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 CPSC 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.
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.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Direction</th>
<th>Run</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle C15</td>
<td>(CCW direction)</td>
<td>4th</td>
</tr>
<tr>
<td>Vehicle D15</td>
<td>(CCW direction)</td>
<td>3rd</td>
</tr>
<tr>
<td>Vehicle I15</td>
<td>(CW direction)</td>
<td>3rd</td>
</tr>
</tbody>
</table>

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)

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 provide 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
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 Initial Slopes: -3.35 -3.21 -3.18 -3.26 -3.53 STD=0.141
- CCW Final Slopes: -7.63 -5.49 -11.3 -11.2 -6.4 STD=2.69
- CCW Ratios: 2.28 1.71 3.54 3.43 1.81 STD=0.879
- CCW Average: 2.56

Speed (m/s)

Yaw Rate (deg/sec)
Vehicle A15 - 50 ft Radius - Constant Steer Test - Clockwise Runs

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 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 -0.916 STD=0.145
CW Ratios: -0.338 -0.364 -0.3 -0.406 -0.461 STD=0.0628
CW Average: 0.374

Average Ratio: 0.346

CCW Initial Slopes: -2.23 -2.47 -2.44 -2.22 -2.36 STD=0.119
CCW Final Slopes: 0.543 1.48 0.67 0.482 0.614 STD=0.411
CCW Ratios: -0.244 -0.6 -0.274 -0.218 -0.26 STD=0.159
CCW Average: 0.319
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

Speed (m/s) vs. Yaw Rate (deg/sec)
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
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
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 Initial Slopes: -3.6, -3.76, -3.61, -3.71, -3.69, STD=0.0694
Vehicle E15 - 50 ft Radius - Constant Steer Test - Counterclockwise Runs

- Final Slope: -5.24, Ratio: 1.46
- Final Slope: -6.3, Ratio: 1.67
- Final Slope: -9.99, Ratio: 2.77
- Final Slope: -6.89, Ratio: 1.86
- Final Slope: -6.14, Ratio: 1.66
Vehicle L15 - 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, 1.76, 3.3, 4.36, STD=1.02
- CCW Initial Slopes: -2.61, -2.52, -3.11, -2.77, -3.07, STD=0.264
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
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
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=0.0659
- **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
Vehicle L15 - 50 ft Radius - Constant Steer Test - Clockwise Runs

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 - Rear Diff Locked - 50 ft Radius - Constant Steer Test

Rear Differential Locked

Average Ratio: 3.33

CPSC – Yaw Rate Ratio Test Results – OPEI Method for Slope Determinations
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: 2.63 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

Speed (m/s)
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 Divergence Ratios - Measured During 50 ft Radius Constant Steer Tests

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Right Turn Yaw Rate Divergence Ratio</th>
<th>Left Turn Yaw Rate Divergence Ratio</th>
<th>Average Yaw Rate Divergence Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>B15</td>
<td>0.37</td>
<td>0.32</td>
<td>0.35</td>
</tr>
<tr>
<td>L15</td>
<td>0.43</td>
<td>0.50</td>
<td>0.41</td>
</tr>
<tr>
<td>M15</td>
<td>0.32</td>
<td>0.38</td>
<td>0.35</td>
</tr>
<tr>
<td>J15</td>
<td>1.49</td>
<td>1.31</td>
<td>1.67</td>
</tr>
<tr>
<td>D15</td>
<td>1.99</td>
<td>1.76</td>
<td>2.11</td>
</tr>
<tr>
<td>E15</td>
<td>2.23</td>
<td>1.88</td>
<td>2.06</td>
</tr>
<tr>
<td>I15</td>
<td>2.86</td>
<td>2.22</td>
<td>2.54</td>
</tr>
<tr>
<td>A15</td>
<td>2.56</td>
<td>2.54</td>
<td>2.55</td>
</tr>
<tr>
<td>K15</td>
<td>2.62</td>
<td>2.31</td>
<td>2.46</td>
</tr>
<tr>
<td>C15</td>
<td>3.72</td>
<td>2.09</td>
<td>2.91</td>
</tr>
<tr>
<td>L15 Rear Differential Locked</td>
<td>4.29</td>
<td>2.37</td>
<td>3.33</td>
</tr>
<tr>
<td>A</td>
<td>7.75</td>
<td>4.08</td>
<td>5.91</td>
</tr>
</tbody>
</table>
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 36 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 -8.7 6.11 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
Vehicle A - 50 ft Radius - Constant Steer Test - Clockwise Runs

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 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
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

Speed (m/s)

Yaw Rate (deg/sec)
Vehicle C15 - 50 ft Radius - Constant Steer Test - Clockwise Runs

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 D15 - 50 ft Radius - Constant Steer Test - Clockwise Runs

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

<table>
<thead>
<tr>
<th>Speed (m/s)</th>
<th>Yaw Rate (deg/sec)</th>
<th>Ratio</th>
<th>Final Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>24</td>
<td>2.86</td>
<td>10.6</td>
</tr>
<tr>
<td>7</td>
<td>30</td>
<td>3.84</td>
<td>14.5</td>
</tr>
<tr>
<td>8</td>
<td>36</td>
<td>2.48</td>
<td>9.49</td>
</tr>
<tr>
<td>9</td>
<td>32</td>
<td>3.31</td>
<td>12.5</td>
</tr>
<tr>
<td>6</td>
<td>24</td>
<td>2.72</td>
<td>10.9</td>
</tr>
</tbody>
</table>
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
Vehicle L15 - 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 26.6 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
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
Vehicle J15 - 50 ft Radius - Constant Steer Test

CPSC – Yaw Rate Ratio Test Results – Slopes Normalized to Speed
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
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
Vehicle L15 - 50 ft Radius - Constant Steer Test - Clockwise Runs

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 - Rear Diff Locked - 50 ft Radius - Constant Steer Test

Rear Differential Locked

Average Ratio: 3.38

CPSC – Yaw Rate Ratio Test Results – Slopes Normalized to Speed
Vehicle L15 - Rear Diff Locked - 50 ft Radius - Constant Steer Test - CW & CCW Runs

Rear Differential Locked
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.

```
Data
ROHVA/OPEI Curve Fit 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.

Conclusion:
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.

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