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Federal Motor Vehicle Safety Standards; Electronic Stability Control Systems for Heavy Vehicles; Proposed Rule

DEPARTMENT OF TRANSPORTATION

National Highway Traffic Safety Administration

49 CFR Part 571

[Docket No. NHTSA–2012–0065]

RIN 2127–AK97

Federal Motor Vehicle Safety Standards; Electronic Stability Control Systems for Heavy Vehicles

AGENCY: National Highway Traffic Safety Administration (NHTSA), Department of Transportation (DOT).

ACTION: Notice of proposed rulemaking (NPRM).

SUMMARY: This document proposes to establish a new Federal Motor Vehicle Safety Standard No. 136 to require electronic stability control (ESC) systems on truck tractors and certain buses with a gross vehicle weight rating of greater than 11,793 kilograms (26,000 pounds). ESC systems in truck tractors and large buses are designed to reduce untripped rollovers and mitigate severe understeer or oversteer conditions that lead to loss of control by using automatic computer-controlled braking and reducing engine torque output.

In 2012, we expect that about 26 percent of new truck tractors and 80 percent of new buses affected by this proposed rule will be equipped with ESC systems. We believe that ESC systems could prevent 40 to 56 percent of untripped rollover crashes and 14 percent of loss-of-control crashes. By requiring that ESC systems be installed on truck tractors and large buses, this proposal would prevent 1,807 to 2,329 crashes, 649 to 858 injuries, and 49 to 60 fatalities at less than $3 million per equivalent life saved, while generating positive net benefits.

DATES: *Comments:* Submit comments on or before August 21, 2012.

Public Hearing: NHTSA will hold a public hearing in the summer of 2012. NHTSA will announce the date for the hearing in a supplemental **Federal Register** document. The agency will accept comments to the rulemaking at this hearing.

ADDRESSES: You may submit comments electronically [identified by DOT Docket Number NHTSA–2012–0065] by visiting the following Web site

- *Federal eRulemaking Portal:* Go to *http://www.regulations.gov.* Follow the online instructions for submitting comments.

Alternatively, you can file comments using the following methods:

- *Mail:* Docket Management Facility: U.S. Department of Transportation, 1200 New Jersey Avenue SE., West Building Ground Floor, Room W12–140, Washington, DC 20590–0001
- *Hand Delivery or Courier:* West Building Ground Floor, Room W12–140, 1200 New Jersey Avenue SE., between 9 a.m. and 5 p.m. ET, Monday through Friday, except Federal holidays.
- *Fax:* (202) 493–2251

Instructions: For detailed instructions on submitting comments and additional information on the rulemaking process, see the Public Participation heading of the **SUPPLEMENTARY INFORMATION** section of this document. Note that all comments received will be posted without change to *http://www.regulations.gov,* including any personal information provided. Please see the Privacy Act heading below.

Privacy Act: Anyone is able to search the electronic form of all comments received into any of our dockets by the name of the individual submitting the comment (or signing the comment, if submitted on behalf of an association, business, labor union, etc.). You may review DOT's complete Privacy Act Statement in the **Federal Register** published on April 11, 2000 (65 FR 19477–78).

Docket: For access to the docket to read background documents or comments received, go to *http://www.regulations.gov.* Follow the online instructions for accessing the dockets.

FOR FURTHER INFORMATION CONTACT: For technical issues, you may contact George Soodoo, Office of Crash Avoidance Standards, by telephone at (202) 366–4931, and by fax at (202) 366–7002. For legal issues, you may contact David Jasinski, Office of the Chief Counsel, by telephone at (202) 366–2992, and by fax at (202) 366–3820. You may send mail to both of these officials at the National Highway Traffic Safety Administration, 1200 New Jersey Avenue SE., Washington, DC 20590.

SUPPLEMENTARY INFORMATION:

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I. Executive Summary

The agency proposes to reduce rollover and loss of directional control of truck tractors and large buses by establishing a new standard, Federal Motor Vehicle Safety Standard (FMVSS) No. 136, *Electronic Stability Control Systems for Heavy Vehicles.* The standard would require truck tractors and certain buses [1] with a gross vehicle weight rating (GVWR) of greater than 11,793 kilograms (26,000 pounds) to be equipped with an electronic stability control (ESC) system that meets the equipment and performance criteria of the standard. ESC systems use engine torque control and computer-controlled braking of individual wheels to assist the driver in maintaining control of the vehicle and maintaining its heading in situations in which the vehicle is becoming roll unstable (*i.e.,* wheel lift potentially leading to rollover) or experiencing loss of control (*i.e.,* deviation from driver's intended path due to understeer, oversteer, trailer swing or any other yaw motion leading to directional loss of control). In such situations, intervention by the ESC system can assist the driver in maintaining control of the vehicle, thereby preventing fatalities and injuries associated with vehicle rollover or collision. Based on the agency's estimates regarding the effectiveness of ESC systems, we believe that an ESC standard could annually prevent 1,807 to 2,329 crashes, 649 to 858 injuries, and 49 to 60 fatalities, while providing net economic benefits.

There have been two types of stability control systems developed for heavy vehicles. A roll stability control (RSC) system is designed to prevent rollover by decelerating the vehicle using braking and engine torque control. The other type of stability control system is ESC, which includes all of the functions of an RSC system plus the ability to mitigate severe oversteer or understeer by automatically applying brake force at selected wheel-ends to help maintain directional control of a vehicle. To date, ESC and RSC systems for heavy vehicles have been developed for air-braked vehicles. Truck tractors and buses covered by this proposed rule make up a large proportion of air-braked heavy vehicles and a large proportion of the heavy vehicles involved in both rollover crashes and total crashes. Based on information we have received to date, the agency has tentatively determined that ESC and RSC systems are not available for hydraulic-braked medium or heavy vehicles.

Since 2006, the agency has been involved in testing truck tractors and large buses with stability control systems. To evaluate these systems, NHTSA sponsored studies of crash data in order to examine the potential safety benefits of stability control systems. NHTSA and industry representatives separately evaluated data on dynamic test maneuvers. At the same time, the agency launched a three-phase testing program to improve its understanding of how stability control systems in truck tractors and buses work and to develop dynamic test maneuvers to challenge roll propensity and yaw stability. By combining the studies of the crash data with the testing data, the agency is able to evaluate the potential effectiveness of stability control systems for truck tractors and large buses.

As a result of the data analysis research, we have tentatively determined that ESC systems can be 28 to 36 percent effective in reducing first-event untripped rollovers and 14 percent effective in eliminating loss-of-control crashes caused by severe oversteer or understeer conditions.[2] As a result of the agency's testing program and the test data received from industry, the agency was able to develop reliable and repeatable test maneuvers that could demonstrate a stability control system's ability to prevent rollover and loss of directional control among the varied configurations of truck tractors and buses in the fleet.

In order to realize these benefits, the agency is proposing to require new truck tractors and certain buses with a GVWR of greater than 11,793 kilograms (26,000 pounds) to be equipped with an ESC system. This proposal is made pursuant to the authority granted to NHTSA under the National Traffic and Motor Vehicle Safety Act (''Motor Vehicle Safety Act''). Under 49 U.S.C. Chapter 301, Motor Vehicle Safety (49 U.S.C. 30101 et seq.), the Secretary of Transportation is responsible for prescribing motor vehicle safety standards that are practicable, meet the need for motor vehicle safety, and are stated in objective terms. The responsibility for promulgation of Federal motor vehicle safety standards is delegated to NHTSA.

This proposal requires ESC system must meet both definitional criteria and performance requirements. It is necessary to include definitional criteria in the proposal and require compliance with them because developing separate performance tests to cover the wide array of possible operating ranges, roadways, and environmental conditions would be impractical. The definitional criteria are consistent with those recommended by SAE International and used by the United Nations (UN) Economic Commission for Europe (ECE), and similar to the definition of ESC in FMVSS No. 126, the agency's stability control standard for light vehicles. This definition would describe an ESC system as one that would enhance the roll and yaw stability of a vehicle using a computer-controlled system that can receive inputs such as the vehicle's lateral acceleration and yaw rate, and use the information to apply brakes individually, including trailer brakes, and modulate engine torque.

The proposal requires that the system be able to detect a malfunction and provide a driver with notification of a malfunction by means of a telltale. This requirement would be similar to the malfunction detection and telltale requirements for light vehicles in FMVSS No. 126. An ESC system on/off switch is allowed for light vehicles; however, there is no provision in this proposal for allowing an ESC system to be deactivated. For truck tractors and large buses, we do not believe such controls are necessary.

[1] As explained later in this notice, the applicability of this proposed standard to buses would be similar to the applicability of NHTSA's proposal to require seat belts on certain buses. These buses would have 16 or more designated seating positions (including the driver), at least 2 rows of passenger seats that are rearward of the driver's seating position and forward-facing or can convert to forward-facing without the use of tools. As with the seat belt NPRM, this proposed rule would exclude school buses and urban transit buses sold for operation as a common carrier in urban transportation along a fixed route with frequent stops.

[2] See Wang, Jing-Shiam, ''Effectiveness of Stability Control Systems for Truck Tractors'' (January 2011) (DOT HS 811 437); Docket No. NHTSA–2010–0034–0043.

After considering and evaluating several test maneuvers, the agency is proposing to use two test maneuvers for performance testing: The slowly increasing steer (SIS) maneuver and the sine with dwell (SWD) maneuver. The SIS maneuver is a characterization maneuver used to determine the relationship between a vehicle's steering wheel angle and the lateral acceleration. This test serves both to normalize the severity of the SWD maneuver and to ensure that the system has the ability to reduce engine torque. The SIS maneuver is performed by driving at a constant speed of 48 km/h (30 mph), and then increasing the steering wheel angle at a constant rate of 13.5 degrees per second until ESC system activation occurs. Using linear regression followed by extrapolation, the steering wheel angle that would produce a lateral acceleration of 0.5g is determined.

Using the steering wheel angle derived from the SIS maneuver, the agency would conduct the sine with dwell maneuver. The SWD test maneuver challenges both roll and yaw stability by subjecting the vehicle to a sinusoidal input. To conduct the SWD maneuver, the vehicle is accelerated to 72 km/h (45 mph) and then turned in a clockwise or counterclockwise direction to reach a set steering wheel angle in 0.5 seconds. The steering wheel is then turned in the opposite direction until the same steering wheel angle is reached in the opposite direction in one second. The steering wheel is then held at that steering wheel angle for one second, and then the steering wheel angle returned to zero degrees within 0.5 seconds. This maneuver would be repeated for two series of test runs (first in the counterclockwise direction and then in the clockwise direction) at several target steering wheel angles from 30 to 130 percent of the angle derived in the SIS maneuver.

The lateral acceleration, yaw rate, and engine torque data from the test runs would be measured, recorded, and processed to determine the four performance metrics: Lateral acceleration ratio (LAR), yaw rate ratio (YRR), lateral displacement, and engine torque reduction. The LAR and YRR metrics would be used to ensure that the system reduces lateral acceleration and yaw rate, respectively, after an aggressive steering input, thereby preventing rollover and loss of control, respectively. These two metrics can effectively measure what NHTSA's testing has found to be the threshold of stability. The lateral displacement metric would be used to ensure that the stability control system is not set to intervene solely by making the vehicle nonresponsive to driver input. The engine torque reduction metric would be used to ensure that the system has the capability to automatically reduce engine torque in response to high lateral acceleration and yaw rate conditions. The manner in which the data would be filtered and processed is described in this proposal.

The agency considered several test maneuvers based on its own work and that of industry. In particular, the agency's initial research focused on a ramp steer maneuver (RSM) for evaluating roll stability. In that maneuver, a vehicle is driven at a constant speed and a steering wheel input that is based on the steering wheel angle derived from the SIS maneuver is input. The steering wheel angle is then held for a period of time before it is returned to zero. A stability control system would act to reduce lateral acceleration, and thereby wheel lift and roll instability, by applying selective braking. A vehicle without a stability control system would maintain high levels of lateral acceleration and potentially experience wheel lift or rollover.

The proposed rule also sets forth the test conditions that the agency would use to ensure safety and demonstrate sufficient performance. All vehicles would be tested using outriggers for the safety of the test driver. The agency would use an automated steering controller to ensure reproducible and repeatable test execution performance. Truck tractors would be tested with an unbraked control trailer to eliminate the effect of the trailer's brakes on testing. Because the agency tests new vehicles, the brakes would be conditioned, as they are in determining compliance with the air brake standard. The agency would also test to ensure that system malfunction is detected.

This proposed rule would take effect for most truck tractors and covered buses produced two years after publication of a final rule. We believe that this amount of lead time is necessary to ensure sufficient availability of stability control systems from suppliers of these systems and to complete necessary engineering on all vehicles. For three-axle tractors with one drive axle, tractors with four or more axles, and severe service tractors, we would provide two years additional lead time. We believe this additional time is necessary to develop, test, and equip these vehicles with ESC systems. Although the agency has statutory authority to require retrofitting of in-service truck tractors, trailers, and large buses, the agency is not proposing to do so, given the integrated aspects of a stability control system.

Based on the agency's effectiveness estimates, the adoption of this proposal would prevent 1,807 to 2,329 crashes per year resulting in 649 to 858 injuries and 49 to 60 fatalities. The proposal also would result in significant monetary savings as a result of prevention of property damage and travel delays.

Based on information obtained from manufacturers, the agency estimates that 26.2 percent of truck tractors manufactured in model year 2012 will be equipped with an ESC system and that 80 percent of covered buses manufactured in model year 2012 will be equipped with an ESC system. Information obtained from manufacturers indicates that the average unit cost of an ESC system is approximately $1,160. In addition, 16.5 percent of truck tractors manufactured in model year 2012 will be equipped with an RSC system. The incremental cost of installing an ESC system in place of an RSC system is estimated to be $520 per vehicle. Based upon the agency's estimates that 150,000 truck tractors and 2,200 buses covered by this proposed rule will be manufactured in 2012, the agency estimates that the total cost of this proposal would be approximately $113.6 million.

The agency believes that this proposal is cost effective. The net benefits of this proposal are estimated to range from $228 to $310 million at a 3 percent discount rate and from $155 to $222 million at a 7 percent discount rate. As a result, the net cost per equivalent live saved from this proposal ranges from $1.5 to $2.0 million at a 3 percent discount rate and from $2.0 to $2.6 million at a 7 percent discount rate. The costs and benefits of this proposal are summarized in Table 1.

TABLE 1—ESTIMATED ANNUAL COST, BENEFITS, AND NET BENEFITS OF THE PROPOSAL

[In millions of 2010 dollars]

	Costs	Injury benefits	Property damage and travel delay savings	Cost per equivalent live saved	Net benefits
At 3% Discount	$113.6	$328–405	$13.9–17.8	$1.5–2.0	$228–310
At 7% Discount	113.6	257–322	11.0–14.1	2.0–2.6	155–222

The agency considered two regulatory alternatives. First, the agency considered requiring truck tractors and large buses to be equipped with RSC systems. When compared to this proposal, RSC systems would result in slightly lower cost per equivalent life saved, but would produce net benefits that are lower than the net benefits from this proposal. This is because RSC systems are less effective at preventing rollover crashes and much less effective at preventing loss-of-control crashes. The second alterative considered was requiring trailers to be equipped with RSC systems. However, this alternative would save fewer than 10 lives at a very high cost per equivalent life saved and would provide negative net benefits.

The remainder of this notice will describe in detail the following: (1) The size of the safety problem to be addressed by this proposed rule; (2) how stability control systems work to prevent rollover and loss of control; (3) the research and testing separately conducted by NHTSA and industry to evaluate the potential effectiveness of a stability control requirement and to develop dynamic test maneuvers to challenge system performance; (4) the specifics of the agency's proposal, including equipment and performance criteria, compliance testing, and the implementation schedule; and (5) the benefits and costs of this proposal.

II. Safety Problem

A. Heavy Vehicle Crash Problem

The *Traffic Safety Facts 2009* reports that tractor trailer combination vehicles are involved in about 72 percent of the fatal crashes involving large trucks, annually.[3] According to FMCSA's *Large Truck and Bus Crash Facts 2008,* these vehicles had a fatal crash involvement rate of 1.92 crashes per 100 million vehicle miles traveled during 2007, whereas single unit trucks had a fatal crash involvement rate of 1.26 crashes per 100 million vehicle miles traveled.[4] Combination vehicles represent about 25 percent of large trucks registered but travel 63 percent of the large truck miles, annually. Traffic tie-ups resulting from loss-of-control and rollover crashes also contribute to in millions of dollars of lost productivity and excess energy consumption each year.

According to *Traffic Safety Facts* 2009, the overall crash problem for tractor trailer combination vehicles is approximately 150,000 crashes, 29,000 of which involve injury. The overall crash problem for single-unit trucks is nearly as large—approximately 146,000 crashes, 24,000 of which are injury crashes. However, the fatal crash involvement for truck tractors is much higher. In 2009, there were 2,334 fatal combination truck crashes and 881 fatal single-unit truck crashes.

The rollover crash problem for combination trucks is much greater than for single-unit trucks. In 2009, there were approximately 7,000 crashes involving combination truck rollover and 3,000 crashes involving single-unit truck rollover. As a percentage of all crashes, combination trucks are involved in rollover crashes at twice the rate of single-unit trucks. Approximately 4.4 percent of all combination truck crashes were rollovers, but 2.2 percent of single-unit truck crashes were rollovers. Combination trucks were involved in 3,000 injury crashes and 268 fatal crashes, and single-unit trucks were involved in 2,000 injury crashes and 154 fatal crashes.

According to FMCSA's *Large Truck and Bus Crash Facts 2008,* cross-country intercity buses were involved in 19 of the 247 fatal bus crashes in 2008, which represented about 0.5 percent of the fatal crashes involving large trucks and buses, annually. The bus types presented in the crash data include school buses, intercity buses, cross-country buses, transit buses, and other buses. These buses had a fatal crash involvement rate of 3.47 crashes per 100 million vehicle miles traveled during 2008. From 1998 to 2008, cross-country intercity buses, on average, accounted for 12 percent of all buses involved in fatal crashes, whereas transit buses and school buses accounted for 35 percent and 40 percent, respectively, of all buses involved in fatal crashes. Most of the transit bus and school bus crashes are not rollover or loss-of-control crashes that ESC systems are capable of preventing. The remaining 13 percent of buses involved in fatal crashes were classified as other buses or unknown. Fatal rollover and loss-of-control crashes are a subset of these crashes.

There are many more fatalities in buses with a GVWR greater than 11,793 kg (26,000 lb) compared to buses with a GVWR between 4,536 kg and 11,793 kg (10,000 lb and 26,000 lb).[5] In the 10-year period between 1999 and 2008, there were 34 fatalities on buses with a GVWR between 4,536 kg and 11,793 kg (10,000 lb and 26,000 lb) compared to 254 fatalities on buses with a GVWR greater than 11,793 kg (26,000 lb). Among buses with a GVWR of greater than 11,793 kg (26,000 lb), over 70 percent of the fatalities were cross-country intercity bus occupants.

Furthermore, the size of the rollover crash problem for cross-country intercity buses is greater than in other buses. According to FARS data from 1999 to 2008, there were 97 occupant fatalities as a result of rollover events on cross-country intercity buses with a GVWR of greater than 11,793 kg (26,000 lb), which represents 52 percent of cross-country intercity bus fatalities.[6] In comparison, rollover crashes were responsible for 21 occupant fatalities on other buses with a GVWR of greater than 11,793 kg (26,000 lb) and 9 occupant fatalities on all buses with a GVWR between 4,536 kg and 11,793 kg (10,000 lb and 26,000 lb). That is, 95 percent of bus occupant rollover fatalities on buses over 4,536 kg (10,000 lb) were occupants on buses with a GVWR of over 11,793 kg (26,000 lb).

[3] DOT HS 811 402, *available at http://www-nrd.nhtsa.dot.gov/Pubs/811402.pdf* (last accessed May 9, 2012).

[4] FMCSA–RRA–10–043 (Mar. 2010), *available at http://www.fmcsa.dot.gov/facts-research/ltbcf2008/index-2008largetruckandbuscrashfacts.aspx* (last accessed May 9, 2012).

[5] This data was taken from the FARS database and was presented in the NPRM that would require seat belts on certain buses. See 75 FR 50,958, 50,917 (Aug. 18, 2010).

[6] See U.S. Department of Transportation Motorcoach Safety Action Plan, DOT HS 811 177, at 13 (Nov. 2009), *available at http://www.fmcsa.dot.gov/documents/safety-security/MotorcoachSafetyActionPlan_finalreport-508.pdf* (last accessed May 9, 2012).

B. Contributing Factors in Rollover and Loss-of-Control Crashes

Many factors related to heavy vehicle operation, as well as factors related to roadway design and road surface properties, can cause heavy vehicles to become yaw unstable or to roll. Listed below are several real-world situations in which stability control systems may prevent or lessen the severity of such crashes.

• *Speed too high to negotiate a curve*—The entry speed of vehicle is too high to safely negotiate a curve. When the lateral acceleration of a vehicle during a steering maneuver exceeds the vehicle's roll or yaw stability threshold, a rollover or loss of control is initiated. Curves can present both roll and yaw instability issues to these types of vehicles due to varying heights of loads (low versus high, empty versus full) and road surface friction levels (*e.g.,* wet, dry, icy, snowy).

• *Sudden steering maneuvers to avoid a crash*—The driver makes an abrupt steering maneuver, such as a single- or double-lane-change maneuver, or attempts to perform an off-road recovery maneuver, generating a lateral acceleration that is sufficiently high to cause roll or yaw instability. Maneuvering a vehicle on off-road, unpaved surfaces such as grass or gravel may require a larger steering input (larger wheel slip angle) to achieve a given vehicle response, and this can lead to a large increase in lateral acceleration once the vehicle returns to the paved surface. This increase in lateral acceleration can cause the vehicle to exceed its roll or yaw stability threshold.

• *Loading conditions*—The vehicle yaw due to severe over-steering is more likely to occur when a vehicle is in a lightly loaded condition and has a lower center of gravity height than it would have when fully loaded. Heavy vehicle rollovers are much more likely to occur when the vehicle is in a fully loaded condition, which results in a high center of gravity for the vehicle. Cargo placed off-center in the trailer may result in the vehicle being less stable in one direction than in the other. It is also possible that improperly secured cargo can shift while the vehicle is negotiating a curve, thereby reducing roll or yaw stability. Sloshing can occur in tankers transporting liquid bulk cargoes, which is of particular concern when the tank is partially full because the vehicle may experience significantly reduced roll stability during certain maneuvers.

• *Road surface conditions*—The road surface condition can also play a role in the loss of control a vehicle experiences. On a dry, high-friction asphalt or concrete surface, a tractor trailer combination vehicle executing a severe turning maneuver is likely to experience a high lateral acceleration, which may lead to roll or yaw instability. A similar maneuver performed on a wet or slippery road surface is not as likely to experience the high lateral acceleration because of less available tire traction. Hence, the result is more likely to be vehicle yaw instability than vehicle roll instability.

• *Road design configuration*—Some drivers may misjudge the curvature of ramps and not brake sufficiently to negotiate the curve safely. This includes ramps with decreasing radius curves as well as curves and ramps with improper signage. A decrease in super-elevation (banking) at the end of a ramp where it merges with the roadway causes an increase in vehicle lateral acceleration, which may increase even more if the driver accelerates the vehicle in preparation to merge.

C. NTSB Safety Recommendations

The National Transportation Safety Board (NTSB) has issued several safety recommendations relevant to ESC systems on heavy and other vehicles. One is H–08–15, which addresses ESC systems and collision warning systems with active braking on commercial vehicles. Recommendations H–11–07 and H–11–08 specifically address stability control systems on commercial motor vehicles and buses with a GVWR above 10,000 pounds. Two other safety recommendations, H–01–06 and H–01–07, relate to adaptive cruise control and collision warning systems on commercial vehicles, and are indirectly related to ESC on heavy vehicles because all these technologies require the ability to apply brakes without driver input.

• H–08–15: Determine whether equipping commercial vehicles with collision warning systems with active braking [7] and electronic stability control systems will reduce commercial vehicle accidents. If these technologies are determined to be effective in reducing accidents, require their use on commercial vehicles.

• H–11–07: Develop stability control system performance standards for all commercial motor vehicles and buses with a gross vehicle weight rating greater than 10,000 pounds, regardless of whether the vehicles are equipped with a hydraulic or pneumatic brake system.

• H–11–08: Once the performance standards from Safety Recommendation H–11–07 have been developed, require the installation of stability control systems on all newly manufactured commercial vehicles with a GVWR greater than 10,000 pounds.

D. Motorcoach Safety Plan

In November 2009, the U.S. Department of Transportation Motorcoach Safety Action Plan was issued.[8] Among other things, the Motorcoach Safety Action Plan includes an action item for NHTSA to assess the safety benefits for stability control on large buses and develop objective performance standards for these systems.[9] Consistent with that plan, NHTSA made a decision to pursue a stability control requirement for large buses.

In March 2011, NHTSA issued its latest Vehicle Safety and Fuel Economy Rulemaking and Research Priority Plan (Priority Plan).[10] The Priority Plan describes the agency plans for rulemaking and research for calendar years 2011 to 2013. The Priority Plan includes stability control on truck tractors and large buses, and states that the agency plans to develop test procedures for a Federal motor vehicle safety standard on stability control for truck tractors, with the countermeasures of roll stability control and electronic stability control, which are aimed at addressing rollover and loss-of-control crashes.

E. International Regulation

The United Nations (UN) Economic Commission for Europe (ECE) Regulation 13, Uniform Provisions Concerning the Approval of Vehicles of Categories M, N and O with Regard to *Braking,* has been amended to include Annex 21, *Special Requirements for Vehicles Equipped with a Vehicle Stability Function.* Annex 21's requirements apply to trucks with a GVWR greater than 3,500 kg (7,716 lb), buses with a seating capacity of 10 or more (including the driver), and trailers with a GVWR greater than 3,500 kg (7,716 lb). Trucks and buses are required to be equipped with a stability system that includes rollover control and directional control, while trailers are required to have a stability system that includes only rollover control. The directional control function must be demonstrated in one of eight tests, and the rollover control function must be demonstrated in one of two tests. For

[7] Active braking involves using the vehicle's brakes to maintain a certain, preset distance between vehicles.

[8] See *supra,* note 6.

[9] *Id.* at 28–29.

[10] See Docket No. NHTSA–2009–0108–0032.

compliance purposes, the ECE regulation requires a road test to be performed with the function enabled and disabled, or as an alternative accepts results from a computer simulation. No test procedure or pass/fail criterion is included in the regulation, but it is left to the discretion of the Type Approval Testing Authority in agreement with the vehicle manufacturer to show that the system is functional. The implementation date of Annex 21 is 2012 for most vehicles, with a phase-in based on the vehicle type.

III. Stability Control Technologies

A. Dynamics of a Rollover

Whenever a vehicle is steered, the lateral forces that result from the steering input lead to one of the following results: (1) Vehicle maintains directional control; (2) vehicle loses directional control due to severe understeer or plowing out; (3) vehicle loses directional control due to severe oversteer or spinning out; or (4) vehicle experiences roll instability and rolls over.

A turning maneuver initiated by the driver's steering input results in a vehicle response that can be broken down into two phases. Phase 1 is the yaw response that occurs when the front wheels are turned. As the steering wheel is turned, the displacement of the front wheels generates a slip angle at the front wheels and a lateral force is generated. That lateral force leads to vehicle rotation, and the vehicle starts rotating about its center of gravity.

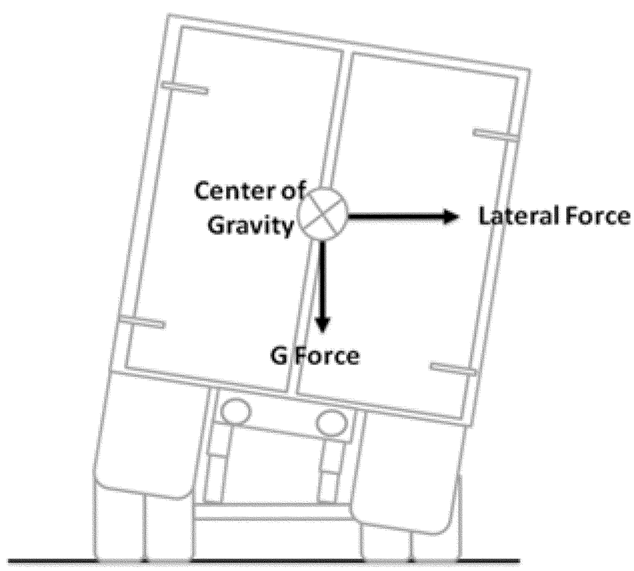
This rotation leads to Phase 2. In Phase 2, the vehicle's yaw causes the rear wheels to experience a slip angle. That causes a lateral force to be generated at the rear tires, which leads to vehicle rotation. All of these actions establish a steady-state turn in which lateral acceleration and yaw rate are constant.

In combination vehicles, which typically consist of a tractor towing a semi-trailer, an additional phase is the turning response of the trailer. Once the tractor begins to achieve a yaw and lateral acceleration response, the trailer begins to yaw as well. This leads to the trailer's tires developing slip angles and producing lateral forces at the trailer tires. Thus, there is a slight delay in the turning response of the trailer when compared to the turning response of the tractor.

If the lateral forces generated at either the front or the rear wheels exceed the friction limits between the road surface and the tires, the result will be a vehicle loss-of-control in the form of severe understeer (loss of traction at the steer tires) or severe oversteer (loss of traction at the rear tires). In a combination vehicle, a loss of traction at the trailer wheels would result in the trailer swinging out of its intended path. However, if the lateral forces generated at the tires result in a vehicle lateral acceleration that exceeds the rollover threshold of the vehicle, then rollover will result.

Lateral acceleration is the primary cause of rollovers. Figure 1 depicts a simplified rollover condition. As shown, when the lateral force (*i.e.,* lateral acceleration) is sufficient large and exceeds the roll stability threshold of the tractor-trailer combination vehicle, the vehicle will roll over. Many factors related to the drivers' maneuvers, heavy vehicle loading conditions, vehicle handling characteristics, roadway design, and road surface properties would result in various lateral accelerations and influences on the rollover propensity of a vehicle. For example, given other factors are equal, a vehicle entering a curve at a higher speed is more likely to roll than a vehicle entering the curve at a lower speed. Also, transporting a high center of gravity (CG) load would increase the rollover probability more than transporting a relatively lower CG load.

Figure 1: Rollover Condition



Stability control technologies help a driver maintain directional control and help to reduce roll instability. Two types of heavy vehicle stability control technologies have been developed. One such technology is roll stability control or RSC, which is designed to help prevent on-road, untripped rollovers by automatically decelerating the vehicle using brakes and engine control. The other technology is electronic stability control, or ESC,[11] which is designed to

[11] In light vehicles, the term ESC generally describes a system that helps the driver maintain directional control and typically does not include the RSC function because these vehicles are much less prone to untripped rollover.

assist the driver in mitigating severe oversteer or understeer conditions by automatically applying selective brakes to help the driver maintain directional control of the vehicle. On heavy vehicles, ESC also includes the RSC function described above.

B. Description of RSC System Functions

Currently, RSC systems are available for air-braked tractors with a GVWR of greater than 11,793 kilograms (26,000 pounds) and for trailers. A tractor-based RSC system consists of an electronic control unit (ECU) that is mounted on a vehicle and continually monitors the vehicle's speed and lateral acceleration based on an accelerometer, and estimates vehicle mass based on engine torque information.[12] The ECU continuously estimates the roll stability threshold of the vehicle, which is the lateral acceleration above which a combination vehicle will roll over. When the vehicle's lateral acceleration approaches the roll stability threshold, the RSC system intervenes. Depending on how quickly the vehicle is approaching the estimated rollover threshold, the RSC system intervenes by one or more of the following actions: Decreasing engine power, using engine braking, applying the tractor's drive-axle brakes, or applying the trailer's brakes. When RSC systems apply the trailer's brakes, they use a pulse modulation protocol to prevent wheel lockup because tractor stability control systems cannot currently detect whether or not the trailer is equipped with ABS. Some RSC systems also use a steering wheel angle sensor, which allows the system to identify potential roll instability events earlier.

An RSC system can reduce rollovers, but is not designed to help to maintain directional control of a truck tractor. Nevertheless, RSC systems may provide some additional ability to maintain directional control in some scenarios, such as in a low-center-of-gravity scenario, where an increase in a lateral acceleration may lead to yaw instability rather than roll instability.

[12] RSC systems are not presently available for large buses.

In comparison, a trailer-based RSC system has an ECU mounted on the trailer, which typically monitors the trailer's wheel speeds, the trailer's suspension to estimate the trailer's loading condition, and the trailer's lateral acceleration. When a high lateral acceleration that is likely to cause the trailer to rollover is detected, the ECU commands application of the trailer brakes to slow the combination vehicle. In this case, the trailer brakes on the outside wheels can be applied with full pressure since the ECU can directly monitor the trailer wheels for braking-related lockup. The system modulates the brake pressure as needed to achieve maximum braking force without locking the wheels. However, a trailer-based RSC system can only apply the trailer brakes to slow a combination vehicle, whereas a tractor-based RSC system can apply brakes on both the tractor and trailer.

C. Description of ESC System Functions

Currently, ESC systems are available for heavy vehicles, including truck tractors and buses, equipped with air brakes. An ESC system incorporates all of the inputs of an RSC system. In addition, an ESC system monitors steering wheel angle and yaw rate of the vehicle.[13] These system inputs are monitored by the system's ECU, which estimates when the vehicle's directional response begins to deviate from the driver's steering command, either by oversteer or understeer. An ESC system intervenes to restore directional control by taking one or more of the following actions: Decreasing engine power, using engine braking, selectively applying the brakes on the truck tractor to create a counter-yaw moment to turn the vehicle back to its steered direction, or applying the brakes on the trailer. An ESC system enhances the RSC functions because it has the added information from the steering wheel angle and yaw rate sensors, as well as more braking power because of its additional capability to apply the tractor's steer axle brakes.[14]

[13] Because ESC systems must monitor steering inputs from the tractor, ESC systems are not available for trailers.

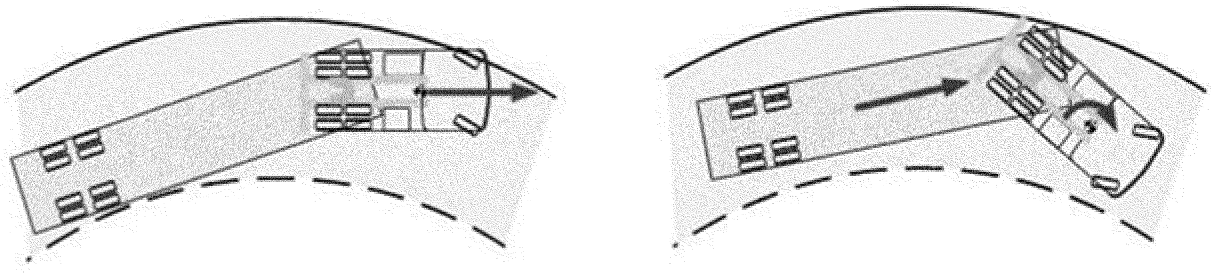
[14] This is a design strategy to avoid the unintended consequences of applying the brakes on the steering axle without knowing where the driver is steering the vehicle.

D. How ESC Prevents Loss of Control

Like an RSC system, an ESC system has a lateral acceleration sensor. However, it also has two additional sensors to monitor a vehicle for loss of directional control, which may result due to either understeer or oversteer. The first additional sensor is a steering wheel angle sensor, which senses the intended direction of a vehicle. The other is a yaw rate sensor, which measures the actual turning movement of the vehicle. When a discrepancy between the intended and actual headings of the vehicle occurs, it is because the vehicle is in either an understeering (plowing out) or an oversteering (spinning out) condition. The ESC system responds to such a discrepancy by automatically intervening and applying brake torque selectively at individual wheel ends on the tractor, by reducing engine torque output to the drive axle wheels, or by both means. If only the wheel ends at one corner of the vehicle are braked, the uneven brake force will create a correcting yaw moment that causes the vehicle's heading to change. An ESC system also has the capability to reduce the engine torque output to the drive wheels, which effectively reduces the vehicle speed and helps the wheels to regain traction. This means of intervention by the ESC system may occur separate from or simultaneous with the automatic brake application at selective wheel ends. An ESC system is further differentiated from an RSC system in that it has the ability to selectively apply the front steer axle brakes while the RSC system does not incorporate this feature.

Figure 2 illustrates the oversteering and understeering conditions. While Figure 2 may suggest that a particular vehicle loses control due to either oversteer or understeer, it is quite possible that a vehicle could require both understeering and oversteering interventions during progressive phases of a complex crash avoidance maneuver such as a double lane change.

Figure 2: Loss-of-Control Conditions



Oversteering. The right side of Figure 2 shows that the truck tractor whose driver has lost directional control during an attempt to drive around a right curve. The rear wheels of the tractor have exceeded the limits of road traction. As a result, the rear of the tractor is beginning to slide. This would lead a vehicle without an ESC system to spin out. If the tractor is towing a trailer, as the tractor in the figure is, this would result in a jackknife crash. In such a crash, the tractor spins and may make physical contact with the side of the trailer. The oversteering tractor in this figure is considered to be yaw-unstable because the tractor rotation occurs without a corresponding increase in steering wheel angle by the driver. In a vehicle equipped with ESC, the system immediately detects that the vehicle's heading is changing more quickly than appropriate for the driver's intended path (*i.e.,* the yaw rate is too high). To counter the leftward rotation of the vehicle, it momentarily applies the right front brake, thus creating a rightward (clockwise) counter-rotational force and turning the heading of the vehicle back to the correct path. It will also cut engine power to gently slow the vehicle and, if necessary, apply additional brakes (while maintaining the uneven brake force to create the necessary yaw moment). The action happens quickly so that the driver does not perceive the need for steering corrections.

Understeering. The left side of Figure 2 shows a truck tractor whose driver has lost directional control during an attempt to drive around a right curve, except that in this case, it is the front wheels that have exceeded the limits of road traction. As a result, the tractor is sliding at the front (''plowing out''). Such a vehicle is considered to be yaw-stable because no increase in tractor rotation occurs when the driver increases the steering wheel angle. However, the driver has lost directional control of the tractor. In this situation, the ESC system rapidly detects that the vehicle's heading is changing less quickly than appropriate for the driver's intended path (*i.e.,* the yaw rate is too low). In other words, the vehicle is not turning right sufficiently to remain on the right curve and is instead heading off to the left. The ESC system momentarily applies the right rear brake, creating a rightward rotational force, to turn the heading of the vehicle back to the correct path. Again, it will also cut engine power to gently slow the vehicle and, if necessary, apply additional brakes (while maintaining the uneven brake force to create the necessary yaw moment).

E. Situations in Which Stability Control Systems May Not Be Effective

A stability control system will not prevent all rollover and loss-of-control crashes. A stability control system has the capability to prevent many untripped on-road rollovers and first-event loss-of-control events. Nevertheless, there are real-world situations in which stability control systems may not be as effective in avoiding a potential crash. Such situations include:

• Off-road recovery maneuvers in which a vehicle departs the roadway and encounters an incline too steep to effectively maneuver the vehicle or an unpaved surface that significantly reduces the predictability of the vehicle's handling

• Entry speeds that are much too high for a curved roadway or entrance/exit ramp

• Cargo load shifts on the trailer during a steering maneuver

• Vehicle tripped by a curb or other roadside object or barrier

• Truck rollovers that are the result of collisions with other motor vehicles

• Inoperative antilock braking systems—the performance of stability control systems depends on the proper functioning of ABS

• Brakes that are out-of-adjustment or other defects or malfunctions in the ESC, RSC, or brake system.

• Maneuvers during tire tread separation or sudden tire deflation events.

F. Difference in Vehicle Dynamics Between Light Vehicles and Heavy Vehicles

On April 6, 2007, the agency published a final rule that established FMVSS No. 126, *Electronic Stability Control Systems,* which requires all passenger cars, multipurpose passenger vehicles, trucks and buses with a GVWR of 4,536 kg (10,000 lb) or less to be equipped with an electronic stability control system beginning in model year 2012.[15] The rule also requires a phase-in of 55 percent, 75 percent, and 95 percent of vehicles produced by each manufacturer during model years 2009, 2010, and 2011, respectively, to be equipped with a compliant ESC system. The system must be capable of applying brake torques individually at all four wheels, and must comply with the performance criteria established for stability and responsiveness when subjected to the sine with dwell steering maneuver test.

For light vehicles, the focus of the FMVSS No. 126 is on addressing yaw instability, which can assist the driver in preventing the vehicle from leaving the roadway, thereby preventing fatalities and injuries associated with crashes involving tripped rollover, which often occur when light vehicles run off the road. The standard does not include any equipment or performance requirements for roll stability.

The dynamics of light vehicles and heavy vehicles differ in many respects. First, on light vehicles, the yaw stability threshold is typically lower than the roll stability threshold. This means that a light vehicle making a crash avoidance maneuver, such as a lane change on a dry road, is more likely to reach its yaw stability threshold and lose directional control before it reaches its roll stability threshold and rolls over. On a heavy

[15] 72 FR 17236.

vehicle, however, the roll stability threshold is lower than the yaw stability threshold in most operating conditions, primarily because of its higher center of gravity height.[16] As a result, there is a greater propensity for a heavy vehicle, particularly in a loaded condition, to roll during a severe crash avoidance maneuver or when negotiating a curve, than to become yaw unstable, as compared with light vehicles.

Second, a tractor-trailer combination unit is comprised of a power unit and one or more trailing units with one or more articulation points. In contrast, although a light vehicle may occasionally tow a trailer, a light vehicle is usually a single rigid unit. The tractor and the trailer have different center of gravity heights and different lateral acceleration threshold limits for rollover. A combination vehicle rollover frequently begins with the trailer where the rollover is initiated by trailer wheel lift. The trailer roll torque is transmitted to the tractor through the vehicles' articulation point, which subsequently leads to tractor rollover. In addition to the trailer's loading condition, the trailer rollover threshold is also related to the torsional stiffness of the trailer body. A trailer with a low torsional stiffness, such as a flatbed open trailer, would typically experience wheel lift earlier during a severe turning maneuver than a trailer with a high torsional stiffness, such as a van trailer. Hence, compared with a light vehicle, the roll dynamics of a tractor trailer combination vehicle is a more complex interaction of forces acting on the units in the combination, as influenced by the maneuver, the loading condition, and the roadway.

Unlike with light vehicles, there is a large range of loading scenarios possible for a given heavy vehicle, particularly for truck tractors towing trailers. A tractor-trailer combination vehicle can be operated empty, loaded to its maximum weight rating, or loaded anywhere in between the two extremes. The weight of a fully loaded combination vehicle is generally more than double that of the vehicle with an empty trailer. Furthermore, the load's center of gravity height can vary over a large range, which can have substantial effects on the dynamics of a combination vehicle.

Third, due to greater length, mass, and mass moments of inertia of heavy vehicles, they respond more slowly to steering inputs than do light vehicles. The longer wheelbase of a heavy vehicle, compared with a light vehicle, results in a slower response time, which gives the stability control system the opportunity to intervene and prevent rollovers.

Finally, the larger number of wheels on a heavy vehicle, as compared to a light vehicle, results in making heavy vehicles less likely to yaw on dry road surface conditions.

As a result of the differences in vehicle dynamics between light vehicles and heavy vehicles, the requirements in FMVSS No. 126 for light vehicle ESC systems cannot translate directly into requirements for heavy vehicles. Nevertheless, many requirements in FMVSS No. 126 are pertinent to heavy vehicles because they do not relate to any difference in vehicle dynamics between light vehicles and heavy vehicles. For example, the ESC system malfunction detection and telltale requirements already developed for light vehicles can be translated to heavy vehicles.

IV. Research and Testing

NHTSA has been studying ways to prevent untripped heavy vehicle rollovers for many years. In the mid-1990s, the agency sponsored the development of a prototype roll stability advisor (RSA) system that displayed information to the driver regarding the truck's roll stability threshold and the peak lateral acceleration achieved during cornering maneuvers. This was followed by a fleet operational test sponsored by the Federal Highway Administration, under the Department of Transportation's Intelligent Vehicle Initiative. The tractors were equipped with a RSA system using an engine retarder, which was an early configuration of an RSC system. As that test program was concluding, industry developers of stability control systems began to add tractor and trailer foundation braking capabilities to increase the effectiveness these systems.

In 2006, the agency initiated a test program at the Vehicle Research and Test Center (VRTC) to conduct track testing on RSC- and ESC-equipped tractors and semitrailers. The initial testing focused only on roll stability testing and provided comparative data on the performance of the different stability control systems in several test maneuvers. Subsequent testing focused on refining test maneuvers and developing performance metrics suitable for a safety standard. The agency studied a slowly increasing steer maneuver that would characterize a tractor's steering system and verify the ability of a tractor-based system to control engine torque. The agency also developed a ramp steer maneuver to evaluate the roll stability performance of a stability control system, and investigated a sine with dwell maneuver to evaluate both yaw and roll stability performance. In addition to tests conducted on combination unit trucks, the VRTC research program included testing of three large buses equipped with ESC using these test maneuvers. As part of the research at VRTC, the agency also developed data collection and analysis methods to characterize the performance of stability control systems.

NHTSA researchers began updating their vehicle dynamics simulation programs to include a stability control model, and coordinated with researchers at the National Advanced Driving Simulator (NADS) at the University of Iowa to add stability control modeling capability to their tractor trailer simulations. NHTSA sponsored a research program with the NADS to evaluate potential RSC and ESC effectiveness in several tractor-trailer driving scenarios involving potential rollover and loss of control, using sixty professional truck drivers who were recruited as test participants.

NHTSA purchased three tractors equipped with ESC or RSC systems for testing: A Freightliner 6x4 [17] tractor that had ESC as a production option, a Sterling 4x2 tractor that had RSC as a production option, and a Volvo 6x4 tractor that had ESC included as standard equipment. NHTSA also obtained a RSC control unit that could be retrofitted on the Freightliner 6x4 tractor so that it could be comparatively tested with both ESC and RSC. The agency also purchased a Heil 9,200-gallon tanker semitrailer that was equipped with a trailer-based RSC system, and retrofitted a Fruehauf 53-foot van semitrailer with a trailer-based RSC system. NHTSA also obtained three large buses equipped with stability control systems: A 2007 MCI D4500 (MCI #1), a 2009 Prevost H3, and a second 2007 MCI D4500 (MCI #2). The MCI buses were equipped with a Meritor WABCO ESC system and the Prevost was equipped with a Bendix ESC system.

Although the manufacturers of truck tractors and large buses and the suppliers of stability control systems have performed extensive development

[16] One instance where a heavy vehicle's yaw stability threshold might be higher than its roll stability threshold is in an unloaded condition on a low-friction road surface.

[17] The 6x4 description for a tractor represents the total number of wheel positions (six) and the total number of wheel positions that are driven (four), which means that the vehicle has three axles with two of them being drive axles. Similarly, a 4x2 tractor has four wheel positions, two of which are driven, meaning that the vehicle has two axles, one of which is a drive axle.

work to bring these systems to the market, there are few sources of objective evaluations for testing on stability control systems in the public domain beyond the research programs described above. The agency coordinated with truck, bus, and stability control system manufacturers throughout the VRTC test program so that industry organizations had the opportunity to contribute additional test data and other relevant information on test maneuvers that the agency could consider for use during the research program. Potential maneuvers suggested by industry included a decreasing radius test from the Truck & Engine Manufacturers Association (EMA),[18] a sinusoidal steering maneuver and a ramp with dwell maneuver from Bendix, and a lane change maneuver (on a large diameter circle) from Volvo.[19] In late 2009, the EMA provided results from their tests of the ramp steer, sine with dwell, and ramp with dwell maneuvers to NHTSA. The agency evaluated these data from a measures-of-performance perspective. EMA provided data in December 2010 discussing additional testing with the sine with dwell, J-turn, and a wet-Jennite drive through maneuver. Additional details on these research programs are included in the sections below.

A. UMTRI Study

NHTSA sponsored a research program with Meritor WABCO and the University of Michigan Transportation Research Institute (UMTRI) to examine the potential safety effectiveness of stability control systems for five-axle tractor-trailer combination vehicles. The systems investigated included both RSC and ESC.[20] The research results are provided in the report ''Safety Benefits of Stability Control Systems for Tractor-Semitrailers.'' A copy of this report has been included in the docket.[21]

The objectives of the study were: (1) To use the Large Truck Crash Causation Study (LTCCS) to define typical pre-crash scenarios and identify factors associated with loss-of-control and rollover crashes for tractor-trailers; (2) to study the effectiveness of RSC and ESC in a range of realistic scenarios through hardware-in-the-loop simulation testing, and through case reviews by a panel of experts; (3) to apply the results of this research to generate national estimates from the Trucks Involved in Fatal Accidents (TIFA) and General Estimates System (GES) crash databases of the safety benefits of RSC and ESC in preventing tractor-trailer crashes; and (4) to review crash data from 2001 through 2007 from a large trucking fleet that had started purchasing RSC on all of its new tractors starting in 2004, to determine if there was an influence of this system on reducing crashes.

The LTCCS was a joint study undertaken by the Federal Motor Carrier Safety Administration (FMCSA) and NHTSA, based on a sample of 963 crashes between April 2001 and December 2003 with a reported injury or fatality involving 1,123 trucks with a GVWR over 10,000 pounds. The LTCCS crash data formed the backbone for this study because of the high quality and consistent detail contained in the case files. Included in the LTCCS are categorical data, comprehensive narrative descriptions of each crash, scene diagrams, and photographs of the vehicle and roadway from various angles. This information allowed the researchers to achieve a high level of understanding of the crash mechanics for particular cases. The LTCCS was used to help develop the crash scenarios for modeling (hardware-in-the-loop) performed as part of the engineering analyses for this stability control project. In addition, LTCCS cases of interest with respect to stability control systems were also reviewed by a panel of three experts (two from UMTRI and one from industry) to help estimate the safety benefits of RSC and ESC.

One method for assessing the safety benefits of vehicle technologies is to analyze crash datasets containing data on the safety performance of vehicles equipped with the subject technology. However, because the deployment of the stability control technologies for large trucks is still in its early stages, national crash databases do not yet have sufficient cases that can be used to evaluate the safety performance of stability control technology. Given this limitation, this study used an indirect method to estimate the safety performance of stability control technologies based on probable outcome estimates derived from hardware-in-the-loop simulation, field test experience, expert panel assessment, and crash data from trucking fleets.

UMTRI's study made several conclusions. First, identifying relevant loss-of-control and rollover crashes within the national databases proved a difficult task because the databases are developed for general use and this project required very precise definitions of loss-of-control and rollover (*e.g.,* tripped versus untripped). Relying on the general loss-of-control or rollover categories captures a wide range of crashes, many of which cannot be prevented by the stability control technology. Furthermore, many of the crashes involved vehicles that were not equipped with ABS. Because ABS is now mandatory for the target population of vehicles, the researchers had to factor in what effect the presence of ABS on the vehicle may have reduced the likelihood of or prevented the crash.

Second, the LTCCS was highly valuable in providing a greater level of detail concerning rollover and loss-of-control crashes, which was used to construct a number of relevant crash scenarios so that the technical potential of the candidate RSC and ESC technologies could be estimated systematically. However, the inability to determine with confidence if a vehicle lost control and the lack of detailed information on driver input and vehicle state placed limitations on the ability to assess the potential for stability control technologies to alter the outcome of a particular crash scenario. In contrast, for rollover crashes, it was clear that rollover occurred. Tire marks and road alignment provide strong evidence of the vehicle path and the point of instability.

Third, UMTRI concluded that ESC systems would provide more overall safety benefits than RSC systems. The difference between the estimated effectiveness of RSC and ESC varied among crash scenarios. ESC systems were slightly more effective at preventing rollovers than RSC systems and much more effective at preventing loss-of-control crashes.

Finally, the safety benefits estimates derived from this study were limited to five-axle tractor-trailer combination vehicles, which constitute a majority of the national tractor fleet. However, the study did not include benefits estimates for multi-trailer combinations or for tractors not towing a trailer.

B. Simulator Study

NHTSA sponsored a research study with the University of Iowa to study the effectiveness of heavy truck electronic stability control systems in reducing jackknife and rollover incidents using the NADS–1 National Advanced Driving Simulator. The NADS–1 is a high-fidelity, full motion driving simulator with a 360-degree visual display system

[18] EMA was formerly known as the Truck Manufacturers Association (TMA). Many docket materials refer to EMA as TMA.

[19] Presentations from briefings NHTSA had with EMA have been included in the docket. See Docket Nos. NHTSA–2010–0034–0025 through NHTSA–2010–0034–0031; Docket Nos. NHTSA–2010–0034–0041 and NHTSA–2010–0034–0042. Research notes provided by EMA, Bendix, and Volvo Trucks have also been included in the docket. See Docket Nos. NHTSA–2010–0034–0032 through NHTSA–2010–0034–0040.

[20] A similar study has been initiated with respect to straight trucks over 10,000 pounds GVWR.

[21] DOT HS 811 205 (Oct. 2009), Docket No. NHTSA–2010–0034–0006

that is typically used for the study of driver behavior. Sixty professional truck drivers were recruited to participate in the study. The participants drove a typical tractor-semitrailer in five scenarios designed to have a high potential for rollover or jackknife. The study used the NADS heavy truck cab and vehicle dynamics model to simulate a typical 6x4 tractor-trailer combination vehicle in a baseline (ABS-only), RSC-equipped, and ESC-equipped configurations, using twenty truck drivers per configuration. The purpose of the study was to determine the effectiveness of both roll stability control and yaw stability control systems, to demonstrate driver behavior while using stability control systems, and to help NHTSA refine safety benefits estimates for heavy truck stability technologies.[22]

The NADS truck model performance was compared with test track data from VRTC. The test maneuver used was a ramp steer maneuver with a steering wheel angle of 190 degrees and an angular steering rate of 175 degrees per second. The steering angle was held constant for five seconds after reaching 190 degrees, and then returned to zero. Steering inputs on the NADS were performed manually rather than by using an automated steering machine. The RSM was performed in the NADS to both the right and left directions to check for any simulation abnormalities, and was performed for the baseline, RSC, and ESC test conditions. Exact matching of values to the test track data was not possible because the NADS model was developed by simulating the braking properties of a Freightliner tractor while using the inertial properties of a Volvo tractor. Also, the NADS was modeled with rigid body tractor and trailer vehicle models that did not include the torsional chassis compliance that is a variable in actual vehicles. The result of the testing was that the NADS model tractor-semitrailer experienced wheel lift at slightly lower speeds in the RSM in all three conditions (baseline, RSC, and ESC) than in the VRTC track tests. An additional comparison of VRTC track test data and the NADS ESC model was performed for lane change maneuvers at 45 and 50 mph and showed that the NADS ESC system responses closely matched the responses of the actual test vehicle.

The maneuvering events used to assess the influence of ESC systems consisted of lane incursion from the left side on a snow-covered road and from the right side on a dry road surface, with each event necessitating a sudden lane change to avoid collision. These events provided a greater challenge for the stability control systems due to the aggressive steering and braking inputs by the drivers. Neither stability control system showed benefits in preventing rollover on the dry road surface. ESC systems did provide improved vehicle control on the snow-covered surface; however, two jackknife events still occurred with the ESC system. A large number of jackknife events occurred on the snow-covered surface with the RSC system (11 loss-of-control events in 20 runs) which may have been a result of the aggressive RSC braking strategy found in the model interfering with the driver's ability to maintain steering control of the tractor.

The NADS research study indicated that the RSC system showed a statistically significant benefit in preventing rollovers on both curves and exit ramps on dry, high-friction road surfaces. The tractors equipped with RSC and ESC systems showed a benefit over the baseline tractor in assisting drivers to avoid a jackknife on a low-friction road surface and a rollover on a high-friction road surface when encountering a directional change due roadway geometry. However, in several instances the ESC system was found to activate at abnormally high levels of lateral acceleration in a curve with a high-friction road surface. Although the reason for this was not determined, there may have been problems with the mass estimation algorithm or vehicle parameter inaccuracies in the model.

C. NHTSA Track Testing

NHTSA researchers at VRTC in East Liberty, Ohio, initiated a test program in 2006 to evaluate the performance of stability control systems under controlled conditions on a test track, and to develop objective test procedures and measures of performance that could form the basis of a new FMVSS. Researchers tested three truck tractors, all of which were equipped with an RSC or ESC system (one vehicle was tested with both an RSC and ESC system), one trailer equipped with a trailer-based RSC system, and three large buses equipped with an ESC system. Additionally, the agency tested five baseline semi-trailers not equipped with a stability control system, including an unbraked control trailer that is used to conduct tractor braking tests as prescribed by FMVSS No. 121, *Air brake systems.*

The testing was conducted in three phases. Phase I research focused on understanding how stability control systems performed. Phase II research focused on the development of a dynamic test maneuver to evaluate the roll stability of tractor semitrailers and large buses. Phase III research focused on the development of a dynamic test maneuver to evaluate the yaw stability of truck tractors and large buses.

The Phase I and II research results are documented in the report ''Tractor Semi-Trailer Stability Objective Performance Test Research—Roll Stability.'' [23] The Phase III research results for truck tractors are documented in the report ''Tractor Semitrailer Stability Objective Performance Test Research—Yaw Stability.'' [24] The information provided in sections IV.C.1, IV.C.2, and IV.C.3 below is based on these two reports. The motorcoach research is documented in the report ''Test Track Lateral Stability Performance of Motorcoaches Equipped with Electronic Stability Control Systems.'' [25] The information in section IV.C.4 is based on this report.

1. Effects of Stability Control Systems—Phase I

The test vehicles used in Phase I included a 2006 Freightliner 6x4 tractor equipped with air disc brakes and a Meritor WABCO ESC system as factory-installed options, a 2006 Volvo 6x4 tractor with S-cam drum brakes and a Bendix ESC system included as standard equipment, and a 2000 Fruehauf 53-foot van trailer that was retrofitted with a Meritor WABCO trailer-based RSC system. Tests were conducted by enabling and disabling the stability control systems on the tractor and the trailer to compare the individual performance of each system, evaluate the performance of the combined tractor and trailer stability control systems, establish the baseline performance of each tractor-trailer combination without any stability control system. All tests were conducted with the tractor connected to the trailer, in either the unloaded condition (lightly loaded vehicle weight (LLVW)) or loaded to a 80,000 pound combination weight with the ballast located to produce either a low or high center of gravity height (low CG or high CG) loading condition. During testing, all

[22] The final report is available in the docket. ''Heavy Truck ESC Effectiveness Study Using NADS'' (DOT HS 811 233, November 2009), Docket No. NHTSA–2010–0034–0007.

[23] DOT HS 811 467 (May 2011), Docket No. NHTSA–2010–0034–0009. Results from Phase I are also summarized in the paper ''NHTSA's Class 8 Truck-Tractor Stability Control Test Track Effectiveness'' (ESV 2009. Paper No. 09–0552). Docket No. NHTSA–2010–0034–0008.

[24] Docket No. NHTSA–2010–0034–0046.

[25] Docket No. NHTSA–2010–0034–0045.

combination vehicles were equipped with outriggers.

The first test maneuver evaluated in Phase I was a constant radius circle test (either a 150 foot or a 200 foot radius) conducted on dry pavement. In this constant radius circle test, the driver maintained the vehicle on the curved path while slowly increasing the vehicle speed until the stability control system activated, wheel lift occurred, or the tractor experienced a severe understeer condition.

With the stability control systems disabled, no cases of wheel lift were observed under the LLVW or low CG condition. Under these load conditions, both tractors went into a severe understeer condition. The LLVW tractor did not reach a velocity greater than 40 mph and the low CG tractor did not reach a velocity greater than 34 mph. However, in the high CG condition with the tractor ESC systems disabled, wheel lift occurred in every test that resulted in a lateral acceleration greater than 0.45g at 30 mph.

With the tractor ESC systems enabled, the performance of the two ESC-equipped vehicles improved during the constant radius tests. Both ESC systems limited the maximum lateral acceleration of the tractor by reducing the engine output torque and prevented wheel lift and severe tractor understeer with the different loads tested. With ESC systems enabled, both tractors tested allowed higher maximum lateral accelerations for the LLVW condition compared to the low CG and high CG conditions. There was little difference in peak lateral acceleration for the low CG and high CG conditions.

The trailer-based RSC system limited the maximum lateral acceleration by applying the trailer brakes, which mitigated wheel lift and understeer with the different loads tested. The maximum lateral acceleration of both tractors was limited by the trailer RSC system to below 0.50g for the LLVW condition, 0.40g to 0.50g for the low CG condition, and 0.35g to 0.40g for the high CG condition.

When both tractor- and trailer-based stability control systems were enabled, results were similar to the results of the tractor-based stability control system for the low CG and high CG conditions. Under the LLVW condition, results were similar to the trailer-based RSC system values observed.

The second maneuver evaluated in Phase I was a J-turn, also conducted on dry pavement, in which the test driver accelerated the vehicle to a constant speed in a straight lane and then negotiated 180 degrees of arc along a 150-foot radius curve. The initial maneuver entrance speed was 20 mph and it was incrementally increased in subsequent runs, until a test termination condition was reached. The test terminated upon the occurrence of one of the following: The trailer outriggers making contact with the ground, indicating that wheel lift was occurring; the tractor experiencing a severe understeer condition; a stability control system brake activating; or the maneuver entry speed reaching 50 mph.

For both tractors in the baseline configuration (stability control disabled), trailer wheel lift occurred in all load combinations except for the Freightliner in the LLVW condition, which went into a severe understeer condition at a maneuver entry speed of 50 mph. For the Volvo in the LLVW load condition, trailer wheel lift was observed when the tractor's maximum lateral acceleration exceeded 0.75g at 48 mph. With stability control disabled in the low CG load condition, trailer wheel lift was observed when the tractor's maximum lateral acceleration was greater than 0.67g at 40 mph for the Freightliner and 0.60g at 38 mph for the Volvo. For the high CG load condition, trailer wheel lift was observed when the tractor's maximum lateral acceleration was approximately 0.45g at 33 mph for the Freightliner and 0.42g at 31 mph for the Volvo.

Tractor ESC systems limited the maximum lateral acceleration for both the tractor and the trailer. Wheel lift was not observed for the range of speeds evaluated. For both tractors tested in the low CG and high CG loading conditions, the tractor's ESC intervened at a speed that was well below the speed that would produce trailer wheel lift. With the trailer in the LLVW load condition, the tractor's maximum lateral acceleration was limited to approximately 0.60g for the Freightliner and the Volvo. With the trailer tested in either the low CG or high CG load conditions, the tractor's lateral acceleration was limited to 0.50g and 0.40g for the Freightliner and Volvo respectively.

The trailer-based RSC system also improved the baseline vehicle's roll stability in the J-turn maneuver. For the LLVW load condition, the trailer-based RSC system activated at speeds similar to those of the tractor-based systems. For the low CG and high CG load conditions, the tractor-based systems activated at approximately a 3 mph lower speed than the trailer-based RSC system. With both systems enabled, the tractor-based system activated and mitigated the roll propensity before the trailer RSC system activated.

The third maneuver evaluated in Phase I was a double-lane-change maneuver, in which the test driver accelerated the vehicle up to a constant speed on a dry road surface and then negotiated a lane change maneuver followed by a return to the original lane within physical boundaries (gates) marked by cones. The maneuver entry speed was incrementally increased in subsequent test runs. Although the top speed in this maneuver was intended to be limited to 50 mph for safety reasons, the test driver performed runs at speeds as high as 51 mph.

In the baseline configuration, both tractors completed the maneuver at 50 mph without wheel lift or yaw instability in the LLVW and the low CG loading conditions. In the high CG loading condition, the Freightliner experienced trailer wheel lift at a maneuver entry speed of 41 mph and the Volvo experienced trailer wheel lift at a maneuver entry speed of 45 mph.

With the ESC system, the Freightliner's stability control system was observed to limit peak lateral acceleration to approximately 0.50g, which prevented trailer wheel lift in the high CG load condition for tests performed up to 50 mph. Tests performed at 51 mph resulted in trailer wheel lift. The Volvo's stability control system limited the tractor's maximum lateral acceleration to approximately 0.40g and prevented trailer wheel lift for the high CG condition up to a maximum test speed of 51 mph.

With only a trailer-based RSC system, trailer wheel lift was observed during the high CG load condition when the system was overdriven at 41mph when tested with the Freightliner, which represented no improvement over the baseline condition. Trailer wheel lift was observed at 50 mph when tested with the Volvo, which represented a 5 mph improvement over the baseline condition. When tested with this maneuver in the high CG load condition, the trailer-based RSC system activated the trailer brakes at entrance speeds of 30 and 33 mph for the Freightliner and Volvo, respectively.

All stability control systems tested improved the roll stability of the vehicle over the baseline condition. For each maneuver, the tractor-based stability control systems were able to mitigate trailer wheel lift at the same or higher maneuver entrance speeds than trailer-based systems. The trailer-based RSC system was typically able to mitigate trailer wheel lift at a higher maneuver entry speed than the baseline condition, with the exception of the double-lane-change maneuver with one of the tractors. In the tests with both tractor-based ESC systems and trailer-based RSC systems enabled, the tractor-based ESC system was often found to be the first system to intervene to reduce wheel lift or understeer.

Based on the results of Phase I, the agency determined that a performance test based on the J-turn was suitable to evaluate tractor and trailer stability control systems. The J-turn maneuver generates a sufficient amount of lateral acceleration to provide a challenging test at reasonable test speeds. The J-turn maneuver is also more representative of the real-world conditions, such as curved off-ramp, that could generate untripped rollover. Because the results from Phase I showed that tractor-based stability control systems increased the roll stability by a larger margin than trailer-based RSC systems, NHTSA concluded that Phase II research should focus on tractor-based stability control systems.

2. Developing a Dynamic Test Maneuver and Performance Measure To Evaluate Roll Stability—Phase II

(a) Test Maneuver Development

The researchers at VRTC conducted Phase II to develop test methods that could evaluate stability control system performance objectively and measures of performance that would ensure that a stability control system could prevent rollover effectively. After Phase I test results demonstrated that a test driver's steering input variation could affect test outcome, an automated steering machine was used for subsequent research. The testing focused on tractor-based stability control systems that were determined to be most effective in preventing rollovers from the Phase I research.

Both the Freightliner and Volvo 6x4 tractors equipped with an ESC system from Phase I were tested, and an RSC electronic control unit was also obtained for the Freightliner. A Sterling 4x2 equipped with a Meritor WABCO RSC system was also tested in Phase II. In addition to the Fruehauf 53-foot van trailer used in Phase I (its trailer-based RSC system was disabled throughout the Phase II testing), five additional trailers were tested, including a second 53-foot van trailer, two 48-foot flatbed trailers, a 9200-gallon tanker trailer, and a 28-foot flatbed trailer which is used as a control trailer in FMVSS No. 121 brake system testing.

The first maneuver evaluated in Phase II was a slowly increasing steer maneuver. The SIS maneuver has been used by the agency and the industry to determine the unique dynamic characteristics of each vehicle. This maneuver is included in the FMVSS No. 126 test procedure for ESC systems on light vehicles. The maneuver provides the steering wheel angle to lateral acceleration relationship for each vehicle, accounting for the differences in steering gear ratios, suspension systems and wheelbases among vehicles. It also normalizes test conditions to account for variations in test conditions, such as road surface friction. The steering wheel angle derived from the SIS test was used to program the automated steering machine for the ramp steer maneuver discussed below.

To initiate the SIS maneuver, the test driver accelerated the vehicle to a constant speed of 30 mph on a dry road surface. The driver then activated the steering machine to input a steadily increasing steering wheel angle up to 270 degrees at a rate of 13.5 degrees per second. The test driver manually maintained constant speed using the accelerator pedal while the tractor's path radius steadily decreased and the tractor's lateral acceleration steadily increased. The SIS maneuvers were conducted with the tractor in the bobtail condition (no trailer attached). The SIS maneuver also demonstrated that tractor-based stability control systems are capable of detecting a high lateral acceleration condition and intervening by reducing the engine output torque.

The SIS maneuver was used to determine the steering wheel angle projected to generate 0.5g of lateral acceleration when traveling at 30 mph. This value varied depending on characteristics of the tractor such as its wheelbase and steering ratio. For tractors, that steering wheel angle and lateral acceleration data was found to have a linear relationship at the lateral acceleration values between 0.05 and 0.3g. Over this range of data a linear regression method followed by linear extrapolation was used to estimate the steering wheel angle at 0.5g lateral acceleration for each SIS maneuver. The final steering wheel angle was then calculated by averaging the values from tests conducted while turning to the left and while turning to the right. The resulting calculated steering wheel angles were 193 degrees for the Freightliner, 199 degrees for the Volvo, and 162 degrees for the Sterling. This indicates that the Sterling, which was a 4x2 configuration, had a higher steering wheel gain than the other tractors which were 6x4 configurations.

The SIS testing was repeated for the three tractors throughout the test program to determine the consistency of the steering wheel angle calculations and the test speeds. The resulting standard deviations in steering wheel angle were 2.5 degrees for the Sterling, 7.4 degrees for the Freightliner, and 10.2 degrees for the Volvo, although the replacement of the tires on the Volvo may have contributed to an increase in steering wheel angle during one of the repeat tests. The tractor speed at the beginning of the SIS steering input ranged from 29.6 to 32.2 mph for all of the tests.

After the SIS testing, tests were conducted using a ramp steer maneuver to assess the roll stability of tractor-trailer combinations and the effectiveness of both types of tractor-based stability control systems. The RSM was derived from and is similar to the J-turn maneuver, but instead of the driver controlling the steering wheel to follow a fixed path, the steering controller turns the steering wheel to an angle determined from the results of the SIS test. One advantage of the RSM over the J-turn maneuver is that the RSM uses a steering machine, which allows for a more consistent and repeatable steering input.

To conduct the RSM, the test driver accelerated the vehicle to a constant speed of one to two mph above the target maneuver entry speed on a dry surface and then released the throttle and de-clutched the engine. Once the vehicle coasted down to the desired maneuver entry speed, the automated steering controller initiated a steering input, at a constant rate of 175 degrees per second, up to the steering wheel angle that was derived for the tractor in the SIS test. Once the steering wheel angle was reached (the end of ramp input), it was held constant for five seconds, and then the controller returned the steering wheel angle back to zero at a steering rate of 175 degrees per second. The initial maneuver entry speed was 20 mph and it was incrementally increased in subsequent runs until a test termination condition was met. The termination conditions were as follows: Two inches of wheel lift occurring at either the tractor drive wheels or the trailer wheels; the tractor reaching a severe oversteer condition (safety cables were installed to limit the tractor-trailer articulation angle for testing safety); or the maneuver entry speed reached 50 mph without a roll or yaw instability condition. Although the intent of the RSM was to evaluate combination vehicle roll stability, testing with the trailers in the unloaded condition resulted in several occurrences of tractor yaw instability.

For all of the RSM tests, each tractor was tested with all six trailers and the trailers were either unloaded, or loaded to a high CG, on-highway combination weight appropriate for the number of axles on the combination vehicle. For the flatbed and van trailers, the load ballast was placed on 24-inch high tables to produce a high CG height, and the tanker trailer was loaded with water.

The purpose of the RSM test is not to cause a rollover, but to create a high lateral acceleration condition to demonstrate that a stability control system has the capability to reduce the likelihood of a rollover. Typically, wheel lift occurred first at the trailer wheels although the flatbed trailer combinations had tractor drive wheel lift occurring first or in unison with the trailer wheels. In the RSM tests with the stability control system disabled and the trailer in the high CG condition, wheel lift occurred at entry speeds between 25 and 31 mph for all combinations of tractors and trailers. The peak tractor lateral acceleration at wheel lift was in the range of 0.45 to 0.50g, showing that the high CG loading condition was representative of fully loaded tractor-trailers with a medium density cargo.

Tractor-based stability control systems applied the foundation brakes on the tractor and trailer, which reduced the vehicle speed and lateral acceleration during the RSM. The entry speed at which wheel lift was first visible improved to between 31 and 42 mph for three of the four tractors tested (Freightliner RSC, Freightliner ESC, and Volvo ESC).

In tests with the trailer brakes disabled, the entry speed at which wheel lift was detected was between 29 and 41 mph, which showed that the contribution of trailer braking to prevent wheel lift was evident, but that it was relatively small in comparison to the deceleration resulting from tractor braking. The Sterling tractor equipped with an RSC system had wheel lift with three of the trailers at the same speed as with the stability control system disabled, and with the other three trailers at speeds between two and four mph over the disabled test condition. In all of the RSM tests, the Sterling tractor's RSC system was not as effective at mitigating wheel lift for this maneuver.

The results indicated that, in general, the ESC systems provided a higher level of deceleration compared to the RSC systems and typically had the higher maneuver entry speeds prior to wheel lift. However, there were individual trailer combinations in which the RSC system performed as well or slightly better than the ESC system on the Freightliner. We believe the better performance by the RSC system in some tests is attributable to the RSC system having a more aggressive braking strategy than the ESC system tested.

The RSM was then performed with each of the six trailers in the unloaded condition, with the tractor stability control system enabled with the trailer brakes disabled. Tests were not conducted with the systems disabled. The initial maneuver entry speed was 20 mph and was incrementally increased in subsequent runs until the speed reached 50 mph, severe oversteer occurred, or wheel lift occurred. The tractors with ESC systems enabled were able to complete all but one of the RSM tests up to 50 mph without any tractor instability or wheel lift. The Volvo tractor towing the empty tanker trailer resulted in wheel lift of the tractor drive wheels and the trailer wheels at a speed of 47 mph.

In comparison, most of the tests with the tractors equipped with RSC systems towing unloaded trailers resulted in severe tractor oversteer, with the tractor-trailer articulation angle typically reaching the limits allowed by the safety cables. This occurred at speeds between 35 and 39 mph for the Freightliner 6x4 tractor and between 34 and 42 mph for the Sterling 4x2 tractor. However, both of these tractors were able to complete the RSM up to 50 mph when coupled to the unloaded 28-foot control trailer, and the Freightliner reached 50 mph without wheel lift or severe understeer when coupled to the unloaded tanker trailer.

In summary, the goal of the Phase II research was to develop a test maneuver to challenge the roll propensity of a truck tractor. The RSM is similar in test severity to the J-turn and demonstrates that the stability control systems are able to mitigate wheel lift in most cases that occurred when the stability control systems were disabled. In the high CG load condition, the ESC systems were observed to mitigate wheel lift at or above the speed observed with RSC-equipped vehicles, with the exception of a few instances with the Freightliner's ESC system. When tested with the unloaded test trailer, substantial improvements in tractor yaw stability were evident in the tractors equipped with ESC systems during RSM tests.

(b) Performance Measure Development

NHTSA's Phase II testing also examined possible performance measures to evaluate roll stability. In situations where the vehicle's stability limits are approached in a gradual manner, engine/power unit control can improve stability in these situations. However, in situations where stability limits of the vehicle are approached rapidly, application of the vehicle's foundation brakes may be a more appropriate means of improving stability.

The agency investigated four measures for development as metrics for engine/power unit control. They were truck tractor speed, truck tractor lateral acceleration, truck tractor longitudinal acceleration, and actual engine torque and driver requested engine torque.

The forward speed of a truck tractor appears to be directly related to the lateral forces generated during an untripped rollover. Test data from four different vehicles with stability control enabled indicated that forward speed was reduced from the target maneuver entrance speed of 30 mph. However, due to the nature of the roll maneuver, it is possible for the vehicle to lose traction on the inside wheels, which results in a reduction in vehicle speed but does not necessarily enhance vehicle stability.

Lateral acceleration was a possible measure of performance because of its direct relationship in producing the forces associated with untripped rollover. Data from four different tractors with the stability control system enabled indicate that each combination of tractor and stability control system had a different lateral limit that the system has allowed. This shows that the control strategy used by the manufacturer is different depending on the vehicle and system used. One strategy allows the vehicle to build lateral acceleration to a set threshold level and then allows that level to be maintained throughout the maneuver. The other strategy allows lateral acceleration to build and then the stability control system reduces the lateral acceleration. Both of these strategies were observed to increase lateral stability. Because the lateral acceleration limits were different for vehicles using these control strategies, lateral acceleration alone was not found to be a good measure for stability control performance.

Longitudinal acceleration of a vehicle is reduced when a vehicle's stability control system is enabled and is directly related to a reduction in forward speed. On the four vehicles tested, the stability control activation had measurable differences in longitudinal acceleration, but had similar disadvantages to forward speed in being used as a performance metric.

Engine torque measures were observed to be a direct way to determine ESC activation during the SIS tests. Engine torque refers to two different measures. The first relates to the torque output from the engine and is expressed as a percentage of maximum engine output. The second relates to the throttle pedal used by the driver to control engine torque output. This value is also expressed as a percentage of maximum engine output and is referred to as the ''driver requested torque.'' During normal operation the ''driver requested torque'' and ''engine torque'' measures were observed to be equal to each other. However, during ESC activation when engine control intervened, the two measures were observed to be separate. In every case, the ''engine torque'' was much less than the ''driver requested torque'' and continued to reduce until vehicle stability was regained. After careful review of the data the torque separation activity was confirmed for all the SIS test series in which stability control was enabled for each vehicle. This led the agency to conclude that this measure was a good candidate for further analysis and development as a measure of performance for truck tractors equipped with a stability control system.

The engine torque data analysis was based on the test driver attempting to maintain a constant vehicle speed at the point of stability control engine torque intervention by making a substantial increase in driver-requested engine torque. For the four vehicles tested, the driver requested engine torque after stability control intervention was between 60 percent and 100 percent of engine output whereas the engine torque output after stability control intervention ranged from zero to 60 percent. The analysis of engine torque differentials was limited to the first four seconds after stability control engine torque intervention since none of the SC systems were observed to make substantial reapplications of engine torque output during this initial time-frame. On two vehicles engine torque interventions reduced engine output torque to zero during the first four seconds, and both systems allowed engine torque to be momentarily reapplied to over 50 percent of engine torque output. The Volvo had the highest engine torque output during the first four seconds after intervention, which ranged from 23 percent to 18 percent of maximum engine torque.

The agency also investigated several other measures for development for foundation braking in rollover tests because stability control systems were observed to improve the vehicle's roll stability by applying the foundation brakes. The measures investigated were wheel lift, lateral acceleration, lateral acceleration ratio, trailer lateral acceleration ratio, and trailer roll angle ratio.

Wheel lift is a direct measure of performance with minimal calculations needed to determine its value. The measure is simple and directly represents the pre-crash condition that immediately precedes a rollover. If wheel lift can be prevented, a rollover cannot occur. For our research, wheel lift was considered to occur upon two inches of lift for the tractor drive axle wheels or the trailer wheels. Wheel lift does not always indicate that rollover is imminent, particularly because certain suspension designs will lift a wheel during hard cornering. We estimated the vehicle speed that produced wheel lift during the ramp steer maneuver and found that between 29 mph and 32 mph, there is a high probability of wheel lift occurring on the combination vehicles tested. Given that only four different truck tractors and six different test trailers were used, we believed that the data may not be sufficient to assess the real world service of tractors with ESC expected to function with different trailers having different torsional stiffness and loads.

Using lateral acceleration as a performance metric is based on the principle that a tractor-trailer combination vehicle with a high center of gravity that achieves a certain level of lateral acceleration would roll over. Tests performed on the Freightliner in combination with all trailers configured with a high-CG load, at a mean entrance speed of 28 mph generated a lateral acceleration. The data showed that using tractor maximum lateral acceleration as a performance criteria would not discriminate between vehicles equipped with stability control and those without it. However, it did show that a ratio-based metric could be more appropriate for such a performance metric.

Lateral acceleration ratio is calculated by dividing the tractor's lateral acceleration at a given time interval by the measured lateral acceleration at the end of ramp input, which is the end of the steering maneuver and the point near which the vehicle experiences its peak lateral acceleration. The LAR was plotted at five equal one-second intervals for several truck tractors and test trailers. The plots indicated sharp decreases in LAR caused by activation of the stability control system.

A similar ratio metric for trailers, trailer lateral acceleration ratio, also showed the ability to discriminate between vehicles with stability control systems and those without. A third ratio metric was considered, trailer roll angle ratio based on a test trailer roll angle, but it did not clearly discriminate between vehicles with stability control systems and those without.

3. Developing a Dynamic Test Maneuver and Performance Measure To Evaluate Yaw Stability—Phase III

(a) Test Maneuver Development

The purpose of the Phase III research was to develop maneuvers to evaluate the yaw stability performance of stability control systems on tractors. Although we have examined several maneuvers to evaluate yaw stability, two maneuvers were fully investigated because other maneuvers were not able to provide a consistent, repeatable performance test. We fully considered a sine with dwell test maneuver that is similar to the test maneuver used in FMVSS No. 126 for light vehicles; and a half-sine with dwell (HSWD) test maneuver. The steering inputs for the SWD and HSWD maneuvers are depicted in the figures below, and as discussed in additional detail, variations on the steering wheel angle, the frequency of the sine wave (cycles per second, Hz), and the dwell time were evaluated for both maneuvers. A steering machine was used to achieve consistent steering wheel inputs for these maneuvers.

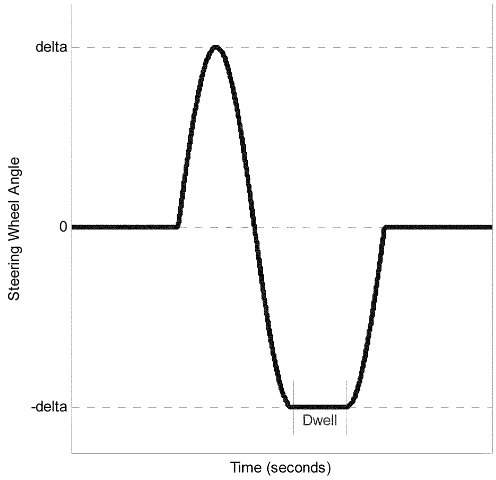


Figure 3: Sine with Dwell profile

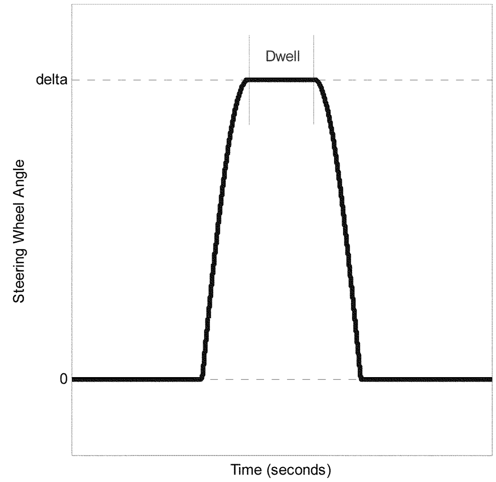


Figure 4: Half Sine with Dwell profile

The test vehicles used in Phase III included: A 2006 Freightliner 6x4, which was tested with both ESC and RSC systems; a 2006 Volvo 6x4 tractor with an ESC system; and a Sterling 4x2 tractor equipped with an RSC system. Although most of the testing was performed using the 28-foot flatbed control trailer, each tractor was also tested with a 53-foot Strick van trailer, a 48-foot Fontaine spread axle flatbed trailer, and a 9600-gallon Heil tanker trailer. Tests were conducted with the trailer brakes both enabled and disabled.

Two tractor loading conditions were used for both the SWD and HSWD testing. Each tractor was tested in the bobtail condition (no trailer attached) and using a trailer loaded over the fifth wheel so that the tractor drive axle(s) was loaded to 60 percent of its gross axle weight rating (GAWR). The yaw instability that occurred in the RSM testing showed that the unloaded 28-foot control trailer was too light to produce yaw instability. Therefore, additional weight was added for these tests. Testing was conducted on two test surfaces: A high-friction dry road surface and a slippery wet Jennite road surface.

Additional SIS tests were performed, similar to the bobtail SIS tests described in Phase II, conducted with each tractor coupled to the 28-foot control trailer and loaded to the 60 percent GAWR condition. The steering wheel angles from these tests were 197 degrees for the Freightliner with ESC, 200 degrees for the Freightliner with RSC, 200 degrees for the Volvo, and 153 degrees for the Sterling. The average tractor lateral acceleration at engine torque intervention in the SIS tests was 0.40g for the Freightliner with ESC, 0.34g for the Freightliner with RSC, 0.35g for the Volvo, and 0.4g for the Sterling.

For the SWD and the HSWD test maneuvers, the maneuver entrance speed for the bobtail tractor tests was 50 mph, and for the tests at 60 percent GAWR the entry speed was 45 mph. The driver accelerated the test vehicle up to a speed slightly over the desired speed in a straight lane, then released the throttle and de-clutched the engine. Once the vehicle coasted down to the desired speed, the automated steering machine initiated either the sinusoidal or half-sine steering input, at a specified test frequency as described below (*e.g.,* 0.3 Hz, 0.5 Hz, etc.), with the steering wheel angle held constant during the dwell, as depicted in the figures. Two dwell times were evaluated as described below, 0.5 and 1.0 second. The initial test run began with a steering wheel angle equal to 30 percent of the angle determined from an SIS test. The test severity was increased in subsequent runs by increasing the steering wheel angle in 10 percentage point increments until reaching 130 percent of the SIS steering wheel angle. Thus, 11 test runs were needed to complete a test series. If severe oversteer or wheel lift greater than two inches was detected, then the test was repeated using the previous steering wheel angle in which the systems was observed to be stable. If the tractor-trailer was stable during the repeated run, additional tests were performed by increasing the steering wheel angle in 5 percent increments until instability was observed.

Tests were conducted on baseline tractors in the 60 percent GAWR condition on dry pavement to evaluate frequency and dwell time for the SWD and HSWD test maneuvers. Frequencies between 0.3 and 0.7 Hz were evaluated. A frequency of 0.5 Hz was found to require the lowest steering scalar to produce severe oversteer in the Sterling and Volvo tractors in the SWD maneuver, and 0.4 Hz was found to require the lowest steering scalar to produce severe oversteer in the Freightliner tractor (and 0.5 Hz was the second-most severe frequency for this tractor). A dwell time of 1.0 second was found to result in severe tractor oversteer at lower steering scalars. Thus the researchers selected a 0.5 Hz frequency and 1.0 second dwell time as the parameters for the SWD and HSWD maneuvers. However, the researchers also found that the SWD maneuver was less sensitive to differences in steering frequency compared to the HSWD maneuver.

In tests conducted with baseline tractors in the bobtail condition, no yaw instability occurred; however, in both the SWD and HSWD tests the Sterling tractor experienced wheel lift at the tractor drive wheels. Seventy test series were conducted on the baseline tractors in the 60 percent GAWR load condition, with fifteen of the series terminated due to roll instability and 28 due to severe tractor oversteer.

In tests conducted with the tractor stability control system enabled and in the 60 percent GAWR load condition, all of the tractors with an ESC system were able to complete the SWD maneuver at test scalars up to 130 percent. However, the tractors equipped with RSC systems experienced severe oversteer in 12 of 15 test series at the steering scalars of 120 and 130 percent. In tests conducted using the HSWD maneuver, the ESC-equipped tractors completed seven of eight test series without tractor yaw instability, and the RSC-equipped tractors experienced severe oversteer at steering scalars ranging from 80 to 125 percent. In both test maneuvers, the RSC systems improved tractor yaw stability compared to the baseline tractor, but they could not maintain yaw stability at the higher steering scalars.

Additional SWD tests were conducted with the 53-foot van trailer and the 48-foot flatbed trailer using the 60 percent GAWR loading condition. In eight test series conducted with the tractor stability control systems enabled, seven were completed without wheel lift or tractor yaw instability, but the Sterling tractor equipped with an RSC system tested with the 48-foot flatbed reached a termination condition at a steering scalar of 105 percent. In tests with stability control enabled, all of the tractors coupled to the tanker trailer experienced wheel lift in the SWD maneuver at scalars between 60 and 95 percent.

SWD tests were also conducted on a low-friction wet Jennite surface using a lower maneuver entry speed of 30 mph. In the baseline condition with the tractor stability control systems disabled, 43 test series were conducted and a termination condition was reached in only four test series. Testing on the dry, high-friction surface was found to result in more yaw instabilities than the testing conducted on the low-friction, wet Jennite surface.

In summary, the purpose of Phase III research was to develop a maneuver to evaluate the yaw stability of a tractor trailer combination vehicle. VRTC researchers found that the SWD maneuver with a one-second dwell time based on a single cycle of steering input with a frequency of 0.5 Hz conducted on a high friction surface appropriately assessed the ability of an ESC system to improve yaw stability. From this maneuver, performance measure were investigated for lateral stability and responsiveness: the lateral acceleration ratio, which is directly correlated to roll stability and the yaw rate ratio, which the performance metric used in FMVSS No. 126 for light vehicle ESC systems and was found to be a direct performance measure of yaw stability. A responsiveness measure was also studied to evaluate the lateral displacement of a vehicle during SWD maneuvers.

(b) Performance Measure Development

Phase III of NHTSA's research also examined potential measures of yaw instability prevention performance. In light of the conclusion in Phase II that lateral acceleration ratio was a suitable metric to measure a stability control system's ability to prevent lateral acceleration, the agency examined a yaw rate ratio metric. The YRR expresses the lateral stability criteria for the sine with dwell test to measure how quickly the vehicle stops turning, or rotating about its vertical axis, after the steering wheel is returned to the straight-ahead position. Similar to the LAR, the YRR metric is the percent of peak yaw rate that is present at a designated time after completion of steer. This performance metric is identical to the metric used in the light vehicle ESC system performance requirement in FMVSS No. 126. Phase III research found that both LAR and YRR were capable of measuring stability during the SWD maneuver. However, while LAR was better at predicting roll instability, YRR was better at predicting yaw instability.

4. Large Bus Testing

Researchers at VRTC tested three large buses equipped with stability control systems: A 2007 MCI D4500 (MCI #1), a 2009 Prevost H3, and a second 2007 MCI D4500 (MCI #2). The MCI buses were equipped with a Meritor WABCO ESC system and the Prevost was equipped with a Bendix ESC system. RSC systems were not offered on large buses and, consequently, were not evaluated. All of the buses were equipped with air disc brakes. Both the MCI #1 and the MCI #2 had a GVWR of 48,000 lb and a wheelbase of 317 in., and the Prevost had a GVWR of 53,000 lb and a wheelbase of 317 in. Each of the buses had three axles: A steer axle, a drive axle, and a non-driven tag axle.

The MCI #1 was equipped with outriggers supplied by MCI and Meritor WABCO. The outriggers limited the use of higher maneuver entry speeds for tests without the ESC system enabled. At higher speeds, the lower support portion of the outrigger would dig into the test surface and influence the dynamics of the vehicle. Therefore, tests of the MCI #1 at higher speeds had no baseline performance to compare to.

The Prevost and MCI #2 buses were tested using NHTSA-designed outriggers. The outriggers designed for combination vehicles were adapted for installation on the mid-section of each bus, just in front of its drive axle and slightly behind its longitudinal center of gravity. Using these outriggers, the vehicles were able to complete testing for all speeds, with or without ESC enabled.

Each bus was tested using two primary simulated load conditions. The first condition was a lightly loaded vehicle weight (LLVW) that included the weight of the test instrumentation, outriggers, and driver. The second load condition, gross person occupancy weight (GPOW), included the LLVW weight plus the addition of 175-lb water dummies in each available passenger seat without exceeding the GVWR of the vehicle. This condition was used to represent a high CG load that a bus may experience while in service. A third loading condition was conducted with the Prevost, which added ballast to the cargo holds under the mid-section of the bus. This condition loaded the vehicle to its GVWR.

Test maneuvers that were conducted included the 150 ft. constant radius increasing velocity test, SIS, RSM, HSWD, and SWD. Tests were conducted using an automated steering machine, except for the constant radius maneuvers. The severity for each test maneuver was increased either by increasing vehicle speed or steering angle.

SIS maneuvers were conducted under both loading conditions, with ESC systems enabled and disabled, and in both left and right directions in order to characterize each vehicle. Initially, the maneuver was executed exactly as it was for the tractor testing. However it was observed that steering to a maximum steering wheel angle of 270 degrees generated barely over 0.3g of lateral acceleration. From this, it was clear that large buses have a larger steering ratio, and it would take a larger steering input to achieve the appropriate lateral acceleration levels. The steering wheel angle necessary to achieve 0.5g in the LLVW loading condition was 405 degrees for the MCI #1, 352 degrees for the Prevost, and 407 degrees for the MCI #2. In the GPOW loading condition, steering wheel angles were found to be 405 degrees for the MCI #1, 383 degrees for the Prevost, and 461 degrees for the MCI #2.

SIS tests were conducted at GPOW to evaluate the ability of the ESC system to reduce speed by limiting engine torque. For the three buses tested the average speed at activation for each SIS maneuver ranged between 29.8 and 30.6 mph. At four seconds following SC activation the average speed for each SIS had been reduced to 27.9 mph for the MCI #1, 26.5 mph for the Prevost, and 26.6 mph for the MCI #2. Without stability control enabled, speeds did not decrease. The average lateral acceleration for a test series observed at activation was 0.32g for MCI #1, 0.27g for the Prevost, 0.31g for MCI #2.

RSM testing was completed for each bus to evaluate their roll propensity while loaded in the LLVW and GPOW conditions. Tests were conducted using the same RSM protocol as the one developed for tractors. Using an automated steering machine programmed with the steering wheel angle calculated from the SIS maneuver, tests were conducted with ESC systems enabled and disabled. The initial maneuver entry speed was 20 mph and was incrementally increased in subsequent runs until two inches of wheel lift occurred at any of the wheels, the vehicle went into a severe oversteer condition, or the entry speed reached 50 mph without a roll or yaw instability condition.

For RSM tests with ESC systems disabled and the buses loaded in the LLVW condition, wheel lift was observed in both MCI test vehicles at speeds of 41 to 45 mph, and no wheel lift was observed for tests with the Prevost for the speeds tested. When tested in the GPOW condition, wheel lift was observed at 35 to 39 mph for all vehicles tested.

For RSM tests with ESC systems enabled and the buses loaded in the LLVW condition, no instances of wheel lift were observed over the range of speeds tested. During tests in the GPOW condition wheel lift was not observed in either MCI over the range of speeds tested, but was observed in some of the Prevost tests at speeds between 42 and 48 mph.[26]

SWD testing was completed for each bus to evaluate its yaw propensity while loaded in the LLVW and GPOW conditions. All tests were conducted with the ESC systems enabled and disabled. Using an automated steering machine, the SWD tests were run using steering frequencies of 0.3, 0.4, 0.5, and 0.6 Hz, dwell times of 0.5 and 1.0 seconds, and a maneuver entry speed of 45 mph. Test severity was increased by increasing the steering wheel angle by a scalar from 30 to 130 percent in 10 percent increments. A test series was terminated if the vehicle experienced wheel lift greater than 2 inches, the vehicle spun out, or the steering input reached a terminating scalar of 130 percent.

No instances of spinout were observed during this testing, but tests at higher steering wheel angles produced drift. Although the buses were yaw stable in the maneuvers, the test results demonstrated that the SWD maneuver was challenging the buses' roll propensity. Several SWD test series with the GPOW condition produced wheel lift when the ESC system was disabled. When the ESC systems were enabled, all vehicles were able to complete their series without exceeding either roll or yaw stability thresholds.

The SWD test data from the GPOW load condition were analyzed to determine a frequency and dwell time for a candidate performance maneuver. For all tests with ESC disabled, maneuvers with a 1.0-second dwell time required an equal or lower steering scalar (0 to 50 percent lower) to exceed a threshold of 6 degrees of yaw angle. As with the tractor testing, this suggested that the 1.0-second dwell time was more challenging to large buses because it required less steering to exceed the threshold.

Using only the 1.0-second dwell time tests, analysis to determine the optimum frequency for the SWD test was completed by evaluating the roll and yaw angles. Review of the test data indicated that the largest roll and yaw angles were produced in the maneuvers using 0.4 and 0.5 Hz frequencies.

The large buses were also tested using the HSWD maneuver. Like the SWD, the test results for the HSWD indicated that the longer dwell time was more challenging to stability. Unlike the SWD, the lower frequencies were observed to produce wheel lift at lower steering wheel angle scalars. Tests results from both the SWD and HSWD maneuvers indicated that both maneuvers generated dynamic responses from the vehicles. There were clear differences in lateral acceleration and yaw rate between test series conducted with ESC systems enabled compared to test series with ESC systems disabled. The data showed that ESC systems were reducing both rollover and spinout propensities. However, the SWD maneuver was favored over the HSWD maneuver because the SWD maneuver could be conducted in a smaller area, would be representative of a crash avoidance or lane change maneuver, and its use in FMVSS No. 126 accelerated performance measure research.

This research indicates that large buses equipped with ESC systems can use the same objective performance maneuver as was developed for tractors. Testing also indicates that the same performance measures can be used to assess lateral stability and responsiveness, but the performance measures must be tailored for the vehicle differences.

D. Truck & Engine Manufacturers Association Testing

The Truck & Engine Manufacturers Association (EMA) performed tests on ten tractors listed in the following table equipped with stability control systems using the three test maneuvers developed at VRTC.

TABLE 2—EMA TEST TRACTORS INCLUDING TYPE, GVWR, AND WHEELBASE

Tractor configuration (EMA Vehicle I.D.)	Stability control type	GVWR (lb)	Wheelbase (inches)
6x4 Typical Tractor (Vehicle A)	ESC	52,000	228
4x2 (Vehicle B)	ESC	32,000	140
4x2 (Vehicle C)	RSC with steering wheel angle sensor	34,700	152
6x4 Severe Service (Vehicle D)	ESC	66,000	220
6x4 w/Pusher Axle (Vehicle E)	ESC	86,000	270
8x6 Tridem Drive Axle (Vehicle F)	ESC	89,000	263
6x4 w/Pusher Axle (Vehicle G)	ESC	92,000	243
6x4 Severe Service (Vehicle H)	RSC	60,600	246
6x4 (Vehicle I)	ESC	52,000	232
6x4 (Vehicle J)	ESC	52,350	245

[26] Initial tests conducted with the Prevost demonstrated that the vehicle was able to complete the RSM at up to 48 mph without wheel lift for the GPOW condition. The Prevost was not tested to 50 mph because there was not enough test area to bring the vehicle up to this speed and allow the driver to recover safely if the test needed to be aborted. RSM tests under the same conditions were repeated less than a week later. During these tests, wheel lift greater than 2 inches was observed at speeds of 42 to 44 mph with ESC enabled. Upon further investigation when preparing to de-instrument the vehicle, a broken roll stabilizer bar was discovered. Researchers attributed the change in performance observed to the broken stabilizer bar.

EMA provided its test data to the agency.[27] Although the tractors were not identified by make or model, EMA provided the configuration and weight ratings for each tractor. Eight tractors were subjected to the SIS and RSM to evaluate rollover prevention, and three tractors were subjected to the SWD maneuver, and the ramp with dwell (RWD) maneuver on a low-friction surface to evaluate yaw stability. Two of the tractors were equipped with RSC systems and seven tractors were equipped with ESC systems. EMA also submitted test data for several maneuvers in which the test parameters were varied. With the exception of Vehicle J, EMA did not submit baseline test data—that is, EMA submitted data only for maneuvers with ESC or RSC systems enabled.

1. Slowly Increasing Steer Maneuver

For all tractors, test data were provided for the SIS tests used to derive the steering wheel angle with each tractor in the bobtail condition. In the first SIS series conducted on eight of the tractors, three SIS tests were conducted in each direction on a dry road surface, and a best fit linear regression was used to project the steering wheel angle for a lateral acceleration of 0.5g. The average of the absolute value of each of the six runs was calculated for the final angle.

Compared to the steering wheel angles that were derived for the three VRTC tractors, a much wider range in SWA was seen among EMA's results. The steering wheel angles generally increased with the tractor's wheelbase from an angle of 126 degrees for the 140-inch wheelbase 4x2 to an angle of 291 degrees for the 270-inch wheelbase 6x4 with a pusher axle. For Vehicle H, EMA also provided data from direct measurement of the steering wheel angle from driving the tractor at 0.5g of lateral acceleration. This angle was 290 degrees, which is slightly larger than the calculated value of 281 degrees extrapolated from the SIS test data in the 0.05 to 0.30g operating region. The EMA data provided for these SIS tests did not include information on stability control engine torque reduction.

Additional SIS tests were conducted on three tractors that were to be subsequently tested using the SWD maneuver to evaluate tractor yaw stability. The SIS test conditions were identical to the prior SIS tests. A best fit linear regression was used to project the steering wheel angle for a lateral acceleration of 0.5g, and the average of the absolute value of each of the six runs was calculated for the final angle as in the prior SIS tests. Comparing these data to the prior SIS test results, Vehicle B, which had the smallest angle of 126 degrees in the prior SIS tests, showed a ten degree reduction of its angle in this test series. Vehicle G's angle was nearly identical (203 degrees in the first series vs. 205 degrees in the second series).

2. Ramp Steer Maneuver

For the RSM tests on eight tractors, the tractors were attached to a FMVSS No. 121 control trailer and were loaded to their GVWR by placing the ballast over the fifth wheel, with the ballast placed directly on the trailer deck resulting in a low center of gravity height. The weight on the FMVSS No. 121 control trailer's single axle ranged between 5,720 and 5,930 lb for all eight tractor tests, and the trailer brakes were not enabled. While the weight on the trailer axle is nominally 4,500 lb when the trailer is used for FMVSS No. 121 stopping distance tests, the increased weight in these RSM tests reflects the added weight of the outriggers installed on the trailer. In general, each of the tractors was loaded to its GVWR with the steer, drive, and auxiliary axles loaded to, or very close to, their respective GAWRs. The only exception was the 140-inch wheelbase 4x2 which only had 9,950 lb on the steer axle, although it was rated for 12,000 lb.

In the tests, the stability control systems automatically applied the tractor's foundation brakes to reduce speed and lateral acceleration. The initial vehicle deceleration generally coincided with the end of ramp steer input, indicating that the stability control systems were effective at reducing the lateral acceleration. The speed at wheel lift for EMA's tests ranged from 33 to 38 mph, as compared to 31 to 39 mph for the VRTC tests that used a similar unbraked trailer, but with a higher center of gravity loading condition and a higher overall vehicle test weight. Both 4x2 tractors tested by EMA experienced oversteer in addition to the wheel lift.

3. Sine With Dwell Maneuver

EMA provided test results for the SWD maneuver for four tractors equipped with ESC systems. The sinusoidal steering frequency used for testing was 0.5 Hz and the dwell time was one second. The amplitude of the steering wheel inputs started at 30 percent of the steering wheel angle derived from SIS testing, and in subsequent test runs was increased by 10 percent increments up to 130 percent of the steering angle. The SWD tests were conducted with two tractor loading conditions: Loaded to 60 percent of the drive axle(s) GAWR with the FMVSS No. 121 unbraked control trailer attached (loaded tests), and in the unloaded condition with no trailer attached (bobtail tests). The maneuver entrance speed was 45 mph and the test was conducted on dry pavement.

The results of the loaded tests for Vehicles G and I indicated that both tractors remained roll and yaw stable through the full range of testing, and there were no indications of tractor wheel lift in the test comments or the unprocessed data. The largest steering wheel angle produced the highest peak lateral acceleration, which occurred during the dwell portion of the maneuver for both tractors. Vehicle I reached approximately 0.75g and Vehicle G reached just under 0.6g. Although both tractors were close in wheelbase and tested with similar steering wheel angles, Vehicle G, tested with its liftable axle in the lowered position, was either less responsive in the SWD maneuver or its ESC performed slightly better than the ESC on Vehicle I. Both tractors had similar overall vehicle decelerations; however, the ESC on Vehicle G commanded higher steer axle braking pressures than the ESC on Vehicle I. Vehicle I appeared to have more lateral sliding in the maneuver, as its yaw rate decay was slower at the end of steering input.

Vehicle B (140-inch wheelbase 4x2) exhibited yaw instability in the SWD maneuver. This tractor had high lateral acceleration that was attained at lower steering wheel angles than for the 6x4 tractors. For example, the peak tractor lateral acceleration was already reaching 0.70g at 80 percent of the SIS-derived steering wheel angle, compared to Vehicle I which reached 0.60g and Vehicle G which reached 0.45g at this steering wheel angle scalar. The yaw rate decay after completion of steer was also much slower than for the 6x4 tractors, which appears to indicate that the vehicle was sliding much more and taking longer to return to the straight-ahead position. This is most evident in the testing at 130 percent of the SIS-derived steering wheel angle, in which the decay yaw rate decay was about 3.5 seconds.

The maneuver entrance speed was reduced to 30 mph in the bobtail SWD tests, which were conducted on a low-friction wet Jennite surface. The short wheelbase 4x2 tractor, Vehicle B, appeared to complete all of the test series without any observed instability

[27] Data from Vehicles A through I are included have been placed in the docket. Docket Nos. NHTSA–2010–0034–0011 through NHTSA–2010–0034–0021 and Docket No. NHTSA–2010–0034–0024. Vehicle J testing is discussed in detail in a later section.

or control issues, and the peak tractor lateral acceleration was limited to approximately 0.3g in all tests. However, both 6x4 tractors (Vehicles G and I) appeared to have steering responsiveness issues that were particularly noticeable at higher steering wheel angles. At the reversal in steering wheel angle direction, the yaw rate and lateral acceleration response was delayed, indicating severe understeer. During the dwell portion of the maneuver at higher steering wheel angles, Vehicle I slowly built lateral acceleration up to 0.3g, while Vehicle G achieved similar but slightly lower acceleration levels. Vehicle G's yaw rate also was slower to respond at the completion of steer, taking as long as 2.5 seconds to decay to zero for the test conducted at the highest steering wheel angle tested.

4. Ramp With Dwell Maneuver

The three tractors equipped with ESC systems tested in the SWD maneuvers were also tested to the RWD maneuver. Once the initial steering wheel angle and test speed were attained, the steering machine increased the steering wheel angle to 180 degrees in one second, held that steering wheel angle constant for three seconds (the dwell portion of the maneuver), and then reduced the steering wheel angle to zero in one second. In subsequent RWD test runs, the steering wheel angle was increased in 90 degree increments up to 540 degrees.

The test results show that for Vehicles B and I, the steady-state lateral acceleration (prior to the ramp steer) was approximately 0.2g, and for Vehicle G the steady-state tractor lateral acceleration was approximately 0.1g. When the steering wheel angle was increased during the initial steering ramp input, the lateral acceleration and yaw rate increased slightly and in many of the test runs was then observed to drop off, indicating that the tractor was not responsive to the steering input. During the first two seconds of the steering dwell portion of the maneuver, the tractor lateral acceleration typically remained at 0.25g or less for all tests. During the last one second of the steering dwell, all of the test runs for Vehicles G and I showed steadily increasing lateral acceleration, as high as 0.5g, even as the steering wheel angle was reduced to zero. This indicates that the tractors were in a severe oversteer condition, and the agency speculates that the relatively high lateral acceleration may have been a result of the tractor running off of the low friction wet Jennite surface and onto a higher friction road surface. The test data show that this was always accompanied by braking on the steer axle, which is indicative of oversteer corrections being commanded by the ESC. Vehicle B had much less increase in lateral acceleration at the end of the maneuver and appeared to be under control. Late in the maneuver the commanded brake pressures for Vehicle B showed that both front and rear brake applications were made on the right side of the tractor, and the application pressures were nearly identical. Whether this is a data collection anomaly or stability control braking strategy is not certain, but Vehicle B was the vehicle that exhibited the least amount of oversteer.

The RWD test results demonstrated that the stability control systems on these tractors correctly identified the vehicle loss of control problems (severe oversteer and understeer) and took corrective action, including engine output torque intervention and commanding individual applications of the tractor's foundation brakes. However, the severity of the RWD test maneuver was sufficiently high to overdrive the capability of the stability control systems to mitigate severe understeer.

In summary, EMA provided test data for nine tractors each tested for the three maneuvers developed by NHTSA researchers. The nine tractors included a wider variety of tractor configurations than those tested by the agency, and included severe service tractors, tractors with auxiliary lift axles, a tridem drive axle tractor, and a very short wheelbase two-axle tractor. Slowly increasing steer vehicle characterization tests were conducted on all nine tractors (two with RSC and seven with ESC) in the bobtail condition and the test data were used to extrapolate the steering wheel angle that would provide 0.5g of lateral acceleration at 30 mph. These data produced a wider range of steering wheel angles than had been seen from the agency's tests on its three tractors, with the short wheelbase 4x2 having an angle of only 116 degrees, and a 6x4 tractor with a liftable pusher axle having the highest angle at 291 degrees.

EMA provided ramp steer maneuver test results for eight tractors that were loaded to their GVWRs using an unbraked 28-foot control trailer. Data were only provided for tests with the stability control system enabled, and the RSM was conducted up to speeds at which the system could successfully intervene. The range of speeds achieved at the point of overdriving the stability control systems was similar to the range of speeds from the VRTC RSM tests, although the loading conditions were slightly different. The two 4x2 tractors (one with RSC, and one with ESC) tested by EMA experienced oversteer and wheel lift, while the other tractors all experienced wheel lift.

SWD test results were provided for three tractors, each equipped with ESC, using a 0.5 Hz sinusoidal steering input frequency and a 1.0 second dwell time, and the tractors were tested in the bobtail condition and loaded to 60 percent of drive axle(s) GAWR. In the tests on dry pavement at a maneuver entrance speed of 45 mph, the typical 6x4 completed all tests, while the 6x4 equipped with a lift axle (tested in the lowered position) also completed all tests but appeared to be slower to respond to the steering inputs. The short wheelbase 4x2 tractor appeared to exhibit control problems and at the highest steering wheel angle tested. The sine with dwell tests on the three tractors in the bobtail condition were conducted on a low-friction wet Jennite test surface with a lower maneuver entrance speed of 30 mph. In these tests, the short wheelbase 4x2 tractor completed all tests, while the two 6x4 tractors appeared to experience severe understeer at the higher steering wheel angles tested.

5. Vehicle J Testing

(a) EMA Testing of Vehicle J

In December 2010, EMA provided testing data on a tenth vehicle they tested.[28] Vehicle J was intended to be representative of a typical 6x4 tractor, with a 245 inch wheelbase and a GVWR of 52,350 pounds. EMA subjected Vehicle J to four different test maneuvers: The slowly increasing steer test; the sine with dwell test; a J-turn maneuver, and a wet Jennite drive through test.

EMA first conducted the slowly increasing steer test maneuver with a steering controller on Vehicle J to determine the steering wheel angle that would produce a lateral acceleration of 0.5g. EMA conducted two series of test runs, one in each direction. A best fit linear regression was used to determine that the average steering angle on the six runs that would produce a lateral acceleration of 0.5g was 197 degrees. This value was used for subsequent testing.

EMA next conducted sine with dwell testing. EMA conducted two series of SWD tests—one with the ESC system on and one with the ESC system off. EMA equipped the vehicle with an FMVSS No. 121 control trailer and loaded the

[28] Vehicle J data provided to the agency has been placed in Docket No. NHTSA–2010–0034–0022 and Docket No. NHTSA–2010–0034–0023.

vehicle so that the drive axles were loaded to 60 percent of the GAWR, which resulted in the vehicle being loaded to approximately 78.6 percent of its GVWR.

EMA provided data on six runs of the SWD maneuver. EMA conducted the test at scalars from 0.8 to 1.3 of the SIS-derived steering wheel angle. EMA also provided data on three runs of the SWD maneuver with the system deactivated. Those tests were conducted at scalars of 1.0 and 1.3, and 1.5.

Each test run with the system enabled showed a 20- to 25-mph reduction of speed during the test maneuver. In contrast, tests conducted with the system off indicated only limited speed reduction of less than five mph. This indicated that the ESC system acted to reduce vehicle speed.

Each test run with the system enabled conducted at scalars between 0.8 and 1.2 resulted in a peak lateral acceleration between 0.6g and 0.7g. The lateral acceleration then quickly dropped to zero within 0.3 to 0.4 seconds after the completion of the steer. Yaw rate during the dwell portion of the maneuver peaked at approximately 18 to 22 degrees per second, except at a scalar of 1.2 where yaw rate peaked at approximately 24 degrees per second) and showed a downward trend during the dwell, dropping by approximately five degrees per second. The yaw rate dropped to zero within 0.2 seconds after completion of steer. The vehicle's ESC system used selective braking to reduce the speed, lateral acceleration, and yaw rate responses.

With the system disabled, the test run at a scalar of 1.0 resulted in a peak lateral acceleration of approximately 0.8g. A 0.2g drop in lateral acceleration was observed at the beginning of the dwell portion of the maneuver followed by a sudden rise of the same amount, indicating possible oversteer. The lateral acceleration dropped to zero less quickly than in tests with the system on (approximately 0.5 seconds) after completion of steer. This was largely due to the drop in lateral acceleration starting later with the system off than with the system on. The yaw rate peaked at approximately 21 degrees per second. Unlike with the system on, there was not a clear drop in yaw rate during the dwell portion of the maneuver. The yaw rate also dropped to zero slower than in tests with the system off (approximately 0.25 seconds after completion of steer).

For test runs at steering wheel angle scalars of 1.3, the peak lateral acceleration was slightly lower with the system on (approximately 0.75g) in comparison to the test run with the system off (over 0.8g). Momentary variability in lateral acceleration was observed in both tests, indicating possible tractor instability. Again, with the system on, the lateral acceleration decayed faster at the completion of steer (approximately 0.4 seconds) than it did with the system off (over 0.6 seconds). This was largely due to the reduction in lateral acceleration starting later with the system off than with the system on. The yaw rate peaked for both tests at approximately 25 degrees per second. Again, however, the yaw rate decreased by approximately five degrees during the dwell portion of the maneuver with the system on while no clear decay was observed with the system off. Also, the yaw rate decreased to zero slower after completion of steer with the system off (0.25 seconds) than it did with the system on (less than 0.2 seconds).

EMA also submitted data on one SWD test run with the system off at a steering wheel angle scalar of 1.5. Peak lateral acceleration observed during this test run was nearly 0.9g. The lateral acceleration rate dropped to zero in slightly over 0.5 seconds after completion of steer. The yaw rate peaked at approximately 24 degrees per second. Unlike in runs with lower steering wheel angles, a reduction in yaw rate was observable during the dwell portion. However, that reduction was much sharper, occurring entirely within a 0.5 second period rather than throughout the entire 1.0 second dwell period. Like in prior tests, the yaw rate dropped to zero within approximately 0.25 seconds.

EMA's SWD maneuver test data from Vehicle J demonstrated that the ESC system activated to lower lateral acceleration and yaw rate during the SWD maneuver. However, even with the ESC system turned off, the lateral acceleration and yaw rates dropped relatively quickly at the end of the test maneuver, indicating that the vehicle did not become unstable during testing. Although EMA only provided test data from three runs with the system off compared to six runs with the system enabled, the runs with the system off did include a run with a steering wheel angle scalar of 1.5, which was higher than any run in NHTSA's testing, and no severe incidents of instability were observed.

EMA next conducted J-turn testing both with the system enabled and disabled. The test was conducted on a 150-foot fixed radius curve. The vehicle was tested with an FMVSS No. 121 control trailer and was loaded to the FMVSS No. 121 loading conditions. The tests were conducted at initial entry speeds of 30 to 36 mph, in increments of two mph.

In tests conducted with the ESC system enabled, system activation occurred at each test speed. The system commanded brake activations to reduce vehicle speed to 18 mph from initial speeds of 30 mph and 32 mph, down to 10 mph from an initial speed of 34 mph, and down to 6 mph at an initial speed of 36 mph. The vehicle was able to maintain the lane at all speeds tested. Lateral acceleration peaked at 0.4 to 0.5g at 30 and 32 mph and peaked at 0.6g at 34 mph and 36 mph. Yaw rate peaked at approximately 15 degrees per second at 30 and 32 mph and peaked at approximately 20 degrees per second at 34 mph and 36 mph. At the higher speeds tested, lateral acceleration and yaw rate were observed to drop coincident with speed.

With the system disabled, no reduction in speed during the maneuver was observed. Thus, lateral acceleration and yaw rates remained relatively constant throughout the maneuver. At test speeds of 30 and 32 mph, lateral acceleration peaked at approximately 0.55 to 0.65g and yaw rate peaked at approximately 20 degrees per second. At 34 mph, the lateral acceleration peaked at approximately 0.9g and the steering wheel angle necessary to maintain the lane decreased substantially. Yaw rate peaked at approximately 22 degrees per second and dropped to approximately 15 degrees per second, indicating the vehicle was starting to plow out. At 36 mph, the vehicle plowed out of the lane.

The fourth maneuver EMA performed on Vehicle J was a wet Jennite drive-through (WJDT) maneuver. This maneuver was intended to test yaw stability. The WJDT maneuver is identical to method for determining the maximum drive-through speed when testing vehicles for compliance with S5.3.6.1 of FMVSS No. 121. The vehicle is driven through a 500-foot radius curve with a wet surface having a peak coefficient of friction of approximately 0.5 at successively increasing speeds (up to 40 mph) to determine the maximum speed at which the vehicle can maintain the curve.[29]

EMA performed this test with both the stability control system enabled and disabled in two load configurations. First, the vehicle was tested in the bobtail (unloaded) configuration.

[29] To conduct the FMVSS No. 121 stability and control during braking compliance test, the vehicle is driven at the lesser of 30 mph or 75 percent of the maximum drive-through speed. A full brake application is made and a vehicle must stop at least three times out of four within the 12-foot lane.

Second, the vehicle was loaded to the FMVSS No. 121 test loading condition.

In the bobtail configuration with the ESC system enabled, test runs at 30 and 32 mph yielded no system activation. At 33 mph, system activation occurred as both engine torque reduction and selective braking to improve yaw stability occurred. As a result, the vehicle speed decreased to approximately 29 mph during the maneuver and the driver responded by rapidly straightening the steering wheel. Vehicle yaw rate peaked at approximately 10 degrees per second. A second run at 33 mph showed only brief system activation and a minimal reduction in speed. During two runs at 34 mph, ESC system intervention was again observed as torque reduction and selective braking reduced vehicle speed to 28 to 29 mph and the driver again responded by rapidly straightening the steering wheel. Yaw rate peaked at near 10 degrees per second and again, as the driver responded, decreased. During two runs at 35 mph, the vehicle was unable to maintain the lane due to understeer, despite system intervention.

In the bobtail configuration with the system disabled, at 32 mph, the driver had to adjust steering by adding steering input during both runs attempted at this speed, indicating substantial understeer. During two runs at 33 mph, the vehicle was unable to maintain the lane, despite large steering inputs from the driver.

In the loaded configuration with the ESC system enabled, system activation occurred at a speed of 30 mph, though only slight (1 to 2 mph) reduction in speed was observed. The driver had to increase his steering input, but there was no corresponding increase in yaw rate, indicating understeer. At 32 mph, both engine torque reduction and selective braking occurred to improve yaw stability occurred. As a result, the vehicle speed decreased to approximately 27 to 28 mph during the maneuver. At 34 mph, the ESC system intervened more substantially, resulting in a reduction of speed to approximately 26 mph. Nevertheless, the vehicle was able to maintain the lane. At 35 mph, the vehicle was unable to maintain the lane due to understeer, despite system intervention.

In the loaded configuration with the system disabled, understeer was observed at 32 mph, as evident by substantial increase in steering input by the driver; however, the vehicle was able to maintain the lane. At 33 mph, the vehicle was unable to maintain the lane.

The maximum drive through speed in both vehicle configurations was only 32 mph with the system off, compared to 34 mph with the system on. This demonstrates that an ESC system has some ability to mitigate understeer when navigating a curve on a low-friction surface, and allow the driver to maintain control at higher curve entrance speeds.

(b) NHTSA Testing of EMA's Vehicle J

At NHTSA's request, EMA provided Vehicle J to NHTSA for NHTSA to duplicate EMA's testing.[30] In particular, the agency was interested in the performance of Vehicle J during the sine with dwell maneuver. NHTSA's two 6x4 tractors that were tested in with the SWD represented the upper and lower size bounds of what would be considered a typical 6x4 tractor and both tractors could not maintain stability during a SWD maneuver with the ESC system disabled. Vehicle J's size is within the bounds of the two typical 6x4 tractors tested by NHTSA.

NHTSA conducted 20 test runs of Vehicle J in the SWD maneuver at steering wheel angle scalars of 0.4 to 1.3 of the SIS-derived steering wheel angle attached to VRTC's FMVSS No. 121-style control trailer. When tested with the ESC system disabled at a steering wheel angle scalar of 1.2, NHTSA was able to detect lateral instability that continued for almost two seconds after completion of the SWD maneuver.[31]

It was discovered that EMA conducted its testing of Vehicle J with a control trailer with different specifications than NHTSA used. NHTSA then attempted to duplicate EMA's Vehicle J's testing using the control trailer used by EMA.[32] The results of NHTSA's tests with EMA's control trailer were not meaningfully different than the results of EMA's testing. That is, there were no instances of substantial roll or yaw instability in 20 test runs conducted by NHTSA.

As a result of NHTSA's testing of Vehicle J, the agency discovered that there exist three areas of variability in FMVSS No. 121-style control trailers and loading which, while not necessarily relevant to FMVSS No. 121 testing, could affect the results of stability control system testing if the specifications for an FMVSS No. 121-style control trailer were simply carried over to a stability control standard. First, EMA's control trailer had a wider track width[33] than NHTSA's trailer, which made EMA's trailer, and thereby the combination vehicle, more stable during SWD testing. Second, EMA's control trailer had a lower deck height than NHTSA's trailer, which contributed to a lower center of gravity on EMA's trailer. Third, EMA loaded its trailer with steel for ballast, whereas NHTSA loaded its trailer with concrete for ballast, which also contributed to the lower center of gravity on EMA's trailer because steel would not have to be stacked as high to achieve a full load.

E. Other Industry Research

The SAE Truck and Bus Control Systems Task Force (renamed as the Truck and Bus Stability Control Committee) was formed in 2007 to facilitate information sharing among the industry and government regarding heavy vehicle stability control systems.[34] The information shared included proposed test maneuvers that could potentially be used to evaluate the performance of stability control systems. Although the Task Force has not published any formal documents describing these test maneuvers, the following provides an overview of the maneuvers that have been discussed.

1. Decreasing Radius Test

A decreasing radius test (DRT) was developed to evaluate the roll stability performance of a heavy vehicle stability control system.[35] With the DRT, the test conditions could also be adjusted to evaluate yaw stability as well. In the DRT, the vehicle is accelerated to a constant speed of 29 mph on a dry road surface, and an initial steering input is made to follow a curve with a 150-foot radius. Once the initial curve radius is achieved, the radius is linearly reduced to a radius of 90 feet as the vehicle negotiates 120 degrees of arc. Thus, it is similar to the J-turn maneuver. The speed of 29 mph was derived based on a vehicle dynamics simulation, which estimated that the maneuver would produce 0.3g of lateral acceleration during the initial steering input and this would steadily increase to 0.6g at the 90-foot radius curve.

Tests would be conducted in a loaded condition with the tractor coupled to a trailer and an unloaded condition in a

[30] A copy of NHTSA's Vehicle J test data has been placed in the docket. Docket No. NHTSA–2010–0034–0044.

[31] NHTSA was able to conduct 19 test maneuvers with Vehicle J that did not result in substantial roll instability. NHTSA did not find any yaw instability in any of the 20 test maneuvers.

[32] NHTSA's test data identifies the trailer used by EMA as a ''Link'' trailer and the trailer used by NHTSA as the ''NHTSA'' or ''VRTC'' trailer.

[33] The track width is the distance between the centerlines of a vehicle's left and right tires. In vehicles with dual tires, the track width would be measured from between the dual tires on each side of the vehicle.

[34] See *http://www.sae.org/events/cve/presentations/2007truckbus.pdf* for an overview of the SAE Truck and Bus Council organizational chart.

[35] See Docket No. NHTSA–2010–0034–0036.

bobtail configuration. Because actual vehicle testing had not been conducted using this maneuver, pass/fail criteria have not yet been developed. Simulations of this test have been run using driver-controlled steering inputs; however, parameters could also be developed to conduct this maneuver using an automated steering controller.

2. Lane Change on a Large Diameter Circle

Volvo provided information on the Lane Change on a Large Diameter Circle (LC–LDC) maneuver that they have used to evaluate stability control system performance.[36] In this maneuver the vehicle is driven at a constant speed, just below the threshold speed for rollover or loss of control, around the inside lane of an 800-foot radius curve that has two lanes. The driver then drifts to the outside lane, and steers back into the inside lane. For rollover testing the asphalt road surface is dry and for yaw testing the surface is wet. The test can be conducted using a bobtail tractor, a tractor towing an FMVSS No. 121 control trailer, or a tractor towing any other type of trailer in a fully loaded condition. Volvo evaluated the roll stability performance during this maneuver based on whether the trailer outrigger made contact with the ground. Volvo considers this maneuver to be representative of certain highway segments that are encountered, and that the maneuver is severe enough to fully challenge a stability control system.

3. Yaw Control Tests

Bendix developed two yaw stability test maneuvers to evaluate the ability of stability control systems to prevent severe oversteer and understeer conditions. The first test maneuver is a Sinusoidal Steering Maneuver (SSM) to evaluate oversteer prevention.[37] The first step in this test is to identify the steering wheel angle that produces a tractor lateral acceleration of 0.5g at 30 mph on dry pavement with the tractor in the bobtail condition. Bendix recommended that this angle be derived by either a slowly increasing steer test (SIS test described in section IV.D.2 above) or an equation developed by Bendix for estimating the angle based on the tractor's wheelbase:

Steering Wheel Angle (δ) = (35.5 × (tractor wheelbase in meters)) + 30.94

The Sinusoidal Steering Maneuver test is then conducted with the tractor in the bobtail condition using a low-friction wet Jennite road surface (nominal peak friction coefficient of 0.5). The vehicle is driven at a constant speed of approximately 30 mph and, as a sinusoidal steering input is initiated (continuous left and right steering inputs using the steering wheel angle determined above), the driver increases the throttle position to request 100 percent of engine torque.

The second test maneuver developed by Bendix was the ramp with a dwell maneuver discussed in section IV.D.4 above.[38] The RWD maneuver is intended to evaluate understeer prevention, though oversteer can also occur during the maneuver. The RWD test is conducted with the tractor in the bobtail condition and using a wet Jennite road surface. The first step in this test is to characterize the vehicle's steering by conducting a series of drive-through speed evaluations at a constant speed on a 500-foot radius curve. Once the maximum constant travel speed is determined (typically between 28 and 32 mph, but not to exceed 35 mph), the steering wheel angle is measured for negotiating the curve at that speed. The RWD test maneuver speed is then conducted at the maximum drive-through speed. Bendix suggested that manual steering by a test driver or an automated steering machine could be used. Once the vehicle has been accelerated to the test maneuver speed, the speed is held constant by the driver and he inputs the drive-through steering wheel angle. After the vehicle reaches a constant lateral acceleration condition, the steering wheel angle is increased to 180 degrees in a period of one second. That increased angle is held constant for three seconds, and then the angle is reduced to zero in a period of one second. Subsequent test runs are conducted by increasing the steering wheel angle in increments of 90 degrees up to 540 degrees.

The RWD test performance measures would be based upon test data showing that the vehicle's stability control system successfully identified a vehicle control problem (understeer or oversteer) and intervened by reducing the engine torque output and commanding the application of individual foundation brakes in a manner that is suitable to mitigate the control problem. Bendix did not believe that vehicle yaw or path-following pass/fail criteria would be appropriate for this test maneuver.

Two maneuvers that the industry has developed to evaluate the performance of stability control systems, lane change on a large diameter circle and sinusoidal steering, can be used to demonstrate that a stability control system is capable of preventing a rollover or a yaw instability condition. The RWD maneuver may exceed the capabilities of stability control systems but provides brake application data that can be reviewed to determine if a stability control system provides the correct control responses to address a severe oversteer or understeer condition.

V. Agency Proposal

Based upon the foregoing research, the agency is proposing a new FMVSS to require ESC systems be installed on truck tractors and buses with a GVWR of greater than 11,793 kilograms (26,000 pounds).[39] There are several issues raised by this proposed rule on which the agency seeks public comment, each of which is discussed in detail in the following sections.

A. NHTSA's Statutory Authority

NHTSA is proposing today's NPRM under the National Traffic and Motor Vehicle Safety Act (''Motor Vehicle Safety Act''). Under 49 U.S.C. Chapter 301, Motor Vehicle Safety (49 U.S.C. 30101 et seq.), the Secretary of Transportation is responsible for prescribing motor vehicle safety standards that are practicable, meet the need for motor vehicle safety, and are stated in objective terms. ''Motor vehicle safety'' is defined in the Motor Vehicle Safety Act as ''the performance of a motor vehicle or motor vehicle equipment in a way that protects the public against unreasonable risk of accidents occurring because of the design, construction, or performance of a motor vehicle, and against unreasonable risk of death or injury in an accident, and includes nonoperational safety of a motor vehicle.'' ''Motor vehicle safety standard'' means a minimum performance standard for motor vehicles or motor vehicle equipment. When prescribing such standards, the Secretary must consider all relevant, available motor vehicle safety information. The Secretary must also consider whether a proposed standard is reasonable, practicable, and appropriate for the types of motor vehicles or motor vehicle equipment for which it is prescribed and the extent to which the standard will further the statutory purpose of reducing traffic accidents and associated deaths. The

[36] See Docket No. NHTSA–2010–0034–0042.

[37] See Docket No. NHTSA–2010–0034–0037.

[38] See Docket No. NHTSA–2010–0034–0038.

[39] To distinguish this new FMVSS from the light vehicle ESC requirement in FMVSS No. 126, we are proposing to revise the title FMVSS No. 126 to reflect that it is applicable only to light vehicles.

responsibility for promulgation of Federal motor vehicle safety standards is delegated to NHTSA. In making the proposals in today's NPRM, the agency carefully considered all the aforementioned statutory requirements.

B. Applicability

1. Vehicle types

Vehicles with a GVWR greater than 10,000 pounds include a large variety of vehicles ranging from medium duty pickup trucks to different types of single unit trucks, buses, trailers and truck tractors. Vehicles with a GVWR of greater than 10,000 pounds are divided into Classes 3 through 8. Class 7 vehicles are those with a GVWR greater than 11,793 kilograms (26,000 pounds) and up to 14,969 kilograms (33,000 pounds), and Class 8 vehicles are those with a GVWR greater than 14,969 kilograms (33,000 pounds).

The vast majority of vehicles with a GVWR of greater than 4,536 kilograms (10,000 pounds) for which stability control systems are currently available are truck tractors. Approximately 150,000 truck tractors with a GVWR of greater than 11,793 kilograms (26,000 pounds) are manufactured each year. In 2009, about 20 percent of Class 7 and 8 truck tractors were equipped with a stability control system.

About 85 percent of truck tractors sold annually in the U.S. are air-braked three-axle (6x4) tractors with a front axle that has a GAWR of 14,600 pounds or less and with two rear drive axles that have a combined GAWR of 45,000 pounds or less, which we will refer to as ''typical 6x4 tractors.'' Two-axle (4x2) tractors and severe service tractors (those with three axles that are not ''typical 6x4 tractors'' or those with four or more axles) represent about 15 percent of the truck-tractor market in the U.S.

The majority of the research on the effectiveness of stability control systems to date has been performed on typical 6x4 tractors. As a result, the agency's research included two typical 6x4 tractors. The agency also included one 4x2 tractor in its testing because two-axle tractors represent the next largest segment of the truck-tractor market. No severe service tractors were tested. EMA performed tests on nine tractors equipped with stability control systems. The tractors included two 4x2 tractors, two typical 6x4 tractors, two severe service 6x4 tractors, two 6x4 tractors with a liftable auxiliary axle in front of the drive axles, and one 8x6 tractor.

This proposal would also require certain buses to be equipped with an ESC system. We intend the applicability of this proposed requirement to be similar to the applicability of the agency's proposal that certain buses be equipped with seat belts.[40] That proposal was applicable to buses with a gross vehicle weight rating (GVWR) of 11,793 kilograms (26,000 pounds) or greater, 16 or more designated seating positions (including the driver), and at least 2 rows of passenger seats that are rearward of the driver's seating position and are forward-facing or can convert to forward-facing without the use of tools.'' That proposal excluded school buses and urban transit buses sold for operation in urban transportation along a fixed route with frequent stops. The agency is proposing a very similar applicability in this NPRM. We have not made this proposal applicable to buses with a GVWR of exactly 11,793 kilograms (26,000 pounds) in order to exclude Class 6 vehicles from this proposal. We believe that this proposal encompasses the category of ''cross-country intercity buses'' represented in the FARS and FMCSA data (identified in section II.A above) that had a higher involvement of crashes that ESC systems are capable of preventing.

The agency tested three buses, all of which had a GVWR over 14,969 kg (33,000 pounds). There are seven manufacturers or distributors of Class 8 buses covered by this proposal for the U.S. market: Prevost, MCI, VanHool, Daimler/Setra, CAIO, BlueBird, and BCI. Three of them (Prevost, MCI, and VanHool), have stated that an ESC system is a standard feature on their buses sold in the U.S. Daimler/Setra indicated that an ESC system will be available as an option on its buses beginning in model year 2011 and that no decision has been made to make it a standard feature. No official information is available from CAIO, Bluebird, and BCI regarding ESC system availability.

There are also at least nine manufacturers of Class 7 buses covered by this proposal for the U.S. market: Champion, ElDorado National, Federal Coach, Glaval, IC Bus, MCI, Rexhall, Stallion, and VanHool. Many Class 7 buses are built on chassis similar to those of single unit trucks for which ESC has not been widely developed, and we are not aware of any Class 7 bus that is equipped or currently available with ESC. Class 7 buses represent less than 20 percent of the market. Although the agency is not aware of any Class 7 bus currently available with ESC, we are aware that stability control systems are available on a limited number of Class 8 single unit trucks, such as ready mix concrete trucks, refuse trucks, and other air-braked trucks, and that the same technology could be developed for use on Class 7 buses, which we believe are also air-braked vehicles.

Although this proposal would not apply to all buses with a GVWR of greater than 11,793 kilograms (26,000 pounds), we seek comment on whether this proposal should be applied to the types of buses that are excluded from the proposed rule such as school buses and transit buses. We also seek comment on the feasibility of including the Class 7 buses described in the prior paragraph that are built on chassis similar to those of single unit trucks within two years. In particular, we believe that ESC systems are readily available for air-braked buses; however, system availability for any hydraulically braked buses that may be covered by this proposed rule may be more limited. If hydraulically braked buses are covered by this proposal, we request comment on manners in which hydraulically braked buses may be differentiated for exclusion or a different phase-in period.

The agency is not proposing to include single unit trucks with a GVWR over 4,536 kg (10,000 pounds) at this time. There are substantial differences in the complexity of the single unit truck population compared to the truck-tractor population. The single unit truck population has wide variations in vehicle weight, wheelbase, number of axles, center of gravity height, and cargo type, among other things that affect the calibration and performance of stability control systems. While some variation exists in the truck tractor market, the degree of complexity and diversity is substantially less.

Further, the single unit truck market is structurally different than the truck tractor market in that the chassis supplier, who is generally responsible for the brake systems and therefore would likely provide stability control systems, is often different than the final body builder. Hence, the chassis supplier may not have knowledge of critical vehicle design parameters that would affect stability control system calibration. In contrast, manufacturers of truck tractors have more complete control of the final, delivered vehicle.

The complexity of the single unit truck population and the limited crash data available present a significant challenge to determining the effectiveness of stability control on these vehicles. We believe that approximately 1 percent of newly manufactured single-unit trucks are equipped with stability control systems, and that few, if any, of those are for

[40] 75 FR 50,958 (Aug. 18, 2010).

vehicles with hydraulic brakes. The development of stability control system for vehicles over 10,000 pounds GVWR has been focused on air-braked vehicles, which include the truck tractors and buses addressed in this proposal. Because we are concerned about the availability of production-ready systems on these vehicles, they are not included in the proposal. However, we seek comment on these observations.

The agency has initiated a safety benefit study to determine the safety need for stability control on single-unit trucks, and has also initiated vehicle research, similar to the research conducted on truck tractors and large buses described in part IV.C above, which is expected to be completed in 2012. However, the agency proposes to require stability control systems on truck tractors without waiting for the study on the effectiveness of stability control systems on single-unit trucks to be completed. Waiting for that study to be completed would unnecessarily delay the benefits of having stability control systems on truck tractors and large buses, for which testing has been completed the benefits of stability control systems identified.

The agency is not proposing to include a requirement for stability control systems on trailers, primarily because trailer-based RSC systems were judged by the agency research to be much less effective than tractor-based RSC or ESC systems in preventing rollover. Trailer-based RSC systems are capable of applying braking only on the trailer's brakes. Tractor-based systems can command more braking authority by using both the tractor and trailer brakes. As a result, trailer-based RSC systems do not appear to provide additional safety benefits when used in combination with tractor-based RSC or ESC systems. The trailer-based RSC systems provide some improvement in roll stability compared to a base trailer without an RSC system, but a vehicle could still be overdriven at a lower speed with trailer-based RSC systems than with a tractor-based system. This means that the maneuver entrance speed beyond which the stability control system is unable to reduce the vehicle speed to prevent a rollover was lower for the trailer-based system than for the tractor-based system. In addition, the typical service life of a trailer is 20 to 25 years compared with about 8 to 10 years for a truck tractor. Because new tractors are added to the U.S. fleet at a faster rate than new trailers, the safety benefits from stability control systems would be achieved at a faster rate by requiring stability control systems to be installed on a tractor.

Therefore, the agency proposes to require stability control systems on truck tractors and buses with a GVWR of greater than 11,793 kilograms (26,000 pounds).

2. Retrofitting In-Service Truck Tractors, Trailers, and Buses

NHTSA has considered proposing to require retrofitting of in-service truck tractors, trailers, and large buses with stability control systems proposed to be required by this NPRM. The Secretary has the statutory authority to promulgate safety standards for ''commercial motor vehicles and equipment subsequent to initial manufacture.'' [41] The Secretary has delegated authority to NHTSA to ''promulgate safety standards for commercial motor vehicles and equipment subsequent to initial manufacture when the standards are based upon and similar to [an FMVSS] promulgated, either simultaneously or previously, under chapter 301 of title 49, U.S.C.'' [42] Additionally, the Federal Motor Carrier Safety Administration (FMCSA) is authorized to promulgate and enforce vehicle safety regulations, including those aimed at maintaining commercial motor vehicles so they continue to comply with the safety standards applicable to commercial motor vehicles at the time they were manufactured. Although this NPRM does not propose requiring truck tractors, trailers, or large buses to be equipped with stability control systems ''subsequent to initial manufacture,'' we are requesting public comment on several issues related to retrofitting in-service truck tractors, trailers, and buses:

- The extent to which a proposal to retrofit in-service vehicles with stability control systems would be complex and costly because of the integration between a stability control system and the vehicle's chassis, engine, and braking systems.
- The changes necessary to an originally manufactured vehicle's systems that interface with a stability control system, such as plumbing for new air brake valves and lines and a new electronic control unit for a revised antilock brake system.
- The additional requirements that would have to be established to ensure that stability control components are at an acceptable level of performance for a compliance test, given the uniqueness of the maintenance condition for vehicles in service, particularly for items such as tires and brake components that are important for ESC performance.
- The original manufacture date of vehicles that should be subject to any retrofitting requirements.
- Whether the performance requirements for retrofitted vehicles should be less stringent or equally stringent as for new vehicles, and, if less stringent, the appropriate level of stringency.
- The cost of retrofitting a stability control system on a vehicle, which we believe would exceed the cost of including stability control on a new vehicle.

In light of these questions, the agency is not proposing that in-service vehicles be required to be retrofitted with stability control systems. Instead, this proposed requirement would be applicable only to newly manufactured vehicles. However, the comments we receive on the issue of retrofitting will help us determine whether we should issue a separate supplemental NPRM to require a retrofit.

3. Exclusions From Stability Control Requirement

Our proposed rule excludes certain types of low-volume, highly specialized vehicle types. In these cases, the vehicle's speed capability does not allow it to operate at speeds where roll or yaw instability is likely to occur.

Specifically, FMVSS No. 121, *Air brake systems,* excludes certain heavy air-braked heavy vehicles from that standard. For truck tractors and buses, these exclusions include:

- Any vehicle equipped with an axle that has a gross axle weight rating of 29,000 pounds or more.
- Any truck or bus that has a speed attainable in two miles of not more than 33 mph.
- Any truck that has a speed attainable in two miles of not more than 45 mph, an unloaded vehicle weight that is not less than 95 percent of its GVWR, and no capacity to carry occupants other than the driver and operating crew.

We believe that the vehicles that are excluded from the requirements of FMVSS No. 121 should also be excluded from the proposed stability control requirements because the speed at which these vehicles operate would make it unlikely that roll or yaw instability would occur. Accordingly, the proposed stability control requirement excludes these vehicles.

C. ESC System Capabilities

1. Choosing ESC vs. RSC

We are proposing to require that truck tractors and large buses be equipped

[41] See Motor Carrier Safety Improvement Act of 1999, sec. 101(f), Pub. L. 106–159 (Dec. 9, 1999).

[42] See 49 CFR 1.50(n).

with ESC systems rather than RSC systems. An ESC system is capable of all of the functions of an RSC system. In addition, an ESC system has the additional ability to detect yaw instability, provide braking at front wheels, and detect the steering wheel angle. These additions, as demonstrated by NHTSA's testing, allow an ESC system to have better rollover prevention performance than an RSC system in addition to the yaw instability prevention component. This is because the steering wheel angle sensor allows the ESC system to anticipate changes in lateral acceleration based upon driver input and to intervene with engine torque reduction or selective braking sooner, rather than waiting for the lateral acceleration sensors to detect potential instability.

As discussed in greater length in Section VI, mandating ESC systems rather than RSC systems will prevent more crashes, injuries, and fatalities. The additional benefits from ESC systems can be attributed to both the ESC's system's ability to intervene sooner and its ability to prevent yaw instability that would lead to loss-of-control crashes.

Mandating ESC systems rather than RSC systems will result in higher costs to manufacturers. Moreover, our benefit and cost estimates lead to the preliminary conclusion that mandating RSC systems would be more cost-effective than mandating ESC systems. However, these extra costs are more than offset by higher net benefits that would accrue by mandating ESC systems rather than RSC systems.

2. Definition of ESC

Definitional requirements in an FMVSS define and describe the type of system that can be used to meet the performance requirements of a particular FMVSS. However, the inclusion of a definitional requirement in an FMVSS may be design restrictive because it would be based on currently available technology. Limiting the equipment that can be used to satisfy an FMVSS may limit future technological advancements and innovation. As stability control technologies are developed even further, a definitional requirement could be a hindrance to safety improvements if it limits the use of a newly developed equipment or technology that is not addressed by the specified definitional requirement. On the other hand, relying solely on performance-based tests without mandating any specific equipment may require a battery of tests to cover the complete operating range of the vehicle. Given the wide array of possible configurations and operating ranges for heavy vehicles, the agency does not believe it is practical to develop performance tests that would address the full range of possibilities and remain cost-effective. Accordingly, the agency is proposing to include a definitional requirement in this proposed rule that includes equipment that would be required as part of a compliant ESC system. We note that, when developing the ESC requirement for light vehicles, the agency chose to include such a requirement in FMVSS No. 126.

SAE International has a Recommended Practice on *Brake Systems Definitions—Truck and Bus,* J2627 (Aug. 2009), which includes a definition of Electronic Stability Control and Roll Stability Control. SAE International's definition of an ESC system requires that a system have an electronic control unit that considers wheel speed, yaw rate, lateral acceleration, and steering angle and that the system must intervene and control engine torque and auxiliary brake systems to correct the vehicle's path.

The UN ECE Regulation 13 definition for the electronic stability control system, promulgated in Annex 21, includes the following functional attributes for directional control: sensing yaw rate, lateral acceleration, wheel speeds, braking input and steering input; and the ability to control engine power output. For vehicles with rollover control, the functions required by the stability control include: sensing lateral acceleration and wheel speeds; and the ability to control engine power output.

In developing a definition for ESC, the agency has reviewed the functional attributes contained in the SAE and the ECE definitions, and has incorporated portions of both of these definitions in this NPRM. We have developed a definition that is similar in wording to the definition from FMVSS No. 126, which specifies certain features that must be present, that ESC be capable of applying all the brakes individually on the vehicle, and that it have a computer using a closed-loop algorithm to limit vehicle oversteer and understeer when appropriate. Unlike the light vehicle standard, which focuses on yaw stability, this NRPM proposes to require a stability control system that also helps to mitigate roll instability conditions. As a result, we have expanded the definition from the one in FMVSS No. 126 to include a requirement that the system be capable of sensing impending rollover and reducing the vehicle's lateral acceleration to prevent rollover.

Furthermore, we believe that the ESC system must be operational during all phases of driving, including acceleration, coasting, deceleration, and braking, except when the vehicle is below a low-speed threshold where loss of control or rollover is unlikely. According to information the agency has obtained from vehicle manufacturers and ESC suppliers, this low speed threshold for a stability control system is 10 km/h (6.2 mph) for yaw stability control and 20 km/h (12.4 mph) for roll stability control. For the purposes of a proposed regulation, we believe that setting a single low speed threshold would be preferable since the yaw and roll stability functions during a test maneuver are closely intertwined, which could make it difficult to differentiate when the roll or yaw function ends. Therefore, we propose a single threshold of 20 km/h (12.4 mph) as the speed below which ESC is not required to be operational.

Therefore, the agency proposes to require the installation of an ESC system on truck tractors and large buses, which has all of the following attributes:

1. Augments vehicle directional stability by applying and adjusting vehicle brake torques individually at each wheel position on at least one front and at least one rear axle of the vehicle to induce correcting yaw moment to limit vehicle oversteer and to limit vehicle understeer;
2. Enhances rollover stability by applying and adjusting the vehicle brake torques individually at each wheel position on at least one front and at least one rear axle of the vehicle to reduce lateral acceleration of a vehicle;
3. Computer-controlled with the computer using a closed-loop algorithm to induce correcting yaw moment and enhance rollover stability;
4. Has a means to determine the vehicle's lateral acceleration;
5. Has a means to determine the vehicle's yaw rate and to estimate its side slip or side slip derivative with respect to time;
6. Has a means to estimate vehicle mass or, if applicable, combination vehicle mass;
7. Has a means to monitor driver steering input;
8. Has a means to modify engine torque, as necessary, to assist the driver in maintaining control of the vehicle; and
9. When installed on a truck tractor, has the means to provide brake pressure to automatically apply and modulate the brake torques of a towed semi-trailer.

The benefit of an ESC system is that it will reduce vehicle rollovers and loss of control under a wide variety of vehicle operational and environmental conditions. However, the performance tests proposed in this NPRM would only evaluate ESC system performance under very specific environmental conditions. To ensure that a vehicle is equipped with an ESC system that meets the proposed definition, we are proposing that vehicle manufacturers make available to the agency documentation that would enable us to ascertain that the system includes the components and performs the functions of an ESC system.

We are proposing that the vehicle manufacturer provide a system diagram that identifies all ESC system hardware; a written explanation, with logic diagrams included, describing the ESC system's basic operational characteristics; and a discussion of the pertinent inputs to the computer and how its algorithm uses that information to prevent rollover and limit oversteer and understeer. Because the proposed definition for ESC systems on truck tractors includes the capability to provide brake pressure to a towed vehicle, the agency is proposing to require that, as part of the system documentation, the manufacturer include the information that shows how the tractor provides brake pressure to a towed trailer under the appropriate conditions.

It is common practice for the NHTSA's Office of Vehicle Safety Compliance to request relevant technical information from a manufacturer prior to conducting many of its compliance test programs. The agency included such a requirement in the light vehicle ESC standard. Prior to conducting any of the FMVSS No. 126 compliance tests, NHTSA requires manufacturers to provide the documentation required by that standard, including identification of all ESC system hardware and an explanation of the system operational characteristics. We also request additional information about the ESC system including manufacturer make and model, telltale(s), pertinent owner's manual excerpts and suggested malfunction scenarios. All of the requested information allows NHTSA to verify that the ESC system meets the definitional and operational requirements that cannot necessarily be verified during the performance test. Furthermore, this information aids the test engineers with execution and completion of the compliance test.

D. ESC Disablement

The agency has also considered whether to allow a control for the ESC to be disabled by the driver; however, heavy vehicles currently equipped with ESC systems do not include on/off controls for ESC that would allow a driver to deactivate or adjust the ESC system. Given the lack of on/off switches on heavy vehicles equipped with ESC, we do not propose to allow an on/off switch for ESC systems in this NPRM. Nevertheless, we seek comment on the need to allow an on/off switch. Such comments should address why manufacturers might need this flexibility and how manufacturers would implement a switch in light of the ABS requirements for truck tractors and large buses.

E. ESC Malfunction Detection, Telltale, and Activation Indicator

1. ESC Malfunction Detection

This proposed rule would require that vehicles be equipped with an indicator lamp, mounted in front of and in clear view of the driver, which is activated whenever there is a malfunction that affects the generation or transmission of control or response signals in the vehicle's ESC system. Heavy vehicles presently equipped with ESC generally do not have a dedicated ESC malfunction lamp. Instead, they share that function with the mandatory ABS malfunction indicator lamp or the traction control activation lamp. The agency proposes requiring a separate ESC malfunction lamp because it would alert the driver to the malfunction condition of the ESC and would help to ensure that the malfunction is corrected at the earliest opportunity.

We believe that there are safety benefits associated with such a warning. An ESC malfunction indicator warns the driver in the event of an ESC system malfunction so that the system can be repaired. ESC system activations on a heavy vehicle will be infrequent events in panic situations, and drivers should not experience the activation of a stability control system during the normal operation of the vehicle. Because most steering maneuvers performed during the normal operation of a heavy vehicle are not severe enough to activate the ESC system, a vehicle may be operated for long periods without an ESC activation event. Without such a malfunction indicator, a driver might have no way of knowing that an ESC system is malfunctioning until a loss of control or rollover event occurs. For example, the agency received a complaint recently in which a heavy truck had an inoperative ESC system, but the driver was unaware of the malfunction, primarily due to the lack of a malfunction indicator lamp. The agency believes that such a warning is important to ensure that the driver could have the malfunction corrected at the earliest opportunity in order to continue to realize the system's safety benefits.

The ESC malfunction telltale would be required to remain illuminated continuously as long as the malfunction exists whenever the ignition locking system is in the ''On'' (''Run'') position. The ESC malfunction telltale must extinguish after the malfunction has been corrected. These proposed requirements are identical to the requirements established in the light vehicle ESC standard, FMVSS No. 126, and help to ensure that the system provides a warning indication in the event of a malfunction.

Because many malfunctions cannot be detected when the vehicle is stationary, this NPRM includes a test that would allow the engine to be running and the vehicle to be in motion as part of the diagnostic evaluation. We are aware that some malfunctions are not time-based, but instead require comparisons of sensor outputs generated when the vehicle is driven. Hence, some malfunctions would require certain driving motions to make the ESC system's malfunction detection possible. We believe that an ESC malfunction should be detected within a reasonable time of starting to drive. As a result, we propose that the malfunction telltale illuminate within two minutes after attaining a test speed of 48 km/h (30 mph) so that the parts of a system's malfunction detection capability that depend on vehicle motion can operate. This two-minute period is identical to the period included in the test procedure in FMVSS No. 126 for ESC malfunction detection.

We anticipate that FMCSA will issue a companion proposal to NHTSA's proposal to require ESC on truck tractors and large buses, which would require that the ESC system on a commercial vehicle be maintained in a fully operating condition. In addition, we expect that the roadside inspection procedures developed for commercial vehicle ESC systems would be facilitated by the ESC malfunction telltale and the format that is required to indicate whether or not the system is operational.

2. ESC Malfunction Telltale

The ESC malfunction lamp requirement in this NPRM states that each truck tractor and large bus must be equipped with a telltale that provides a warning to the driver when one or more malfunctions that affect the generation of control or response signals in the vehicle's electronic stability control system is detected. Specifically, the ESC malfunction telltale will be required to be mounted in the driver's compartment in front of and in clear view of the driver and be identified by the symbol shown for ''ESC Malfunction Telltale'' or the specified words or abbreviations listed in Table 1 of FMVSS No. 101, *Controls and displays.* FMVSS No. 101 includes a requirement for the telltale symbol, or abbreviation, and the color required for the indicator lamp to show a malfunction in the ESC system.

The agency believes that the symbol used to identify ESC malfunction should be standardized with the symbol used on light vehicles. The symbol established in FMVSS No. 126 is the International Organization for Standardization (ISO) ESC symbol, designated J.14 in ISO Standard 2575. The symbol shows the rear of a vehicle trailed by a pair of ''S'' shaped skid marks, shown below in Figure 5. The agency found that the ISO J.14 symbol and close variations were the symbols used by the greatest number of vehicle manufacturers that used an ESC symbol before the requirement was established. Furthermore, FMVSS No. 126 allows, as an option, the use of the text ''ESC'' in place of the telltale symbol. This same option is being proposed.

Figure 5: ESC Malfunction Telltale Symbol in FMVSS No. 101

The color of the ESC malfunction telltale specified in Table 1 of FMVSS No. 101 for light vehicles equipped with ESC is yellow, which is the color used to communicate to the driver the condition of a malfunctioning vehicle system that does not require immediate correction. The agency chose to associate indication of an ESC system malfunction with a yellow telltale color as a warning to the driver because we believe that it communicates the level of urgency with which the driver must seek to remedy the malfunction of the ESC system.

For this proposed rule, we believe that the ESC malfunction telltale and color designation developed for light vehicles would be appropriate for use on heavy vehicles. Accordingly, the agency proposes that the ESC malfunction telltale symbol and color requirements of FMVSS No. 101 be proposed for use on truck tractors and buses, and that the abbreviation ''ESC'' should be allowed as an option instead of the symbol.

In addition to the ESC malfunction telltale being used to warn the driver of a malfunction in the ESC, the telltale is also used as a check of lamp function during vehicle start-up. We believe that the ESC malfunction telltale should be activated as a check of lamp function either when the ignition locking system is turned to the ''On'' (''Run'') position whether or not the engine is running. This function provides drivers with the information needed to ensure that the ESC system is operational before the vehicle is driven. It also provides Federal and State inspectors with the means to determine the operational status of the ESC system during a roadside safety inspection.

Accordingly, this NPRM proposes that the ESC malfunction telltale must be activated as a check of lamp function either when the ignition locking system is turned to the ''On'' (''Run'') position when the engine is not running or when the ignition locking system is in a position between the ''On'' (''Run'') and ''Start,'' which is designated by the manufacturer as a check position.

3. ESC Activation Indicator

The agency is requesting comment on whether there is a safety need for an ESC activation indicator. In the light vehicle ESC rulemaking, the agency considered the safety need for an ESC activation indicator to alert the driver during an emergency situation that the ESC is activating. NHTSA conducted a study using the National Advanced Driving Simulator (NADS), which included experiments to gain insight into the various possibilities regarding ESC activation indicators. The study compared the performance of 200 participants in driving maneuvers on a wet pavement, and used road departures and eye glances to the instrument panel as measures of driver performance. The significant finding was that the drivers who received various ESC activation indicators did not perform better than drivers who were given no indicator. That finding formed the basis for the agency's decision not to require an ESC activation indicator for light vehicles.

F. Performance Requirements and Compliance Testing

The agency's research initially focused on a variety of maneuvers which we could use to evaluate the roll stability performance and the yaw stability performance of truck tractors and large buses. Several of these maneuvers were also tested by industry and some of them are allowed for use in testing for compliance to the UN ECE stability control regulation. The agency's goal was to develop one or more maneuvers that showed the most promise as repeatable and reproducible roll and yaw performance tests for which objective pass/fail criteria could be developed.

As the research program progressed, the data indicated that the ramp steer maneuver to evaluate roll stability performance and the sine with dwell maneuver to evaluate yaw stability performance were the most promising. The slowly increasing steer maneuver was developed to normalize testing conditions for each vehicle so that the level of stringency for each test vehicle would be similar. The agency also found that the SIS maneuver could also be used to evaluate the engine torque reduction capability of a vehicle's ESC system, which is important because engine torque reduction may bring a vehicle under control before brakes are applied. After further testing, the agency was able to develop test parameters for the SWD maneuver so that both roll stability and the yaw stability could be evaluated using a single maneuver and loading condition. This development eliminated the need for the ramp steer maneuver to evaluate roll stability performance.

Therefore, based on testing at VRTC and the results from industry-provided test data, two stability proposed performance tests have been chosen to evaluate ESC systems on truck tractors and large buses—the SIS test and the SWD test.

The agency also considered the ECE performance tests for heavy vehicle stability control systems, which are included in the brake systems regulation, ECE Regulation 13. The performance test for a heavy vehicle with a directional control function includes meeting the requirements in one of eight tests allowed for compliance. The eight tests are as follows: Reducing radius test (which is identical to the decreasing radius test discussed above), step steer input test, sine with dwell, J-turn, mu-split lane change, double lane change, reversed steering test or ''fish hook'' test, and asymmetrical one period sine steer or pulse steer input test. No test procedure or pass/fail criteria are included in ECE Regulation 13, but it is left to the discretion of the Type Approval testing authority in agreement with the vehicle manufacturer to show that the system is functional.

The issue of whether the U.S. should adopt the stability control requirements similar to those in ECE Regulation 13 is addressed in the context of whether a definitional requirement specifying required equipment along with a performance test that does not include a test procedure or pass/fail criteria would be considered sufficiently objective for a safety standard. The agency considered several of the eight ECE tests that we believed showed the most promise for repeatability and reproducibility, and decided to focus on the SWD test, which is one of the eight tests allowed for compliance testing to ECE Regulation 13. However, in light of the requirement in the Motor Vehicle Safety Act that FMVSSs be stated in objective terms, NHTSA is required to develop objective performance criteria for the SWD test to be set forth in the regulatory text.

1. Characterization Test—SIS

The agency is proposing to conduct compliance testing characterization using a slowly increasing steer to determine the steering wheel angle needed to achieve 0.5g of lateral acceleration at 30 mph and also to evaluate the capability of the ESC system to reduce engine torque. The SIS maneuver has been used for many years by the agency and the industry to determine the unique dynamic characteristics of a vehicle. This maneuver allows the agency to determine the relationship between the steering wheel angle and lateral acceleration for a vehicle, which varies due to different steering gear ratios, different suspension systems, and wheelbase and other dimensions, among other things. To normalize the severity of the SWD maneuver that follows, each vehicle is tested based on its steering wheel angle determined in the SIS maneuver. The agency is proposing a 0.5g lateral acceleration target because our test results indicated that a truck tractor or large bus is highly likely to experience instability at that level of lateral acceleration. Even though the vast majority of truck tractors are typical 6x4 tractors, there are other configurations, such as those with 2-axle or 4-axle configurations and buses, which would require a different steering wheel angle to normalize the test conditions for each different vehicle.

To perform the SIS maneuver, the tractor or bus is driven at a constant speed of 30 mph, and then the steering controller increases the steering wheel angle at a slow, continuous rate of 13.5 degrees per second. The steering wheel angle is increased linearly from zero to 270 degrees and then held constant for one second, after which the maneuver concludes. The vehicle is subjected to two series of runs, one using clockwise steering and the other using counterclockwise steering, with three tests performed for each test series. During each test run, ESC system activation must be confirmed. If ESC system activation does not occur during the maneuver, then the commanded steering wheel angle is increased by 270-degree increments up to the vehicle's maximum allowable steering angle until ESC activation is confirmed.

From the SIS tests, the value ''A'' is determined. ''A'' is the steering wheel angle, in degrees, that is estimated to produce a lateral acceleration of 0.5g for that vehicle. Using linear regression on the lateral acceleration data recorded between 0.05g and 0.3g for each of the six valid SIS tests, a linear extrapolation is used to calculate a steering wheel angle where the lateral acceleration would be 0.5g. If ESC system activation occurs prior to the vehicle experiencing lateral acceleration of 0.3g, then the data used during the linear regression will be that data recorded between 0.05g and the lateral acceleration measured at the time of ESC system activation. The six values derived from the linear regression are then averaged and rounded to the nearest 0.1 degree to produce the final quantity, ''A,'' used during the SWD maneuver.

As part of the SIS characterization test, the engine torque reduction test is also conducted. As mentioned above, during each of the six completed SIS maneuvers, ESC activation is confirmed by verifying that the system automatically attempts to reduce engine torque. To confirm ESC activation, engine torque output and driver requested torque data are collected from the vehicle's J1939 communication data link and compared. During the initial stages of each maneuver, the rate of change over time of engine torque output and driver requested torque will be consistent. Upon ESC activation, the ESC system activation causes a commanded engine torque reduction, even though the driver requests increased torque by attempting to accelerate the vehicle to maintain the required constant speed. Therefore, the rate of change over time of engine torque output and driver requested torque will diverge.

For each of the six SIS test runs, the commanded engine torque and the driver requested torque signals must diverge at least 10 percent 1.5 seconds after the beginning of ESC system activation. This test demonstrates that the ESC system has the capability to reduce engine torque, as required in the functional definition.

The metric used to measure the engine torque reduction performance is stated in terms of the difference in percent between the actual engine torque output and driver requested torque input just after ESC activation. The pass-fail criterion that the agency proposes for this test is that the stability control system must be able to reduce engine torque output by a minimum of 10 percent from the torque output requested by the driver, which will be measured 1.5 seconds after the time when the ESC activated. The vehicles that the agency tested were all able to meet this proposed performance level.

2. Roll and Yaw Stability Test—SWD

The objective of the sine with dwell test is to subject a vehicle to a maneuver that will cause both roll and yaw instabilities and to verify that the ESC system activates to mitigate those instabilities. The SWD test is based on a single cycle of a sinusoidal steering input. For testing, we are proposing to use a frequency of 0.5 Hz (½ cycle per second or 1 cycle in 2 seconds) was used with a pause or dwell of 1.0 second after completion of the third quarter-cycle of the sinusoid. We chose a 0.5 Hz frequency because it produces the most consistently high severity on the majority of the vehicles tested by the agency. Hence, the total time for the steering maneuver is three seconds.

Conceptually, the steering profile of this maneuver is similar to that expected to be used by real drivers during some crash avoidance maneuvers. As the agency found in the light vehicle ESC research program, the severity of the SWD maneuver makes it a rigorous test while maintaining steering rates within the capabilities of human drivers. We believe that the maneuver is severe enough to produce rollover or vehicle loss-of-control without a functioning ESC system on the vehicle.

For a truck tractor, the SWD test would be conducted with the truck tractor coupled to an unbraked control trailer and loaded with ballast directly over the kingpin. The combination vehicle would be loaded to 80 percent of the tractor's GVWR. Testing indicates that this is sufficient load on the tractor to enable the tractor's stability control mass estimation program to provide full tractor braking intervention during the SWD maneuver. The ballast is placed low on the trailer to minimize the likelihood of actual trailer rollover, and the trailer is equipped with outriggers in case the ESC system does not function properly to prevent the trailer from rolling over.

For a bus, the vehicle is loaded with a 68-kilogram (150-pound) water dummy in each of the vehicle's designated seating positions, which would bring the vehicle's weight to less than its GVWR. No ballast is placed in the cargo hold beneath the passenger compartment so that the desired CG height of the test load can be attained.

The SWD test would be conducted at a speed of 72 km/h (45 mph). An automated steering machine would be used to initiate the steering maneuver. Each vehicle is subjected to two series of test runs. One series uses counterclockwise steering for the first half-cycle, and the other series uses clockwise steering for the first half-cycle. The steering amplitude for the initial run of each series is 0.3A, where A is the steering wheel angle determined from the SIS maneuvers discussed in section V.F.1 above. In each of the successive test runs, the steering amplitude would be increased by increments of 0.1A until a steering amplitude of 1.3A or 400 degrees, whichever is less, is achieved. Upon completion of the two series of test runs, post-processing of the yaw rate and lateral acceleration data to determine the lateral acceleration ratio, yaw rate ratio, and lateral displacement, as discussed below.

(a) Roll Stability Performance

The LAR is a performance metric developed to evaluate the ability of a vehicle's ESC system to prevent rollovers. Lateral acceleration is measured on a bus or a tractor and corrected for the vehicle's roll angle. As a performance metric, the corrected lateral acceleration value is normalized by dividing it by the maximum lateral acceleration that was determined at any time between 1.0 seconds after the beginning of steering and the completion of steering.

Conceptually, stability control system intervention will reduce lateral acceleration of the vehicle during a crash avoidance steering maneuver. This intervention increases the roll stability of the vehicle by reducing the vehicle speed, which results in a reduction in the lateral acceleration, A_y, because $A_y = V^2/R$, where V is the vehicle speed, and R is the radius of curvature of vehicle path. However, lateral acceleration was found to be less favorable than a ''normalized'' calculation, lateral acceleration ratio, developed from the vehicle's lateral acceleration measured during the maneuver because the lateral acceleration alone does not account for different stability thresholds among different vehicles. The agency believes that LAR has the most potential for an accurate measure of an ESC system to prevent rollovers. From the agency's testing, we have noted that LAR differentiates vehicles equipped with stability control systems as well as the potential determine and quantify roll instability. Lateral acceleration ratio is calculated by dividing the vehicle's lateral acceleration, corrected for roll angle, at a specified time after the completion of steer (COS) by the peak corrected lateral acceleration experienced during the second half of the sine maneuver (including the dwell period). The LAR at two time intervals after completion of steer is calculated to determine the change in lateral acceleration from the peak lateral acceleration. A reduction or decay in the lateral acceleration ratio at specified intervals after completion of steer is an indication that the stability control system has intervened to reduce the likelihood of vehicle rollover. The lateral acceleration ratio, LAR, is determined as follows:

$$LAR = \frac{A_{y\_Veh}(COS + 0.75\ sec, + 1.5\ sec)}{MAX\,(A_{y\_Veh})}$$

Where $A_{\_y\ Veh}$ (COS + 0.75 sec, + 1.5 sec,) is the corrected for roll lateral acceleration value at the specified time after the completion of steer, and Max A_y is the peak corrected lateral acceleration measured during the second half of the sine maneuver (including the dwell period), *i.e.,* from time 1.0 second after the beginning of steer to the completion of steer.

In developing the performance requirements for light vehicle ESC systems, several commenters requested that the agency include a definition for the term ''lateral acceleration'' and define a method for determining the lateral acceleration at the vehicle's center of gravity. In FMVSS No. 126, the agency uses the definition from SAE J670e, Vehicle Dynamics Terminology, which states, ''Lateral Acceleration means the component of the vector acceleration of a point in the vehicle perpendicular to the vehicle x axis (longitudinal) and parallel to the road plane.'' This definition was carried over, effectively unchanged, to the more recent revision of SAE's Vehicle Dynamics Terminology, SAE J670_200801. The agency is proposing to use the same definition of lateral acceleration for this standard as was used in FMVSS No. 126.

The agency's research also looked at wheel lift measurement as a possible performance measure. Wheel lift is the most intuitive performance measure we considered because wheel lift precedes all rollovers. Wheel lift is considered to be lift that is two inches or greater, which occurs for any wheel of the vehicle, including the control trailer for the tractor during a test. One challenge with using wheel lift is that it does not necessarily indicate that rollover is imminent. For example, certain vehicle suspension designs are likely to cause wheel lift during severe cornering maneuvers, and also non-uniform test surfaces can cause brief instances of wheel lift.

Therefore, the agency proposes evaluating vehicle roll stability performance by calculating the LAR at 0.75 seconds and at 1.5 seconds after the completion of steer. The two performance criteria are described below:

• From data collected from each SWD maneuver executed, a vehicle equipped with a stability control system must have a LAR of 30 percent or less 0.75 seconds after completion of steer. This

LAR will be calculated from the vehicle's lateral acceleration, corrected for roll angle, at its center of gravity position.

- From data collected from each SWD maneuver executed, a vehicle equipped with stability control must have a LAR of 10 percent or less at 1.5 seconds after completion of steer. This LAR will be calculated from the vehicle's lateral acceleration, corrected for roll angle, at its center of gravity position.

The performance criteria mean that 0.75 seconds after the completion of the steering input, the corrected lateral acceleration must not exceed 30 percent of the maximum lateral acceleration recorded during the steering maneuver, and at 1.5 seconds after the completion of the steering input, the lateral acceleration must not exceed 10 percent of the maximum lateral acceleration recorded during the steering maneuver. The agency believes that these criteria represent an appropriate stability threshold. NHTSA's research indicates that an ESC system's ability to maintain an LAR above these criteria would provide an acceptable probability that the vehicle would remain stable and that a level of LAR above these criteria would result in a high probability of the vehicle becoming unstable.

(b) Yaw Stability Performance

The yaw rate ratio is a performance metric used to evaluate the ability of a vehicle's ESC system to prevent yaw instability. The YRR expresses the lateral stability criteria for the sine with dwell test to measure how quickly the vehicle stops turning, or rotating about its vertical axis, after the steering wheel is returned to the straight-ahead position. A vehicle that continues to turn or rotate about its vertical axis for an extended period after the steering wheel has been returned to a straight-ahead position is most likely experiencing oversteer, which is what ESC is designed to prevent. The lateral stability criterion, expressed in terms of YRR, is the percent of peak yaw rate that is present at designated times after completion of steer.

The yaw rate ratio, YRR, is determined as follows:

$$YRR = \frac{\Psi_{Vehicle}\,(COS + 0.75\text{ sec}, +1.5\text{ sec})}{MAX\ \Psi_{Vehicle}}$$

Where $\Psi_{Vehicle}$ (COS + 0.75 sec, + 1.5 sec) is yaw rate value at a specified time after the completion of steer, and Max $\Psi_{Vehicle}$ is the maximum yaw rate measured during the second half of the sine maneuver including the dwell period from time 1.0 second after the beginning of steer until the completion of steer during each maneuver.

This performance metric is identical to the metric used in the light vehicle ESC system performance requirement in FMVSS No. 126. We believe that this metric is equally applicable to truck tractors and large buses, though it is calculated at different time intervals after the completion of steer.

Therefore, the agency proposes to evaluate yaw stability performance by calculating the YRR at 0.75 seconds and at 1.5 seconds after the completion of steer. The two performance criteria are described below:

- From data collected from each 45-mph SWD maneuver executed, a vehicle equipped with a stability control system must have a YRR of 40 percent or less 0.75 seconds after completion of steer.
- From data collected from each 45-mph SWD maneuver executed, a vehicle equipped with stability control must have a YRR of 15 percent or less at 1.5 seconds after completion of steer.

The performance criteria mean that 0.75 seconds after the completion of the steering, the yaw rate must not exceed 40 percent of the peak yaw rate recorded during the second half of the sine maneuver including the dwell period, and at 1.5 seconds after the completion of the steering input, the yaw rate must not exceed 15 percent of the peak yaw rate recorded. The agency believes that these criteria represent an appropriate stability threshold. NHTSA's research indicates that an ESC system's ability to maintain an YRR above these criteria would provide an acceptable probability that the vehicle would remain stable and that a level of YRR above these criteria would result in a high probability of the vehicle becoming unstable.

(c) Lateral Displacement

Lateral displacement is a performance metric used to evaluate the responsiveness of a vehicle, which relates to its ability to steer around objects. Stability control intervention has the potential to significantly increase the stability of the vehicle in which it is installed. However, we believe that these improvements in vehicle stability should not come at the expense of poor lateral displacement in response to the driver's steering input.

A hypothetical way to pass a stability control performance test would be to make either the vehicle or its stability control system intervene simply by making the vehicle poorly responsive to the speed and steering inputs required by the test. An extreme example of this potential lack of responsiveness would occur if an ESC system locked both front wheels as the driver begins a severe avoidance maneuver that might lead to vehicle rollover. Front wheel lockup would create an understeer condition in the vehicle, which would result in the vehicle plowing straight ahead and colliding with an object the driver was trying to avoid. It is very likely that front wheel lockup would reduce the roll instability of the vehicle since the lateral acceleration would be reduced. This is clearly, however, not a desirable compromise.

Because a vehicle that simply responds poorly to steering commands may be able to meet the proposed stability criteria, a minimum responsiveness criterion is also proposed for the SWD test. Using a lateral displacement metric to measure responsiveness ensures that the vehicle responds to an initial steering input to avoid an obstacle. This metric was chosen because it is objective, easy to measure, has good discriminatory capability, and has a direct relation to obstacle avoidance.

The proposed lateral displacement criterion is that a truck tractor equipped with stability control must have a lateral displacement of 7 feet or more at 1.5 seconds from the beginning of steer, measured during the sine with dwell maneuver. For a bus, the proposed performance criterion is a lateral displacement of 5 feet or more at 1.5 seconds after the beginning of steer. The lateral displacement criteria is less for a bus because a large bus has a longer wheelbase than a truck tractor and higher steering ratio, which makes it less responsive than a truck tractor. The value will be calculated from the double integral with respect to time of the measurement of the corrected for roll lateral acceleration at the vehicle center of gravity, as expressed by the formula:

$$\text{Lateral Displacement} = \iint Ay_{CG}\, dt$$

Where: Ay_{CG} is the corrected for roll lateral acceleration at the center of gravity height of the vehicle

This is the same performance metric used in FMVSS No. 126. Furthermore, the vehicle would be required pass this requirement during the every execution the SWD maneuver where the steering wheel angle is 0.7A or greater.

3. Alternative Test Maneuvers Considered

We have considered other test maneuvers besides the sine with dwell test. The SWD maneuver was tentatively selected over the other maneuvers discussed above and below because our research demonstrates that it has the most optimal set of characteristics, including the severity of the test, repeatability and reproducibility of results, and the ability to address rollover, lateral stability, and responsiveness.

The agency's research initially focused on developing the ramp steer maneuver to evaluate the roll stability performance and the sine with dwell maneuver to evaluate the yaw stability performance. However, after additional testing, we were able to develop test parameters for the sine with dwell maneuver so that both roll stability and yaw stability could be evaluated using a single loading condition and test maneuver. The sine with dwell maneuver has typically been used to evaluate only the yaw instability of a vehicle. The agency has previously used a lightly loaded vehicle weight condition for such evaluations where the lightly loaded condition and the resulting lower CG height were much more likely to cause vehicle directional loss-of-control as opposed to rollover. In the light vehicle ESC standard, the sine with dwell maneuver is used to evaluate only yaw instability, not roll instability, with the vehicle loaded to LLVW only but not to GVWR. Given the different dynamics of heavy vehicles when compared to light vehicles, NHTSA evaluated several loading conditions and found that a loading condition which equals 80 percent of the tractor's GVWR enables us to evaluate roll instability as well as yaw instability.

The number of tests that would be needed to cover all likely vehicle operational conditions for varying vehicle designs is potentially large, and many tests (particularly those using low friction surfaces) may not be sufficiently repeatable for an objective performance requirement. Our testing indicates that the SWD maneuver is sufficiently severe to ensure that nearly all vehicles without ESC would not be able to comply with the proposed performance requirements. For example, the vehicles we tested without ESC either had wheel lift or spun out during the SWD maneuver. Hence, a vehicle that avoids loss of control according to our objective lateral acceleration and yaw rate decay definitions demonstrates that it has an ESC system typical of today's technology and would have safety benefits.

In addition to our test results, the agency thoroughly evaluated the test vehicles and test data submitted by EMA and others to the agency. EMA provided information on one tractor that appeared to satisfy the agency's proposed SWD performance criteria without a stability control system. After careful review of this data, we do not believe this fact means the test has no value.[43] It is possible that there are currently truck tractors or large buses sold today that are exceptionally yaw stable, even in a severe maneuver such as a double lane change, which the SWD maneuver is designed to simulate. When evaluating light vehicles, the agency noted that there was a very small number of vehicles that were stable enough without a stability control system to pass our performance criteria without an ESC system. Therefore, the existence of vehicles that could pass the proposed SWD test without a stability control system simply indicates that it would take many tests to cover all potential instability scenarios across varying vehicle designs in order to design a perfect test regime, as discussed earlier. Such a complex test regime would require excessive costs to manufacturers to ensure compliance and excessive costs to the agency to determine and enforce compliance.

We recognize that manufacturers may wish to base their certification of compliance with this proposed standard on their vehicles' performance in NHTSA's proposed test maneuvers. If manufacturers intend to conduct the maneuvers proposed by the agency, they may need to make additional investments in their facilities or have their certification testing performed at a contractor's facility. However, we believe some manufacturers may have already made these investments, and others would make similar investments as they develop and validate ESC systems for their vehicles. This is based on our understanding of the maneuvers used by the heavy-vehicle industry for ESC system development and validation, some of which include variations of the agency's proposed maneuver.

[43] As discussed earlier, EMA's testing of Vehicle J used a control trailer with a wider track width and a lower deck and used ballast that resulted in a lower vehicle center of gravity than used by NHTSA's researchers. Each of these differences caused EMA's combination vehicle to be more stable than NHTSA's during testing.

We also recognize that, over time, manufacturers will be able to develop other methods for certifying compliance with the proposed standard. For example, manufacturers can develop computer models or simulations to demonstrate ESC system performance. However, we recognize that these alternative methods may not be suitable for atypical vehicles that are custom-built for customers. We seek comment on the issues surrounding manufacturers' certification of compliance including the assumptions made regarding manufacturers' current and future test facilities, the methods used by manufacturers to validate ESC system performance, the ability of manufacturers to use other methods (such as computer modeling, simulation, or alternative test maneuvers) to certify compliance, the cost of certification, and the issues surrounding certification of atypical truck tractors.

Below, we discuss the alternative test maneuvers that were considered and what we considered to be acceptable performance criteria for each test. We also discuss why we are choosing the SWD maneuver for compliance testing in lieu of each of these maneuvers. We invite comment on each of these test maneuvers, including whether they should be used instead of, or along with, the proposed compliance test maneuvers.

(a) Characterization Maneuver

While NHTSA has conducted extensive testing using the SIS maneuver, we believe that alternative methods may be used to determine the steering wheel angle needed to achieve 0.5g of lateral acceleration at 30 mph. For example, a test based on the SAE J266 circle test may yield a similar steering wheel angle without requiring the track space necessary to conduct the SIS maneuver. The steering wheel angle that produces 0.5g of lateral acceleration at 30 mph may be above the ESC system's activation threshold for some vehicles, making it impractical to conduct a direct measurement of the steering wheel angle. The agency seeks comment on the feasibility of an alternative characterization test based upon the SAE J266 circle test.

(b) Roll Stability Test Maneuvers

To evaluate roll instability, we have considered two alternative roll stability test maneuvers—the J-turn and the ramp steer maneuver. The two tests are similar in that both maneuvers require the tested vehicle to be driven at a constant speed and then the vehicle is turned in one direction for a certain period of time. The test speed and the severity of the turn are designed to cause a test vehicle to approach or exceed its roll stability threshold such that, without a stability control system, the vehicle would exhibit signs of roll instability. Both tests would be performed with the tractor loaded to its GVWR. Furthermore, we would not expect a vehicle that could pass one test to fail the other.

The most notable difference between the J-turn and the RSM maneuvers is that the J-turn is a path-following maneuver. That is, it is performed on a fixed path curve. In contrast, the RSM maneuver is a non-path-following maneuver that is performed with a fixed steering wheel input. For example, during the agency's and EMA's testing, the J-turn maneuver was performed on a 150-foot radius curve. In contrast, the RSM is performed based on a steering wheel angle derived from the SIS test. We would expect that, with the RSM, the radius of the curve would be close to the fixed radius used in the J-turn maneuver. However, in the RSM, the driver would not have to make adjustments and corrections to steering to maintain the fixed path.

When comparing the J-turn to the RSM, the agency considers the RSM to be a preferable test maneuver because the RSM maneuver can be performed with an automated steering wheel controller. Because the J-turn is a path-following maneuver, a test driver must constantly make adjustments to the steering input for the vehicle to remain in the lane throughout the test maneuver. Moreover, driver variability could be introduced from test to test based upon minor variations in the timing of the initial steering input and the position of the test vehicle in the lane.

In addition, the RSM appears to be more consistent because it involves a fixed steering wheel angle rather than a fixed path. There is negligible variability based on the timing of the initial steering input because the test is designed to begin at the initiation of steering input, rather than the vehicle's position on a track. Moreover, an automated steering wheel controller can more precisely maintain the required steering wheel input than a driver can. Therefore, we tentatively conclude that the RSM is more consistent and more repeatable than the J-turn, which is critical for agency compliance testing purposes.

Notwithstanding the above observations, we recognize that many manufacturers perform NHTSA's compliance tests in order to certify that their vehicles comply with NHTSA's safety standards. We also recognize that, over time, manufacturers are likely to use other methods such as simulation, modeling, etc., to determine compliance with Federal Motor Vehicle Safety Standards. In this regard, we observe that, because the J-turn and the ramp steer maneuvers are so similar, manufacturers may be able to determine compliance with a stability control standard by using the J-turn maneuver even if the agency ultimately decides to use the RSM for compliance testing. Thus, if a manufacturer sought to certify compliance based upon performance testing, a manufacturer would not necessarily need to perform compliance testing with an automated steering controller.

In considering the RSM test conditions, the agency looked to its test data and the data submitted by EMA. Data analysis indicated that the RSM test performed from at an initial speed of 30 mph is sufficient to demonstrate effective stability control performance for truck tractors. At GVWR, the tested buses were observed to have different speed thresholds at which wheel lift occurred and stability control initially activated. Without stability control, buses were observed to produce wheel lift between 35 and 39 mph in the RSM, compared to tractors, which ranged from 28 to 30 mph. Large bus stability control systems initially activated at speeds greater than 30 mph in the RSM, which was higher than the 26 mph observed with tractors. In light of these differences, an initial speed of 36 mph was selected for buses to ensure an appropriate level of test severity and that stability control would intervene.

Another issue in conducting the RSM is whether to use fixed rate steering or to steer at a rate such that the full steering input is reached in a fixed time. Using fixed rate steering, the steering wheel is turned a 175 degrees per second until the desired steering wheel angle is reached. If a vehicle with a lower steering wheel angle input, such as a short wheelbase 4x2 tractor, is tested using this steering method, the desired steering wheel angle would be reached relatively quickly after the initial steering input. In contrast, for a longer wheelbase truck or a large bus, the desired steering wheel angle would be reached relatively slowly after the initial steering input. This results in a more severe test for vehicles with a lower steering wheel angle because the predicted lateral acceleration of 0.5g would be reached more quickly than for vehicles with a higher steering wheel angle. In an extreme case with an exceptionally large steering wheel angle, such as a bus with a long wheelbase the system may activate before the full steering wheel is input.

Using a fixed-time steering input, we would program the steering wheel controller to reach the desired steering wheel angle in exactly 1.5 seconds using a constant steering rate, which was derived from the manually steered 150-foot J-turn maneuver. Using this steering method would prevent the RSM results from varying with steering wheel angle input. We are requesting comment as to whether fixed-rate steering or fixed-time steering is a preferable manner for conducting the RSM.

The RSM would use a similar, but not identical lateral acceleration ratio performance metric to evaluate roll stability. As with the SWD maneuver, the LAR used in the RSM would indicate that the stability control system is applying selective braking to lower lateral acceleration experienced during the steering maneuver. In the SWD maneuver, the LAR is the ratio of the lateral acceleration at a fixed point in time to the peak lateral acceleration during the period from one second after the beginning of steer to the completion of steer. In contrast, the LAR metric we would use for the RSM would be the ratio of the lateral acceleration at a fixed point in time to the lateral acceleration at the end of ramp input, which is the moment at which the steering wheel angle reaches the target steering wheel angle for the test. Also, in contrast to the SWD maneuver, the LAR measurements for the RSM would be taken at a time when the steering wheel is still turned. This means that, although the SWD maneuver is a more dynamic steering maneuver, the LAR criteria for the RSM would be greater than the LAR criteria for the SWD maneuver.

The performance criteria for the RSM would depend on whether fixed-rate steering or fixed-time steering input is used. For truck tractors and large buses using fixed-time steering input, we would expect that the LAR would be less than 1.05 two seconds after the end of ramp input and less than 0.8 three seconds after the end of ramp input. For truck tractors tested using fixed-rate steering inputs, we would expect that the LAR would be less than 1.1 two seconds after the end of ramp input (the point in time at which the target steering wheel angle is reached) and less than 0.9 three seconds after the end of ramp input. For buses using fixed-rate steering, we would expect that the LAR would be less than 1.0 two seconds after the end of ramp input and less than 0.7 three seconds after the end of ramp input. The performance criteria for large buses would be lower because, as we stated above, when using fixed-rate steering input, the longer wheelbases of buses cause the maneuver to be less dynamic.

In a March 2012 submission, which was revised with additional details in April 2012, EMA suggested that NHTSA use different test speeds and performance criteria for the J-turn maneuver.[44] EMA suggested that a test speed that is 30 percent greater than the minimum speed at which the ESC system intervenes with engine, engine brake, or service brake control. Instead of measuring LAR, EMA suggested that, during three out of four runs, the vehicle would be required to decelerate at a minimum deceleration rate. NHTSA has conducted testing on variations of this EMA maneuver, and we plan to conduct further testing. We request comments on EMA's suggested test procedure and performance criteria for the J-turn maneuver.

Based on our testing to date, the agency tentatively concludes that the RSM is a preferable test to the J-run to demonstrate a stability control system's ability to prevent roll instability. However, as discussed in greater detail below, in order to reduce the number of compliance tests that the agency and those manufacturers who choose to demonstrate compliance by conducting the agency's performance tests must perform, the agency proposes using on test maneuver, the SWD, to demonstrate both roll and yaw stability performance. Although we are proposing to use the SWD maneuver for evaluating roll stability, we request comment on issues related to the RSM and J-turn tests, including test conditions, steering input method, and performance criteria.

(c) Yaw Stability Test Maneuvers

After evaluating several maneuvers on different surfaces, the agency was unable to develop any alterative performance-based dynamic yaw test maneuvers that were repeatable enough for compliance testing purposes. Bendix described two maneuvers intended to evaluate the yaw stability of tractors.[45] However, neither of these test maneuvers was developed to a level that would make them suitable for the agency to consider using as yaw performance tests.

In July 2009, EMA provided research information on several yaw stability test maneuvers.[46] One of these maneuvers was the SWD on dry pavement that is similar to what is proposed in this notice. The second maneuver was an SWD maneuver conducted on wet Jennite. The third maneuver was a ramp with dwell maneuver on wet Jennite.[47] EMA did not provide any test data on the last two maneuvers. Thus, we considered them to be concepts rather than fully developed maneuvers that we could consider using for yaw stability testing.

We received no other alternative yaw performance tests from industry until EMA's submission of Vehicle J data in late 2010.[48] EMA suggested using a wet Jennite drive through test maneuver demonstrated yaw performance in a curve on a low friction surface. The maneuver is based upon a maneuver the agency currently conducts on heavy vehicles to verify stability and control of antilock braking systems while braking in a curve. As part of the test, a vehicle is driven into a 500-foot radius curve with a low-friction wet Jennite surface at increasing speeds to determine the maximum drive-through speed at which the driver can keep the vehicle within a 12-foot lane. As with the J-turn, we are concerned about the repeatability of this test maneuver because of variability in the wet Jennite test surface and the driver's difficulty in maintaining a constant speed and steering input in the curve.

In a March 2012 submission, which was revised with additional details in April 2012, EMA provided information about another yaw stability test along with additional information on the J-turn maneuver.[49] This maneuver would simulate a single lane change on a wet roadway surface. It would be conducted within a 4 meter (12 foot) wide path. The roadway condition would be a wet, low friction surface such as wet Jennite with a peak coefficient of friction of 0.5. The other test conditions (*i.e.,* road conditions, burnish procedure, liftable axle position, and initial brake temperatures) would be similar to those proposed in this NPRM. In this maneuver, the truck would enter the path at progressively higher speeds to establish the minimum speed at which the ESC system intervenes and applies the tractor's brakes. The maneuver would then be repeated four times at that speed with the vehicle remaining within the lane at all times during the maneuver. EMA suggests, as a performance criterion, that during at least three of the four runs, the ESC system must provide a minimum level (presently unspecified) of differential braking. The agency has not had an opportunity to conduct testing of this maneuver, but we intend to do so to determine whether this is a viable alternative yaw stability test.

In light of the inability to develop a different performance-based yaw stability test, the agency is proposing to use the SWD test maneuver to evaluate yaw stability performance. Although we are proposing to use the SWD maneuver for evaluating yaw stability, we request comment on other yaw stability tests that could be suitable for performance testing and possible performance criteria for any such test. Furthermore, we specifically request comment on all aspects of EMA's yaw stability test discussed in its March and April 2012 submissions, including the test conditions, test procedure, and possible performance criteria that would allow the agency to test both trucks and buses with this maneuver.

(d) Lack of an Understeer Test

The SWD maneuver is designed to induce both roll and yaw responses from the vehicle being evaluated. However, the agency has no test to evaluate how the ESC responds when understeer is induced. The technique used by a stability control system for mitigating wheel lift, excessive oversteer or understeer conditions is to apply unbalanced wheel braking so as to generate moments (torques) to reduce lateral acceleration and to correct excessive oversteer or understeer. However, for a vehicle experiencing excessive understeer, if too much oversteering moment is generated, the vehicle may oversteer and spin out with obvious negative safety consequences. In addition, excessive understeer mitigation acts like an anti-roll stability control where it momentarily increases the lateral acceleration the vehicle can attain. Hence, too much understeer mitigation can create safety problems in the form of vehicle spin out or rollover.[50]

During the testing to develop FMVSS No. 126, the agency concluded that understanding both what understeer mitigation can and cannot do is complicated, and that there are certain

[44] Docket No. NHTSA–2010–0034–0032; Docket No. NHTSA–2010–0034–0040.

[45] These tests are discussed in section IV.E.3. See Docket No. NHTSA–2010–0034–0037 and Docket No. NHTSA–2010–0034–0038.

[46] Docket No. NHTSA–2010–0034–0035.

[47] This ramp with dwell maneuver is the same one identified by Bendix referenced in the prior paragraph and in section IV.E.3.

[48] Docket No. NHTSA–2010–0034–0022; Docket No. NHTSA–2010–0034–0023.

[49] Docket No. NHTSA–2010–0034–0032; Docket No. NHTSA–2010–0034–0040.

[50] EMA's testing of Vehicle J on the 500-foot wet Jennite curve shows understeer mitigation at maneuver entry speeds up to 34 mph, but at 35 mph, the vehicle could not overcome understeer. See Docket No. NHTSA–2010–0034–0022; Docket No. NHTSA–2010–0034–0023. At these low levels of lateral acceleration, no adverse effects appeared to occur as a result of the understeer mitigation.

situations where understeer mitigation could potentially produce safety disbenefits if not properly tuned. Therefore, the agency decided to enforce the requirements to meet the understeer criterion included in the ESC definition using a two-part process. First, the requirement to meet definitional criteria ensured that all had the hardware needed to limit vehicle understeer. Second, the agency required manufacturers to submit engineering documentation at the request of NHTSA's Office of Vehicle Safety Compliance to show that the system is capable of addressing vehicle understeer.

Based on the agency's experience from the light vehicle ESC rulemaking and the lack of a suitable test to evaluate understeer performance, the agency is not proposing a test for understeer to evaluate ESC system performance for truck tractors and large buses. The agency requests comment on this NPRM's lack of a proposed understeer test.

4. ESC Malfunction Test

During execution of a compliance test the agency proposes simulating several malfunctions to ensure the system and corresponding malfunction telltale provides the required warning to the vehicle operator. Malfunctions are generally simulated by disconnecting the power source to an ESC system component or disconnecting an electrical connection to or between ESC system components. Examples of simulated malfunctions might include the electrical disconnection of the sensor measuring yaw rate, lateral acceleration, steering wheel angle sensor, or wheel speed. When simulating an ESC system malfunction, the electrical connections for the telltale lamp would not be disconnected. Also, because a vehicle may require a driving phase to identify a malfunction, the vehicle would be driven for at least two minutes including at least one left and one right turning maneuver. A similar drive time exists in the FMVSS No. 126 test procedure.

After a malfunction has been simulated and identified by the system, the system is restored to normal operation. The engine is started and the malfunction telltale is checked to ensure it has cleared.

5. Test Instrumentation and Equipment

For the truck tractor and large bus stability control system research program, each test vehicle was fitted with specific instrumentation and equipment necessary to execute each test safely and to collect necessary performance data. The compliance test program proposed in this NPRM would use essentially the same equipment and a subset of the instrumentation. As was done for FMVSS No. 126, the agency proposes including in the regulatory text the basic design parameters for the automated steering machine, outriggers, and the control trailer because this test equipment and instrumentation can influence test vehicle performance. However, the proposed regulatory text does not include a list of the less critical test instrumentation used during the compliance test. The agency's common practice has been to provide instrumentation details, test instrumentation range, resolution, and accuracy for all the required instrumentation in the separate NHTSA Laboratory Test Procedure. Furthermore, the agency is aware that manufacturers and test facilities will be interested in knowing what instruments will be used for a compliance test program. The following table and corresponding discussions identify the critical equipment and instrumentation used by NHTSA's researchers and for the most part, the same or similar is proposed for use by NHTSA's Office of Vehicle Safety Compliance.

TABLE 3—CRITICAL TEST INSTRUMENTATION USED FOR DATA COLLECTION BY NHTSA RESEARCH

Vehicle test instrumentation	Output/input	Range	Resolution	Accuracy	Make/model used
Programmable Steering Machine with Steering Angle Encoder.	Controls Steering Wheel Angle Input.	Max 40–60Nm (29.5–44.3 lb-ft) torque at a hand wheel rate up to 1200 deg/sec.			Automotive Testing Inc. (ATI) Model: Spirit.[3]
	Handwheel Angle	±800 deg	0.25 deg	±0.25 deg.	
Multi-Axis Inertial Sensing System.	Longitudinal, Lateral and Vertical Acceleration.	Accelerometers: ±2 g	Accelerometers: ≤10 ug.	Accelerometers: ≤0.05% of full range	Make: BEI Motion Pak Model: MP–1.
	Roll, Yaw, and Pitch Rate.	Angular rate sensors: ±100 deg/sec.	Angular Rate Sensors: ≤0.004 deg/s.	Angular Rate Sensors: 0.05% of full range.	
Speed Sensor	Vehicle Speed to DAS and Steering Machine.	0–201 km/h (0–125 mph).	.014 km/h (.009 mph)	0.1 km/h full scale	Make: RaceLogic Model: VBox.
Infrared Distance Measuring Sensor.	Left and Right Side Vehicle Height (For calculated vehicle roll angle).	350–850 mm (14–35 inches).	0.3–8.0 mm (0.01–0.3 inches).	1%	Sensor Make: Wenglor. Model: HT66MGV80.

During research additional instrumentation was used for collecting data outside the scope of the proposed standard and that instrumentation is not discussed here. Furthermore, this table does not include a discussion of non-critical instrumentation like the brake pedal load cell used to ensure the test driver does not apply the brake during the maneuver, or the thermocouples used to monitor brake temperatures.

(a) Outriggers

Throughout the agency's research program, truck tractors and buses were equipped with outrigger devices to prevent vehicle rollover. During the program, the agency encountered many instances of wheel lift and outrigger contact with the ground indicating that it was probable that rollover could occur during testing. Over many years of research of ESC systems, it has been proven that outriggers are essential to ensure driver safety and to prevent vehicle and property damage during NHTSA's compliance testing. Although NHTSA conducted some of its testing with ESC systems disabled, thereby increasing the need for outriggers, outriggers are still necessary as a safety measure during testing of vehicles equipped with an ESC system in case the system fails to activate.

The agency proposes that outriggers be used on all truck tractors and buses tested. Nevertheless, the agency acknowledges, as it did during the development of the light vehicle ESC system testing program, that outriggers have the potential to influence the dynamics of a vehicle during performance testing. For light vehicles, the agency determined that outrigger influence could be noticeable. However, we believe that outrigger influence on heavy vehicles is minimal because of the higher vehicle weight and test load. The agency has invested significant effort in outrigger designs that are both functional and minimize the impact to the test vehicle dynamic performance. To reduce test variability and increase the repeatability of the test results, the agency proposes to specify a standard outrigger design for the outriggers that will be used for compliance testing. The agency used this same approach in FMVSS No. 126 for compliance testing of light vehicle ESC systems. The agency also made available the detailed design specifications by reference to a design document located in the agency public docket.

For truck tractors, the document detailing the outrigger design to be used in testing has been placed in a public docket.[51] This document provides detailed construction drawings, specifies materials to be used, and provides installation guidance. For truck tractor combinations, the outriggers would be mounted on the trailer. The outriggers are mounted mid-way between the center of the kingpin and the center of the trailer axle (in the fore and aft direction of travel), which is generally near the geometric center of the trailer. They will be centered geometrically from side-to-side and bolted up under the traditional flatbed control trailer. Total weight of the outrigger assembly, excluding the mounting bracket and fasteners required to mount the assembly to the flatbed trailer, is approximately 1,490 pounds. The bulk of the mass, over 800 pounds, is for the mounting bracket which is located under the trailer near the vehicle's lateral and longitudinal center of gravity so that its inertial effects are minimized. The width of the outrigger assembly is 269 inches and the contact wheel to ground plane height is adjustable to allow for various degrees of body roll. A typical installation on a flatbed type trailer involves clamping and bolting the outrigger mounting bracket to the main rails of the flatbed.

For buses, the outrigger installations will not be as straightforward as the outrigger installations on the control trailers, and we desire comments on bus outrigger design. This is because outriggers cannot be mounted under the flat structure, but instead must extend through the bus. NHTSA used outriggers on the three large buses tested during its research program and proposes using outriggers for testing buses for compliance with this rule. The agency will use the same outrigger arms of the standard outrigger design that it plans to use for truck tractor testing. Therefore, the size, weight, and other design characteristics will be similar.

The location and manner of mounting the outriggers on buses cannot be identical to truck tractors. Nonetheless, there are a limited number of large bus manufacturers, which results in a limited number of unique chassis structural designs. Also, the agency understands that large bus structural designs do not change significantly from year-to-year. We believe that once outrigger mounts have been constructed for several different bus designs, those mountings can be modified and reused during subsequent testing. The agency has, in the document described above, provided additional engineering design drawings and further installation guidelines for installing the standard outrigger assemble to large buses.

(b) Automated Steering Machine

As part of the heavy vehicle ESC system research programs, the agency performed testing that compared multiple runs with test-driver-generated steering inputs, and found that test drivers cannot provide the same repeatable results as those obtained with an automated steering machine. Therefore, this NPRM proposes that an automated steering machine be used for the test maneuvers on the truck tractors and large buses in an effort to achieve highly repeatable and reproducible compliance test results.

An essential element of any compliance test program is for the test being executed to be reproducible, a test that can be easily executed the same way by different testing facilities, and repeatable, test results from repeated tests of the same vehicle are identical. The proposed 0.5 Hz SWD maneuver is a complex test maneuver where the steering must follow an exact sinusoidal pattern over a three-second time period. For the SWD maneuver, each test vehicle is subjected to as many 22 individual test runs all requiring activation at a specific vehicle speed, each of which will require a different peak steering wheel angle and corresponding steering wheel turning rate. To ensure the agency has an effective compliance program that will not vary from one test laboratory to another, from one test driver to another, or from one test vehicle to another, each maneuver must be repeatable and reproducible. The agency has extensive experience with execution of these and other steering maneuvers utilizing both human drivers and automated steering controllers. Based upon this experience, the agency has determined that a test driver cannot consistently execute these kinds of dynamic maneuvers exactly as required repeatedly. We note that, for the same reasons, the agency currently requires that automated steering machines be used for execution of the steering maneuvers performed under both the NCAP Rollover program and the FMVSS No. 126 light vehicle ESC program.

(c) Anti-Jackknife Cables

The agency proposes using anti-jackknife cables when testing truck tractors. Anti-jackknife cables would prevent the trailer from striking the tractor during testing in the event that a jackknife event occurs during testing. This would prevent damage to the tractor that may occur during testing. We do not believe that the use of anti-jackknife cables would affect test results, nor have we observed any damage to test vehicles, including vehicle finishes, caused by anti-jackknife cables. Nevertheless, we request comment on the necessity of the use of anti-jackknife cables during agency compliance testing.

(d) Control Trailer

The agency proposes using a control trailer to evaluate the performance of a tractor in its loaded condition. A control trailer would not be used when testing buses. In FMVSS No. 121, the agency specifies the use of an unbraked control trailer for compliance testing purposes. An unbraked control trailer minimizes the effect of the trailer's brakes when testing the braking performance of a tractor in its loaded condition.

The agency has also considered using a braked control trailer in ESC performance testing for truck tractors because the tractor-based stability control systems have the capability to apply the trailer brakes during stability

[51] Docket No. NHTSA–2010–0034–0010.

control intervention. This ability provides a slightly greater vehicle retardation that could further help prevent an impending rollover or reduce yaw instabilities.

As described in section IV.C above, the agency conducted numerous vehicle research test maneuvers using six different trailers. For each trailer, a test series was conducted collecting data for each trailer in a braked and unbraked condition. The effects of stability control, trailer brakes, and trailer type were analyzed using a logistical regression model to predict if wheel lift occurred during the test. A test was conducted to determine the effects of trailer brakes when stability control systems were enabled. With stability control systems enabled and trailer braking in the ''off'' position, the trailer was found not to be a significant factor in predicting wheel lift. Hence, the results indicate that the current FMVSS No. 121 unbraked control trailer can be used effectively in the stability control system testing to determine the capability of the tractor-based stability control system.

NHTSA's compliance tests must be objective, repeatable and reproducible. The goal of the testing program is to ensure that the ESC system takes the necessary actions of reducing engine torque and applying brakes to prevent yaw and roll instability. To achieve this goal any trailer type could be used as long as that trailer type becomes the ''standard'' trailer or ''control trailer'' used for all tractor trailer testing. Because it is the tractor performance that is being evaluated, the use of a standardized trailer will allow the test to distinguish the performance differences between different ESC systems and tractor types.

We believe that the current FMVSS No. 121 unbraked control trailer can be used effectively in the stability control testing to determine the capability of an ESC system. However, as discussed in section IV.D.5.(b) earlier, NHTSA's testing of EMA's Vehicle J revealed that the specifications for the control trailer in FMVSS No. 121 were not sufficient to ensure test repeatability.[52]

There were three specifications, not set forth in FMVSS No. 121, which could affect test performance and prevent repeatable, consistent test results using different control trailers. First, the track width of the control trailer is not specified. A trailer with a wider track width would be more stable than a trailer with a narrower track width, potentially affecting test results. Second, the center of gravity of the control trailer is not specified in FMVSS No. 121. The center of gravity of the trailer may be affected by the height of the load deck. A trailer with a higher load deck height would be less stable than a trailer with a lower load deck height. Third, the center of gravity of the load in FMVSS No. 121 testing is only specified to be less than 24 inches above the top of the tractor's fifth wheel. However, a load with a lower center of gravity (for example 12 inches) would be more stable than a load with a higher center of gravity (for example 24 inches).

The performance measures specified in this proposal were based upon NHTSA's testing using the control trailer used by VRTC researchers. Although the track width and center of gravity of the trailer are not specified in the proposed regulatory text and the center of gravity of the load is specified only by an upper bound, we request comment on possible specifications and appropriate levels of variability in trailer track width, trailer CG height, and load CG height for a control trailer to be used during ESC system testing.

(e) Sensors

A multi-axis inertial sensing system would be used to measure longitudinal, lateral, and vertical linear accelerations and roll, pitch, and yaw angular rates. The position of the multi-axis inertial sensing system must be measured relative to the center of gravity of the tractor when loaded. To simplify testing, the vertical center of gravity location is assumed to be at the top of the frame rails for tractors. For buses, the center of gravity height is assumed to be at the height of the main interior floor of the bus. The measured lateral acceleration and yaw rate data are required for determining the lateral displacement, LAR and YRR performance criteria. All six of the sensing system signals are utilized in the equations required to translate the motion of the vehicle at the measured location to that which occurred at the actual center of gravity to remove roll, pitch, and yaw effects.

The vehicle speed would be measured with a non-contact GPS-based speed sensor. Accurate speed data is required to ensure that the SWD maneuver is executed at the required 72.4 ± 1.6 km/h (45.0 ± 1.0 mph) test speed. Sensor outputs are available to allow the driver to monitor vehicle speed and data are provided as input to the automated steering machine for maneuver activation.

Infrared height sensors would be used to collect left and right side vertical ride height or displacement data for calculating vehicle roll angle. One sensor would be mounted on each side of the vehicle. With these data, roll angle is calculated during post-processing using trigonometry and would be used for correcting the measured lateral acceleration data due to the effects caused by body roll.

6. Test Conditions

(a) Ambient Conditions

The ambient temperature range specified in other FMVSSs for outdoor brake performance testing is 0 °C to 38 °C (32 °F to 100 °F). However, when the agency proposed a range of 0 °C to 40 °C (32 °F to 104 °F) for FMVSS No. 126, the issue of tire performance at near freezing temperatures was raised. The agency understood that near freezing temperatures could impact the variability of compliance test results. As a result, the agency increased the lower bound of the temperature range to 7 °C (45 °F) to minimize test variability at lower ambient temperatures. For the same reasons, this NPRM proposes an ambient temperature range of 7 °C to 40 °C (45 °F to 104 °F) for testing.

The agency proposes that the maximum wind speed for conducting the compliance testing for be no greater than 5 m/s (11 mph). This is the same value specified for testing multi-purpose passenger vehicles (MPVs), buses, and trucks under FMVSS No. 126. This is also the same value used for compliance testing for FMVSS No. 135, *Light Vehicle Brake Systems.* For FMVSS No. 126, the agency initially proposed a maximum wind speed of 10 m/s (22 mph) for all vehicles. However, the agency decided to reduce the speed for MPVs, buses, and trucks because of a concern that the higher wind speeds could impact the performance of certain vehicle configurations (*e.g.,* cube vans, 15 passenger vans, vehicles built in two or more stages).[53] Commenters to the proposed rule had estimated that a cross wind of 22 mph could reduce lateral displacement by 0.5 feet, compared to the same test conducted under calm conditions. The agency agreed that wind speed could have some impact on the lateral displacement for certain vehicle configurations and believes that the same argument is applicable testing truck tractors and large buses.

[52] The FMVSS No. 121 control trailer specifications, set forth in S6.1.10.2 and S6.1.10.3 of FMVSS No. 121 provide that the center of gravity of the ballast on the loaded control trailer be less than 24 inches above the top of the tractor's fifth wheel and that the trailer have a single axle with a GAWR of 18,000 pounds and a length, measured from the transverse centerline of the axle to the centerline of the kingpin, of 258 ± 6 inches.

[53] See 72 FR 17286 (Apr. 6, 2007).

Nevertheless, the agency notes that specifying such a low maximum wind speed can impose additional burdens on testing by restricting the environmental conditions under which testing can be conducted.

(b) Road Test Surface

The SWD maneuver executed on a high friction surface is a dynamically challenging maneuver that evaluates the effectiveness of an ESC system. Low friction surfaces, such as wet Jennite, are well known for producing a high degree of braking and handling tests variability compared to similar tests on high friction surfaces. The variability is exacerbated by the difficulty in ensuring a consistent water depth across the test surface. Therefore, this NPRM proposes conducting the SWD test on a dry test surface with a PFC of 0.9, which is typical of a dry asphalt surface or a dry concrete surface. As in other standards where the PFC is specified, we propose that the PFC be measured using an ASTM E1136 standard reference test tire in accordance with ASTM Method E1337–90, at a speed of 64.4 km/h (40 mph), without water delivery. We are proposing incorporating these ASTM provisions into the Standard.

(c) Vehicle Test Weight

The agency proposes that the combined weight of the truck tractor and control trailer be equal to 80 percent of the tractor's GVWR. To achieve this load condition the tractor is loaded with the fuel tanks filled to at least 75 percent capacity, test driver, test instrumentation and ballasted control trailer with outriggers. Center of gravity of all ballast on the control trailer is proposed to be located directly above the kingpin. When possible, load distribution on non-steer axles is in proportion to the tractor's respective axle GAWRs. Load distribution may be adjusted by altering fifth wheel position, if adjustable. In the case where the tractor fifth wheel cannot be adjusted so as to avoid exceeding a GAWR, ballast is reduced so that axle load equals specified GAWR, maintaining load proportioning as close as possible to specified proportioning.

The agency is proposing that liftable axles be in the down position for testing. This is because we are conducting our proposed performance test in a loaded condition. Typically, in real world use, we believe that a truck tractor loaded to 80% of its GVWR would operate with the liftable axle in the down position. Consequently, we propose to conduct compliance testing in that configuration.

For testing large buses, the agency proposes loading the vehicle to a simulated multi-passenger configuration. For this configuration the bus is loaded with the fuel tanks filled to at least 75 percent capacity, test driver, test instrumentation, outriggers and simulated occupants in each of the vehicle's designated seating positions. The simulated occupant loads are obtained by securing a 68 kilogram (150 pound) water dummy in each of the test vehicle's designated seating positions without exceeding the vehicle's GVWR and GAWR. The 68 kilogram (150 pound) occupant load was chosen because that is the occupant weight specified for use by the agency for evaluating a vehicle's load carrying capability under FMVSS Nos. 110 and 120. During loading, if any rating is exceeded the ballast load would be reduced until the respective rating or ratings are no longer exceeded.

(d) Tires

We propose testing the vehicles with the tires installed on the vehicle at time of initial vehicle sale. The agency's compliance test programs generally evaluate new vehicles with new tires. Therefore, we are proposing as a general rule that a new test vehicle have less than 500 miles on the odometer when received for testing.

For testing, the agency proposes that tires be inflated to the vehicle manufacturer's recommended cold tire inflation pressure(s) specified on the vehicle's certification label or the tire inflation pressure label. No tire changes would occur during testing unless test vehicle tires are damaged before or during testing. We are not proposing using inner tubes for testing because we have not seen any tire debeading in any test.

Before executing any SIS and SWD maneuvers, the agency is proposing to condition tires to wear away mold sheen and achieve operating temperatures. To begin the conditioning the test vehicle would be driven around a circle 46 meters (150 feet) in radius at a speed that produces a lateral acceleration of approximately 0.1g for two clockwise laps followed by two counterclockwise laps.

(e) Mass Estimation Drive Cycle

Both truck tractors and large buses experience large changes in payload mass, which affects a vehicle's roll and yaw stability thresholds. To adjust the activation thresholds for these changes, stability control systems estimate the mass of the vehicle after ignition cycles, periods of static idling, and other driving scenarios. To estimate the mass, these systems require a period of initial driving.

The agency proposes to include a mass estimation drive cycle as a part of pre-test conditioning. To complete this drive cycle the test vehicle is accelerated to a speed of 64 km/h (40 mph), and then, by applying the vehicle brakes, decelerated at 0.3g to 0.4g to a stop.

(f) Brake Conditioning

Heavy vehicle brake performance is affected by the original conditioning and temperatures of the brakes. We believe that incompletely burnished brakes and excessive brake temperatures can have an effect on ESC system test results, particularly in the rollover performance testing, because a hard brake application may be needed for the foundation brakes to reduce speed to prevent rollover.

FMVSS No. 126 uses a simple conditioning procedure by executing ten stops from 35 mph followed by three stops at 45 mph. Subsequently, a cool down period of between 90 seconds and 5 minutes is required between each SWD maneuver allowing sufficient time for the brakes to cool down but not so long that the brakes lose all their retained heat. However, for heavy vehicles, brake conditioning and operating temperatures are more critical to brake performance than for light vehicles primarily because the vast majority of heavy vehicles use drum brakes, which require more conditioning than disc brakes. We believe that conditioning needs to be more extensive and a brake temperature range is preferable to a specified cool-down period because each vehicle may have different cooling rates based on its configuration.

The agency is proposing that the brakes be burnished before any testing is executed. We believe that the burnish procedure specified in S6.1.8 of FMVSS No. 121, *Air Brake Systems,* provides the brake conditioning needed for the stability control system testing. The burnish procedure is performed by conducting 500 brake snubs [54] between 40 mph and 20 mph at a deceleration of 10 fp ^{2}. If the vehicle has already completed testing to FMVSS No. 121, we are not proposing to require the procedure be repeated. Instead, the brakes would be conditioned for the ESC with 40 snubs. The agency proposes that the brake temperatures be in the range of 65 °C to 204 °C (150 °F to 400 °F) at the beginning of each test maneuver. We also propose that the

[54] A snub is a brake application where the vehicle is not braked to a stop but to a lower speed.

brake temperature be measured by plug-type thermocouples installed on all brakes and that the hottest brake be used for determining whether cool-down periods are required.

After the brakes are burnished, immediately prior to executing any SIS or SWD maneuvers, the agency would perform 40 brake application snubs from a speed of 64 km/h (40 mph), with a target deceleration of approximately 0.3g. At end of the 40 snubs, the hottest brake temperature would be confirmed within the temperature range of 65 °C to 204 °C (150 °F to 400 °F). If the hottest brake temperature is above 204 °C (400 °F) a cool-down period would be provided until the hottest brake temperature is measured within that range. If the hottest brake temperature is below 65 °C (150 °F) individual brake stops would be repeated to increase any one brake temperature to within the target temperature range before the compliance testing can be continued.

7. Data Filtering and Post Processing

To determine if a test vehicle meets the performance requirements of the proposed standard, data needs to be measured and processed and ultimately used to calculate the lateral displacement, lateral acceleration ratio and yaw rate ratio performance measures. The agency understands that filtering and post processing methods, if not defined, can have a significant impact on the final test results used for determining vehicle compliance. When developing FMVSS No. 126 the agency received several comments recommending that filtering and processing methods be defined and included in the regulatory text. The agency decided to add to the test procedures section of the final rule's regulatory text a section that specified the critical test filtering protocols and techniques to be used for test data processing. We propose to include the same information in this standard. In addition, the agency proposes to make available on NHTSA's Web site the actual MATLAB code used for post-processing the critical lateral acceleration, yaw rate and lateral displacement performance data.

During post-processing the following data signals will be filtered and conditioned as follows:

1. Filter raw steering wheel angle data with a 12-pole phaseless Butterworth filter and a cutoff frequency of 10 Hz. Zero the filtered data to remove sensor offset utilizing static pretest data.

2. Filter raw yaw, pitch and roll rate data with a 12-pole phaseless Butterworth filter and a cutoff frequency of 3 Hz. Zero the filtered data to remove sensor offset utilizing static pretest data.

3. Filter raw lateral, longitudinal and vertical acceleration data with a 12-pole phaseless Butterworth filter and a cutoff frequency of 3 Hz. Zero the filtered data to remove sensor offset utilizing static pretest data.

4. Filter raw speed data with a 12-pole phaseless Butterworth filter and a cutoff frequency of 2 Hz.

5. Filter left side and right side ride height data with a 0.1-second running average filter. Zero the filtered data to remove sensor offset utilizing static pretest data.

6. The J1939 torque data collected as a digital signal does not get filtered. J1939 torque data collected as an analog signal is to be filtered with a 0.1-second running average filter.

There are several events in the calculation of performance metrics that require determining the time and/or level of an event, including: Beginning of steer, 1.5 seconds after beginning of steer, completion of steer, 0.75 second after completion of steer, and 1.50 seconds after completion of steer. The agency proposes using interpolation [55] for all of these circumstances because interpolation provides more consistent results than other approaches, such as choosing the sample that is closest in time to the desired event.

The beginning of steer is a critical moment during the maneuver because the lateral displacement performance measure is determined at exactly 1.5 seconds after the beginning of steer. For compliance purposes it is essential that the beginning of steer be determined accurately and consistently during each maneuver and each test. The process proposed in this NPRM to identify the beginning of steer uses three steps. The first step identifies when the steering wheel velocity exceeds 40 degrees per second. From this point, steering wheel velocity must remain greater than 40 degrees per second for at least 200 ms. If the condition is not met, the next time steering wheel velocity exceeds 40 degrees per second is identified and the 200 ms validity check is applied. This iterative process continues until the conditions are satisfied. In the second step, a zeroing range defined as the 1.0 second time period prior to the instant the steering wheel velocity exceeds 40 degrees per second. In the third step, the first instance the filtered and zeroed steering wheel angle data reaches minus 5 degrees (when the initial steering input is counterclockwise) or plus 5 degrees (when the initial steering input is clockwise) after the end of the zeroing range is identified. The time identified is taken to be the beginning of steer.

The agency understands that an unambiguous reference point to define the start of steering is necessary in order to ensure consistency when computing the performance metrics measured during compliance testing. The practical problem is that typical ''noise'' in the steering measurement channel causes continual small fluctuations of the signal about the zero point, so departure from zero with very small steering angles does not reliably indicate that the steering machine has started the test maneuver. NHTSA's extensive evaluation of zeroing range criteria has confirmed that the method successfully and robustly distinguishes the initiation of the SWD steering inputs from the inherent noise present in the steering wheel angle data channel. The value for time at the beginning of steer used for calculating the lateral displacement metric is interpolated.

The completion of steer is a critical moment during the maneuver because the LAR and YRR metrics are determined at specific time intervals after the completion of steer. The agency believes that an unambiguous point to define the completion of steer is also necessary for consistency in computing the required performance metrics during compliance testing. The agency proposes considering the first occurrence of the ''zeroed'' steering wheel angle crossing zero degrees after the second peak of steering wheel angle during the sine maneuver to be the completion of steer. Although signal noise results in continual zero crossings as long the data is being sampled, the first zero crossing after the steering wheel has begun to return to the zero position is a logical end to the steering maneuver.

Given the potential for the accelerometers used in the measurement and determination of lateral acceleration and lateral displacement to drift over time, the agency uses the data one second before the start of steering to ''zero'' the accelerometers and roll signal. Prior to the test maneuver, the driver must orient the vehicle to the desired heading, position the steering wheel angle to zero, and be coasting down (*i.e.,* not using throttle inputs) to the target test speed of 45 mph. This process, known as achieving a ''quasi steady-state,'' typically occurs a few seconds prior to initiation of the maneuver, but can be influenced by external factors such as test track traffic,

[55] Interpolation is a way of computing data values at the exact time that any of these events occur, even though the digital samples did not coincide with the exact event point. Rather, one sample is collected slightly before the time of the event and a second sample slightly after the time of the event.

differences in vehicle deceleration rates, etc. Any zeroing performed on test data must be performed after a quasi-steady-state condition has been satisfied, but before the maneuver is initiated. The proposed zeroing duration of one second provides an adequate combination of sufficient time (*i.e.,* enough data is present so as to facilitate accurate zeroing of the test data) and performability (*i.e.,* the duration is not so long that it imposes an unreasonable burden on the driver).

The lateral acceleration data are collected from an accelerometer, corrected for roll angle effects, and resolved to the vehicle's CG using coordinate transformation equations. The use of accelerometers is commonplace in the vehicle testing community, and installation is simple and well understood. However, in most cases, it is not possible to install a lateral acceleration sensor at the location of the vehicle's exact center of gravity. For this reason, it is important to provide a coordinate transformation to resolve the measured lateral acceleration values to the vehicle's center of gravity location. The specific equations proposed to perform this operation, as well as those used to correct lateral acceleration data for the effect of chassis roll angle, will be incorporated into the laboratory test procedure and are included in the MATLAB post processing routines used by the agency.

The equations used for coordinate transformation and vehicle body roll are as follows:

Equation 1: $x''_{corrected} = x''_{accel} - (\Theta'^2 + \Psi'^2)x_{disp} + (\Theta'\Phi' - \Psi'')y_{disp} + (\Psi'\Phi' + \Theta'')z_{disp}$

Equation 2: $y''_{corrected} = y''_{accel} + (\Theta'\Phi' + \Psi'')x_{disp} - (\Phi'^2 + \Psi'^2)y_{disp} + (\Psi'\Theta' - \Phi'')z_{disp}$

Equation 3: $z''_{corrected} = z''_{accel} + (\Psi'\Phi' - \Theta'')x_{disp} + (\Psi'\Theta' + \Phi'')y_{disp} - (\Phi'^2 + \Theta'^2)z_{disp}$

Where:

$x''_{corrected}$, $y''_{corrected}$, and $z''_{corrected}$ = longitudinal, lateral, and vertical accelerations, respectively, at the vehicle's center of gravity

x''_{accel}, y''_{accel}, and z''_{accel} = longitudinal, lateral, and vertical accelerations, respectively, at the accelerometer location

x_{disp}, y_{disp}, and z_{disp} = longitudinal, lateral, and vertical displacements, respectively, of the center of gravity with respect to the accelerometer location

Φ' and Φ'' = roll rate and roll acceleration, respectively

Θ' and Θ'' = pitch rate and pitch acceleration, respectively

Ψ' and Ψ'' = yaw rate and yaw acceleration, respectively

If the sensors used to measure the vehicle responses are of sufficient accuracy, and have been installed and configured correctly, use of the analysis routines provided by NHTSA are expected to minimize the potential for performance discrepancies among NHTSA and industry test efforts. The equations utilized are the same equations used by the agency for its NCAP rollover program and the FMVSS No. 126 light vehicle ESC program, and were derived from equations of general relative acceleration for a translating reference frame utilizing the SAE convention for Vehicle Dynamics Coordinate Systems.

Furthermore, NHTSA does not propose using inertially stabilized accelerometers for this test procedure. Therefore, lateral acceleration must be corrected for vehicle roll angle during data post processing. Non-contact displacement sensors are used to collect left and right side vertical displacements for the purpose of calculating vehicle roll angle. One sensor is mounted on each side of the vehicle, and is positioned at the longitudinal CG. With these data, roll angle is calculated during post-processing using trigonometry as follows:

Equation 4: $a_{yc} = a_{ym}\cos\Phi - a_{zm}\sin\Phi$

Where:

a_{yc} is the corrected lateral acceleration (*i.e.,* the vehicle's lateral acceleration in a plane horizontal to the test surface)

a_{ym} is the measured lateral acceleration in the vehicle reference frame

a_{zm} is the measured vertical acceleration in the vehicle reference frame

Φ is the vehicle's roll angle

Note: The z-axis sign convention is positive in the downward direction for both the vehicle and test surface reference frames.

G. Compliance Dates and Implementation Schedule

The agency proposes that all new typical 6x4 truck tractors and all buses covered by this proposal would be required to meet this proposed standard effective two years after the final rule is published. The current annual installation rate for stability control systems on new truck tractors is approximately 18 percent. Because there are currently only two suppliers of truck tractor and large bus stability control systems, Bendix and Meritor WABCO, we believe that the industry will need lead time to ensure that the necessary production stability control systems are available to manufacturers.

For severe service tractors and tractors with four axles or more, the agency believes that manufacturers of these atypical truck tractors, which represent about 5 percent of annual truck tractor sales, may need additional lead time to develop, test and equip these vehicles with a stability control system. Therefore, we are proposing to require that severe service tractors and other atypical tractors be equipped with ESC systems beginning four years after the final rule is published. We note that we made a similar distinction between typical 6x4 tractors and other tractors in specifying the lead time for amendments to FMVSS No. 121 mandating improved stopping distance performance.[56]

However, in our stopping distance rulemaking, we allowed extra time for two-axle tractors to comply because shorter wheelbase tractors (*i.e.,* two-axle tractors) showed a risk of instability resulting from the improved stopping distance requirements. However, the increased risk of instability in shorter wheelbase vehicles led us to the opposite tentative conclusion in this rulemaking. Because two-axle tractors have a particular risk of instability, we do not believe extending lead time for two-axle tractors is warranted.

The vast majority of new truck tractors are three-axle (6x4) vehicles, which facilitates standardization of ESC for these vehicles. The available test data for typical three-axle (6x4) tractors with stability control systems show that the existing ESC technology should enable these vehicles to readily comply with stability control requirements proposed by the agency. In addition, the agency's benefit analysis indicates that ESC provides substantial safety benefits to truck tractors. Hence, we believe that it is important that the implementation date for ESC on these vehicles be as early as practicable so that these safety benefits could be achieved.

Several manufacturers of Class 8 buses are already offering ESC as standard equipment on their vehicles but we are not aware of any Class 7 bus that is available with ESC. We believe that the manufacturers of Class 7 buses would need some lead time to have the ESC systems developed, tested and installed on their vehicles. Hence, for large buses, the agency proposes an effective date of two years after the final rule is published, primarily to accommodate manufacturers of Class 7 buses.

VI. Benefits and Costs

A. System Effectiveness

As discussed above, direct data that would show the effectiveness of stability control systems is not available

[56] See 49 CFR 571.121, Table IIA.

because stability control system technology on heavy vehicles is so new. Accordingly, NHTSA sponsored a research program with Meritor WABCO and UMTRI to examine the potential effectiveness of stability control systems on the fleet of truck tractors. A copy of UMTRI's report has been placed in the docket.

However, for NHTSA to calculate the effectiveness of stability control systems for truck tractors, two modifications were necessary. First, the UMTRI study based its effectiveness estimates on a simple aggregation of cases rather than weighting the likelihood of occurrence of each case. Second, based on NHTSA's independent review of the 159 cases, two cases were incorrectly categorized as loss of control rather than untripped rollover and the effectiveness rating of six cases were revised downward.

The results of UMTRI's study and the agency's revised effectiveness estimates were published in a January 2011 research note entitled ''Effectiveness of Stability Control Systems For Truck Tractors'' (DOT HS 811 437).[57] The effectiveness estimates from that research note are summarized in the following table.

TABLE 4—EFFECTIVENESS RATES FOR ESC AND RSC BY TARGET CRASHES

[Current NHTSA estimates]

Technology	Overall effectiveness (%)	Untripped rollover effectiveness (%)	Loss of control effectiveness (%)
ESC	28–36	40–56	14
RSC	21–30	37–53	3

For large buses, it was not feasible to conduct a similar statistical analysis because of limited crash data. However, NHTSA's testing revealed that an identical set of test maneuvers could be used to evaluate truck tractor and large bus systems' ability to prevent rollover and loss-of-control crashes. Therefore, for the purpose of this proposal, the effectiveness of ESC and RSC systems on large buses was assumed to be identical to the performance of systems on truck tractors.

B. Target Crash Population

The initial target crash population for estimating benefits includes all crashes resulting in occupant fatalities, MAIS 1 and above nonfatal injuries, and property damage only crashes that were the result of either (a) first-event untripped rollover crashes and (b) loss-of-control crashes (*e.g.,* jackknife, cargo shift, avoiding, swerving) that involved truck tractors or large buses and might be prevented if the subject vehicle were equipped with a stability control system. For this analysis, particularly in multi-vehicle crashes, the subject vehicle is the at-fault or striking vehicle. The initial target crash populations were retrieved from the 2006–2008 Fatality Analysis Reporting System (FARS) and General Estimate System (GES). The FARS data were used for evaluating fatal crashes and the GES data were used for evaluating nonfatal crashes. The injury data were converted to MAIS format and the following number of crashes, fatalities, injuries, and deaths were estimated.

TABLE 5—INITIAL TARGET CRASHES, MAIS INJURIES, AND PROPERTY DAMAGE ONLY VEHICLE CRASHES BY CRASH TYPE

Crash type	Crashes	Fatalities	MAIS 1–5 Injuries	PDOVs
Rollover	5,510	111	2,217	3,297
Loss of control	4,803	216	1,141	3,935
Total	10,313	327	3,358	7,332

Source: 2006–2008 FARS, 2006–2008 GES.
PDOVs: property damage only vehicles.

The 2006–2008 crash data were then adjusted to take account of ESC and RSC system installation rates in 2006–2008 and in model year 2012. To determine the number of crashes that could be prevented by requiring that ESC systems be installed on new truck tractors, the agency had to consider two subsets of the total crash population—those vehicles that would not be equipped with stability control systems (Base 1 population) and those vehicles that would be equipped with RSC systems (Base 2 population). The Base 1 population would benefit fully from this proposal. However, the Base 2 population would benefit only from the incremental increased effectiveness of ESC systems over RSC systems.

Based upon data obtained from industry, the agency estimates that about 1.9 percent of truck tractors in the on-road fleet in 2008 were equipped with ESC systems and 3.3 percent were equipped with RSC systems. Based upon manufacturer production estimates, about 26.2 percent of truck tractors manufactured in model year 2012 would be equipped with ESC systems and 16.0 percent would be equipped with RSC systems. Adjusting the initial target crash populations using these estimates, the agency was able to estimate the Base 1 and Base 2 populations and the projected target crash population (Base 1 + Base 2) expressed in the following table.

[57] Docket No. NHTSA–2010–0034–0043.

TABLE 6—PROJECTED CRASHES, MAIS INJURIES, AND PROPERTY DAMAGE ONLY VEHICLE CRASHES BY CRASH TYPE, CRASH SEVERITY, INJURY SEVERITY, AND VEHICLE TYPE FOR 2012 LEVEL

Crash type	Crashes	Fatalities	MAIS 1–5 Injuries	PDOVs
Base 1				
Rollover	3,263	66	1,313	1,952
Loss of Control	2,786	125	662	2,283
Total	6,049	191	1,975	4,235
Base 2				
Rollover	903	18	364	540
Loss of Control	771	35	183	632
Total	1,674	53	547	1,172
Base 1 + Base 2 (Projected Target Population)				
Rollover	4,166	84	1,677	2,492
Loss of Control	3,557	160	845	2,915
Total	7,723	244	2,522	5,407

Source: 2006–2008 FARS, 2006–2008 GES.
PDOVs: property damage only vehicles.

The agency has also examined the same crash data sources for large buses. Based upon this examination, the agency estimates that an average of one target bus rollover and one target bus loss-of-control crash occurs per year that would be affected by this proposal.

C. Benefits Estimate

ESC systems are crash avoidance countermeasures that would mitigate and even prevent crashes. Preventing a crash not only would save lives and reduce injuries, it also would alleviate crash-related travel delays and property damage. Therefore, the estimated benefits include both injury and non-injury components. The injury benefits are the estimated fatalities and injuries that would be mitigated or eliminated by ESC. The non-injury benefits include the travel delay and property damage savings from crashes that were avoided by ESC. Savings from reducing property-damage-only vehicle crashes also were included in the non-injury benefits.

The benefits estimates for rollover crashes are presented in a range in this analysis. This is the result of a range of ESC effectiveness figures in addressing rollover crashes that were used for the analysis. In contrast, at the publication, there is only one effectiveness estimate for addressing loss-of-control crashes.

The benefits of this proposal were derived by multiplying the projected target population by the corresponding effectiveness rates. As shown in Table 7, this proposal would prevent 1,807 to 2,329 target crashes, 49 to 60 fatalities, and 649 to 858 MAIS 1–5 injuries. Furthermore, the proposal would eliminate 1,187 to 1,499 property-damage-only crashes. Table 7 presents the benefits by target crash type.

TABLE 7—ESTIMATED BENEFITS OF THE PROPOSAL

Crash type	Crashes	Fatalities	MAIS 1–5 Injuries	PDOVs
Base 1 Benefits				
Rollover	1,305–1,827	26–37	526–735	781–1,093
Loss of Control	390	18	93	320
Total	1,695–2,217	44–55	619–828	1,101–1,413
Base 2 Benefits				
Rollover	27	1	11	16
Loss of Control	85	4	19	70
Total	112	5	30	86
Benefits of the Proposal (Base 1 + Base 2)				
Rollover	1,332–1,854	27–38	537–746	797–1,109
Loss of Control	475	22	112	390
Total	1,807–2,329	49–60	649–858	1,187–1,499

Source: 2006–2008 FARS, 2006–2008 GES.
PDOVs: property damage only vehicles.

The non-injury benefits also include savings from the elimination of crash-related travel delay and vehicle property damage. Table 8 shows the total travel delay and property damage savings from this proposal, broken down by target crash type. These benefits were derived by determining the unit cost of property damage and travel delay for each level of crash severity (*e.g.,* fatal, MAIS 1–5, or property damage only) and multiplying that cost by the number of incidents of each type of crash prevented. As shown in Table 8, this proposal would save (undiscounted) $17.1 to $22.0 million from travel delays and property damage as a result of crashes that would be prevented by this proposal.

TABLE 8—TOTAL TRAVEL DELAY AND PROPERTY DAMAGE SAVINGS

[Undiscounted 2010 $]

	Property damage	Travel delay	Property damage + travel delay
Rollover—Lower Bound	$7,713,841	$4,655,187	$12,369,028
Rollover—Upper Bound	10,735,872	6,475,446	17,211,318
Loss of Control	3,006,977	1,765,804	4,772,781
Total—Lower Bound	10,720,818	6,420,991	17,141,809
Total–Upper Bound	13,742,849	8,241,250	21,984,099

D. Cost Estimate

The cost of this proposal is derived from the product of the average unit cost of an ESC system and the number of vehicles affected by this proposal. The number of vehicles affected by this proposal would include vehicles that would have no stability control systems and vehicles that would be equipped with RSC systems. Therefore, when considering vehicles equipped with RSC systems, the average cost would be the difference between the cost of an ESC system and the cost of an RSC system.

Based upon data received from manufacturers, the agency estimates that the average unit cost for an ESC system is $1,160 and the average unit cost for an RSC system is $640; therefore, the incremental cost of installing an ESC system instead of an RSC system is $520 per vehicle. The agency did not receive cost information from large bus manufacturers. However, because the components used on truck tractors and buses are nearly identical, the unit cost estimates for truck tractors are used for buses.

The agency has estimated that 150,000 truck tractors and 2,200 buses covered by this proposal would be produced in model year 2012. As stated earlier, the agency estimates that 26.2 percent of truck tractors and 80 percent of buses covered by this proposal manufactured in model year 2012 would be equipped with ESC systems. In addition, 16.5 percent of truck tractors would be equipped with RSC systems. Accordingly, 57.8 percent of truck tractors and 20 percent of buses would be required to be equipped with an ESC system and 16.5 percent of truck tractors would be required to upgrade from an RSC system to an ESC system.

Table 9 summarizes the costs of this proposal based on the estimated unit cost of an ESC system and the number of vehicles that would need to be equipped with ESC systems. As shown in Table 10, the incremental cost of providing ESC systems compared to manufacturers' planned production in model year 2012 would cost $113.1 million for truck tractors and $0.5 million for large buses. Therefore, the total cost of this proposal is estimated to be $113.6 million.

TABLE 9—ANNUAL TOTAL COSTS FOR THE PROPOSAL

[2010 $]

	Technology upgrade needed		
	None	Incremental ESC	ESC
Truck Tractors:			
% Needing Upgrade	26.2%	16.0%	57.8%
150,000 Sales Estimated	39,300	24,000	86,700
Costs per Affected Vehicle	0	$520	$1,160
Total Costs	0	$12.5 M	$100.6 M
Large Buses:			
% Needing Upgrade	80%	0%	20%
2,200 Sales Estimated	1,760	0	440
Costs per Affected Vehicle	0	$520	$1,160
Total Costs	0	0	$0.5 M

M: million.

TABLE 10—SUMMARY OF VEHICLE COSTS

[2010 $]

	Average vehicle costs	Total costs
Truck Tractors	$753.7	$113.1 M
Large Buses	232.0	0.5 M
Total	746.1	113.6 M

M: million.

We also note that manufacturers may incur costs to certify their vehicles as compliant with the proposed standard. We have estimated the cost to conduct the proposed test maneuvers. We believe that the execution of the proposed SIS and SWD maneuvers would cost approximately $15,000 per test, assuming access to test facilities, tracks, and vehicles. Because it is not possible to anticipate how many tests manufacturers might choose to run to certify a specific make, model, and configuration, the agency cannot estimate the total compliance costs for manufacturers. However, compliance costs are implicitly included in the estimated consumer cost, which includes a 150% markup to account for fixed and overhead costs.

E. Cost Effectiveness

Safety benefits can occur at any time during the vehicle's lifetime. Therefore, the benefits are discounted at both 3 and 7 percent to reflect their values in 2010 dollars, as reflected in Table 11. Table 11 also shows that the net cost per equivalent life saved from this proposal ranged from $1.5 to $2.0 million at a 3 percent discount rate and from $2.0 to $2.6 million at a 7 percent discount rate. The net benefits of this proposal are estimated to range from $228 to $310 million at a 3 percent discount rate and from $155 to $222 million at a 7 percent discount rate.

TABLE 11—SUMMARY OF COST-EFFECTIVENESS AND NET BENEFITS BY DISCOUNT RATE

[2010 $]

	3% Discount		7% Discount	
	Low	High	Low	High
Fatal Equivalents	51	63	40	50
Injury Benefits	$328,197,087	$405,419,931	$257,409,480	$321,761,850
Property Damage and Travel Delay Savings	$13,862,581	$17,778,541	$11,006,756	$14,115,990
Vehicle Costs *	$113,562,400	$113,562,400	$113,562,400	$113,562,400
Net Costs	$99,699,819	$95,783,859	$102,555,644	$99,446,410
Net Cost Per Fatal Equivalent	$1,954,898	$1,520,379	$2,563,891	$1,988,928
Net Benefits	$228,497,268	$309,636,072	$154,853,836	$222,315,440

* Vehicle costs are not discounted, since they occur when the vehicle is purchased, whereas benefits occur over the vehicle's lifetime and are discounted back to the time of purchase.

F. Comparison of Regulatory Alternatives

The agency considered two alternatives to the proposal. The first alternative was requiring RSC systems be installed on all newly manufactured truck tractors and buses covered by this proposal. The second alternative was requiring RSC systems be installed on all newly manufactured trailers.

Regarding the first alternative, requiring RSC systems be installed on truck tractors and large buses, our research has concluded that RSC systems are less effective than ESC systems. Overall for the target crash population, our research has indicated that RSC systems have a 21 to 30 percent effectiveness rate, whereas ESC systems have a 28 to 36 percent effectiveness rate. An RSC system is only slightly less effective at preventing rollover crashes than an ESC system (37 to 53 percent versus 40 to 56 percent effective, respectively), but it is much less effective at preventing loss of control crashes (3 percent versus 14 percent). However, RSC systems are only estimated to cost $640 per unit, whereas ESC systems are estimated to cost $1,160 per unit. Furthermore, only approximately 57.8% of truck tractors would be required to install RSC systems based on the data discussed earlier regarding manufacturers' plans.

A summary of the cost effectiveness of RSC systems is set forth in Table 12. When comparing this alternative to the regulatory proposal, requiring RSC systems rather than ESC systems would be slightly more cost effective. However, this alternative would save fewer lives and have lower net benefits than this proposal.

TABLE 12—SUMMARY OF COST-EFFECTIVENESS AND NET BENEFITS BY DISCOUNT RATE ALTERNATIVE 1—REQUIRING TRACTOR-BASED RSC SYSTEMS

[2010 $]

	3% Discount		7% Discount	
	Low	High	Low	High
Fatal Equivalents	31	43	24	34
Injury Benefits	$199,492,347	$276,715,191	$154,445,688	$218,798,058
Property Damage and Travel Delay Savings	$9,714,383	$13,649,563	$7,713,126	$10,837,621
Vehicle Costs *	$55,769,600	$55,769,600	$55,769,600	$55,769,600
Net Costs	$46,055,217	$42,120,037	$48,056,474	$44,931,979
Net Cost Per Fatal Equivalent	$1,485,652	$979,536	$2,002,353	$1,321,529
Net Benefits	$153,437,130	$234,595,154	$106,389,214	$173,866,079

* Vehicle costs are not discounted, since they occur when the vehicle is purchased, whereas benefits occur over the vehicle's lifetime and are discounted back to the time of purchase.

The second alternative considered was requiring trailer-based RSC systems to be installed on all newly manufactured trailers. Trailer-based RSC systems would only be expected to prevent rollover crashes. Based on 2006–2008 GES data, 98 percent of the target truck-tractor crashes involve truck tractors with trailers attached. Therefore, the base crash population would be 98 percent of Base 1 discussed above.

As discussed in the proposal, it became apparent during testing that trailer-based stability control systems were less effective than tractor-based systems because trailer-based systems could only control the trailer's brakes. Based upon the agency's test data, it is estimated that the effectiveness of trailer-based RSC systems in preventing rollover crashes is 7 to 10 percent. Therefore, the benefits of trailer-based RSC systems in preventing rollover are about 17.2 percent of tractor-based ESC systems.

The agency estimates that about 203,000 new trailers are manufactured each year. Further, based on information from manufacturers, the agency estimates that a trailer-based RSC system would cost $400 per trailer. Available data indicates that less than 0.2 percent of the current annual production of trailers comes with RSC systems installed. Assuming all new trailers would be required to install RSC, the cost of this alternative is estimated to be $81.2 million.

Table 13 sets forth a summary of the cost effectiveness of trailer-based RSC systems. Because the operational life of a trailer (approximately 45 years) is much longer than that of a truck tractor, it would take longer for trailer-based RSC systems to fully penetrate the fleet than it would for any tractor-based system. Therefore, when the benefits of trailer-based RSC systems are discounted at a 3 and 7 percent rate, there is a much higher discount factor. As can be seen in Table 13, this results in this alternative having negative net benefits and a high cost per life saved. Also, this alternative would have no effect on buses. Accordingly, the agency does not favor this alternative.

TABLE 13—SUMMARY OF COST-EFFECTIVENESS AND NET BENEFITS BY DISCOUNT RATE ALTERNATIVE 2—REQUIRING TRAILER-BASED RSC SYSTEMS

[2010 $]

	At 3% Discount		At 7% Discount	
	Low	High	Low	High
Fatal Equivalents	5	7	3	5
Injury Benefits	$30,754,672	$43,935,246	$20,700,937	$29,572,767
Property Damage and Travel Delay Savings	$1,459,169	$2,038,560	$982,165	$1,372,153
Vehicle Costs *	$81,200,000	$81,200,000	$81,200,000	$81,200,000
Net Costs	$79,740,831	$79,161,440	$80,217,835	$79,827,847
Net Cost Per Fatal Equivalent	$15,948,166	$11,308,777	$26,739,278	$15,965,569
Net Benefits	−$48,986,159	−$35,226,194	−$59,516,898	−$50,255,080

* Vehicle costs are not discounted, since they occur when the vehicle is purchased, whereas benefits occur over the vehicle's lifetime and are discounted back to the time of purchase.

The information in Tables 12 and 13 can be contrasted with this proposal. A summary of the total costs and benefits and annualized costs and benefits of this proposal appears in Table 14.

TABLE 14—ESTIMATED TOTAL COSTS AND BENEFITS OF THE PROPOSAL

[In millions of 2010 dollars]

	Total costs	Injury benefits	Property damage and travel delay savings	Cost per equivalent live saved	Net benefits
At 3% Discount	$113.6	$328–$405	$13.9–$17.8	$1.5–$2.0	$228–$310
At 7% Discount	113.6	257–322	11.0–14.1	2.0–2.6	155–222

VII. Public Participation

How do I prepare and submit comments?

Your comments must be written and in English. To ensure that your comments are correctly filed in the Docket, please include the docket number of this document in your comments.

Your comments must not be more than 15 pages long (49 CFR 553.21). We established this limit to encourage you to write your primary comments in a concise fashion. However, you may attach necessary additional documents to your comments. There is no limit on the length of the attachments.

Please submit two copies of your comments, including the attachments, to Docket Management at the beginning of this document, under ADDRESSES. You may also submit your comments electronically to the docket following the steps outlined under ADDRESSES.

How can I be sure that my comments were received?

If you wish Docket Management to notify you upon its receipt of your comments, enclose a self-addressed, stamped postcard in the envelope containing your comments. Upon receiving your comments, Docket Management will return the postcard by mail.

How do I submit confidential business information?

If you wish to submit any information under a claim of confidentiality, you should submit the following to the NHTSA Office of Chief Counsel (NCC–110), 1200 New Jersey Avenue SE., Washington, DC 20590: (1) A complete copy of the submission; (2) a redacted copy of the submission with the confidential information removed; and (3) either a second complete copy or those portions of the submission containing the material for which confidential treatment is claimed and any additional information that you deem important to the Chief Counsel's consideration of your confidentiality claim. A request for confidential treatment that complies with 49 CFR Part 512 must accompany the complete submission provided to the Chief Counsel. For further information, submitters who plan to request confidential treatment for any portion of their submissions are advised to review 49 CFR part 512, particularly those sections relating to document submission requirements. Failure to adhere to the requirements of Part 512 may result in the release of confidential information to the public docket. In addition, you should submit two copies from which you have deleted the claimed confidential business information, to Docket Management at the address given at the beginning of this document under **ADDRESSES**.

Will the Agency consider late comments?

We will consider all comments that Docket Management receives before the close of business on the comment closing date indicated at the beginning of this notice under **DATES**. In accordance with our policies, to the extent possible, we will also consider comments that Docket Management receives after the specified comment closing date. If Docket Management receives a comment too late for us to consider in developing the proposed rule, we will consider that comment as an informal suggestion for future rulemaking action.

How can I read the comments submitted by other people?

You may read the comments received by Docket Management at the address and times given near the beginning of this document under **ADDRESSES**.

You may also see the comments on the Internet. To read the comments on the Internet, go to *http://www.regulations.gov* and follow the on-line instructions provided.

You may download the comments. The comments are imaged documents, in either TIFF or PDF format. Please note that even after the comment closing date, we will continue to file relevant information in the Docket as it becomes available. Further, some people may submit late comments. Accordingly, we recommend that you periodically search the Docket for new material.

VIII. Regulatory Analyses and Notices

A. Executive Order 12866, Executive Order 13563, and DOT Regulatory Policies and Procedures

NHTSA has considered the impact of this rulemaking action under Executive Order 12866, Executive Order 13563, and the Department of Transportation's regulatory policies and procedures. This rulemaking is considered economically significant and was reviewed by the Office of Management and Budget under E.O. 12866, ''Regulatory Planning and Review.'' The rulemaking action has also been determined to be significant under the Department's regulatory policies and procedures. NHTSA has placed in the docket a Preliminary Regulatory Impact Analysis (PRIA) describing the benefits and costs of this rulemaking action. The benefits and costs are summarized in section VI of this preamble.

Consistent with Executive Order 13563 and to the extent permitted under the Vehicle Safety Act, we have considered the cumulative effects of the new regulations stemming from NHTSA's 2007 ''NHTSA's Approach to Motorcoach Safety'' plan and DOT's 2009 Motorcoach Safety Action Plan, and have taken steps to identify opportunities to harmonize and streamline those regulations. By coordinating the timing and content of the rulemakings, our goal is to expeditiously maximize the net benefits of the regulations (by either increasing benefits or reducing costs or a combination of the two) while simplifying requirements on the public and ensuring that the requirements are justified. We seek to ensure that this coordination will also simplify the implementation of multiple requirements on a single industry.

NHTSA's Motorcoach Safety Action Plan identified four priority areas—passenger ejection, rollover structural integrity, emergency egress, and fire safety. There have been other initiatives on large bus performance, such as ESC systems—an action included in the DOT plan—and an initiative to update the large bus tire standard.[58] In deciding how best to initiate and coordinate rulemaking in these areas, NHTSA examined various factors including the benefits that would be achieved by the rulemakings, the anticipated vehicle designs and countermeasures needed to comply with the regulations, and the extent to which the timing and content of the rulemakings could be coordinated to lessen the need for multiple redesign and to lower overall costs. After this examination, we decided on a course of action that prioritized the goal of reducing passenger ejection and increasing frontal impact protection because many benefits could be achieved expeditiously with countermeasures that were readily available (using bus seats with integral seat belts, which are already available from seat suppliers) and whose installation would not significantly impact other vehicle designs. Similarly, we have also determined that an ESC rulemaking would present relatively few synchronization issues with other rules, because the vehicles at issue already have the foundation braking systems needed for the stability control technology and the additional equipment necessary for an ESC system are sensors that are already available and that can be installed without significant impact on other vehicle systems. Further, we estimate that 80 percent of the affected buses already have ESC systems. We realize that a rollover structural integrity rulemaking, or an emergency egress rulemaking, could involve more redesign of vehicle structure than rules involving systems such as seat belts, ESC, or tires.[59] Our decision-making in these and all the rulemakings outlined in the ''NHTSA's Approach to Motorcoach Safety'' plan and DOT's Motorcoach Safety Action Plan will be cognizant of the timing and content of the actions so as to simplify requirements applicable to the public and private sectors, ensure that requirements are justified, and increase the net benefits of the resulting safety standards.

B. Regulatory Flexibility Act

Pursuant to the Regulatory Flexibility Act (5 U.S.C. 601 *et seq.,* as amended by the Small Business Regulatory Enforcement Fairness Act (SBREFA) of 1996), whenever an agency is required to publish a notice of rulemaking for any proposed or final rule, it must prepare and make available for public comment a regulatory flexibility analysis that describes the effect of the rule on small entities (*i.e.,* small businesses, small organizations, and small governmental jurisdictions). The Small Business Administration's regulations at 13 CFR Part 121 define a small business, in part, as a business entity ''which operates primarily within the United States.'' (13 CFR 121.105(a)).

[58] 75 FR 60037 (Sept. 29, 2010).

[59] The initiative on fire safety is in a research phase. Rulemaking resulting from the research will not occur in the near term.

No regulatory flexibility analysis is required if the head of an agency certifies the rule will not have a significant economic impact on a substantial number of small entities. SBREFA amended the Regulatory Flexibility Act to require Federal agencies to provide a statement of the factual basis for certifying that a rule will not have a significant economic impact on a substantial number of small entities.

NHTSA has considered the effects of this NPRM under the Regulatory Flexibility Act. I certify that this NPRM will not have a significant economic impact on a substantial number of small entities. This proposed rule would directly impact manufacturers of truck-tractors, large buses, and stability control systems for those vehicles. NHTSA believes these entities do not qualify as small entities.

C. Executive Order 13132 (Federalism)

NHTSA has examined today's final rule pursuant to Executive Order 13132 (64 FR 43255, August 10, 1999) and concluded that no additional consultation with States, local governments or their representatives is mandated beyond the rulemaking process. The agency has concluded that the rulemaking would not have sufficient federalism implications to warrant consultation with State and local officials or the preparation of a federalism summary impact statement. The final rule would not have ''substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government.''

NHTSA rules can preempt in two ways. First, the National Traffic and Motor Vehicle Safety Act contains an express preemption provision: When a motor vehicle safety standard is in effect under this chapter, a State or a political subdivision of a State may prescribe or continue in effect a standard applicable to the same aspect of performance of a motor vehicle or motor vehicle equipment only if the standard is identical to the standard prescribed under this chapter. 49 U.S.C. 30103(b)(1). It is this statutory command by Congress that preempts any non-identical State legislative and administrative law addressing the same aspect of performance.

The express preemption provision described above is subject to a savings clause under which ''[c]ompliance with a motor vehicle safety standard prescribed under this chapter does not exempt a person from liability at common law.'' 49 U.S.C. 30103(e). Pursuant to this provision, State common law tort causes of action against motor vehicle manufacturers that might otherwise be preempted by the express preemption provision are generally preserved. However, the Supreme Court has recognized the possibility, in some instances, of implied preemption of such State common law tort causes of action by virtue of NHTSA's rules, even if not expressly preempted. This second way that NHTSA rules can preempt is dependent upon there being an actual conflict between an FMVSS and the higher standard that would effectively be imposed on motor vehicle manufacturers if someone obtained a State common law tort judgment against the manufacturer, notwithstanding the manufacturer's compliance with the NHTSA standard. Because most NHTSA standards established by an FMVSS are minimum standards, a State common law tort cause of action that seeks to impose a higher standard on motor vehicle manufacturers will generally not be preempted. However, if and when such a conflict does exist—for example, when the standard at issue is both a minimum and a maximum standard—the State common law tort cause of action is impliedly preempted. See *Geier* v. *American Honda Motor Co.,* 529 U.S. 861 (2000).

Pursuant to Executive Order 13132 and 12988, NHTSA has considered whether this rule could or should preempt State common law causes of action. The agency's ability to announce its conclusion regarding the preemptive effect of one of its rules reduces the likelihood that preemption will be an issue in any subsequent tort litigation.

To this end, the agency has examined the nature (*e.g.,* the language and structure of the regulatory text) and objectives of today's rule and finds that this rule, like many NHTSA rules, prescribes only a minimum safety standard. As such, NHTSA does not intend that this rule preempt state tort law that would effectively impose a higher standard on motor vehicle manufacturers than that established by today's rule. Establishment of a higher standard by means of State tort law would not conflict with the minimum standard announced here. Without any conflict, there could not be any implied preemption of a State common law tort cause of action.

D. Executive Order 12988 (Civil Justice Reform)

With respect to the review of the promulgation of a new regulation, section 3(b) of Executive Order 12988, ''Civil Justice Reform'' (61 FR 4729; Feb. 7, 1996), requires that Executive agencies make every reasonable effort to ensure that the regulation: (1) Clearly specifies the preemptive effect; (2) clearly specifies the effect on existing Federal law or regulation; (3) provides a clear legal standard for affected conduct, while promoting simplification and burden reduction; (4) clearly specifies the retroactive effect, if any; (5) specifies whether administrative proceedings are to be required before parties file suit in court; (6) adequately defines key terms; and (7) addresses other important issues affecting clarity and general draftsmanship under any guidelines issued by the Attorney General. This document is consistent with that requirement.

Pursuant to this Order, NHTSA notes as follows. The issue of preemption is discussed above. NHTSA notes further that there is no requirement that individuals submit a petition for reconsideration or pursue other administrative proceedings before they may file suit in court.

E. Protection of Children From Environmental Health and Safety Risks

Executive Order 13045, ''Protection of Children from Environmental Health and Safety Risks'' (62 FR 19855, April 23, 1997), applies to any rule that: (1) Is determined to be ''economically significant'' as defined under Executive Order 12866, and (2) concerns an environmental, health, or safety risk that the agency has reason to believe may have a disproportionate effect on children. If the regulatory action meets both criteria, the agency must evaluate the environmental health or safety effects of the planned rule on children, and explain why the planned regulation is preferable to other potentially effective and reasonably feasible alternatives considered by the agency.

This notice is part of a rulemaking that is not expected to have a disproportionate health or safety impact on children. Consequently, no further analysis is required under Executive Order 13045.

F. Paperwork Reduction Act

Under the Paperwork Reduction Act of 1995 (PRA), a person is not required to respond to a collection of information by a Federal agency unless the collection displays a valid OMB control number. There is not any information collection requirement associated with this NPRM.

G. National Technology Transfer and Advancement Act

Section 12(d) of the National Technology Transfer and Advancement Act (NTTAA) requires NHTSA to evaluate and use existing voluntary consensus standards in its regulatory activities unless doing so would be inconsistent with applicable law (*e.g.,* the statutory provisions regarding NHTSA's vehicle safety authority) or otherwise impractical. Voluntary consensus standards are technical standards developed or adopted by voluntary consensus standards bodies. Technical standards are defined by the NTTAA as ''performance-based or design-specific technical specification and related management systems practices.'' They pertain to ''products and processes, such as size, strength, or technical performance of a product, process or material.''

Examples of organizations generally regarded as voluntary consensus standards bodies include ASTM International, the Society of Automotive Engineers (SAE), and the American National Standards Institute (ANSI). If NHTSA does not use available and potentially applicable voluntary consensus standards, we are required by the Act to provide Congress, through OMB, an explanation of the reasons for not using such standards.

This NPRM proposes to require truck tractors and large buses to have electronic stability control systems. In the proposed definitional requirement, the agency adapted the criteria from the light vehicle ESC rulemaking, which was based on (with minor modifications) SAE Surface Vehicle Information Report on Automotive Stability Enhancement Systems J2564 Rev JUN2004 that provides an industry consensus definition of an ESC system. In addition, SAE International has a Recommended Practice on Brake Systems Definitions—Truck and Bus, J2627 AUG2009 that has been incorporated into the agency's definition. The agency has also incorporated by reference two ASTM standards in order to provide specifications for the road test surface. These are: (1) ASTM E1136–93 (Reapproved 2003), ''Standard Specification for a Radial Standard Reference Test Tire,'' and (2) ASTM E1337–90 (Reapproved 2008), ''Standard Test Method for Determining Longitudinal Peak Braking Coefficient of Paved Surfaces Using a Standard Reference Test Tire.''

H. Unfunded Mandates Reform Act

Section 202 of the Unfunded Mandates Reform Act of 1995 (UMRA) requires federal agencies to prepare a written assessment of the costs, benefits, and other effects of proposed or final rules that include a Federal mandate likely to result in the expenditure by State, local, or tribal governments, in the aggregate, or by the private sector, of more than $100 million annually (adjusted for inflation with base year of 1995). Before promulgating a NHTSA rule for which a written statement is needed, section 205 of the UMRA generally requires the agency to identify and consider a reasonable number of regulatory alternatives and adopt the least costly, most cost-effective, or least burdensome alternative that achieves the objectives of the rule. The provisions of section 205 do not apply when they are inconsistent with applicable law. Moreover, section 205 allows the agency to adopt an alternative other than the least costly, most cost-effective, or least burdensome alternative if the agency publishes with the final rule an explanation of why that alternative was not adopted.

This NPRM will not result in any expenditure by State, local, or tribal governments or the private sector of more than $100 million, adjusted for inflation. When $100 million is adjusted by the implicit gross domestic product price deflator for the year 2010, the result is $136 million. This NPRM is not subject to the requirements of sections 202 and 205 of the UMRA because it is not estimated to result in an expenditure of more than $136 million annually by State, local, or tribal governments or the private sector.

I. National Environmental Policy Act

NHTSA has analyzed this rulemaking action for the purposes of the National Environmental Policy Act. The agency has determined that implementation of this action will not have any significant impact on the quality of the human environment.

J. Plain Language

Executive Order 12866 requires each agency to write all rules in plain language. Application of the principles of plain language includes consideration of the following questions:

- Have we organized the material to suit the public's needs?
- Are the requirements in the rule clearly stated?
- Does the rule contain technical language or jargon that isn't clear?
- Would a different format (grouping and order of sections, use of headings, paragraphing) make the rule easier to understand?
- Would more (but shorter) sections be better?
- Could we improve clarity by addling tables, lists, or diagrams?
- What else could we do to make the rule easier to understand?

If you have any responses to these questions, please include them in your comments on this proposal.

K. Regulatory Identifier Number (RIN)

The Department of Transportation assigns a regulation identifier number (RIN) to each regulatory action listed in the Unified Agenda of Federal Regulations. The Regulatory Information Service Center publishes the Unified Agenda in April and October of each year. You may use the RIN contained in the heading at the beginning of this document to find this action in the Unified Agenda.

L. Privacy Act

Anyone is able to search the electronic form of all comments received into any of our dockets by the name of the individual submitting the comment (or signing the comment, if submitted on behalf of an association, business, labor union, etc.). You may review DOT's complete Privacy Act Statement in the **Federal Register** published on April 11, 2000 (65 FR 19477–78).

List of Subjects in 49 CFR Part 571

Imports, Incorporation by reference, Motor vehicle safety, Motor vehicles, Rubber and rubber products, and Tires.

Proposed Regulatory Text

In consideration of the foregoing, we propose to amend 49 CFR part 571 to read as follows:

PART 571—FEDERAL MOTOR VEHICLE SAFETY STANDARDS

1. The authority citation for part 571 continues to read as follows:

Authority: 49 U.S.C. 322, 30111, 30115, 30166 and 30177; delegation of authority at 49 CFR 1.50.

2. Revise paragraphs (d)(32) and (d)(33) of § 571.5 to read as follows:

§ 571.5 Matter incorporated by reference.

* * * * *

(d) * * *

(32) ASTM E1136–93 (Reapproved 2003), ''Standard Specification for a Radial Standard Reference Test Tire,'' approved March 15, 1993, into §§ 571.105; 571.121; 571.126; 571.135; 571.136; 571.139; 571.500.

(33) ASTM E1337–90 (Reapproved 2008), ''Standard Test Method for

Determining Longitudinal Peak Braking Coefficient of Paved Surfaces Using a Standard Reference Test Tire,'' approved June 1, 2008, into §§ 571.105; 571.121; 571.126; 571.135; 571.136; 571.500.

* * * * *

3. Revise the heading of § 571.126 to read as follows:

§ 571.126 Standard No. 126; Electronic stability control systems for light vehicles.

* * * * *

4. Add § 571.136 to read as follows:

§ 571.136 Standard No. 136; Electronic stability control systems for heavy vehicles.

S1. *Scope.* This standard establishes performance and equipment requirements for electronic stability control (ESC) systems on heavy vehicles.

S2. *Purpose.* The purpose of this standard is to reduce crashes caused by rollover or by directional loss-of-control.

S3. *Application.* This standard applies to truck tractors and buses with a gross vehicle weight rating of greater than 11,793 kilograms (26,000 pounds). However, it does not apply to:

(a) Any truck tractor or bus equipped with an axle that has a gross axle weight rating (GAWR) of 29,000 pounds or more;

(b) Any truck tractor or bus that has a speed attainable in 2 miles of not more than 33 mph;

(c) Any truck tractor that has a speed attainable in 2 miles of not more than 45 mph, an unloaded vehicle weight that is not less than 95 percent of its gross vehicle weight rating (GVWR), and no capacity to carry occupants other than the driver and operating crew;

(d) Any bus with fewer than 16 designated seating positions (including the driver);

(e) Any bus with fewer than 2 rows of passenger seats that are rearward of the driver's seating position and are forward-facing or can convert to forward-facing without the use of tools;

(f) School buses; and

(g) Any urban transit buses sold for operation as a common carrier in urban transportation along a fixed route with frequent stops.

S4. *Definitions.*

Ackerman Steer Angle means the angle whose tangent is the wheelbase divided by the radius of the turn at a very low speed.

Electronic stability control system or *ESC system* means a system that has all of the following attributes:

(1) That augments vehicle directional stability by applying and adjusting the vehicle brake torques individually at each wheel position on at least one front and at least one rear axle of the vehicle to induce correcting yaw moment to limit vehicle oversteer and to limit vehicle understeer;

(2) That enhances rollover stability by applying and adjusting the vehicle brake torques individually at each wheel position on at least one front and at least one rear axle of the vehicle to reduce lateral acceleration of a vehicle;

(3) That is computer-controlled with the computer using a closed-loop algorithm to induce correcting yaw moment and enhance rollover stability;

(4) That has a means to determine the vehicle's lateral acceleration;

(5) That has a means to determine the vehicle's yaw rate and to estimate its side slip or side slip derivative with respect to time;

(6) That has a means to estimate vehicle mass or, if applicable, combination vehicle mass;

(7) That has a means to monitor driver steering inputs;

(8) That has a means to modify engine torque, as necessary, to assist the driver in maintaining control of the vehicle and/or combination vehicle; and

(9) That, when installed on a truck tractor, has the means to provide brake pressure to automatically apply and modulate the brake torques of a towed semi-trailer.

Initial brake temperature means the average temperature of the service brakes on the hottest axle of the vehicle immediately before any stability control system test maneuver is executed.

Lateral acceleration means the component of the vector acceleration of a point in the vehicle perpendicular to the vehicle x axis (longitudinal) and parallel to the road plane.

Oversteer means a condition in which the vehicle's yaw rate is greater than the yaw rate that would occur at the vehicle's speed as result of the Ackerman Steer Angle.

Peak friction coefficient or *PFC* means the ratio of the maximum value of braking test wheel longitudinal force to the simultaneous vertical force occurring prior to wheel lockup, as the braking torque is progressively increased.

Sideslip or *side slip angle* means the arctangent of the lateral velocity of the center of gravity of the vehicle divided by the longitudinal velocity of the center of gravity.

Understeer means a condition in which the vehicle's yaw rate is less than the yaw rate that would occur at the vehicle's speed as result of the Ackerman Steer Angle.

Yaw Rate means the rate of change of the vehicle's heading angle measure in degrees per second of rotation about a vertical axis through the vehicle's center of gravity.

S5. *Requirements.* Each vehicle must be equipped with an ESC system that meets the requirements specified in S5 under the test conditions specified in S6 and the test procedures specified in S7 of this standard.

S5.1 *Required Equipment.* Each vehicle to which this standard applies must be equipped with an electronic stability control system, as defined in S4.

S5.2 *System Operational Capabilities.*

S5.2.1 An electronic stability control system must be operational over the full speed range of the vehicle except at vehicle speeds less than 20 km/h (12.4 mph), when being driven in reverse, or during system initialization.

S5.2.2 An electronic stability control system must remain capable of activation even if the antilock brake system or traction control is also activated.

S5.3 *Performance Requirements.*

S5.3.1 *Slowly Increasing Steer Maneuver.* During the slowly increasing steer test maneuver performed under the test conditions of S6 and the test procedure of S7.6, the vehicle with the ESC system enabled must satisfy the engine torque reduction criteria of S5.3.1.1.

S5.3.1.1 The engine torque reduction when measured 1.5 seconds after the activation of the electronic stability control system must be at least 10 percent less than the engine torque requested by the driver.

S5.3.2 *Sine With Dwell Maneuver.* During each sine with dwell maneuver performed under the test conditions of S6 and the test procedure of S7.10, the vehicle with the ESC system enabled must satisfy the roll stability criteria of S5.3.2.1 and S5.3.2.2, the yaw stability criteria of S5.3.2.3 and S5.3.2.4, and the responsiveness criterion of S5.3.2.5 during each of those tests conducted with a commanded steering wheel angle of 0.7A or greater, where A is the steering wheel angle computed in S7.6.2.

S5.3.2.1 The lateral acceleration measured at 0.75 seconds after completion of steer of the sine with dwell steering input must not exceed 30 percent of the peak value of the lateral acceleration recorded during the 2nd half of the sine maneuver (including the dwell period), *i.e.,* from time 1 second after the beginning of steer to the completion of steer during the same test run.

S5.3.2.2 The lateral acceleration measured at 1.5 seconds after completion of steer of the Sine With

Dwell steering input must not exceed 10 percent of the peak value of the lateral acceleration recorded during the 2nd half of the sine maneuver (including the dwell period), *i.e.,* from time 1 second after the BOS to the COS during the same test run.

S5.3.2.3 The yaw rate measured at 0.75 seconds after completion of steer of the Sine With Dwell steering input must not exceed 40 percent of the peak value of the yaw rate recorded during the 2nd half of the sine maneuver (including the dwell period), *i.e.,* from time 1 second after the BOS to the COS during the same test run.

S5.3.2.4 The yaw rate measured at 1.5 seconds after completion of steer of the Sine With Dwell steering input must not exceed 15 percent of the peak value of the yaw rate recorded during the 2nd half of the sine maneuver (including the dwell period), *i.e.,* from time 1 second after the BOS to the COS during the same test run.

S5.3.2.5 The lateral displacement of the vehicle center of gravity with respect to its initial straight path must be at least 2.13 meters (7 feet) for each truck tractor and at least 1.52 meters (5 feet) for each bus when computed 1.5 seconds after the BOS.

S5.3.2.5.1 The computation of lateral displacement is performed using double integration with respect to time of the measurement of lateral acceleration at the vehicle center of gravity, as expressed by the formula:

Lateral Displacement = $\iint Ay_{CG}\, dt$

S5.3.2.5.2 Time t = 0 for the integration operation is the instant of steering initiation, known as the BOS.

S5.4 *ESC System Malfunction Detection.* Each vehicle shall be equipped with an indicator lamp, mounted in front of and in clear view of the driver, which is activated whenever there is a malfunction that affects the generation or transmission of control or response signals in the vehicle's electronic stability control system.

S5.4.1 The ESC malfunction telltale must illuminate only when a malfunction exists and must remain continuously illuminated for as long as the malfunction exists, whenever the ignition locking system is in the ''On'' (''Run'') position.

S5.4.2 The ESC Malfunction telltale must be identified by the symbol shown for ''Electronic Stability Control System Malfunction'' or the specified words or abbreviations listed in Table 1 of Standard No. 101 (49 CFR 571.101).

S5.4.3 The ESC malfunction telltale must be activated as a check of lamp function either when the ignition locking system is turned to the ''On'' (''Run'') position when the engine is not running, or when the ignition locking system is in a position between the ''On'' (''Run'') and ''Start'' that is designated by the manufacturer as a check position.

S5.4.4 The ESC malfunction telltale need not be activated when a starter interlock is in operation.

S5.4.5 The ESC malfunction telltale lamp must extinguish at the next ignition cycle after the malfunction has been corrected.

S5.5 *ESC System Technical Documentation.* To ensure that a vehicle is equipped with an ESC system that meets the definition of ''ESC System'' in S4, the vehicle manufacturer must make available to the agency, upon request, the following documentation:

S5.5.1 A system diagram that identifies all ESC system hardware. The diagram must identify what components are used to generate brake torques at each controlled wheel, determine vehicle lateral acceleration and yaw rate, estimate side slip or the side slip derivative, monitor driver steering inputs, and for a tractor, generate the towed vehicle brake torques.

S5.5.2 A written explanation describing the ESC system basic operational characteristics. This explanation must include a discussion of the system's capability to apply brake torques at each wheel, how the system estimates vehicle mass, and how the system modifies engine torque during ESC system activation. The explanation must also identify the vehicle speed range and the driving phases (acceleration, deceleration, coasting, during activation of ABS or traction control) under which the ESC system can activate.

S5.5.3 A logic diagram that supports the explanation provided in S5.5.2.

S5.5.4 Specifically for mitigating, avoiding, and preventing vehicle rollover, oversteer, and understeer conditions, a discussion of the pertinent inputs to the computer or calculations within the computer and how its algorithm uses that information and controls ESC system hardware to limit these loss of control conditions.

S6. *Test Conditions.* The requirements of S5 shall be met by a vehicle when it is tested according to the conditions set forth in the S6. On vehicles equipped with automatic brake adjusters, the automatic brake adjusters must remain activated at all times.

S6.1 *Ambient conditions.*

S6.1.1 The ambient temperature is between 7 °C (45 °F) and 40 °C (104 °F).

S6.1.2 The maximum wind speed is no greater than 5 m/s (11mph).

S6.2 *Road test surface.*

S6.2.1 The tests are conducted on a dry, uniform, solid-paved surface. Surfaces with irregularities and undulations, such as dips and large cracks, are unsuitable.

S6.2.2 The road test surface produces a peak friction coefficient (PFC) of 0.9 when measured using an American Society for Testing and Materials (ASTM) E1136–93 (Reapproved 2003) standard reference test tire (incorporated by reference,, in accordance with ASTM Method E 1337–90 (Reapproved 2002), at a speed of 64.4 km/h (40 mph), without water delivery (both documents incorporated by reference, see § 571.5).

S6.2.3 The test surface has a consistent slope between 0% and 1%.

S6.3 *Vehicle conditions.*

S6.3.1 The ESC system is enabled for all testing, except for the ESC Malfunction test in S7.11.

S6.3.2 *Test Weight.*

S6.3.2.1 *Truck tractors.* The combined total weight of the truck tractor and control trailer (specified in S6.3.4) is 80 percent of the tractor GVWR. The tractor is loaded with the fuel tanks filled to at least 75 percent capacity, test driver, test instrumentation, and a ballasted control trailer with outriggers. Center of gravity of all ballast on the control trailer is located directly above the kingpin. The load distribution on non-steer axles is adjusted so that it is proportional to the tractor's respective rear axles GAWRs by adjusting the fifth wheel position, if adjustable. If the fifth wheel of the truck tractor cannot be adjusted without exceeding a GAWR, ballast is reduced so that axle load is equal to or less than the GAWR, maintaining load proportioning as close as possible to specified proportioning.

S6.3.2.2 *Buses.* A bus is loaded to a simulated multi-passenger configuration. For this configuration the bus is loaded with the fuel tanks filled to at least 75 percent capacity, test driver, test instrumentation and simulated occupants in each of the vehicle's designated seating positions. The simulated occupant loads are attained by securing a 68-kg (150-lb) water dummy in each of the test vehicle's designated seating positions without exceeding the vehicle's GVWR and each axle's GAWR. If any rating is exceeded the ballast load is reduced until the respective rating or ratings are no longer exceeded.

S6.3.3 *Transmission selector position.* The transmission selector control is in a forward gear during all maneuvers.

S6.3.4 *Control Trailer.*

S6.3.4.1 The control trailer is an unbraked flatbed semi-trailer that has a single axle with a GAWR of 8,165 kilograms (18,000 pounds) and a length of 655 + 15 cm (258 + 6 inches) when measured from the transverse centerline of the axle to the centerline of the kingpin.

S6.3.4.2 The center of gravity height of the ballast on the loaded control trailer is less than 61 cm (24 inches) above the top of the tractor's fifth wheel.

S6.3.5 *Tires.* The vehicle is tested with the tires installed on the vehicle at time of initial vehicle sale. The tires are inflated to the vehicle manufacturer's recommended cold tire inflation pressure(s) specified on the vehicle's certification label or the tire inflation pressure label.

S6.3.6 *Outrigger.* An outrigger is used for testing each vehicle. The outrigger is designed with a maximum weight of 726 kg (1,600 lb), excluding mounting fixtures.

S6.3.7 *Automated steering machine.* A steering machine programmed to execute the required steering pattern is used during the slowly increasing steer and sine with dwell maneuvers. The steering machine is capable of supplying steering torques between 40 to 60 Nm (29.5 to 44.3 lb-ft). The steering machine is able to apply these torques when operating with steering wheel velocities up to 1200 degrees per second.

S6.3.8 *Truck Tractor Anti-jackknife System.* The truck tractor is equipped with anti-jackknife cables that allow a minimum articulation angle of 45 degrees between the tractor and the control trailer.

S6.3.9 *Special drive conditions.* A vehicle equipped with an interlocking axle system or a front wheel drive system that is engaged and disengaged by the driver is tested with the system disengaged.

S6.3.10 *Liftable axles.* A vehicle with a liftable axle is tested with the liftable axle down.

S6.3.11 *Initial brake temperature.* The initial brake temperature is not less than 65 °C (150 °F) and not more than 204 °C (400 °F).

S6.3.12 *Thermocouples.* The brake temperature is measured by plug-type thermocouples installed in the approximate center of the facing length and width of the most heavily loaded shoe or disc pad, one per brake. A second thermocouple may be installed at the beginning of the test sequence if the lining wear is expected to reach a point causing the first thermocouple to contact the rubbing surface of a drum or rotor. The second thermocouple is installed at a depth of 0.080 inch and located within 1.0 inch circumferentially of the thermocouple installed at 0.040 inch depth. For center-grooved shoes or pads, thermocouples are installed within 0.125 inch to 0.250 inch of the groove and as close to the center as possible.

S6.4 *Selection of compliance options.* Where manufacturer options are specified, the manufacturer shall select the option by the time it certifies the vehicle and may not thereafter select a different option for the vehicle. Each manufacturer shall, upon request from the National Highway Traffic Safety Administration, provide information regarding which of the compliance options it has selected for a particular vehicle or make/model.

S7. *Test Procedure.*

S7.1 *Tire inflation.* Inflate the vehicle's tires to the cold tire inflation pressure(s) provided on the vehicle's certification label or tire information label.

S7.2 *Telltale lamp check.* With the vehicle stationary and the ignition locking system in the ''Lock'' or ''Off'' position, activate the ignition locking system to the ''On'' (''Run'') position or, where applicable, the appropriate position for the lamp check. The ESC system must perform a check of lamp function for the ESC malfunction telltale, as specified in S5.3.3.

S7.3 *Mass Estimation Cycle.* While driving in a straight line, one stop is performed from a speed of 65 km/h (40 mph), with a target longitudinal deceleration between 0.3–0.4g.

S7.4 *Tire Conditioning.* Condition the tires using the following procedure to wear away mold sheen and achieve operating temperature immediately before beginning the Brake Conditioning, SIS and SWD maneuver test runs.

S7.4.1 The test vehicle is driven around a circle 46 meters (150 feet) in radius at a speed that produces a lateral acceleration of approximately 0.1g for two clockwise laps followed by two counterclockwise laps.

S7.5 *Brake Conditioning.* Conditioning and warm-up the vehicle brakes must be completed before and during execution of the SIS and SWD maneuver test runs.

S7.5.1 Prior to executing the first series of SIS maneuvers for a test vehicle, the brakes are burnished according to the procedure in S6.1.8 of Standard No. 121, *Air brake systems.*

S7.5.2 After the brakes are burnished in accordance with S7.5.1, initiate the vehicle compliance test according to S7.6. For a vehicle on which a full FMVSS No. 121 compliance test was performed, immediately prior to executing any slowly increasing steer or sine with dwell maneuvers, the brakes are burnished using 40 brake application snubs from a speed of 64 km/h (40 mph) to a speed of 32 km/h (20 mph), with a target deceleration of approximately 0.3g. After each brake application, accelerate to 64 km/h (40 mph) and maintain that speed until making the next brake application at a point 1 mile from the initial point of the previous brake application. At end of the 40 snubs, the hottest brake temperature is confirmed to be within the temperature range of 65 °C–204 °C (150 °F–400 °F). If the hottest brake temperature is above 204 °C (400 °F) a cool down period is performed until the hottest brake temperature is measured within that range. If the hottest brake temperature is below 65 °C (150 °F) individual brake stops shall be repeated to increase any one brake temperature to within the target temperature range of 65 °C–204°C (150 °F–400 °F) before the subject maneuver can be performed.

S7.6 *Slowly Increasing Steer Test.* The vehicle is subjected to two series of runs of the slowly increasing steer test using a constant vehicle speed of 48.3 ± 1.6 km/h (30.0 ± 1.0 mph) and a steering pattern that increases by 13.5 degrees per second until ESC system activation is confirmed. Three repetitions are performed for each test series. One series uses counterclockwise steering, and the other series uses clockwise steering. During each run ESC activation is required for the Engine Torque Reduction test and is confirmed as specified in S7.7.

S7.6.1 The slowly increasing steer maneuver sequence is started using a commanded steering wheel angle of 270 degrees. If ESC activation did not occur during the maneuver then the commanded steering wheel angle is increased by 270 degree increments up to the vehicle's maximum allowable steering angle or until ESC activation is confirmed.

S7.6.2 From the slowly increasing steer tests, the quantity ''A'' is determined. ''A'' is the steering wheel angle in degrees that is estimated to produce a lateral acceleration of 0.5g for the test vehicle. Utilizing linear regression on the lateral acceleration data recorded between 0.05g and 0.3g, and then linear extrapolation out to a lateral acceleration value of 0.5g, A is calculated, to the nearest 0.1 degrees, from each of the six satisfactory slowly increasing steer tests. If ESC activation occurs prior to the vehicle experiencing a lateral acceleration of 0.3g then the data used during the linear regression will be that data recorded between 0.05g and the lateral acceleration measured at the time of ESC activation. The absolute value of the six A's calculated is averaged and rounded to the nearest 0.1 degrees to produce the final quantity, A, used during the sine with dwell maneuvers below.

S7.7 *Engine Torque Reduction Test.* During each of the six completed slowly increasing steer test maneuvers, ESC activation is confirmed by comparing the engine torque output and driver requested torque data collected from the vehicle J1939 communication data link. During the initial stages of each maneuver the two torque signals with respect to time will parallel each other. Upon ESC activation, the two signals will diverge when ESC system activation causes a commanded engine torque reduction and the driver attempts to accelerate the vehicle maintaining the required constant test speed causing an increased driver requested torque.

S7.7.1 During each of the six slowly increasing steer test runs, verify the commanded engine torque and the driver requested torque signals diverge at least 10 percent 1.5 seconds after the beginning of ESC activation occurs as defined in S7.12.15.

S7.7.2 If ESC activation does not occur in all of the six slowly increasing steer test maneuvers the test is terminated.

S7.8 After the quantity A has been determined in S7.6, without replacing the tires, the tire and brake conditioning procedures described in S7.4 and S7.5 are performed immediately prior to conducting the sine with dwell test.

S7.9 Check that the ESC system is enabled by ensuring that the ESC malfunction telltale is not illuminated.

S7.10 *Sine With Dwell Test.* The vehicle is subjected to two series of test runs using a steering pattern of a sine wave at 0.5 Hz frequency with a 1.0 sec delay beginning at the second peak amplitude as shown in Figure 1 (sine with dwell maneuver). One series uses counterclockwise steering for the first half cycle, and the other series uses clockwise steering for the first half cycle. Before each test run brake temperatures are monitored and the hottest brake is confirmed to be within the temperature range of 65 °C–204 °C (150 °F–400 °F).

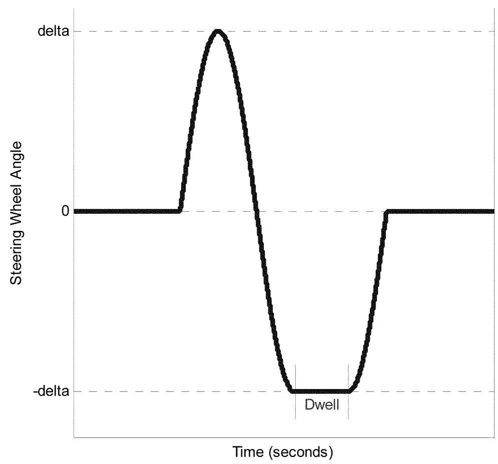


Figure 1. Steering wheel input for Sine with Dwell Maneuver.

S7.10.1 For manual transmissions, the steering motion is initiated with the vehicle coasting (dropped throttle) with the clutch disengaged at 72.4 ± 1.6 km/h (45.0 ± 1.0 mph). For automatic transmissions, the steering motion is initiated with the vehicle coasting and the transmission in the ''drive'' selection position.

S7.10.2 In each series of test runs, the steering amplitude is increased from run to run, by 0.1A, provided that no such run will result in steering amplitude greater than that of the final run specified in S7.10.4.

S7.10.3 The steering amplitude for the initial run of each series is 0.3A where A is the steering wheel angle determined in S7.6.

S7.10.4 The steering amplitude of the final run in each series is the lesser of 1.3A or 400 degrees. If any 0.1A increment, up to 1.3A, is greater than 400 degrees, the steering amplitude of the final run shall be the 0.1A amplitude that is closest or equal to, but not exceeding, 400 degrees.

S7.10.5 Upon completion of the two series of test runs, post processing of the yaw rate and lateral acceleration data to determine Lateral Acceleration Ratio (LAR), Yaw Rate Ratio (YRR) and lateral displacement, is done as specified in S7.12.

S7.11 *ESC Malfunction Detection.*

S7.11.1 Simulate one or more ESC malfunction(s) by disconnecting the power source to any ESC component, or disconnecting any electrical connection between ESC components (with the vehicle power off). When simulating an ESC malfunction, the electrical connections for the telltale lamp(s) are not to be disconnected.

S7.11.2 With the vehicle initially stationary and the ignition locking system in the ''Lock'' or ''Off'' position, activate the ignition locking system to the ''Start'' position and start the engine. Place the vehicle in a forward gear and obtain a vehicle speed of 48.3 ± 8.0 km/h (30.0 ± 5.0 mph). Drive the vehicle for at least two minutes including at least one left and one right turning maneuver and at least one service brake application. Verify that within two minutes of obtaining this vehicle speed the ESC malfunction indicator illuminates in accordance with S5.3.

S7.11.3 Stop the vehicle, deactivate the ignition locking system to the ''Off'' or ''Lock'' position. After a five-minute period, activate the vehicle's ignition locking system to the ''Start'' position and start the engine. Verify that the ESC malfunction indicator again illuminates to signal a malfunction and remains illuminated as long as the engine is running or until the fault is corrected.

S7.11.4 Deactivate the ignition locking system to the ''Off'' or ''Lock'' position. Restore the ESC system to normal operation, activate the ignition system to the ''Start'' position and start the engine. Verify that the telltale has extinguished.

S7.12 *Post Data Processing—Calculations for Performance Metrics.* Engine torque reduction, lateral acceleration and yaw rate decay calculations, and lateral responsiveness checks must be processed utilizing the following techniques:

S7.12.1 Raw steering wheel angle data is filtered with a 12-pole phaseless Butterworth filter and a cutoff frequency of 10Hz. The filtered data is then zeroed to remove sensor offset utilizing static pretest data.

S7.12.2 Raw yaw, pitch and roll rate data is filtered with a 12-pole phaseless Butterworth filter and a cutoff frequency of 3 Hz. The filtered data is then zeroed to remove sensor offset utilizing static pretest data.

S7.12.3 Raw lateral acceleration data is filtered with a 12-pole phaseless Butterworth filter and a cutoff frequency of 6Hz. The filtered data is then zeroed to remove sensor offset utilizing static pretest data. The lateral acceleration data at the vehicle center of gravity is determined by removing the effects caused by vehicle body roll and by correcting for sensor placement via use of coordinate transformation. For data collection, the lateral accelerometer shall be located as close as possible to the position of the vehicle's longitudinal and lateral centers of gravity.

S7.12.4 Raw vehicle speed data is filtered with a 12-pole phaseless Butterworth filter and a cutoff frequency of 2 Hz.

S7.12.5 Left and right side ride height data is filtered with a 0.1-second running average filter.

S7.12.6 The J1939 torque data collected as a digital signal does not get filtered. J1939 torque collected as an analog signal is filtered with a 0.1-second running average filter.

S7.12.7 Steering wheel velocity is determined by differentiating the filtered steering wheel angle data. The steering wheel velocity data is then filtered with a moving 0.1-second running average filter.

S7.12.8 Lateral acceleration, yaw rate and steering wheel angle data channels are zeroed utilizing a defined ''zeroing range.'' The ''zeroing range'' is the 1.0-second time period prior to the instant the steering wheel velocity exceeds 40 deg/sec. The instant the steering wheel velocity exceeds 40 deg/sec is the instant defining the end of the ''zeroing range.''

S7.12.9 The beginning of steer (BOS) is the first instance filtered and zeroed steering wheel angle data reaches -5 degrees (when the initial steering input is counterclockwise) or +5 degrees (when the initial steering input is clockwise). The value for time at the BOS is interpolated.

S7.12.10 The Completion of Steer for the sine with dwell maneuver (COS) is the time the steering wheel angle returns to zero. The value for time at the COS is interpolated.

S7.12.11 The peak lateral acceleration is the maximum lateral acceleration measured during the second half of the sine maneuver, including the dwell period from 1.0 second after the BOS to the COS. The lateral accelerations at 0.75 and 1.0 seconds after COS are determined by interpolation.

S7.12.12 The peak yaw rate is the maximum yaw rate measured during the second half of the sine maneuver, including the dwell period from 1.0 second after the BOS to the COS. The yaw rates at 0.75 and 1.0 seconds after COS are determined by interpolation.

S7.12.13 Determine lateral velocity by integrating corrected, filtered and zeroed lateral acceleration data. Zero lateral velocity at BOS event. Determine lateral displacement by integrating zeroed later velocity. Zero lateral displacement at BOS event. Lateral displacement at 1.50 seconds from BOS event is determined by interpolation.

S7.12.14 The ESC activation point is the point where the measured driver demanded torque and the engine torque first begin to deviate from one another (engine torque decreases while driver requested torque increases) during the slowly increasing steer maneuver. The torque values are obtained directly from each vehicle's SAE J1939 communication data bus. Torque values used to determine the ESC activation point are interpolated.

S8. *Compliance Date.*

S8.1 *Buses.* All buses manufactured on or after [date that is two years after publication of a final rule implementing this proposal] must comply with this standard

S8.2 *Truck tractors.*

S8.2.1 All two-axle and three-axle truck tractors with a front axle that has a GAWR of (14,600 pounds) or less and with two rear drive axles that have a combined GAWR of (45,000 pounds) or less manufactured on or after [date that is two years after publication of a final rule implementing this proposal] must comply with this standard.

S8.2.2 All truck tractors manufactured on or after [date that is four years after publication of a final rule implementing this proposal] must comply with this standard.

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Christopher J. Bonanti,

Associate Administrator for Rulemaking.

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