

Objective Measurement of Vehicle Steering and Handling Performance When a Tire Loses Its Air

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ABSTRACT

There have been several recent articles published concerning the effect of a tire tread separation on vehicle handling, but lately the literature has been silent on the situation where a tire airs out. This paper studies how various vehicles steer and handle during and after a tire deflates while the vehicle is traveling at speed. Utility vehicles, pickup trucks, and vans were tested by deflating front and rear tires. The air out condition was created by using a special test device that fired a twelve gauge shotgun shell at the sidewall of a tire while the vehicle was traveling at freeway speeds. The vehicles were instrumented with on board video equipment and a computer with transducers to measure both driver inputs and vehicle responses during the testing. The results show that a rapid tire air out creates a slight pull to the side of the deflated tire which then requires a small corrective steer to maintain a straight ahead course. A deflated tire also experiences a reduction in the cornering stiffness so that steering and handling is degraded. However, the air out did not force any of the test vehicles out of the driver's control. Vehicles still maintained maneuvering capacity which allowed the driver to control the vehicle and to easily bring it to a stop.

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INTRODUCTION

There have been several papers and studies in the last decade that have shown how a vehicle steers and handles following a full or partial tire tread belt separation (references [1](#), [2](#), [3](#), [4](#), [5](#), [6](#), [7](#), [8](#), [9](#), [10](#), [11](#)). However, there have been no recent papers written dealing with a tire air out condition.

This paper focuses on what occurs when a tire loses its air pressure while a vehicle is traveling at freeway speeds. Sport utility vehicles, pickup trucks, and vans were tested with a special device that would make a circular hole in both sidewalls of a tire to allow it to rapidly lose air. These vehicles encompass various suspension types, weights, wheelbases, lengths, and other characteristics. The vehicles were instrumented with on board video equipment and a data acquisition system to measure driver inputs as well as vehicle responses during the testing. The drivers were instructed to accelerate to highway speeds (in the range of 100 kilometers per hour) and maintain a straight ahead bearing on a test track. The metric chosen to evaluate the effect on the vehicle of the tire air out was the steering magnitude input by the drivers to maintain the intended course. This metric is consistent with what drivers are instructed to do in the event of a tire disablement. Experienced and trained drivers were used so that a repeatable test could be performed. The

purpose of this study is to measure the steering correction required to maintain the lane of travel, not how unsuspecting drivers may respond to a tire air out.

A series of tests were also run looking at the cornering response of a vehicle with four properly inflated intact tires, an aired out rear tire, and a properly inflated fully delaminated rear tire. As part of this study, several runs were also made to determine at what lateral acceleration level a deflated tire pulls away from the flange of the rim in a steady turn.

METHODOLOGY

The methodology employed in this study is divided into four sections. The first section describes the tire air out device, and the second section lists the vehicles and configurations tested. The third section describes the vehicle preparation, including the instrumentation and video equipment used to document the tests. The fourth and final section describes the test procedures employed.

Tire Air Out Device

There are different ways to cause a tire to deflate. These methods can be broken down into two method types: "On vehicle" and "Off vehicle". "Off vehicle" devices typically

involve driving over a blade that either engages the front tire then moves out of the way of the rear tire or springs up to cut the rear tire after the front tire runs over it in the stored condition. For this study, the authors decided to employ an "On vehicle" device so that the driver had control over when and where the tire airs out. The air out device was a cylinder that was bolted to the frame or unitized body of a vehicle. The cylinder had a solenoid which would release a trigger when the driver would push a button on the floor with his foot. In the cylinder was a standard twelve gauge clay target shotgun shell (see [Figure 1](#) for a photograph of the air out device).



Figure 1. Tire Air Out Device

Test Vehicles

Twenty-six vehicles were tested as part of this study. [Table 1](#) lists the vehicles and their configurations. [Figures A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A12, A13, A14, A15, A16, A17, A18, A19, A20, A21, A22, A23, A24, A25, A26, A27, A28, A29, A30, A31, A32, A33, A34, A35, A36, A37, A38, A39, A40, A41, A42, A43, A44, A45, A46, A47, A48, A49, A50, A51, A52, A53, A54, A55, A56, A57, A58, A59, A60, A61, A62, A63, A64, A65, A66, A67, A68, A69, A70, A71, A72](#) in Appendix A contain photographs of the test vehicles and data plots of the driver inputs and vehicle responses recorded during the tests.

Vehicle Preparation / Test Documentation

The test vehicles were equipped with outriggers, video equipment, instrumentation, and either loaded to the manufacturer's gross vehicle rating (GVW) or left at curb plus driver and instrumentation. The air out device was then placed in the right rear location in most tests. Some testing was performed with the air out device mounted at the right front tire position.

Vehicle instrumentation

The test equipment consisted of a set of instrumentation capable of measuring the following signals:

- Longitudinal, lateral, and vertical acceleration at approximately the vehicle center of gravity (cg)
- Vehicle longitudinal speed
- Steering wheel angle
- Yaw rate, roll rate, and pitch rate as well as roll angle relative to ground
- Brake pedal force on some vehicles

Vehicle video equipment

Video equipment consisted of cameras that recorded the following views:

- Steering view over the driver's shoulder
- Right rear outside tire view on the rear outrigger
- Rear axle view on some vehicles
- High speed camera view of the right rear outside tire view from the rear outrigger on some vehicles
- View of a digital display that recorded the longitudinal velocity

Table 1. Vehicles Used in Tire Deflation Study

Vehicle	Vehicle Configuration	Drive Option	Wheelbase (Inches)	Front / Rear Suspension	Tire Size	Air-Out Position(s)
1	'86 Compact SUV	4WD	94	Ind. / Dep.	P205/75R15	RR
2	'87 Mini-van	RWD	88	Ind. / Dep.	P195/70R15	RR
3	'89 Full-Size Van	RWD	138	Ind. / Dep.	LT235/85R16E	RR
4	'90 Mini-van	RWD	119	Ind. / Dep.	P215/75R14	RR
5	'92 Compact SUV	RWD	102	Ind. / Dep.	P235/75R15	RF & RR
6	'93 Compact SUV	RWD	112	Ind. / Dep.	P235/75R15	RR
7	'94 Full-Size SUV	4WD	105	Ind. / Dep.	P265/75R15	RR
8	'96 Full-Size Van	RWD	138	Ind. / Dep.	LT245/75R16E	RR
9	'97 Compact SUV	RWD	102	Ind. / Dep.	P235/75R15	RR
10	'97 Compact SUV	RWD	112	Ind. / Dep.	P235/75R15	RF & RR
11	'97 Mid-Size SUV	AWD	100	Dep. / Dep.	235/70R16	RR
12	'99 Compact SUV	RWD	106	Ind. / Dep.	P235/75R15	RF & RR
13	'99 Compact SUV	4WD	112	Ind. / Dep.	235/75R15	RR
14	'00 Heavy Duty Pickup	4WD	173	Dep. / Dep.	LT265/75R16E	LR
15	'00 Mini-van	FWD	121	Ind. / Dep.	P215/70R15	LR
16	'00 Compact Pickup	RWD	112	Ind. / Dep.	P225/70R15	RR
17	'00 Heavy Duty Pickup	4WD	156	Dep. / Dep.	LT265/75R16	RR
18	'00 Compact SUV	4WD	107	Ind. / Dep.	P235/70R15	RR
19	'01 Full-Size SUV	RWD	119	Ind. / Dep.	P275/60R17	RF & RR
20	'01 Mid-Size SUV	AWD	109	Dep. / Dep.	255/55R18	RR
21	'02 Compact SUV	RWD	102	Ind. / Dep.	P235/70R16	RF & RR
22	'02 Heavy Duty SUV	RWD	137	Ind. / Dep.	LT265/75R16E	RF & RR
23a	'02 Compact SUV	RWD	112	Ind. / Dep.	P255/65R16	RR*
23b	'02 Compact SUV	RWD	112	Ind. / Dep.	P245/65R17	RR
24	'03 Full-Size SUV	RWD	119	Ind. / Ind.	P265/70R17	RR
25	'03 Full-Size SUV	4WD	119	Ind. / Ind.	P265/70R17	RR
26	'04 Mid-Size SUV	4WD	114	Ind. / Ind.	P235/70R16	RR

* Note: Right Rear Tire was Fully Delaminated Prior to Testing

Test Procedure

The test procedure was consistent for all tests. The following steps were followed:

- Place the tire air out device on the vehicle at the desired tire position and aim it at the inner sidewall
- Set tire pressures to factory settings
- Initiate recording data and video

- Accelerate the vehicle to highway speeds and hold constant speed on a portion of the test track where there are no bystanders or vehicles present
- When the vehicle is driven to the agreed upon location on the test track, the air out device trigger on the floor is depressed to air out the tire
- Maintain straight ahead direction with steering correction
- Slow vehicle and turn off data and video equipment

GENERAL RESULTS AND DISCUSSION

The main focus of this study was to objectively measure how different vehicles handle after they have experienced a rapid air loss or “blow-out”. Table 2 contains the results of all the tire air out tests performed where the driver was instructed to maintain a straight ahead course. The column labeled as “Ave. SWA Change” contains values which were calculated by comparing the averaged steering angle right before the tire was aired out to the average steering wheel angle after the air out and once the transients settled out. This value represents the amount of steering necessary to counteract the increased drag from the deflated tire. The column labeled “Peak SWA Change” represents the maximum change in steering during the air out event.

Table 2. Summary of Steering Wheel Angles Recorded in Tire Air Out Study

Vehicle	Vehicle Configuration	Drive Option	Air-Out Position(s)	Loading	Avg. SWA Change During Air-Out [degrees]	Peak SWA Change During Air-Out [degrees]
1	'86 Compact SUV	4WD	RR	Curb+	7	12
2	'87 Mini-van	RWD	RR	GVW	1	4
			RR	GVW	1	4
3	'89 Full-Size Van	RWD	RR	Curb+	5	11
			RR	GVW	6	12
			RR	GVW	10	13
4	'90 Mini-van	RWD	RR	Curb+	17	20
			RR	Curb+	10	16
			RR	GVW	0	12
			RR	GVW	11	21
5	'92 Compact SUV	RWD	RR	GVW	3	3
			RF	Curb+	58	58
6	'93 Compact SUV	RWD	RR	GVW	8	9
7	'94 Full-Size SUV	4WD	RR	Curb+	7	8
			RR	GVW	14	16
			RR	GVW	9	16
8	'96 Full-Size Van	RWD	RR	Curb+	14	15
			RR	GVW	11	15
9	'97 Compact SUV	RWD	RR	Curb+	7	20
10	'97 Compact SUV	RWD	RR	GVW	5	5
			RF	GVW	21	21
			RF	Curb+	19	27
11	'97 Mid-Size SUV	AWD	RR	GVW	12	12
12	'99 Compact SUV	RWD	RR	Curb+	18	23
			RR	GVW	19	19
			RF	GVW	19	19
13	'99 Compact SUV	4WD	RR	RGAWR	6	6
14	'00 Heavy Duty Pickup	4WD	LR	GVW	14	33
			LR	GVW	11	23
15	'00 Mini-van	FWD	LR	GVW	0	5
16	'00 Compact Pickup	RWD	RR	GVW	0	14
17	'00 Heavy Duty Pickup	4WD	RR	GVW	7	9
18	'00 Compact SUV	4WD	RR	Curb+	9	10
19	'01 Full-Size SUV	RWD	RR	Curb+	3	10
			RF	GVW	19	21
20	'01 Mid-Size SUV	AWD	RR	Curb+	2	9
			RR	GVW	3	7
21	'02 Compact SUV	RWD	RR	Curb+	9	22
			RF	Curb+	27	29
22	'02 Heavy Duty SUV	RWD	RR	GVW	9	9
			RF	GVW	52	52
23a	'02 Compact SUV	RWD	RR*	GVW	8	14
23b	'02 Compact SUV	RWD	RR	GVW	1	1
24	'03 Full-Size SUV	RWD	RR	GVW	3	3
25	'03 Full-Size SUV	4WD	RR	GVW	12	12
26	'04 Mid-Size SUV	4WD	RR	GVW	4	10

* Note: Right Rear Tire was Fully Delaminated Prior to Testing

The results show that when a tire experiences a rapid air loss it provides both tactile and audible feedback to the driver and occupants. The vehicle will also experience a noticeable vertical change at the location of the “blow-out”, shortly after which the tire will generate increased rolling resistance that slows the vehicle and generates a yaw moment. This moment is in the direction of the side of the vehicle which suffered the air out event. A small steering correction is needed by the driver to counteract this moment imbalance and maintain the vehicle's original heading. This is true for all vehicles tested. All of the tires maintained their bead seats under normal circumstances and allowed the vehicle to be maneuvered.

It is also important to note that in all tests the deflated tire made a moan type noise which provided a signal to the driver that something was wrong. An loud “pop” or “bang” sometimes occurs in cases of rapid deflation.

Rear Tire Deflation Tests

Testing performed where a rear tire was aired out on a moving vehicle confirmed that there was no meaningful difference between the performances of pickup trucks, vans, or utility vehicles tested in terms of steering input required from a driver in order to maintain the lane of travel. The measured average steering angles were relatively small and all vehicles were controllable. In fact, none of the average steering angles exceeded 25 degrees. All the measured peak steering wheel angles were under 35 degrees, with all but one under 25 degrees and with the majority under 15 degrees. Figure B1 in Appendix B presents a comparison of the measured steering angles during a rear air out event.

Front Tire Deflation Tests

The front tire deflation testing confirmed that there was no meaningful difference related to the size of utility vehicles in terms of steering inputs needed to maintain the lane of travel during a front rapid air loss. The measured steering angles were small and did not overwhelm any vehicle tested. In fact, none of these steering angles exceeded sixty degrees, with the majority falling below twenty-five degrees of steering. Figure B2 in Appendix B presents a comparison of the measured steering angles.

Dynamics of a Front Versus a Rear Tire Deflation

Since tests were performed on the front and rear axle of the test vehicles, comparisons can be made concerning the performance differences between these two events (see Table 2 and Figure B3 in Appendix B). Note that the bars in Figure B3 demonstrate the difference between the average steering wheel angles required to drive the test vehicles straight before the air out events and the average steering wheel angles required after the air out events. The vertical lines extending from the bars represent the peak steering wheel angle change experienced during the events themselves. The steering angle inputs required to keep the vehicle in a straight line path with

a front tire air out were slightly higher and more variable than those found in the rear tire air out tests. This difference is to be expected. When the deflated tire is placed on a steered axle, more steering input may be required to compensate for the inherent compliance found in the steering system and the increased drag moment the deflated tire creates around the kingpin axis.

It is important to note that it is true that once the tire is flat and if the driver decides to turn the vehicle, that the placement of the flat tire can have a large effect. This is the result of the diminished capacity of the deflated tire to resist lateral forces. However, with steering demands generally used to navigate roads designed to meet AASHTO requirements, the deflated tire provides enough capacity to respond to reasonable braking and steering inputs no matter what the position.

The Deceleration Associated with a Deflated Tire

Some of the tests described above were performed such that the driver would release the throttle just before triggering the tire blowout device and would keep his foot off the brake and throttle after the air out. Running the test in this way allowed for a measurement of the deceleration associated with a vehicle coasting with one deflated tire. The measured deceleration was then compared to that from vehicle testing with four intact tires. [Figure B4](#) in Appendix B shows the incremental change in longitudinal deceleration from the deflated tire. As can be seen, the increased measured deceleration associated with the deflated tire ranged from 0.03g to 0.10g, with no notable difference between positions on the vehicle (i.e. front versus rear). The measured deceleration from each test is also included in [Appendix B](#) and is presented as [Figure B5](#). As with the incremental decelerations, the overall measured levels were independent of the position of the aired out tire. Furthermore, all of the measured levels of deceleration were less than 0.15g.

The Physical Evidence Created When a Tire Deflates

[Figure 2](#) shows a tire mark deposited onto the asphalt test surface by Vehicle 21, the 2002 compact sport utility vehicle. Note that there are two defined lines in the tire mark itself. With the absence of air pressure to support the middle of the tire, the outer edges of the tire are all that separate the rim flanges from the asphalt surface. The two distinct lines in the tire mark are made by the weight of the vehicle's right rear corner passing through the rim flanges to the asphalt surface through the tire rubber. The rim itself is not in direct contact with the asphalt.



Figure 2. Deflated Tire Mark from 2002 Compact SUV

[Figures 3, 4, 5](#) are a series of police photographs that show a tire mark deposited on a public road by a deflated right rear tire from a vehicle that was eventually crashed. [Figure 3](#) demonstrates the character of the tire mark near the beginning. Note that, similar to the tire mark deposited by the test vehicle and visible in [Figure 2](#), there are two defined lines in the tire mark itself. This behavior indicates the absence of air pressure to support the middle of the tire, and the outer edges of the tire are all that separate the rim flanges from the asphalt surface. As with the test vehicle, the rim itself is not in direct contact with the asphalt at this point. [Figure 4](#) presents the same tire mark, but farther down the road. At this point, the tire has become at least partially unseated from the rim, allowing intermittent contact between the rim flange and the asphalt. This contact is evident by the dashed white rim marks.



Figure 3. Start of Tire Mark from Right Rear Deflated Tire

The end of the tire mark is shown in [Figure 5](#) which is also where the vehicle has been steered to the left and is yawing into the median. Note that the width of the tire mark has increased, and the mark itself has become solid from the increased contact between the degraded tire structure and the asphalt. Additionally, the gouge mark deposited by the rim has become more continuous, indicating a more complete unseating of the tire at the rim flange. Finally, note the additional tire mark on the shoulder of the road. The presence of this tire mark, most likely from the right front tire, indicates a significant counterclockwise slip angle of the vehicle as it was exiting the paved roadway. [Figure 6](#) depicts the condition of the right rear wheel and tire assembly after depositing the tire mark and gouges shown in [figures 2, 3, 4](#). Note the heavy abrasions around the circumference of the rim, the complete separation of the tire from the rim flange, and the radial splits to the tire itself.



Figure 6. Right Rear Wheel & Tire



Figure 4. Rim Contact from Right Rear Rim

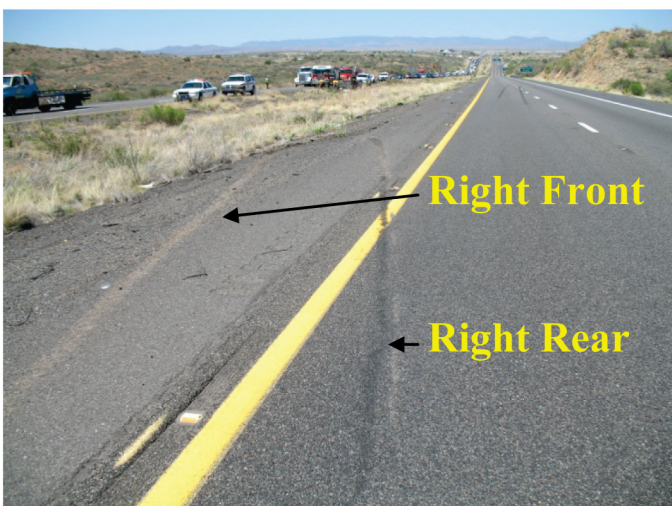


Figure 5. End of Tire Marks from Right Side Tires

In order to understand what it takes to create a tire similar to that in [Figure 6](#), vehicle 23, the 2002 model year compact sport utility vehicle, was tested in the same manner as described throughout this paper. The tire depicted in [Figure 7](#) is typical of the tested tires immediately after the vehicle has been brought to a safe stop after the air out test. Note the rubber appears fully intact and even the tire make and brand can be read off the sidewall. This same vehicle was then tested with a right rear tire set to an air pressure of zero pounds per square inch prior at the start of the test. The vehicle was then accelerated from a stop to a speed of approximately 100 kilometers per hour over a period of time of approximately 25 seconds. The driver then drove at 100 kilometers per hour for approximately 14 seconds and then brought the vehicle to a controlled stop. During the maneuver, the tread completely separated from the body of the tire, and the tire split radially in several places. Review of the test video revealed pieces of the tread blocks separating from the tire as the vehicle's speed approached 100 kilometers per hour, and full separation of the tread occurred approximately fourteen seconds after that. [Figure 8](#) shows the tire immediately after the maneuver had been completed. The over deflection of the tire carcass caused heat to build up which melted the body plies and other components causing the whole tire to disintegrate.



Figure 7. Right Rear Tire After Air Out Event



Figure 9. 2000 4×4 Sport Utility Vehicle



Figure 8. Right Rear Tire After Being Driven Deflated



Figure 10. 2001 4×2 Sport Utility Vehicle

Cornering Capacity with Various Tire Disablements

As part of this study, additional testing was conducted with a 2000 compact 4×4 sport utility vehicle and a 2001 compact 4×2 sport utility vehicle (Figure 9 and Figure 10, respectively). In these tests automated steering controllers were used (see Figures 11 and 12) to input a slowly increasing steer of constant steer rate to the left after the right rear tire was completely deflated. Speed was kept as constant as possible at around 100 kilometers per hour. The steering input rate was maintained constant until the tire eventually debanded from the rim. For comparison purposes the vehicle responses were compared to the same vehicles and steering inputs with four good tires and with delaminated tires at the right rear positions. As documented in previous studies, there were noticeable differences in understeer and lateral acceleration capability between the runs with four good tires and those with a delaminated tire on the right rear.



Figure 11. Automated Steering Controller, 2000 SUV Testing



Figure 12. Automated Steering Controller, 2001 SUV Testing

Figures 13 and 14 are examples of the deflated right rear tires before the steering input was applied for both test vehicles. Note that neither rim is in contact with the asphalt immediately after the air out event. The rubber stiffness and centrifugal force of the tires rotating at highway speeds provides this gap between the rim and the asphalt as long as the tires' structures remain intact.



Figure 13. 2000 Compact SUV w/ Deflated Right Rear Tire

For the 2000 4×4 compact sport utility vehicle, the average understeer value, corrected for the Ackerman steer angle, with the four good tires was 3.5 degrees per g. The average understeer value for the testing completed with a fully delaminated but inflated right rear tire was 1.4 degrees per g. The differences in understeer and lateral acceleration capability between runs with four good tires and those with a deflated rear tire were less. In fact, for the linear range between 0.1 and 0.4 g's, the average understeer value for the deflated tire was found to be higher than that with the four good tires. The average understeer value for the tests run with the deflated right rear tire was 5.0 degrees per g. Once the

lateral acceleration exceeded the linear range of the deflated tire, however, the tire became unseated from the rim at approximately 0.6 to 0.7 g's, and the vehicle spun out. See Figure 15 for the steering wheel angle versus lateral acceleration comparison plot between the test cases.



Figure 14. 2001 Compact SUV w/ Deflated Right Rear Tire

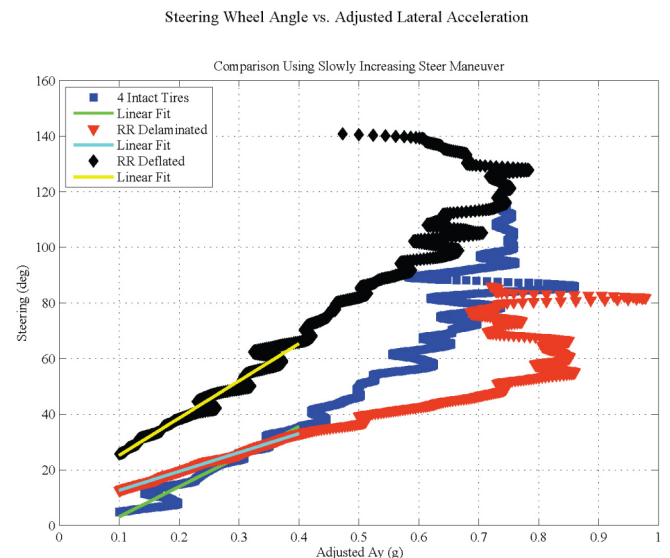


Figure 15. Steer Angle vs. Lateral Acceleration, 2000 SUV

Additional review of the data indicates that differences in performance between the vehicle with four good tires and that with a delaminated tire became pronounced at approximately 0.4 g's, while the deflated tire's performance diverged from the four good tires at around 0.5 g's. Figure 16 demonstrates the difference between the three test cases when looking at the relationship between steering wheel angle and yaw rate. When the video of the slowly increasing steer tests with a deflated right rear tire was reviewed, it appeared that the change in performance occurred approximately when the

tire began to debead from the rim, indicating that the vehicle essentially maintained significant capability until that point.

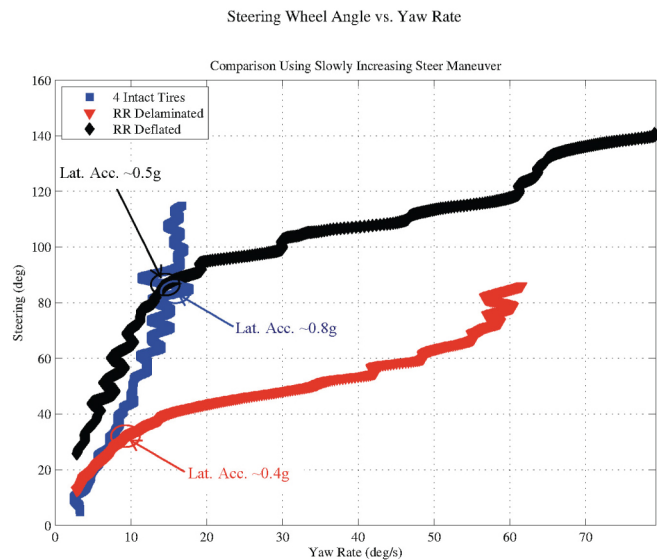


Figure 16. Steer Angle vs. Yaw Rate, 2000 SUV

The lateral acceleration at which the tire pulls free from the rim flange was also able to be quantified using the video documentation of the slowly increasing steer tests. The outboard video camera on the outrigger which recorded the right rear tire was synchronized with the test data file in order to analyze what the lateral acceleration was exactly when the tire debeaded and the rim contacted the ground. In the runs with the 2000 4×4 SUV, the tire stayed firmly seated on the rim until a lateral acceleration of 0.61 g's for one run and 0.68 g's for the other. See Figures 17 and 18 for the video stopped just as the rim flange contacted the asphalt. As evident in Figures 19 and 20, screen shots approximately 2/3 of a second prior to rim contact, the video also documented that the rim did not contact the asphalt until just after the tire debeaded. This means even at a significant lateral acceleration the tire remained seated on the rim. At this point, the vehicle in both tests spun out.

The 2001 4×2 compact sport utility vehicle was evaluated in a similar manner as the 2000 4×4 SUV. The average understeer value for the 4×2 SUV, corrected for the Ackerman steer angle, with the four good tires was 2.2 degrees per g. The average understeer value for the testing completed with a fully delaminated but inflated right rear tire was 0.5 degrees per g. The differences in understeer and lateral acceleration capability between runs with four good tires and those with a deflated tire were much less. The average understeer value for the tests run with the deflated right rear tire was 1.8 degrees per g. See Figure 21 for the steering wheel angle versus lateral acceleration comparison plot between the test cases.



Figure 17. Run 1 Showing Rim Contact During Test



Figure 18. Run 2 Showing Rim Contact During Test



Figure 19. Run 1, 2/3 Second Prior to Rim Contact



Figure 20. Run 2, 2/3 Second Prior to Rim Contact

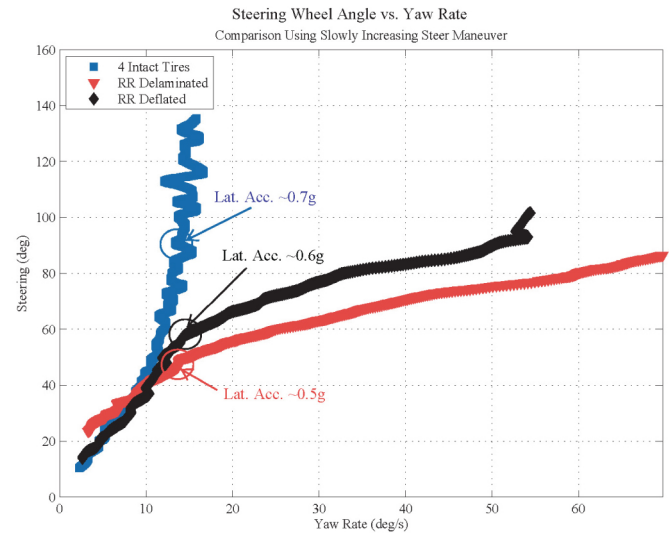


Figure 22. Steer Angle vs. Yaw Rate, 2001 SUV

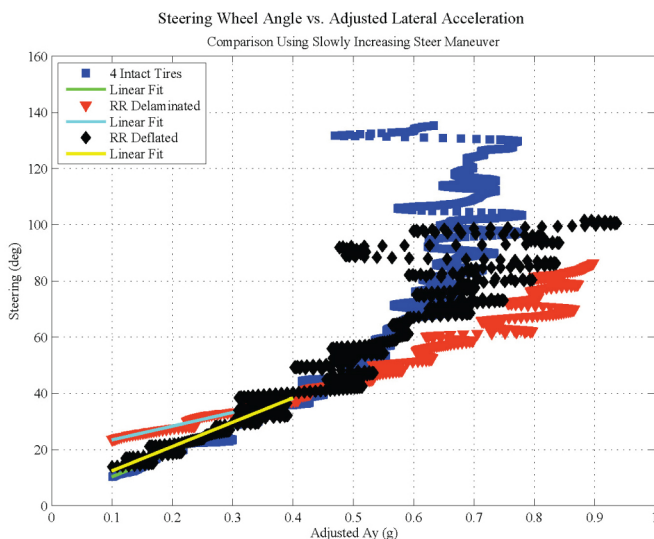


Figure 21. Steer Angle vs. Lateral Acceleration, 2001 SUV

Additional review of this data indicates that differences in performance between the vehicle with four good tires and that with a delaminated tire became pronounced at approximately 0.5 g's, while the deflated tire's performance diverged from the four good tires at around 0.6 g's. Figure 22 demonstrates the difference between the three test cases when looking at the relationship between steering wheel angle and yaw rate. When the video of the slowly increasing steer tests with a deflated right rear tire was reviewed, similar to the 2000 4×4 compact SUV, it appeared that the change in performance occurred approximately when the tire began to debead from the rim, again indicating that the vehicle essentially maintained significant capability until that point.

The lateral acceleration at which the tire pulls free from the rim flange was also quantified using the video documentation of the slowly increasing steer tests. As in the case of the 4×4 SUV, the outboard video camera on the outrigger which recorded the right rear tire was synchronized with the test data file in order to analyze what the lateral acceleration was exactly when the tire debeaded and the rim contacted the ground. In these runs, the tire stayed firmly seated on the rim until a lateral acceleration of 0.78 g's for one run and 0.66 g's for the other. See Figures 23 and 24 for the video stopped just as the rim flange contacted the asphalt. As evident in Figures 25 and 26, screen shots approximately 2/3 of a second prior to rim contact, the video also documented that the rim did not contact the asphalt until just after the tire debeaded. At this point, the vehicle in both tests spun out.



Figure 23. Run 1 Showing Rim Contact During Test