

Steering and Handling Performance During a Full Tire Tread Belt Separation

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ABSTRACT

In this study, tests were performed with modified tires at the various front and rear positions on seventeen different vehicles to determine the effect of a full tire tread belt separation on a vehicle at highway speeds. The driver's steering and braking inputs were measured along with the vehicle responses during the event. The results show that the forces of a full tread belt separation generally do not force a vehicle out of a driver's control and that only small steering corrections are required to remain in the original lane of travel during the tread belt separation event. Additionally, forces due to the separating tires do not result in violent hop or tramp suspension responses during the separation event.

INTRODUCTION

There have been various papers published that study the effect of a tire tread belt separation on the handling characteristics of a motor vehicle while the tire is separating. Many of these studies have been focused on one specific vehicle [1,2,3,4,5,6,7,8,9]. The most extensive study on this subject was conducted by Ford Motor Company in 2000 and 2001 and involved many different vehicles. These findings were not published in a formal paper but can be found in a presentation to the National Highway Traffic Safety Administration [10].

This paper focuses on how a full tire tread belt separation disturbs a vehicle that is traveling at highway speeds. The intent of this study is not to focus on the handling and steering characteristics of a vehicle with a tire that has already been disabled. Utility vehicles, pickup trucks, and a mini-van with various suspension types were tested with specially prepared front and rear tires. These tires were cut so that the tread and upper belt would separate while the vehicle

was traveling at freeway speeds and the tire would remain inflated. 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 sixty to seventy miles per hour) and maintain a straight ahead bearing on a test track. The metric chosen to evaluate the effect on the vehicle of the tread belt separation was the steering magnitude input by the drivers to maintain 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 what is required to maintain the lane of travel, not how unsuspecting drivers may respond to a tire disablement.

The results show that tire tread belt separations are of varying duration and make beating noises and vibrations which can be felt in the vehicle. The delaminating tire also creates a drag force that causes a yaw moment and pull to the side of the separating tire which then requires a small corrective steer by the driver to maintain a straight ahead course. Once the tread comes free from the tire, this pull disappears. Although the separating tire created a vibration and motion of the wheel end, at no time did any vehicle tested experience a suspension tramp or bounce mode where the rear tires bounced free from the ground. Since the tire itself and the separating pieces are not uniform and the out of balance force is not necessarily aligned with forces from the missing tread portions and attached tread pieces interacting with the vehicle and road surface, the force time history is best characterized as "noise" rather than "exciting" some narrow frequencies.

The full tread belt separation testing revealed that steering required to maintain straight-line vehicle performance was insensitive to the type of vehicle, the tire size, the suspension type, the drive option, and the position where the disabled tire was installed on the vehicle.

METHODOLOGY

The methodology employed in this study is divided into four sections. The first section describes the tire preparation 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 procedure.

TIRE PREPARATION

Tires were prepared to simulate a tread separation by cutting circumferentially at the tread/belt interface. The area is scored and then cut with a box knife on both sides of the tire to a depth of approximately two inches from the sidewall. The tread is then scored across the tread from one side to the other at an angle and the first one and one half inches cut through the tread and belt. This allows a region for the tread separation process to initiate (see Figures 1 and 2 for an example of a prepared tire).



Figure 1. Test Tire Prepared to Simulate a Tread Separation



Figure 2. Test Tire Prepared to Simulate a Tread Separation

TEST VEHICLES

Seventeen vehicles were tested as part of this study. Table 1 lists the vehicles and their configurations. Figures 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55 in Appendix A contain photographs of the test vehicles and the driver inputs recorded during the tire tread separation tests.

Table 1. Vehicles Used in Tire Tread Separation Study

Veh. No.	Veh. Config.	Drive Option	Front Susp.	Rear Susp.	Rear Shocks w.r.t. Springs	Tire Size	Tread Sep. Position(s)
1	'99 Compact Pickup	RWD	Ind.	Dep.	Inboard	P225/70R15	RR
2	'00 Mini-van	FWD	Ind.	Dep.	Outboard	P215/70R15	RR
3	'92 Compact SUV	RWD	Ind.	Dep.	Inboard	P235/75R15	RF & RR
4	'94 Compact SUV	4WD	Ind.	Dep.	Inboard	P235/75R15	RR
5	'98 Compact SUV	4WD	Ind.	Dep.	Inboard	P255/70R16	RR
6	'99 Compact SUV	RWD	Ind.	Dep.	Outboard	P235/75R15	RF & RR
7	'97 Compact SUV	RWD	Ind.	Dep.	Inboard	P235/75R15	RF & RR
8	'01 Full-Size SUV	RWD	Ind.	Dep.	Outboard	P275/60R17	RR
9	'00 Full-Size SUV	4WD	Dep.	Dep.	Inboard	LT265/75R16E	RF & RR
10	'02 Full-Size SUV	RWD	Ind.	Dep.	Inboard	LT265/75R16E	RR
11	'97 Mid-Size SUV	AWD	Dep.	Dep.	Inboard	235/70R16	RR
12	'00 Compact Pickup	RWD	Ind.	Dep.	Inboard	P225/70R15	RR
13	'96 Compact Pickup	4WD	Ind.	Dep.	Inboard	P235/75R15	RF & RR
14	'02 Compact SUV	RWD	Ind.	Dep.	Outboard	P255/65R16	RR
15	'03 Full-Size SUV	RWD	Ind.	Ind.	Outboard	P265/70R17	RF & RR
16	'00 Full-Size Pickup	RWD	Ind.	Dep.	Outboard	P235/70R16	LR
17	'99 Compact SUV	4WD	Ind.	Dep.	Inboard	P235/75R15	RR

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. A modified tire was then placed in the right rear location in most tests; however, some limited testing was performed with a prepared tire at the left rear and right front positions.

Vehicle Instrumentation

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

- Longitudinal, lateral, and vertical acceleration at approximately the vehicle center of gravity (cg).
- Vehicle speed
- Steering wheel angle, rate and torque
- Yaw rate
- Vehicle roll angle with respect to ground
- Left and right rear axle displacements and vertical accelerations 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
- Speed view

TEST PROCEDURE

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

- Place the modified tire at the desired position and set tire pressures to factory settings
- Initiate recording data and video
- Accelerate the vehicle to highway speeds and hold constant speed
- When tread belt separation occurs maintain straight ahead direction with steering correction
- After separation is fully completed, slow vehicle and turn off data and video equipment

GENERAL RESULTS AND DISCUSSION

When a tread separates from a tire the outer steel belt either partially or totally “peels off” of the inner rubber and belt. The focus of this study was on tires which have experienced a full tread belt separation (i.e. the entire tread comes free). Although it is difficult to determine if a tire will or will not experience a tread separation at a given time, this study found that the process involved during a tread separation event on a

moving vehicle does provide definite feedback to the driver and passengers in most circumstances. The feedback usually begins with a vibration in the vehicle similar to that created by an unbalanced tire. The vibration is followed by a “slapping” sound caused by the loose tread rubber contacting the pavement as the tire rotates. As the length of the loose tread grows, it begins to hit against vehicle body parts such as the inner fender well and outer sheet metal. The sound created by the tread hitting the vehicle body is very loud and resembles that of a beating drum which typically lasts for about a second or two. As the tread is separating, the effective rolling resistance of the tire increases which creates a force and moment on the vehicle. This moment acts to pull the vehicle to the side of the separating tire.

The testing that is the subject of this paper involved multiple runs made at speeds ranging from fifty five to seventy five miles per hour. In every test run, the vibration and the “slapping” sound of the separated tread as it hit the ground and vehicle body were apparent prior to the tread ripping totally free from the tire casing, even though the test tire had been pre-cut to assure the separation process began in a minimal amount of time. During each of the full belt tread separation events, the tire did pull the vehicle slightly to one side, but the driver kept a straight line path with a small steering correction. This amplitude of steering correction was small and within the range of steering inputs seen in normal driving and similar to those required to keep a properly functioning vehicle in its travel lane on curved highways. All vehicles were videotaped so that vehicle motion could also be shown visually.

Although the tire separation caused vibration at the rear suspension of all vehicles, at no time did the separating tires or the axle companion tires leave the ground in a tramp or bounce mode. The drivers did not feel any lateral displacement or shifting of the rear of the vehicle similar to what may occur on a rough, washboard road. The steering inputs recorded during the tire separation event were small and are presented for all vehicles in [Appendix A](#) and summarized in [Table 2](#). Note that the steering wheel angles in these plots do not start at zero but some small magnitude of input. This is due to road crown and the drag created by the tire as it is separating but prior to the release of the tread and upper belt.

In order to provide some objective insight into the repeatability of this test procedure, three of the test vehicles, the 1992, 1998, and 1999 compact sport utility vehicles, were each tested three times with right rear tread belt separations. For each of these vehicles, the magnitude of the maximum steering wheel angle required to maintain the original lane of travel was consistent between the test runs. The 1992 compact SUV required approximately eleven to twenty-five degrees of steering angle during its three tests, while the 1998 compact SUV required approximately sixteen to

eighteen degrees, and the 1999 compact SUV needed approximately seven to twelve degrees. Figure 3 provides a comparison of the steering wheel magnitudes between the individual test runs and the three test vehicles. Also, the character of the steering correction is similar for each of the vehicles. Figures 4, 5, 6 show the steering wheel traces during the actual tread separation events.

Table 2. Summary of Steering Wheel Angles Recorded in Tire Tread Separation Study

Vehicle Number	Vehicle Configuration	Drive Option	SWA During Tread Sep [degrees]	Tread Separation Position
1	1999 Compact Pickup	RWD	15	RR
2	2000 Mini-van	FWD	3	RR
3	1992 Compact SUV	RWD	5	RF
4	1994 Compact SUV	4WD	12	RR
5	1998 Compact SUV	4WD	17	RR
6	1999 Compact SUV	RWD	17	RR
7	1997 Compact SUV	RWD	20	RF
8	2001 Full-Size SUV	RWD	20	RR
9	2000 Full-Size SUV	4WD	13	RR
10	2002 Full-Size SUV	4WD	24	RF
11	2002 Full-Size SUV	RWD	6	RR
12	1997 Mid-Size SUV	RWD	21	RR
13	2000 Compact Pickup	4WD	26	RF
14	1996 Compact Pickup	RWD	17	RR
15	2002 Compact SUV	AWD	18	RR
16	2000 Compact SUV	RWD	19	RR
17	1999 Compact SUV	4WD	38	RF
18	2002 Compact SUV	RWD	15	RR
19	2003 Full-Size SUV	RWD	12	RR
20	2003 Full-Size SUV	RWD	9	RF
21	2000 Full-Size Pickup	RWD	12	RR
22	1999 Compact SUV	4WD	22	LR
23	1999 Compact SUV	4WD	8	RR

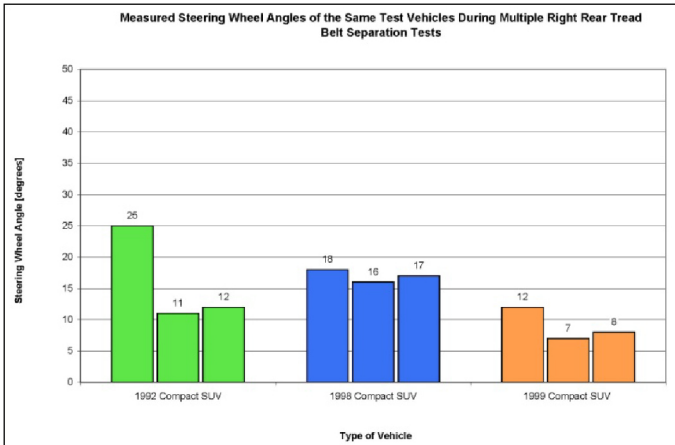


Figure 3. Comparison of Vehicles Tested Multiple Times

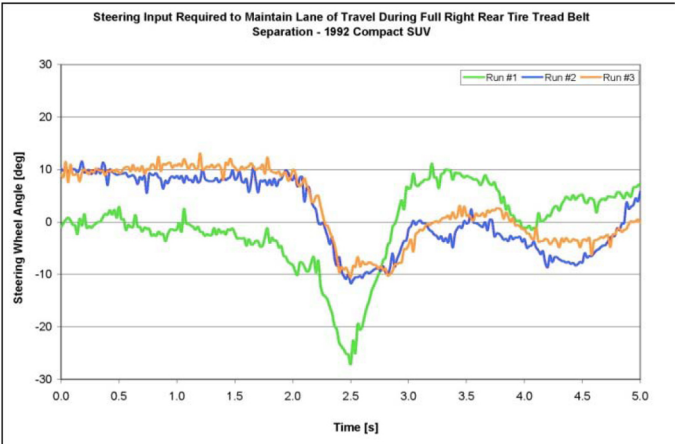


Figure 4. Steering Wheel Traces for 1992 Compact SUV

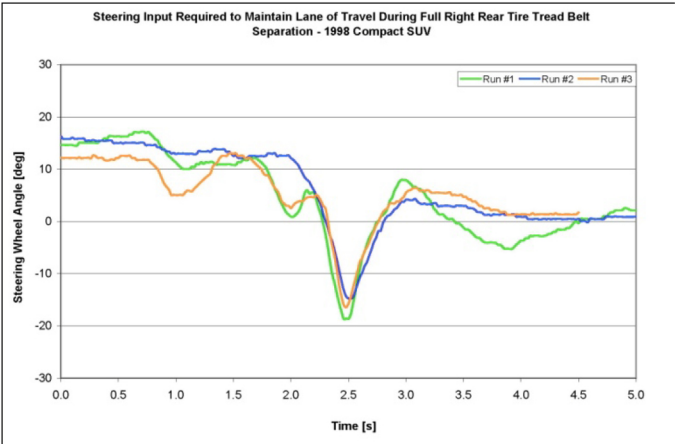


Figure 5. Steering Wheel Traces for 1998 Compact SUV



Figure 6. Steering Wheel Traces for 1999 Compact SUV

REAR TIRE TREAD SEPARATION TESTS

COMPARISON OF VEHICLE TYPES

This testing 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 steering angles were relatively small and did not overwhelm any vehicle tested. In fact, none of these steering angles exceeded 25 degrees. [Figure 7](#) presents a comparison of the measured steering angles.

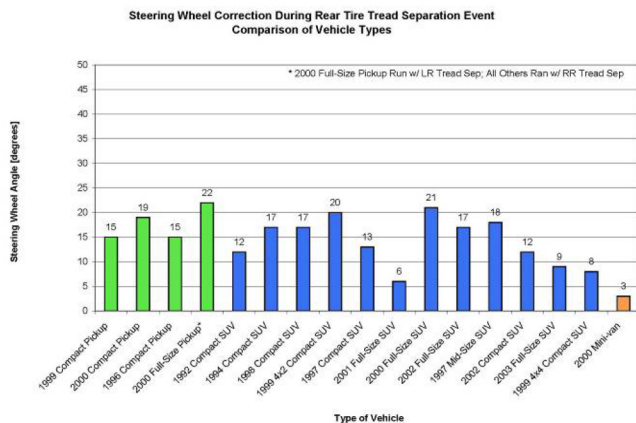


Figure 7. Comparison of Steering Angles During Rear Tread Separations on Different Types of Vehicles

EFFECT OF TIRE SIZE

Five of the compact sport utility vehicles (SUV's) that were tested were substantially similar and were able to be used to compare the effect of wheel and tire size on a vehicle's response to a rear tire tread separation. Of these five compact SUV's, four were tested with P235/75R15 tires and one with P255/70R16 tires. All five of the compact SUV's required 20 degrees or less of steering wheel input to maintain the original lane of travel, and the test run with the P255/70R16 tires required no more steering input than that found in the tests run with the P235/75R15 tires. [Figure 8](#) documents the steering requirements of all five compact SUV's. It should be noted that only original equipment tires were tested here. These results should not be used to suggest that oversized tires would require similar steering corrections. A large tire might have much heavier tread pieces and may have less clearance to the wheel well and other suspension and frame components and therefore could require more work from the driver to keep it in the lane.

EFFECT OF DRIVE OPTION

Five of the compact sport utility vehicles (SUV's) that were tested were substantially similar and were able to be used to

compare the effect of final drive on a vehicle's response to a rear tire tread separation. Of these five compact SUV's, two were two-wheel rear-wheel drive vehicles and three were four-wheel drive vehicles. All five of the compact SUV's required 20 degrees or less of steering wheel input to maintain the original lane of travel, with no noticeable difference between two- and four-wheel drive vehicles. The steering requirements of all five compact SUV's is shown in [Figure 9](#).

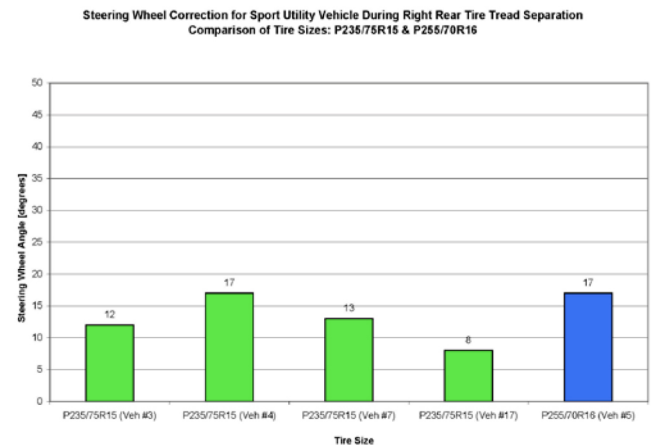


Figure 8. Comparison of Steering Angles During Right Rear Tread Separations with Two Sizes of Tires

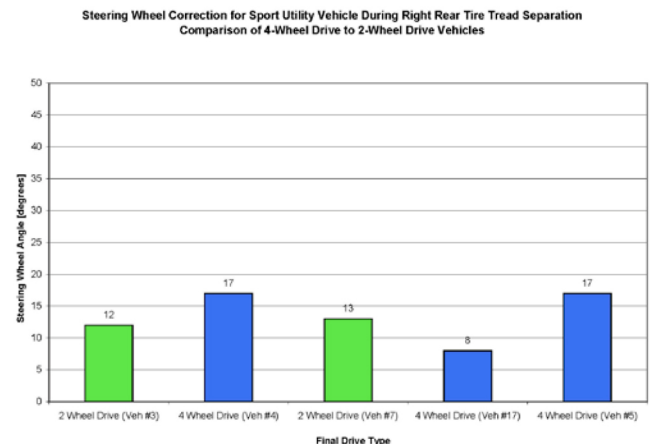


Figure 9. Comparison of Steering Angles During Right Rear Tread Separations: Two- and Four-Wheel Drive Vehicles

EFFECT OF SUSPENSION TYPE

The 2001 full-size SUV and the 2003 full-size SUV were similar enough in size and weight to compare the effect of rear suspension architecture on a vehicle's performance during a rear tread separation. As can be seen in [Table 2](#) and [Figure 10](#), there was no noticeable difference in the steering angle required between the 2003 full-size SUV with an