TRANSPORT ENGINEERING RESEARCH NEW ZEALAND LIMITED

Tilt Table Tests - SRT Calculator Validation

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Acknowledgements

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Mills Tui Ltd who provided the tilt table and an operator.

McCarthy Transport Ltd who provided the test vehicle and a driver.

Tilt Table Tests - SRT Calculator Validation

Summary

The SRT predicted by the SRT calculator and Yaw Roll simulation software was in very good agreement with that measured on the Mills Tui tilt table. The differences between predicted and measured SRT was no greater than 4.5 % and smaller than the test to test variability of the tilt table measured SRT.

When conducting tilt tests to determine SRT for compliance purposes it is recommended that a minimum of three tilt tests be conducted on both the left and right sides of a test vehicle with the suspensions being equalised between each test. The tilt rate should be no greater than 0.25 degree/s when nearing suspension lash and wheel liftoff. The difference in tilt angle measured at each lifting ram should be less than 0.5 degrees.

1 INTRODUCTION

A series of tilt tests as conducted on a fully loaded 4 axle logging trailer using the Mills Tui tilt table.

The primary purpose of the tests was to provide data on this vehicle's Static Rollover Threshold (SRT) that could be used to compare with the SRT predicted from the SRT Calculator[1] [1] developed for the Land Transport Safety Authority (LTSA).

The tilt table tests were also used to compare the measured SRT with that predicted from the Yaw/Roll[2] software [2] and to compare the tilt table test procedure with the Society of Automotive Engineers (SAE) heavy vehicle tilt table testing recommended practice J2180[3] [3].

1.1 Background

LTSA's proposed Vehicle Dimension and Mass Rule (Rule 41001) will require that all trailers over a Gross Vehicle Weight (GVW) of 10 tonnes will need to be retrospectively certified to meet an SRT of 0.35 g. Because of this proposed requirement the SRT calculator was developed to enable certifying engineers to confidently and accurately determine SRT. Part of the development process was to validate the SRT Calculator against tilt table tests and other, more detailed simulation software.

[1] The SRT Calculator is internet based software developed for LTSA to allow the determination of SRT with minimal required input data.
[2] Yaw/Roll software was developed by the University of Michigan's Transport Research Institute for the purpose of predicting the directional and roll response of single and multiple articulated vehicles up to the rollover limit.
[3] J2180 is the SAE's recommended procedure for determining SRT for heavy trucks with a tilt table.

2 THEORY

A tilt table can be used to simulate the roll plane behaviour of a vehicle in a steady turn. The test vehicle is tilted to an angle ϕ on a table inclined in the roll direction see, Figure 1. In this state, one component of gravity (gSinϕ) acts laterally while the other component (gCosϕ) acts perpendicular to the simulated road surface (the table surface). Assuming (gCosϕ) simulates gravity then, the simulated lateral acceleration (in simulated g's) is (gSinϕ)/(gCosϕ) or Tanϕ. Therefore if the tilt table angle is slowly increased, the tangent of the tilt angle at which the vehicle rolls over can estimate the lateral acceleration (in g's) at which the static roll stability of the vehicle is reached. Tilt tests should be conducted at a very low rate of change in tilt angle. The dynamic response of the test vehicle as it transitions various events (suspension lash, wheel liftoff) of the tilt table procedure is typically very low. An example is when the roll stability limit is reached and the vehicle begins to "fall" it accelerates very slowly. If the tilt rate is too fast identifying the point of instability is difficult.

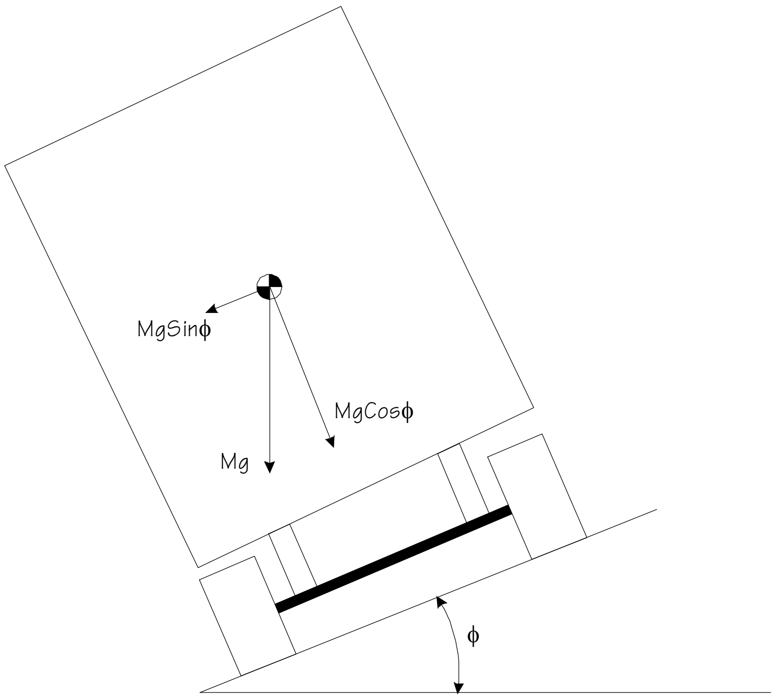

Figure 1: Tilt Table Roll Notation

How well the tilt table simulation predicts the roll stability of the vehicle during a steady turn depends primarily on how closely Cosϕ approximates unity. On the tilt table gCosϕ represents gravitational acceleration of one g and gSinϕ represents a lateral acceleration of gTanϕ. Because of the reduced loading perpendicular to the tilt table bed, the vehicle may rise on its compliant tyres and suspensions relative to it's normal ride height, resulting in a higher centre of gravity position and possibly, an unrealistically low static rollover threshold. On the other hand the simulated lateral acceleration is also reduced. This may result in compliant and lateral roll motions of the vehicle that are unrealistically small tending to make the vehicle appear more stable than it actually is. That is, the two effects tend to offset each other. For loaded commercial vehicles, these error sources are generally small, since rollover will usually occur at a simulated lateral acceleration of less than 0.5 g, that is a tilt angle (ϕ) of less than 27 degrees, ($\text{Cos}\phi \geq 0.9$).

3 TEST PROCEDURE AND DATA ACQUISITION

3.1 Test Procedure

To ensure that the static rollover threshold can be determined with sufficient accuracy and to allow for test variations, a minimum of six tests should be conducted. The test procedure followed that recommended by the SAE J2180 [3] with the exceptions that the suspensions were not equalised after each lift, the orientation of the vehicle was not reversed (load/suspension eccentricity test), the lift rate was not controlled to less than 0.25 degrees/sec and the tilt angle alignment at each axle group was not less than ± 0.1 degrees.

The steps that were taken were:

1. Position vehicle on tilt table; align axles within ± 25 mm of the tilt axis.
2. Attach restraint chains, initially allowing the minimum unconstrained roll motion
3. Attach measurement equipment
4. Conduct preliminary tests to adjust restraints
5. Conduct tests 1 – 6, to determine the point at which all wheel lift off occurs
6. Record angles as suspension lash is encountered and at all wheel lift off
7. Remove vehicle and equalise suspensions by taking for at short road trip
8. Repeat steps 1 – 7 for tests 7 – 12.

3.2 Data Acquisition

Data was acquired from two dual axis tilt sensors and a displacement transducer, at a sampling rate of 30 Hz. The analogue signals from the transducers were filtered at 10 Hz, using a low-pass filter, prior to digital conversion and recording. An extra channel where the voltage could be varied at a button push, was also recorded to mark events during the data acquisition. A laptop computer, Intel Celeron 333, running a 16-channel analogue to digital converter in the form of a PCMCIA card (IO-Tech) data acquisition system was used to record the signal inputs. A total of 6 channels were recorded.

The recorded signals were post processed by digitally filtering with a one hertz, eight pole, Butterworth filter in MATLAB™ and by converting the voltage signals to engineering units. Conversion factors for each transducer are listed in APPENDIX E.

Figures 2 - 3 show the tilt sensor placement for tests 1 – 6, Figure 4 shows the tilt sensor placement for tests 7 – 12. The tilt sensor placement for tests 1 – 6 allowed the tilt angle at each axle group to be recorded, while the placement for tests 7 – 12 meant the sprung mass roll angle could be recorded. The displacement transducer was placed so that the movement of the sprung mass relative to axle three could be measured.

Figure 2: Tilt Sensor Placement, tests 1 – 6, front axle group (box clamped to tilt table)

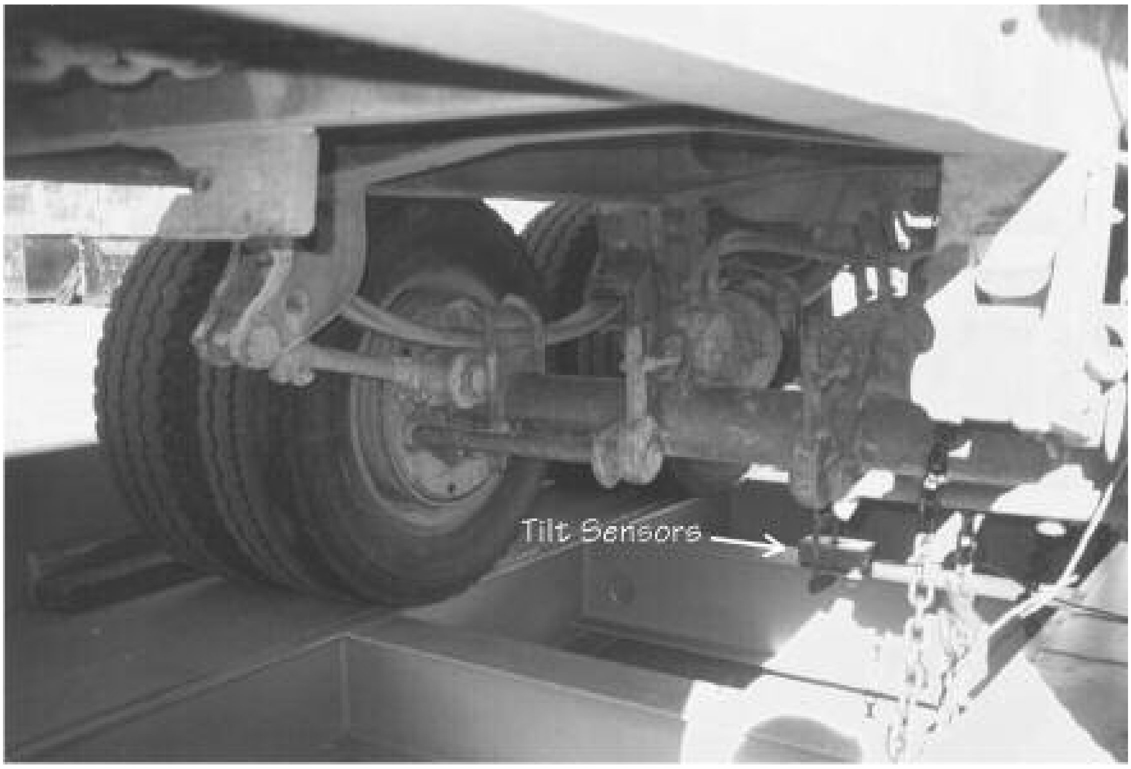

Figure 3: Tilt Sensor Placement, tests 1 – 6, rear axle group (box clamped to tilt table)

Figure 4: Tilt Sensor Placement, tests 7 – 12

4 VEHICLE SPECIFICATIONS AND LOADING

Table 1 lists the dimensions and masses of the test vehicle.

Table 1: Vehicle dimensions and masses

Vehicle	McCarthy Transport # 23 (4 Axle Trailer)	
Wheelbase (m)	4.620	
Tare weight (tonnes)	4.680	
Tyre size	265/70R19.5	
Drawbar length (m)	3.303	
Rear overhang (m)	1.273	
Log length (m)	5.500	
	Front axle group	Rear axle group
Bolster bed height (m)	1.420	1.420
Payload Height (m)	3.17 – 3.32	3.17 – 3.32
Track width (m)	0.790	0.790
Dual tyre gap (m)	0.300	0.300
Spring track (m)	1.07	1.07
Lash (m)	0.025	0.042
Spring hanger height (m)	0.680	0.710
Axle group spacing (m)	1.245	1.245
Axle group load (tonnes)	10.08	9.84

5 RESULTS

5.1 Tilt Table Tests

After the first six tests and before the vehicle was removed from the tilt table to equalise the suspensions the bolster bed height was measured at the front and rear bolsters on the left and right sides.

Table 2: Bolster Bed heights during testing

	Bolster	Left	Right
Before Equalise	Front	1.43	1.405
	Rear	1.41	1.405
After Equalise	Front	1.42	1.42
	Rear	1.42	1.42

This highlights the effect of coulomb (stickslip) friction in the suspension and linkages and the need to equalise the suspensions after each test if possible. The effect of not equalising the suspensions on the simulated SRT is small, but can have a pronounced effect on the point of suspension lash and first wheel liftoff.

Figures 5 - 8 plot the recorded data for a selection of the twelve tilt tests. Data plots for all twelve tests are included in APPENDIX A. For tests 1 – 6 a description of the legend labelling is shown in Table 3. For tests 7 – 12 a description of the legend labelling, where different from tests 1 – 6, is shown in Table 4.

Table 3: Legend label description, tests 1 - 6

Legend label	Description
Displacement	Displacement Transducer mounted between sprung mass and axle three at the outside of the spring, uphill side of vehicle.
Align Front	Tilt sensor measuring longitudinal bed alignment at the front axle group
Tilt Front	Tilt sensor measuring tilt angle at the front axle group
Align Rear	Tilt sensor measuring longitudinal bed alignment at the rear axle group
Tilt Rear	Tilt sensor measuring tilt angle at the rear axle group
Event	Used to mark data files at specific events i.e. suspension going through lash

Table 4: Legend label description, tests 7 - 12

Legend label	Description
Long Align	Tilt sensor measuring longitudinal bed alignment half way between the front and rear axle groups
Tilt Table	Tilt sensor measuring tilt angle half way between the front and rear axle groups
S M Long	Tilt sensor measuring longitudinal alignment of the sprung mass
S M Tilt	Tilt sensor measuring tilt angle of sprung mass

Perfect tilt alignment along the tilt table bed would mean the ‘Tilt Front’ and ‘Tilt Rear’ lines in Figures 5 and 6 would be on top of each other. Figure 5 is an example of typical levels of tilt alignment along the bed, Figure 6 is from test 3 where the best level of tilt alignment was achieved. Figures 7 and 8 are examples from tests 7 – 12, in these tests one of the tilt sensors had been mounted on the vehicle sprung mass, this is highlighted by the divergence of the ‘S M Tilt’ and ‘Tilt Table’ lines.

Not all tests were continued through to the point of all wheel lift off. Comments recorded for each test are shown in Table 5. At the point of all wheel lift off the simulated lateral acceleration will be equal to the SRT. All wheel lift off occurred in tests 6 – 12. Table 6 lists the simulated lateral acceleration for each of these tests. In some of these tests the table was tilted past the point of all wheel lift off and therefore the simulated lateral acceleration will be higher than the actual SRT. The average simulated lateral acceleration (SRT) for tests 6 – 12 is 0.418 g with a standard deviation of 0.0073. This corresponds to a tilt angle of 22.68 degrees.

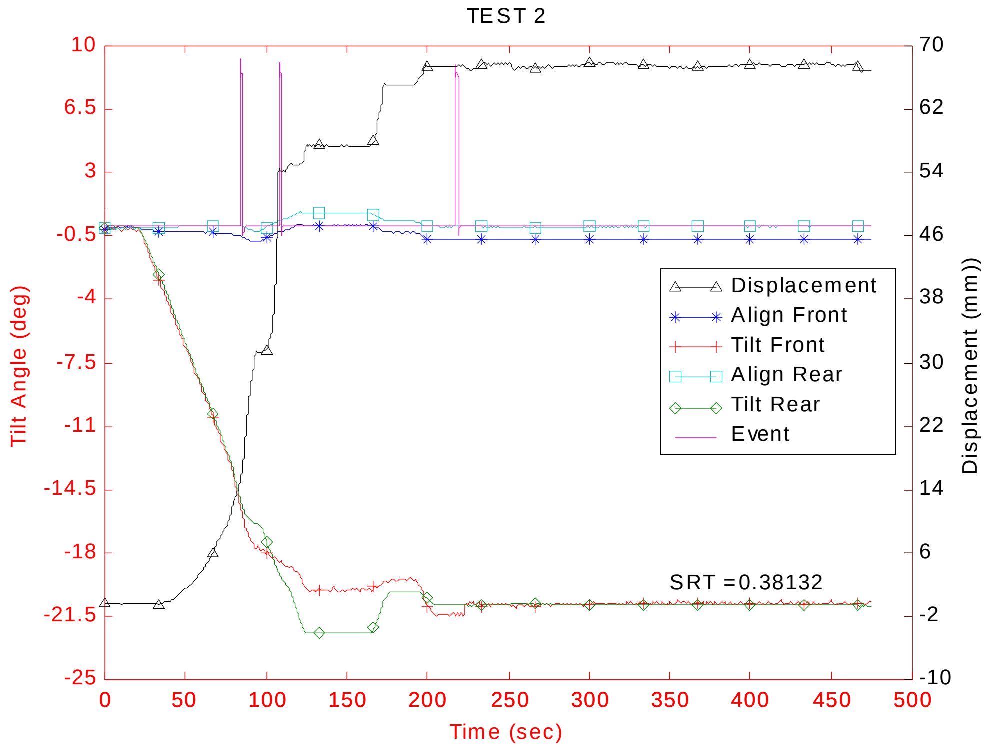

Figure 5: Data Plot for Test 2

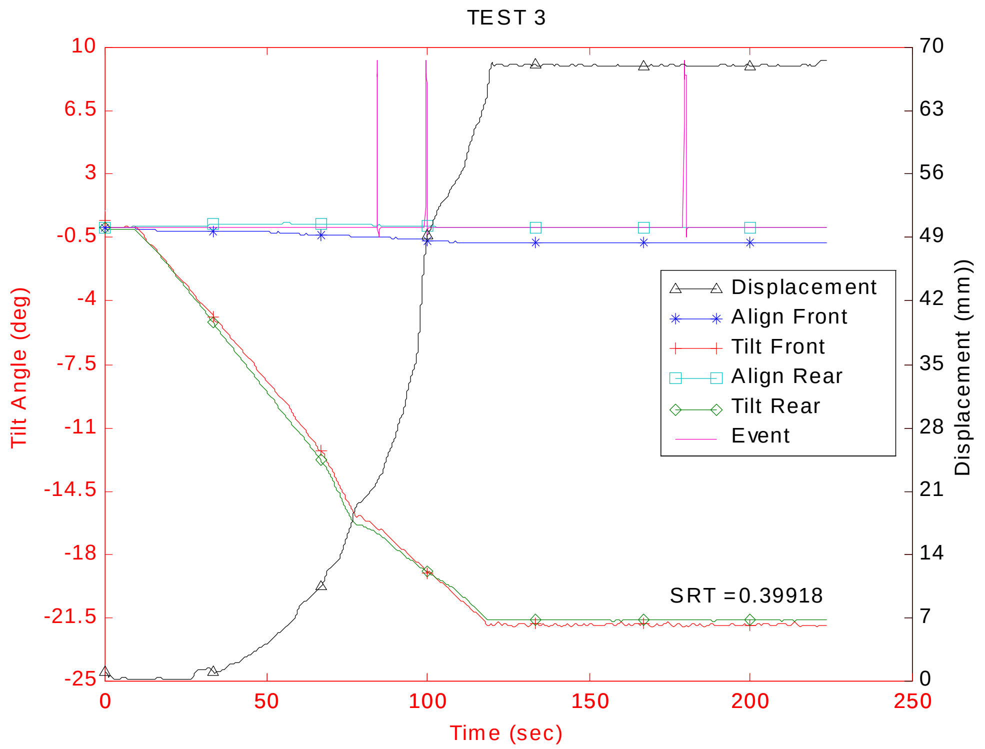

Figure 6: Data Plot for Test 3

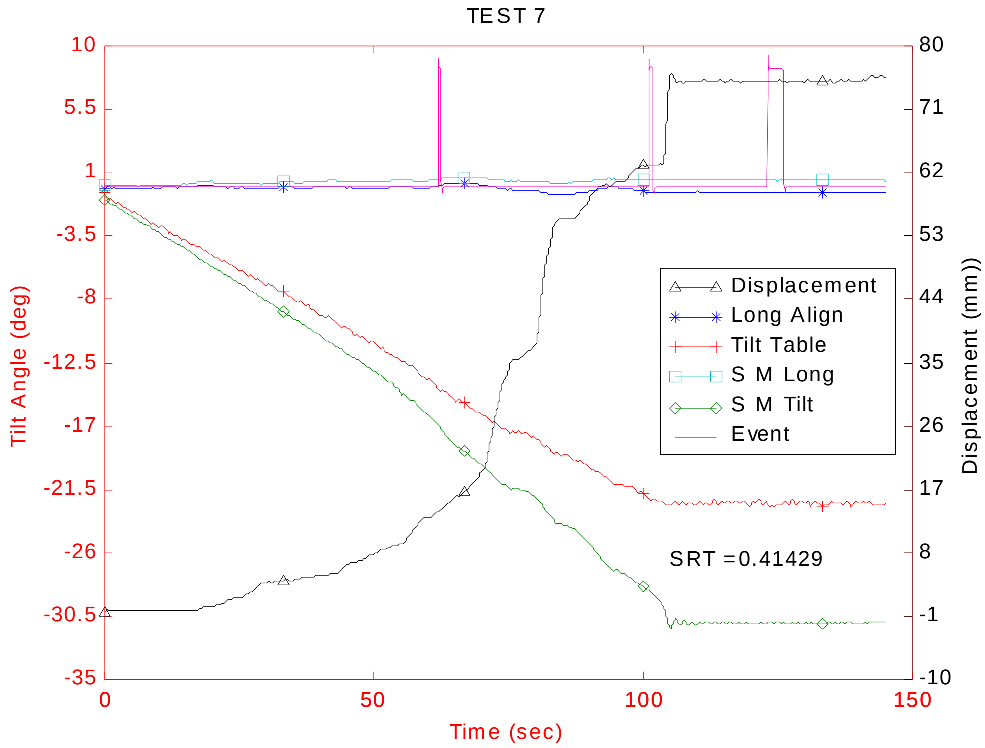

Figure 7: Data Plot for Test 7

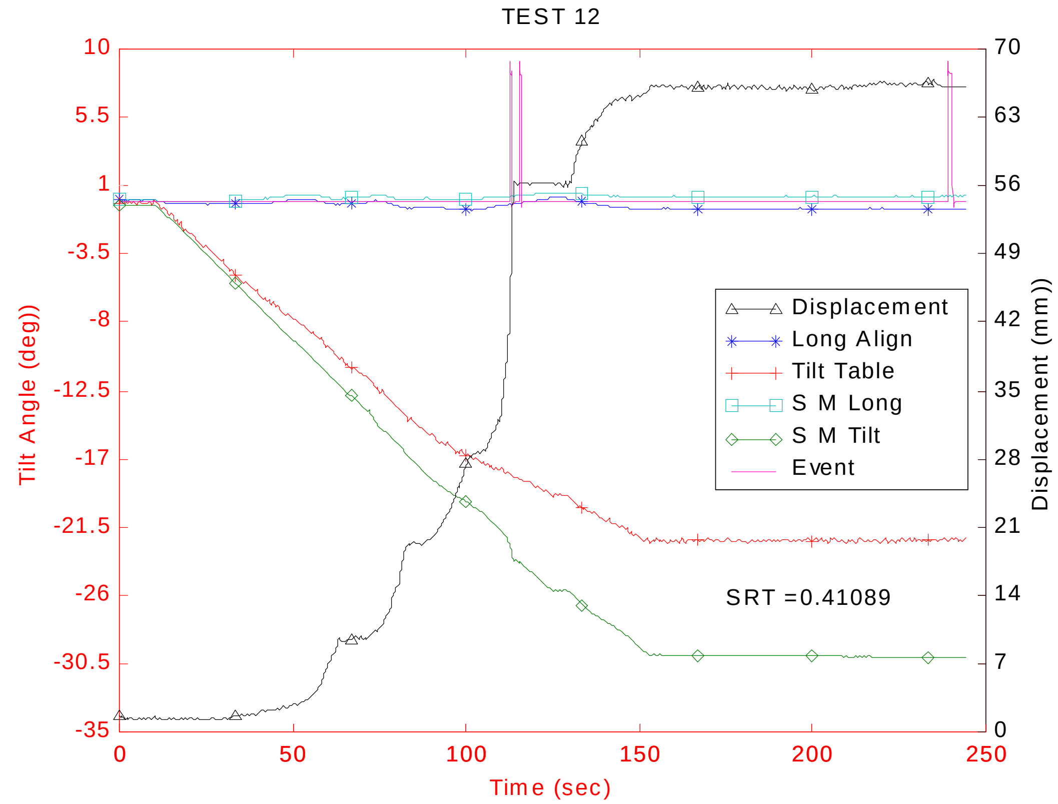

Figure 8: Data Plot for Test 12

Table 5: Test comments and event mark description

Test	Comments	Event Marks		
		1st	2nd	3rd
1	Didn't tilt to wheel lift off,	Lash front	Lash rear	
2	Shift restraints to outboard of springs Rear wheel lift only	Lash front	Lash rear	Lift rear
3	Rear wheel lift only	Lash front	Lash rear	Lift rear
4	Partial lift only, no wheel lift off	Lash rear		
5	Continuation of Test 4 Rear wheel lift off only	Lash rear	Lash front	Lift rear
6	Put digital level in operator position All wheel lift off	Lash front	Lash rear	Lift all
7	Shift position of tilt sensors	Lash front	Lash rear	Lift all
8	Bad longitudinal alignment in first part of lift	Lash front	Lash rear	Lift all
9	Longitudinal alignment 0.13	Lash front	Lash rear	Lift all
10		Lash front	Lash rear	Lift all
11	Equalise suspensions (road test) Front to rear axle group misalignment 40 mm	Lash front	Lash rear	Lift all
12	Holding on rear axle restraint chain	Lash front	Lash rear	Lift all
General observations for all tests:	- No cross wind - Right side axle four, outer dual tyre pressure down			

Table 6: Predicted SRT for test with all wheel lift off

TEST	Simulated Lateral Acceleration (g)	
6	0.42254	
7	0.41437	
8	0.41553	
9	0.4286	
10	0.42477	
11	0.40934	
12	0.41094	

Average	0.418013	22.69 degrees
Standard Deviation	0.007336	1.76 %

The simulated lateral acceleration for tests 2, 3 and 5 is shown in Table 7. For these tests only, one axle group was seen to lift off and therefore the simulated lateral acceleration will be lower than the true SRT for this vehicle/load combination.

Table 7: Simulated lateral acceleration for tests 2, 3 and 5

TEST	Simulated Lateral Acceleration (g)	
2	0.3813	
3	0.39912	
5	0.3986	
Average	0.393007	21.46 degrees
Standard Deviation	0.010142	2.58 %

Variances in the predicted SRT will be due to the tilt rate being to high, poor tilt angle alignment along the tilt table and coulomb friction in the springs and linkages.

A measure of the longitudinal alignment is the difference in tilt angles between the front and rear axle groups. This was measured for Tests 1 – 6 and is shown in Figures 9 and 10 for the best and an average test respectively. The positive and negative limit lines in the figures correspond to the SAE recommendation of ± 0.1 degree between axle groups [3]. Plots of tilt angle difference for tests 1 – 6 are shown in APPENDIX B. The minimum, maximum and range of misalignments between the front and rear axle groups for tests 1 – 6 is shown in Table 8. The smallest (best) range was 1.16 degrees for test 3, with an improved control system on the tilt table a range of 1.0 degrees or ± 0.5 degrees between axle groups should be readily attainable.

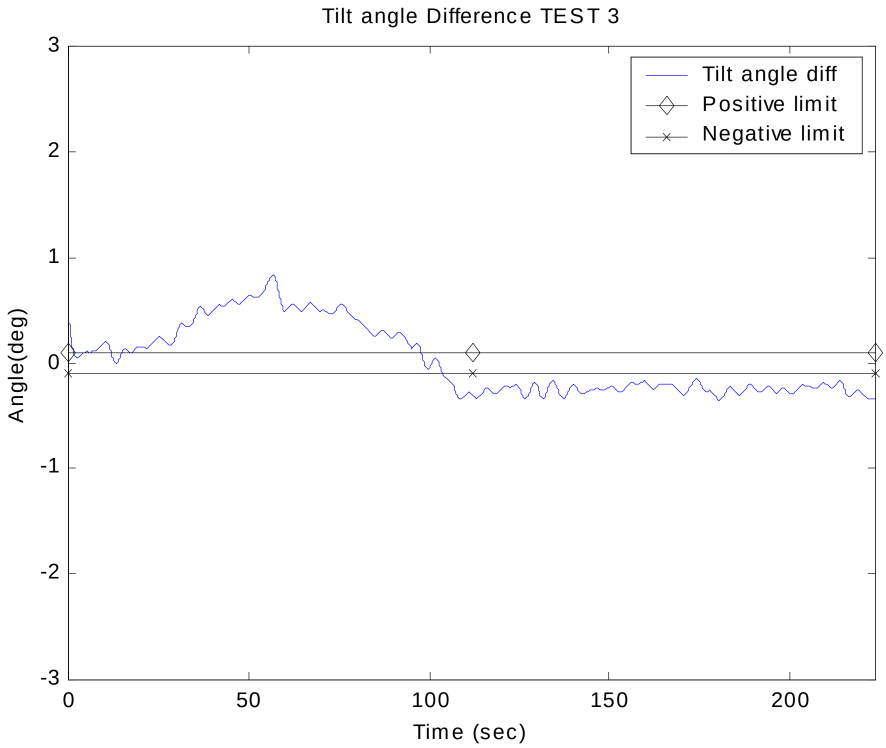

Figure 9: Tilt angle difference between front and rear axle groups – Test 3

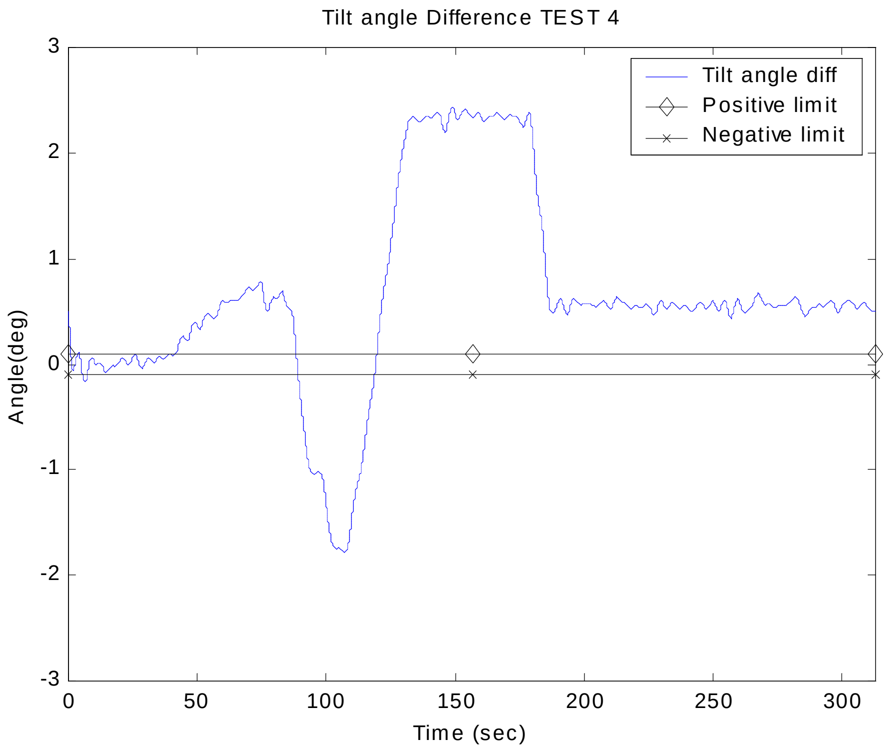

Figure 10: Tilt angle difference between front and rear axle groups – Test 4

Table 8: Minimum, Maximum and Range of alignment between front and rear axle groups for test 1 – 6

Test	Minimum (deg)	Maximum (deg)	Range (deg)
1	-2.5	1.97	4.47
2	1.38	2.52	3.90
3	-0.36	0.83	1.19
4	-1.79	2.44	4.22
5	0.09	2.03	1.94
6	-0.14	2.79	2.93

Figures 11 and 12 plot the tilt rate for tests 1 and 3 respectively, the limit line shown corresponds to the SAE recommendation ≤ 0.25 deg/s, tilt rate plots for tests 1 – 12 are shown in APPENDIX D.

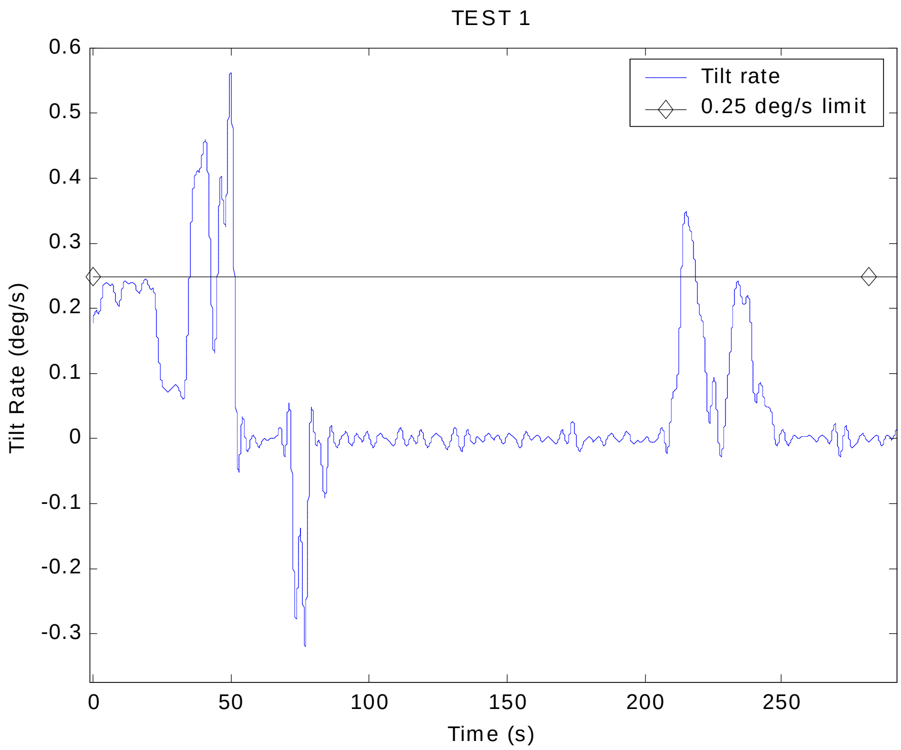

Figure 11: Tilt Rate – Test 1

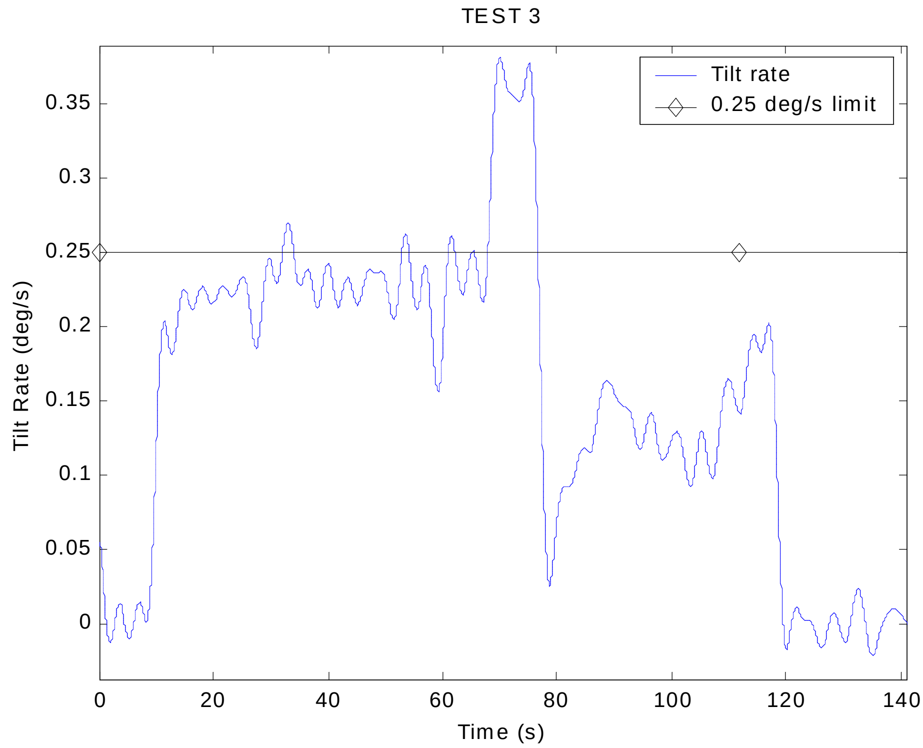

Figure 12: Tilt Rate Test 3

For tests 7 – 12, where the sprung mass roll angle was recorded, it is useful to plot the simulated lateral acceleration (i.e. tangent of the table angle) versus the sprung mass roll angle relative to the table. This allows points such as the suspension lash, wheel liftoff and the rollover point to be easily seen, a commented example is given in Figure 13, using data from test 10. Figure 14 is the same type of plot, but the points of interest are less discernable due to the table being realigned just after the rear axle group went through lash, after alignment the axle group had gone back through the lash. This highlights the need for good tilt angle alignment along the bed. The plots for tests 7 – 12 are shown in APPENDIX C.

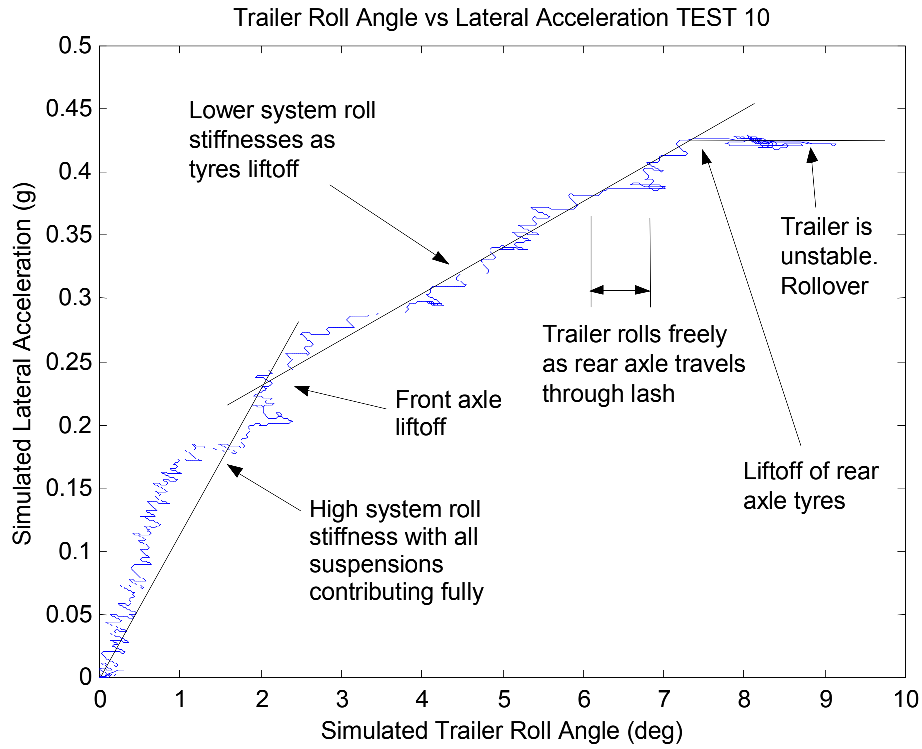

Figure 13: Trailer Roll Angle versus Lateral Acceleration – Test 10

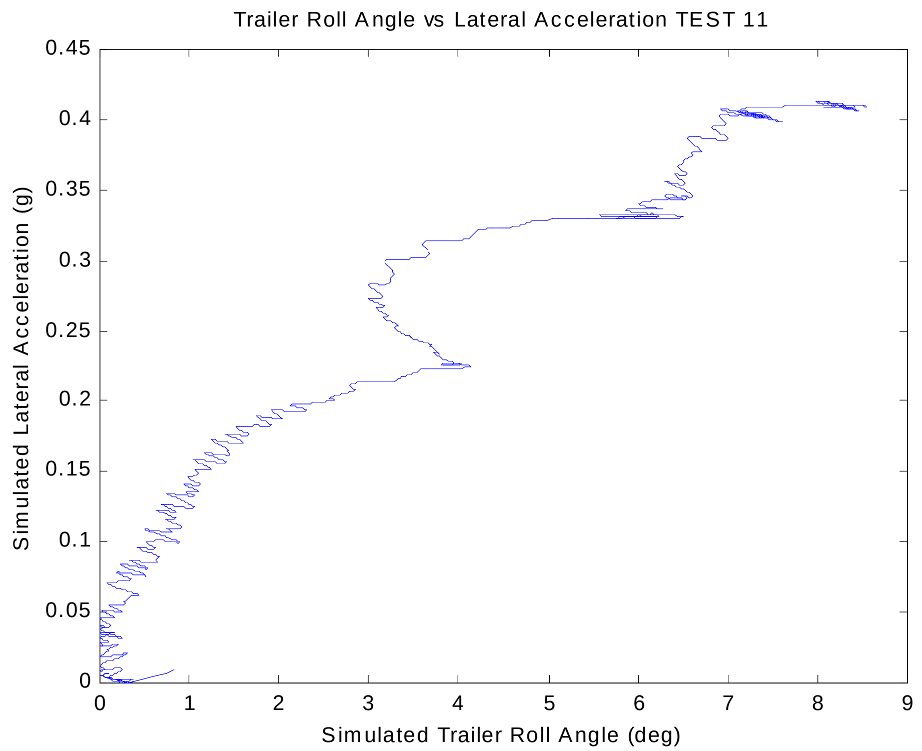

Figure 14: Trailer Roll Angle versus Lateral Acceleration – Test 11

5.2 SRT – Calculator and Yaw Roll

The predicted SRT for the test vehicle using the SRT calculator and Yaw Roll simulation software at two load heights and with different suspension options is listed in Table 9.

Table 9: Predicted SRT from SRT – calculator and Yaw Roll software

Load Height	Yaw Roll	SRT Calculator – Generic Steel	SRT Calculator – User defined suspension
3.17	0.428	0.407	0.415
3.32	0.421	0.391	0.399

The input data used for the SRT calculator and the Yaw Roll software is listed in APPENDIX F. The SRT was determined at two load heights because the precise load height was difficult to determine due to the crowning of the load. The two load heights were chosen from measurements of the load and covered the most likely equivalent load height range.

The Yaw Roll results were determined using an average suspension lash for all axles, using the actual suspension lash for each axle may have provided a better result.

6 DISCUSSION

6.1 Predicted and Tilt Test SRT Differences

The SRT predicted by the SRT calculator and Yaw Roll simulation software compared well with the SRT determined through the tilt table tests. Table 10 lists the SRT determined by each method and the percentage differences between tilt tests and predicted SRT.

Table 10: Predicted and Tilt Test SRT differences

	Load Height (m)	Predicted SRT[4]	Tilt Test SRT	Percentage Difference
SRT Calculator	3.17	0.415	0.418	0.7
	3.32	0.399	0.418	4.5
Yaw Roll	3.17	0.428	0.418	-2.4
	3.32	0.421	0.418	-0.7

The SRT determined using the SRT calculator under predicted the tilt table SRT, by 0.7 % and 4.5% for the 3.17 m and 3.32 m load height respectively. SRT determined using Yaw Roll was 2.4% and 0.7% greater than that measured for load heights of 3.17 m and 3.32 respectively. These differences are small and given the variability in the tilt test SRT agree remarkable well.

6.2 Tilt Testing Procedures

The tilt table testing procedure differs significantly from that recommended by SAE J2180. The lifting rate and the tilt angle alignment between the two lifting rams were the major sources of variability. Because a four axle trailer was used and it was positioned on the table with each axle group equi-distant from the two rams, the longitudinal position of the vehicle centre of gravity would have been close to the mid point between the two rams thereby minimising the effects of the longitudinal misalignment in this case. With an improved control system alignment of less than ± 0.5 degrees should be readily attainable.

The lifting rate in some cases was more than double the recommended maximum 0.25 degrees/s. In this case the effect on the SRT was small, but coupled with poor tilt bed alignment and the suspensions not being equalised between each test lead to significant variability in the tilt angle at which lash and first wheel lift off occurred.

The test vehicle was not tilted to the left side, as the layout of the tilt table did not allow for the trailer unit to be driven forwards onto the table. It is recommended that test vehicles be

[4] Using SRT values determined with the 'User defined' suspension option

tilted on both the left and right sides with a minimum of three tests per side and equalising the suspensions after each test.

7 REFERENCES

1. Land Transport Safety Authority, *Land transport rules. Vehicle Dimensions and Mass - Yellow Draft 18 April 2001*. 2001, Land Transport Safety Authority: Wellington, New Zealand. 70 p.
2. Gillespie, T.D., *Constant velocity yaw/roll program - User's manual*. 1982, University of Michigan Transportation Research Institute: Ann Arbor.
3. *A Tilt Table Procedure for Measuring the Static Rollover Threshold for Heavy Trucks*. 1998, SAE J2180: Warrendale. 8 p.

APPENDIX A DATA PLOTS

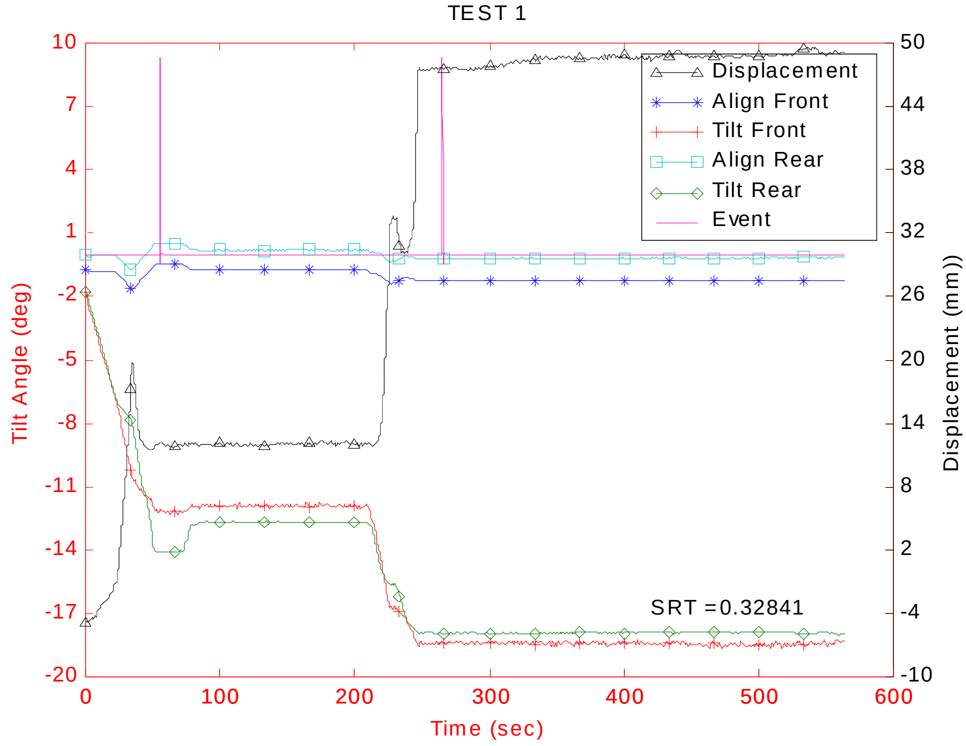

Figure 15: Test 1

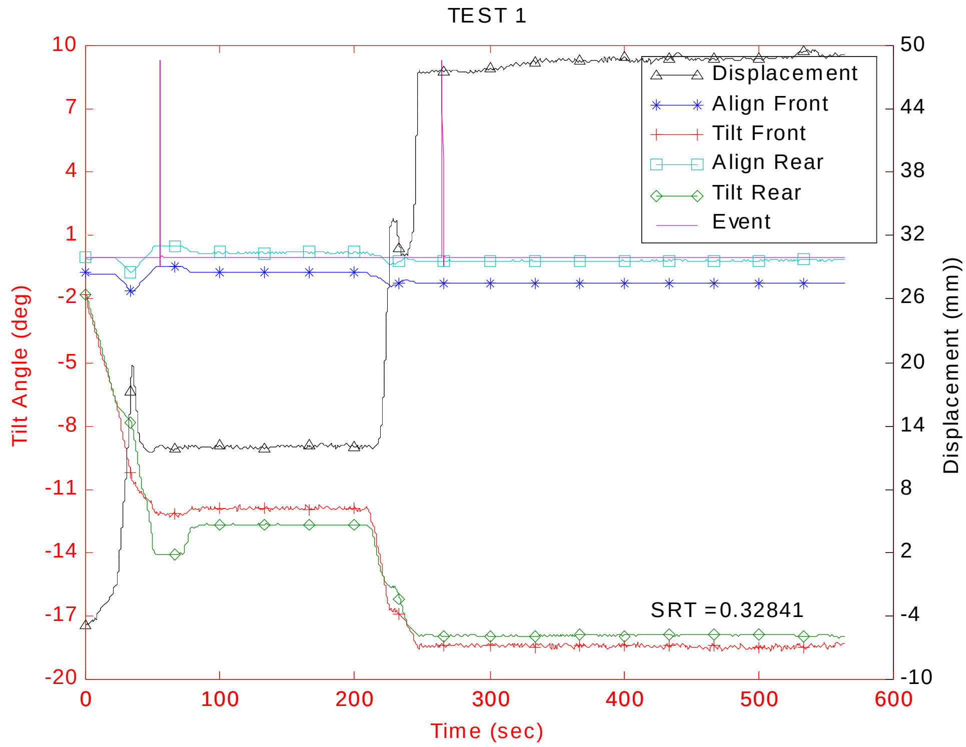

Figure 16: Test 2

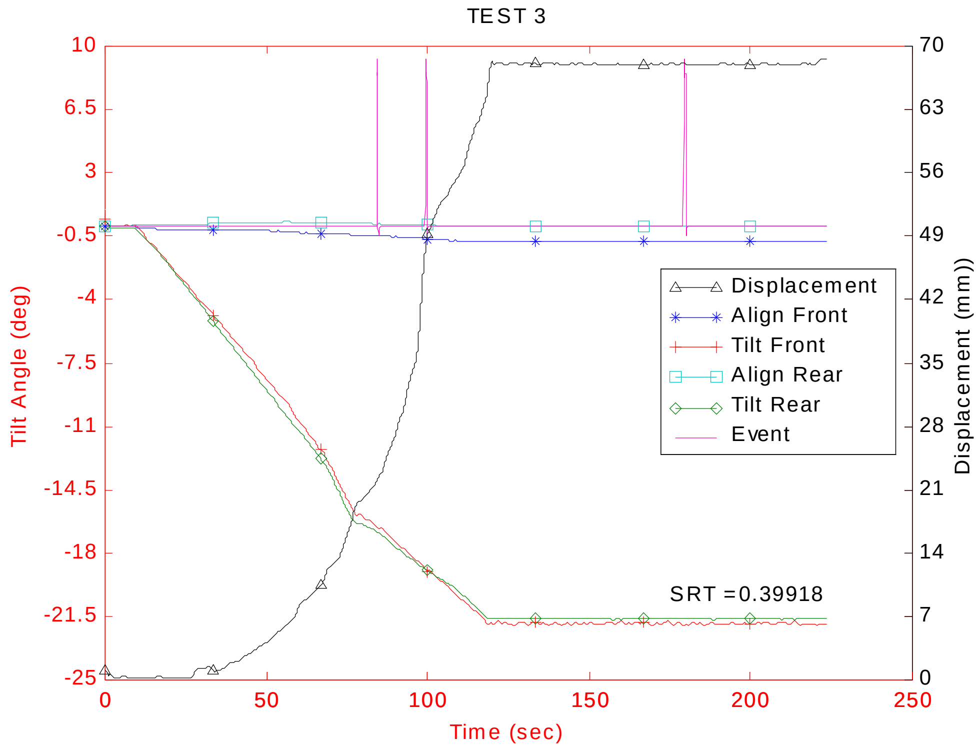

Figure 17: Test 3

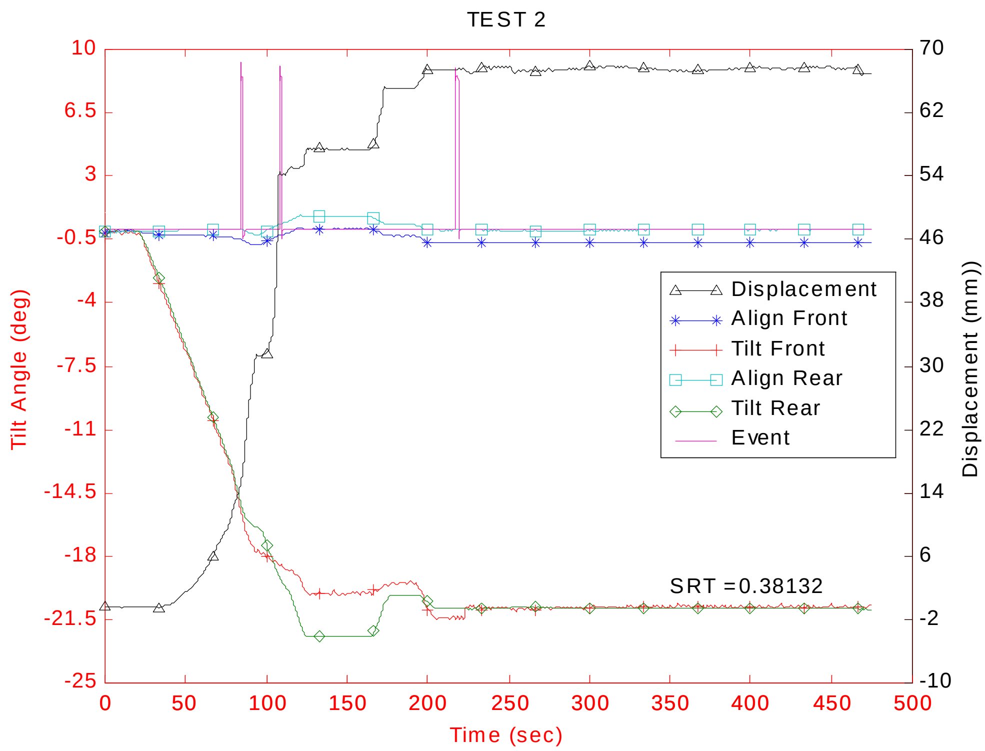

Figure 18: Test 4

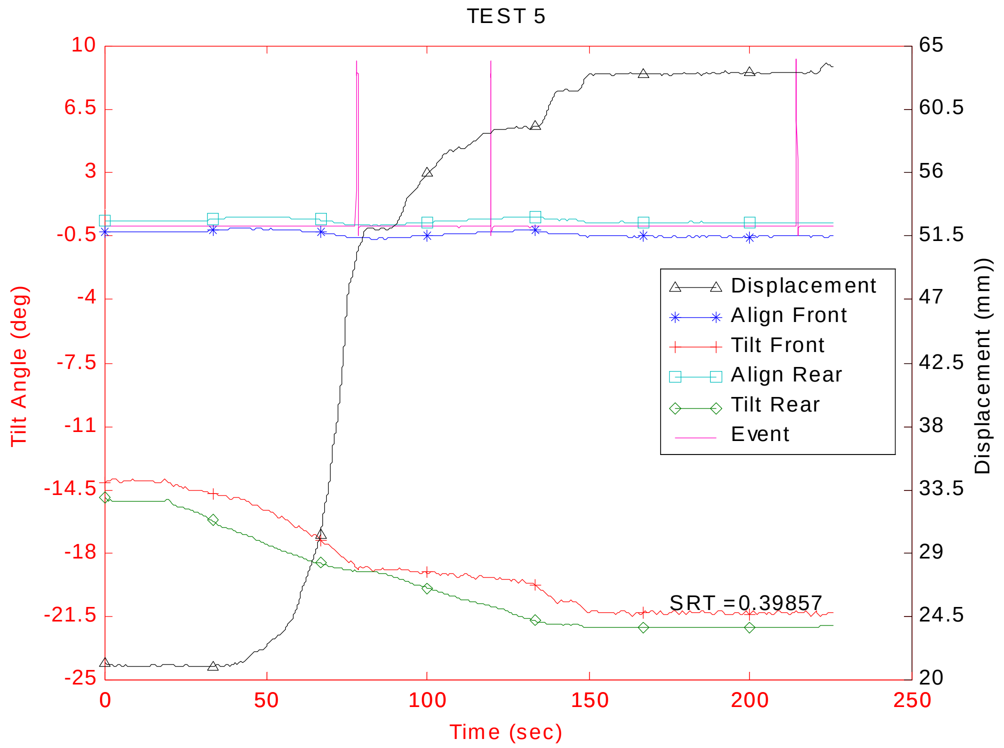

Figure 19: Test 5

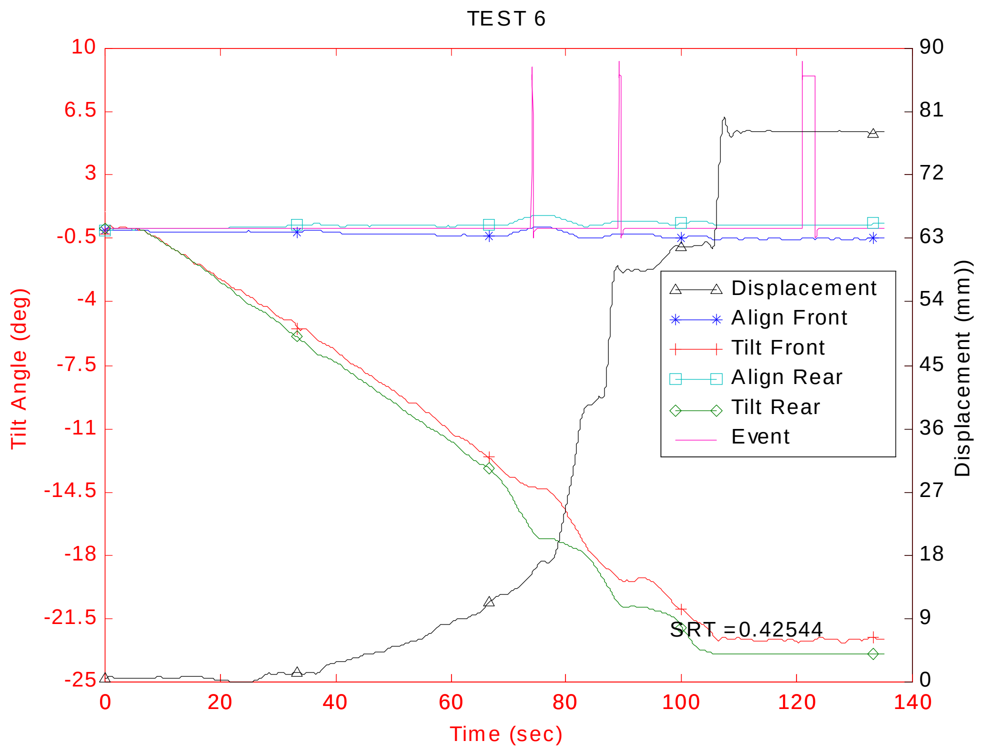

Figure 20: Test 6

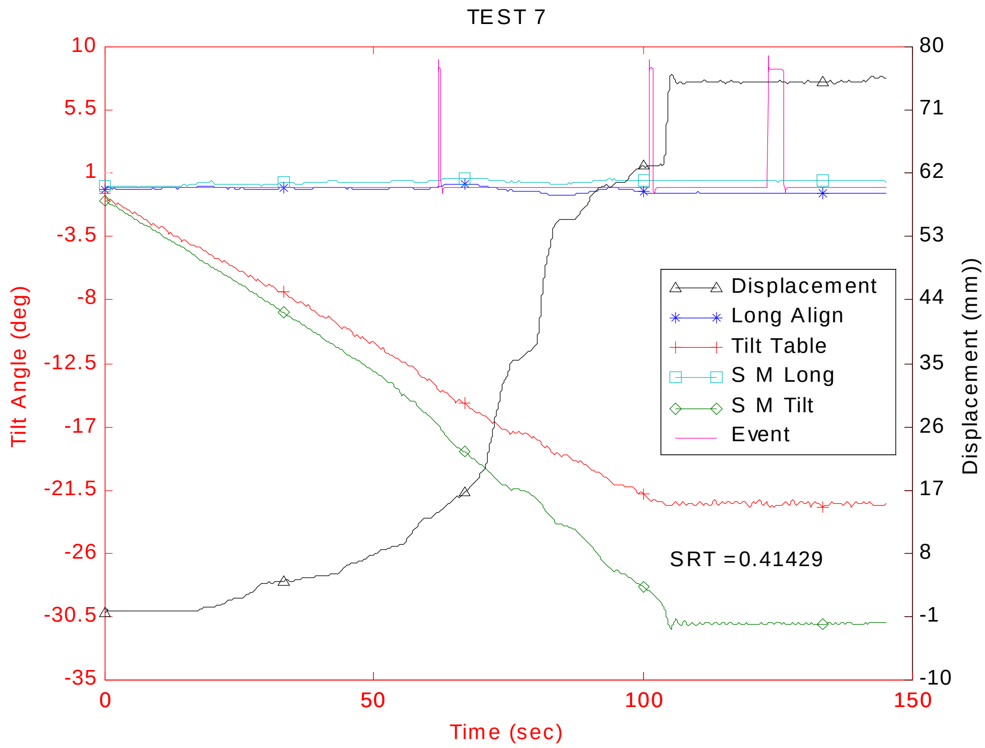

Figure 21: Test 7

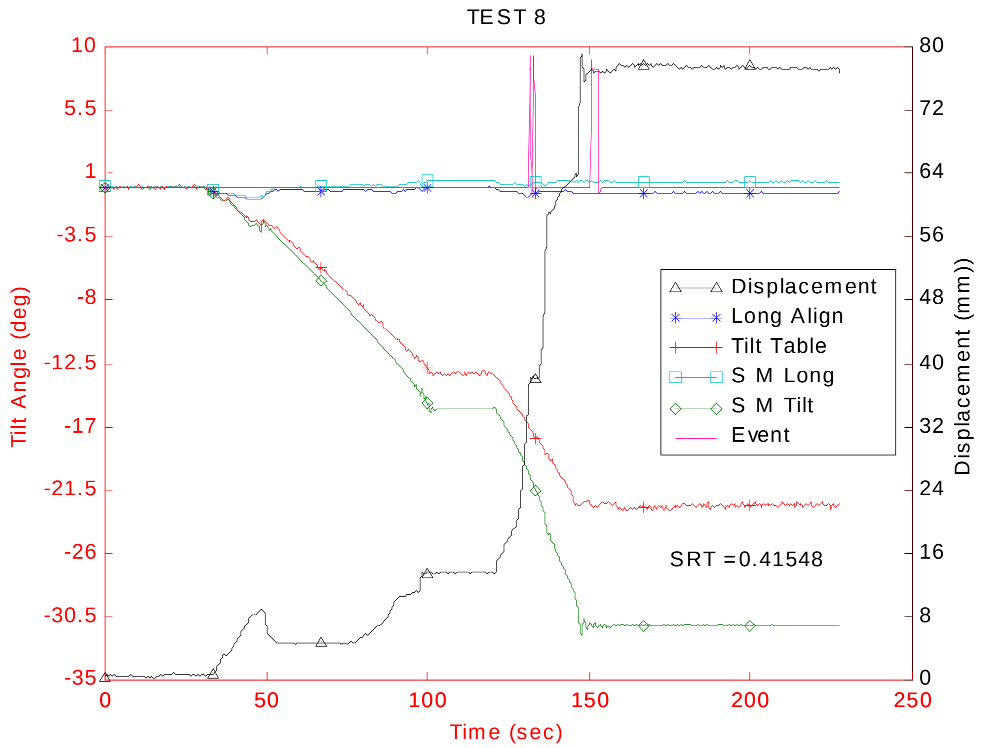

Figure 22: Test 8

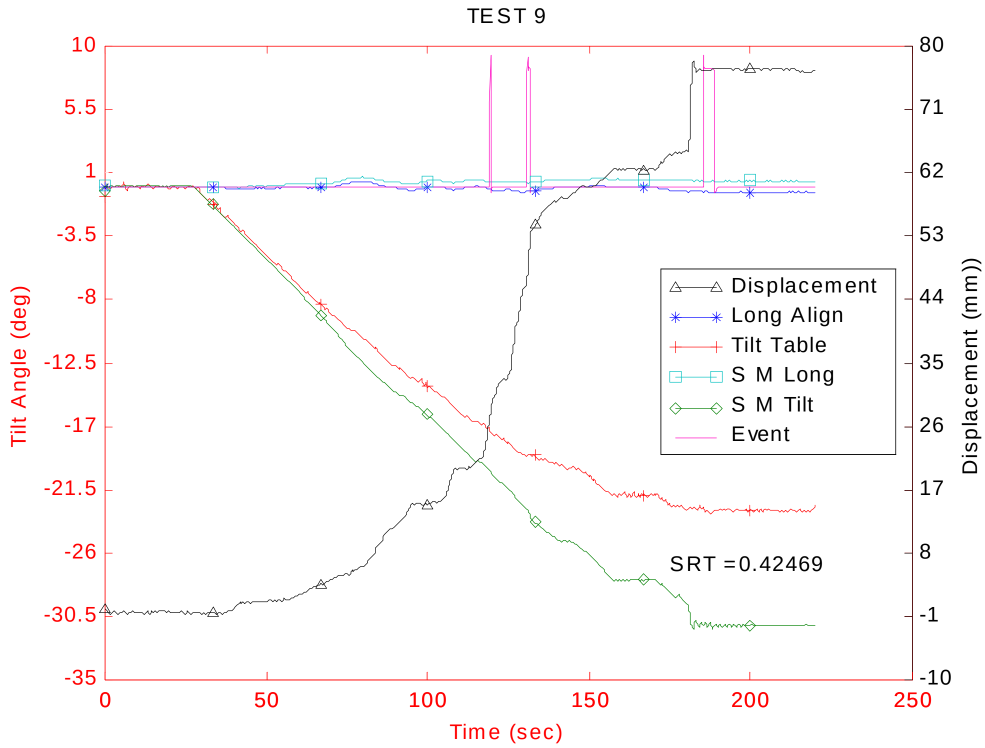

Figure 23: Test 9

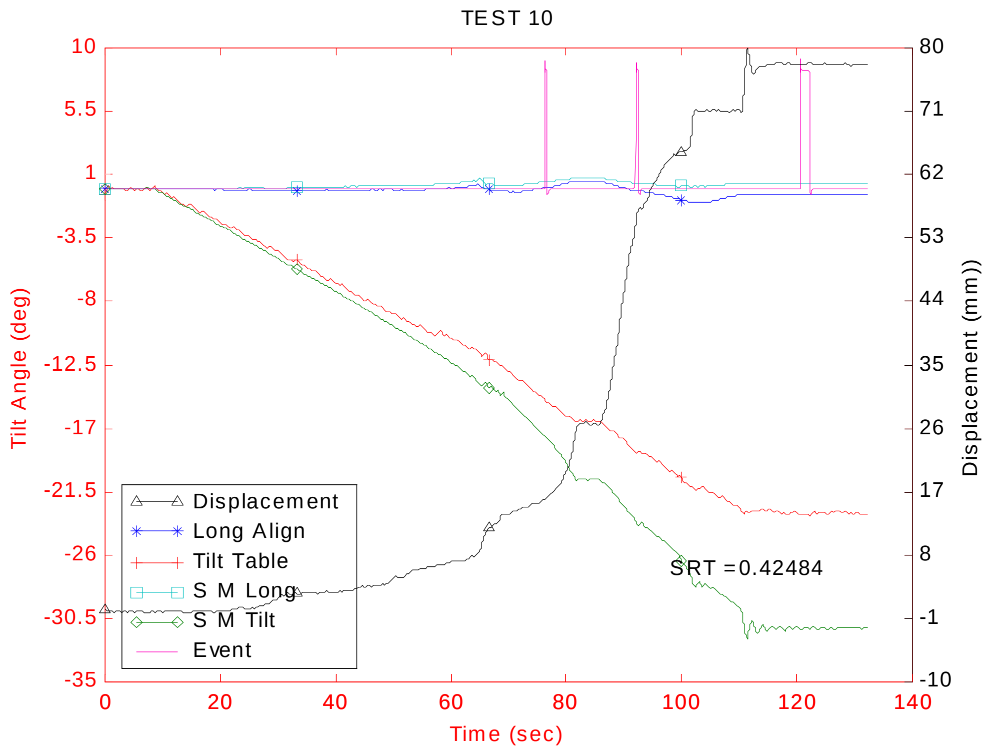

Figure 24: Test 10

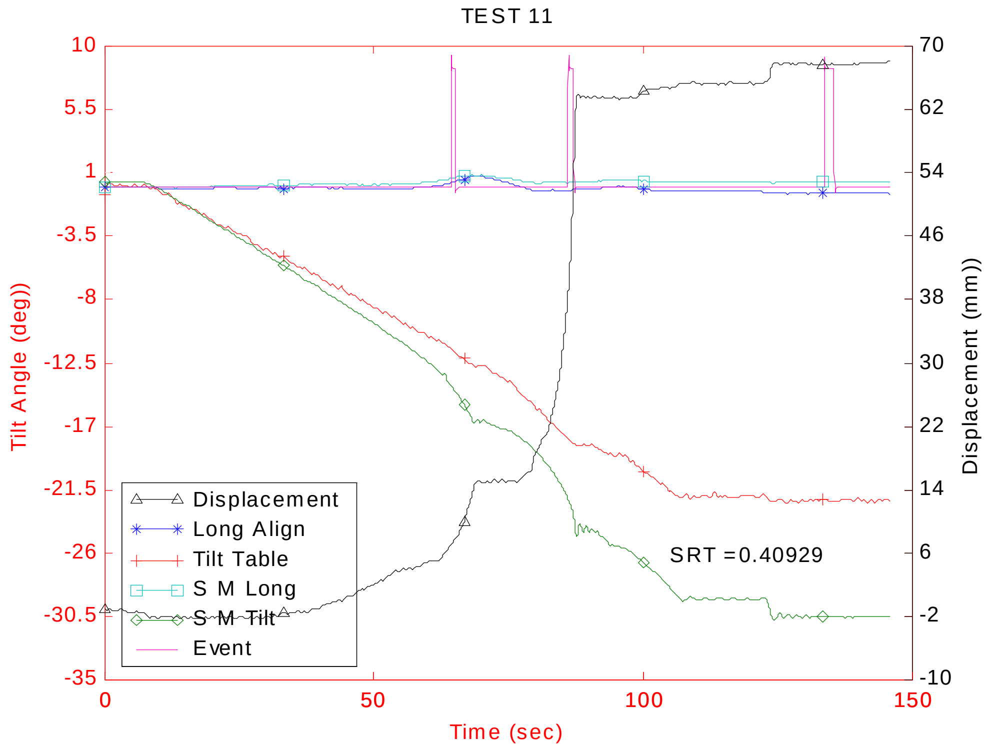

Figure 25: Test 11

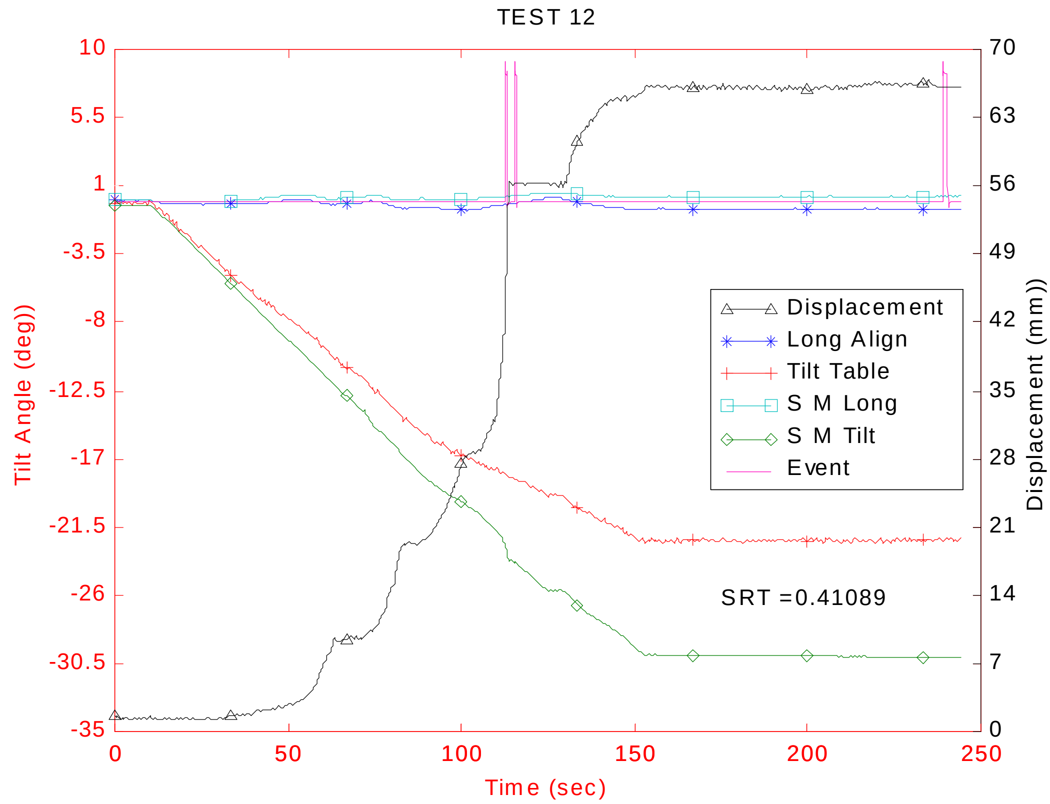

Figure 26: Test 12

APPENDIX B TILT ANGLE DIFFERENCE

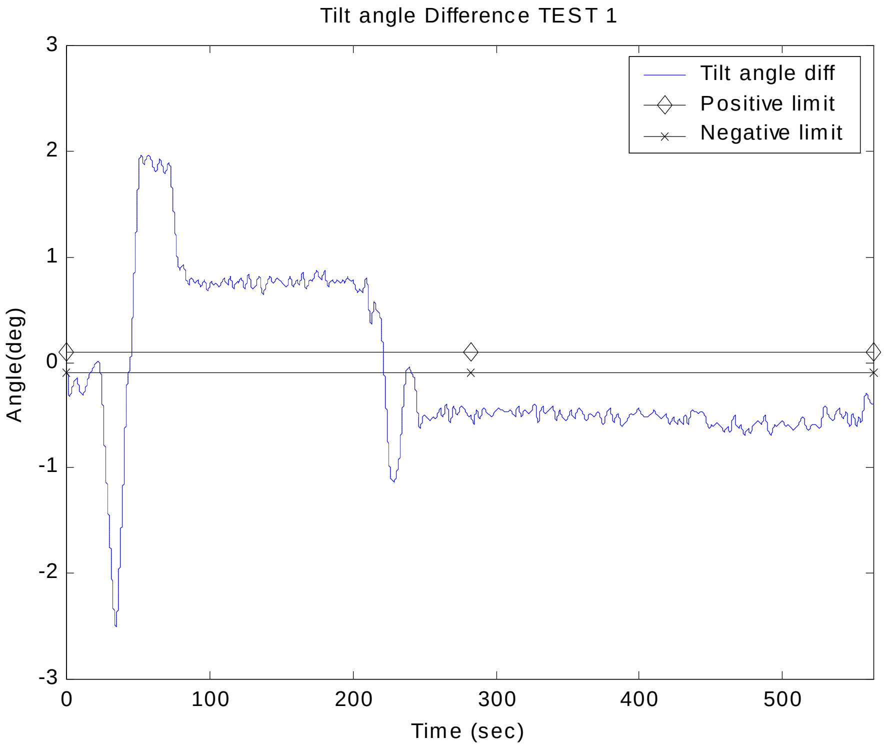

Figure 27: Tilt angle difference between front and rear axle groups – Test 1

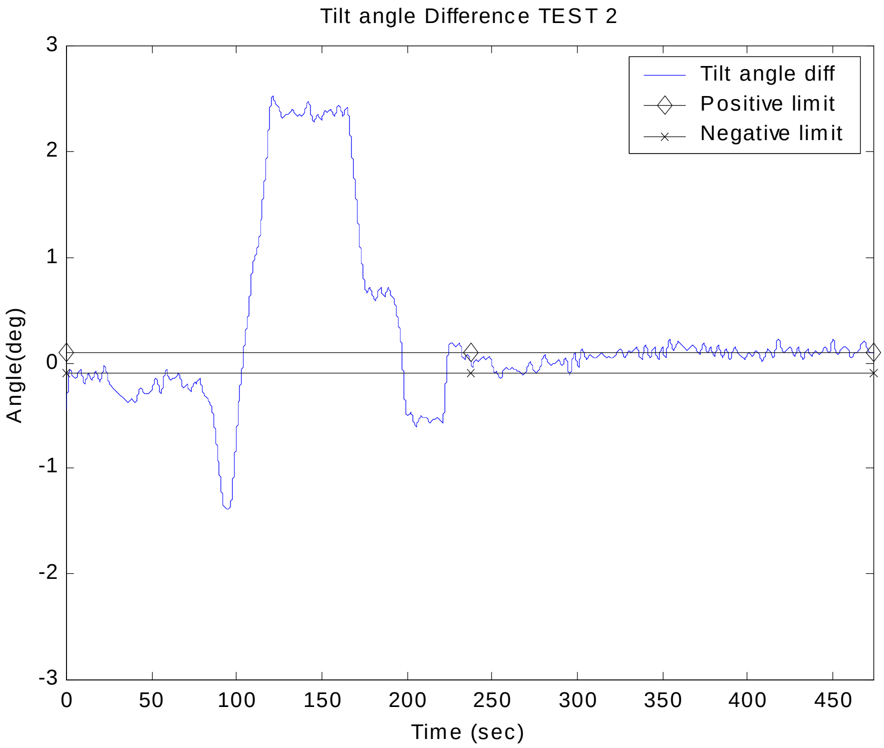

Figure 28: Tilt angle difference between front and rear axle groups – Test 2

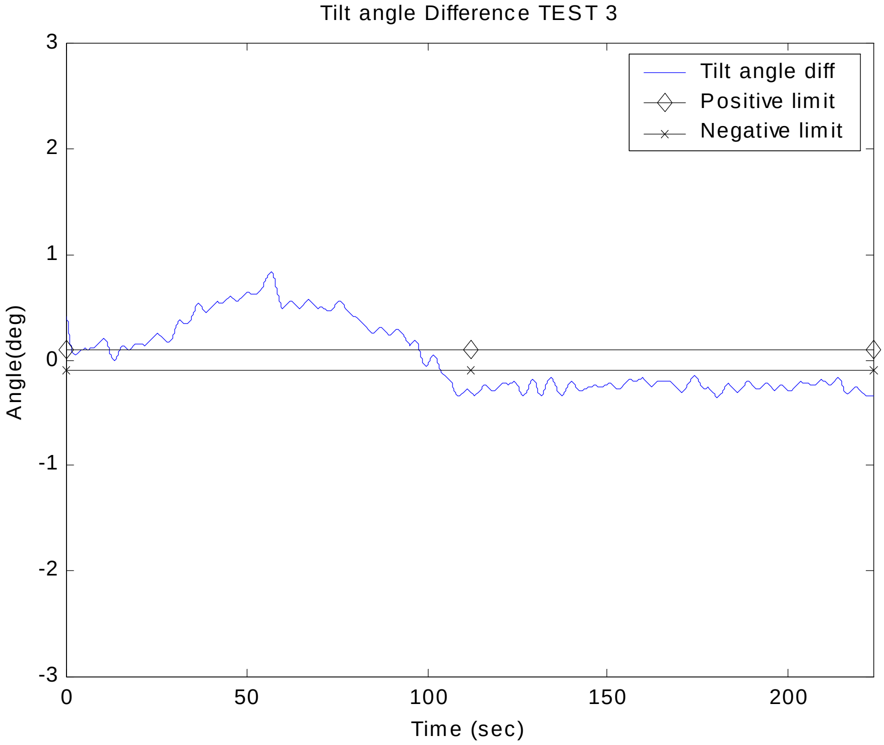

Figure 29: Tilt angle difference between front and rear axle groups – Test 3

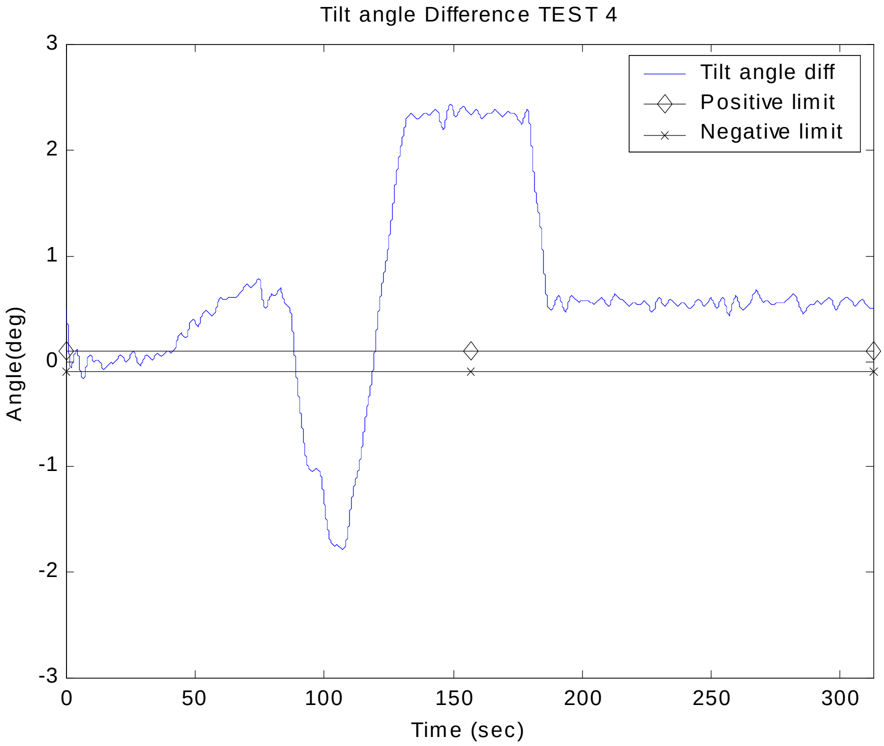

Figure 30: Tilt angle difference between front and rear axle groups – Test 4

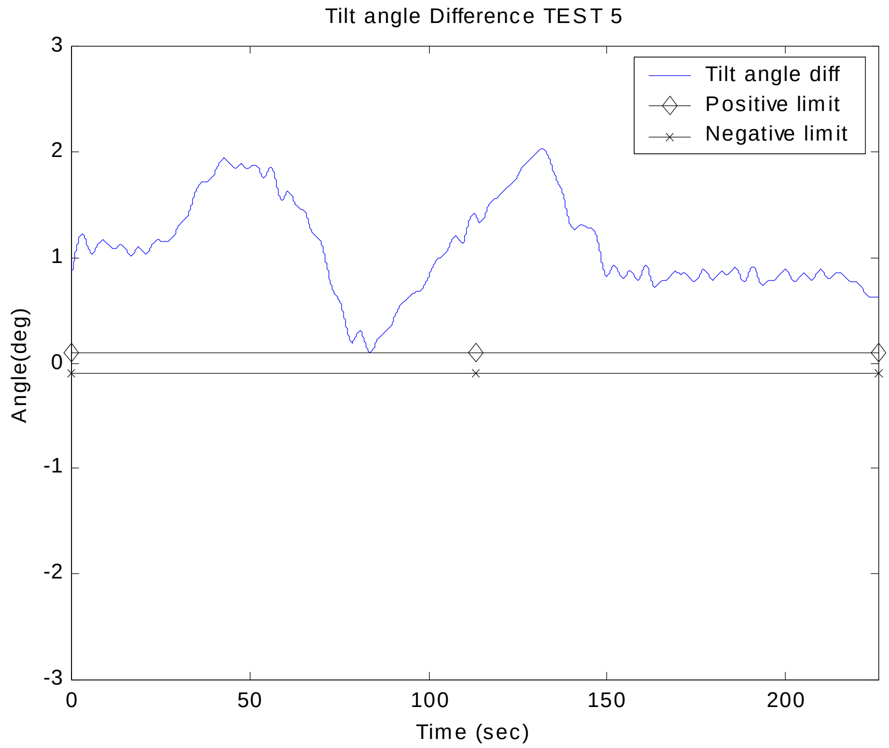

Figure 31: Tilt angle difference between front and rear axle groups – Test 5

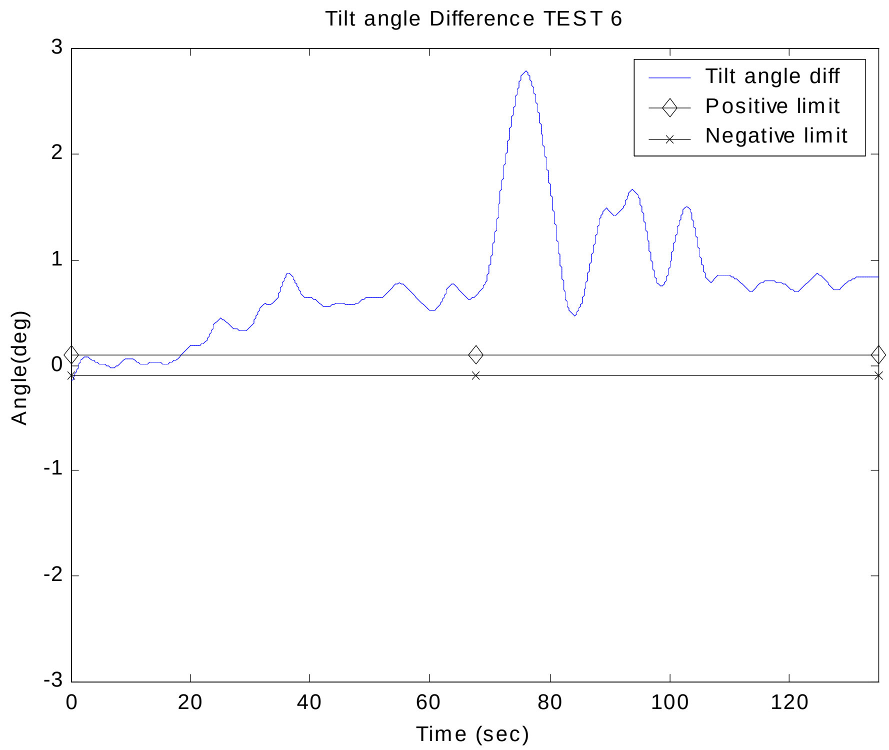

Figure 32: Tilt angle difference between front and rear axle groups – Test 6

APPENDIX C TRAILER ROLL ANGLE VERSUS LATERAL ACCELERATION

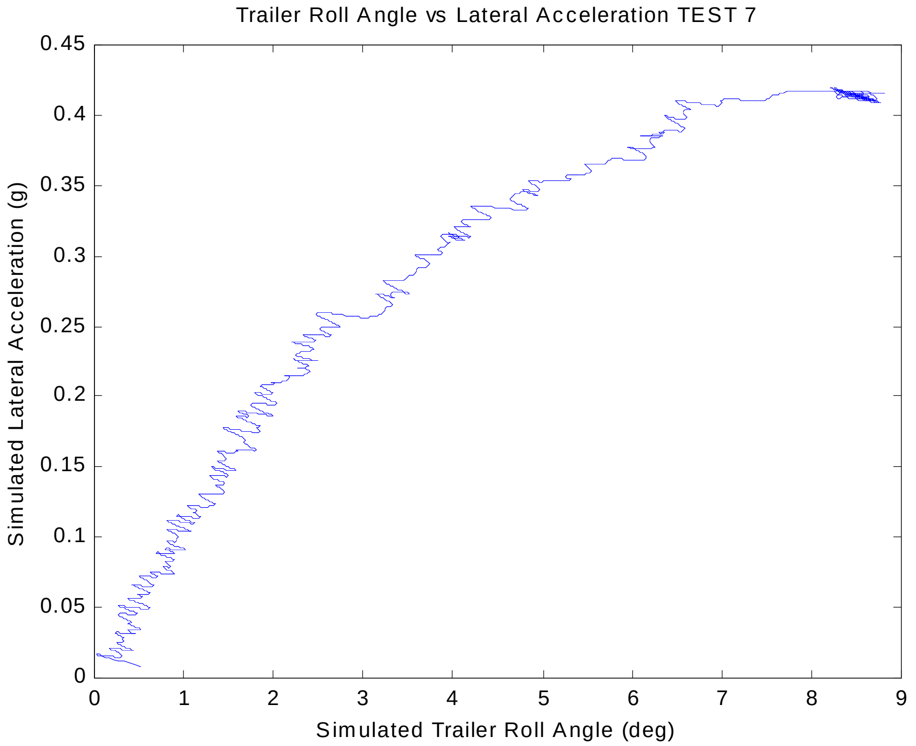

Figure 33: Trailer Roll angle versus lateral acceleration – Test 7

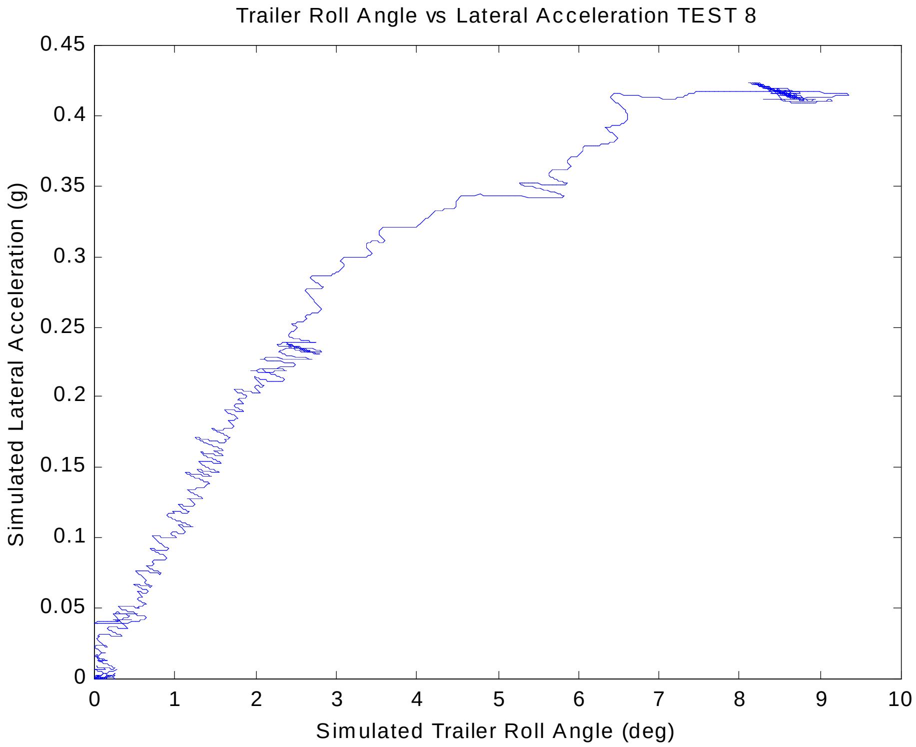

Figure 34: Trailer Roll angle versus lateral acceleration – Test 8

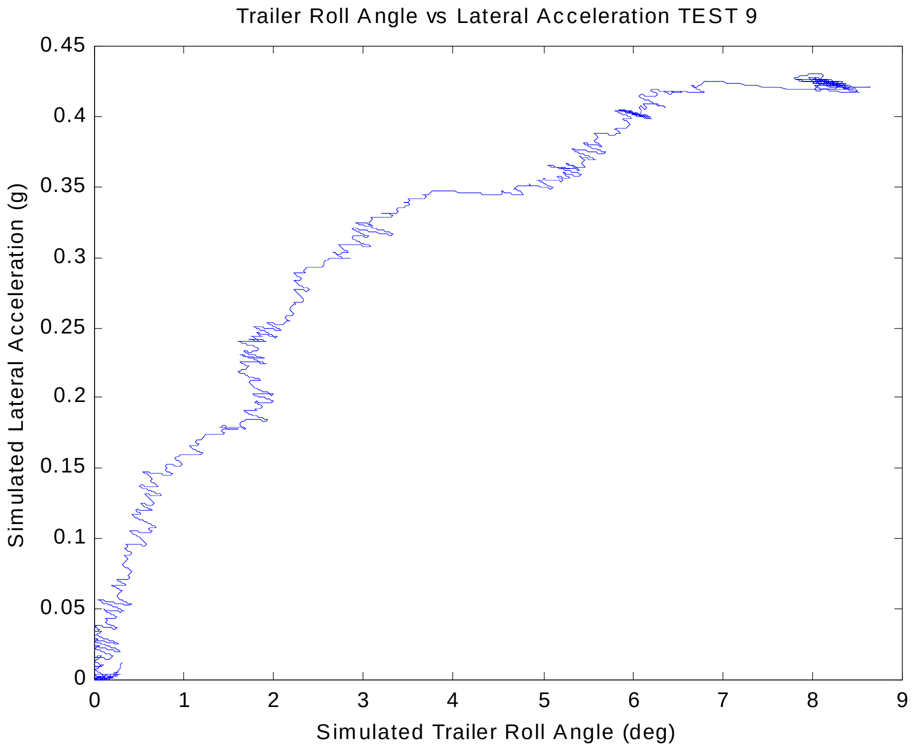

Figure 35: Trailer Roll angle versus lateral acceleration – Test 9

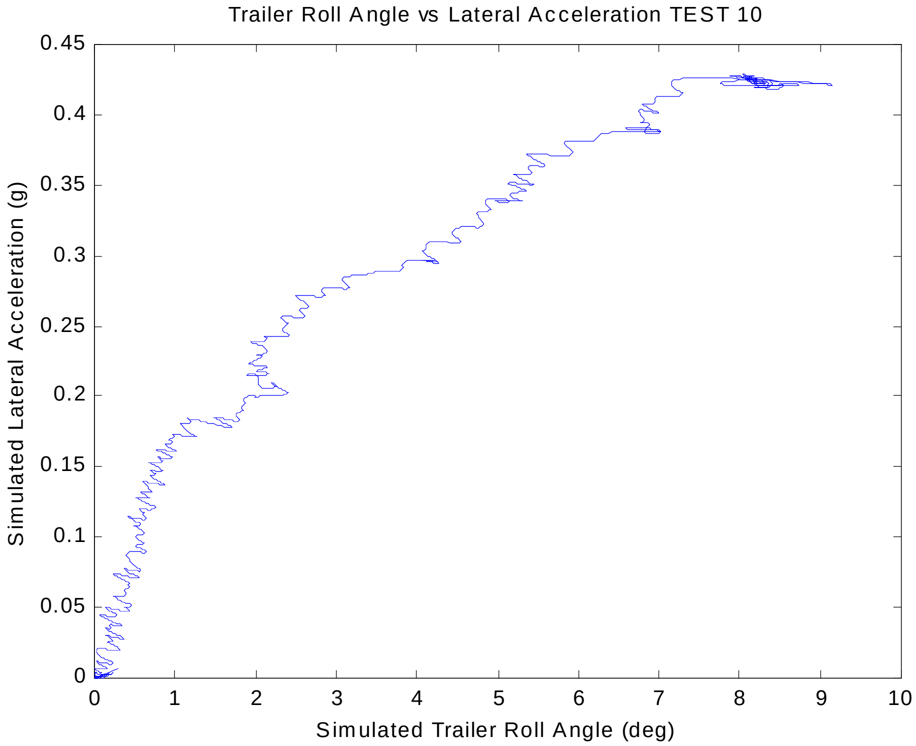

Figure 36: Trailer Roll angle versus lateral acceleration – Test 10

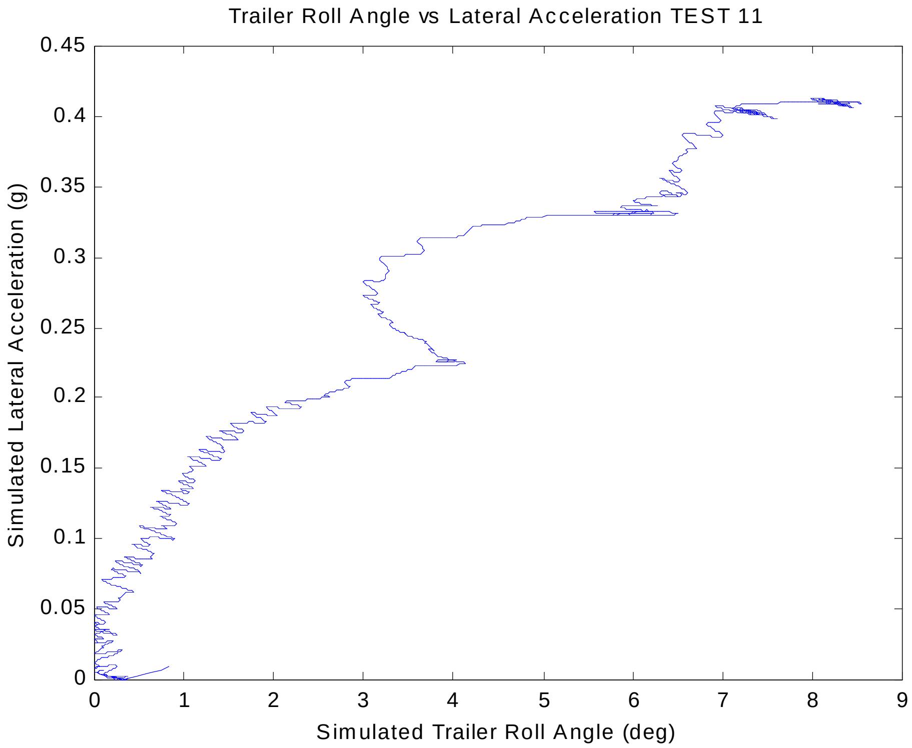

Figure 37: Trailer Roll angle versus lateral acceleration – Test 11

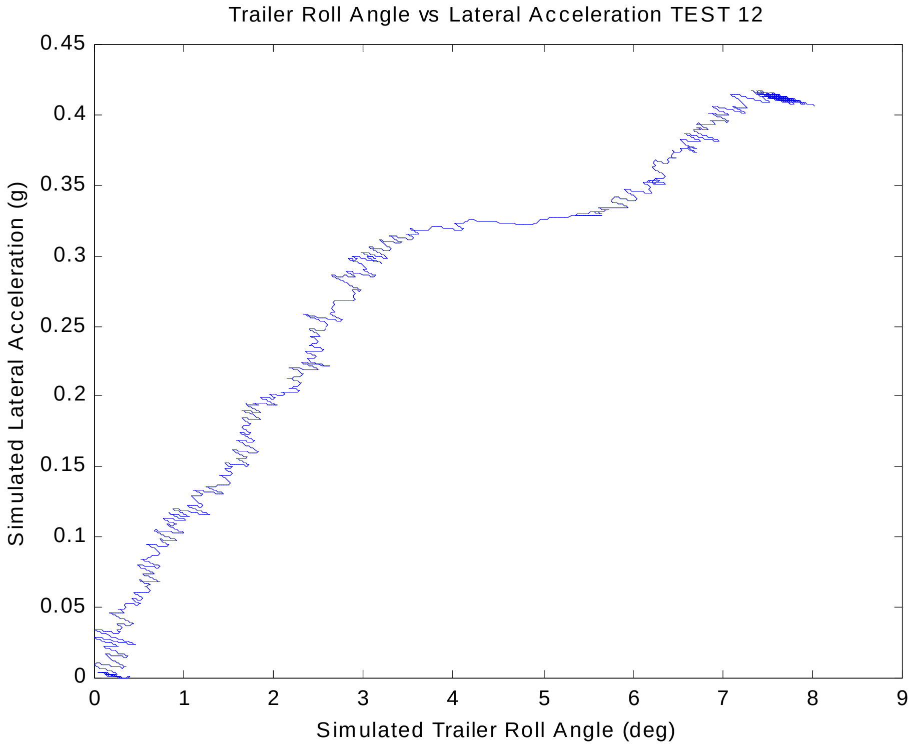

Figure 38: Trailer Roll angle versus lateral acceleration – Test 12

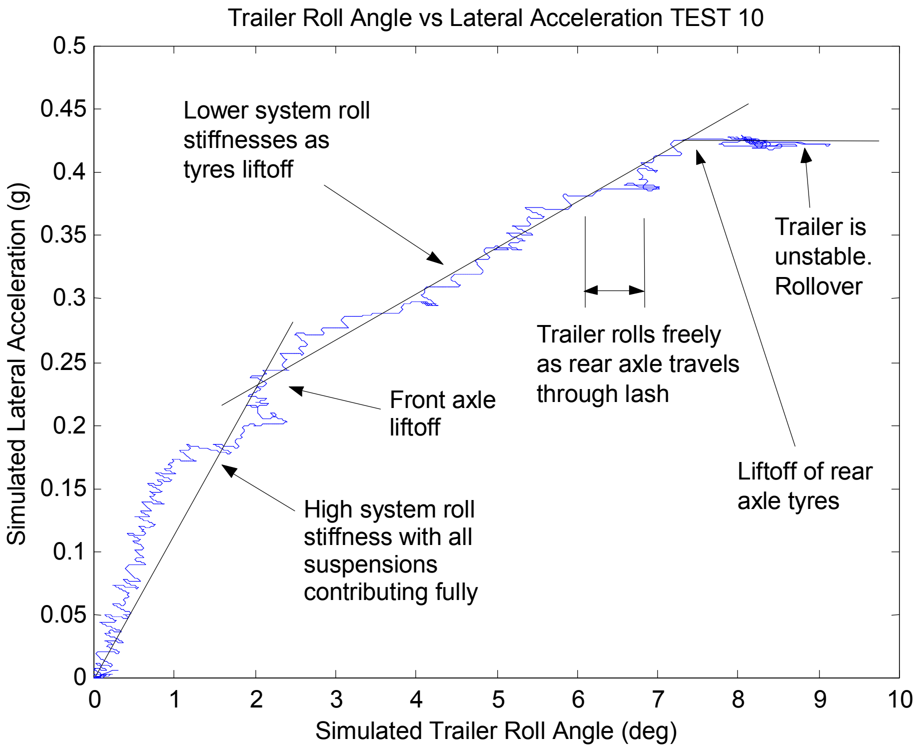
Trailer Roll Angle vs Lateral Acceleration TEST 10
Simulated Lateral Acceleration (g)
Simulated Trailer Roll Angle (deg)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
1
2
3
4
5
6
7
8
9
10
Lower system roll stiffnesses as tyres liftoff
Trailer is unstable. Rollover
Trailer rolls freely as rear axle travels through lash
Front axle liftoff
Liftoff of rear axle tyres
High system roll stiffness with all suspensions contributing fully

Figure 39:

APPENDIX D TILT RATE PLOTS, TEST 1 -12

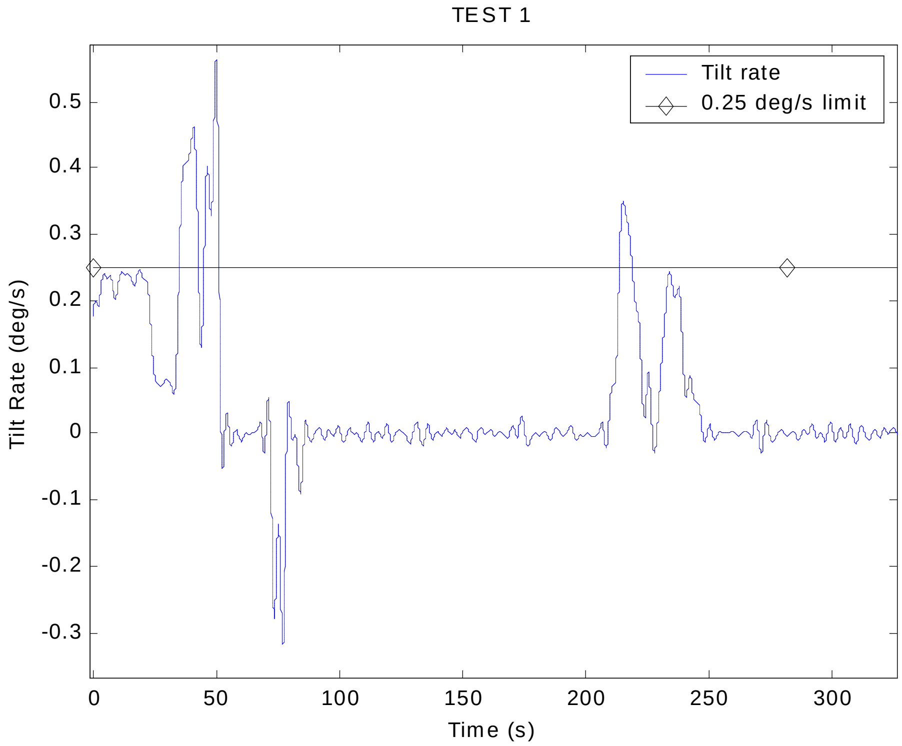

Figure 40: Tilt Rate Test 1

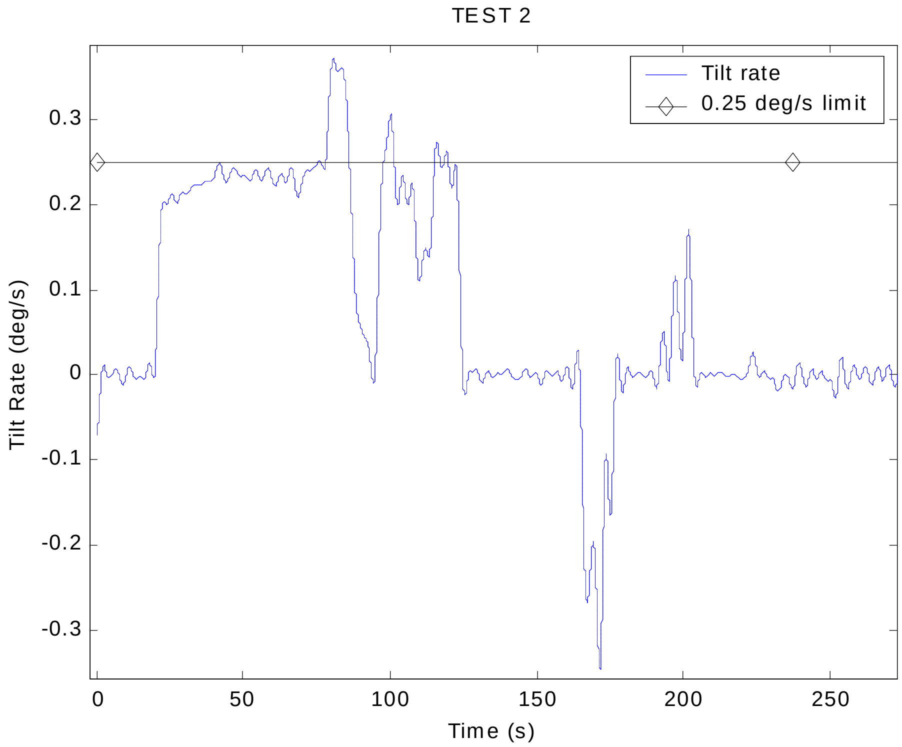

Figure 41: Tilt Rate Test 2

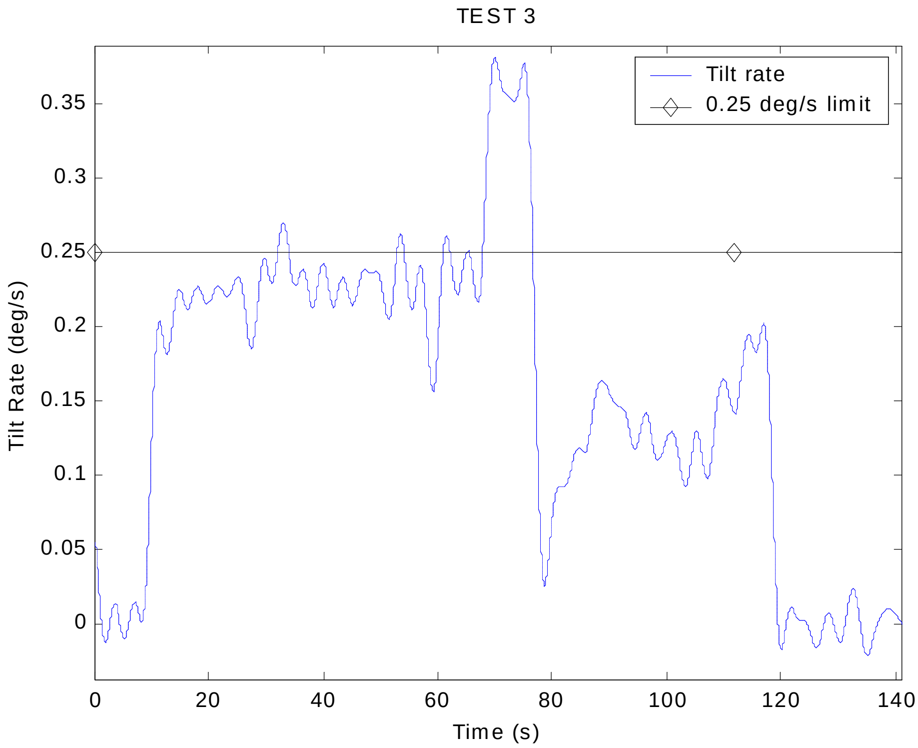

Figure 42: Tilt Rate Test 3

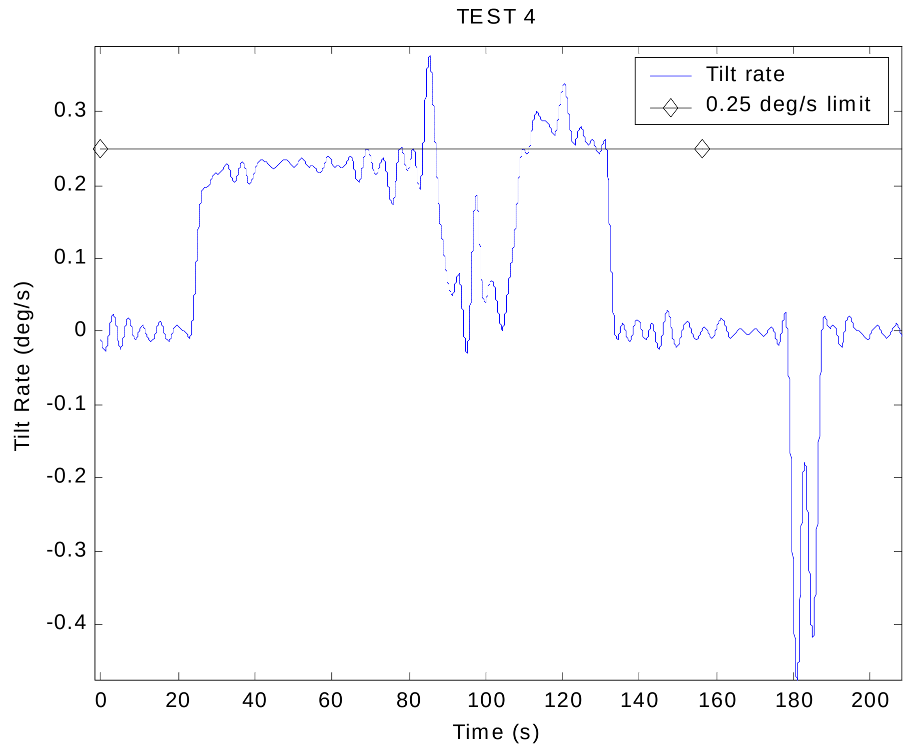

Figure 43: Tilt Rate Test 4

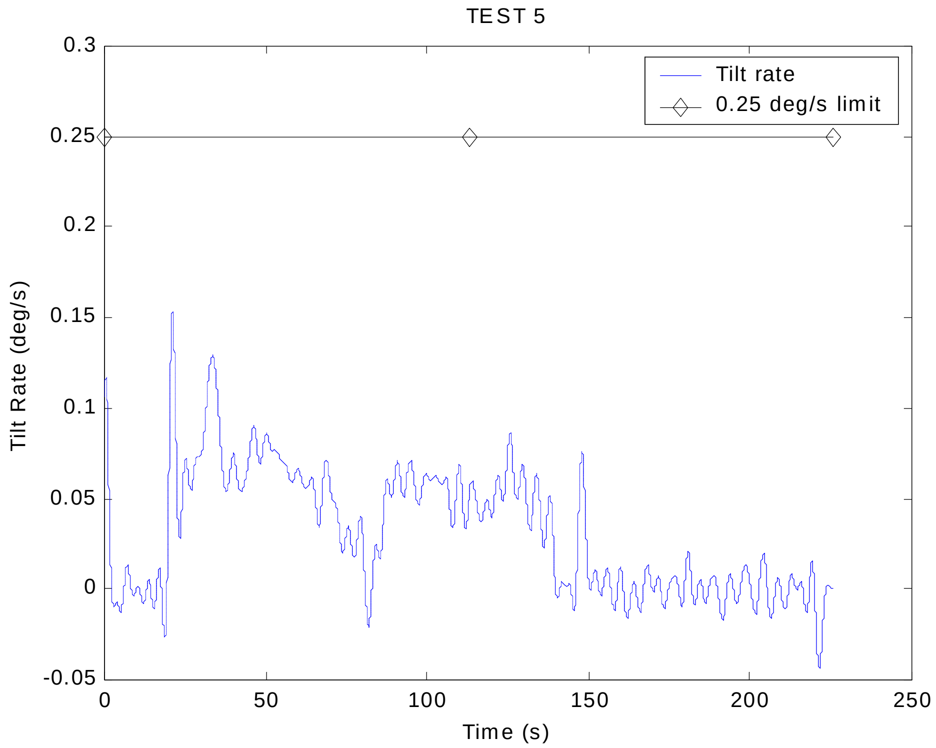

Figure 44: Tilt Rate Test 5

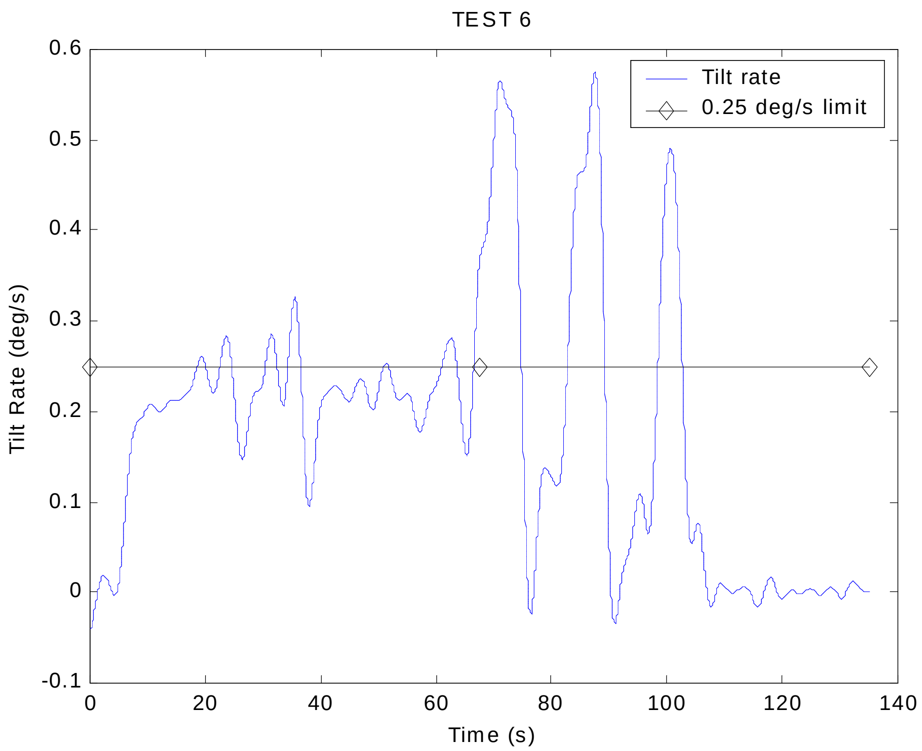

Figure 45: Tilt Rate Test 6

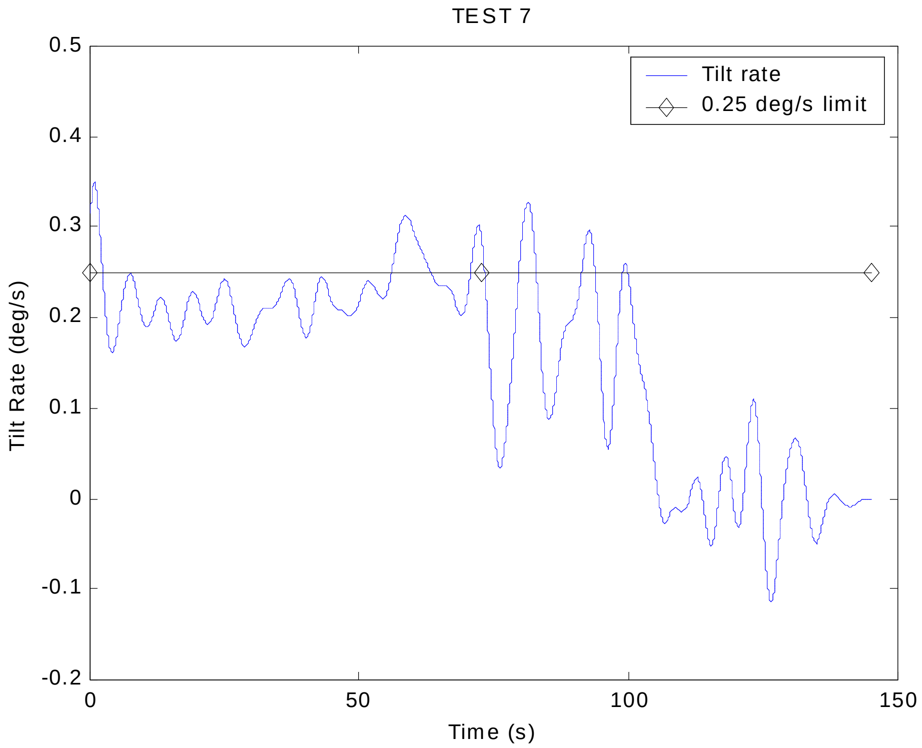

Figure 46: Tilt Rate Test 7

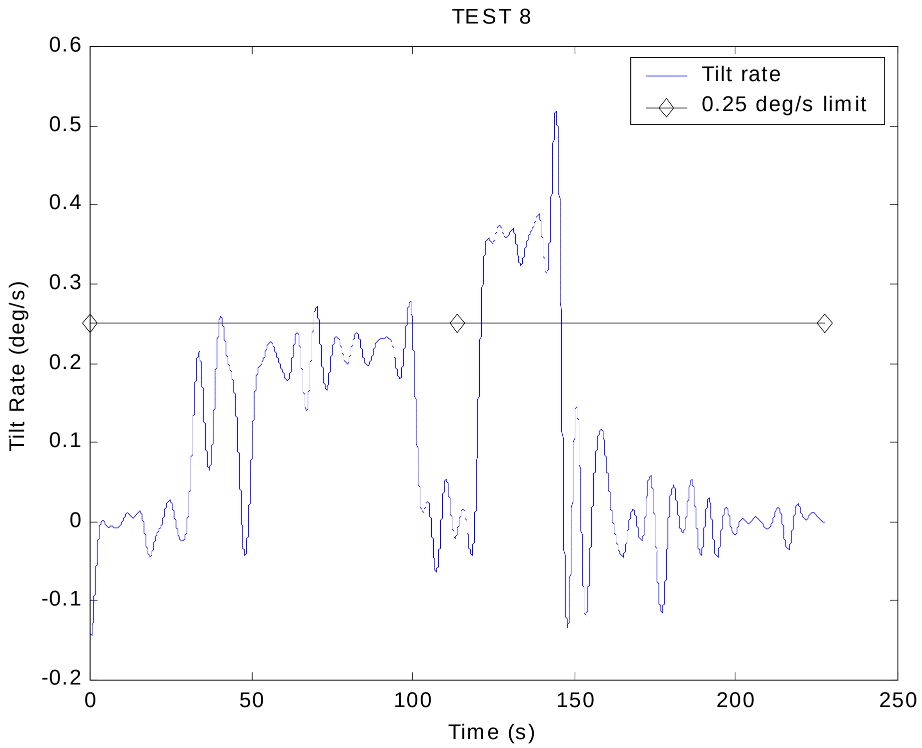

Figure 47: Tilt Rate Test 8

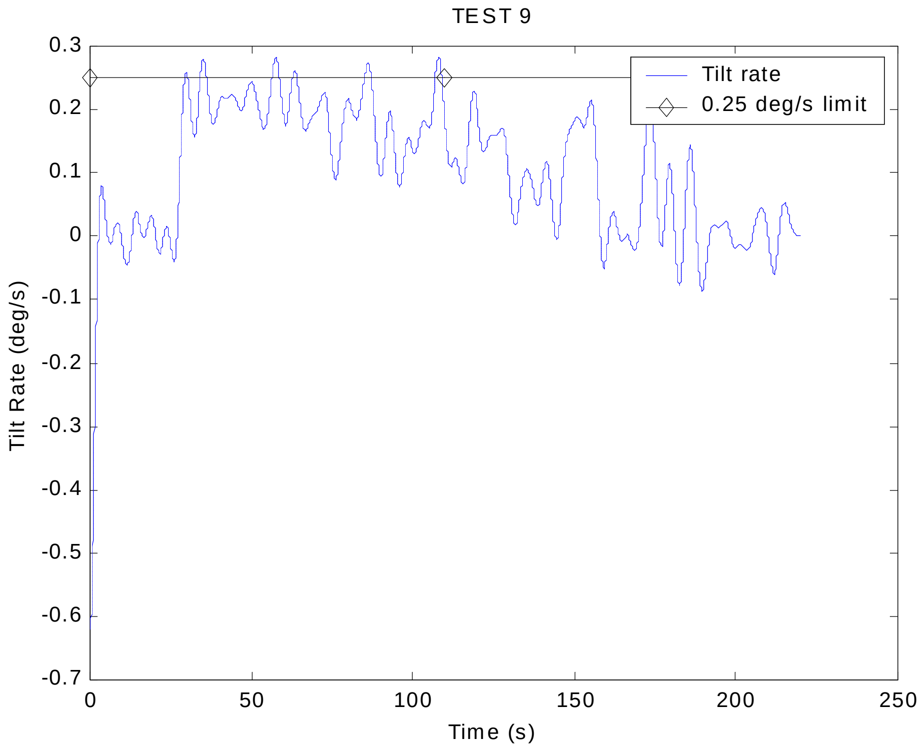

Figure 48: Tilt Rate Test 9

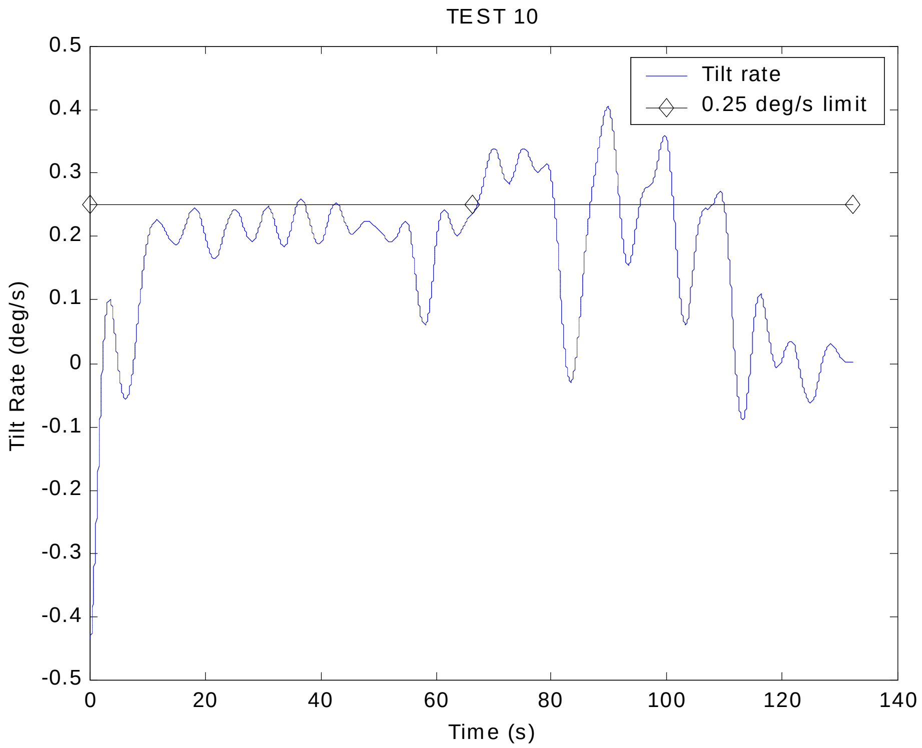

Figure 49: Tilt Rate Test 10

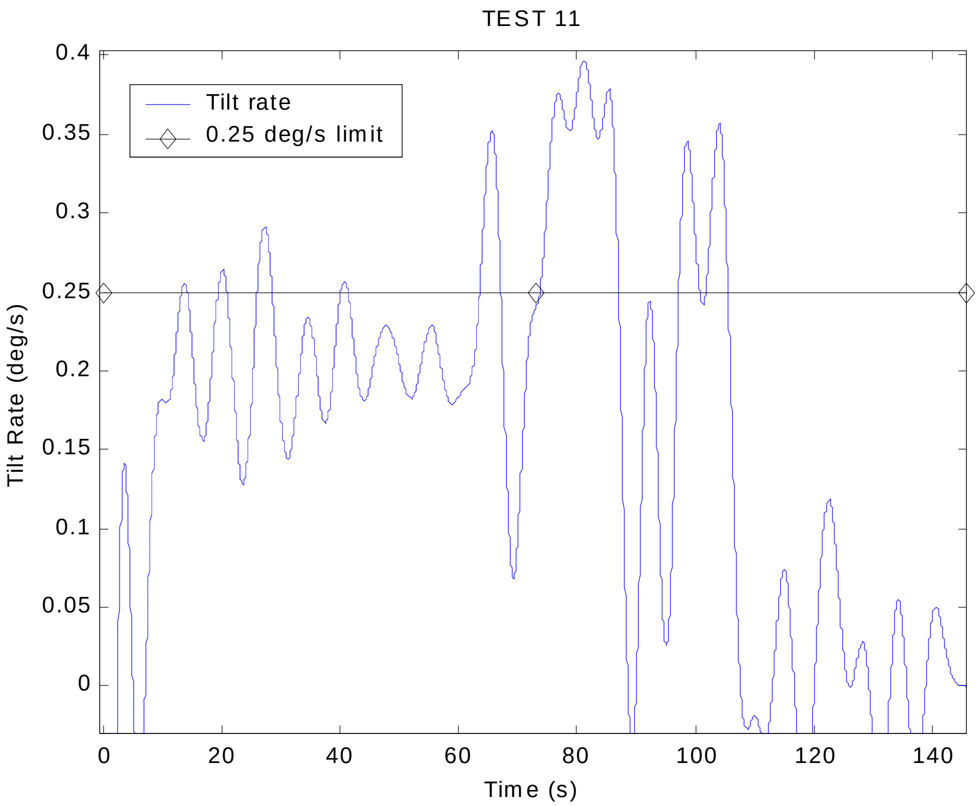

Figure 50: Tilt Rate Test 11

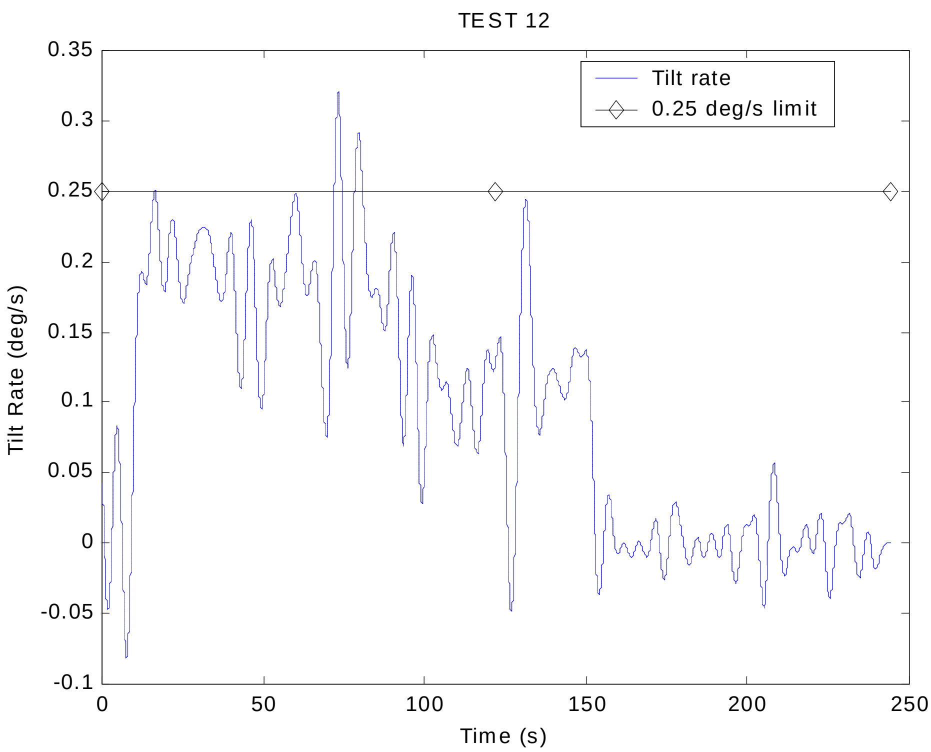

Figure 51: Tilt Rate Test 12

APPENDIX E

E.1 Transducer Specifications

E.1.1 Inclinometers

Two Crossbow Tilt Sensors were used to measure the tilt angle. They were dual axis with an angle range of ± 75°. Specifications are listed in the Table 11 below.

Table 11: Tilt Sensor Specifications

Crossbow Model	CXTA02
Full Angular Range	± 75°
Angular Resolution (°rms)	0.05
Temperature Range	-40 to 85 °C
Bandwidth (Hz)	125
Supply Voltage (V)	+8 to 30
Sensitivity – small angles (mV/°)	35 ± 2
Zero Angle Voltage (V)	2.5 ± 0.15

E.1.2 Displacement Transducer

Table 12: Displacement Transducer Specifications

Siko Model:	SGP-500-S-10_M
Supply Voltage (V)	12 – 28
Output Current (mA)	4 – 20
Voltage – Displacement (V/mm)	0.0079
Operating Temperature	0 – 60°C
Linearity Tolerance	± 1 %

APPENDIX F SRT – CALCULATOR AND YAW ROLL INPUT DATA

F.1 SRT Calculator Input

Tyre Data:

Axle:	**Tyre Size**	**Tyre Configuration**
1	19.5	Dual
2	19.5	Dual
3	19.5	Dual
4	19.5	Dual

Axle Load Data:

	Front	**Rear**
Payload Mass: (kg)	7740	7500
Tare Mass: (kg)	2340	2340

Load Categories:

Uniform Density

Load Geometry:

Load Bed Height: (m)	1.42
Load Height: (m)	3.17

User Defined:

Suspension Brand/Model	Hutch 9600 363-00	Hutch 9600 363-00
Total Roll Stiffness / axle:(Nm/radian)	714500	714500
Spring Stiffness / spring:(N/m)	1002500	1002500
Suspension Track Width:(m)	1.07	1.07
Axle lash:(mm)	38	38
Roll Center Height:(m)	0.28	0.31

F.2 Yaw Roll Input Data

McC23a2	McCarthy no23			
3	8			'no. of units, axles
4	2	2		'no. axles ea. unit
20809	508		17092	'spr. masses
16992	1130		15322	'roll MoIs
144839	565		56171	'pitch MoIs

142708	678		55143					'yaw MoIs
1.772	0.918		2.234					'CG hts
5111.2	5111.2	7098.8	7098.8	5040.0	5040.0	4920.0	4920.0	'axle loads
564.2	564.2	1241.1	1241.1	574.8	574.8	585.2	585.2	'unspr masses
418.1	418.1	576.3	576.3	463.3	463.3	463.3	463.3	'roll MoI
3.910	2.030	-1.630	-2.980	-0.623	0.623	-1.653	-2.903	'ax posn
0.450	0.450	0.508	0.508	0.395	0.395	0.395	0.395	'ax CG ht
0.464	0.464	0.838	0.838	0.680	0.680	0.710	0.710	'roll ctr ht
0.413	0.413	0.413	0.413	0.535	0.535	0.530	0.530	'susp track
1.028	1.028	0.760	0.760	0.790	0.790	0.790	0.790	'tyre track
0.000	0.000	0.320	0.320	0.300	0.300	0.300	0.300	'duals gap
4500.0	4500.0	4500.0	4500.0	4600.0	4600.0	4600.0	4600.0	'tyre vert K (lb/in)
0.00	0.0	0.20	0.20	0.23	0.23	0.23	0.23	'roll steer
1								'forced steer
2								
0.0279	0.000	0.000	0.000					
3824	3824.0	6894	6894	6000	6000	6000	6000	'aux roll K (in.lb/deg)
475.0	475.0	700.0	700.0	400.0	400.0	400.0	400.0	'susp frictn (lb)
22.3	22.3	10.0	10.0	0.0	0.00	0.0	0.00	'visc damp (lb.s/in)
0								'no.self-steer
-4.890	3.303	0.000	2.345					'artic pts posn
0.700	1.250							'artic ht
0.00	1000000							'artic rollK (in.lb/deg)
0.00	0.00							'GLA,KLA
3	4							'artic type
3								'no.spr table
1	1	2	2	3	3	3	3	'axle spr
9								'tab size
-20550.00	-15.00							
-1170.00	-0.75							
-150.00	0.00							
1250.00	1.00							
2550.00	2.00							
3825.00	3.00							
7240.00	5.50							
11127.50	8.50							
20076.50	15.50							
9								'spr.tab2
-35200	-2.08							
-19000	-1.58							
-10000	-1							
-4000	-0.5							
0	0							
4000	0.5							
10000	1							
19000	1.58							
35200	2.08							
10								'spr.tab3
-20000.0	-3.1							
-17500.0	-3.1							
-13000.0	-2.9							
-7500.0	-2.4							

0.0	-1.4							
0.0	0.1							
7500.0	1.0							
13000.0	1.5							
17500.0	1.7							
20000.0	1.8							
0.80								'peak mu
3								
1	1	2	2	3	3	3	3	
4.00	7.00							
0.00	1.00	2.00	3.00	4.00	5.00	6.00		
3698.00	649.90	1191.50	1651.90	2031.00	2356.00	2599.70		
7397.00	1137.40	2085.20	2951.70	3628.70	4224.50	4684.90		
14344.00	1435.20	2762.20	4062.00	5199.40	6228.40	7040.80		
4.00	6.00							
0.00	1.00	2.00	4.00	8.00	12.00			
1983.00	356.90	634.60	1070.80	1526.90	1804.50			
5967.00	835.40	1611.10	2804.50	3938.20	4355.90			
9441.00	944.10	1793.80	3398.80	5192.60	5759.00			
4.00	7.00							
0.00	1.00	2.00	3.00	4.00	5.00	6.00		
2753.00	507.00	918.00	1239.00	1549.00	1831.00	2084.00		
5511.00	974.00	1746.00	2394.00	2985.00	3492.00	3858.00		
8269.00	1127.00	2225.00	3154.00	3887.00	4591.00	5154.00		
3								
1	1	2	2	3	3	3	3	
4.00	7.00							
0.00	1.00	2.00	3.00	4.00	5.00	6.00		
3687.00	63.60	105.00	132.70	138.20	129.90	110.60		
7385.00	116.10	287.50	351.00	370.40	356.60	315.10		
11084.00	295.80	508.60	657.80	724.20	732.50	657.80		
6.00	6.00							
0.00	1.00	2.00	4.00	8.00	12.00			
2000.00	28.00	44.00	55.00	37.00	21.00			
3980.00	85.00	143.00	188.00	144.00	91.00			
5970.00	147.00	263.00	362.00	270.00	182.00			
7950.00	207.00	384.00	560.00	442.00	298.00			
9440.00	250.00	468.00	717.00	592.00	385.00			
4.00	7.00							
0.00	1.00	2.00	3.00	4.00	5.00	6.00		
2753.00	44.00	75.00	91.00	97.00	100.00	100.00		
5511.00	106.00	184.00	241.00	270.00	280.00	278.00		
8269.00	187.00	332.00	431.00	489.00	510.00	503.00		
25.00								'steer ratio
25000.00	25000.00	0.03						'Ks, trail