

# The Effect of Electronic Stability Control Following a Rear Tire Tread Belt Separation

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## ABSTRACT

In this study, tests were performed on four different vehicles, each equipped with a version of electronic stability control ("ESC"). Tests were performed on a 2000 four door sedan, a 2002 four door sedan, a 2002 five door hatchback, and a 2003 large rear wheel drive sport utility vehicle. This selection allowed for the evaluation of different ESC systems and strategies on their ability to accommodate a separated rear tire. The steer inputs were applied to the vehicles manually by test drivers and were purposely selected to generate displacements so that the ESC systems would activate. The results of this study demonstrate that ESC systems can be overwhelmed by some steering demands when a rear tire has lost its tread. This fact does not constitute a problem with the ESC systems or the vehicles tested. It merely confirms that ESC systems will not always keep a vehicle from sliding or spinning out when a tire is disabled.

## INTRODUCTION

The basic defining characteristics of an ESC system include a computer with a closed-loop algorithm to alter vehicle response in some situations, the capacity to measure vehicle responses, such as yaw velocity, the ability to estimate other state variables, such as slip angle, and the capacity to measure driver inputs, such as steering input. Furthermore, the ESC system must be able to apply brakes at individual wheels. These systems can incorporate two wheels or all four, as well as engine control ([ref 1](#)).

There have been many papers published in recent years that have attempted to evaluate the effect of ESC on the occurrence of a variety of different crashes ([ref 2,3,4,5,6,7,8,9,10,11](#)). Another paper, "The Response Characteristics of Several Vehicles Equipped With Electronic Stability Control to Violent Steering Demands on Different

Surfaces" ([ref 12](#)), evaluates the effects of steering demands on vehicles equipped with ESC on dry, wet, and snow covered surfaces utilizing tires that are not disabled.

The only paper known to these authors relating to the effect of ESC on the handling of a vehicle with a disabled tire was written by Arndt ([ref 13](#)). Arndt ran Slowly Increasing Steer ("SIS") and Sine With Dwell ("SWD") tests using a robotic steering controller on two SUVs equipped with a form of ESC. The paper indicates that vehicle understeer gradients, calculated using a lateral acceleration range of 0.1 to 0.375 g's in the SIS test, remained the same whether ESC was on or off since it did not trigger in those tests. Arndt found greater differences in vehicle response in the higher lateral acceleration range. The study did not investigate whether a vehicle with ESC could be overwhelmed by a human driver input with a separated rear tire.

The authors are not aware of any ESC system on the market today that specifically monitors if a tire has experienced a tread separation and thereby adjusts the computer strategy to try and accommodate for the change in tire capacity. Relying in part on the previously referenced "effectiveness" studies, some investigators who reconstruct or analyze individual crashes of vehicles without ESC quickly conclude that had the crash involved vehicle been equipped with a well designed ESC system the crash would not have occurred.

The intent of this paper is to evaluate and understand if modern ESC systems can be overwhelmed by some steering demands when a rear tire experiences a tread belt separation. Steering inputs were selected subjectively, and the goal was not to test each vehicle identically to compare their performance, rather to see if there were maneuvers that could induce loss of control for each vehicle tested. The intent of this paper was not to compare different algorithms between vehicles or quantify whether one system performs more

effectively than another. The previously mentioned studies also did not attempt to do this. What was found was that ESC cannot prevent a vehicle from spinning or sliding in the event of a driver steering abruptly when a rear tire experiences a tread belt separation. Drivers can still lose control and cause these vehicles to enter into broadside slides under these conditions.

## METHODOLOGY

The methodology for this study is divided into four sections. The first section describes the tire preparation of the circumferentially cut tires used to simulate a tire that has experienced a full tread separation. The second section describes the vehicle preparation and the instrumentation and video equipment used to document the tests. Next, the test location and surfaces are discussed. Finally, the test procedure is described.

### TIRE PREPARATION

Four new tires were purchased for each test vehicle. The tires selected were the size and type as originally specified for each vehicle. Tires were prepared by cutting circumferentially at the tread/belt interface using a razorblade knife. The tread and outer steel belt was completely removed from the remaining tire system (see [Figure 1](#)).

### VEHICLE PREPARATION

The test vehicles used for these evaluations were a 2000 four door sedan ([Figure 2](#)), a 2002 four door sedan ([Figure 3](#)), a 2002 five door hatchback ([figure 4](#)), and a 2003 large rear wheel drive sport utility vehicle ([Figure 5](#)). The vehicles were equipped with video equipment, instrumentation, and loaded only with a driver and no cargo. The modified tire was then placed at a rear location for all of the tests. The three other tires on the vehicle were new and not modified. All tire pressures were at the factory recommended pressure settings.

### VEHICLE INSTRUMENTATION

Test equipment was installed on the vehicle to record the inputs to the vehicles and responses of the vehicles. The driver's steering inputs to the vehicle were recorded using video equipment for the sedans and a steering potentiometer for the hatchback and full size SUV. Vehicle response signals recorded near the vehicle's center of gravity location included vehicle longitudinal and lateral velocity, vehicle lateral, longitudinal, and vertical acceleration, yaw rate, vehicle roll angle with respect to ground, and vehicle position. ESC activation was determined with monitoring the ESC telltale strictly as a guide to show whether activation occurred, not as an attempt to monitor precise application or compare algorithm strategies. Additionally, brake pressures at the calipers were measured on the hatchback and large SUV.

## VEHICLE VIDEO EQUIPMENT

The video equipment installed on the vehicle included four real time cameras. The interior camera locations included a view over the driver's shoulder of the steering wheel, a view of a digital speed display, and a view of the ESC telltale on the cluster. Another camera was installed on the body directed toward the rear wheel. Additionally, there were two manned external cameras capturing footage from a lift and from the pad level.

## TEST LOCATIONS

The test surface used for the testing was the dry Vehicle Dynamics Area at the Continental-General Tire Proving Grounds in Uvalde, Texas. The VDA is 800 feet by 800 feet with a one percent slope, and was used dry. The dry test surface condition allowed a driver to maneuver quickly and also provided the ESC system with high levels of restoring force when it activated. In order to fully document the vehicle motion, the tire marks were measured for the tests on the passenger cars with GPS survey equipment.

## TEST PROCEDURE

The delaminated tire was mounted on the vehicle at a rear wheel position. Tire pressures were set to factory recommendations.

The following steps were followed by the driver and test team for all tests:

- Initiate recording data and video
- Accelerate the vehicle to a range of 60 to 70 mph
- Drive on to the test surface, release the throttle, and apply an abrupt steering input in one or multiple directions
- The tire marks were recorded with photographs and videotape. GPS survey data was measured on the tests involving the passenger cars.

Note: Tests were run by steering right only, right and then left, or left and then right

## VEHICLE RESPONSE WHEN DELAMINATED TIRE IS ON OUTSIDE OF THE TURN

Testing was conducted using either single or double steering inputs. In the case of the single steer maneuvers, the vehicle was steered away from the side where the delaminated tire was mounted. This forced the separated tire to be on the outboard side of the vehicle during the turn. In the case of the two steer maneuvers, the vehicle was first steered towards the side where the delaminated tire was mounted, then the steering was reversed. This forced the separated tire to be on the outboard side of the vehicle after the second steering

input. Several tests were run on each vehicle and in all tests conducted, the steering inputs caused the vehicles to attain relatively high side slip angles as well as the tires to slide and generate yaw marks. All vehicles experienced a “spinout” in these tests.

### 2000 Four Door Sedan

Figure 6 is a photograph of the tire marks created by a single test on the 2000 sedan. Tire marks have been highlighted to show them clearly on the test surface. Note that the delaminated tire mounted at the left rear position generates a white marking in its yaw mark (Figure 7). It is also important to notice the diverging yaw marks confirming that the vehicle spun completely broadside. Figure 8 is the corresponding data chart for that run. The steering wheel trace shown in Figure 8 was taken from in-vehicle video footage of the test run. The data shows that the test generated high accelerations and yaw rates and that the ESC system was not able to keep the vehicle from spinning out. ESC telltale video confirmed ESC intervention attempts. Figures 9 and 10 are renderings of computer generated models showing vehicle positions created using GPS survey data of the tire marks.

### 2002 Four Door Sedan

Figure 11 is a photograph of the tire marks of the 2002 sedan showing the overlap documenting the spin of the vehicle. The delaminated tire was on the left rear for this test. Figure 12 is the test data for that run. The steering wheel trace shown in Figure 12 was taken from in-vehicle video footage of the test run. The data indicates once again that the steering demand forced the vehicle into an out-of-control spin. ESC telltale video confirmed ESC intervention attempts. Figures 13 and 14 are renderings of computer generated models showing vehicle positions created using GPS survey data of the tire marks.

### 2002 Five Door Hatchback

Figure 15 is a photograph of the 2002 hatchback at rest on the test surface, documenting the tire marks. The right rear delaminated tire is visible in this photo. Figure 16 is a different view where the tire marks have been highlighted. The tire mark crossing point indicates the point where the vehicle was traveling at a sideslip angle of ninety degrees. Figures 17 and 18 depict the test data for that run. ESC telltale video and individual brake line pressures confirm ESC activation. Figures 19 and 20 are renderings of computer generated models showing vehicle positions created using GPS survey data of the tire marks.

### 2003 Full Size Sport Utility Vehicle

Figure 21 is a photograph of the tire marks generated by the SUV during the testing with the delaminated tire on the right rear position. Figure 22 is an overhead view where the tire marks were highlighted so that they can be more easily seen.

Figures 23 and 24 are test data charts for that run. The steering inputs on the SUV created large responses due to the effect of the separated tire on the rear suspension. Note the large yaw rates, side slip angles, and lateral accelerations. ESC telltale video and brake line pressure data confirm ESC intervention attempts.

## **VEHICLE RESPONSE WHEN DELAMINATED TIRE IS ON INSIDE OF THE TURN**

Additional testing was conducted using two steer maneuvers that forced the separated rear tire to be on the inboard side of the second turn. With the delaminated tire on the inside of the turn, the effect of the separated tire is reduced since the dynamics of the vehicle causes more force to be applied to the unmodified tire on the rear suspension and less on the disabled tire. Several tests were run on each vehicle and in all tests conducted, the steering inputs caused the vehicles to spin out.

### 2000 Four Door Sedan

Figure 25 is a photograph of the tire marks created by a test on the 2000 sedan. Note the light mark made by the delaminated left rear tire. Figure 26 is the corresponding data chart for that run. The steering wheel trace shown in Figure 26 was taken from in-vehicle video footage of the test run. The data shows very high yaw rates in the test. ESC telltale video confirmed ESC intervention attempts. Figures 27 and 28 are renderings of computer generated models showing vehicle positions created using GPS survey data of the tire marks. This data confirms a full spin out response of the vehicle, even when the separated tire is on the inside, or less loaded position.

### 2002 Four Door Sedan

Figure 29 is a photograph of the tire marks of the 2002 sedan showing the spin out. Tire marks have been highlighted to show them clearly on the test surface. Figure 30 is the test data for that run. The steering wheel trace shown in Figure 30 was taken from in-vehicle video footage of the test run. The delaminated tire was mounted on the left rear of this vehicle. The data indicates again a spinout response. ESC telltale video confirmed ESC intervention attempts. Figures 31 and 32 are renderings of computer generated models showing vehicle positions created using GPS survey data of the tire marks.

### 2002 Five Door Hatchback

Figure 33 is a photograph of the tire marks created by the 2002 hatchback. The unique markings of the right rear delaminated tire are visible, and show that the vehicle was traveling at a significant sideslip angle, such that both rear tires were tracking outside the fronts. Figure 34 and 35 depict

the test data for that run. ESC telltale video and individual brake line pressures confirm ESC activation. [Figures 36 and 37](#) are renderings of computer generated models showing vehicle positions created using GPS survey data of the tire marks

### 2003 Full Size Sport Utility Vehicle

[Figure 38](#) is a photograph of the tire marks generated by the SUV during a run with the second steer unloading weight from the delaminated right rear tire. ESC telltale video confirmed ESC intervention attempts. [Figure 39](#) is an overhead view where the tire marks were highlighted with image editing software. [Figures 40 & 41](#) are test data charts for that run. Note the large yaw rates, side slip angles, and lateral accelerations. The brake pressures shown in [Figure 41](#) show the brake line pressures confirming ESC activity.

## DISCUSSION OF RESULTS

These tests confirm that the all ESC equipped vehicles were made to spin out when a separated tire is placed on the rear suspension. Spin responses were generated whether the separated tire was on the inside or outside of the turn. This is not something that is isolated to just these ESC systems or vehicle designs. In order to allow drivers to maneuver their vehicles when required, the ESC systems must allow some vehicle side slip and corresponding tire slip angles. Also, ESC can only attempt to redirect a vehicles motion by applying brakes, not steering. Under steering situations when a rear tire is separated, steering demands can be made which force a vehicle with a well designed ESC system to slide and spin out.

## UNSUCCESSFUL ATTEMPT TO TEST A 1999 TWO DOOR SPORTS CAR

A fifth vehicle was included in this study but could not be tested under the conditions where ESC was active ([Figure 42](#)). When the separated tire was placed on the right rear position it was noticed that this wide, low profile tire ballooned out and therefore had a much larger rolling radius than the unmodified tires ([Figure 43](#)). When the vehicle was driven up to the test speed, the ESC warning lamp turned on. It is believed that the ESC or ABS braking system sensed a large change in tire rolling radius and turned off the ESC system.

## CONCLUSIONS

1. When a rear tire experiences a tread belt separation, some steering demands can be made which force any vehicle, including those with a modern ESC system to slide and spin out.
2. A spinout response can occur in an ESC equipped vehicle when the delaminated rear tire is on the inside or the outside of the turn. The reduction in tire traction created by the

separation cannot always be accommodated by these ESC systems.

3. This testing confirms that any claims that ESC systems can accommodate all tire disablements is without basis. Drivers of vehicles with ESC systems can still lose control of their vehicles if they steer abruptly when a tire becomes disabled. However, as with vehicles without ESC systems, small steering corrections can keep a vehicle on the intended path in the event of most rear tire tread separations.

4. One point that needs to be made is that ESC is a very promising technology. It is a system that attempts to help the driver and will under some situations. This paper is not intending to say that ESC cannot aid the driver in maintaining control with or without tire disablements. However, there are other situations in which ESC will not be able to prevent a vehicle from sliding, spinning, or crashing. When a driver steers abruptly following a rear tire disablement is one such situation.

## ACKNOWLEDGEMENTS

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**Figure 1. Delaminated Tire**



**Figure 2. 2000 Four Door Sedan**



**Figure 3. 2002 Four Door Sedan**



**Figure 4. 2002 Five Door Hatchback**



*Figure 5. 2003 Full Sized SUV*



*Figure 6. 2000 Four Door Sedan Tire Marks Highlighted*



*Figure 7. 2000 Four Door Sedan Tire Marks*

# **Step Steer Demonstration w/ LR Delaminated Tire – 63 mph** **2000 Four Door Sedan (Curb +)**

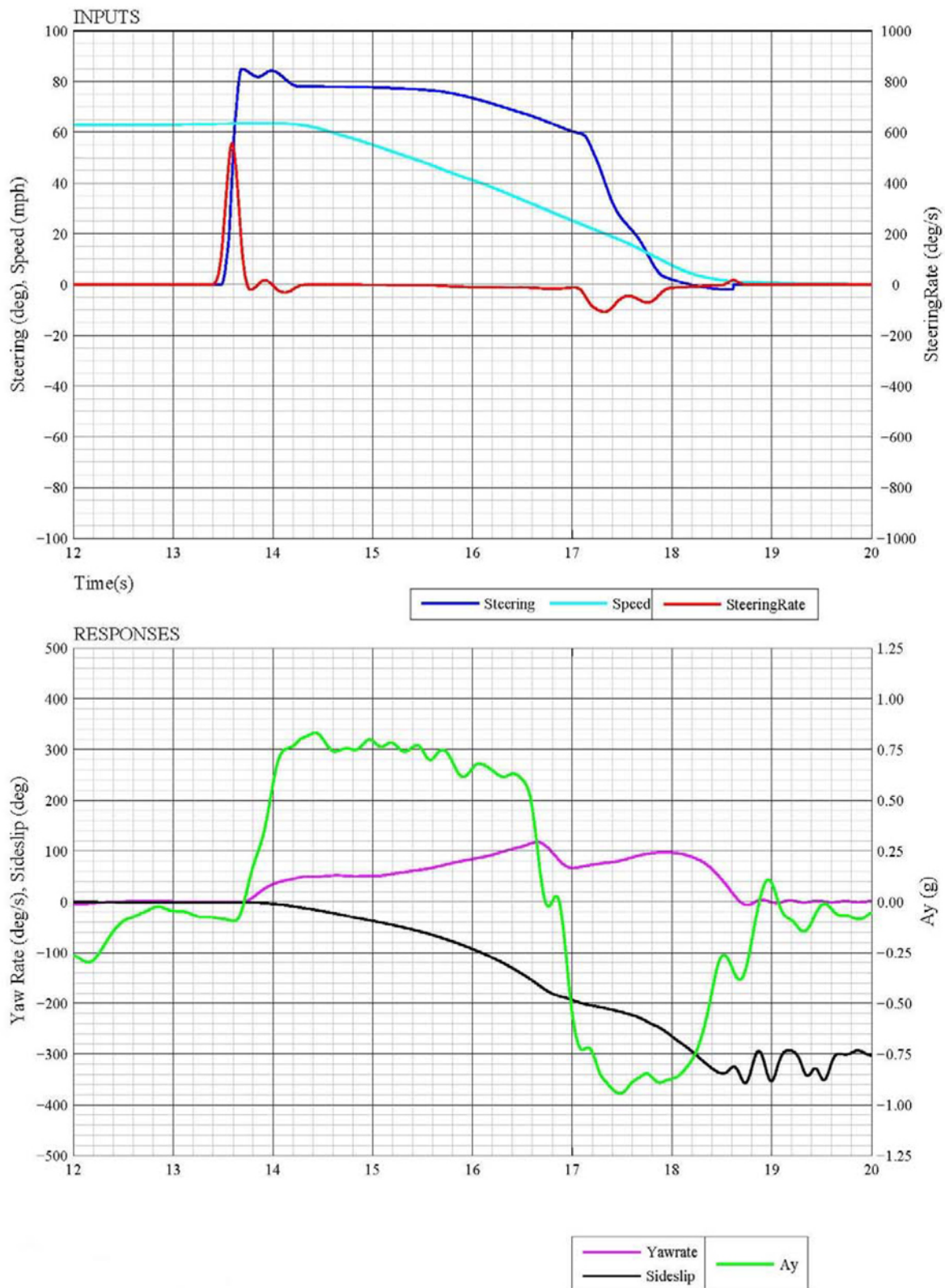


**Figure 8. 2000 Four Door Sedan Input and Response Data**

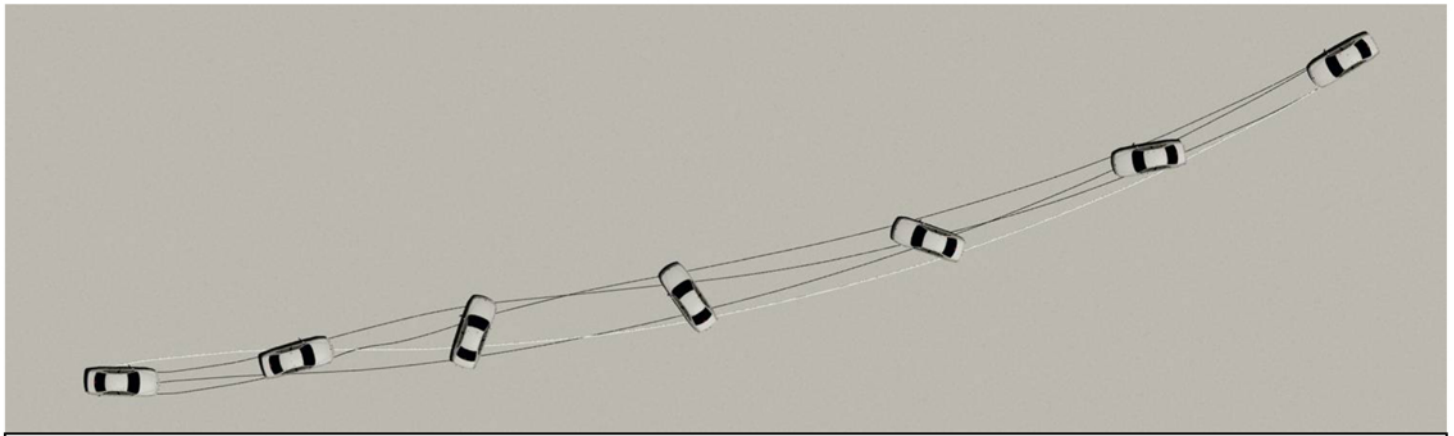


*Figure 9. Top View of 2000 Sedan Vehicle path*

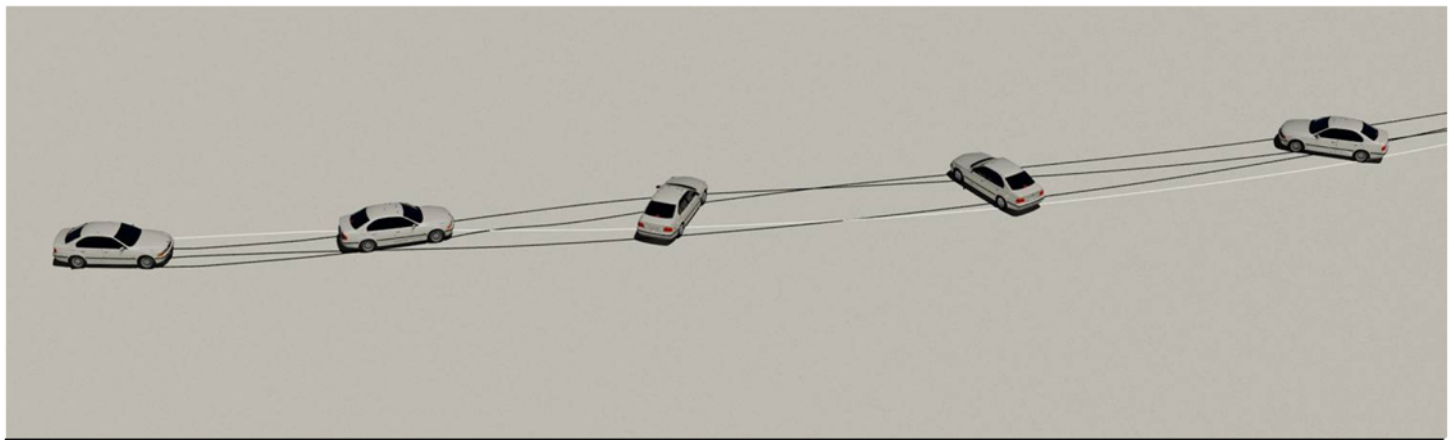


*Figure 10. Side View of 2000 Sedan Vehicle Path*



*Figure 11. 2002 Four Door Sedan Tire Marks*