Vehicle Characteristics Measurements Of Recreational Off-Highway Vehicles – Additional Results for Vehicle J

for:
Consumer Product Safety Commission

August 2011

Scientific Expert Analysis™

Vehicle Dynamics Division
7349 Worthington-Galena Rd.
Columbus, Ohio 43085

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

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1. OVERVIEW

This report contains results from measurements made by S-E-A, Ltd. for the Consumer Product Safety Commission (CPSC) under contract CPSC-S-10-0014. The objectives of contract CPSC-S-10-0014 are:

- To obtain vehicle characteristic data that is accurate and repeatable using measurement and test methods that are proven and accepted in the academic and industrial communities.

- To document, study, and compare the dynamic performance characteristics of commonly available recreational off-highway vehicles (ROV's).

A previous report titled "*Vehicle Characteristics Measurements Of Recreational Off-Highway Vehicles"* containing measurement results for nine vehicles (Vehicles A through I) was published in April 2011[1]. This August 2011 report contains results for measurements made on a tenth recreational off-highway vehicle, Vehicle J.

The April 2011 report contains results for the nine vehicles in a number of static and dynamic test loading conditions including conditions representing a Gross Vehicle Weight Rating (GVWR) loading configuration. Vehicle J was not tested in a GVWR loading configuration.

Vehicle J was selected by CPSC, and it can be classified as a recreational off-highway vehicle (ROV). It has side-by-side seating, and a steering wheel, brake pedal, and throttle pedal for operator control inputs. Vehicle J is a two-passenger vehicle. The measured curb weight (weight with full fluids and no occupants or cargo) of Vehicle J is 1417.2 lb, and it has a measured average maximum speed of 66.0 mph in a loading condition representing Operator plus Passenger loading.

Vehicle J was evaluated using both laboratory measurements and dynamic tests. The laboratory measurements were made by S-E-A, Ltd. in Columbus, Ohio using their Vehicle Inertia Measurement Facility (VIMF), tilt table, and other laboratory equipment. The dynamic tests were performed on May 20, 2011, at the Transportation Research Center, Inc. (TRC) in East Liberty, Ohio. The dynamic test evaluations included steering maneuvers on the flat dry asphalt surface of TRC's Vehicle Dynamics Area (VDA).

This report contains four main sections and ten appendices that contain test results. The four report sections are Overview, Laboratory Testing, Dynamic Testing, and Discussion of Test Results. Appendix A contains laboratory test results for all ten vehicles (Vehicles A-J) in all loading configurations tested. Appendix B contains summary laboratory and dynamic test results for all ten vehicles (Vehicles A-J) in the Operator and Passenger loading configuration. Appendices C through J contain primarily only test results for Vehicle J in the Operator and Passenger loading configuration.

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

2. LABORATORY TESTING

The April 2011 report contains a detailed discussion of the laboratory measurements made for this test program as well as computations made to compute various rollover resistance metrics and other vehicle characteristics. (The discussion and description of computations made are not repeated in this report.) All of the same measurements were made for Vehicle J, except no measurements were made in the GVWR loading configuration. Tabular results for all laboratory testing measurements and metrics are contained in Appendix A for Vehicles A through J.

For Vehicle J, the VIMF tests and Tilt Table tests were conducted in the following loading conditions:

1. **Operator**
   This loading condition was specified to be the vehicle curb condition (with full fluids and with the vehicle manufacturers' specified tires and tire pressures) plus one occupant in the Operator's seating position. Each occupant (Operator and Passenger) load used was equivalent to a 95th percentile adult male weighing nominally 213 lb. For the laboratory testing, Hybrid II test dummies weighing 164 lb were used and ballast was added to their laps to bring the total occupant weights up to nominally 213 lb.

2. **Operator and Passenger**
   This loading condition was specified to be the vehicle curb condition plus two occupants, one in the Operator's seating position and one in the front Passenger's seating position. Again, for this loading condition Hybrid II test dummies weighing 164 lb were used and ballast was added to their laps to bring the total occupant weights up to nominally 213 lb.

3. **Operator, Instrumentation, and Outriggers**
   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, S-E-A's Automated Steering Controller (ASC), ASC controller box, and ASC battery box), and safety outriggers. This is the loading condition that was used during the dynamic testing phase for Vehicle J, and it was designed to represent the Operator and Passenger loading condition (Loading Condition #2). The total vehicle weight of Loading Condition #3 was set to match as closely as possible the total weight of Loading Condition #2. Also, for Loading Condition #3, the vehicle's lateral, longitudinal, and vertical CG positions were made to match those of Loading Condition #2 as closely as practically possible.

3. DYNAMIC TESTING

The April 2011 report contains a detailed discussion of the dynamic measurements made for this test program as well as computations made to compute various rollover resistance metrics and other vehicle characteristics. (The discussion and description of computations made are not repeated in this report.) All of the same dynamic tests were conducted on Vehicle J, except no tests were made in the GVWR loading configuration.

All of the dynamic tests were performed in one loading configuration, namely:

1. **Operator, Instrumentation, and Outriggers**
   This dynamic testing 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, S-E-A's Automated Steering Controller (ASC), ASC controller box, and ASC battery box), and safety outriggers. Table 1 lists the nominal weights of the test driver and test equipment, including the outriggers. The total weight of the driver, instrumentation, and safety outriggers is nominally 426 lb, which is the same weight as two 213 lb occupants. As mentioned previously, this dynamic loading condition was designed to match as closely as possible the total weight of the Operator and Passenger (each weighing nominally 213 lb) loading condition used during the laboratory testing. The test equipment and safety outriggers were adjusted so that the vertical, lateral and longitudinal CG positions of the dynamic loading configurations would match those of Operator and Passenger loading configurations as closely as practically possible. This dynamic loading configuration is referred to as the representative Operator and Passenger loading configuration.

Table 1: Weights of Driver and Test Equipment

Object	Weight (lb)
Test Driver with Helmet	182
ASC Handwheel Unit	34
ASC Battery Box	27
ASC Electronics Box and Cables	25
SEA Data Acquisition Computer	10
Auxiliary 12V Battery	25
RT3002 GPS/IMU, Antenna, and Cables	10
SEA Power Distribution Box and Misc. Straps	7
CPSC Triangulated Aluminum Safety Outriggers	106
Total Nominal Weight	**426**

The same test driver, test instrumentation and CPSC outriggers that were used for testing Vehicles A through I were used for testing Vehicle J.

The dynamic tests, conducted on May 20, 2011, included steering maneuvers on the flat dry

asphalt surface of TRC's Vehicle Dynamics Area (VDA). TRC's measurements of peak and sliding skid numbers for the VDA surface where the tests were conducted, nearest the time when the tests were conducted, are listed in Table 2.

Table 2: TRC Skid Number Measurements		
Location	VDA	
Pad #	V-5, dry	
Pavement	Asphalt	
Surface	Untreated	
Condition	Dry	
Date	Peak PBC	Slide SN
5/11/2011	92.7	85.0

Table 3 lists the instrumentation used during the dynamic testing. The RT3002 was mounted near the CG of the vehicle. Nonetheless, the longitudinal, lateral, and vertical offsets from the center of the RT3002 to the actual vehicle CG location was measured and entered into the RT3002 system software. This information was used to translate the measured quantities to those at CG of the vehicle. The longitudinal and lateral accelerations measured and reported herein are accelerations parallel to the road plane, as opposed to vehicle body fixed accelerations. The vertical acceleration is the acceleration orthogonal to the longitudinal and lateral accelerations.

Table 3: Instrumentation Used During Dynamic Testing			
Transducer	**Measurement**	**Range**	**Accuracy or Linearity**
Oxford Technical Solutions RT3002 Inertial and GPS Navigation System	Longitudinal, Lateral, and Vertical Accelerations	± 10 g	0.1% 1σ
	Roll, Pitch, and Yaw Rates	± 100 deg/s	0.1% 1σ
	Speed	No Limit Specified	0.2% 1σ
	Roll and Pitch Angles	No Limit Specified	0.03° 1σ
	Vehicle Heading and Sideslip Angle	No Limit Specified	0.1° 1σ
Encoder on SEA, Ltd. ASC	Steering Wheel Angle	± 800 deg	± 0.25 deg

In total, over 90 dynamic tests were performed on Vehicle J. The following suite of seven different types of dynamic tests was performed:

- **Constant Radius (100 ft) Circle Tests**
- **Constant Speed (30 mph) Slowly Increasing Steer Tests**
- **Dropped Throttle J-Turn (Step Steer) Tests (Initial Speed of 30 mph)**
- **Constant Throttle J-Turn (Step Steer) Tests (Initial Speed of 30 mph)**
- **Sinusoidal Sweep Steering (Frequency Response) Tests (20 mph)**
- **Constant Speed (30 mph) Steering Flick Tests**
- **Maximum Speed Tests**

Detailed discussion of each of the dynamic test maneuvers is contained in the April 2011 report. Results from the dynamic tests for Vehicle J are contained in Appendices C through I.

4. DISCUSSION OF TEST RESULTS

Table 4 lists the appendices that contain test results. Appendix A contains tables with all of the results from the laboratory testing for all ten vehicles (Vehicles A through J), with the exception of the graphs from the steering ratio tests. Appendix B contains a collection of bar charts, graphs, and tables summarizing selected results from both laboratory and dynamic testing for all ten vehicles (Vehicle A through J) in the Operator and Passenger loading configuration. Detailed results from all of the dynamic testing of Vehicle J are contained in Appendix C through Appendix I. The steering ratio test results for Vehicle J are contained in Appendix J.

Table 4: List of Appendices Containing Test Results

Appendix	Title
Appendix A	Laboratory Test Results
Appendix B	Summary Bar Charts, Graphs, and Tables
Appendix C	Constant Radius (100 ft) Circle Test Results
Appendix D	Constant Speed (30 mph) Slowly Increasing Steer Test Results
Appendix E	Dropped Throttle J-Turn (Step Steer) Test Results (30 mph)
Appendix F	Constant Throttle J-Turn (Step Steer) Test Results (30 mph)
Appendix G	Sinusoidal Sweep Steering (Frequency Response) Test Results (20 mph)
Appendix H	Constant Speed (30 mph) Steering Flick Test Results
Appendix I	Maximum Speed Test Results
Appendix J	Steering Ratio Test Results

The April 2011 report contains a detailed discussion of the contents of Appendices A through J, so this discussion is not repeated in this report.

As mentioned previously, dynamic tests on Vehicle J were performed only in the Operator, Instrumentation, and Outriggers loading configuration (representative Operator and Passenger loading configuration). In this loading configuration, Vehicle J was found to exhibit transition from understeer to oversteer in both the constant radius circle tests and slowly increasing steer (SIS) tests.

Vehicle A

	Curb	Operator	Operator & Passenger	Operator, Passenger & Cargo (GVWR)	Operator, Inst & Outriggers	Operator, Inst, Cargo & Outriggers (GVWR)
VIMF Test Number		4180	4181	4182	4183	4184
Total Vehicle Weight (lb)	1218.7	1431.7	1644.5	1998.4	1644.2	1998.8
Left Front Weight (lb)	259.8	317.5	343.9	334.5	357.3	341.6
Right Front Weight (lb)	278.7	309.4	371.6	357.2	352.2	350.9
Left Rear Weight (lb)	319.5	441.2	444.0	629.4	462.4	621.5
Right Rear Weight (lb)	360.7	363.6	485.0	677.3	472.3	684.8
Front Track Width (in)	45.20	45.20	45.40	45.25	45.40	45.25
Rear Track Width (in)	43.60	43.60	44.25	45.50	44.25	45.50
Average Track Width (in)	44.40	44.40	44.83	45.38	44.83	45.38
Wheelbase (in)	75.15	75.15	75.15	75.15	75.15	75.15
CG Longitudinal (in)	41.94	42.24	42.45	49.14	42.72	49.11
CG Lateral (in)	1.09	-1.33	0.94	0.80	0.07	0.82
CG Height (in)		24.56	25.52	25.35	25.26	
Roll Inertia - I_{XX} (ft-lb-s^2)		129	155	159	190	
Pitch Inertia - I_{YY} (ft-lb-s^2)		274	286	365	298	
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		288	299	376	338	
Roll/Yaw - I_{XZ} (ft-lb-s^2)		9	15	24	12	
SSF		0.904	0.878	0.895	0.887	
KST		0.906	0.880	0.894	0.889	
CSV (mph)		7.32	7.17	7.17	7.47	
Tilt Table: Direction		Driver	Driver	Driver	Driver	
Tilt Table: First Wheel Lift		Rear	Rear	Rear	Rear	
Tilt Table Angle (deg)		33.0	32.8	32.7	32.7	
Tilt Table Ratio (TTR)		0.649	0.645	0.643	0.643	
Tilt Table: Direction		Passenger	Passenger	Passenger	Passenger	
Tilt Table: First Wheel Lift		Rear	Rear	Rear	Rear	
Tilt Table Angle (deg)		37.7	32.1	32.0	33.3	
Tilt Table Ratio (TTR)		0.773	0.626	0.626	0.658	
Average Tilt Table Angle (deg)		35.3	32.4	32.4	33.0	
Average Tilt Table Ratio (TTR)		0.711	0.635	0.635	0.650	
Front Ground Clearance (in)			8.60			
Rear Ground Clearance (in)			10.20			
Steering Ratio (deg/deg)			13.2			

Vehicle B

	Curb	Operator	Operator & Passenger	Operator, Passenger & Cargo (GVWR)	Operator, Inst & Outriggers	Operator, Inst, Cargo & Outriggers (GVWR)
VIMF Test Number		4162	4164	4166	4187	4186
Total Vehicle Weight (lb)	1025.0	1237.6	1450.1	1727.4	1475.7	1749.9
Left Front Weight (lb)	201.2	282.1	298.4	296.0	306.3	303.1
Right Front Weight (lb)	228.9	243.4	317.5	331.8	325.6	322.7
Left Rear Weight (lb)	288.3	381.7	409.0	546.3	428.5	551.5
Right Rear Weight (lb)	306.6	330.4	425.2	553.3	415.3	572.6
Front Track Width (in)	43.00	43.00	43.50	43.50	43.50	43.50
Rear Track Width (in)	40.30	40.30	41.00	41.60	41.00	41.60
Average Track Width (in)	41.65	41.65	42.25	42.55	42.25	42.55
Wheelbase (in)	76.85	76.85	76.85	76.85	76.85	76.85
CG Longitudinal (in)	44.60	44.22	44.21	48.92	43.94	49.37
CG Lateral (in)	0.93	-1.51	0.51	0.53	0.09	0.49
CG Height (in)		21.73	22.17	23.38	22.67	
Roll Inertia - I_{XX} (ft-lb-s^2)		100	122	128	145	
Pitch Inertia - I_{YY} (ft-lb-s^2)		241	250	301	272	
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		243	257	303	289	
Roll/Yaw - I_{XZ} (ft-lb-s^2)		-2	2	19	-2	
SSF		0.958	0.953	0.910	0.932	
KST		0.963	0.957	0.916	0.936	
CSV (mph)		7.52	7.55	7.10	7.56	
Tilt Table: Direction		Driver	Driver	Driver	Driver	
Tilt Table: First Wheel Lift		Front	Front	Front	Front	
Tilt Table Angle (deg)		34.0	35.4	31.7	33.1	
Tilt Table Ratio (TTR)		0.675	0.710	0.617	0.652	
Tilt Table: Direction		Passenger	Passenger	Passenger	Passenger	
Tilt Table: First Wheel Lift		Front	Front	Front	Front	
Tilt Table Angle (deg)		38.3	34.1	31.6	34.1	
Tilt Table Ratio (TTR)		0.790	0.678	0.615	0.676	
Average Tilt Table Angle (deg)		36.2	34.8	31.6	33.6	
Average Tilt Table Ratio (TTR)		0.733	0.694	0.616	0.664	
Front Ground Clearance (in)			5.95			
Rear Ground Clearance (in)			6.90			
Steering Ratio (deg/deg)			14.9			

Vehicle C

	Curb	Operator	Operator & Passenger	Operator, Passenger & Cargo (GVWR)	Operator, Inst & Outriggers	Operator, Inst, Cargo & Outriggers (GVWR)
VIMF Test Number		4169	4170	4171	4172	4189
Total Vehicle Weight (lb)	1441.4	1654.1	1866.6	2368.1	1882.5	2369.0
Left Front Weight (lb)	359.4	439.8	446.9	445.0	467.5	445.5
Right Front Weight (lb)	352.2	375.8	467.7	459.9	459.9	462.4
Left Rear Weight (lb)	334.8	418.6	457.4	707.6	472.1	706.5
Right Rear Weight (lb)	395.0	419.9	494.6	755.6	483.0	754.6
Front Track Width (in)	50.90	50.90	51.60	51.60	51.60	51.60
Rear Track Width (in)	50.10	50.10	51.48	51.85	51.48	51.85
Average Track Width (in)	50.50	50.50	51.54	51.73	51.54	51.73
Wheelbase (in)	75.15	75.15	75.15	75.15	75.15	75.15
CG Longitudinal (in)	38.05	38.10	38.33	46.43	38.13	46.35
CG Lateral (in)	0.93	-0.96	0.80	0.69	0.05	0.71
CG Height (in)		24.76	26.10	27.27	26.01	
Roll Inertia - I_{XX} (ft-lb-s^2)		180	211	228	236	
Pitch Inertia - I_{YY} (ft-lb-s^2)		347	363	488	381	
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		372	384	505	421	
Roll/Yaw - I_{XZ} (ft-lb-s^2)		2	8	38	8	
SSF		1.020	0.987	0.948	0.991	
KST		1.020	0.987	0.948	0.991	
CSV (mph)		8.70	8.51	8.02	8.67	
Tilt Table: Direction		Driver	Driver	Driver	Driver	
Tilt Table: First Wheel Lift		Rear	Rear	Front	Rear	
Tilt Table Angle (deg)		40.1	39.5	36.1	38.8	
Tilt Table Ratio (TTR)		0.843	0.824	0.729	0.805	
Tilt Table: Direction		Passenger	Passenger	Passenger	Passenger	
Tilt Table: First Wheel Lift		Rear	Rear	Front	Rear	
Tilt Table Angle (deg)		41.6	37.5	34.6	38.7	
Tilt Table Ratio (TTR)		0.887	0.768	0.690	0.801	
Average Tilt Table Angle (deg)		40.9	38.5	35.3	38.8	
Average Tilt Table Ratio (TTR)		0.865	0.796	0.709	0.803	
Front Ground Clearance (in)			9.10			
Rear Ground Clearance (in)			9.90			
Steering Ratio (deg/deg)			15.7			

Vehicle D

	Curb	Operator	Operator & Passenger	Operator, Passenger & Cargo (GVWR)	Operator, Inst & Outriggers	Operator, Inst, Cargo & Outriggers (GVWR)
VIMF Test Number		4190	4191	4192	4193	4194
Total Vehicle Weight (lb)	1294.9	1508.2	1720.9	2720.5	1728.6	2711.2
Left Front Weight (lb)	280.3	351.3	384.1	365.0	398.9	364.0
Right Front Weight (lb)	304.5	331.1	395.8	369.6	390.4	362.1
Left Rear Weight (lb)	341.6	451.7	448.3	976.6	460.5	975.0
Right Rear Weight (lb)	368.5	374.1	492.7	1009.3	478.8	1010.1
Front Track Width (in)	51.65	51.65	52.18	51.90	52.18	51.90
Rear Track Width (in)	48.28	48.28	49.23	49.90	49.23	49.90
Average Track Width (in)	49.96	49.96	50.70	50.90	50.70	50.90
Wheelbase (in)	75.80	75.80	75.80	75.80	75.80	75.80
CG Longitudinal (in)	41.57	41.50	41.45	55.33	41.19	55.50
CG Lateral (in)	0.99	-1.62	0.83	0.35	0.14	0.31
CG Height (in)		26.11	27.07	28.15	26.91	
Roll Inertia - I_{XX} (ft-lb-s^2)		162	185	198	219	
Pitch Inertia - I_{YY} (ft-lb-s^2)		319	333	523	353	
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		340	353	546	399	
Roll/Yaw - I_{XZ} (ft-lb-s^2)		9	11	49	10	
SSF		0.957	0.937	0.904	0.942	
KST		0.960	0.939	0.912	0.944	
CSV (mph)		8.14	7.99	7.41	8.23	
Tilt Table: Direction		Driver	Driver	Driver	Driver	
Tilt Table: First Wheel Lift		Rear	Rear	Front	Rear	
Tilt Table Angle (deg)		34.3	34.5	31.4	33.5	
Tilt Table Ratio (TTR)		0.681	0.688	0.611	0.662	
Tilt Table: Direction		Passenger	Passenger	Passenger	Passenger	
Tilt Table: First Wheel Lift		Rear	Rear	Front	Rear	
Tilt Table Angle (deg)		37.9	32.8	30.4	33.9	
Tilt Table Ratio (TTR)		0.779	0.644	0.587	0.673	
Average Tilt Table Angle (deg)		36.1	33.6	30.9	33.7	
Average Tilt Table Ratio (TTR)		0.730	0.666	0.599	0.667	
Front Ground Clearance (in)			9.30			
Rear Ground Clearance (in)			10.75			
Steering Ratio (deg/deg)			18.0			

Vehicle E

	Curb	Operator	Operator & Passenger	Operator, Passenger & Cargo (GVWR)	Operator, Inst & Outriggers	Operator, Inst, Cargo & Outriggers (GVWR)
VIMF Test Number		4200	4201	4202	4203	4204
Total Vehicle Weight (lb)	1402.2	1615.3	1827.9	2328.1	1831.4	2327.3
Left Front Weight (lb)	300.4	375.6	394.5	369.6	406.5	385.5
Right Front Weight (lb)	317.9	329.2	395.8	380.9	382.7	366.5
Left Rear Weight (lb)	397.4	502.3	512.7	794.3	526.3	778.5
Right Rear Weight (lb)	386.5	408.2	524.9	783.3	515.9	796.8
Front Track Width (in)	49.38	49.38	50.10	49.35	50.10	49.35
Rear Track Width (in)	48.50	48.50	48.93	49.55	48.93	49.55
Average Track Width (in)	48.94	48.94	49.51	49.45	49.51	49.45
Wheelbase (in)	75.90	75.90	75.90	75.90	75.90	75.90
CG Longitudinal (in)	42.43	42.78	43.08	51.43	43.19	51.38
CG Lateral (in)	0.12	-2.13	0.18	0.00	-0.46	-0.01
CG Height (in)		24.73	25.55	26.39	25.66	
Roll Inertia - I_{XX} (ft-lb-s^2)		147	173	187	201	
Pitch Inertia - I_{YY} (ft-lb-s^2)		326	341	461	352	
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		351	363	482	403	
Roll/Yaw - I_{XZ} (ft-lb-s^2)		9	16	40	13	
SSF		0.989	0.969	0.937	0.965	
KST		0.991	0.970	0.936	0.966	
CSV (mph)		8.18	8.08	7.67	8.21	
Tilt Table: Direction		Driver	Driver	Driver	Driver	
Tilt Table: First Wheel Lift		Rear	Rear	Front	Rear	
Tilt Table Angle (deg)		37.4	37.7	34.6	37.2	
Tilt Table Ratio (TTR)		0.765	0.773	0.689	0.759	
Tilt Table: Direction		Passenger	Passenger	Passenger	Passenger	
Tilt Table: First Wheel Lift		Rear	Rear	Front	Rear	
Tilt Table Angle (deg)		41.6	37.7	34.2	38.9	
Tilt Table Ratio (TTR)		0.888	0.774	0.681	0.808	
Average Tilt Table Angle (deg)		39.5	37.7	34.4	38.1	
Average Tilt Table Ratio (TTR)		0.826	0.774	0.685	0.784	
Front Ground Clearance (in)			10.40			
Rear Ground Clearance (in)			10.80			
Steering Ratio (deg/deg)			14.9			

Vehicle F

	Curb	Operator	Operator & Passenger	Operator, Passenger & Cargo (GVWR)	Operator, Inst & Outriggers	Operator, Inst, Cargo & Outriggers (GVWR)
VIMF Test Number		4195	4196	4197	4198	4199
Total Vehicle Weight (lb)	1262.4	1475.2	1688.0	2288.6	1688.1	2289.1
Left Front Weight (lb)	279.1	346.1	362.2	339.4	371.3	325.1
Right Front Weight (lb)	287.9	301.6	367.8	339.3	357.0	349.1
Left Rear Weight (lb)	349.7	462.8	477.3	805.4	485.5	822.4
Right Rear Weight (lb)	345.7	364.7	480.7	804.5	474.3	792.5
Front Track Width (in)	50.20	50.20	50.35	50.35	50.35	50.35
Rear Track Width (in)	48.35	48.35	48.70	49.35	48.70	49.35
Average Track Width (in)	49.28	49.28	49.53	49.85	49.53	49.85
Wheelbase (in)	75.05	75.05	75.05	75.05	75.05	75.05
CG Longitudinal (in)	41.34	42.10	42.59	52.79	42.67	52.95
CG Lateral (in)	0.09	-2.38	0.13	-0.01	-0.37	-0.06
CG Height (in)		27.08	28.47	29.27	28.10	
Roll Inertia - I_{XX} (ft-lb-s^2)		167	203	210	217	
Pitch Inertia - I_{YY} (ft-lb-s^2)		313	329	468	353	
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		326	338	470	374	
Roll/Yaw - I_{XZ} (ft-lb-s^2)		16	26	46	27	
SSF		0.910	0.870	0.852	0.881	
KST		0.912	0.872	0.855	0.883	
CSV (mph)		7.78	7.52	7.13	7.69	
Tilt Table: Direction		Driver	Driver	Driver	Driver	
Tilt Table: First Wheel Lift		Rear	Rear	Front	Rear	
Tilt Table Angle (deg)		34.9	35.2	30.8	35.9	
Tilt Table Ratio (TTR)		0.697	0.707	0.595	0.725	
Tilt Table: Direction		Passenger	Passenger	Passenger	Passenger	
Tilt Table: First Wheel Lift		Rear	Rear	Front	Rear	
Tilt Table Angle (deg)		40.0	35.2	30.9	37.0	
Tilt Table Ratio (TTR)		0.838	0.706	0.599	0.753	
Average Tilt Table Angle (deg)		37.4	35.2	30.8	36.4	
Average Tilt Table Ratio (TTR)		0.768	0.706	0.597	0.739	
Front Ground Clearance (in)			10.50			
Rear Ground Clearance (in)			9.70			
Steering Ratio (deg/deg)			14.8			

Vehicle G

	Curb	Operator	Operator & Passenger	Operator, Passenger & Cargo (GVWR)	Operator, Inst & Outriggers	Operator, Inst, Cargo & Outriggers (GVWR)
VIMF Test Number		4224	4225	4226	4227	4228
Total Vehicle Weight (lb)	1753.4	1966.8	2179.2	3100.6	2188.5	3099.9
Left Front Weight (lb)	375.1	458.3	497.8	507.0	500.7	502.6
Right Front Weight (lb)	373.4	413.1	494.5	497.9	491.3	492.4
Left Rear Weight (lb)	499.3	567.2	580.8	1032.6	598.8	1052.0
Right Rear Weight (lb)	505.6	528.2	606.1	1063.1	597.7	1052.9
Front Track Width (in)	50.20	51.45	51.73	51.45	51.73	51.45
Rear Track Width (in)	51.40	51.53	51.75	51.53	51.75	51.53
Average Track Width (in)	50.80	51.49	51.74	51.49	51.74	51.49
Wheelbase (in)	79.15	79.15	79.15	79.15	79.15	79.15
CG Longitudinal (in)	45.36	44.08	43.11	53.50	43.27	53.74
CG Lateral (in)	0.07	-1.10	0.26	0.18	-0.12	-0.08
CG Height (in)		24.45	25.33	26.52	25.10	
Roll Inertia - I_{XX} (ft-lb-s^2)		168	187	213	210	
Pitch Inertia - I_{YY} (ft-lb-s^2)		465	482	649	496	
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		486	503	666	540	
Roll/Yaw - I_{XZ} (ft-lb-s^2)		3	-2	40	0	
SSF		1.053	1.021	0.971	1.031	
KST		1.053	1.021	0.971	1.031	
CSV (mph)		8.74	8.50	7.90	8.69	
Tilt Table: Direction		Driver	Driver	Driver	Driver	
Tilt Table: First Wheel Lift		Front	Front	Front	Front	
Tilt Table Angle (deg)		39.0	38.9	34.0	38.7	
Tilt Table Ratio (TTR)		0.811	0.808	0.675	0.803	
Tilt Table: Direction		Passenger	Passenger	Passenger	Passenger	
Tilt Table: First Wheel Lift		Front	Front	Front	Front	
Tilt Table Angle (deg)		41.7	38.9	33.8	39.2	
Tilt Table Ratio (TTR)		0.891	0.807	0.668	0.817	
Average Tilt Table Angle (deg)		40.4	38.9	33.9	39.0	
Average Tilt Table Ratio (TTR)		0.851	0.808	0.672	0.810	
Front Ground Clearance (in)			9.60			
Rear Ground Clearance (in)			9.80			
Steering Ratio (deg/deg)			14.7			

Vehicle H

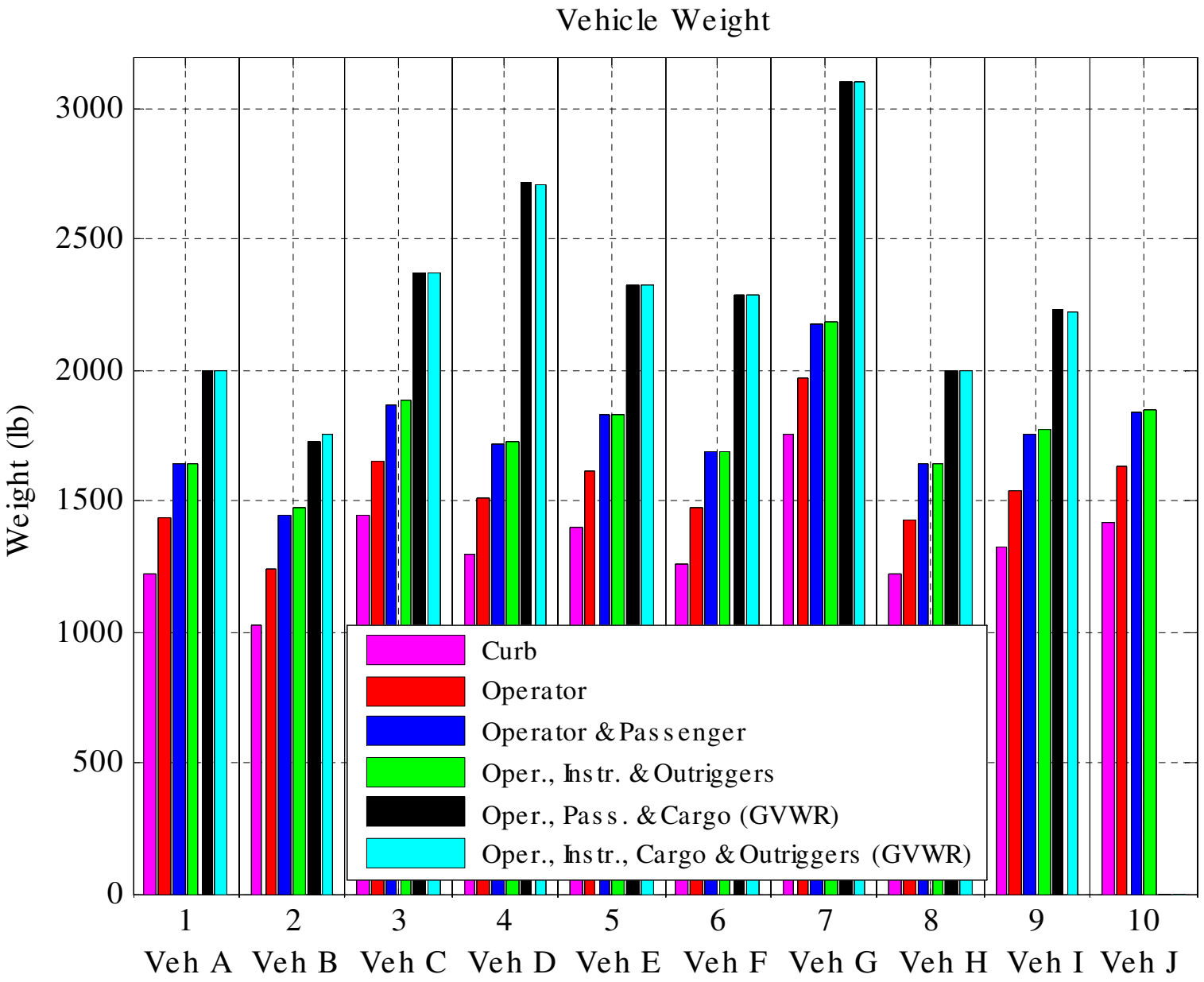
	Curb	Operator	Operator & Passenger	Operator, Passenger & Cargo (GVWR)	Operator, Inst & Outriggers	Operator, Inst, Cargo & Outriggers (GVWR)
VIMF Test Number		4251	4252	4253	4254	4255
Total Vehicle Weight (lb)	1218.5	1430.3	1643.2	2000.5	1645.1	2001.9
Left Front Weight (lb)	252.4	326.6	340.4	343.2	348.5	342.2
Right Front Weight (lb)	284.3	300.8	374.1	345.0	364.9	349.7
Left Rear Weight (lb)	326.6	433.5	453.8	631.3	466.7	656.1
Right Rear Weight (lb)	355.2	369.4	474.9	681.0	465.0	653.9
Front Track Width (in)	44.00	44.70	45.03	45.00	45.03	45.00
Rear Track Width (in)	46.60	47.58	48.58	49.70	48.58	49.70
Average Track Width (in)	45.30	46.14	46.80	47.35	46.80	47.35
Wheelbase (in)	75.10	75.10	75.10	75.10	75.10	75.10
CG Longitudinal (in)	42.02	42.16	42.44	49.26	42.53	49.14
CG Lateral (in)	1.12	-1.45	0.78	0.61	0.21	0.06
CG Height (in)		24.96	25.72	25.39	25.50	
Roll Inertia - I_{XX} (ft-lb-s^2)		136	162	165	196	
Pitch Inertia - I_{YY} (ft-lb-s^2)		277	288	368	301	
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		289	301	378	346	
Roll/Yaw - I_{XZ} (ft-lb-s^2)		9	16	22	12	
SSF		0.924	0.910	0.932	0.918	
KST		0.921	0.905	0.918	0.913	
CSV (mph)		7.60	7.54	7.57	7.82	
Tilt Table: Direction		Driver	Driver	Driver	Driver	
Tilt Table: First Wheel Lift		Rear	Rear	Front	Rear	
Tilt Table Angle (deg)		35.4	36.0	35.3	35.8	
Tilt Table Ratio (TTR)		0.711	0.726	0.707	0.722	
Tilt Table: Direction		Passenger	Passenger	Passenger	Passenger	
Tilt Table: First Wheel Lift		Rear	Rear	Front	Rear	
Tilt Table Angle (deg)		38.8	35.2	35.5	36.0	
Tilt Table Ratio (TTR)		0.805	0.705	0.714	0.725	
Average Tilt Table Angle (deg)		37.1	35.6	35.4	35.9	
Average Tilt Table Ratio (TTR)		0.758	0.716	0.710	0.724	
Front Ground Clearance (in)			9.15			
Rear Ground Clearance (in)			10.95			
Steering Ratio (deg/deg)			13.3			

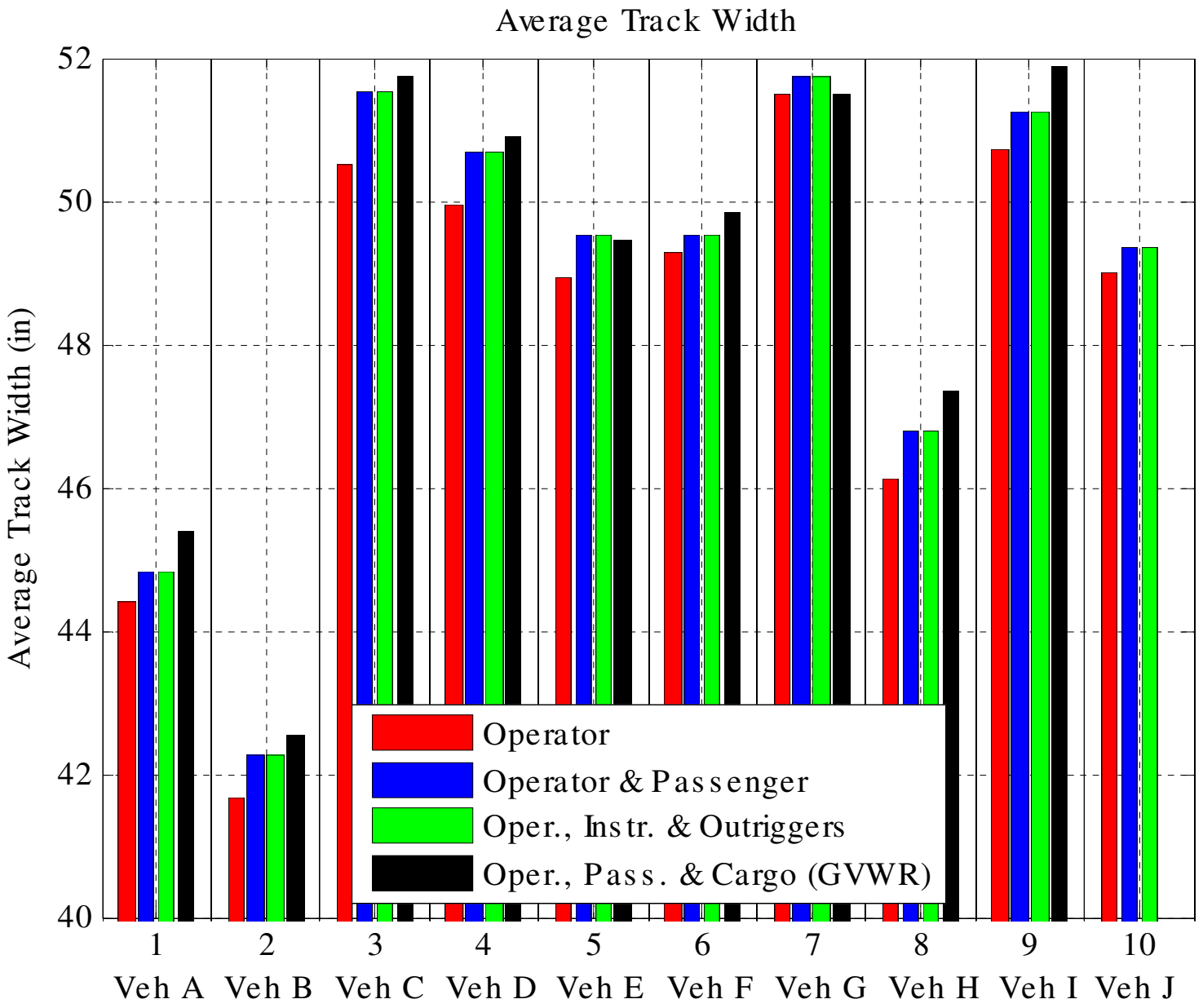
Vehicle I

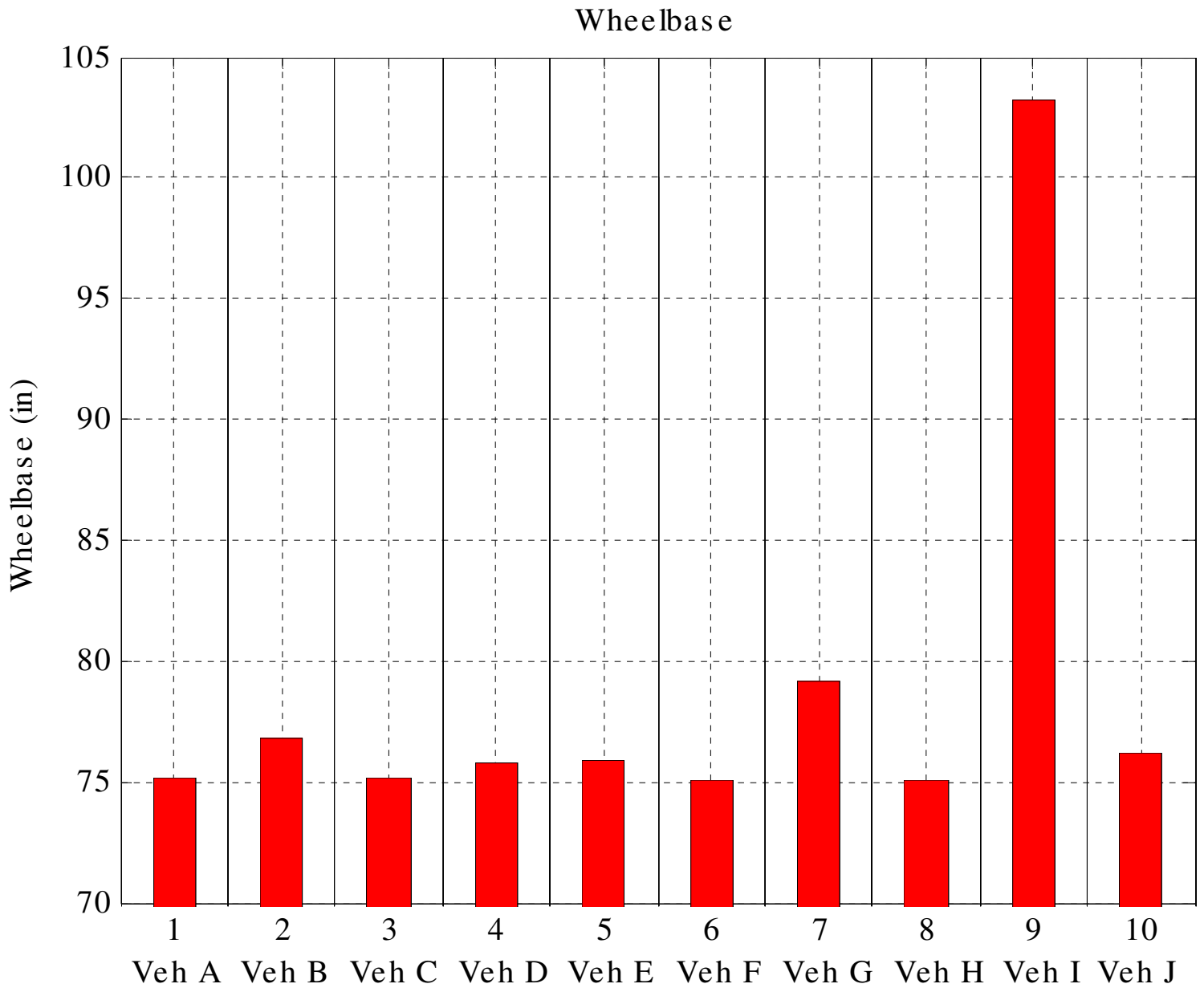
	Curb	Operator	Operator & Passenger	Operator & 3 Passenger	Operator, Passenger & Cargo (GVWR)	Operator, Inst & Outriggers	Operator, Inst, Cargo & Outriggers (GVWR)
VIMF Test Number		4259	4260	4261	4262	4263	4264
Total Vehicle Weight (lb)	1326.0	1539.0	1753.3	2177.7	2227.0	1769.3	2226.8
Left Front Weight (lb)	276.8	347.0	399.3	461.7	459.5	399.2	456.9
Right Front Weight (lb)	277.8	330.4	400.7	449.9	452.5	410.3	464.5
Left Rear Weight (lb)	367.9	459.6	461.9	618.0	646.4	487.6	657.8
Right Rear Weight (lb)	403.5	402.0	491.4	648.1	668.6	472.2	647.6
Front Track Width (in)	51.30	51.30	52.00	52.28	52.35	52.00	52.28
Rear Track Width (in)	50.15	50.15	50.50	51.30	51.40	50.50	51.30
Average Track Width (in)	50.73	50.73	51.25	51.79	51.88	51.25	51.79
Wheelbase (in)	103.25	103.25	103.25	103.25	103.25	103.25	103.25
CG Longitudinal (in)	60.07	57.80	56.14	60.03	60.97	56.01	60.53
CG Lateral (in)	0.70	-1.22	0.45	0.22	0.18	-0.06	-0.03
CG Height (in)		23.91	24.35	25.45	25.45	24.53	
Roll Inertia - I_{XX} (ft-lb-s^2)		150	165	193	196	201	
Pitch Inertia - I_{YY} (ft-lb-s^2)		517	534	579	597	560	
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		528	544	585	601	584	
Roll/Yaw - I_{XZ} (ft-lb-s^2)		-9	-11	8	15	-7	
SSF		1.061	1.052	1.017	1.019	1.045	
KST		1.062	1.054	1.019	1.021	1.046	
CSV (mph)		8.92	8.83	8.50	8.51	9.00	
Tilt Table: Direction		Driver	Driver	Driver	Driver	Driver	
Tilt Table: First Wheel Lift		Rear	Rear	Rear	Rear	Rear	
Tilt Table Angle (deg)		36.5	36.0	32.8	32.8	35.0	
Tilt Table Ratio (TTR)		0.739	0.726	0.644	0.645	0.699	
Tilt Table: Direction		Passenger	Passenger	Passenger	Passenger	Passenger	
Tilt Table: First Wheel Lift		Rear	Rear	Rear	Rear	Rear	
Tilt Table Angle (deg)		39.1	35.1	32.4	32.6	35.9	
Tilt Table Ratio (TTR)		0.811	0.702	0.635	0.639	0.725	
Average Tilt Table Angle (deg)		37.8	35.5	32.6	32.7	35.4	
Average Tilt Table Ratio (TTR)		0.775	0.714	0.640	0.642	0.712	
Front Ground Clearance (in)			10.25				
Rear Ground Clearance (in)			10.15				
Steering Ratio (deg/deg)			14.6				

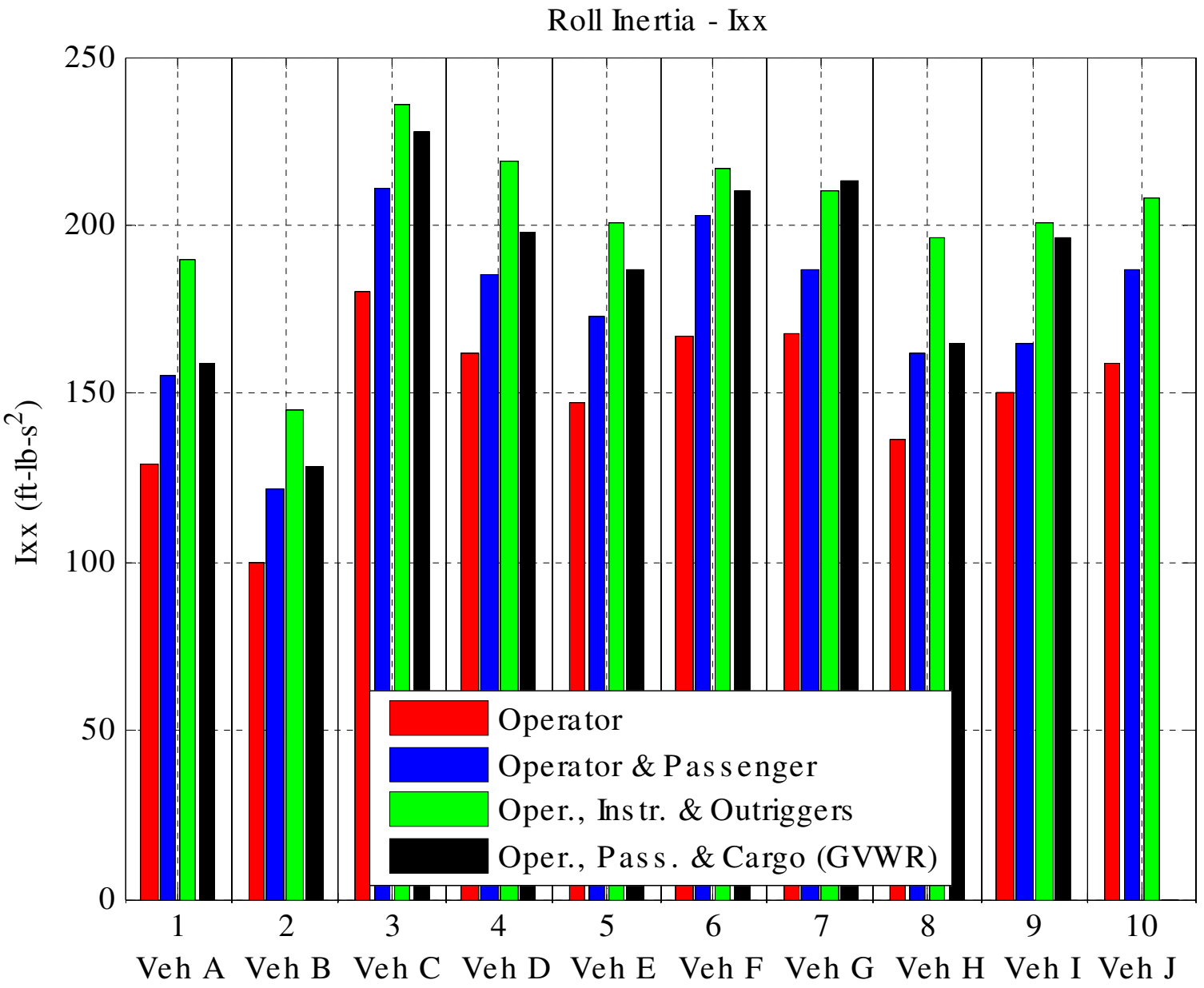
Vehicle J

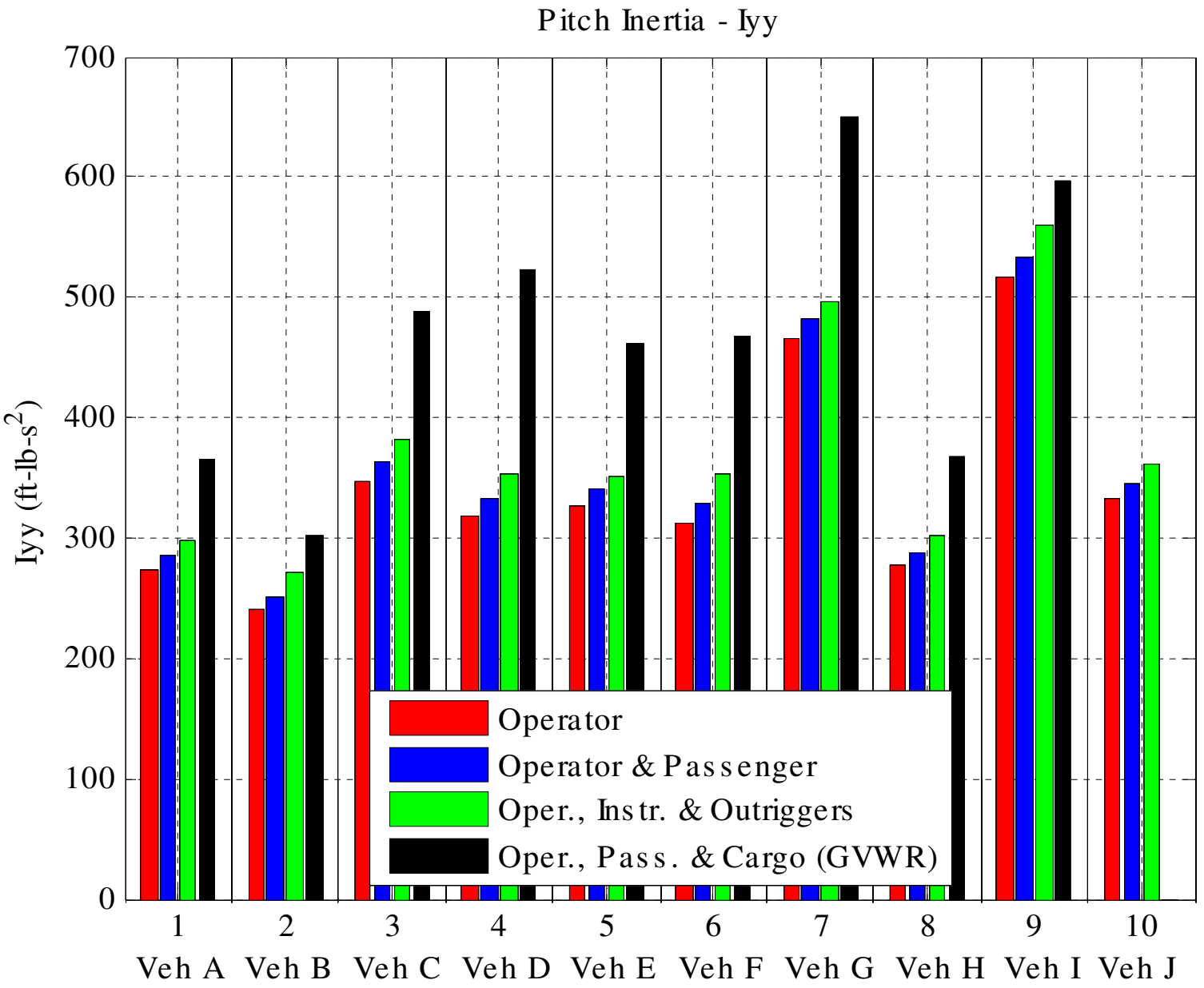
	Curb	Operator	Operator & Passenger	Operator, Passenger & Cargo (GVWR)	Operator, Inst & Outriggers	Operator, Inst, Cargo & Outriggers (GVWR)
VIMF Test Number		4366	4367	NA	4368	NA
Total Vehicle Weight (lb)	1417.2	1631.0	1841.9	NA	1848.8	NA
Left Front Weight (lb)	312.5	349.5	390.2	NA	394.9	NA
Right Front Weight (lb)	313.1	356.5	394.9	NA	389.2	NA
Left Rear Weight (lb)	381.4	524.7	519.4	NA	550.7	NA
Right Rear Weight (lb)	410.2	400.3	537.4	NA	514.0	NA
Front Track Width (in)	49.65	49.65	50.38	NA	50.38	NA
Rear Track Width (in)	48.33	48.33	48.33	NA	48.33	NA
Average Track Width (in)	48.99	48.99	49.35	NA	49.35	NA
Wheelbase (in)	76.05	76.05	76.20	NA	76.20	NA
CG Longitudinal (in)	42.48	43.13	43.72	NA	43.88	NA
CG Lateral (in)	0.51	-1.76	0.30	NA	-0.57	NA
CG Height (in)		24.98	25.46	NA	25.66	
Roll Inertia - I_{XX} (ft-lb-s^2)		159	187	NA	208	
Pitch Inertia - I_{YY} (ft-lb-s^2)		332	345	NA	362	
Yaw Inertia - I_{ZZ} (ft-lb-s^2)		356	370	NA	403	
Roll/Yaw - I_{XZ} (ft-lb-s^2)		9	16	NA	14	
SSF		0.981	0.969	NA	0.962	
KST		0.982	0.972	NA	0.965	
CSV (mph)		8.19	8.15	NA	8.21	
Tilt Table: Direction		Driver	Driver	NA	Driver	
Tilt Table: First Wheel Lift		Rear	Rear	NA	Rear	
Tilt Table Angle (deg)		36.0	36.5	NA	35.0	
Tilt Table Ratio (TTR)		0.726	0.740	NA	0.700	
Tilt Table: Direction		Passenger	Passenger	NA	Passenger	
Tilt Table: First Wheel Lift		Rear	Rear	NA	Rear	
Tilt Table Angle (deg)		40.7	36.1	NA	37.3	
Tilt Table Ratio (TTR)		0.859	0.729	NA	0.761	
Average Tilt Table Angle (deg)		38.3	36.3	NA	36.1	
Average Tilt Table Ratio (TTR)		0.793	0.735	NA	0.730	
Front Ground Clearance (in)			10.25			
Rear Ground Clearance (in)			8.10			
Steering Ratio (deg/deg)			13.2			

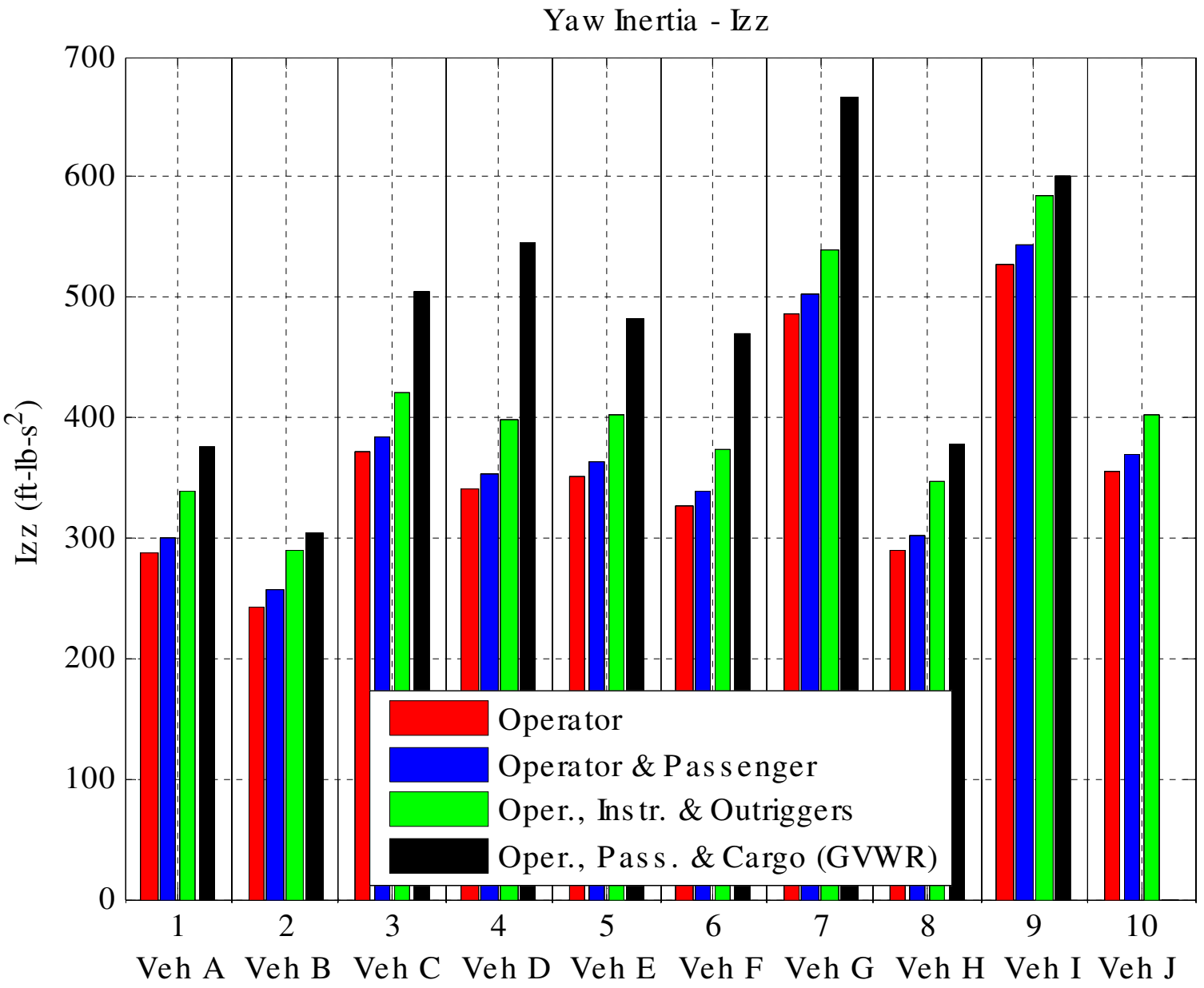

Vehicle Weight
Weight (lb)
3000
2500
2000
1500
1000
500
0
Curb
Operator
Operator & Passenger
Oper., Instr. & Outriggers
Oper., Pass. & Cargo (GVWR)
Oper., Instr., Cargo & Outriggers (GVWR)
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

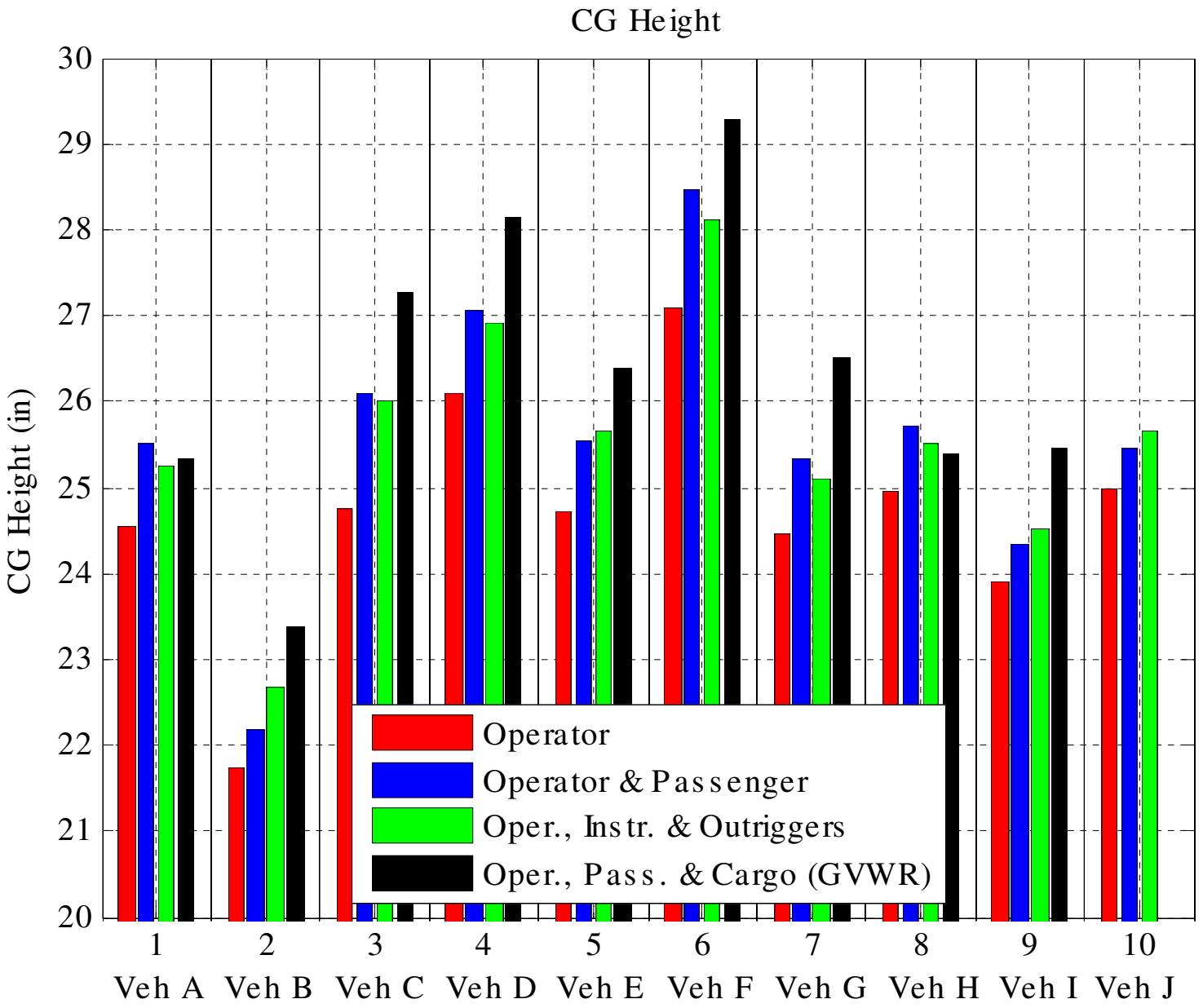

Average Track Width
Average Track Width (in)
52
50
48
46
44
42
40
Operator
Operator & Passenger
Oper., Instr. & Outriggers
Oper., Pass. & Cargo (GVWR)
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

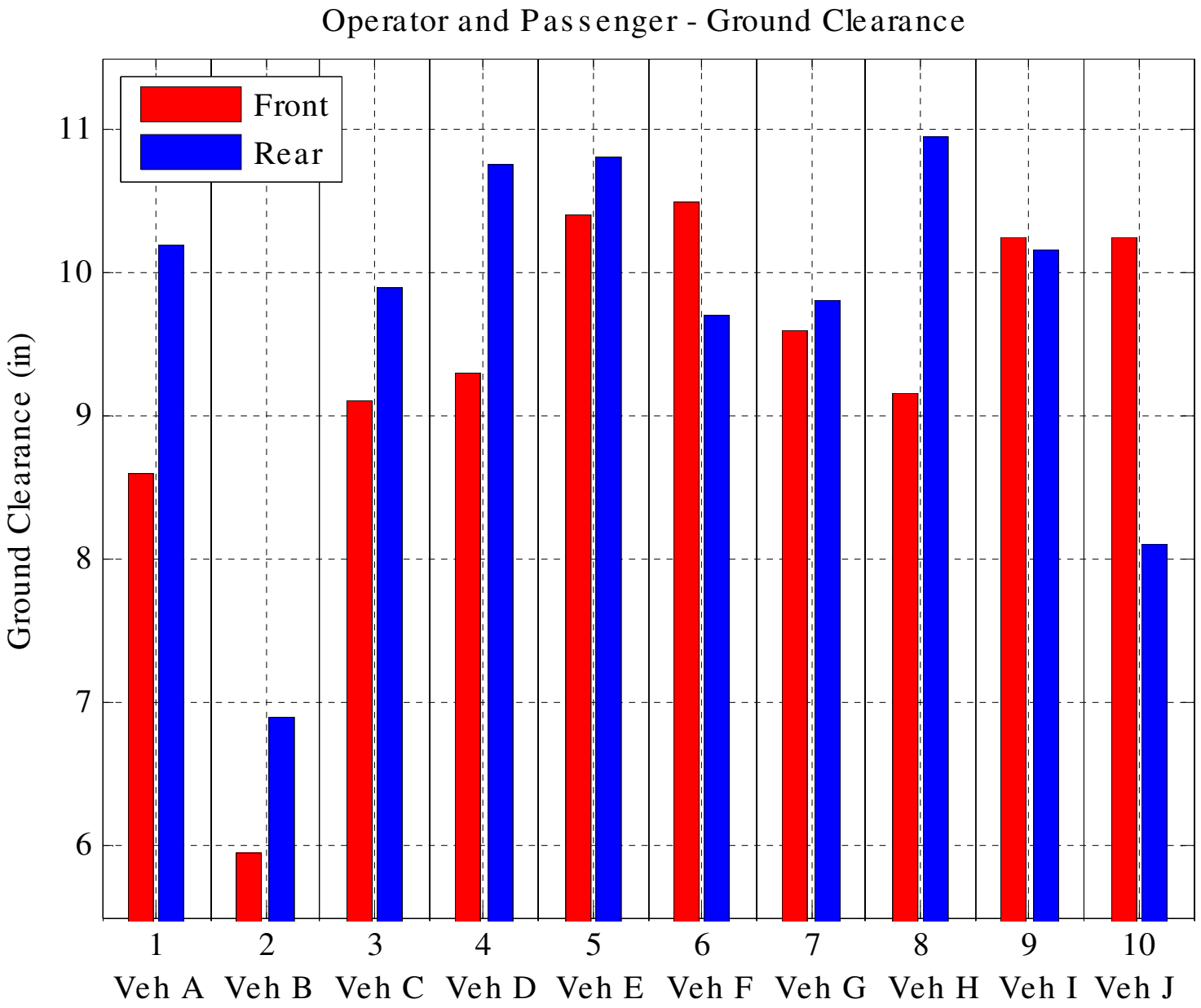

Wheelbase
Wheelbase (in)
105
100
95
90
85
80
75
70
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

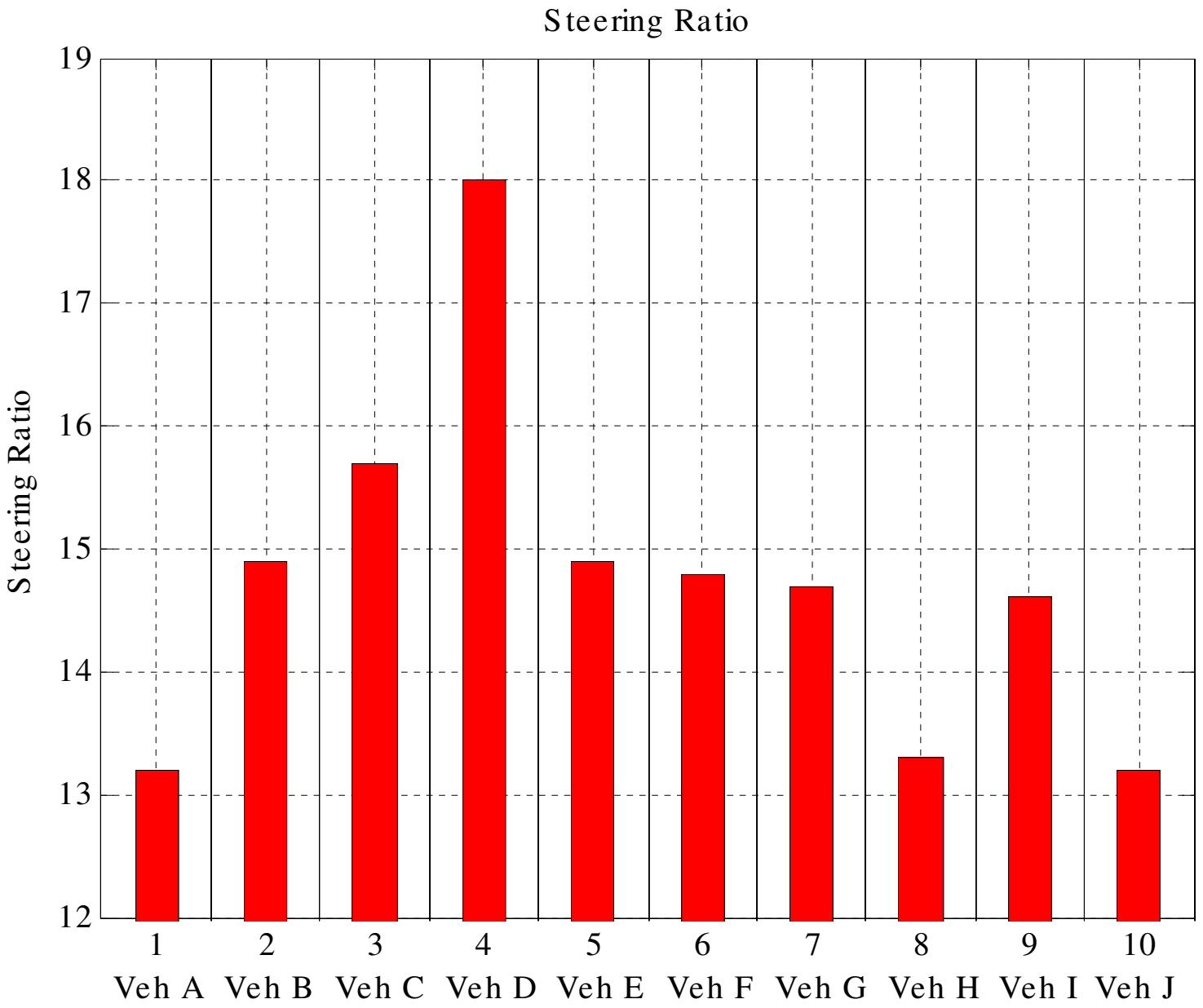

Roll Inertia - Ixx
Ixx (ft-lb-s2)
250
200
150
100
50
0
Operator
Operator & Passenger
Oper., Instr. & Outriggers
Oper., Pass. & Cargo (GVWR)
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

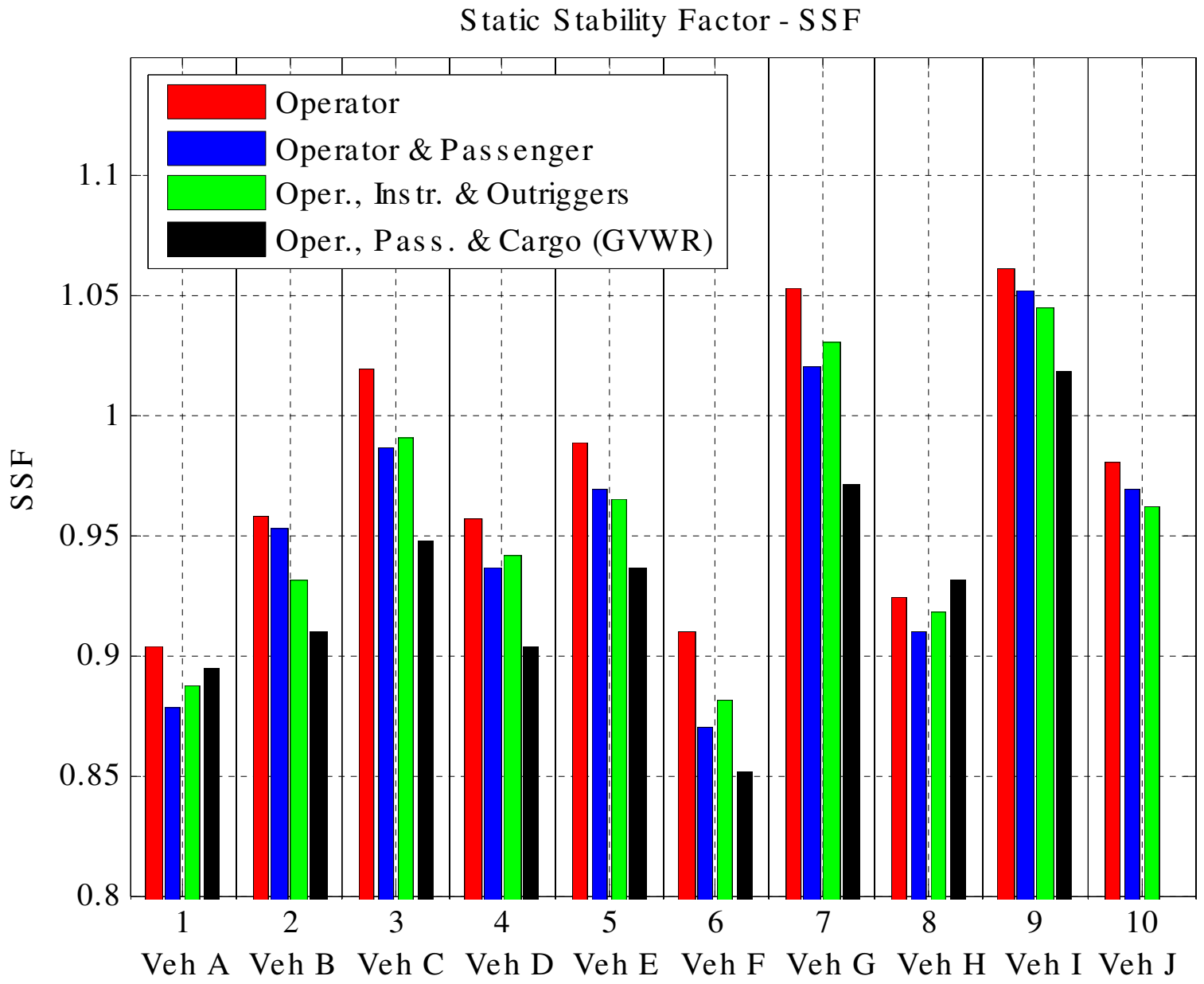

Pitch Inertia - Iyy
Iyy (ft-lb-s2)
700
600
500
400
300
200
100
0
Operator
Operator & Passenger
Oper., Instr. & Outriggers
Oper., Pass. & Cargo (GVWR)
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

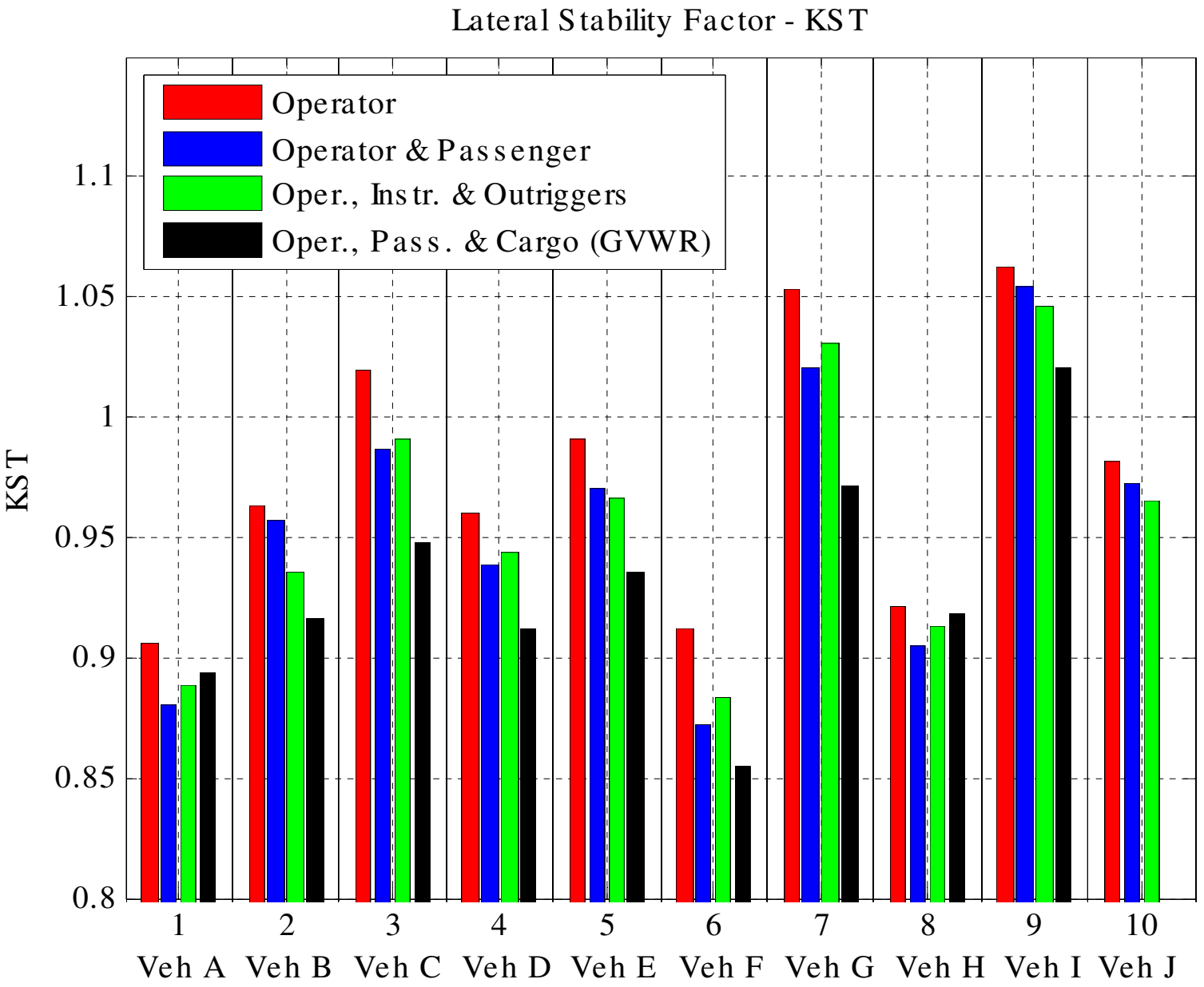

Yaw Inertia - Izz
Izz (ft-lb-s2)
700
600
500
400
300
200
100
0
Operator
Operator & Passenger
Oper., Instr. & Outriggers
Oper., Pass. & Cargo (GVWR)
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

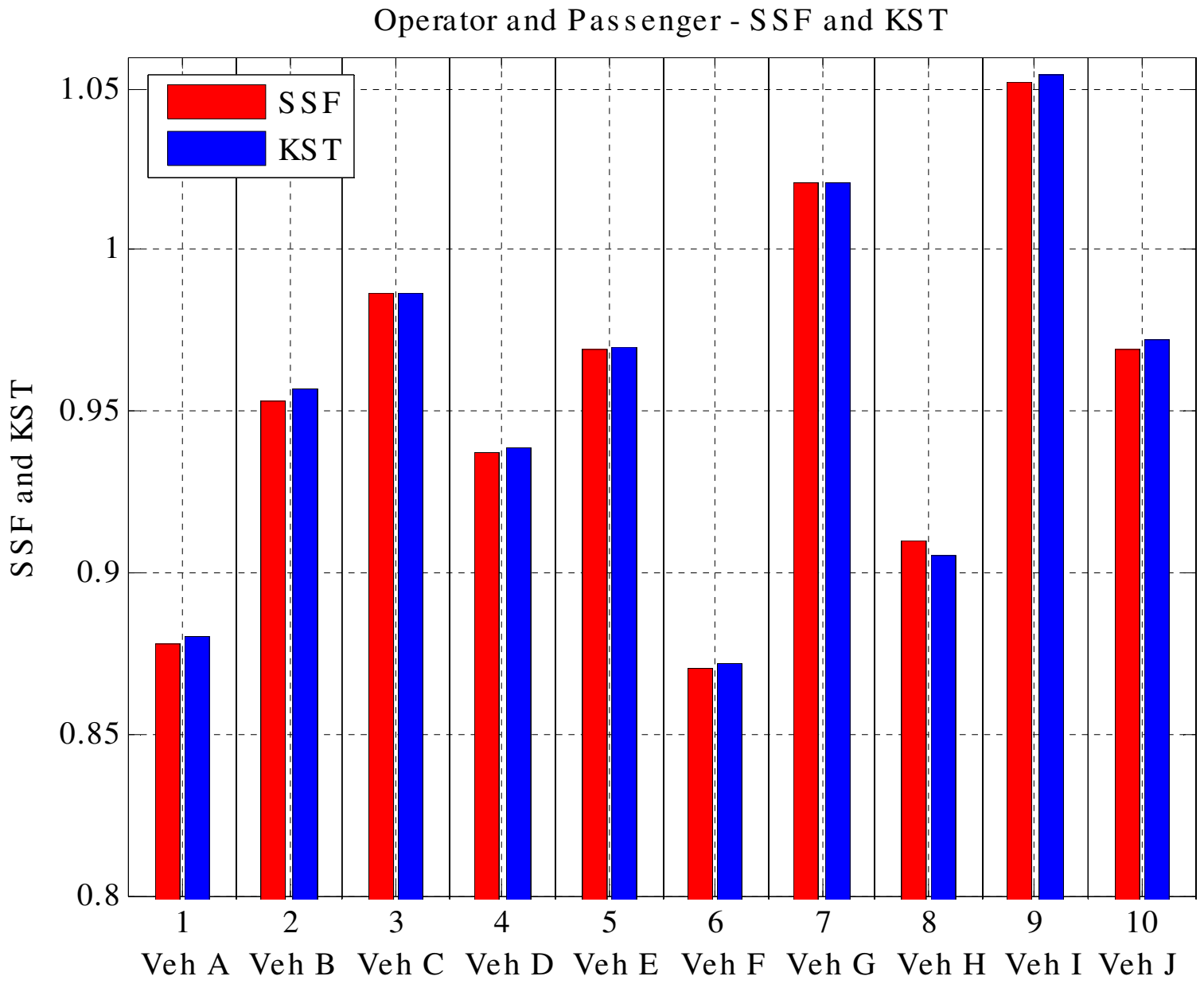

CG Height
CG Height (in)
30
29
28
27
26
25
24
23
22
21
20
Operator
Operator & Passenger
Oper., Instr. & Outriggers
Oper., Pass. & Cargo (GVWR)
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

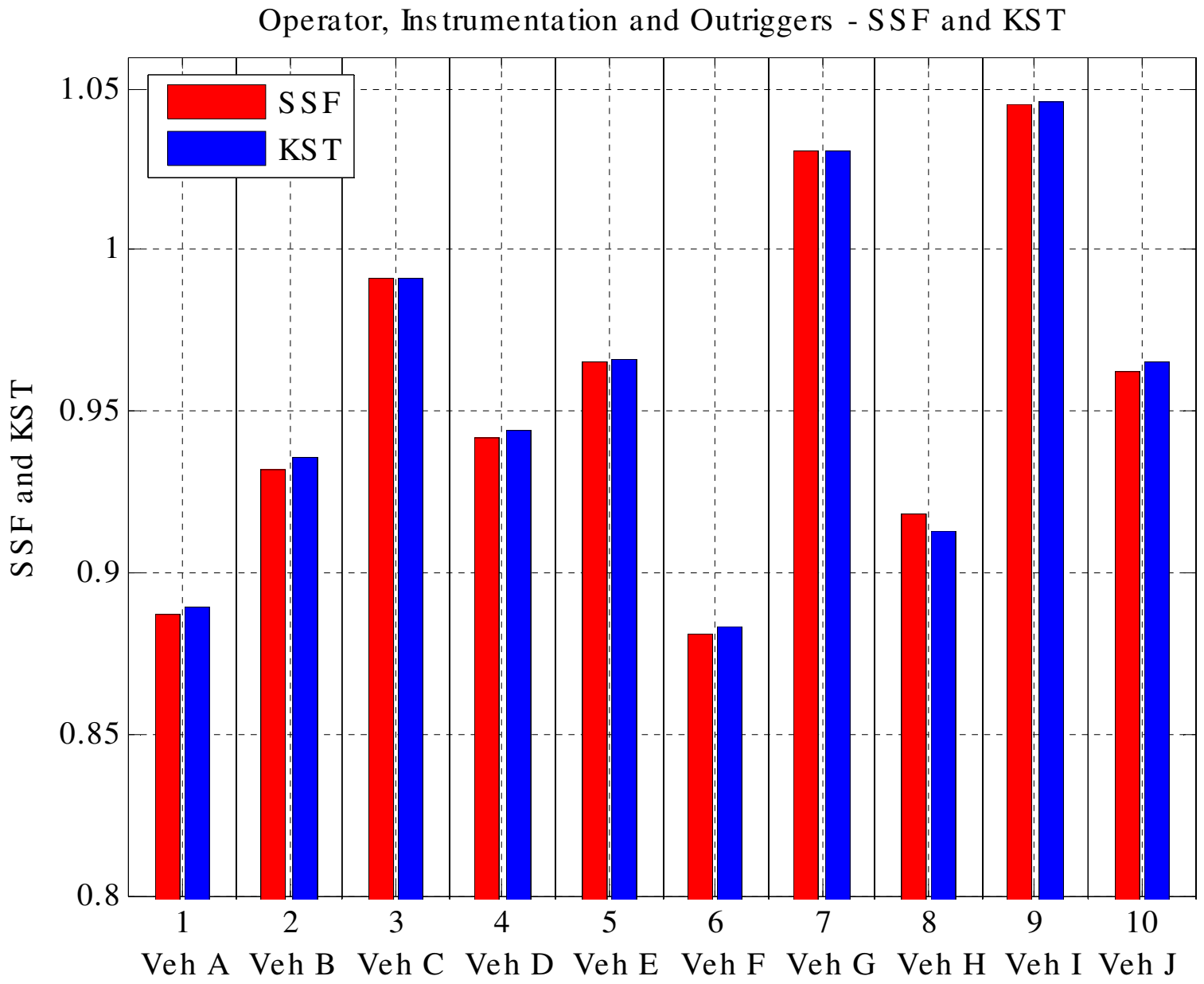

Operator and Passenger - Ground Clearance
Front
Rear
Ground Clearance (in)
11
10
9
8
7
6
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

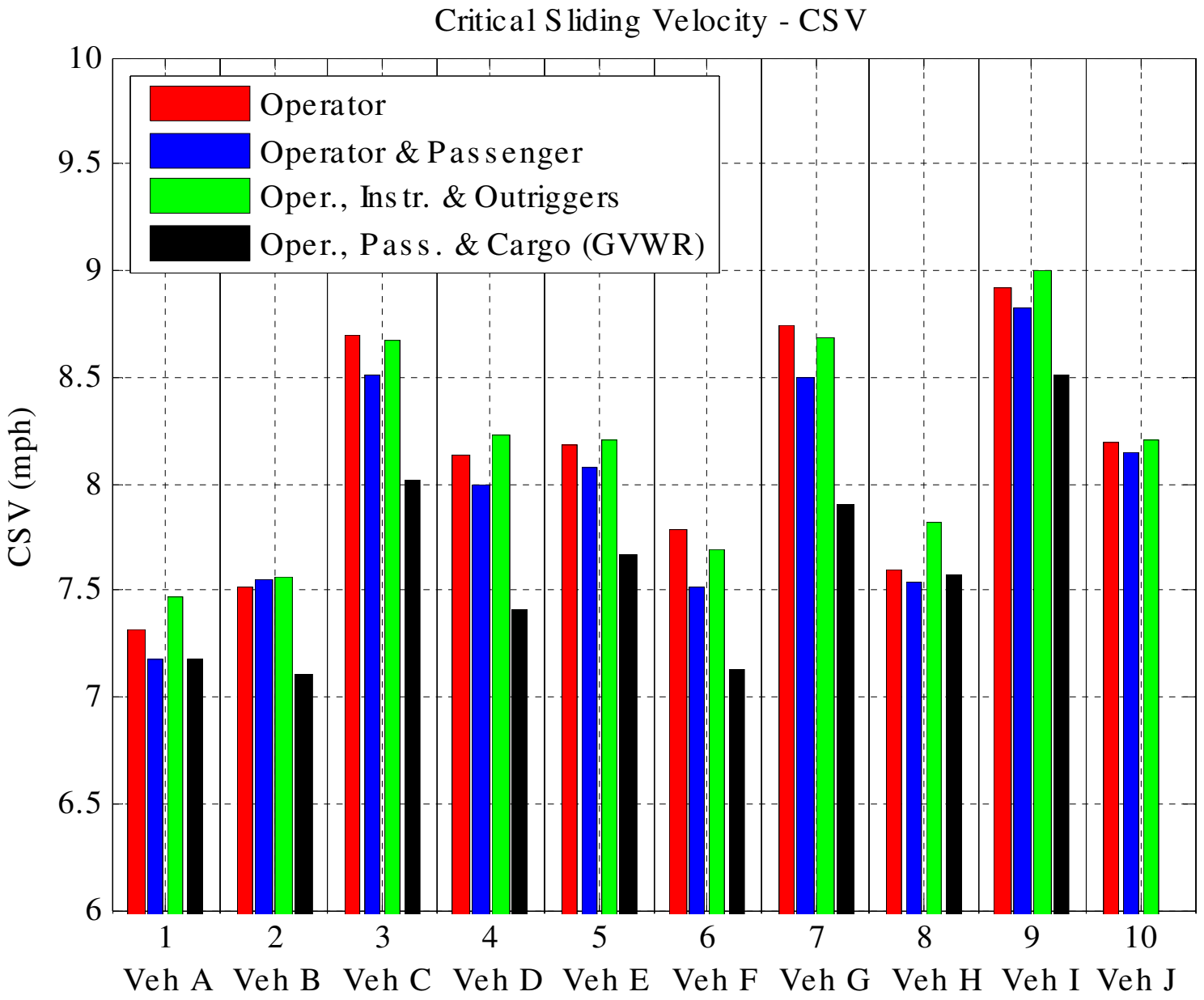

Steering Ratio
Steering Ratio
19
18
17
16
15
14
13
12
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

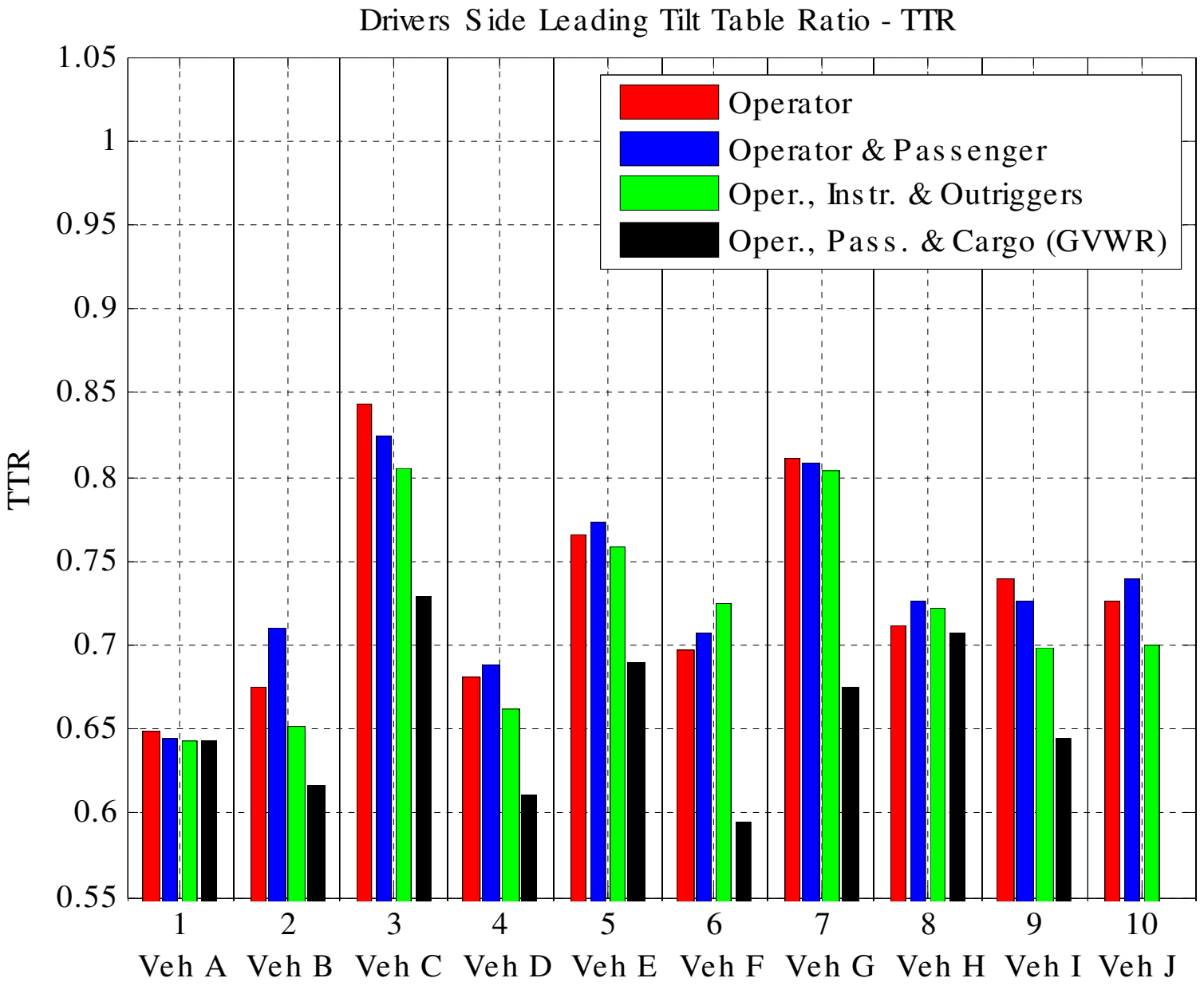

Static Stability Factor - SSF
Operator
Operator & Passenger
Oper., Instr. & Outriggers
Oper., Pass. & Cargo (GVWR)
SSF
1.1
1.05
1
0.95
0.9
0.85
0.8
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

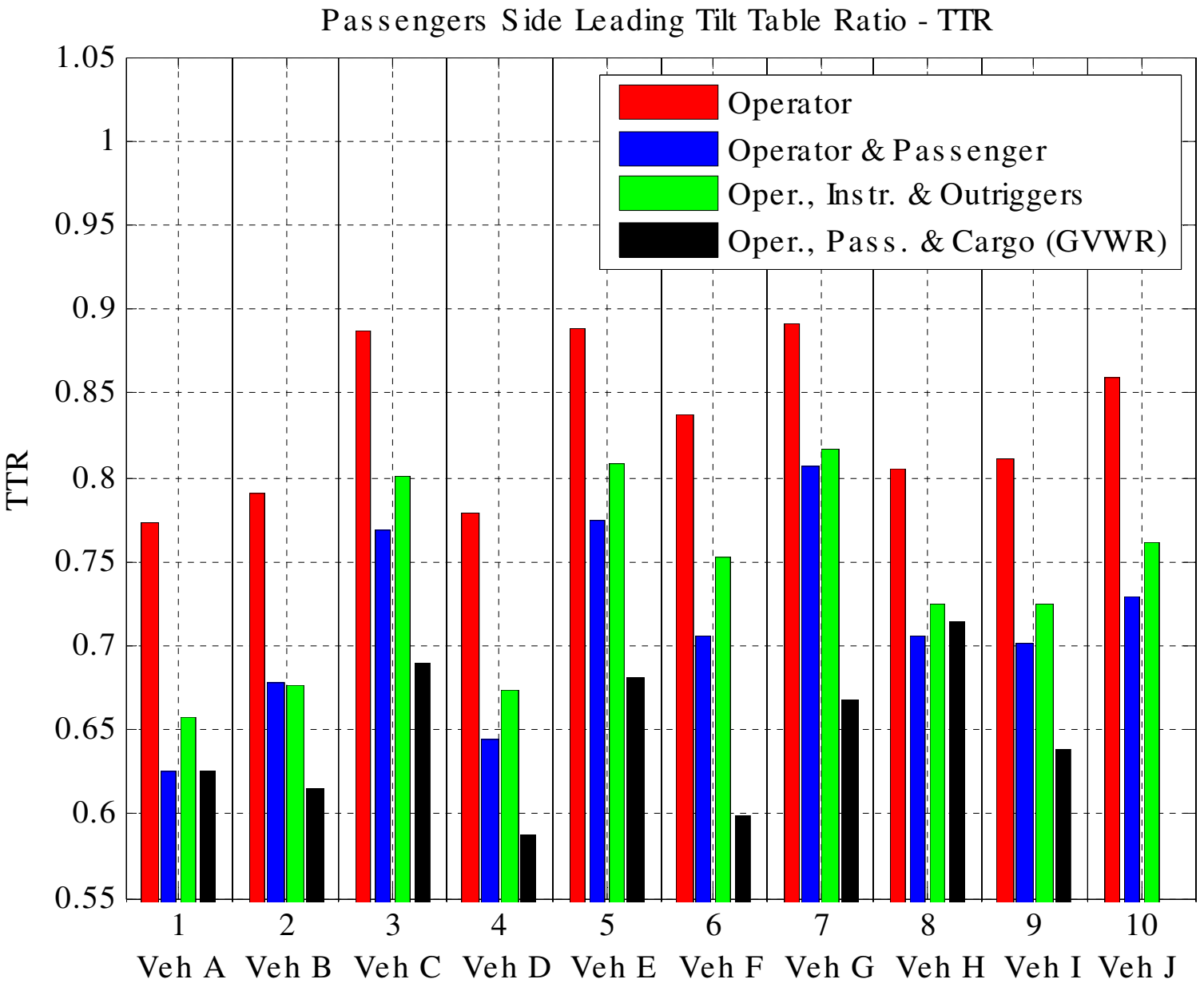

Lateral Stability Factor - KST
Operator
Operator & Passenger
Oper., Instr. & Outriggers
Oper., Pass. & Cargo (GVWR)
KST
1.1
1.05
1
0.95
0.9
0.85
0.8
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

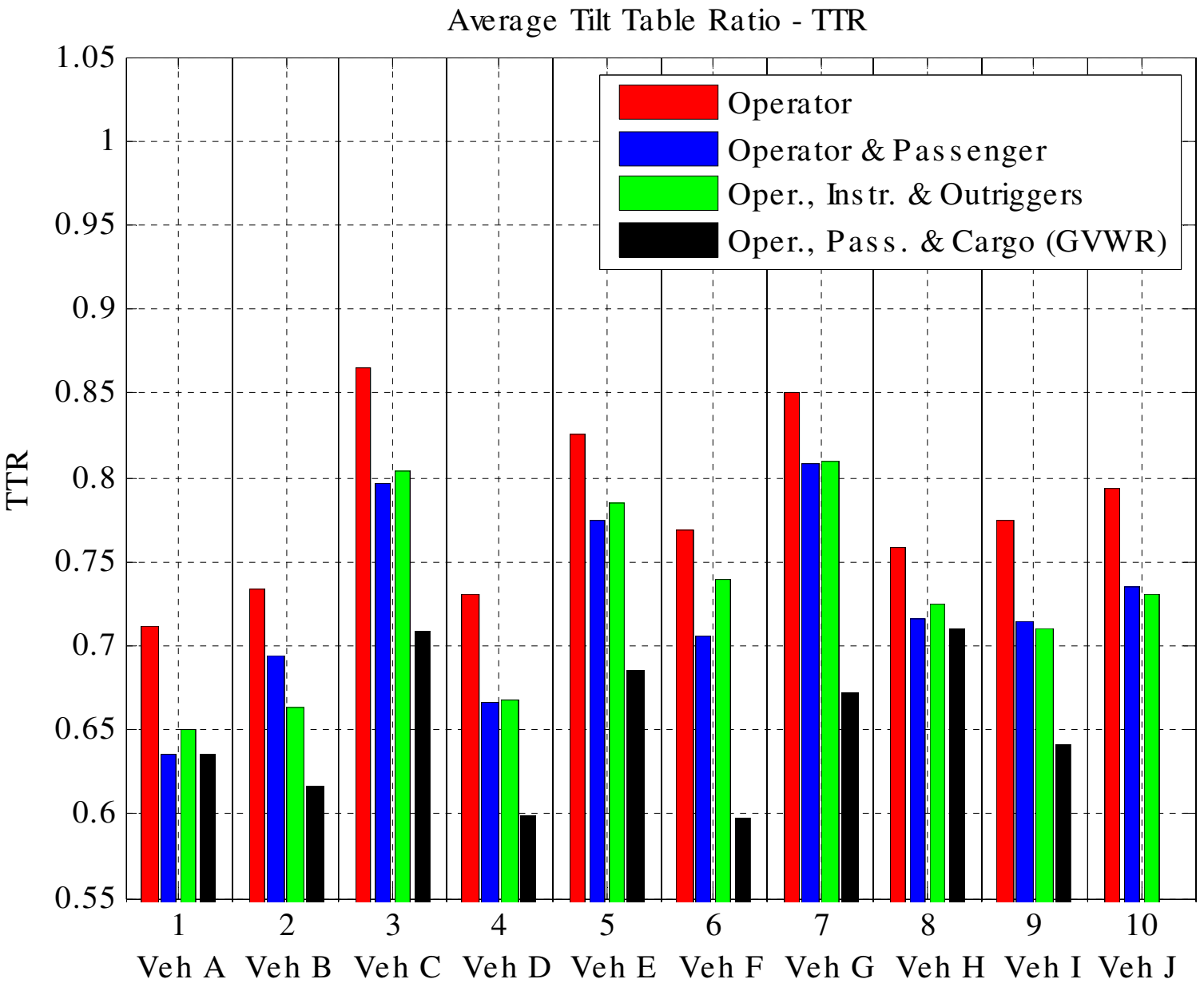

Operator and Passenger - SSF and KST
SSF
KST
SSF and KST
1.05
1
0.95
0.9
0.85
0.8
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

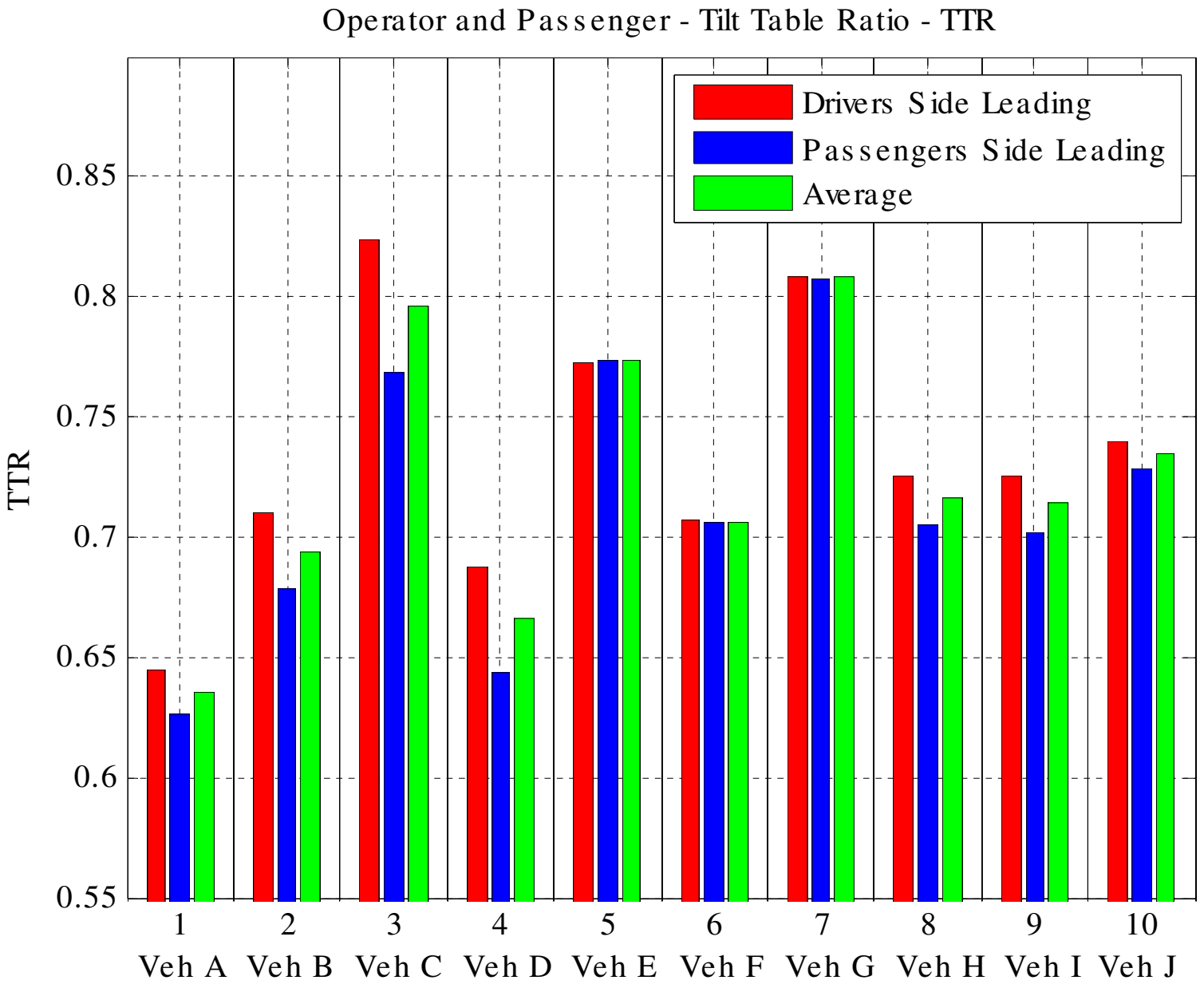

Operator, Instrumentation and Outriggers - SSF and KST
SSF
KST
SSF and KST
1.05
1
0.95
0.9
0.85
0.8
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

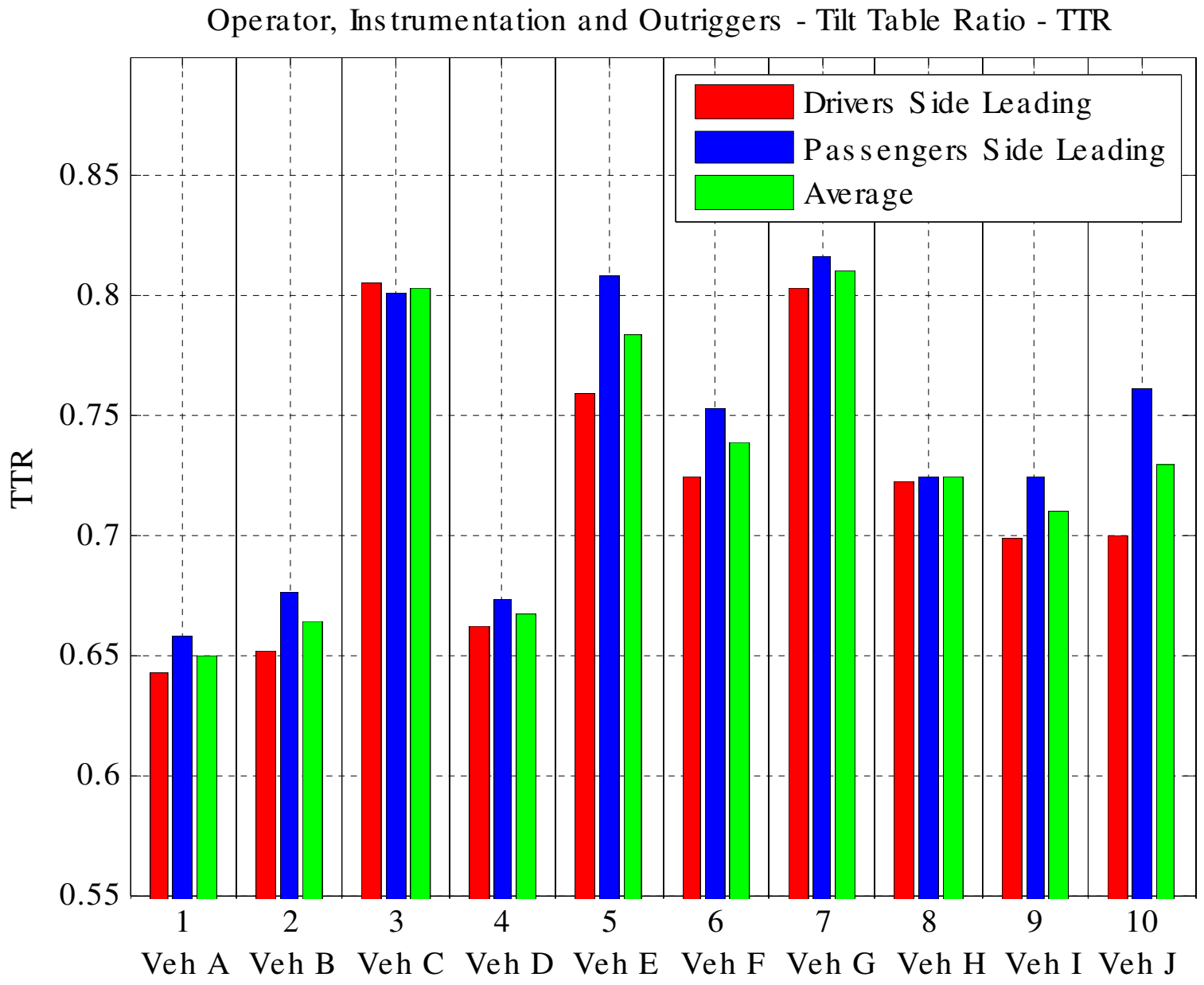

Critical Sliding Velocity - CSV
Operator
Operator & Passenger
Oper., Instr. & Outriggers
Oper., Pass. & Cargo (GVWR)
CSV (mph)
10
9.5
9
8.5
8
7.5
7
6.5
6
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

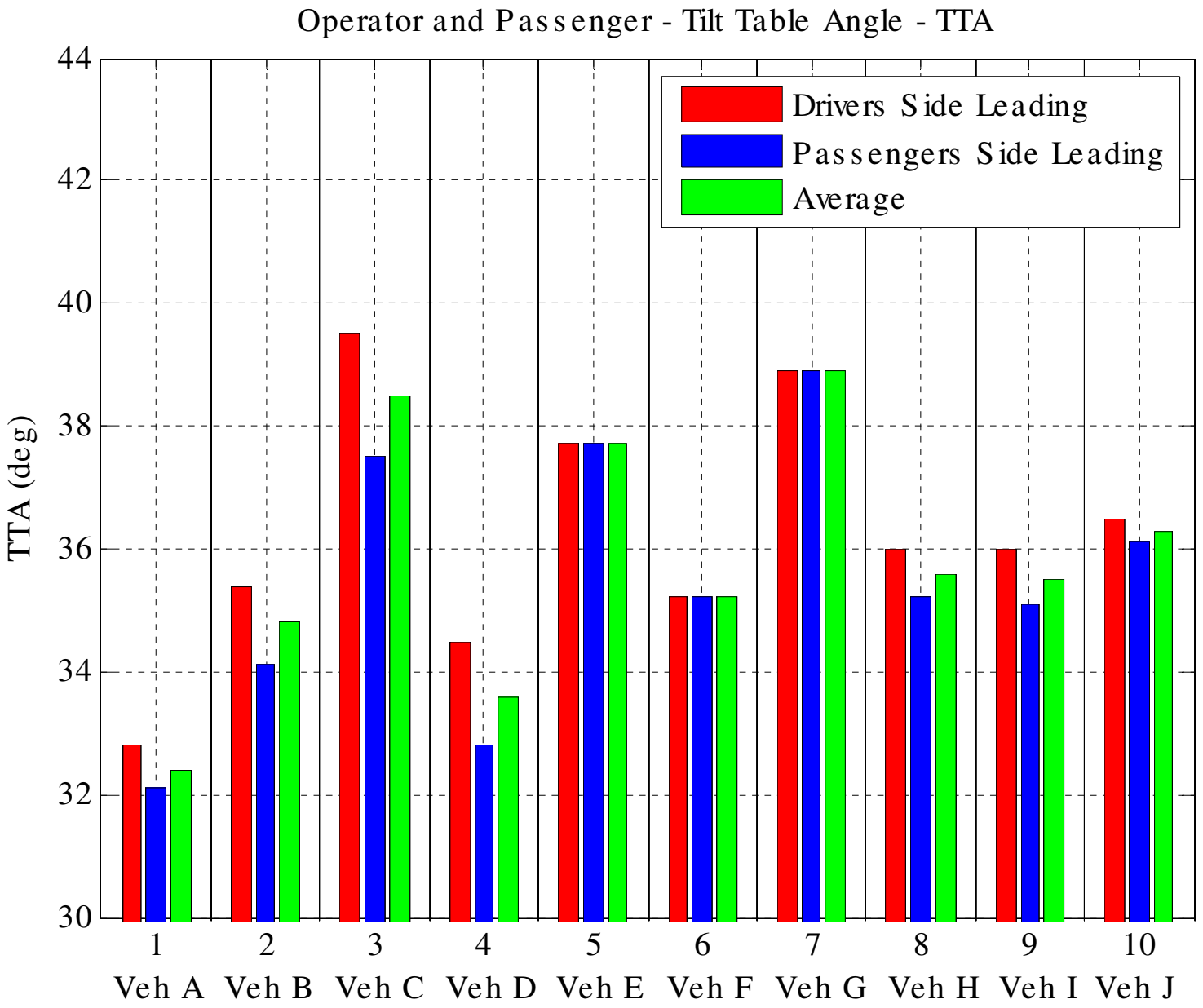

Drivers Side Leading Tilt Table Ratio - TTR
TTR
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
Operator
Operator & Passenger
Oper., Instr. & Outriggers
Oper., Pass. & Cargo (GVWR)
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

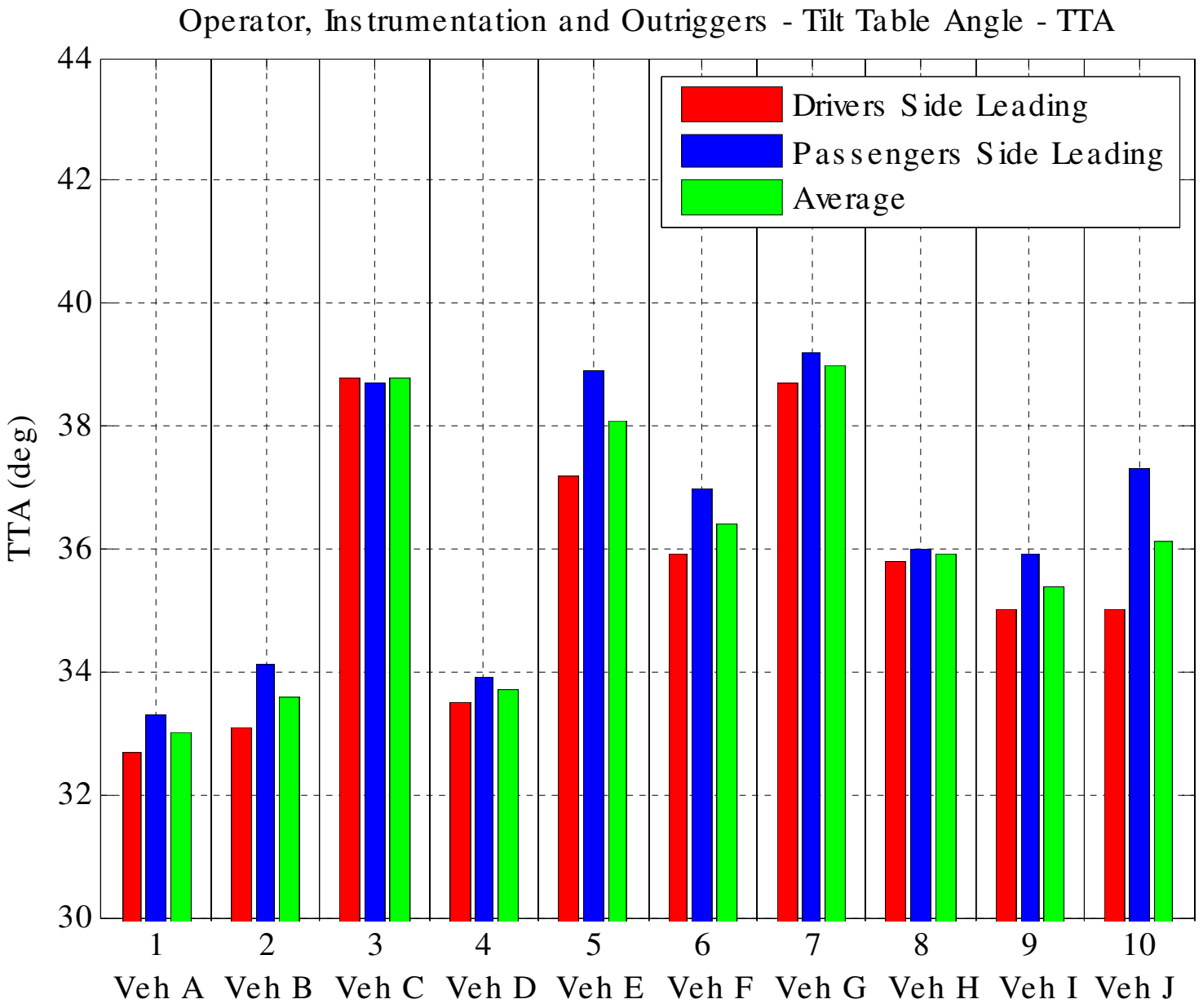

Passengers Side Leading Tilt Table Ratio - TTR
TTR
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
Operator
Operator & Passenger
Oper., Instr. & Outriggers
Oper., Pass. & Cargo (GVWR)
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

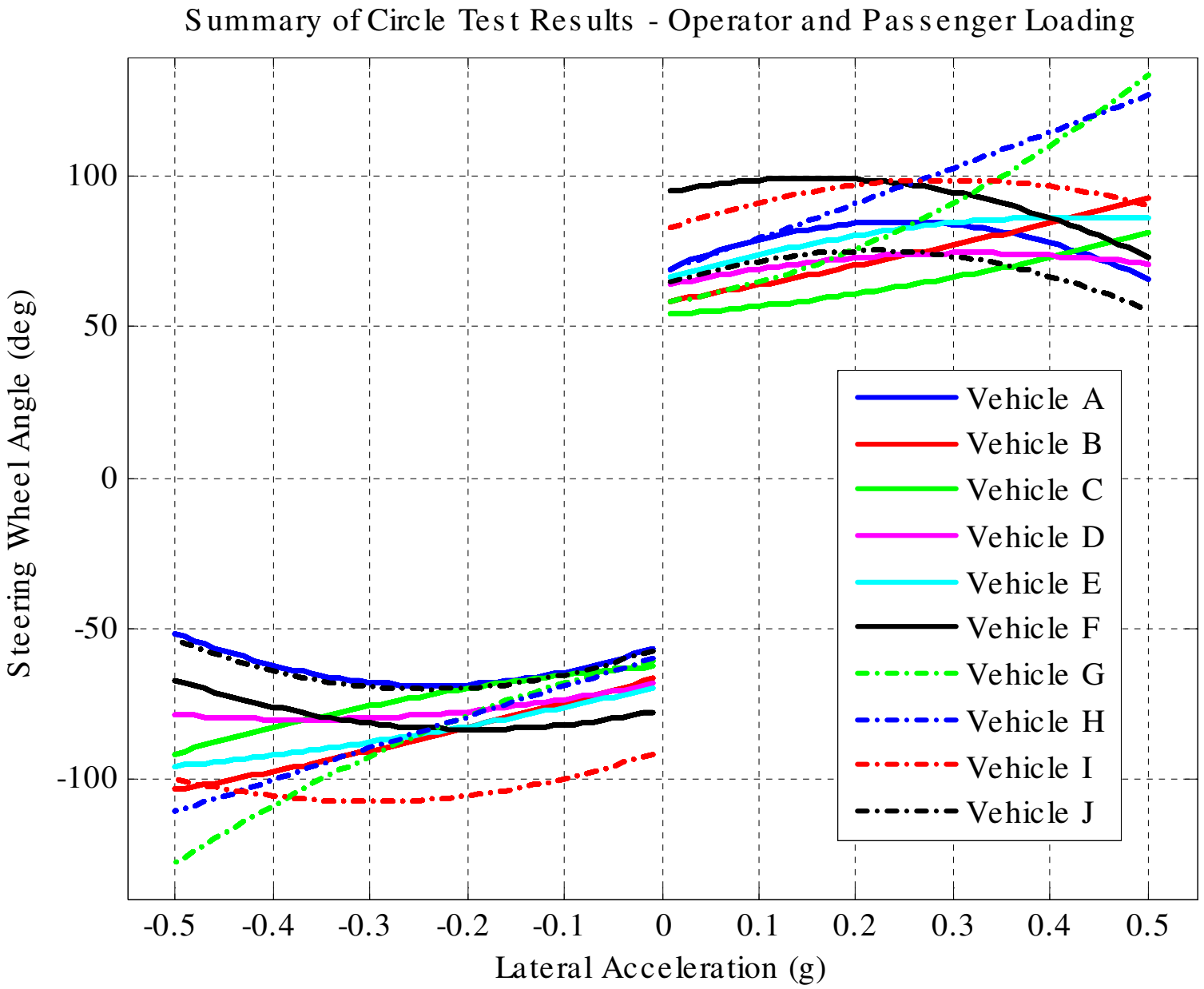

Average Tilt Table Ratio - TTR
TTR
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
Operator
Operator & Passenger
Oper., Instr. & Outriggers
Oper., Pass. & Cargo (GVWR)
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

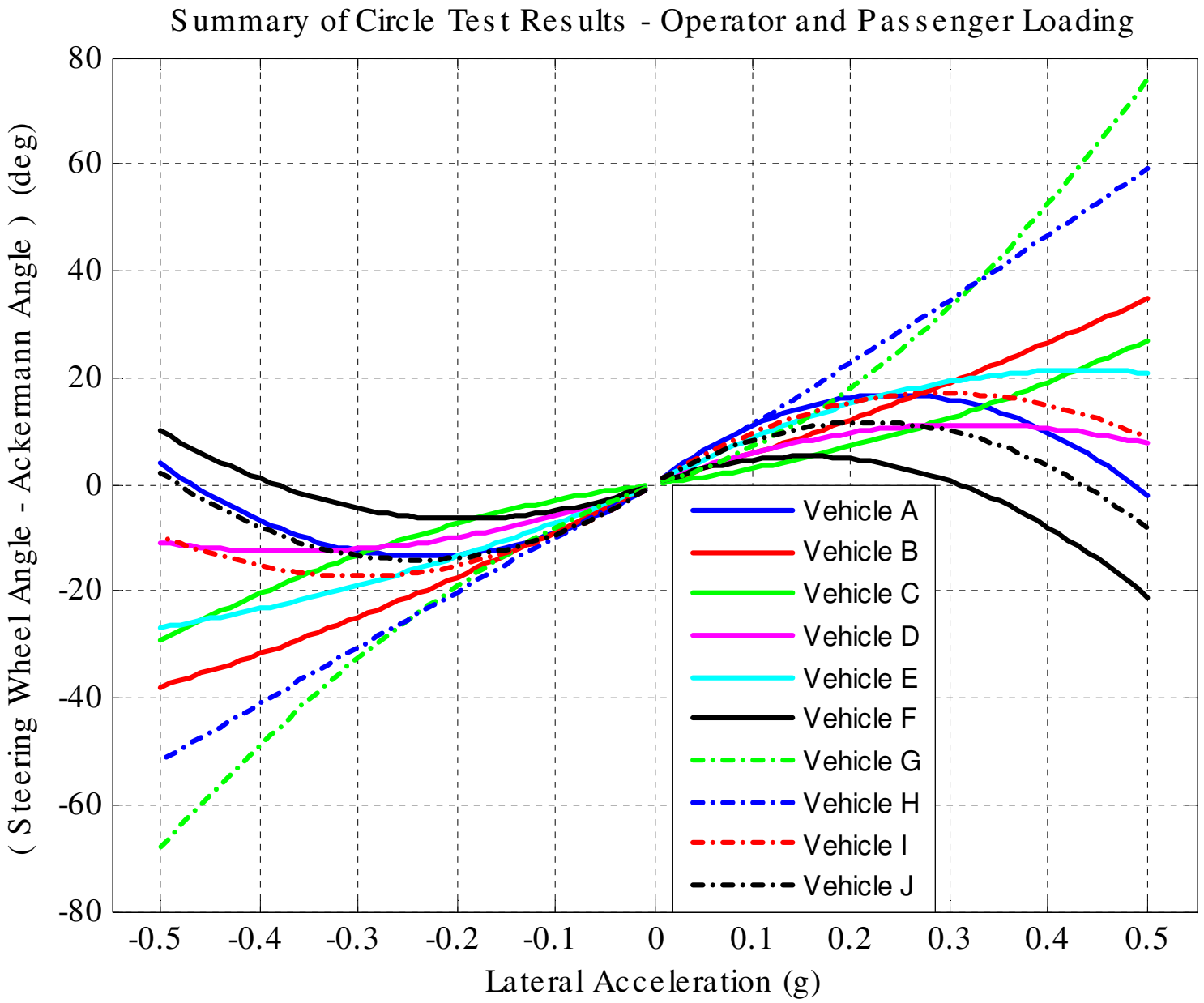

Operator and Passenger - Tilt Table Ratio - TTR
Drivers Side Leading
Passengers Side Leading
Average
TTR
0.85
0.8
0.75
0.7
0.65
0.6
0.55
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

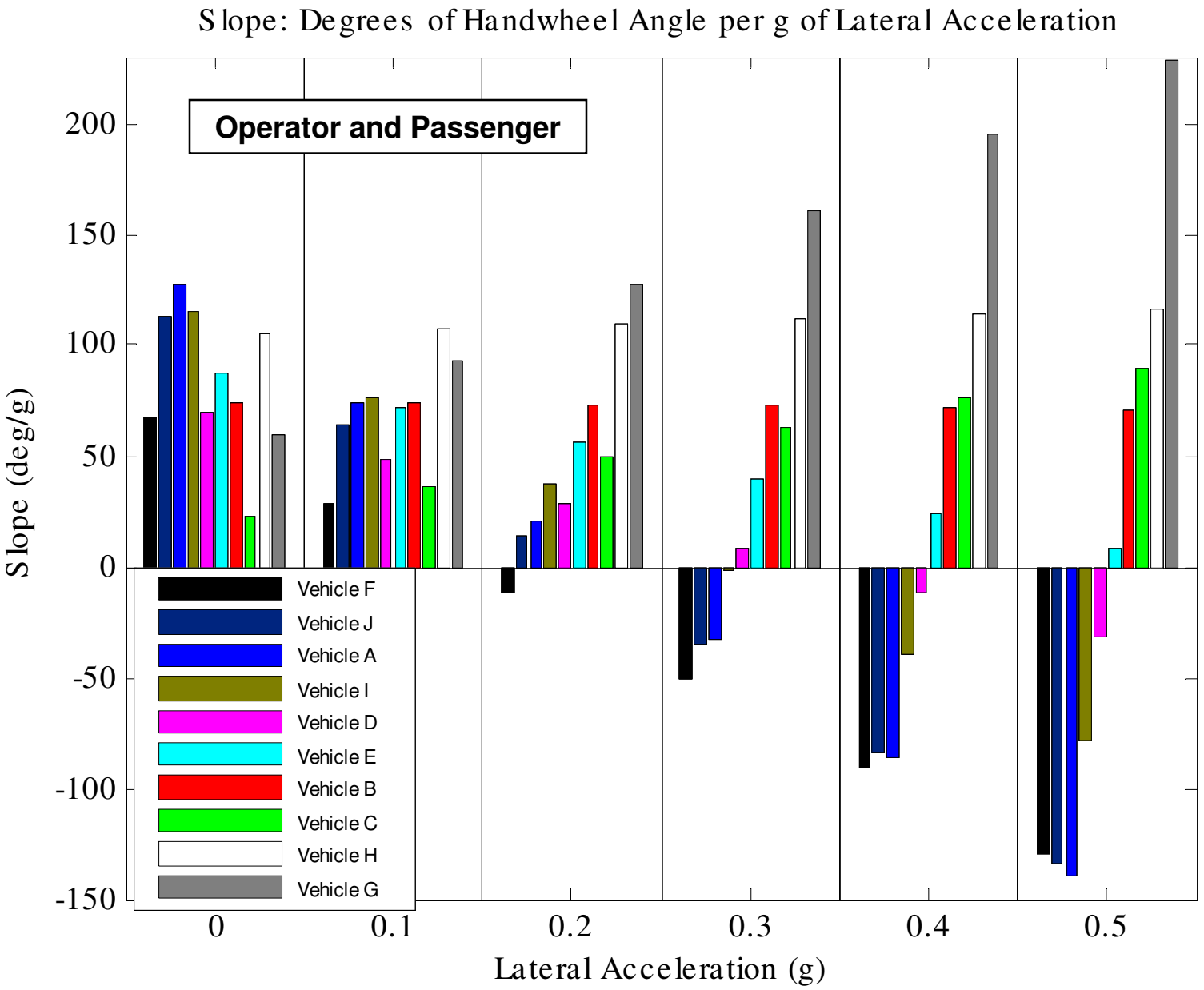

Operator, Instrumentation and Outriggers - Tilt Table Ratio - TTR
Drivers Side Leading
Passengers Side Leading
Average
TTR
0.85
0.8
0.75
0.7
0.65
0.6
0.55
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

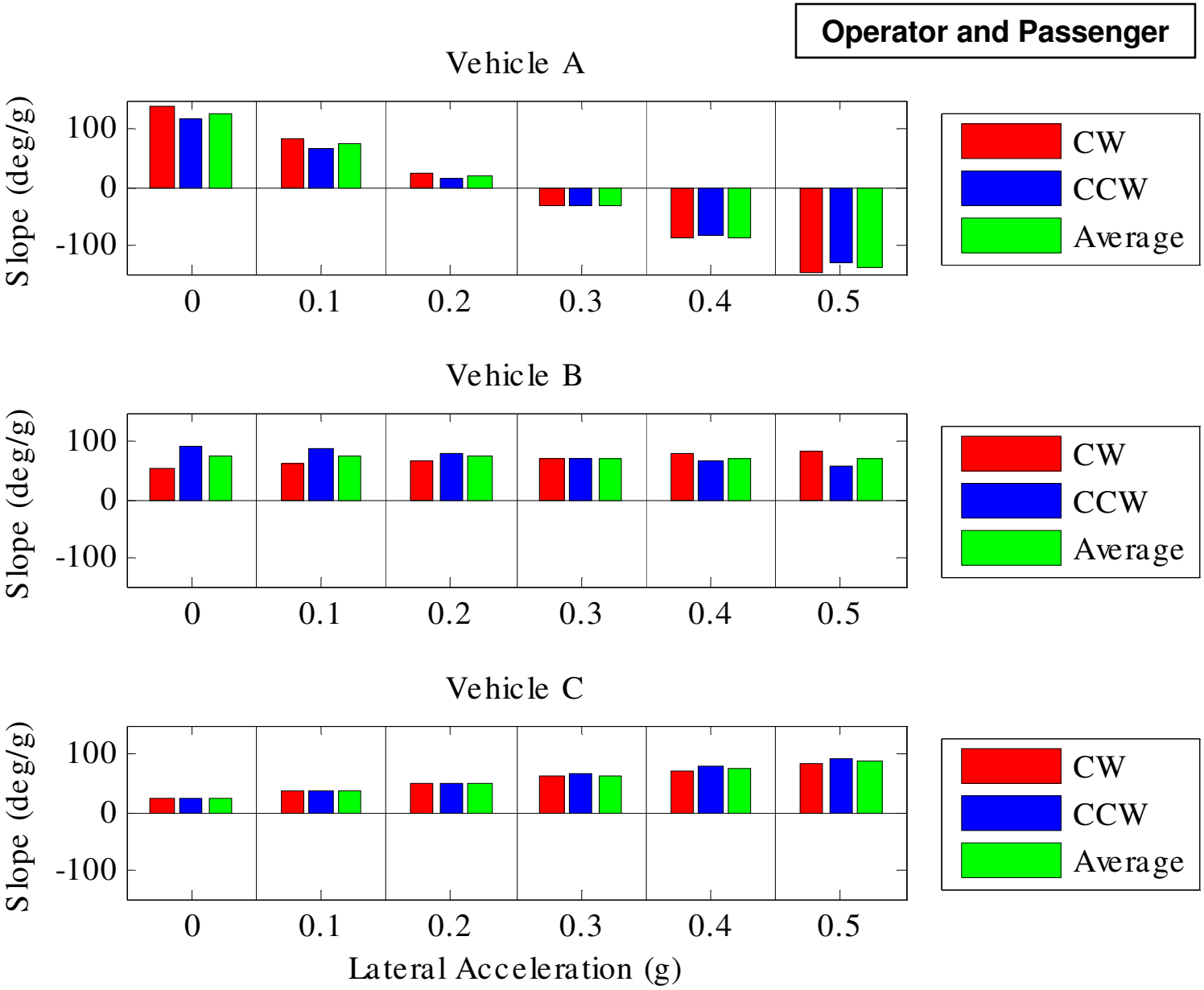

Operator and Passenger - Tilt Table Angle - TTA
Drivers Side Leading
Passengers Side Leading
Average
TTA (deg)
44
42
40
38
36
34
32
30
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

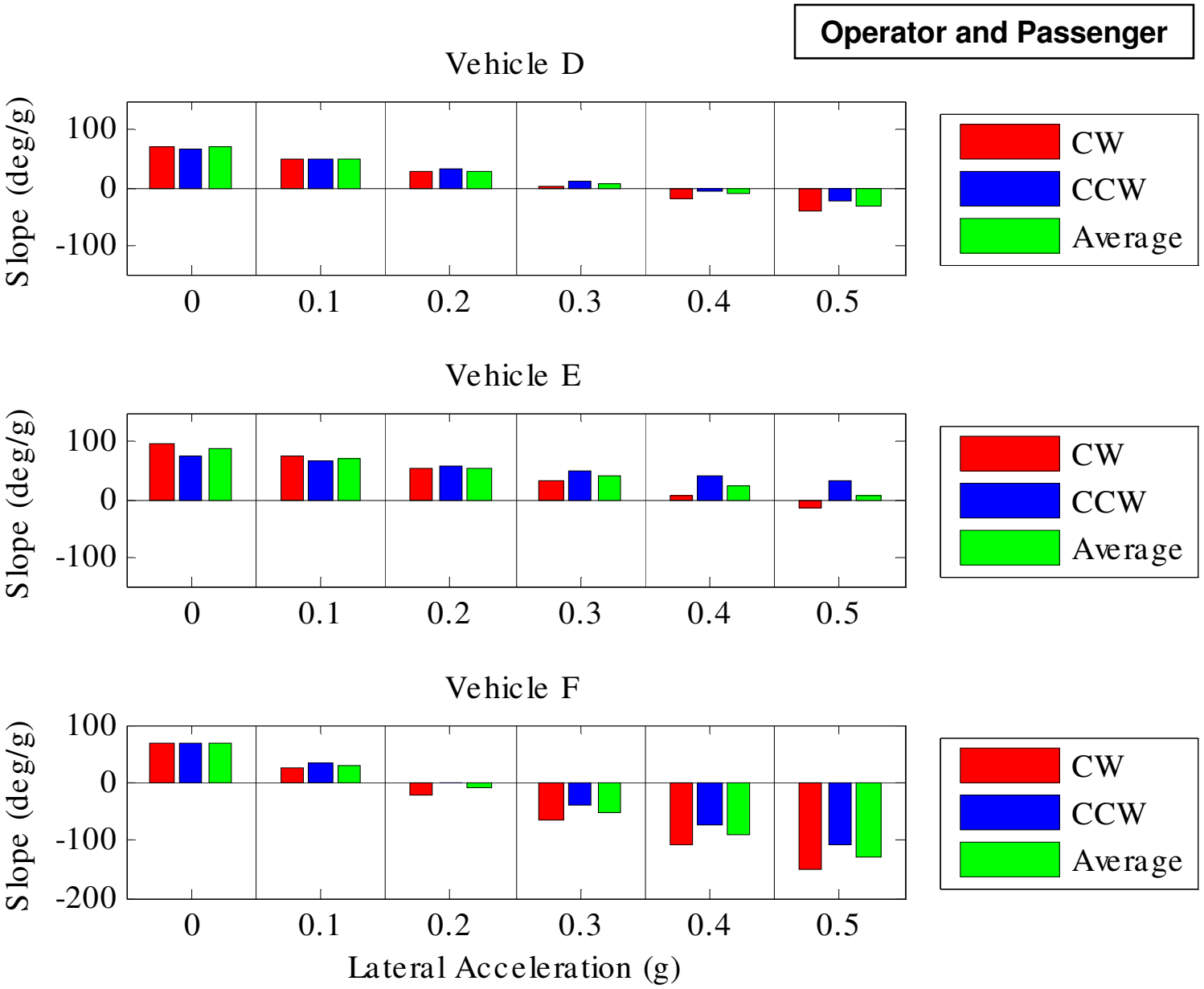

Operator, Instrumentation and Outriggers - Tilt Table Angle - TTA
Drivers Side Leading
Passengers Side Leading
Average
TTA (deg)
44
42
40
38
36
34
32
30
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

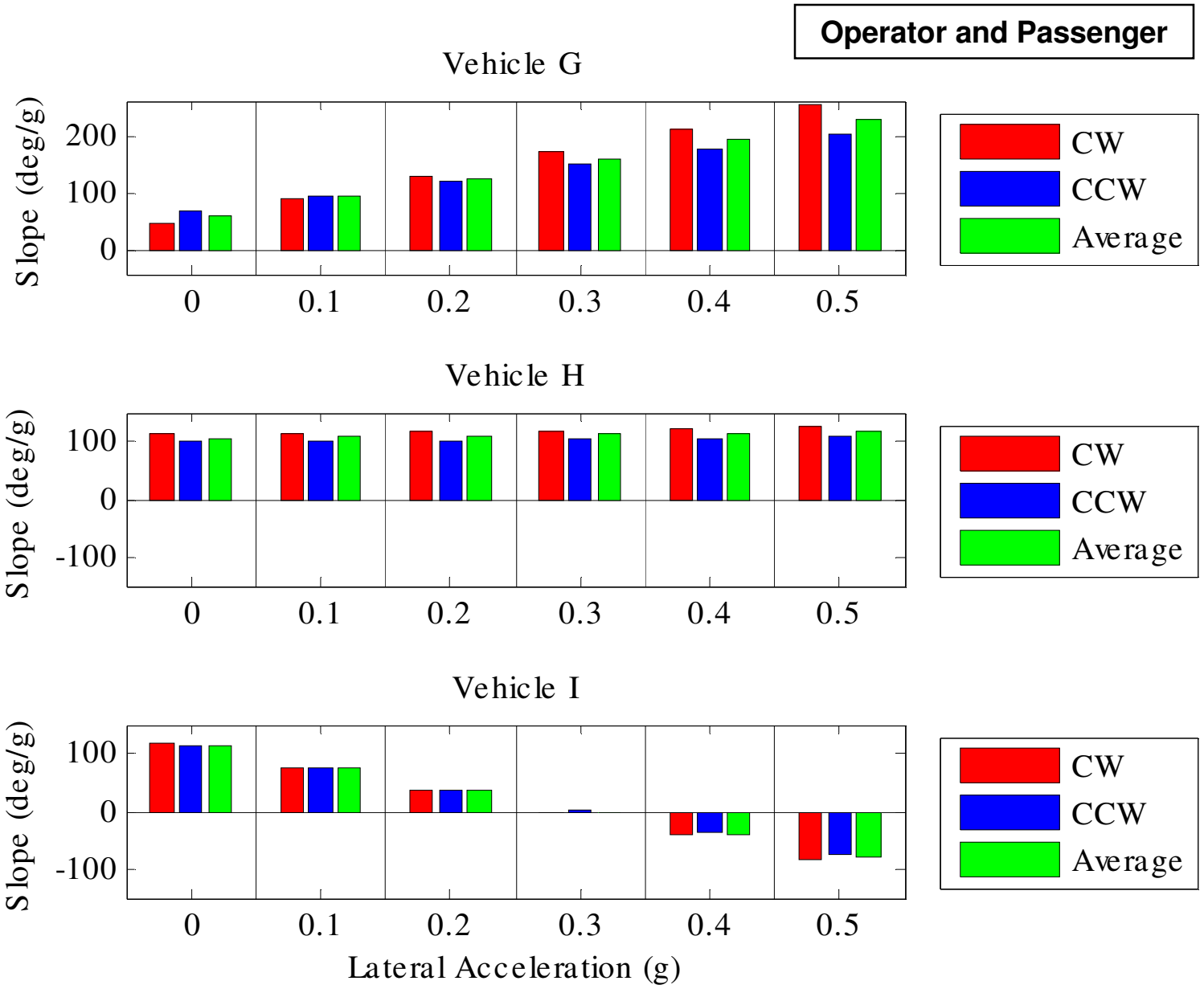

Summary of Circle Test Results - Operator and Passenger Loading
Steering Wheel Angle (deg)
100
50
0
-50
-100
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
Lateral Acceleration (g)
Vehicle A
Vehicle B
Vehicle C
Vehicle D
Vehicle E
Vehicle F
Vehicle G
Vehicle H
Vehicle I
Vehicle J

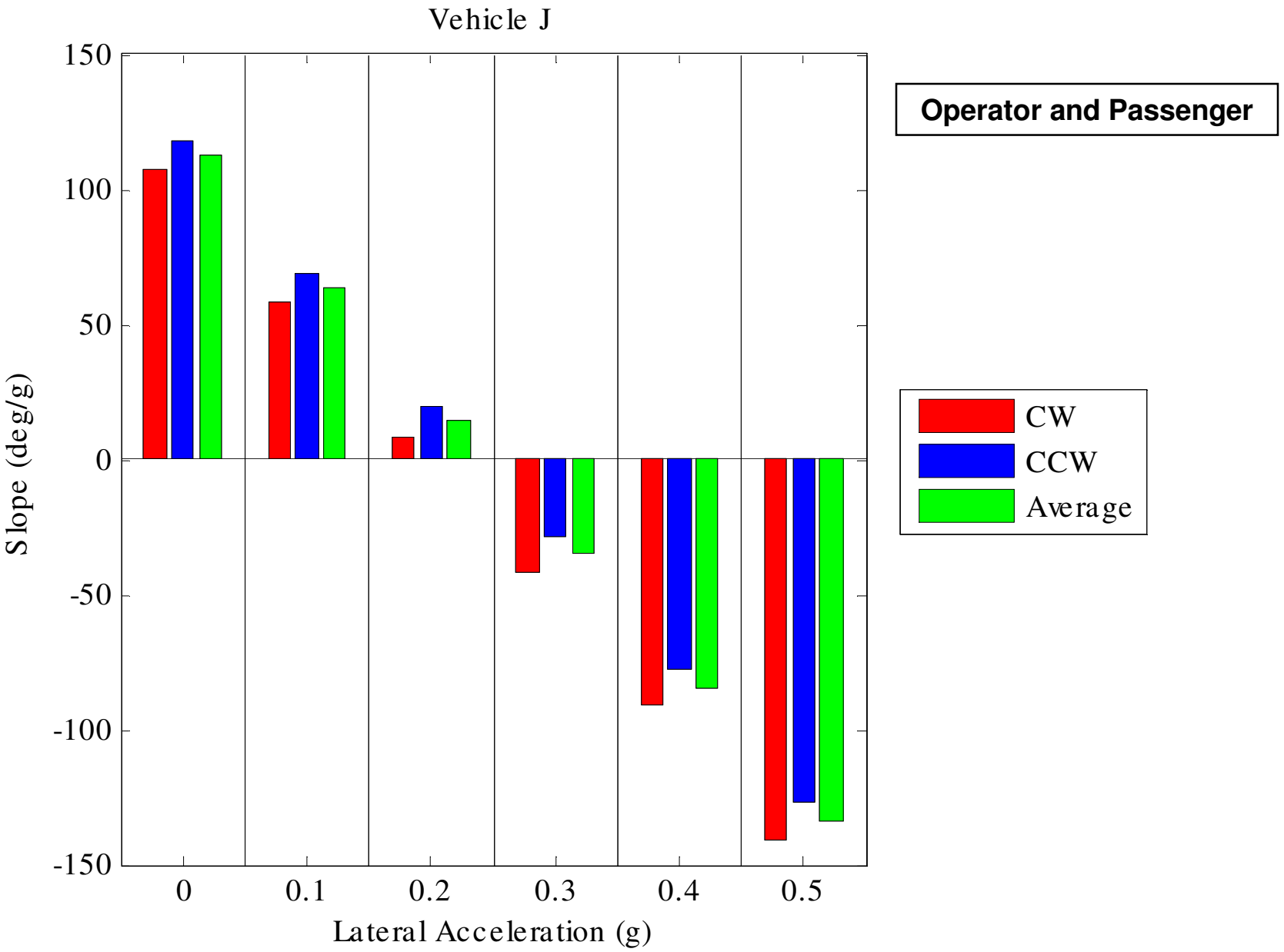

Summary of Circle Test Results - Operator and Passenger Loading
(Steering Wheel Angle - Ackermann Angle) (deg)
80
60
40
20
0
-20
-40
-60
-80
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
Lateral Acceleration (g)
Vehicle A
Vehicle B
Vehicle C
Vehicle D
Vehicle E
Vehicle F
Vehicle G
Vehicle H
Vehicle I
Vehicle J


Slope: Degrees of Handwheel Angle per g of Lateral Acceleration
Operator and Passenger
Slope (deg/g)
200
150
100
50
0
-50
-100
-150
0
0.1
0.2
0.3
0.4
0.5
Lateral Acceleration (g)
Vehicle F
Vehicle J
Vehicle A
Vehicle I
Vehicle D
Vehicle E
Vehicle B
Vehicle C
Vehicle H
Vehicle G


Operator and Passenger
Vehicle A
Slope (deg/g)
100
0
-100
0
0.1
0.2
0.3
0.4
0.5
CW
CCW
Average
Vehicle B
Slope (deg/g)
100
0
-100
0
0.1
0.2
0.3
0.4
0.5
CW
CCW
Average
Vehicle C
Slope (deg/g)
100
0
-100
0
0.1
0.2
0.3
0.4
0.5
CW
CCW
Average
Lateral Acceleration (g)


Operator and Passenger
Vehicle D
Slope (deg/g)
100
0
-100
0
0.1
0.2
0.3
0.4
0.5
CW
CCW
Average
Vehicle E
Slope (deg/g)
100
0
-100
0
0.1
0.2
0.3
0.4
0.5
CW
CCW
Average
Vehicle F
Slope (deg/g)
100
0
-100
-200
0
0.1
0.2
0.3
0.4
0.5
Lateral Acceleration (g)
CW
CCW
Average

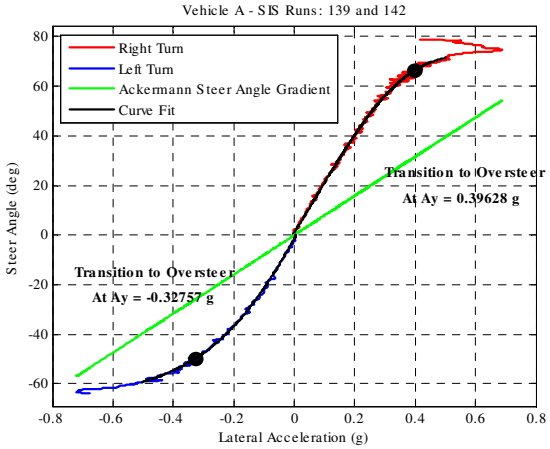

Operator and Passenger
Vehicle G
Slope (deg/g)
200
100
0
0
0.1
0.2
0.3
0.4
0.5
CW
CCW
Average
Vehicle H
Slope (deg/g)
100
0
-100
0
0.1
0.2
0.3
0.4
0.5
CW
CCW
Average
Vehicle I
Slope (deg/g)
100
0
-100
0
0.1
0.2
0.3
0.4
0.5
Lateral Acceleration (g)
CW
CCW
Average

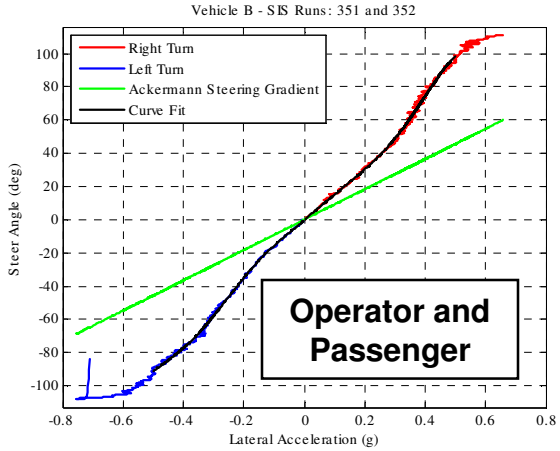

Vehicle J
Operator and Passenger
CW
CCW
Average
Slope (deg/g)
150
100
50
0
-50
-100
-150
0
0.1
0.2
0.3
0.4
0.5
Lateral Acceleration (g)

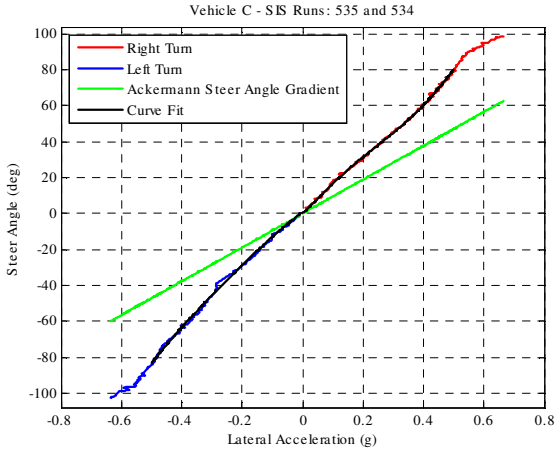
Constant Radius (100 ft) Circle Tests

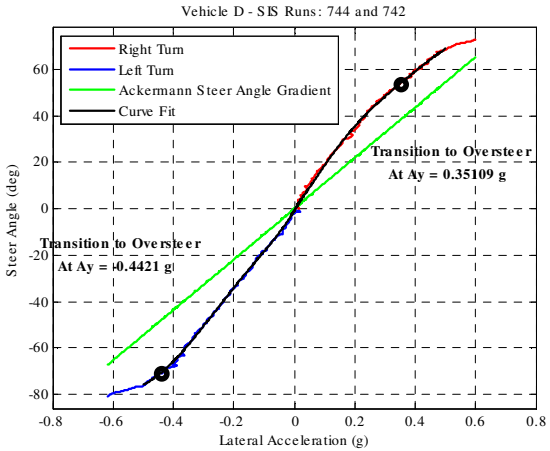
Lateral Acceleration Level at Point of Transition from Understeer to Oversteer (Operator and Passenger Loading)

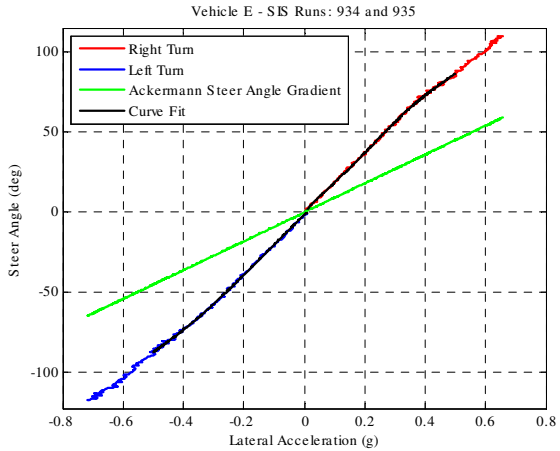
	Clockwise (g)	Counterclockwise (g)	Average (g)
Vehicle A	**0.24**	**0.23**	**0.24**
Vehicle B	**NA**	**NA**	**NA**
Vehicle C	**NA**	**NA**	**NA**
Vehicle D	**0.32**	**0.37**	**0.35**
Vehicle E	**0.44**	**NA**	**NA**
Vehicle F	**0.15**	**0.19**	**0.17**
Vehicle G	**NA**	**NA**	**NA**
Vehicle H	**NA**	**NA**	**NA**
Vehicle I	**0.29**	**0.30**	**0.30**
Vehicle J	**0.22**	**0.24**	**0.23**

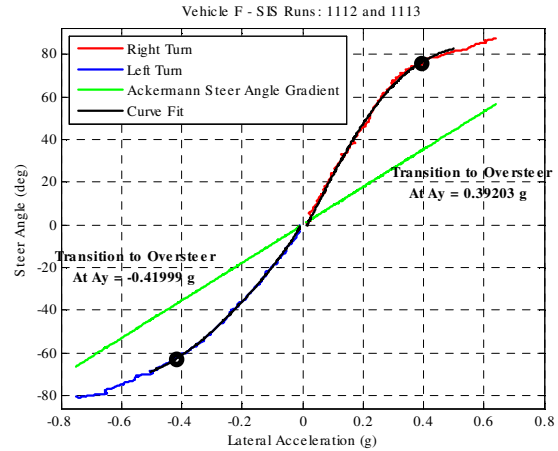

Vehicle A - SIS Runs: 139 and 142
Right Turn
Left Turn
Ackermann Steer Angle Gradient
Curve Fit
Transition to Oversteer
At Ay = 0.39628 g
Transition to Oversteer
At Ay = -0.32757 g
Steer Angle (deg)
Lateral Acceleration (g)

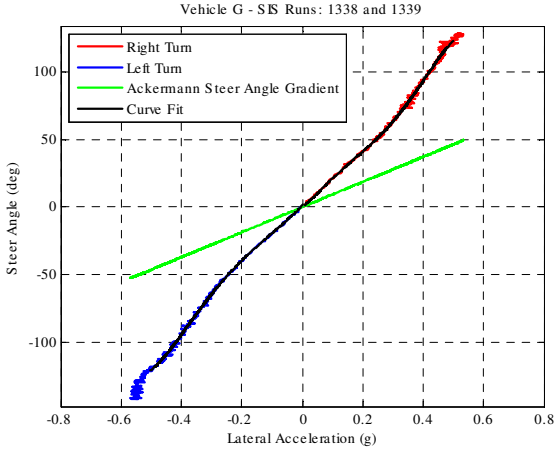

Vehicle B - SIS Runs: 351 and 352
Right Turn
Left Turn
Ackermann Steering Gradient
Curve Fit
Operator and Passenger
Steer Angle (deg)
Lateral Acceleration (g)

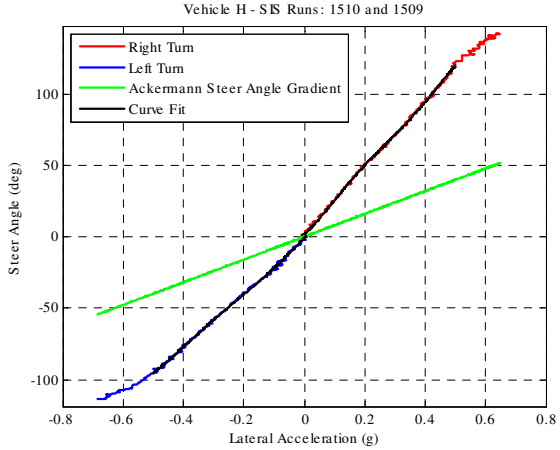

Vehicle C - SIS Runs: 535 and 534
Right Turn
Left Turn
Ackermann Steer Angle Gradient
Curve Fit
Steer Angle (deg)
Lateral Acceleration (g)

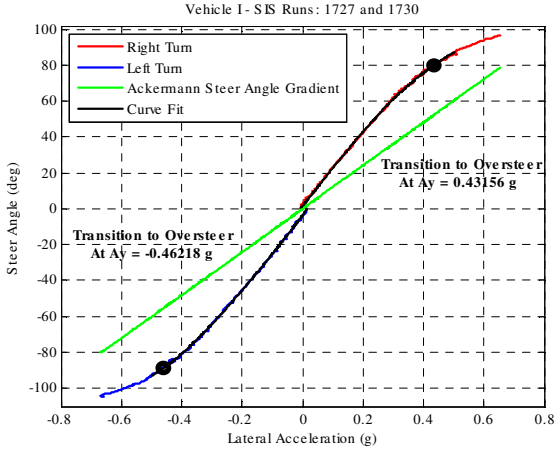

Vehicle D - SIS Runs: 744 and 742
Right Turn
Left Turn
Ackermann Steer Angle Gradient
Curve Fit
Transition to Oversteer
At Ay = 0.35109 g
Transition to Oversteer
At Ay = -0.4421 g
Steer Angle (deg)
Lateral Acceleration (g)

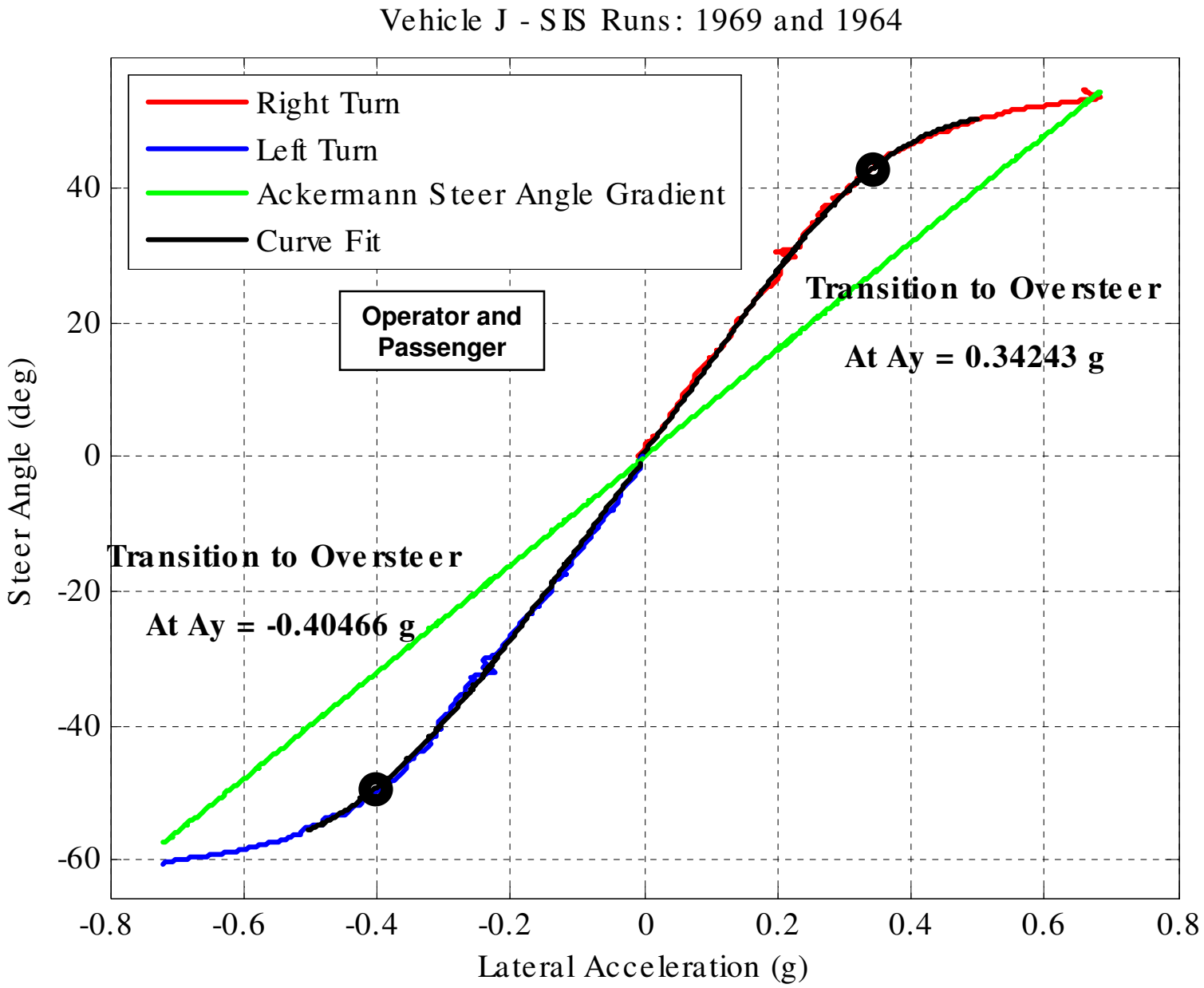

Vehicle E - SIS Runs: 934 and 935
Right Turn
Left Turn
Ackermann Steer Angle Gradient
Curve Fit
Steer Angle (deg)
Lateral Acceleration (g)


Vehicle F - SIS Runs: 1112 and 1113
Right Turn
Left Turn
Ackermann Steer Angle Gradient
Curve Fit
Transition to Oversteer
At Ay = 0.39203 g
Transition to Oversteer
At Ay = -0.41999 g
Steer Angle (deg)
Lateral Acceleration (g)


Vehicle G - SIS Runs: 1338 and 1339
Right Turn
Left Turn
Ackermann Steer Angle Gradient
Curve Fit
Steer Angle (deg)
Lateral Acceleration (g)


Vehicle H - SIS Runs: 1510 and 1509
Right Turn
Left Turn
Ackermann Steer Angle Gradient
Curve Fit
Steer Angle (deg)
Lateral Acceleration (g)

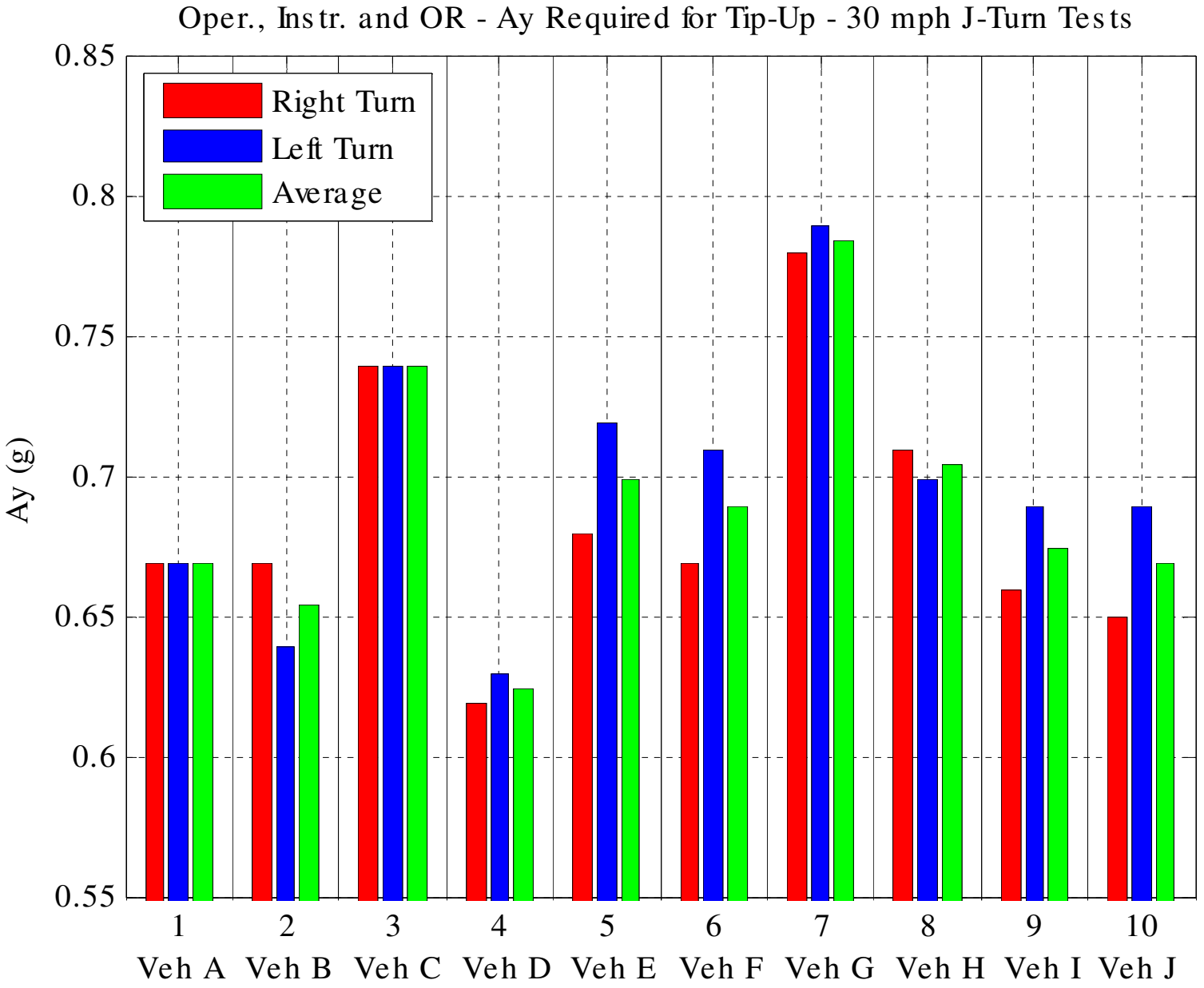

Vehicle I - SIS Runs: 1727 and 1730
Right Turn
Left Turn
Ackermann Steer Angle Gradient
Curve Fit
Transition to Oversteer
At Ay = 0.43156 g
Transition to Oversteer
At Ay = -0.46218 g
Steer Angle (deg)
Lateral Acceleration (g)

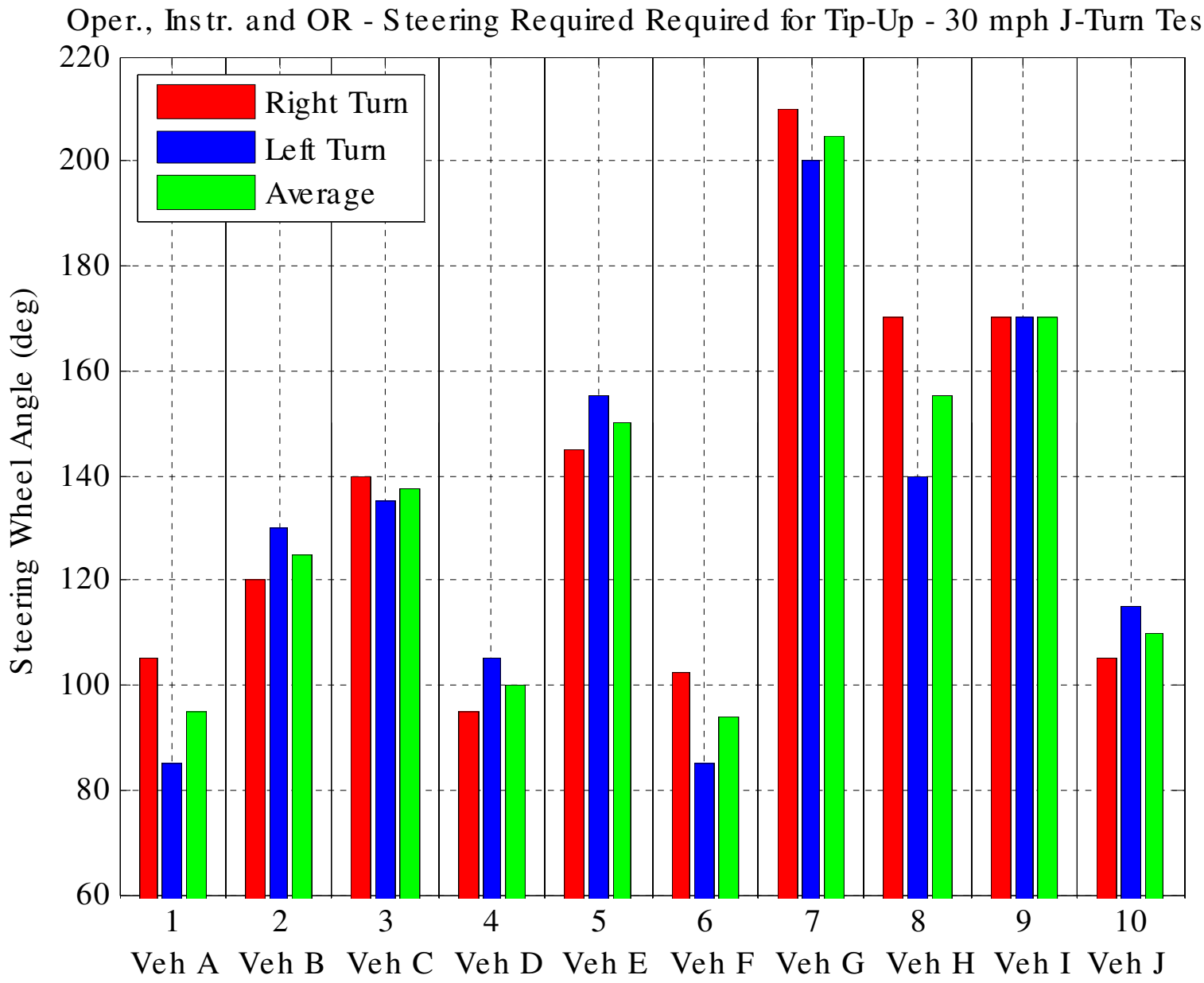

Vehicle J - SIS Runs: 1969 and 1964
Right Turn
Left Turn
Ackermann Steer Angle Gradient
Curve Fit
Operator and Passenger
Transition to Oversteer
At Ay = 0.34243 g
Transition to Oversteer
At Ay = -0.40466 g
Steer Angle (deg)
40
20
0
-20
-40
-60
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
Lateral Acceleration (g)

Constant Speed (30 mph) Slowly Increasing Steer Tests

Lateral Acceleration Level at Point of Transition from Understeer to Oversteer (Operator and Passenger Loading)

	Right Turn (g)	Left Turn (g)	Average (g)
Vehicle A	0.40	0.33	0.37
Vehicle B	NA	NA	NA
Vehicle C	NA	NA	NA
Vehicle D	0.35	0.44	0.40
Vehicle E	NA	NA	NA
Vehicle F	0.39	0.42	0.41
Vehicle G	NA	NA	NA
Vehicle H	NA	NA	NA
Vehicle I	0.43	0.46	0.45
Vehicle J	0.34	0.40	0.36

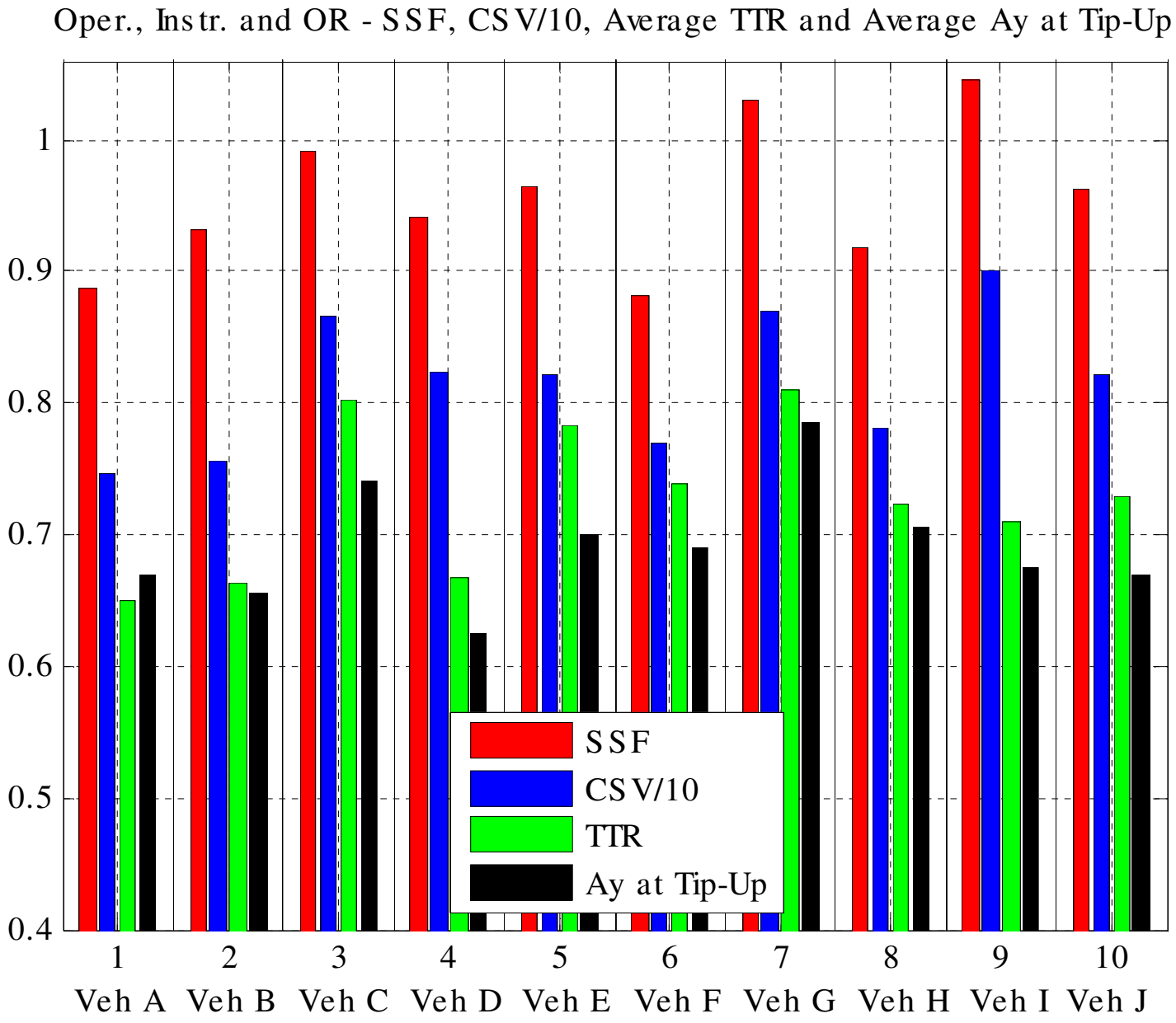

Oper., Instr. and OR - Ay Required for Tip-Up - 30 mph J-Turn Tests
Right Turn
Left Turn
Average
Ay (g)
0.85
0.8
0.75
0.7
0.65
0.6
0.55
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

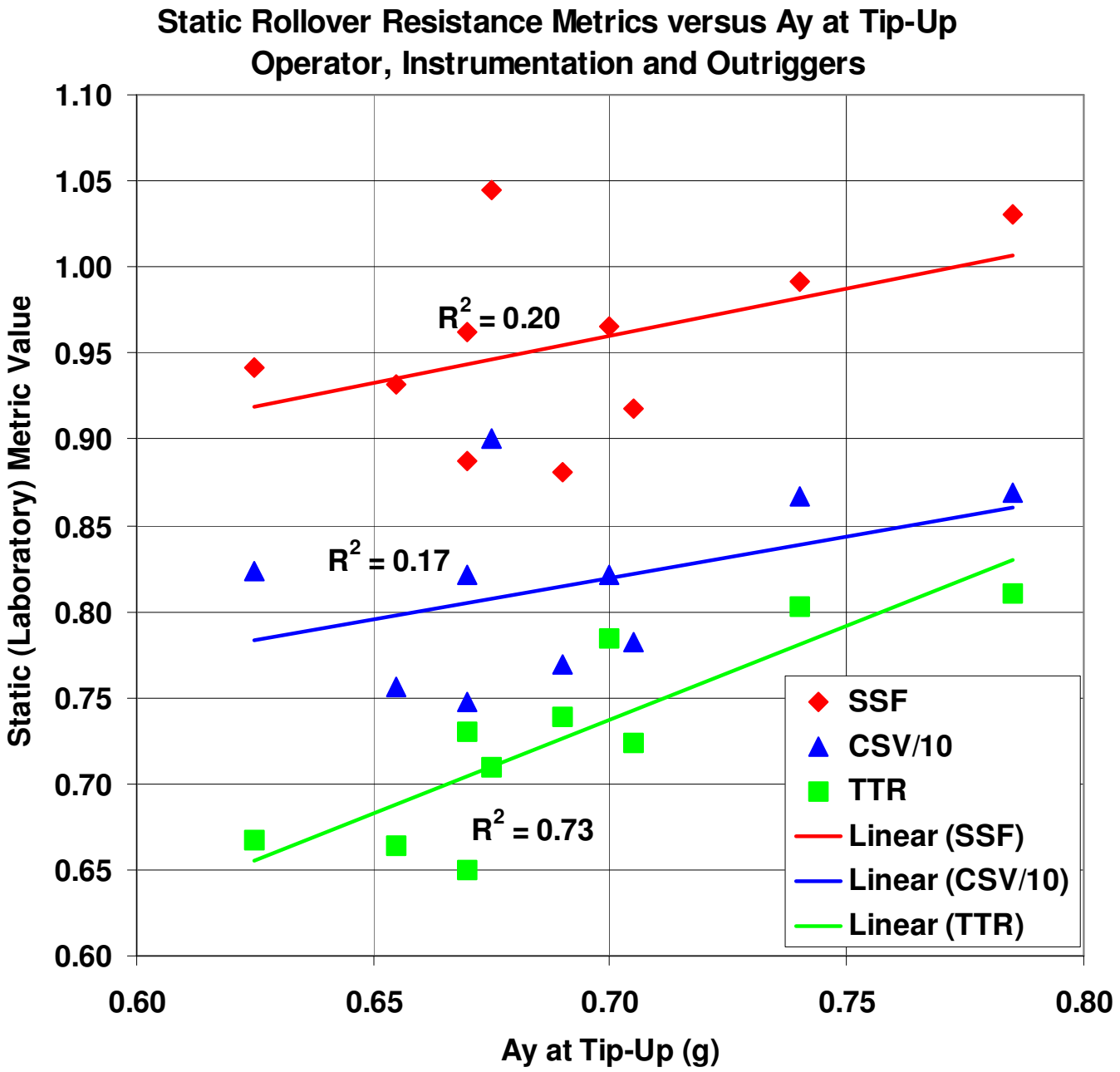

Oper., Instr. and OR - Steering Required Required for Tip-Up - 30 mph J-Turn Tests
Right Turn
Left Turn
Average
Steering Wheel Angle (deg)
220
200
180
160
140
120
100
80
60
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

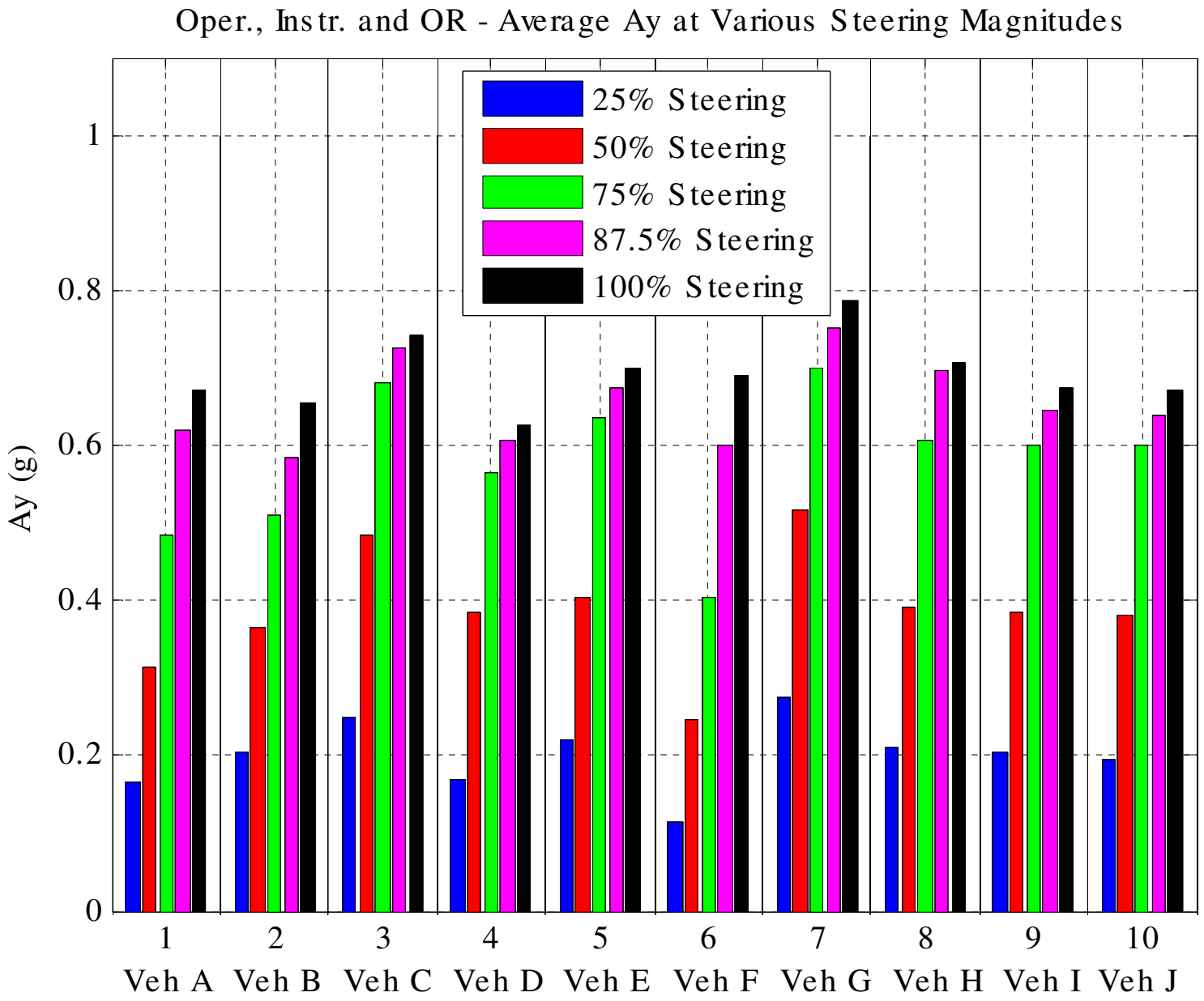
Summary of Ay and Steering Required for Tip-Up in 30 mph J-Turns and Static Rollover Resistance Metrics (Operator, Instrumentation and Outriggers)					
Vehicle	Ay at Tip-Up (g)	Steering at Tip-Up (deg)	SSF (--)	CSV/10 (mph/10)	TTR (--)
A	0.670	95.0	0.887	0.747	0.650
B	0.655	125.0	0.932	0.756	0.664
C	0.740	137.5	0.991	0.867	0.803
D	0.625	100.0	0.942	0.823	0.667
E	0.700	150.0	0.965	0.821	0.784
F	0.690	93.8	0.881	0.769	0.739
G	0.785	205.0	1.031	0.869	0.810
H	0.705	155.0	0.918	0.782	0.724
I	0.675	170.0	1.045	0.900	0.712
J	0.670	110.0	0.962	0.821	0.730

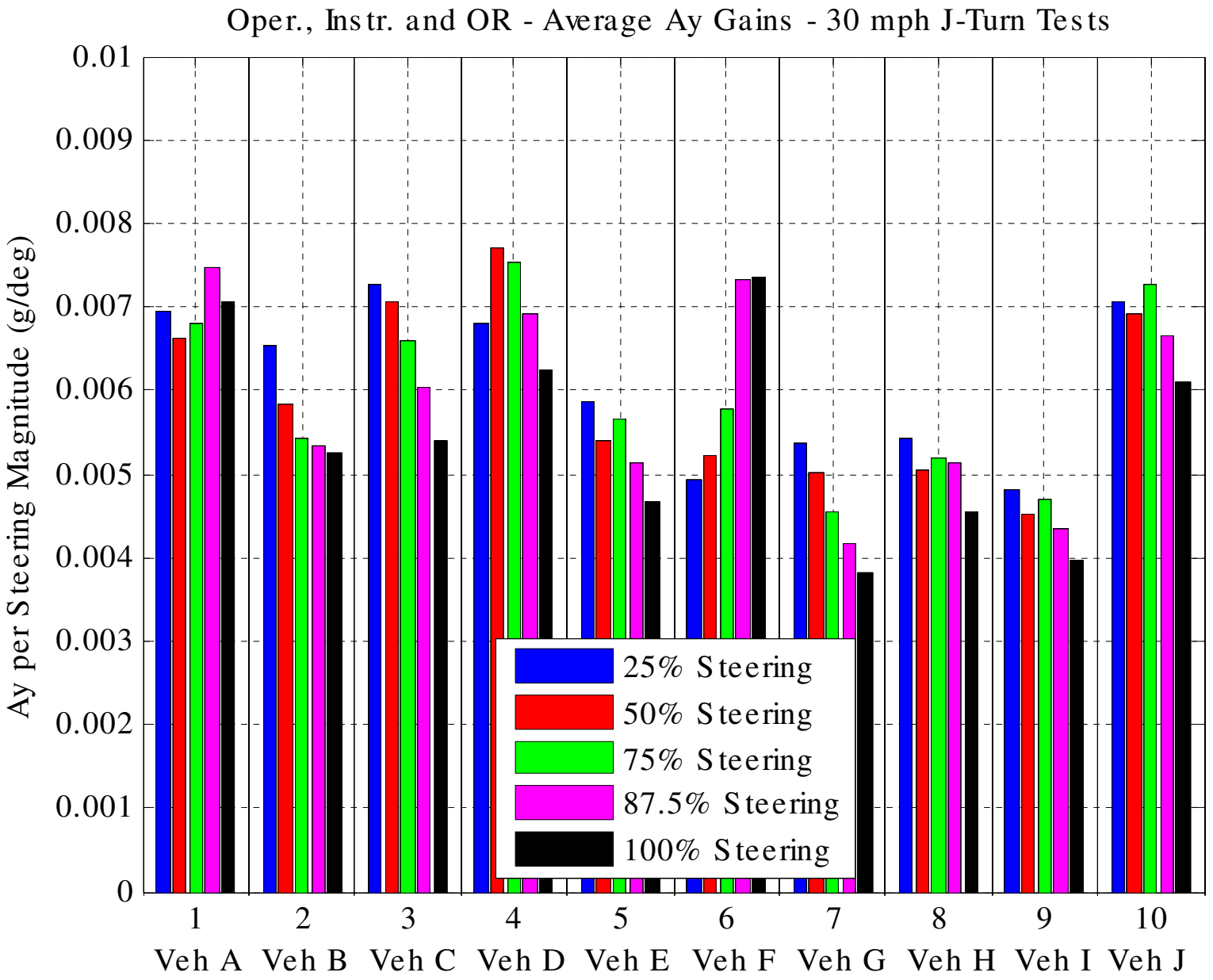
Vehicle Ascending Rank Order of Ay and Steering Required for Tip-Up in J-Turns and Static Rollover Resistance Metrics (Operator, Instrumentation and Outriggers)				
Ay at Tip-Up (g)	Steering at Tip-Up (deg)	SSF (--)	CSV/10 (mph/10)	TTR (--)
D	F	F	A	A
B	A	A	B	B
A	D	H	F	D
J	J	B	H	I
I	B	D	E	H
F	C	J	J	J
E	E	E	D	F
H	H	C	C	E
C	I	G	G	C
G	G	I	I	G

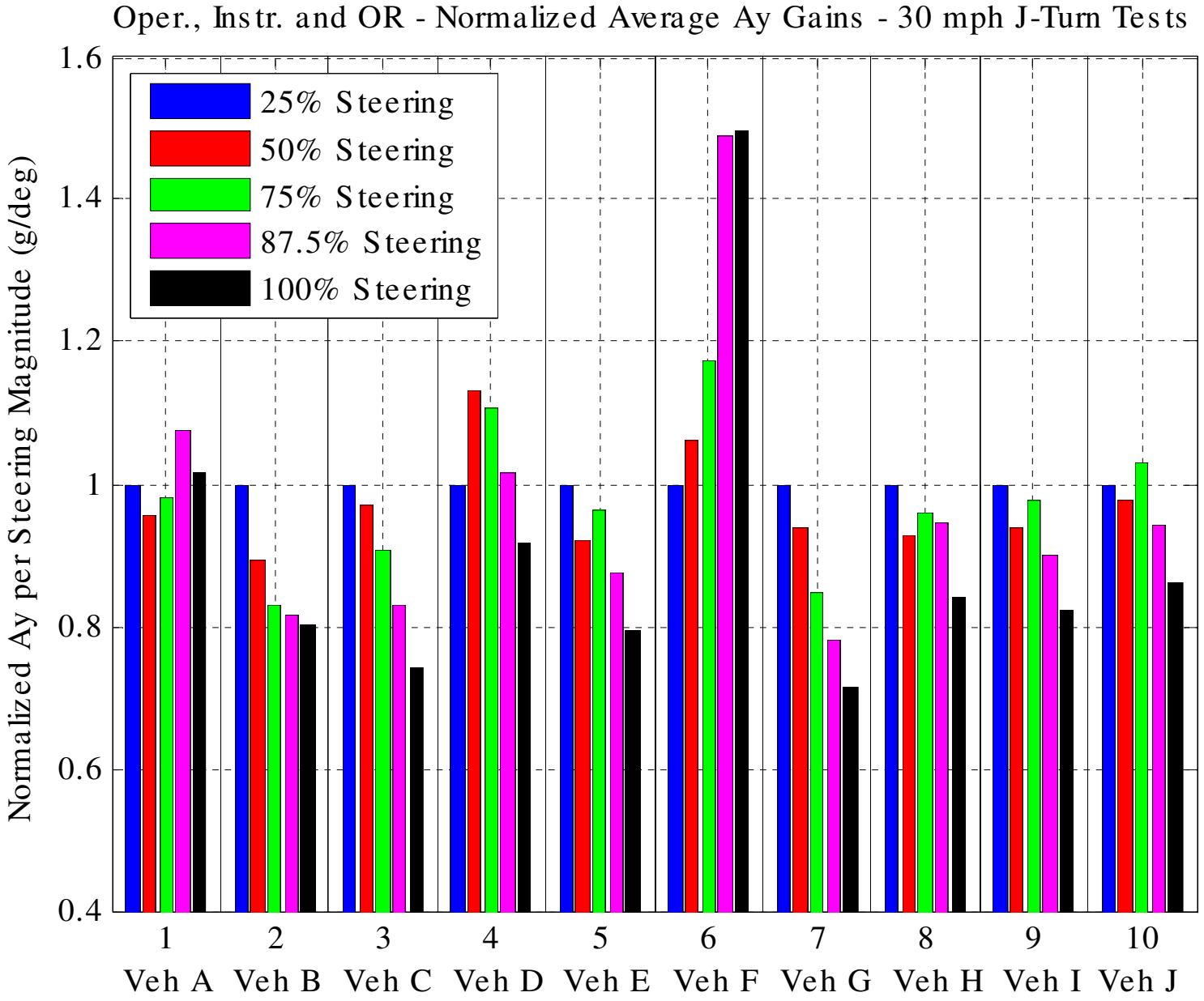
Vehicles A, D, F, I and J exhibited transient from Understeer to Oversteer in Circle and SIS Tests
Vehicle I is the 4-Passenger Vehicle

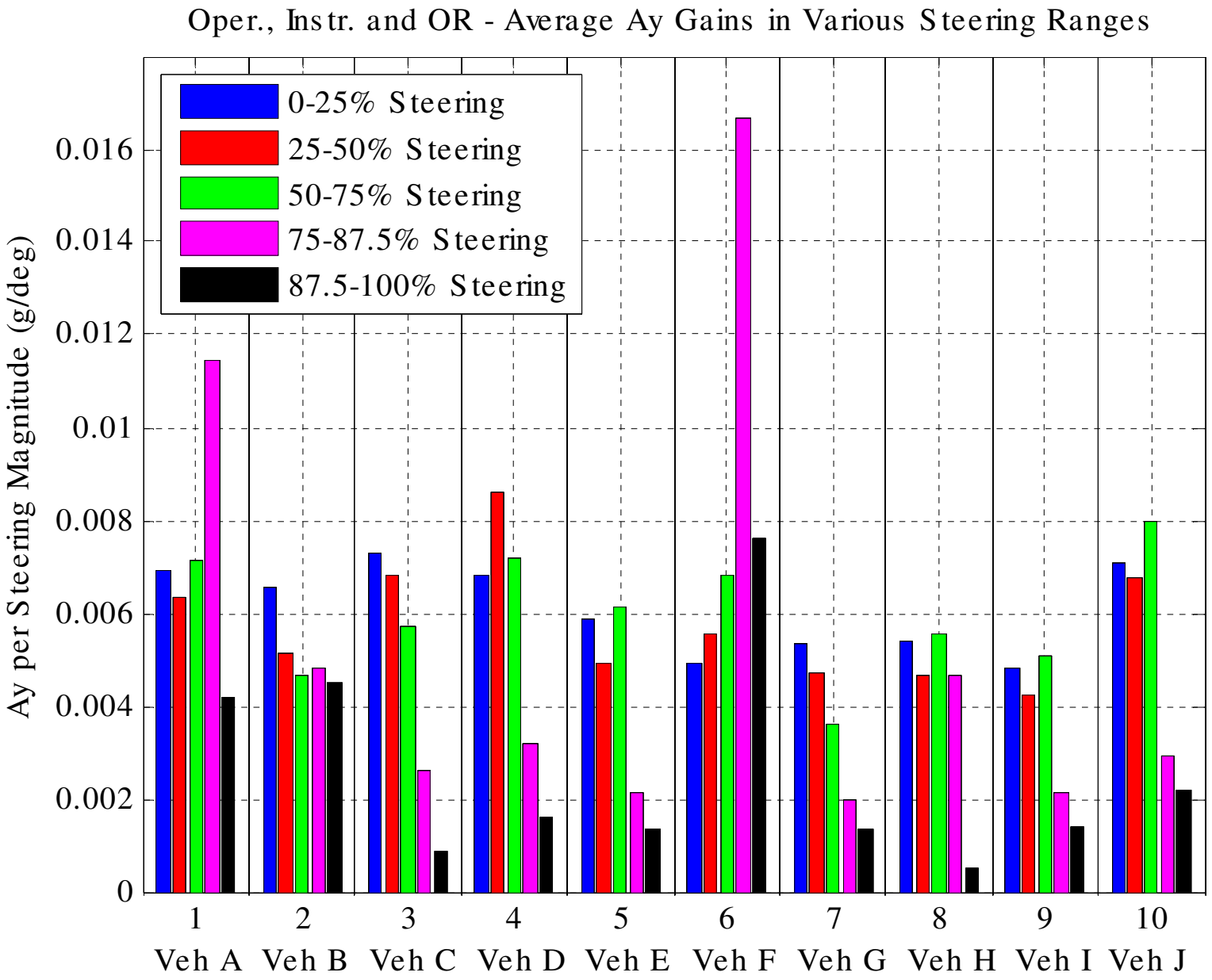

Oper., Instr. and OR - SSF, CSV/10, Average TTR and Average Ay at Tip-Up
1
0.9
0.8
0.7
0.6
0.5
0.4
SSF
CSV/10
TTR
Ay at Tip-Up
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

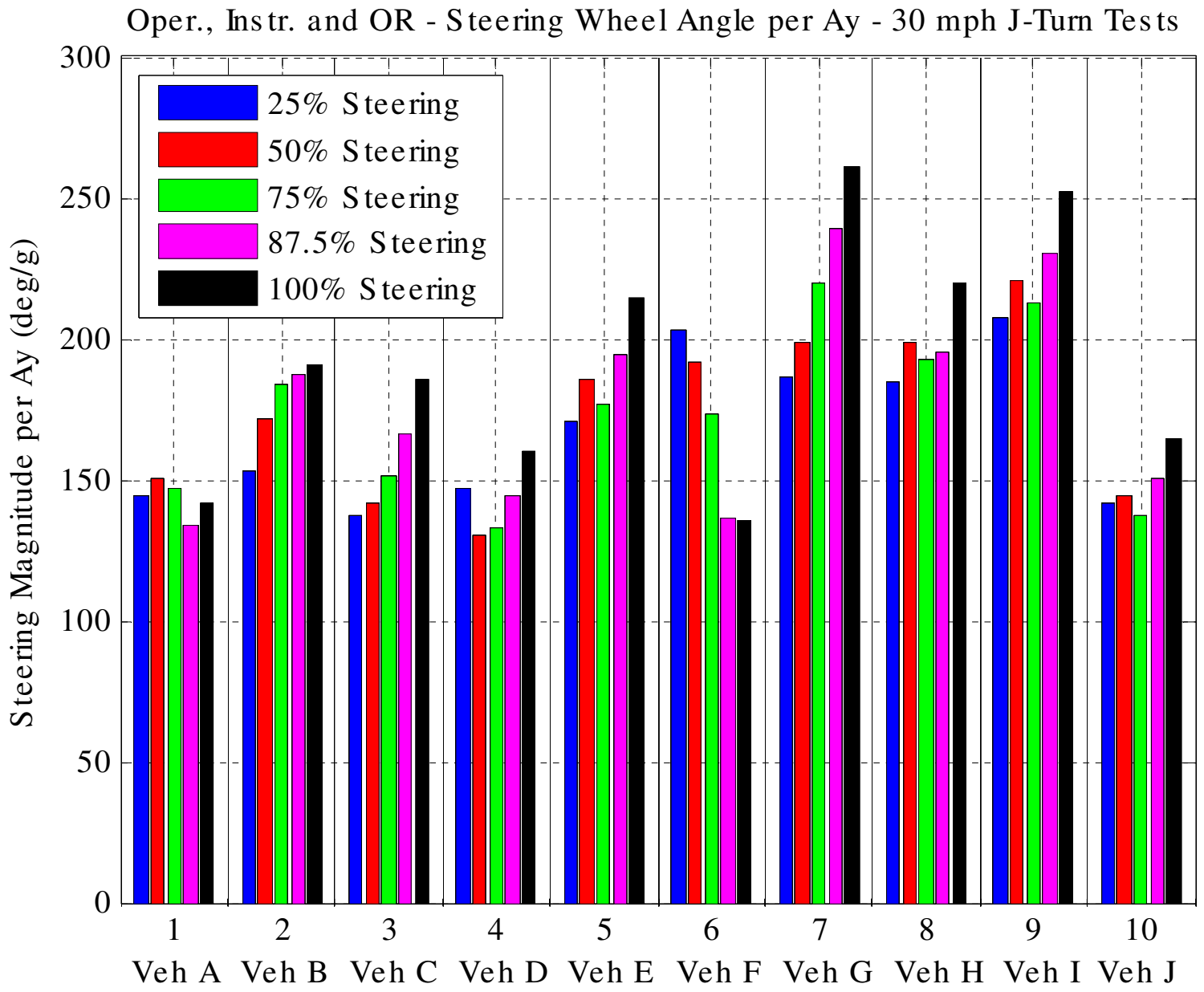

Static Rollover Resistance Metrics versus Ay at Tip-Up
Operator, Instrumentation and Outriggers
Static (Laboratory) Metric Value
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.60
0.65
0.70
0.75
0.80
Ay at Tip-Up (g)
R2 = 0.20
R2 = 0.17
R2 = 0.73
SSF
CSV/10
TTR
Linear (SSF)
Linear (CSV/10)
Linear (TTR)

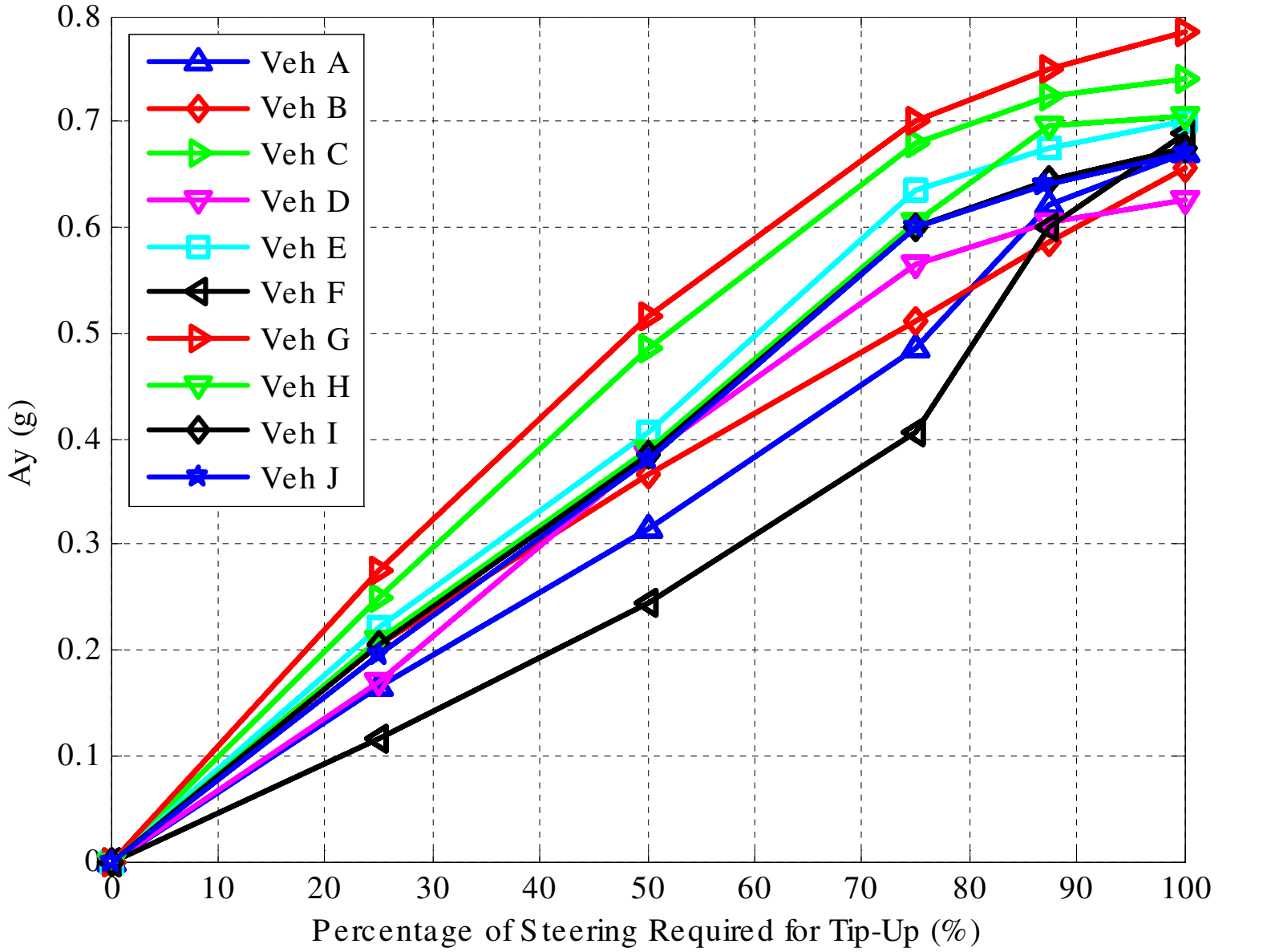

Oper., Instr. and OR - Average Ay at Various Steering Magnitudes
25% Steering
50% Steering
75% Steering
87.5% Steering
100% Steering
Ay (g)
0
0.2
0.4
0.6
0.8
1
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

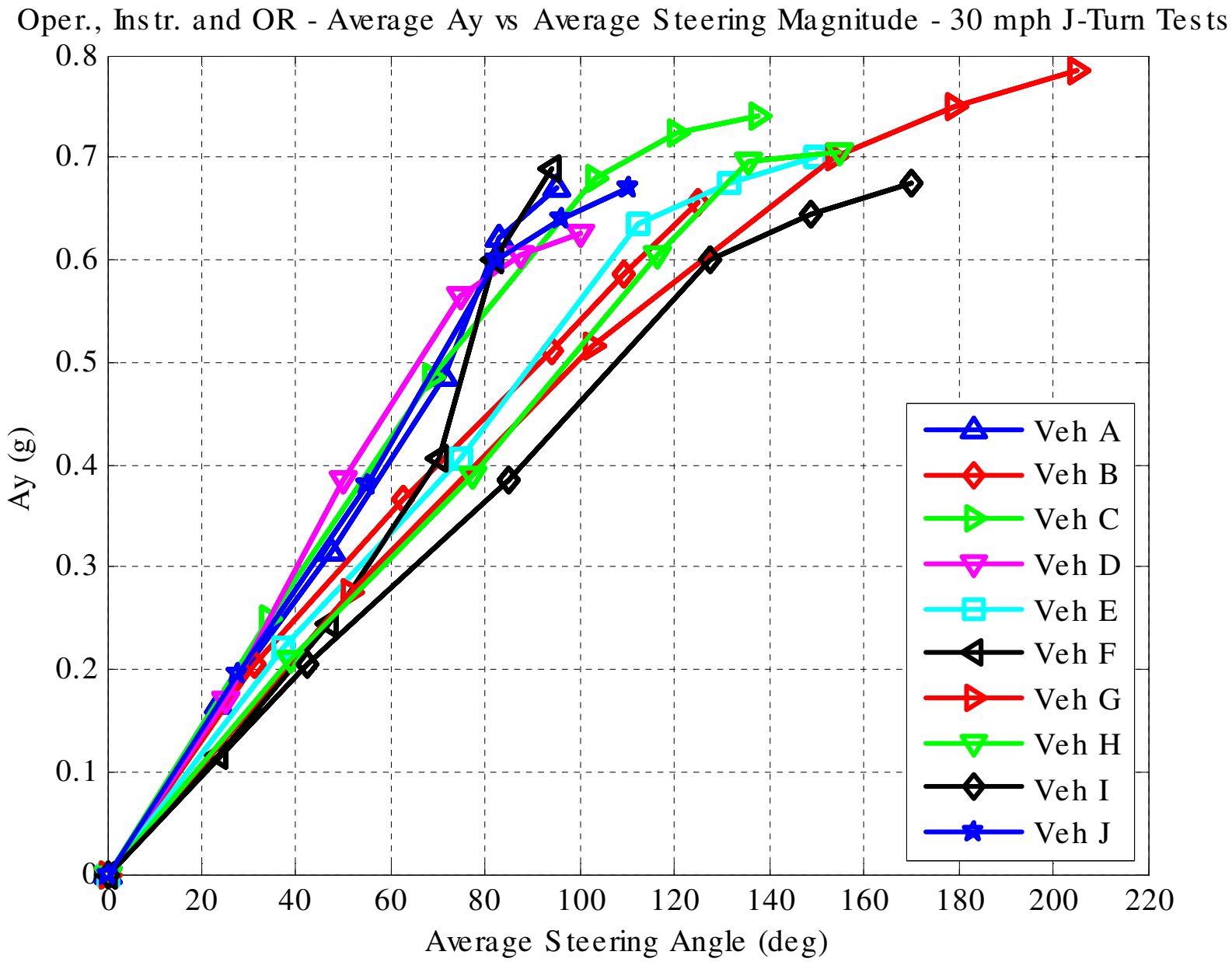

Oper., Instr. and OR - Average Ay Gains - 30 mph J-Turn Tests
Ay per Steering Magnitude (g/deg)
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
25% Steering
50% Steering
75% Steering
87.5% Steering
100% Steering
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

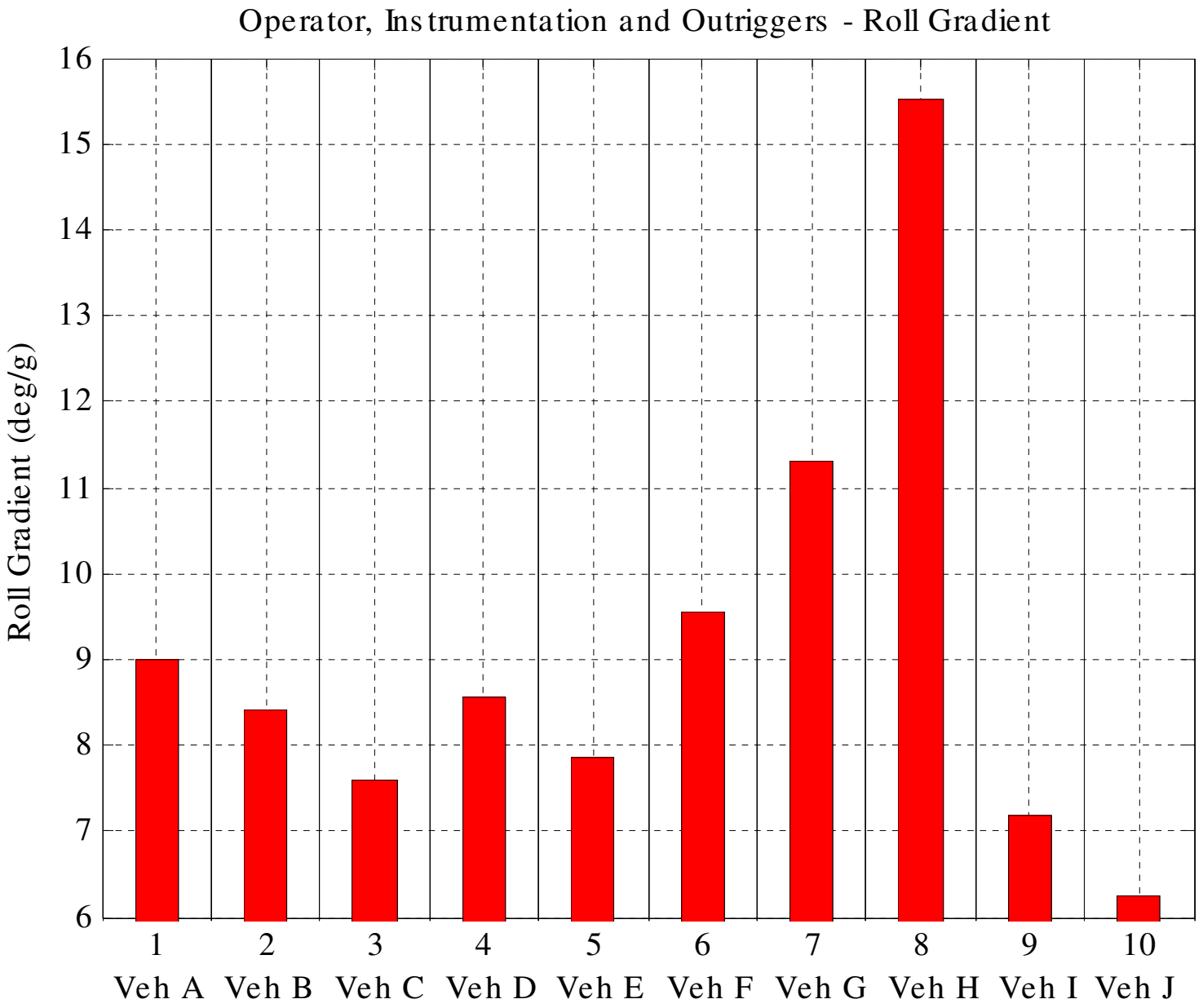

Oper., Instr. and OR - Normalized Average Ay Gains - 30 mph J-Turn Tests
Normalized Ay per Steering Magnitude (g/deg)
1.6
1.4
1.2
1
0.8
0.6
0.4
25% Steering
50% Steering
75% Steering
87.5% Steering
100% Steering
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

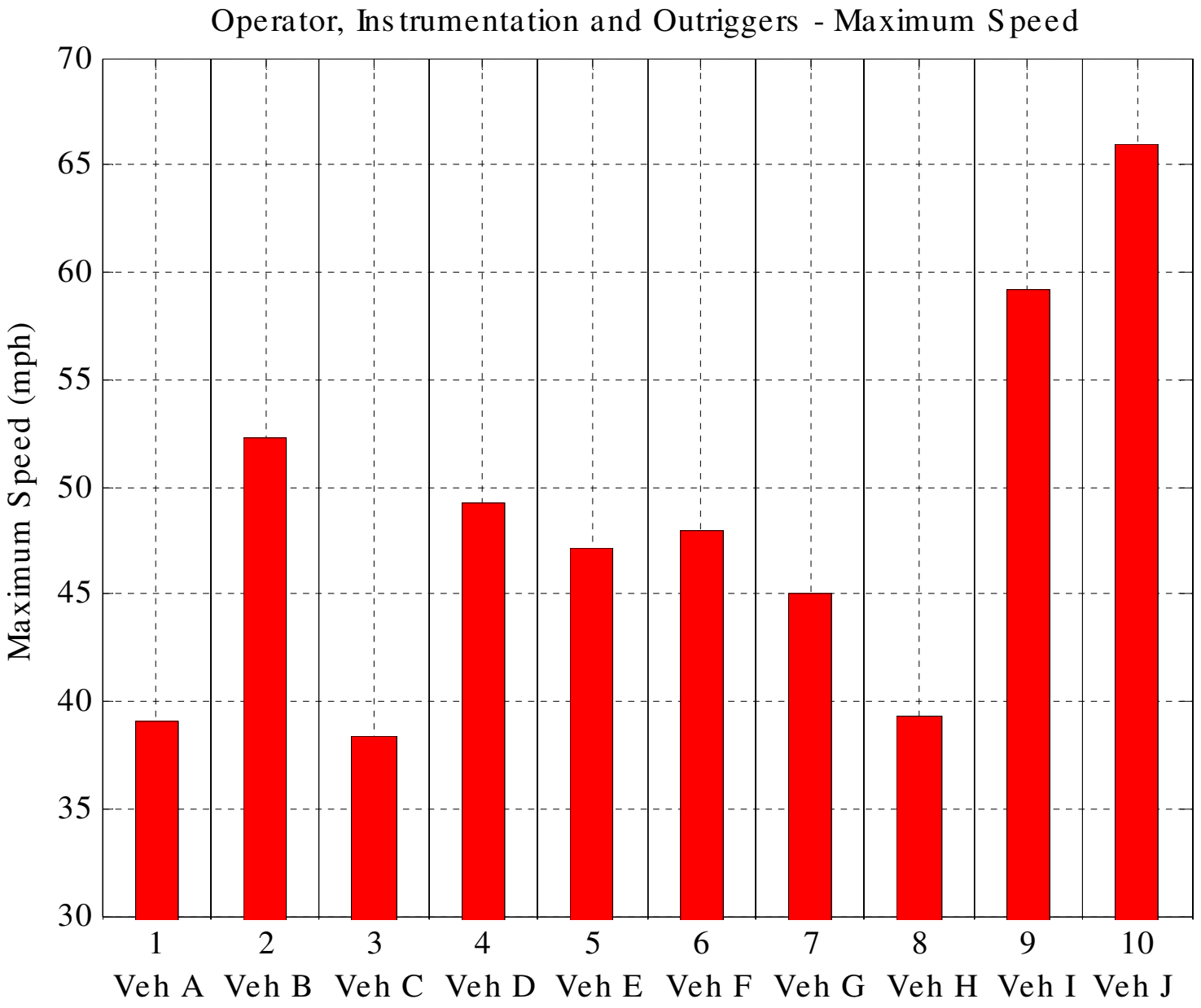

Oper., Instr. and OR - Average Ay Gains in Various Steering Ranges
0-25% Steering
25-50% Steering
50-75% Steering
75-87.5% Steering
87.5-100% Steering
Ay per Steering Magnitude (g/deg)
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
0.016
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

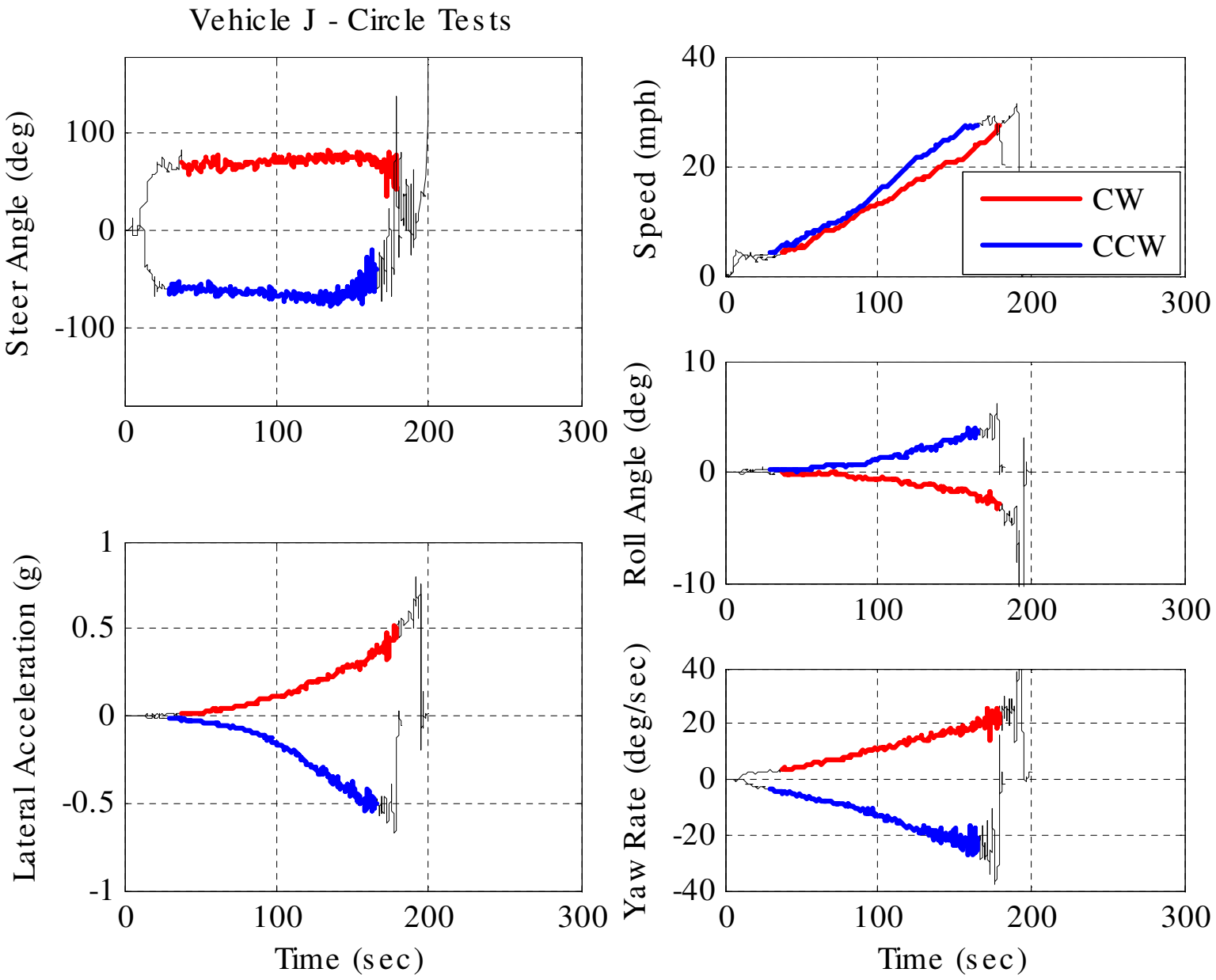

Oper., Instr. and OR - Steering Wheel Angle per Ay - 30 mph J-Turn Tests
25% Steering
50% Steering
75% Steering
87.5% Steering
100% Steering
Steering Magnitude per Ay (deg/g)
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

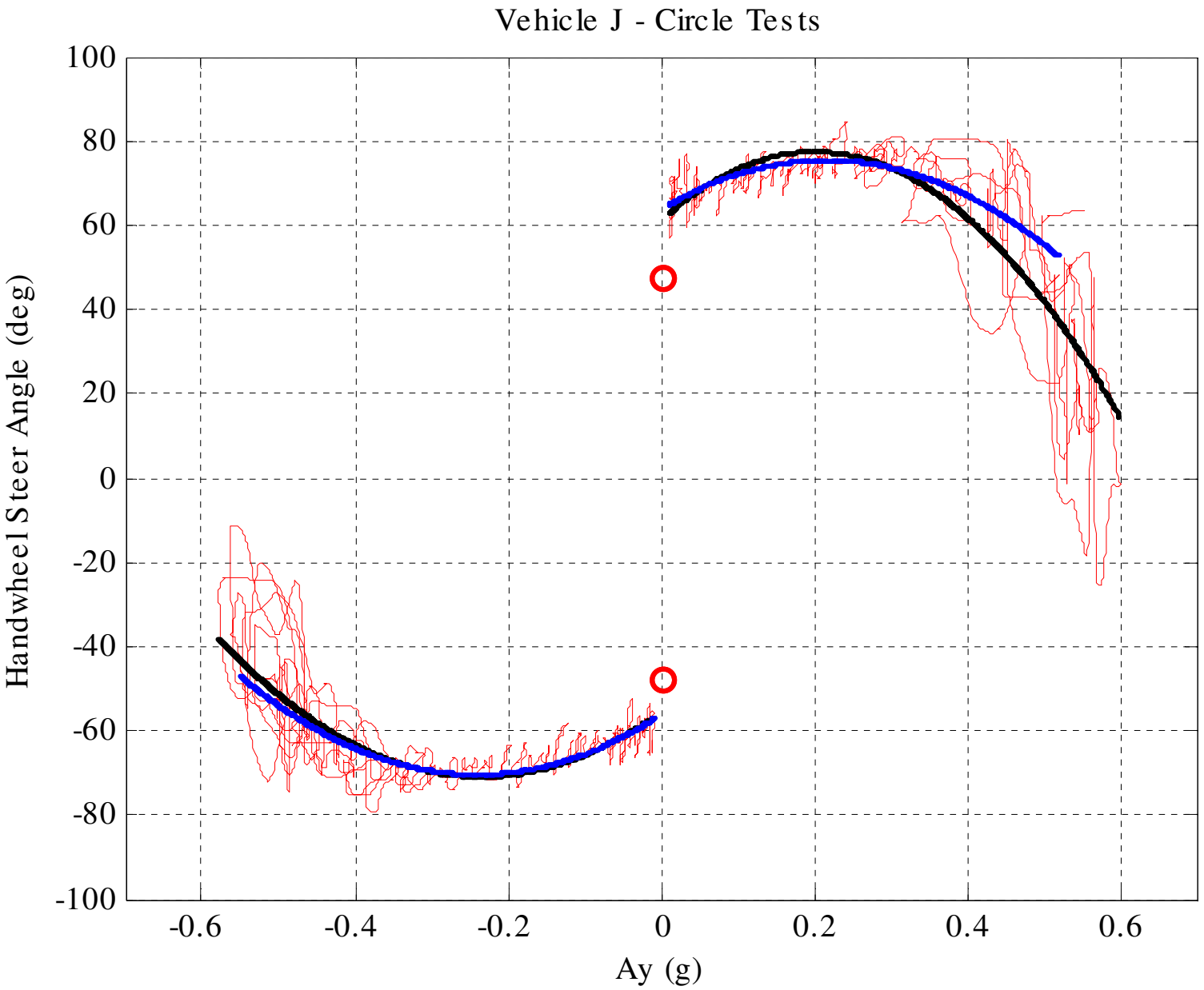

Oper., Instr. and OR - Average Ay at Various Steering Magnitudes - 30 mph J-Turn Tests
Ay (g)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
100
Percentage of Steering Required for Tip-Up (%)
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

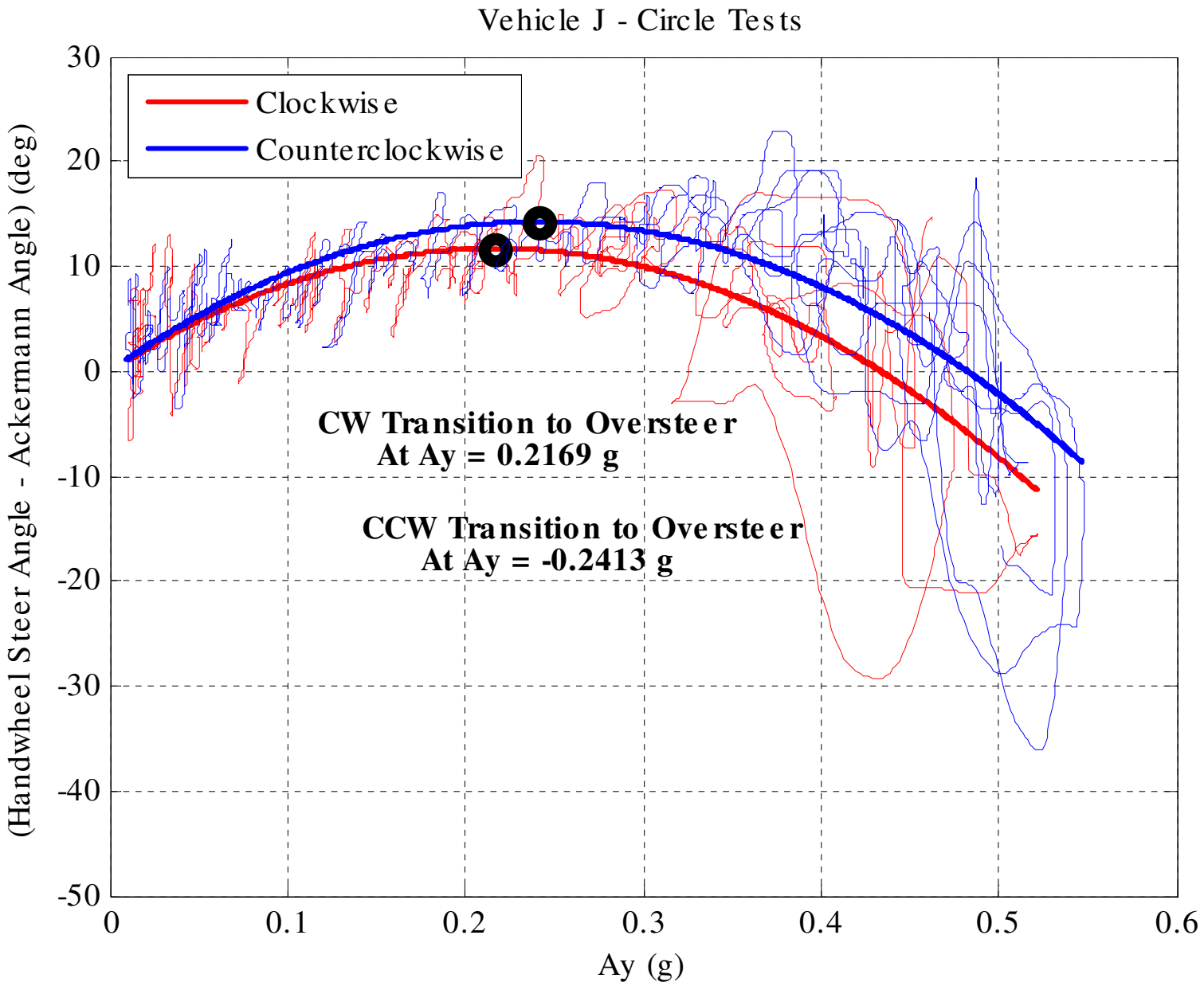

Oper., Instr. and OR - Average Ay vs Average Steering Magnitude - 30 mph J-Turn Tests
Ay (g)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
160
180
200
220
Average Steering Angle (deg)
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

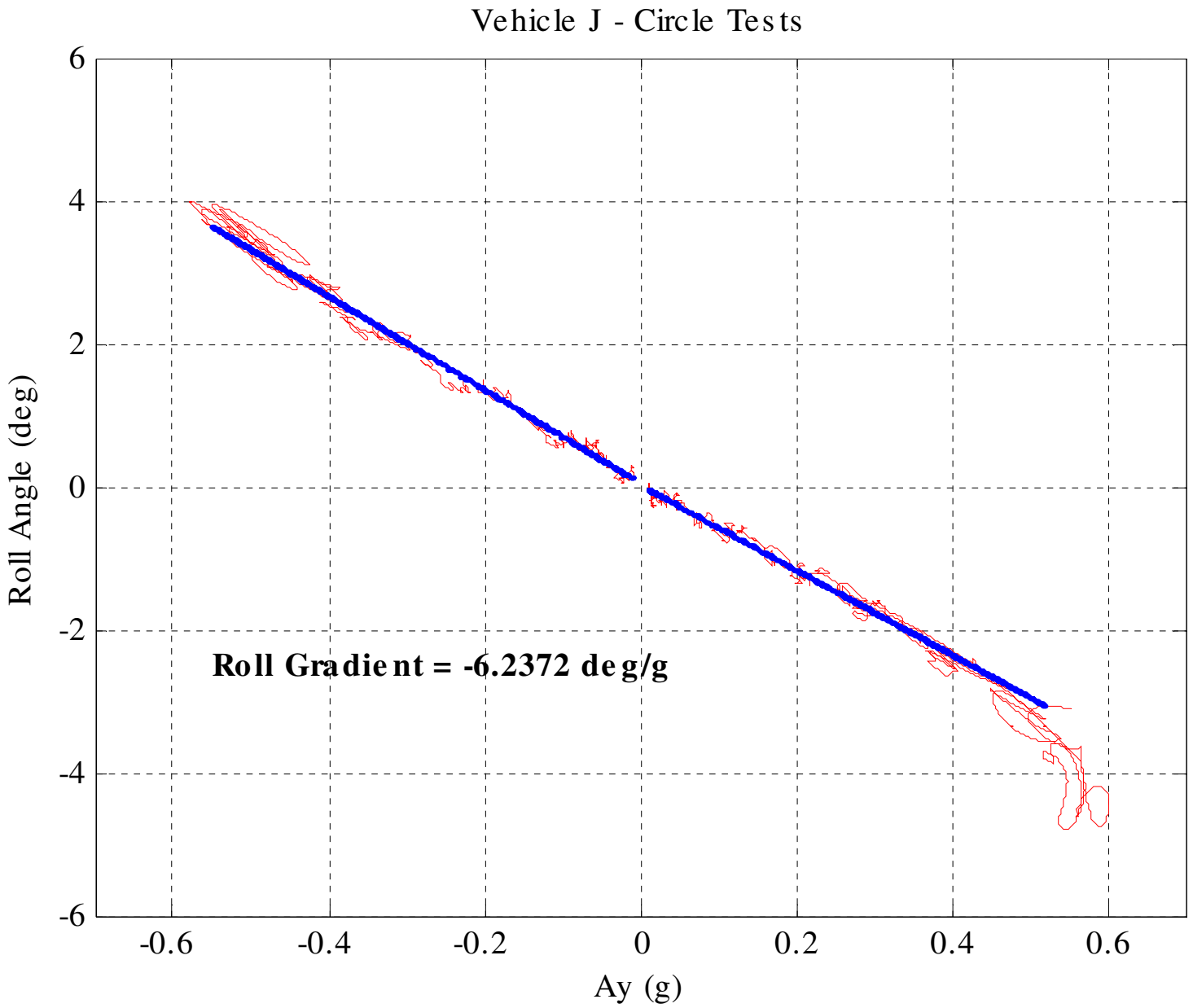

Operator, Instrumentation and Outriggers - Roll Gradient
Roll Gradient (deg/g)
16
15
14
13
12
11
10
9
8
7
6
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

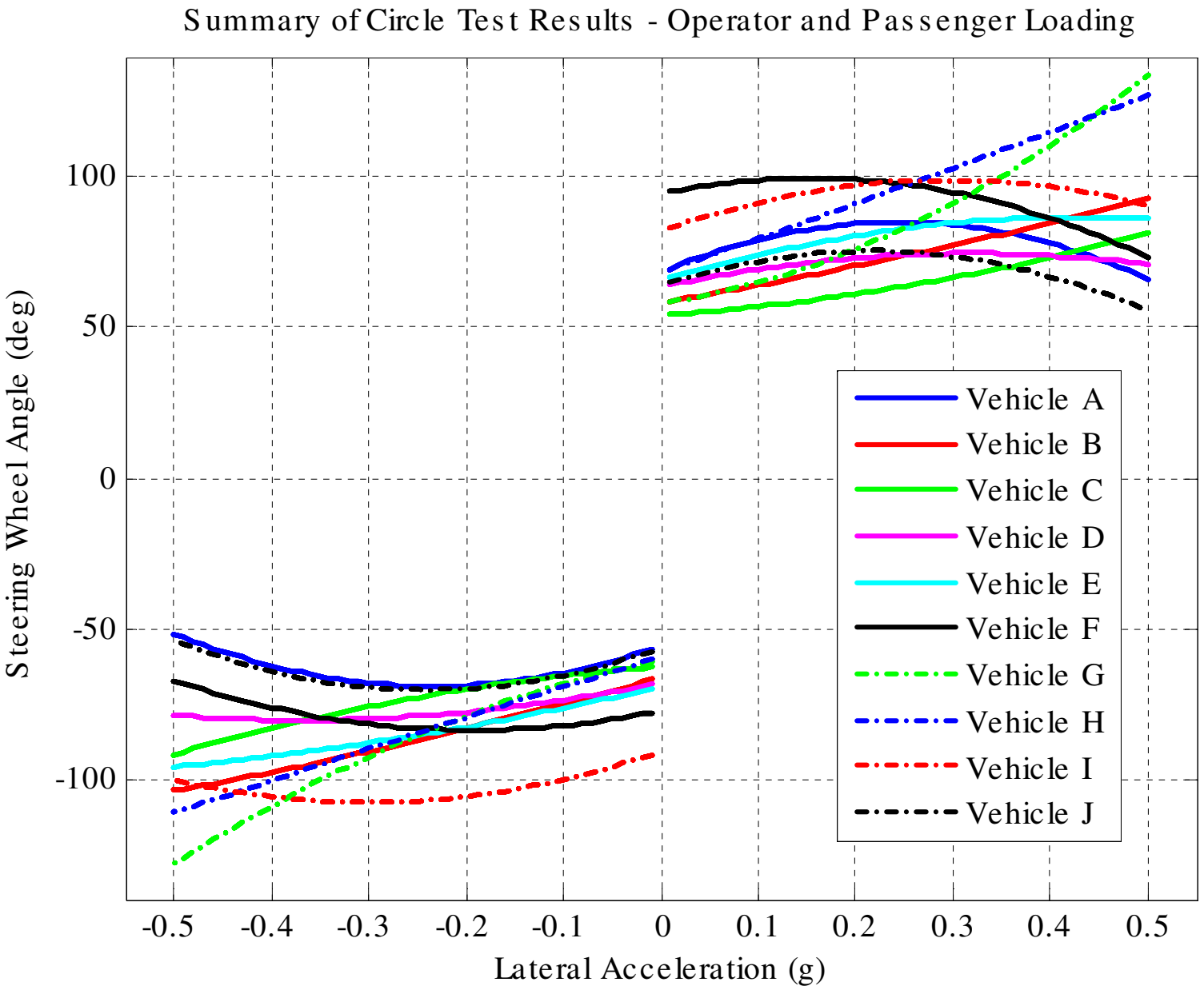

Operator, Instrumentation and Outriggers - Maximum Speed
Maximum Speed (mph)
70
65
60
55
50
45
40
35
30
1
2
3
4
5
6
7
8
9
10
Veh A
Veh B
Veh C
Veh D
Veh E
Veh F
Veh G
Veh H
Veh I
Veh J

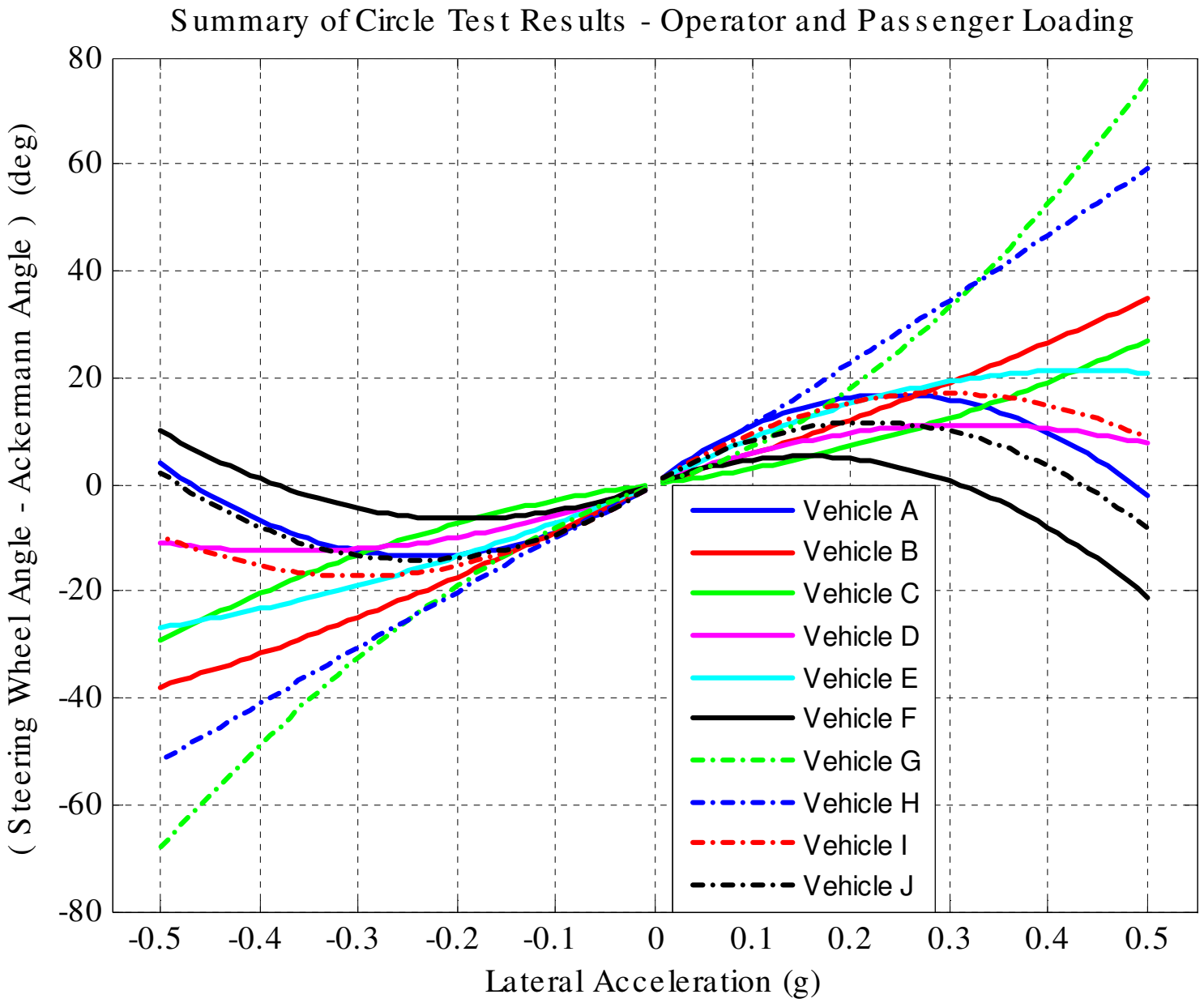

Vehicle J - Circle Tests
Steer Angle (deg)
100
0
-100
0
100
200
300
Speed (mph)
40
20
0
CW
CCW
Roll Angle (deg)
10
0
-10
Lateral Acceleration (g)
1
0.5
0
-0.5
-1
Yaw Rate (deg/sec)
40
20
0
-20
-40
Time (sec)
Time (sec)

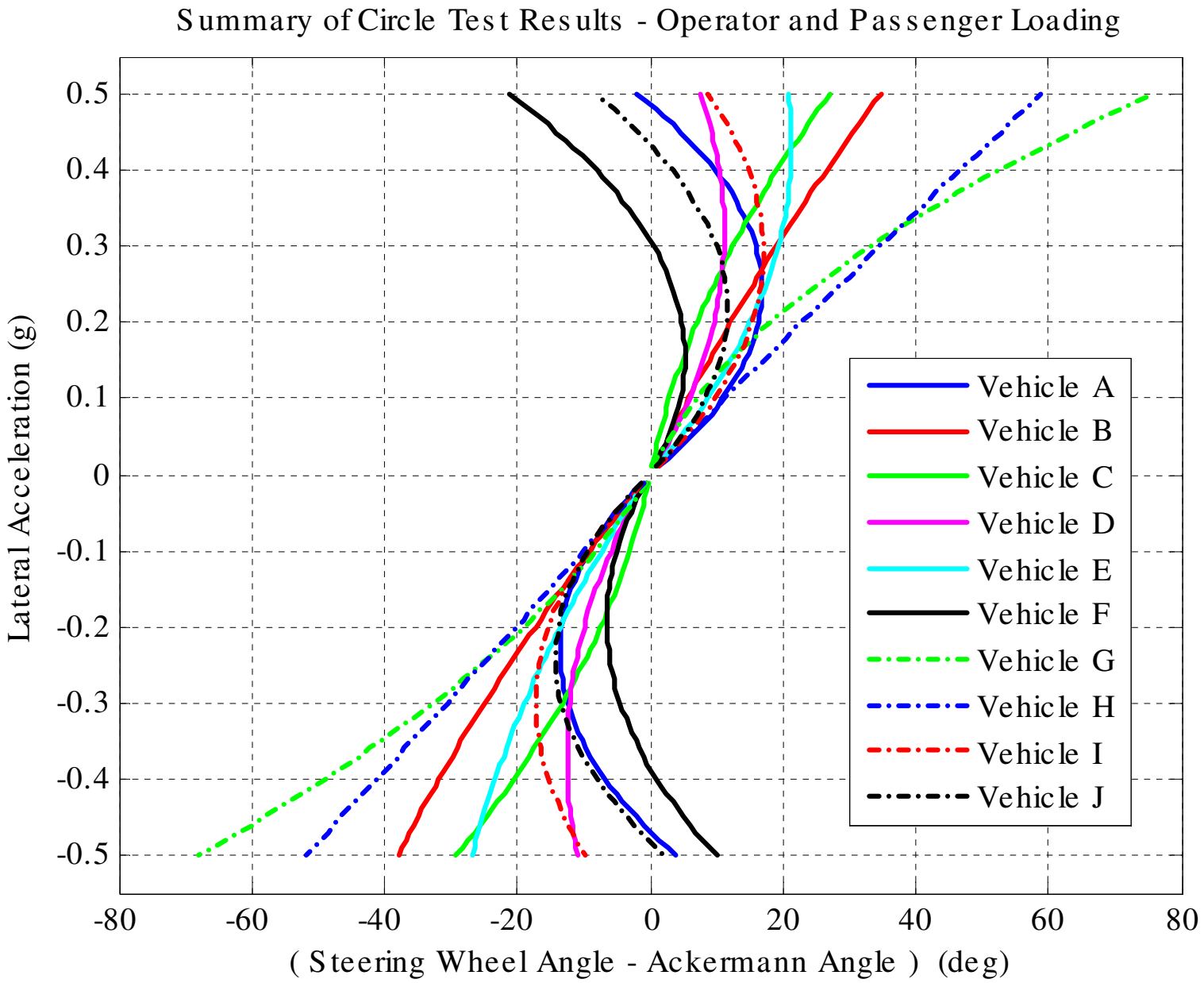

Vehicle J - Circle Tests
Handwheel Steer Angle (deg)
100
80
60
40
20
0
-20
-40
-60
-80
-100
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
Ay (g)

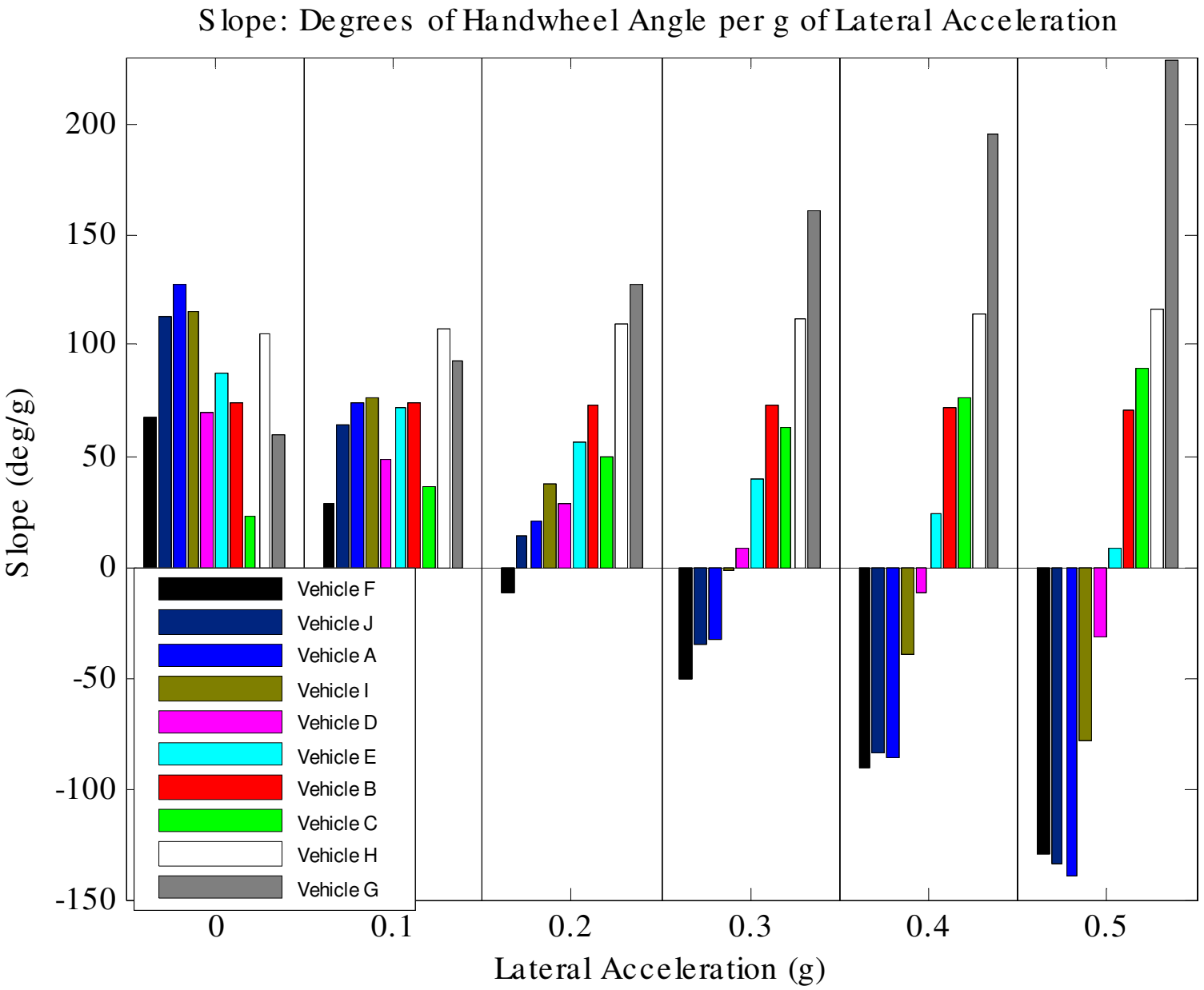

Vehicle J - Circle Tests
Clockwise
Counterclockwise
CW Transition to Oversteer
At Ay = 0.2169 g
CCW Transition to Oversteer
At Ay = -0.2413 g
(Handwheel Steer Angle - Ackermann Angle) (deg)
Ay (g)
30
20
10
0
-10
-20
-30
-40
-50
0
0.1
0.2
0.3
0.4
0.5
0.6

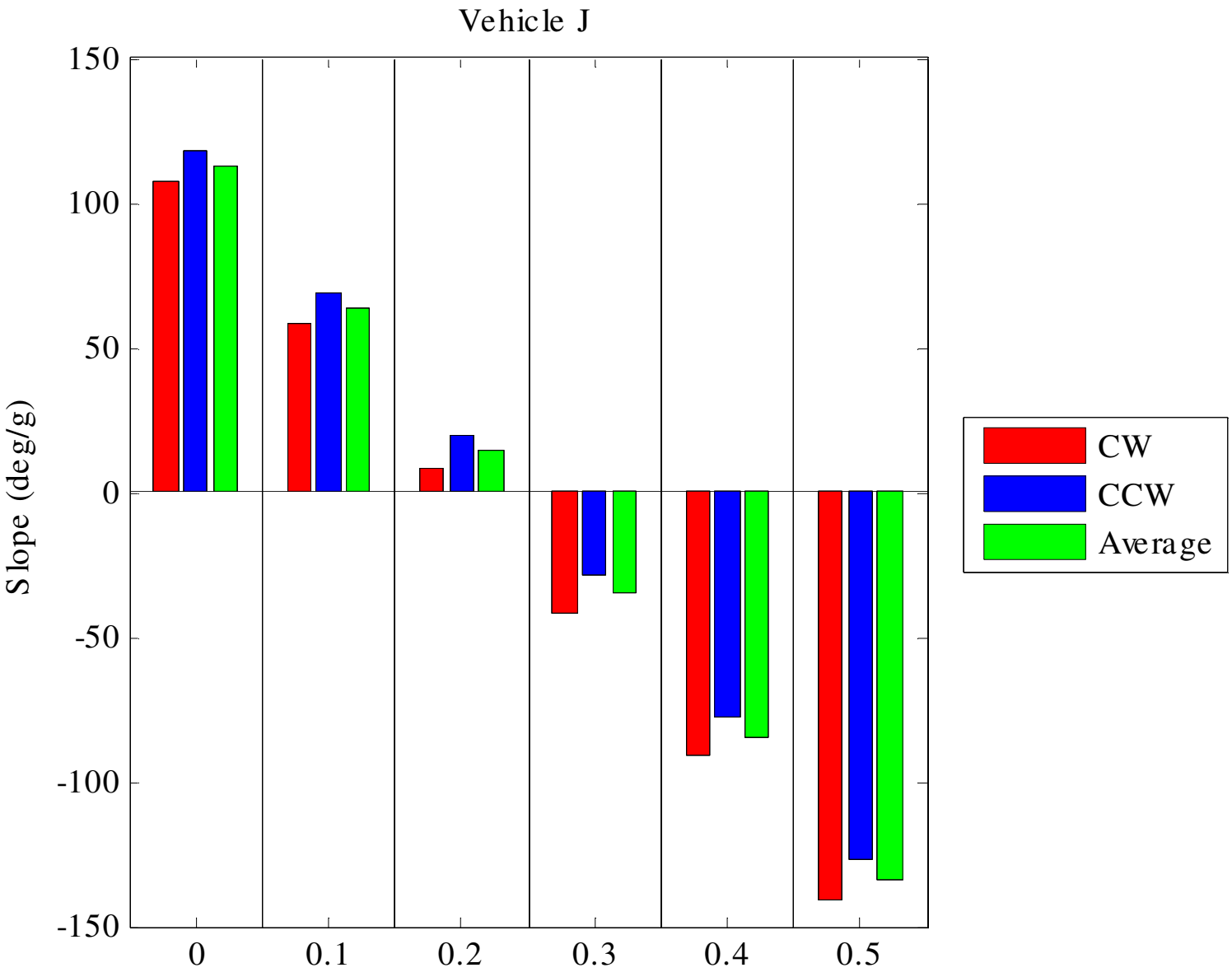

Vehicle J - Circle Tests
Roll Angle (deg)
Ay (g)
Roll Gradient = -6.2372 deg/g
6
4
2
0
-2
-4
-6
-0.6
-0.4
-0.2
0
0.2
0.4
0.6


Summary of Circle Test Results - Operator and Passenger Loading
Steering Wheel Angle (deg)
100
50
0
-50
-100
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
Lateral Acceleration (g)
Vehicle A
Vehicle B
Vehicle C
Vehicle D
Vehicle E
Vehicle F
Vehicle G
Vehicle H
Vehicle I
Vehicle J


Summary of Circle Test Results - Operator and Passenger Loading
(Steering Wheel Angle - Ackermann Angle) (deg)
80
60
40
20
0
-20
-40
-60
-80
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
Lateral Acceleration (g)
Vehicle A
Vehicle B
Vehicle C
Vehicle D
Vehicle E
Vehicle F
Vehicle G
Vehicle H
Vehicle I
Vehicle J


Summary of Circle Test Results - Operator and Passenger Loading
Lateral Acceleration (g)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-80
-60
-40
-20
0
20
40
60
80
(Steering Wheel Angle - Ackermann Angle) (deg)
Vehicle A
Vehicle B
Vehicle C
Vehicle D
Vehicle E
Vehicle F
Vehicle G
Vehicle H
Vehicle I
Vehicle J

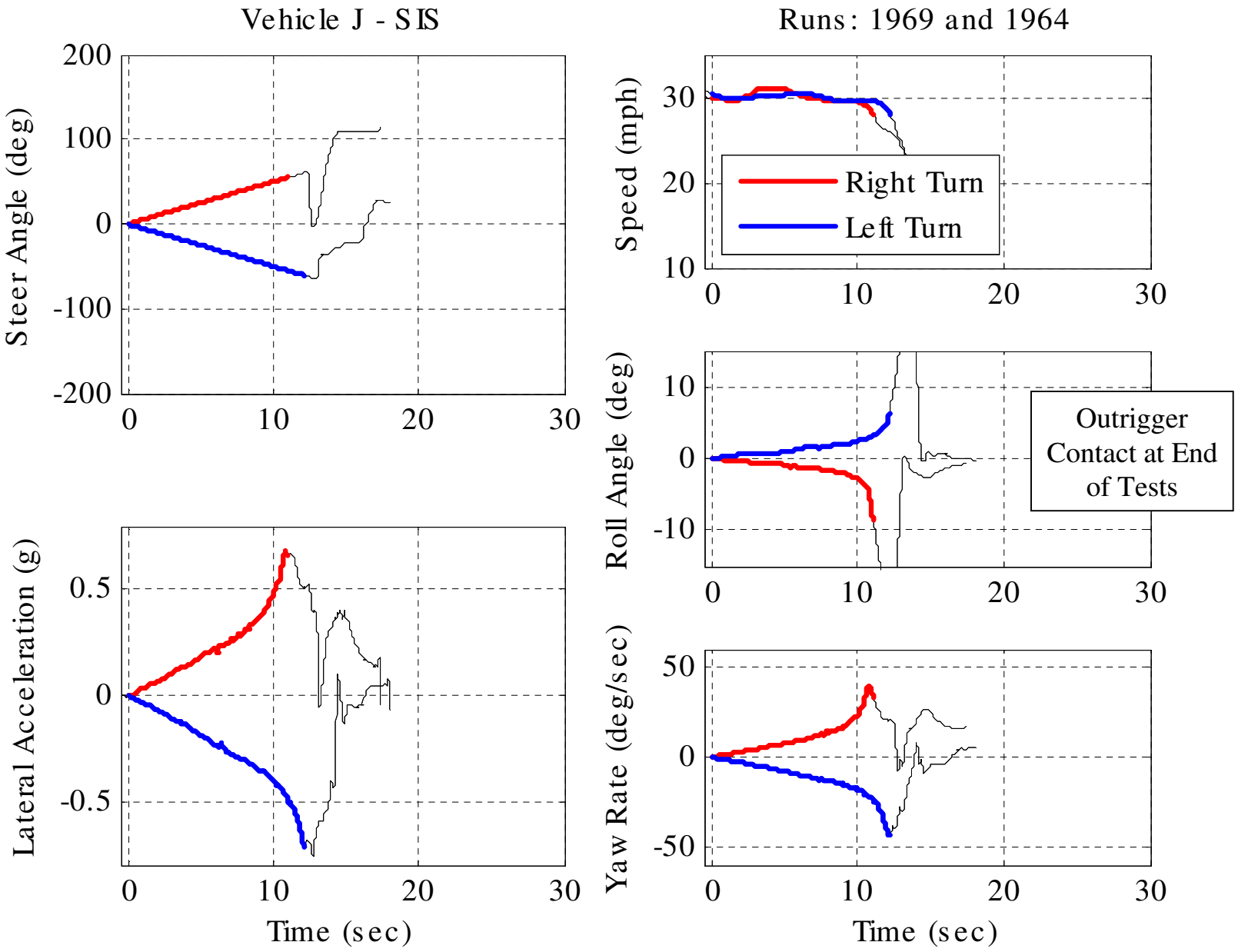

Slope: Degrees of Handwheel Angle per g of Lateral Acceleration
Slope (deg/g)
200
150
100
50
0
-50
-100
-150
0
0.1
0.2
0.3
0.4
0.5
Lateral Acceleration (g)
Vehicle F
Vehicle J
Vehicle A
Vehicle I
Vehicle D
Vehicle E
Vehicle B
Vehicle C
Vehicle H
Vehicle G

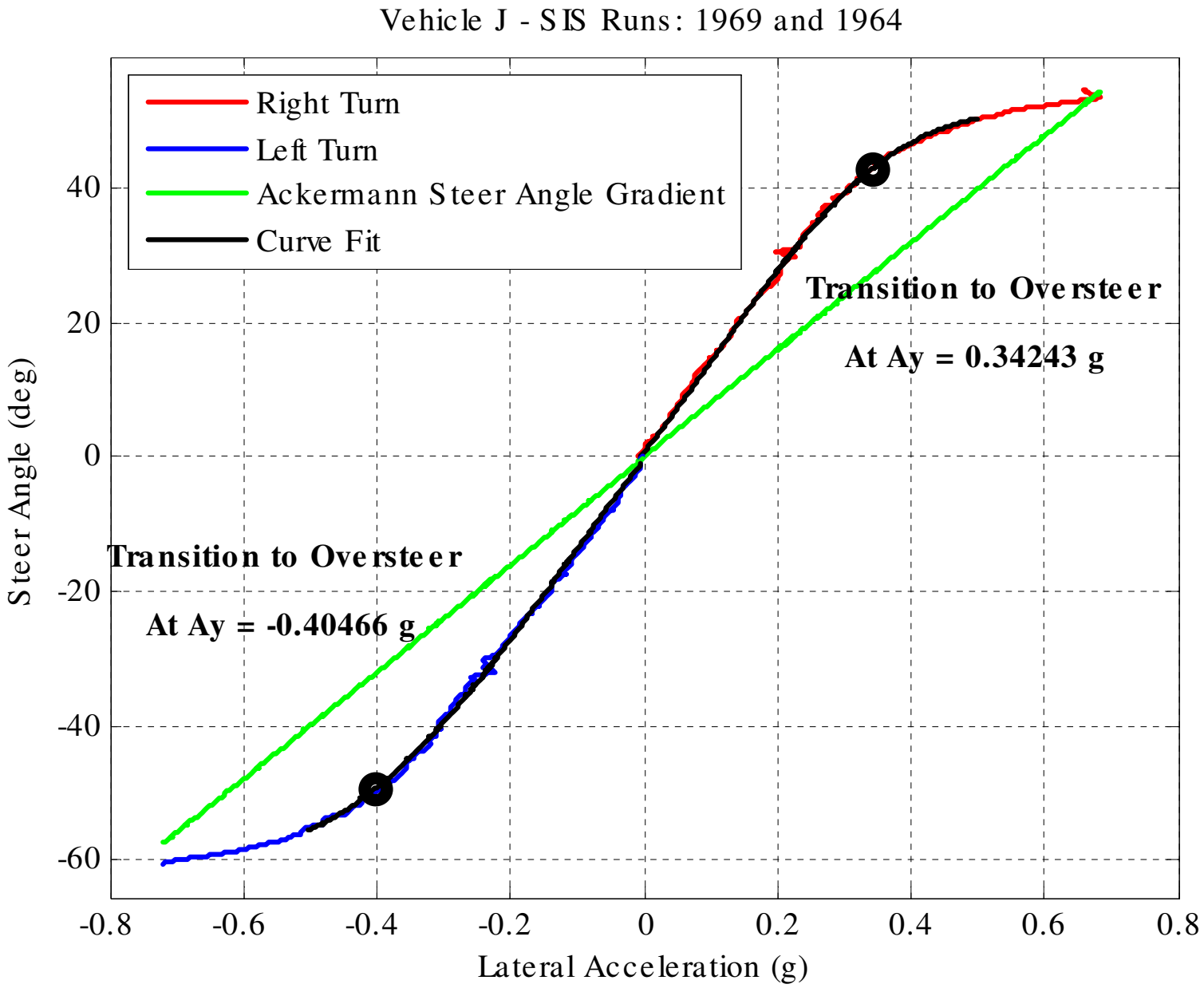

Vehicle J
Slope (deg/g)
150
100
50
0
-50
-100
-150
0
0.1
0.2
0.3
0.4
0.5
CW
CCW
Average

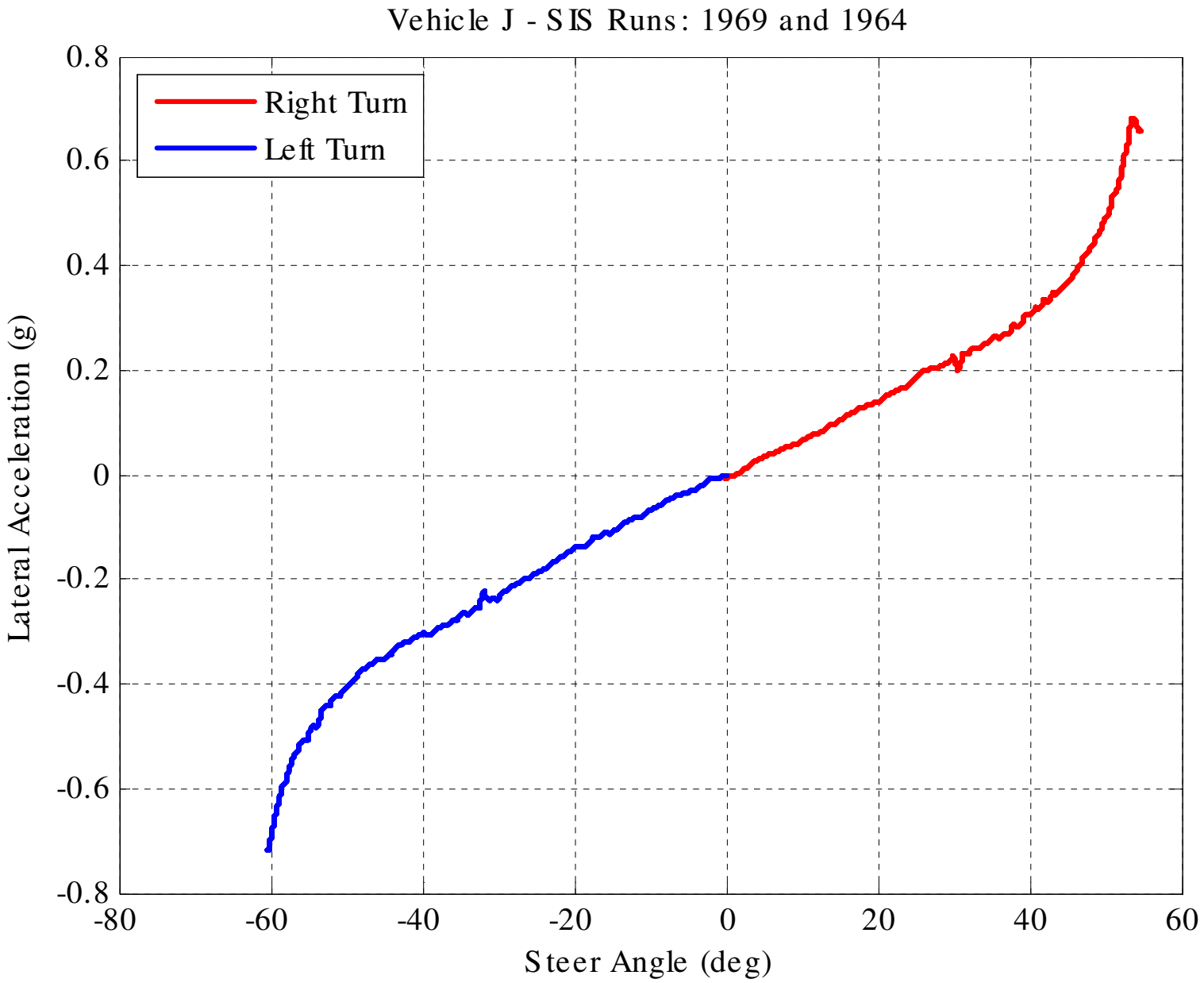
Constant Radius (100 ft) Circle Tests

Lateral Acceleration Level at Point of Transition from Understeer to Oversteer (Operator and Passenger Loading)

	Clockwise (g)	Counterclockwise (g)	Average (g)
Vehicle A	0.24	0.23	0.24
Vehicle B	NA	NA	NA
Vehicle C	NA	NA	NA
Vehicle D	0.32	0.37	0.35
Vehicle E	0.44	NA	NA
Vehicle F	0.15	0.19	0.17
Vehicle G	NA	NA	NA
Vehicle H	NA	NA	NA
Vehicle I	0.29	0.30	0.30
Vehicle J	0.22	0.24	0.23


Vehicle J - SIS
Runs: 1969 and 1964
Steer Angle (deg)
200
100
0
-100
-200
Speed (mph)
30
20
10
Right Turn
Left Turn
Roll Angle (deg)
10
0
-10
Outrigger Contact at End of Tests
Lateral Acceleration (g)
0.5
0
-0.5
Yaw Rate (deg/sec)
50
0
-50
0
10
20
30
Time (sec)

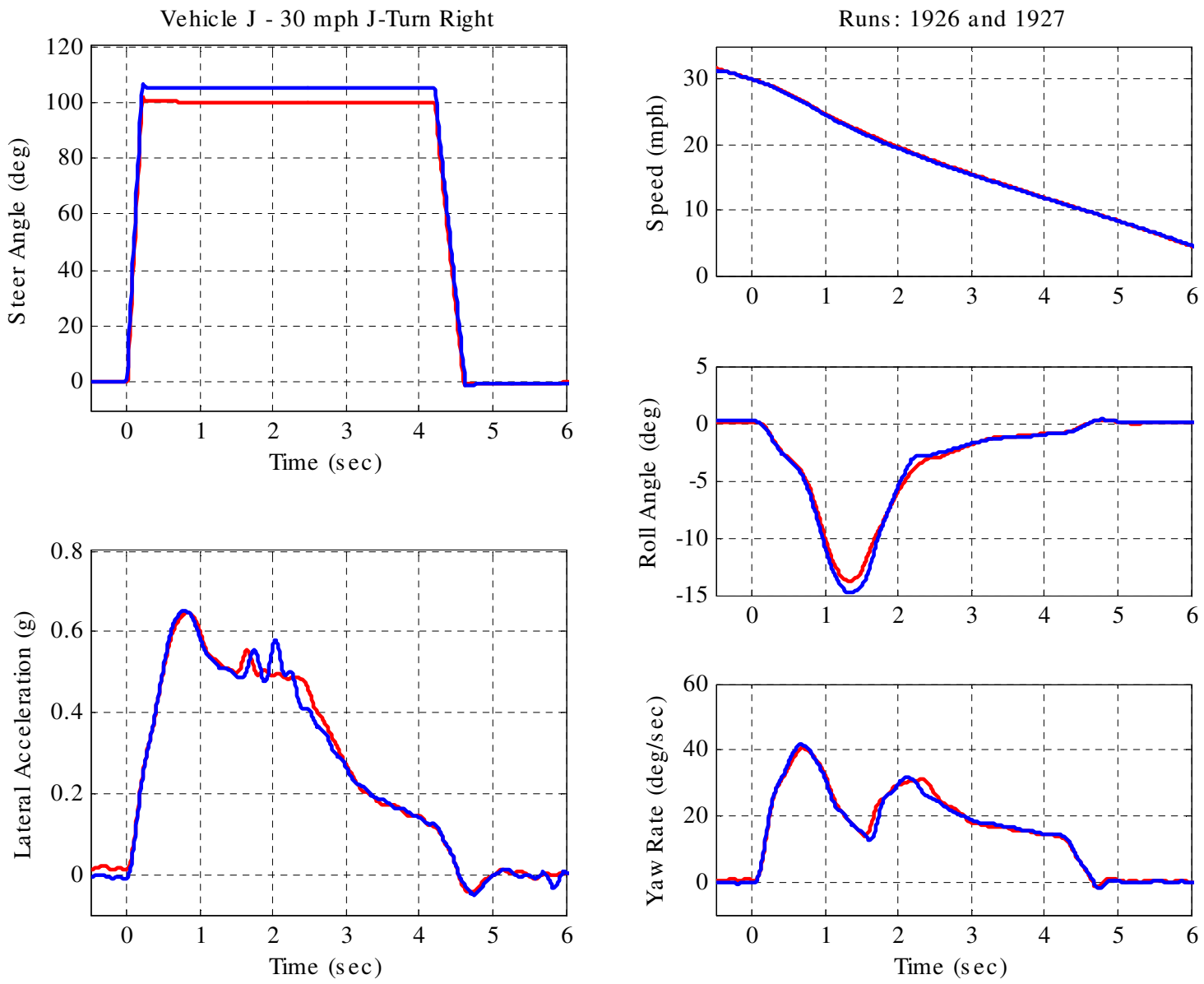

Vehicle J - SIS Runs: 1969 and 1964
Right Turn
Left Turn
Ackermann Steer Angle Gradient
Curve Fit
Transition to Oversteer
At Ay = 0.34243 g
Transition to Oversteer
At Ay = -0.40466 g
Steer Angle (deg)
40
20
0
-20
-40
-60
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
Lateral Acceleration (g)

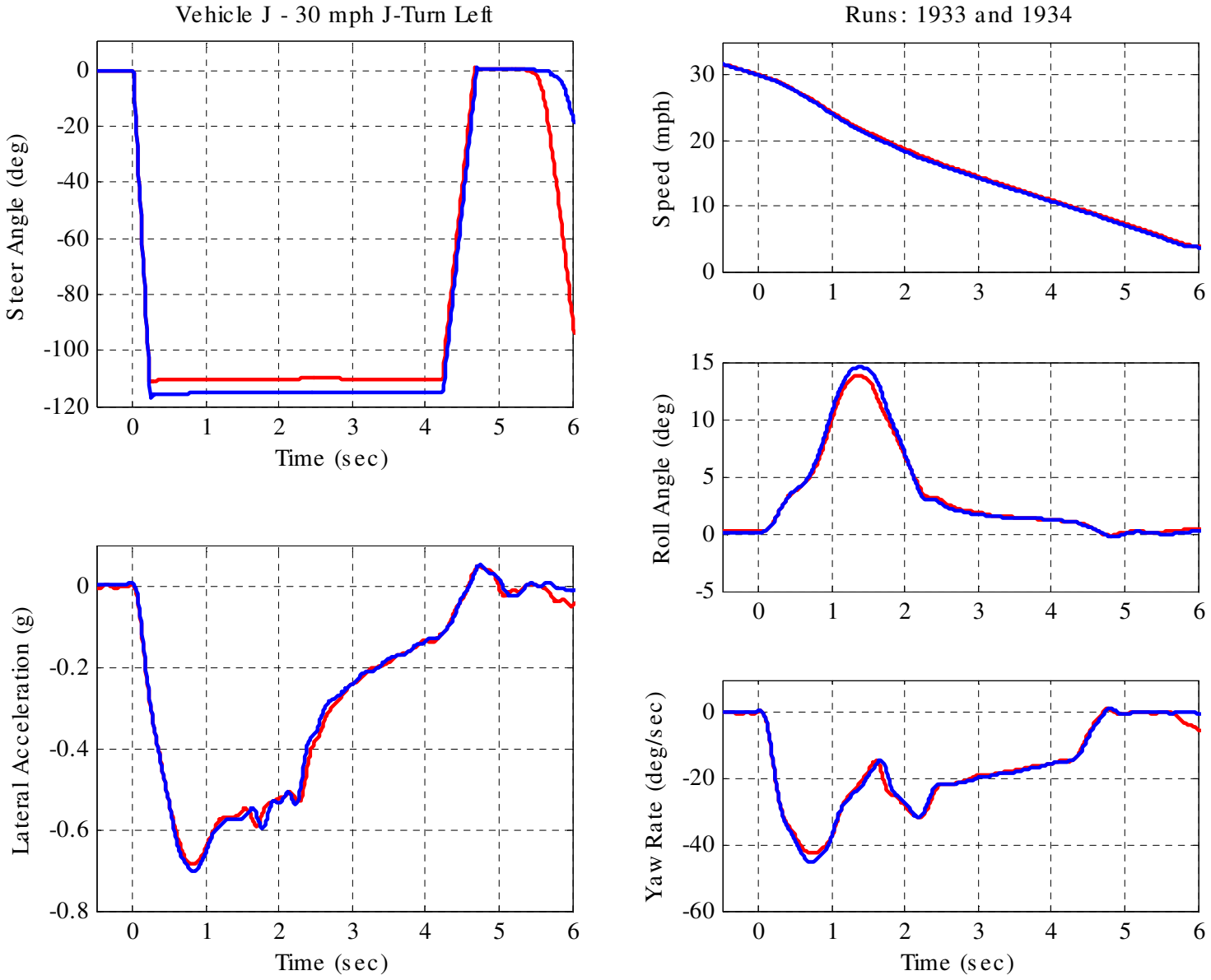

Vehicle J - SIS Runs: 1969 and 1964
Right Turn
Left Turn
Lateral Acceleration (g)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-80
-60
-40
-20
0
20
40
60
Steer Angle (deg)

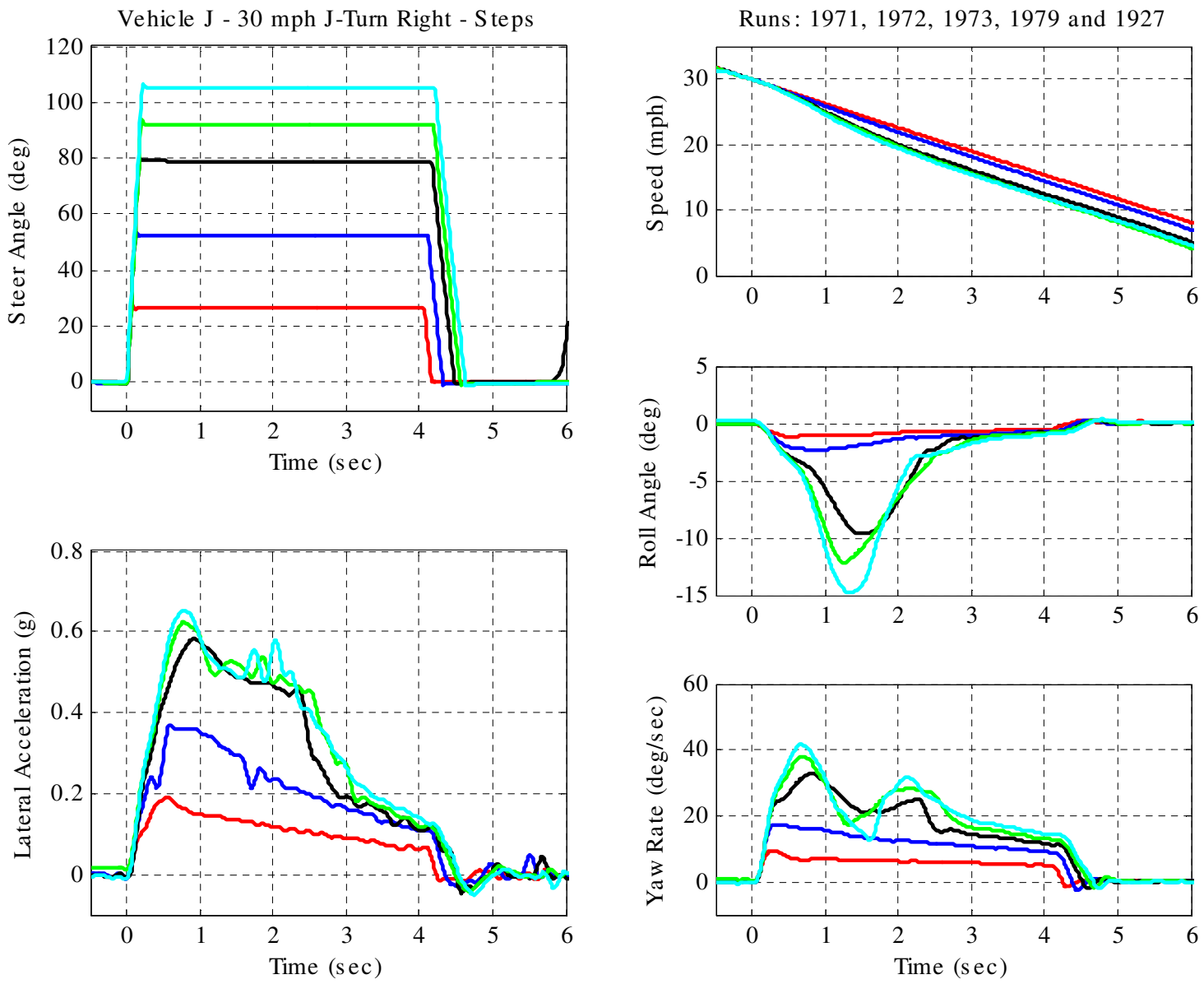
Constant Speed (30 mph) Slowly Increasing Steer Tests

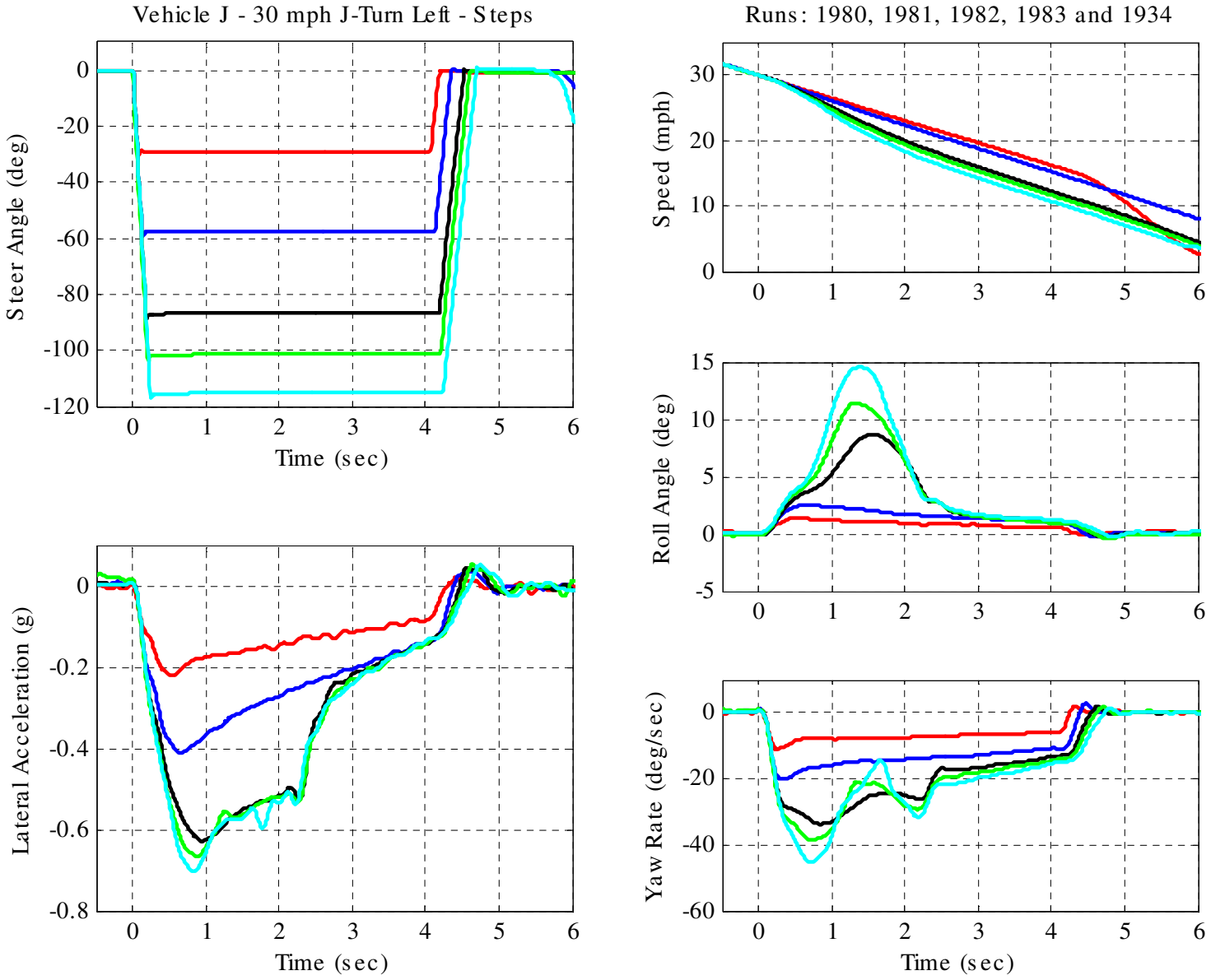
Lateral Acceleration Level at Point of Transition from Understeer to Oversteer (Operator and Passenger Loading)

	Right Turn (g)	Left Turn (g)	Average (g)
Vehicle A	0.40	0.33	0.37
Vehicle B	NA	NA	NA
Vehicle C	NA	NA	NA
Vehicle D	0.35	0.44	0.40
Vehicle E	NA	NA	NA
Vehicle F	0.39	0.42	0.41
Vehicle G	NA	NA	NA
Vehicle H	NA	NA	NA
Vehicle I	0.43	0.46	0.45
Vehicle J	0.34	0.40	0.36

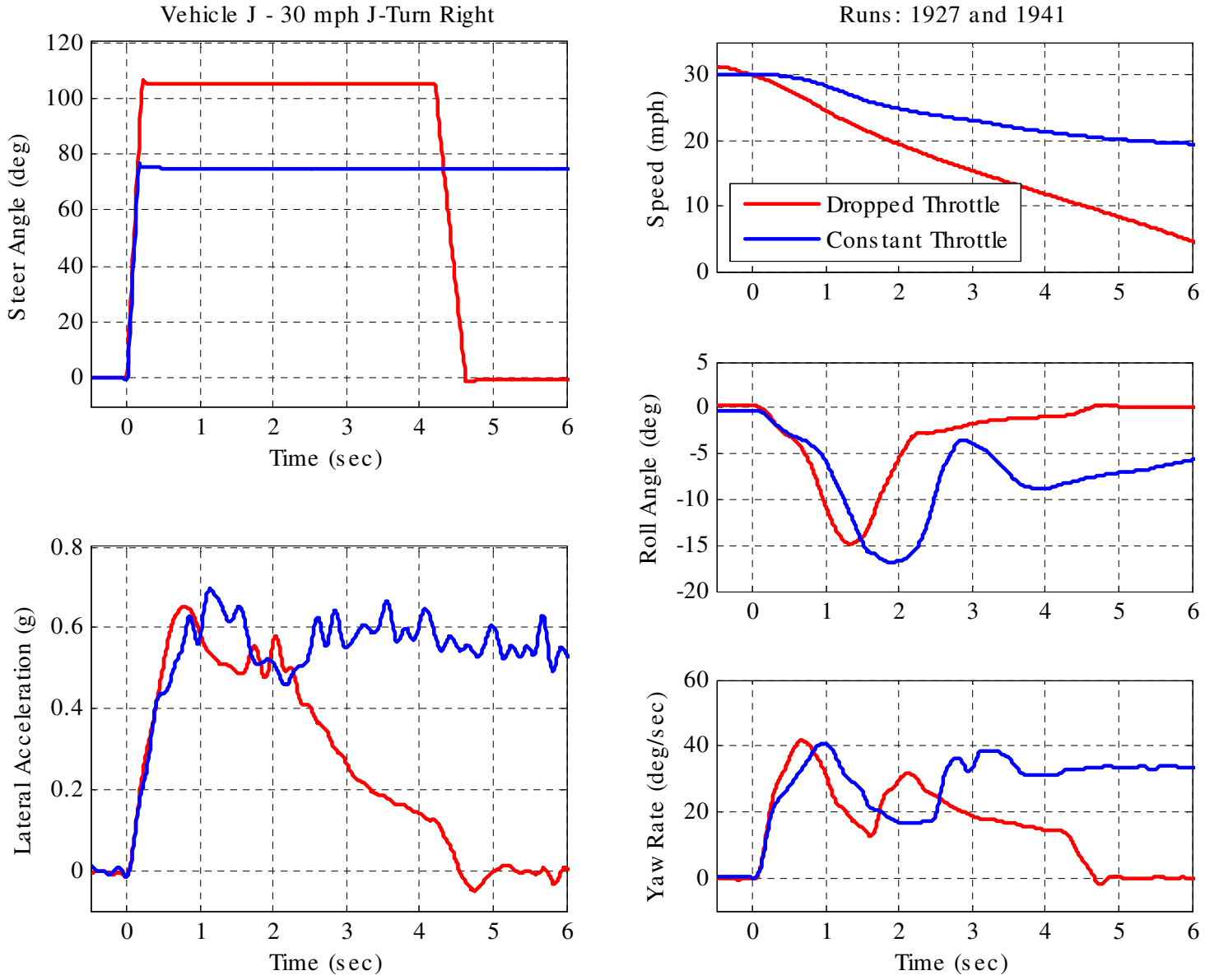

Vehicle J - 30 mph J-Turn Right
Runs: 1926 and 1927
Steer Angle (deg)
Speed (mph)
Roll Angle (deg)
Lateral Acceleration (g)
Yaw Rate (deg/sec)
Time (sec)
Time (sec)

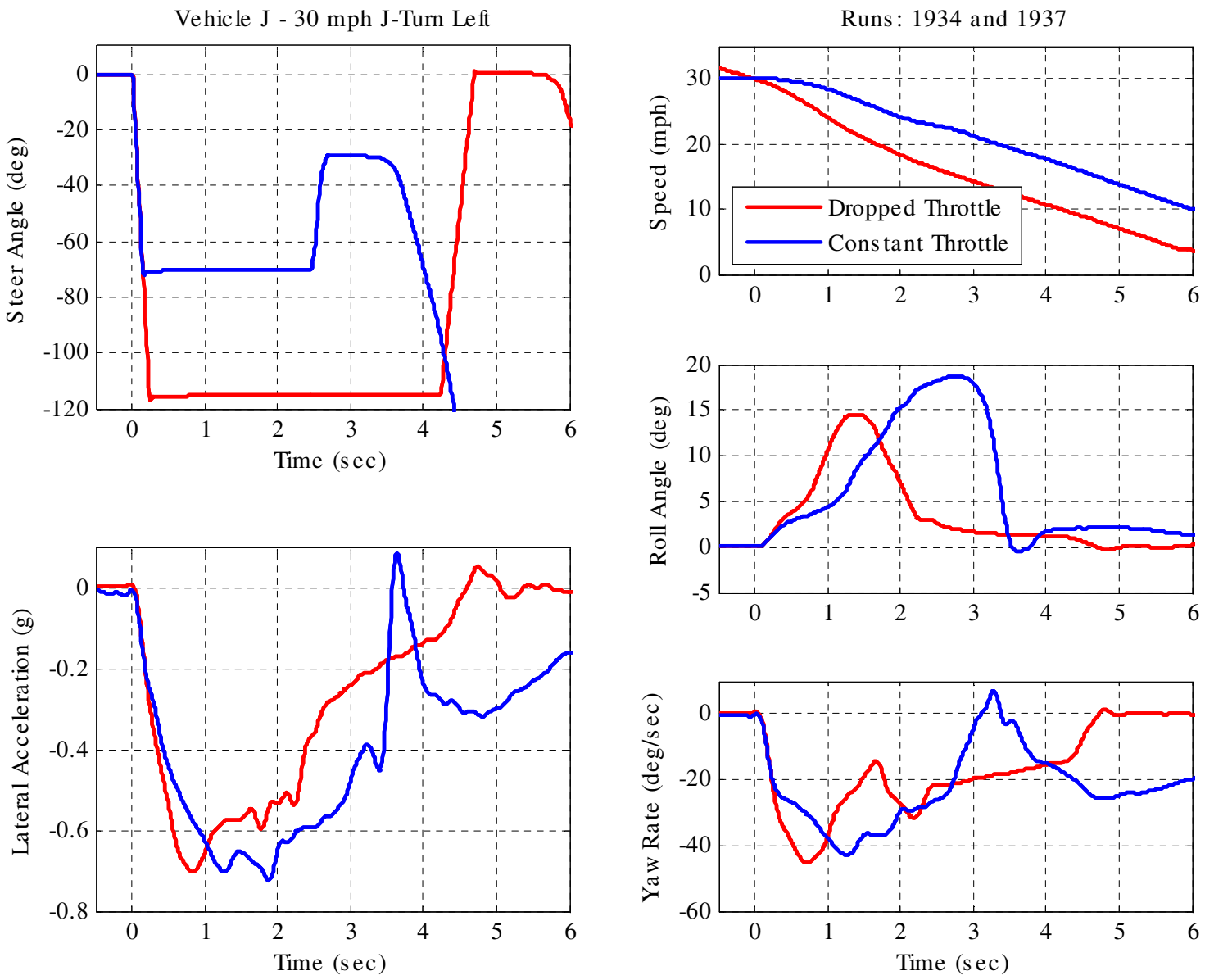

Vehicle J - 30 mph J-Turn Left
Runs: 1933 and 1934
Steer Angle (deg)
0
-20
-40
-60
-80
-100
-120
Time (sec)
Speed (mph)
30
20
10
0
Roll Angle (deg)
15
10
5
0
-5
Lateral Acceleration (g)
0
-0.2
-0.4
-0.6
-0.8
Yaw Rate (deg/sec)
0
-20
-40
-60
0
1
2
3
4
5
6
Time (sec)

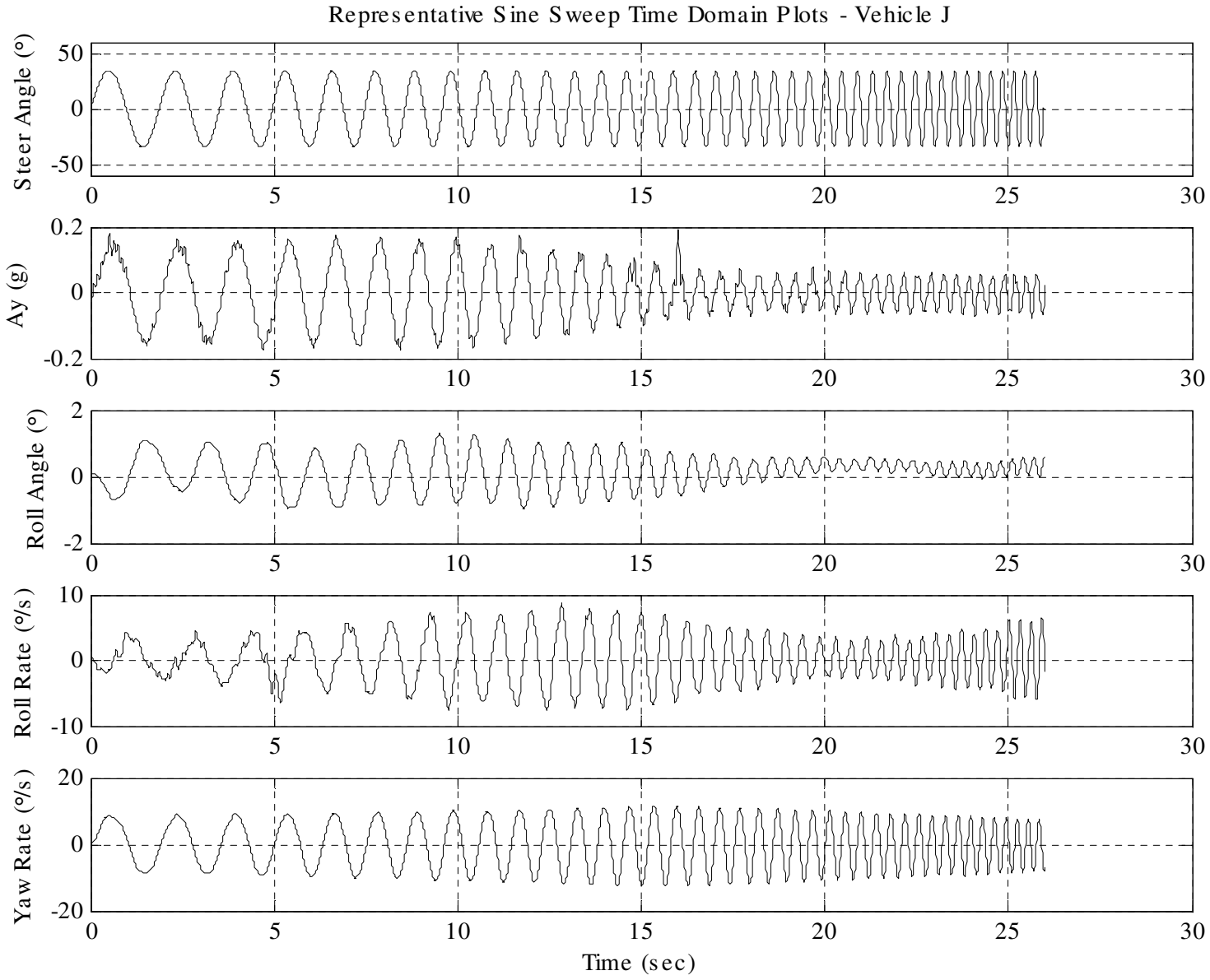

Vehicle J - 30 mph J-Turn Right - Steps
Runs: 1971, 1972, 1973, 1979 and 1927
Steer Angle (deg)
Speed (mph)
Roll Angle (deg)
Lateral Acceleration (g)
Yaw Rate (deg/sec)
Time (sec)
Time (sec)

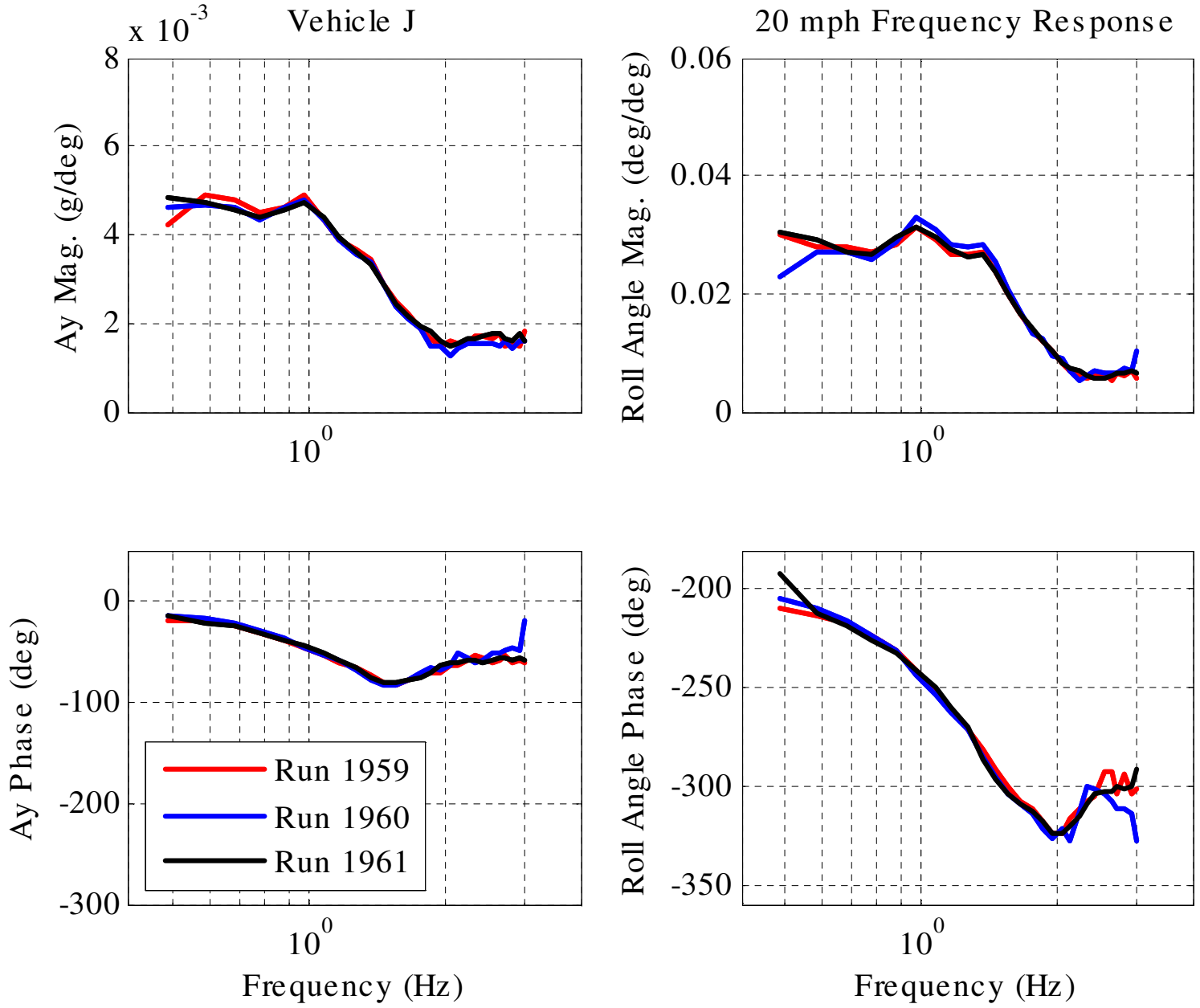

Vehicle J - 30 mph J-Turn Left - Steps
Runs: 1980, 1981, 1982, 1983 and 1934
Steer Angle (deg)
0
-20
-40
-60
-80
-100
-120
Time (sec)
Speed (mph)
30
20
10
0
Roll Angle (deg)
15
10
5
0
-5
Lateral Acceleration (g)
0
-0.2
-0.4
-0.6
-0.8
Yaw Rate (deg/sec)
0
-20
-40
-60
0
1
2
3
4
5
6
Time (sec)

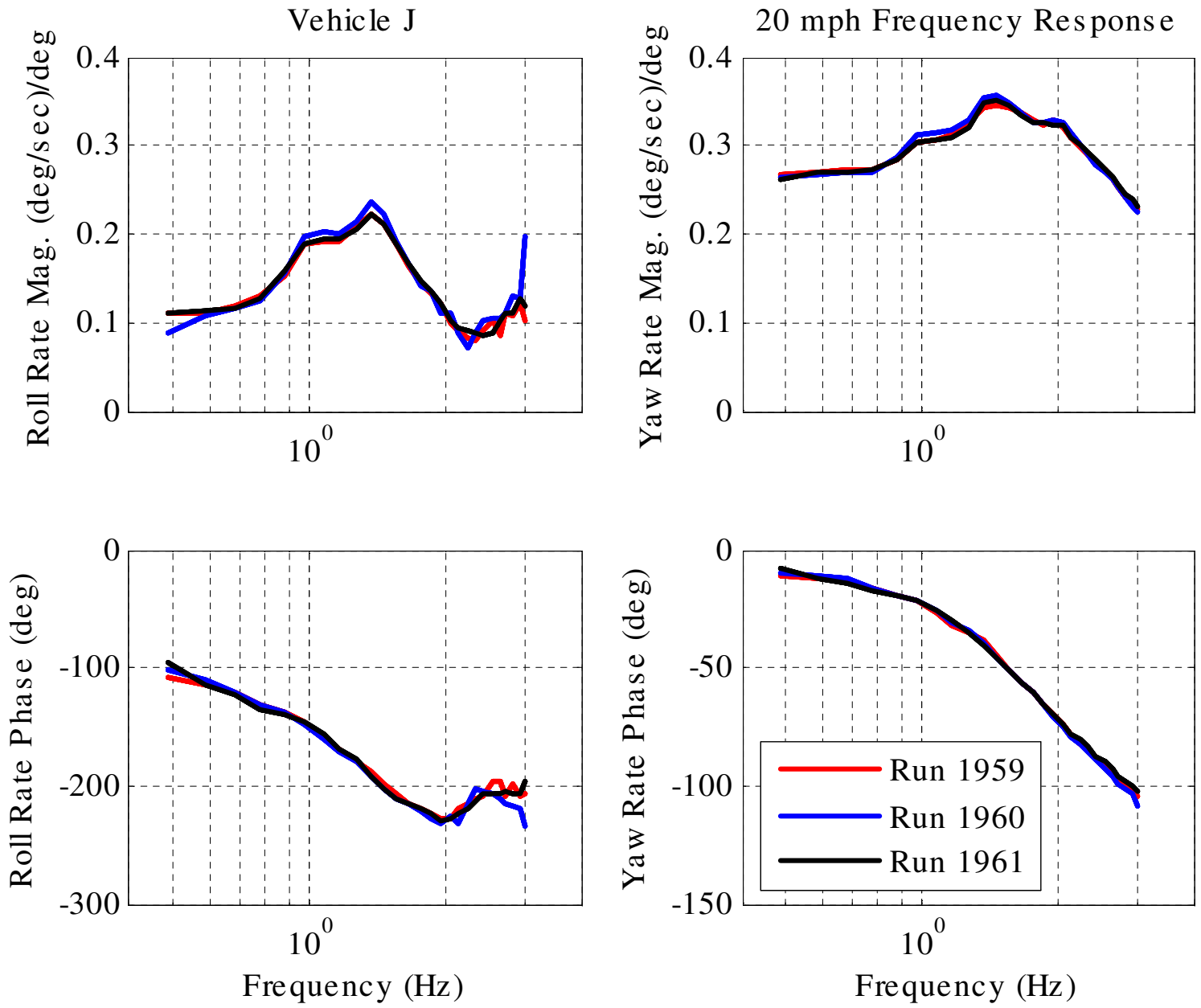
Maximum Lateral Accelerations During Dropped Throttle J-Turns Vehicle J – Operator and Passenger Loading						
	Right Steer Maneuvers		Left Steer Maneuvers		Average of Right and Left Maneuvers	
Percentage of Steering Required for Two Wheel Lift (%)	Steering Angle (deg)	Lateral Accel. (g)	Steering Angle (deg)	Lateral Accel. (g)	Steering Angle (deg)	Lateral Accel. (g)
0.0	0.0	0.00	0.0	0.00	0.0	0.000
25.0	26.3	0.18	-28.8	-0.21	27.6	0.195
50.0	52.5	0.36	-57.5	-0.40	55.0	0.380
75.0	78.8	0.58	-86.3	-0.62	82.6	0.600
87.5	91.9	0.62	-100.6	-0.66	96.3	0.640
100.0	105.0	0.65	-115.0	-0.69	110.0	0.670

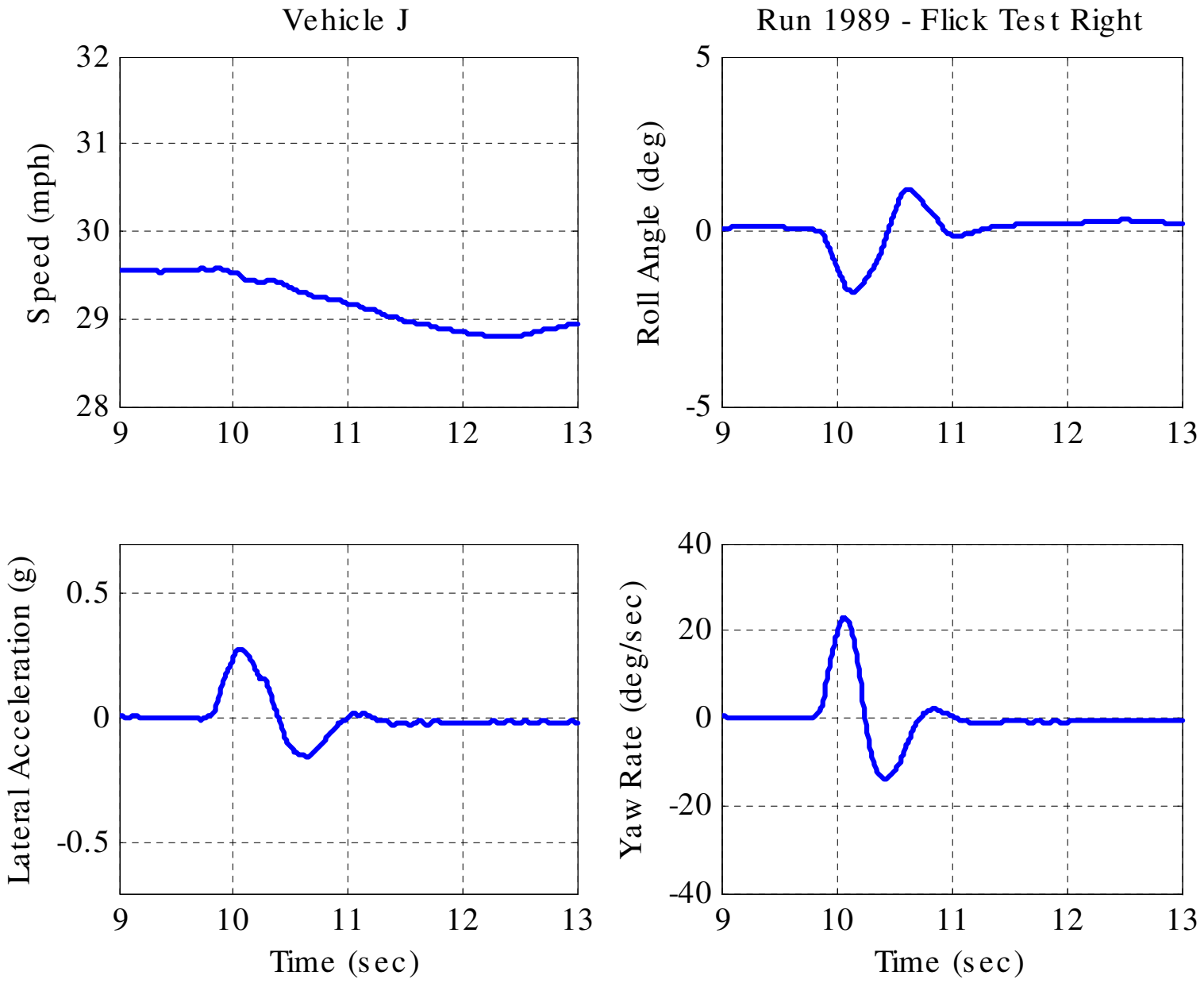

Vehicle J - 30 mph J-Turn Right
Runs: 1927 and 1941
Steer Angle (deg)
Speed (mph)
Dropped Throttle
Constant Throttle
Roll Angle (deg)
Lateral Acceleration (g)
Yaw Rate (deg/sec)
Time (sec)
Time (sec)

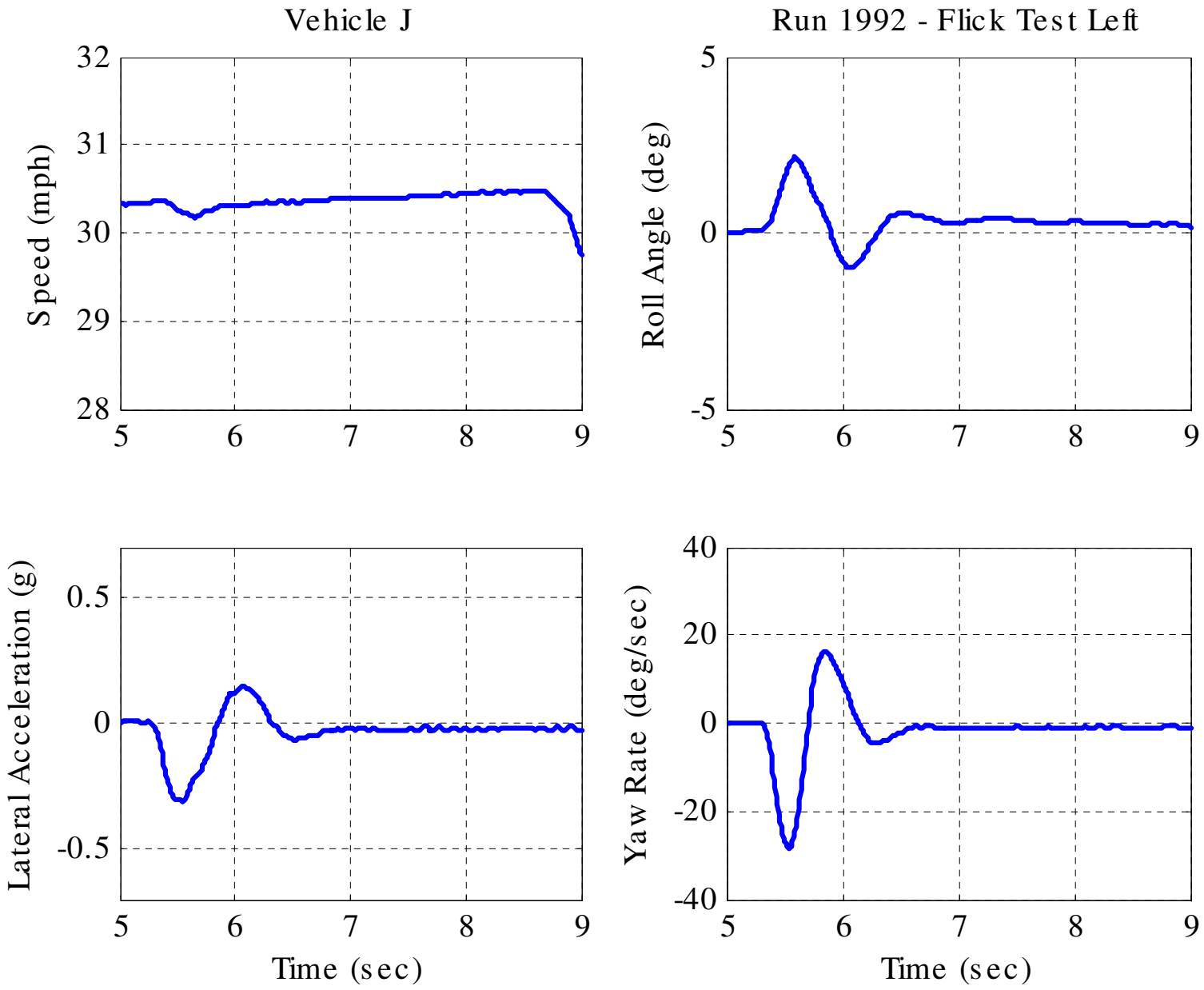

Vehicle J - 30 mph J-Turn Left
Runs: 1934 and 1937
Steer Angle (deg)
0
-20
-40
-60
-80
-100
-120
Time (sec)
Speed (mph)
30
20
10
0
Dropped Throttle
Constant Throttle
Roll Angle (deg)
20
15
10
5
0
-5
Lateral Acceleration (g)
0
-0.2
-0.4
-0.6
-0.8
Yaw Rate (deg/sec)
0
-20
-40
-60
0
1
2
3
4
5
6
Time (sec)

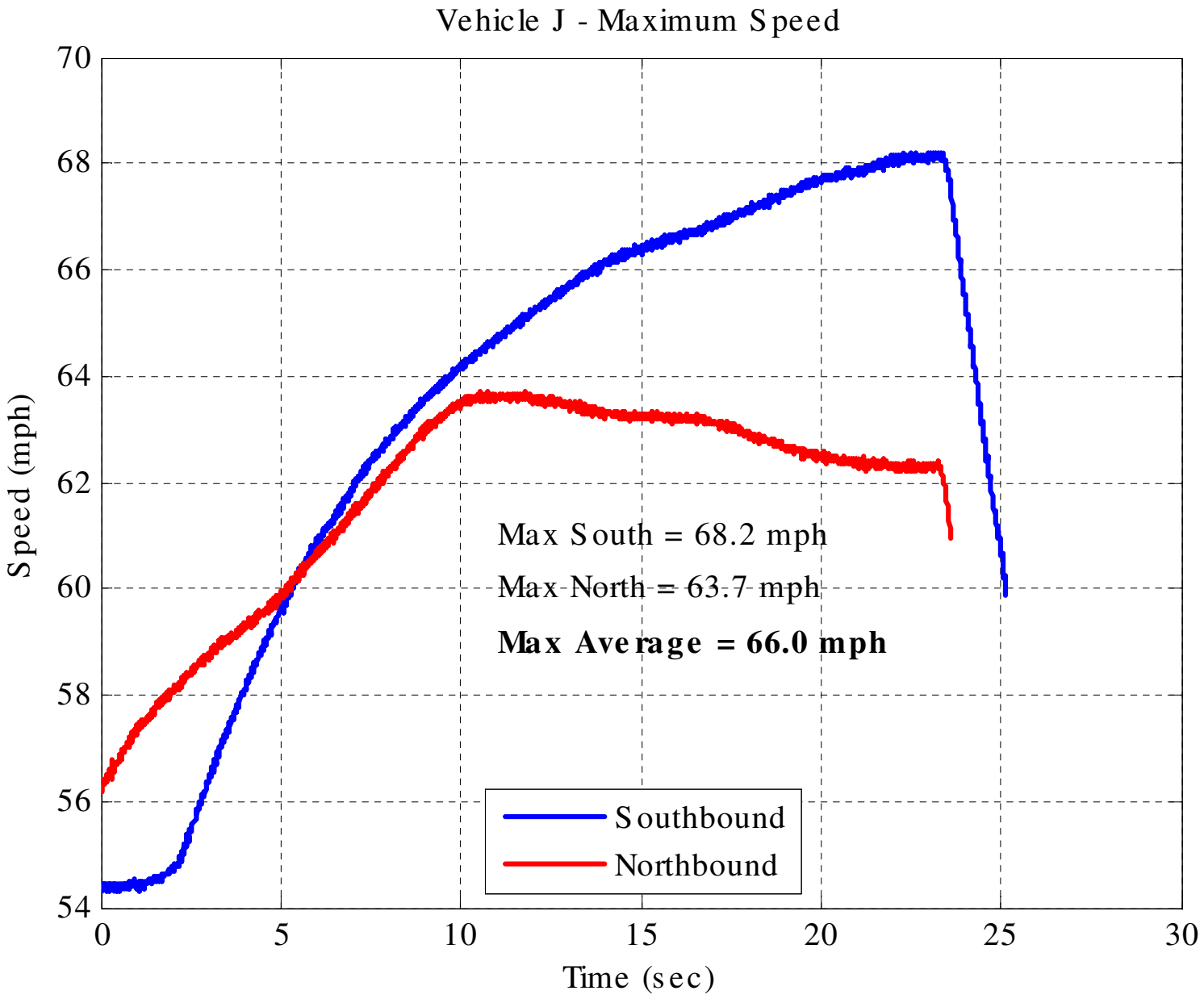

Representative Sine Sweep Time Domain Plots - Vehicle J
Steer Angle (°)
50
0
-50
Ay (g)
0.2
0
-0.2
Roll Angle (°)
2
0
-2
Roll Rate (°/s)
10
0
-10
Yaw Rate (°/s)
20
0
-20
0
5
10
15
20
25
30
Time (sec)

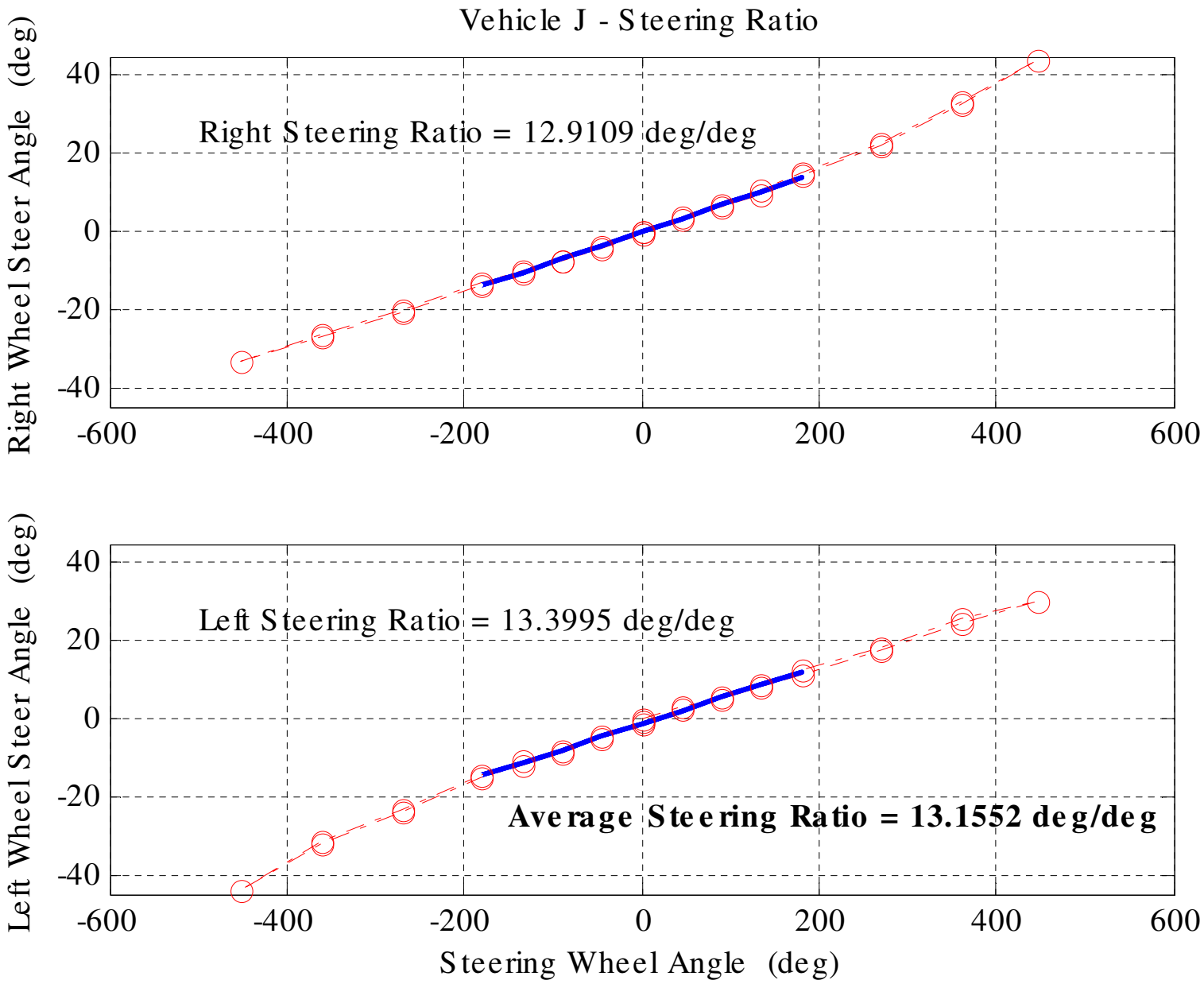

Vehicle J
x 10^-3
Ay Mag. (g/deg)
8
6
4
2
0
10^0
20 mph Frequency Response
Roll Angle Mag. (deg/deg)
0.06
0.04
0.02
0
10^0
Ay Phase (deg)
0
-100
-200
-300
Run 1959
Run 1960
Run 1961
10^0
Frequency (Hz)
Roll Angle Phase (deg)
-200
-250
-300
-350
10^0
Frequency (Hz)


Vehicle J
20 mph Frequency Response
Roll Rate Mag. (deg/sec)/deg
Yaw Rate Mag. (deg/sec)/deg
Roll Rate Phase (deg)
Yaw Rate Phase (deg)
Frequency (Hz)
Frequency (Hz)
Run 1959
Run 1960
Run 1961


Vehicle J
Run 1989 - Flick Test Right
Speed (mph)
32
31
30
29
28
Roll Angle (deg)
5
0
-5
Lateral Acceleration (g)
0.5
0
-0.5
Yaw Rate (deg/sec)
40
20
0
-20
-40
9
10
11
12
13
Time (sec)
Time (sec)


Vehicle J
Run 1992 - Flick Test Left
Speed (mph)
32
31
30
29
28
Roll Angle (deg)
5
0
-5
Lateral Acceleration (g)
0.5
0
-0.5
Yaw Rate (deg/sec)
40
20
0
-20
-40
5
6
7
8
9
Time (sec)
Time (sec)


Vehicle J - Maximum Speed
Speed (mph)
70
68
66
64
62
60
58
56
54
0
5
10
15
20
25
30
Time (sec)
Max South = 68.2 mph
Max North = 63.7 mph
Max Average = 66.0 mph
Southbound
Northbound


Vehicle J - Steering Ratio
Right Steering Ratio = 12.9109 deg/deg
Left Steering Ratio = 13.3995 deg/deg
Average Steering Ratio = 13.1552 deg/deg
Right Wheel Steer Angle (deg)
Left Wheel Steer Angle (deg)
Steering Wheel Angle (deg)
40
20
0
-20
-40
-600
-400
-200
0
200
400
600