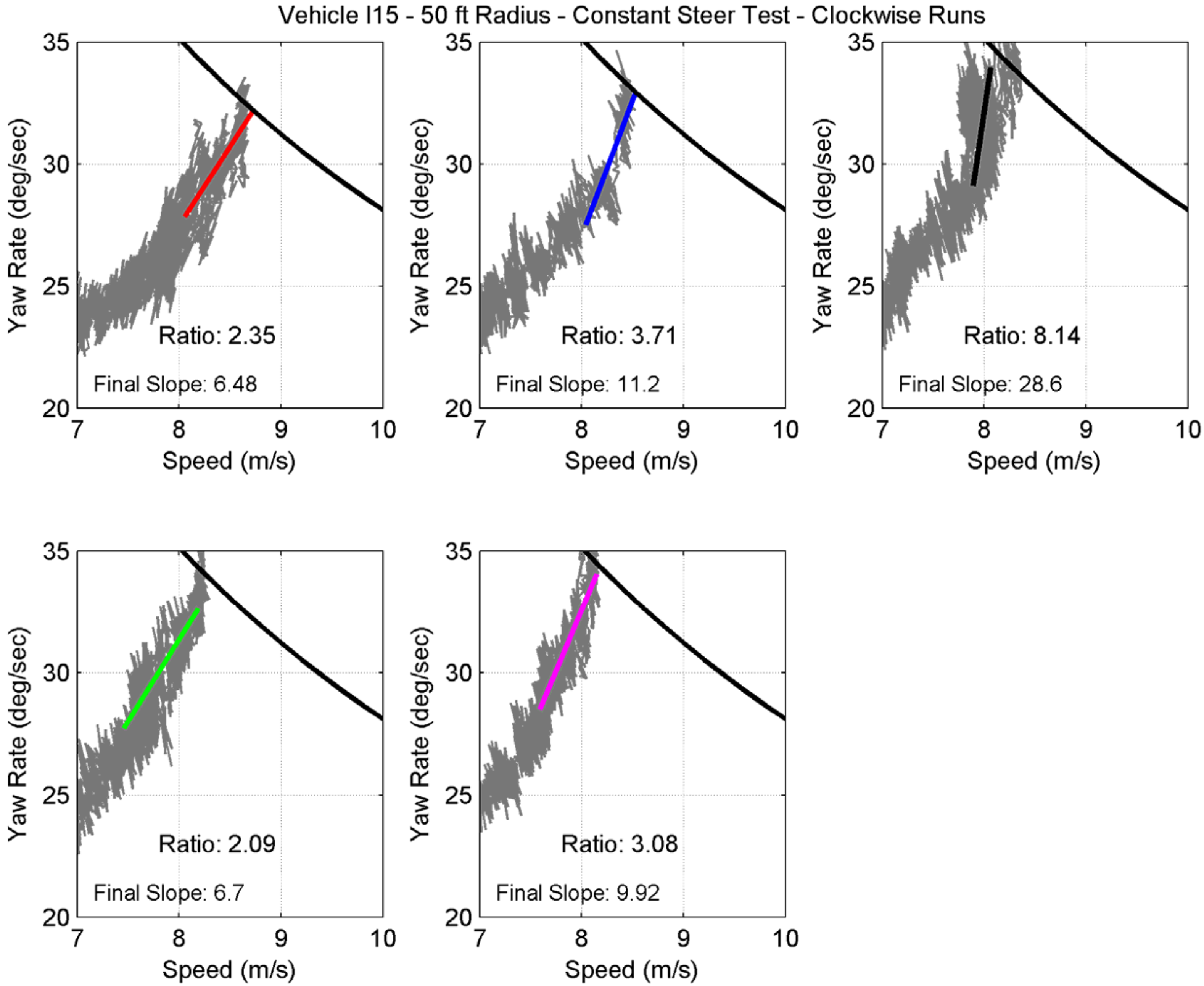


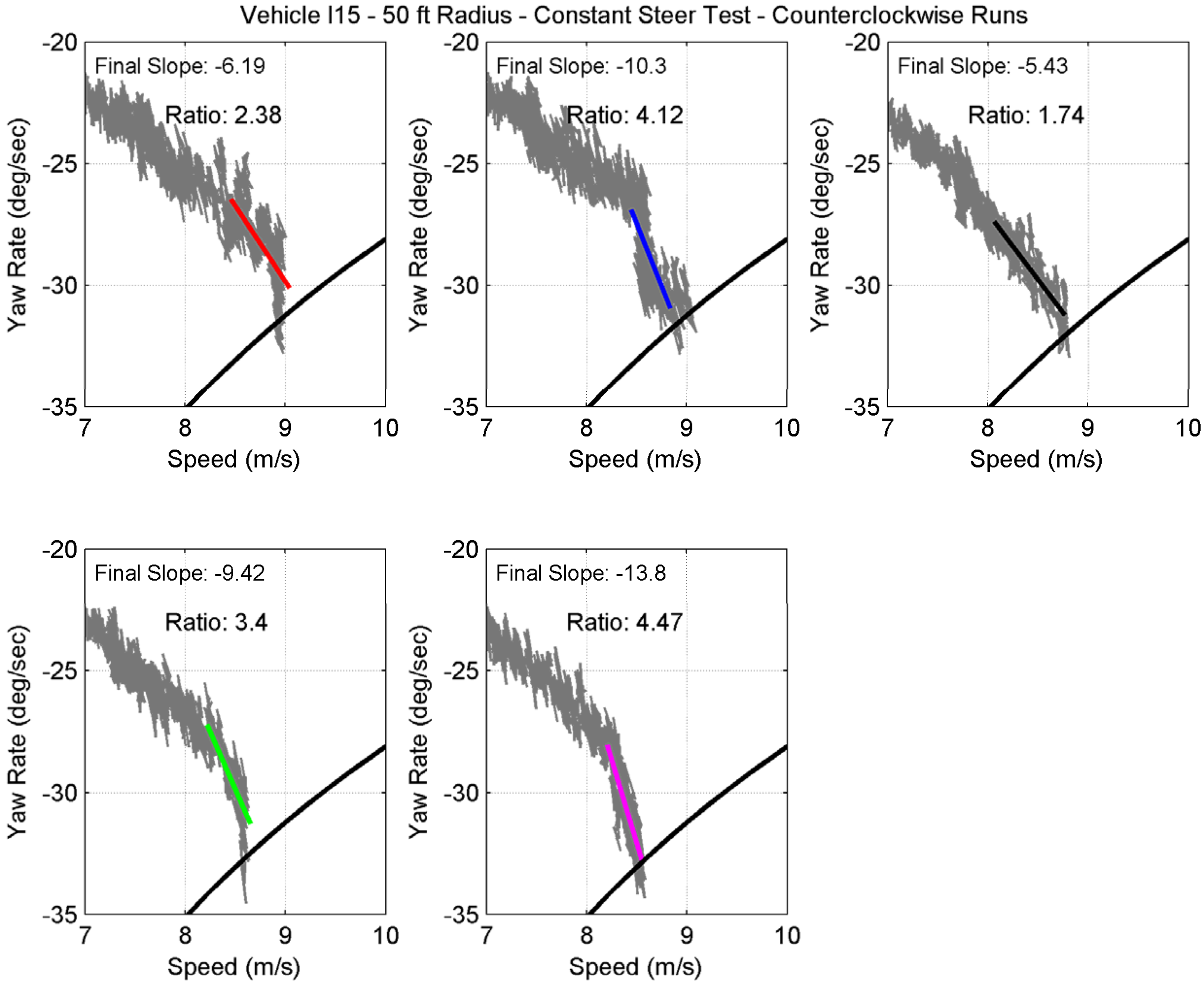
Vehicle E15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 2.86
Final Slope: 10.6
Ratio: 3.84
Final Slope: 14.5
Ratio: 2.48
Final Slope: 9.49
Ratio: 3.31
Final Slope: 12.5
Ratio: 2.72
Final Slope: 10.9

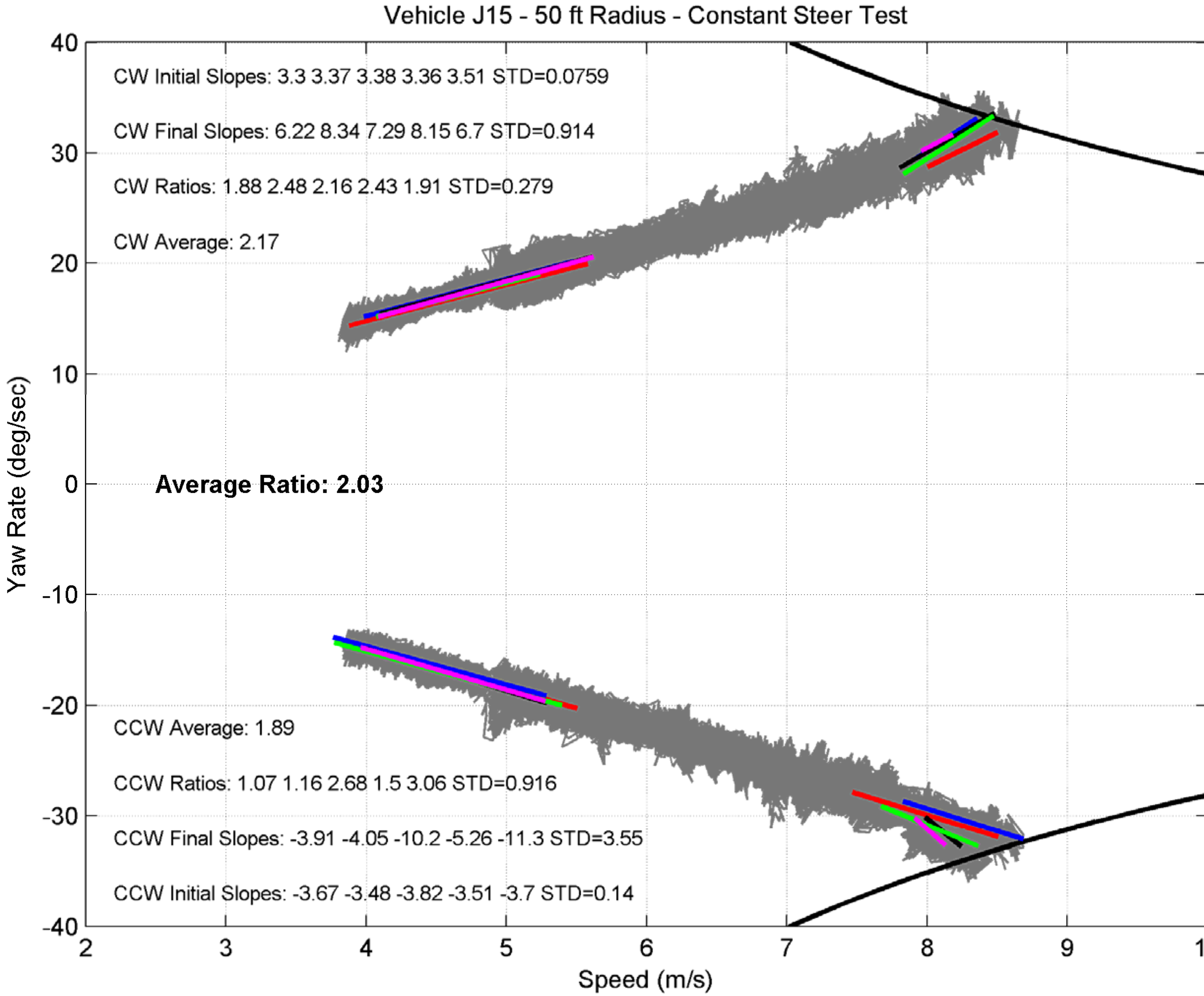
Vehicle E15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs

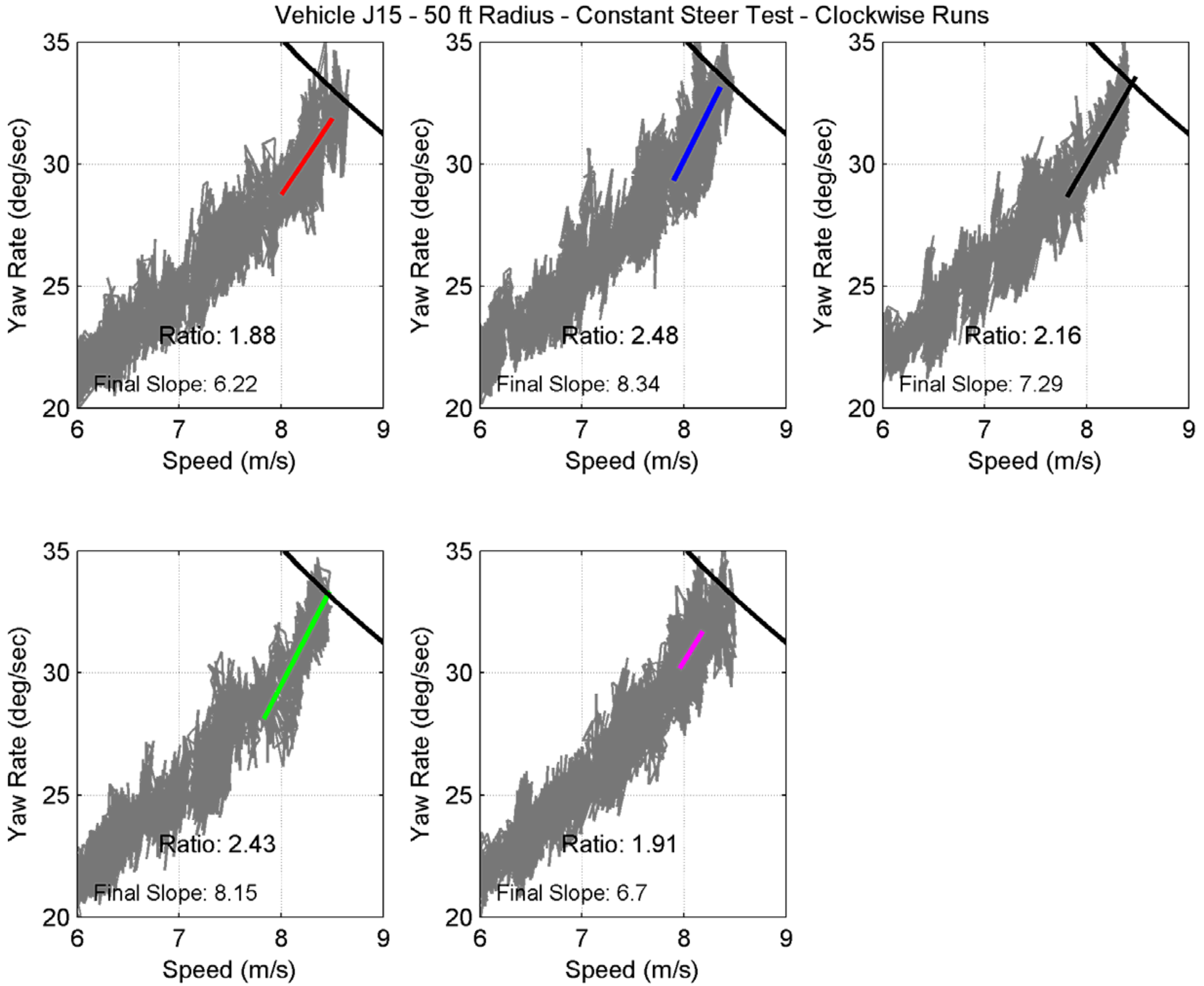



Vehicle I15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.75 3.02 3.51 3.2 3.22 STD=0.279
CW Final Slopes: 6.48 11.2 28.6 6.7 9.92 STD=9.17
CW Ratios: 2.35 3.71 8.14 2.09 3.08 STD=2.47
CW Average: 3.88
Average Ratio: 3.55
CCW Average: 3.22
CCW Ratios: 2.38 4.12 1.74 3.4 4.47 STD=1.15
CCW 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

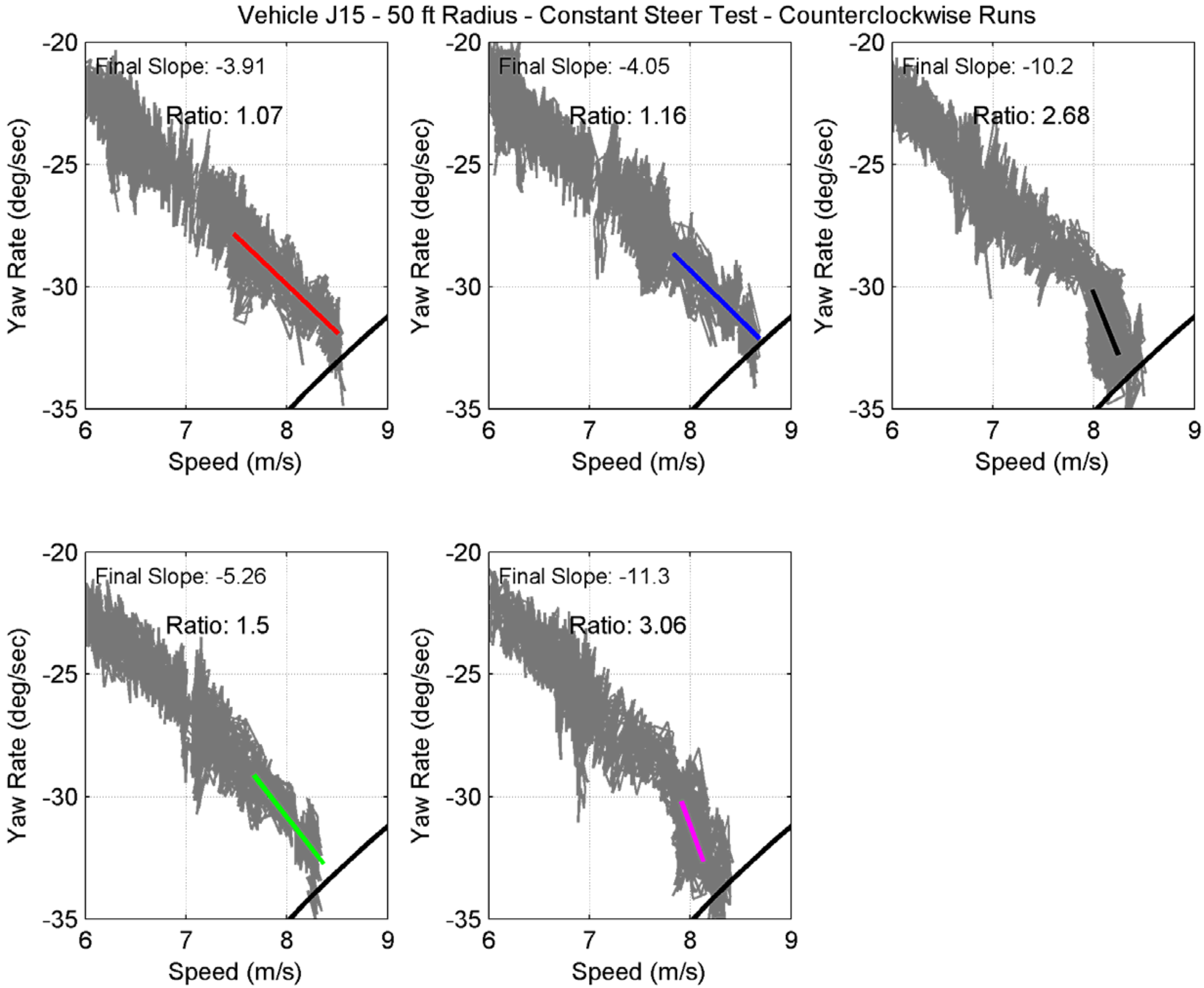

Vehicle I15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 2.35
Final Slope: 6.48
Ratio: 3.71
Final Slope: 11.2
Ratio: 8.14
Final Slope: 28.6
Ratio: 2.09
Final Slope: 6.7
Ratio: 3.08
Final Slope: 9.92
35
30
25
20
7
8
9
10


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

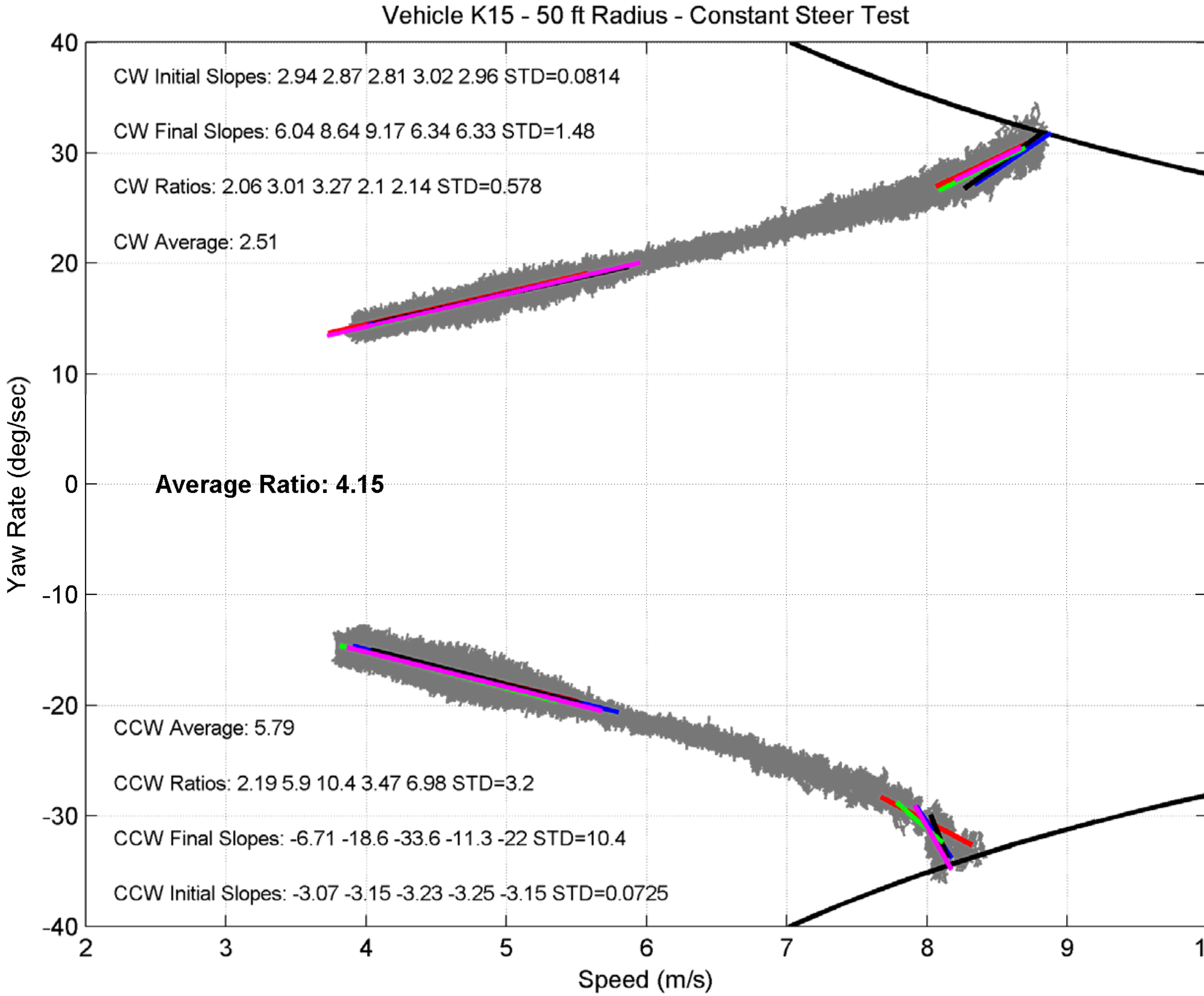

Vehicle J15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.3 3.37 3.38 3.36 3.51 STD=0.0759
CW Final Slopes: 6.22 8.34 7.29 8.15 6.7 STD=0.914
CW Ratios: 1.88 2.48 2.16 2.43 1.91 STD=0.279
CW Average: 2.17
Average Ratio: 2.03
CCW Average: 1.89
CCW Ratios: 1.07 1.16 2.68 1.5 3.06 STD=0.916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

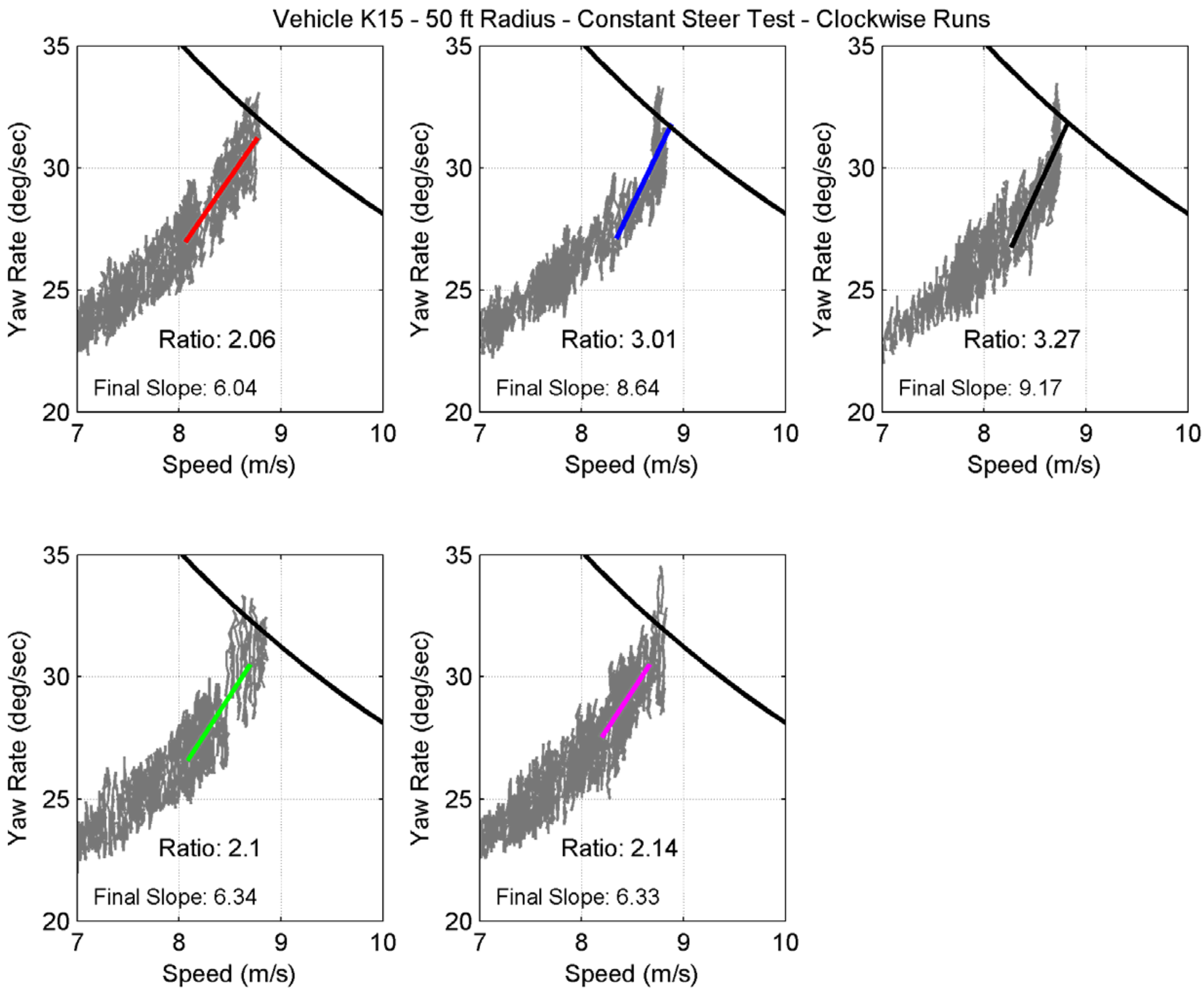


Vehicle J15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 1.88
Final Slope: 6.22
Ratio: 2.48
Final Slope: 8.34
Ratio: 2.16
Final Slope: 7.29
Ratio: 2.43
Final Slope: 8.15
Ratio: 1.91
Final Slope: 6.7

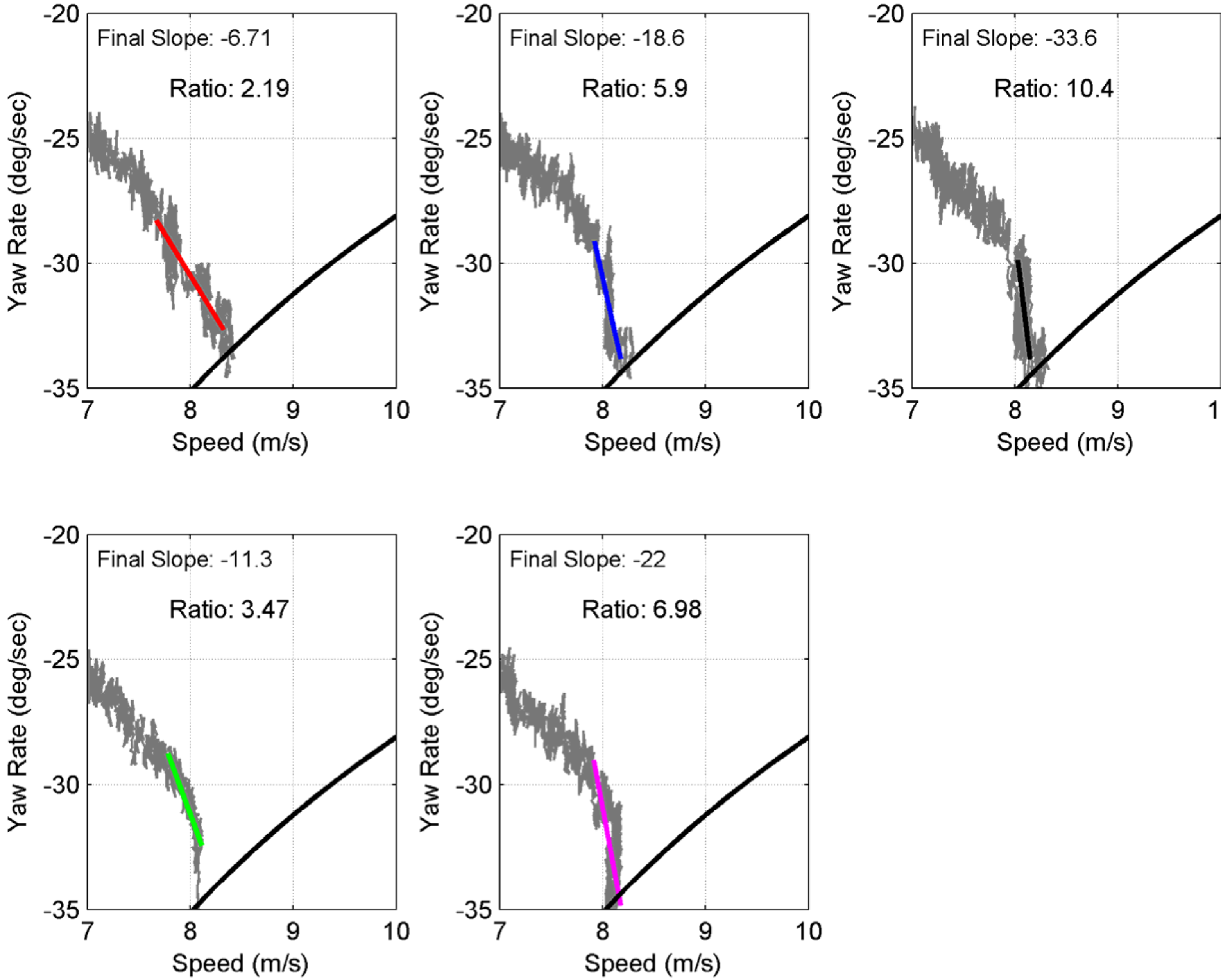


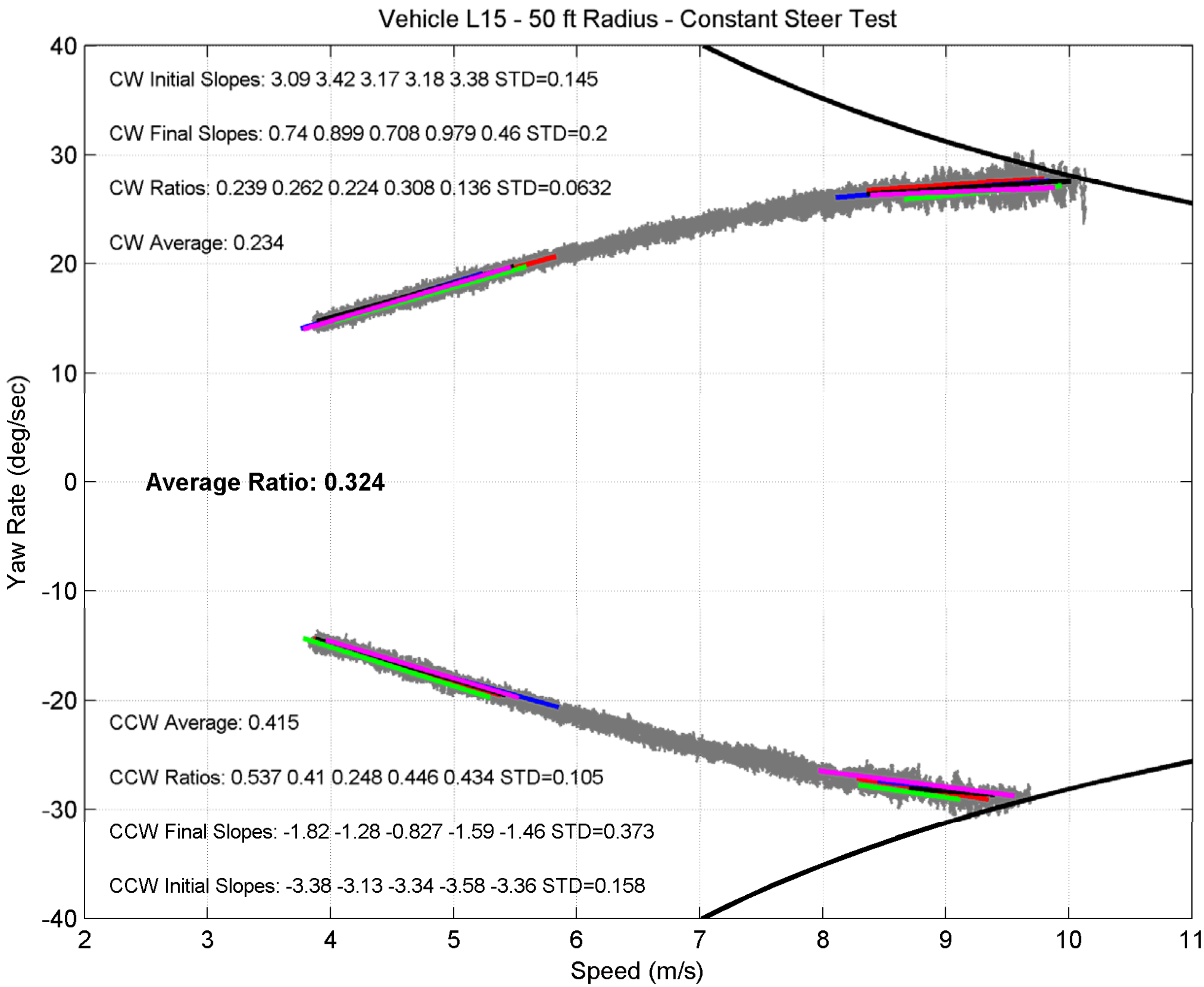
Vehicle J15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -3.91
Ratio: 1.07
Final Slope: -4.05
Ratio: 1.16
Final Slope: -10.2
Ratio: 2.68
Final Slope: -5.26
Ratio: 1.5
Final Slope: -11.3
Ratio: 3.06
Yaw Rate (deg/sec)
Speed (m/s)
-20
-25
-30
-35
6
7
8
9


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

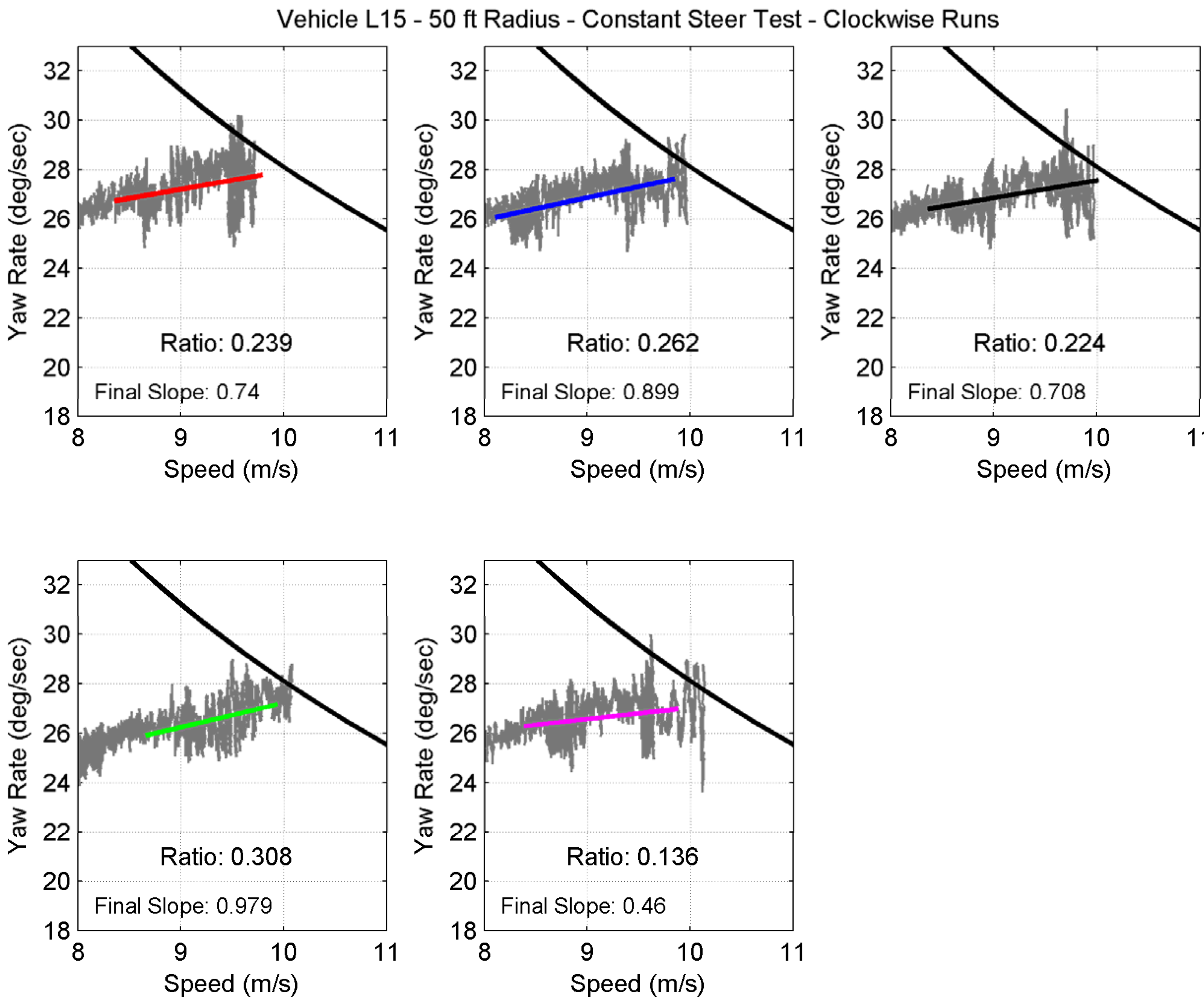

Vehicle K15 - 50 ft Radius - Constant Steer Test - Clockwise Runs
Yaw Rate (deg/sec)
Speed (m/s)
Ratio: 2.06
Final Slope: 6.04
Ratio: 3.01
Final Slope: 8.64
Ratio: 3.27
Final Slope: 9.17
Ratio: 2.1
Final Slope: 6.34
Ratio: 2.14
Final Slope: 6.33

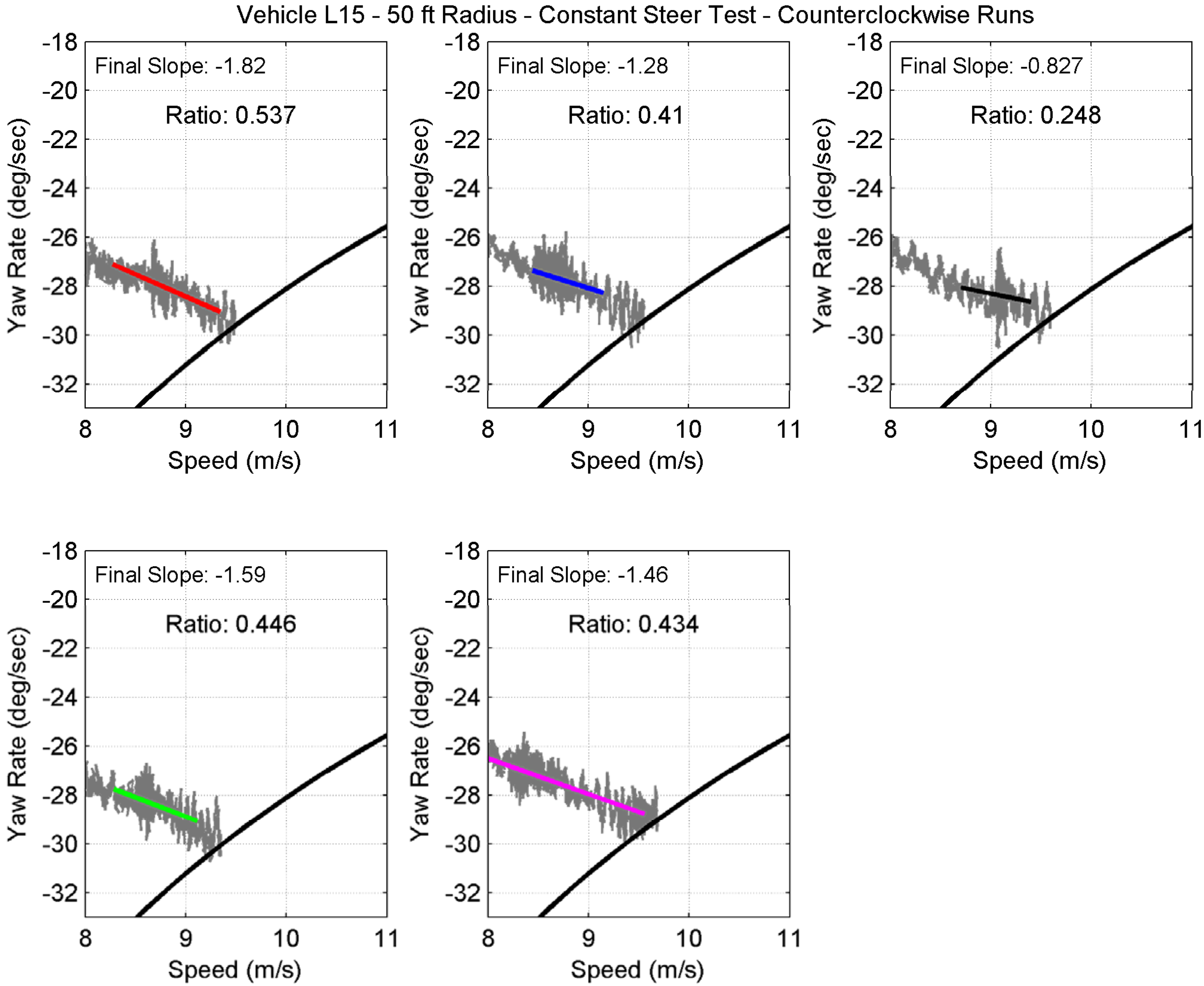
Vehicle K15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs



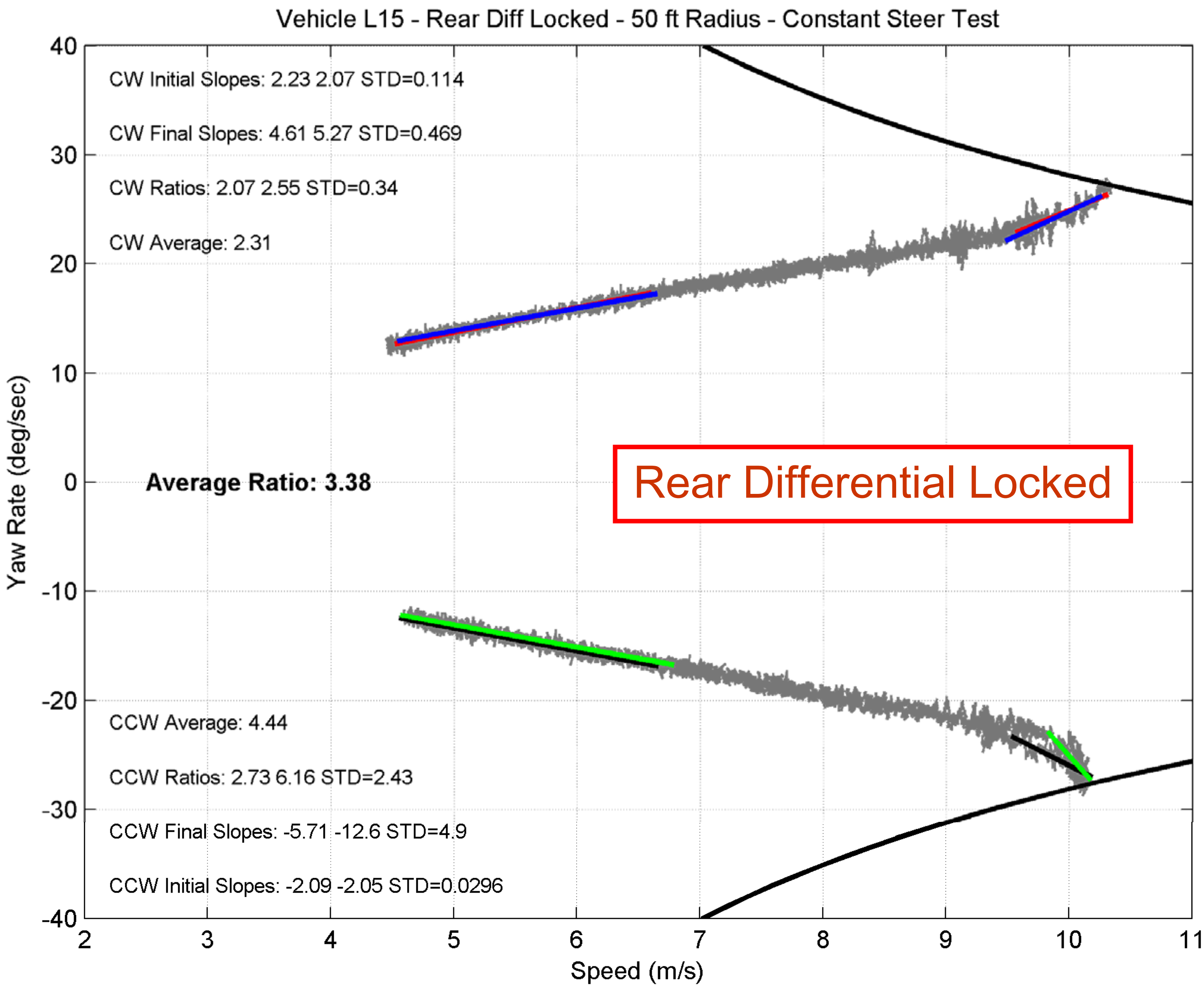


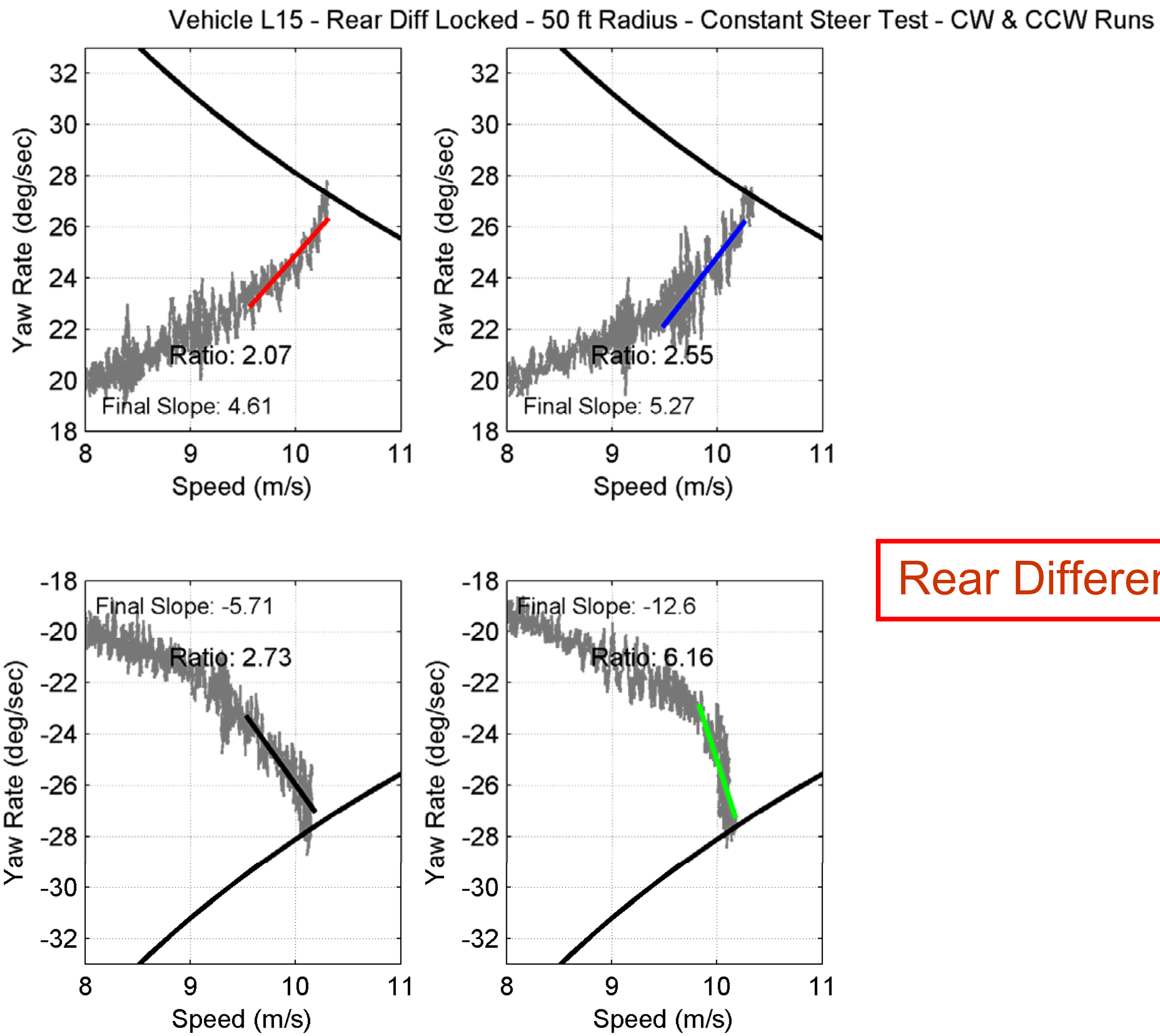
Vehicle L15 - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 3.09 3.42 3.17 3.18 3.38 STD=0.145
CW Final Slopes: 0.74 0.899 0.708 0.979 0.46 STD=0.2
CW Ratios: 0.239 0.262 0.224 0.308 0.136 STD=0.0632
CW Average: 0.234
Average Ratio: 0.324
CCW Average: 0.415
CCW Ratios: 0.537 0.41 0.248 0.446 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)
40
30
20
10
0
-10
-20
-30
-40
2
3
4
5
6
7
8
9
10
11
Speed (m/s)


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

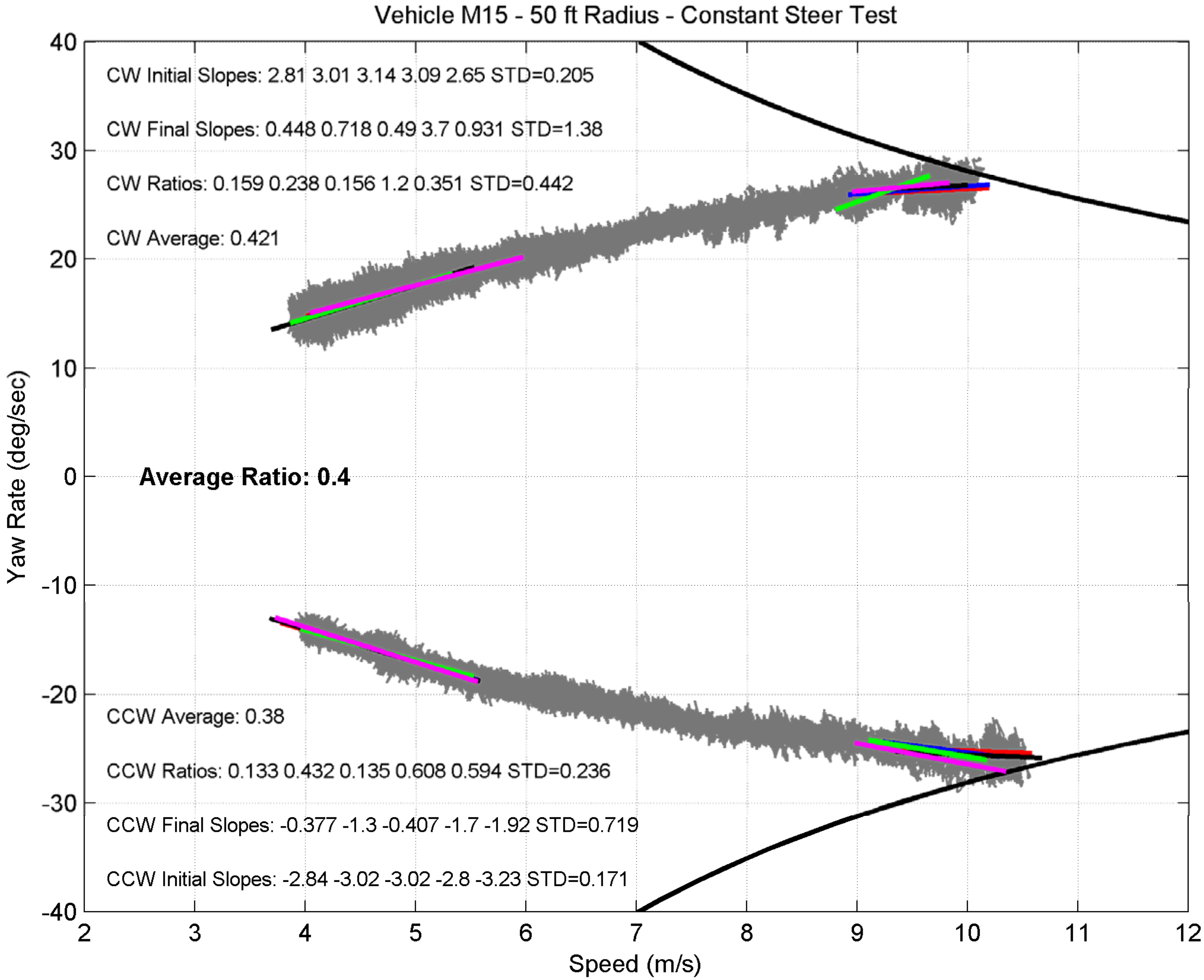


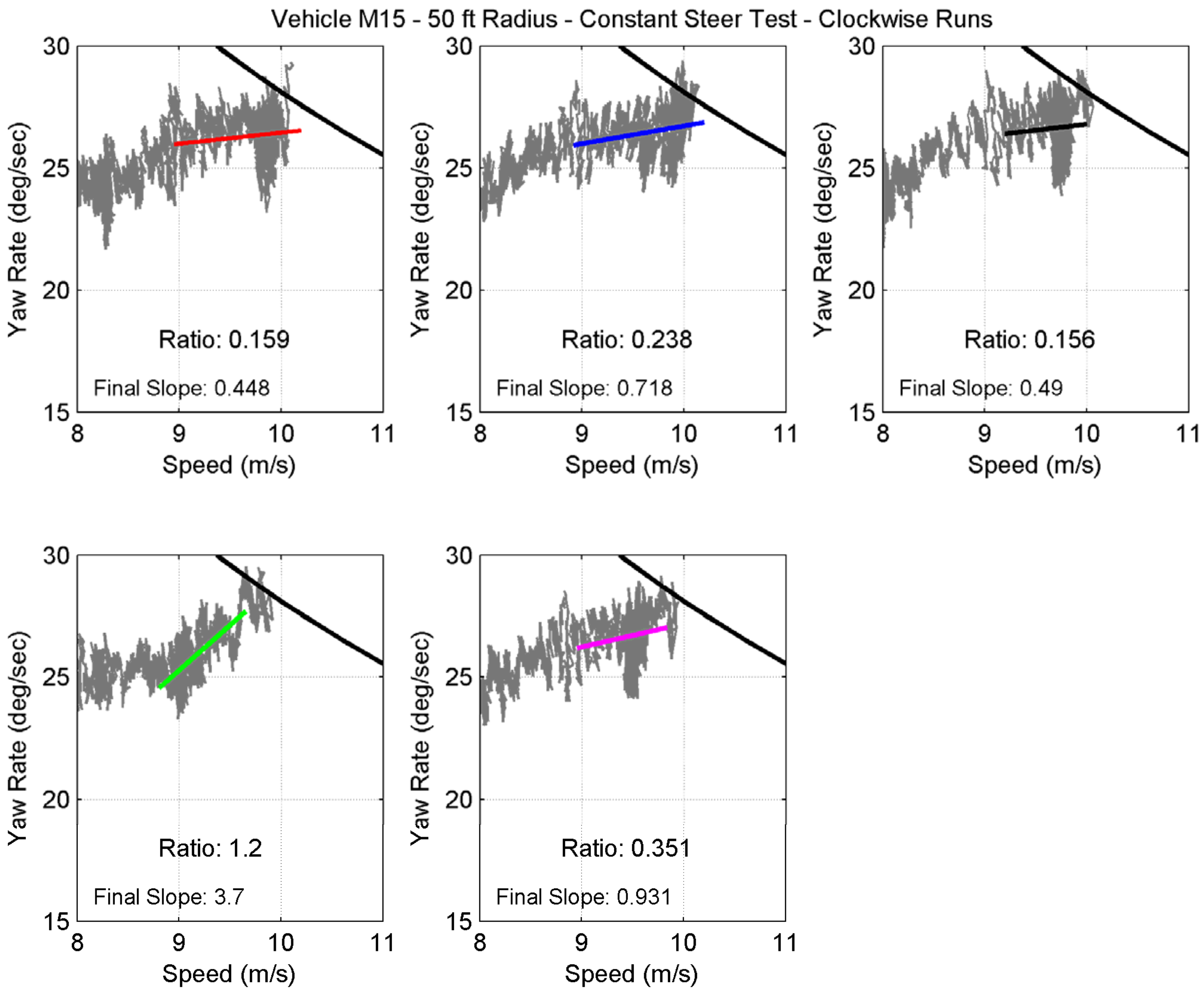
Vehicle L15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs
Final Slope: -1.82
Ratio: 0.537
Final Slope: -1.28
Ratio: 0.41
Final Slope: -0.827
Ratio: 0.248
Final Slope: -1.59
Ratio: 0.446
Final Slope: -1.46
Ratio: 0.434
Yaw Rate (deg/sec)
Speed (m/s)
-18
-20
-22
-24
-26
-28
-30
-32
8
9
10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

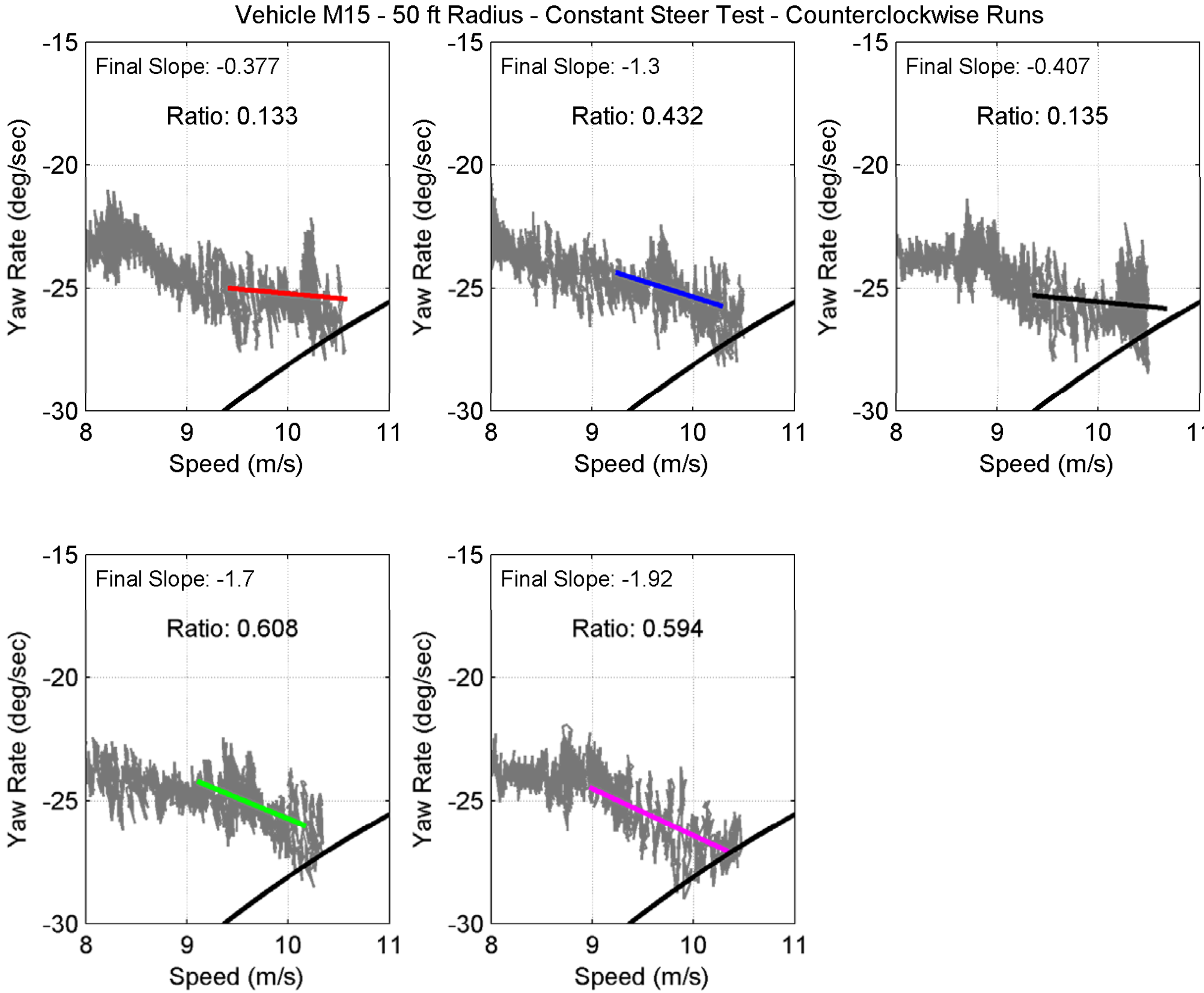

Vehicle L15 - Rear Diff Locked - 50 ft Radius - Constant Steer Test
CW Initial Slopes: 2.23 2.07 STD=0.114
CW Final Slopes: 4.61 5.27 STD=0.469
CW Ratios: 2.07 2.55 STD=0.34
CW Average: 2.31
Average Ratio: 3.38
Rear Differential Locked
CCW Average: 4.44
CCW Ratios: 2.73 6.16 STD=2.43
CCW Final Slopes: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

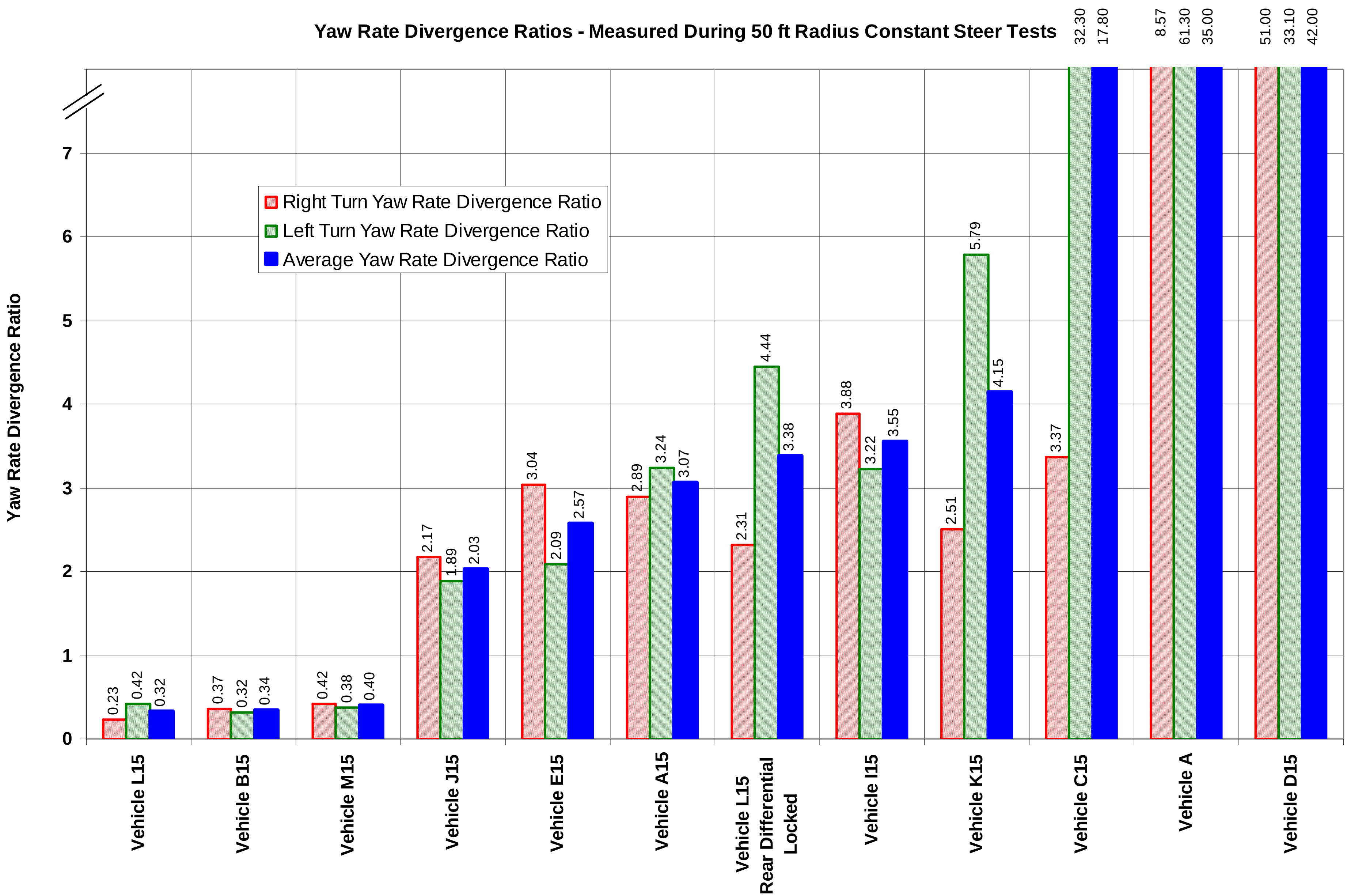


Rear Differential Locked


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
0
1
2
3
4
5
6
7
0.23
0.42
0.32
0.37
0.32
0.34
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 L15
Vehicle B15
Vehicle M15
Vehicle J15
Vehicle E15
Vehicle A15
Vehicle L15 Rear Differential Locked
Vehicle I15
Vehicle K15
Vehicle C15
Vehicle A
Vehicle D15

Appendix C

Proposed Method for Computing
Slopes of Yaw Rate Versus Speed Graphs

Background:
The method for computing "slopes" of the Yaw Rate versus Speed graphs is described in the computations section of the vehicle handling requirement in the pre-canvass draft of ANSI/OPEI B71.9-201X. The OPEI method calls for computing a linear curve fit of the graph of Yaw Rate versus Speed (in the estimated lateral acceleration (Ay) ranges of 0.1 g to 0.2 g and 0.4 g to 0.5 g). The slope of the linear curve fit in each range is the "slope" for the range and the linear curve fit is a least-squares linear curve fit.

Discussion:
Using the OPEI method, the linear curve fit of the yaw rate data from 0.4 g to 0.5 of Ay for an ROV that was tested by SEA is shown below in Figure 1.

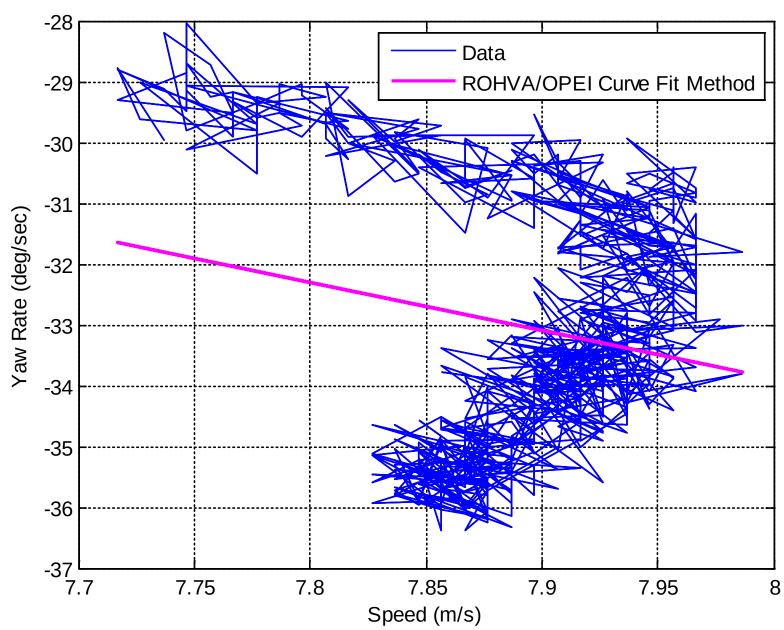


Figure 1. Slope Determined using ROHVA/OPEI Method

The Matlab routine called "polyfit" produces linear curve fits of data. The "polyfit" routine is described by Matlab as:

> *polyfit Fit polynomial to data.*
> *P = polyfit(X,Y,N) finds the coefficients of a polynomial P(X) of degree N that fits the data Y best in a least-squares sense. P is a row vector of length N+1 containing the polynomial coefficients in descending powers, P(1)*X^N + P(2)*X^(N-1) +...+ P(N)*X + P(N+1).*

The linear curve fit on Figure 1 was generated using "polyfit(Speed, YawRate, 1)". This provides the coefficients of a first-order polynomial (*i.e.*, a straight line) that best fits the graph of Yaw Rate versus Speed and is a least-squares linear curve fit.

Figure 2 shows separate graphs of Yaw Rate and Speed, and these are plotted versus data point number (which is essentially time) in the range of 0.4 g to 0.5 g. For this run (which is the same run/data as Figure 1), Yaw Rate is fairly linear over the Ay range, but the Speed actually increases and then decreases in the Ay range.

The same Matlab curve-fitting algorithm was used to generate linear curve fits for the Yaw Rate and Speed plots in Figure 2. The linear curve fit for Yaw Rate was generated using "polyfit(Point Number, Yaw Rate, 1)" and the linear curve fit for Speed was generated using "polyfit(Point Number, Speed, 1)."

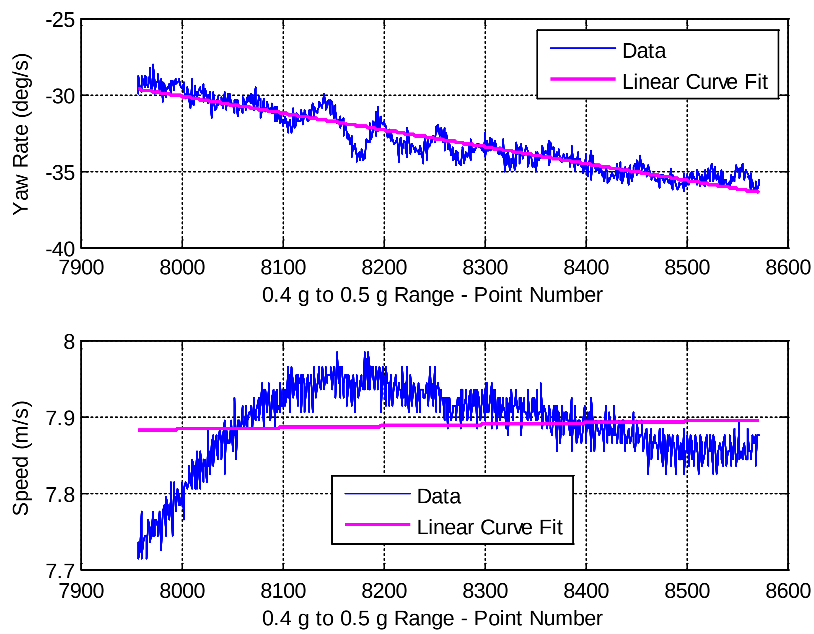


Figure 2. Separate Plots and Curves Fits of Yaw Rate and Speed

The separate Yaw Rate slope divided by the separate Speed slope provides the final slope of the Yaw Rate versus Speed graph shown below in Figure 3. In other words, the Yaw Rate slope in Figure 2 divided by the Speed slope in Figure 2 provides the final slope shown below in Figure 3, and the final slope appears to fit the data better than the slope generated using the OPEI curve fit method.

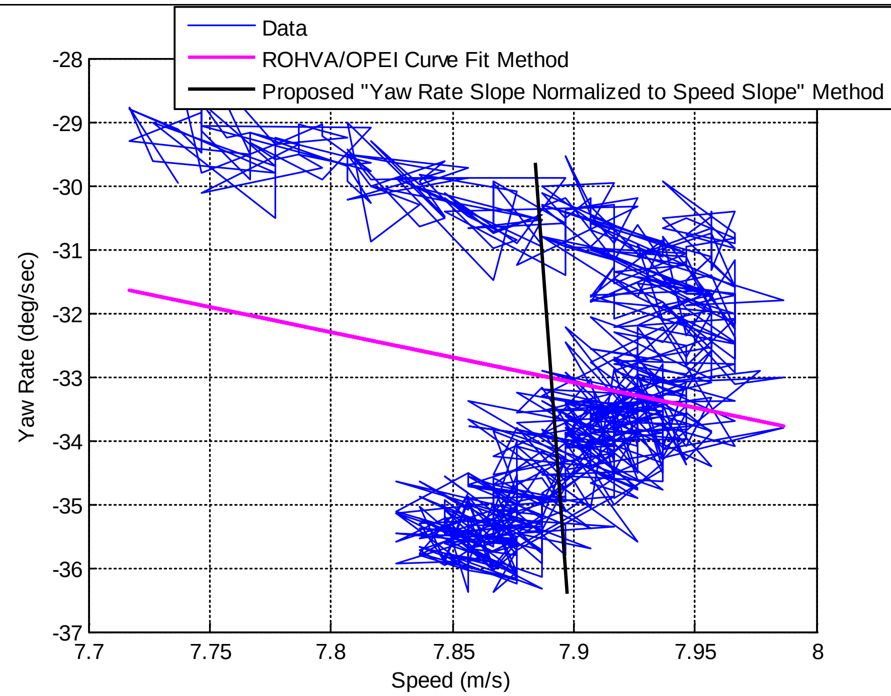


Figure 3: Slope Determined using Proposed Method
(and also Showing Slope Determined using ROHVA/OPEI Method)

<u>Conclusion:</u>
In situations where the data are like the example presented in this document, the proposed method for determining slopes of the Yaw Rate versus Speed data does a better job of representing the underlying data than the ROHVA/OPEI method for determining slopes. In situations where the Yaw Rate and Speed are both varying in a near linear fashion (which is typical in the Ay range of 0.1 g to 0.2 g), the ROHVA/OPEI method and the proposed method result in very similar slope calculations.