J-Turn Repeatability Study

Repeatability Study Protocol and Results

Off Road Vehicle Division

4 different vehicle models were chosen for this test

- Each vehicle started a sub-limit steering angle and the steering angle was increased in 5 degree increments until two-wheel lift (TWL) occurred
- The entire process was then repeated – starting at a sub-limit steering wheel angle once again
- Each vehicle was tested 5 times to the left and 5 times to the right.
- Results for steering wheel angle achieving TWL and the max lateral acceleration, filtered at both 2Hz and 6Hz were recorded

Vehicle A	LH Turn			RH Turn		
	Steering Wheel Angle (degrees)	2 Hz Peak Ay Lateral Acceleration (g)	6 Hz Peak Ay Lateral Acceleration (g)	Steering Wheel Angle (degrees)	2 Hz Peak Ay Lateral Acceleration (g)	6 Hz Peak Ay Lateral Acceleration (g)
Run 1	115	0.689	0.718	105	0.640	0.665
Run 2	115	0.698	0.709	105	0.641	0.676
Run 3	115	0.696	0.710	105	0.642	0.685
Run 4	115	0.696	0.725	105	0.639	0.628
Run 5	115	0.709	0.751	105	0.639	0.656
Average	115	0.698	0.723	105	0.640	0.662
Min	115	0.689	0.709	105	0.639	0.628
Max	115	0.709	0.751	105	0.642	0.685
Range	0	0.020	0.043	0	0.003	0.057
St. Dev.	0	0.007	0.017	0	0.001	0.022
St. Dev. %	0.0%	1.0%	2.4%	0.0%	0.2%	3.3%

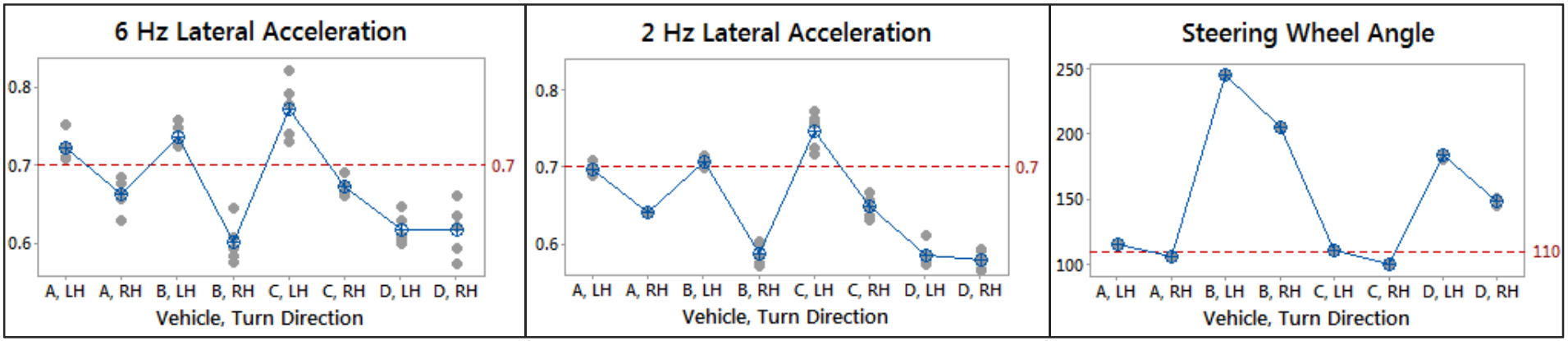
Vehicle B	LH Turn			RH Turn		
	Steering Wheel Angle (degrees)	2 Hz Peak Ay Lateral Acceleration (g)	6 Hz Peak Ay Lateral Acceleration (g)	Steering Wheel Angle (degrees)	2 Hz Peak Ay Lateral Acceleration (g)	6 Hz Peak Ay Lateral Acceleration (g)
Run 1	245	0.708	0.723	205	0.575	0.583
Run 2	245	0.700	0.757	205	0.583	0.606
Run 3	245	0.710	0.723	205	0.598	0.593
Run 4	245	0.715	0.748	205	0.602	0.644
Run 5	245	0.703	0.730	205	0.570	0.575
Average	245	0.707	0.736	205	0.585	0.600
Min	245	0.700	0.723	205	0.570	0.575
Max	245	0.715	0.757	205	0.602	0.644
Range	0	0.015	0.034	0	0.032	0.069
St. Dev.	0	0.006	0.016	0	0.014	0.027
St. Dev. %	0.0%	0.8%	2.1%	0.0%	2.4%	4.5%

Vehicle C	LH Turn			RH Turn		
	Steering Wheel Angle (degrees)	2 Hz Peak Ay Lateral Acceleration (g)	6 Hz Peak Ay Lateral Acceleration (g)	Steering Wheel Angle (degrees)	2 Hz Peak Ay Lateral Acceleration (g)	6 Hz Peak Ay Lateral Acceleration (g)
Run 1	110	0.773	0.821	100	0.656	0.666
Run 2	110	0.758	0.778	100	0.667	0.661
Run 3	110	0.764	0.792	100	0.637	0.674
Run 4	110	0.718	0.741	100	0.647	0.690
Run 5	110	0.724	0.730	100	0.631	0.674
Average	110	0.747	0.772	100	0.648	0.673
Min	110	0.718	0.730	100	0.631	0.661
Max	110	0.773	0.821	100	0.667	0.690
Range	0	0.056	0.091	0	0.037	0.029
St. Dev.	0	0.025	0.037	0	0.015	0.011
St. Dev. %	0.0%	3.3%	4.8%	0.0%	2.3%	1.6%

Vehicle D	LH Turn			RH Turn		
	Steering Wheel Angle (degrees)	2 Hz Peak Ay Lateral Acceleration (g)	6 Hz Peak Ay Lateral Acceleration (g)	Steering Wheel Angle (degrees)	2 Hz Peak Ay Lateral Acceleration (g)	6 Hz Peak Ay Lateral Acceleration (g)
Run 1	180	0.575	0.599	150	0.592	0.659
Run 2	185	0.580	0.629	145	0.567	0.573
Run 3	185	0.573	0.608	145	0.579	0.634
Run 4	185	0.586	0.602	150	0.591	0.620
Run 5	185	0.609	0.646	150	0.563	0.591
Average	184	0.585	0.617	148	0.578	0.616
Min	180	0.573	0.599	145	0.563	0.573
Max	185	0.609	0.646	150	0.592	0.659
Range	5	0.037	0.047	5	0.029	0.086
St. Dev.	2.236067977	0.015	0.020	3	0.013	0.034
St. Dev. %	1.2%	2.5%	3.2%	1.9%	2.3%	5.5%

Repeatability Variation

Off Road Vehicle Division



The plots above show the individual values (gray dots) and the average values (blue circles) for each vehicle and each turn direction

The five Steering Wheel Angle (SWA) values are so close, they appear to be a single gray dot

With SWA, each vehicle/turn direction combination is distinct from all of the others, while for Lateral Acceleration (Ay), some combinations are indistinguishable (*e.g.* B,RH; D,LH; D,RF)

Virtually no variation, excellent distinction with Steering Wheel Angle vs. Lateral Acceleration

Repeatability Statistics

Percent of Study Variation (%SV)

This measures the ability to distinguish between the different vehicles (lower numbers are better)

Standards for judgment:

- %SV > 30% is considered an incapable measurement
- %SV 30%-10% is considered a gray area for acceptability
- %SV < 10% indicates a very capable measurement

For the measurements studied:

- 6 Hz Ay: 36% study variation
- 2 Hz Ay: 21% study variation
- SWA: 2% study variation

Steering Wheel Angle is a very capable measurement method and Lateral Acceleration is not nearly as capable

Repeatability Statistics

Number of Distinct Categories

This value represents the number of non-overlapping confidence intervals that will span the range of vehicle set variation. Thought of as the number of groups within your process data that your measurement system can discern. (Adapted from Minitab documentation)

Standards for judgment:

- < 5 distinct categories = an unacceptable metric
- 5 or greater categories may be an acceptable metric (for repeatability), but more categories reflect increased confidence

For the measurements studied:

- 6 Hz Ay: 3 distinct categories
- 2 Hz Ay: 6 distinct categories
- SWA: 61 distinct categories

Steering Wheel Angle has a great ability to distinguish vehicles and Lateral Acceleration is not nearly as capable

Repeatability Conclusion

- **SWA is an excellent metric for repeatedly measuring a vehicle stability based on all statistical comparisons used in this study**
- **Filtering Ay down to 2Hz improves the repeatability of Ay, but it is still significantly less repeatable than SWA**

Additional Concern

- **Low-pass filtering Ay down to 2Hz (NPR proposal) from 6HZ (ROHVA RRR is 6Hz, original SEA J-Turn was 5Hz) reduces the average Ay value by .026 g.**
  - Based on this data, if a passing metric for Ay, filtered at 6Hz is 0.700 g, then the equivalent passing metric when Ay is filtered at 2Hz would be **0.674 g**

SWA Metric Is Significantly More Repeatable Than Ay Metric