

Effectiveness of Electronic Stability Control on Maintaining Yaw Stability When an SUV Has a Rear Tire Tread Separation

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ABSTRACT

Electronic Stability Control (ESC) has the potential of improving yaw stability and reducing the occurrence of a crash when a vehicle experiences a rear tire tread separation. Two instrumented 4-door, RWD SUV's equipped with ESC were tested to evaluate the effectiveness of their ESC systems on maintaining yaw stability under these circumstances. The test vehicles were evaluated with the tread and outer steel belt removed from the right rear tire. Tests were run with the ESC engaged and then repeated with the ESC disengaged. All runs were completed with the tires inflated to the manufacturer's recommended pressure. An analysis of the data collected shows that there are significant differences in the steering input required to generate a loss of control response with and without ESC enabled. Results of Sine with Dwell testing demonstrate a significant reduction in vehicle spinout response with the ESC engaged. Over three times more steering input was required before the vehicle exhibited a spinout response with ESC enabled when compared to the ESC disabled vehicle. This will likely have a positive effect on a driver's ability to maintain control when faced with a rear tire tread separation under real world circumstances.

INTRODUCTION

A rear tire tread separation event can lead to loss of vehicle control as a result of an unexpected deviation to the vehicle's intended path in combination with the significant change that occurs to the vehicle's understeer/oversteer characteristics (references 1, 2, and 3). Designers have had difficulty providing substantial improvements in the basic vehicle response and handling changes caused by a rear tire tread separation event. The National Highway Transportation Safety Administration (NHTSA) commissioned a study (reference 4) that found that increasing a vehicle's understeer coefficient will improve a driver's chances of maintaining control in the event of a rear tire tread separation. Continuing to increase a vehicle's understeer coefficient to eliminate loss of control events caused by tread separations ultimately comes at the expense of vehicle responsiveness. A vehicle that is too unresponsive will generate a whole new set of problems for a driver in other emergency situations.

ESC was designed to enhance yaw stability when a vehicle is experiencing an excess understeer (plow out) or oversteer (spinout) response (Figures 1 and 2) (reference 5) by managing the throttle and applying individual wheel brakes as necessary in an attempt to maintain the driver's intended path.

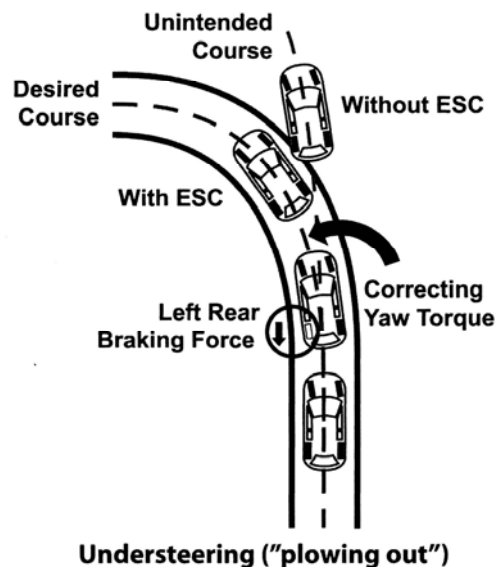


Figure 1. ESC brake application during understeer (reprinted from reference 5)

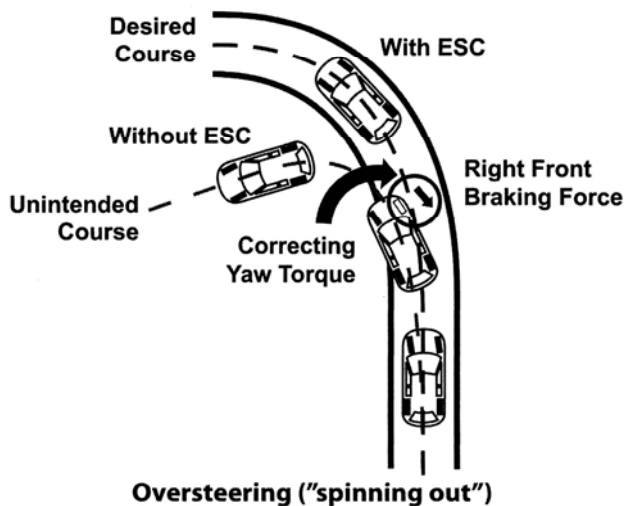


Figure 2. ESC brake application during oversteer (reprinted from reference 5)

A rear tire tread separation reduces the yaw stability of a vehicle and can lead to a loss of control crash. A vehicle that has experienced a rear tire tread separation will often experience an extreme oversteer response resulting in vehicle spinout and loss of control. The purpose of this research program was to evaluate the effectiveness of a typical SUV ESC system on improving the yaw response of a vehicle that has experienced a rear tire tread separation.

TEST VEHICLES

Two popular SUV's were tested as part of the research program. They were a 2004 4-door, RWD Mercury Mountaineer (Figure 3) and a 2004 4-door, RWD Chevrolet Tahoe (Figure 4). All tests were completed

with original equipment make, model, and size tires inflated to the pressure stated on the certification placard. The tires utilized were B.F. Goodrich Rugged Trail T/A, size P245/65R17 and Firestone Destination LE, size P265/70R17 on the Mercury Mountaineer and Chevrolet Tahoe respectively. Baseline testing was completed with four unmodified, as purchased, tires on both vehicles. After completion of the baseline tests, the right rear tire of the test vehicle was replaced with a modified tire which had been prepared to simulate the condition of a complete tread separated tire. The modified right rear tire was prepared by removing the tread and outer steel belt prior to the initiation of the test (Figure 5).



Figure 3. 2004 4-door, RWD Mercury Mountaineer



Figure 4. 2004 4-door, RWD Chevrolet Tahoe

The load configuration for both vehicles during all of the tests was curb plus driver plus instrumentation. Both front and rear bumpers were removed from the test vehicles and replaced with titanium outriggers built to NHTSA specifications (reference 6). The original steering wheel was replaced with an AB Dynamics steering robot capable of providing a programmed steering input. Additional instrumentation included a

triaxial accelerometer mounted near the vehicle's center of gravity (CG), a triaxial angular rate sensor mounted near the vehicle's CG, a Corrsys-Datron velocity sensor mounted on the centerline of the rear outrigger, four pressure transducers to measure individual wheel brake pressure, two laser height sensors positioned on the front outrigger and aligned with the centerline of the front tires, and two laser height sensors positioned outboard of the rear tires on the centerline of the rear axle. The Corrsys-Datron velocity sensor was set up to measure speed and slip angle. A high definition video camera was positioned near the maneuver start gate to record each run from behind the vehicle.



Figure 5. View of modified right rear tire on Tahoe

TEST MANEUVERS

Two basic vehicle handling test maneuvers were employed throughout the research program. These two test maneuvers were the Slowly Increasing Steer (SIS) test and the Sine with Dwell test as defined by NHTSA in reference 7.

SIS TEST – The SIS test had two objectives. The first was to determine the steer constant to be employed in the Sine with Dwell test. The steer constant is the hand wheel angle input necessary to generate 0.3 G lateral acceleration at a test speed of 80 km/hr (50 mph). The second objective was to evaluate the effectiveness of the ESC system during a quasi-steady state maneuver. The SIS test consisted of driving the test vehicle in a straight line up to the defined speed and then initiating steering wheel input at a rate of 13.5 deg/sec while maintaining vehicle speed by throttle control.

The first series of SIS tests was completed with the test vehicles in their baseline configurations to establish the steer constants to be utilized in the Sine with Dwell tests. The right rear tire on the test vehicles was then replaced by a modified tire and the SIS tests were rerun. The procedure was varied from that defined by the NHTSA protocol to achieve objective two. The changes included running the test at speeds of 40, 56, 72, and 89 km/h

(25, 35, 45, and 55 mph) with and without the ESC engaged. Each run was terminated after the vehicle slip angle exceeded 10 degrees.

SINE WITH DWELL TEST – The objective of the Sine with Dwell test was to determine the effectiveness of the ESC system in maintaining yaw stability with a tread separated tire on the right rear of the test vehicles during a dynamic maneuver. The Sine with Dwell test procedure followed the NHTSA procedure defined in reference 7. This maneuver consists of driving the vehicle up to a steady state speed of 80 km/h (50 mph) in a straight line and then initiating a sinusoidal steer input whose magnitude is based on the steering constant defined during the SIS test multiplied by a steering scalar ranging in magnitude from 1.0 to 5.5.

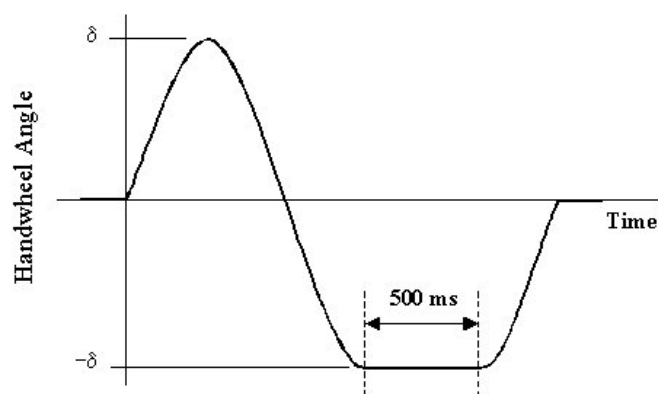


Figure 6. Sine with Dwell steering profile (reprinted from reference 7).

The sinusoidal steer was input right/left at a 0.7 HZ frequency for all runs. A 0.5 second dwell was initiated at the peak of the steer reversal (Figure 6). The left steer loaded the tread separated right rear (outboard) tire during the dwell phase of the maneuver. The pass/fail criterion for this test was determined by comparing the measured yaw rate at 1.0 and 1.75 seconds after the steering was returned to neutral to the first local peak yaw rate resulting from the steer reversal. The test was considered a pass if the yaw rate did not exceed 35 percent and 20 percent of the first local peak yaw rate at 1.0 and 1.75 seconds respectively.

TEST RESULTS

SIS TEST – The understeer gradient for the two test vehicles was determined from the SIS test under the baseline condition and the right rear modified tire condition with the ESC enabled and disabled. The results of the understeer gradient analysis are presented in Figures 7 and 8 for the Mountaineer and Tahoe respectively.

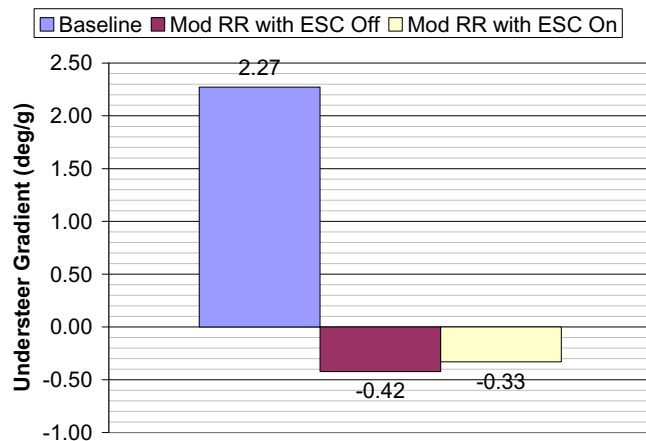


Figure 7. 2004 Mountaineer Understeer Gradient

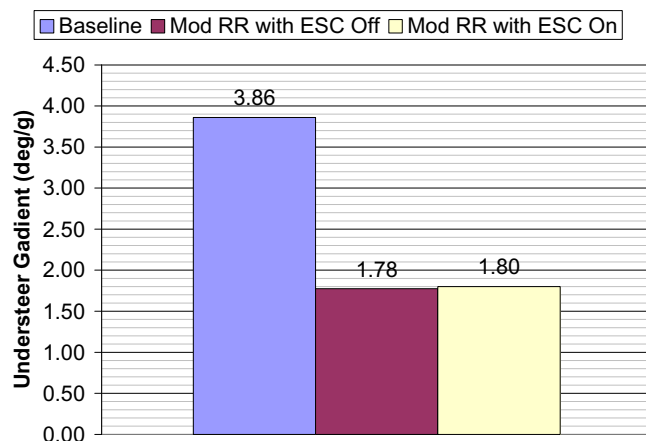


Figure 8. 2004 Tahoe Understeer Gradient

The understeer gradients were evaluated over the linear range of 0.100 to 0.375 g lateral acceleration. The understeer gradient analysis was conducted as described in SAE J266, Steady-State Directional Control Test Procedures (reference 8). Both vehicles show a significant drop in their respective understeer gradients when a tread separated tire is on the rear of the vehicle when compared to the baseline. The data also indicate that ESC is not affecting the results. This is because the ESC did not actuate during the test over the lateral acceleration range being analyzed.

The ESC was observed to have actuated on both test vehicles when their slip angle was at 8 degrees. This slip angle value was used to analyze the SIS test data. Plots of the handwheel angle required to generate an 8 degree slip angle at various speeds are shown in Figures 9 and 10 for the Mountaineer and Tahoe respectively. These charts show that both test vehicles require greater steer input to generate an 8 degree slip angle when the ESC is enabled. An 8 degree slip angle was never achieved for either test vehicle in the baseline configuration.

The steering constants resulting from the baseline tests were 31.8 and 38.7 degrees of the handwheel angle for

the Mountaineer and Tahoe respectively. These results were used during the Sine with Dwell test.

SINE WITH DWELL TEST – The Sine with Dwell test's yaw rate pass/fail criteria as defined by NHTSA in reference 7 was utilized to analyze the effectiveness of the ESC system for both test vehicles. The NHTSA pass/fail criteria is more strict than has been employed in previous tire tread separation tests designed to evaluate the yaw stability of a vehicle during a transient maneuver. Past tire tread separation transient tests (reference 1 and 2) have relied on step steer (J-turn) maneuvers to evaluate the yaw stability of a vehicle that has a tread separated rear tire. A classic spinout response where the vehicle ends up traveling backwards was a common result of the J-turn maneuver when there was a tread separated tire at the outboard rear wheel position.

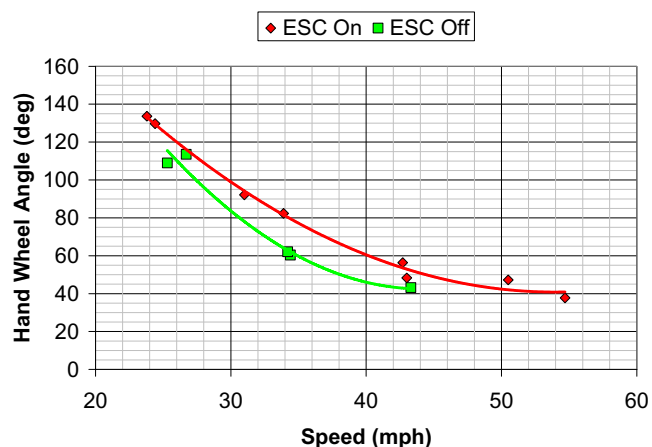


Figure 9. Mountaineer handwheel angle vs. speed at an 8 degree slip angle during the SIS test

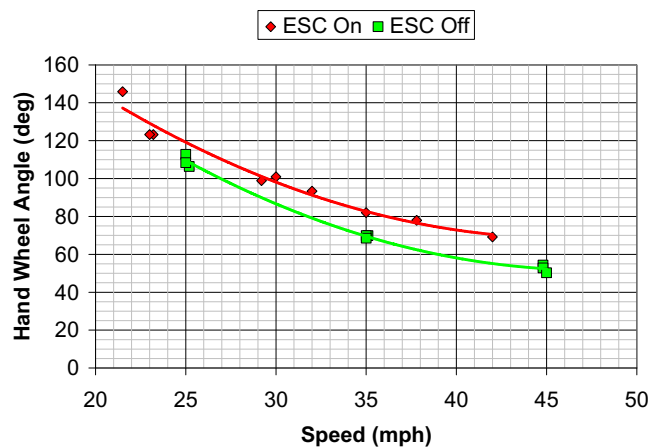


Figure 10. Tahoe handwheel angle vs. speed at an 8 degree slip angle during the SIS test

It was desirable to include a spinout pass/fail criteria to the evaluation of the Sine with Dwell test in order to be consistent with the prior J-turn test analysis. The spinout response can be seen in the Sine with Dwell test results. Tests that resulted in vehicle spinout had a continually

increasing slip angle that never leveled off. An example of this is shown in figure 11 from a run where there was a classic spinout response by the test vehicle. This is in contrast to the slip angle data shown in figure 12 which represents a run where the test vehicle did not have a spinout response and also did not pass the NHTSA yaw rate pass/fail criteria. The steering scalar for the run shown in Figure 12 was 3.5. This same high slip angle/no spinout behavior was also demonstrated during runs with steering scalars of 4.5 and 5.5.



Figure 11. Typical slip angle trace when the test vehicle has a classic spinout response



Figure 12. Typical slip angle trace when the test vehicle does not spinout or pass the NHTSA yaw rate criteria

An analysis of the slip angle data was used as an objective way to confirm what was visually observed during the test as a classic spinout response by the test vehicle. Using this criteria, a run was considered a failure if the vehicle spun out as a result of the Sine with Dwell maneuver. The run was considered a pass if the test vehicle did not have a spinout response. The results of both the NHTSA yaw rate pass/fail criteria and the spinout pass/fail criteria are presented in Figures 13 through 16.

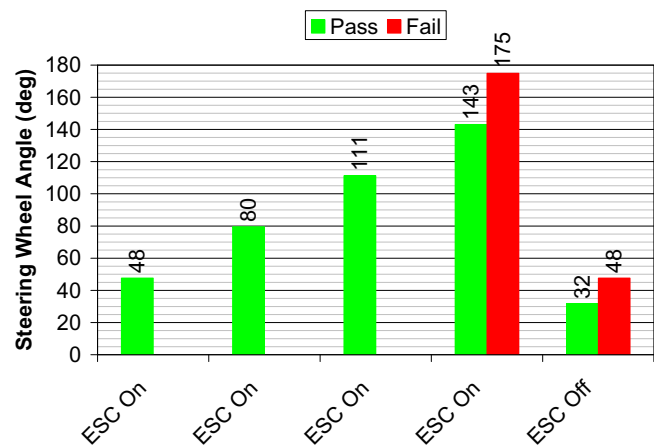


Figure 13. Mountaineer Sine with Dwell test results using the NHTSA yaw rate pass/fail criteria

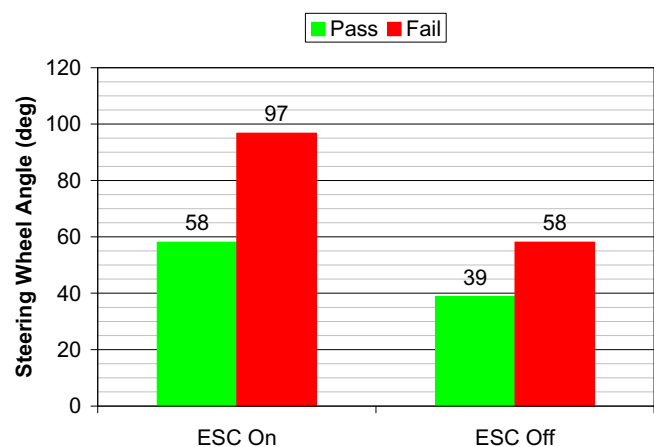


Figure 14. Tahoe Sine with Dwell test results using the NHTSA yaw rate pass/fail criteria

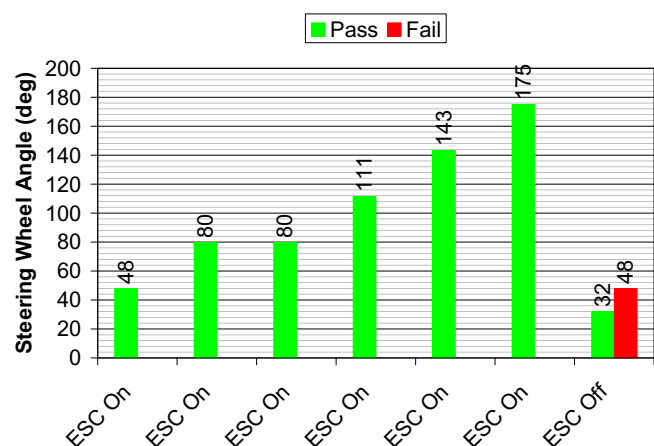


Figure 15. Mountaineer Sine with Dwell test results using the spinout pass/fail criteria

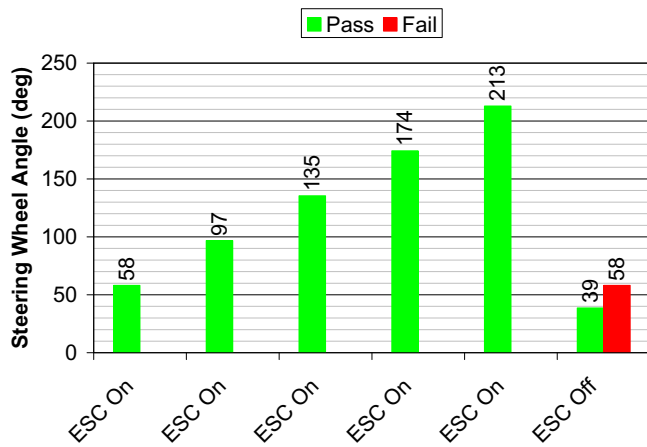


Figure 16. Tahoe Sine with Dwell test results using the spinout pass/fail criteria

Handwheel angle and yaw rate data are presented for all test runs in Appendices A and B for the Explorer and Tahoe respectively. A marker is printed on the yaw rate data plots indicating the peak value after the steer reversal. Additional markers are plotted at 35 and 20 percent of the peak yaw rate value at 1.00 and 1.75 seconds after the handwheel angle returns to neutral respectively.

DISCUSSION

Both the SIS test and Sine with Dwell test demonstrated that the ESC systems on the two SUV's evaluated improved yaw stability when there is a tread separated tire on the rear of the vehicle.

SIS TEST – The effectiveness of the ESC could not be seen by looking at the understeer gradients of the test vehicles as documented in Figure 7 and Figure 8. This is because the ESC does not activate during the portion of the SIS test where the understeer gradient is determined.

An analysis of the SIS test data at the time when the slip angle equaled 8 degrees showed that the ESC had activated for both test vehicles. The handwheel angle required to generate an 8 degree slip angle increased when the ESC was engaged. The larger handwheel angle required to achieve the 8 degree slip angle would likely provide a driver with more opportunity to prevent a loss of control event. Both vehicles with the ESC engaged appear to be more tolerant to larger driver steer inputs.

The ESC system on the Tahoe was more aggressive than that on the Mountaineer. This was most apparent during the SIS test while trying to maintain the target speed throughout the maneuver. The ESC system cut the throttle and aggressively applied the outboard front brake causing the Tahoe to slow substantially below the target speed. This can be seen in Figure 10 where the red data points do not align with the green data points which fall close to the target speeds.

SINE WITH DWELL TEST – The effectiveness of the ESC system in improving the yaw stability of both test vehicles with a tread separated tire on the right rear was easily demonstrated during the Sine with Dwell test. The handwheel angle of the Mountaineer could be steered up to 143 degrees and it would still pass the test based on the NHTSA yaw rate criteria when the ESC was engaged (Figure 13). The maximum handwheel angle resulting in a pass was only 32 degrees when the ESC was disengaged.

The Tahoe results did not demonstrate as great a difference with and without ESC when using the NHTSA yaw rate criteria. The Tahoe would pass the Sine with Dwell test with a handwheel angle of 58 degrees with the ESC engaged and 39 degrees with the ESC disengaged (Figure 14). The steering margin of safety gained with ESC was substantially less than that demonstrated by the Mountaineer.

With the ESC engaged, the Tahoe behaved like it was still in a turning maneuver after the handwheel was returned to neutral during runs where the steering scalar was 3.5 or greater. It did not exhibit a classic spinout response where the front and rear swap ends and the vehicle ends up traveling backwards during any of these runs. This was distinctly different to the behavior of the Tahoe when the ESC was disengaged. Both test vehicles had a classic spinout response without ESC.

Neither test vehicle exhibited a classic spinout response when the ESC was engaged during any of the Sine with Dwell test runs. Using the spinout criterion, the Mountaineer passed all runs when the ESC was engaged with handwheel angles up to 175 degrees (5.5 steering scalar) (Figure 15). The maximum handwheel angle was only 32 degrees when the ESC was disengaged. Results for the Tahoe were equally impressive, passing all runs when the ESC was engaged with handwheel angles up to 213 degrees (Figure 16). The maximum handwheel angle was only 39 degrees when the ESC was disengaged.

It is noted that all of the Sine with Dwell tests were completed on a large asphalt test surface which had large amounts of room for the test vehicles to maneuver. High speed U.S. highways vary dramatically from narrow two-lane roads with little or no shoulder to expansive multi-lane divided highways with large shoulders both inboard and outboard. Given this variation of the nation's highways and the path deviation that a tread separation event can produce, it is difficult to say how many tread separation related crashes will be eliminated by incorporation of ESC technology. It is clear, however, that the technology will have a positive effect on the yaw stability of vehicles that have experienced a rear tire tread separation.

CONCLUSION

All ESC systems are not alike. Some will provide greater benefit to the driver in the event of a rear tire

tread separation than others. In the case of the vehicles tested, it appears that the Mountaineer's ESC system outperformed the Tahoe's ESC system based on the Sine with Dwell test results. In general, it does appear that ESC systems will provide drivers a greater steering margin of safety when their vehicle has experienced a rear tire tread separation.

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