**DEPARTMENT OF TRANSPORTATION**

**National Highway Traffic Safety Administration**

**49 CFR Part 571**

**[Docket No. 92–29; Notice 5]**
**[Docket No. 93–69; Notice 2]**

**RIN 2127–AA00**
**RIN 2127–AE75**

# Federal Motor Vehicle Safety Standards; Stability and Control of Medium and Heavy Vehicles During Braking

**AGENCY:** National Highway Traffic Safety Administration (NHTSA), DOT.

**ACTION:** Final rule.

**SUMMARY:** In response to the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, this final rule amends Standard No. 105, *Hydraulic Brake Systems*, and Standard No. 121, *Air Brake Systems*, to require medium and heavy vehicles to be equipped with an antilock brake system (ABS) to improve the directional stability and control of these vehicles during braking. For truck tractors, the ABS requirement is supplemented by a 30-mph braking-in-a-curve test on a low coefficient of friction surface using a full brake application. By improving directional stability and control, these requirements will significantly reduce deaths and injuries caused by jackknifing and other losses of directional stability and control during braking.

In addition, this final rule requires all powered heavy vehicles to be equipped with an in-cab lamp to indicate ABS malfunctions. Truck tractors and other towing trucks are required to be equipped with two separate in-cab lamps: one indicating malfunctions in the towing truck ABS and the other indicating malfunctions in the towed trailer or dolly ABS. Trailers produced during an initial eight-year period must also be equipped with an external malfunction indicator that will be visible to the driver through the rearview mirror of the towing truck or tractor. More specifically, the external trailer indicator will indicate an ABS malfunction to the driver, if the trailer is being towed by an older vehicle that is not equipped with an in-cab lamp for trailer ABS malfunction indication. In general, the indicators will provide valuable information about ABS malfunctioning to the driver and to maintenance and Federal and State inspection personnel.

**DATES:** *Effective Dates:* The amendments to 49 CFR 571.105 become effective on March 1, 1999. The amendments to 49 CFR 571.121 become effective on March 1, 1997. Compliance to § 571.121 with respect to air-braked trailers and single unit trucks and buses will be required as of March 1, 1998.

*Petitions for Reconsideration:* Any petitions for reconsideration of this rule must be received by NHTSA no later than April 10, 1995.

**ADDRESSES:** Petitions for reconsideration of this rule should refer to Docket 92–29; Notice 5 and should be submitted to: Administrator, National Highway Traffic Safety Administration, 400 Seventh Street, S.W., Washington, D.C. 20590.

**FOR FURTHER INFORMATION CONTACT:** Mr. George Soodoo, Office of Crash Avoidance, National Highway Traffic Safety Administration, 400 Seventh Street, SW., Washington, D.C. 20590 (202) 366–5892.

**SUPPLEMENTARY INFORMATION:**



## I. Overview

As part of NHTSA's plans to improve the braking performance of medium and heavy vehicles,[1] this final rule amends the agency's two brake standards for those vehicles by adopting requirements to improve the directional stability and control characteristics of these vehicles while braking. The two Federal Motor Vehicle Safety Standards (FMVSSs) are Standard No. 105, *Hydraulic Brake Systems*, and Standard No. 121, *Air Brake Systems*. In formulating this final rule, NHTSA has relied on extensive fleet studies of tractor trailer combinations equipped with antilock systems, road testing of such vehicles at the agency's Vehicle Research Test Center (VRTC), review of its Fatal Accident Reporting Systems (FARS) data and other crash data, the positive experience with ABS-equipped heavy vehicles in Europe and throughout the world, comments to the public docket about this rulemaking, and other available information.

In order to fully understand the safety problem being addressed by this rulemaking, it is necessary to examine in detail the reasons for wheel lockup and the consequences of such lockup. Moreover, in order to fully understand the reasons for the agency's decision to require that heavy vehicles be equipped with a closed-loop ABS, it is necessary to understand the general characteristics of brake systems, the force-generating characteristics of tires, and the interactions between brake systems and tires.

To provide the reader with a means for gaining this understanding, NHTSA has included an Appendix in this document, which provides a discussion of basic service brake systems, loss-of-control crashes, and ABS characteristics. The Appendix discusses the types of heavy brake systems that

[1] Hereinafter referred to as "heavy vehicles."

are currently in use, how brake systems work, and why lockup occurs. It also discusses the force-generating characteristics of tires and how they are affected by varying levels of wheel slip and the need to take these characteristics into account in addressing the problem of loss-of-control crashes. Finally, the Appendix discusses the need for ABS and describes their method of operation. Several terms, such as ''wheel slip'' that are used throughout this notice are discussed in detail and defined in the Appendix. When terms whose precise meaning affects the understanding of the agency's rationale are introduced, the reader could refer to the Appendix for a discussion of the term.

Therefore, readers who lack a technical background and who desire a more complete understanding of this rulemaking may wish at this point to read the Appendix before moving on to the rest of the preamble.

NHTSA has decided to require the installation of ''closed-loop'' [2] antilock systems on all heavy vehicles. The agency, in accordance with Supreme Court precedent that required the agency to consider mandating the installation of a particular type of automatic restraint system (i.e., ''airbags only'') for passenger cars,[3] is adopting a rule that defines antilock brake systems, in performance terms, as systems that ''automatically control the degree of rotational wheel slip [4] during braking'' through sensors and transmitters that measure, transmit, and generate signals concerning the rate of wheel angular rotation to controlling devices which adjust brake application pressure to prevent wheel lockup. In addition, for truck tractors, the rule prescribes a 30-mph braking-in-a-curve dynamic test on a low coefficient of friction surface.

Although some commenters characterized NHTSA's definition as an impermissible design standard, NHTSA has specifically sought to avoid imposing unnecessary design restrictions or impeding the future development of ABS, by adopting a definition that permits any antilock brake system that ensures feedback between what is actually happening at the tire-road surface interface and what the device is doing to respond to excessive wheel slip. To the extent that NHTSA's definition restricts design choices, e.g., by requiring a ''feedback'' system in which control devices must respond to signals that monitor wheel slip, the requirements are stated broadly and in performance terms. Such an approach is consistent with that adopted in numerous other Federal Motor Vehicle Safety Standards, including Standard No. 108 which requires vehicles to be equipped with specified lamps and reflective devices, Standard No. 111 which requires that vehicles be equipped with rearview mirrors, and Standard No. 208 which requires vehicles be equipped with safety belts.

Moreover, the United States Court of Appeals for the Sixth Circuit has upheld a dimensional restriction on rectangular headlamps, reasoning that ''uniformity of headlamp size is an element of headlamp performance.'' [5] Accordingly, NHTSA has decided to reject the conceptual objections to ''closed-loop'' ABS systems expressed by commenters whose economic self-interest militates against the requirement, including manufacturers of alternative, non-electronic braking systems that are incapable of sensing and adjusting braking pressures to control that wheel slip, and an association of fleet owners that may wish to avoid incurring the added expense of purchasing vehicles that are equipped with electronic ABS systems.

Currently, all powered [6] heavy vehicles equipped with ABS are required to be equipped with an in-cab ABS malfunction indicator lamp indicating malfunctions in the powered vehicle's ABS. Today's final rule requires trucks (including truck tractors) equipped to tow another air-braked vehicle to be equipped with another, separate in-cab lamp indicating malfunctions in the ABS(s) of the towed vehicle(s). For an eight-year period, the amendment requires trailers to be equipped with an external ABS malfunction indicator that will be visible to the driver of the towing truck or truck tractor through the rearview mirror. In particular, the external trailer indicator lamp will provide information to the driver, if the trailer is being towed by an older vehicle that is not equipped with an in-cab lamp indicating trailer ABS malfunctions. In general, the indicators will provide valuable information about ABS malfunctioning to the driver and to maintenance and Federal and State inspection personnel.

In separate, related documents published elsewhere in today's **Federal Register**, NHTSA announces its decision to reinstate stopping distance requirements for air-braked heavy vehicles and to establish such requirements for hydraulically-braked heavy vehicles. In addition, to carry out the antilock requirement, the Federal Highway Administration (FHWA) is announcing its intent to require such systems on heavy vehicles to be operational.

NHTSA is issuing this final rule on directional stability and control pursuant to the Motor Carrier Act of 1991, a part of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. Section 4012 directs the Secretary of Transportation to initiate rulemaking concerning methods for improving braking performance of new commercial motor vehicles,[7] including truck tractors, trailers, and their dollies. Congress specifically directed that such a rulemaking examine antilock systems, means of improving brake compatibility, and methods of ensuring effectiveness of brake timing. The Act requires that the rulemaking be consistent with the Motor Carrier Safety Act of 1984 (49 U.S.C. § 31147) and be carried out pursuant to, and in accordance with, the National Traffic and Motor Vehicle Safety Act of 1966 (Safety Act) (49 U.S.C. 30101 *et seq.*).

NHTSA notes that, in the mid-1970's, Standard No. 121 was amended to include stringent stopping distance requirements, coupled with a ''no lockup'' requirement, which had the effect of requiring heavy vehicles to be equipped with antilock brake systems. In response to a legal challenge, the U.S. Court of Appeals for the 9th Circuit invalidated the stopping distance and ''no lockup'' requirements in Standard No. 121, along with certain other provisions, holding that the standard was ''neither reasonable nor practicable at the time it was put into effect.'' [8]

As explained throughout this document, the underlying conditions related to equipping heavy vehicles with antilock brake systems differ markedly from 20 years ago when the petitioners challenged the agency in *PACCAR*. First, antilock brake technology has advanced dramatically since the mid-1970's, and antilock brake systems are now in widespread, everyday use, both in this country and

[2] A closed-loop (control) system is one which examines the output of the system and adjusts the input to the system in response to that output. This inclusion of the output (or some function of the output) as part of the input to such a system is referred to as feedback.

[3] (*Motor Vehicle Manufacturers' Association* v. *State Farm Insurance,* 463 U.S. 29, (1983))

[4] See the Appendix for a discussion of this term and directional stability.

[5] *Chrysler Corp.* v. *DOT*, 515 F.2d 1053, 1058–59 (1975).

[6] By powered vehicle, the agency means a vehicle equipped with an engine that propels the vehicle. In contrast, a non-powered vehicle, such as a trailer, is towed by another vehicle.

[7] Vehicles with a gross vehicle weight rating (GVWR) of 26,001 or more pounds.

[8] *PACCAR* v. *NHTSA*, 573 F.2d 632 (9th Cir. 1978), *cert. denied,* 439 U.S. 862 (1978)

throughout the world. Second, NHTSA's extensive fleet study about heavy vehicle antilock systems demonstrates that these systems are reliable when placed in use. Third, the agency's testing of truck tractors equipped with antilock systems indicates that they provide significantly improved directional stability and control compared to vehicles without antilock systems. Fourth, while the antilock systems used in the mid-1970s also incorporated significantly larger, more aggressive foundation brakes, which were sometimes incompatible with less aggressive systems on existing vehicles when the antilock system malfunctioned, the requirements being adopted today do not necessitate such aggressive brakes. Therefore, they do not have the potential for creating a more dangerous highway environment. Fifth, the performance requirements adopted in today's final rule do not raise practicability concerns. Based on these and other considerations discussed throughout this document, NHTSA believes that today's final rule satisfies the concerns raised by the *PACCAR* court.

## II. Background

### *A. The Safety Problem: Loss of Control Crashes*

Crashes involving heavy vehicles result in a significant number of fatalities and injuries, and a significant amount of property damage each year. Based on available statistics, NHTSA has estimated the number of crashes in 1992 for several different groups of heavy vehicles. For heavy combination vehicles, the agency estimates that there were about 168,000 crashes. These crashes resulted in about 13,600 injuries and 387 fatalities to the occupants of heavy combination vehicles and about 51,500 injuries and 2,452 fatalities to the occupants of the other vehicles involved. For truck tractors operating without a trailer, also known as ''bobtail'' truck tractors, the agency estimates that there were about 8,400 crashes, resulting in about 1,200 injuries and 39 fatalities to truck tractor occupants and about 2,600 injuries and 178 fatalities to occupants of other involved vehicles. For heavy single-unit trucks and school buses, the agency estimates that there were about 192,600 crashes, resulting in about 15,700 injuries and 165 fatalities to truck and school bus occupants and about 48,300 injuries and 891 fatalities to occupants of other involved vehicles. For transit and intercity buses, the agency estimates that there were about 49,500 crashes, resulting in about 19,500 injuries and 28 fatalities to bus occupants and about 9,100 injuries and 230 fatalities to occupants of other involved vehicles.

Based on analyses of both national and state accident data, NHTSA estimates that between 10 percent and 15 percent of the crashes involving heavy combination vehicles (including bobtail truck tractors) involved in a jackknife or other braking-induced instability or loss of control. For a more detailed discussion of the injury statistics, the reader should refer to the Final Economic Assessment (FEA) for this rulemaking.

This rulemaking focuses on crashes involving loss-of-control. Such incidents result from braking-induced wheel lockup with subsequent loss of the ability of the vehicle's tires to generate ''stabilizing forces.''[9] This loss of tire stabilizing forces can result in either vehicle directional instability if it occurs at the vehicle's rear wheels or loss of steering control if it occurs at the vehicle's steering (front) wheels.

### *B. Braking Systems, Tires, Wheel Lockup, and Loss of Control Crashes*

When a vehicle driver makes a brake application that is too ''hard'' for conditions, the driver is likely to lock some or all of the vehicle's wheels (i.e., the wheels will be ''sliding'' rather than ''rolling''). Locking up wheels is more likely to occur under conditions where the maximum forces that can be generated by the vehicle's tires are reduced, i.e., when the vehicle is lightly loaded or empty and/or when the road is slippery. When wheel lockup occurs, vehicle loss-of-control can result. Incorporation of an ABS decreases the likelihood of wheel lockup, and increases the driver's ability to maintain control during severe braking maneuvers, that would otherwise lead to wheel lockup and resultant loss of directional stability and control, if the vehicle is not equipped with an ABS.

## III. US and Foreign Activities Related to Stability and Control During Braking Performance

### *A. Early US Regulatory History*

NHTSA has been concerned about the safety of heavy vehicle braking systems since the agency's inception. On October 11, 1967, the predecessor of NHTSA, the FHWA's National Highway Safety Bureau, published a notice of its intention to promulgate brake standards for hydraulic and air-braked trucks and buses, and air-braked trailers. (32 FR 14279.) The initial notice of proposed rulemaking (NPRM) for air-braked systems proposed various requirements, including requiring vehicles equipped with such systems to stop within certain distances, from certain speeds, without leaving a 12-foot wide lane and without lockup of any wheel ''more than momentarily.'' (35 FR 10368, June 25, 1970.) A companion NPRM for hydraulic brake systems proposed essentially identical performance requirements for heavy vehicles equipped with those systems. (35 FR 17345, November 11, 1970.) These notices proposed that heavy vehicles would have to stop from 60-mph within 216 feet on a surface with a skid number of 75.[10] The ''no lockup'' provision was intended to minimize skidding, spinning, and jackknifing due to wheel lockup and loss of directional stability.

In the final rule establishing Standard No. 121, the agency decided to increase the 60-mph stopping distance from 216 feet to 245 feet. (36 FR 3817, February 27, 1971.) The final rule amending Standard No. 105 to extend its applicability to heavy vehicles, also increased the 60-mph stopping distance for those vehicles to 245 feet. (37 FR 17970, September 2, 1972.) The requirements for air-braked vehicles were to become effective on September 1, 1973, and those for hydraulic-braked vehicles, on September 1, 1974.

Although neither standard specifically required antilock, NHTSA anticipated that manufacturers would equip heavy vehicles with antilock brake systems to comply with these requirements. The agency explained that the less stringent stopping distance was being required to reflect more accurately the vehicle performance given the test track road surface's friction characteristics.

Since the required stopping distances were shorter than the stopping performance achieved by certain heavy vehicles, new, more aggressive foundation braking systems were necessary for those vehicles. In particular, vehicles with short wheelbases needed to have considerably more aggressive front axle brakes to meet the shorter stopping distance requirements. If not kept properly adjusted, these more aggressive front brakes might produce a brake ''pull'' to one side, which was disconcerting to drivers, particularly on vehicles without power steering. In addition, drivers were concerned about loss of steering control caused by wheel lockup on the

[9] See the Appendix which defines and discusses this term.

[10] A skid number describes the friction properties of pavement. A skid number of 75 is representative of a dry surface with a relatively high coefficient of friction. See the Appendix for a discussion of this term.

steering axle. At the time, most manufacturers equipped their vehicles with antilock devices because the standards required stops to be made without more than momentary lockup of the wheels. These devices served to prevent steering axle lockup problems as well, but there was concern that safety problems could result on short-wheelbase, high-center-of-gravity vehicles, in the event that the antilock system should malfunction.

NHTSA extended the effective dates for the stopping distance requirements in Standard No. 105 and Standard No. 121. (37 FR 3905, February 24, 1972; 38 FR 3047, February 1, 1973; 39 FR 17550, 17563, May 17, 1974.) Prior to the final effective date for Standard No. 105, the amendments pertaining to heavy vehicles were withdrawn, so the requirements for heavy hydraulic-braked trucks and buses never went into effect. (40 FR 18411, April 28, 1975.) Standard No. 121 became effective on January 1, 1975, for trailers, and on March 1, 1975, for trucks and buses. At that time, the 60-mph stopping distance requirement remained at 245 feet. However, after several revisions to the stopping distance requirements, NHTSA amended the standard by extending the 60-mph stopping distance requirement to 293 feet, as requested by Freightliner in a petition for reconsideration. (41 FR 8783, March 1, 1976.)

*B. PACCAR Case*

In January 1975, PACCAR (a truck manufacturer), the American Trucking Associations (ATA), and the Truck Equipment and Body Distributors Association (TEBDA) sued the agency, challenging the stopping distance requirements in Standard No. 121, which they believed required the use of antilock brake systems.

Specifically, the petitioners challenged the 245-foot stopping distance. The subsequent increase to 293 feet, a distance that did not necessitate such aggressive front brakes, occurred after the suit was filed. The petitioners argued that the agency failed to demonstrate a safety need for the standard and that the testing procedures were not objective, impracticable, and unreasonable. TEBDA objected to the standard's certification requirements.

In response to the suit, the stopping distance and ''no lockup'' requirements in Standard No. 121, along with certain other provisions, were invalidated by the United States Court of Appeals for the 9th Circuit in *PACCAR.* The court held that NHTSA was justified in promulgating a standard requiring improved air brake systems and stability mechanisms. However, after reviewing the record about reliability problems with antilock brake systems then in use, the court further held that the standard was ''neither reasonable nor practicable at the time it was put into effect.'' *Id.* at 640. Among the court's other findings were that the agency had a responsibility (1) to examine the results of its rulemakings by investigating more fully the safety of vehicles in use, (2) to assure that the new systems it requires are reliable when placed in use, and (3) to determine that its regulations do not produce a more dangerous highway environment than that which existed prior to government intervention. Based on these findings, the court stated that

> * * * those parts of the Standard requiring heavier axles and the antilock device should be suspended. The evidence indicates that this can be accomplished if we hold, as we do, that the stopping distance requirements from 60 mph are invalid * * * We hold only that more probative and convincing data evidencing the reliability and safety of vehicles that are equipped with antilock and in use must be available before the agency can enforce a standard requiring its installation.

*Id.* at 643.

The court also ruled on the objectivity and practicability of the testing procedures in Standard No. 121. First, the court stated that road surface skid numbers used for testing certified vehicles were ''ill-chosen'' where they assumed the use of a particular tire no longer in production. *Id.* at 644. Second, the skid number method of testing was not objective. *Id.* at 644. Third, the testing procedure was not practicable because fluctuations in skid numbers on a given road surface made it impracticable for manufacturers to conduct tests that assure that their vehicles will exactly meet the objective standard when tested by NHTSA. *Id.* at 644. Fourth, manufacturers are entitled to testing criteria that they can rely on with certainty. *Id.* at 644. Fifth, the standard failed to specify formal and reasonably specific testing criteria about the time intervals between tests, the duration of permissible wheel lockup during tests, and the amount of curving in testing track roadways. *Id.* at 645. Sixth, the agency's suggestions of alternative methods of satisfying the Safety Act's ''due care'' provision were inadequate since such alternatives were not set forth in the regulations. Id. at 645.

The court remanded the matter to NHTSA to clarify certain provisions in Standard No. 121. In response to *PACCAR,* the agency issued several notices amending the standard to be consistent with the decision. (43 FR 39390, September 5, 1978; 43 FR 48646, October 19, 1978; 43 FR 58820, December 18, 1978; 44 FR 46849, August 9, 1979.) In the September 1978 notice, the agency amended the standard to specify test procedures and conditions for frictional characteristics of the test track surface, duration of time intervals between road tests, duration of permissible wheel lockup during road tests, the amount of curving in the test track, and the means for establishing the frictional resistance of the road test surface. In the October 1978 notice, the agency set forth its interpretation of *PACCAR* to guide continuing compliance with the standard. Specifically, the notice explained that the court had invalidated the ''no lockup'' provisions in S5.3.1 and S5.3.2 as they apply to trucks and trailers, along with the related stopping distances established for 60-mph stopping tests for heavy vehicles. That notice also amended the requirements to provide for ''due care certification.'' In the December 1978 notice, NHTSA responded to petitions for reconsideration of certain aspects of the September 1978 notice, including vehicle exclusions and road test procedures. The agency withdrew the changes to specification of initial brake temperatures, skid number ranges, and duration of wheel lockup that were made in the September notice. In the August 1979 notice, the agency further clarified its interpretation of certain findings of *PACCAR.*

*C. US and Foreign Experience With ABS Since PACCAR*

As a result of the 1978 *PACCAR* decision, U.S. manufacturers chose to halt development and production of ABS for heavy vehicles. For instance, before the 1978 ruling, A-C Sparkplug, a domestic manufacturer of ABS, produced about 180,000 ABS units per year. By 1984, it was producing only about 500 units annually.

NHTSA continued to study the effectiveness of heavy truck antilock brake systems. Among other things, the agency studied the in-use experience with ABS in other countries, conducted performance testing of ABS equipped heavy vehicles, and conducted an extensive domestic fleet in-use test of ABS equipped heavy vehicles.

In response to section 9107 of the Truck and Bus Regulatory Reform Act of 1988, NHTSA submitted a report to Congress titled ''Improved Brake Systems for Commercial Vehicles'' (Report No. DOT HS 807 706). (April 1991) After discussing crash data concerning heavy vehicle brake systems, the report examined factors related to braking effectiveness, stability and control during braking, and braking system compatibility of heavy combination vehicles. Among other things, the report indicated that the stopping distances and directional stability of heavy vehicles could be improved by equipping those vehicles with ABS.

With respect to the in-use experience with ABS in other countries, NHTSA conducted a study of the performance, reliability, and maintainability of in-service commercial air-braked vehicles equipped with ABS in Europe and Australia.[11] At the time of the study in 1987, there were approximately 1.5 million ABS-equipped trucks and tractors, and 0.9 million ABS-equipped trailers in use in Western Europe, and 92,000 trucks and tractors and 80,000 trailers in Australia. ABS market penetration, at that time, in Western Europe was estimated to be 4.5 percent for trucks and tractors and 5.6 percent for trailers, while in Australia the comparable figures were 1.3 percent for trucks and tractors, and less than 1 percent for trailers. Based on data derived from interviews with fleets which were using ABS and surveys conducted by ABS and vehicle manufacturers, the reliability of ABS when equipped on European vehicles was estimated to be 1 to 2 ABS component failures per 1000 vehicles per month. Based on those data, it was predicted that between 4 and 20 malfunctions would occur with the 200 ABS-equipped truck tractors involved in the NHTSA-sponsored two-year in-service fleet study, which was subsequently performed between 1989–91. In fact, nineteen ABS components failed, which is within the range predicted by the European study.

Among the study's other findings were that maintenance was done only when a malfunction indicator activated; malfunction indications did not cause drivers to disrupt their operations and stop en route; no special maintenance was performed on the ABS beyond routine periodic inspections; no problems with electronic and radio frequency interference (RFI) were reported; with proper maintenance, ABS life was expected to equal that of the vehicle; and carriers reported that drivers liked driving ABS-equipped vehicles. Although some problems were encountered with wiring and connector failures, ABS manufacturers believed that their systems were generally reliable and expected future improvements.

[11] ''European/Australian Experience with Antilock Braking Systems in Fleet Service,'' U.S. Department of Transportation, NHTSA, DOT HS 807 269, March 1988.

Since the completion of NHTSA's study, several European countries have issued regulations requiring heavy vehicles to be equipped with antilock brake systems. Specifically, the Economic *Commission for Europe*[12] (ECE) Regulation No. 13 includes technical requirements for antilock systems in Annex 13 of its regulation.[13] Annex 13 sets forth definitions of antilock brake systems and component parts, various ''types'' of antilock systems, and test procedures. ECE's Annex 13 specifies a design requirement and dynamic performance requirements. The European Economic Community (EEC Common Market) directive has identical requirements. As a result, since October 1, 1991, all heavy trucks (with GVWR greater than 16 metric tons), interurban buses (with GVWR greater than 12 metric tons), and heavy trailers (with GVWR greater than 10 metric tons) submitted for new type approvals in European countries adopting the standard have been required to be equipped with ABS. Accordingly, ABS have been installed on tens of thousands of European heavy vehicles that have traveled millions of miles over the last few years. All vehicles for which ABS is mandatory under Annex 13 are required to have a Category 1 system. Such systems are essentially the same as those required by today's final rule.

With respect to performance testing, NHTSA has issued two reports on the stopping distance capability of several different types of heavy air-braked vehicles at various loading conditions.[14] The agency also tested some vehicles equipped with ABS, thus allowing comparisons about stopping distances with and without these devices. At the beginning of each test series, these vehicles were equipped with new tires and with new original equipment brake system components to provide consistency in test results. At the beginning of each testing series, the tests were conducted on various vehicles (school buses, transit buses, single unit trucks, tractor trailers) at the loaded and empty conditions and with various equipment (with ABS activated and deactivated). All the tests were straight line stops from 60 mph on a dry concrete surface. The test results indicated that: (1) All stops made with ABS were stable, regardless of whether the vehicle was operating fully loaded or empty, and (2) stopping distance improvements with ABS (compared to no ABS) were greatest in the bobtail configuration (+47 percent in one case), were significant with an empty trailer (+29 percent in one case) and were smallest (+4 percent) in the fully loaded condition.[15]

[12] The Economic Commission for Europe (ECE) is a United Nations organization comprised of European countries plus the United States and Canada, which establishes requirements applicable to the type approval of motor vehicles and other products for sale in those nations that choose to apply the requirements.

[13] Annex 13 is titled ''Requirements Applicable to Tests for Braking Systems Equipped with Anti-Lock Devices (Wheel-Lock Preventers).'' It is Annex 13 of ECE Regulation No. 13, which is titled ''Uniform Provisions Concerning the Approval of Vehicles with Regard to Braking.'' Regulation No. 13 is Addendum 12 of the ''United Nations Agreement Concerning the Adoption of Uniform Conditions of Approval and Reciprocal Recognition of Approval for Motor Vehicle Equipment and Parts,'' done at Geneva on March 20, 1958, which is commonly known as the ''1958 Agreement.''

[14] ''NHTSA Heavy Duty Vehicle Brake Research Program Report No. 9, Stopping Distances of 1988 Heavy Vehicles,'' (DOT HS 807 531, February 1990)

NHTSA's fleet testing program of ABS-equipped truck tractors evaluated the reliability, maintainability, and durability of 200 truck tractors equipped with ABS. The fleet study found that current generation ABSs are reliable and can be successfully installed on commercial motor vehicles.[16] The agency added trailers to the fleet study program in 1990–1991 and found similar results. A copy of that study has been submitted to the public docket.[17] The findings of the fleet testing program are discussed later in this preamble.

## IV. Advance Notice of Proposed Rulemaking (ANPRM)

On June 8, 1992, NHTSA responded to Congress' 1991 mandate in ISTEA by publishing an advance notice of proposed rulemaking (ANPRM) announcing the agency's interest in measures to improve the directional stability and control of heavy vehicles during braking. (57 FR 24212.) The advance notice stated the agency's tentative conclusion that ABS represents the best available and most reliable technology to reduce jackknifing and other loss-of-control crashes during braking. The notice posed questions about such matters as the occurrence of loss-of-control crashes; the availability and performance of systems to improve directional stability and control under all conditions of braking and vehicle

[15] DOT HS 807 531, Table 4, page 19; Table 5, page 23; Table 6, page 25)

[16] ''An In-Service Evaluation of the Reliability, Maintainability, and Durability of Antilock Braking Systems (ABS) for Heavy Truck Tractors,'' (DOT HS 807 846, Final Report, March 1992.)

[17] ''An In-Service Evaluation of the Performance, Reliability, Maintainability, and Durability of Antilock Braking Systems (ABSs) for Semitrailers'' (DOT HS 808 059, Final Report, October 1993.)

load; potential regulatory approaches to improve the directional stability and control of heavy vehicles during braking, including anticipated performance requirements, test procedures, and equipment requirements; a schedule for implementing requirements; diagnostic equipment to ensure in-use functioning of the systems; and anticipated costs of such requirements.

## V. Agency Proposal

On September 28, 1993, NHTSA proposed to amend Standard No. 105 and Standard No. 121, to add requirements that would improve the directional stability and control of heavy vehicles during braking. (58 FR 50738.) NHTSA decided to propose that each heavy vehicle must be equipped with an antilock braking system that satisfies the agency's proposed definition of ABS. In addition, as a verification of the performance of the ABS, the agency proposed that a heavy vehicle comply with a braking-in-a-curve test.

NHTSA stated that, in proposing these amendments, its overriding goal was to ensure the directional stability and control of heavy vehicles during braking. The agency stated that, to ensure adequate ABS performance by means of dynamic test requirements, it would need to establish a broad array of performance requirements that would test the directional stability and control of vehicles under a number of loading conditions, travel speeds, and deceleration rates, and on a wide variety of road surfaces, including roads that are dry, wet, icy, and ''split mu.'' In addition, to ensure that directional stability and control are not provided at the expense of stopping distance, each of these tests would need to require the vehicle to stop within a specified distance.

NHTSA explained, however, that an approach that relied exclusively on dynamic test requirements would raise serious practicability concerns, given the inherent variability of stopping distance performance on low coefficient of friction surfaces and the costs associated with requiring such an extensive array of dynamic performance test requirements. NHTSA, therefore, focused its efforts on expressly requiring that heavy vehicles be equipped with ABS, and on supplementing that requirement with feasible and practicable dynamic tests that check the directional stability and control, and stopping distance of vehicles under a limited set of circumstances that may be experienced in the real world.

The proposal that heavy vehicles be equipped with antilock systems would have required that the front axle and at least one rear axle of each heavy vehicle be equipped with an ABS that would automatically control rotational wheel slip during braking by (1) sensing the rate of angular rotation of the wheels, (2) transmitting signals regarding the rate of wheel angular rotation to one or more devices which interpret those signals and generate controlling output signals, and (3) transmitting those controlling signals to one or more devices which adjust brake actuating forces in response to those signals. The agency stated its belief that these characteristics, specified in the definition of ABS, would permit the installation of any antilock braking system, provided that it is a ''closed-loop'' system that ensures feedback between what is actually happening at the tire-road surface interface and what the device is doing to respond to excessive wheel slip. NHTSA tentatively concluded that these criteria were necessary to ensure the introduction of systems that control wheel slip and sustained wheel lockup under a wide variety of real world conditions and thus would significantly improve safety.

In addition, the NPRM contained a detailed discussion of the braking-in-a-curve test, including the test track's configuration, lane width, and test surface, the vehicle's test speed, the type and number of brake applications, loading conditions, control trailer requirements, and the initial brake temperature.

NHTSA also proposed requirements for the ABS malfunction lamps and the power source for trailer antilock systems. The agency also addressed such considerations as requirements for diagnostic systems, the types of vehicles to be covered by the rulemaking, the implementation schedule for the proposed requirements, the rulemaking's potential effects on intermediate and final stage manufacturers and trailer manufacturers, and its costs and benefits.

## VI. Comments on the Proposal

NHTSA received over 60 comments in response to the NPRM. Commenters included heavy vehicle manufacturers, brake manufacturers, safety advocacy groups, heavy vehicle users, trade associations, State entities, and other individuals.

Most commenters agreed that the agency should issue requirements to improve the stability and control of heavy vehicles during braking, thereby reducing the number of loss-of-control crashes. Advocates for Highway and Auto Safety (Advocates), the Heavy Duty Brake Manufacturers Council (HDBMC), the Insurance Institute for Highway Safety (IIHS), and Rockwell WABCO generally supported the agency's proposal to require heavy vehicles to be equipped with an ABS. These commenters stated that ABS will improve vehicle safety by providing improved braking performance and vehicle stability and control during braking.

The American Automobile Manufacturers Association (AAMA) [18], the American Trucking Associations (ATA), and fleet operators expressed mixed support for the rulemaking. AAMA stated that it ''reluctantly accepts the design specific proposal,'' given its concerns about the proposed braking-in-a-curve test procedure. ATA stated that it supports the use of ABS, but is concerned that the proposed effective dates would require universal use of ABS too soon to assure safety and reliability. AAMA and ATA stated that they would fully support the rulemaking, if the agency revised various aspects of the proposals. AAMA was primarily concerned about the practicability of the braking-in-a-curve test. ATA was primarily concerned about the ABS equipment requirement and alleged problems with the reliability of separate tractor-to-trailer electrical cables/connecters. The agency notes that some of ATA's requested revisions would be major departures from the original proposal.

The National Private Truck Council (NPTC), the National Truck Equipment Association (NTEA), the National Association of Fleet Administrators (NAFA), and the National Association of Trailer Manufacturers (NATM) opposed requiring heavy vehicles to be equipped with ABSs. These commenters were primarily concerned about the costs that an ABS requirement would impose on fleets, final stage manufacturers of vehicles produced in multiple stages, and small trailer manufacturers. NTEA stated that it would be impracticable for final stage manufacturers to certify compliance with the braking-in-a-curve test.

Commenters also addressed specific issues raised in the NPRM, including the proposal to require vehicles to be equipped with ABS, the type of and definition for ABS, the braking-in-a-curve test procedure, the implementation schedule for the

[18] AAMA submitted joint comments on behalf of eight major domestic manufacturers of heavy vehicles: Chrysler, Ford, Freightliner, General Motors (GM), Mack Trucks, Navistar, PACCAR, and Volvo-GM).

requirements, the malfunction indicator requirements, the power requirement, and the rulemaking's cost. A more specific discussion of the comments, and the agency's responses, are set forth below.

*VII. Agency's Supplemental Proposal*

Based on its analysis of comments on the NPRM and other available information, NHTSA issued a supplemental notice of proposed rulemaking (SNPRM) proposing a modified implementation schedule for the requirements in the agency's September 1993 NPRM and a requirement for independent wheel control on at least one axle. (59 FR 17326, April 12, 1994.)

With respect to leadtime, the agency proposed concurrent effective dates for the heavy vehicle stability and control requirements and for the heavy vehicle stopping distance requirements. Specifically, the agency proposed the following implementation schedule for both sets of requirements:

Truck tractors—2 years after final rule (1996)
Trailers—3 years after final rule (1997)
Air-braked single unit Trucks and buses—3 years after final rule (1997)
Hydraulic-braked single unit trucks and buses—4 years after final rule (1998)

With respect to independent wheel control, NHTSA proposed to require heavy vehicles to be equipped with an ABS that controls the wheels on at least one front and one rear axle, and independently controls the wheels on at least one of these two axles. The agency tentatively concluded that this would provide a necessary level of stopping distance performance on low mu and split mu surfaces. The agency posed a number of questions about the need for independent wheel control.

**VIII. Comments on the Supplemental Proposal**

NHTSA received comments from AAMA, other vehicle manufacturers, brake manufacturers, safety advocacy groups, ATA, and others.[19] Aside from ATA, almost all the commenters favored the proposed implementation schedule. Several commenters, including AAMA, Ford, Bendix, and Midland-Grau were concerned that the proposed requirements addressing independent wheel control were unreasonably design restrictive.

Among the other issues raised by commenters were whether the proposal is a performance requirement, alleged reliability and maintenance problems with ABS, alleged safety problems caused by ABS, the regulation's benefits and costs, its applicability to hydraulic systems, and the possible need for a phased-in implementation schedule and a separate power circuit for operating the ABS.

**IX. Agency Decision**

*A. Requirement for and Definition of ABS*[20]

In developing the proposal for this rulemaking, NHTSA considered what requirements are necessary to ensure improved stability and control for heavy vehicles. Among other things, the agency considered whether adequate performance relating to stability and control could be ensured solely by means of dynamic vehicle performance test requirements.

The agency stated in the NPRM its belief that, in order for an approach relying solely on dynamic tests to be successful, it would be necessary to establish a broad array of dynamic performance requirements that would test the directional stability and control of vehicles under a variety of loading conditions, travel speeds, and deceleration rates, and on a variety of road surfaces, including ones that have coefficients of friction that are low, high, and split mu. In addition, in order to ensure that stopping distance performance is not compromised in the attempt to improve directional stability and control during braking, it would be necessary for these performance requirements to specify maximum stopping distances.

NHTSA explained, however, that the poor correlation between stopping distance performance and the peak friction coefficient[21] (PFC) of low coefficient of friction surfaces, combined with the costs associated with such an extensive array of dynamic performance requirements, would, at this time, raise serious practicability concerns about any approach that included such an array of dynamic test requirements.[22] NHTSA therefore focused its efforts on a single provision expressly requiring that heavy vehicles be equipped with antilock systems, and on identifying feasible and practicable dynamic tests that could supplement that provision by directly assessing the directional stability, control and stopping distance of vehicles under some of the wide variety of circumstances that may be experienced in the real world.

This section discusses the proposed provision expressly requiring that heavy vehicles be equipped with antilock systems. More specifically, NHTSA proposed to require that each heavy vehicle be equipped with an ABS that satisfies the following definition:

''*Antilock braking system*'' means a portion of a service brake system that automatically controls the degree of rotational wheel slip during braking by:

(1) sensing the rate of angular rotation of the wheels;

(2) transmitting signals regarding the rate of wheel angular rotation to one or more devices which interpret those signals and generate responsive controlling output signals; and

(3) transmitting those controlling signals to one or more devices which adjust brake actuating forces in response to those signals.

In developing this definition, the agency specifically sought to avoid unnecessary design restrictions or impede the future development of ABS. NHTSA stated in the NPRM that it believed that the proposed requirement would permit any ABS, provided that it was a closed-loop system that ensures feedback between what is actually happening at the tire-road surface interface and what the device is doing to respond to changes in wheel slip.

For a number of reasons discussed in the NPRM (and below), NHTSA tentatively concluded that a device that satisfies these criteria is necessary in order to prevent wheel lockup under a wide variety of real world conditions, thereby significantly improving safety.

A number of commenters, including vehicle manufacturers and brake manufacturers, recognized the practicability problems currently associated with some dynamic performance requirements and accordingly supported the agency's proposal to require heavy vehicles to be equipped with ABSs. AAMA stated that despite its strong preference for what it termed ''performance requirements,'' it would accept an explicit ABS requirement, provided that the braking-in-a-curve test is not adopted and the effective date for the proposed stopping distance requirement is made concurrent with the other effective dates for this rulemaking.[23] That organization stated that, in general, manufacturers ''much prefer performance over design specifications because performance

[19] Comments on the SNPRM will be specifically labeled as such. Other comments will be assumed to be in response to the NPRM.

[20] The reader may wish to review the Appendix which provides a technical explanation of how antilock brakes work, including various methods of wheel control.

[21] See the Appendix for a discussion of this term.

[22] ''MVMA/NHTSA/SAE Round Robin Brake Test,'' Transportation Research Center of Ohio, Report No. 091194, August 26, 1991.

[23] AAMA's specific concerns about the braking-in-a-curve test are discussed in a later section of this document.

requirements allow new, improved and more cost-efficient technological means to achieve desired safety ends.'' Nevertheless, AAMA indicated that it was willing to accept an ABS equipment requirement because it believes there are significant practicability problems associated with various dynamic tests that the agency has considered, including the braking-in-a-curve test.

Similarly, Rockwell WABCO stated that it ''reluctantly accepts the proposal for an ABS equipment standard rather than a performance standard.'' That commenter stated that it normally opposes equipment standards since they have the potential of restricting the implementation of new technology. However, it stated that, in this case, ''the current difficulty in formulating valid, repeatable performance criteria prohibit a true performance standard at this time.'' Rockwell WABCO concluded that ''the proposed combination of an equipment specification and a performance test is both understandable and acceptable'' for now.

Advocates stated that it is convinced that:

> The agency's resolve to mandate a basic level of ABS as required equipment on all tractors, trucks, trailers, and buses with verification of desirable safety performance gained through a single major operating test, is the most appropriate way to ensure that the substantial safety benefits of heavy vehicle ABS are realized quickly.

Midland-Grau stated that the characteristics specified in the proposed definition will permit any antilock brake system, provided that it is a ''closed-loop'' system that ensures feedback between what is actually happening at the tire-road surface interface and what the device is doing to respond to changes in wheel slip.

Mr. John Kourik, a brake engineer, stated that the proposed definition:

1. Selects the proper technology to assure optimum stability and control, [and]
2. Supplements the intent of the original definition with a high degree of sophistication. This should eliminate the inferior mechanisms and devices that have been offered by 'toying' with the brevity of the original definition while making representations and distorted claims to suggest equivalency to ABS. Thus, the new definition should end the ''smoke and mirrors'' promotions of alleged substitutes for ABS.

According to Mr. Kourik, the proposed definition would preclude the use of unsophisticated equipment that does not sense changes in the wheel rotation rate, e.g., equipment such as mechanical devices, pneumatic dampeners, hydraulic dampeners, hydro/mechanical units, and electro/mechanical units.

Other commenters strongly opposed the proposed ABS requirement. ATA argued that NHTSA had proposed a ''design standard for ABS'' that is ''unlawful because it is contrary to the agency's statutory mandate to issue only performance standards.'' Citing the statutory definition of ''motor vehicle safety standard,'' that organization stated that, under the Safety Act, the requirements in Federal motor vehicle safety standards must prescribe performance, not design obligations.

ATA claimed that, despite the statutory mandate, much of the agency's proposal represents design requirements. Specifically, ATA stated that there were additional impermissible design aspects to the proposal, including the definition of ABS, and the requirements for trailer electrical power to be transmitted by a separate circuit specifically provided for that purpose and for warning systems to be electrical.

ATA also argued that the proposed definition for ABSs is unnecessarily design-restrictive, and would stifle innovation and require continual updating of the standard. ATA stated that the requirements would preclude anything but electronic systems, thereby prohibiting mechanical systems. That organization also argued that the requirements would impair efforts to develop new electronic technologies.

Several small companies which manufacture or sell brake products also argued that the proposed requirements are inappropriately design-restrictive. They argued that NHTSA should change the proposed definition of ABS so that devices other than computerized ABS can be used to meet the requirements. Trade International Corporation (TIC) argued that the proposed definition for ABS is fundamentally flawed because it does not specify what the system is supposed to accomplish but rather specifies how the system is supposed to work. It argued that a system could satisfy the definition but not accomplish the desired function.

After carefully considering the comments, NHTSA has decided to adopt the proposed requirement for and definition of ABS. The agency's response to the comments, including a more detailed discussion of some of the comments summarized above, is presented in the sections which follow.

### 1. Legal Authority

NHTSA disagrees with ATA's allegation that the agency does not have the statutory authority to issue a ''design standard.'' NHTSA's longstanding position [24] on this subject, which is presented in the form of a hypothetical discussion concerning the agency's authority to regulate the width of motor vehicles, is set forth below:

> We believe that the National Traffic and Motor Vehicle Safety Act * * * would permit issuance of a safety standard that regulated or limited vehicle width, if it were found that such a regulation ''meets the need for motor vehicle safety'' (§ 103(a), 15 U.S.C. 1392(a)). As is true with every motor vehicle safety standard, however, it would be necessary to establish a reasonable, objective basis for the conclusion that this regulation can be justified by safety benefits obtainable, to avoid a judicial conclusion that the action is ''arbitrary, capricious, [or] an abuse of discretion.'' (5 U.S.C. 706). The issue, in other words, would not be one of basic authority, but of justification.
>
> Although it may be argued that such a safety standard would be a regulation of ''design, and not performance'', for reasons set forth below we feel that this argument is insubstantial and reflects an inadequate understanding of the Act and the safety standards * * *.
>
> Section 102(2) of the Act (15 U.S.C. 1391) defines a motor vehicle safety standard as ''a minimum standard for motor vehicle performance, or motor vehicle equipment performance, which is practicable, which meets the need for motor vehicle safety and which provides objective criteria.'' Section 103(f) of the Act also requires the standards to be ''reasonable, practicable and appropriate for the particular type of motor vehicle * * * for which it is prescribed.''
>
> It has sometimes been suggested that the inclusion of the word ''performance'' in this definition suggests the existence of a dichotomy between vehicle design and performance. We do not, however, consider that there is a dividing line between standards that regulate performance and standards that affect design. Senator Magnuson recognized the absence of any dichotomy when he said that some safety standards would necessarily determine the configuration of some vehicle components. (112 C.R. 20600 (Aug. 31, 1966.)). In fact, all safety standards have a strong *effect* on vehicle or equipment design, in spite of their being phrased in ''performance'' terms. This is necessarily so since the design of vehicles and equipment determines the quality of their performance. (Some confusion over ''design'' may arise from the common use of the word to mean appearance or shape. In our work, however, the word means the sum of all of the characteristics that a product is intended to have, e.g., size, weight, interrelationship of components, materials, and markings.)
>
> Each of our safety standards meets the need for motor vehicle safety by specifying requirements for the performance of a particular vehicle or item of equipment. Any design that will satisfy the requirements may be used for the system or item of equipment. The extent to which the choice of a design

[24] This discussion has been presented in past NHTSA letters, including a May 2, 1979 letter to the Insurance Institute for Highway Safety.

is restricted by a particular standard is purely a matter of degree, depending on the specificity of the requirement. We try, in carrying out the congressional mandate, to make the requirements as broad as the safety need allows. We will probably never have to reach the level of a true ''design specification'' as an engineer would use the term, i.e., a detailed description of every significant aspect of a product including the materials and manufacturing processes used. This is true because the standards deal only with the safety-related *characteristics* of the regulated items, e.g., the height, width, and strength of a head restraint and the light output of a headlamp.

In some cases, the *configuration* of a vehicle component or item of equipment is the characteristic that relates to safety. A good example of this is our standard on transmission shift levers (No. 102), which standardizes the position of Park, Reverse, etc., on all our passenger cars today. There, standardization of at least some external aspects of the component is needed for safety's sake. A second example is our standard on control identification (No. 101), where again an enforced similarity in the words and symbols used to identify vehicle controls is the heart of the safety requirement * * *.

Thus, if the width of a vehicle is, in fact, the characteristic that is found to require regulation for safety purposes (analogously to the spacing of headlamps in Standard 108 or the width of a head restraint in Standard 202), there should be no doubt of NHTSA's authority to regulate it.

NHTSA's requirements for specified safety equipment are at the heart of many of the Federal motor vehicle safety standards. Indeed, thousands of the lives saved and the injuries reduced or prevented by Federally-mandated safety features are the direct result of requirements for specific types of equipment. Most prominent among these requirements is the 25-year-old requirement in Standard No. 208, *Occupant Crash Protection*, for the installation of specific types of safety belts. This is the most heavily judicially and Congressionally scrutinized safety standard, and no question has ever been raised about the agency's authority to issue such a standard.

Equipment requirements are critical for helping to ensure that vehicles have many of the items necessary to guarantee safety. For example, it is critical for drivers to be able to see where they are going, and for their vehicle to be seen by other drivers. The safety standards therefore require items that are critical for driver visibility and vehicle conspicuity in the rain and at night. Standard No. 104 requires vehicles to have a windshield wiping system, Standard No. 108 requires vehicles to be equipped with specified lamps and reflective devices, Standard No. 111 requires that vehicles be equipped with rearview mirrors, and Standard No. 205 specifies the types of glazing which may be used in various locations.

Many other safety standards, including the existing brake standards, specify equipment requirements that meet equally important safety needs. Thus, the extremely narrow reading of the word ''performance'' advocated by ATA is inconsistent with the entire history of the Federal program for motor vehicle safety standards, and indeed with a majority of the existing standards.

The case law addressing this issue has clearly upheld NHTSA's authority to issue safety standards that directly affect design. In *Chrysler v. DOT*, 515 F.2d 1053 (6th Cir. 1975), for example, the court upheld a dimensional restriction on rectangular headlamps. That court reasoned that:

> Uniformity of headlamp size is an element of headlamp performance. Design freedom would inhibit safety, and certainly the congressional purpose of encouraging safety-related competition among manufacturers is meaningless in this context.
>
> We conclude that the dimension restriction at issue here essentially serves to ensure proper headlamp performance and lies within the regulatory authority granted by Congress to the NHTSA.

515 F.2d at 1058, 1059.

Moreover, in *Motor Vehicle Manufacturers Association v. State Farm*, 463 U.S. 29 (1983), the United States Supreme Court held that, before rescinding a general requirement for automatic restraints because one type of automatic restraint (e.g., the detachable automatic safety belt) might be ineffective, NHTSA must consider establishing an airbag-only requirement. The Court further stated that the agency could prohibit detachable automatic safety belts if the agency determined that they would not provide effective passenger protection. Therefore, the Supreme Court clearly recognized NHTSA's authority both to require specific safety equipment deemed to provide superior safety protection and to prohibit specific equipment that the agency deemed to provide inferior safety protection.

NHTSA therefore rejects ATA's argument concerning the agency's authority to require specified safety equipment. However, as indicated above, the agency does, in carrying out its statutory mandate, attempt to make its safety requirements as broad as the safety need allows. The relevant issue for this rulemaking is thus not whether the agency proposed an unlawful ''design standard,'' but instead whether the proposed requirement/definition for ABS is unnecessarily design-restrictive. For the reasons discussed below, NHTSA has concluded that each element of the proposed requirement/definition for ABS is necessary to meet the safety need for improved stability and control.

2. Elements of the Requirement/Definition for ABS

Far from proposing a detailed ''design requirement,'' NHTSA simply proposed to require vehicles to be equipped with an ABS consistent with the generally understood meaning of that term among brake engineers. The agency used this approach precisely to avoid imposing unnecessary design restrictions or impeding the future development of ABS. As discussed in the NPRM, the definition is sufficiently broad to permit the installation of any antilock braking system, provided that it is a ''closed-loop'' system that ensures feedback between what is actually happening at the tire-road surface interface and what the device is doing to respond to changes in wheel slip.

In developing the proposed definition, the agency relied on the Society of Automotive Engineers [25] (SAE) J656 (Apr88) ''Automotive Brake Definitions and Nomenclature'' and the Economic Commission for Europe's Regulation 13, Annex 13 (1988). SAE J656 refers to ABSs as ''wheel slip brake control systems'' that automatically control rotational wheel slip during braking. Among the terms related to ABS that are defined in SAE J656 are ''modulator'' and ''wheel slip sensor.'' These terms are used in SAE's test procedure for antilock systems, as specified in SAE J46 (JUN80) ''Wheel Slip Brake Control System Road Test Code.'' Similarly, Annex 13 of ECE Regulation 13 refers to ''anti-lock devices'' as systems which automatically control the degree of slip, in the direction of rotation of the wheel(s). The Annex 13 definition of ABS also states that such devices include ''a sensor or sensors, a controller or controllers and actuating valves.'' The agency's proposed definition of ABS incorporated the terms set forth in SAE J656 and ECE Regulation 13 to reflect the attributes of antilock systems as commonly understood by the automotive engineering industry.

The proposed equipment requirement specifies simply that vehicles must be equipped with an ABS which is defined

[25] The Society of Automotive Engineers is a voluntary professional organization that establishes recommended practices related to various aspects of motor vehicles.

as a system that automatically controls the degree of rotational wheel slip during braking, by (1) sensing the rate of wheel rotation, (2) transmitting signals regarding the rate of wheel rotation to a device which interprets those signals and generates responsive controlling signals, and (3) transmitting those controlling signals to a device which adjusts brake actuating forces in response to those signals. For reasons discussed below, each of these elements is necessary to meet the need for safety. In addition, the definition only states the *performance* required of the ABS components, not *how* the components must detect wheel rotation, etc.

As discussed earlier in this preamble, the safety problem being addressed by this rulemaking is that whenever the driver applies the brakes with too much force relative to extant tire and road conditions, sustained wheel lockup occurs. This usually results in loss of vehicle directional stability and/or steering control; i.e., a jackknife, spin-out or skid, and often a crash. Such sustained lockup most often occurs when the road is slippery or when the vehicle is lightly loaded or has no cargo. This is because drivers are likely to make a hard brake application in a panic situation, and the resulting braking forces easily cause lockup when the road is slippery or when the vehicle is lightly loaded or empty. Moreover, drivers are unable to sense lockup quickly enough to control it.[26]

In order to address this safety problem, NHTSA has determined that it is necessary to prevent the brake system from generating forces that result in uncontrolled lockup. This need is addressed in part by the first element of the requirement/definition: each ABS must automatically control the degree of rotational wheel slip during braking.[27] Automatic control is necessary since drivers cannot control lockup in an emergency situation. By the time a driver can sense that lockup has occurred, it is often too late to prevent the sustained lockup that results in loss of directional stability or control.

The second element of the requirement/definition (sensing rate of wheel rotation and transmitting signals about the rate to a device that generates responsive control signals) is necessary to ensure that lockup will be prevented or controlled for all road surfaces and under all load conditions, and also to ensure that stability is not provided at the expense of stopping distance. The prevention of sustained lockup, and resulting loss of directional stability and control, should not be accomplished simply by putting weak brakes on the vehicle or lowering braking forces under all conditions. Thus, in addressing this safety problem, the agency must consider the twin goals of preventing/controlling lockup *and* ensuring good stopping distance under all road surface and load conditions.

In a braking situation, the more the driver depresses the brake pedal, and thereby increases braking forces, the more quickly the vehicle will stop, so long as the braking force is not so high that it causes wheel lockup. Thus, if stopping distances are to be minimized during braking, it is necessary to permit the hydraulic or air pressure to rise to a point just below the point where lockup would occur.

Moreover, the amount of pressure that causes lockup will vary dramatically depending on the road surface and vehicle loading. In order to ensure that braking force rises to a point just below the point where lockup would occur, it is necessary for an ABS to sense *either* each of the factors on which lockup is dependent, i.e., road surface friction, vehicle loading, dynamic weight transfer during braking, condition of brake linings, etc., *or* the product of all of those factors, i.e., the rate of wheel rotation from which wheel slip can be determined. Since it may not be technologically feasible for an ABS to sense all of the factors which may lead to lockup, the definition specifies that an ABS must sense the product of those factors, i.e., the rate of wheel rotation.

The rest of the second element of the definition is necessary to ensure that an ABS uses the relevant information, i.e., rate of wheel rotation, to control wheel slip and prevent lockup. The relevant information must be transmitted to a device which interprets the information and generates responsive controlling signals. Those controlling signals must then be transmitted to a device which adjusts brake actuating forces in response to those signals.

NHTSA has determined, based on all available information, that a device that lacks any one of the elements specified in the definition could not meet the need for safety addressed by this rulemaking, since, for the reasons discussed above, its operation would not be dependent on factors that are relevant to the desired safety performance.

The agency notes that while several commenters asserted that the proposed definition is unnecessarily design restrictive, none attempted to explain how a device not meeting one or more of the elements could ensure stability and control for heavy vehicles for a wide range of test surfaces and loading conditions.

Most of the commenters arguing that the proposed definition is unnecessarily design restrictive were small companies which manufacture or sell brake products. In essence, they wished the agency to change the proposed definition of ABS so that their devices can be used to meet the requirements. These companies are, of course, free to develop and sell products that meet the definition. Also, to the extent that these companies produce products that do not meet the definition, they are free to sell them as supplemental equipment, so long as the products do not create compliance problems or contain safety defects. However, for the reasons discussed above, and expanded on below in the context of these comments, products which do not meet the definition would not prevent sustained wheel lockup.

Strait-Stop, a company which manufactures what it calls a ''noncomputerized ABS,'' argued that the proposed ABS definition is discriminatory and excessively design-restrictive because it necessitates the use of electronic computerized systems with wheel speed sensors. It argued that the agency's tests ''(do) not prove, conclusively, that the computerized ABS is the only alternative to accomplish stability and control.'' Strait-Stop also stated that NHTSA's fleet study indicated that computerized ABS activated very rarely, only 1.4 times per 10,000 brake applications or 1.1 times per 10,000 miles driven, and that it is a tool with which drivers will not gain familiarity. In contrast, Strait-Stop stated that its device activates approximately 98 percent of the time that the driver applies the brakes, thereby enabling drivers to become familiar with the system. While Strait-Stop did not describe how its ''non-computerized ABS'' works or precisely what it does, that company stated that its device uses ''modulation but not reduction of braking pressure.'' Moreover, literature about its system indicates that the air flow from the foot (treadle) valve to the relay valve is interrupted through the Strait-Stop system and pulsates the brake chambers. The ''system intermittently repeats the on and off cycle at a pre-set rate.''

Jenflo Brake-Aid (Jenflo) also argued that the proposed ABS definition is discriminatory, and that the definition should be revised to permit braking devices other than the ones tested by the

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[26] ''Improved Brake Systems for Commercial Motor Vehicles,'' DOT 807 706 Section 3.2.2; pages 3–5.

[27] As discussed in the Appendix, wheel slip refers to the proportional amount of wheel/tire skidding relative to vehicle forward motion, and lockup is simply the condition of 100 percent wheel slip.

agency. Jenflo manufactures a device for air brake systems which causes a ''pulsing (or air pressure to) the brake actuators hundreds of times per minute, (that will) cause the tires to approach lock-up, then the brakes are off for a 'small' fraction of a second and are just as rapidly reapplied.'' As a result, the air pressure is continually released and reapplied on all the controlled wheels during all but ''normal'' braking.

Trade International Corporation (TIC) stated that the proposed ABS definition is unnecessarily narrow and could preclude the use of available, beneficial products and technologies, and also impede the development of other useful products and technologies. TIC argued that a system which continuously modulates the braking force applied to every wheel whenever braking force is applied would not satisfy the definition because it lacks the specified sensing and transmitting functions, regardless of its ability to prevent wheel lockup and/or enhance braking effectiveness.

The devices referred to by Strait-Stop, Jenflo Brake-Aid, and TIC all ''pulse'' the air pressure for essentially all but normal brake applications. These commenters did not explain in detail how these products work. However, based on the available information, they provide the same ''pulsing'' of air pressure at a fixed pulsation rate for all brake applications above some braking or turning threshold. Regardless of how they work, however, the devices cannot ensure the twin goals of preventing/controlling lockup *and* ensuring good stopping distance under all road surface and load conditions, if they do not meet the proposed definition. This is because, for the reasons explained above, their operation would not be dependent on the factors that are relevant to the desired safety performance. Only by continuously sensing and responding to what is actually happening at the tire/road surface interface can an ABS system optimize the braking pressure so as to both prevent lockup and minimize stopping distances. As discussed in the ABS Wheel Slip Control Strategies section of the Appendix, one effect of varying road surface and vehicle load conditions on the operation of ABSs is the varying controlling frequencies that are needed to adapt to these varying conditions. The fact that these other devices incorporate a fixed pulsation rate demonstrates their lack of adaptability to varying road surface and vehicle load conditions. As shown in Figures 17 and 18 in the Appendix, the ABS controlling frequency needs to be relatively slow, between 1 and 2 cycles per second, in order to prevent sustained excessive wheel slip on very low friction surfaces and needs to be much faster, approaching 10 cycles per second, in order to achieve very short stopping distances on high friction surfaces. The increase in stopping distance on high friction road surfaces that would result from a system which exhibited a slower than optimum ABS controlling frequency may not be great. However, the impact of a much faster than optimum ABS controlling frequency on a very low friction surface would be sustained and excessive wheel lockup. As shown in Figure 17 in the Appendix, wheel lockup can occur very rapidly. Figure 17 also shows that from the time that the ABS solenoid is activated to reduce brake pressure it takes about 0.25 seconds before the wheel even begins to spin up, about 0.35 seconds for the wheel to reach one-half of the vehicle's speed and more than 0.6 seconds for the wheel to reach the vehicle's speed. If the devices referred to by Strait-Stop and Jenflo Brake-Aid pulse the brakes several times a second, the ''off'' portion of pulsation cycle would not be sufficiently long to allow the locked wheel to spin up prior to the next ''on'' portion of the cycle which would result in sustained wheel lockup.

The basic problem with devices that do not incorporate feedback on what is happening at the tire/road surface interface (as required by the definition of ABS mandated by this amendment) such as those described by Strait-Stop, Jenflo and TIC, is that they are ''blind'' to the road and surface conditions on which the vehicle is operating and thus make the same response each time, regardless of whether that response is appropriate for the existing circumstances. In other words, the systems cannot appropriately adjust their cycle rate or the degree of pressure variation to compensate for the effects that load condition and road surface friction can have on the lockup and spinup times of a vehicle's wheels. This lack of ''adaptability'' to changes in load and road surface conditions results either in sustained wheel lockup (and resultant loss of stability and control) or in stopping distances that are much longer than the vehicle would otherwise be able to achieve under those conditions for which the system was not optimized. As a result, even if these systems enhanced vehicle stability on one type of surface, they would provide inferior braking on a different surface. For instance, the relatively high brake pressure required for short stopping distance on a high coefficient of friction surface would lock the wheels on a slippery surface because wheel lockup occurs when the braking force at the tire/road surface interface, needed to resist the torque generated by the brake, is greater than that which can be generated from the available surface friction. Because wet surfaces have lower friction levels, vehicles on these roads will lock up at lower levels of brake pressure. Conversely, if the pulsating mechanical system were designed so that brake pressure was reduced in a manner that ensured that lockup would not occur during hard braking on a slippery surface, stopping distances would be very long when braking on high coefficient of friction surfaces.

NHTSA also notes that in order to optimize stopping distance and maintain vehicle stability, an antilock system must be capable of reducing, holding, and reapplying braking pressure to each controlled wheel. The wheel speed sensor monitors the rotational speed of the wheel. When a monitored wheel approaches a lockup condition, there is a sharp rise in peripheral wheel deceleration and in wheel slip. If this rise exceeds the designed threshold levels, the ECU sends signals to the modulator device to hold or reduce the build-up of wheel brake pressure until the danger of wheel lockup has passed. The brake pressure must then be increased again to ensure that the wheel is not underbraked for the road surface conditions. During automatic brake control, it is important for the wheel speed to be constantly monitored so that the maximum braking force for the conditions could be achieved by a succession of pressure-reduction, pressure-holding, and pressure-reapplication phases. The agency notes that the systems described by Strait-Stop, Jenflo and TIC reduce and reapply pressure, without reference to road conditions, brake forces, or impending wheel lockup.

With respect to Strait-Stop's argument that drivers will not gain familiarity with the kinds of ABS systems tested by NHTSA because the systems activate only rarely, the agency notes that no special familiarity is necessary to operate the system properly. ABS is a safety device which operates automatically in emergency situations.

Strait-Stop also alleged that the system defined and tested by NHTSA does not prevent lockup. While that company did not explain this comment, the agency assumes that Strait-Stop is distinguishing between momentary lockup and sustained lockup. All of the systems tested by NHTSA prevent sustained lockup.

Strait-Stop argued that the inference that the screened-out systems would not meet the braking-in-a-curve test requirement is unsupported since the agency has not tested and, in some cases has refused to provide testing for them. As discussed above, it is possible that a system not meeting the proposed definition could be optimized to provide enhanced stability for a particular test on a particular test surface. However, such a system would provide inferior braking performance on other surfaces and/or under different test conditions.

There is no requirement or reason for the agency to test every invention identified by commenters in a rulemaking proceeding. The agency can use its technical and engineering analysis to determine what performance attributes are necessary to meet the need for safety, and it can also often make determinations about whether particular devices would provide safety benefits by the same means.

NHTSA has also analyzed another type of device, from Emergency Brake Technologies, described by Dr. Barry Wells. This is an emergency braking device that is manually activated by the driver through a dash-mounted switch that activates arms that drop polyurethane wedges and rubber flaps under the vehicle's wheels. After the device is activated, the vehicle must be stopped and reversed so that the wedges can be removed from beneath the wheels. Emergency Brake Technologies claims that this device ''could stop a fully loaded vehicle in the same distance as an automobile and completely eliminate jackknifing.'' While NHTSA does not have any opinion concerning whether this device might provide benefits in some emergency stopping situations, the device would not meet the need for safety being addressed by this rulemaking, i.e., ensuring stability and control during braking. In fact, the dropping of polyurethane wedges and rubber flaps under the wheels would create essentially the same condition as fully-locked wheels, and therefore could result in a loss of control. Once the driver activated this system, the driver would be committed to a quick, sliding stop. The driver would have no capability to release the device once applied, and could also have difficulty steering around a problem. While such a device could provide short stopping distances under dry-road conditions, it would do so by sacrificing vehicle stability and control.

ATA and Strait-Stop commented that the proposed definition would preclude anything but electronic systems, thereby prohibiting mechanical systems. NHTSA notes that this is incorrect, since the definition does not require electronics for the sensing of the wheel rotation, or transmission of wheel rotation or controlling signals. Such functions could be performed using pneumatic, hydraulic, optic, or other mechanical means. The agency notes that it is likely that electronic systems will be used, given currently available technologies. All ABSs currently marketed in the United States are electronic in nature.

In the case of an ABS that does not require electrical power for operation, the only mandatory electrical requirement in this rulemaking (addressed later in this document) is for malfunction indicator lamps used to signal a problem in the ABS.

ATA also argued that the requirements would impair efforts to develop new electronic technologies. ATA stated that the restrictions would limit engineers' abilities to develop electronic braking (brake-by-wire) systems (EBS) by forcing the logic for such systems to be based on existing ABS designs. According to ATA, EBS is designed to handle all braking functions: compatibility, load sensing/brake proportioning, balance, timing, ABS, traction control, and failure control. ATA stated that successful development of these systems may require that designers not be tied to a rotational slip view of wheel lockup.

NHTSA disagrees that the proposed ABS requirements will impair efforts to develop EBS. The agency notes that Robert Bosch GmbH currently markets the Bosch-ELB Electronically Controlled Commercial Vehicle Brake, in Europe. This system includes ABS, traction control, and electronic service braking (with pneumatic backup) functions, and uses the same wheel speed sensor arrangement as does Bosch's ABS sold without EBS. This indicates that EBS is fully compatible with current ABS technology, including wheel speed sensors. Furthermore, a combination-unit vehicle with good brake balance, compatibility, and timing may still be capable of being over-braked by the driver, especially when operated lightly-loaded or on slippery road surfaces, and such a vehicle would still require ABS to prevent wheel lockup when operated under these conditions. The development of the Bosch electronic braking system proves that the rotational slip view of wheel lockup does not hinder the development of successful EBS.

ATA also stated that the requirements could ''hold back'' disc brake technology since disc brakes are ''virtually incompatible'' when used together with drum brakes on a combination vehicle. ATA appears to believe that because EBS can make the ''decisions'' to compensate for those major differences, it is needed for disc brake technology to come into general use. The agency notes that, according to product literature, the Bosch-ELB system measures wheel speeds and brake actuator pressures at each wheel position, and microcomputers in the electronic control unit store and process these data and transmit the correcting commands accordingly. This system could, therefore, compensate for incompatibilities in brake force balance on a vehicle, and would permit safe introduction of disc brakes on vehicles. This system incorporates ABS technology that complies with the agency's proposed ABS requirements, as well as ECE Regulation 13. Therefore, NHTSA disagrees with ATA's argument that ABS requirements will hold back disc brake technology.

In a somewhat different vein, TIC argued that a system could satisfy the proposed definition but not accomplish the desired function of preventing lockup. As part of this argument, TIC stated that the proposed definition for ABS is fundamentally flawed because it does not specify what the system is supposed to accomplish but rather specifies how the system is supposed to work. TIC's comment in essence raises the issue of whether the definition is sufficient, by itself or with other requirements, to meet the need for safety.

As indicated at the beginning of this section, the agency developed a broad definition precisely to avoid imposing unnecessary design restrictions or impeding the future development of ABS. The ABS definition is based on the premise that wheel lockup is the source of a vehicle's loss of directional stability and steering control during braking, and that any device designed to improve such stability during braking must control the source of that instability. Hence, the definition establishes a linkage between the input, signals that sense wheel lockup, and the output, modulated brake pressure to prevent wheel lockup. This is essentially the extent of the design constraints established by the agency, and it gives the industry considerable latitude to design and develop individual components, ranging from sensor design and placement, to the ECU control algorithm and to brake pressure modulation frequency.

NHTSA rejects TIC's argument that the definition does not specify what the system is supposed to accomplish but rather how the system is supposed to work. Modulating brake pressure in response to information about rate of angular rotation is part of what is supposed to be accomplished. As discussed above, the rate of angular rotation reflects what is happening at the tire/surface interface.

NHTSA further concludes that the requirement/definition for ABS is sufficient at this time to meet the need for safety. In arguing that a system can satisfy the definition but not accomplish the desired function, TIC provided the following ''extreme example'':

Consider the following system: (1) a set of angular rate of rotation sensors, one on every wheel; which (2) transmit signals whose level is proportional to the rate of angular wheel rotation to a device which compares the signals and generates control signals; and (3) transmits those control signals to devices which *increase* the braking force applied to any wheel which has an angular rotation rate higher than the wheel which has the lowest angular rotation rate. Such a system satisfies every element of the proposed definition, however, the result of implementing such a system would be that if any wheel locked up during braking *all wheels would lock up*!

While TIC itself acknowledged that its example was ''extreme,'' NHTSA notes that its basic premise also is silly, since it assumes that a manufacturer would deliberately build a brake system that could not work. In considering the impacts of its standards, NHTSA must assess how manufacturers are likely to respond, not unrealistic hypothetical situations. The basic premise underlying this rulemaking is that manufacturers will respond to the definition/requirement for ABS by providing systems that will prevent wheel lockup. This view is confirmed by the comments of the vehicle and brake manufacturers. There is no evidence that manufacturers would respond by deliberately building systems that do not prevent lockup but instead cause lockup.

Moreover, the definition for ABS does not stand in a theoretical vacuum. Manufacturers must design their brake systems to meet other safety requirements (including stopping distance requirements and, for some vehicles, the braking-in-a-curve test). It might not be possible to meet those requirements with systems that did not prevent lockup but instead caused lockup. Manufacturers are also subject to Federal requirements concerning safety-related defects. And, of course, manufacturers must ensure customer satisfaction.

The agency also notes that there is absolutely no incentive for manufacturers to provide ABS systems that do not function as they intended. TIC's comment essentially raises the possibility that a manufacturer might spend all the money necessary to meet the definition of ABS and then include a faulty ECU control algorithm. However, there is no basis to believe that this would happen. The agency only addresses unreasonable safety risks in developing safety standards and need not address unrealistic hypothetical possibilities.

3. Dynamic Versus Equipment Requirements

As discussed in the NPRM and above, NHTSA considered whether adequate performance relating to directional stability and control could be ensured solely by means of dynamic test requirements, but concluded that, at this time, there would be practicability problems associated with the broad array of dynamic test requirements that would be associated with such an approach. The agency therefore decided to propose a single provision expressly requiring that heavy vehicles be equipped with antilock systems, and on identifying feasible and practicable dynamic tests that could supplement that provision by directly assessing the directional stability, control and stopping distance of vehicles under some of the wide variety of circumstances that may be experienced in the real world.

ATA commented that the desired result from mandating the installation of ABS is ensuring that a vehicle can be controlled during a stop, and asserted that the proposed braking-in-a-curve performance requirement, with certain changes, would accomplish this conceptually. However, ATA did not substantiate its assertion about the efficacy of such a requirement, standing by itself. ATA did not address the practicability problems of adopting a set of dynamic performance requirements, or even the practicability problems associated with applying the braking-in-a-curve requirement to all affected vehicles. ATA did, however, suggest that the agency initiate additional research and development for what it called ''true performance tests.''

While NHTSA plans to continue research on dynamic performance tests for trucks, buses and trailers, it has concluded that the desired safety benefits of ABSs could be achieved now by means of a specific equipment requirement for ABS and (as discussed below) a dynamic performance test requirement applicable to truck tractors only. NHTSA is charged by the Safety Act with promulgating safety standards that meet the need for safety. Moreover, Congress was sufficiently concerned about the directional stability and control problems associated with heavy vehicles that it specifically required NHTSA to conduct a rulemaking that examines and could result in requiring the installation of ABSs in these vehicles. The agency has concluded that large safety benefits can be obtained by requiring ABSs on heavy vehicles, and has developed requirements that will ensure installation of this safety equipment.

NHTSA disagrees with the suggestion that it delay implementation of this life-saving rule while it conducts further research in search of the type of rule ATA desires. The overall history of agency rulemaking is one of gradual progression, when and where practicable and beneficial to safety, toward increasingly sophisticated and increasingly more dynamic performance standards. However, relying exclusively on dynamic performance requirements has never been a statutorily mandated requirement. Were it so, there would be many fewer Federal motor vehicle safety standards today—and many thousands more deaths and injuries, occurring annually.

*B. Independent Wheel Control*

In the NPRM, NHTSA proposed to require that the antilock brake system monitor and control the wheels of the front axle (i.e., steering axle) and the wheels of at least one rear axle. NHTSA believed that this would ensure that the wheels on the steering axle and the wheels on the selected rear axle were directly controlled by the ABS. By ''directly controlled,'' the agency meant that the signal provided at the wheel or on the axle of the wheel would directly modulate the braking forces of that wheel or axle. The agency tentatively concluded that it is necessary to specify that the ABS directly control the steering axle because some ABSs control only a vehicle's drive-axle, which could result in the loss of steering control if the front wheels locked during braking.

Several commenters addressed the need for front wheel control. ATA strongly opposed mandating ABS for the steering axle of single-unit trucks and suggested that the agency reconsider the requirement for tractors. In contrast, Rockwell, WABCO, Freightliner, AAMA, Advocates, and IIHS favored requiring that an ABS be installed on front axles. AAMA favored equipping each vehicle with an ABS that has at least one independent channel of control for the wheels on a front axle and at least one independent channel of control for the wheels on a rear axle. However, AAMA objected to mandating more than two independent channels of control.

NHTSA did not specifically address the concept of independent control in the NPRM, but addressed it in the SNPRM by proposing that the wheels on at least one axle be independently controlled. The agency in today's final rule defines an ''independently controlled wheel'' to mean a directly controlled wheel for which the modulator device does not modulate the brake forces at any other wheel on the same axle. This means that a side-by-side control strategy on a tandem axle could have the wheels on the sensed axle of the tandem being independently controlled by a modulator, and the wheels of the other axle of the tandem being indirectly controlled by the modulator for the wheel on the sensed axle on the same side of the vehicle.

Rockwell, Freightliner, Advocates, and IIHS commented that the regulatory language in the NPRM requiring each axle to be directly controlled by an ABS would allow select low [28] antilock systems on any axle. These commenters believed that an antilock system must provide independent control at each wheel of a heavy vehicle to ensure good, overall ABS performance in the areas of stability and stopping distance. Accordingly, they recommended that the equipment requirement include language that would require ''independent control of each wheel'' of the axles that are required to be ABS-controlled. They believed that the inclusion of such a requirement would prevent significant degradation in stopping performance, particularly on a split mu surface. Bosch recommended a minimum requirement of a four-sensor, three- modulator-valve (which is referred to as a 4S/3M system) ABS. Freightliner favored requiring at least four independent channels of control, i.e., two for each axle, to allow independent control of each wheel on the front and a rear axle. Similarly, IIHS favored requiring the brakes for each wheel on the front axle and the brakes for each wheel on one rear axle to be independently controlled. Advocates recommended that the ABS be functional on all axles, not just one axle in each multiple axle set on a heavy vehicle.

Based on its analysis of these comments and other available information, NHTSA issued an SNPRM proposing modifications to the NPRM to require heavy vehicles to be equipped with systems that independently control each wheel on at least one axle of a truck, a truck tractor, or a bus (i.e., 4S/3M systems). As explained in the SNPRM, the agency tentatively concluded that a minimum requirement that ABS provide independent wheel control on at least one axle would provide an acceptable level of stopping distance performance on low mu and split mu surfaces. The agency believed that a vehicle with independent ABS wheel control would stop in a shorter distance than either a vehicle equipped with an axle-by-axle ''select low'' control ABS, or a non-ABS equipped vehicle operated by a driver making his or her best efforts to minimize stopping distance through manually modulating the brake pedal. The agency also proposed to prohibit tandem control [29] by an ABS, by requiring that no more than two wheels be controlled by one modulator valve. NHTSA requested comments about its proposal for independent control of each wheel on at least one axle and about prohibiting tandem control by an antilock system.

In response to the SNPRM, NHTSA received comments from Ford, AAMA, Strait-Stop, GM, Navistar, White GMC, Bosch, PACCAR, Eaton, Midland-Grau, Truck Trailer Manufacturers Association (TTMA), Advocates, and ATA about the proposal to require independent control on at least one axle. Aside from Freightliner, WABCO, Bosch, Advocates, and IIHS, most other commenters opposed the proposal claiming that requiring independent control would be unreasonably design-restrictive. Bosch stated that the proposal is appropriate since at least one of the axles that contributes most to vehicle deceleration in the loaded condition should have the ability to have its wheels individually controlled. Ford, AAMA, GM, Navistar, PACCAR, Eaton, and Midland-Grau stated that the agency should specify direct control as a minimum requirement but not require independent control. AAMA stated that the standard should permit any control system that provides stability without substantial degradation in stopping distance. Ford claimed that any requirement that ABS must employ more than two channels of control would not result in any safety advantage over its two-channel system, but would result in substantial and unnecessary incremental costs to Ford and might jeopardize its ability to meet early implementation dates. Midland-Grau strongly opposed the SNPRM's approach, claiming that it presented a major change in scope from performance requirements and minimal design requirements. Specifically, it complained that the SNPRM changed the rulemaking's focus from directional stability and control to stopping distance on split mu surfaces.

Consistent with their comments on control philosophies, AAMA, GM, White GMC, PACCAR, and Midland-Grau also opposed the proposed definition of ''independently controlled wheels.'' [30] AAMA and PACCAR claimed that the proposed definition does not accommodate widely used ABS algorithms and control technologies. It requested that the word ''only'' be omitted since its inclusion in the definition would inappropriately preclude antilock systems that ''rely on wheel speed information from both wheels on an axle to modulate brake pressure at each of the wheels.''

Ford, AAMA, GM, Navistar, White GMC, PACCAR, Eaton, and Midland-Grau opposed prohibiting tandem control. TTMA requested that trailers equipped with more than three axles be excluded from the requirements, claiming that it would be very expensive to equip these vehicles, which account for only four percent of trailer production, with ABS.

ATA and Strait-Stop opposed specifying the type of wheel control, claiming that doing so creates an impermissible design requirement. Strait-Stop stated that the proposed approach prohibits creativity in the development of other technology that may accomplish the performance standards more effectively with greater economic efficiency.

Several commenters submitted test data about various ABS configurations. WABCO and Freightliner submitted simulated test data showing that 4S/2M systems on truck tractors provide very poor stopping distance performance on split mu surfaces, compared with 4S/4M systems. These commenters reported that the 4S/2M systems they tested took between 316 percent and 353 percent of the norm to stop on a split mu surface, with driver best effort being defined as the norm, or 100 percent. Ford and Bendix submitted simulated data showing that 4S/2M systems incorporating the modified select high regulation (MSHR [31]) wheel slip control strategy on truck tractors perform acceptably. Bendix also submitted vehicle test data showing that the stopping distance performance with

[28] See the Appendix for a discussion of this term.

[29] As explained in the appendix, tandem control refers to having two adjacent axles being controlled by the same modulator valve. Specifically, while each axle has its own wheel speed sensor, the brakes on two axles are controlled by one modulator valve.

[30] The agency proposed to define ''Independently Controlled Wheel'' as a ''wheel at which the degree of rotational wheel slip is sensed and corresponding signals are transmitted to one controlling device that adjusts the brake actuating forces only at that wheel in response to those signals.''

[31] See the Appendix for a discussion of this term.

tandem control ABS incorporating the MSHR wheel slip control strategy (2S/1M) on trailers is comparable to the performance of a 2S/2M system.

As explained above, in establishing the requirements applicable to the stability and control of heavy vehicles, NHTSA has decided that, at a minimum, wheels on the steering axle and at least one rear axle of a powered vehicle must be controlled by a closed-loop antilock system. Similarly, the wheels on at least one axle of a semitrailer and dolly, and the wheels of at least one front axle and one rear axle of a full trailer must be controlled by a closed-loop antilock system. The agency has decided that requiring a closed-loop antilock system is necessary to ensure the directional stability and control of heavy vehicles during braking.

NHTSA emphasizes that requiring a closed-loop antilock system is a *minimum* requirement that the agency believes will ensure the safety of heavy vehicles. The agency has also decided to establish supplementary requirements beyond these minimum requirements that address the type of wheel control for various types of vehicles. In establishing these supplementary requirements, the agency has sought an approach that is responsive to the many and oftentimes disparate views of the commenters and that ensures safety performance objectives, while considering practicability, costs and, to the extent possible, stated industry practice.

The supplementary equipment requirements, which specify the type of wheel control, are based on the philosophy that, for the reasons set forth below, an incrementally higher level of stability performance during braking is warranted for truck tractors compared to that which is appropriate and needed for trailers, single-unit trucks, and buses. First, truck tractors, when used in a combination vehicle, are articulated and therefore are more likely to lose control than single-unit vehicles. Second, truck tractors typically have shorter wheelbases than single-unit trucks, trailers and buses and therefore are more susceptible to locked wheel-induced, unrecoverable loss of control than are any of these other vehicle types. This loss of control typically manifests itself as a jackknife when tractors are coupled to semitrailers. Third, truck tractors typically travel approximately five times more annual miles than single-unit trucks, three times more miles than trailers (since there are proportionally three times as many trailers in use than there are tractors which tow them), and approximately seven times as many miles as buses. This substantially larger use proportionally increases a truck tractor's exposure to risk. Fourth, truck tractors typically operate on roads (i.e., interstate highways and rural State and U.S. routes) that have comparatively higher posted speed limits and vehicle operating speeds than the roads on which single-unit trucks and many buses generally operate. A higher operating speed exacerbates the consequences of braking-induced wheel lockup and loss-of-control. This is a significant contributing factor to the high proportion of heavy vehicle braking instability-related crashes, fatalities and injuries that involve combination-unit trucks.

Based on the above considerations, NHTSA has decided that the requirements for truck tractors must be more stringent than those for the other vehicle types. Specifically, on at least one of the truck tractors's axles, each wheel must be independently controlled by an ABS modulator. With respect to a given wheel, ''independently controlled'' means a wheel at which the degree of rotational wheel slip is sensed and corresponding signals are transmitted to a modulator that adjusts the brake actuating forces at that wheel on the axle or at other wheels on other axles. The agency has decided to revise the definition in response to AAMA's comment on the definition of independently controlled, since its inclusion might inadvertently prohibit acceptable systems. Requiring independent control ensures that a wheel provides optimal braking forces on all surfaces, enabling the vehicle to achieve near optimal braking on all surfaces, especially split mu ones.

In most cases, the axle with independent wheel control will likely be the tractor's drive axle(s). Commenters, including AAMA, Midland-Grau, and Bendix, submitted to the agency road testing data about how certain antilock systems improved the braking efficiency and directional control and stability of various vehicle configurations. Based on these data, the agency believes that independently controlling the drive axle(s) will result in incrementally better braking performance on split mu road surfaces than the other ABS equipment configurations that are permitted on the other vehicle types covered by this rule.

Rockwell WABCO correctly stated that allowing select low ABS on all axles will result in substantially longer stopping distances on split mu surfaces, particularly when the differences between the coefficients of friction on the two surfaces is large. Notwithstanding this shortcoming, the agency believes that a select low system is appropriate for the front axle for the following reasons. First, since the front axle brakes typically provide about 25 percent of the braking on a truck tractor, the stopping distance degradation with select low on the front axle will be small. Second, having equal braking forces at each wheel alleviate steering wheel ''pull'' that would occur on a split mu surface with ABS independently controlled front brakes. Third, current antilock systems installed on the front axle of heavy vehicles tend to use SLR, MSHR, or MIR wheel slip control strategies.[32] No vehicle manufacturer uses a system in which front axle control is purely independent wheel control. Accordingly, the agency has determined that it would be inappropriate and impracticable to prohibit the use of select low control on front axles.

NHTSA has also decided that it is necessary to prohibit tandem control on tractors to further ensure the safe braking performance for tractor trailers. This decision is based on test data[33] which indicate that tandem control does not provide an acceptable level of stopping distance performance for truck tractors, even though it may ensure a heavy vehicle's stability and control.

Notwithstanding its decision to prohibit tandem control on truck tractors, NHTSA has decided that tandem control is appropriate for vehicles other than truck tractors, such as trailers and single unit vehicles. Vehicle test data submitted by Ford, Bendix, and Midland showed comparable vehicle stopping distance performance, and in some cases superior performance, of tandem control (2S/1M) systems compared with side-by-side control (2S/2M) systems, without any difference in vehicle stability performance. Vehicle test data also showed comparable ABS performance with MSHR tandem control on trailer axles. Accordingly, today's requirements permit direct control 2S/1M systems for converter dollies, semitrailers, and the front axles of full trailers. The agency further notes that single unit vehicles equipped with 4S/2M systems have been approved for use in Europe as ''Category 1'' systems.

### *C. Braking-In-A-Curve Test*

#### 1. General Considerations

As explained in the previous section on equipment requirements, NHTSA proposed requiring heavy vehicles to be

[32] SLR, MSHR, MIR and other wheel slip control strategies are discussed in the Appendix.

[33] ''Improved Brake Systems for Commercial Motor Vehicles,'' DOT HS 807 706, April 1991,

equipped with antilock systems, and supplementing that requirement with dynamic performance requirements to check the directional stability, control and stopping distance of such vehicles. The agency proposed only those dynamic performance requirements that it believed would be feasible and practicable for checking the directional stability of a vehicle when it is maximally braked. Specifically, in its September 1993 NPRM, the agency proposed a ''braking-in-a-curve requirement'' on a low coefficient of friction surface without a stopping distance requirement. Under this proposed requirement, heavy vehicles would have to be capable of stopping without loss of directional stability or control, while turning on a slippery surface during an aggressive or ''hard'' stop. Separately, in its February 1993 NPRM, the agency proposed braking effectiveness requirements through the use of high speed (60 mph) stopping distance requirements on a high coefficient of friction road surface.

NHTSA explained, in the September 1993 NPRM, its tentative conclusion that the braking-in-a-curve test on a low mu surface is an objective, repeatable, and practicable procedure for evaluating a heavy vehicle's directional stability and directional control. The agency further explained that the proposed braking-in-a-curve test is consistent with industry's views, since the Antilock Test Procedure Task Force of the Motor Vehicle Safety Research Advisory Committee (MVSRAC) recommended this procedure and the SAE has proposed it in Recommended Practice J1626, *Braking, Stability, and Control Performance Test Procedures for Air-Brake-Equipped Truck Tractors.*

In response to the NPRM, Advocates stated that the agency's proposal to specify both an equipment and dynamic performance requirement was the most appropriate way to ensure that the substantial safety benefits of heavy vehicle ABS are realized quickly. Rockwell WABCO reluctantly supported the proposed combination of an equipment specification and a dynamic performance test, given the current difficulty in formulating valid additional, repeatable performance criteria. Midland-Grau favored this approach for truck tractors since it believed that merely issuing an ABS requirement, without an accompanying performance requirement, would allow ineffective systems in the marketplace.

Allied Signal supported the braking-in-a-curve test for truck tractors, but opposed the test for other vehicles, stating that vehicles other than truck tractors have not been tested using this maneuver. Midland-Grau was also concerned that very little test data have been collected on vehicle types other than truck tractors. Volvo-GM stated that the test is unsafe for many vehicles, and that a dynamic performance requirement is not necessary, given the provision requiring ABSs. AAMA stated that although it generally favors performance-based dynamic requirements for Federal Motor Vehicle Safety Standards, it opposes the braking-in-a-curve test given what it perceives as its ''overwhelming practicability and objectivity problems.'' Among AAMA's concerns were that (1) there has been no test program by NHTSA to decide whether the test is suitable for single-unit trucks, buses, and trailers, (2) the braking-in-a-curve test alone cannot evaluate the effectiveness of an ABS, (3) there is a lack of repeatability of the braking-in-a-curve test procedure, and (4) no suitable test facilities exist for vehicle manufacturers to conduct compliance testing. Given these concerns, AAMA favored adopting, on an interim basis, an equipment requirement only.

ATA, Strait-Stop, and several other commenters supported a dynamic performance-based requirement instead of an equipment requirement. They believed that this approach would encourage further development of antilock technology and would enable users to find the system that best suits their operation. ATA was concerned that an equipment requirement would preclude the development of more effective systems for different applications.

TTMA believed that the braking-in-a-curve test is inappropriate for trailers. It stated that trailer manufacturers, many of which are small entities, do not have the financial resources or the facilities to conduct road testing.

After reviewing the comments and other available information, NHTSA has decided to amend the Standard to include the braking-in-a-curve test for certain vehicles. The agency considered requiring surface transition tests (i.e., a test maneuver in which vehicle braking begins on a high coefficient of friction surface and then completes the stop on a low mu surface, and vice versa), a lane change test, and split mu or side-to-side differential coefficient of road surface friction tests, to achieve that objective. The tests would ideally be conducted at various speeds with different loading conditions and test surfaces. However, the agency has decided that it would be unnecessarily burdensome and costly to impose such an array of tests on heavy vehicle manufacturers. NHTSA has determined that the performance testing and equipment requirements imposed in today's final rules are the most appropriate method of ensuring directional control and stability.

NHTSA has decided at this time to apply the braking-in-a-curve test to truck tractors, but not to other heavy vehicles. The agency believes that opposition by AAMA, Volvo-GM, and Midland Grau to the braking-in-a-curve test requirement is based primarily on uncertainty about whether the test would also be required for single-unit vehicles, since the MVSRAC ABS Task Force developed the braking-in-a-curve test procedure for testing only truck tractors. Since neither the agency nor the Task Force included single-unit vehicles in the test program, NHTSA believes that AAMA and the others are concerned about whether the braking-in-a-curve test would appropriately evaluate directional stability and control of single-unit vehicles. Accordingly, NHTSA's decision to apply the braking-in-a-curve test at this time only to truck tractors should reduce the concerns of AAMA and other commenters that opposed this dynamic performance test.

With respect to truck tractors, NHTSA has concluded that the road tests performed by the agency and the ABS Task Force provide sufficient justification to apply the braking-in-a-curve test to these vehicles. The agency notes that the industry, through the MVSRAC, previously endorsed and recommended to the agency, essentially the same dynamic performance test that is contained in this final rule. The Task Force test data and final report indicate that the braking-in-a-curve procedure is safe, practicable, and repeatable for truck tractors. Accordingly, the agency believes that this recommendation remains valid for tractor trailers.[34]

NHTSA has decided not to require single unit trucks, buses, and trailers to comply with the braking-in-a-curve test requirement at this time. The agency's limited testing of single unit trucks to the braking-in-a-curve maneuver revealed no specific safety problems. However, additional testing on a wider variety of trailers, dollies, and single-unit vehicles, including buses and trucks, would be appropriate to ensure that these vehicles could be safely tested to the braking-in-a-curve maneuver. Specifically, the agency is concerned that certain vehicles, especially ones with a high center of gravity, might be prone to roll over or otherwise lose control during such tests. NHTSA intends to develop performance test requirements equivalent to the braking-

[34] TRC of Ohio, Report No. 091194, page 4, August 26, 1991.

in-a-curve test for the other vehicle types covered by this rule, assuming that future research indicates it possible to conduct the test in a safe fashion and to obtain meaningful, repeatable results. The agency anticipates conducting additional research and road tests to decide whether heavy vehicles other than truck tractors should be subject to this road test.

Today's notice, including the agency's decision not to apply the braking-in-a-curve test to vehicles other than truck tractors, completes the comprehensive rulemaking to establish directional stability and control requirements that was initiated by the June 1992 ANPRM. If NHTSA decides that it is in the interest of motor vehicle safety to apply the braking-in-a-curve test to single-unit vehicles or trailers, then it will issue a new proposal to initiate a subsequent rulemaking on this matter.

2. *Test Surface*

In the NPRM, NHTSA proposed that the braking-in-a-curve test be conducted on a test surface with a peak friction coefficient (PFC) of 0.5 to represent a low coefficient of friction surface. In formulating the proposal, NHTSA considered whether the proposed test surface specification raised practicability or objectivity concerns in light of *PACCAR*. The agency specifically requested comments on the proposed test surface specification.

Three commenters addressed the test surface specification. Midland-Grau stated that since maintaining a precise PFC value is not feasible, reasonable fluctuations of ±10 percent are to be expected. Notwithstanding these inherent fluctuations, Midland-Grau commented that its testing shows that variability in the test surface PFC value of less than 10 percent does not affect the braking-in-a-curve test since no stopping distance is prescribed. AAMA stated that it is not possible to maintain a surface at a precise PFC. It further stated that it is not apparent whether it would be more conservative to conduct testing at a higher PFC than the proposed PFC. AAMA stated that the variability in the peak to slide ratio is significantly greater on wet surfaces than on dry surfaces, and that this ratio directly affects performance. Mr. Robert Crail, a brake engineer, stated without elaboration that using PFC rather than skid numbers will ensure that the test surfaces and test conditions will be reasonable and repeatable during actual vehicle testing.

Before addressing the specific comments about the test surface, the following discussion summarizes the *PACCAR* decision's findings with respect to variability and how today's rulemaking responds to that ruling. As a result of that case, NHTSA has considered ways to better specify test surface adhesion. Prior to the Standard No. 135, *Passenger Car Brake Systems*, rulemaking, NHTSA defined road test surfaces by specifying skid numbers. A skid number is the frictional resistance of a pavement measured in accordance with a test procedure defined by the American Society for Testing and Materials (ASTM). However, given the fluctuations of skid numbers on a given surface, the *PACCAR* ruling invalidated certain aspects of Standard No. 121's reliance on this measure based on its potential impracticability. In the rulemaking proposing Standard No. 135, several commenters advocated specifying the peak friction coefficient as an alternative measure of a test surface's adhesion. The agency has concluded that PFC is more relevant for the stopping distance tests required by the standard because, unlike a skid number, the maximum attainable deceleration in a non-locked wheel stop is more directly related to PFC. As discussed in the Appendix, the skid number characterizes the slide (locked wheel) value of the coefficient of friction of a given road surface, and the PFC characterizes the peak (rolling wheel) value of the coefficient of friction of a given road surface. Since the agency's brake test procedures generally prohibit or limit wheel lockup during brake testing, specifying the peak friction coefficient is more relevant than specifying the skid number of the surface.

NHTSA has also conducted ''Round Robin'' testing to understand further how fluctuations of PFC affect the stopping performance of heavy vehicles. Based on the above, NHTSA has decided that the braking-in-a-curve test should be performed on a test surface with a PFC of 0.5, which appropriately represents a typical low coefficient of friction road surface. Moreover, in today's companion rule adopting stopping distance requirements, the agency has decided it is appropriate to perform the primary 60 mph stopping distance tests on a test surface with a PFC of 0.9. Agency and industry testing indicate that a PFC of 0.9 represents a typical dry road surface.

The requirement to specify test surfaces in terms of PFC rather than skid numbers also responds to *PACCAR*'s concern about practicability problems caused by skid number fluctuations. Because the PFC values of surfaces measured may also indicate some fluctuation, the agency has considered whether the fluctuation significantly affects the requirement's objectivity. In an earlier rulemaking about Standard No. 208, the agency explained that since some variability in any test procedure is inherent, the agency need only be concerned about preventing ''unreasonable'' or ''excessive'' variability to avoid causing manufacturers to ''overdesign'' vehicles to exceed the minimum levels of protection specified by the Federal safety standards. (49 FR 20465, May 14, 1984; 49 FR 28962, July 17, 1984.) With respect to the braking-in-a-curve test, variability of the PFC value of the test surface will have a negligible impact on a vehicle's ability to comply with the requirements, which is to stay within the 12-foot lane. Since the test speed is set at the lesser of 30 mph or 75 percent of the maximum drive-through speed [35] of the vehicle in the curve, any variability in the test surface will be compensated for by an increase or decrease of the maximum drive-through speed of the vehicle. If the maximum drive-through speed is less than 40 mph, this will result in a corresponding increase or decrease of the test speed, which cannot be higher than 30 mph. As a result, the variability of the test surface is not as critical an issue for the braking-in-a-curve test as it is for a stopping distance test on a high coefficient of friction surface, which includes a stopping distance measurement that is more affected by test surface variation. Based on these considerations, the agency has determined that the results of the braking-in-a-curve test will not be affected by minor variations in the test surface.

The road surface requirements comply with *PACCAR*'s holding that manufacturers are entitled to testing criteria that they can rely on with certainty, since they include objective terms and requirements, i.e., the test surface is at a PFC of 0.5. For the same reason, the requirements also comply with *PACCAR*'s requirement that all methods to demonstrate compliance with the requirement be set forth in the regulation.

In evaluating the requirement's practicability, NHTSA has considered possible difficulties with respect to building and maintaining test surfaces with a PFC of 0.5 for the braking-in-a-curve test and 0.9 for the high coefficient stopping test. (Those interested in building and maintaining a test surface should refer to NHTSA's

[35] Maximum-drive-through-speed is defined as ''the highest possible constant speed that the vehicle can be driven through 200 feet of a 500-foot radius curve arc without leaving the 12-foot lane.''

''Manual for the Construction and Maintenance of Skid Surfaces,'' (DOT HS 800 814.) Variations in PFC for high coefficient of friction surfaces do not affect stopping distance test results appreciably. Moreover, while variations in PFC for low coefficient friction surfaces may affect the distance in which a vehicle stops, such variations are not relevant for the braking-in-a-curve test, which requires a vehicle to remain stable while it is stopped, not that it stop within a specified distance. After reviewing the comments and available information, NHTSA has concluded that specified test surfaces can be achieved and maintained. As explained above, recent ''Round Robin'' testing related to research about heavy vehicle braking by the agency and others on several test tracks indicates that the test surface specification does not raise practicability or objectivity concerns.[36]

One of the *PACCAR* court's concerns was that the road surface skid numbers were based on an out-of-production tire. That concern is not relevant to today's final rule since it specifies a currently-produced tire. The requirements comply with *PACCAR*'s concern about the testing method's objectivity because the peak coefficient of friction is an objective measure.

NHTSA disagrees with AAMA's comment that it is not apparent whether it would be more conservative to conduct testing at a higher PFC than the proposed PFC. Data from the round-robin testing and other sources show that the stringency of a braking-in-a-curve test increases as the PFC of the test surface decreases, if the tests are conducted at the same vehicle speed. Since the requirement specifies a test speed based on the vehicle's maximum drive-through speed, which decreases as the test sequence PFC decreases, the resulting test speed will also be lower as the PFC decreases. Hence, the stringency of the braking-in-a-curve test should not change with minor changes in the PFC of the test surface.

NHTSA has decided that AAMA's other comments about the test surface requirement are without merit. That organization did not provide any data to substantiate its statements. Nor did it explain why it believes that ''variability in the peak to slide ratio'' is relevant. Similarly, AAMA's comment about ''simultaneously maintaining a given surface at a precise PFC and sliding coefficient (i.e., skid number) [being] completely infeasible'' is irrelevant to this rulemaking. The agency has never proposed a test surface requirement that specifies both the PFC and skid number values.

3. Test Speed

In the NPRM, NHTSA proposed that the braking-in-a-curve test be conducted at 30 mph, unless the vehicle could not stay within the 12-foot lane when driven through the curve at 30 mph. If the vehicle could not do so, the braking-in-a-curve test would be conducted at 75 percent of the maximum drive-through speed. NHTSA believed that the proposed vehicle test speed was sufficiently high to test ABS performance, but low enough so as not to pose an unsafe condition during the maneuver to the test driver of most vehicles, based on testing conducted by the agency[37] and SAE J1626 Proposed Recommended Practice. The agency requested comments about the proposed test speed.

Advocates opposed any reduction in the test speed below 30 mph. Specifically, it opposed permitting vehicles that cannot negotiate the curve at 30 mph to be tested at the 75 percent drive-through speed because it believed that this would be a ''free-floating criterion'' that could lead to ineffective antilock systems.

Rockwell WABCO, Allied Signal, Midland-Grau, and AAMA requested that the test speed be clarified. Rockwell WABCO recommended that the vehicle test speed requirement be revised to read ''stopped from 30 mph or 75% of the maximum drive through speed, whichever is less.'' Similarly, Allied Signal suggested that the vehicle test speed be clarified to say that testing cannot exceed 30 mph. Midland-Grau recommended that the agency revise the requirement so that the test be conducted at only 75 percent of the maximum drive-through speed capability. It further stated that conducting the braking-in-a-curve test at speeds greater than 30 mph on a low mu surface could cause safety problems. AAMA stated that the NPRM incorrectly applied SAE J1626, which requires testing at 75 percent of drive-through speed to a maximum of 30 mph braking speed. It stated that under the proposal, a vehicle with a drive-through speed of 30 mph would be tested at 30 mph, while a vehicle with a drive-through speed of 29 mph would be tested at less than 22 mph. In opposing the proposed requirement, AAMA further stated that the determination of the drive-through speed is highly sensitive to driver skill, subtle vehicle maneuvers, and environmental conditions, and is therefore not repeatable.

ATA recommended that NHTSA establish stopping or snubbing distance requirements for vehicles in a curve, using a braking speed which is between 95 and 100 percent of their maximum drive through speed.

After reviewing the comments and available information, NHTSA has decided to specify that a vehicle's test speed for the braking-in-a-curve test is ''30 mph or 75% of the maximum drive-through speed, whichever is less.'' This modification responds to the comments by Rockwell WABCO, Allied Signal, and Midland-Grau that the proposal was not consistent with SAE J1626. The agency believes that making the speed consistent with SAE 1626 will eliminate the possibility of discontinuities in the test's stringency for different vehicles. As AAMA correctly stated, the proposed test speed created an anomaly that benefitted vehicles with a maximum drive-through speed slightly below 30 mph. For example, a vehicle with a maximum drive-through speed of 29 mph would have been tested at 22 mph, while a vehicle with a maximum drive-through speed of 30 mph would have been tested at 30 mph. This would have meant that a 1 mph difference in maximum drive-through speed would have resulted in a 8 mph difference in test speed. This could have caused significant variations in test results for vehicles with slight differences in maximum drive-through speed. By establishing a test speed that is adjusted for differences in maximum drive-through speed and that would be more specific and distinct for each vehicle and test surface, the agency has minimized potential compliance testing problems that might occur due to variability in the test speeds for different vehicle and road test surface conditions.

NHTSA notes that ATA's requested test speed and test conditions have not been tested by the agency or industry and therefore their adoption would not be appropriate at this time. The agency may evaluate ATA's proposal in future test programs.

NHTSA believes that Advocates' opposition to permitting test speeds below 30 mph is unfounded. Similarly, the agency believes that AAMA's concern about the drive-through speed being unrepeatable is irrelevant. By allowing vehicles to be tested at 30 mph or 75 percent of maximum drive-through speed, whichever is less, the effects of test surface variation are eliminated.[38]

[36] TRC Report, August 21, 1991, page 6.

[37] TRC Report, August 26, 1991.

[38] TRC Report, page 10.

4. Type of Brake Application

In the NPRM, NHTSA proposed that the stops be achieved through full brake applications in which the pressure at the treadle valve must reach 100 psi within 0.2 seconds after the application is initiated. The agency believed that these values properly represent full brake applications, in terms of both the application's degree of force and its duration. The agency stated that the stability and control requirements should evaluate worst case braking applications in an aggressive or ''hard'' stop and that full brake applications are more readily repeatable than the ''driver best effort'' applications.

Midland-Grau agreed with the proposal to specify a full treadle application of 100 psi in 0.2 seconds for air braked vehicles. According to Midland-Grau's test data, full treadle applications at 100 psi were achieved in 0.12 to 0.18 seconds, with the measurement taken at the treadle valve's primary output circuit located at the rear axle brakes. However, more time is needed to reach 100 psi at the secondary circuit located at the front axle brakes because its output supplies air to the quick release valves and then to the front axle brake chambers. Allied Signal stated that it is not possible to reach 100 psi within 0.2 seconds at the front axle output circuit of the treadle valve.

After reviewing these comments, NHTSA has decided to revise the brake application requirement for air braked vehicles to require 100 psi in at least one of the treadle valve's output circuits within 0.2 seconds, thereby allaying Allied Signal's concern. This modification to the test condition should eliminate potential ambiguity concerning where the application pressure is to be measured.

5. Number of Test Stops for Certification

In the NPRM, NHTSA proposed that a vehicle comply with the proposed braking-in-a-curve test in each of three consecutive stops for each combination of weight and road conditions. In contrast, the vehicle stopping performance tests in Standard No. 105 and Standard No. 121 specify that the vehicle must meet the requirements at least once in six attempts through a best effort brake application. The agency tentatively concluded that six stops should not be needed to achieve the required performance in the braking-in-a-curve test, given the presence of an antilock brake system. The agency requested comments about the number of brake applications that should be required.

Advocates, Midland-Grau, and Mr. Crail stated that three stops are sufficient for a vehicle with an antilock brake system to display compliance with the braking-in-a-curve test. They stated that without stopping distance requirements, this test procedure entails a simple performance test for the vehicle to maintain control in the 12-foot lane. Midland-Grau added that it uses three stops when conducting ABS performance tests, and that this number of brake applications is consistent with the SAE J1626 Recommended Practice and with the MVSRAC Antilock Brake System Task Force's final recommendations.

AAMA argued that specifying three passes in three consecutive stops places an unrealistic burden on the driver to control the vehicle immediately with no opportunity to become familiar with the vehicle or test surface. AAMA recommended that manufacturers be given the option of conducting ten or more stops and certifying that the vehicle stayed within the 12-foot lane for any three consecutive stops.

After reviewing the comments and the available information, NHTSA has decided that requiring compliance with the braking-in-a-curve requirements during three consecutive stops is appropriate. The agency notes that specifying three consecutive full treadle test stops is consistent with both the agency's own testing at VRTC and its testing in conjunction with the motor vehicle industry through the MVSRAC ABS Task Force. The use of full treadle brake applications to test an ABS-equipped vehicle to the braking-in-a-curve maneuver requires less driver skill than the use of a driver's-best-effort modulated brake application (i.e., the type of application used in stopping distance performance tests) because the ABS automatically modulates the brakes. Further, more than three stops are unnecessary since the braking-in-a-curve test requirement is not coupled with a stopping distance requirement. Therefore, NHTSA has decided not to adopt AAMA's suggestion that manufacturers be given the option of complying with only three of ten stops. Adopting that suggestion would make the braking-in-a-curve requirement unreasonably lenient.

6. Test Weight

In the NPRM, NHTSA proposed that single unit trucks, buses and bobtail truck tractors be tested at their curb weight (including full fuel tanks) plus 500 pounds to account for the driver and instrumentation. The agency also proposed to allow a manufacturer to conduct the braking-in-a-curve test with a roll bar structure weighing up to an additional 1,000 pounds to protect the driver, based on a recommendation by the MVSRAC ABS Task Force. The agency requested comments about the appropriate unloaded test weight.

Rockwell WABCO recommended that unloaded heavy vehicles be allowed to have less than 500 pounds added in the unloaded condition.

After reviewing Rockwell WABCO's comment, NHTSA has decided to amend the test condition in the braking-in-a-curve test to specify the weight in the unloaded condition to be ''up to 500 pounds'' for driver and instrumentation.[39] The agency notes that instrumentation hardware has been getting more compact and lightweight. Using the regulatory language ''up to 500 pounds'' will simplify the test condition since manufacturers will not have to add ballast to ensure that the weight is 500 pounds. This change provides manufacturers with greater incentive to use the newer, lighter hardware. The agency believes that this modification will have no measurable effect on a vehicle's performance during the braking-in-a-curve test since a weight range of a few hundred pounds is of little significance in relation to a tractor's typical empty weight of more than 26,000 pounds.

7. Loading Conditions

In the NPRM, NHTSA proposed that braking-in-a-curve tests be performed in both the empty and loaded conditions, since a vehicle's braking performance varies depending on the amount of load that it is carrying. With respect to testing truck tractors in the loaded condition, the agency proposed two alternatives regarding the use of control trailers: (1) use a braked control trailer and (2) use an unbraked control trailer.

Most commenters, including AAMA, Rockwell WABCO, and Midland-Grau, supported the unbraked control trailer alternative. These commenters believed that using an unbraked control trailer instead of a braked control trailer would eliminate many sources of variability and would provide more consistent and repeatable test data. AAMA stated that if the braked control trailer alternative were adopted, every aspect of the control trailer brake system would have to be precisely specified because the tractor's performance is directly affected by the performance of the control trailer. Midland-Grau stated that using an unbraked control trailer is consistent with SAE J1626 and the testing

[39] The final rule also adopts the 1,000 pound allowance for a roll bar.

performed by the MVSRAC ABS Task Force.

Similarly, commenters on the February 1993 stopping distance NPRM strongly supported the unbraked control trailer alternative. Those commenters believed that the agency would have great difficulty defining the required performance of a braked control trailer and its ABS if the braked control trailer alternative were adopted.

Mr. Crail and Strait-Stop stated that a truck tractor should be tested with an ABS-equipped control trailer because it is not normal for a combination vehicle to be operated with an unbraked control trailer. They believed that a braked control trailer would more closely reflect real world braking. Mr. Crail also stated that an unbraked control trailer could result in instability during testing.

After reviewing the comments and other available information, NHTSA has decided to specify that truck tractors be tested with an unbraked control trailer for the braking-in-a-curve test. As the agency explained in the NPRM, the unbraked control trailer eliminates certain types of variability and provides more repeatable test data. Moreover, this approach eliminates the need for the agency to specify and vehicle manufacturers to comply with detailed foundation brake design requirements for the control trailer. Accordingly, the unbraked control trailer will provide more readily comparable test data among vehicles and more repeatable test parameters for manufacturers.

NHTSA acknowledges that an unbraked control trailer does not represent a typical operating condition for a combination vehicle. As a result, real world combination vehicles will stop more effectively than a test combination vehicle that has brakes on its tractor but not on its trailer. Nevertheless, as most commenters stated, the unbraked control trailer provides significant benefits for testing a loaded truck tractor. Further, using the unbraked control trailer is consistent with SAE J1626 and the testing performed by the MVSRAC Task Force.

As for Mr. Crail's concern about stability problems during testing, NHTSA does not agree that the use of an unbraked control trailer will result in such problems. It is true that using an unbraked control trailer will result in the kingpin receiving additional forces, since the trailer will still be pushing on the kingpin while the tractor is braking. However, the agency and industry conducted several braking-in-a-curve tests with unbraked control trailers that indicated that these additional kingpin forces will not increase a vehicle's instability during testing.[40]

8. Initial Brake Temperature

In invalidating parts of Standard No. 121, the court in *PACCAR* stated that the standard failed to specify formal and reasonably specific testing criteria about the time intervals between tests. The time interval between tests is important because it may affect brake temperature and thus brake lining performance. In response to *PACCAR*, the agency amended the standard to specify that the average brake lining temperature of the hottest axle be between 150° and 200 °F before performance tests could be conducted.

In the February 1993 NPRM on stopping distance and the September 1993 NPRM on stability during braking, NHTSA proposed that the average brake lining temperature of the hottest axle be between 250° and 300° F before performance tests could be initiated. This range was based on testing conducted by VRTC[41]. The agency believed that compared to current requirements, this provision would allow tests on heavy vehicles to be conducted within a shorter time between measurements at temperatures representative of in-service conditions, without affecting brake performance.

Only Advocates commented on the proposal in the stability and control NPRM to increase the initial brake temperature from 150–200 °F to 250–300 °F. Advocates supported the higher temperature range, stating that it is reasonable and representative of in-service temperature conditions. However, NHTSA received numerous comments about this issue in response to the stopping distance NPRMs. All commenters addressing the issue of initial brake temperature in those rulemakings strongly opposed the proposed change in temperature from 150–200 °F to 250–300 °F. Lucas argued that the higher initial brake temperature would be detrimental to drum brake performance. Lucas, HDBMC, and Rockwell WABCO stated that the proposed initial brake temperature would invalidate the vehicle manufacturer's data bank from Standard No. 121 testing at 150–200 °F, which has been accumulating since the 1970s. Midland-Grau commented that, among other things, the higher initial brake temperature would lead to more aggressive lining materials and vehicle compatibility problems.

[40] TRC Report #091194, page 4.

[41] ''Heavy Duty Vehicle Brake Research Program—Report No. 1,'' April 1985.

Abex, AAMA, and HDBMC stated that the proposed higher initial brake temperature would shorten testing time between 5 and 10 hours. However, they believed that problems associated with brake fade resulting from the higher initial brake temperature would far outweigh the nominal cost savings obtained by having a shorter test time. Test data provided by AAMA showed that while the higher initial brake temperature has a slight adverse effect (a 7–28 foot increase) on full service brake stopping distance, it has a significant adverse effect (a 25–98 foot increase) on emergency brake stopping distance.

Rockwell WABCO stated that the perceived benefits of the higher initial brake temperature do not justify the increased vehicle testing and redesign that would be required to meet the proposed initial brake temperature.

After reviewing the comments, the test data, and other available information, NHTSA has decided that an initial brake temperature in the 150 °F to 200 °F range is more appropriate than the proposed temperature range. As the commenters stated, testing using the 150 °F to 200 °F temperature range is more repeatable and results in less variation between runs, compared to testing conducted using an initial brake temperature of 250 °F to 300 °F, particularly for the emergency brake stops. The agency further notes that an initial brake temperature of 150 °F to 200 °F is within the 150 °F to 300 °F range recommended by the VRTC test report. The agency is aware that the lower temperature range increases the total test time by 5 to 10 hours. Nevertheless, because the other advantages to the lower temperature range outweigh this concern, NHTSA has decided not to change the specification that the initial brake temperature be between 150 to 200 °F.

9. Transmission Position

In the NPRM, NHTSA proposed that the transmission be in neutral or the clutch pedal be depressed (clutch disengaged).

ATA commented that, in real world panic stops, drivers will neither put the transmission in neutral nor depress the clutch pedal before making a brake application. Nevertheless, ATA acknowledged that retardation by the drivetrain could cause vehicle instabilities that would necessitate testing at speeds lower than the drive through speed.

NHTSA has concluded that testing with the transmission in neutral or the clutch disengaged is appropriate to ensure that engine retardation does not affect a test which is intended to evaluate the influence of brake systems on vehicle dynamic stability. Engine and drivetrain retardation forces vary from vehicle to vehicle and can affect vehicle stability on low coefficient of friction surfaces. Nevertheless, this is not the purpose of this test. By requiring that the transmission be placed in neutral for brake testing, the standard attempts to reduce these drive-train related braking influences on the service brake performance. Therefore, testing with the transmission in neutral or the clutch disengaged will eliminate influences that engine or drivetrain retardation would have on braking performance. This test condition therefore helps to ensure test repeatability and reproducibility.

10. Summary of General Test Conditions

For the convenience of the reader, this section summarizes the general test conditions being adopted in this notice, as follows:

- Vehicle Position—Centered in the test lane at the initiation of braking.
- Steering—Driver to steer as necessary during braking to maintain vehicle control.
- Initial Brake Temperature—The average brake lining temperature of the hottest axle between 150 to 200 °F.
- Transmission—Neutral (or clutch pedal depressed).
- Loading for Truck Tractors

*Empty (Bobtail):* Curb Weight (including full fuel tanks) plus up to 500 pounds for driver and instrumentation, and, at the manufacturer's option, a roll bar weighing up to 1,000 pounds.

*Loaded:* Tractor is loaded with an unbraked control trailer, loaded above the kingpin only, so that the tractor is at GVWR and the trailer axle is at 4500 pounds. Tractor weight is distributed in accordance with the Gross Axle Weight Ratings (GAWRs). If the tractor's fifth wheel is fixed, preventing such loading, then the trailer is loaded until any one tractor axle reaches its GAWR.

- Brake Burnish—Follow procedures in S6.1.8(b) of Standard No. 121.

*Low Mu Braking-In-A-Curve Test*

- Run vehicle, empty and loaded.
- Test Surface—PFC of 0.5, as determined with the ASTM E1136 SRTT tire on ASTM traction trailer using ASTM E1337–90 procedure.
- Track Configuration—500 foot radius at lane center line.
- Test Speed—30 mph or 75 percent of the maximum drive-through speed, whichever is less. Maximum drive-through speed is the highest constant speed at which the vehicle can be driven through 200 feet of curve arc without any part of the vehicle leaving the 12-foot lane.
- Brake Application—Three full-treadle applications (i.e., air pressure of 100 psi at any treadle valve output circuit within 0.2 second) for each loading condition.
- Test Failure Condition—Vehicle must stay within the 12- foot lane during all three stops in order to comply with requirement.

*D. Reliability and Maintenance*

In response to the SNPRM, ATA, United Parcel Service (UPS), and Tramec expressed concern about the durability, reliability, and maintenance of ABSs. ATA stated that the rule, if adopted, would result in significant maintenance problems, especially with respect to failures of electrical circuits and of the power source. It claimed that ABS components fail too often and that real world failure rates are higher than those in NHTSA's demonstration program. ATA further stated that it is inappropriate to compare the failure rates of ABS components that are not subject to wear with the rates for components, like brake linings and tires, that are subject to wear. ATA stated that existing connectors fail in large numbers and that what it mistakenly termed a ''separate connector requirement'' would double the failure rate, resulting in unreasonable costs.[42] It also stated that there have been many problems resulting from inadequate installation of ABSs, since malfunctions are frequently due to design problems, faulty installation, and lack of knowledge about ABS maintenance. ATA also stated that NHTSA did not take seriously enough malfunctions noted during the agency-sponsored in-service fleet study, which were rectified with only the expenditure of labor, namely corrections that involved inspections or minor adjustments.

ATA and UPS stated that new ABS equipped heavy vehicles have a high percentage of ''direct from factory'' ABS failures. UPS stated that ''these systems are still plagued by incidents of failure that far exceed the normal level of problems encountered with other components of heavy duty trucks.'' ATA also stated that NHTSA did not take labor only failures (i.e., malfunctions that can be fully corrected through the use of labor without the need for new parts) seriously enough. ATA believes that they are a costly and serious problem that takes vehicles out of service.

To evaluate the reliability of current-generation ABSs, NHTSA has conducted extensive field studies of ABS-equipped heavy truck tractors and semitrailers in developing this final rule. In response to the *PACCAR* decision, these studies were structured to assess whether current-generation heavy vehicle antilock brake systems were reliable and fail-safe, whether they inordinately increased vehicle maintenance costs, and whether they could be successfully maintained and would remain functioning in typical U.S. heavy truck operating environments.

Between 1988 and 1993, NHTSA tracked the maintenance performance histories of 200 truck tractors and 50 semitrailers equipped with ABS, as well as the histories of a comparison group of 88 truck tractors and 35 semitrailers not equipped with ABS, to determine the incremental maintenance costs and patterns associated with installing ABS on these heavy vehicles. Additionally, special on-board vehicle recorders were used to monitor the functioning and performance of the ABSs. Finally, drivers and mechanics at the participating test fleets were periodically interviewed to ascertain their views about the ABS test vehicles' performance and ease of maintenance. This multimillion dollar program was the largest of its kind that has ever been conducted by the agency or throughout the world. The study's authors concluded that, based on the data collected during the fleet study, currently available antilock braking systems are reliable, durable and maintainable.

While ABS is not a zero-cost maintenance item, its presence on a vehicle did not substantially increase maintenance costs (less than 1 percent for tractors, less than 2 percent for trailers) or decrease vehicle operational availability. Specifically, ABS use does not involve appreciably more intensive maintenance than present brake systems. The agency finds that the average annualized increase in lifetime maintenance costs ($3.47–$27.49 per vehicle) occasioned by the use of ABS, as indicated in the Final Economic Assessment (FEA) for this rulemaking, is a reasonable amount of additional maintenance. Further, the agency notes that a significant portion of the costs noted during the fleet study (i.e., those attributed to intermittent malfunction warning indications for which no problem was found and the system was simply reset or a simple adjustment was made) are likely to be reduced or eliminated as the algorithms inside the ECU that trigger ABS malfunction warnings are further refined to make them more discriminating, and as

[42] The agency notes that it is requiring powering through a separate circuit, not a separate connector.

quality control and installation skill improve.

NHTSA further emphasizes that system malfunctions do not render the vehicle's braking system unsafe, since the brake system merely reverts to one without an ABS; in other words, foundation brakes are unchanged when ABS is added. The few incidents noted during the test program in which an ABS malfunction did compromise the vehicle's underlying brake system performance involved defective components.

In both the tractor and the trailer studies, some test vehicles either arrived in the test fleets with faulty ABS or had ABS malfunction indications shortly thereafter, as a result of what was termed installation or pre-production design related problems. In general, these problems were easily remedied. Many were corrected by adjustments or minor repairs. Most were at least partially attributable to the prototype nature of many of the installations accomplished for this test program.

The following examples illustrate the relatively minor nature of correcting most of the problems. (The agency notes that none of the problems listed affected vehicle braking.)

- The electrical power source for the ABS ECU on a group of four trucks was incorrectly wired, at the time of installation, through the starter solenoid. These four trucks had to be rewired to make the ABS function properly.
- Intermittent failure warnings were noted on three trucks from the beginning of their operation. Upon inspection, the trucks were found to have an incompletely assembled connector in the wiring harness. When this problem was corrected, the failure warnings ceased.
- A group of 23 tractors had to be rewired to provide a separate electrical power source for the dash-mounted failure warning lamp so that it could function properly. The miswiring occurred during installation.
- The ABS modulator valves on a group of 12 tractors had to be relocated on the vehicles' frame rails to eliminate an inadvertent physical interference problem with the vehicles' driveshafts. This problem occurred as a result of an oversight during installation.
- On one truck, a sensor cable needed to be rerouted and resecured because of an interference/pinching problem with the wire and the steering gear.

NHTSA emphasizes that these problems and others like them do not reflect inherent design flaws with ABS's principal components (i.e., the ECU, modulators, and wheel speed sensing hardware). Instead, they involve wiring and installation problems. This highlights the importance of using high quality wiring components and paying close attention to installation details. The agency anticipates that the frequency of these problems will be lower than that experienced during the agency's test program once ABS production/installations increase to a level high enough to enable the quality control programs typically utilized by suppliers and truck manufacturers to take effect.

An average of 1.35 labor hours and $106.46 in replacement component parts costs per test truck tractor were necessary to rectify these installation/pre-production design related problems. Comparable figures for semitrailers were 1.9 labor hours and $65.36 in parts costs. All these costs are usually recovered by fleets under the terms of typical warranties offered by ABS suppliers and/or truck manufacturers. NHTSA notes that the start-up or installation/pre-production design related problems that the test fleets experienced are similar to the experiences that fleets were reported to have had with other devices such as electronically-controlled engines when they were first introduced on heavy trucks in the mid-1980's.

During the two-year period in which the reliability of these systems was evaluated, 200 ABS-equipped test tractors accumulated 39,818,659 miles of travel. During that time period, 126 trucks (63 percent) needed ABS-related maintenance that could best be attributed to normal service wear factors rather than installation or pre-production design related problems. A total of 421 incidents of this type occurred with the 125 trucks, the majority (321 or 76 percent) of which involved inspections/adjustments. The remainder (100 or 24 percent) involved repairs/replacements. All brands of the ABSs involved in the test program experienced incidents of this type at one time or another during their in-service operation.

Forty vehicles experienced more than one failure warning, interspersed over time, with two vehicles experiencing 35 and 31 separate indications (23 percent of the total resets), respectively, without the source of the problem being uncovered. Two other trucks experienced 12 and 10 separate indications respectively. These four vehicles (4.5 percent of the trucks experiencing this problem) accounted for 30 percent of the total intermittent failure warning indications and resets.

All five ABS suppliers' systems experienced intermittent failure indications with at least one of their forty test trucks involved in the test program. In each case, the ABS was either manually reset or the warning light did not reactivate when the truck's ignition was turned off and subsequently turned on again at some later time. However, 61 percent of the total failure warning indications of this type, and 34 percent of the vehicles experiencing intermittent failure indications, were attributable to one supplier's ABS. Another supplier's system accounted for another 18 percent of total failure warning indications and an additional 28 percent of the total vehicles involved. Since the time of the agency's test, both suppliers' systems have been modified to reduce the number of these false-positive malfunction indications.

The table shown below indicates the maintenance related to in-service wear that was required during the tractor portion of the program on each of the ABS components. Data are displayed by maintenance category (adjustments/inspections and repairs/replacements). Inspections and ECU resets associated with intermittent failure warning indications were the principal occurrence. In general, most of the work did not involve parts replacements. Parts replacement incidents totaled 40, with 55 percent of these (22) involving failure warning lamp bulbs or fuses. The total average number of in-service wear related maintenance incidents, including all inspections, adjustments, repairs and replacements was 2.11 incidents per truck over the two-year period of the test.

ABS IN-SERVICE WEAR RELATED MAINTENANCE INCIDENTS OVER THE TWO-YEAR PERIOD OF THE TEST, BY SYSTEM COMPONENT NEEDING WORK

| ABS component | Number of trucks requiring inspections, adjustments, or repairs on this component | Number of trucks requiring replacement of this component |
|---|---|---|
| Wiring Cables | 26 | 4 |
| Wiring Connectors | 19 | 2 |
| Sensors and Related Parts | 22 | 3 |
| Modulator Valves and Related Parts | 3 | 2 |
| ECUs | 19 | 7 |
| Fuses and Lamps | 7 | 18 |
| System Resets | 84 | 0 |
| Total No. of Trucks per Column | 118 | 32 |
| Overall No. of Trucks Involved in the In-Service Related Incidents | 125 | |

Note: Columns are not additive.

Replacing the 19 faulty major ABS components, and performing all the other inspections, adjustments and repairs that were in-service wear related, resulted in approximately 403 hours of labor expenditure and $4,068 for parts replacements. At a standard hourly rate of $35 per hour, the total cost of $18,173 for labor and parts amounts to 0.046 cent-per-mile (based on 39,818,659 total miles of travel) for the cost of maintaining the ABSs over the two-year period.

Inspections/ECU resets, which only involved labor expenditure, accounted for 45 percent of these total costs. Even though they occurred infrequently, ECU replacements tend to be costly, accounting as they did for 21 percent of the in-service wear related maintenance costs.

Similar findings were noted for the 50 ABS-equipped semitrailers that also were evaluated. The test vehicles accumulated 4,001,369 miles of in-service use during almost two years of operation during the program. During that time period, 23 semitrailers (46 percent) needed ABS-related maintenance that could best be attributed to normal service factors, rather than installation or pre-production design related problems. This compares favorably to the 63 percent of tractors requiring ABS service during the tractor program. A total of 44 incidents of this type occurred with the semitrailers, with the majority (29, or 66 percent) involving inspections or adjustments. The remainder (15, or 34 percent) involved repairs or replacements. These percentages are similar to the 76 percent for adjustments and inspections and 24 percent for repairs and replacements seen during the tractor program.

The following table shows in-service trailer maintenance that was required during the program for each category of ABS components. Inspections and ECU resets associated with failure warning indications were the principal occurrence. Parts replacement incidents totaled six, with three of these being status light bulbs and three speed sensors. In general most of the work did not involve parts replacement.

The average number of in-service maintenance incidents, including all inspections, adjustments, repairs, and replacements was 0.88 incidents per semitrailer over the two-year test period. This compares well with the 2.11 incidents per tractor seen during the tractor portion of this program.

Replacing six faulty ABS components, plus performing all other inspections, adjustments, and repairs that were in-service related, resulted in about 44 man-hours of labor expenditure and $234 for parts replacements. At a standardized hourly rate of $35 per hour, the total cost of maintaining the ABSs, for labor and parts, over two years ($1774) amounts to 0.044 cents-per-mile (based on 4,001,369 total miles of travel). The inspections and ECU resets (which only involved labor expenditure) accounted for 35 percent of the total costs. Comparable tractor figures are 0.046 cents-per-mile for total costs and 45 percent of the total costs for inspection and ECU reset, indicating that semitrailers performed very much like tractors.

ABS IN-SERVICE WEAR RELATED MAINTENANCE INCIDENTS OVER THE TWO-YEAR TEST PERIOD BY SYSTEM COMPONENT NEEDING WORK

| ABS component | Number of semitrailers requiring inspections, adjustments or repairs on this component | Number of semitrailers requiring replacements of this component |
|---|---|---|
| Wiring Cables | 4 | 0 |
| Wiring Connectors | 2 | 0 |
| Sensors and Related Parts | 10 | 3 |
| Inspection, with No Problem Found (NPF) | 12 | 0 |
| ECUs | 4 | 0 |
| Fuses and Lamps | 3 | 3 |

ABS IN-SERVICE WEAR RELATED MAINTENANCE INCIDENTS OVER THE TWO-YEAR TEST PERIOD BY SYSTEM COMPONENT NEEDING WORK—Continued

| ABS component | Number of semitrailers requiring inspections, adjustments or repairs on this component | Number of semitrailers requiring replacements of this component |
|---|---|---|
| Total No. of Semitrailers per Column | 23 | 6 |
| Overall No. Semitrailers Involved in the In-Service Related Incidents | 23 | |

Note: Columns are not additive.

At the completion of the overall 5-year test program, NHTSA conducted a final follow-up survey among the participating fleets. Among the 13 fleets that were continuing to maintain the ABS on the original test tractors, 97 percent of those tractors had functioning ABS. On the other hand, ABSs were not functioning on two-thirds of the original test tractors in the three fleets surveyed that chose not to continue maintaining the systems. This demonstrates that fleets must be willing to maintain the ABS if it is to be kept operational. An analogy can be drawn between the need to periodically inflate tires and the need to periodically perform minor, routine maintenance of ABS systems. Even though neither is time-consuming or costly, this type of maintenance is necessary if anticipated performance is to be achieved.

ATA commented on the SNPRM that the ABS repair/replacement rate (14–33 incidents per 100 vehicles per year) indicated in the agency's fleet study significantly understated the actual rate, citing the experience of one of its member carriers which recorded six to thirteen times as many ''repair incidents.''

Although NHTSA has not had the opportunity of reviewing the records ATA cited, the agency is inclined to believe that the difference in rates may be attributable to a difference in the definition of a ''repair incident.'' The agency fleet study data cited by the ATA (i.e., 14–33 incidents per 100 vehicles per year) were for ''repairs/replacements'' of ABS components. They did not include instances in which ''inspections'' or ''adjustments'' were made. For instance, adjustments of wheel speed sensors are not included in this total. This exclusion was necessary because comparable inspection/adjustment data were not available for the other vehicle components whose maintenance histories were being compared in the fleet study to that for the ABSs.

The above discussion accounts for all the in-service maintenance activity that was performed on the test ABSs. The ''monitoring'' to which ATA refers did not in any way contribute to or detract from the reliability data for the ABSs under evaluation. That monitoring was intended to ensure that all the maintenance work that was performed was recorded, so that a complete picture could be portrayed of the extent and nature of maintenance work that could be expected if U.S. heavy trucks were equipped with ABSs. Based on those data, the agency concludes that, overall neither unreasonable amounts or excessively costly additional maintenance will be imposed on U.S. heavy truck operators in order to maintain ABS. Thus, the agency disagrees with ATA's assessment that significant maintenance problems will arise ''* * * when the equipment is used outside the close monitoring it received in the NHTSA demonstration program.''

ATA further stated that ABSs are ''* * * not yet as durable as they must be for successful operation * * * in the U.S.'' That organization cited the fact that, as described above, three of the original participating fleets which ceased participating in the test program had appreciable proportions of non-functioning ABSs on their original test vehicles because they no longer maintained the systems.

NHTSA notes that this outcome could be anticipated with many other components besides ABS, that are installed on motor vehicles, for example, tires, engines, etc. All such components require periodic, and occasionally non-periodic, non-scheduled maintenance, in order to remain functional. Notwithstanding, the agency believes that the data contained in the two fleet study reports indicate that equipping vehicles with ABS is appropriate. Taken in total, those data indicate that, while ABS is not a zero-maintenance component, it is neither difficult nor unduly expensive to maintain. The fleet test results indicate that the level of maintenance attention needed to keep ABS functional is reasonable relative to the safety benefits that are estimated to result from use of these systems.

ATA also disagreed with the comparisons that were made in the agency's fleet study of repair and malfunction rates of ABS compared to other components on the vehicle that were susceptible to wear-related replacement. In the fleet study, comparisons were made between the maintenance histories of ABS and comparable histories for wheels/hubs, foundation brake components, pneumatic brake components, electrical system components, and tires.[43] These items were chosen because the agency believed that the maintenance patterns and costs of only these components could have been affected by the presence of ABS on the vehicle. The agency decided that it would be inappropriate to compare ABS maintenance results to items, such as engines and other drivetrain components, whose maintenance histories and costs would be unaffected by the presence of ABS.

ATA also questioned whether maintenance problems could have been underreported by a factor of 2.5 because the on-board recorders used during the trailer fleet study recorded less miles of travel (1.6 million vehicle miles of travel) than were accumulated by all the test trailers (4 million miles) during the test program. NHTSA notes that the maintenance history and cost data reported in the two studies were not affected by this discrepancy. The recorders were primarily used to obtain statistical information on the relative frequency of ABS activations per mile of travel. While their secondary purpose was to monitor ABS functioning, this was done only as a backup to the standard maintenance reporting and

[43] DOT HS 8070846, pages 3–24; DOT HS 808–059, pages 3–19, 3–20.

record-keeping activities of the participating fleets. The ABS maintenance histories that are reported in the fleet studies were derived from those maintenance records and are known to be thorough and complete.

ATA further believed that NHTSA's fleet studies underreported ABS maintenance problems. That organization cited incidents in which drivers failed to couple the second tractor-to-trailer electrical connector that was installed to power the ABS and instances in which drivers drove for an extended time period without reporting an ABS malfunction.

NHTSA believes that ATA's additional concerns about maintenance problems with ABSs are without merit. With regard to the first point, even though a limited number of drivers did not, in some instances, couple the separate tractor-to-trailer electrical connector, this fact does not affect whether those trailers' antilock systems received electrical power. The trailer ABSs in question were all wired redundantly to accept backup power from the stop lamp circuit on the other tractor-to- trailer electrical connector that the drivers did connect. Therefore, the ABSs on these trailers were functioning throughout the test using backup power from the standard tractor-to-trailer electrical connector, and were exposed to the possibility of malfunctioning just as much as the other test trailers in the study were.

As to ATA's claim that some drivers did not report a malfunction for an extended period of time, there were only a few instances of drivers driving for a time with non-functioning ABSs. The functional status of ABSs on test vehicles was checked, no less than monthly, by test study personnel, and often more frequently by fleet maintenance personnel. Therefore, in each case, the existence of a nonfunctioning ABS was detected after only a limited number of trips were made under that condition.

ATA attached to its comments letters from some of its members, including Consolidated Freightways, Inc. (Consolidated), UPS, and Ruan Transportation Management Systems (Ruan). ATA characterized these letters as indicating that ABS ''* * * failures are still happening and that other things are going wrong also''. Consolidated's submittal contained a sample listing of maintenance shop orders describing various repairs performed on ABS installed on its vehicles.

NHTSA could not ascertain the statistical prevalence of these incidents in Consolidated's fleet, given the way Consolidated presented its data. Thus, these incidents have only anecdotal value. Nevertheless, the nature and description of these incidents parallels those experienced and recorded during the agency's fleet study. For instance, several incidents cited by Consolidated involved faulty wheel bearings that knocked wheel speed sensors out of adjustment. NHTSA believes that these incidents should not be viewed as ABS failures. Further, other carriers have suggested that the ABS' ability to detect faulty wheel bearing conditions, which fail regardless of whether a vehicle is equipped with ABS, is a safety and maintenance benefit, not a detriment. The majority of other incidents cited by Consolidated involved minor wiring/connector problems that can be readily solved by tractor manufacturers' use of higher quality wiring/connector components or better attention to installation quality control. Carriers may address such situations through traditional warranty and customer complaint channels and, if necessary, through buying vehicles from manufacturers with higher overall product quality ratings.

UPS cited data indicating that the ABS malfunction warning light on 40 percent of a sample of ABS-equipped vehicles received from the factory since 1990 was activated when the vehicles were delivered. UPS did not provide detailed information listing the causes of these malfunction indications. Further, UPS did not explain whether the problems were remedied by simple adjustments of the same sort that are typically done during ''dealer preparation,'' prior to a dealer's delivering a vehicle to the customer. The agency notes that many large fleets such as UPS assume the dealership role when they receive large orders of vehicles directly from the factory. As a result, they assume responsibility for making this type of minor ''make-ready'' adjustments.

UPS also cited high proportions of ABS ''hard repairs or replacements,'' but did not define what constituted a ''hard repair.'' Thus, it is not possible for NHTSA to determine whether some of these might have been considered ''inspections/adjustments'' under the reporting scheme used in the agency fleet study or to put any of these figures in context or interpret them relative to the study's findings.

Ruan indicated that it was having difficulty getting an ABS supplier to respond to its requests for problem-solving help. Ruan listed a series of problems, similar to those noted in the agency's fleet study and cited by other carriers. Ruan's comments were anecdotal in nature and did not include any statistical information that would help portray the extent to which this affected their overall maintenance activities or costs. Nevertheless, all of the ABS suppliers and the major truck manufacturers have indicated, in the discussions they held with the agency on May 3, 4, and 19, 1994 [44], that they are committed to providing field service support staff, training, maintenance information, and other help to remedy the problems cited by Ruan and others. NHTSA has repeatedly stated that manufacturers must make service support available to fleets to ensure the success of this rulemaking effort. The agency anticipates that the ABS suppliers and major truck manufacturers will provide this support, given their statements in response to the NPRM that they are prepared to and are now doing so.

In response to ATA's comment about the occurrence of ABS malfunctions due to out of adjustment wheel speed sensors, NHTSA believes that there are several reasons other than faulty ABS design for this phenomenon. Among the most common reasons observed during the agency's fleet study were sensor misadjustment during initial installation; faulty sensor retaining clips; sensor wires being installed with too little slack, resulting in the sensor's being partially pulled out from its mounting block when the vehicle's steering gear or suspension moved; faulty or improperly installed wheel bearings; or failure to readjust the sensor after performing maintenance work in the wheel end area that results in the sensor being knocked out of adjustment. NHTSA emphasizes that the relative frequency of these types of incidents was not high. Five of the two hundred test trucks experienced problems of this type before being, or shortly after being placed in service. In addition, twenty-two of the trucks experienced problems of this type over the two year, 40 million mile test program. With the exception of the faulty clip problem, which has been permanently rectified, all the remaining reasons for the occurrence of this condition are the result of installation quality control lapses, faults with other components, or misinformed maintenance practices. The failures were not caused by faulty sensor design. The agency anticipates that the rate of incidence of even these few events will decrease as quality control efforts and mechanics' awareness and skill in maintaining ABS improves.

[44] Memos about these meetings have been placed in the public docket.

In response to ATA's comment that mechanics will have difficulty installing and maintaining ABS, NHTSA recognizes that mechanic training will be necessary to ensure the long term viability of ABS systems. However, based on the agency's fleet test results, the agency finds that, once trained, mechanics can successfully maintain the systems. The study's results indicate that those fleets committed to providing mechanics the support needed to deal with ABSs can keep the systems operational with relative ease and efficiency and at reasonable cost. ABS suppliers and truck manufacturers have indicated a commitment to providing field service support for the systems. If fleets begin utilizing these services now, mechanics will be capable of maintaining the systems as more ABS-equipped vehicles are introduced into fleet service.

Based on its anecdotal experience with electronic engines, ATA stated that truck manufacturers will not correct the wiring and installation related problems evidenced in the test. Specifically, ATA stated that ''* * * none of the OEM's yet follow the engine manufacturer's guidelines on how wiring/sensors are to be placed and no two of them do it the same way''.

NHTSA believes that ATA's comparison between electronic engines and ABS is not relevant. That organization's comparison fails to portray the extent of problems that were reported to have occurred with electronic engines when they were first introduced in the mid to late 1980's. The lower malfunction rates now being experienced with electronic engines are the result of having worked through initial design and installation problems, a pattern the agency notes is now repeating with ABS, as it becomes more widely installed and used. In addition, ATA's comments about wiring/sensor placement on electronic engines appear to imply that the lack of uniformity in this regard adds complexity to the task of maintaining these engines, rather than implying that truck manufacturers are improperly or inadequately installing engines in vehicles they produce. Unless there is some compelling reason or requirement for manufacturers to install a given component in a single way, the fact that they do it differently is to be expected, given the need and desire for design flexibility. The same flexibility is likely to be true with ABS installations. Electronic engines are in widespread use within the trucking industry today. It is therefore reasonable to infer that truck manufacturers are installing them properly. Based on the data collected in its two fleet studies, the agency believes that the carriers can and will be able to successfully maintain ABS as well.

ATA further stated that the agency's thinking was ''* * * seriously flawed * * *'' because the agency-supported fleet study contained listings of ABS malfunctions that were remedied with only the expenditure of labor and did not require repair or replacement of a component part, with added parts-associated costs. ATA claimed that the report's inclusion of these type malfunctions implied ''* * * some lesser class of failure''. ATA's reference in this regard was to instances in which a false- positive ABS malfunction indication occurred which necessitated an inspection and system reset, with no other problem being found or remedy needed.

NHTSA disagrees. Rather than minimizing the consequences of these occurrences, the inclusion of them in the two reports highlighted the agency's concern about such events. During the tractor portion of the study, they occurred comparatively frequently with 88 of the 200 test tractors experiencing a total of 290 intermittent malfunction warning indications.[45] The situation improved markedly, however, in the later trailer portion of the study. Here, 12 of the 50 test trailers experienced a total of 15 of these false-positive malfunction warnings.[46] The cost impact of these occurrences is noted in the fleet study reports. The reports further noted that such malfunctions accounted for 45 percent of the total in-service maintenance costs for tractors and 35 percent for trailers. Notwithstanding these findings, the fact that a significant reduction in the frequency of these occurrences was noted between the time of the tractor and trailer portions of the study, indicates that the reliability of the components greatly improved.

ATA further implied that these types of failures resulted in lost vehicle productivity, because an affected vehicle would have to be taken out of service to remedy the situation. Contrary to ATA's assertion, none of the test vehicles were pulled out of operational service by the fleets as a result of these malfunction indications. Instead, corrections were made when the vehicle returned to its dispatch point and before it was next dispatched. Further, no dispatch opportunities were missed because of these incidents.

NHTSA notes that the agency's fleet study summarized the cost impact of ''false-positive'' ABS malfunctions. Specifically, these incidents accounted for 45 percent of the total in-service maintenance costs for tractors and 35 percent for trailers. The agency's fleet study report summarized the cost impacts as follows: In the case of tractors, those costs were $0.00021 per mile, while for trailers the figure was $0.00015 per mile. These figures are reasonable, given that it costs $1.38–$1.54 per mile to operate a truck with a driver.[47] Moreover, based on the trailer fleet study, NHTSA expects these costs to decrease significantly over time, since many of them were associated with ECU malfunction warning algorithms that ABS suppliers have since modified to make them less prone to inappropriate activation.

Based on the above considerations, NHTSA concludes that there is no basis for accepting ATA's position that more leadtime beyond that specified in this final rule is needed to successfully implement ABS use in heavy vehicles. NHTSA further concludes that maintenance costs associated with ABS are neither excessive nor unreasonable compared to other maintenance costs and that these costs will not be significantly reduced if the implementation dates of this rule are further delayed.

*E. Requirements for Durability, Reliability, and Maintainability*

ATA requested that the Standard include requirements to address the durability, reliability, and maintainability of ABSs. ATA was concerned that premature degradation of ABS performance would create a safety risk associated with loss of ABS. Specifically, that organization requested requirements addressing corrosion resistance and electromagnetic susceptibility. It stated that such requirements are ''necessary to assure that the equipment provided to meet the stability and control requirements proposed in this standard can do so repeatedly.[48]''

NHTSA concludes that separate requirements addressing the durability, reliability, and maintainability of ABS are not needed at this time. As detailed above, the ABS fleet evaluation conducted by the agency on 200 tractors and 50 trailers demonstrated that current generation ABSs are durable, reliable, and maintainable. Based on the fleet study and comments by manufacturers, NHTSA concludes that

[45] DOT HS 807–846, page 3–17.

[46] DOT HS 808 059, page 3–14.

[47] *Modern Bulk Transport* Magazine, June 1994, page 84.

[48] NHTSA responds to the issue of the alleged safety risk in the next section.

separate component tests are not necessary.

*F. Alleged Safety Problems*

ATA contends that current-generation ABSs can fail ''unsafe,'' i.e., ABS malfunction can result in the foundation brakes becoming inoperative. That organization states that this is a ''significant * * * safety problem'' and cites five incidents, two of which occurred during the agency's fleet studies, as corroboration for this suggestion. No other commenter alleged that current-generation ABSs fail in an unsafe manner.

The issue raised by ATA concerns the likelihood of ABS malfunctions that would either reduce brake system performance or render a vehicle's underlying brake system completely inoperative. Based on the data collected during the NHTSA's in-service fleet evaluation of ABS, the agency finds that the likelihood of such occurrences is negligible. Therefore, NHTSA concludes that ATA's concern is unwarranted and unsubstantiated.

During the two-year evaluation of 200 ABS-equipped truck tractors, a total of 421 incidents were recorded involving in-service wear related ABS malfunctions. The vast majority (99.8 percent) of these malfunctions were benign. When the ABS became inoperative, the vehicle reverted to a normally-braked vehicle without ABS protection and remained fully operational until the malfunction was remedied. Similarly, during the two-year evaluation of 50 ABS-equipped semitrailers, 44 such incidents were noted. All (100 percent) were benign.

Only one ABS malfunction incident occurred during the tractor fleet study that resulted in the vehicle having reduced, braking performance. Even this incident, which involved a manufacturing defect in the surface coating of a piston slide valve in the modulator section of a drive-axle-only ABS on one tractor, did not totally compromise the brake performance. When the ABS supplier involved found the cause of this failure, a design change was made to rectify the problem and all the other test units in the fleet study were retrofitted with the improved design. Despite making this change, the ABS supplier involved subsequently chose not to produce this system. The agency emphasizes that this failure did not result in the complete loss of braking power on the vehicle. When the failure occurred, the vehicle experienced reduced braking capability on two of its five axles. The driver was able to maintain control of the vehicle and stop it. Despite the fact that it took longer than usual for the vehicle to stop, there were no adverse consequences as a result of this incident.

As ATA acknowledged in its comments, failures such as this are rare. In this case, the failure was the result of a manufacturing defect, an atypical situation. This incident is not indicative of a general flaw in presently designed ABS systems of the type that would support the contention that ABSs typically fail unsafely.

By comparison, during the same time period, the fleet studies reported 580 incidents involving the tractors, and 170 incidents involving the trailers, in which repairs or replacements were made to brake system components that were not related to the ABS.[49] These malfunctions could have compromised the brake system performance of the affected vehicles. Included among these were repairs or replacements of leaking or faulty relay or quick release valves, leaking or worn brake chambers or air hoses, and other miscellaneous repairs of leaking fittings. The agency notes that, despite their potential gravity, these failures went unheralded, and were simply repaired when detected. Fleet maintenance personnel expressed no special concern about this type of malfunction, treating them as routine occurrences.

NHTSA's fleet study experience parallels the experience found during roadside inspections of heavy vehicles. FHWA's Office of Motor Carriers[50], reports that in 1992, 1,655,668 heavy vehicles were inspected by state and federal officials under the Motor Carrier Safety Assistance Program (MCSAP), and 461,715 (28 percent) of these were placed out-of-service for mechanical defects that were deemed significantly hazardous enough to warrant repairs at that location before the vehicle was operated again. A total of 908,184 out-of-service defects were noted, 54 percent (487,238) of which were brake system related. The majority of these (68 percent) involved out-of-adjustment brakes, but the remainder (157,717) involved defects in either the foundation or pneumatic portions of the system (e.g., cracked brake drums, chafed or worn air hoses, leaking brake chamber diaphragms, etc.), all of which could significantly compromise brake system performance in a severe braking maneuver. These data indicate that, on average, nearly one of every ten in-use heavy vehicles is operating with at least one significant non-adjustment related brake system defect, that, for whatever reason, goes unnoticed and/or is not repaired by fleet personnel, until the condition is discovered in an inspection. The National Transportation Safety Board[51], among others, has concluded that this situation is already serious enough to warrant more ''* * * consistent attention to brake system maintenance.''

Problems associated with the foundation brakes appear to far exceed those caused by a potential malfunction to the ABS. Moreover, neither the frequency of ABS malfunctions nor their consequences, as noted in the fleet study, indicate that adding ABS will worsen this situation. In fact, the agency concludes that adding ABS will significantly contribute to improving it by partially compensating for brake system force imbalances that result from poorly performing or inoperative individual brakes on a vehicle. Ordinarily, under lightly loaded or empty operating conditions, the operative/properly performing brakes attempt to compensate for the reduced braking power absent from the inoperative/poorly performing brake(s). As a result, they over-brake and tend to lock up as increasing levels of brake pressure are applied in an effort to stop the vehicle. Although ABS is not a substitute for proper maintenance, under these conditions, its addition to a vehicle's braking system will be beneficial, since it will prevent lockup.

NHTSA emphasizes that the one isolated incident identified in its fleet study that involved an ABS malfunction that compromised the vehicle's braking performance is markedly different from those described in *PACCAR*. In that case, it was argued that when an ABS failed, the vehicle's underlying brake system was unsafe. The circumstances that gave rise to such concerns are very different from those of today. ABS technology for motor vehicles was very new in the 1970s. In response to aggressive stopping distance requirements and a prohibition against wheel lockup, manufacturers equipped their vehicles with ABSs and extensively redesigned the pneumatic and foundation brake portions of their braking systems. The new foundation brakes in many cases incorporated highly aggressive brake linings. When malfunctions occurred with a vehicle's ABS, the vehicle was left with a much more aggressive and powerful foundation brake system than the brake

[49] DOT HS 808 059, page 3–18; DOT 807 846, page 3–23.

[50] *Annual Report on Program Quality and Effectiveness, Fiscal Year 1992,* U.S. Federal Highway Administration, Office of Motor Carriers, June 1993

[51] *Heavy Vehicle Air Brake Performance,* National Transportation Safety Board Report No. SS–92/01, April, 1992.

systems that had been in general use. Additionally, since the pneumatic portion of the system was different from what had been in use, brake application and release timing on vehicles with malfunctioning ABSs were also different. Thus, for example, if the ABS on an ABS equipped tractor became inoperative, and the tractor was coupled to a non-ABS-equipped trailer, the tractor's brakes still functioned but were extremely incompatible with those of the trailer. The tractor's brakes applied and released differently and were much more aggressive. These differences led to braking force imbalance problems that were very disconcerting to drivers. While situations such as this did not constitute brake failures per se, drivers nevertheless perceived the performance of their vehicles to be very unacceptable and termed these situations brake system failures.

In the 1970s, there were several highly publicized incidents in which radio frequency interference (RFI) problems caused the ABS to cycle continuously during a brake application, thereby greatly diminishing braking power by venting brake system air pressure. The agency notes that manufacturers have completely eliminated the potential for RFI problems since current generation ABSs have been designed with shielded wiring systems and more sophisticated electronics that are better able to recognize spurious signals. No RFI problems have been reported with current-generation ABSs.

The numerous complaints of brake system malfunctions reported by drivers prompted the *PACCAR* court to find that the agency had a responsibility to determine that its regulations do not produce a more dangerous highway environment than that which existed prior to government intervention.

NHTSA has determined that today's final rule requiring heavy vehicles to be equipped with ABSs will result in a significantly safer highway environment than if no regulation were issued. Unlike 20 years ago, the manufacturers will not need to significantly redesign their braking system or use aggressive brake linings to meet stopping distance requirements. Further, ABS is no longer an immature technology. It has undergone 20 more years of development, been installed on tens of thousands of European vehicles pursuant to the 1991 ECE requirement, and been fleet tested extensively in this country by NHTSA and the industry.

NHTSA is aware of no consistent pattern of incidents in this country in which current generation antilock systems have experienced malfunctions like those that concerned the *PACCAR* court. As for the incidents cited by ATA alleging that an ABS malfunction resulted in an unsafe condition, the first one involving a manufacturing defect is discussed above. The second incident involved leaking air in the relay valve portion of a combined relay valve/ABS modulator valve on the steer axle of one truck involved in the agency's fleet study. Strictly speaking, this is not an ABS malfunction, since the air leak that occurred involved the service brake portion of this combined ABS/relay valve. The leakage was caused by oily sludge in the air system, which clogged the relay valve, thereby allowing service brake air pressure to vent, rather than being directed to the brake chamber controlled by that relay valve. The vehicle was equipped with an aftercooler type air cleaner/dryer. Such a leak would result in reduced braking performance, not total loss of the vehicle's brakes. This type of failure is similar to the non ABS related malfunctions that are described above and which were noted in both the fleet study and during roadside MCSAP inspections.

ATA's comments implied that the ABS suppliers' recommended solution for this problem (i.e., that tractors be equipped with desiccant style air cleaners, in order to provide cleaner air), was unacceptable and that to use such cleaner/dryers demonstrates that ABS require a higher level of maintenance. NHTSA believes that it is reasonable to expect that fleets will use desiccant air dryers, or another type of comparably performing air cleaning system, since such systems will enhance the durability and safety of tractor and trailer braking systems by keeping the pneumatic portion of the brake system cleaner. The marketplace appears to have recognized this fact and is responding accordingly. Air cleaning/drying systems are now being installed on more than 80 percent of all new air brake-equipped powered heavy vehicles, with more than 90 percent of these being the desiccant type. Based on current usage, the agency anticipates that air cleaning/drying systems will be in almost universal use within the next few years.

ATA provided few details about the third incident cited in its comments. That incident involved an ABS equipped tractor trailer combination participating in an ATA test program. That organization stated that the vehicle was "* * * generating consistent stopping distance results when, in the middle of one run, there was a loss of braking which significantly increased the stopping distance." ATA offered no explanation or reason for this outcome, except to indicate that "* * * no indication of an ABS failure by either the tractor or trailer ABS warning lamps * * *" was noted. Since ABS malfunction was not indicated as the reason for the unexplained increase in stopping distance that occurred during the test of one of its fleet member's trucks, there is no reason to believe that this incident is indicative of an ABS problem.

The fourth incident ATA cited involved a vehicle that was retrofitted with an ABS by the carrier and experienced reduced braking effectiveness during a test stop. Agency discussions with ATA staff and with the ABS supplier indicate that the vehicle was a truck tractor that was tested after the tractor had been equipped with an upgraded ABS. The ABS supplier subsequently concluded that a soldered connection had broken in the ECU and that this may have caused intermittent activation of one of the four modulators controlled by the ECU. Based on its investigation of the ECU in question, and its knowledge of how the ABS was configured, the ABS supplier believed that the truck had experienced a reduction in braking, but not a total loss of braking power. NHTSA emphasizes that this incident is atypical and not indicative of normal ABS performance, since the fleet study identified no similar incident.

The fifth and final incident described by ATA is reminiscent of the "phantom failures" that were reported to have occurred with early 1970's vintage ABSs. The causes of most of those "failures" were neither fully explained nor linked to ABS flaws. In this incident, the accident report simply claimed that "* * * the vehicle would not stop." ATA's account of this incident indicates that no problems were found in either the tractor's or the trailer's braking system after this incident.

NHTSA notes that other factors such as slippery road conditions or improperly adjusted brakes are just as likely as ABS malfunction to have caused the driver to believe that the vehicle would not stop or that it was stopping too slowly. Without additional information, it is not possible for the agency to assess the cause of this incident, or respond to the implication that the incident is somehow indicative of an inherent ABS flaw.

Contrary to ATA's allegations that existing ABSs have significant safety problems, most commenters, including vehicle and brake manufacturers, appear to agree with NHTSA's assessment that current generation ABSs are safe and reliable. Unlike the 1970's when several vehicle and brake manufacturers objected to the rulemaking, and ATA, TEBDA, and PACCAR challenged the antilock standard in court, comments to the September 1993 NPRM indicate that vehicle and brake manufacturers now generally believe that the proposal was appropriate and today's antilock systems provide significant safety benefits. Along with the safety advocacy groups, HDBMC, AAMA, GM, Rockwell WABCO, Midland-Grau, and Bendix generally supported the agency's September 1993 proposal to require heavy vehicles to be equipped with an antilock brake system. No vehicle or brake manufacturer opposed the rulemaking, aside from objecting to details in the proposal. These commenters stated that ABS will improve vehicle safety by providing improved braking and vehicle stability and control. Specifically, such systems will prevent wheel lockup, thereby preventing jackknifing and other loss of control accidents. Neither the vehicle nor brake manufacturers expressed concern that today's ABSs would fail in such a way as to compromise basic braking performance, as ATA alleges.

Strait-Stop stated that computerized ABSs will not prevent brake fade since these systems do not avoid or minimize heat build up. As a result, it alleged that computerized ABSs will not avert accidents related to runaway trucks. In contrast, it stated that its system results in cooler and therefore better brakes. The agency is not in a position to respond to Strait-Stop's claim that its product minimizes brake heat build up. Strait-Stop did not submit any data to substantiate its claim and the agency has no data of its own on this issue.

NHTSA emphasizes that Strait-Stop has not suggested that an ABS will contribute to brake heat build-up, but merely stated that it will not reduce brake heating. Reducing brake heating, and thus the potential for brake fade, is not one of the design goals of an ABS, nor is it the focus of this rulemaking. ABS is intended to prevent wheel lockup. Brake fade is most typically caused by one or more of the brakes on a vehicle being out of adjustment, thereby causing the other properly adjusted brakes to have to absorb a disproportionate share of the kinetic energy that needs to be dissipated when a fully loaded heavy truck attempts to descend a grade. In this situation, the properly adjusted brakes are overworked, causing them to overheat and fade. This in turn results in a loss of braking power. Equipping a vehicle with either ABS or the Strait-Stop product will not rectify brake maladjustment(s). Likewise, equipping a vehicle with ABS will not decrease the motor carriers' existing need to properly adjust their vehicles' brakes in order to avoid brake overheating and fade on downgrades.

### *G. ABS Malfunction Indicator Lamps*

Since the discussion on ABS malfunction indicator lamps is lengthy, NHTSA first summarizes its decisions regarding this subject and then addresses the details of each decision. In today's final rule, NHTSA is amending Standard No. 105 and Standard No. 121 to require all powered heavy vehicles to be equipped with an in-cab lamp for indicating a malfunction of the ABS on that vehicle. In addition, the final rule requires truck tractors and other trucks that are equipped to tow trailer(s) to be equipped with a second in-cab lamp. The purpose of the second lamp is to indicate malfunctions in the trailer ABS. Finally, trailers manufactured during an interim eight-year period are required to be equipped with an external malfunction indicator lamp.

Each of these ABS malfunction indicator lamps is required to activate whenever there is a malfunction affecting the generation or transmission of response or control signals in the ABS that it is monitoring. In addition, the lamp is required to store information about a malfunction in that ABS until the next start up. Vehicle manufacturers are prohibited from equipping their vehicles with a device to disable any malfunction indicator lamp.

NHTSA also has amended the failed ABS system requirements to prohibit any change in brake timing in the event of an ABS malfunction that affects the generation or transmission of response or control signals.

#### 1. Number and Location; Duration of Trailer Requirement

Standard No. 121 now requires that each tractor, truck, and bus be equipped with an in-cab lamp that indicates malfunctioning in the ABS of that vehicle. In the NPRM, the agency proposed that truck tractors be equipped with a second in-cab lamp that would indicate malfunctions in the trailer ABS. The agency proposed further that the in-cab lamps be required to be ''mounted in front of and in clear view of the driver.'' The agency noted that this requirement is essentially the same as the current requirements in Standard No. 105 and Standard No. 121. These existing provisions require a continuous message to a driver when the ignition is in the ''on'' or ''run'' position.

NHTSA has decided to adopt its proposal that each truck tractor and single unit vehicle be equipped with an in-cab lamp to indicate malfunctions in the ABS of that vehicle. The agency believes that it is essential that a driver be notified about an ABS malfunction, so that the problem can be corrected. The commenters, including vehicle manufacturers and brake manufacturers, generally supported the proposal for an in-cab malfunction indicator. Only Strait-Stop opposed this proposal, stating that it would necessitate the use of an electrical ABS.

NHTSA proposed to require that each trailer equipped with ABS be capable of sending a signal about a malfunction in the trailer ABS to a towing vehicle, and that all powered towing vehicles equipped with ABS have an in-cab lamp that would be activated when the towing vehicle receives signals indicating malfunctions in a trailer ABS. In addition, the agency proposed to require the installation of an external ABS malfunction lamp on trailers and dollies manufactured during the eight-year period after trailers are first required to be equipped with ABS.[52] The agency believed that the external lamp would not be necessary on new trailers manufactured after the end of that period because, by that time, a significant majority of tractors in the heavy vehicle fleet, which would be responsible for the vast majority of miles driven by tractors, would be manufactured in compliance with the requirement for an in-cab lamp capable of receiving a malfunction signal from a trailer.

Commenters offered mixed views about requiring each towing vehicle to have a separate in-cab lamp to indicate a malfunction in a trailer ABS. Bosch, Midland-Grau and several other commenters supported the agency's proposal for requiring tractors to have two separate in-cab ABS malfunction indicator lamps: one indicating malfunctions in the tractor ABS, and the other, malfunctions in the trailer ABS. They stated that a driver would be able to respond to and possibly alter braking actions in the event of an ABS malfunction during emergency situations if the driver knew whether the malfunction was in the tractor ABS or in the trailer ABS. Midland-Grau strongly opposed having a single indicator, claiming that the tractor lamp sequence would camouflage the situation in which the trailer ABS lacked power. Midland-Grau further

[52] The eight-year time period for this interim proposal was intended to represent the average lifespan of a truck tractor.

stated that a single lamp would make it difficult to identify which vehicle had a malfunction without using separate diagnostic equipment.

ATA, Allied Signal and fleet operators opposed the proposal that tractors have a separate in-cab malfunction lamp for the trailer ABS, claiming that these indicators were ''neither needed nor practicable at this time.'' AAMA supported a single in-cab malfunction lamp for each tractor to indicate an ABS malfunction on either the tractor or the trailer. It believed that there is no safety need for the driver to know immediately whether the ABS malfunction is in the tractor or the trailer. While AAMA stated that separate indicators would cause needless complexity to the instrument panel, it did not state that such a requirement would be impracticable.

After reviewing the comments and other available information, NHTSA has decided to require each powered towing vehicle to have one in-cab malfunction lamp for the towing vehicle's ABS and another in-cab lamp for the trailer ABS. The agency believes that the ABS trailer fleet study final report [53] indicated that drivers are more likely to observe an in-cab malfunction indicator for a trailer than a malfunction indicator lamp on the front of the trailer, particularly if the trailer ABS is powered through the stoplamp circuit. This is so because the stoplamp circuit only activates when the brake is applied, a time when the driver will be paying more attention to the traffic conditions ahead. The report also indicated that ABS malfunctions were present on some vehicles for a long time, but were not reported, primarily because the drivers ''spent very little time looking in their mirrors while stopping'' and did not notice that the trailer ABS malfunction lamp was lighted.

NHTSA does not agree with AAMA's recommendation for a single in-cab malfunction lamp for both the tractor and trailer antilock systems. As Midland-Grau stated, a driver would not be able to identify which vehicle in a combination was experiencing an ABS malfunction if only a single in-cab malfunction indicator lamp were required, since a single in-cab lamp would result in some trailer ABS malfunctions being camouflaged. Further, notwithstanding comments by AAMA and ATA that separate in-cab lamps add unnecessary complexity, combination vehicles in Europe have been equipped with such indicators for several years.

NHTSA believes that it is appropriate also to require an external malfunction lamp on trailers and dollies for the eight-year period during which some non-ABS-equipped tractors are likely to be towing ABS-equipped trailers. The external lamp will indicate trailer ABS malfunctions to the driver of a non-ABS tractor, and will also assist Federal or State inspectors in determining the operational status of a trailer's antilock system. Nevertheless, notwithstanding Midland-Grau's recommendation to require the external trailer lamp permanently, the agency has decided not to do so, since after the transition period, the vast majority of trailer malfunctions would be expected to be indicated in-cab.

In response to the SNPRM, TTMA stated that instead of locating the trailer lamp on the ''roadside nose of trailer, it should be located near the electronic control unit where the driver can check it during his walk-around inspection of the tractor trailer combination.'' It stated that some ABS may require that the trailer be moved at a low speed (less than 5 mph) to activate the check function (i.e., some antilock systems check the status of wheel speed sensors by looking for proper signals as the vehicle goes from 0 to 8 mph). TTMA also commented that it is not practical to mount an ABS malfunction lamp on converter dollies in a location in which the lamp will be visible in a driver's rearview mirror, yet not be susceptible to damage.

While NHTSA recognizes the possibility of some susceptibility to damage, placing the external malfunction lamp in a different location on dollies would largely negate its benefits, because it would not be visible to the driver. For that reason, the agency has decided that the requirement will apply to dollies as well as other trailers.

NHTSA is revising Standard No. 101, *Controls and Displays*, to clarify that the malfunction indicator lamp must be labeled with the words ''ABS'' or ''Antilock'' for trucks and truck tractors with air brakes. The agency notes that Table 2 in Standard No. 101 currently refers to Standard No. 105, but makes no reference to Standard No. 121. For the in-cab trailer ABS malfunction indicator, NHTSA is adopting the identification of controls in Standard No. 101 (i.e., ''Trailer ABS'' or ''Trailer Antilock'') as proposed in the NPRM.

2. Conditions for Activation

Before this amendment, S5.1.6 of Standard No. 121 required the ABS warning signal to activate ''in the event of total electrical failure.'' In the NPRM, NHTSA proposed that the malfunction indicator lamp activate ''in the event of any malfunction in the system.'' The agency tentatively concluded that a driver needs to be informed about any malfunction because every ABS malfunction could affect the way in which drivers respond to a safety problem. The agency invited comments about when and in what situations the malfunction lamp should be required to activate.

Fleet operators, AAMA, Rockwell WABCO, HDBMC, and Midland-Grau stated that the proposal to require the ABS malfunction lamp to activate upon ''any'' malfunction in the antilock system is impracticable, unreasonably costly, and overly broad. These commenters believed that it is only practicable and realistic for current technology to detect certain types of electrical malfunctions, namely those involving electrical discontinuities or electronic malfunctions, not mechanical failures of ABS components. AAMA and HDBMC stated that it would be unreasonably costly to provide continuous monitoring of all ABS malfunctions because many possible malfunctions are temporary in nature or may not directly affect ABS performance.

Commenters suggested various ways to narrow the requirement. Rockwell WABCO recommended that the ABS malfunction indicator activate whenever a ''malfunction occurs affecting the generation and/or transmission of response and control signals.'' It stated that this should be a minimum requirement applicable to electrical faults in sensors, control valves and associated wiring. ATA, Allied Signal and fleet operators stated that a more practicable requirement for the ABS malfunction indicator would be to require activation in the event of (1) failure to sense angular rotation, (2) failure of the controlling device to generate controlling output signals, and (3) failure to transmit controlling signals to devices that modulate brake actuating forces.

Based on the comments and other available information, NHTSA has decided to require ABS malfunction indicator lamps to activate for any malfunction that affects the generation or transmission of response or control signals in the vehicle's antilock brake system. The requirement does not apply to malfunctions such as sticking solenoid valves, small air leaks in the solenoid valve, or mechanical binding of a valve. The agency agrees with the commenters' arguments that the malfunction indicator requirement

[53] ''An In-Service Evaluation of the Performance, Reliability, Maintainability, and Durability of Antilock Braking Systems for Semitrailers,'' (October 1993),

should be modified because requiring activation in the case of ''any'' malfunction might have been impracticable. Under the modified requirement, only those malfunctions that are directly related to the antilock brake system must be indicated. Applying the indicator requirement to the ''generation'' of response and control signals serves to cover the components in the ABS that produce these signals. These components include wheel speed sensors which produce response signals for the control unit, and the control unit which produces control signals for input into the valves that modulate brake pressure. Applying the indicator requirement to the ''transmission'' of response and control signals serves to cover the components in the ABS through which the generated signals are transmitted. These components include wiring, connectors, belts used in mechanical systems, and all components through which a generated signal can be transmitted.

NHTSA notes that the generation and transmission of signals in ABSs are typically electrical in nature. Nevertheless, the agency has decided not to include the term ''electrical'' in the requirement so that the malfunction indicator requirements are applicable to non-electrical, i.e., mechanical, ABSs as well. Accordingly, mechanical ABSs will have to comply with the malfunction indicator requirements.

3. Activation Protocol for Malfunction Indicators

In the NPRM, NHTSA proposed standardizing the ABS malfunction indicator lamp system so that trucks and trailers would have the same activation pattern [54] and same colored lamps to indicate an ABS malfunction. The agency believed that such a common indicator pattern would reduce ambiguity and confusion and expedite Federal and state inspections. The agency proposed that each ABS malfunction indicator lamp be yellow and activate when a problem exists but not activate when the system is functioning properly. In addition, the proposal would have required that whenever the ABS receives electrical power, the indicator lamp would provide a continuous visible indication until a function check of the ABS was completed. Under the proposal, the check function would have to be completed and the lamp extinguished (assuming that there was no underlying condition that warranted activating the lamp) before the vehicle was driven.

Rockwell WABCO stated that both the existing format in which a continuous signal is activated upon the ABS's total electrical failure and the proposed format for the ABS malfunction lamp are acceptable approaches. That company strongly recommended that the agency adopt a single approach for all heavy vehicles. Midland-Grau accepted the agency's proposal to require the lamp to extinguish before the vehicle is driven, even though it was concerned about an incomplete sensor check function.

AAMA stated that the agency ''should allow the ABS malfunction indicator to be either illuminated or extinguished during low speed drive away after key-on.'' That organization requested that the agency affirm its view that the proposed language did not require the ABS indicator to be either illuminated or extinguished during low-speed driveaway after key-on. That organization was concerned that the proposal might prohibit certain existing systems that have an illuminated indicator until the vehicle reaches a speed of five to seven mph after key-on.

Bosch recommended that an ''on-off-on'' blink sequence be used to indicate an ABS malfunction when the ignition is turned to the ''on'' or ''run'' position. It believed that this pattern would inform a relief driver of the presence of a malfunction and would assist Federal and State inspectors in determining the operational status of the vehicle's ABS.

After reviewing the comments and other available information, NHTSA has decided to require the malfunction indicator lamp to activate when a problem exists and not activate when the system is functioning properly. Under this requirement, the indicator lamp is required to provide a continuous indication until a function check of the ABS is completed. The agency believes that this ABS malfunction lamp format, together with the requirement that the system stores malfunctions until the next key-on, is necessary to enable Federal and State inspectors to determine the operational status of an ABS without moving the vehicle. Elsewhere in today's **Federal Register**, the FHWA's Office of Motor Carrier Standards is issuing a notice explaining its intent to issue a companion regulation requiring that the ABSs on heavy vehicles be operational.

NHTSA further notes that all vehicles will be required to have a continuously burning lamp in response to a malfunction. Accordingly, this requirement will standardize the activation format for all vehicles. Under that format, the ABS malfunction lamp extinguishes after a function check, and before the vehicle is driven. Since light vehicle ABSs currently use this format, the agency believes that heavy vehicle drivers will find it easier to understand the heavy vehicle ABS malfunction indicator if the same format is used. Furthermore, the adopted format is also consistent with the ECE requirement and therefore is consistent with the goal of international harmonization.

NHTSA has concluded that the ''on-off-on'' blink sequence recommended by Bosch to indicate a malfunction during vehicle start-up would place an unwarranted burden on the driver, who would have to pay close attention to the malfunction lamp to observe the blink sequence during vehicle start-up and drive-away. Therefore, the agency rejects this recommendation.

4. Signal Storage

In the NPRM, NHTSA proposed that the ABS indicator lamp system be capable of storing information regarding any malfunction that existed when the ignition was last turned to the ''off'' position. For instance, if the wheel speed sensors were malfunctioning before the vehicle was turned ''off,'' the system would be required to store a signal for that malfunction. As a result, the malfunction would be displayed when the vehicle was turned ''on'' again, as part of the function check.

AAMA, Midland-Grau, Rockwell WABCO and several other commenters opposed the proposal to require the storage of ABS malfunctions that exist when the ignition is turned to the ''off'' position. AAMA stated that it is not appropriate to mandate this capability, claiming that many error messages are spurious or represent transient conditions, and therefore do not warrant automatic reactivation the next time the key is turned to the ''on'' position. It further stated that if a malfunction is non-transient, then the warning will reappear and that therefore it need not be stored. Midland-Grau believed that the proposal was design restrictive and would eliminate systems that do not have non-volatile memory (i.e., a system that remembers malfunctions when the system is shut down). Rockwell WABCO stated that this area does not need to be regulated, even though it acknowledged that all current electronic ABS have non-volatile memories to store and communicate current and past malfunctions. After reviewing the comments and other available information, NHTSA has decided that the malfunction storage requirement is necessary to ensure that relief drivers

[54] By pattern, the agency meant a common way that an indicator would react in response to a malfunction. Specifically, upon a failure, the indicator would activate and provide a continuous yellow signal.

and Federal and State inspectors are advised about any malfunctions in a vehicle's ABS without having to move the vehicle. This capability is important since inspectors would need to determine the operational status of the vehicle's ABS without moving the vehicle. Moreover, this capability is necessary since the agency has decided to require that the ABS malfunction indicator lamp extinguish before the vehicle is driven, provided that there is no existing ABS malfunction that warrants activation of the indicator.

NHTSA disagrees with AAMA's claim that nontransient malfunctions will always reappear at the next key-on and therefore do not need to be ''stored.'' A nontransient malfunction of the wheel sensor, which involves the generation of a wheel speed signal, is typically detected only when the vehicle is moving at a speed exceeding 8 to 10 mph, since a signal is only produced when the wheel rotates at some threshold wheel speed. Therefore, no signal is generated and hence no sensor malfunction is indicated if the vehicle is stationary. As explained in the NPRM and in the previous paragraph, one reason for requiring malfunctions to be stored is to ensure that preexisting malfunctions involving sensors are indicated before the vehicle is driven.

5. Disabling Switch

NHTSA, in response to a rulemaking petition from ATA, proposed in a separate NPRM to allow a switch that a driver could use to turn ''off'' and ''on'' the in-cab malfunction lamp for a vehicle's ABS. (58 FR 50732, September 28, 1993.)

Advocates and vehicle and brake manufacturers strongly opposed the proposal. AAMA, Bosch, and Midland-Grau believed that such a switch would encourage drivers to disable the malfunction indicator of an important safety system, and thus set an undesirable precedent for allowing mechanisms that would disable other vehicle safety systems. These commenters stated that a constant reminder of a malfunction is the best way to inform drivers of a malfunction condition and encourage them to seek a repair of an ABS malfunction. In addition, they claimed that if the switch were used to turn off the malfunction lamp and the ignition remained ''on,'' a relief driver would not necessarily be informed of an ABS malfunction unless the relief driver used the switch to reactivate the malfunction indicator.

ATA, Allied Signal, and fleet operators supported the proposal to allow an optional switch for turning the ABS malfunction indicator off, claiming it would enable the driver to prevent the malfunction indicator from being a distraction, especially at night when the amber light can appear to be excessively bright.

NHTSA recognizes that some drivers view the malfunction indicator as an annoyance and thus might favor having a switch to turn it off. The agency is also aware of isolated cases in the truck tractor ABS fleet study in which malfunction indicators were disabled or taped over. Nevertheless, NHTSA agrees with AAMA and the brake manufacturers that permitting a disabling switch is inconsistent with motor vehicle safety. The information about a malfunction of an important safety system such as an antilock brake system should be communicated to the driver and should not be disregarded. Allowing drivers to turn off the ABS malfunction indicator would reduce the likelihood that a malfunction would be reported and corrected in a timely fashion. Use of such a switch might mask a potential safety problem, since an ABS malfunction could go undetected by the driver, if the disabling switch were activated. Allowing such a switch would also implicitly condone actions by some drivers that disable the malfunction indicator, since the agency would be allowing a disabling switch based on the argument that without a disabling switch drivers would defeat the switch. Moreover, allowing a malfunction indicator to be turned off would be inconsistent with Standard No. 101. Based on the above considerations, NHTSA has decided not to permit an optional disabling switch.

NHTSA notes that ATA's concern about driver distraction may be reduced if the antilock malfunction indicator is dimmed at night. In specifying requirements for the illumination of various controls and displays including the ABS malfunction indicator, Section S5.3.4(b) of Standard No. 101 states that

> The means for providing the required visibility may be adjustable manually or automatically, except that the telltales and identification for brakes, highbeams, turn signals, and safety belts may not be adjustable under any driving condition to a level that is invisible.

Under this provision, an ABS malfunction lamp may be manually or automatically dimmed, provided that it is still visible to the driver. Nevertheless, the agency emphasizes that a malfunction indicator that is not visible to the driver would be prohibited.

6. ABS Failed System Requirements

Section S5.5.1 of Standard No. 121 currently requires that the application and release times of the service brakes not increase when there is an electrical failure in the ABS. In the NPRM, NHTSA proposed removing the word ''electrical.'' That change would prohibit any malfunction in an ABS, whether or not electrical, from increasing the application and release times of the service brakes. The change would also make the requirement applicable to nonelectronic ABSs.

ATA stated that the proposed requirement in Standard No. 121 for failed ABSs would be difficult to meet. It further stated that the failed ABS requirement for heavy vehicles in Standard No. 105 is more reasonable than the proposed requirements in Standard No. 121,[55] since some types of ABS malfunctions in a vehicle with air brakes, such as a leaky valve, could result in an increase in service brake actuation and release times.

NHTSA acknowledges that the proposed failed ABS requirement for heavy vehicles in Standard No. 121 is more stringent than the requirement in Standard No. 105. The agency could resolve this difference by making Standard No. 105 more stringent by deleting the word ''electrical'' or by amending Standard No. 121 to prohibit any change in brake timing in the event of certain, but not all, ABS malfunctions.

After reviewing the alternatives, NHTSA has decided to revise Standard No. 121 to prohibit any change in brake timing in the event of those ABS malfunctions that affect the generation or transmission of response or control signals. The agency believes that this modification will ensure that the brake system reverts to normal braking without antilock control, in the event of such a malfunction in the antilock system. NHTSA notes that this modification parallels the change the agency made to the requirements governing the types of malfunctions that must be indicated by the malfunction lamp. This requirement will not apply to mechanical ABS malfunctions such as sticky valves. While mechanical malfunctions do happen, electrical malfunctions are far more prevalent. The agency believes that simply deleting the word ''electrical'' would have made the requirement too broad and potentially impracticable, while

[55] Section S5.5.2 of Standard No. 105 requires that in the event of any failure in the antilock system, the vehicle must be capable of meeting the stopping distance requirement of 613 feet, as specified for a service brake system partial failure.

leaving the word in without additional changes would make the requirement too narrow.

NHTSA notes that Standard No. 105's stringency cannot be increased in this final rule because the agency did not propose amending that Standard's failed ABS requirements. Nevertheless, the agency may conduct future rulemaking to make Standard No. 105's ABS failed systems requirements more consistent with the requirements in Standard No. 121 and proposed Standard No. 135.

*H. Power Source*

Section S5.5.2 currently permits the power source for trailers equipped with ABSs to be either the stop lamp circuit or a separate electrical circuit specifically provided to power the trailer ABS. In the NPRM, NHTSA proposed that ABSs be required to receive full-time power through a separate circuit, and to have backup powering through the stop lamp circuit. The agency tentatively decided that a full-time power source would be necessary to ensure that adequate power for the trailer's ABS is available, particularly for doubles and triples, and that a driver is aware of any ABS malfunction related to the trailer, since the stop lamp circuit is powered only when brakes are applied.

The commenters had mixed views about whether full-time power for trailer ABSs should be provided through a separate circuit. AAMA, ABS suppliers, TTMA, and Advocates believed that the agency's proposed approach is appropriate and that the industry will be able to develop appropriate voluntary standards through the SAE for electrical circuits or connectors. Upon standardizing with one approach, uniformity would be ensured. Midland-Grau stated that it ''strongly supports'' the agency's proposal for full-time powering for the following reasons:

1. The antilock systems being produced today are very reliable, but only as reliable as the power supply circuit which is supplying power to the antilock system.

2. Having continuous power to the trailer ABS will allow for full-time diagnostics continually updating the driver of the status of the trailer antilock system, and not just during braking.

3. A separate electrical circuit is needed to have adequate and reliable power available should all the solenoids in the control valves be activated in double and triple combinations.

4. To provide incentive to the industry (SAE, TTMA, TMC, etc.) to develop a ''common'' circuit for ABS on trailers, which may or may not ultimately involve a separate connector.

5. To facilitate the use of higher capability trailer antilock systems, along with other electronic systems such as low air pressure, height sensing, and electronic braking.

Midland-Grau further stated that ''Because of cost, most fleets would prefer to power through the stop lamp switch not realizing that they are asking for the ABS reliability problems of the late 1970s to reappear again.''

ATA and fleet operators opposed requiring full-time power for trailer ABSs. ATA stated that this requirement is an untested, unnecessary, and costly burden that NHTSA did not justify on a safety basis. ATA is concerned that a full-time power requirement would result in significant maintenance and reliability problems, basing its claims on the agency's fleet study. ATA also stated that requiring full-time power is premature since the industry is working on multiplexing systems,[56] which, when fully developed and proven, would provide many opportunities for powering accessories on trailers.

In response to the SNPRM, ATA elaborated on its initial comments opposing a requirement that trailer ABSs be electrically powered using a separate electrical circuit. ATA alleged that the requirement could not be justified and that no practicable method had been demonstrated for providing this separate source of power. Specifically, it stated that NHTSA's fleet study did not identify a single electrical powering system that performed in a reliable manner in the test. ATA further stated that it is impermissible for the agency to require a separate dedicated circuit after it had permitted stop signal powering as an option. (57 FR 30911, July 13, 1992.) It claimed that the agency has not justified what it terms a ''proposed rescission of the prior rulemaking decision to allow power through the stop lamp circuit.''

NHTSA has decided to adopt the proposed full-time power requirement for trailer ABSs. The wording of the standard has also been amended to clarify that towing vehicles must have a corresponding separate circuit. By requiring a separate circuit, the agency will ensure the strongest possible source of electrical power from the tractor to ensure the functioning of all the ECUs and modulators that are employed in the antilock brake system, or systems, on single trailers, or multiple trailers and converter dollies in multitrailer combinations. Another important safety justification is that a separate circuit will ensure a continuous malfunction indication whenever a malfunction exists. As noted above, an ABS malfunction indicator powered by a stop lamp circuit would function only when the driver is applying the brakes. During braking, a driver would most likely be concentrating on traffic conditions ahead, and would therefore be less likely to see an ABS malfunction indication on the trailer. However, a driver is more likely to be aware of a trailer ABS malfunction, if the tractor has an in-cab malfunction indicator for the trailer ABS, since a continuous malfunction indication could be more noticeable.

Typically, shared circuits that power other electrical devices besides the trailer ABS, such as stoplamps, cannot provide as much electrical power to the ABS as can a separate circuit dedicated to powering only the trailer ABS. This was demonstrated during the agency's trailer fleet study [57] in which all the alternative approaches that utilized a separate dedicated electrical circuit to power the ABS, (except one approach involving the trailer battery approach, which has been abandoned by the ABS supplier that suggested it), provided higher voltage levels than did the shared stoplamp circuit system approach. The data shown in the table cited in Footnote 33 [58] were for single semitrailer combinations. Voltage levels would have been even lower had doubles or triples combinations been part of the fleet study.

If electrical voltage levels drop below 7–10 volts, an ECU cannot function properly and will automatically shut down. The system will automatically reset itself if sufficient power is once again provided. However, during periods of low power, the ABS will not operate. The likelihood of power dropping below the point at which the trailer ABS shuts down increases as the number of additional stoplamps, or other power draining devices, such as ABS ECUs and modulators, increases.

Trailer ABS systems on a single semitrailer typically consist of one ECU and one or two modulators. A two-trailer combination (i.e., a double) would utilize 3 ECUs and 3 to 6 modulators, while a three-trailer combination (i.e., a triple) would utilize 5 ECUs and 5 to 10 modulators. While the electrical current draw of ECUs is minimal, modulators typically draw 2–2.5 amps each. Depending on a system's configuration, the ABS on a single semitrailer could draw 2–5 amps, that

[56] Multiplexing is the process of combining several measurements for transmission over the same signal path.

[57] Reference Table 3.4, DOT Report No. HS 808 059.

[58] DOT HS 808 059, Table 3.4, page 3–27.

on a doubles combination could draw 6–15 amps, and that on a triple combination 10–25 amps. If a stoplamp circuit of the existing 7-pin cable connector/plug system were used to power the trailer ABS, the current draw of the stop lamp bulbs, added to that of the ABS, would create an overall current draw that could exceed 45 amps on a triples combination. Under such levels of current draw, there is a greatly increased likelihood that the ABS will no longer function on the second and third trailers in a triples combination.

At present, standard industry practice throughout the trucking industry is to provide electrical power for a trailer from the tractor through a cable and connector/plug assembly, the SAE J560 connector. This connector uses a 7-pin configuration, with six power circuits and one common ground. All six power pins are now utilized for one electrical function or another.

Although never directly stated, ATA's comments appear to be based on the premise that NHTSA's proposed requirement for a *separate circuit* is a directive that a *second separate tractor-to-trailer cable and connector/plug system* be used. Such a requirement would preclude the continued exclusive use of a single SAE J560 connector. However, the agency wishes to clarify that a second separate connector is not required. Accordingly, the agency has not specified a set method for providing the separate circuit. The agency intentionally left this choice to the industry in an effort to provide design latitude.

NHTSA notes that there are many alternative ways of providing a separate circuit to power ABS. During the trailer fleet study, the agency evaluated several alternative methods of providing electrical power. To provide a baseline for comparisons with other approaches, the stoplamp circuit of the standard tractor-to-trailer electrical cable/connector supplied power to the trailer ABSs for two of the five participating fleets. For these systems, the ABS received power every time the stoplamps were activated, but received no power when the brakes were not being applied.

In addition, NHTSA evaluated three distinct methods of supplying a constant source of electrical power to trailer ABSs. First, one fleet used a 15-pin ''halo'' cable/connector/plug system (supplied by the Cole Hersee Company,[59] which completely replaced the SAE J560 cable/connector/plug. Two of the additional 8 pins (one for power, the other for a separate ground as well) were used to power the trailer ABSs. Second, another fleet used a second 6-pin connector/plug/cable, with backup power provided by the stoplamp circuit of the SAE J560 connector. Third, another fleet used an auxiliary battery which was mounted on the semitrailer and was charged by electrical power from the semitrailer's refrigeration unit.

NHTSA is studying the SAE J560 stoplamp-circuit-powered approach further, using ABS-equipped LCV combinations (known as Rocky Mountain doubles and triples). This study is part of the joint NHTSA/FHWA operational test program being conducted in response to Section 4007(d) of ISTEA. The basis for wiring these combinations in this manner was not, as ATA suggested in its comments, a decision by the agency that ''* * * there is no safety need for separate new requirements related to the ABSs electrical system.'' Instead, the agency's decision was based on the need to determine the ability of the redundant stoplamp-circuit to provide sufficient electrical power to operate the ABSs on all the trailers and dollies of a triples combination. In this test, the stoplamp circuit was wired in parallel with additional heavy duty wiring to the ABS, in an effort to maximize the possibility of success.

NHTSA evaluated two aspects of the separate connector powering for trailer ABS in its in-service fleet studies: (1) the ability of each approach to provide a robust source of electrical power, through a separate dedicated circuit, to the trailer ABS, and; (2) the durability, reliability, and maintainability of these secondary powering approaches as well as the incremental costs associated with using any of those approaches. With respect to the first point, the data contained in Table 3.4, DOT Report No. HS 808 059, page 3–27 indicate that all but one of the separate connector/separate circuit approaches provided higher voltage levels than did the shared stoplamp-circuit-system approach. The exception was the battery approach which, as previously stated, has been abandoned. NHTSA has concluded that these data justify the requirement for separate circuit powering of ABS.

NHTSA has also concluded that providing a separate source of power to trailers can be done practicably and economically. Regardless of whether a separate circuit or a shared circuit is used to power trailer ABS, ATA and other truck users have stated their preference for only one electrical cable/connector/plug system between tractors and trailers. The principal reason for wanting only one cable/connector is cost. All else being equal, utilizing two connectors would double the truck-user's replacement maintenance costs for these items, regardless of (and separate from) any costs associated with maintaining trailer ABSs by themselves. UPS commented that, on average, it already replaces two entire SAE J560 cable/connectors for each of their 15,791 vehicles each year. TNT Red Star Express fared somewhat better in this regard, reporting that it replaces 1.2 of these connectors per vehicle per year.

In comparison, in NHTSA's fleet study of electrical system maintenance, the agency found that 0.4 SAE J560 cable/connector repairs/replacements were made per vehicle per year. This is a level substantially better than either UPS or TNT reported but, nevertheless twice the repair/replacement rate noted for ABS components (0.2 per vehicle per year). Since the cost of these cables/connectors is less than ABS component part costs, repair/replacement costs were less for these SAE J560 cable/connectors ($0.0002 per mile) than the overall repair replacement costs for all the ABS components ($0.00044 per mile).

ATA commented that the overall cost of ABS-related maintenance would be on the order of 50 percent higher than indicated in the fleet study (i.e., $0.0002 + $0.00044 = $0.00064 per mile), if trailer ABS use necessitated a second tractor-to- trailer cable/connector/plug.

As NHTSA has stated repeatedly, although today's final rule requires a separate *circuit*, it in no way mandates that a second *cable/connector be used. The agency has left the decision to the industry about what approach to use. Moreover, even if the industry decides to use two connectors temporarily or permanently, the agency believes the associated incremental maintenance costs associated with doing so are reasonable.*

NHTSA expects that one of four approaches will be chosen with respect to trailer ABS powering. First, the industry, through the SAE committees that are now considering this issue, could voluntarily settle on a new pin/circuit assignment scheme for the existing SAE J560 connector, thereby ''freeing up'' a dedicated power circuit for the ABS. This approach could involve multiplexing of some signals. Second, the industry could develop and standardize a variant of the SAE J560 connector that is compatible with the existing connector but which provides additional pins/circuits. Third, the industry could develop a totally new connector that will handle present and future tractor-to-trailer powering and signalling/communication needs, and a transition could be made away from the

[59] Herein after referred to as the 15-pin plug.

SAE J560 connector to this new connector. Fourth, the industry could decide to use a separate connector in addition to the existing SAE J560 connector.

NHTSA is aware that the industry, through the SAE and the ATA's Maintenance Council, is actively considering the first three of these alternatives and that prototypes and, in some cases, production versions representing each alternative are currently available and being evaluated. A connector for the fourth approach has been standardized by the International Organization for Standardization (ISO). This connector (ISO 7638) is mandated for ABS connections in Europe, and thus is commercially available and in widespread use. The agency does not wish to hinder industry options in this regard or limit the design development process. Therefore, the agency has not specified the exact method for providing a separate circuit to trailer ABSs. NHTSA notes that hardware for one of these approaches is currently commercially available, and hardware for the other three may evolve within the time period between now and the effective date for implementing trailer ABS. Thus, practicable methods for achieving the separate circuit requirement are currently available, and either market forces or industry consensus is all that is needed to determine which will be the standardized method.

Advocates were concerned that allowing the industry to develop a connector without government regulation could result in several connectors being available, which in turn would lead to incompatibility between tractors and trailers. AAMA stated that it was developing appropriate standards for trailer ABS power supply in cooperation with trailer manufacturers. In addition, SAE is interested in standardizing the ABS power supply.

Based on the available information, NHTSA believes that the industry will decide on an appropriate electrical circuit and standardized connector to meet the proposed full-time power and in-cab malfunction lamp requirements, without the need for a detailed requirement. The agency emphasizes that it is important that the industry standardize on only one approach, to ensure compatibility between towing vehicles and their trailers. If the industry cannot voluntarily agree on a single approach, additional rulemaking may be necessary.

NHTSA is aware that the industry is also working on multiplexing for tractor trailer electrical circuits, which could reduce the number of electrical wires needed for the various systems on the trailer. Nevertheless, multiplexing for combination vehicles is still in the developmental stage for most tractor trailer applications. The agency further notes that requiring that trailer ABSs receive full-time power will not prohibit multiplexing. Therefore, the agency believes that ATA's comments about multiplexing are not relevant.

NHTSA further notes that ATA has misinterpreted the agency's previous 1992 rule to permit powering through either the stop lamp circuit or through a separate circuit. That rulemaking responded to a petition for rulemaking from WABCO, a brake manufacturer, to amend Standard No. 121 to eliminate a design restriction. Specifically, while trailer ABS was required to be powered by the stop lamp signal circuit prior to the amendment, the amendment permitted trailer ABS powering through either the stop lamp signal circuit or a separate circuit. The agency was concerned that the pre-amendment requirement might inhibit the use of some state-of-the-art trailer ABS that have more performance features, but also have higher power requirements. Therefore, contrary to ATA's statements that the agency was acting prematurely thereby preventing the development of multiplexing, the 1992 amendment broadened the flexibility afforded to manufacturers rather than limited it. In the notice adopting that amendment, NHTSA stated that the approach it adopted to remove the design restriction

> will provide truck and trailer manufacturers and operators the flexibility needed to develop and use new trailer ABS systems. By providing such flexibility, the agency anticipates that more vehicle operators will decide to purchase ABS-equipped trailers. This is consistent with the agency's attempt [at that time] to foster voluntary adoption of trailer ABS by avoiding the specification of costly regulations that would act as disincentives for voluntarily equipping trailers and converter dollies with ABS. 57 FR at 30914.

Moreover, in the September 1993 NPRM proposing a full-time power requirement, NHTSA emphasized that the 1992 amendment was issued to ''provide regulatory relief to manufacturers in developing new trailer ABS designs, at a time when trailer ABS was optional'' and that ''the agency would revisit the issue of trailer ABS powering in the context of rulemaking in which trailer ABS would be required.''

Today's final rule culminates precisely the type of rulemaking envisioned in the 1992 notice. In today's final rule mandating that heavy vehicles be equipped with ABSs, the agency is addressing an entirely different situation from the one it was considering in 1992. NHTSA is analyzing how best to ensure safety through a mandatory requirement, not how to encourage the use of an optional safety device.

*I. Applicability of Amendments*

In the NPRM, NHTSA proposed applying the ABS requirements to all vehicles with GVWRs exceeding 10,000 pounds. The agency explained that this proposal went beyond ISTEA's statutory directive for the agency to initiate rulemaking concerning methods for improving braking performance of ''new commercial motor vehicles,'' which are defined as vehicles with a GVWR of 26,001 or more pounds, including truck tractors, trailers, and their dollies.

1. Trailers With Hydraulic or Electric Brakes

Manufacturers of trailers with electric or hydraulic brakes commented that they could not comply with the requirement because ABSs are not available for these types of vehicles.

NHTSA wishes to clarify that the equipment requirement in today's final rule applies to powered heavy vehicles and to air-braked trailers and dollies, but not to trailers equipped with hydraulic or electric brakes. NHTSA notes that no FMVSS addresses vehicles equipped with electric brakes and that Standard No. 105 applies ''to passenger cars, multipurpose passenger vehicles, trucks and buses with hydraulic service brake systems.'' (see S3 ''Application.'') Since electric brakes are not covered by any FMVSS and Standard No. 105 does not cover trailers equipped with hydraulic brakes, today's amendment is not applicable to trailers with these types of brakes. The agency notes, however, that a trailer equipped with an air-over-hydraulic brake system will have to comply with the ABS requirement, since an air-over-hydraulic system is a subsystem of an air-braked system, and is therefore subject to Standard No. 121.

2. Hydraulically Braked Vehicles

NAFA stated that it is premature to mandate ABSs on medium vehicles with a GVWR between 10,000 and 26,000 pounds, claiming that there are no accident or safety data supporting an ABS requirement for these vehicles. In response to both the NPRM and the SNPRM, ATA commented that the agency should not require ABSs on hydraulically braked commercial vehicles until proven ABSs are available. It stated that it is not aware of any proven ABS for hydraulic systems nor of any effort by the government to obtain such systems for fleet tests, which it believed is necessary before mandating such equipment. In response to the SNPRM, UPS stated that this requirement should not be adopted because NHTSA has performed no tests or demonstrations on hydraulically braked vehicles. Moreover, it stated that it is aware of no proven technology that could be applied to satisfy the new NHTSA rule.

Allied Signal and Midland-Grau, two antilock brake system manufacturers, commented on the proposed requirements for ABSs on hydraulically braked heavy vehicles. Allied Signal stated that the technology for ABSs on heavy vehicles is the same as that used on passenger cars and light trucks and should not present significant technological problems. It indicated that some components such as the modulator and ECU are identical or nearly identical to those used in light vehicle applications. In addition, wheel speed sensors for hydraulically braked heavy vehicles incorporate the same technology used in wheel speed sensors for light vehicles and air braked heavy vehicles. Allied Signal commented that the agency's time frame can be achieved with proven technology. (i.e., ABS are increasing in use in this country on vehicles under 10,000 pounds GVWR). Midland-Grau commented that the industry is only about three years away from having ABSs for hydraulic braked single-unit trucks. In response to the SNPRM, AAMA stated that it is optimistic that validated ABSs will be available for all hydraulic vehicles within the proposed time frames. Nevertheless, because the availability of such systems is uncertain, it stated that there may be delays for certain types of hydraulic vehicles if development problems arise.

Based on the available information, NHTSA believes that a March 1999 effective date for requiring antilock brake systems on hydraulic braked single-unit trucks and buses provides sufficient time for vehicle manufacturers and ABS manufacturers to complete the development and testing of these systems. In addition, some Japanese and European manufacturers are currently marketing ABS for medium and large hydraulically braked vehicles. In their comments, brake manufacturers expressed confidence that such antilock systems will be available in this country.

NHTSA notes that ATA and UPS are incorrect in their belief that the agency can only issue a requirement after conducting tests or demonstrations on that specific subcategory of vehicles. Nothing in the Safety Act mandates such specific vehicle testing. Based on comments by vehicle and ABS manufacturers and the positive experience in other countries with ABS-equipped hydraulic vehicles, NHTSA has determined that requiring hydraulic vehicles with ABS is practicable and appropriate. Moreover, the agency notes that manufacturers, which have fully developed antilock systems for hydraulic brakes on passenger cars and light vehicles, will be able to apply the underlying technology (i.e., wheel speed sensors, ECU, and modulators) to heavy vehicles. The agency has provided a lead time of four years to ensure that manufacturers will have sufficient time to develop and test antilock systems for hydraulic braked heavy vehicles.

The agency is aware that Isuzu and Mitsubishi Fuso have marketed hydraulic braked heavy trucks with GVWRs of up to 16,000 pounds, with optional ABS since 1991. The ECU of the hydraulic ABS available on the Isuzu trucks is manufactured by Akebono and the remainder of the system is manufactured by Transtron. The hydraulic ABS on the Mitsubishi Fuso Trucks is manufactured by Japan ABS Co. Mercedes-Benz, offers hydraulic-braked heavy trucks with GVWRs of up to 26,000 pounds, with Bosch's ABS.

Based on this information on the current availability of hydraulic ABS in Europe and Japan and comments by vehicle and ABS manufacturers, NHTSA is confident that there will be sufficient time for the development and testing of reliable antilock brake systems for hydraulically braked vehicles. Accordingly, NHTSA believes that it is appropriate and necessary for motor vehicle safety to require hydraulically-braked vehicles to be equipped with antilock brake systems. Nevertheless, the agency plans to monitor this development closely and could modify the implementation schedule if development of antilock systems for hydraulically braked vehicles faced unexpected development problems.

*J. Implementation*

In the NPRM, NHTSA stated that its goal is to achieve significant improvements in braking performance at a reasonable cost to manufacturers and consumers. The agency proposed the following implementation schedule:

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| Truck Tractors | 2 years after final rule (1996). |
| Trailers, including converter dollies. | 3 years after final rule (1997). |
| Single-unit trucks | 4 years after final rule (1998). |
| Buses | 5 years after final rule (1999). |

NHTSA stated that this implementation schedule was appropriate, given the current state of ABS technology. The agency believed that the schedule would provide the industry, ABS manufacturers, and maintenance personnel sufficient leadtime to prepare for the changes that would be required to accommodate the new technology.

AAMA recommended that the effective dates for the proposed heavy vehicle stability and control requirements and the previously proposed stopping distance requirements be ''synchronized for the various vehicle types.'' [60] AAMA recommended that the agency adopt the following effective dates for both the stability and control requirements and the stopping distance requirements, assuming that the two rules are issued before September 1994:

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|---|---|
| Truck tractors | 2 years after final rule (1996). |
| Trailers, including converter dollies. | 3 years after final rule (1997). |
| Air-braked single-unit trucks and buses. | 3 years after final rule (1997). |
| Hydraulic-braked single-unit trucks and buses. | 4 years after final rule (1998). |

Similarly, HDBMC requested that the implementation schedule for the directional stability and control requirements be accelerated and that the effective dates of this rulemaking and the stopping distance rulemaking be ''made coincident to allow the industry to maximize its efforts by effectively utilizing its limited resources.''

ATA recommended effective dates of December 31, 1999 for tractors and December 31, 2001 for trailers, claiming that this schedule would permit each fleet, through its own tests, to determine which ABS is best suited to its operations and to phase in ABS accordingly. In contrast, Advocates favored the proposed implementation schedule and opposed any schedule that moved the compliance calendar to the next century.

Based on its analysis of these comments, NHTSA issued a SNPRM that proposed the following implementation schedule for both sets of requirements:

[60] On February 23, 1993, NHTSA proposed that the stopping distance requirements take effect two years after the final rule for all applicable vehicles. (58 FR 11009)

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|---|---|
| Truck tractors .......... | 2 years after final rule (1996). |
| Trailers .................... | 3 years after final rule (1997). |
| Air-braked single-unit trucks and buses. | 3 years after final rule (1997). |
| Hydraulic-braked single unit trucks and buses. | 4 years after final rule (1998). |

The agency stated that making the effective dates for the two rulemakings concurrent would facilitate a more orderly implementation process, avoid the need for manufacturers to redesign the brakes on individual vehicles twice, and reduce the development and compliance costs that manufacturers would face as a result of these regulations. NHTSA requested comments about the implementation schedule proposed in the supplemental notice.

AAMA, HDBMC, Ford, GM, White GMC, Bosch, Eaton, Midland-Grau, Allied Signal, Advocates, and Gillig favored the implementation schedule proposed in the SNPRM. AAMA stated that the supplemental proposal would provide a more orderly and cost effective implementation of new requirements, thereby helping to avoid unnecessary redesign and redundant testing. Ford requested that the agency specify that the requirements have September 1 effective dates. Strait-Stop favored keeping the stopping distance requirements separate from the stability and control ones.

ATA favored a phased in implementation schedule under which manufacturers would be required to sell (or consumers would be required to purchase) air braked powered vehicles with at least 25 percent ABS in 1996, 50 percent in 1997, 75 percent in 1998, and 100 percent in 1999. Trailers would have a similar phase-in beginning in 1998. ATA stated that a phase-in is necessary to allow manufacturers the opportunity to offer a wider selection of ABS and to provide time to improve existing systems. Moreover, ATA claimed that a phase-in was essential to users because it would allow experimentation with different systems, thereby increasing public acceptance of the ABS mandate. Similarly, Tramec favored introducing the requirements over a period of time instead of all at once. Eaton cautioned that unforeseen manufacturing problems may impact product quality and availability. Therefore, it stated that a gradual increase in ABS usage would reduce concerns about manufacturer capacity and end-user support abilities.

After reviewing the available information, NHTSA has decided to adopt an implementation schedule similar to the one proposed in the SNPRM. Specifically, truck tractors manufactured on or after March 1, 1997 will have to be equipped with ABS and comply with the braking-in-a-curve test and high coefficient of friction stopping distance requirements; trailers and single-unit air braked trucks and buses manufactured on or after March 1, 1998 will have to be equipped with ABS, and single-unit air braked trucks and buses will also have to comply with the high coefficient of friction stopping distance requirements; and hydraulic braked trucks and buses manufactured on or after March 1, 1999 will have to be equipped with ABS and comply with the high coefficient of friction stopping distance requirements. The agency has decided that these effective dates, which were widely supported by vehicle manufacturers, brake manufacturers, and safety advocacy groups, will provide for an efficient implementation of Congress's desire that NHTSA require heavy vehicles to be equipped with ABSs. This implementation schedule phases in ABS for heavy vehicles over a three-year period. Truck tractors, the vehicle type with the largest potential safety benefit from ABS, are required to comply with the rule first.

This phase-in should facilitate consumer acceptance, since truck tractors, the most standardized type of heavy vehicle, will be subject to the regulation first. Only after this relatively uniform type of vehicle is equipped with ABS, will single unit vehicles which include more niche vehicles (e.g., dump trucks) be required to comply with the regulation?

In deciding on the most appropriate implementation schedule, NHTSA gave serious consideration to ATA's suggestion that the requirements of this rule be phased in on a percentage basis over a four-year period. However, for the reasons set forth below, NHTSA has determined that the implementation schedule being adopted in today's final rule will provide the most benefits in the most cost effective manner. The agency emphasizes that adopting ATA's recommended phase-in would have resulted in needless and protracted delay, thereby resulting in a significantly less safe highway environment.

Such a delay is unnecessary given the current state of development for ABS. At the time of publication of this final rule, six of the seven major U.S. manufacturers of heavy trucks, Freightliner Corporation, Peterbilt Motors Corporation, Kenworth Truck Company, Ford Motor Company, Mack Corporation, and Navistar International Corporation, have publicly announced that some or all of their product line of truck tractors, and in some cases single-unit trucks, will be equipped with ABS, as standard equipment, beginning with the 1995 model year. For heavy vehicle manufacturers, that model year began the summer of 1994. Thus, it appears that the marketplace has already addressed ATA's concern that manufacturers cannot meet increasing market demand for ABS. Also, manufacturers are typically warranting ABS for 300,000 miles or three years, a fact that should allay ATA's concerns that manufacturers will not support their product offerings.

NHTSA further notes that the final rule includes a phase-in requirement in which the vehicles for which braking stability is the greatest concern (truck tractors and trailers) are required to be equipped with ABS first. Single-unit trucks and buses follow at a later date. This will facilitate vehicle manufacturers' efforts to engineer these systems into their entire line of product offerings over a period of time spanning four years, instead of having to do it all in one year. This should substantially reduce burdens on manufacturers and give them sufficient time to engineer and accomplish high quality installations of ABS, which is a major concern of ATA.

*K. Intermediate and Final Stage Manufacturers/Trailer Manufacturers*

In the NPRM, NHTSA provided an extensive discussion about the potential effect of the proposed requirements on intermediate, final stage, and trailer manufacturers. The agency explained that it is aware of the concerns of final stage and intermediate stage manufacturers about road testing their vehicles. In particular, the agency explained how an incomplete vehicle manufacturer could pass through certification to the final stage manufacturer and how a final stage manufacturer could certify compliance with the proposed requirements.

NTEA commented that many of its members, most of whom are final stage manufacturers of vehicles produced in two or more stages, would not be able to use the pass-through certification because it believed that the guidelines provided by the incomplete vehicle manufacturer would be very restrictive. NTEA stated that these final stage manufacturers would, therefore, have no practicable and objective means of demonstrating compliance with the braking-in-a-curve requirement because they have neither the financial nor engineering resources to conduct their own compliance testing. NTEA therefore requested that the agency exclude from this requirement all ''multi-staged produced vehicles that are equipped with a cargo-carrying body or work-related equipment.'' Likewise, Midland-Grau stated that final stage manufacturers do not have the resources to certify their vehicles, and believed that it would be difficult for chassis manufacturers to establish comprehensive guidelines for final stage manufacturers to follow. AM General commented that small vehicle manufacturers will face undue burdens, and suggested that the rulemaking be limited to only Class 7 and 8 vehicles (which are the largest heavy vehicles, typically truck tractors over 26,000 pounds).

As explained above, NHTSA has decided to apply the braking-in-a-curve test only to truck tractors at this time. These vehicles are manufactured almost exclusively by large, single stage manufacturers. This final rule does not require manufacturers of single-unit vehicles and trailers, such as NTEA's members, to establish compliance with today's amendments through road testing. While incomplete single unit vehicles and trailers will have to be equipped with ABSs, the final stage and trailer manufacturers can ensure the presence of the equipment on their vehicles and can reasonably rely on a brake manufacturer's assurances that its ABS complies with the standard. Specifically, certification of compliance with the equipment requirement for ABS does not necessitate road testing.

Nothing in the preceding discussion should be understood as indicating that the agency agrees with NTEA's comment that it would be impracticable for a final stage manufacturer to certify compliance with the braking-in-a-curve test. As explained in the NPRM, while a manufacturer must certify that its vehicles meet all applicable safety standards, a manufacturer need not necessarily conduct the specific tests set forth in an applicable standard. Certifications may be based on, among other things, engineering analyses, actual testing, and computer simulations. Moreover, a manufacturer need not conduct these operations itself. A manufacturer can utilize the services of independent engineers and testing laboratories. It can also join together with other manufacturers through trade associations to sponsor testing or analysis. Finally, it can rely on testing and analysis performed by other parties, including the brake manufacturers.

*L. Benefits*

As detailed in the FRE, NHTSA estimates that the use of ABS on all heavy vehicles will help prevent between 320 and 506 fatalities, between 15,900 and 27,413 injuries, and between $458 million and $553 million of property damage each year. Based on its evaluation, NHTSA believes that the rulemaking is cost beneficial since a significant number of crashes resulting in fatalities and property damage will be prevented by this rulemaking.

In its comments, ATA questioned NHTSA's benefit analysis, arguing that recent accident data analyses have indicated that ABS on passenger cars does not result in significant reductions in crashes. The agency believes that it is neither appropriate nor possible to project effectiveness estimates for ABS, or for that matter, other safety equipment/features from one type of vehicle to another. As ATA is aware, vehicle loading characteristics for heavy vehicles differ significantly from those of passenger cars. Although the study upon which NHTSA based its benefit estimates did not specifically analyze whether heavy vehicles equipped with ABS have statistically lower accident rates, the results of that study carefully analyzed and reconstructed heavy vehicle crashes to estimate the likely benefit of ABS. The agency believes that its benefit analysis accurately estimates the benefits of heavy vehicle ABS.

ATA also argues that ''the presence of ABS did not lead to a reduction in the accident rate, since in NHTSA's tractor fleet study, the proportion of crashes involving ABS-equipped tractors is the same as their proportion of the total fleet. NHTSA disagrees with this contention. The agency's fleet studies of ABS were never intended to result in estimates of the safety benefit of ABS. The total number of crashes that occurred during the tractor fleet study, fourteen, is too small to draw any statistically significant conclusions about the relative safety of ABS-equipped versus non-ABS-equipped vehicles.

*M. Costs*

In the ANPRM, NHTSA estimated that the unit cost to a manufacturer for a complete six-channel ABS installed on a 6 x 4 tractor would be approximately $1400 or approximately $1100 for a full Select Low ABS. It estimated that the unit cost to a manufacturer to install ABS on a trailer would be $900.

In response to comments to the ANPRM, NHTSA reevaluated its initial cost estimates to include several additional components including the wiring harnesses, mounting hardware, and in-cab warnings. As the Preliminary Regulatory Impact Analysis (PRIA) explained in detail, the agency estimated that the unit cost for a vehicle purchaser to comply with the proposed requirements (including the connectors and cables that provide full-time power) would be approximately $2900 for the average truck tractor, $2350 for the average single-unit truck and bus, $1850 for a non-towing trailer, $1700 for a towing trailer, and $1475 for a trailer converter dolly. Based on these estimates of consumer costs and estimated annual production of 137,000 truck tractors, 160,000 single unit trucks and school buses, and 7000 transit and intercity buses, the agency estimated that the annual costs for these vehicles would be $790 million. For trailers, these consumer cost estimates together with an annual production of 115,000 non-towing trailers, 32,000 towing trailers, and 3,000 trailer converter dollies yields an estimated annual cost of $272 million.

Since the preparation of the PRIA, NHTSA has completed a detailed engineering process-cost analysis study in which antilock braking systems from three ABS manufacturers were evaluated. The cost evaluation entailed a physical tear-down of the system, in which the cost of each part was determined based on the actual manufacturing process used in its production. The study estimated the weight and various costs related to the production and installation of three 4S/4M tractor ABS, each from a different ABS manufacturer, and three different trailer ABS configurations, a 6S/3M, a 4S/2M and a 2S/1M, each from a different manufacturer. Based on that cost information, the agency estimates that the cost for the minimum ABS needed to comply with the requirements in this amendment would be: $749.33 for a truck tractor, $682.51 for a single-unit truck, and $439.64 for a trailer. Separate analyses estimated the cost and weight of tractor-to-trailer connectors/cables and related wiring ($93.97 for a truck tractor, $39.52 for a non-towing trailer, and $133.49 for a towing trailer or trailer converter dolly), and of in-cab ABS malfunction indicator lamps (MIL) for tractors and trailer-mounted ABS MILs for trailers ($13.66 for a truck tractor, $9.47 for a single-unit truck, and $9.43 for a trailer). The total estimated cost to the vehicle purchaser is estimated to be: $856.96 for a truck tractor, $691.98 for a single-unit truck or bus, $488.59 for a non-towing trailer, and $582.56 for a towing trailer or trailer converter dolly. Based on these estimates of increased cost to the vehicle purchaser and estimated annual production of 147,600 truck tractors, 248,300 single unit trucks and school buses, and 7000 transit and intercity buses, the agency estimates that the annual costs for these vehicles would be $303 million. For trailers and trailer converter dollies, these estimates of increased cost to the vehicle purchaser together with an annual production of 139,400 non-towing trailers, 46,700 towing trailers, and 2,900 trailer converter dollies yields an estimated annual cost of $97 million. Therefore, the agency estimates that the total annual increased cost for equipping heavy vehicles with ABS will be $400 million.

Along with estimating the cost increases to the new vehicle purchaser, NHTSA also estimated the increases in the cost of operating heavy vehicles equipped with ABS. Three categories of operating costs were examined: lifetime maintenance costs, lifetime fuel costs due to the additional weight of the ABS, and lifetime revenue loss due to payload displacement. The range of the increase in total lifetime operating costs related to equipping heavy vehicles with ABS is from $201.47 to $786.65. Since the estimates for these various operating costs are dependent upon the type of fuel used for powered vehicles and on the estimated lifetime vehicle miles travelled (VMT) for the various vehicle types, the heavy vehicles were divided into 18 different fuel type/VMT categories. The total estimated increase in vehicle operating costs associated with ABS for all heavy vehicles is $232 million. The reader is referred to the FEA for a detailed discussion of the costs for these different categories.

In its comments, ATA questioned NHTSA's portrayal of the increases in vehicle maintenance costs as not being significant compared to overall cost of maintaining the air brake system on heavy vehicles. ATA did not, however, question the actual increased maintenance cost per mile estimates derived from the agency's fleet studies. It is these estimates of the increased maintenance cost per mile that were used in estimating the total cost impact of this rulemaking and determining that the amendment is cost effective. As such, the agency believes that the relative increase in vehicle maintenance that would result in different fleets is not the important factor in evaluating the impact of this Final Rule.

## IX. Rulemaking Analyses and Notices

### *A. Executive Order 12866 and DOT Regulatory Policies and Procedures*

NHTSA has considered the impacts of this rulemaking action and determined that it is ''significant'' within the meaning of the Department of Transportation's regulatory policies and procedures. In addition, the Office of Management and Budget has determined that it is ''significant'' within the meaning of Executive Order 12866. The agency has prepared a Final Economic Assessment describing the economic and other effects of this rulemaking action. Summary discussions of those effects are provided above. For persons wishing to examine the full analysis, a copy is being placed in the docket.

### *B. Regulatory Flexibility Act*

NHTSA has also considered the effects of this rulemaking action under the Regulatory Flexibility Act. I hereby certify that it will not have a significant economic impact on a substantial number of small entities. Accordingly, the agency has not prepared a final regulatory flexibility analysis.

The primary cost effect of the requirements will be on manufacturers of heavy vehicles which are generally large businesses. However, final stage manufacturers are generally small businesses. A detailed discussion about the anticipated economic impact on these businesses is provided in the FRIA.

### *C. 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.

### *D. Executive Order 12612 (Federalism)*

NHTSA has analyzed this action under the principles and criteria in Executive Order 12612. The agency has determined that this notice does not have sufficient Federalism implications to warrant the preparation of a Federalism Assessment. No State laws will be affected.

### *E. Civil Justice Reform*

This final rule does not have any retroactive effect. Under 49 U.S.C. 30103, whenever a Federal motor vehicle safety standard is in effect, a State may not adopt or maintain a safety standard applicable to the same aspect of performance which is not identical to the Federal standard, except to the extent that the State requirement imposes a higher level of performance and applies only to vehicles procured for the State's use. 49 U.S.C. 30161 sets forth a procedure for judicial review of final rules establishing, amending or revoking Federal motor vehicle safety standards. That section does not require submission of a petition for reconsideration or other administrative proceedings before parties may file suit in court.

## List of Subjects in 49 CFR Part 571

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

In consideration of the foregoing, the agency is amending Section 571.3, Standard No. 101, *Controls and Displays*, Standard No. 105, *Hydraulic Brake Systems* and Standard No. 121, *Air Brake Systems*, in Title 49 of the Code of Federal Regulations at Part 571 as follows:

## PART 571—[AMENDED]

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

**Authority:** 49 U.S.C. 322, 30111, 30115, 30117, and 30166, delegation of authority at 49 CFR 1.50.

2. Part 571.3 is amended in paragraph (b) to add a definition of ''Full Trailer'' as follows:

### § 571.3 Definitions.

* * * * *

*Full trailer* means a trailer, except a pole trailer, that is equipped with two or more axles that support the entire weight of the trailer.

* * * * *

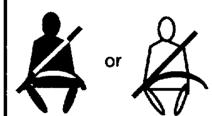
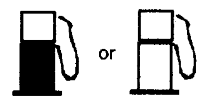
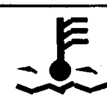
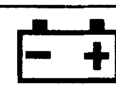
3. In § 571.101, Table 2 is revised to appear as follows:

### § 571.101 Standard No. 101; Controls and Displays.

* * * * *

BILLING CODE 4910–59–P

## Table 2
## Identification and Illustration of Displays

| Column 1 | Column 2 | Column 3 | Column 4 | Column 5 |
|---|---|---|---|---|
| *Display* | *Telltale Color* | *Identifying Words or Abbreviation* | *Identifying Symbol* | *Illumination* |
| Turn Signal Telltale | Green | Also see FMVSS 108 |  [1] [6] | ——— |
| Hazard Warning Telltale | | Also see FMVSS 108 |  [2] [6] | ——— |
| Seat Belt Telltale | ———[7] | Fasten Belts or Fasten Seat Belts Also see FMVSS 208 |  | ——— |
| Fuel Level Telltale | | Fuel |  | ——— |
| Gauge | ——— | | | Yes |
| Oil Pressure Telltale | | Oil |  | ——— |
| Gauge | ——— | | | Yes |
| Coolant Temperature Telltale | | Temp |  | ——— |
| Gauge | ——— | | | Yes |
| Electrical Charge Telltale | | Volts, Charge or Amp |  | ——— |
| Gauge | ——— | | | Yes |
| Highbeam Telltale | Blue or Green [4] | Also see FMVSS 108 |  [6] | ——— |
| Brake System [8] | Red [4] | Brake, Also see FMVSS 105 & 135 | ——— | ——— |
| Malfunction in Anti-Lock or | Yellow | Antilock, Anti-lock, or ABS. Also see FMVSS 105 & 135 | ——— | ——— |
| Variable Brake Proportioning System [8] | Yellow | Brake Proportioning Also see FMVSS 135 | ——— | ——— |
| Parking Brake Applied [8] | Red [4] | Park or Parking Brake Also see FMVSS 105 & 135 | ——— | ——— |
| Malfunction in Antilock | Yellow | ABS, or Antilock; Trailer ABS, or Trailer Antilock. Also see FMVSS 121 | ——— | ——— |
| Brake Air Pressure Position Telltale | | Brake Air, Also see FMVSS 121 | ——— | ——— |
| Speedometer | ——— | MPH [5] | ——— | Yes |
| Odometer | ——— | ———[3] | ——— | ——— |
| Automatic Gear Position | ——— | Also see FMVSS 102 | ——— | Yes |

[1] The pair of arrows is a single symbol. When the indicator for left and right turn operate independently, however, the two arrows will be considered separate symbols and may be spaced accordingly.
[2] Not required when arrows of turn signal tell-tales that otherwise operate independently flash simultaneously as hazard warning telltale.
[3] If the odometer indicates kilometers, then "KILOMETERS" or "km" shall appear, otherwise, no identification is required.
[4] Red can be red-orange. Blue can be blue-green.
[5] If the speedometer is graduated in miles per hour and in kilometers per hour, the identifying words or abbreviations shall be "MPH and km/h" in any combination of upper or lower case letters.
[6] Framed areas may be filled.
[7] The color of the telltale required by S4.5.3.3 of Standard No 208 is red; the color of the telltale required by S7.3 of Standard No. 208 is not specified.
[8] In the case where a single telltake indicates more than one brake system condition, the word for Brake System shall be used.

MVSS Tables–Jobs 2b Disk

BILLING CODE 4910–59–C

* * * * *

4. Section 571.105 is amended in S4 by removing the definition of ''Antilock system'' and by adding the definitions of ''Antilock brake system,'' ''Directly controlled wheel,'' ''Indirectly controlled wheel,'' and ''Peak friction coefficient;'' by revising S5.1, S5.3, S5.3.1(c), S5.3.3; and S5.5; and adding S5.3.3(a), S5.3.3(b), S5.5.1 and S5.5.2 to read as follows:

**§ 571.105 Standard No. 105, hydraulic brake systems.**

* * * * *

*Antilock brake system* or *ABS* means a portion of a service brake system that automatically controls the degree of rotational wheel slip during braking by:

(1) Sensing the rate of angular rotation of the wheels;

(2) Transmitting signals regarding the rate of wheel angular rotation to one or more controlling devices which interpret those signals and generate responsive controlling output signals; and

(3) Transmitting those controlling signals to one or more modulators which adjust brake actuating forces in response to those signals.

* * * * *

*Directly Controlled Wheel* means a wheel at which the degree of rotational wheel slip is sensed and corresponding signals are transmitted to one or more modulators that adjust the brake actuating forces at that wheel. Each modulator may also adjust the brake actuating forces at other wheels in response to the same signal[s].

* * * * *

*Indirectly Controlled Wheel* means a wheel at which the degree of rotational wheel slip is not sensed, but at which the modulator of an antilock braking system adjusts its brake actuating forces in response to signals from one or more sensed wheels.

* * * * *

*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.

* * * * *

S5.1 *Service brake systems.* Each vehicle shall be equipped with a service brake system acting on all wheels. Wear of the service brake shall be compensated for by means of a system of automatic adjustment. Each passenger car and each multipurpose passenger vehicle, truck, and bus with a GVWR of 10,000 pounds or less shall be capable of meeting the requirements of S5.1.1 through S5.1.6 under the conditions prescribed in S6, when tested according to the procedures and in the sequence set forth in S7. Each school bus with a GVWR greater than 10,000 pounds shall be capable of meeting the requirements of S5.1.1 through S5.1.5 under the conditions prescribed in S6, when tested according to the procedures and in the sequence set forth in S7. Each multipurpose passenger vehicle, truck, and bus (other than a school bus) with a GVWR greater than 10,000 pounds shall be capable of meeting the requirements of S5.1.1, S5.1.2, and S5.1.3 under the conditions prescribed in S6, when tested according to the procedures and in the sequence set forth in S7. Except as noted in S5.1.1.2 and S5.1.1.4, if a vehicle is incapable of attaining a speed specified in S5.1.1, S5.1.2, S5.1.3, or S5.1.6, its service brakes shall be capable of stopping the vehicle from the multiple of 5 mph that is 4 to 8 mph less than the speed attainable in 2 miles, within distances that do not exceed the corresponding distances specified in Table II. If a vehicle is incapable of attaining a speed specified in S5.1.4 in the time or distance interval set forth, it shall be tested at the highest speed attainable in the time or distance interval specified.

* * * * *

S5.3 *Brake system indicator lamp.* Each vehicle shall have a brake system indicator lamp or lamps, mounted in front of and in clear view of the driver, which meet the requirements of S5.3.1 through S5.3.5. A vehicle with a GVWR of 10,000 pounds or less may have a single common indicator lamp. A vehicle with a GVWR of greater than 10,000 pounds may have an indicator lamp which is common for gross loss of pressure, drop in the level of brake fluid, or application of the parking brake, but shall have a separate indicator lamp for antilock brake system malfunction. However, the options provided in S5.3.1(a) shall not apply to a vehicle manufactured without a split service brake system; such a vehicle shall, to meet the requirements of S5.3.1(a), be equipped with a malfunction indicator that activates under the conditions specified in S5.3.1(a)(4). This warning indicator shall, instead of meeting the requirements of S5.3.2 through S5.3.5, activate (while the vehicle remains capable of meeting the requirements of S5.1.2.2 and the ignition switch is in the ''on'' position) a continuous or intermittent audible signal and a flashing warning light, displaying the words ''STOP-BRAKE FAILURE'' in block capital letters not less than one-quarter of an inch in height.

* * * * *

S5.3.1 * * *

(c) A malfunction that affects the generation or transmission of response or control signals in an antilock brake system, or a total functional electrical failure in a variable proportioning brake system.

* * * * *

S5.3.3 (a)Each indicator lamp activated due to a condition specified in S5.3.1 shall remain activated as long as the malfunction exists, whenever the ignition (start) switch is in the ''on'' (run) position, whether or not the engine is running.

(b) For vehicles with a GVWR greater than 10,000 pounds, each message about the existence of a malfunction in an antilock brake system shall be stored after the ignition switch is turned to the ''off'' position and automatically reactivated when the ignition switch is turned to the ''on'' position. The indicator lamp shall also be activated as a check of lamp function whenever the ignition is turned to the ''on'' (run) position. The indicator lamp shall be deactivated at the end of the check of the lamp function unless there is a malfunction or a message about a pre-existing malfunction.

* * * * *

S5.5. *Antilock and Variable Proportioning Brake Systems.*

S5.5.1 Each vehicle with a GVWR greater than 10,000 pounds, except for any vehicle that has a speed attainable in 2 miles of not more than 33 mph, shall be equipped with an antilock brake system that directly controls the wheels of at least one front axle and the wheels of at least one rear axle of the vehicle. Wheels on other axles of the vehicle may be indirectly controlled by the antilock brake system.

S5.5.2 In the event of any failure (structural or functional) in an antilock or variable proportioning brake system, the vehicle shall be capable of meeting the stopping distance requirements specified in S5.1.2 for service brake system partial failure.

* * * * *

**§ 571.121 Standard No. 121, air brake systems.**

5. Section 571.121 is amended in S4 by removing the definitions of ''Antilock system'' and ''skid number'' and by adding the definitions of ''Antilock brake system,'' ''Directly Controlled Wheel,'' ''Full-treadle brake application,'' ''Independently Controlled Wheel,'' ''Indirectly Controlled Wheel,'' ''Maximum drive-

through speed,'' ''Peak friction coefficient;'' by revising S5.1.6 and adding S5.1.6.1, S5.1.6.2, and S5.1.6.3; by adding S5.2.3, S5.2.3.1, S5.2.3.2, and S5.2.3.3; by revising S5.3; by adding S5.3.6, S5.3.6.1, and S5.3.6.2; by revising S5.5.1, S5.5.2, S6.1.7, S6.1.10, S6.1.10.2, S6.1.10.3, and S6.1.10.4; by removing and reserving S6.1.10.1; by removing S6.1.10.5, S6.1.10.6, and S6.1.10.7, and by adding S6.1.15 to read as follows:

**§ 571.121 Standard No. 121; air brake systems.**

* * * * *

*Antilock Brake System* or *ABS* means a portion of a service brake system that automatically controls the degree of rotational wheel slip during braking by:

(1) Sensing the rate of angular rotation of the wheels;

(2) Transmitting signals regarding the rate of wheel angular rotation to one or more controlling devices which interpret those signals and generate responsive controlling output signals; and

(3) Transmitting those controlling signals to one or more modulators which adjust brake actuating forces in response to those signals.

* * * * *

*Directly Controlled Wheel* means a wheel at which the degree of rotational wheel slip is sensed and corresponding signals are transmitted to one or more modulators that adjust the brake actuating forces at that wheel. Each modulator may also adjust the brake actuating forces at other wheels in response to the same signal[s].

* * * * *

*''Full-treadle brake application''* means a brake application in which the treadle valve pressure in any of the valve's output circuits reaches 100 psi within 0.2 seconds after the application is initiated.

* * * * *

*Independently Controlled Wheel* means a directly controlled wheel for which the modulator does not adjust the brake actuating forces at any other wheel on the same axle.

* * * * *

*Indirectly Controlled Wheel* means a wheel at which the degree of rotational wheel slip is not sensed, but at which the modulator of an antilock braking system adjusts its brake actuating forces in response to signals from one or more sensed wheel(s).

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*''Maximum drive-through speed''* means the highest possible constant speed at which the vehicle can be driven through 200 feet of a 500-foot radius curve arc without leaving the 12-foot lane.

* * * * *

*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.

* * * * *

S5.1.6 *Antilock Brake System.*

S5.1.6.1(a) Each single-unit vehicle manufactured on or after March 1, 1998 shall be equipped with an antilock brake system that directly controls the wheels of at least one front axle and the wheels of at least one rear axle of the vehicle. Wheels on other axles of the vehicle may be indirectly controlled by the antilock brake system.

S5.1.6.1(b) Each truck tractor manufactured on or after March 1, 1997 shall be equipped with an antilock brake system that directly controls the wheels of at least one front axle and the wheels of at least one rear axle of the vehicle, with the wheels of at least one axle being independently controlled. Wheels on other axles of the vehicle may be indirectly controlled by the antilock brake system. A truck tractor shall have no more than three wheels controlled by one modulator.

S5.1.6.2 *Antilock Malfunction Circuit and Signal.*

(a) Each truck tractor manufactured on or after March 1, 1997 and each single unit vehicle manufactured on or after March 1, 1998 shall be equipped with an electrical circuit that is capable of signalling a malfunction that affects the generation or transmission of response or control signals in the vehicle's antilock brake system.

(b) Each truck tractor manufactured on or after March 1, 1997 and each single unit vehicle manufactured on or after March 1, 1998 shall have 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 the response or control signals in an antilock brake system. The indicator lamp shall remain activated as long as the malfunction exists, whenever the ignition (start) switch is in the ''on'' (run) position, whether or not the engine is running. Each message about the existence of a malfunction in an antilock brake system shall be stored after the ignition switch is turned to the ''off'' position and automatically reactivated when the ignition switch is turned to the ''on'' position. The indicator lamp shall also be activated as a check of lamp function whenever the ignition is turned to the ''on'' or ''run'' position. The indicator lamp shall be deactivated at the end of the check of lamp function unless there is a malfunction or a message about a pre-existing malfunction.

(c) Each truck tractor manufactured on or after March 1, 1997 and each single unit vehicle manufactured on or after March 1, 1998 that is equipped to tow another air-braked vehicle, shall be equipped with an electrical circuit that is capable of transmitting information about a malfunction in the antilock brake system on one or more towed vehicle(s) (e.g., trailer(s) and dolly(ies)). Each such vehicle shall also be equipped with an indicator lamp, mounted in front of and in clear view of the driver, capable of receiving, from one or more antilock equipped towed vehicle(s), information transmitted about a malfunction of a towed vehicle's antilock system and then activating the indicator lamp when there is a malfunction in the towed vehicle's antilock brake system. The indicator lamp shall remain activated as long as the malfunction exists, whenever the ignition (start) switch is in the ''on'' (run) position, whether or not the engine is running. The indicator lamp shall also be activated as a check of lamp function whenever the ignition is turned to the ''on'' or ''run'' position. The indicator lamp shall be deactivated at the end of the check of lamp function unless there is a malfunction or a message about a pre-existing malfunction.

S5.1.6.3 *Antilock Power Circuit for Towed Vehicles.* Each truck tractor manufactured on or after March 1, 1997 and each single unit vehicle manufactured on or after March 1, 1998 that is equipped to tow another air-braked vehicle shall be equipped with one or more separate electrical circuits, specifically provided to power the antilock system on the towed vehicle(s). Such a circuit shall be adequate to enable the antilock system on each towed vehicle to be fully operable.

* * * * *

S5.2.3 *Antilock Brake System.*

S5.2.3.1(a) Each semitrailer (including a trailer converter dolly) manufactured on or after March 1, 1998 shall be equipped with an antilock brake system that directly controls the wheels of at least one axle of the vehicle. Wheels on other axles of the vehicle may be indirectly controlled by the antilock brake system.

(b) Each full trailer manufactured on or after March 1, 1998 shall be equipped with an antilock brake system that directly controls the wheels of at least one front axle of the vehicle and at least one rear axle of the vehicle. Wheels on other axles of the vehicle may be indirectly controlled by the antilock brake system.

S5.2.3.2 *Antilock Malfunction Circuit and Signal.* Each trailer (including a trailer converter dolly) manufactured on or after March 1, 1998 that is equipped with an antilock brake system shall be equipped with an electrical circuit that is capable of signalling a malfunction in the trailer antilock brake system, and shall comply with the requirements of S5.2.3.3. A trailer manufactured on or after March 1, 1998 that is not designed to tow another air brake equipped trailer shall have the means for connection of the antilock malfunction signal circuit and ground, at the front of the trailer. A trailer manufactured on or after March 1, 1998 that is designed to tow another air brake equipped trailer shall be capable of transmitting a malfunction signal from the antilock systems of additional trailers in a combination and shall have means for the connection of the antilock malfunction signal circuit and ground, at both the front and rear of the trailer. Each message about the existence of a malfunction in an antilock brake system shall be stored whenever power is no longer supplied to the system. The indicator lamp shall also be activated as a check of lamp function whenever power is supplied to the antilock brake system. The indicator lamp shall be deactivated at the end of the check of lamp function unless there is a malfunction or a message about a pre-existing malfunction.

S5.2.3.3 *Antilock Malfunction Indicator.* Each trailer (including a trailer converter dolly) manufactured on or after March 1, 1998 and before March 1, 2006 shall be equipped with a lamp indicating a malfunction of a trailer's antilock brake system. Such a lamp shall remain activated as long as the malfunction exists whenever the power is supplied to the antilock brake system. The display shall be visible within the driver's forward field of view through the rearview mirror(s), and shall be visible once the malfunction is present and power is provided to the system.

* * * * *

S5.3 *Service Brakes—road tests.* The service brake system on each truck tractor manufactured before March 1, 1997 shall, under the conditions of S6, meet the requirements of S5.3.3 and S5.3.4, when tested without adjustments other than those specified in this standard. The service brake system on each truck tractor manufactured on or after March 1, 1997 shall, under the conditions of S6, meet the requirements of S5.3.1, S5.3.3, S5.3.4, and S5.3.6, when tested without adjustments other than those specified in this standard. The service brake system on each bus and truck (other than a truck tractor) manufactured before March 1, 1998 shall, under the conditions of S6, meet the requirements of S5.3.3, and S5.3.4, when tested without adjustments other than those specified in this standard. The service brake system on each bus and truck (other than a truck tractor) manufactured on or after March 1, 1998 shall, under the conditions of S6, meet the requirements of S5.3.1, S5.3.3, and S5.3.4 when tested without adjustments other than those specified in this standard. The service brake system on each trailer shall, under the conditions of S6, meet the requirements of S5.3.3, S5.3.4, and S5.3.5 when tested without adjustments other than those specified in this standard. However, a heavy hauler trailer and the truck and trailer portions of an auto transporter need not meet the requirements of S5.3.

* * * * *

S5.3.6 *Stability and Control During Braking—Truck Tractors.* When stopped three consecutive times for each combination of weight, speed, and road condition specified in S5.3.6.1 and S5.3.6.2, each truck tractor manufactured on or after March 1, 1997 shall stop each time within the 12-foot lane, without any part of the vehicle leaving the roadway.

S5.3.6.1 Using a full-treadle brake application, stop the vehicle from 30 mph or 75% of the maximum drive-through speed, whichever is less, on a 500-foot radius curved roadway with a wet level surface having a peak friction coefficient of 0.5 when measured using an American Society for Testing and Materials (ASTM) E1136 standard reference test tire, in accordance with ASTM Method E1337–90, at a speed of 40 mph, with water delivery.

S5.3.6.2 Stop the vehicle with the vehicle

(a) loaded to its GVWR, and

(b) at its unloaded weight plus up to 500 pounds (including driver and instrumentation), or at the manufacturer's option, at its unloaded weight plus up to 500 pounds (including driver and instrumentation) and plus not more than an additional 1000 pounds for a roll bar structure on the vehicle.

* * * * *

S5.5.1 *Antilock System Malfunction.* On a truck tractor manufactured on or after March 1, 1997 and a single unit vehicle manufactured on or after March 1, 1998 that is equipped with an antilock brake system, a malfunction that affects the generation or transmission of response or control signals of any part of the antilock system shall not increase the actuation and release times of the service brakes.

* * * * *

S5.5.2 *Antilock System Power—Trailers.* On a trailer (including a trailer converter dolly) manufactured on or after March 1, 1998 that is equipped with an antilock system that requires electrical power for operation, the power shall be obtained from one or more separate electrical circuits specifically provided to power the trailer antilock system. The antilock system shall automatically receive power from the stop lamp circuit, if the separate power circuit or circuits are not in use. Each trailer (including a trailer converter dolly) manufactured on or after March 1, 1998 that is equipped to tow another air-braked vehicle shall be equipped with one or more separate electrical circuits specifically provided to power the antilock system on the towed vehicle(s). Such circuits shall be adequate to enable the antilock system on each towed vehicle to be fully operable.

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S6.1.7 Unless otherwise specified, stopping tests are conducted on a 12-foot wide level, straight roadway having a peak friction coefficient of 0.9. For road tests in S5.3, the vehicle is aligned in the center of the roadway at the beginning of a stop. Peak friction coefficient is measured using an ASTM E1136 standard reference test tire in accordance with ASTM method E1337–90, at a speed of 40 mph, without water delivery for the surface with PFC of 0.9, and with water delivery for the surface with PFC of 0.5.

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S6.1.10 In a test other than a static parking test, a truck tractor is tested at its GVWR by coupling it to an unbraked flatbed semi-trailer (hereafter, control trailer) as specified in S6.1.10.2 to S6.1.10.4.

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S6.1.10.1 [RESERVED]

S6.1.10.2 The center of gravity height of the ballast on the loaded control trailer shall be less than 24 inches above the top of the tractor's fifth wheel.

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S6.1.10.3 The control trailer has a single axle with a gross axle weight rating 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.

S6.1.10.4 The control trailer is loaded so that its axle is loaded at 4,500 pounds and the tractor is loaded to its GVWR, loaded above the kingpin only, with the tractor's fifth wheel adjusted so that the load on each axle measured at the tire-ground interface is most nearly proportional to the axles' respective GAWRs, without exceeding the GAWR of the tractor's axle or axles or control trailer's axle.

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S6.1.15 *Initial Brake Temperature.* Unless otherwise specified, the initial brake temperature is not less than 150 °F and not more than 200 °F.

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Issued on: March 1, 1995.

**Ricardo Martinez,**

*Administrator.*

**Note.—**The following appendix will not appear in the Code of Federal Regulations:

**Appendix—Braking Systems, Tires, Wheel Lockup, and Loss-of-Control Crashes**

*1. Introduction*

NHTSA is providing a brief discussion [1] of braking systems, tires, wheel lockup, and loss-of-control crashes in this Appendix; interested persons are referred to several agency reports [2] for a more complete discussion.

An ABS is a closed-loop feedback control system that, above a preset minimum speed, automatically modulates brake pressure in response to measured wheel speed performance to control the degree of wheel slip during braking and provide improved utilization of the friction available between the tires and the road. These systems, therefore, could justifiably be called antilock brake/tire systems since their function is to balance brake torque with tire/road friction to obtain that wheel slip which optimizes braking performance. Antilock system designers must take into consideration the characteristics of brake systems and tires—both must be understood in order to optimize the performance of antilock systems.

*2. Heavy Vehicle Brake Systems*

The function of a motor vehicle's brake system is to slow or stop the vehicle or to hold it stationary. Service brake systems [3] consist of foundation brake assemblies (the portion of the system that actually creates brake torque and the resulting retarding forces at the tire/road interface) and a service brake control system.

There are two principal types of foundation brakes in use: drum and disc brakes. Drum brakes create retarding friction by pressing contoured brake linings against the inside walls of brake drums that are attached the vehicle's wheels. Disc brakes perform the same function by squeezing or clamping both sides of a brake rotor between two or more brake pads.

There are two principal types of service brake control systems, hydraulic and pneumatic. These service brake control systems consist of the components necessary to distribute and control the fluid pressure to the foundation brake assemblies. In the case of an air brake system, this is pneumatic pressure; i.e., compressed air, and in the case of an hydraulic brake system, this is hydrostatic pressure; i.e., pressurized brake fluid.

In the case of an air brake system, the service brake control system modulates the air pressure in the service brake system. Pressurized (compressed) air stored in reservoirs is supplied through a foot-actuated service brake control valve (treadle valve). This air pressure, which varies in proportion to how far the treadle valve is depressed, is then applied through a series of pneumatic valves (relay valves, and in the case of vehicles equipped with antilock brake systems, modulator valves) to the service brake chambers located near each wheel on the vehicle. This air pressure in the service brake chambers in turn applies forces to the brake linings or pads within the foundation brakes to create brake torque. Pneumatic systems are open, in that air, once utilized at a brake chamber, is exhausted to atmosphere. Air pressure levels in reservoirs are maintained by an engine-driven compressor.

Hydraulic brake systems utilize an incompressible fluid (a petroleum-based brake fluid), metered through a combined valve and reservoir (brake master cylinder), to create variable amounts of hydrostatic pressure within a closed system of brake lines. The brake lines transmit this pressure to wheel cylinders or brake caliper pistons which, in turn, apply force to the brake linings or pads in proportion to the amount of manual force being applied to the brake pedal.

It should be noted that hydraulic foundation brake assemblies (either drum or disc brakes) are sometimes used in air brake systems (commonly called air-over-hydraulic brake systems) with the hydraulic pressure produced by a hydraulic master cylinder which is powered by an air brake chamber.

One important characteristic of brake systems that effects the control modes used by ABSs to control wheel slip is the hysteresis [4] of both the service brake control systems and foundation brakes. In the case of service brake control systems, the hysteresis of concern is the time lag between the ECU signalling the modulator valve to release (reduce) or apply (increase) brake application pressure and the time at which that increased or decreased pressure is actually applied at the foundation brakes. This pneumatic hysteresis time lag can be up to several tenths of a second for an air braked system, but for a hydraulic brake system, this time lag is very short, usually less than one-tenth of a second.

The foundation brakes' hysteresis significantly affects ABS design. This hysteresis is characterized by the foundation brake's torque output not immediately falling in response to and in proportion to a reduction in brake application pressure. This is shown in Figure 1 for an air-actuated foundation brake. As is the case for service brake control systems, the hysteresis in hydraulic foundation brakes is much less than that of air-actuated foundation brakes.

The amount of deceleration that a braking vehicle can attain is dependent on three factors: the amount of brake torque that can be generated; tire-friction properties; and road surface friction characteristics.

The ability to generate braking torque is primarily dependent upon the size of the foundation brake components used (i.e., brake drums, linings, and actuating chambers or pistons) and the amount of hydraulic or pneumatic pressure delivered to these components. Brake system designers size systems to provide sufficient brake torque generating capability to lock (or come relatively close to locking) the brakes (wheels) on the vehicle (except those on the steering axle) when it is loaded with the maximum weight it is designed to carry and when operating on all types of road surfaces. It is necessary to provide such brake torque generating capability if a vehicle is to have adequate stopping distance performance when it is fully loaded.

Most heavy trucks built today can thus generate sufficient brake torque to lock (or come relatively close to locking) all their wheels (except those on the steering axle) on all road surfaces at all loading conditions. If a brake is ''big'' enough to lock a wheel, the issue of stopping capability of that wheel then focuses on tire properties and not the brake since, in effect, any further increase in braking torque cannot be utilized. The limit of tire traction in such a case determines the maximum capability of each wheel (brake) to contribute to the vehicle's stopping ability.

For passenger cars, maximum loaded weight includes the empty weight of the vehicle, up to as many as six adult passengers, assorted luggage or cargo, and a full tank of fuel. For a heavy truck, maximum loaded weight includes the empty weight of the vehicle, typically one or two passengers, a full load of fuel, and the maximum weight of cargo that can be carried in the truck. The ratio of loaded to empty weight for passenger cars is generally in the range of 1.5 to 1 or less. For heavy vehicles, especially combination-unit trucks, this ratio can exceed 3 to 1.

Standard design practice in the U.S. is to use fixed brake force distributions on heavy vehicles (i.e., a brake force distribution that does not change with axle load changes). The

[1] Much of the discussion which follows is adapted from *U.S.* v. *General Motors Corp.,* 656 F.Supp 1555, 1562–1566 (D.D.C. 1987,), ''The Anatomy of a Tractor Trailer Jackknife'' by Richard Radlinski, Vehicle Research and Test Center, National Highway Traffic Safety Administration, and ''Antilock Systems for Air-Braked Vehicles'' by William A. Leasure, Jr. and Sidney F. Williams, Jr., National Highway Traffic Safety Administration, SP–789, Society of Automotive Engineers, Inc., February 1989.

[3] A vehicle's brake system includes both the service brake system which the driver uses to slow or stop the vehicle, and the parking brake system which the driver uses to hold the vehicle stationary while unattended. The notice only addresses the service brake system and does not discuss parking brake system performance.

[4] Hysteresis is:

1. the time lag exhibited by a body in reacting to changes in the forces affecting it, and

2. the phenomenon exhibited by a system in which the reaction of the system to changes is dependent upon its past reactions to change.

force distribution is established by selecting particular ''size'' or torque capacity brakes for each axle. Because load distribution is so variable on heavy vehicles, a fixed brake balance is a compromise and cannot be expected to provide high braking efficiency (i.e., high braking rates without locking wheels) under all conditions. Generally speaking, heavy vehicle brakes are balanced for the fully loaded, low deceleration stop. This results in too much braking at the rear axle(s) when the vehicles are empty.

Heavy vehicles have a comparatively much greater propensity for brake-induced wheel lockup than passenger cars for two reasons. The first is the much less than optimum brake force distribution in the lightly loaded and empty load conditions, which leads to rear wheel lockup under such conditions. The second is the difference in loaded to empty weight ratio and the resulting difference in brake sizing. Since a heavy vehicle's brakes must be sized for the fully loaded condition, such a vehicle tends to be very overbraked when it operates lightly loaded or empty or when it operates on a slippery, low friction road surface. Under either of these operating conditions, and especially when both conditions exist, it is very easy for the driver to inadvertently lock some or all of the vehicle's wheels, even when making only a moderate or light brake application.

*3. Tire/Road Friction*

Ultimately, the retarding (braking) forces at the tire/road interface, that result from the braking torque that is applied to the vehicle's wheels, are transmitted to the road surface at that interface. Tire and road surface friction properties that affect these forces are significant factors in determining the amount of deceleration that the vehicle can achieve. In fact, the forces and moments [5] that the vehicle's tires are capable of generating at the tire/road interface are not only the only means by which a driver is able to control the velocity of the vehicle (not only slowing and stopping the vehicle by applying the brakes, but also accelerating the vehicle by actuating the accelerator), but they are also the only means by which the driver is able to control the direction and path of a vehicle by turning the steering wheel.

These forces and moments result when the driver turns the steering wheel, applies the brakes and/or actuates the accelerator and are reactions to the inertial forces [6] and moments [7] that act on the vehicle. Therefore, in order to understand those factors that influence the control and stability (and the loss thereof) of a vehicle, it is necessary to understand how tires generate those forces and moments.

Tire-road friction is an interaction between the tire and the road resulting in reaction forces and moments acting in the plane of the road at the tire-road interface. Reaction forces and moments result from control inputs (e.g., braking, accelerating, steering) and/or external disturbances (e.g., wind, road geometry and condition, etc.). The direction and magnitude of the resultant reaction forces and moments are determined by these inputs.

Before discussing these tire-road friction properties, several terms need to be defined. In order to understand the conditions under which a tire generates forces at the tire-road interface, the axis system used to define a tire's operating condition needs to be defined.[8] First, the position of the tire is defined by the wheel plane, the road plane, and the center of tire contact. The wheel plane is the central plane of the tire, normal (perpendicular) to the spin axis, which is the axis of rotation of the wheel (tire). The road plane is the plane of the road surface. The center of tire contact is the intersection of the wheel plane and the vertical projection of the spin axis of the wheel onto the road plane. The axis system is then defined as follows:

1. The origin of the tire axis system is the center of the tire contact.

2. The X′ axis is the intersection of the wheel plane and the road plane with a positive direction forward. The X′ axis defines the longitudinal [9] axis of the tire and is positive in the direction in which the tire is pointed.

3. The Z′ axis is perpendicular to the road plane with a positive direction downward. If the road surface is flat and level, the Z′ axis is vertical.

4. The Y′ axis is in the road plane, its direction being chosen to make the axis system orthogonal and right-handed. The Y′ axis defines the lateral [10] axis of the tire and is perpendicular to the direction in which the tire is pointed and positive to the right when looking in the direction in which the tire is pointed.

With this axis system as a basis, the tire angles which affect the forces and moments generated by a tire are defined as follows:

1. Slip angle is the angle between the X′ axis and the direction of travel of the center of tire contact. In simple terms, the slip angle is the angle between the direction in which the tire is pointed and the direction in which the tire is moving.

2. Inclination (camber) angle is the angle between the Z′ axis and the wheel plane. In simple terms, the inclination angle is a measure of how far the top of the tire is tilted to one side or the other when looking in the direction in which the tire is pointed.

The other important operating condition of a tire is that which produces braking and driving forces. This condition, which is referred to as longitudinal slip in the SAE terminology, is also called percent slip, wheel slip, or simply, slip. Throughout this notice, the term wheel slip is used and is defined as: the ratio of the longitudinal slip velocity to the spin velocity of the straight free-rolling tire, expressed as a percentage, where:

1. the longitudinal slip velocity is the difference between the spin velocity of the driven or braked tire and the spin velocity of the straight free-rolling tire, with both spin velocities measured at the same linear velocity at the wheel center in the X′ direction,

2. the spin velocity is the angular velocity of the wheel on which the tire is mounted, about its spin axis, and

3. the straight free-rolling tire is a loaded rolling tire operated without application of driving or braking torque moving in a straight line at zero inclination angle and zero slip angle.

It should be noted that wheel slip is sometimes expressed as the ratio of the difference between the velocity of the wheel center and the velocity of a point on the tread of the tire that is not in contact with the road to the velocity of the wheel center. Using this definition, a free-rolling tire operates at a small amount of wheel slip, usually less than 1 or 2 percent, due to the rolling resistance of the tire. Throughout the preamble, the definition of longitudinal slip given above is used.

The final terms that need to be defined are those that describe the forces and moments generated by the tire. Tire force is the external force acting on the tire by the road. Longitudinal force is the component of tire force in the X′ direction, i.e., in the direction which the tire is pointed. Braking force is the negative longitudinal force resulting from braking force application. Lateral force is the component of tire force in the Y′ direction, i.e., perpendicular to the direction the tire is pointed. Normal force is the component of tire force in the Z′ direction. Vertical force is the normal reaction of the tire on the road which is equal to the negative of the normal force. Braking force coefficient, $mu_X$, is the ratio of the braking force to the vertical load. Lateral force coefficient, $mu_Y$, is the ratio of the lateral force to the vertical load.

With these definitions as a basis, the following discusses the forces and moments generated by a tire, how those forces are affected by wheel slip, and how those forces influence a vehicle's control and stability.

Tire-road traction properties determine the maximum limits of forces and moments which can be developed at the tire-road interface at given operating and environmental conditions. They also affect tire force and moment slip characteristics, i.e., relationships between lateral tire force and slip angle (and camber angle); [11] and

[5] A moment, or the moment of a force, is a torque, and is a measure of the tendency of that force acting on an object to produce torsion and rotation of that object about an axis.

[6] Inertial forces are those forces occurring within an object that resist the tendency of external forces on the object to accelerate the object. They are defined by Newton's Second Law, which basically states that an object at rest tends to remain at rest and an object in motion tends to remain in motion, and are equal to the mass of the object times its rate of acceleration.

[7] Inertial moments are those moments occurring within an object that resist the tendency of external moments on the object to accelerate the rotation of the object. They are also defined by Newton's Second Law and are equal to the moment of inertia of the object times its rate of rotational acceleration.

[8] The following definitions are based on those which appear in ''SAE J670e—Vehicle Dynamics Terminology, Society of Automotive Engineers, Inc. July 1976. The reader is referred to that document for a more complete description of these terms.

[9] Similarly for the vehicle, the vehicle's longitudinal axis, direction, is the direction in which the vehicle is pointed.

[10] Similarly for the vehicle, the vehicle's lateral axis, direction, is perpendicular to the direction in which the vehicle is pointed.

[11] Throughout the remainder of this discussion, the effects of camber angle are not addressed, and

braking or driving torque and wheel slip. These properties have a substantial effect on a vehicle's dynamics and its control and stability characteristics.

a. Braking (Longitudinal) Friction

Application of braking torque inputs to a wheel, rolling at zero slip and camber angles, results in a longitudinal force acting parallel to the wheel plane in a direction opposite to the direction of wheel motion. Longitudinal reaction force is modified by the rolling resistance of the tire which increases braking force.

As the braking force at the wheel is increased, slippage will occur between the tire and the road surface. To generate slippage, the rotational speed of the tire must be less than the speed of the wheel center and, therefore, the vehicle. This slippage between the tire and road surface is the longitudinal slip defined earlier.

Longitudinal friction properties of tires have been measured and tabulated for numerous combinations of tire/load/road/environmental conditions in the form of $mu_X$-slip curves. (This type of data is quite prevalent in the public domain for passenger car tires while similar data for truck tires are sparse.)

The braking force that a tire is capable of developing varies with wheel slip in accordance with the typical curve shown in Figure 2. The shape of the $mu_X$-slip curve illustrates the classic features of longitudinal force generation. The braking or longitudinal force is zero when the tire is free rolling, reaches a peak at about 10–20 percent slip and then falls off to a somewhat lower level when the tire is operating at 100 percent slip, i.e., fully locked (sliding).

The initially steep increase of longitudinal force with increasing slip reflects the circumferential elasticity of the tire's carcass and tread structure. As the brakes are applied with increasing amounts of torque, the elastic capability of the tire in the footprint area is exceeded and sliding begins to take place at the rear of the footprint. Beyond the elastic region, the force output reaches a peak as all of the tread elements traversing the contact patch begin to slide relative to the roadway. Beyond peak friction, any increase in brake torque causes sliding across the entire footprint and the tire rapidly goes into full lockup. In this regime, frictional coupling between the tire and road degrades due to rubbing speed and heating effects, hence, the characteristically negative slope at high slip level.

The shape of this curve (see Figure 3) is dependent upon the tire characteristics and the road surface properties. Typically, the peak is relatively high on dry roads but tire force fall-off is small. On wet roads, the peak is lower and the fall-off as the wheel locks is much greater.

Another form of hysteresis that affects ABS design is related to the braking force versus wheel slip characteristics. As both the peak and slide coefficients of friction become lower on more slippery road surfaces, the time necessary for a locked (or nearly locked) wheel to spin up to near the vehicle's velocity increases. This results from the reduced force generating capability of tires on low friction road surfaces together with mass of the rotating components that include the wheel. On the drive axles of heavy vehicles, this mass, which includes the tire, wheel, axle assembly and axle differential components, can be great enough to require more than one-half second for a locked wheel to spin up to the vehicle's speed on very slippery road surfaces such as ice.

For pneumatic tires, the magnitude of the braking force is dependent upon tire construction properties, tread depth, amount of loading, wheel speed (velocity), the type and condition of the road surface and the amount of slippage between the tire and the roadway. With regard to maximum braking capability, the pertinent features of the $mu_X$-slip curve are the peak value of braking force coefficient, the peak coefficient of friction, and the slide value under the locked-wheel condition at 100 percent slip, the sliding coefficient of friction.

In the preamble of this notice, the terms skid number and peak friction coefficient (PFC) are used. These terms represent the results of a test to determine the longitudinal friction characteristics of a road surface using a specific test procedure, the American Society for Testing and Materials (ASTM) Method E1337–90 procedure, a specific tire, the ASTM E1136 SRTT tire, and a specific test device, an ASTM traction trailer. Skid number is the result of the ASTM test which characterizes the slide value of the friction coefficient between the ASTM tire and the road surface being measured. The peak friction coefficient, PFC, is the result of the ASTM test which characterizes the peak value of the friction coefficient between the ASTM tire and the road surface being measured.

The friction force potential of truck tires is significantly less than that for car tires. The difference is due primarily to the rubber compounding used to achieve the high tread life typically achieved with truck tires and the higher pressures in the tires that result in higher footprint loading. The braking performance of any vehicle is ultimately limited by its tire properties. Thus, given current truck tire properties, heavy vehicles cannot perform as well as passenger cars in braking situations even if they have braking systems that are 100 percent efficient (i.e., a braking system that would utilize all of the available tire/road friction).

b. Cornering (Lateral) Friction

In addition to braking forces, tires must also generate lateral—or cornering—forces to direct the vehicle in accordance with steering inputs from the driver or in response to other lateral forces such as crosswinds.

Tire friction characteristics in cornering are described by the relationship between lateral force coefficient and slip angle.

The lateral force that an unbraked tire is capable of developing varies with slip angle in accordance with the typical curve shown for the free rolling tire in Figure 4. The single most important feature of the force generating capability of a tire, as it relates to vehicle control and stability, is the ability of a rolling tire to generate forces perpendicular to the tire's direction of travel.

c. Combined Braking/Cornering Friction

When braking a vehicle, it is necessary to generate both braking and cornering forces at the wheels if the vehicle is to be stopped without deviating from its intended path. The situation is identical when a driver must brake severely while negotiating a curve or lane change where cornering forces are required to keep the vehicle from sliding towards the outside of the turn while the braking forces decelerate the vehicle.

In braking-in-a-curve maneuvers, tire friction properties are determined primarily by the peak and slide values of the resultant braking-cornering coefficients. Figure 4 shows the lateral force coefficient versus slip angle relationships for a free rolling tire and for a braked tire at different amounts of wheel slip, including 100 percent (locked wheel condition). All of the curves converge at a slip angle of 90° as expected, since the tire is perpendicular to the direction of travel.

At small slip angles, the lateral force capability under locked wheel conditions is much lower than that of a free-rolling wheel. It should be noted that although this figure shows that the tire is capable of generating lateral force in the locked wheel, 100 percent wheel slip condition, this force is ''lateral'' in relation to the tire itself. In this situation, the only force generated by the tire is opposite to its direction of travel, and its ''lateral'' component results from the tire's being steered away from its direction of travel. This locked wheel, ''lateral'' force is basically equal to the sliding coefficient of friction of the tire times the vertical load on the tire times the sine of the slip angle.

Lateral is a relative term whose meaning depends upon the object or direction to which it relates, i.e., lateral in relation to the vehicle is not the same as lateral in relation to a tire steered relative to the vehicle, and is also not the same as lateral with respect to the vehicle's direction of travel.[12] Earlier in this notice and in the previous notices related to this Final Rule, the phrase lateral stability has been used to describe whether or not a vehicle can resist yawing or spinning in response to some external lateral force acting on the vehicle. As long as the vehicle's direction of travel is the same as or very close to the direction in which the vehicle is pointed no significant confusion results. However, once a vehicle has begun to yaw or spin and its direction of travel is significantly different than the direction in which the vehicle is pointed, confusion can result regarding the meaning of lateral stability and lateral tire forces. To eliminate any confusion, the term directional stability (or directional stability and control) will be used throughout the remainder of this notice in place of lateral stability (or lateral stability and steering control).

With respect to the tire forces related to a vehicle's directional stability and control, the phrase, ''stabilizing tire forces'' will be used to describe tire forces that act perpendicular to the vehicle's direction of travel, instead of

when discussing the operating condition of a tire, the camber angle is assumed to be zero.

[12] To eliminate confusion regarding the meaning of lateral, several technical terms are defined that will be used throughout the remainder of this notice.

the phrase ''lateral tire forces'' the meaning of which can be unclear relative to the vehicle's direction of travel. As indicated earlier, a tire's ability to generate such ''stabilizing tire forces'' is the single most important feature of the force generating capability of a tire, as it relates to vehicle directional control and stability.

The graph in Figure 4 can be used to illustrate how tire traction characteristics influence vehicle directional stability. For example, if a single-unit vehicle negotiates a cornering maneuver with the front wheels at 4° slip angle and the rear wheel at 3° slip angle, and the application of braking pressure results in 20 percent slip at the front tires while the rear tires become locked, the data indicate that the lateral force coefficient at the front would decrease from 0.55 to 0.25 while the corresponding decrease at the rear would be from 0.45 to 0.03. In this case, the lateral force capability at the front would be eight times greater than at the rear. Because of the greatly reduced stabilizing forces on the rear tires, they would no longer be capable of resisting the vehicle yaw induced by the forces on the front tires, and the vehicle would spin out.

Tire loading also affects the amount of slip which occurs at the various wheels on a vehicle. For example, weight is transferred from the inside to the outside wheels of a vehicle when it is driven around a corner. Therefore, the wheels on the inside of the vehicle will operate at a lighter tire load and hence, when generating the same braking force, will operate at a higher percentage of wheel slip than their counterparts on the outside of the vehicle. In tractor-trailer combinations, improper load distribution can produce unequal axle loadings between the tractor and trailer. If both the tractor and trailer brakes are applied equally, increased wheel slip will occur at the wheels which are carrying the lightest load. If the improper load distribution is severe enough, wheel lockup and skidding can occur at otherwise normally acceptable deceleration rates.

*4. Vehicle Loss of Control*

Heavy vehicles are likely to experience wheel lockups in maximum braking situations because of the friction properties of their tires and the less than optimal force distributions of their brake systems. Lockup of all of the wheels on one or more of a vehicle's axles, if not responded to by the driver, will usually result in either a loss of steering control or loss of the vehicle's directional stability.

a. Single-Unit Trucks

A single-unit truck behaves much like a passenger car when wheel lockup occurs. Figure 5 shows a simple single unit vehicle (car or truck) with only its front wheels locked. Such a vehicle, with only the front wheels locked and the rear wheels rolling, will experience a loss of steering control. The vehicle cannot be steered, but it is stable due to the stabilizing forces provided by the rolling rear wheels and does not tend to yaw or spin out.

Figure 6 shows a simple single unit vehicle (car or truck) with only its rear wheels locked. In this case, the vehicle will experience a loss of directional stability. It is very unstable and the slightest side force disturbance (i.e., lateral force due to steering, side slope or road crown, crosswind, unequal front axle braking, etc.) results in the vehicle yawing significantly or spinning out.

If all wheels are locked, the vehicle cannot be steered but is not as likely to spin.

b. Combination-Unit Vehicles

With combination-unit vehicles, the effect of wheel lockup is more complex but can easily be inferred from the simple single-unit vehicle case by treating each vehicle in the combination as a single-unit vehicle.

If the wheels on the steering axle lock, the vehicle, experiencing a loss of steering control, will travel essentially in a straight path, stable but unsteerable, as illustrated in Figure 7. Usually a driver immediately senses this condition and, if conditions permit, can modulate the brakes to allow the steering axle wheels to spin up and regain steerability.

If the trailer wheels lock, the trailer will experience a loss of directional stability and (if side force disturbances are present) will swing to the outside of the vehicle path, as shown in Figure 8. However, because trailer wheelbases are long in comparison to the tractor, this unstable yawing response is slower. Thus, a driver again, if conditions permit and if the driver is aware of the condition soon enough, may have time to modulate the brakes to spin up the trailer wheels and bring the trailer back in line. As a trailer becomes shorter, this possibility of correction becomes less likely.

If the tractor's drive axle wheels lock, the truck tractor will experience a loss of directional stability and the combination vehicle will begin to jackknife if a side force disturbance exists, as shown in Figure 9. When this occurs, the process usually becomes irreversible as the driver is unable to react fast enough to prevent total loss of vehicle control, particularly when the tractor has a short wheelbase. This instability condition is the one which a driver is least likely to be able to control.

As more units (and more articulation points) are added to the combination, the situation becomes more complex and the modes of instability increase in number.

*5. The Need for Antilock*

As mentioned earlier, the only means by which a driver is able to control the direction, velocity, and path of a vehicle is to apply steering, braking, and/or accelerator inputs to the vehicle which in turn result in forces and moments being generated by the vehicle's tires. A tire can only generate a limited amount of frictional force. As the tire is required to generate more force for braking, its capability to generate stabilizing force is reduced. Since the capability of a tire to generate both braking (longitudinal) and stabilizing (lateral) forces is determined by the amount of wheel slip at which the tire is operating, controlling wheel slip is the only means by which it is possible to have a tire generate a significant amount of longitudinal force to decelerate a vehicle while still maintaining the capability to also produce sufficient amounts of stabilizing force to steer the vehicle and to retain directional stability.

As illustrated earlier, when the wheel slip goes beyond the point at which maximum (peak) braking force occurs, the tire's stabilizing force capability drops dramatically, leading to a situation that can result in loss of vehicle control. By sensing and controlling wheel slip, an antilock system automatically reduces the amount of brake application pressure to prevent prolonged, excessive wheel slip which would compromise the vehicle's directional stability by reducing the stabilizing force capabilities of the vehicle's tires. An antilock system which operates in such a manner is referred to as a closed-loop system. The basic closed-loop control algorithm for an ABS is as follows:

1. The driver actuates the brake pedal (or treadle valve) resulting in an application of brake pressure to the vehicle's foundation brakes,
2. this generates brake torque at the vehicle's wheels that creates braking forces at the tire/road interface,
3. this results in wheel slip (as discussed above), the level of which is determined by the ABS by sensing the rotational speed of the vehicle's wheels,
4. if the amount of wheel slip is not within an ''acceptable'' range (which is determined by the ECU, based on a predetermined set of logic) the brake application pressure is adjusted to return the level of wheel slip to the acceptable range; i.e., if the level of wheel slip is excessive, the brake application pressure is reduced and if the level of wheel slip is too low, the brake application pressure is increased, but never to a level higher than that which results from the driver's actuation of the brake pedal (or treadle valve).

Vehicles equipped with ABS, operating in such a manner, usually have shorter stopping distances compared to the same vehicle without ABS, particularly on low mu surfaces.[13] An antilock system which controls the wheel slip at the level that results in the maximum amount of braking force at the tire/road interface maximizes a vehicle's stopping capability and also provides some directional stability enhancement. On the other hand, antilock systems which control wheel slip at levels below that which results in peak braking force generation will result in a greater degree of directional stability but provide lower levels of braking force resulting in longer stopping distances.

*6. General Antilock System Operation*

The following discussion addresses three different aspects of ABS operation. The first aspect discussed is the control strategies used by an ABS to monitor wheel rotational speed and adjust brake application pressure to control wheel slip at an individual wheel. The second relates to the various component configurations that are used to control the wheels on an axle or a tandem axle set. The third is the control strategies used to control the wheels on an axle or tandem axle set.

[13] A low mu surface is one that is relatively slippery and thus provides lower levels of braking force and poorer directional stability and control during braking. These surfaces, which are typical on wet roads, are also referred to as low coefficient of friction surfaces.

a. ABS Wheel Slip Control Strategies

The goal of an antilock system is to prevent wheel slip on the controlled wheels from exceeding that which provides a good compromise between providing near maximum levels of braking force and providing sufficient levels of stabilizing forces to assure that the vehicle will remain directionally stable without reducing the wheel slip below that which produces braking force which utilizes most of the friction (adhesion) that is available at the tire/road interface. Once wheel slip goes beyond the point which provides peak braking traction, both braking and cornering traction are reduced, as shown in Figure 10 for a truck tire cornering at an 8° slip angle.

Early mechanical antilock systems controlled slip by the use of an assembly at the wheel which contained an inertia disc that rotated freely with the wheel when brakes were not applied. Braking the wheel caused it to decelerate while the inertia disc tried to continue to rotate at the original speed, but was restrained by a triggering mechanism. This triggering mechanism controlled an air valve (modulator valve) which when activated, shut off air pressure to the foundation brake air chambers and exhausted pressure already in the chambers. When deceleration of the wheel exceeded about ''1g,'' the inertia of the disc generated enough force to trip the mechanism activating the modulator valve. As braking force decreased and the wheel speeded up, the force exerted by the inertia disc decreased, allowing the trip mechanism to deactivate the modulator valve, thus, reapplying the brakes.

Electronic antilock systems act in a manner similar to the early mechanical systems except they are more sophisticated as a result of their computational capability. With electronic systems, the mechanical wheel assembly is replaced by a wheel speed sensor and an electronic control module (ECU). Wheel speed sensors, which are located at the wheels or within the axle housings, constantly monitor wheel speed (or a component whose speed is proportional to the wheel speed) sending electrical signals to the ECU which are proportional to the wheel speed. The ECU determines wheel speed and changes in wheel speed (acceleration and deceleration) based on these signals.

The following discusses two basic control modes [14] used by electronic ABSs to control brake applications at a wheel in response to wheel speed sensor signals.

In the acceleration/deceleration threshold mode of operation, the ECU recognizes the rapid wheel deceleration that occurs as wheel slip exceeds the peak friction wheel slip (Figure 11), and electrically commands the modulator valve to reduce brake application pressure and, thus, brake torque. When brake torque decreases enough to cause braking force to be less than the friction force at the tire/road interface, the wheel stops decelerating and begins to accelerate. The rate of acceleration increases with the increasing friction associated with a reduction in wheel slip. When wheel slip falls to the level corresponding to peak braking force, the acceleration rate peaks and starts to decrease with wheel slip. The ECU senses this change in acceleration rate and commands the modulator valve to start increasing brake application pressure and the cycle repeats.

In the reference speed mode of operation, the ECU tracks wheel speed information which it uses to estimate vehicle speed. The antilock system uses this estimated speed to compute a ''reference speed'' which is less than the estimated speed by a preprogrammed factor. The reference speed is updated throughout a stop as illustrated in Figure 12. This figure also illustrates how the ECU in one manufacturer's 1970's system uses this reference speed as a cue to modulate the brake application pressure. When the brakes are applied as shown in the figure, the wheel starts decelerating. As wheel speed falls below the reference speed (point ''G–1''), the antilock system acts to reduce brake pressure. After brake pressure has been reduced long enough to allow the wheel speed to roll up to that of the reference speed (point ''G–2''), the antilock system acts to increase brake pressure. This cycle continues until the vehicle is stopped.

Today's antilock systems usually combine acceleration/deceleration threshold logic and speed reference logic in some fashion. Both are believed necessary to improve the efficiency of antilock systems to account for the variance of tractor performance with surface (Figure 13), slip angle (Figure 14, vehicle speed (Figure 15), etc.

If an antilock system waits for the threshold deceleration associated with peak braking friction under some conditions, the ability of the wheel to provide cornering friction will have been compromised severely. Therefore, a threshold reference speed needs to be established around 30 percent to prevent excessive wheel slip.

Figure 16 shows a typical control cycle for one manufacturer's antilock system which uses a ''hold'' pressure phase, as well as a release pressure phase. This ECU uses two wheel slip thresholds (K1 and K2) and two deceleration thresholds ($-$b and b) in making decisions regarding control of the modulator. The ECU tracks the information from all of the vehicle's wheel speed sensors (even when the brakes are not applied) and uses this information to compute a reference speed which it continually updates. In the panic stop in Figure 16, the wheel decelerates until the wheel speed sensors indicate a deceleration which the vehicle cannot physically attain (point 1). At this point, the reference speed, which until this instant has corresponded to the wheel speed, now separates from the wheel speed and decreases according to an empirically determined rate of deceleration.

At point 2, the deceleration threshold $-$b is reached and the wheel runs into the unstable range of the traction curve. The wheel has exceeded the maximum braking force and any further increase in braking torque only increases wheel deceleration. Brake pressure is, therefore, quickly reduced and wheel deceleration falls after a short time. This deceleration time is determined by the hysteresis time lag between the time the modulator valve actuates to release the air pressure to the time that the air pressure in the air brake chamber, the hysteresis of the foundation brakes and the hysteresis related to the time needed for the wheel (and its associated rotating components) to spin up after it has been locked. Only after this delay does a further pressure fall also lead to reduction of wheel deceleration.

The deceleration signal $-$b is traversed at point 3 and brake pressure is held constant for a fixed time T1. Normally wheel acceleration will rise above the threshold +b at a point 4 within this holding time T1.

Provided this happens, brake pressure will continue to be held constant. (Were the +b signal not produced within the time T1, as with very low friction surfaces, then brake pressure would be again reduced in response to the slip signal. The time constant, T1, is determined for each vehicle/brake system based on the influences of the various kinds of hysteresis previously discussed).

During the constant pressure phase, the wheel accelerates in the stable slip range, the +b signal being traversed again at point 5 at which time utilized adhesion is just below the maximum on the traction curve. The +b threshold is used this time to signal a rapid pressure increase over time T2 to overcome brake hysteresis.

The time T2 is preprogrammed for the first control cycle and then recalculated for each subsequent control operation depending upon the response of the wheels. After this rapid pressure increase stage, brake pressure is raised again but at a lesser gradient by alternate pressure increase and hold pulses.

As a rule, the deceleration threshold $-$b is again reached during the pulsing phase at point 9, and brake pressure falls. The procedure repeats itself as long as the brake pedal is depressed too forcefully for the existing road conditions or until the vehicle speed drops below a specified value.

The logic presented here in principle is not fixed, but, matched by microcomputers to the dynamic response of the wheel under differing adhesion conditions. Not only are ABSs capable of ''adapting'' to various conditions by employing complex algorithms to control wheel slip, but they are also able to ''adapt'' the parameters of those algorithms, as with the T2 parameter discussed above, to improve the system's ability to control wheel slip over the broad range of road surface and vehicle load conditions under which heavy vehicles operate. One obvious result of this adaptability is the range of ABS cycle times, or controlling frequencies, that result when controlling wheel slip under various road surface and vehicle load conditions.

Figures 17 and 18 illustrate the effects of two very different situations of load and road surface conditions on the ABS cycle times and how an air brake ABS adapts its control of wheel slip. Figure 17 shows treadle valve pressure, and brake chamber pressure, wheel speed and ABS modulator solenoid activity

[14] The following discussion, which is largely based on the previously referenced Leasure and Williams SAE, paper specifically addresses ABS control modes for air brake systems. Similar control strategies are used in hydraulic ABSs with the specific parameters of the control modes differing due to differences in the brake torque versus brake pressure application characteristics of air and hydraulic brake systems.

for the left wheel of the intermediate drive axle for a full treadle application stop of a Freightliner 6×4 conventional truck tractor with a WABCO 6S/6M ABS in a lightly loaded condition on a very low friction surface, ice. The figure shows the first five ABS cycles for that stop. To characterize ABS cycle time, the ABS cycle is assumed to begin when brake pressure begins to rise in the brake chamber and that rising brake chamber pressure leads to excessive wheel slip or wheel lockup. This excessive wheel slip is sensed by the ECU which actuates the modulator valve to decrease brake chamber pressure to reduce wheel slip to an acceptable level. This ''initial'' rise in brake chamber pressure can result from an increase in the driver's level of brake application, i.e., rising treadle valve pressure, or from an increase resulting from the ECU signaling the modulator valve to increase brake chamber pressure. The ABS cycle ends when, after the reduction in brake chamber pressure resulting from actuation of the modulator valve, the brake chamber pressure begins to again rise in response to the ECU signaling the modulator valve to increase brake chamber pressure. For the five ''ABS cycles'' shown in Figure 17–a, the ABS cycle times range from 0.72 seconds to 0.80 seconds, i.e., an ABS controlling frequency of from about 1.2 to 1.4 cycles per second.

Two things shown in Figure 17–b are of note. The first is the time required for the wheel to lock after the initial brake application which is very short, about 0.04 seconds. The second is the time required for the wheel's speed to increase to that of the vehicle after the wheel has locked, i.e., the wheel's spin up time. The spin up times shown in Figure 17–b range from 0.20 seconds for the fourth ABS cycle (wheel spin up begins at about 3 seconds on the time scale) to 0.34 seconds for the first ABS cycle (wheel spin up begins at about 0.5 seconds on the time scale). The rate of wheel spin up can be characterized by the acceleration of the outer surface of the tire, i.e., the tread of the tire, relative to the wheel center. In the case of the wheel spin up during the first ABS cycle, the spin up time is 0.34 seconds and the change in wheel speed over that time is 11.3 mph; the wheel's acceleration is therefore 33.2 mph per second or 48.8 feet per second per second.

In contrast to the ABS cycle time and wheel spin up rates shown in Figure 17, Figure 18 illustrates a situation where the ABS cycle times are much shorter and the wheel spin up rates are much faster. Figure 18 shows treadle valve pressure, and brake chamber pressure, wheel speed and ABS modulator solenoid activity for the left wheels of the tandem drive axles for a full treadle application stop of a Volvo-GM 6×4 conventional truck tractor with a Bosch 6S/4M ABS in a lightly loaded or bobtail condition on what is believed to be a high friction surface. The reason for the uncertainty of the conditions under which this stop took place is that this data resulted from the monitoring and recording of ABS event occurrences during the agency's truck tractor fleet study and no details are available regarding the exact circumstances of this stop. However, given the high average deceleration rate of this stop, more than 16 feet per second per second which if sustained during a stop from 60 mph would result in a stopping distance of less than 240 feet, it is reasonable to assume that the surface had a rather high coefficient of friction. Given this and the low level of brake chamber pressure at which excessive wheel slip occurs, between 15 and 30 psi, it is reasonable to assume that the vehicle was lightly loaded and may even have been a bobtail situation.

It should be noted that the various data traces shown in Figure 18 are rough ''stairsteps'' during the first second of data. The reason for this is that the data monitoring/recording equipment used in the truck tractor fleet study used a data sampling rate of 10 samples per second while monitoring ABS activity. When an ''ABS braking event'' was detected the equipment began to use a data sampling rate of 50 samples per second. The equipment then stored the data for the one second prior to the ''ABS braking event'' at a 10 sample per second rate and for the entire ''event'' at a 50 sample per second rate.

With regard to the ABS controlling frequency shown in Figure 18, unlike the situation shown in Figure 17, the ABS cycles are not discrete cycles where the wheel goes to complete lockup and then the brake application pressure is reduced to zero. To estimate the ABS controlling frequency in this situation, an ABS cycle is characterized by a decrease in brake chamber pressure followed by an increase in brake chamber pressure where these pressures are less than the treadle valve pressure so as to be sure that the brake chamber pressure is being controlled by the ABS. Using this criteria, Figure 18–a shows that between two and three seconds on the time scale the brake chamber pressure goes through about 9 such ''cycles'', i.e., an ABS controlling frequency of about 9 cycles per second. This is more than 6 times faster than the fastest ABS controlling frequency shown in Figure 17–a for the stop on an ice surface.

With regard to the wheel spin up time for the stop shown in Figure 18–b, just after time equals 3 seconds, there is a large decrease in wheel speed for left rear drive wheel followed by a steep increase in speed of that wheel. This wheel speed increase is 7.3 mph and occurs over 0.06 seconds, i.e., a wheel acceleration of 121.7 mph per second or 178.4 feet per second per second. This is more than 3.5 times higher than the wheel acceleration rate for the ''ice'' stop shown in Figure 17–b. Since, as indicated earlier, hydraulic brake systems generally have much lower levels of hysteresis than air brake systems, everything tends to happen faster in hydraulic brake systems and, as such, the controlling frequency for hydraulic brake ABS can be significantly higher. The logic used in different systems also varies with the control strategy utilized and the number of wheel speed sensors.

A difficult task for air brake antilock systems, with regard to controlling slip, is the prevention of wheels going into ''deep cycles'' (wheel slips in the high wheel slip part of the friction curve where both braking and cornering friction are reduced). Deep cycles are particularly undesirable in the first cycle of an antilock system operation where the demand for cornering friction can be the highest because of the speed of the vehicle. The extent to which an antilock system goes into a deep cycle depends on how effectively the modulator controls air into and out of the air chambers. Figure 19 shows how a 1970's antilock system was not able to reduce the air pressure fast enough in a panic application to prevent some wheel lockup. The electronic antilock systems of today, because of the versatility of digital technology (and compatible pneumatic valving) have an expanded control range that provides for better air pressure control to respond to conditions and to prevent overpressurizing air chambers. This makes possible the reductions in deep cycling shown in Figure 20.

The hysteresis of foundation brakes can have significant effect on the ability of an antilock system to prevent ''deep cycles.'' Although an antilock system may quickly detect impending wheel lock and rapidly actuate the modulator valve to reduce the air pressure in the air chambers, the three types of brake system hysteresis discussed earlier may prevent an immediate reduction in brake torque and rapid spin up of the wheel causing deeper wheel cycles than desired. Figure 19 shows an example of how the inherent hystereses of the pneumatic components and foundation brakes of air brake systems, and the hysteresis related to wheel spin up times affect how quickly an ABS can respond to and control wheel slip. The effect of the pneumatic hysteresis can easily be seen in the release of chamber pressure portions of the ABS cycles. It takes from 0.08 to 0.22 seconds for the chamber pressure to decrease to 3 pounds per square inch, the chamber pressure at which wheel spin up begins for several of the ABS cycles. The effect of foundation brake hysteresis can not be estimated without data on the brake torque acting on the wheel. However, it may not be significant since this type of hysteresis is most significant at high brake chamber pressures. As shown in Figure 17, the hysteresis time lags related to wheel spin up range from 0.20 to 0.34 seconds. The ABS cycle times of up to 0.80 seconds shown in Figure 17, are the result of these properties of the foundation brakes and tires used on heavy vehicles today.

The inherent hystereses of the pneumatic components and foundation brakes of air brake systems and in the tire spin up rates of heavy vehicle wheel/tire assemblies have to be considered in the design of antilock systems. It also has to be recognized that different brake types/configurations can have different amounts of hysteresis. An antilock system which works efficiently with one type of brake may not work as efficiently with another type of brake.

b. ABS Single and Tandem Axle Component Configurations

Several types of ABS configurations are currently available for heavy vehicles. In order of decreasing complexity and cost, the systems for tractors include those with: (1) individual control of the wheels on an axle; (2) side-to-side control of the wheels on a tandem axle set; (3) axle-by-axle control of the wheels on a tandem axle set; and (4) tandem control of all of the wheels on a tandem set. With individual wheel control, the most complicated and costly type of ABS, each of the wheels on an axle is individually monitored and controlled using wheel-speed sensors and modulator control valves for each wheel. This prevents lockup at each wheel and thus provides optimum stability and control, especially on a split mu surface.[15] With side-to-side control,[16] all of the wheels on one side of a tandem axle set are controlled together by one modulator in response to wheel speed sensor signals from one or more of those wheels. With axle-by-axle (or simply, axle) control, the wheels on an axle (either on a single axle or on each axle of a tandem axle set) are controlled together by one modulator in response to wheel speed signals from the wheels on that axle. With tandem control,[17] all four (or in some cases, six) wheels on a tandem (or tridem) axle set are controlled together by one modulator in response to wheel speed signals from the wheels on one or more of the axles in the tandem (or tridem) axle set.

ABS technology has improved dramatically in recent years given the use of computerized components. Unlike the antilock brake systems in the 1970s that primarily relied on an analog control technology, current generation antilock systems use advanced digital control technology that enhances the systems' efficiency. Digital logic permits the use of more complex and sophisticated control strategies and reduces the time lags in the antilock computer. More generally, digital technology applied to motor vehicles has been significantly refined in the last twenty years to control motor vehicle fuel systems so that vehicles can comply with fuel efficiency and pollution prevention regulations.

c. ABS Single and Tandem Axle Control Strategies

As discussed above, there are several different component configurations used to equip an axle or axles with ABS.

For each of the configurations for which more than one wheel is controlled by one modulator, different wheel slip control strategies can be used by the ABS to control wheel slip of those wheels. These are select low regulation (SLR), select high regulation (SHR), and modified select high regulation (MSHR), also called ''Select Smart'' (Bendix) or select low high regulation (SLHR).

The select low regulation strategy modulates the brake pressure application at both wheels of an axle at the same level based on the wheel speed signals from the wheel that experiences the higher level of wheel slip. On split mu surfaces, this control strategy results in near peak braking force on the wheel that experiences the higher level of wheel slip (the wheel that is on the lower friction side of the road) and less than peak braking force on the wheel with the lower level of wheel slip (the wheel on the higher friction side of the road). One wheel operating at a lower level of wheel slip and on a surface with a higher friction level means that wheel has a greater capability to provide additional stabilizing force; therefore, providing a higher level of directional stability and control for the vehicle. However, on split mu surfaces with the coefficient of friction on one side of the road surface being very different than on the other side, this can result in extended stopping distances since the wheel on the high coefficient of friction side is providing much less than the maximum level of braking force than can be provided by that surface.

The select high regulation strategy modulates the brake pressure application at both wheels of an axle at the same level based on the wheel speed signals from the wheel that experiences the lower level of wheel slip. On split mu surfaces, this control strategy results in lockup of the wheel that experiences the higher level of wheel slip, which results in that wheel providing less than peak braking force and near peak braking force on the wheel with the lower level of wheel slip. One wheel operating at a locked wheel condition means that wheel has essentially no capability to provide any stabilizing force, and the other wheel operating at a higher level of braking force (near the maximum available on the high friction side of the road) means that wheel would have a reduced capability to provide stabilizing force. This results in a reduced level of directional stability and control for the vehicle compared to the SLR strategy. However, on split mu surfaces with the coefficient of friction on one side of the road surface being very different than on the other side, SHR results in shorter stopping distances compared to the SLR strategy since the wheel on the high coefficient of friction side is providing near peak braking force.

The modified select high regulation strategy combines the SLR and SHR control strategies. At the beginning of a stop which results in excessive wheel slip at one wheel, the ABS controls wheel slip using the SLR strategy. While doing so, the ECU monitors the level of wheel slip on the wheel which has the lower level of wheel slip (the wheel on the high friction side of the road), and from that information, the ECU estimates the ratio of the coefficient of friction on the high friction side of the road to that on the low friction side. If this ratio exceeds a preset threshold and the vehicle speed is above a preset threshold, the ECU increases the brake application pressure to the wheels which increases the braking force provided by the wheel with the lower level of wheel slip (the wheel on the high friction side of the road) and which locks the wheel with the higher level of wheel slip (the wheel on the low friction side of the road). The ECU then begins to control wheel slip using the SHR strategy which results in a higher level of vehicle deceleration (shorter stopping distance) than would result from the use of the SLR strategy. However, as noted above, this results in a reduced capability of the both wheels to provide stabilizing forces, therefore reducing the vehicle's overall level of directional control and stability. Another feature of the MSHR strategy is that even when the vehicle velocity and ratio of coefficients of friction of the split mu surface thresholds are exceeded, the ECU does not immediately switch to the SHR control strategy to reduce the risk that the driver will be surprised by an unexpected steering wheel ''pull'' that can result in that control mode. Instead, the time period over which the system transitions from SLR to SHR control is adjusted based on the vehicle's velocity.

For the individual wheel control configuration in which each wheel is controlled by its own modulator, there are two wheel slip control strategies: independent regulation (IR) and modified independent regulation (MIR). As its name implies, the independent regulation control strategy controls the wheel slip of each wheel on the axle independently, allowing each wheel's ABS to modulate the brake application pressure to each wheel in response to the signals from the wheel speed sensor at that wheel to maximize braking forces while maintaining sufficient capability to produce stabilizing forces to ensure vehicle directional stability. Although this control strategy is the most effective at both minimizing stopping distance as well as ensuring vehicle stability, when used on the steering axle of trucks, truck tractors and buses, this can lead to significant steering wheel ''pull'' on split mu surfaces which can be difficult for the driver to control. Therefore, ABS manufacturers have developed the MIR control strategy in which the wheel slip is controlled using the SLR strategy at the beginning of the stop. This results in equal braking forces at each wheel which alleviates steering wheel ''pull'' that would occur on a split mu surface with IR control of the steering axle brakes. After a short period of time, the ECU smoothly transitions to true IR control so that the buildup of any steering wheel pull is gradual so that it can easily be controlled by the driver. NHTSA understands that MIR control strategy is used exclusively by all vehicle manufacturers on vehicles which have independent sensor/modulator ABS on the steering axle. It should be noted that the SLR strategy also eliminates the problem of steering wheel ''pull'' on split mu surfaces, but as indicated above does not provide as effective use of the friction available on the high friction side of such surfaces, resulting in longer stopping distances.

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[15] With a split mu surface, the road is divided along its length so that the wheels on one side of the vehicle are on a high friction surface and the wheels on the other side are on a low friction surface. One example of a split mu surface is when one portion of a lane is dry and another part is covered with ice.

[16] Side-by-side control ABS can have two different wheel speed sensor configurations. Either all of the wheels on the tandem axle set have their own wheel speed sensors, or only the wheels on one axle of the tandem axle set have wheel speed sensors.

[17] Tandem control ABS can have two different wheel speed sensor configurations. Either all of the wheels on the tandem axle set have their own wheel speed sensors, or only the wheels on one axle of the tandem axle set have wheel speed sensors.

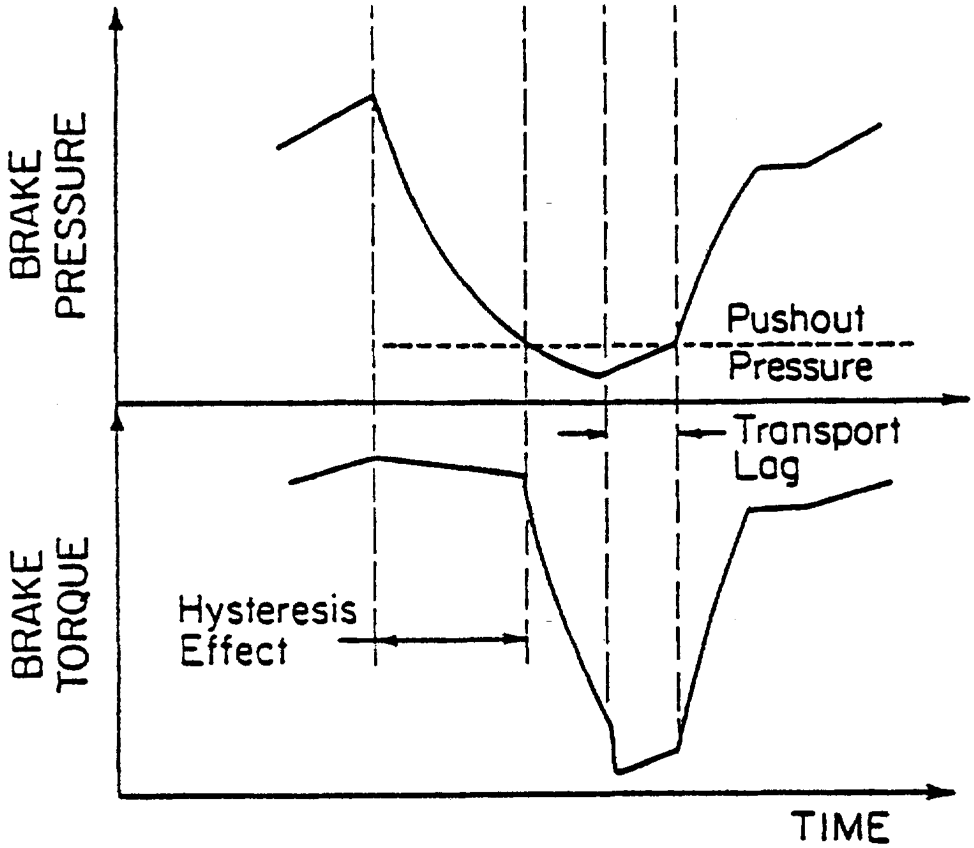



**Figure 1 - Effect of Foundation Brake Hysteresis on Brake Torque vs. Brake Application Pressure**

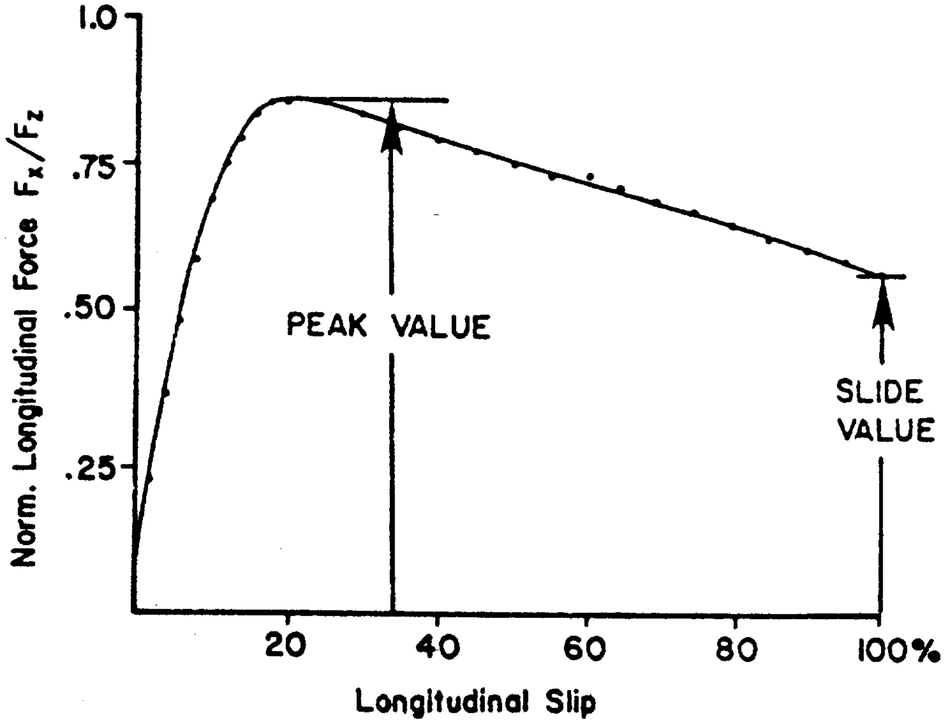



Figure 2 - Example Mu-Slip Curve

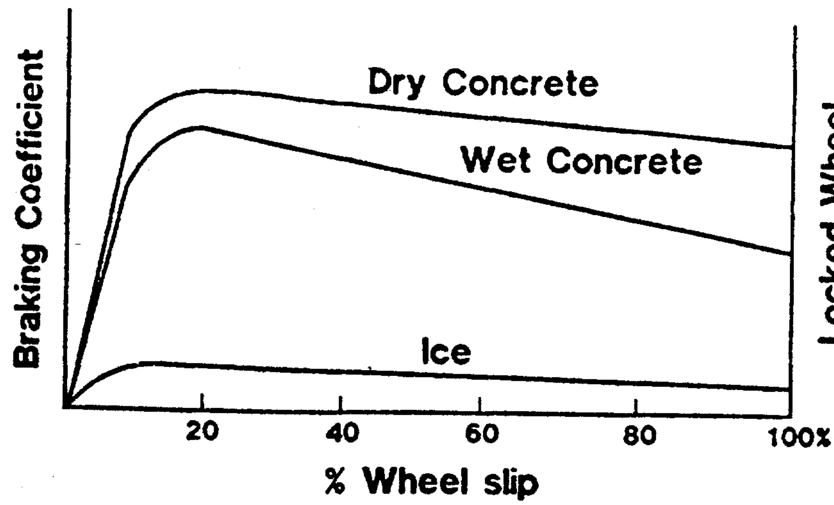



Figure 3 - Mu-Slip Curves
Dry Concrete, Wet Concrete, and Ice

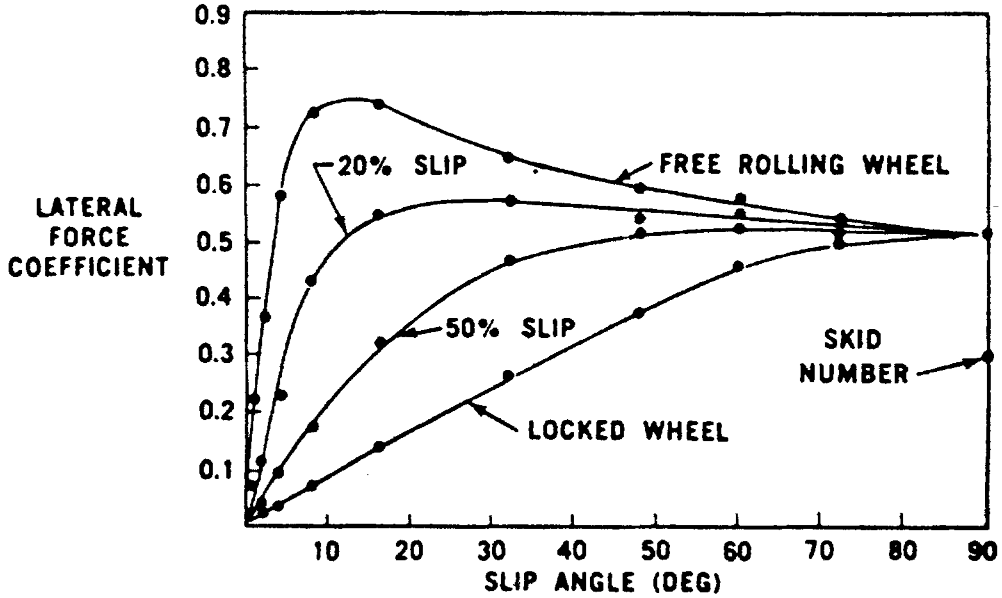



Figure 4 - Lateral Force Coefficient vs. Slip Angle
for a J78-15 Passenger Car Tire
Both Free Rolling and Braked Wheel
Skid Number 30 - Wet Road Surface

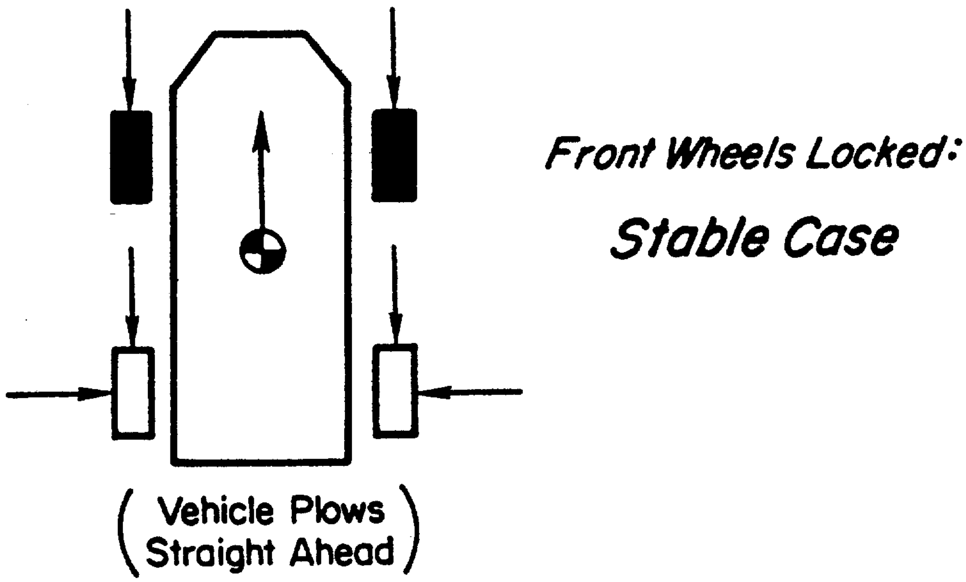



Figure 5 - Dynamics of a Single-Unit Vehicle
Front Wheels Locked - Stable Case

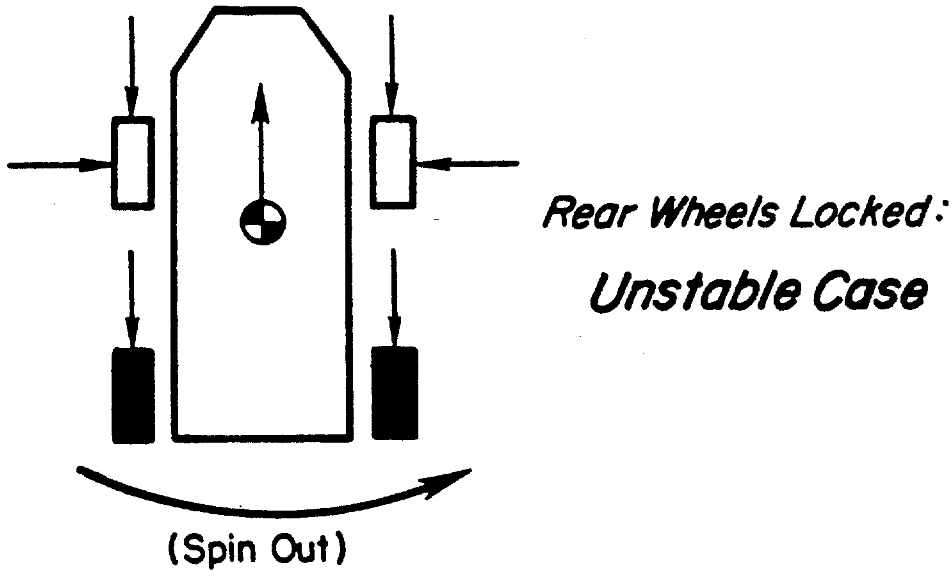
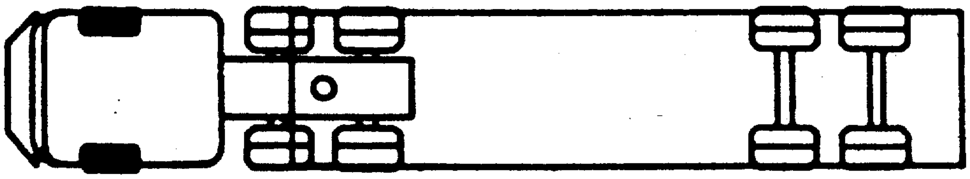



Figure 6 - Dynamics of a Single-Unit Vehicle
Rear Wheels Locked - Unstable Case

STEERING AXLE LOCK-UP



VEHICLE REMAINS DIRECTIONALLY STABLE

STEERING CAN BE RECOVERED

Figure 7 - Steering Loss

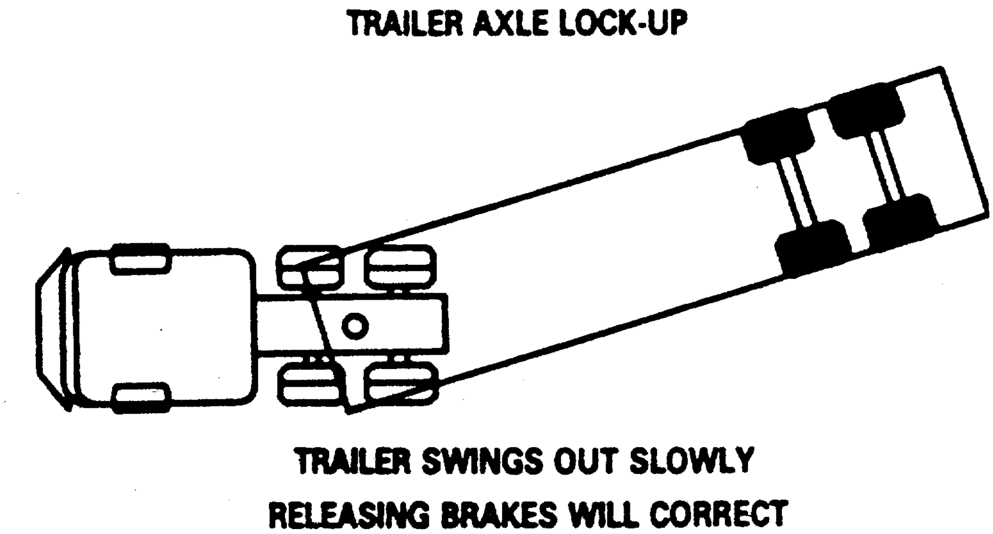
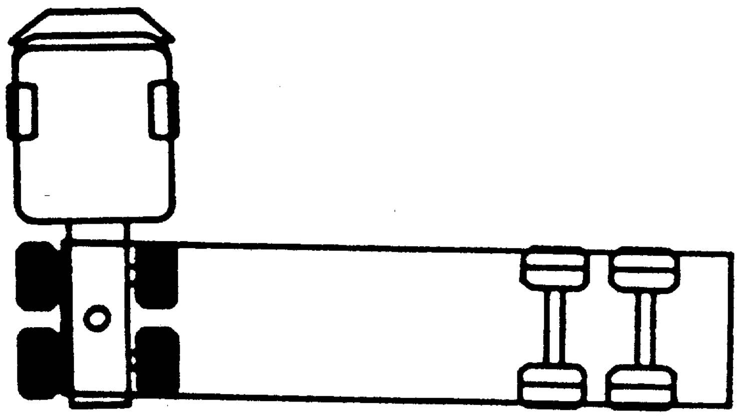



Figure 8 - Trailer Swing

DRIVE AXLE LOCK-UP



JACKKNIFING OCCURS RAPIDLY

PROCESS IS IRREVERSIBLE

Figure 9 - Jackknife

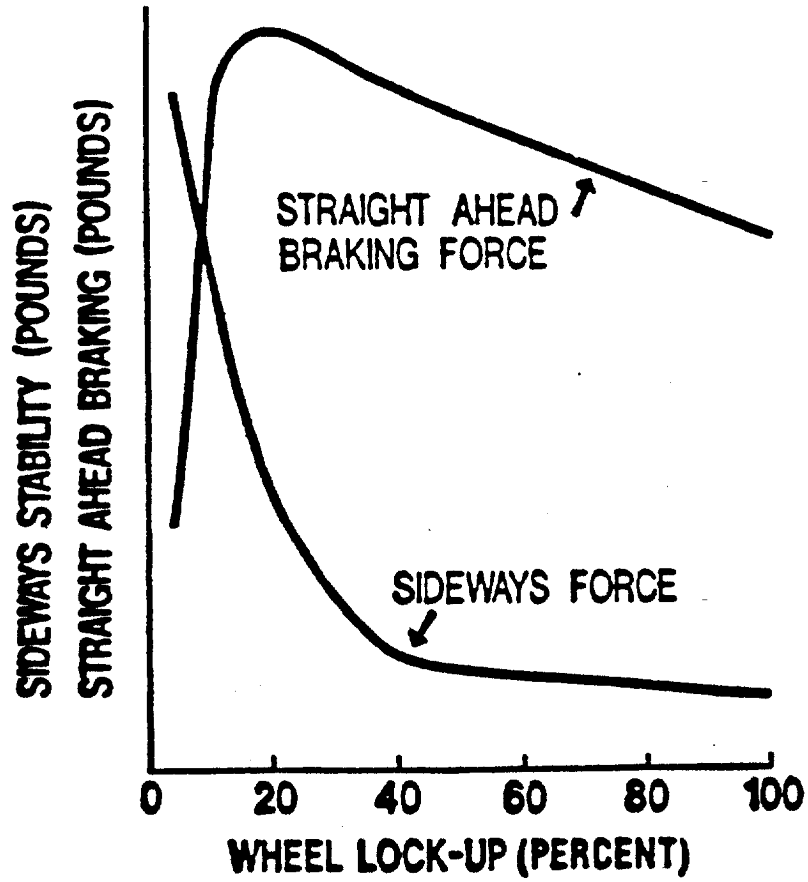



Figure 10 - Combined Tire/Road Friction Performance of a Heavy Truck Tire

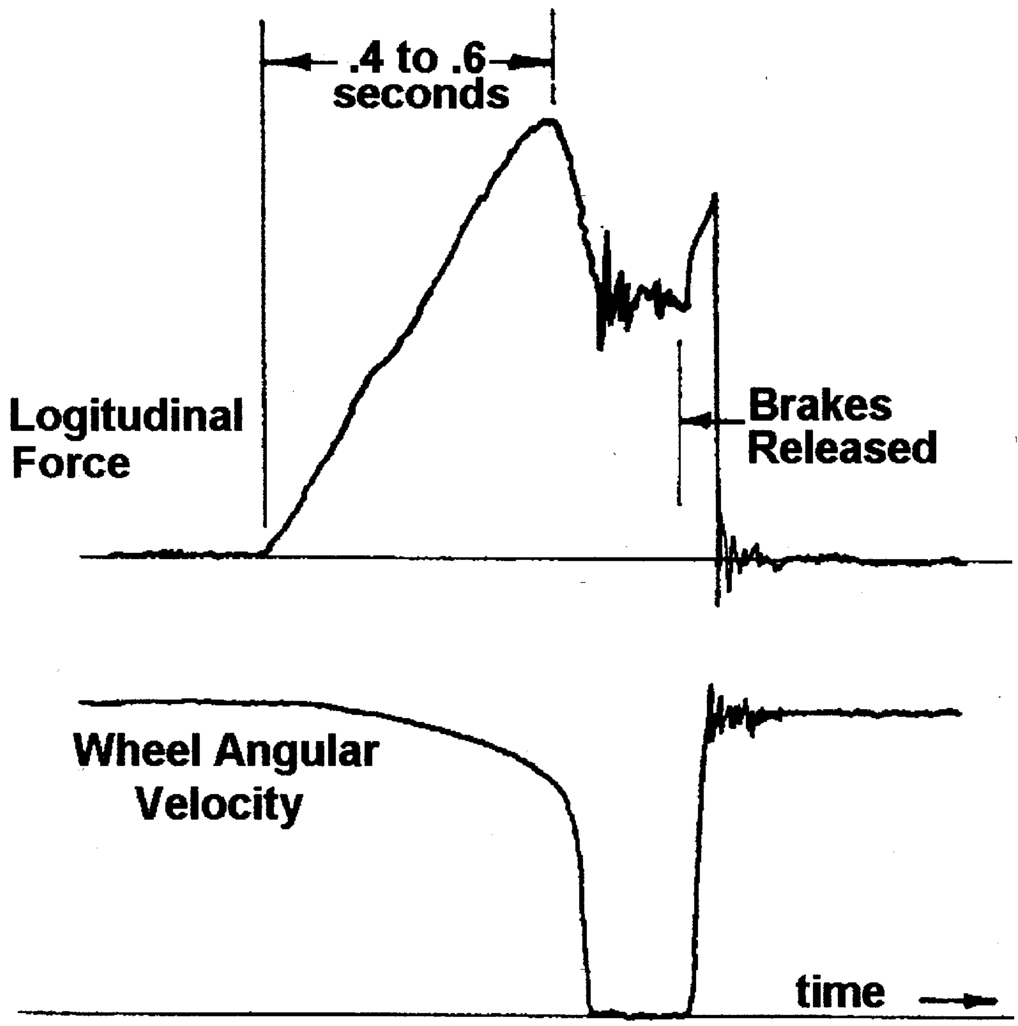



Figure 11 - Approximate Time Scale
of a Typical Lockup Cycle

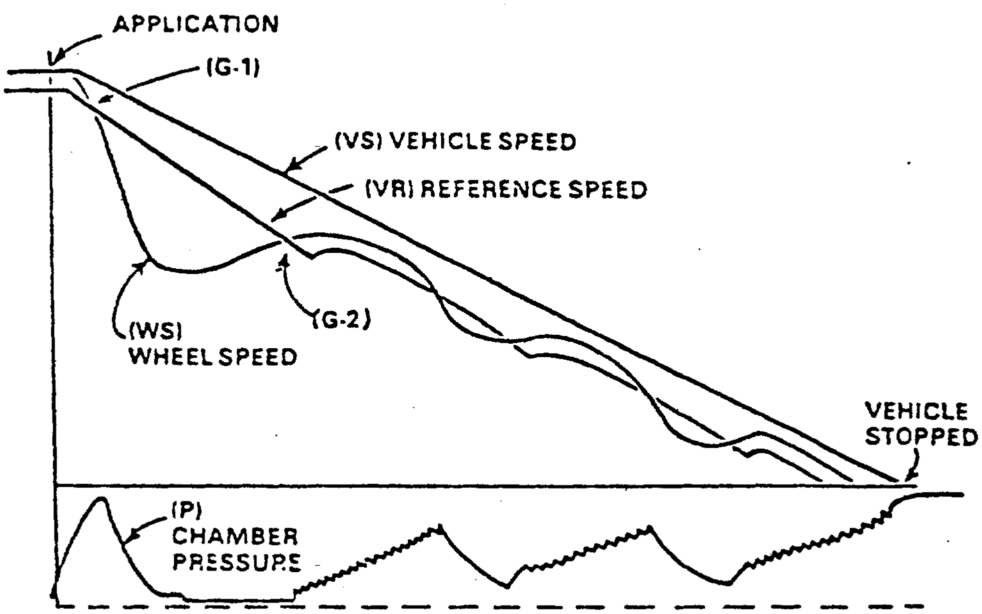



Figure 12 - Reference Speed Control Cycle

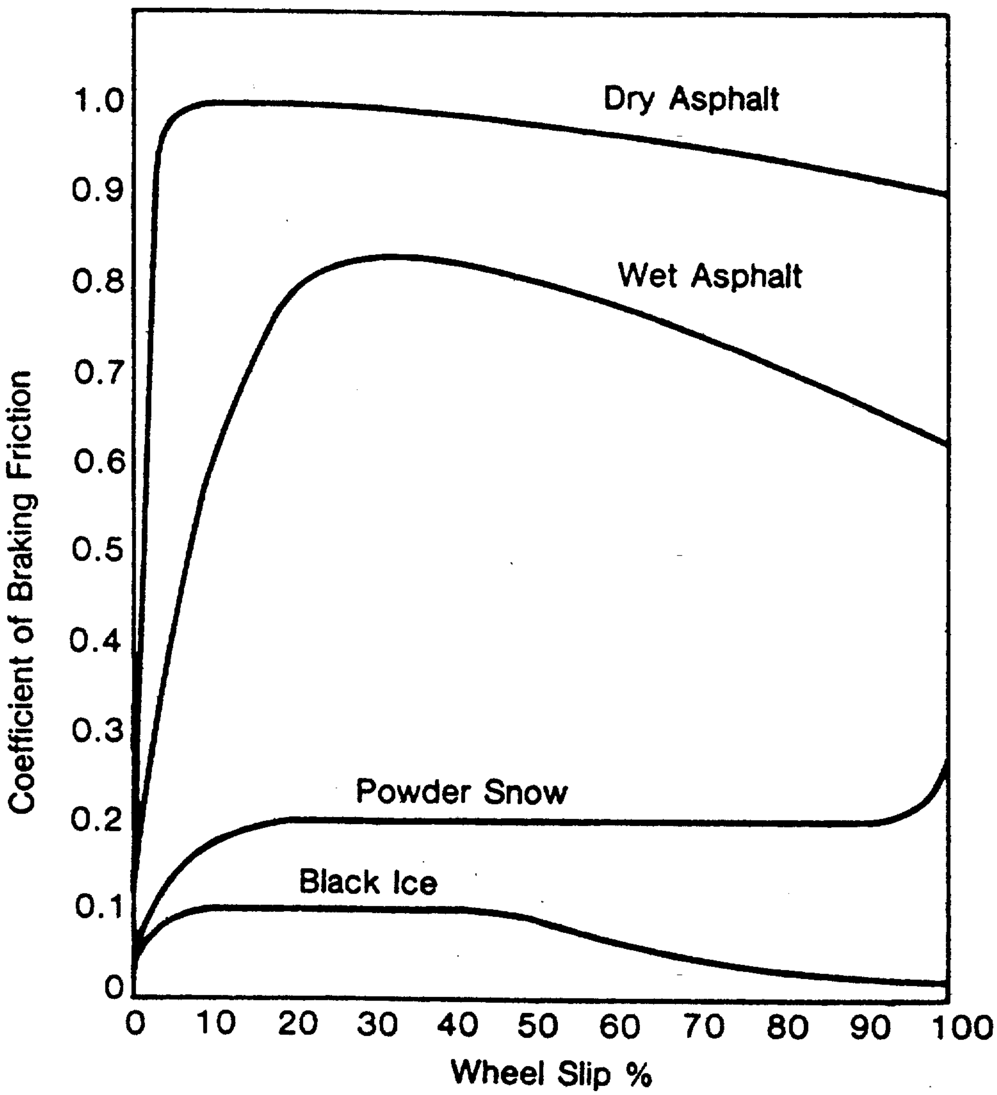



**Figure 13 - Effect of Surface on Braking Friction**

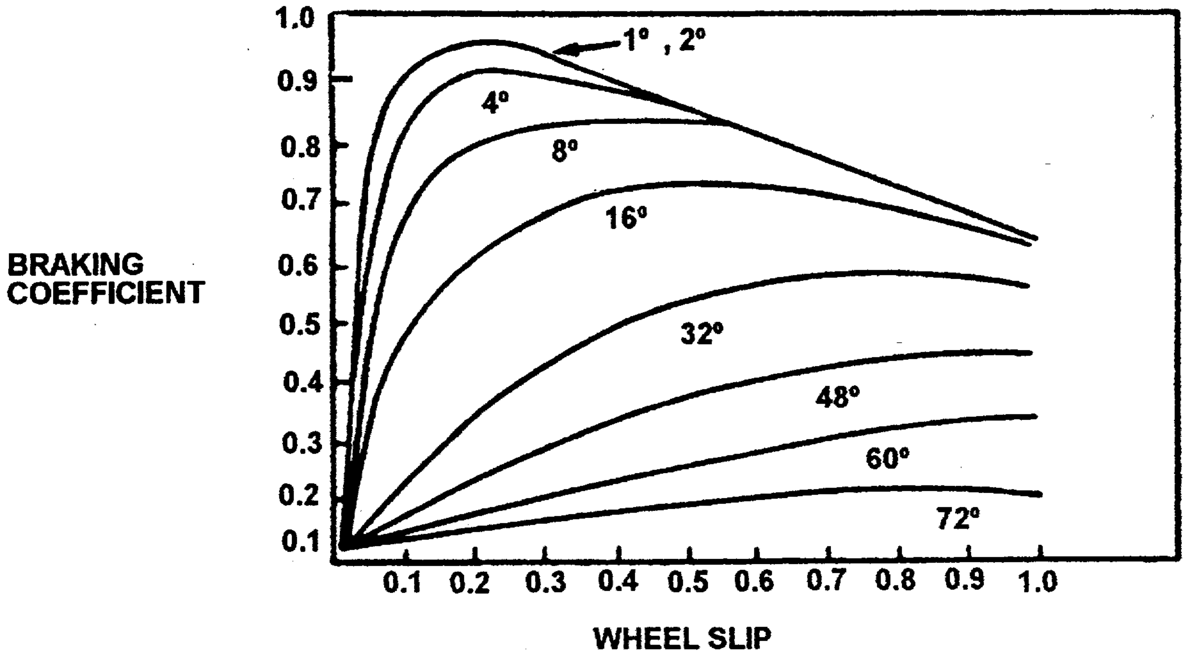



Figure 14 - Effect of Slip Angle on Braking Friction

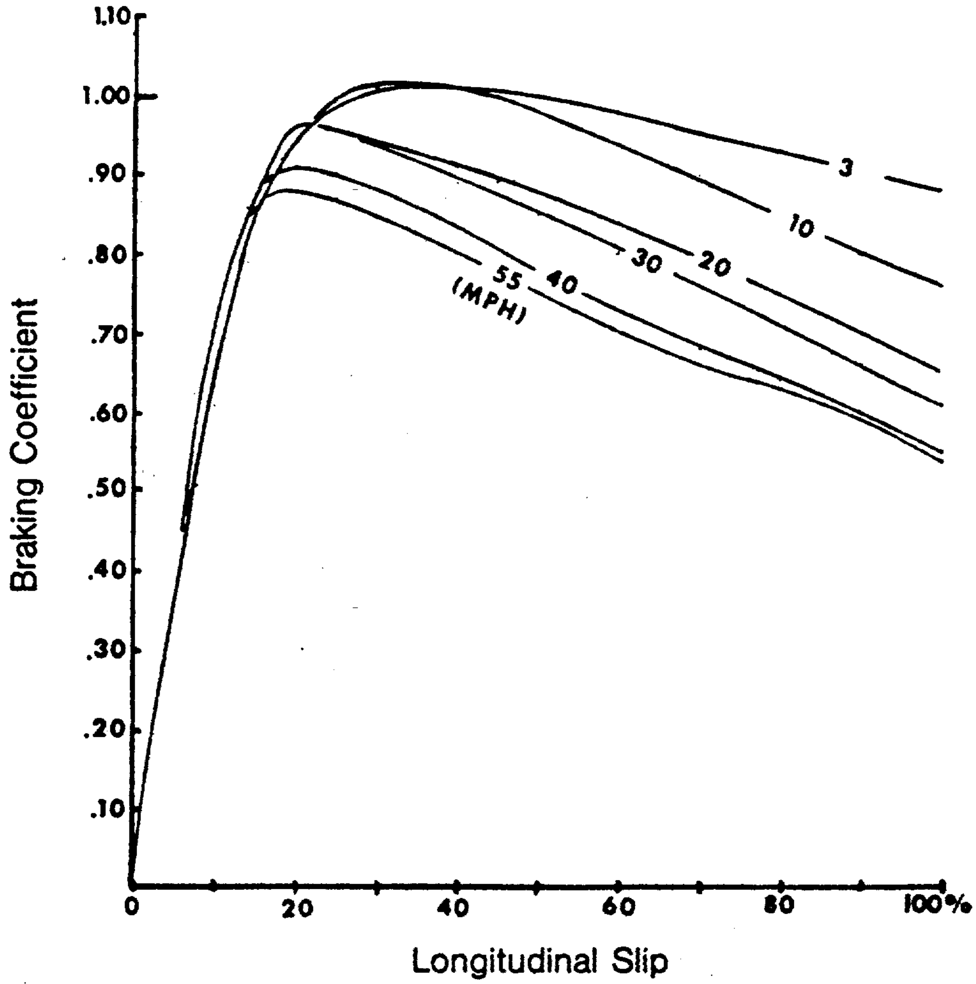



Figure 15 - Effect of Vehicle Speed on Braking Friction

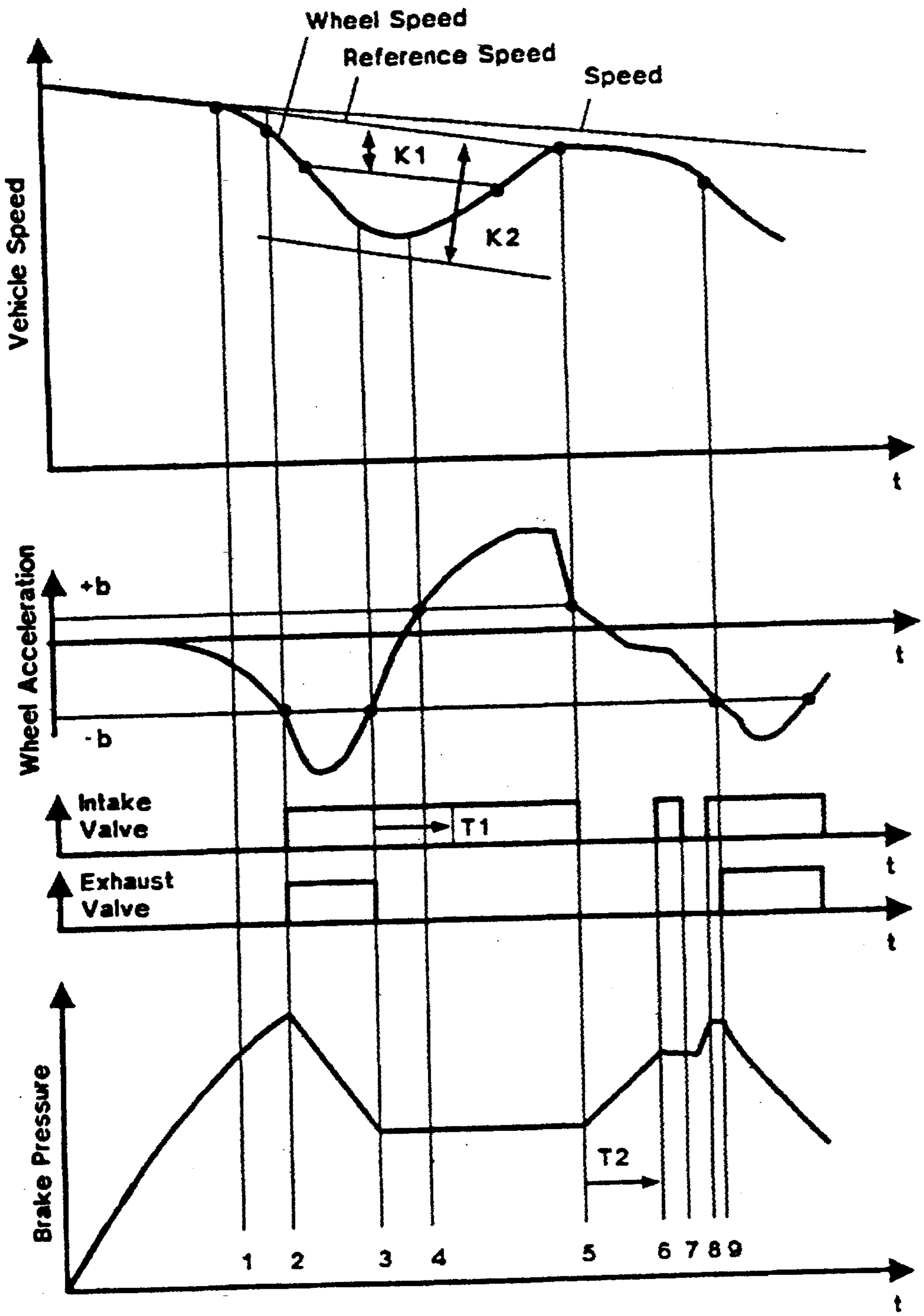



Figure 16 - An Antilock Control Cycle

Figure 17-a

Brake Chamber Pressure, Treadle Valve Pressure and ABS Modulator Activity

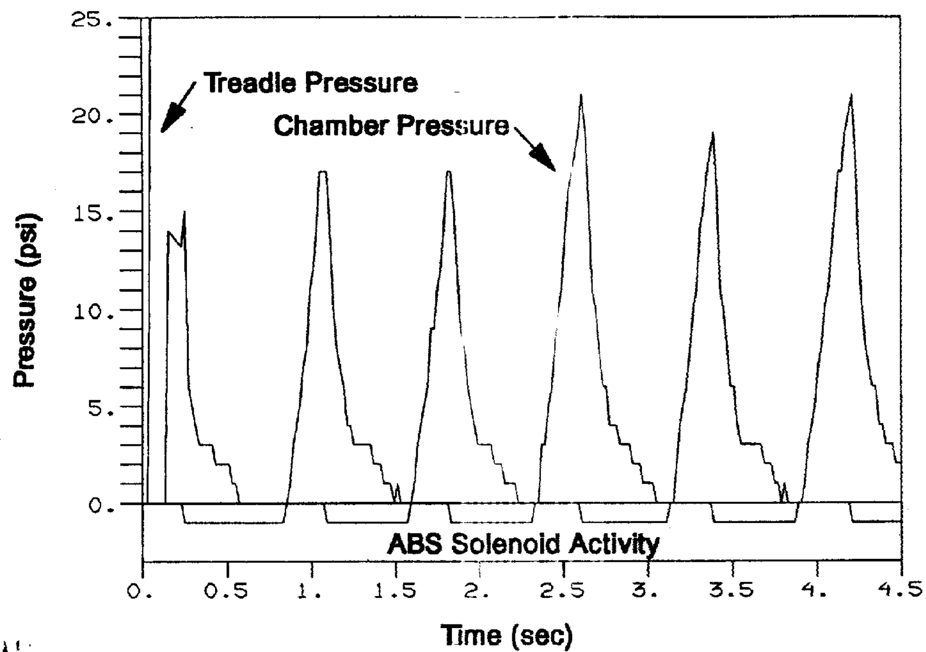



Figure 17-b

Wheel Speed and ABS Modulator Activity

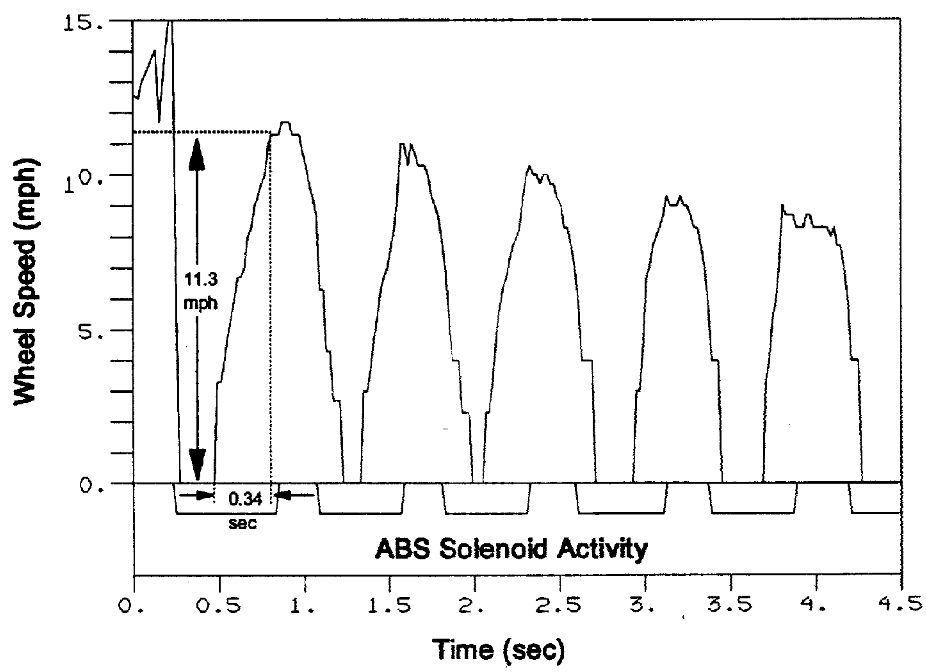



Figure 17

Data for the Left Wheel of the Intermediate Drive Axle of a 6X4 Truck Tractor with a 6S/6M ABS During a Lightly Loaded, Full Treadle Application Stop on Ice

**Figure 18-a**

**Brake Chamber Pressure and Treadle Valve Pressure**

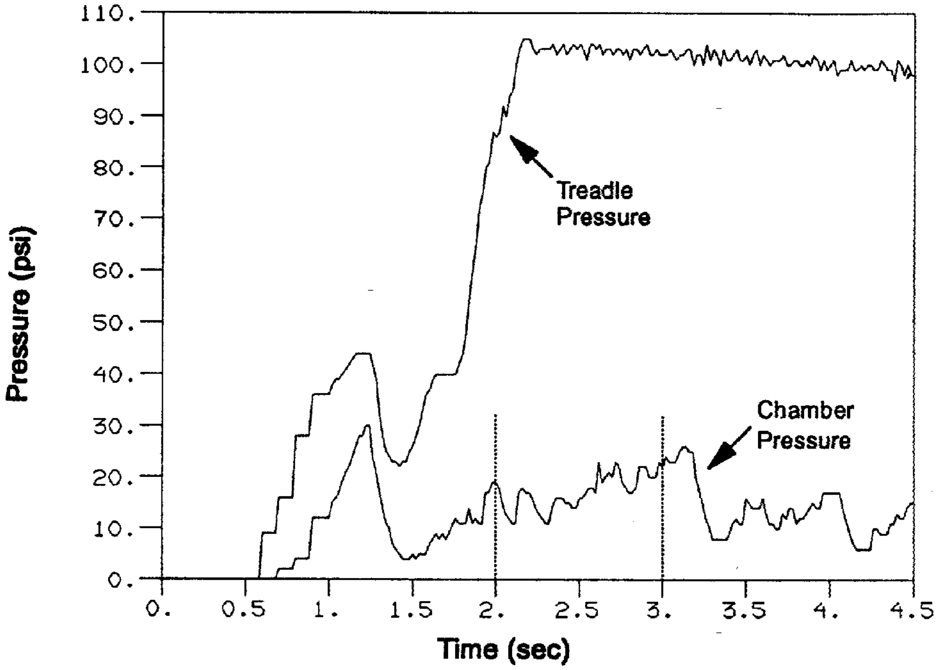



**Figure 18-b**

**Wheel Speed**

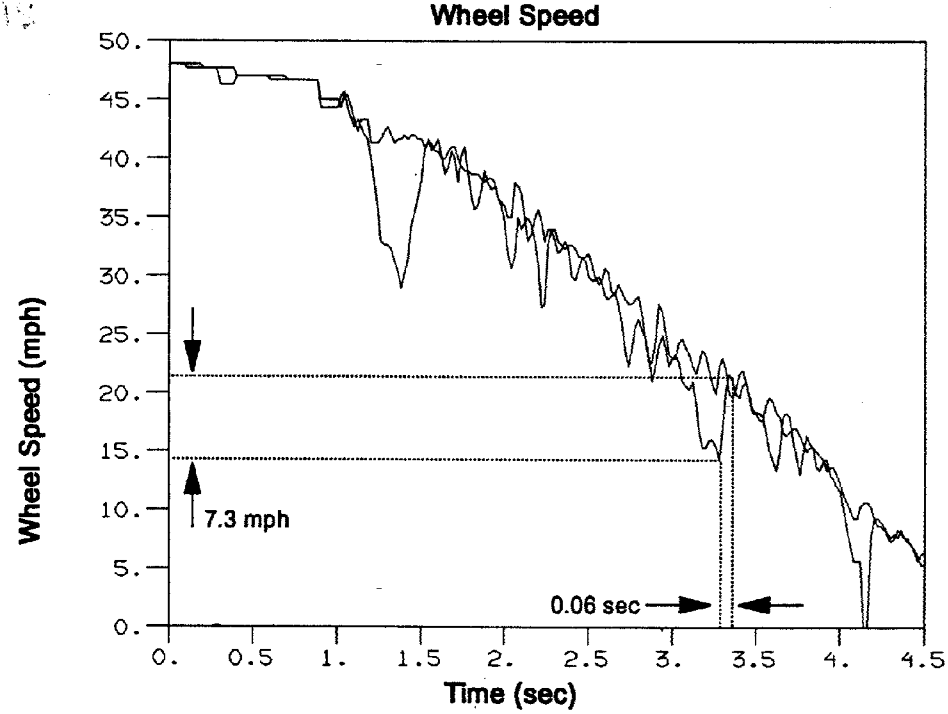



**Figure 18**

**Data for the Left Wheels of theTandem Drive Axle of a 6X4 Truck Tractor with a 6S/6M ABS During a Lightly Loaded, Full Treadle Application Stop on aHigh Friction Surface.**

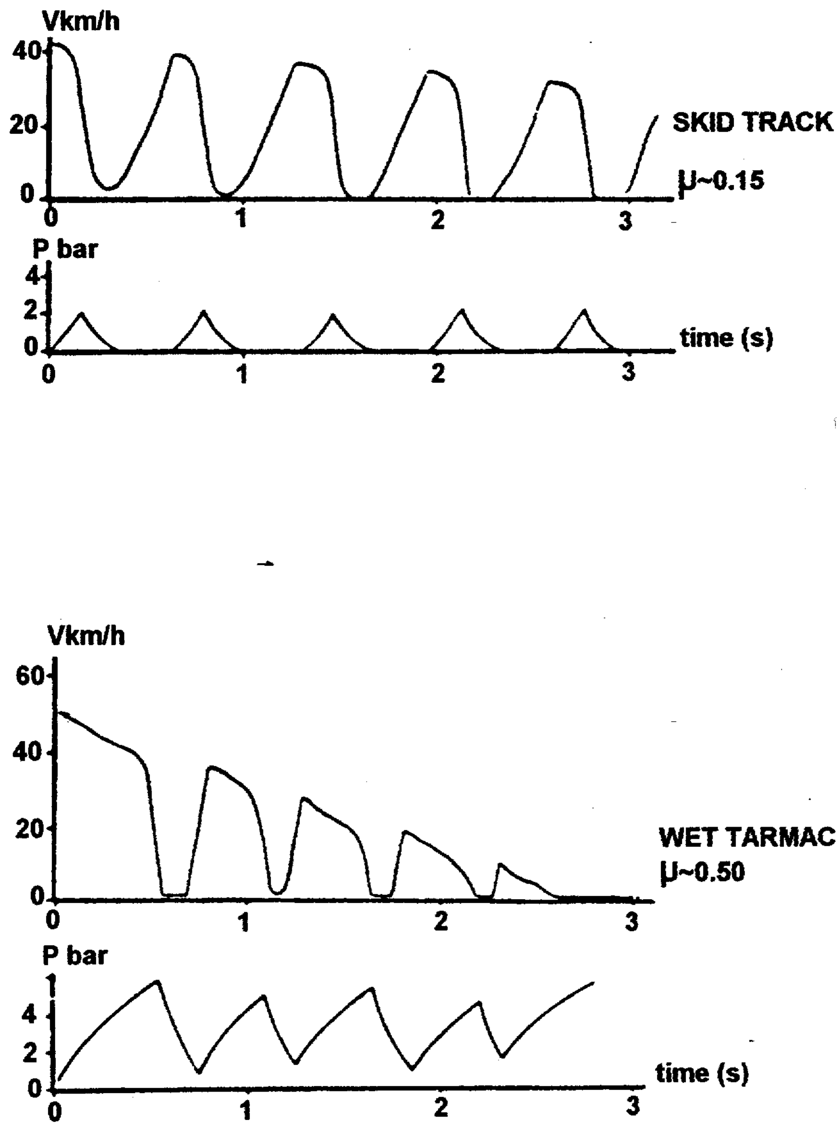



Figure 19 - Wheel Speed and Brale Pressure Response - 1970's Antilock System

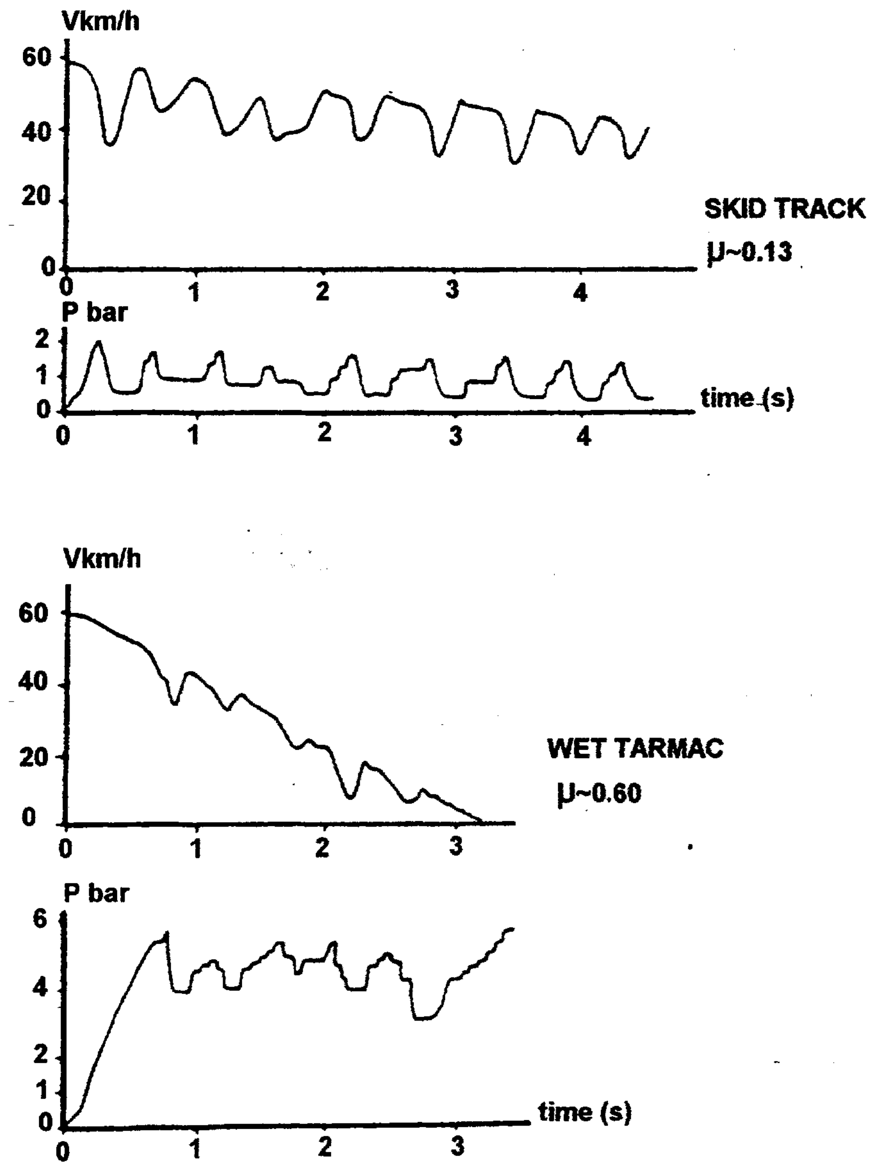



Figure 20 - Wheel Speed and Brale Pressure Response - 1980's Antilock System

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