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National Transportation Safety Board Safety Study
Heavy Vehicle Airbrake Performance

(U.S.) National Transportation Safety Board, Washington, DC

29 Apr 92

U.S. Department of Commerce
National Technical Information Service
NTIS

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NTSB/SS-92/01 PB92-917003

# NATIONAL TRANSPORTATION SAFETY BOARD

## WASHINGTON, D.C. 20594

## SAFETY STUDY

## ADOPTED: APRIL 29, 1992

## NOTATION 5692


This study focuses on brake system issues and makes recommendations that address the systemic problems associated with heavy vehicle brake-related accidents.

The accident and inspection data highlighted three safety issues: the difficulty of keeping commercial vehicle brake systems adjusted; the problem of maintenance deficiencies; and the role of brake system components in vehicle instability accidents.

As a result of this study, recommendations were issued to the National Highway Traffic Safety Administration, the Federal Highway Administration, the 50 States and the District of Columbia, the Interstate Towing Association, the Towing and Recovery Association of America, the National Private Truck Council, the Owner-Operator Independent Drivers Association, the American Trucking Associations, the Motor Vehicle Manufacturers Association, the Professional Truck Driver Institute of America, the Society of Automotive Engineers, and airbrake component manufacturers.

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## EXECUTIVE SUMMARY


In accidents investigated by the National Transportation Safety Board (Safety Board), numerous brake deficiencies are cited as causal factors. Although the Safety Board has recommended changes to address these recurring problems, brake system deficiencies continue to be factors in accidents. In 1989, the Safety Board began a study to determine the effectiveness of airbrake systems on heavy trucks and buses. This study focuses on brake system issues, highlights potential problems, and makes recommendations that address the systemic problems associated with heavy vehicle brake-related accidents.

The Safety Board developed two data sources in support of this study. Over a 17-month period, the Safety Board investigated selected brake-related accidents involving heavy trucks and buses. In addition, an extensive program to inspect heavy trucks was conducted in five States. This inspection program enabled the Safety Board to assess the mechanical condition of heavy truck brake systems.

The Safety Board also used several national and State data sources in support of this study. Data sources on heavy vehicle accidents were analyzed to identify the scope of brake-related accidents as well as the potential costs to society associated with such accidents. The analysis indicated that this type of accident may be substantially underrepresented in the available data sources, primarily because of underreporting by investigating agencies.

The accident and inspection data highlighted three safety problems. First, it is difficult to keep the brakes found on most commercial vehicles adjusted appropriately; these brakes have only a small tolerance range before becoming out of adjustment. Second, most brakes on heavy vehicles are not well maintained, often resulting in out-of-adjustment brakes. Third, the accident investigations illustrated that brake system components were factors in certain vehicle instability accidents.

As a result of this study, recommendations were issued to the National Highway Traffic Safety Administration, the Federal Highway Administration, the 50 States and the District of Columbia, the Interstate Towing Association, the Towing and Recovery Association of America, the National Private Truck Council, the Owner-Operator Independent Drivers Association, the American Trucking Associations, the Motor Vehicle Manufacturers Association, the Professional Truck Driver Institute of America, the Society of Automotive Engineers, and airbrake component manufacturers.

NATIONAL TRANSPORTATION SAFETY BOARD
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# SAFETY STUDY

# HEAVY VEHICLE AIRBRAKE PERFORMANCE

## CHAPTER 1

## PURPOSE OF STUDY

### Background

Over the last 22 years, the Safety Board has investigated numerous major accidents involving commercial vehicles over 10,000 pounds gross vehicle weight. Because these accidents were catastrophic, the Safety Board conducted in-depth investigations to determine primary and contributing causal factors. In certain accidents, mechanical issues such as brakes were highlighted.

Historically, the Safety Board has investigated two types of commercial vehicle accidents in which brakes have been cited as factors: downhill runaways and loss of control accidents. From 1974 to 1985, the Safety Board investigated at least 12 major downhill runaway highway accidents that resulted in a total of 67 fatalities and 169 injuries. Although the accidents involved various human performance issues, one common factor cited in each accident was either defective or improperly adjusted brakes. In most of these accidents, the condition of the vehicle service brakes before the accident significantly reduced the driver's ability to stop or slow on steep downgrades. (See **table 1**.)

The Safety Board also has investigated loss of control accidents involving commercial vehicles. Many of these accidents occurred on wet pavement and involved some form of vehicle instability. Although these accidents also involved various human performance issues, a factor cited in these accidents was the condition of the vehicle service brakes or brake components.

Two recent Safety Board studies--one in 1988 and another in 1990--have addressed brake deficiencies in accidents. In 1988, the Safety Board issued a safety study after investigating 189 heavy truck accidents of which 32 involved braking problems.[1] The most prevalent braking problem cited in these accidents was out-of-adjustment brakes. The final report concluded that the braking performance of heavy trucks is affected significantly by improper or inadequate maintenance, and made recommendations to the National Highway Traffic Safety Administration,

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[1] Safety Study--*Braking Deficiencies on Heavy Trucks in 32 Selected Accidents* (NTSB/SS-88/05).

the American Trucking Associations, and the National Private Truck Council to address brake maintenance issues.[2]

**Table 1.--Downhill runaway accidents in which brakes were a factor.**

| Location/Report Number | Number Injured | Number Killed | Date |
|---|---|---|---|
| 1. Bishop, CA (NTSB/HAR-75/05) | 1 | 7 | 6/29/74 |
| 2. Ashland, OR (NTSB/HAR-76/01) | 15 | 3 | 5/9/75 |
| 3. Valley View, OH (NTSB/HAR-77/03) | 16 | 8 | 8/20/76 |
| 4. Marion, NC (NTSB/HAR-78/03) | 3 | 5 | 5/21/77 |
| 5. Marion, NC (NTSB/HAR-78/06) | 3 | 1 | 1/25/78 |
| 6. Jasper, AR (NTSB/HAR-81/01) | 13 | 20 | 6/5/80 |
| 7. Frostburg, MD (NTSB/HAR-81/03) | 12 | 3 | 2/18/81 |
| 8. Birmingham, AL (NTSB/HAR-85/03) | 17 | 0 | 4/12/84 |
| 9. Wofford Heights, CA (NTSB/HAR-85/01) | 39 | 2 | 7/7/84 |
| 10. Van Buren, AR (NTSB/HAR-86/03) | 0 | 9 | 6/21/85 |
| 11. Eureka Springs, AR (NTSB/HAR-87/01-SUM) | 20 | 5 | 9/13/85 |
| 12. Bramwell, WV (NTSB/HAR-87/01-SUM) | 30 | 4 | 10/13/85 |
| TOTALS | 169 | 67 | |

[2]See appendix A for a summary of prior Safety Board recommendations on heavy vehicle airbrakes.

Although the 1988 safety study identified problems with the maintenance of commercial vehicle brakes, it did not determine the scope of brake system problems in heavy vehicle accidents. Further, the investigations did not focus on reasons for poor maintenance, such as improper carrier practices, inadequate training of service staff, lack of procedures for inspecting and adjusting vehicle brakes, and problems with brake system design.

A 1990 Safety Board study also identified problems with brake deficiencies. This study focused on driver fatigue and drug/alcohol use in heavy truck accidents.[3] All 182 accidents involving a fatal injury to a driver of a heavy truck in California, Colorado, Georgia, Maryland, New Jersey, North Carolina, Tennessee, and Wisconsin were investigated over a 1-year period from October 1, 1987, through September 30, 1988. Although the Safety Board did not specifically address brakes, braking system deficiencies were noted in eight of the accidents. Because this sample of heavy truck accidents included only those accidents in which the driver of the heavy truck was a fatality, the findings on the vehicle condition in these accidents could not be extrapolated. In fact, the Safety Board cautioned "readers to avoid generalizing the results of the study to either all fatal truck or all truck accidents."

The purpose of the current study is to determine how brake system maintenance and components influence heavy vehicle accidents and to formulate potential solutions for reducing braking problems related to maintenance and design.[4] In support of the study, various data sources were reviewed to determine the scope of brake-related accidents involving commercial vehicles over 10,000 pounds gross vehicle weight.

## Scope of Problem

Data Sources.--The Safety Board reviewed several national and State data sources to identify how frequently vehicles equipped with airbrakes are involved in brake-related accidents. In the past, studies that indicated that heavy trucks were disproportionately involved in crashes were challenged because they did not include proper exposure data (vehicle miles of travel for trucks). Other studies used a stratification of data that produced contradictory results.[5,6]

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[3]Safety Study--*Fatigue, Alcohol, Other Drugs, and Medical Factors in Fatal-to-Driver Heavy Truck Crashes* (NTSB/SS-90/01).

[4]See appendix B for a list of references and appendixes C and D for lists of terms and acronyms used in this study.

[5]Crabtree, Joseph D., and Agent, Kenneth R., *Accident Rates by Vehicle Type*, May 1982 (UKTRP-82-12).

[6]Meyers, Warren S., *A Comparison of Truck and Passenger Car Accident Rates on 34 Limited Access Facilities*, Automobile Club of New York, January 1981.

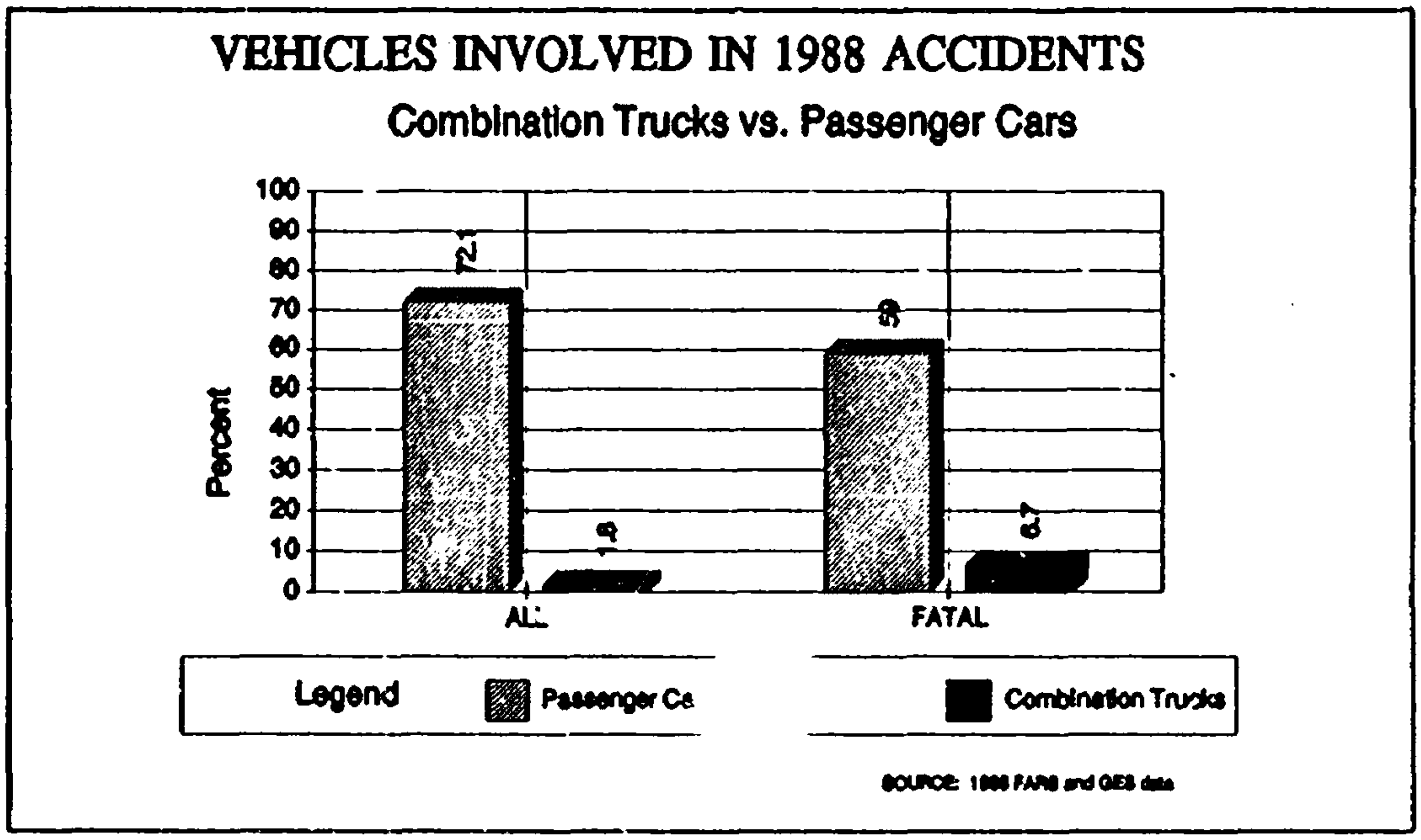


**Figure 1.--Analysis of 1988 vehicle accidents.**

During the last decade, increased efforts have been made to collect data on vehicle exposure through the collection of transportation census data, carrier data, and other established national data. Data from the National Highway Traffic Safety Administration (NHTSA) for 1988-1990 indicate that combination trucks[7] accounted for about 1 percent of the registered vehicles, but for almost 5 percent of the vehicle miles traveled.[8]

Combined 1988 figures from both the Fatal Accident Reporting System (FARS)[9] and the General Estimates System (GES)[10] show that combination trucks represented 6.7 percent of all vehicles involved in fatal accidents, compared to 59 percent for passenger cars (See **figure 1.**) However, these percentages can be misleading. When the accident data are normalized based on

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[7]A combination truck is a truck/tractor with one or more trailing units.

[8]*Selected Highway Statistics and Charts for 1988, 1989, and 1990,* Federal Highway Administration, October 1989, 1990, and 1991.

[9]Fatal Accident Reporting System data are collected by the NHTSA. This system includes data beyond the normal police report, such as information on the accident, the vehicles, and the persons involved.

[10]GES data are obtained from a nationally representative probability sample selected from all police investigated crashes that occur annually. The system provides data about all types of crashes involving all types of vehicles.

exposure, a different picture emerges. Data from FARS and GES permit accurate assessment of long-term trends in accident rates. (See **figures 2** and **3**.) Although combination vehicles are involved in only half as many total accidents per 100 million miles as passenger cars (**figure 2**), **figure 3** suggests that in fatal accidents the statistics are reversed, with combination vehicles being involved in about twice as many fatal accidents per 100 million miles as passenger cars.

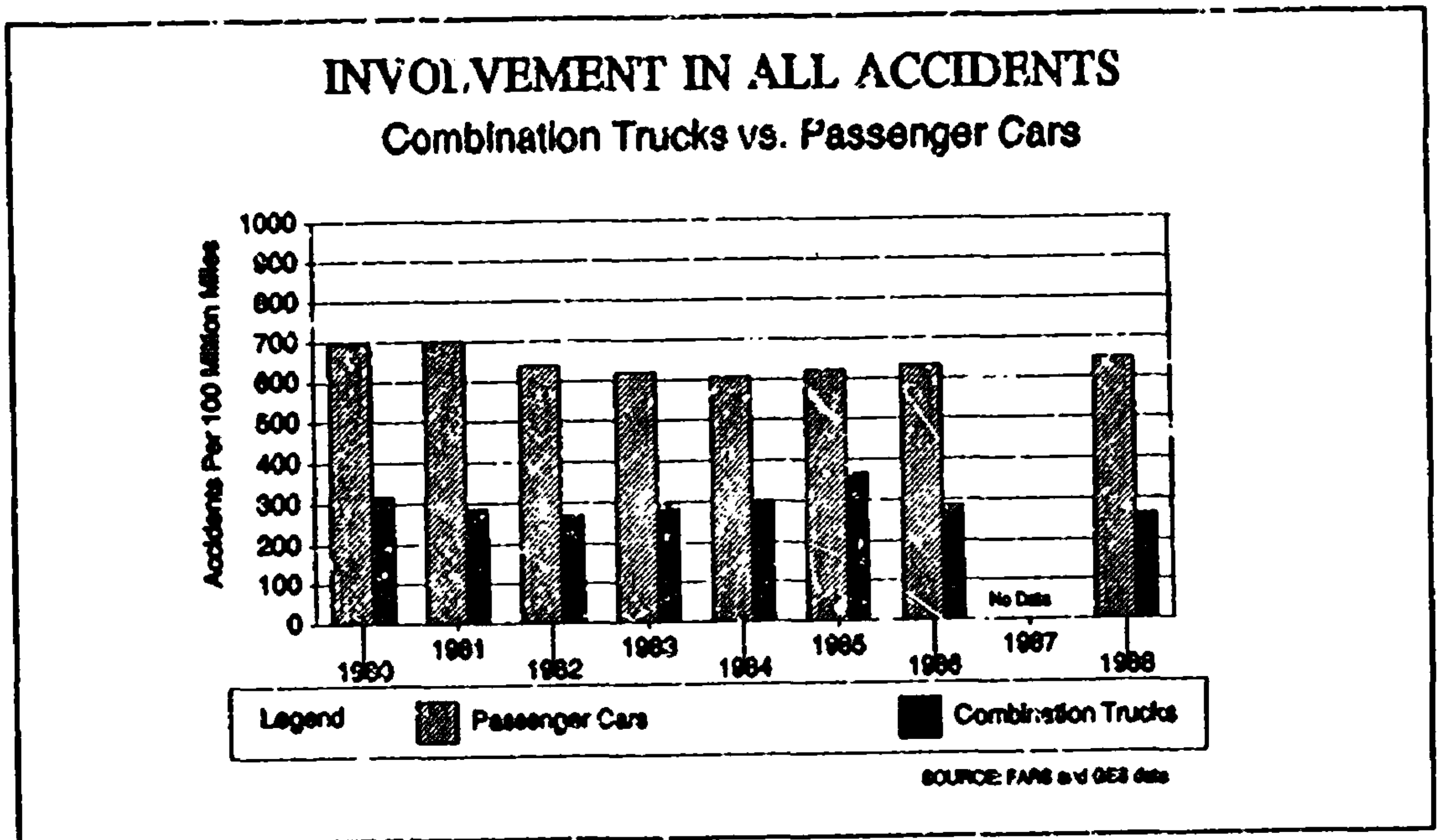


**Figure 2.--Combination truck involvement in all accidents.**

A study[11] by the Federal Highway Administration (FHWA) indicated that the reduced number of truck crashes may have resulted in part from increased vehicle inspections sponsored by the Motor Carrier Safety Assistance Program (MCSAP). The study, which analyzed data from 13 States over a 4-year period (1984-1988), revealed that the number of truck crashes involving mechanical deficiencies decreased by 12 percent. Reported brake defects[12] decreased more than 15 percent. Also, a review of the 1988 to 1990 FARS data indicates that the number of fatal crashes involving combination trucks decreased by 15.6 percent. (See **table 2**.) Despite this favorable trend, the Safety Board believes that further improvements to truck brake systems are necessary for continued reduction in the number of severe truck accidents.

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[11] *Evaluation of Vehicle Out-of-Service Criteria--Final Report*, Jack Faucett Associates, FHWA-OMCS, May 1991 (DTFJGI-89-C-00062).

[12] The term defect is used in many police reports and FARS data to denote maintenance deficiencies rather than gross component failures.

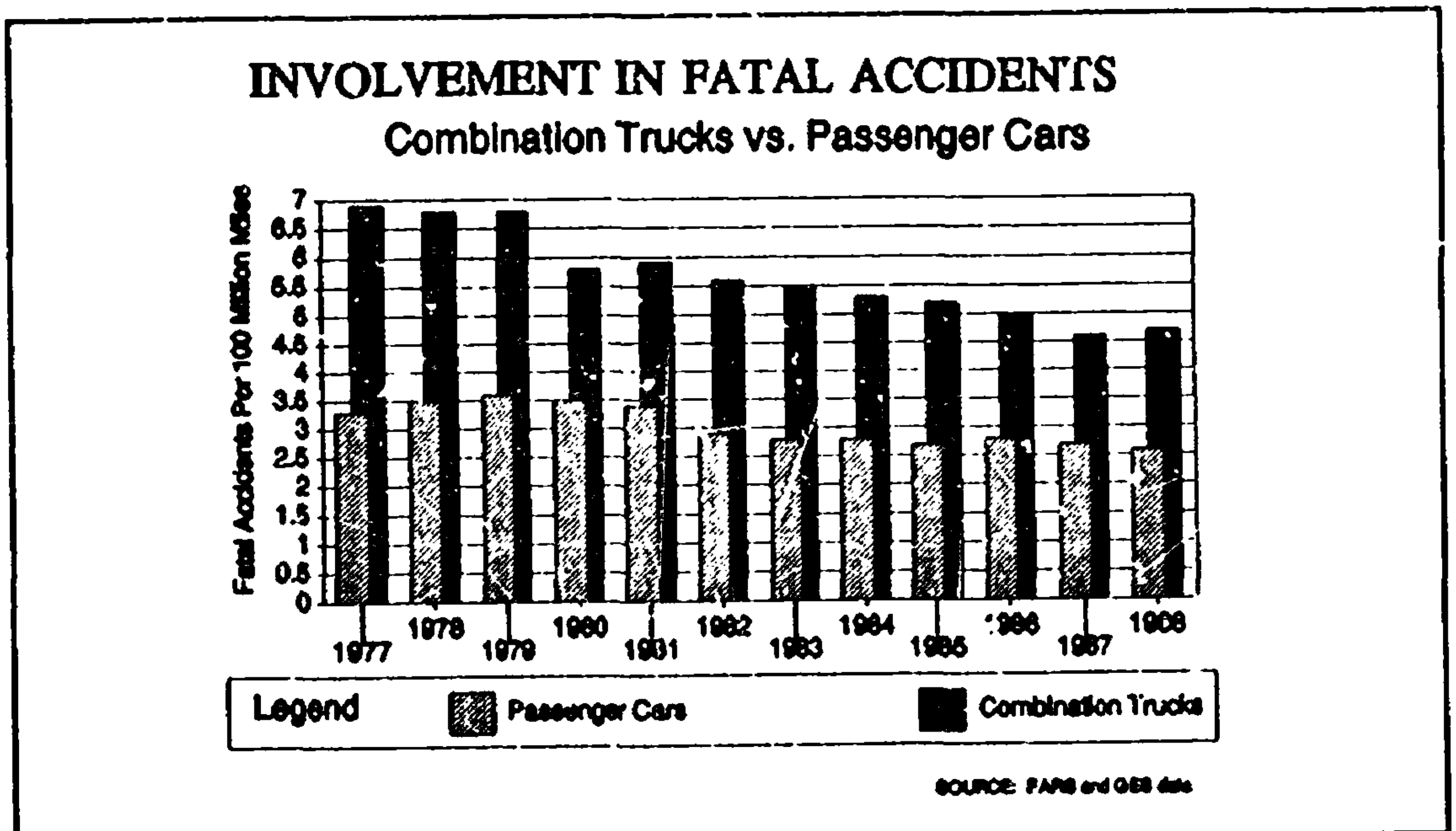


Figure 3.--Combination truck involvement in fatal accidents.

Table 2.--Fatal truck accidents involving deficient brakes.

| Category | 1988 | 1989 | 1990 | TOTAL |
|---|---|---|---|---|
| Fatal accidents involving medium/heavy single-unit trucks | 1,014 | 1,056 | 973 | 3,043 |
| Deficient brakes cited (single-unit trucks) | 34 (3.4%) | 44 (4.2%) | 50 (5.1%) | 128 (4.2%) |
| Fatal accidents involving combination trucks | 3,798 | 3,467 | 3,207 | 10,472 |
| Deficient brakes cited (combination trucks) | 111 (2.9%) | 102 (2.9%) | 88 (2.7%) | 301 (2.9%) |

The Safety Board also reviewed the 1988 to 1990 FARS data to determine the number of fatal accidents involving trucks over 10,000 pounds where a "defective brake system" was coded based on police reports. Accident statistics were compiled for both single-unit and combination trucks by number of trailer units. The data (see table 2) indicated that from 138 to 146 fatal accidents per year involving heavy trucks with defective brakes occurred over the 3-year period.

Defective brake systems were reported in the FARS data in 4.2 percent of the fatal accidents involving single-unit trucks. The data indicated that from 34 to 50 fatal accidents per year involving single-unit trucks with defective brakes were reported over the 3-year period.

A defective brake system was reported in the FARS data in 2.9 percent of the fatal accidents involving combination trucks, 93.4 percent of which were tractors with single trailer units. The data indicated that from 88 to 111 fatal accidents per year involving combination trucks with defective brakes occurred over the 3-year period. According to this FARS data, combination trucks with defective brakes had a lower percentage of fatal accidents than single-unit trucks, but were involved in almost two to three times as many fatal accidents as single-unit trucks.

This report will focus primarily on combination vehicles equipped with airbrake systems. However, many problems highlighted for combination vehicles also apply to single-unit vehicles (straight trucks and school buses) over 10,000 pounds because they are equipped with similar airbrake systems. Therefore, single-unit vehicles will also be discussed in the report.

The NHTSA combined the 1989 FARS and GES data in a study of truck crashes.[13] The data from the study indicated that for all types of trucks with gross vehicle ratings (GVRs) over 10,000 pounds, nationwide, about 150 fatal and 2,000 injury crashes involved brake system deficiencies as reported by the police. The GES data indicated that about 60 percent of all truck crashes involved combination trucks or tractors.[14] Extrapolating from this data, it can be estimated that in 1989, about 60 percent of the 2,000 injury crashes (1,200) involved combination trucks with brake deficiencies.

The Safety Board attempted to estimate the costs of brake-related fatal, injury, and property damage accidents from the limited national data available. These estimates were calculated from FARS, GES, and FHWA data and indicated that the minimum cost to society of accidents involving combination trucks with braking deficiencies was about $360 million for 1989. See appendix B for details.

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[13]*Summary of Medium & Heavy Truck Crashes in 1989*, U.S. Department of Transportation, National Highway Traffic Safety Administration, DOT HS 807 739, July 1991.

[14]Clarke, R.M., Radlinski, R.W., and Knipling, R.R., *Improved Brake Systems for Commercial Motor Vehicles*, National Highway Traffic Safety Administration, DOT HS 807 706, April 1991.

Underreporting.--The Safety Board found that brake deficiencies are not commonly reported as factors in heavy vehicle accidents. Thus, a further analysis was conducted of the FARS and GES data for information about accidents that may have been brake related, but were not coded as brake related.

Jackknife accidents, particularly where the jackknife was the first event in the accident sequence, have a high probability of being brake related. Most jackknifes occur after hard braking situations in which undesirable brake system characteristics (for example, unbalanced brake torque at different axles) and roadway characteristics (wet pavement) combine to produce the rapid sequence of events leading to wheel lock-up and loss of control. Typically, jackknifes can occur during hard brake applications under three conditions if certain brakes are out of adjustment, if a limiting valve restricts braking at the front axle, or, to a lesser extent, if tire frictional properties vary on specific axles. In the 3-year period (1988-1990), 248 fatal accidents involved combination trucks in which jackknife was reported as the first event. Only 14 of these accidents were reported to involve deficient brakes.

According to the 1989 GES data, 316 fatal, 2,000 injury, and 6,000 property damage only (pdo) accidents involved jackknifes before and during the impact. However, FARS data for 1988 to 1990 indicated that about 30 percent of the jackknifes were reported to have occurred as the first event The Safety Board was unable to determine the percentage of jackknife accidents that result directly from brake deficiencies. However, it was assumed that about 50 to 90 percent of those accidents in which jackknife was the first event were brake related.[15] By projecting the FARS data results for jackknifes as the first event to fatal accidents, it can be estimated that annually about 47 to 85 (as compared to the 14 reported above) fatal accidents occurred (1988-1990).

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[15]In a technical review meeting with industry representatives on February 20, 1991, it was agreed that the 50- to 90-percent range was a reasonable estimate.

# CHAPTER 2

# PROJECT METHODOLOGY

## Preparation

At the beginning of the project, a comprehensive literature review was completed. NHTSA reports from its Crash Avoidance Research division and its Heavy Duty Vehicle Research office, University of Michigan Transportation Research Institute (UMTRI) reports, Society of Automotive Engineers (SAE) papers, and information from brake manufacturers were studied during the project planning. (See appendix F for accident case summaries, and appendix G for a matrix containing causal factors in these accidents.)

An attempt was made to solicit as much information and input as possible from a wide variety of sources before the project was begun. Representatives of UMTRI, the NHTSA, the American Trucking Associations (ATA), and the Motor Vehicle Manufacturers Association (MVMA) attended meetings and discussed accident selection criteria, accident sample size, types of data to gather, methods of analysis, and issues to examine. The Safety Board gained much valuable information and assistance from suggestions made by representatives of these groups.

The literature review and technical briefings shaped almost all phases of the planned project. As a result of this input, the Safety Board established accident notification criteria, developed investigative procedures, and selected the equipment necessary for a thorough and objective evaluation of the data collected. The brake inspections in five States were planned later to relate the accident data findings to the larger context of operational heavy trucks.

## Accident Selection Criteria

To keep the notification criteria as simple as possible, accidents were grouped into two categories--stopping accidents and instability accidents. This included accidents in which the responding police agency judged that the vehicle appeared to have taken longer than normal to stop or in which a pre-impact jackknife or instability existed. To limit the number of notifications, accidents were considered only if they resulted in tow-away damage to the heavy vehicle or serious injury to one of the involved vehicle occupants. Police agencies were asked to contact the appropriate Safety Board office when the above criteria were met.

Several types of accidents that met the criteria could not be thoroughly investigated. Accidents taking place on busy interstates in metropolitan areas where the roadway could not be closed to gather needed evidence were not investigated. Accidents in which police already had released the heavy vehicle or where someone had inadvertently altered the vehicle evidence also were not investigated.

The Safety Board investigated 189 heavy truck accidents from 1985 through 1987[16] and found that brake-related evidence was often altered after an accident. Investigations of 182 heavy truck accidents during 1987 and 1988 identified the same problem.[17] Often, slack adjusters on some or all springbrake-equipped axles were completely "backed off," or altered, to more easily move wrecked vehicles. In some cases, investigators found that wrecker drivers were unfamiliar with the practice of "caging"[18] springbrakes and thus unintentionally destroying valuable evidence when they altered the brake adjustment.

This situation could be remedied if all States would adopt regulations similar to those in Washington State prohibiting the alteration of brake adjustment evidence. If a towing company is found to have altered a brake adjustment, the company is eliminated from the list of companies called to accidents by the State. This would help to protect the evidence needed to evaluate the role of brake-related deficiencies in heavy vehicle accidents.

Problems with busy roadways and unpreserved vehicle evidence prevented the Safety Board from investigating numerous accidents for this study. The Safety Board believes that both situations affect the reliability of current databases for use in quantifying accident-related brake deficiencies. Information in these databases is provided by police who respond to the accidents. Although the police can respond more quickly to an accident than can the Safety Board, the police are also under pressure to open busy roadways as quickly as possible. As a result, the police may not have the time to identify brakes as a factor causing or contributing to an accident. Police also face the problem, as did the Safety Board, of towing companies backing off the springbrakes.

Safety Board investigators were notified when an accident occurred that matched the study criteria. Once notified, the Safety Board investigator first verified with an on-scene source that the braking system on the air-braked vehicle had not been disturbed during the rescue or vehicle removal procedures. If all vehicle evidence had been preserved and the roadway could be accessed, the investigator traveled to the scene. This would begin an investigation to determine if the cause of the accident might be brake related.

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[16]NTSB Report--*Case Summaries of 189 Heavy Truck Accident Investigations*, October 12, 1988 (NTSB/SS-88/05).

[17]NTSB Report--*Fatigue, Alcohol, Other Drugs, and Medical Factors in Fatal-to-Driver Heavy Truck Crashes* (Volume 2), February 5, 1990 (NTSB/SS-90/02).

[18]When air is lost in an airbrake system, a safety feature results in the mechanical application of springbrakes installed on certain air chambers. The vehicle is immovable until the brake is released by recompression of the spring. This release can be accomplished either by reapplying air to the chamber or by mechanically compressing the spring through use of a caging bolt. To release the brake, the caging bolt is inserted through the back of the springbrake housing and turned to recompress the spring. Either of the methods will preserve brake adjustment evidence.

Soon after the study began, it became apparent that instability accidents were difficult to identify. Often a police investigator did not determine that a jackknife was pre-impact until long after the police accident investigation began. By this time, many other items of evidence could have been lost or destroyed. Because the Safety Board investigations in this study required independently collected evidence and because much of the on-scene data were not available, these cases were not investigated.

Toward the later stages of the study, the instability portion of the criteria was expanded to seek accidents in which a tractor in combination with at least one trailer crossed the centerline of a nondivided highway and struck an oncoming vehicle. In these cases, the Safety Board investigator attempted to determine whether it was likely that the heavy vehicle's inability to stay in its travel lane was brake related. Several of these accidents proved to be fatigue related where the driver, after falling asleep, drifted over the centerline and collided with an oncoming vehicle.

Press reports with suspicious sounding vehicle dynamics prompted several preliminary investigations. When investigators checked into the circumstances of these accidents, a few were determined to be brake-related accidents.

The Safety Board did not attempt to obtain a random or statistical sample of heavy vehicle accidents. The Safety Board only sought to analyze heavy vehicle brake-related accidents and determine how the braking system contributed to the cause or severity of the accident.

**Investigative Procedures**

The Safety Board decided to establish the probable cause of each accident, necessitating comprehensive and thorough investigations. This was done so that the issue of brake performance could be placed in proper context with other factors in the accident. As a result, Safety Board investigators analyzed driver and environmental factors as thoroughly as vehicle factors.

The driver's medical history, driving record, and driving experience and activities in the 72 hours preceding the accident provided insight in evaluating how human performance issues fit into the cause of the accident. If possible, a toxicological analysis for the presence of alcohol or other drugs was performed. Interviews of occupants and other witnesses also yielded useful information that helped to evaluate driver and vehicle performance in the accidents.

Investigators gathered information relating to environmental factors such as weather, roadway surface, sight distance, signing, highway geometry, and roadway evidence; in addition, a scale diagram was drawn for reconstruction purposes. When appropriate, investigators documented both the scene and the vehicles with photographs.

To calculate stopping ability, a three-axis decelerometer[19] mounted in a passenger vehicle established the sliding coefficient of friction[20] for the tire/road interface. A decelerometer measures the rate of deceleration as a percentage of gravity, which relates directly to the sliding coefficient of friction when all wheels are locked and sliding. Based upon extensive Safety Board testing during the planning stages of this study and for consistency in our analysis, the resulting coefficient of friction was reduced 20 percent[21] to account for the difference between passenger car tires and heavy truck tires. In some of the investigations, a drag sled or skid trailer operated by the State was used to obtain the tire/road sliding coefficient of friction.

Because maintenance was suspected as an important and perhaps causal issue in brake-related accidents, the Safety Board questioned both the carrier and the driver about maintenance practices, especially as they related to the vehicle's braking system. In some cases the carrier and driver could not be questioned because of advice from the carrier's or driver's attorney.

A complete description of the braking system was recorded, including the chamber size, drum diameter, slack adjuster type and length, condition of linings, pushrod stroke, and tire rolling radius. Timing of the application air to each set of axles was measured, as was the threshold pressure--the pressure at which each lining first touched the brake drum. Investigators also recorded the air pressure at each set of axles as pressure was gradually increased at the connection between the tractor and trailer.

Safety Board investigators gathered dimensional data and axle weights for each heavy vehicle. Tire and suspension data were also collected so that computer models could be used accurately to simulate the accident dynamics. (See appendix H for heavy truck investigation data collection forms.) The specific vehicle parameters were obtained and used for input into the computer simulation. Specific input variables are identified in the NHTSA publication, "A Factbook of the Mechanical Properties of the Components For Single-Unit and Articulated Heavy Trucks" (DOT HS 807 125).

In several cases, the airbrake system was rebuilt due to extensive accident damage. Safety Board investigators worked with hired mechanics to rebuild the system. The rebuilt system was matched as closely as possible to that of the accident vehicle, including line lengths and diameters.

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[19]This instrument measures acceleration along the yaw, pitch, and roll axes of the vehicle.

[20]The sliding coefficient of friction is defined by J. S. Baker and L. B. Fricke in *The Traffic-Accident Investigation Manual* as "a number representing the resistance to sliding of two surfaces in contact; . . . the force parallel to a surface required to keep in motion an object sliding on that surface, divided by the force of the object against that surface; measured in pounds per pound."

[21]The Safety Board realizes that there is variability in the adhesive properties between truck and car tires, primarily due the differences in the rubber compounds. The truck tire friction values range from 70 to 90 percent of the sliding coefficient of friction for passenger car tires.

**Analysis of Accident Data**

The Safety Board developed methodology that related the braking system's condition to the vehicle's ability to stop. This analytical method was used to evaluate those accidents where stopping distance was a factor. Instability accidents required additional evaluation accomplished by using a computer simulation model. Some of the more complex accident reconstructions required the use of both analytical methods.

The accident summaries in appendix F and in the rest of the document frequently use the term "brake efficiency." The Safety Board defines this as the vehicle's ability to use the available tire/road sliding coefficient of friction. Thus, a vehicle with a 50-percent braking efficiency could only decelerate at a rate of 0.35 g's if the sliding coefficient of friction for the tire/road interface were 0.70. To calculate the efficiency and actual braking forces at each wheel, the torque output, which depends on the mechanical components at each wheel and their states of adjustment, must be determined for each brake. The procedures used by the Safety Board for these calculations are outlined in appendix I.[22]

After evaluating several computer programs that simulate heavy vehicle dynamics, the Safety Board chose UMTRI's most recent work, Phase 4, for this study. This computer model, titled, "A Computerized Model For Simulating the Braking and Steering Dynamics of Trucks, Tractor-semitrailers, Doubles, and Triples Combinations,"[23] was funded by the Motor Vehicle Manufacturers Association. The model provides for the simulation of up to three trailers as well as a wide variety of roadway geometry. The computer simulation predicted jackknifes, opposing lane encroachments, and successful braking and steering maneuvers for the various component and brake adjustment changes.[24]

Each instability accident was replicated using the phase 4 model. This replication provided a baseline for assessing brake system improvements. Brake components were then hypothetically changed to evaluate the potential role of brake improvements in the crash. The simulation then predicted vehicle position and speed on the roadway, vehicle heading, yaw rotational speed, and articulation angle in relation to time. This allowed the Safety Board to evaluate how proper brake adjustments or changes in components would affect a vehicle's position, thus predicting the jackknifes and opposing lane encroachments.

A "path following model" was used to simulate a driver attempting to keep the vehicle on a specific path, both with and without an antilock braking system. For each instability

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[22]*Heavy Truck Deceleration Rates as a Function of Brake Adjustment* (SAE 919126).

[23]See appendix J for a description of the Phase 4 program, applications, input parameters, and validation.

[24]The Phase 4 model was run on a VAX 3500 computer at the mechanical engineering department of the University of Washington in Seattle. The computer time was donated by the university.

accident, a path which the driver was most likely seeking to follow was put into the computer model. The computed results reported how closely the driver was able to stay on the desired path, given the braking and other conditions of the vehicle. Factored into the model were operator response lag and the distance ahead the driver could see.[25]

Each instability accident was evaluated with the same antilock model. The simple antilock model used in the simulation program was applied to the drive axles and sensed wheel lock-up at each wheel. The antilock model provided modulation for each axle independently.

The Safety Board evaluated each vehicle's stopping ability and stability characteristics in conjunction with driver performance issues and environmental factors. Factors such as driver inattention, driver impairment, sight distances, and roadway geometry were routinely considered in evaluating the probable cause and contributing factors for these accidents. As a result, 6 of the 18 accidents in which brake deficiencies affected the outcome were found to be primarily caused by deficiencies in driver performance. (See case summaries 3, 6, 7, 8, 15, and 16 in appendix F.) In Case 6 (Rochester, Washington), for example, a driver failed to perceive stopped vehicles in his lane.

**Safety Board Heavy Truck Inspection Project**

Accidents investigated for this study were not randomly selected. Because of the biased selection of the accidents, it was important to compare the condition of the accident vehicles with the condition of heavy trucks nationwide. The Safety Board developed an inspection project for this purpose during which investigators documented a sample of heavy trucks' brake systems and their conditions. The Safety Board then compared the deficiencies from this sample group with those found in the accident investigations.

Two samples were taken from each of the five selected States. One sample was taken on the interstate system and another sample was taken off the interstate system to ensure that a variety of trucking operations were represented. The States included in the inspection projects were Florida, Pennsylvania, Oregon, Illinois, and Texas. These States were selected for their geographical and operational representation, past inspection activity, and willingness to participate in the projects. From late March through early December 1990, 910 five-axle vehicles were inspected in the interstate sample, and 610 five-axle combination vehicles were inspected in the off-interstate sample.

The inspections were conducted by 5 to 6 Safety Board investigators along with 7 to 21 State personnel. For consistency and quality control, the same data collection procedure was used at each site. All inspections applied the Commercial Vehicle Safety Alliance (CVSA) North

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[25] Generic values for operator response lag and distance viewed ahead were used at the suggestion of UMTRI engineers.

American Standards.[26] The project director was present at all 10 inspection sites; 3 days were spent at each location, with the actual inspections taking place between the hours of 7 a.m. and 3 p.m. While all inspection locations had easily accessible by-pass routes, no attempt was made to deter vehicles from avoiding inspections or to inspect the traffic on by-pass routes. This mirrors the commonly used procedures of State inspection teams.

The sampling procedure was designed to eliminate any systematic bias and is believed to have achieved a representative sample of five-axle combination trucks. To ensure that every five-axle truck passing through the scales had the same opportunity to be inspected, every "n"th vehicle was stopped. Depending on the traffic flow at each site, the value of "n" was adjusted to avoid backed up traffic. At one inspection site, every 5th (n=5) five-axle combination was inspected, while at another, every 12th (n=12) truck was examined. The value of "n" ranged from 1 truck at one site to 20 at another.

Although some of the State agencies chose to conduct a full Level 1[27] inspection independently, the Safety Board looked primarily at braking systems. For the Safety Board sample, about 100 items of data were gathered for each vehicle, and all dimensional items were measured.[28] The entire braking system was documented, including the types of slack adjusters, the manufacturer of any automatic adjusters, the lengths of the slack adjusters, the chamber sizes, the measured pushrod strokes at a 90-psi brake application,[29] the drum diameters, and the tire rolling radii. In addition, axle weights were recorded for each combination vehicle.

Much of the data gathered on the brake systems were used to generate braking efficiencies. These values were calculated according to the procedures set forth in appendix I.

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[26]The CVSA has developed uniform methods for inspecting commercial vehicles and uniform standards for placing those vehicles out of service. The CVSA's authority derives from the Federal Highway Administration regulations in 49 CFR 350, established pursuant to Section 402 of the Surface Transportation Assistance Act of 1982 and reauthorized by the Commercial Motor Vehicle Safety Act of 1986.

[27]A level 1 inspection is defined as an inspection that includes each of the items specified by the North American Uniform Driver/Vehicle Inspection criteria. As a minimum, North American standard inspections must include an examination of the following: driver's license, medical examiner's certificate and waiver if applicable, driver's record of duty status as required, hours of service, seat belt, vehicle inspection report, brake system, steering mechanism, wheels, tires, coupling devices, suspension, frame, fuel system, exhaust system, windshield wipers, lighting devices, cargo securement, and hazardous material requirements as applicable.

[28]See appendix K.

[29]Application pressure commonly used by State commercial vehicle inspectors to measure pushrod travel. This pressure was verified by monitoring cab instruments or a pressure gauge inserted at the service gladhand connection.

These efficiencies were calculated for a variety of brake temperatures: cold,[30] 400 °F, 600 °F, and 900 °F. Braking efficiencies were projected for the combination vehicles both at actual weight and gross vehicle weight rating (GVWR).

After the first inspection sample on the interstate system, a pressure gauge was installed at the trailer air line connections to monitor the pressure applied by the driver while the pushrod strokes were measured. Data collected at the inspections included information about type and size of the carrier, CVSA decal[31] information, origin and destination of the trip, and the individual responsible for brake adjustments. Vehicle description information and manufacturer's data were recorded. A sample database form is included in appendix K.

**Project Time Span**

The preparation work and research phase was completed during the first 6 months of 1989. No set time span was established for the investigative work. The first accident investigation began in July 1989, and the last case investigation began in November 1990. Two cases initiated before the investigative phase of the project were added to the study because they met the criteria and because the necessary data had been gathered during the Safety Board investigation.[32]

The last case file was completed in March 1991. The comparative analysis of all accident data, including the computer simulation analyses of the instability accidents, was performed from February through April 1991.

Two technical reviews were held in conjunction with this study. The first technical review was held in May 1991 in Washington, D.C., in which representatives from both Government and industry were invited to comment on methodology and preliminary findings of the data. Organizations represented were the American Trucking Associations, the Truck Trailer Manufacturers Association, the Motor Vehicle Manufacturers Association, Roadway Express, Inc., Ryder Transportation Resources, Freightliner Corporation, Mack Trucks, Navistar International, U.S. Department of Transportation Office of Motor Carriers, National Highway Traffic Safety Administration, and University of Michigan Transportation Research Institute. The second technical review was held in February 1992 to discuss relevant sections of the draft report and potential areas of recommendation.

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[30]For the purposes of these calculations, cold brakes were defined as 70 °F.

[31]The CVSA decal indicates that both the vehicle and driver have passed a Level I inspection and generally exempts the vehicle from being selected for reinspection during the following 3-month period.

[32]These two accidents took place in Buna, Texas, in December 1988, and in Lyons, Colorado, in June 1989. See appendix F.

**Summary of Findings**

In the 18 brake-related accidents investigated and analyzed, the brake system was found to have been a causal or contributing factor in 15 of the accidents and to have influenced the severity of the other 3 accidents. Thirteen of the 18 accidents involved maintenance deficiencies, the majority of which were out-of-adjustment brakes. Closely associated with the maintenance deficiencies was a lack of awareness by drivers and carriers regarding when to have brakes adjusted. Inadequate brake adjustments contributed to both an increase in stopping distance and a stability-related loss of control. Both conditions resulted in serious accidents.

Other accident factors involved the braking components themselves. These included small brakes on the steering axle and automatic limiting valves installed on the steering axle, both of which contributed to the premature lock-up of the drive or trailer axle wheels. The accidents included in this study demonstrate how certain brake components brought about increased stopping distances and handling problems.

The inspections of 1,520 five-axle combinations revealed that approximately 60 percent of the inspected vehicles had brake defects[33] serious enough for the vehicles to be placed out of service.[34] The out-of-service percentages for all identified defects varied from a low of 40 percent at the Pennsylvania interstate inspection location to a high of 82 percent at the Texas off-interstate inspection location. The percentage of vehicles placed out-of-service for brake system deficiencies varied from a low of 37 percent at the Oregon interstate inspection location to a high of 76 percent at the Texas off-interstate inspection location. Further discussion of the inspection-related data can be found in chapter 4; the Safety Board also intends to examine this issue in a subsequent report.

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[33] Brake defects include deficiencies such as out-of-adjustment brakes, excessive air leaks, and grease contaminated linings. A single brake is considered defective due to adjustment when the pushrod stroke reaches 1/4 inch past the manufacturer's recommended adjustment limit. However, two brakes that are slightly out-of-adjustment (less than 1/4 inch past the adjustment limit) can also equal one defective brake. A vehicle is placed out of service when 20 percent of its brakes are found defective.

[34] Vehicles placed out of service generally must be parked until repairs are made. In some situations, the inspector may allow the vehicle to be driven to the nearest available repair facility.

# CHAPTER 3

## OPERATION OF AIRBRAKE SYSTEMS

Most heavy road vehicles use an airbrake system to decelerate. The most common is an S-cam system; a much less frequently used system is the wedge system. Both systems will be discussed below. Although some tractors and trailers now have air disc brakes, no vehicles with this system were involved in the accidents investigated for this study.

This chapter explains the design and function of airbrake systems by discussing components of the three major subsystems: the supply, control, and foundation brake subsystems. **Figure 4** provides a diagram displaying the structure of an airbrake system. This chapter also discusses requirements for and problems with inspecting airbrake systems.

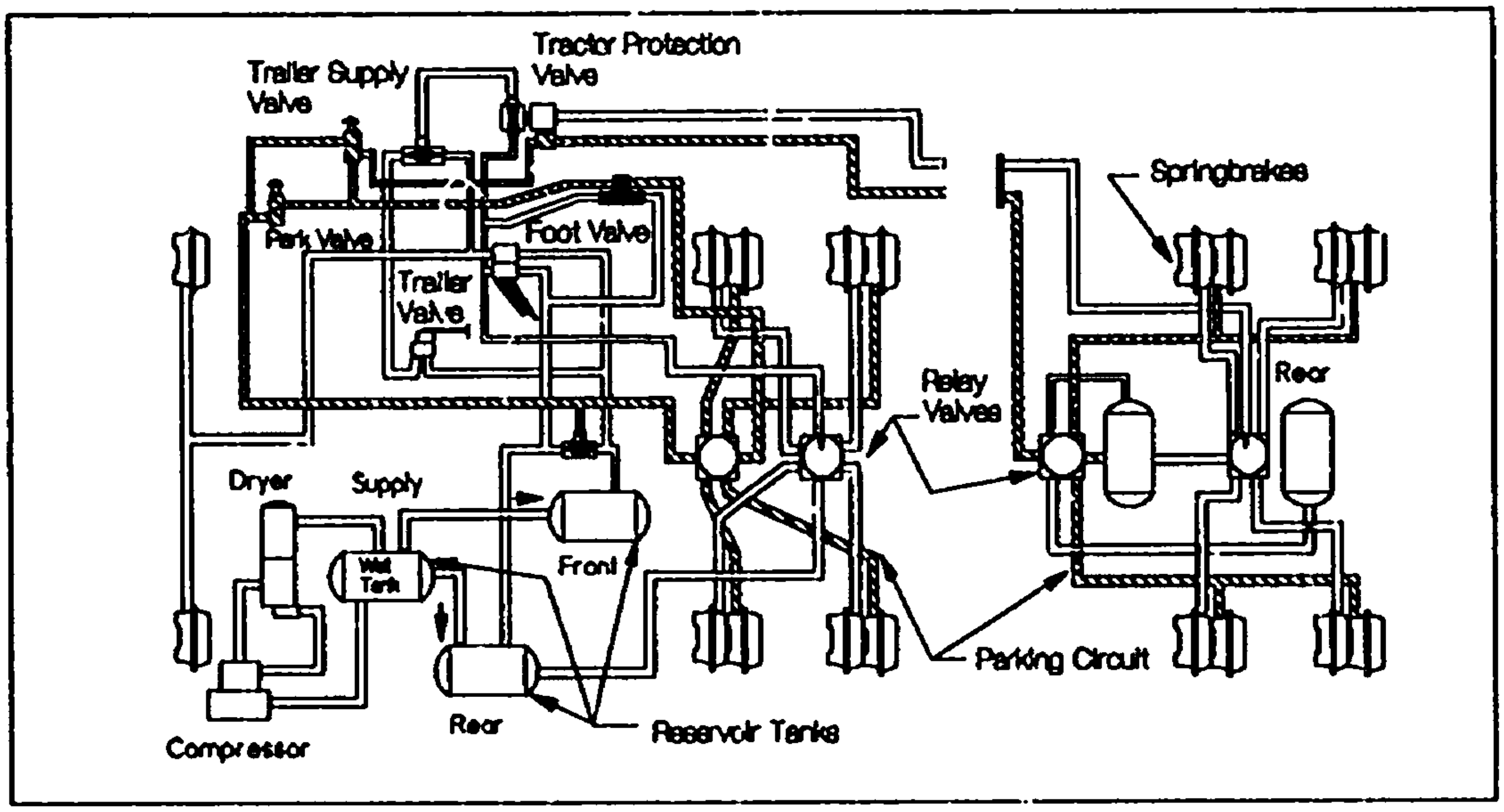



**Figure 4.--Basic dual circuit airbrake system.**

### Supply System Components

Both the S-cam and the wedge brake systems use the same air supply components. The air compressor, which provides the pressurized air to the system, is driven by the engine through either a belt or gear. The compressor is normally equipped with a governor that unloads the compressor at a predetermined pressure, usually around 120 psi, and signals the compressor to begin pumping air again at 90 to 100 psi. When a low pressure switch senses a pressure below

60 psi, the switch will send a signal to a l'w air warning device, usually activating a buzzer, light, or flag.

The air compressor pumps air into one of several reservoir tanks, the first of which is referred to as the "wet tank." These reservoirs are protected from being overpressurized by safety valves that release air above a set pressure. As air is compressed, it heats up. Then, as it enters a cooler tank, the moisture in the air condenses. This moisture collects in the tank closest to the compressor, along with any oil that leaks past the piston rings of the compressor. For this reason, the first tank (wet tank) has a drain valve installed, so these contaminates can be expelled. Check valves are installed between the reservoirs to prevent air from passing back to the compressor while it is in an unloaded condition. Many vehicles use an air dryer to extract as much moisture or oil as possible before it enters the wet reservoir tank.

**Control System Components**

This portion of the a brake system is composed mainly of valves and hoses that direct and regulate the flow of compressed air to foundation brake components. When the foot valve (or treadle valve) is pressed, air is directed from the air reservoirs to all brake chambers. This foot valve supplies air at varying pressures, depending on how far the brake pedal is depressed.

The foot valve normally releases air directly to the steering axle air chambers. The foot valve is also used to release air through a relay valve to the drive axles of a tractor and the trailer axle brake chambers. This is accomplished by using the air that passes through the foot valve as control air to trigger the relay valve. The relay valve opens and allows air to flow from an air reservoir to the brake chambers. The reservoirs, normally located close to the air chambers they serve, supply air to these chambers more quickly than if it had to flow from the wet tank through the foot valve. The delay in time from when the foot valve is pressed to when the brake is applied is referred to as lag time. The foot valve simply sends a signal of air (usually through a smaller diameter line for speed purposes) to the relay valve, directing it to release air from its reservoir to the brake chambers.

On most vehicles the foot valve is a dual-control foot valve. Dual circuit brake systems split their air flow after the wet tank (the first tank after the air compressor), with air flowing into a primary and a secondary reservoir. Splitting the air system provides a safeguard that ensures that if one circuit develops an air leak, the other circuit will still be able to provide some braking. It is common practice for the primary circuit to control the air to the drive axles, while the secondary circuit controls the brakes on the steering axle. A two-way check valve senses air from both the primary and secondary brake circuits and allows the circuit with the greater pressure to supply the air to the trailer. Vehicle manufacturers may vary this routing at times, splitting up the drive axles if the vehicle is equipped with a tandem drive axle.

When foot valve is released, air is exhausted from the air chambers, releasing the brakes. Most systems use a quick release valve, located near the brake chambers, that allows the air to exhaust more quickly than it would if it had to travel all the way back to the foot valve. The quick release valve may be combined with a relay valve or installed separately as it commonly is on many steering axle brakes. Minimum release times are specified in Federal Motor Vehicle Safety Standard 121 (appendix L).

A trailer hand valve is found on many tractors. This valve enables a driver to apply only the trailer brakes by sending a signal of control air to a relay valve on the trailer. When the air reaches the relay valve, it opens a port and allows air from the trailer reservoir to flow to the trailer air chambers.

The control system includes a number of other valves that control the flow of air. A parking brake valve, mounted on the dash, controls the application of air to the spring or parking brakes. This valve can either exhaust air from the springbrake, which allows a spring to apply the brake, or direct air to the springbrake, which collapses the spring with air pressure, and thus releases the mechanically applied brake. The springbrake is discussed further in the section about the foundation brake components. The trailer supply valve, generally mounted on the dash, is used to direct air back to charge the trailer air reservoirs. A tractor protection valve is installed on vehicles pulling trailers to protect the towing vehicles' air supply in the event of a major loss of air. Also, should a break occur in either line to the trailer, the relay emergency valve on the trailer would exhaust the reservoir air to the brake chambers, applying the trailer brakes. If the trailer were equipped with springbrakes, the emergency relay valve would exhaust the air from the springbrake chamber, allowing the large spring to apply the brakes.

**Foundation Brake Components**

The purpose of the foundation brake components is to convert air pressure into mechanical forces used to decelerate the vehicle. Once air has been directed through various lines and valves, it ends up at a brake chamber (air chamber). (See **figure 5.**) Brake chambers are available in various sizes and provide a wide range of output forces. Compressed air flows into the brake chamber and acts on a pressure plate attached to a pushrod. The air forces the pressure plate inside the brake chamber to move, extending the pushrod with a force proportional to the air pressure applied to the brake chamber. (This movement is referred to as the pushrod stroke or travel.) Under ideal circumstances, a pressure of 40 psi supplied to a brake chamber with a pressure plate area of 30 square inches (a Type 30 brake chamber) would result in 1,200 pounds of force on the pushrod. This ideal situation does not include any losses due to friction, loose bearing surfaces, and component stretch and expansion. Such losses cause actual pushrod forces to be somewhat less. Appendix I discusses the magnitude of these losses and includes charts documenting actual pushrod forces at various application pressures and levels of adjustment for specific sizes of brake chambers.

Springbrakes were discussed earlier in the section on control system components. The application of the springbrake is accomplished in the same manner as a conventional brake chamber, yet it has emergency and parking features. If no air is supplied to this chamber, a heavy coiled spring will act on the second pressure plate and apply the brake with force equivalent to a 60-psi air application. To release the brake, air must be routed into the spring portion of the chamber to collapse the spring. Most heavy vehicles use the springbrake on at least one drive axle and one axle on the trailer.

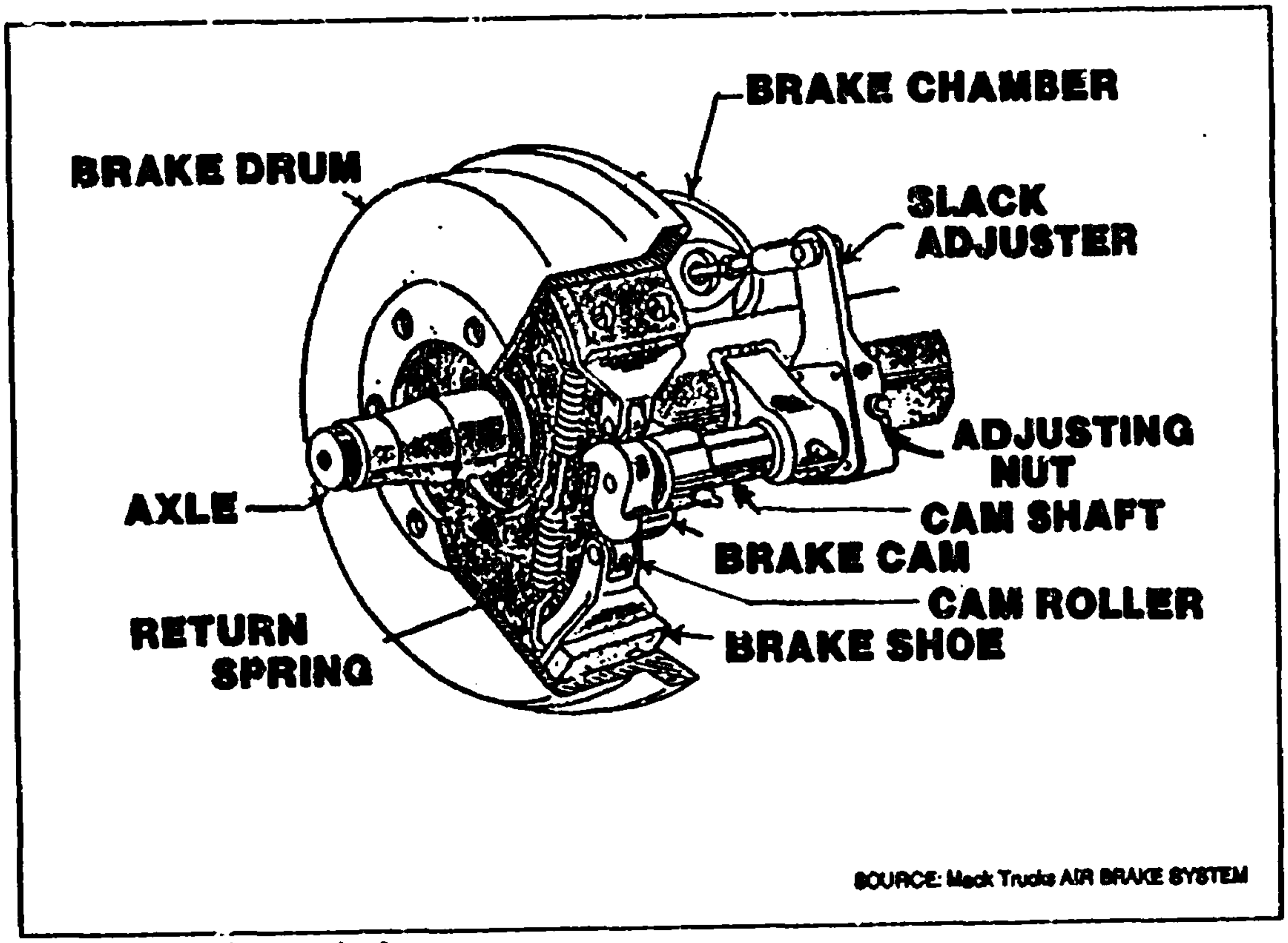
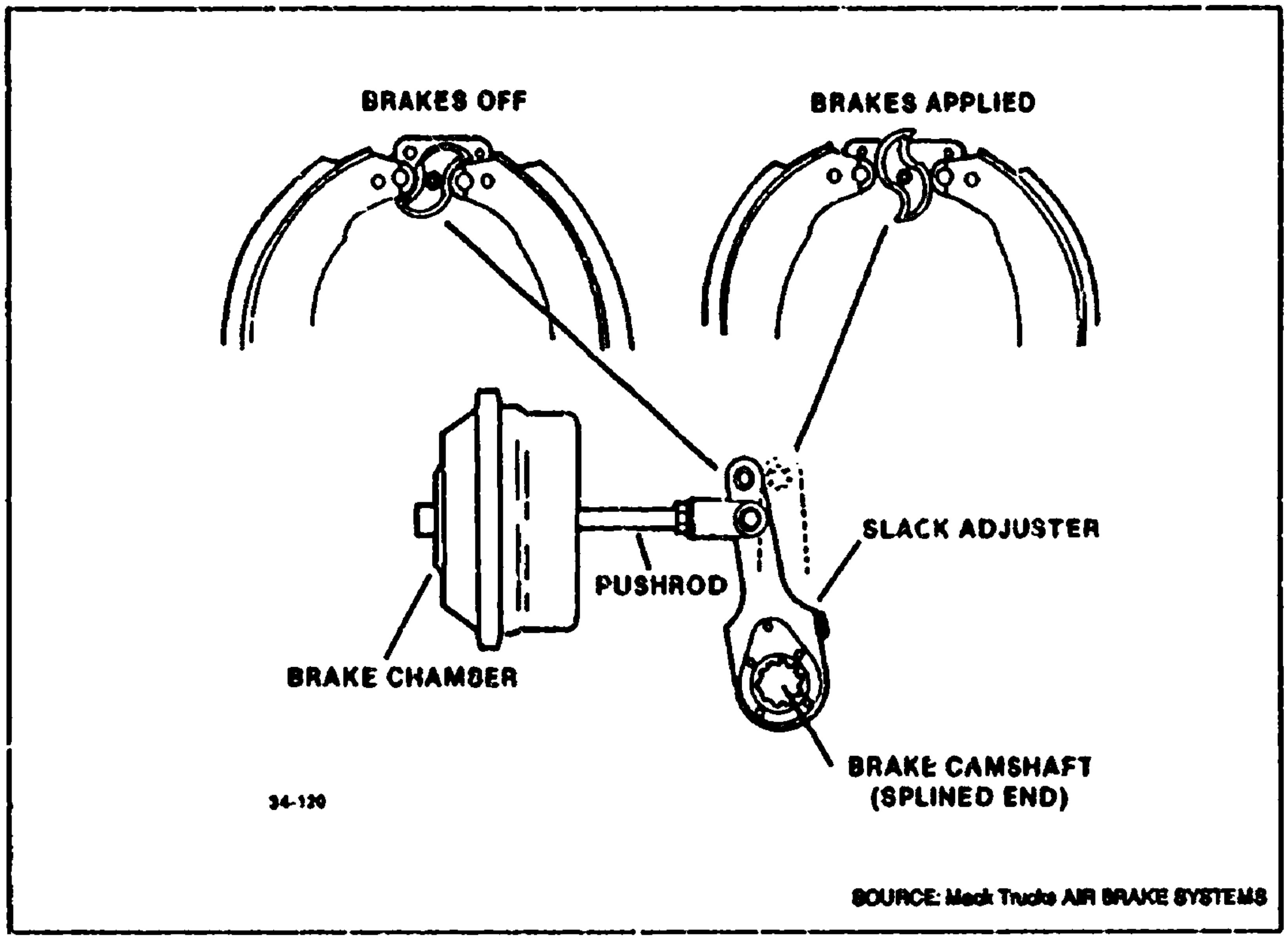



**Figure 5.--Brake terminology.**

In an S-cam airbrake system, the pushrod is attached to one end of a lever called a slack adjuster. (See figure 6.) The slack adjuster multiplies and converts the force from the pushrod into torque on the shaft running perpendicular to the brake drum. As the pushrod is extended from the brake chamber, the slack adjuster rotates, and in turn rotates the shaft connected to it. The S-cam also rotates, spreading the brake shoes inside the brake drum. When the brake shoes are spread apart, the brake linings (riveted to the shoes), come into contact with the inside of the brake drum. The friction created slows the rotation of the brake drum, and thus the wheel and the vehicle.

The slack adjuster is equipped with an adjusting mechanism that compensates for lining wear. Otherwise, as the lining wears down, the pushrod would be required to extend farther out until the pressure plate in the brake chamber came in contact with the bottom of the brake chamber. This is known as "bottoming out" a brake chamber, and the resulting pushrod stroke



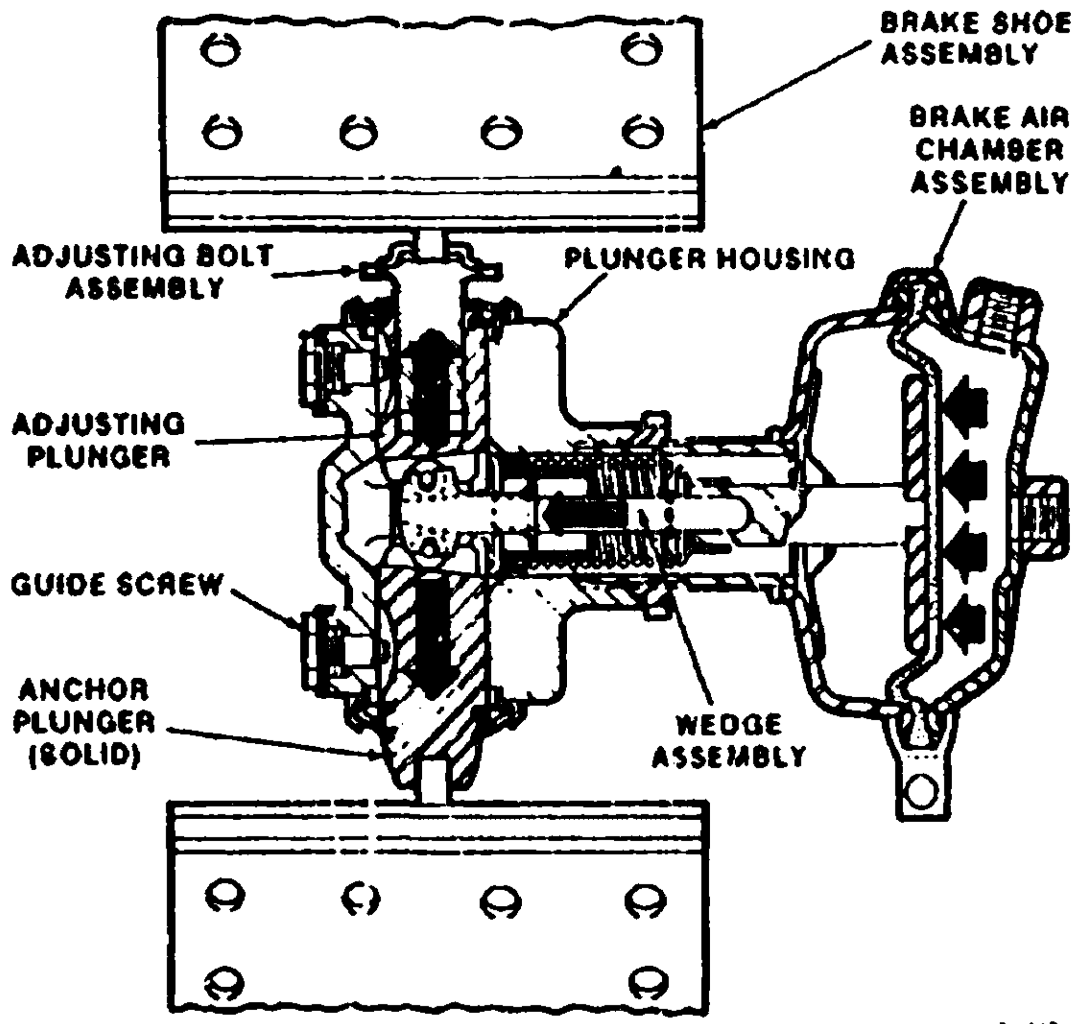

SOURCE: Mack Trucks AIR BRAKE SYSTEMS

**Figure 6.--S-cam brake operation.**

will be the maximum stroke listed in the manufacturer's brake literature. When this happens, no braking results because there is not enough travel of the pushrod to rotate the S-cam sufficiently to expand the brake shoes into contact with the drum. Some slack adjusters must be adjusted manually with a wrench, while others, called automatic slack adjusters, are designed to compensate for the lining wear automatically.

Heated airbrakes can also cause "bottoming out," resulting in loss of brakes. When heavy vehicle airbrakes heat up, several components can be severely affected. As the brake drums are heated, they expand and therefore increase the distance the brake shoes must move for the lining to contact the drum. This causes the S-cam to be rotated farther and results in a longer pushrod stroke requiring an extra, or reserve, stroke. The reserve stroke is the distance left at the time of a brake application before the pressure plate in the brake chamber contacts the bottom of the chamber. If there is very little reserve stroke left on a cool brake, a hot brake could very easily use up this small amount of extra stroke. Should the brakes become too hot and not have enough reserve stroke left, the pressure plate could "bottom out" in the chamber, and the shoes would not contact the brake drum. This is how an air-braked vehicle loses its brakes when descending a grade. Usually this takes place when brakes that are near their limit of adjustment are repeatedly applied during a long descent.

Wedge brakes use an air chamber with a pressure plate similar to the S-cam system, but the method for expanding the brake shoes differs. (See figure 7.) On an S-cam system, the pushrod is perpendicular to the axle and uses the rotating S-cam to spread the brake shoes. In a wedge brake system, the pushrod is parallel to the axle and a wedge is pushed between two rollers attached to the ends of the brake shoes, forcing the brake shoes against the brake drum. The force from the pushrod is multiplied by the mechanical advantage of the wedge. Wedge angles normally range from $10^{\circ}$ to $18^{\circ}$.




SOURCE: Mack Trucks AIR BRAKE SYSTEMS

**Figure 7.--Wedge brake operation (brakes applied).**

Some trucks with wedge brakes have two brake chambers installed on every drum, so both ends of the brake shoes can be expanded. These systems are referred to as "twinplex" systems.

Some wedge brake systems also utilize the springbrake concept, only the heavy spring forces the wedge between the brake shoes rather than rotating an S-cam Wedge brake systems have a smaller air chamber because the mechanical advantage of the wedge multiplies the pushrod force by a larger amount than the lever arm (slack adjuster) on the S-cam system.

Because of the way wedge brake systems are installed, the pushrod stroke can not be seen as it can on the S-cam, and thus it is difficult to know if the brake needs to be adjusted. Wedge brake adjustments are usually determined by measuring the unapplied gap between the drum and the lining. If the gap is less than 1/16 inch (0.0625 inch), the brake is considered to be in adjustment and capable of providing braking force.

**Airbrake System Inspection Requirements**

The only Federal regulations requiring an inspection of airbrake systems are the Federal Highway Administration (FHWA) annual inspection and the driver's daily inspection regulations in Federal Motor Carrier Safety Regulation 49 CFR 392.7. The FHWA inspection requires that a vehicle be certified in proper operating order once each year. This inspection can be performed by qualified carrier personnel or outside maintenance facilities. The burden of ensuring the daily condition of the vehicle rests upon the driver. The driver is required to satisfy himself that the service brakes, parking brake, and trailer brake connections are in good working order.

It is difficult to check the working order of an airbrake system without a detailed and systematic examination of the components. For example, pushrod stroke on an S-cam brake must be measured to determine if adjustment is necessary. This generally cannot be accomplished without assistance. A simple check for system air leaks also requires assistance; one person applies service air at the treadle valve while an assistant locates the leaks. The Safety Board believes that due to the complex nature of inspecting and maintaining an airbrake system, many carriers and drivers neglect this responsibility. Yet the airbrake system's performance depends heavily on the level of maintenance and inspection.

# CHAPTER 4

# INFLUENCE OF BRAKE SYSTEM MAINTENANCE ON VEHICLE PERFORMANCE

Improper maintenance on a heavy vehicle's braking system can lead to problems in both the ability of the vehicle to stop and its ability to be controlled during emergency stopping situations. Brake deficiencies usually become apparent when the brakes are heated or subjected to panic or emergency applications. Airbrake systems found on heavy trucks today provide limited tactile feedback during routine brake application to alert the driver about the brakes' adjustment level.

In the accident investigations, the absence of proper maintenance was manifested primarily by out-of-adjustment brakes. Brakes that were not kept within the manufacturer's recommended adjustment limits decreased the braking efficiency of the vehicle, increased the demands on the other properly adjusted brakes, and sometimes produced jackknifing dynamics. Accidents investigated by the Safety Board provided documentation of maintenance deficiencies, their resulting effect on vehicle dynamics, and the catastrophic consequences of loss of life and property damage. The roadways were not factors in the accident unless specifically discussed.

## Maintenance Effects on Stopping Capability

Fort Worth, Texas.--The lack of braking system maintenance on a tractor-trailer was the major factor in reducing the combination's braking capability in an accident in Fort Worth, Texas, on August 18, 1989. The 1981 Freightliner tractor pulling a loaded flatbed trailer had just entered a work zone on Interstate 30 where vehicles were stopping because of congestion. As the combination vehicle's driver approached within several hundred feet of the stopped vehicles, witnesses reported that he was traveling about 50 mph and was sounding his horn. In an attempt to avoid striking any of the passenger cars, the truckdriver steered his vehicle into the concrete median barrier. After hitting the barrier, the tractor continued forward, colliding with seven passenger cars and one motorcycle. The motorcycle was destroyed and its driver killed. Six of the seven passenger cars were substantially damaged, and four of the occupants received minor to moderate injuries.

A postcrash inspection of the tractor and semitrailer revealed that 9 out of the 10 brakes were more than 1/4 inch past the manufacturer's recommended limit of adjustment. (For manufacturer's recommended limit of adjustment, see table 3.) Additionally, the linings on both steering axle brakes were contaminated with grease, the trailer brake drums were badly grooved, and the air reservoir on the tractor was leaking air.

The condition of the braking system and the loading on the axles resulted in a calculated braking efficiency of 11 percent with cold brakes. This means that the tractor-trailer could use only 11 percent of the available tire/road sliding coefficient of friction. Thus, with properly adjusted brakes during a panic brake application from 50 mph, this vehicle should have been able

**Table 3.--Manufacturer's recommended strokes (clamp-type brake chambers).**

| Type | Maximum Stroke When Brake Should Be Adjusted | Max. Possible Stroke |
|---|---|---|
| 9 | 1 3/8 | 1 3/4 |
| 12 | 1 3/8 | 1 3/4 |
| 16 | 1 3/4 | 2 1/4 |
| 20 | 1 3/4 | 2 1/4 |
| 24 | 1 3/4 | 2 1/4 |
| 24 LS | 2 | 2 1/2 |
| 30 | 2 | 2 1/2 |
| 30 LS | 2 1/4 | 3 |
| 36 | 2 1/4 | 3 |

to stop in about 137 feet on level pavement, while in its degraded condition it would have taken about 1,190 feet--an increase of about 768 percent.[35] The bar chart in figure 8 displays these values in comparison to a passenger car's optimal slide-to-stop distance.[36]

One full-time mechanic was employed by the carrier. When interviewed by the Safety Board, the mechanic stated that he checked the brakes on the carrier's four tractors and four trailers monthly, or on an as-needed basis. He thought he had serviced the accident tractor's brakes about 2 weeks before the accident and the trailer's brakes about 3 weeks before the accident. There was so much layered mud and grease on the slack adjuster nut that the brakes

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[35]All stopping distance values were calculated using a common slide-to-stop formula: distance in feet = (speed in mph)$^2$ / [30 x (sliding coefficient of friction)]. Distances indicated do not include reaction distance or distance traveled due to brake lag time.

[36]The primary difference in slide-to-stop values between a passenger car and a heavy vehicle is the reduced tire/road friction of heavy vehicle tires. Safety Board experiments have consistently shown that the sliding coefficient of friction for a heavy vehicle tire is approximately 80 percent of that for a passenger car tire. Another factor that increases the slide-to-stop distances for heavy vehicles is that many heavy vehicles are unable to lock up various wheels, even with all brakes in proper adjustment.

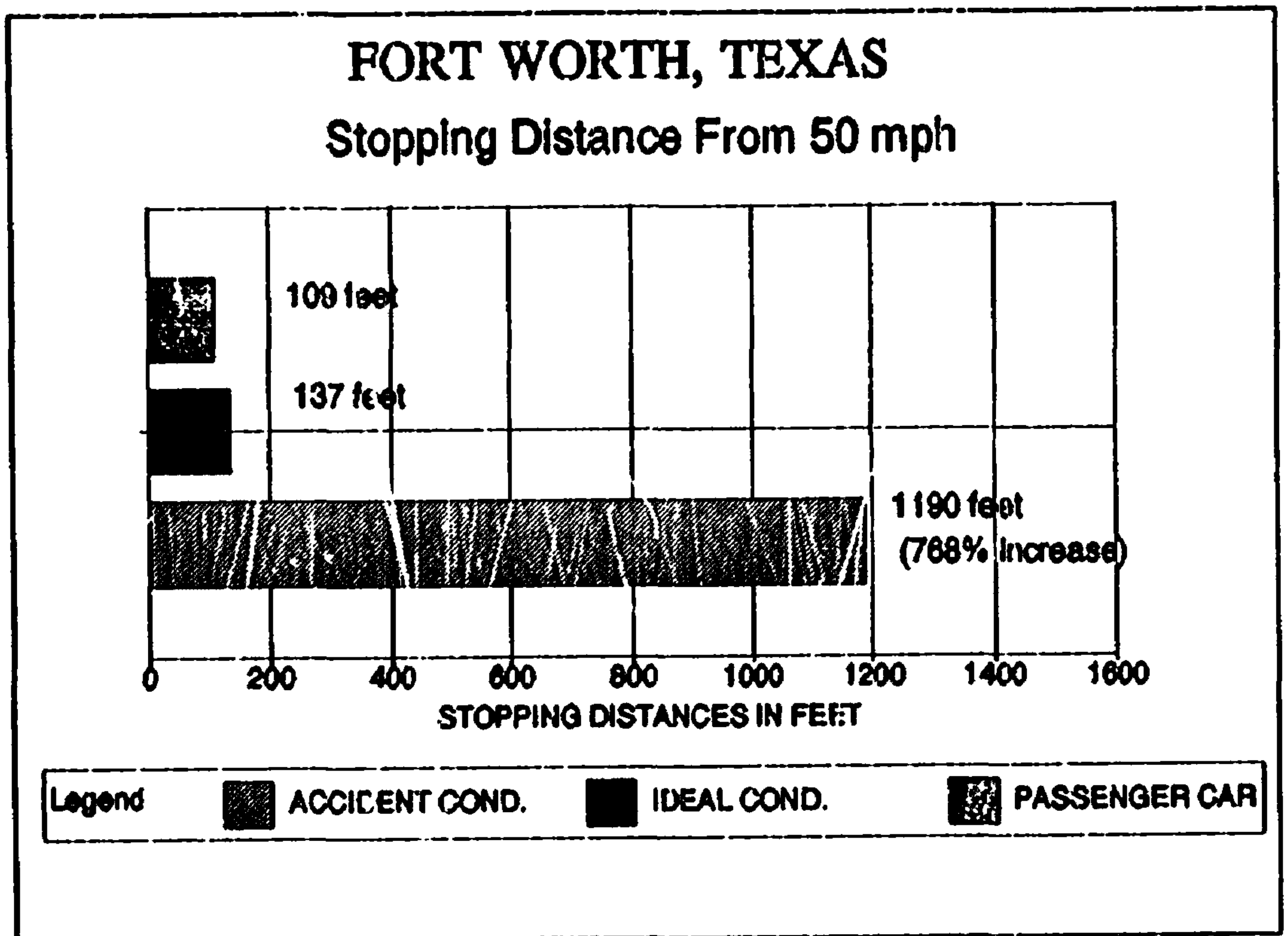


**Figure 8.--Combination vehicle's braking capacity in the Fort Worth, Texas, accident.**

probably had not been adjusted for months. The mechanic stated to Safety Board investigators that on another one of his trailers, "Brake service has not been needed for over three and one-half years." The mechanic's statement and the condition of the braking system indicate that the mechanic probably adjusted the brakes more on an as-needed basis than on a monthly basis.

Even under degraded conditions, the heavy vehicle brakes are capable of stopping the vehicle in most normal stopping conditions and may not have been perceived by the driver or mechanic to need any attention. The mechanic's openness with the Safety Board investigators suggests that he was not attempting to hide details of the maintenance program. He was under the impression that the periodic maintenance was not needed.

Kent, Washington.--A case illustrating both the carrier's and driver's failure to adhere to preventative maintenance practices was investigated in Kent, Washington, on February 8, 1990. The fully loaded 1974 International dump truck was in combination with a fully loaded, long-tongue, homebuilt dump trailer. The combination vehicle was traveling down a 1.25-mile, 6.5-percent grade at an estimated speed of 45 mph, approaching an intersection where cars were stopped waiting for the traffic signal to change. As the dump truck and trailer passed through the intersection against the red signal, it struck 11 passenger vehicles before pinning a 1980 Dodge Ram pickup between the front of the dump truck and a building. The driver of the Dodge pickup received fatal injuries, while the driver of the combination vehicle received disabling injuries. Of the 15 other involved occupants, 1 had disabling injuries, 5 had minor injuries, 4 had possible injuries, and 5 were not injured. Two of the passenger vehicles were destroyed, and three received substantial damage.

An inspection of the combination vehicle's braking system revealed that three out of six S-cam brakes on the dump truck were more than 1/4 inch past the manufacturer's recommended adjustment limit. All four of the trailer's wedge brakes were past the recommended adjustment limit. In addition, a major air leak was found in the brake service line on the trailer. When 120 psi of air was supplied just before the connection, 40 psi was measured at the coupling itself, and no pressure was measured at the left rear brake chamber. The Safety Board determined that the hole in the air line was old and most likely resulted from the air line having been pinched repeatedly between the pintle hook on the truck and the eye on the trailer tongue (truck-trailer connection) when the connection was being made.

Also, the Safety Board found the following evidence illustrating further lack of maintenance on the dump truck and trailer:

1. One and one-half pints of oil and water were found in the first air reservoir tank on the tractor.
2. One brake shoe on the trailer was installed improperly, with the rotation direction reversed.
3. Automatic adjustment components were either installed improperly or mismatched on two of the trailer's wedge brake actuators.
4. Two of the trailer's brake drums and their linings were contaminated with grease.
5. Two of the trailer's brake drums were worn past the manufacturer's recommended limit.
6. As a result of after-market modification, the steering axle brakes were supplied with air from the drive axle relay valve instead of from the treadle valve; this slowed the steering axle brake application timing.

Because of the poorly maintained condition of the braking system, this vehicle was capable of using only 27 percent of the available tire/road sliding coefficient of friction. The distance required to bring this vehicle to a stop from 45 mph with a panic or emergency brake application was about 490 feet. Had the brakes been adequately maintained, the truck and trailer should have been able to stop in about 130 feet on a level surface. The poor maintenance resulted in an approximate 277 percent increase in stopping distance. Figure 9 compares these stopping distances with the requirements for a passenger vehicle at the same speed.[37] The efficiency and stopping distances illustrated are all based on cold brake temperatures. When brakes are heated, they may become less efficient even if they are within adjustment limits. Moreover, if some brakes are out of adjustment, the brakes that are within or at the adjustment limit provide a disproportionate share of the braking, and, as a result, heat more rapidly than they would have if all the brakes had been adjusted properly. Thus, if some brakes are out of adjustment, a hot brake condition can develop more quickly when the vehicle is subjected to prolonged or heavy brake use.

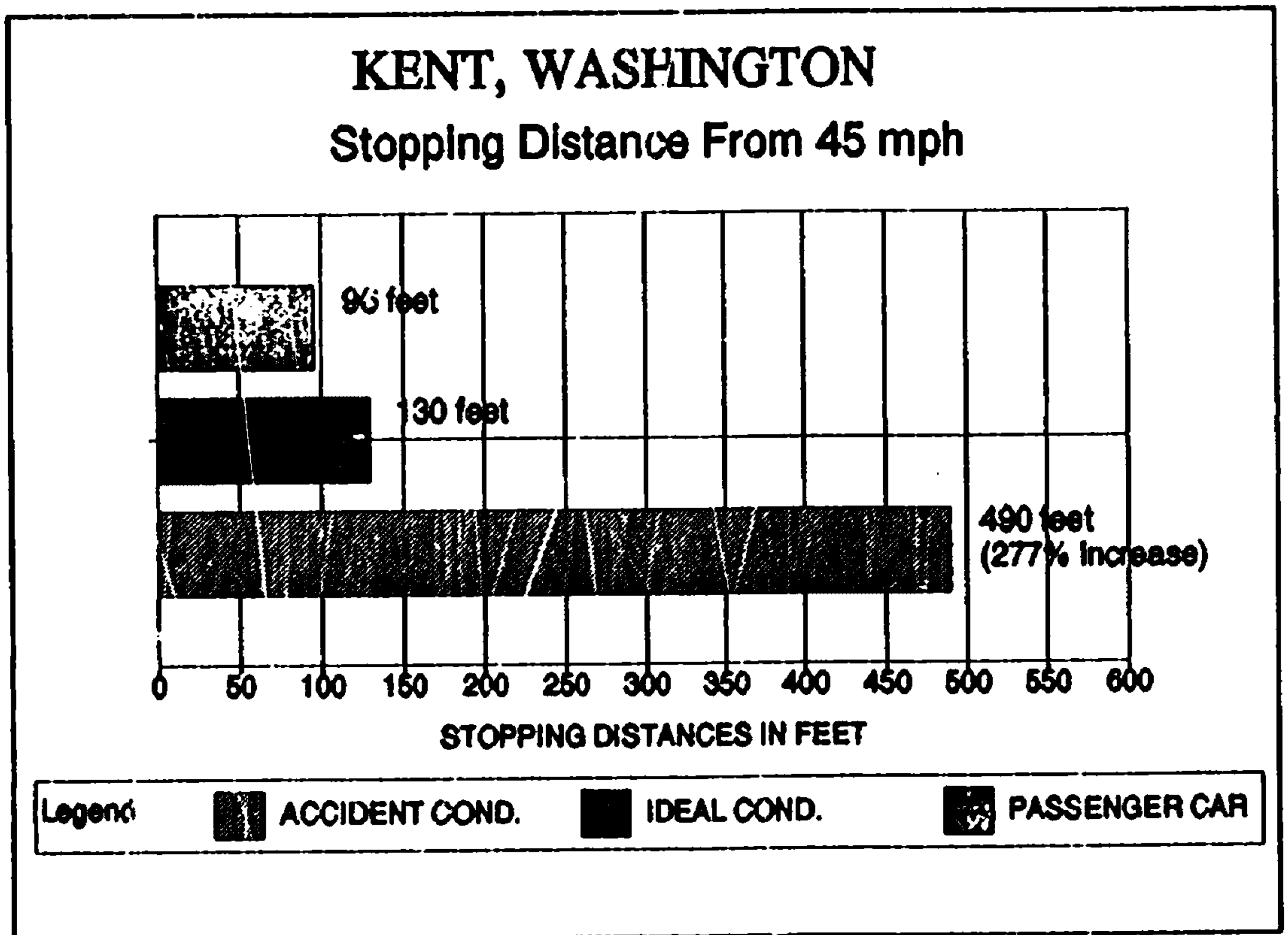


**Figure 9.--Combination vehicle's braking capacity in the Kent, Washington, accident.**

The carrier kept no vehicle maintenance reports and performed no systematic inspections on his three trucks and trailers. State records showed that this carrier had been audited at its terminal and cited for defective equipment violations in addition to having been inspected at

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[37]All stopping distance values were calculated using a common slide-to-stop formula.

roadside facilities. Two weeks after the accident, the State Utilities and Transportation Commission audited the carrier's records and equipment. As a result of this audit, the two remaining trucks and one of the two trailers were placed out of service. Although the audit was scheduled with the carrier several days in advance, one of the trucks was placed out of service for defective brakes, raising questions about whether the carrier knew how to inspect or maintain brakes properly.

### Maintenance Effects on Downgrade Speed Control

Big Pine, California--On State Route 168 near Big Pine, California, an accident took place in which problems with a poorly maintained braking system were compounded by heat resulting from applying the brakes on a downgrade. On May 18, 1990, a 1987 TMC 102 AC intercity coach bus was carrying 45 occupants from Las Vegas, Nevada, to Mammoth Lakes, California. The bus was descending Westgard Pass, near Big Pine, California, where warning signs posted at the beginning of the descent indicated that the maximum safe speed was 30 mph and that steep downgrades and sharp curves were present for the next 9 miles. The average downgrade for this section of road was 8 percent.

As the driver began the descent, he shifted his five-speed manual transmission into third gear. The driver stated that he had to still use his service brakes as he continued down the grade. After he descended the grade for 5 or 6 miles, the bus was traveling around 40 to 45 mph. He attempted to shift into a lower gear, but his high speed prevented him from shifting the transmission out of neutral. The speed of the bus increased to 60 mph, and the driver lost control in a curve. The bus struck a dirt embankment on the left side of the road and came to rest across the road in an upright position. Ten passengers were reportedly ejected from the bus; 2 received fatal injuries. Of the other passengers, 3 sustained critical injuries, 3 had serious injuries, 19 received moderate injuries, and 18 had minor injuries.

Two of the bus' four primary service brakes were more than 1/4 inch past the manufacturer's recommended limit of adjustment, and the other two were at the limit. This produced a calculated braking efficiency of 38 percent with the brakes cold.

A grade severity computer analysis[38] was run to determine the effect heat would have had on the braking capability. The analysis showed that when the bus lost control, the brake temperature was approximately 910 °F. At this temperature, the braking efficiency was further reduced to 1 percent, at which effective braking is not possible. The computer analysis also showed that if all the brakes had been properly adjusted, they would have heated to only 289 °F while negotiating the downgrade. At 289 °F, the driver should have been able to slow the bus to a safe speed even from 60 mph and avoided the accident.

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[38]The "Grade Severity Rating System" (GSRS) is a computer program developed through a project funded by the Federal Highway Administration. It was developed to assist highway engineers in signing grades in order to reduce the number of runaway heavy trucks. In the process, the program predicts the brake temperature as the vehicle travels down the grade.

The charter company operating the bus had been audited by the Office of Motor Carriers in 1986, 1987, and 1988. It was audited again in 1990, after the accident. The audits before the accident showed that the carrier had committed 1,698 violations of the Federal Motor Carrier Safety Regulations (FMCSR), resulting in civil penalties of $11,650. The Safety Board interviewed a former operations manager for the carrier who left the company 3 days before the accident. He stated that the carrier did not have a maintenance program for the 20-bus fleet and that the owners dispatched buses with mechanical deficiencies that had been discovered during pre-trip inspections. He believed reported deficiencies were not repaired because of operational demands for bus service. No spare buses were available.

In this case, the carrier's inadequate maintenance program was not due to a lack of knowledge about procedures or adjustment intervals. Regulations and the previous fines did not alter the carrier's maintenance practices.

Other Downhill Speed Control Accidents.--The Safety Board investigated two other accidents involving vehicles with out-of-adjustment brakes. (See case summaries 2 and 9 in appendix F.) In both these cases, the vehicles lost most of their braking capability and were involved in accidents that resulted in fatalities. When cold, the vehicles had calculated braking efficiencies of 64 and 65 percent, respectively, which would produce a large increase in stopping distance during a panic brake application. During normal driving, however, brake system inadequacies might not be apparent. If the drivers had been controlling their speeds on the downgrades with only brakes, the efficiencies would have dropped to zero as the brake temperatures increased.

**Maintenance Effects on Stability and Handling**

All the stability-related accidents investigated for this study involved vehicles that were lightly loaded on at least the drive or trailer axles. None of the vehicles had adequate steering axle brakes, and all but one accident took place on a wet roadway with reduced frictional properties.

Brownsville, Texas.--Five fatalities resulted from this March 1, 1990, accident in which the entire braking system except for the steering axle brakes was most likely in proper adjustment. The 1981 International conventional tractor in combination with a lightly loaded van semitrailer was traveling eastbound on Texas State Highway 48 during a light rain. The Safety Board determined through analysis that after the driver of the combination vehicle had applied his brakes to reduce speed while negotiating a curve to the left, his tractor began jackknifing in a counterclockwise rotation. The left rear of a 1979 Ford LTD was struck as the tractor first crossed the centerline. As the tractor continued to rotate past a 90° angle, its right front bumper and steering axle struck an oncoming 1989 Oldsmobile Cutlass. The Oldsmobile was destroyed, and all four occupants were killed.

The jackknifing tractor continued across the westbound lane. As the tractor continued to jackknife, a 1990 Toyota Camry struck the rear of the tractor. The Toyota was pushed rearward and came to rest lodged under the rear of the tractor's frame, against the rear drive axle. One of the two occupants in the Toyota received fatal injuries.

When Safety Board personnel examined the tractor and trailer, they discovered that the trailer brakes had been backed off by the towing company to facilitate removing the vehicle. The rear drive axle of the tractor was damaged so badly that its braking system could not be reconstructed and its adjustment could not be checked. Because the towing company had to back off the locked trailer brakes to move the trailer, Safety Board investigators assumed that the brakes were probably below or at least near the adjustment limit. The rear drive axle was also assumed to have been in adjustment because the more difficult to adjust forward drive axle was well within the limits of adjustment. Both brakes on the forward drive axle had pushrod travel measuring 1 1/2 inches on their Type 30 air chambers. The steering axle brakes with Type 20 air chambers were both more than 1/4 inch past the manufacturer's 1 3/4 inch recommended limit of adjustment and would have been considered defective by CVSA criteria. (See **table 3**.)

**Figure 10** illustrates various vehicle dynamics with different axles locked. While the Safety Board does not believe that the lock-up of all axles is a desirable solution to jackknife instabilities, the Brownsville accident illustrates the stability problems that can occur when the drive axle wheels lock prematurely. When a wheel is locked, the tire cannot generate significant lateral forces, only longitudinal braking forces in the direction of travel. Research indicates that

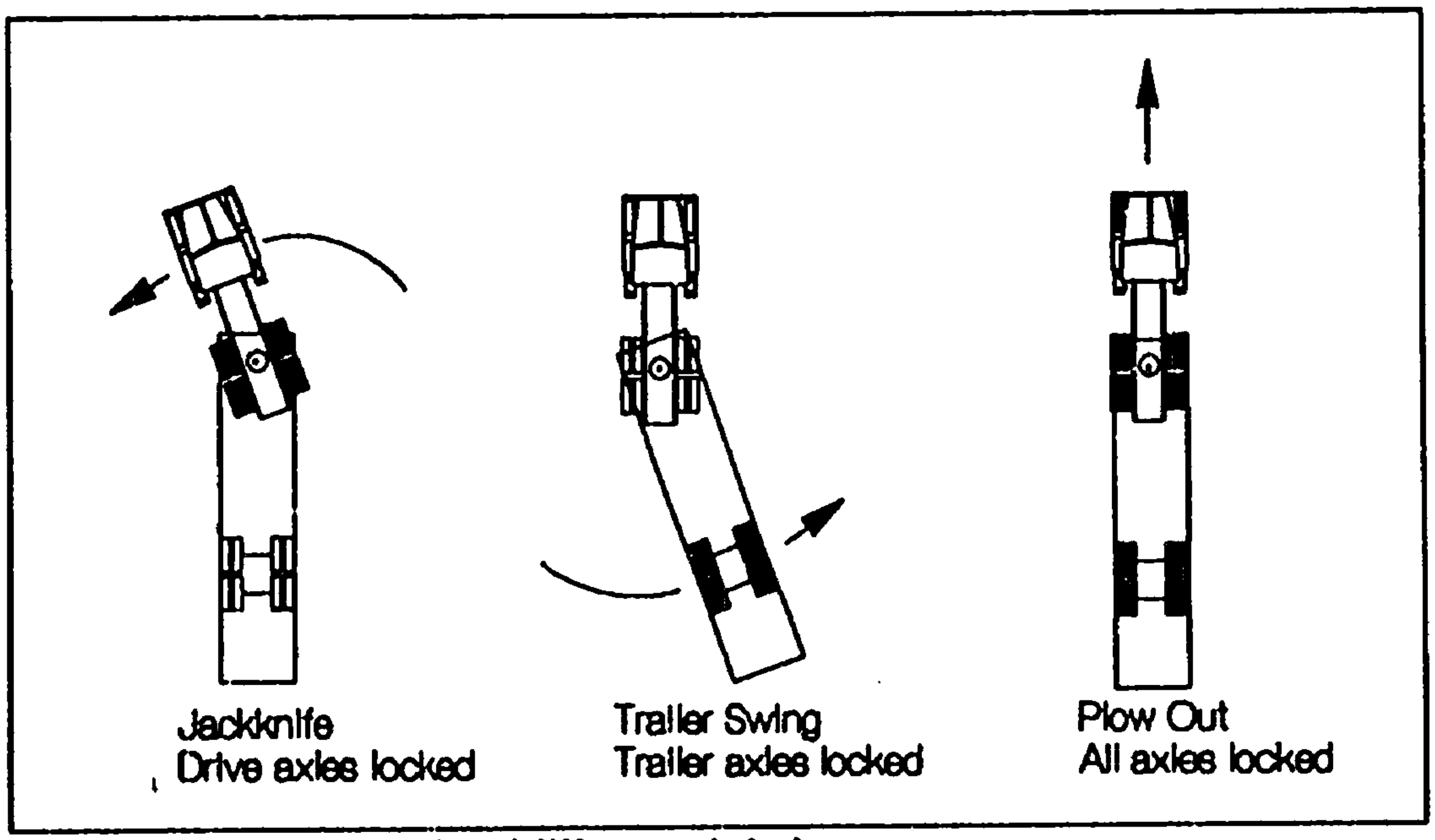


**Figure 10.--Vehicle dynamics of different axle lock-ups.**

lateral force approaches zero when wheel locks occur (100-percent longitudinal slip).[39] Therefore, when the drive axle wheels on a tractor are locked and the steering axle wheels are not locked, this vehicle becomes unstable and will begin to rotate. The combination vehicle usually will rotate in the direction the tractor is turning. Also, trailer swing can occur if the trailer axles lock and the tractor steering and drive axles do not.

The left diagram in **figure 10** illustrates the Brownsville accident, where the drive axles locked. As the driver of the tractor trailer was traversing the curve to the left, his tractor was already rotated a few degrees to the left due to the curve. When the brakes were applied, the drive axles locked and lost their lateral resisting force. In this situation, the tractor would continue to rotate rapidly in a counterclockwise direction.

The Safety Board used the Phase 4 computer model to project how brake adjustment may have influenced vehicle dynamics. **Figure 11** illustrates the Brownsville accident with and without brakes adjusted as projected by the Phase 4 program. The Phase 4 model indicates that if the steering axle brakes had been adjusted properly, they could have generated sufficient braking force to prevent the jackknife. The combination vehicle with properly adjusted steering

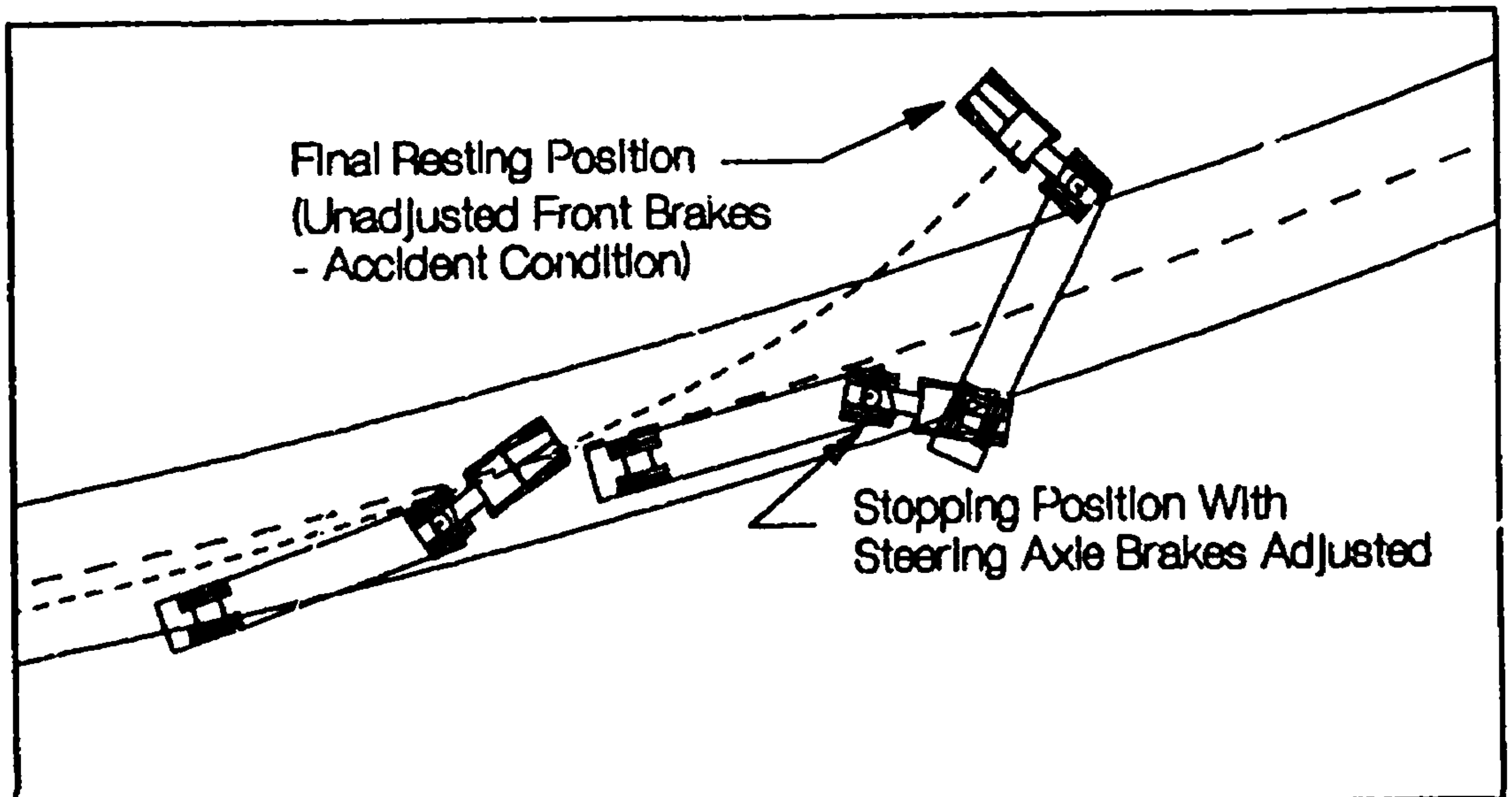


**Figure 11.--Phase 4 computer simulation of Brownsville, Texas, accident with and without brake adjustment.**

[39] Radlinski, Richard W., *The Anatomy of a Tractor Trailer Jackknife*, NHTSA Vehicle Research and Test Center, no date.

axle brakes would not have crossed the centerline but would have slid ahead and partially out of the left-hand curve.

Although the accident truck had other brake maintenance deficiencies, the unadjusted steering axle brakes were the greatest contributor to the instability accident. Given the common misconception among drivers and carriers that operational steering axle brakes are a hindrance on slippery surfaces,[40] it appears that either the carrier or the driver may not have wanted operational steering axle brakes because the two drive axle brakes that could be checked were found in proper adjustment. The Safety Board was unable to interview the driver due to advice from his attorney, so this matter was not resolved.

Buna, Texas.--Another accident, which illustrates maintenance deficiencies, took the lives of six people in Buna, Texas, on December 28, 1988. A 1979 White straight truck with a light load of steel was approaching the rear of a passenger car that was stopped to make a left turn off the two-lane highway. As the driver of the truck applied his brakes, the vehicle began to rotate counterclockwise into the oncoming lane of traffic. A 1977 Oldsmobile was approaching from the opposite direction. The truck continued rotating across the oncoming lane of traffic, and the Oldsmobile struck the truck frame between the cab and the drive axles. The roof and all four doors were torn from the Oldsmobile and all six occupants were fatally injured. The truck overturned, slid 43 feet, and came to rest on its top. A diagram of the accident is reproduced in **figure 12**.

When the Safety Board investigators inspected the White truck, it was found that all the brakes were within the manufacturer's recommended limit of adjustment except the steering axle wedge brakes. Both of these brakes were past the limits for clearance between the lining and the drum, and the lining on the top shoe on the right side of the steering axle was saturated with grease. In addition, the truck's owner had lengthened the truck's wheelbase by 94 inches, but had not checked to see if any of the brake component sizes should have been increased. Calculations indicated that the existing components--Type 9 air chambers on the steering axle with 18° wedges--were not capable of providing adequate brake torque even if adjusted properly. Volvo/GM[41] engineers stated that the steering axle brakes should have been equipped with Type 12 chambers after the truck's wheelbase was lengthened.

The axle placement was examined with a laser alignment instrument. This revealed that the forward drive axle on the left side was positioned 13/16 of an inch too far forward, and the rear drive axle on the left was positioned 1/4 inch too far forward. However, because the drive axle wheels were locked and sliding, the misaligned axles did not contribute to the rotational dynamics.

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[40]Radlinski, R.W., and Flick, M.A, *A Demonstration of the Safety Benefits of Front Brakes on Heavy Trucks*, U.S. DOT, National Traffic Safety Administration, 1986 (Report DOT HS 807 061).

[41]Volvo/GM Heavy Truck Corporation bought the assets of White Motor Corporation on September 1, 1981.

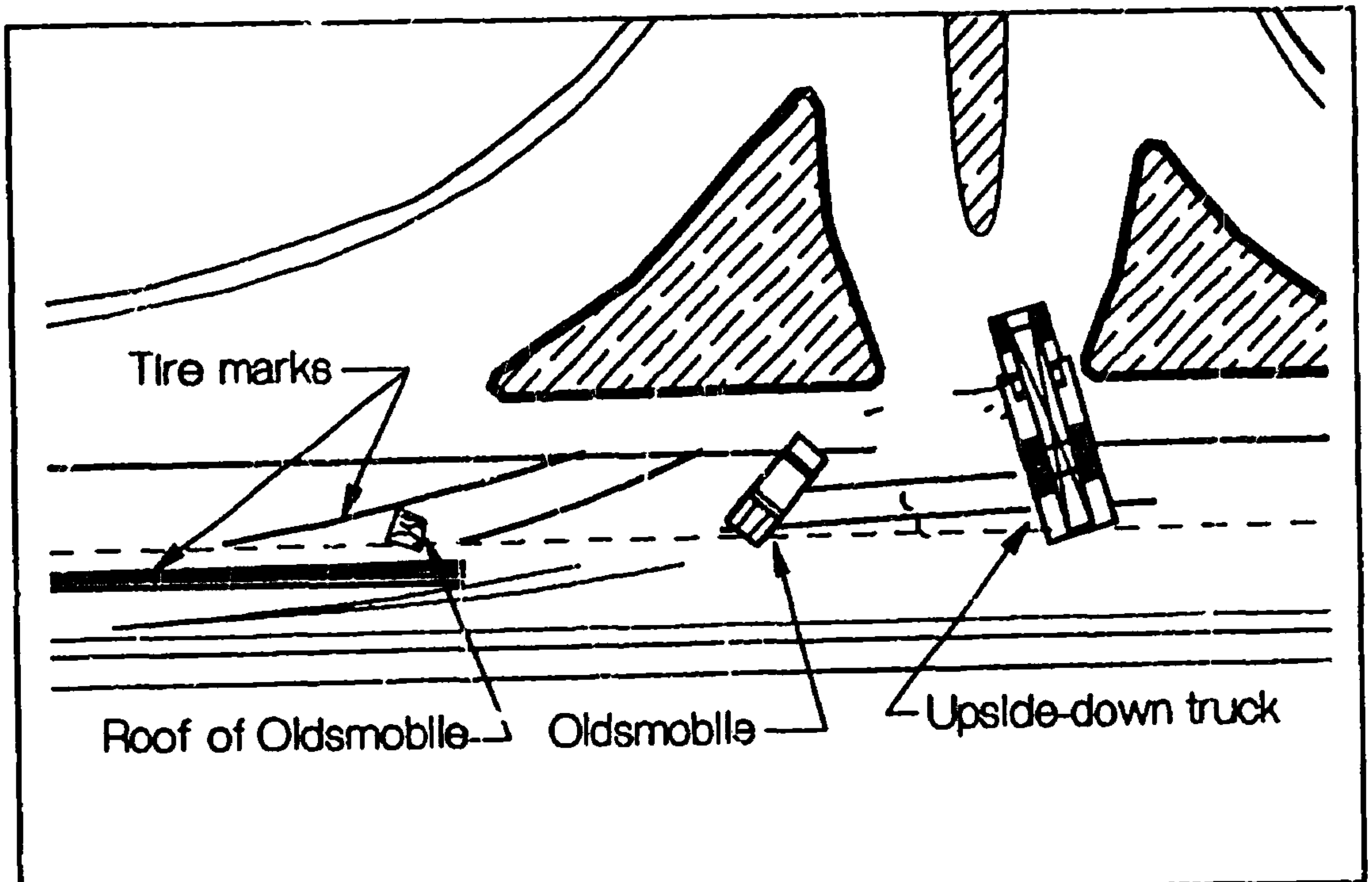


**Figure 12.--Diagram of Buna, Texas, accident--Final resting positions and evidence.**

Even though both drive axles were equipped with Type 24 air chambers instead of the more common Type 30 chambers, tire marks at the scene indicate that the drive wheels locked up before the truck rotated across the centerline of the highway. This accident illustrates how the locking rear axle wheels will cause the vehicle to rotate out of its travel lane.

The dynamics of this accident were analyzed using the Phase 4 computer simulation. The simulation showed that with the proper adjustment of the steering axle brakes and proper frame alignment, the truck's rotation would have been reduced from 102° to 74° and its lateral movement would have been reduced from 10 feet to 7 feet. Further simulations indicate that had the steering axle brakes been properly maintained and upgraded to accommodate the lengthened wheelbase with Type 12 chambers and 12° wedges on the steering axle, and had the frame been properly aligned, the rotation would have been only 0.5° and the lateral movement would have been 4 feet to the right instead of the left.

The simulations also indicated that if an antilock system had been installed on the truck in its accident configuration, the truck would have rotated only 0.7° and would have moved 0.01 feet to the left. Thus, either a properly maintained high torque steering axle brake system or an antilock system would have prevented this accident. Antilock systems are discussed in detail in chapter 6.

Other Maintenance-Affected Stability Accidents.--During this study, the Safety Board investigated two other accidents in which maintenance was a factor in the instability-related collision. (See case summaries 7 and 18 in appendix F.) These accidents were influenced by steering axle brakes that were not properly adjusted. Steering axle brakes that are out of adjustment or intentionally backed off contribute to the same type of instabilities as steering axles without front brakes. This type of brake deficiency does not always indicate a deficient maintenance program for the carrier, but often reflects the misconception that aggressive steering axle brakes can lead to a loss of steering.

In an attempt to dispel these popular misconceptions, the NHTSA conducted extensive research and published several reports for the trucking community evaluating the need for steering axle brakes. In DOT HS 807 061 "A Demonstration of the Safety Benefits of Front Brakes on Heavy Trucks," NHTSA engineers in East Liberty, Ohio, ran a series of stopping tests in a straight line and in a curve, and concluded:

> With the exception of one driver in one series of tests, drivers were clearly able to achieve better performance with full front brakes than without under all circumstances. They stopped in shorter distances under full control with full front brakes. Without front brakes, best stopping distances were 5 to 130 percent longer and drivers were more likely to lose control.

The same authors stated in SAE paper 870493, "Benefits of Front [Steering Axle] Brakes on Heavy Trucks":

> With the exception of tests that were run almost 40 years ago (on vehicles that are not representative of today's vehicles), all work that has been done to evaluate the performance of heavy vehicles with and without front wheel brakes indicates that performance of vehicles is degraded when front brakes are removed. Not only is stopping distance increased significantly, but vehicle stability and control is compromised.

The NHTSA tests support the Safety Board's accident investigation findings; it is difficult at times to separate instability problems from increased stopping distances. As NHTSA's tests concluded, a driver will sense the beginning of the instability, let up on the brakes, and thus increase the stopping distance by attempting to control the vehicle.

**Accident Brake Deficiencies Compared to Inspection Data**

Four of the accidents described in this chapter could have been prevented through a maintenance program that at least kept the brake systems in proper condition. As the accidents demonstrated, the problem of brake adjustment is one that not only affects the stopping capability of the vehicle, but also its stability. Sixteen of the 18 accident vehicles examined during this special study had 1 or more of their brakes past the manufacturer's recommended limit of adjustment. In 14 of the investigated accidents, improperly adjusted brakes were cited as a factor. (See appendix F.)

Because of the maintenance problems highlighted in the accident investigations, the Safety Board conducted roadside inspections to determine if similar problems occurred in commercial vehicles not involved in accidents. Five-axle truck inspections were performed in five States on both the interstate and secondary highway system. After analyzing the project and the data, a statistician from UMTRI concluded the following:

> Based on the sample design, comparisons with the 1987 Truck in Use Survey data, and our own analysis of the NTSB brake inspection data, it is my opinion that the sample reasonably characterizes brake adjustment in the United States at the time of the survey. The NTSB sample closely matches the national statistics in some important characteristics (model year and cargo body style), and the proportion of brakes out of adjustment does not appear to be sensitive to the differences that were observed (in cab style and carrier type).

In **figure 13**, the percentage of vehicles placed out of service from the Safety Board inspections is shown for the entire five-State sample. Of the 1,520 vehicles inspected, 59.4 percent were placed out of service. Slightly more than 56 percent of all inspected five-axle tractor-trailers were placed out of service for brake violations, including 46.1 percent placed out of service because of out-of-adjustment brakes.

The Safety Board also compared 1990 MCSAP data for four of the five States (Florida did not participate in MCSAP during 1990). The wide disparity between Safety Board out-of-service rates and MCSAP out-of-service rates is reflected in **figure 14**, and indicates that current MCSAP inspection and data collection procedures need to be examined. The Safety Board recognizes a variety of reasons for the difference in rates, and intends to explore those issues in a subsequent report.

On the interstate system, five-axle combination vehicles averaged 2.32 brakes per vehicle either at or past the manufacturer's recommended limit of adjustment. The off-interstate sample showed 2.89 brakes per vehicle at or past this limit. (See **figure 15**.) **Figure 16** shows that the calculated average brake efficiencies for each five-axle combination sample displayed by State and road system.

**Figures 14** through **16** indicate that the problem of trucks with deficient or out-of-adjustment brakes is widespread. Although current statistics (see chapter 1) indicate that very few accidents are actually caused by deficient or out-of-adjustment brakes, this can probably be attributed in part to underreporting, as was discussed in chapter 1. Often the law enforcement agencies investigating the accident do not investigate thoroughly enough to determine whether brakes were a factor.

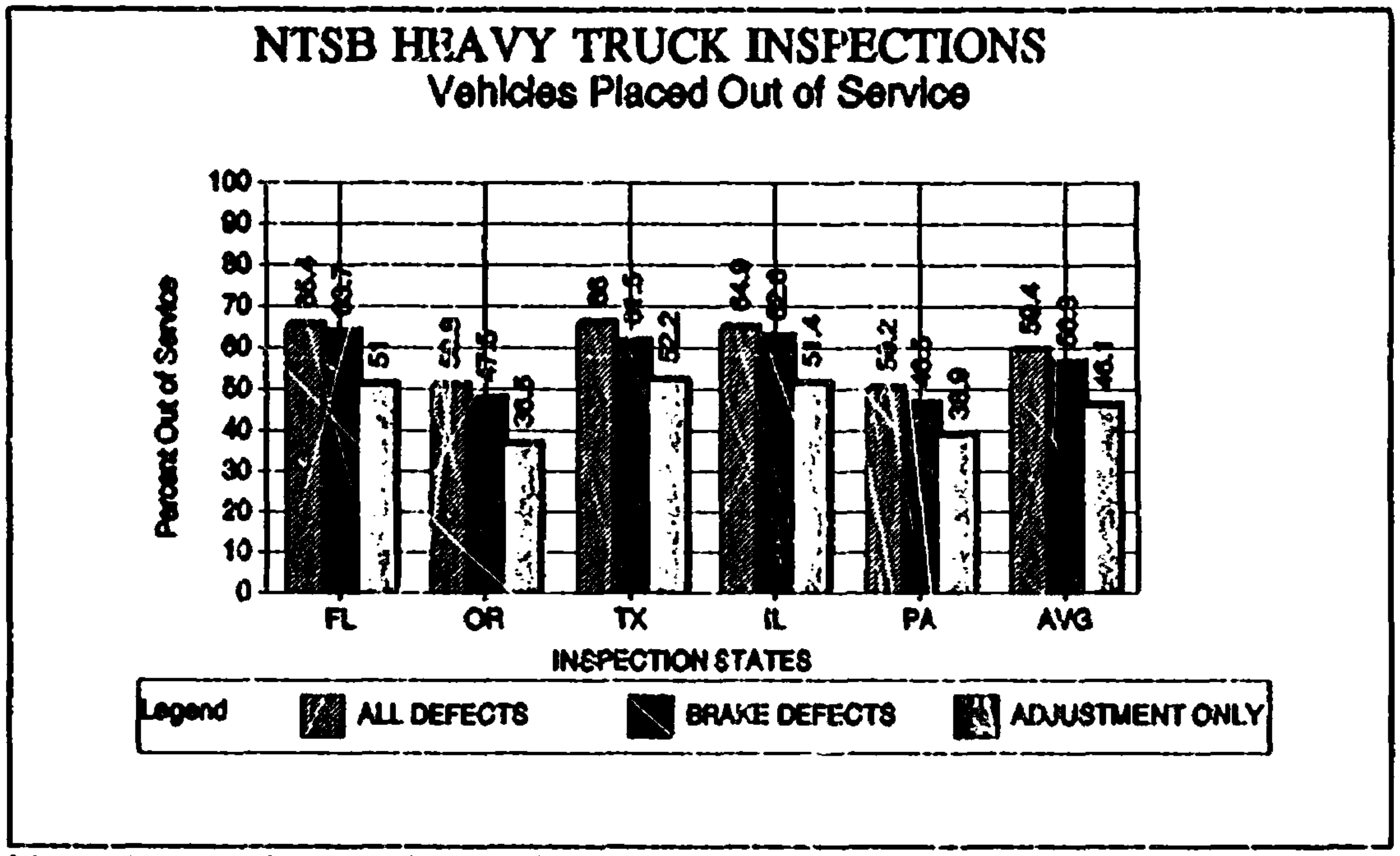


**Figure 13.--Result of NTSB five-State sample for percentage of vehicles placed out of service.**

For example, Safety Board investigators determined in one accident that involved a heavy truck that 1 of its 10 brakes was more than 1/4 inch past the manufacturer's recommended limit of adjustment and 2 were at the limit. In addition, the right front brake lining was saturated with grease, and the brake on the left side of the forward trailer axle had a ruptured diaphragm that was leaking excessive air. Yet, in its accident report, the investigating law enforcement agency listed an inoperative low air warning as the only brake system deficiency, and improperly coded the sizes of five of the vehicle's air chambers. This accident illustrates the problem with the way data are collected, coded, and later analyzed.

Often if an obvious factor such as a drunk driver or a driver failing to stop at a stop sign is involved in an accident the condition of the heavy truck's brakes is not examined. As a result, the accident is presumed to have been caused by the more apparent human factor and is coded accordingly in the accident database

Although Safety Board investigators determined that 7 of the 18 accidents investigated for this study were influenced by a brake-related instability, State investigating agencies failed to code deficient brakes as a factor in six of the seven accidents (86 percent). In 9 of 15 cases (60 percent) in which the Safety Board cited brake deficiencies as a contributing factor to the accident, investigating agencies did not code deficient brakes as a factor. Thus, none of these would show up in the databases as brake-related accidents.

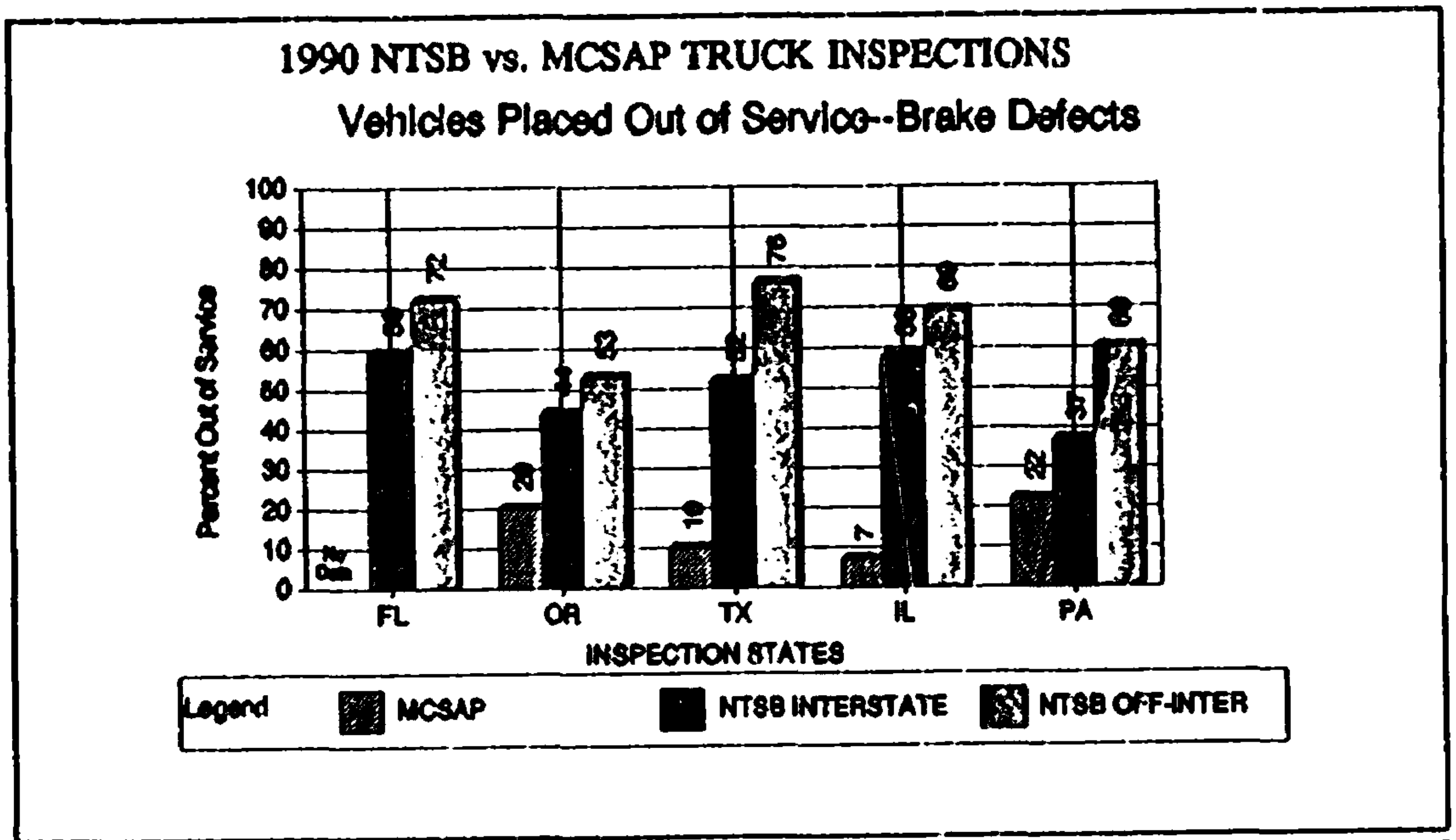


**Figure 14.--Comparison of NTSB versus MCSAP inspections for vehicles placed out of service because of brake defects.**

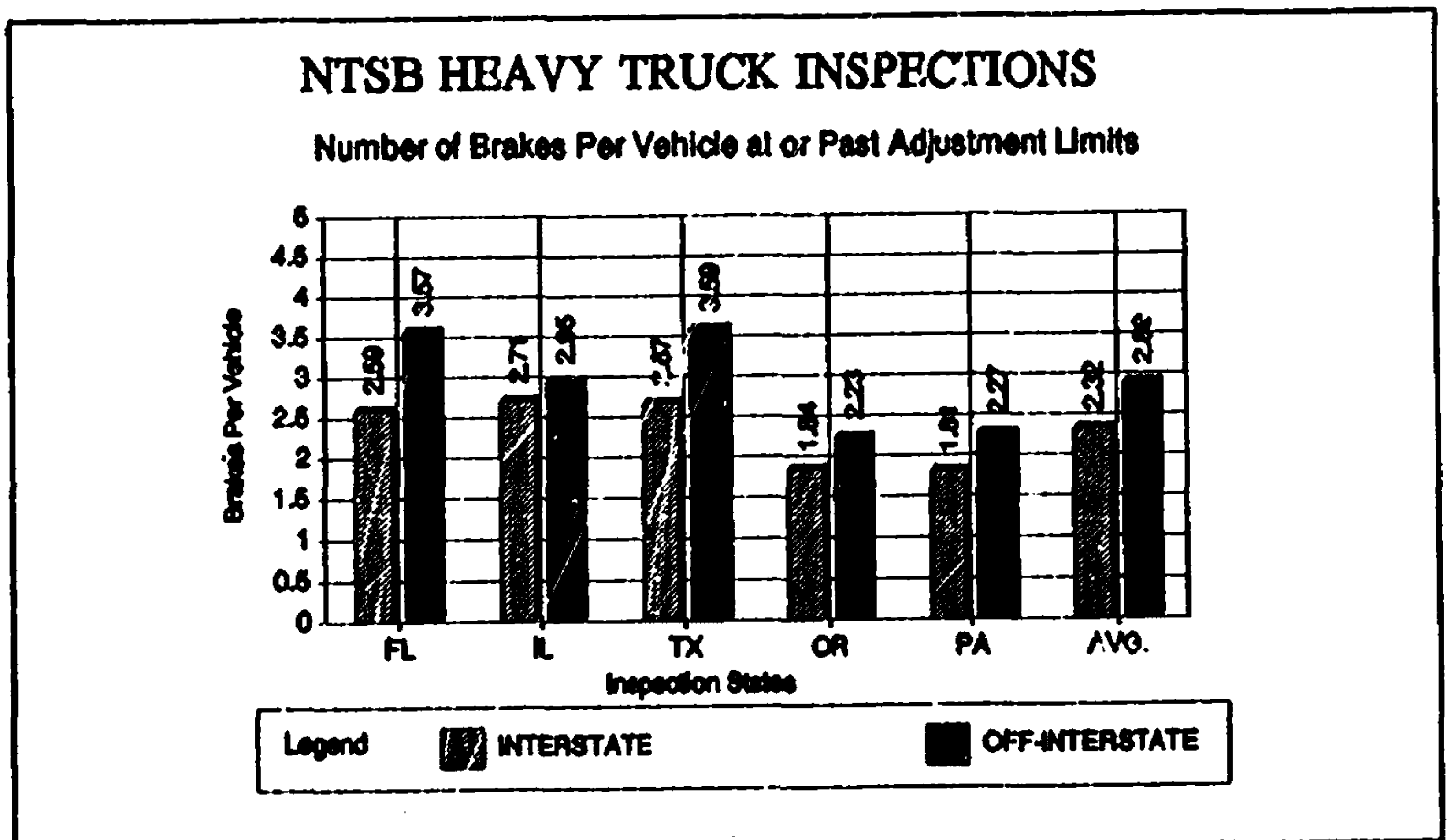


**Figure 15.--NTSB five-State sample of brakes at or past adjustment limits.**

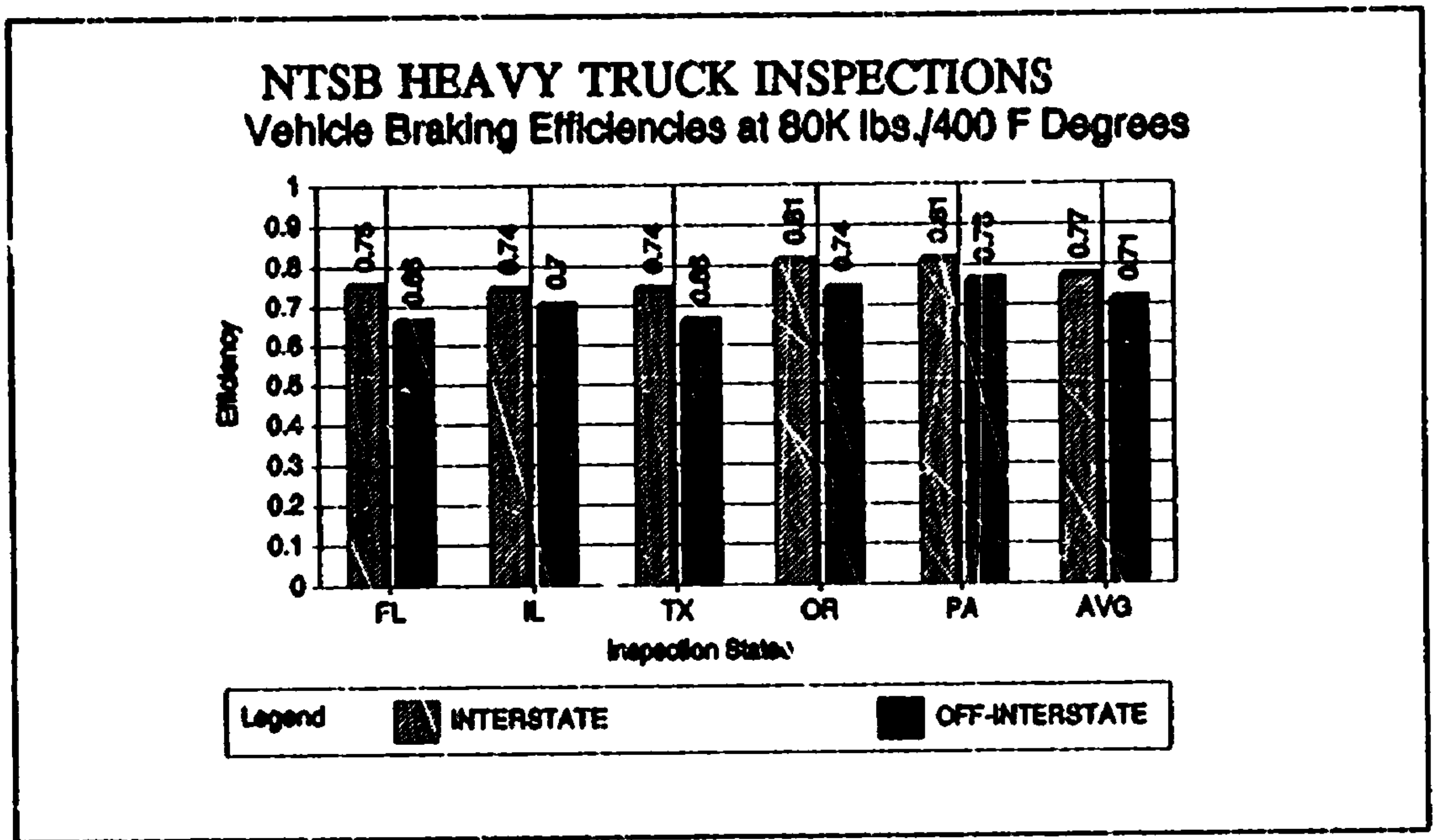


**Figure 16.--NTSB five-State sample of vehicle braking efficiencies.**

Because the Safety Board's heavy truck inspections represent the condition of five-axle combination vehicles, it can be concluded that 56 percent of these combination vehicles have brakes in such a condition that they would be placed out of service if thoroughly inspected. These trucks would be high risk candidates for an accident, should conditions demand optimal or near optimal brake performance. It is apparent that not all of these vehicles are getting involved in accidents; therefore, it appears that the high risk conditions do not occur very often.

Carriers vary substantially in how they address brake maintenance: some are vigilant in performing proper maintenance procedures, while others do not appear to even understand what constitutes proper maintenance procedures. The large numbers of vehicles placed out of service, in combination with accident findings, indicate inadequate carrier maintenance programs. However, for a few of the accidents involving carriers that were interviewed, the problem seems to be more that the carriers were unaware that the brakes were out of adjustment or were unaware of when brakes needed to be adjusted.

**Accident Carrier Policies for Brake Adjustment and Adjustment Intervals**

During the accident investigations, the carriers involved were interviewed and asked about their procedures for adjusting S-cam brakes. All related that they begin the process by tightening the adjusting nut.[42] Only one carrier stated that it instructs its mechanics to "ring the drum"[43] to make sure the lining is contacting the drum; another said that its mechanics are told to watch the lining to make sure there is contact with the brake drum. Both reported that this procedure was used to make sure the brake was indeed being tightened rather than backed off. All agreed that the next step was to back off the adjusting nut by some amount although they disagreed about the amount. The shortest amount was one notch, which converts to less than 1/10 of a turn (most slack adjusters have 12 clicks or notches for 1 complete revolution of the adjusting nut). The greatest distance any carrier backed off the adjusting nut was one complete turn.

Determining an appropriate brake adjustment interval can be a complex process for a carrier because factors such as the type of terrain traveled and the type and weight of load carried influence the wear on the brakes and thus the need for periodic brake adjustment. Moreover, even if a carrier knows the proper brake adjustment interval for its operation, the adjustments will not necessarily be made systematically and accurately.

**Manufacturers' Policies and Industry Guidelines--Brake Adjustment**

A review of various manufacturers' recommended brake adjustment guidelines and policies are discussed below.

Bendix Heavy Vehicle Systems Group.--In the Bendix Service Data literature, document SD-05-1, adjustment procedures and suggested intervals are discussed. The preferred method for adjusting manual slack adjusters is stated:

> Raise the vehicle wheel that is to be adjusted off the ground so that it turns freely. Turn the slack adjuster adjusting mechanism until the brakes begin to drag. Adjustment is then backed off until the wheel turns freely. This adjustment method will result in the shortest possible actuator stroke without the brakes dragging.

The alternate method for adjusting brakes is suggested following the preferred method:

> Regardless of the brake chamber size or the slack arm length, adjust the slack adjuster so that there is 3/8" travel of the pushrod when manually extended to contact the brake shoes to the brake drum. After adjustment, check for brake drag by gently striking the brake drum with a hammer. When the brake shoes are away from the drum, a ringing sound will be

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[42] Tightening the adjusting nut decreases the lining to drum clearance, while backing off the nut increases this clearance.

[43] *Ringing the drum* is a phrase used to describe the tapping on the brake drum in order to determine whether the lining is touching the drum. If there is no lining contact with the drum, a clear ringing sound is heard, while a duller thud is heard if there is lining to drum contact.

heard. A dull sound indicates brake drag and requires readjustment until the drag is eliminated.

The Bendix literature also recommends that the pushrod travel for their manual slack adjusters should be checked "every month, 8000 miles, or 300 operating hours." For their ASA-5 automatic slack adjuster, Bendix recommends that the "... brake actuator pushrod stroke should be measured while making an 80-90 psi service brake application," every 25,000 miles, 3 months, 500 operating hours, or at the time of routine vehicle chassis lubrication.

Rockwell International.--Rockwell outlines its suggested practice for adjusting its manual slack adjusters in "Field Maintenance Manual No. 4 Cam-Master Brakes":

1. For the first adjustment, turn the adjusting nut until the brake lining touches the drum.
2. Turn the adjusting nut in the opposite direction for only one or two clicks so that the brake lining just clears the drum. Rotate the drum to check the clearance.
3. To adjust for lining wear, rotate the adjusting bolt 1/4 turn. Each 1/4 turn moves the lining 0.0025 inch (0.06 mm) at the center of the shoe.

Rockwell recommends taking pushrod stroke measurements with 80- to 90-psi air pressure in the brake chambers. Rockwell further recommends adjusting the brake whenever the stroke exceeds the limits shown in **table 3**. For example, the stroke for a Type 30 chamber should not exceed 2.0 inches.

Information concerning Rockwell's automatic slack adjusters is found in their "Field Maintenance Manual No. 4B - Paymaster Automatic Slack Adjuster," revised in June 1987. A minor inspection and lubrication is suggested a minimum of four times during the life of the lining. This involves checking the pushrod stroke, adjusting if needed, inspecting the condition of the rubber boot, and lubricating the slack adjuster through the grease fitting. A major inspection is recommended at the time the brakes are relined. At that time, the stroke should be checked and the pawl should be removed and the grease checked. In both cases, if the stroke is out of adjustment, Rockwell states that one should "... use the troubleshooting chart to find and correct the cause of the problem before you adjust the stroke."

Eaton Corporation.--Eaton's "Service Manual EB-32, June 1988 - Eaton Axles & Brakes" also discusses adjustment procedures and intervals for its manual slack adjusters. Kenworth Truck Company includes this section in its "Custom Shop Manual" when its truck is equipped with Eaton brake components. Eaton's recommended method is to measure what it calls the "free stroke," which is the pushrod stroke applied by the use of a lever. The desired "free stroke" should be between 3/8 inch and 5/8 inch without drag. If the stroke is outside this range, then the following procedure should be used:

> To adjust the free stroke, depress locking sleeve on slack adjuster adjustment nut and turn in direction required. Recheck free stroke to verify it is within range. Make sure sleeve is "locked" when adjustment is completed. Verify that brakes are not dragging by spinning wheels by hand or tapping drum lightly with a hammer and listening for a sharp ringing sound.

The manual recommends that to determine whether an adjustment is necessary, a measurement of pushrod stroke be taken with 80 psi of air applied. This measurement is compared to maximum applied stroke for a particular size chamber. The manual states, "If applied stroke equals or exceeds maximum applied stroke shown, adjust brakes. If less than the maximum, no adjustment is required." The maximum applied stroke listed for a Type 30 chamber is 2.0 inches. A few pages later, the manual states, "Brake adjustment should be checked (and adjusted if necessary) WEEKLY or any time applied stroke exceeds the maximums . . . ." Under "Brake Adjustment," the Eaton manual states, "on automatic slack adjusters, refer to the slack adjuster manufacturer's manual."

Kenworth Truck Company.--In Kenworth's "Operation and Service Manual," which is given to owners of new trucks, the company addresses both the adjustment procedure and the adjustment interval. In a manual dated January 1990, Kenworth suggested that pushrod travel be checked and adjusted as required every 6,000 miles. "For the maximum, desirable brake adjustment, tighten the brakes until there is a slight drag, then back off the brakes approximately 6 mm (1/4 turn of the slack adjusting nut) until there is no drag between the shoe and the drum." No mention is made of automatic slack adjusters.

American Trucking Associations.--The Maintenance Council of the American Trucking Associations has a specified method for adjusting S-cam brakes with manual slack adjusters in its recommended practice number RP-609. ATA suggests jacking up the wheel to be adjusted, and then turning the adjusting nut on the slack adjuster until there is some drag of the lining on the brake drum. At that time, the adjusting nut is backed off until no brake drag is felt.

Motor Vehicle Manufacturers Association.--The MVMA has developed an emergency procedure for adjusting airbrakes when it is not practical or possible to raise a wheel from the ground. The MVMA recommends tightening the adjusting nut on the manual slack adjuster until resistance is felt, indicating shoe-to-drum contact. To be certain of shoe-to-drum contact, MVMA suggests tapping the drum with the wrench used to make the adjustments. If the drum rings rather than making a dull thudding sound, the shoe is not making contact with the drum, and the brake needs to be tightened further. If the drum rings, the adjusting nut may have been turned in the wrong direction. Once shoe-to-drum contact is confirmed by ringing the drum, the adjusting nut should be backed off 90° (or three notches with 12 notches per revolution). The drum should be tapped again with the wrench to verify that the brake shoes are not dragging.

**Potential Solutions to Maintenance Problems**

The Safety Board's investigations and inspections revealed a wide range of maintenance deficiencies in the airbrake systems of heavy vehicles including grease-contaminated linings and drums, contaminated air lines and tanks, leaking air lines and tanks, improperly installed critical components, broken components, and improperly adjusted brakes. Many of these deficiencies could be corrected with systematic inspections by the driver and scheduled maintenance. Roadside inspections funded through MCSAP helped to identify deficiencies that had not been identified by either the driver or the carrier. However, the most glaring deficiency, out-of-adjustment brakes, did not respond to the increased attention. The Safety Board believes that this is because today's air/mechanical brake systems are too maintenance sensitive and because many carriers do not establish maintenance policies that ensure proper brake adjustment under ordinary operating conditions. This section offers several solutions that could help significantly lower the number of out-of-adjustment brakes.

Define Adjustment Method.--A simple, clear, and standardized method is needed for adjusting airbrakes on heavy vehicles. The Safety Board believes that at least part of the problem of out-of-adjustment brakes results from a lack of knowledge concerning brake adjustment procedures. Carriers' policies for adjusting brakes vary as do manufacturers' policies and industry guidelines. In addition, Safety Board interviews with carriers, drivers, and mechanics revealed that some do not understand how to adjust airbrakes.

In 1988, the Safety Board issued Recommendation H-88-31 to the ATA and National Private Truck Council to adopt written policies regarding on-the-road brake adjustment and to provide drivers responsible for performing such adjustments with the necessary training. The lack of a standard procedure for adjusting airbrakes is being addressed by an effort coordinated by the American Trucking Associations. Minutes from the February 1991 Commercial Vehicle Safety Alliance meeting discuss this project:

> Concern was raised that even though people have known for years that brakes out of adjustment is a serious problem, the problem shows no sign of abating. Several activities are currently underway to help address this situation. First, there is no universally accepted procedure for one-person brake adjustment. Some authorities recommend using a pry bar technique to adjust brakes, while others recommend "ringing the drum," and still others say it must be done by two people and jacking each wheel. These mixed signals confuse those trying to find out how to do the job. The Office of Motor Carriers has been asked by ATA to (with the help of ATA and others) develop a booklet on brake adjustment. Composition of this brochure is proposed to be one page with an adjustment procedure all can agree on, one page giving a procedure to determine how often readjustment is required, one page addressing both automatic slack adjusters and marked pushrods and a final page to be used for advertising or whatever other message those printing the material want to use. The committee was asked

if it would support the development of such a booklet and encourage its ultimate distribution. The answer was a unanimous yes.

The Safety Board anticipates that the proposed publication will provide needed clarification on brake adjustment procedures and should result in an increased understanding of this crucial maintenance practice. Pending the completion of this publication, the recommendation has been classified "Open--Acceptable Action."

Define Adjustment Interval.--Results from Safety Board interviews with carriers, drivers, and mechanics in the investigation of the 18 accidents revealed that some did not understand how to adjust airbrakes, but a larger number did not know when to adjust the brakes. The Safety Board believes that more guidance and help is needed in this area.

A recent unpublished study in Canada has proven this to be the case. The current test for a commercial driver's license (CDL) in Canada requires that the driver be able to demonstrate to the examiner that he knows how to adjust the airbrakes on his vehicle. To determine whether this requirement has made any difference on the number of trucks placed out of service due to defective brakes, Transport Canada compared the out-of-service inspection numbers from before the requirement to the number of trucks placed out of service after the requirement. Even though these drivers knew how to adjust airbrakes, as evidenced by passing the CDL test, the inspections found virtually no difference in out-of-service rates for those trucks inspected before and after the requirement. The Canadian study did not determine who was responsible for adjusting the vehicle brakes on trucks inspected.

The Transport Canada results are reinforced by the Safety Board heavy truck inspections that also found little difference in the brake adjustment condition of those trucks with the driver responsible for brake adjustment. Those trucks with the driver expressing responsibility for brake adjustment averaged 2.53 brakes per combination at or past the manufacturer's recommended adjustment limit, while 2.66 brakes per combination were at or past the same limits for the remainder of the sample. This is further evidence that it is not only how to adjust brakes that the trucking community does not understand, but when. Several advances may provide some solutions to this problem. A suggested ATA procedure (discussed earlier), NHTSA Notice of Proposed Rulemaking, and a NHTSA proposed adjustment indicator all address the issue of when to adjust brakes.

In 1981, the Safety Board issued Recommendation H-81-1 to the NHTSA requiring manufacturers of airbrake actuation devices to incorporate indicators that will warn users when brakes must be adjusted. In 1988, the Safety Board issued Recommendation H-88-30 to the NHTSA that automatic slack adjusters be required on all newly manufactured vehicles equipped with air-mechanical brakes. As a result, the NHTSA published a Notice of Proposed Rulemaking, Docket No. 91-21, Notice 1, dated May 3, 1991, proposing to amend the Federal Motor Vehicle Safety Standards 49 CFR 571.121 S5.1.8 to read as follows:

Each vehicle shall be equipped with a service brake system acting on all wheels. Wear of the service brakes shall be compensated for by means of a system of automatic adjustment, which maintains brake adjustment within the manufacturer's recommended adjustment limits. The condition of service brake adjustment shall be provided by a brake adjustment indicator that is discernable when viewed with 20/40 vision using an ordinary flashlight with two D-cell batteries from a position 8 feet away on the adjacent pavement surface. The brake adjustment indicator shall be capable of displaying the service brake adjustment conditions of under-adjustment, over-adjustment, and fully adjusted within the manufacturer's specified limits.

If adopted, the amended standard will help carriers and drivers keep their vehicle brakes in proper adjustment.

However, the Safety Board now believes that the requirement should be amended further to require that the adjustment indicator be able to display the brake adjustment condition with the brakes in an unapplied position. **Figure 17** shows adjustment indicators. The indicator that remains visible after release would allow one person to walk around a vehicle and visually check the brake adjustment. Most current adjustment indicators (such as pushrod marking) generally requ ` two people to perform this task: one to apply the brakes and the other to watch the indicators.

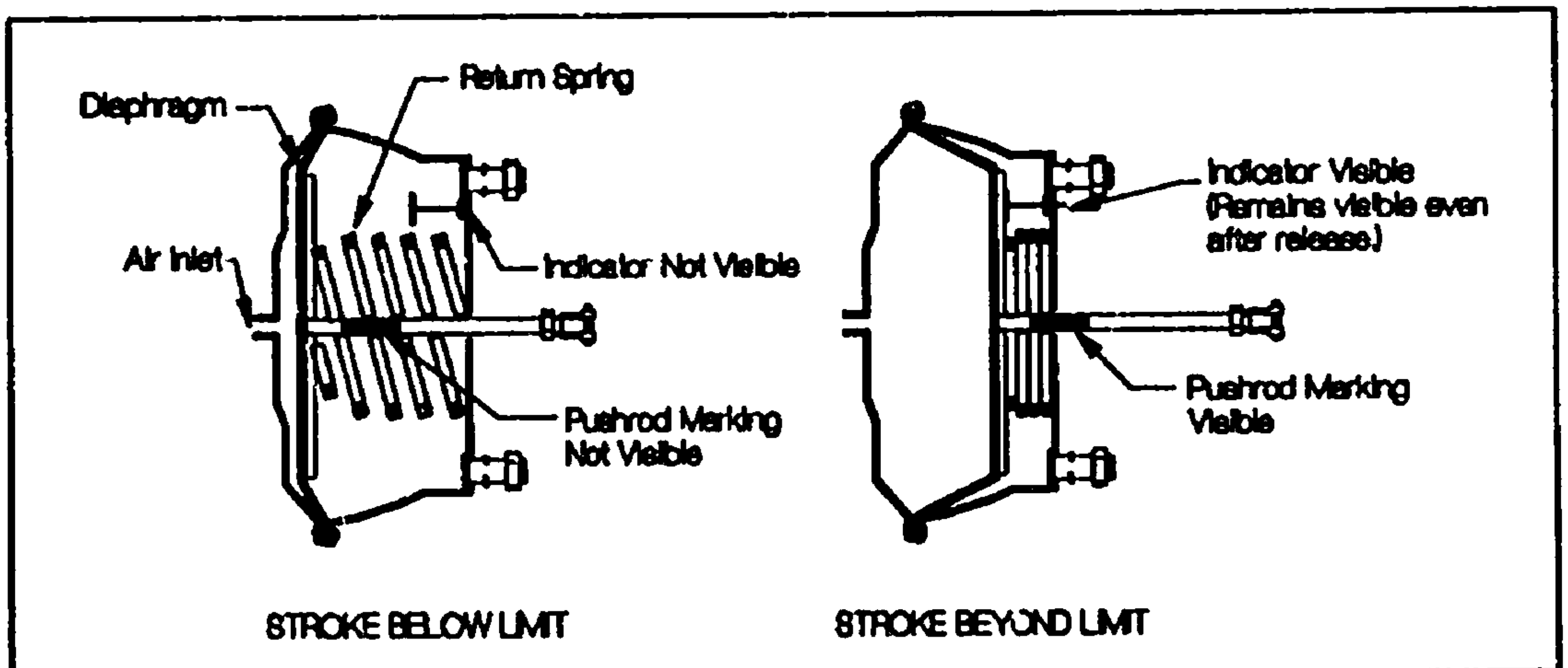


**Figure 17.--Examples of brake adjustment indicators (pushrod marking/visible indicator).**

Require Automatic Slack Adjusters.--Based on NTSB data and recent NHTSA studies, the most notable gain in reducing out-of-adjustment brakes has been the installation of automatic adjusters, a trend that is already underway. The majority of truck tractors and about half the trailers currently being manufactured are equipped with automatic adjusters. Current generation hardware is durable and, for the most part, reliable.

In the 18 accidents investigated by the Safety Board, investigators found that 56 percent of the manual slack adjusters were at or past the manufacturer's recommended limit of adjustment, and 41 percent were more than 1/4 inch past the manufacturer's limit of adjustment. Of the automatic slack adjusters installed on the accident vehicles, 40 percent were found at or past the adjustment limit, and 39 percent were found more than 1/4 inch past the limit. These values, graphed in **figure 18**, include some automatic adjusters on wedge brakes and are from a small sample of 18 vehicles. The investigations revealed that the poor performance of these adjusters resulted from either improper or nonexistent maintenance.

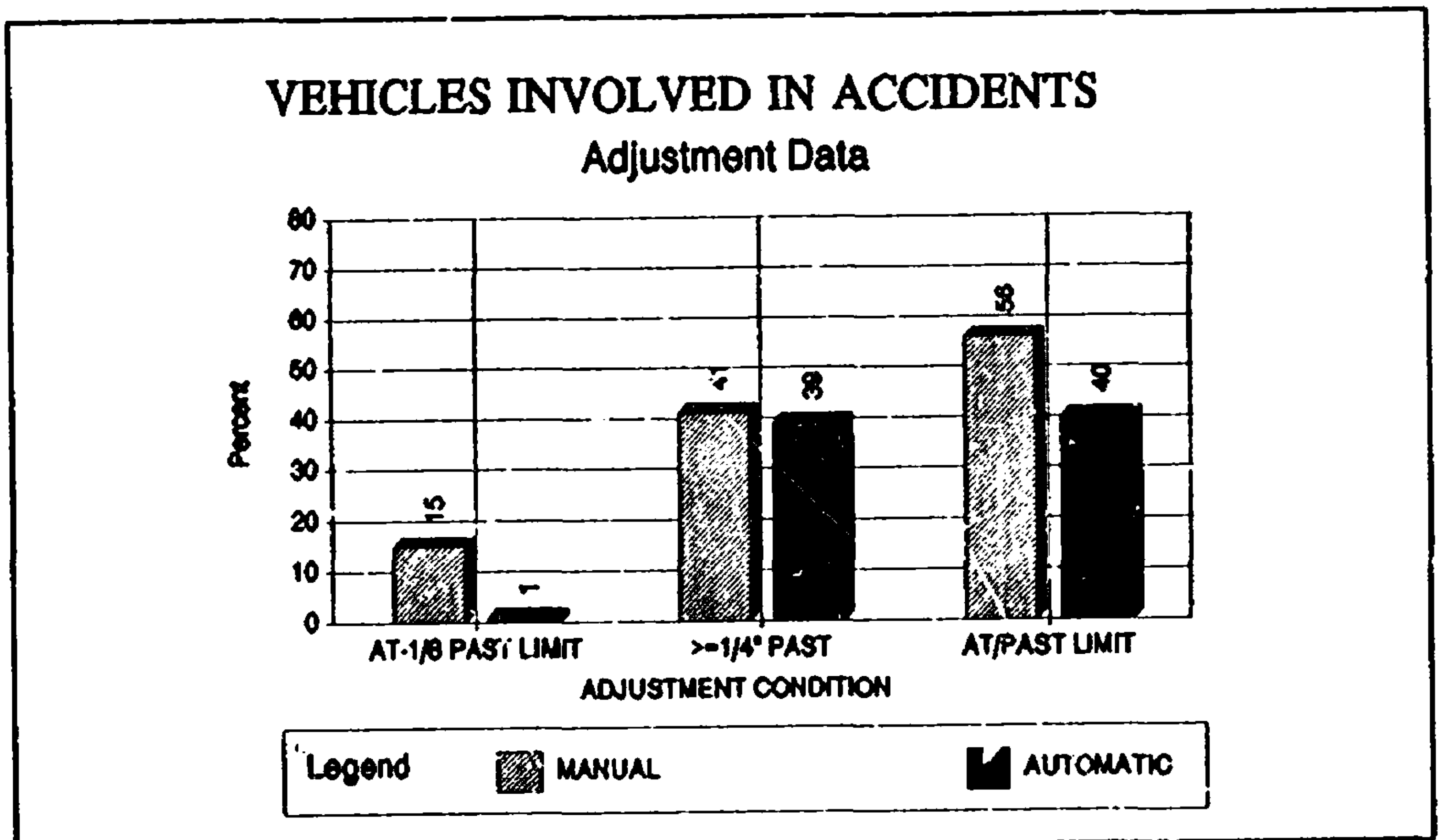


**Figure 18.--Slack adjustment data for 18 accident vehicles.**

The large percentage of automatic slack adjusters found out of adjustment in the accident investigations demonstrates the need for a preventative maintenance program to monitor these components (see **figure 18**). Some carriers and drivers believe the adjusters are not only "automatic" but also maintenance free.

Results from the Safety Board's five-State inspection project are more valuable in evaluating the effectiveness of automatic slack adjusters in the fleet as a whole (see **figure 19**). From the total inspection sample of Type 30 air chambers, 26 percent of the manual slack adjusters were either at or past the recommended adjustment limit; only 15 percent of the automatic slack adjusters were at or past the limit. These data further support the Safety Board's position that the installation of automatic adjusters on all axles of air-braked vehicles would enhance truck safety.

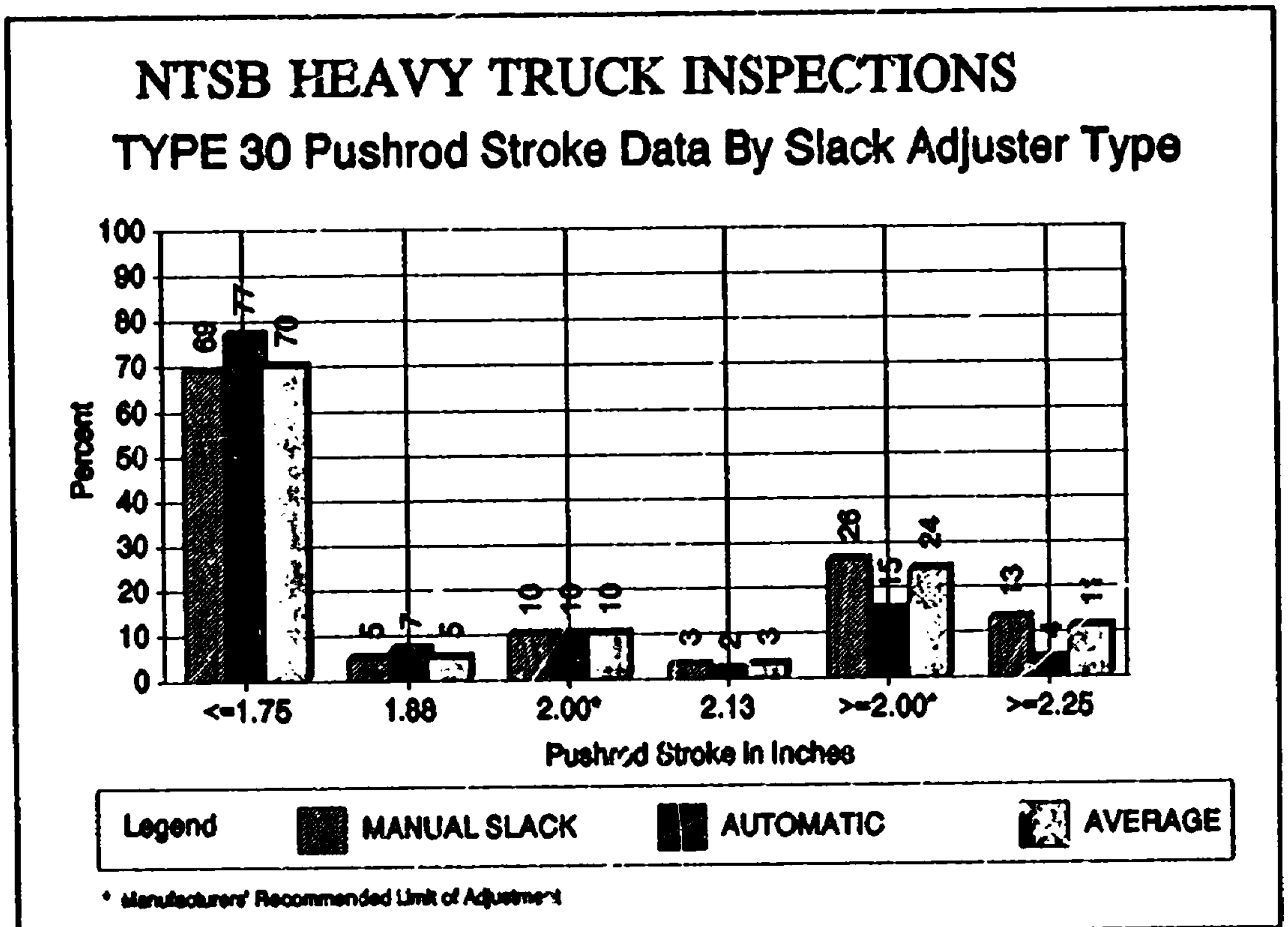


Figure 19.--NTSB five-State survey of automatic slack adjusters.

Encourage Long Stroke Chambers.--Automatic brake adjusters are not a panacea for commercial vehicle airbrakes. Airbrakes still will need periodic adjustment checks, and they still will suffer from performance degradation at high operating temperatures when they approach the upper limits of their in-adjustment range. Brake hardware that is less sensitive to adjustment or more forgiving to an out-of-adjustment condition is also needed.

One solution to the problem associated with the large number of trucks with out-of-adjustment brakes would be to supply vehicles equipped with airbrakes with long stroke air chambers. The long stroke air chamber requires less frequent adjustment because it has a wider band of acceptable pushrod stroke than a conventional stroke air chamber.

For the most common size brake chamber now used, the Type 30, adjustment and reserve limits are fairly small and appear to be difficult to maintain. A typical within-limit adjustment range for the Type 30 is 0.75 inch (pushrod travel is from 1.25 inches to 2.0 inches), and the chamber has only 0.5 inch left before the piston bottoms out and braking force is lost. One-half inch of pushrod stroke reserve is not enough to ensure stopping capability, especially when a vehicle's brakes are misused in a long downhill descent and components expand due to heat.

A long stroke Type 30 chamber would have a maximum pushrod stroke of 3.0 inches. (See **figure 20.**) This would increase the range of the in-adjustment stroke to 1.0 inch (from 1.25 inches to 2.25 inches) and would also increase the reserve travel before losing all effectiveness to 0.75 inch (from 2.25 inches to 3.0 inches). **Figure 21** shows a comparison of the pushrod force for a normal stroke Type 30 air chamber and a long stroke Type 30 chamber.

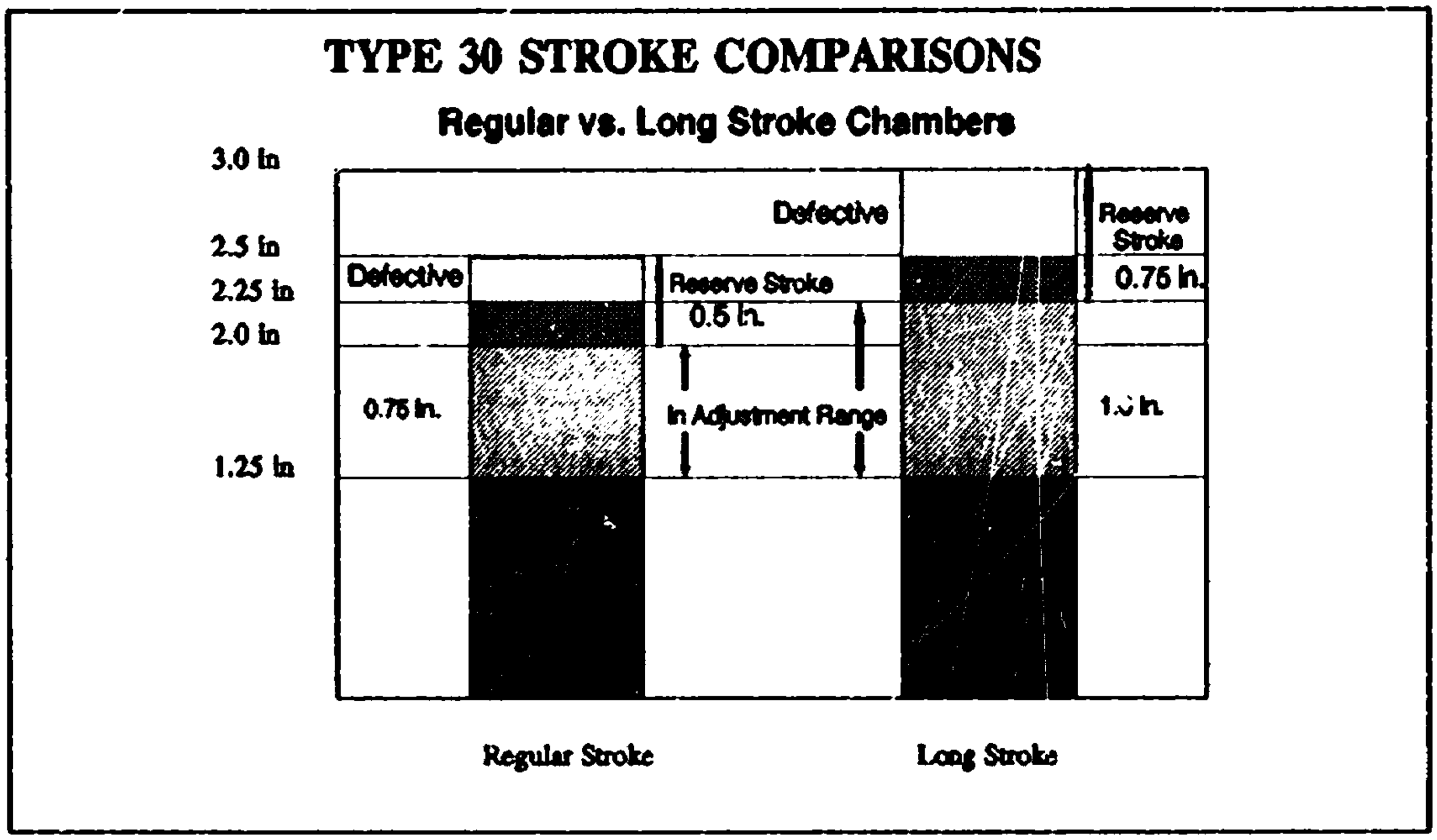


**Figure 20.--Comparison of pushrod stroke: regular versus long stroke Type 30 chambers.**

The Safety Board is aware that converting a vehicle to Type 30 long stroke chambers would require resizing some air reservoirs to accommodate the increased volume demanded by the larger chambers as they reach the limits of adjustment. Long stroke chambers reaching that limit consume more air when brakes are applied because of the greater swept volume of the chamber diaphragm. The long stroke chambers can therefore have greater reservoir air storage requirements. These larger components may also create some packaging difficulties for those manufacturers who are attempting to lower the suspension heights of their vehicles. Yet the Safety Board is convinced that the changes required to install long stroke chambers would be a small price to pay for reducing the number of out-of-adjustment brakes. Government and industry representatives familiar with heavy vehicle airbrake systems agree that the addition of a long stroke air chamber would cause few compatibility problems.

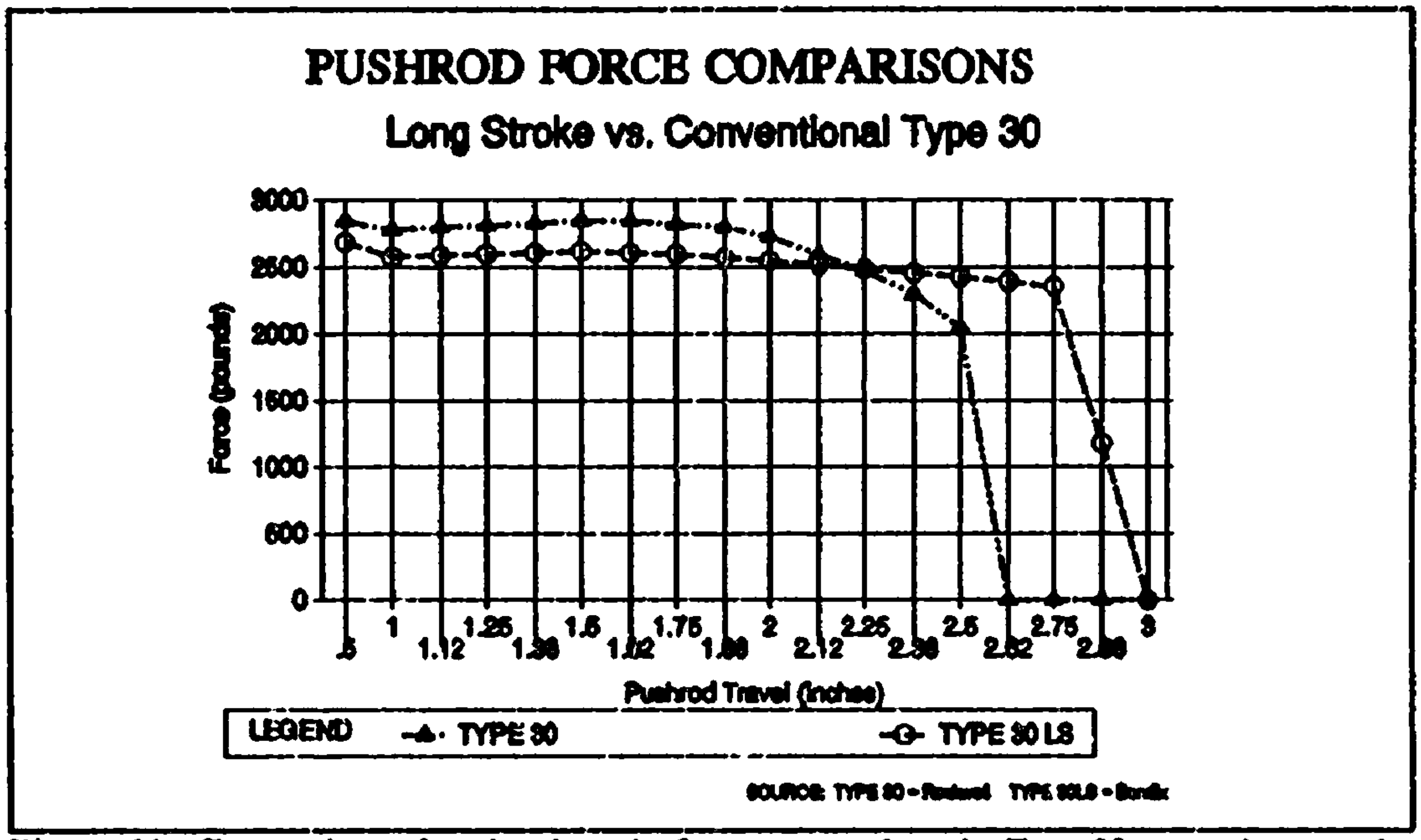


**Figure 21.--Comparison of pushrod stroke force: normal stroke Type 30 versus long stroke Type 30 chambers.**

<u>Benefits of Combining Long Stroke Chambers With Automatic Slack Adjusters</u>.--A previous NHTSA study[44] illustrated that automatic adjusters will reduce the frequency of out-of-adjustment brakes on heavy trucks. Data from the Safety Board's five-State inspections indicate that automatic slack adjusters do keep brakes in better adjustment than manual adjusters. The average pushrod stroke for automatic slack adjusters with Type 30 chambers over the entire interstate sample was about 1.60 inches, or 0.4 inch below the manufacturer's recommended limit of adjustment of 2.0 inches.

The off-interstate sample produced an average pushrod stroke for the automatic slack adjusters of 1.65 inches on the Type 30 chambers. In both the interstate and the off-interstate sample, the manual slack adjusters installed on the trailers were found to have the longest average

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[44]Improved Brake System for Commercial Motor Vehicles, U.S. Department of Transportation, NHTSA Report No. DOT-HS-807-706, 1991.

pushrod stroke. (See **figures 22 and 23.**) These average pushrod strokes would have provided even greater reserve capacity if long stroke Type 30 chambers had been used.

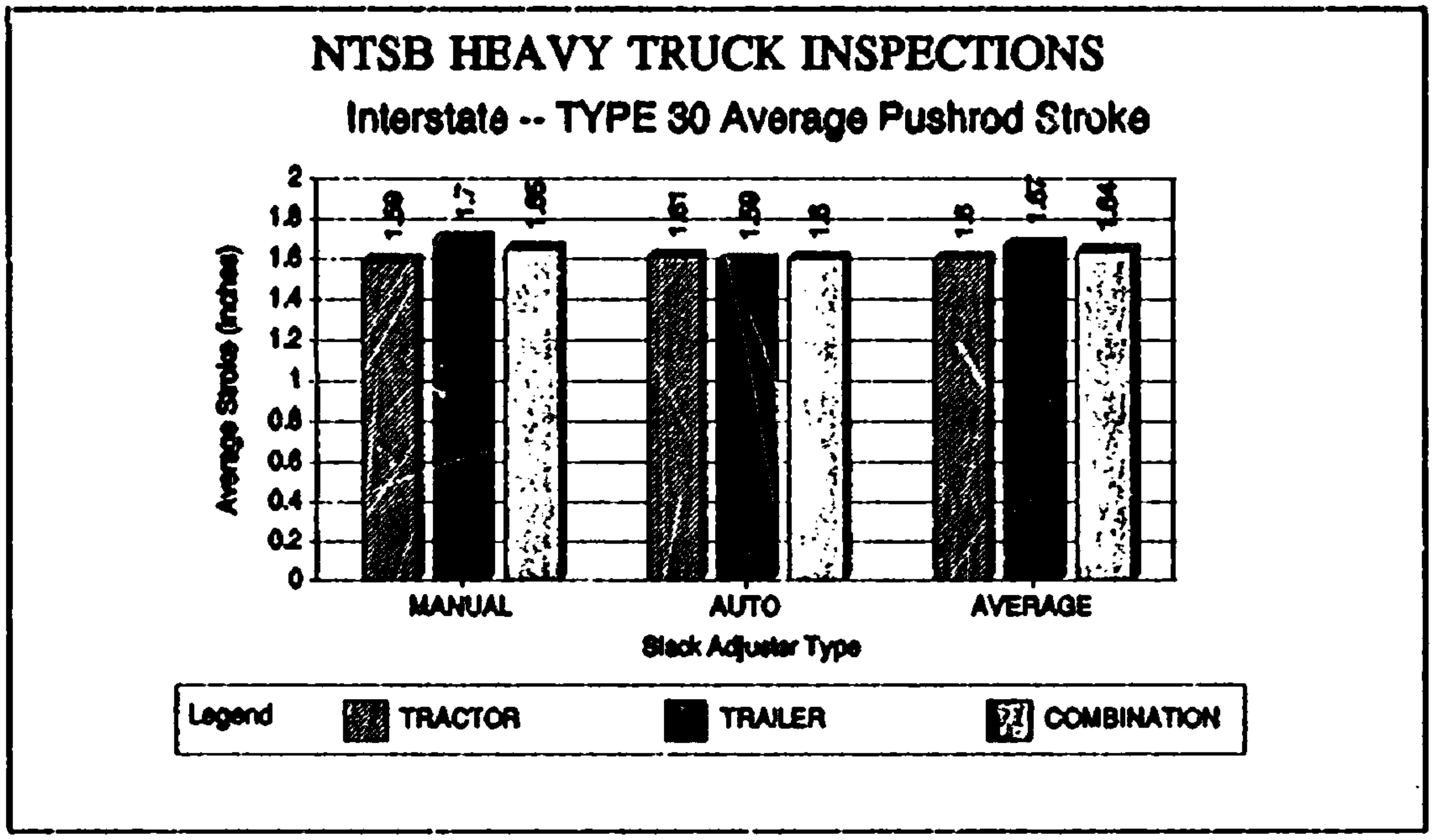


**Figure 22.--Pushrod stroke analysis (interstate sample).**

Measurements from the total sample showed that 26 percent of the brakes equipped with manual slack adjusters were either at or past the manufacturer's recommended limit of adjustment. An analysis of the effectiveness of the automatic slack adjusters from the total sample revealed that 15 percent were allowing the stroke to reach or exceed the manufacturer's recommended limit on regular stroke chambers.

The inspection data showed that only 4 percent of the brakes with automatic slack adjusters were at 1/4 inch or more past the manufacturer's recommended limit of adjustment. (See **table 3.**) Because the adjustment range of a properly installed and maintained automatic adjuster should remain consistent regardless of the chamber's reserve stroke, the benefits of combining automatic adjusters with long stroke Type 30 chambers can be demonstrated.

A regular stroke Type 30 chamber using an automatic adjuster 1/4 inch past the adjustment limit would be equivalent to a long stroke Type 30 chamber with an automatic adjuster at its adjustment limit because the 1/4 inch of reserve stroke has been added to the available adjustment range. Thus, combining a properly installed and maintained automatic slack adjuster with a long stroke chamber could reduce the percentage of brakes at or past the limit of adjustment from the 26-percent figure for the manual slack adjusters on a regular stroke chamber to the 4-percent figure for the automatic adjusters installed on a long stroke chamber. Not only would the long stroke chambers greatly increase the reserve stroke, but, used in combination with automatic slack adjusters, could also greatly decrease the number of heavy vehicles placed out of service due to brake adjustment violations. The industry should consider installing and using brake system actuators and components that are less sensitive to adjustment and more resistant to brake system fade. Although the installation of improved components could bring about a significant improvement in brake adjustment levels, these improvements would not be attainable without consistent attention to brake system maintenance.

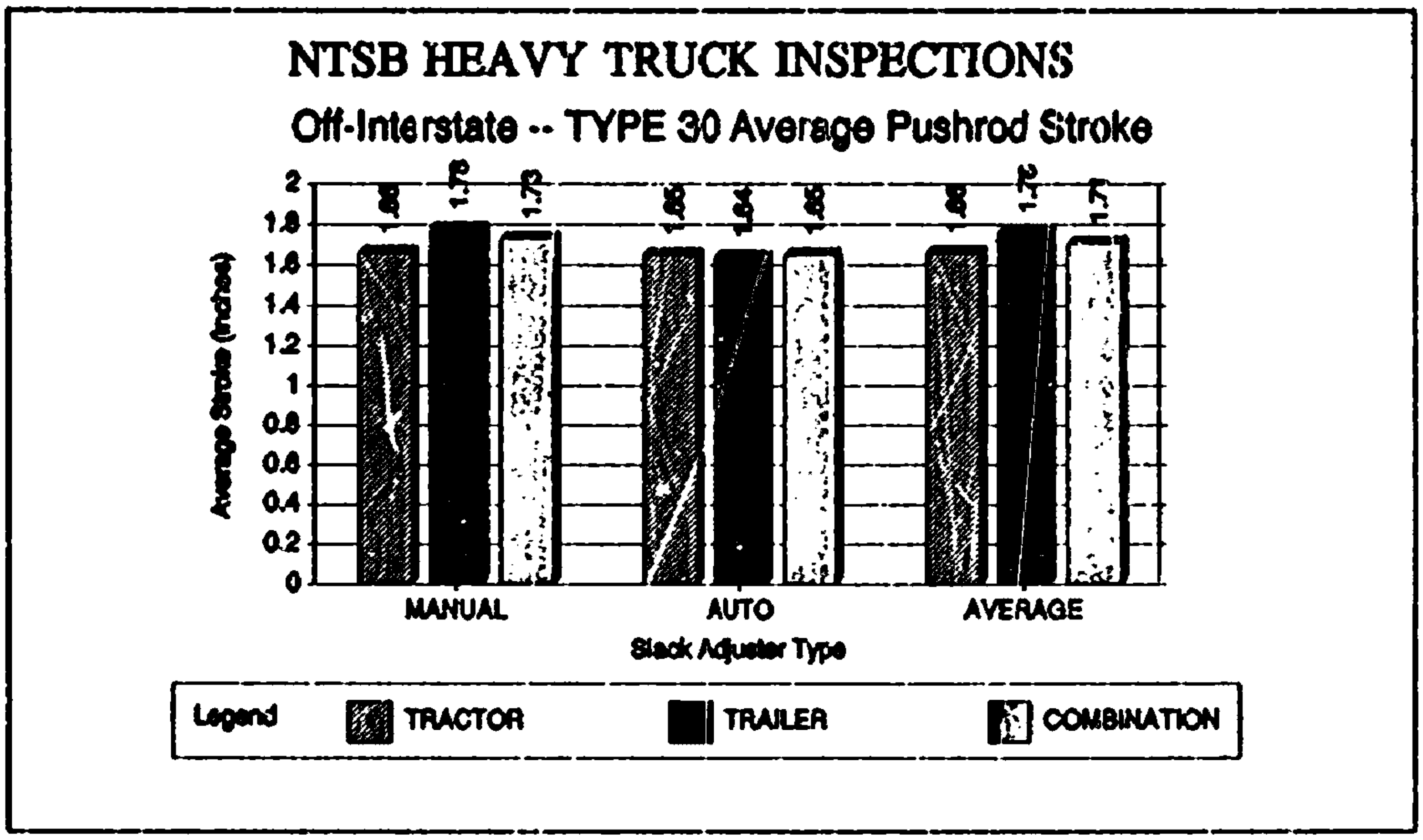


**Figure 23.--Pushrod stroke analysis (off-interstate sample).**

# CHAPTER 5

## INFLUENCE OF BRAKE SYSTEM COMPONENTS ON VEHICLE PERFORMANCE

This study identified automatic limiting valves installed on steering axles, low torque brakes on steering axles, and the lack of brakes on steering axles as contributing factors in truck accidents. Further, the Safety Board's inspections of heavy truck brakes show that the presence of these conditions is not a rare or isolated occurrence. Although the focus of this chapter is to highlight accidents influenced by brake components, the Safety Board determined that each of the cited accidents would have been prevented had the vehicle been equipped with an antilock braking system. Antilock brakes are discussed in detail in chapter 6.

### Limiting (Ratio) Valves

Issaquah, Washington.--This accident illustrates how both mechanical and human factors can combine to cause an accident and how a component in the braking system can contribute to the cause of an accident.

On November 20, 1989, a lightly loaded 65-passenger school bus was approaching two passenger vehicles. The vehicles were stopped in the bus' lane and preparing to turn left. As the bus traveled through the rain-slick curve to the left with 6-percent superelevation, the busdriver gradually began to apply the brakes to slow for the stopped traffic. The rear wheels of the bus locked and began sliding across the centerline. Afraid to have any part of the bus over the centerline, the busdriver let up on the brakes. When the driver realized that the bus was not going to stop in time, she reapplied the brakes and slid into the stopped pickup in front of her.

No injuries resulted from this accident. If, however, oncoming traffic had been in the opposite lane as the back end of the bus swung across the centerline, another more serious collision could have taken place.

Safety Board investigators found all the bus' brakes well within the manufacturer's recommended limit of adjustment. Pressure balance testing revealed that the bus was equipped with an automatic limiting valve (ALV) on the steering axle. This particular valve limits the service air pressure to the steering axle brake chambers to 50 percent of the applied pressure value from 0 psi to 40 psi. When the applied air is between 40 psi and 60 psi, the service air to the chambers will increase from 50 percent at 40 psi to 100 percent at 60 psi. See **figure 24** for a graph of the pressure characteristics of this valve. When Safety Board investigators measured the service air supplied to the steering axle chambers, they found it never fully reached 100 percent of what was applied, but remained close to 90 percent. Calculations revealed that the lightly loaded bus on the low friction road surface would become unstable at an application pressure of 50 psi. Actual road tests with the accident bus in similar weather conditions verified that the rear axle would lock and begin sliding toward the centerline during a brake application.

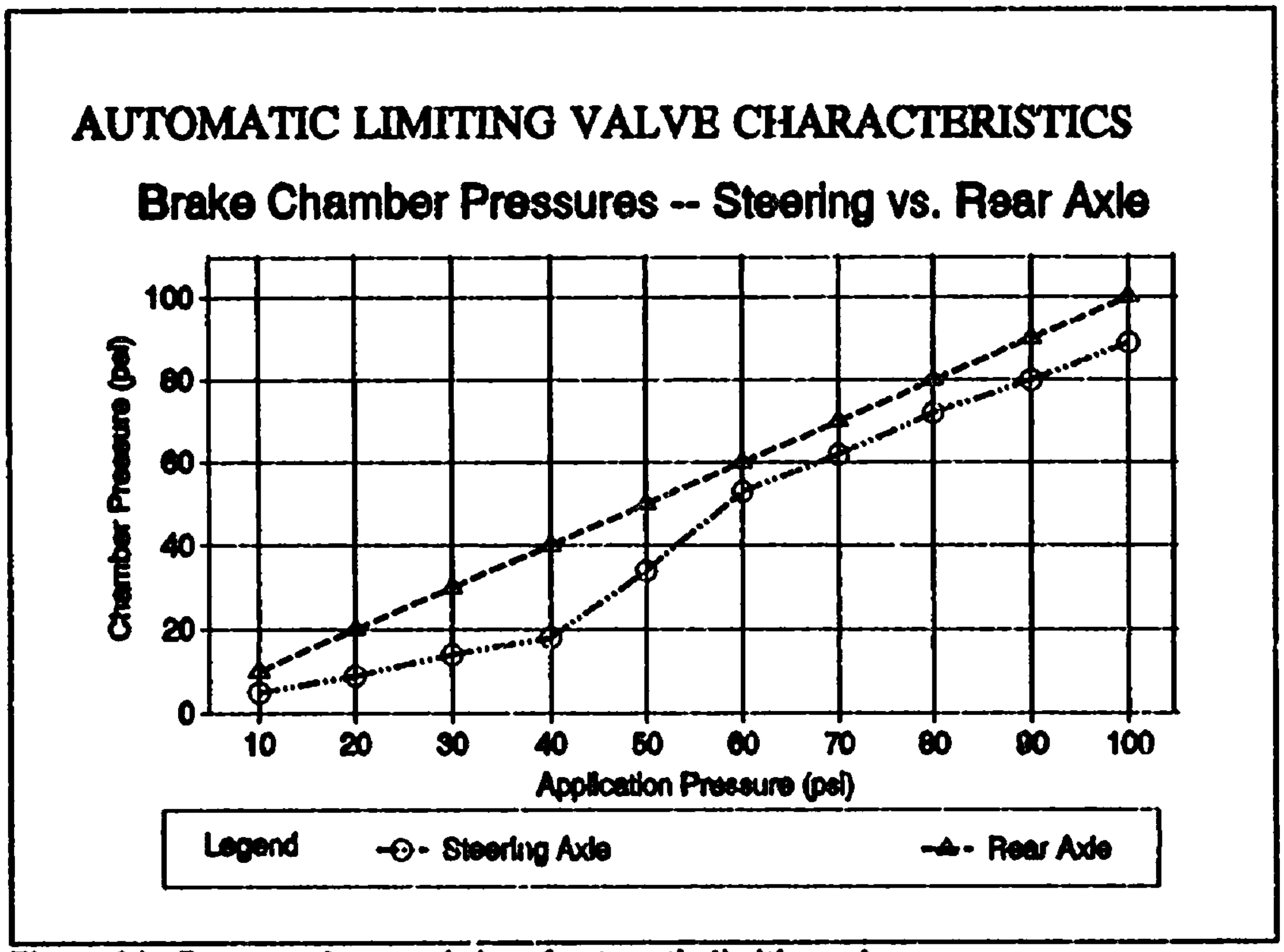


Figure 24.--Pressure characteristics of automatic limiting valves.

The accident was not caused by the rotation of the bus or by the instability perceived by the driver. However, these factors did contribute to the driver's indecisive action, which resulted in a longer than necessary stopping distance. Time/distance calculations also revealed that the driver of the bus probably did not begin to apply the brakes soon enough for a normal slow-deceleration stop on the wet pavement. Tests revealed that the bus could have been brought to a sliding stop without a collision, but the driver became concerned when the bus slid across the centerline, let up on the brakes, and was unable to stop in time.

Limiting Valve Influence on Stopping Distance.--In a Special Investigation Report, "Emergency Fire Apparatus" (NTSB/SIR-91/01), the Safety Board identified a limiting valve as having contributed to a loss of stopping capability and a subsequent crash. Although the valve discussed in the Special Investigation Report was a manual "wet/dry switch,"[45] which functions differently from an ALV, it limited the vehicle's braking capability and contributed to a downhill runaway. The Safety Board determined that the limiting valve in the "wet" position, coupled with the poorly maintained brake system, reduced the vehicle's braking efficiency to about 36 percent.

As a result of the Special Investigation, the Safety Board made the following recommendation:

--to the U.S. Fire Administration of the Federal Emergency Management Agency and to the International Association of Fire Chiefs:

H-91-5 and -9
Notify fire departments of the hazards of using fire apparatus manual brake limiting valves, and urge them to discontinue the use of these devices.

The International Association of Fire Chiefs has not yet responded to this recommendation. However, the U.S. Fire Administration of the Federal Emergency Management Agency responded on June 5, 1991, that it had recommended fire apparatus users discontinue the use of manual brake limiting valves. Based on that response, the Safety Board has classified the recommendation to the U.S. Fire Administration of the Federal Emergency Management Agency as "Closed--Acceptable Action."

Other Government agencies have also analyzed the influence of limiting valves on the stopping capability of heavy vehicles. In the DOT document "A Demonstration of the Safety Benefits of Front Brakes on Heavy Trucks" (HS 807 061), the authors describe the results of their testing. The document states that "when automatic limiting valves were operational on front axles, the drivers always took longer to stop under full control than when the vehicles had full front brakes." Another research paper entitled "The Performance of Trucks Braking on Ice" (FHWA-MC-88-045) reaches similar conclusions on the ALV. The authors note:

> Most air-braked trucks in this country are so under-braked at the front axle that limiting valves are of no value whatsoever, regardless of the surface or loading conditions and, in fact, cause braking performance to be degraded.

Limiting Valve Influence on Stability and Handling.--Stability and handling greatly affect the stopping distance of a vehicle. When a vehicle becomes unstable, it is natural for the driver to let up on the brakes, thus increasing the stopping distance. Therefore, the effects are very

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[45] Many older vehicles used a manual limiting valve (commonly called a dry road/slippery road valve or wet/dry switch) that was controlled by a switch in the cab. In the "dry road" position, the valve was a 1:1 valve. In the "slippery road" position, it reduced front brake pressure to 50 percent of the service line pressure at all application pressure levels.

much linked and difficult to separate. The Issaquah, Washington, accident mentioned previously is a case in point. It was the instability caused by the premature lock-up of the drive axles that caused the driver to let up on her brakes; this resulted in increasing the distance in which the bus could be safely stopped. The accidents and issues discussed in this section of the report relate more to stability control problems caused by brake system components than to a lengthened stopping distance caused by the instability.

In "Improved Brake Systems for Commercial Motor Vehicles" (DOT HS 807 706), the performance of the automatic limiting valve is summed up:

> ALVs can compromise the safety performance of vehicles in certain situations. First, ALVs mask front brake maintenance problems. A braking imbalance may be present but not discernible to the driver during "normal" braking. In an emergency/limit-performance braking situation, the braking imbalance could result in a significant steering wheel pull that the driver is not prepared to handle due to the element of surprise. Secondly, ALVs have a negative effect on limit performance stopping capability when the vehicle is operating bobtail, empty, or on slippery surfaces. The Agency has conducted numerous tests over the years to evaluate the effect of ALVs with different types of vehicles in braking and turning maneuvers on surfaces ranging from dry pavement to ice. In every case, the results have conclusively indicated that ALVs degrade braking performance by lengthening stable stopping distances and increasing the likelihood of drive and trailer wheel lock-up (resulting in jackknife, spin-out, or trailer swing).

In the Issaquah accident, neither the investigating police agency nor the school district identified the presence of the ALV or its contribution to the cause of the accident. This accident illustrates that an ALV can contribute to an accident but go undetected and, thus, unreported. The Safety Board believes that the ALV may be a contributing factor in other instability accidents and normally is not detected.

The Safety Board's five-State inspection project revealed that 33 percent of the five-axle combination vehicles inspected on the interstate system and 47 percent on the off-interstate system had an automatic limiting valve installed on the steering axle brakes. These percentages reflect only those tractors with brakes installed on the steering axles. (See **figure** 25.) Numerous NHTSA studies and published reports agree that ALVs result in increased stopping distances and in some instances, dynamic instability.

Reasons for Restricting the Automatic Limiting Valve.--NHTSA engineers have conducted tests involving ALVs, all with the same conclusion: they see limited practical use for ALVs on steering axles. Brake systems are designed to match the maximum axle weight proportions on a vehicle capable of carrying varying loads. When a limiting valve is added to the system, it upsets the load proportions considered in the design of the vehicle's brake system.

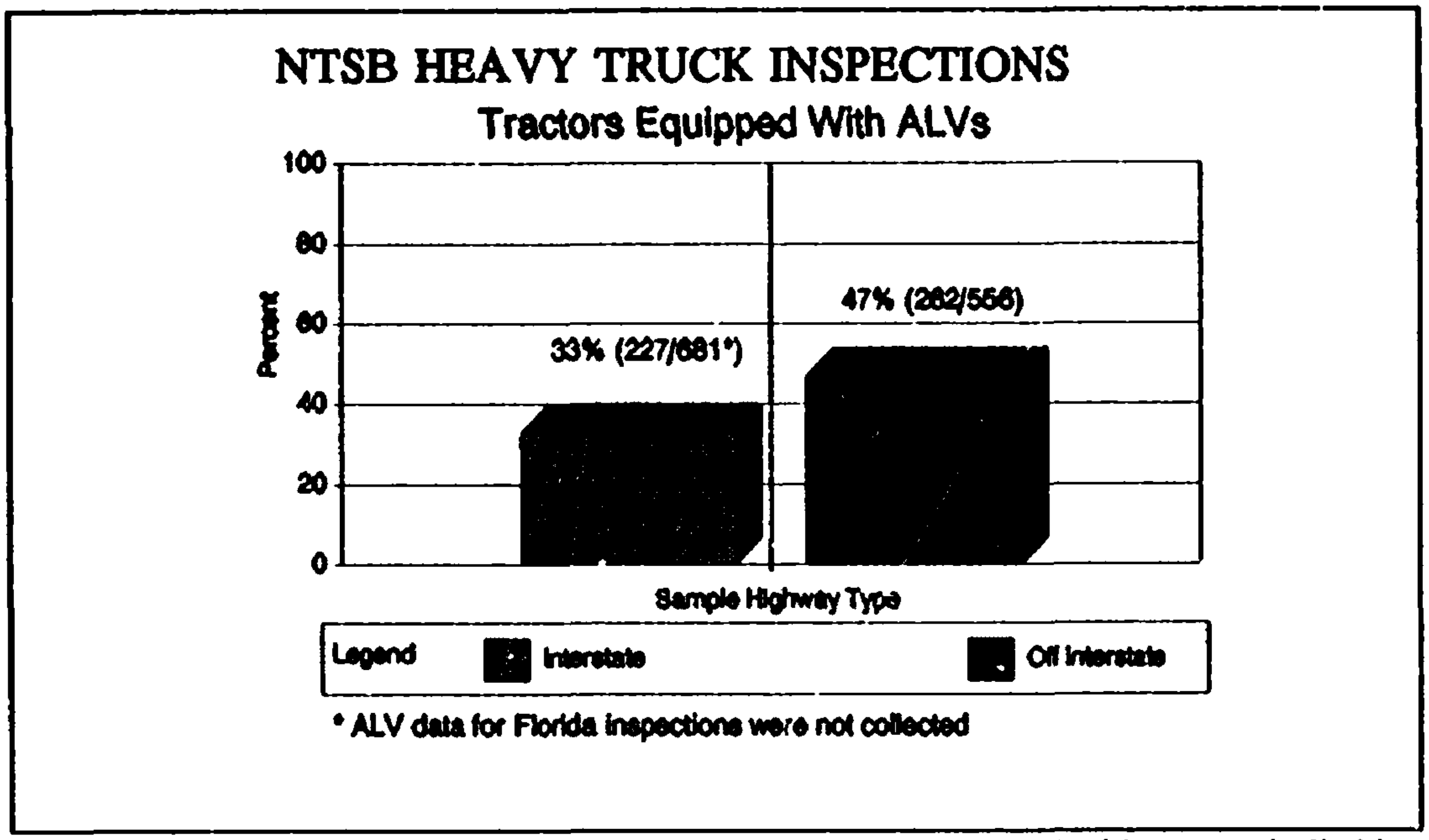


**Figure 25.--NTSB five-State sample of combination vehicles equipped with automatic limiting valves.**

After discussing how the steering axle brake limiting valve degrades braking performance, the authors of "Improved Brake Systems for Commercial Motor Vehicles" (DOT HS 807 706) wrote,

> Given these concerns about the performance ramifications of ALV use, NHTSA's goal is to discourage ALV use. It is encouraging that most U.S. truck manufacturers now install ALVs only if specifically asked to do so by their customers. Unfortunately many truck purchasers continue to believe that ALVs are desirable and include them in their purchase specifications. The agency is considering proposing in 1991 a rule reinstating stopping distance requirements for air-braked heavy trucks. One of the objectives sought by NHTSA in this effort will be to establish performance requirements that will be difficult to achieve with ALV-equipped vehicles.

The Safety Board agrees with the NHTSA's objectives but believes that the use of the ALV on buses should also be restricted. Most buses also carry a varying load, although the proportions of weight on each axle do not typically change as much as those on a heavy truck with a gross vehicle weight rating of 80,000 pounds. Nevertheless, an ALV on a bus can greatly upset the brake proportioning designed into its braking system and, therefore, create undesirable lateral instability problems.

The carrier or owner needs to be careful when removing an ALV from a heavy vehicle. The vehicle's manufacturer should be consulted to make sure that no incompatibilities are introduced into the system when the ALV is removed. For instance, the crack pressure--the pressure at which the valve opens--on the quick release valve retrofitted onto the steering axle brake system must be balanced with the pressures of the existing valving on the other axles to properly balance the front and rear brake system.

**Vehicle Manufacturers' Policies on Brake Component Sizing**

The Safety Board became concerned with the sizing of airbrake components for heavy vehicles when its investigators examined some of the brake maintenance literature. As they searched for a way to calculate braking force at the tire/road surface, the investigators found the AL-Factor formula in the Kenworth Manual and in the "Grey-Rock Diagnostic Engineering Service Manual." The Kenworth Manual states: "AL-Factor is an index number used to select the best combination of A - the Area of the brake chamber, and L - the Length of the cam lever or slack adjuster." The Grey-Rock literature asserts that as its engineers analyze a fleet's operation, they also check "the AL-Factor (effective area of brake chamber diaphragm X length of slack adjuster) to determine whether a change in slack adjuster length or brake chamber size is desirable or necessary." Investigators compared calculated results of braking force using the AL-Factor formula to results from NHTSA dynamometer work. They found that the AL-Factor formula predicted braking force values that were consistently 40 percent higher than the measured values from the NHTSA dynamometer. Details and some examples of this work are found in SAE paper 910126, "Heavy Truck Deceleration Rates as a Function of Brake Adjustment." (See appendix I.) As a result of questions about the AL-Factor, the Safety Board interviewed manufacturers to determine the extent to which truck brakes are sized based on the AL-Factor formula. The results of a sample of these interviews are presented below.

Mack Trucks, Inc.--Engineers at Mack Trucks use the axle weight rating at the maximum available tire static load rating to determine the wheel's brake power requirements as set forth in 49 CFR 571.121 S5.4.2 and S6.2. (See chapter 6 for discussion of brake performance requirements.) These values define the loading used on the dynamometer and eventually dictate the sizing combinations for the air chamber size and the slack adjuster length, as well as the lining grade to install. For axles with a gross axle weight rating of 34,000 to 44,000 pounds, Mack Trucks uses a 16.5-inch by 7-inch s-cam foundation brake with a Type 24 long stroke air chamber, a 6.0-inch slack adjuster, and NAB 9M friction lining. The smaller air chambers were selected to allow packaging of the high mount chamber position on Mack suspensions for vehicles with 34.5-inch frame widths. This certified combination (with the NAB-9M lining) was first used in production in 1982.

Ford Motor Company.--Ford sizes its brake system components using a procedure similar to that used by Mack Trucks. Once the tire, wheel, and axle rating are determined, the required braking power is calculated. A variety of combinations of linings, air chamber sizes, and slack adjuster lengths are available that can provide the required braking power. The brake power criteria and any space constraints determine the final configuration of the vehicle's brakes.

Although none of the major tractor manufacturers interviewed said that they used the AL-Factor formula in sizing brakes, this methodology is discussed often in the literature available to the fleets. The literature suggests that a 10-percent linkage loss or a safety factor of 1.1 should be included; however, this formula still produces braking force values higher than those that actually occur according to dynamometer tests. In one example of sizing brake components, the Grey Rock literature uses an application pressure of 60 psi. The calculated values of braking force using a 60-psi application pressure compare closely to dynamometer measured values with an actual application pressure of 90 to 100 psi. The 90- to 100-psi pressure would be consistent with a maximum pressure brake application during an emergency stop. The Safety Board is concerned that some maintenance facilities may be using this procedure to size replacement parts and thus are undersizing brake components. The Safety Board also believes that suppliers of brake components and companies that offer their services as brake consultants should discontinue the use of the AL-Factor formula.

**Steering Axle Brakes**

Seattle, Washington, November 19, 1990.--The lightly loaded drive axles, the rain on the roadway, and the condition and size of the braking system were all factors that, when combined, created the potential for a jackknife accident. The fatal jackknife resulted when the driver, operating on slick road conditions, initiated a quick, hard brake application.

A 41-foot lowboy trailer carrying three forklifts was loaded with the majority of the weight on the trailer's axles and very little on the tractor's drive axles. The driver, traveling on a wet roadway, applied his brakes, and the tractor began to rotate rapidly clockwise. After the tractor rotated past 90°, the left side of the tractor struck a guardrail at the edge of the shoulder and crashed into a steel support pole. The unrestrained driver was ejected and pronounced dead at the scene. The tractor was destroyed during the collision.

An examination of the combination vehicle's braking system revealed that 5 of the 10 brakes were more than 1/4 inch past the manufacturer's recommended limit of adjustment and the steering axle brakes were at the limit. The three remaining brakes, which were within the adjustment tolerances, were on the lightly loaded drive axles.

Studies have found that once a tractor rotates past 12-15° in a jackknife, it is very difficult to recover, even for a well-trained and experienced driver. The UMTRI Phase 4 computer simulation model[46] of the accident predicted that this tractor would have rotated over 12° in 1.3 seconds and past 90° in 3.1 seconds.

[46]See appendix J for a description and the program application, input parameters, and validation.

The simulation of this accident also added an antilock system. Even with all the other deficiencies, the vehicle with the added antilock system was able to make a lane change within 100 feet in a controlled manner. This simulates an accident in which the driver might perceive cars slowing in front of him, apply his brakes, and attempt to steer around the cars on the shoulder.

Rochester, Washington, November 13, 1989.--Another jackknife investigated by the Safety Board involved a tractor with no brakes on its steering axle. The combination vehicle was driven by an inattentive driver forced to apply his brakes in a panic situation.

The 1974 Peterbilt tractor in combination with a lightly loaded van trailer was approaching several cars stopped on the wet roadway, waiting for the first vehicle to make a left turn. The tractor rotated into the oncoming lane of traffic and collided with an approaching passenger car; the driver of the passenger car was killed. By the time the truckdriver realized the cars ahead were stopped, a hard brake application was necessary.

When the tractor and trailer were examined by Safety Board investigators, they found that there were no brakes on the tractor's steering axle and none were required. All but one of the vehicle's eight brakes were within the manufacturer's recommended limit of adjustment. The one brake not in adjustment was near the limit and, in a non-heated condition, was still capable of generating enough braking torque to lock its wheel. When the braking efficiency was calculated, the braking system was found to be 76-percent efficient. The 24-percent efficiency reduction resulted from the lack of brakes on the steering axle and from the light load.

Calculations indicated that all axles equipped with brakes would lock; the tire marks on the roadway supported this conclusion. The distance required to stop was not a problem, as the combination vehicle stopped without striking any of the passenger vehicles ahead. **Figure 26** is a diagram of the accident scene, showing the final resting positions of the vehicles.

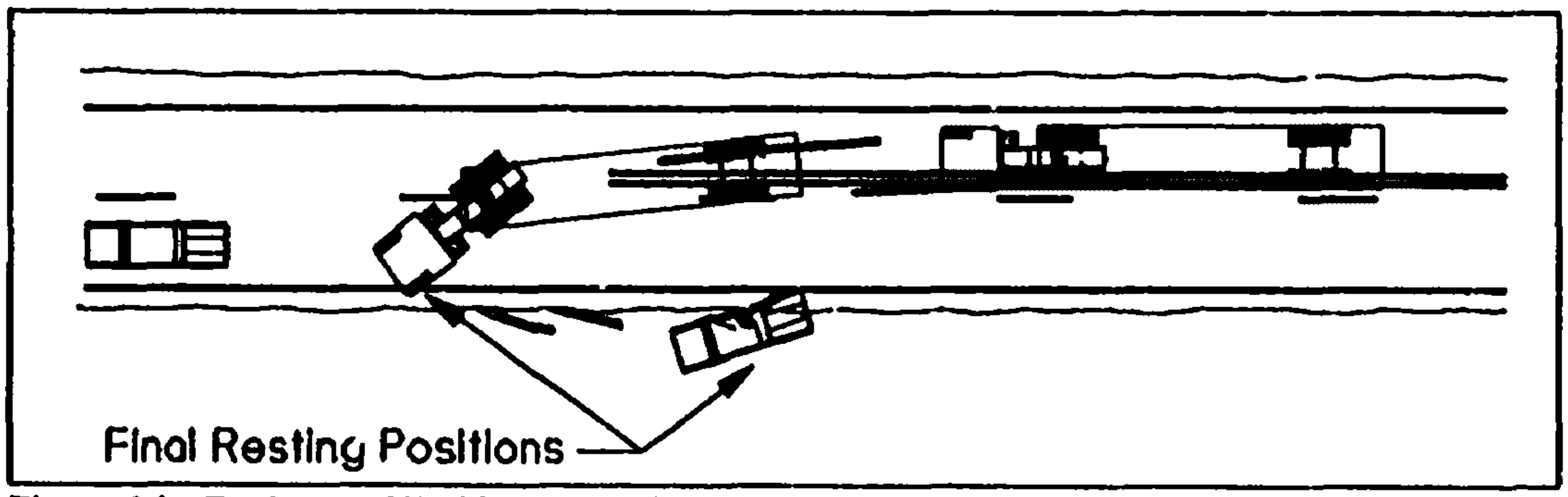


**Figure 26.--Rochester, Washington, accident dynamics.**

A Phase 4 computer simulation was used to analyze the accident. The accident parameters were entered into the UMTRI simulation, and the accident dynamics were reproduced with the 0.01 foot per foot crown in the roadway that influenced the vehicle's counterclockwise rotation. When a simple antilock system was added to the Phase 4 analysis, the combination vehicle stopped in its own lane of travel and rotated only 0.3° in the process.

Analysis of Steering Axle Brakes.--In all but one of the accidents investigated by the Safety Board that were related to the vehicle's stopping capability, maintenance played a larger role in causing the accident than did low brake torque components (low output components). Yet, many combination vehicles involved in the collisions also had brake chamber sizes smaller than the typical Type 20 on the steering axle. The longer stopping distances were caused more by improper maintenance than the size of the air chambers.

The Safety Board's five-State vehicle inspections found that 6.6 percent of the tractors had no steering axle brakes, 0.4 percent were equipped with Type 9 air chambers on the steering axle, 4.1 percent with Type 12, 20.3 percent with Type 16, 65.9 percent with Type 20, and 0.5 percent with Type 24 air chambers. Wedge brakes were found on the steering axles of 2.1 percent of the inspected combination vehicles. These figures are displayed in **figure 27** and include all of the inspected vehicles.

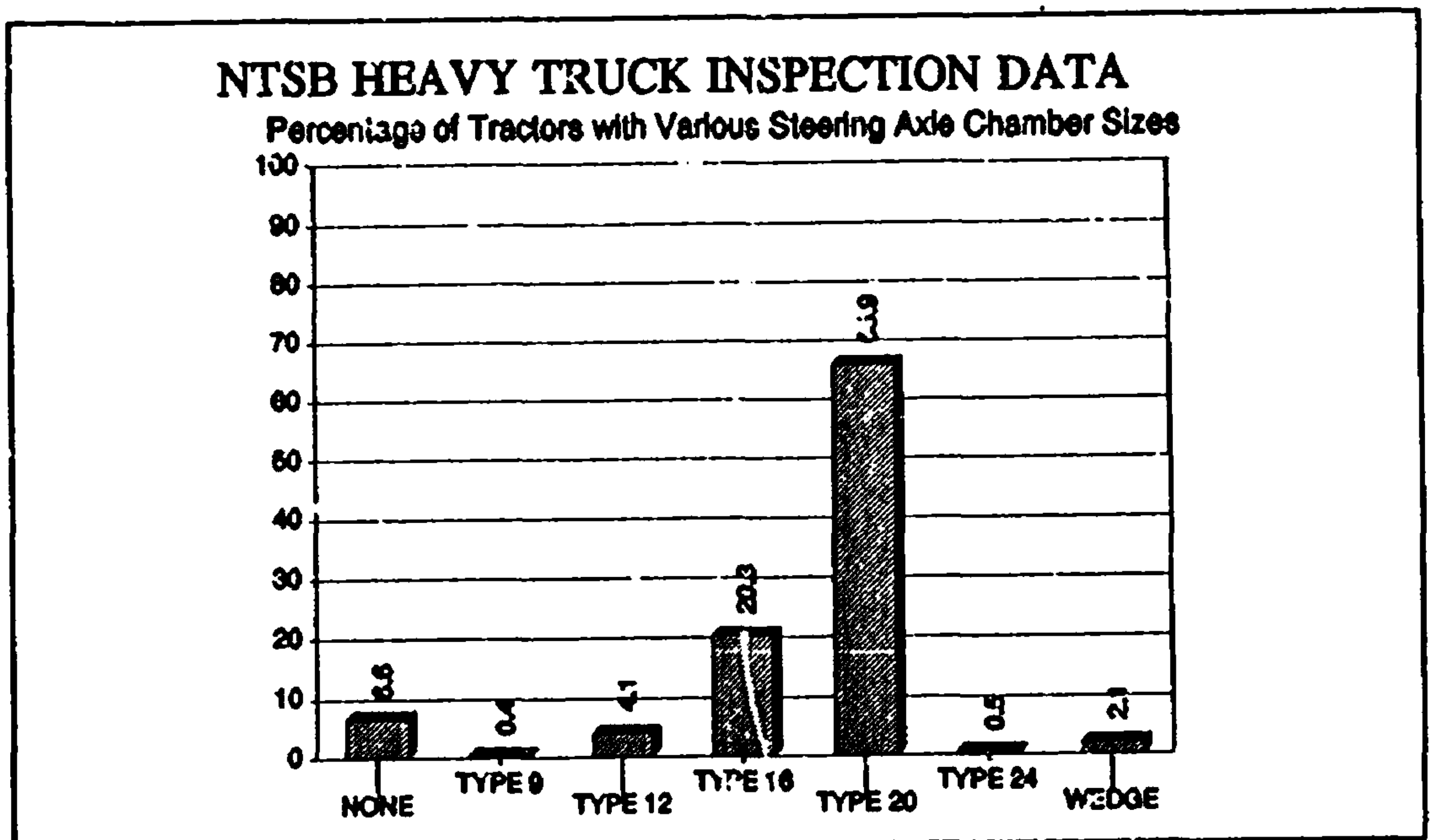


**Figure 27.--NTSB five-State sample of combination vehicles with steering axle brakes.**

Even though many vehicles have brake chamber sizes smaller than the typical Type 20, and even though many vehicles involved in the investigated accidents also had the smaller brake chambers, very few heavy truck accidents are attributed in accident data to small brake chambers on the front axle. The Safety Board suspects that the small brake chamber size on the front axle is another contributing factor that has often gone undetected. The reasons that prevent poor maintenance and defective brakes from being identified as causes in accidents also apply to steering axle brakes. Most police agencies do not have the time, and in some instances the training or equipment, to analyze how the brake components contribute to the cause of an accident.

Figure 28 displays the braking efficiency of vehicles equipped with steering axle air chambers of varying sizes.[47] Configuring a tractor with either Type 9 or Type 12 air chambers on its steering axle brakes can reduce the empty weight braking efficiency by 15 and 12 percent compared to a combination vehicle with Type 20 chambers on the steering axle. These figures assume that the brake lining coefficient of friction remains constant at 0.35.

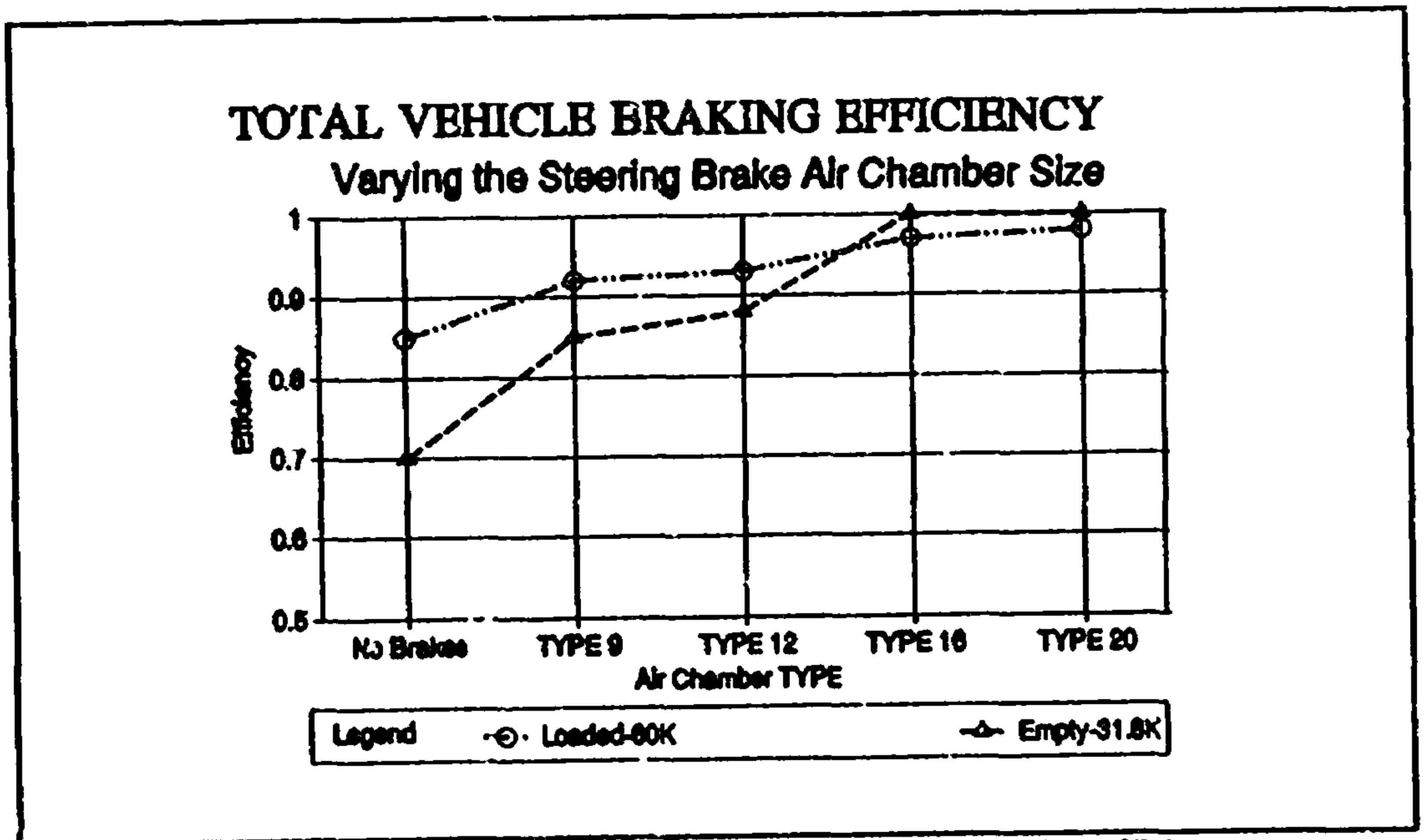


Figure 28.--Effect of air chamber size and weight on vehicle braking efficiency.

[47]The values plotted in figure 28 are efficiencies calculated according to the procedures outlined and explained in SAE Paper 910126. See appendix I.

**Figure 28** also compares the braking efficiency of loaded and empty vehicles. The graph indicates that the brakes on the loaded combination vehicle are more efficient than brakes on the empty vehicle. This is because the steering axle brakes on an empty vehicle normally contribute a greater percentage of the total braking force than they do on a loaded vehicle. When a vehicle is loaded, the load on the drive and trailer axles can increase almost three times, but the load on the steering axle usually increases only about 1.2 times. Thus, an empty tractor-trailer depends more on its steering axle brakes. Deficient steering axle brakes or air chambers that are too small cause larger reductions in braking efficiency.

Some older tractors are not equipped with steering axle brakes. This is another component problem that affects the stopping capability of combination vehicles. In the course of the Safety Board's accident investigations, three vehicles were examined that did not have brakes installed on their steering axle. In two of the accidents, the lack of front axle brakes contributed to the vehicle's difficulty stopping though it was not the main factor.

**Figure 28** also compares the braking efficiency of a vehicle with no brakes installed on the steering axle to that of vehicles equipped with air chambers of varying sizes. This comparison shows that the lack of brakes can reduce the braking efficiency of an empty vehicle to 70 percent of what it would be if the same vehicle had Type 20 air chambers on the steering axle. Why? The percentage of weight distributed on unbraked axles is directly proportional to the reduction in braking efficiency. For example, an empty combination vehicle weighing 31,800 pounds (100 percent of total) with 9,540 pounds (30 percent of total) of unbraked steering axle weight would only be 70-percent efficient because the full weight of the vehicle is being braked by wheels supporting only 70 percent of the combination vehicle weight.

In 1987, the Federal Highway Administration revised the Federal Motor Carrier Safety Regulations to require that front axle brakes be kept in a functional condition on all heavy trucks and on all tractors manufactured with steering axle brakes. Federal Motor Carrier Safety Regulation 49 CFR 393.42(b)(1)(i) now states that three-axle tractors manufactured before July 25, 1980, are not required to have brakes installed on the steering axle but that any brakes or brake components on these vehicles must be operational. Before this change, a tractor or truck operator could remove the front axle brakes if the truck or tractor had three or more axles. The 1987 regulation was not made retroactive past July 1980.

The Safety Board's five-State truck inspections on the interstate revealed that 5 percent of the sample's five-axle tractor semitrailers had no brakes installed on their steering axles. The off-interstate sample showed that 8.9 percent of the five-axle combination units were without brakes on the steering axles. In the total sample of 1,520 tractors, 6.6 percent (or 100 vehicles) did not have brakes installed on their steering axles. All 100 vehicles had been manufactured before July 1980. A graph showing the sample breakdown by State and road system is shown in **figure 29**.

Evaluate Low Brake Force Steering Axles.--While low brake force components on steering axle brakes contribute to the cause of accidents, it does not appear that equipping all heavy trucks with large steering axle air chambers is the best solution. The Phase 4 computer simulations show that larger air chambers, such as the Type 24 on steering axle brakes, produce more deceleration but also cause more weight shift. In some cases, the increased weight shift can greatly unload the drive axles. When the drive axles become unloaded, they are much more susceptible to lock-up and a resulting jackknife. Because of the complex nature of heavy truck braking dynamics, the Safety Board does not believe it would be wise to mandate any stopping performance requirements that would require larger than optimum brakes on the steering axle.

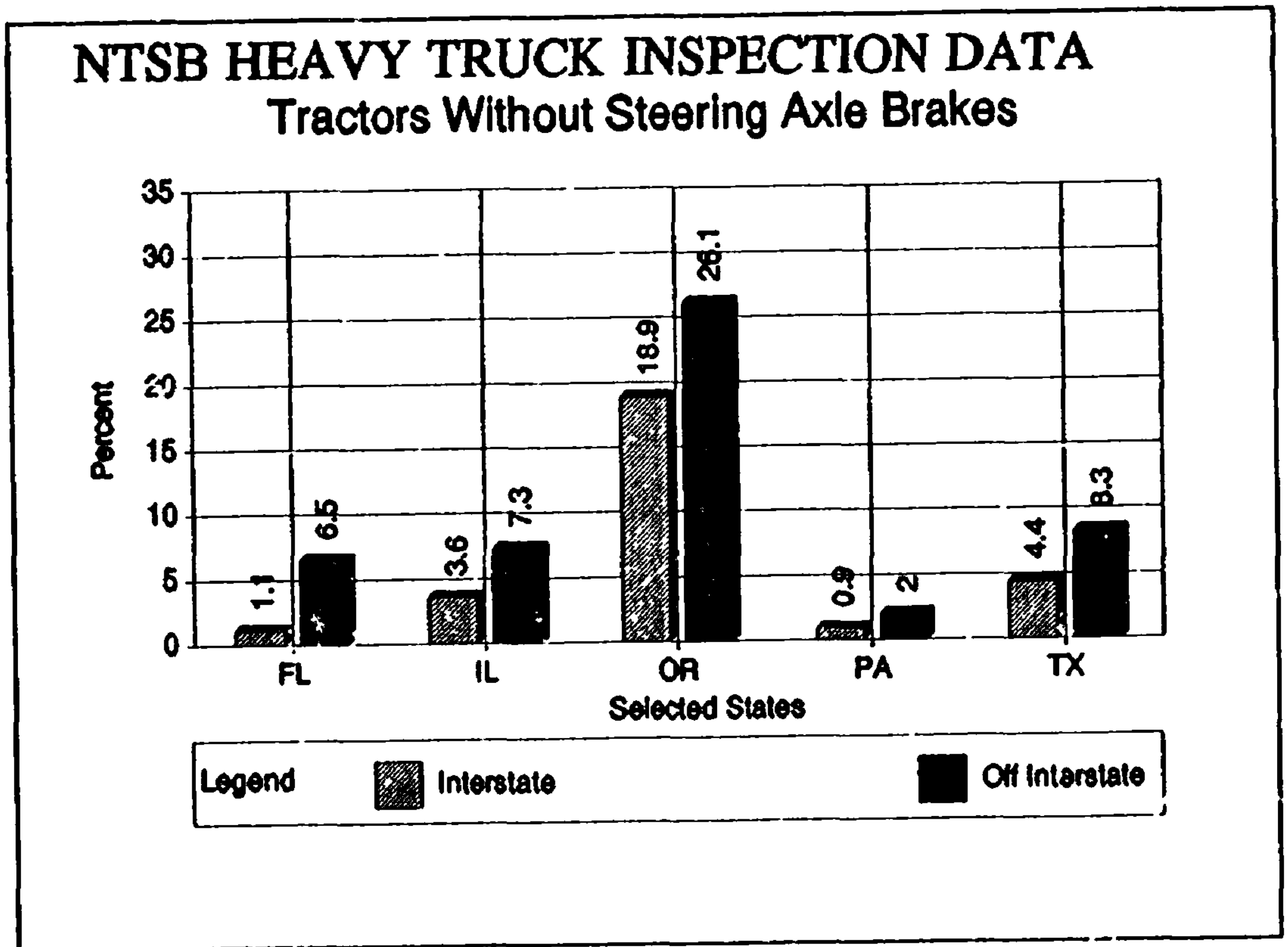


Figure 29.--NTSB five-State sample of combination vehicles without steering axle brakes.

As the Safety Board understands the matter, the NHTSA agrees with the Board's position not to require larger steering axle brakes on all heavy vehicles. NHTSA's 1991 paper, "Improved Brake Systems for Commercial Motor Vehicles" (DOT HS 807 706), relates this position:

> The Agency's consideration of reinstating stopping distance requirements would have the practical effect of encouraging brake system designs that fully utilize currently sized front-wheel brakes. Stopping performance will

improve significantly as a result. It seems prudent, therefore, to wait and assess the effects and benefits of this change, as well as the effects of ABS, assuming its more widespread use, before deciding whether larger front brakes are needed. Accordingly, the agency does not plan to propose that heavy trucks be required to have higher capacity front brakes at this time.

Encourage Steering Axle Brakes on All Heavy Vehicles.--The lack of steering axle brakes reduces a combination vehicle's stopping capability and increases its susceptibility to jackknifing. Given the conditions of a light load, a road surface with reduced friction, and the need for a panic brake application, a vehicle without front axle brakes may not be able to avoid a jackknife situation.

The absence of brakes on the steering axle also greatly increases the likelihood of overworking the other brakes on a loaded truck. This problem is especially critical when one or more of the remaining brakes are inoperative. In this situation, the vehicle's braking efficiency would drop and the other brakes, while attempting to slow the vehicle, would heat up more quickly. For instance, if three brakes on a loaded five-axle combination with no steering axle brakes are at the limit of adjustment (an acceptable condition), the efficiency would drop from a value of 82 percent at a cold temperature to 64 percent at 400 $^{o}$F and to 50 percent at 600 $^{o}$F. Consequently, if the vehicle's brakes were misused while traveling on a downgrade, the risk of a runaway would be extremely high. (See **figure** 30.)

Because all tractors manufactured since July 25, 1980, are required to have brakes on their steering axles, this safety problem is thought to be diminishing. However, because the Safety Board's five-State five-axle truck inspection program found that 5 percent of the combination vehicles on the interstate system and 8.9 percent on the off-interstate system were without brakes on their steering axles, the Safety Board maintains that this condition is still a problem. (See **figure** 29.) Yet, the number of vehicles without steering axle brakes is small enough that equipping the remaining vehicles with brakes on the steering axles would not impose a large economic burden on the carriers.

The Safety Board believes that there are significant safety advantages in retrofitting the pre-1980 tractors with steering axle brakes. Once a vehicle is equipped with steering axle brakes, one more factor is eliminated that, when combined with other less controllable factors, could lead to a jackknife. Thus, the Safety Board urges fleet owners and operators to voluntarily install steering axle brakes on their older air-braked vehicles to improve stopping capability and help reduce the number of vehicles susceptible to instability-related accidents.

**Use of Aftermarket Brake Linings**

Problems Associated With Aftermarket Linings.--One of several practices that can greatly upset a heavy vehicle's brake system balance is the use of brake linings that do not meet the original equipment specifications. While these aftermarket linings can degrade the available brake torque on all axles, this reduced torque manifests itself more on the steering axle, due to being equipped with smaller brake chambers.

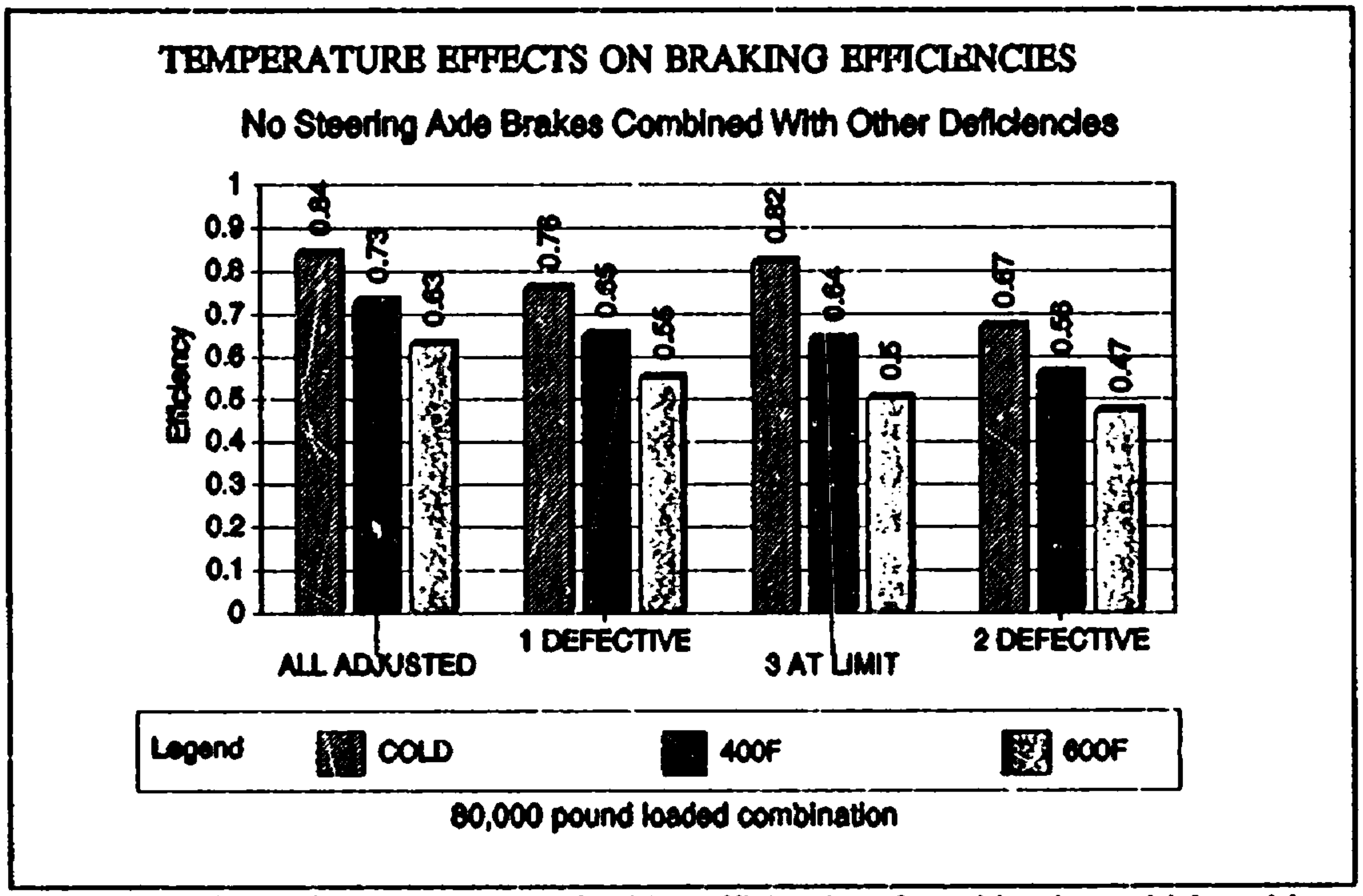


**Figure 30.--Effect of temperature on braking efficiencies of combination vehicles without steering axle brakes.**

The Safety Board is aware that truck manufacturers that equip their vehicles with smaller chambers on the front axle also use a higher friction coefficient brake lining to compensate for the smaller chamber. However, interviews with some of the accident-involved carriers and industry representatives indicated that vehicle owners are less careful than manufacturers to compensate for the smaller chambers. These interviews suggested that owners may replace linings with cheaper, lower coefficient linings. The interviews also indicated that most of the carriers did not know the frictional ratings of their brake linings.

It is unclear how widespread this practice is in the trucking industry. However, the Safety Board is concerned that the potential is great for aftermarket installation of linings with frictional characteristics less than the manufacturer's recommendations, which would result in a reduced brake torque output.

Develop a Consistent Lining Code and Effective Marking Method.--SAE paper 910126, "Heavy Truck Deceleration Rates as a Function of Brake Adjustment," defines how to calculate the performance of air chambers under varying conditions. These calculations were used to evaluate how the Type 9 and 12 air chambers would perform under different loads using various grades of brake lining material. Figure 31 shows the results, comparing the vehicle's deceleration capability to the effect of varying air chamber sizes, lining types, axle ratings, and slack adjuster lengths.

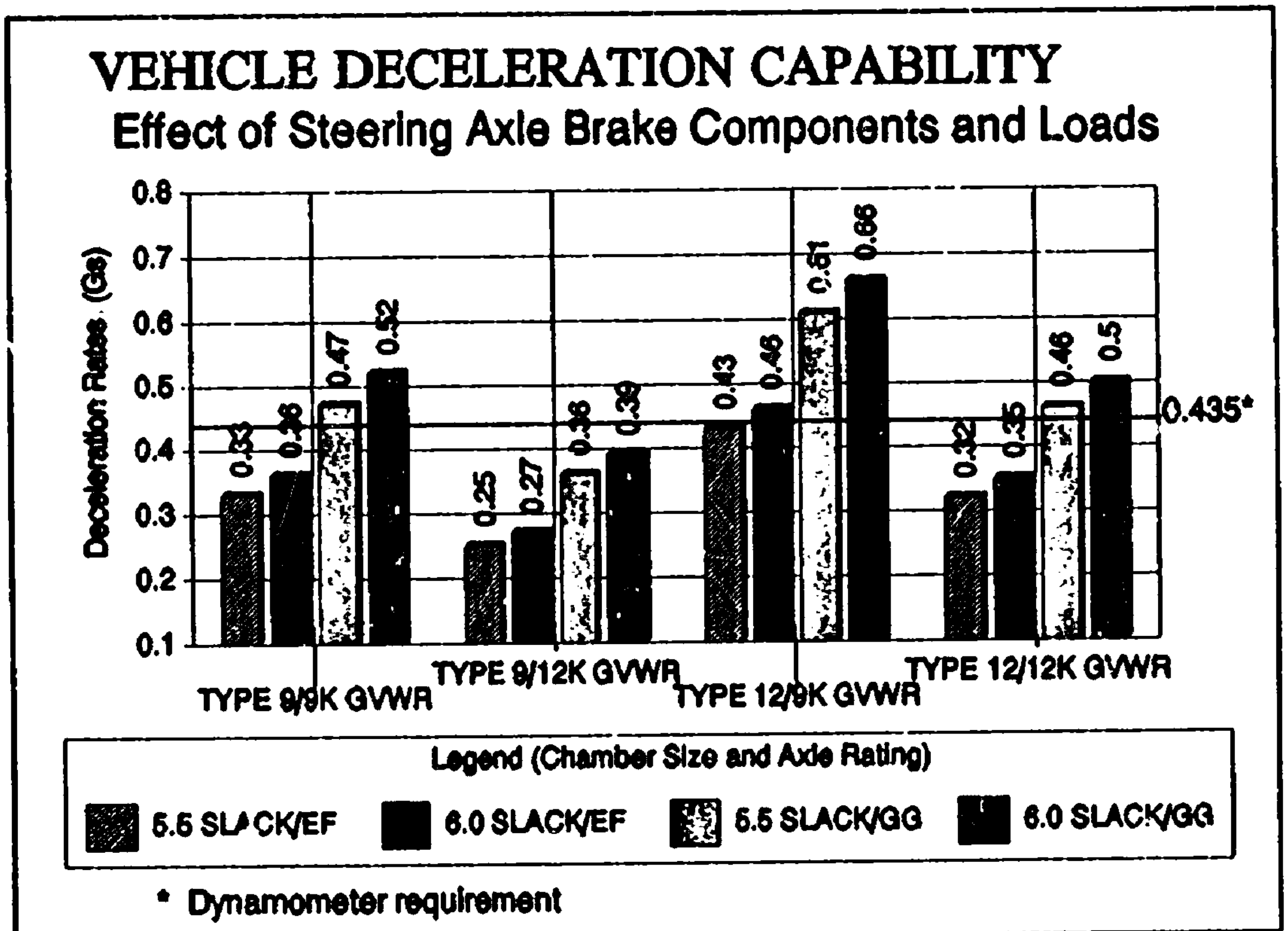


**Figure 31.--Effect of brake components on a vehicle's deceleration capacity.**

Only one combination of brake components using a common grade of brake lining, 0.35 drum-to-lining coefficient of friction or EF, met the dynamometer requirements of the 20-mph stopping test found in 49 CFR 571.121 S5.4.2, "Brake Power." The Type 12 chamber used on a 9,000-pound axle with a 6.0-inch slack adjuster was the only combination to meet the requirements. Neither the Type 9 chambers with the lower grade lining nor the Type 9 or the Type 12 installed on a 12,000-pound-rated axle met the requirement.

When a more aggressive lining, such as a "GG" (0.45 - 0.55 drum-to-lining coefficient of friction) was used, all combinations met the 0.435g deceleration requirement (See chapter 6) except Type 9 chambers used on a 12,000-pound axle. The only brake system with Type 9 chambers that meets the Federal dynamometer requirement for brake power is one combined with the higher coefficient lining and used on a 9,000-pound-rated axle. With the higher coefficient lining, all the brake systems with Type 12 chambers met the brake power requirement.

This analysis assumes that the frictional characteristics of lining materials can be manufactured, tested, coded, and marked in a consistent manner. Past testing by NHTSA engineers indicates that the variability in the brake linings manufactured today makes it extremely difficult to evaluate the friction ratings of the linings by the commonly used two-letter designator codes, "EF" and "GG." The difficulty occurs because linings are now tested using 1 square inch of material on a specialized friction testing machine. According to the NHTSA, the results from the friction testing machine have not correlated well to the results from tests using a full-scale brake with an inertia dynamometer.

As a result, an SAE committee has been working on two Recommended Practices. The first, "Brake Block Effectiveness Rating" (J1802), will describe the testing procedures using the dynamometer and the full size brake assembly. It also will propose that the frictional characteristics of the lining be described by the term "brake effectiveness," which is a ratio of the output torque to the input torque. The second, "Brake Effectiveness Marking For Brake Blocks" (J1801), is a draft document that describes "a uniform method for marking numerical values of Normal and Hot Effectiveness based on test data obtained from reference full size brake assemblies on single station brake dynamometers." The Safety Board believes that once an accurate rating method is agreed upon for describing the frictional characteristics of a brake lining, the proposed analysis displayed in **figure 31** for evaluating the combinations of brake system components could be utilized.

Such decisions concerning brake system performance can be very significant. More information in the owner's and the truck maintenance manual alerting the owner or the shop of the need to use linings that meet the original equipment specifications may help prevent accidents. A more consistent coding scheme for the frictional ratings for linings as well as a more permanent method for marking the linings, as proposed by the SAE committee, would help ensure that replacement linings are in accordance with the vehicle manufacturer's specifications.

Although the Safety Board does not believe that the size of the front brakes on all heavy vehicles should be increased, it does believe that attention should be given to the grade of linings installed with Type 9 and Type 12 air chambers. Further, certain minimum frictional ratings of linings for specific brake component combinations should be specified along with some means of determining what grade of lining is installed on a vehicle.

With such requirements, a commercial vehicle inspector could determine the size of the brake chamber and the frictional rating of the lining and then could compare those to the axle's weight rating and the slack adjuster length. This would allow the inspector to determine whether the brake system meets the requirements.

A simple chart, as shown in figure 32, could provide the inspector with all the information to make the decision. For example, an inspector finding a heavy truck equipped with a 12,000-pound gross axle weight rating (GAWR) steering axle, Type 9 air chambers, 5.5-inch slack adjusters, and linings with a code of EF could determine easily that the truck does not meet requirements (the intersection of column one with line one). On the other hand, a vehicle with a 9,000-pound GAWR steering axle, Type 12 air chambers, 6.0-inch slack adjusters, and linings with a code of EF would meet the requirements (the intersection of column 2 with line 4).

| Allowable Component Combinations | 5.5 Slack EF Lining | 6.0 Slack EF Lining | 5.5 Slack GG Lining | 6.0 Slack GG Lining |
|---|---|---|---|---|
| Type 9 <= 12K GAWR | No | No | No | No |
| Type 9 <= 9K GAWR | No | No | Yes | Yes |
| Type 12 <= 12K GAWR | No | No | Yes | Yes |
| Type 12 <= 9K GAWR | No | Yes | Yes | Yes |

**Figure 32.--Sample chart for inspectors.**

**Relationship of Brake System Maintenance to Components**

The component issues discussed above can affect both the braking capability and the stability of a heavy vehicle. Yet, attention to proper components will not solve many problems without the consistent preventative maintenance programs discussed in chapter 4. For instance, if a carrier always replaces a vehicle's linings to original equipment specifications but fails to periodically adjust the brakes, the use of proper linings is negated Even the benefits of an antilock system would be reduced without a proper maintenance program. Consequently, the Safety Board is convinced that proper maintenance is paramount.

# CHAPTER 6

## BRAKE PERFORMANCE REQUIREMENTS

Currently, airbrake performance requirements for new vehicles require that components be tested using inertial dynamometers at the gross axle weight rating (GAWR). The previous "no wheels locked" vehicle performance requirements specified under Federal Motor Vehicle Safety Standard (FMVSS) No. 121 were repealed in 1978. The only performance requirement that applies to in-service heavy vehicles is a 20-mph stopping test specified in the Federal Motor Carrier Safety Regulations (FMCSR). Appendix M provides a history of airbrake performance standards.

### Review of Federal Regulations Applicable to New Vehicles

Current Standards.--Federal regulation defines testing and standards for brake components. For example, 49 CFR 571 requires that burnished airbrake assemblies on trailers develop deceleration forces at the given air chamber pressures when tested at GAWR on an inertial dynamometer. (See table 4.) In addition, 49 CFR 571.121 S5.4.1.1 describes the following procedure to test for these deceleration rates:

**Table 4.--Brake performance standards outlined in 49 CFR 571.**

| Brake Retardation (Br ke Force/GAWR) | Required Brake Chamber Pressure (psi) |
|---|---|
| 0.05 | 20 psi |
| 0.12 | 30 psi |
| 0.18 | 40 psi |
| 0.25 | 50 psi |
| 0.31 | 60 psi |
| 0.37 | 70 psi |
| 0.41 | 80 psi |

> After burnishing the brake pursuant to S6.2.6, retain the brake assembly on the inertia dynamometer. With an initial brake temperature between 125 °F and 200 °F, conduct a stop from 50 mph, maintaining brake chamber air pressure at a constant 20 psi. Measure the average torque exerted by the brake from the time the specified air pressure is reached until the brake stops and divide by the static loaded tire radius specified by the tire manufacturer to determine the retardation force. Repeat the procedure six times, increasing the brake chamber pressure 10 psi each time. After each stop, rotate the brake drum or disk until the temperature of the brake falls to between 125 °F and 200 °F.

Section S5.4.2 of 49 CFR 571.121, Brake Power, applies to airbrake assemblies on trucks, truck tractors, buses, and trailers. This section requires that brake assemblies be capable of making 10 consecutive decelerations on an inertia dynamometer at an average of 9 f.p.s.p.s.[48] from 50 mph to 15 mph (0.28 g), at intervals of 72 seconds. This section also requires that the airbrake assemblies be capable of deceleration to a stop from 20 mph at an average deceleration rate of 14 f.p.s.p.s. (0.435 g) 1 minute after the 10th deceleration. The brake power test is conducted at an initial brake temperature of 150-200 °F with an airbrake chamber pressure that does not exceed 100 psi.

Section S5.4.3, Brake Recovery, defines the testing procedure for brake recovery in trucks, truck tractors, buses, and trailers. This test, which excludes the front axle brakes of a truck tractor from the requirement, begins 2 minutes after the brake power test has been completed. The brake recovery test requires that each assembly be able to make 20 consecutive stops from 30 mph at an average deceleration rate of 12 f.p.s.p.s. (0.37 g). The stops must occur at intervals of 1 minute measured from the start of each brake application. The service line air pressure needed to attain this deceleration rate must not exceed 85 psi. For a brake without an antilock system, the pressure must not be less than 20 psi; for a brake with an antilock system, the pressure must not be less than 12 psi.

The requirements cited above do not require full-scale vehicle testing. Only combinations of components are certified by the dynamometer tests. Although the current standards address deceleration requirements, they do not adequately address the stability of a heavy vehicle under panic or emergency braking conditions.

<u>Need for New-Vehicle Brake Performance Requirements</u>.--As a result of its review of current Federal regulations for new vehicles, the Safety Board believes that Federal regulations should be upgraded to stipulate stopping distances for air-braked vehicles, both in straight and curved sections of roadway, and particularly under light load or variant friction conditions.

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[48] The term f.p.s.p.s. defines a deceleration rate in feet per second per second. It is also written as $ft/sec^2$.

However, the Safety Board believes that any new standards should require the use of an antilock system.

During the course of its investigations, the Safety Board identified six accidents that involved an unstable situation. In three accidents, the instability resulted from improperly adjusted steering axle brakes that had been poorly maintained. In two other cases, component incompatibility led to the instability. One of the component problems was an ALV, which allowed the drive axles to lock prematurely (case summary 8). The other component-related instability (case summary 18) was brought about by Type 9 steering axle brakes, which resulted in the premature lock-up of the drive axles. In the sixth accident (case summary 14), air leaks for which the air compressor could not compensate caused the trailer emergency brakes to apply. When the trailer brakes were applied and the wheels locked, the condition initiated an uncontrollable trailer swing.

In all six cases, the instability resulted from locked wheels losing their ability to resist lateral movement. With some wheels locked and some rolling, the vehicle's dynamics changed, causing either the tractor or trailer to rotate uncontrollably. Each case was analyzed using the UMTRI Phase 4 computer simulation. First, parameters were entered describing the accident vehicle and road surface. After the simulation reproduced an accurate depiction of the accident sequence, hypothetical parameters were added to the simulation.

In five cases, the tractor or truck drive axles locked prematurely. In every simulated case, adding an antilock system to the drive axles of the vehicle eliminated the instability and allowed the driver to avoid the accident. All the other adjustments and component sizes were left as they were found on the accident vehicles.

If the antilock system were installed on all axles of the tractor or truck, the driver in all of the above five accidents would have avoided the instability, and also would have been able to steer the vehicle accurately and bring it to a safe stop. Figure 33 compares the rotation of these five vehicles in their accident configuration with and without the antilock braking system (ABS) installed.

The Safety Board realizes that an antilock system is no substitute for a preventative maintenance program. In four of the six instability accidents, the antilock system would have freed the drivers from emergency situations caused by a lack of maintenance. Because of inadequate maintenance, an antilock system would not have prevented eight of the accidents where high deceleration was required. Thus, an antilock system is not the sole answer to preventing all combination-vehicle accidents. However, in many situations, the ABS can get a driver out of trouble when he makes an error in judgment, when he has a lapse in attention to the roadway and traffic, or when there are minor maintenance problems.

NHTSA has spent much time evaluating the effectiveness of ABS. Before 1978, Standard 121 "no-wheels locked" regulation was in place. However, in 1978, the Ninth Circuit Court of Appeals set aside this rule because the NHTSA had not demonstrated that available ABSs were

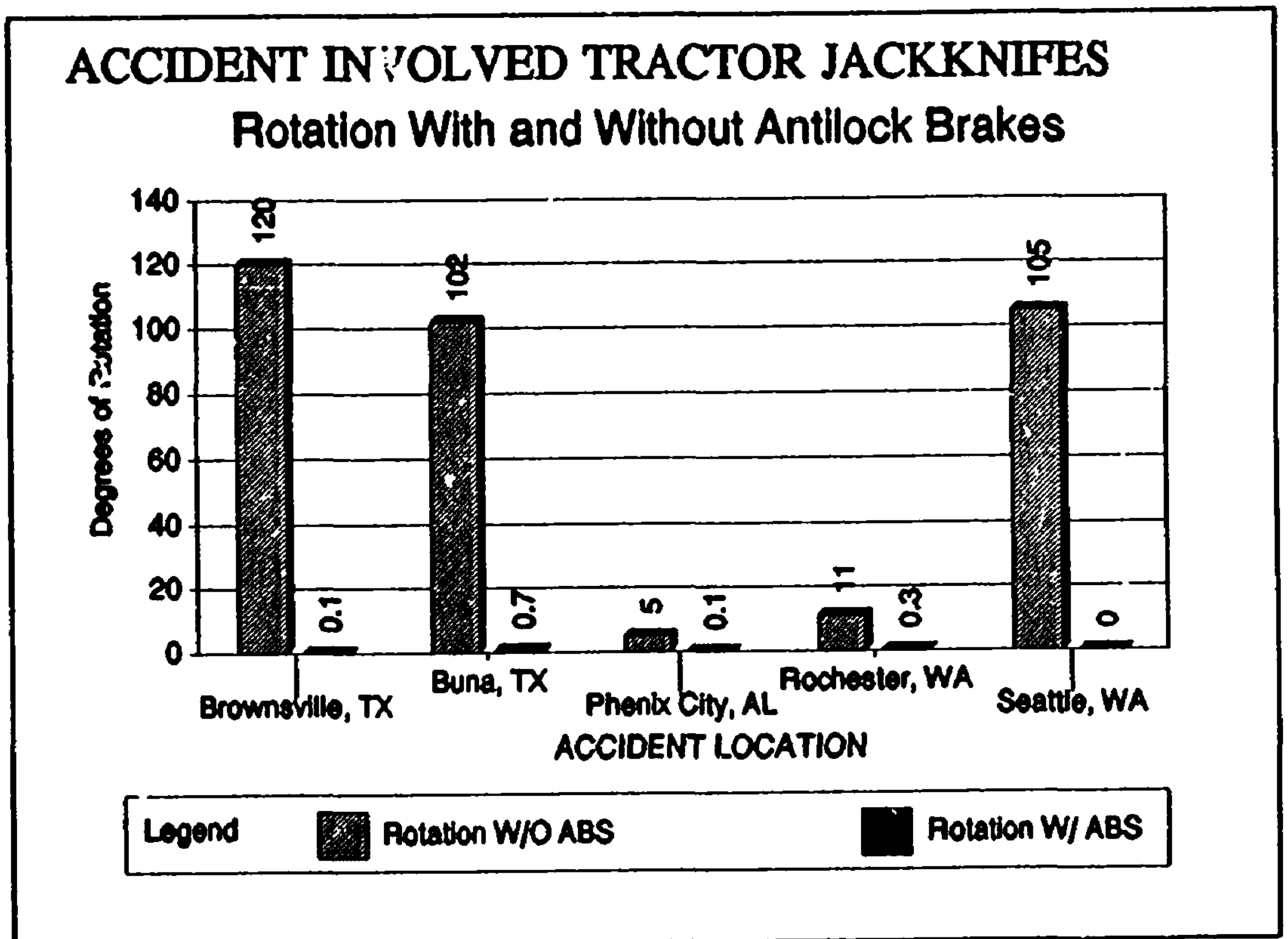


**Figure 33.--Phase 4 computer simulation of adding antilock brakes to vehicles involved in five instability accidents.**

durable and reliable.

To address the problems that caused the overturn of the previous regulation, the NHTSA began to implement its "ABS Fleet Evaluation Program" in the fall of 1988. The evaluation focused on the reliability, maintainability, and durability of antilock braking systems. Seventeen fleets made up of 200 tractors were chosen for the study. The preliminary NHTSA report indicated that the 200-vehicle test fleet had accumulated approximately 19,800,000 miles as of April 30, 1990. Although the evaluated fleets included vehicles that had been in operation for as long as 18 months, all had participated for at least 1 winter season. While many of the ABSs tested were prototype designs, only 52 of the 200 vehicles experienced minor start-up problems requiring adjustments or repairs of ABS system components (a number that NHTSA attributed to the "newness" of the tested systems). In addition, only 42 of the trucks required replacement of ABS components during the 19.8 million mile period. Results of this study (as of April 1991) are presented in "Improved Brake Systems for Commercial Motor Vehicles" (DOT HS 807 706), which states in part:

> There can be no doubt that the problems that have occurred are real and would render the ABSs inoperative if not addressed. This highlights the need to provide service assistance to motor carriers to enable them to quickly and easily diagnose minor problems and quickly fix them. If this does not occur, carriers will likely form strongly adverse opinions about these systems, as they did in the case of early "121" systems. On the other hand, if quality control is kept high, and if good service support is available, the preliminary results of this field study indicate that, from a reliability and maintenance perspective, ABS can be successfully installed and maintained on U.S. heavy trucks.

The NHTSA fleet evaluation program has demonstrated that current antilock technology can overcome the reliability and durability problems noted in systems previously required. The successful demonstration should dispel the criticisms that brought about overturn of 121 antilock requirements. Analysis of Safety Board investigations clearly illustrates the benefits an antilock system would provide. The Safety Board believes that antilock in combination with proper system maintenance would result in a significant improvement in heavy vehicle safety, both in terms of stability and stopping capability.

**Review of Federal Regulations Applicable to In-Service Vehicles**

Once the airbrake assembly passes the required tests, the vehicle manufacturer, in accordance with 49 CFR Part 567, must certify to NHTSA that the vehicle was manufactured in compliance with all Federal Motor Vehicle Safety Standards. Unless there is a manufacturing defect, the NHTSA's role in stopping-performance requirements ends. Once a vehicle is in-service, the Federal Highway Administration Office of Motor Carriers is responsible for enforcing stopping performance.

In-service performance standards are found at 49 CFR 393.52. These standards apply to heavy trucks under any condition of loading on a public highway. According to these standards, when a heavy truck's service brakes are applied, the truck must be capable of:

1. developing a braking force at least equal to 0.435 times its gross vehicle weight,
2. decelerating to a stop from 20 mph at not less than 14 f.p.s.p.s., and
3. stopping from 20 mph in not more than 40 feet, measured from the point at which movement of the service brake pedal or control begins.

Testing for these standards must meet two conditions. First, vehicles must be tested on a hard surface that is substantially level, dry, smooth, and free of loose material. Second, vehicles must be in the center of a 12-foot-wide lane when the test begins and must not deviate from that lane during the test.

These regulations are the only performance requirements that apply to in-service vehicles No provisions exist for any higher speed tests of stopping ability or stability during the stop. In practice these tests are only performed routinely by police, fleet, or owner/operators in those States that require annual safety inspections. The FHWA annual inspection does not require full-scale brake stopping performance testing.

Adequacy of In-Service Brake Performance Requirements.--The Safety Board does not believe that existing performance requirements can predict a vehicle's stopping performance or stability when the vehicle is traveling 30 to 65 mph, speeds common to highway travel. In addition, the facilities needed to conduct a stopping test of a heavy vehicle are not commonly available at inspection sites.

The brake system components of a heavy vehicle stopping at 20 mph do not experience the same dynamic forces as those of a vehicle stopping at higher speeds such as 50 mph. These higher speed forces result in significantly greater component deflection and higher temperatures that expand brake drums and affect the frictional characteristics of the lining.

The testing requirement that a heavy vehicle maintain position within a 12-foot-wide lane during a 20-mph stop also does not predict how stable that vehicle will be during a higher speed stop or on wet road conditions. For example, based upon a Phase 4 simulation, a tractor that might rotate $15^{\circ}$ during a 20-mph emergency stop could easily rotate as much as 90 degrees during a 50-mph stop. This increased rotation could place the vehicle out of the 12-foot-wide lane and into an opposing lane.

The 12-foot lane, 20-mph stopping requirement has other problems. The 20-mph stopping test cannot practically be applied during routine roadside inspections. Most existing inspection facilities do not have enough space to conduct any type of stopping performance test. During its heavy vehicle inspections, the Safety Board observed that many facilities had only limited space to park a few out-of-service vehicles While most facilities could set aside the 40 feet needed for the actual stop, few have the distance necessary for acceleration and turn-around. In addition, the Safety Board believes that most drivers would be hesitant to subject their vehicle and load to the demands of an emergency stop from any speed.

Need for Practical In-Service Brake Performance Regulations.--The Safety Board believes that the braking performance of in-service vehicles could be regulated better and more safely by means other than a full-scale vehicle stop. For example, the technology exists to develop relatively inexpensive roller dynamometers to install at roadside inspection facilities. Another method for evaluating stopping ability at higher speeds could be developed from calculations of braking efficiencies, which will be discussed later in this chapter.

Mobile dynamometers capable of measuring brake force output of assembled vehicles at various speeds are commercially available and could be adapted for use at inspection facilities. The Safety Board believes that a dynamometer capable of measuring brake force at each axle end would enable an inspector to isolate deficiencies within the braking system that could lead to unbalanced braking and vehicle instabilities. Any brake force values measured by the dynamometer could be converted to a braking efficiency value that inspectors could use in deciding if a vehicle should be placed out of service. The advantage of using a dynamometer is that force and efficiency values are calculated for a vehicle's actual loading and maintenance conditions. These devices could simplify an evaluation of brake system component performance and reduce the risk of full scale stops.

A method that could be used as an alternative to the dynamometer would be braking efficiency calculations. The Safety Board believes that software could be written for small, handheld calculators that would enable an inspector to input measured values from the vehicle. Using these values, the software would calculate brake force and efficiency. This output could be used to determine if the vehicle should be placed out of service. This method has the advantage of allowing the inspector to evaluate braking efficiencies at various brake adjustments, temperatures, and loads.

Both methods--dynamometer testing and brake efficiency calculations--have the single advantage of not subjecting the vehicle and cargo to the rigors of stopping tests. Both would also allow the prediction of unbalanced braking forces, thus providing some instability analysis. While the Safety Board acknowledges that either method will require additional research and further development, the Board believes that after adequate development the appropriate method should be implemented in the commercial vehicle inspection program. The Board believes that either method is a reasonable solution to the inadequacies of the current brake performance requirement for in-service vehicles.

# CHAPTER 7

## FUTURE TRENDS

Commercial vehicle airbrake systems have changed comparatively little during recent decades. This study and other research have concluded that airbrake improvements are necessary. Fortunately, hardware is being developed that will refine current systems or provide a more contemporary approach to brake performance. These hardware refinements are the result of continued industry and Government research, motor carrier acceptance of proven technology, and vehicle safety regulations. These improvements are diverse and often interrelated but basically provide for more controlled stops at higher deceleration levels and reduced periodic maintenance. Better procedures for inspecting commercial vehicle brakes also show promise. Brief discussions of these expected future improvement areas are provided; improvements currently being implemented (automatic slack adjusters) are discussed in chapter 5.

One change that will help to reduce the frequency and consequences of out-of-adjustment brakes is the more frequent installation and use of air disc brakes. Air disc brakes have several advantages over drum brakes. When subjected to intense braking demands, disc brakes do not suffer from the same performance degradations as do drum brakes. Disc brakes also reduce downhill runaways as well as brake imbalances caused by varied brake adjustments on the same vehicle.

Two primary problems are caused by the increased use of disc brakes on tractor semitrailer combinations: increased cost and the difficulty achieving proper brake balance when disc brakes are mixed with drum brakes in the same vehicle combination. In private fleets where tractor and semitrailer are mated with the same or identical unit for their effective service life, this is not a problem. However, most private and common carriers cannot afford this luxury, given the logistics of their fleet operations and the difference in service life of each piece of equipment. Air disc brakes are expected to make a slow transition into the general commercial fleets relative to that of disc brakes into the hydraulically braked light vehicle market. It is not anticipated that vehicle safety regulations will influence the demand for air disc brakes.

Current-generation antilock braking systems (ABSs) are proving very reliable with many users testifying about their effectiveness through the Department of Transportation's current fleet evaluation program. Along with automatic adjustment hardware, antilock brake systems appear to offer the greatest potential for safety improvements in heavy truck brake performance. The major improvement lies with improved stability. Installing ABS on the tractor drive axles minimizes the likelihood of jackknife when these axles lock and lateral force capability drops. Installing ABS on the steering axle of the tractor improves steering control as compared to straight ahead skidding with locked front wheels. Installing ABS on the trailer axles reduces trailer swing into adjacent travel lanes when lock-up occurs at the rear of the trailer. Positive feedback from the DOT fleet evaluation program, positive user experience in Europe with air-braked heavy vehicles, and positive worldwide experience with hydraulically braked light vehicles will hopefully promote a rapid increase in installing ABS on both tractors and trailers.

Recently issued DOT regulations are expected to result in additional heavy truck brake performance improvements through the fine tuning of air valves. These subtle changes will provide for more precise timing of the application and release times for tractor and trailer brakes. Many tractor brakes are actuating before those of the trailer. In certain situations this imbalance can contribute to trailer push and to jackknife. Brake release times of many trailers are also inordinately slow. Simple changes in valves and air system plumbing will help to alleviate these problems.

Although not specifically part of the foundation brake system, vehicle engine and driveline retardation devices are expected to gain in popularity. When installed, these retarders may result in improved safety levels, reduced brake wear and maintenance, and perhaps improved drive times resulting from the ability to maintain higher safe downhill speeds. These retarders will be installed more commonly on vehicles used in mountainous terrain.

Increased vehicle safety is also possible through the use of improved procedures for checking the status of heavy truck brake systems in road use. Simple, low cost, high torque brake dynamometers for roadside inspection teams show the greatest promise. Prototype systems are being used in other countries and the DOT is attempting to obtain similar devices to test in this country. Such devices could conceivably test truck brake performance in a more relevant fashion and in less time than the current and traditional method of manually checking brake pushrod adjustment.

# CHAPTER 8

## CONCLUSIONS

1. Combination trucks are involved in nearly twice as many fatal accidents per 100 million miles as passenger cars.

2. Available data do not allow the role of braking deficiencies in accidents to be readily evaluated.

3. The Safety Board's investigations suggest that deficient brakes on heavy vehicles are a factor in more accidents than statistics currently reveal.

4. In 9 of 15 brake-related accidents that the Safety Board investigated, State and local investigating agencies failed to identify deficient brakes as a factor in their final reports.

5. Accident investigations conducted by the Safety Board for this study revealed a variety of brake system deficiencies. The deficiency found to occur most frequently as a factor was out-of-adjustment brakes, but other maintenance-related and component issues also contributed to these accidents.

6. Current Federal regulations for in-service heavy vehicles do not adequately address stability under variant load and road surface conditions.

7. Current Federal regulations for in-service heavy vehicles do not adequately address stopping situations at speeds over 20 mph.

8. Current Federal regulations for newly manufactured heavy vehicles do not specify stopping distance or within-lane stability requirements.

9. Maintenance deficiencies in the accident vehicles' brake systems degraded stopping capability and directional stability.

10. Many carriers do not have adequate policies for brake inspection and adjustment intervals.

11. The Safety Board was not able to establish a significant correlation between the adjustment level of heavy vehicle brakes and the carrier's knowledge of how to adjust brakes.

12. Because it is difficult for carriers or drivers to readily detect the adjustment levels of the airbrakes on their vehicles in normal operation, many carriers and drivers of commercial vehicles fail to understand the need for well maintained and properly balanced brake systems.

13. Brake maintenance literature presents various methods for proper adjustment of brakes, and no universally accepted brake adjustment procedures exist.

14. Investigations of downhill runaway accidents revealed that vehicles with marginal cold-brake efficiencies may lose all braking effectiveness once the brakes heated up.

15. Of 1,520 five-axle heavy trucks inspected through a joint Safety Board/State project, 56.3 percent were placed out of service due to brake system violations, including 46.1 percent for brake adjustment deficiencies.

16. There was significant variance between MCSAP reported inspections and Safety Board inspections in the percentage of heavy vehicles placed out of service for brake-related defects.

17. Of the manual slack adjusters checked in the brake inspection project, 26 percent were found at or past the manufacturer's recommended adjustment limit, while 15 percent of the automatic adjusters were at or past the limit.

18. The use of long stroke air chambers in combination with automatic adjusters could substantially reduce the number of heavy vehicles placed out of service due to brake adjustment.

19. An automatic limiting valve on the steering axle of a school bus was a contributing factor in one of the accidents investigated for this study. Automatic limiting valves may also adversely affect brake performance in heavy trucks.

20. Small brake chambers on steering axles of combination vehicles or the absence of steering axle brakes can contribute to jackknife accidents or increased stopping distances. In the total brake inspection sample, the Safety Board found 6.6 percent of the five-axle vehicles with no brakes installed on the front axle, 0.4 percent with Type 9 air chambers installed, and 4.1 percent with Type 12 air chambers installed.

21. Many component manufacturers used a higher friction lining when they installed brake chambers smaller than Type 16 on the steering axle. However, many carriers may replace original equipment linings with ones having lesser frictional characteristics, which could adversely influence stopping distances.

22. Full-scale brake block testing procedures and consistent brake block effectiveness ratings are needed so that appropriate brake lining materials can be selected.

23. An antilock braking system could have prevented all six of the instability-related accidents simulated for this study.

24. The use of the AL-Factor formula found in brake component supplier and brake consultant literature produced values that overestimated available brake torque and may have resulted in the installation of inadequate brake components.

# CHAPTER 9

## RECOMMENDATIONS

As a result of this safety study, the National Transportation Safety Board made the following recommendations:

--to the National Highway Traffic Safety Administration:

Require that air-braked vehicles be equipped with visible adjustment indicators that will allow one person to check the level of adjustment. (Class II, Priority Action) (H-92-50)

Expedite the proposed rulemaking to require automatic adjusters on vehicles equipped with airbrake systems. (Class II, Priority Action) (H-92-51)

Adopt braking performance regulations that restrict the general use of automatic limiting valves on steering axle brakes of vehicles equipped with airbrake systems. (Class II, Priority Action) (H-92-52)

Adopt performance standards for vehicles equipped with airbrake systems that require stopping performance criteria on varying friction surfaces, with varying loading conditions for both straight and curved sections of roadways. (Class II, Priority Action) (H-92-53)

Require through a performance standard the use of antilock braking systems on all newly manufactured vehicles with airbrake systems. (Class II, Priority Action) (H-92-54)

Promote, in conjunction with the Federal Highway Administration, the development and use of hardware, such as the roller dynamometer, capable of measuring the braking capability of a heavy vehicle at roadside inspection facilities. (Class II, Priority Action) (H-92-55)

--to the Federal Highway Administration:

Develop adequate performance criteria for allowable combinations (brake size, lining friction, and axle rating) of airbrake system components on heavy vehicles, and prohibit the use of component combinations that do not meet the criteria. (Class II, Priority Action) (H-92-56)

Encourage the installation of visible brake adjustment indicators on all vehicles equipped with airbrake systems for easy detection of adjustment levels. (Class II, Priority Action) (H-92-57)

Promote, in conjunction with the National Highway Traffic Safety Administration, the development and use of hardware, such as the roller dynamometer, capable of measuring the braking capability of a heavy vehicle at roadside inspection facilities. (Class II, Priority Action) (H-92-58)

Review the national highway data system to ensure that sufficient data can be obtained to readily evaluate the role of braking deficiencies in commercial vehicle accidents. (Class II, Priority Action) (H-92-59)

--to the 50 States, the District of Columbia, the Commonwealth of Puerto Rico, the Virgin Islands, and the Territories:

Encourage the commercial vehicle accident investigative agencies to develop policies requiring the systematic inspection of and the compilation of data from commercial vehicles that are involved in injury or fatal accidents. The policies should include inspection of brake systems and components. (Class II, Priority Action) (H-92-60)

Review the national highway data for your jurisdiction to ensure that sufficient information can be obtained to readily evaluate the role of braking deficiencies in commercial vehicle accidents. (Class II, Priority Action) (H-92-61)

In order to preserve evidence from accident investigations, require towing companies during wreckage removal to employ methods of releasing locked airbrakes that do not alter brake adjustment. (Class II, Priority Action) (H-92-62)

--to the Interstate Towing Association and to the Towing and Recovery Association of America:

> Encourage members to voluntarily discontinue the practice of "backing off" the airbrakes on commercial vehicles during wreckage removal operations. (Class II, Priority Action) (H-92-63)

--to the National Private Truck Council:

> Encourage members to use replacement parts that meet original equipment specifications (particularly brake linings and valves) when replacing brake components. (Class II, Priority Action) (H-92-64)
>
> Encourage members to voluntarily install steering axle brakes on all heavy vehicles that currently do not have steering axle brakes. (Class II, Priority Action) (H-92-65)
>
> Advise members about the propensity of lightly loaded combination vehicles to jackknife, especially when traveling on low-friction road surfaces. (Class II, Priority Action) (H-92-66)
>
> Work with the American Trucking Associations to complete and distribute to member carriers appropriate brake maintenance materials that clearly establish standard inspection techniques (including adjustment indicators), inspection and adjustment interval guidelines, and an adjustment method (covering both manual and automatic slack adjusters) for S-cam brakes on heavy vehicles. Encourage members to provide a copy of the information to each driver of a heavy vehicle and to each mechanic who services heavy vehicles. (Class II, Priority Action) (H-92-67)
>
> Encourage members to discontinue the use of the AL-Factor formula. (Class II, Priority Action) (H-92-68)

--to the Owner-Operator Independent Drivers Association:

> Encourage members to use replacement parts that meet original equipment specifications (particularly brake linings and valves) when replacing brake components. (Class II, Priority Action) (H-92-69)

Encourage members to voluntarily install steering axle brakes on all heavy vehicles that currently do not have steering axle brakes. (Class II, Priority Action) (H-92-70)

Advise members about the propensity of lightly loaded combination vehicles to jackknife, especially when traveling on low friction road surfaces. (Class II, Priority Action) (H-92-71)

Work with the American Trucking Associations to complete and distribute to member carriers appropriate brake maintenance materials that clearly establish standard inspection techniques (including adjustment indicators), inspection and adjustment interval guidelines, and an adjustment method (covering both manual and automatic slack adjusters) for S-cam brakes on heavy vehicles. (Class II, Priority Action) (H-92-72)

Encourage members to discontinue the use of the AL-Factor formula. (Class II, Priority Action) (H-92-73)

--to the American Trucking Associations:

Complete and distribute to member carriers appropriate brake maintenance materials that clearly establish standard inspection techniques (including adjustment indicators), inspection and adjustment interval guidelines, and an adjustment method (covering both manual and automatic slack adjusters) for S-cam brakes on heavy vehicles. Encourage members to provide a copy of the materials to each driver of a heavy vehicle and to each mechanic who services heavy vehicles. (Class II, Priority Action) (H-92-74)

Encourage members to use replacement parts that meet original equipment specifications (particularly brake linings and valves) when replacing brake components. (Class II, Priority Action) (H-92-75)

Encourage members to voluntarily install steering axle brakes on all heavy vehicles that currently do not have steering axle brakes. (Class II, Priority Action) (H-92-76)

Advise members about the propensity of lightly loaded combination vehicles to jackknife, especially when traveling on low friction road surfaces. (Class II, Priority Action) (H-92-77)

Encourage members to discontinue the use of the AL-Factor formula. (Class II, Priority Action) (H-92-78)

--to the Motor Vehicle Manufacturers Association:

Encourage member manufacturers of heavy air-braked vehicles to develop, promote, and install brake systems that are less sensitive to adjustment and more resistant to brake system fade (such as long stroke chambers and air disc brakes). (Class II, Priority Action) (H-92-79)

Encourage members to discontinue the use of the AL-Factor formula. (Class II, Priority Action) (H-92-80)

--to the Professional Truck Driver Institute of America:

Incorporate brake maintenance materials developed by the American Trucking Associations into a training curriculum that cautions drivers about the instabilities of lightly loaded combination vehicles when operated on low-friction road surfaces. (Class II, Priority Action) (H-92-81)

--to the Society of Automotive Engineers:

Expedite the completion of Surface Vehicle Recommended Practices, SAB J1802, "Brake Block Effectiveness Rating," and SAE J1801, "Brake Effectiveness Marking For Brake Blocks." (Class II, Priority Action) (H-92-82)

--to airbrake component manufacturers:

Develop, promote, and install brake systems that are less sensitive to adjustment and more resistant to brake system fade (such as long stroke chambers and air disc brakes). (Class II, Priority Action) (H-92-83)

Discontinue the use of the AL-Factor formula. (Class II, Priority Action) (H-92-84)

**BY THE NATIONAL TRANSPORTATION SAFETY BOARD**

/s/ Susan M. Coughlin
Acting Chairman

/s/ John K. Lauber
Member

/s/ Christopher A. Hart
Member

/s/ John A. Hammerschmidt
Member

/s/ James L. Kolstad
Member

April 29, 1992

# APPENDIXES

## APPENDIX A

## PRIOR SAFETY BOARD HEAVY VEHICLE AIRBRAKE RECOMMENDATIONS

1. The Highway Accident Report "Collision Between Mission Consolidated Independent School District School Bus and Valley Coca-Cola Bottling Company, Inc., Tractor-Semitrailer, Intersection of Bryan Road and Texas Farm-to-Market Road 676, Alton, Texas, September 21, 1989" (NTSB/HAR-90/02) included the following recommendations:

--to the Coca-Cola Enterprises, Inc.:

Conduct a review and evaluate the number of mechanics and the provided resources in each of its operations to ensure that proper vehicle maintenance is performed in accordance with manufacturer specifications. (Open--Await Reply) (H-90-87)

--to the Valley Coca-Cola Bottling Co., Inc.:
Establish procedures and provide adequate resources to ensure that proper vehicle maintenance is performed in accordance with manufacturer specifications. (Open--Await Reply) (H-90-89)

2. The Safety Study "Braking Deficiencies on Heavy Trucks in 32 Selected Accidents" (NTSB/SS-88/06) made the following recommendations:

--to the National Highway Traffic Safety Administration:

Publish a final rule by June 1990 that will require automatic slack adjuster on all new trucks equipped with air/mechanical brake systems. (Open--Acceptable Response) (H-88-30)

--to the American Trucking Associations and the National Private Truck Council:

Recommend that your member carriers adopt written policies regarding on-the-road brake adjustment; if the drivers are responsible for performing such adjustments, provide them with the necessary training. (Open--Acceptable Response) (H-88-31)

Recommend that your member carriers, as they replace worn brake chambers, install airbrake actuation devices that incorporate indicators to warn users when brakes must be adjusted. (Open--Acceptable Response) (H-88-32)

3. The Highway Accident Report "Tractor-Semitrailer/Station Wagon Runaway, Collision, and Fire, Van Buren, Arkansas, June 21, 1985" (NTSB/HAR-86/03) reiterated Safety Recommendation H-78-48 issued June 23, 1978:

--to the National Highway Traffic Administration:

Develop a Federal Motor Vehicle Safety Standard stating a performance requirement for all newly manufactured commercial vehicles to have equipment that would ensure brakes being in proper adjustment at all times. (Closed--Superseded by H-88-30, December 12, 1988)

4. The Highway Accident Report "DeQueen, Arkansas Police Patrol Car and Terrel Trucking Co., Tractor-Semi, Ashdown, Arkansas, July 5, 1984" (NTSB/HAR-84/07) made the following recommendations:

--to the Bureau of Motor Carrier Safety of the Federal Highway Administration:

Issue an "on-guard" bulletin which discusses the circumstances of the accident in Ashdown, Arkansas, on July 5, 1984, with particular reference to tailgating by trucks, improper adjustment of truck brakes, and the tendency to jackknife on wet pavement. (Closed--Acceptable Action, June 3, 1985) (H-84-93)

5. The Highway Accident Report "Church Bus Loss of Control on Long Steep Grade, State Route 155 Near Wofford Heights, California, July 7, 1984" (NTSB/HAR-85/01) made the following recommendation:

--to the California Yearly Meeting of Friends Church:

Urge member churches to establish a systematic maintenance program which requires frequent inspections of brakes and tires on all activity vehicles. (Open--Acceptable Response) (H-85-3)

6. The Recommendation Letter "Ran off Road--1973 Kenworth, Pittsburgh, Pennsylvania, April 28, 1980," in addition to urging that a higher priority be assigned to Safety Recommendation H-78-48, made the following recommendation:

--to the National Traffic Safety Administration:

Require manufacturers of airbrake actuation devices to incorporate indicators which will warn users when brakes must be adjusted. (Closed--Superseded by H-88-32, December 12, 1988) (H-81-1)

7. The Highway Accident Report "Central Texas Bus Lines, Inc., Charter Bus, State Route 7 Near Jasper, Arkansas, June 5, 1980" (NTSB/HAR-81/01) made the following recommendations:

--to the Federal Highway Administration:

Develop national standards for the signing of brake check areas. (Closed--Unacceptable Action, March 11, 1988) (H-81-11)

Conduct research to develop guidelines for the location and illumination of brake check areas. (Closed--Acceptable Alternate Action, September 5, 1984) (H-81-12)

8. The Highway Accident Report "Head-on; Kohler Co. GMC 1977 Astro 95 and Greene McKinney Chevrolet Cheyenne 10, Marion, North Carolina, January 25, 1978" (NTSB/HAR-78/06) made the following recommendation:

--to the Ryder Truck Rental:

Amend its maintenance program relative to brake adjustment by requiring an adjustment at least at each preventive maintenance inspection. (Closed--Acceptable Action, December 7, 1978) (H-78-70)

9. The Highway Accident Report "Fire/Explosion, Long Transportation Co. 1975 Peterbilt, Valley View, Ohio" (NTSB/HAR-77/03) made the following recommendation:

--to the Bureau of Motor Carrier Safety:

Request added resources to give greater priority to increased roadside inspections of commercial motor vehicles and safety compliance surveys of carrier operations to ensure greater compliance of vehicle maintenance and records. (Closed--Acceptable Action, October 10, 1978) (H-77-43)

10. The Highway Accident Report "Fire/Explosion, Union Oil Co. 1975 Peterbilt, Seattle, Washington, December 4, 1975" (NTSB/HAR-76/07), made the following recommendation:

--to the National Highway Safety Administration:

Test and resolve the apparent problem of operating any vehicle combination over the full-speed range and road and weather conditions encountered in normal operations if one of the units is equipped with a Federal Motor Vehicle Safety Standard No. 121 (FMVSS-121) antilock brake system and the other unit is not. (Closed--No Longer Applicable, September 5, 1985) (H-76-28)

11. The Highway Accident Report "Fire/Explosion, Heavy Haul Service, Inc., 1966 Freightliner and 1964 GMC Pickup, Bishop, California, June 29, 1974" (NTSB/HAR-75/05) made the following recommendation:

--to the Federal Highway Administration:

Develop and disseminate throughout the motor carrier industry, an "On-Guard" bulletin alerting drivers of commercial vehicles equipped with externally adjustable braking system of: A) The need to be familiar with company policies and practices with respect to on-road adjustment of brakes; B) Methods and techniques for detecting potential or existing problems in adjustment; C) The scope of the problem in ensuring proper brake adjustment; D) Methods and techniques for the proper on-road adjustment of ranking systems currently and generally in use. (Closed--Acceptable Action, October 20, 1977) (H-75-17)

12. The Special Study "Commercial Motor Vehicle Braking" (NTSB/HSS-72/05) made the following recommendations:

--to the Bureau of Motor Safety (Federal Highway Administration) and the National Highway Traffic Safety Administration of the Department of Transportation, cooperatively:

Initiate a research and development program to reduce substantially the incompatibility of braking performances of passenger cars and commercial motor vehicles, and to eliminate other braking inadequacies in commercial vehicles. (Closed--Unacceptable Action, September 3, 1985) (H-72-60)

Make Federal funds available to design, construct, and test an Experimental Safety Vehicle-Truck Brake (ESV-TB), which will incorporate the best available braking technology in an integrated system. The results of this work should be published periodically to guide voluntary changes as well as timely changes in existing standards. (Closed--Reconsidered, September 3, 1985) (H-72-61)

Form a technical advisory committee for the ESV-TB program which will include not only the technical viewpoint of the commercial vehicle industry and its suppliers, but also the viewpoint of brake suppliers for the aerospace industry and passenger car suspension technologists, as well as a technically qualified representative of the interests of passenger car occupants. (Closed--Reconsidered, September 3, 1985) (H-72-62)

13. The Highway Accident Report "Overturn, Greyhound Bus Lines, Inc., Motor Coach Industries 1970 MC-7 and 1966 Dodge Dart Station Wagon, Marshfield, Missouri, October 10, 1971" (NTSB/HAR-73/01) made the following recommendation:

--to the National Highway Administration:

Expedite rulemaking under Docket 70-16 (MNSS 121) to improve the antilock braking capability of bus (and truck) braking systems. (Closed--Acceptable Action, January 1, 1980) (H-73-2)

14. The Highway Accident Report "Fire/Explosion, Ventura, California, August 18, 1971" (NTSB/HAR-72/04) made the following recommendation:

--to the National Traffic Safety Administration:

Continue the commendable efforts exemplified in Federal Motor Vehicle Safety Standard No. 121, effective September 1, 1974, toward more effective braking performance requirements for trucks, trailers, and certain vehicle combinations, not only toward closer compatibility between the performance criteria for truck and passenger-car braking, but toward more extensive use of available technology. Continuing effort toward such improved truck braking is essential in recognition of the basic fact that the potential to inflict destruction and death is proportional to weight, at equal speeds, and that the control of truck speed under all reasonably foreseeable conditions, and especially when heavily laden, is vital to the safety of all highway users. (Closed--Acceptable Action, January 1, 1980) (H-72-15)

15. The Highway Accident Report "Fire/Explosion, Cherry Hill, New Jersey, November 29, 1969" (NTSB/HAR-71/03) made the following recommendations:

--to the National Highway Traffic Safety Administration:

Set a high priority on establishing performance requirements for new buses, trucks, trailers, and combination in regard to: (1) Improved braking capabilities with balanced skid resistance, reduced "fade," and shorter stopping with maximum load; (2) The use of energy-absorbing underride and override barriers to reduce passenger-car impact decelerations through controlled yielding; and (3) Minimum limits on stability factors for loaded vehicles. (Stability factor is defined as one-half the track width between centers of outside tire footprints, divided by the height of the center of gravity of a loaded vehicle.) (Closed--Acceptable Action, January 1, 1980) (H-71-18)

--to the Bureau of Motor Carrier Safety, Federal Highway Administration:

Consider the promulgation of regulations to require improved braking capabilities of regulated vehicles, and inclusion of numerical statement of the stability factor (value) on the identification plate of all tank trailers which transport hazardous materials, in implementing NTSB Safety Recommendation H-71-18. (Closed--Acceptable Action, October 29, 1975) (H-71-19)

# APPENDIX B

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# APPENDIX C

## GLOSSARY OF TERMS

The following definitions were taken and reprinted with permission from Chilton's 1988 edition of the *Commercial Carrier Journal: The Air Brake Book.* Although Chilton's publication includes additional definitions, only the terms referred to in this report have been included here.

**Antilock:** Currently optional, a safety-oriented system that senses wheel rotation (at one or more axles) during braking and cycles the brakes to prevent locking those wheels.

**Application time:** Time elapsed between depression of the brake treadle and engagement of the linings with drums (or, per FMVSS 121, point at which all service chambers reach 60 psi).

**Brake balance:** Basically, balance is achieved when all brakes on all axles do their fair share of the work.

**Brake chamber:** Device inside which a diaphragm converts air pressure to mechanical force via a pushrod.

**Brake chamber diaphragm:** Bellows type device within brake chamber that converts air pressure to mechanical force via pushrod.

**Brake proportioning:** Optional, safety-oriented system for limiting drive-axle brakes while a tractor is operated without a trailer. Also, system that varies individual axle braking effort in response to weight or other variable.

**Brake treadle:** Functionally, the brake pedal; a mechanical level attached to the foot brake valve.

**Edge codes:** Developed by Friction Materials Standards Institute, a double-letter code (ex: EE, FF, GG, FG) printed on the edge of a brake block to designate its range of aggressiveness. Currently, this coding system is being revised.

**Foot valve:** A foot-operated valve controlling air pressure delivered to the brake chambers.

**Gladhand:** Mechanical connector used to attach a tractor's or converter dolly's service (i.e., control) and emergency (i.e., supply) air line to those on a trailer.

**Jackknife:** Uncontrollable articulation of a tractor-trailer, typically resulting from lock-up of tractor drive axle(s). The risk of jackknife is greatest on a slippery road with an empty or lightly-laden trailer in tow.

**Pushrod:** A rod, protruding from a brake chamber, which is connected to the arm of a slack adjuster via a clevis pin.

**Ratio limiting valve:** Prevents locking of front brakes by automatically limiting application pressure to steer axle during normal braking. Progressively harder braking, however, will progressively increase steer-axle braking until maximum torque is applied.

**Relay valve:** Used to speed the application of brakes, especially in multiple-trailer applications.

**Release time:** Time between release of brake treadle and total disengagement of brake linings and brake drums. Or, per FMVSS-121, that time required to reduce pressure to 5 psi from 95 psi within all service chambers.

**Retarder:** Auxiliary braking device: engine brake, exhaust brake, hydraulic retarder, or electric retarder.

**S-cam brake:** Type of brake where mechanically-induced rotation of an S-shaped cam forces brake linings against the drum.

**Service brakes:** As opposed to parking brakes, that portion of the brake system used for normal brake applications.

**Slack adjuster:** A lever, connecting the brake chamber pushrod with the foundation brake camshaft, which provides torque to rotate the brake camshaft when the brake treadle is depressed. Used only on a cam-actuated brake, it also provides a means of adjusting clearance between brake shoes and the drum to compensate for lining wear. Some models are automatic; others require manual adjustment.

**Springbrake:** Generally refers to a tandem-chamber brake actuator that incorporates: an air-applied service brake chamber; an air-released/spring-applied parking or emergency brake chamber. Springbrakes apply upon sudden air loss (emergency mode) or activation of a dash-mounted parking brake control. Springbrakes remain applied until that chamber is recharged or the spring is manually compressed or caged. The spring portion often is referred to as the piggyback. Some springbrake actuators do not incorporate a service air chamber and are solely parking and emergency brakes. For example, some parking brakes are applied by air pressure and subsequently held mechanically by a pawl that drops into a notch on the brake chamber pushrod.

**Stroke:** Refers to total distance traveled by a brake chamber pushrod or slack adjuster arm during brake application.

**Tire rolling radius:** Distance, expressed in inches, from the center of a tire to the pavement, measured when mounted on a vehicle and loaded to its maximum rated capacity.

**Trailer swing:** Articulation of trailer caused by locking only the trailer brakes.

**Treadle valve:** A foot-operated, brake actuation valve.

**Wedge brake:** As opposed to a brake applied by an S-cam, this type of brake is applied by a single or double wedge-type mechanism. This type of brake is self-adjusting and, as such, does not utilize a slack adjuster.

**Wet tank:** Also known as the supply air tank, that reservoir nearest the air compressor where water and oil are mostly likely to accumulate (assuming the lack of a functional air dryer).

# APPENDIX D

## ACRONYMS

| | |
|---|---|
| ABS | Antilock Braking System |
| ALV | Automatic Limiting Valve |
| ASA | Automatic Slack Adjuster |
| ATA | American Trucking Associations |
| CDL | Commercial Driver's License |
| CFR | Code of Federal Regulations |
| CVSA | Commercial Vehicle Safety Alliance |
| DOT | U.S. Department of Transportation |
| EDVTS | Engineering Dynamics Vehicle Trailer Simulator (Computer Program) |
| FARS | Fatal Accident Reporting System |
| FHWA | Federal Highway Administration |
| FMCSR | Federal Motor Carrier Safety Regulations |
| FMVSS | Federal Motor Vehicle Safety Standard |
| GAWR | Gross Axle Weight Rating |
| GES | General Estimates System |
| GMC | General Motors Corporation |
| GSRS | Grade Severity Rating System |
| GVR | Gross Vehicle Rating |
| GVWR | Gross Vehicle Weight Rating |

| | |
|---|---|
| ICC | Interstate Commerce Commission |
| MCSAP | Motor Carrier Safety Assistance Program |
| MVMA | Motor Vehicle Manufacturers Association |
| NHSB | National Highway Safety Bureau |
| NHTSA | National Highway Traffic Safety Administration |
| NPRM | Notice of Proposed Rulemaking |
| OMCS | Office of Motor Carrier Safety |
| pdo | property damage only |
| SAE | Society of Automotive Engineers |
| T3DRS | Truck and Tractor-Trailer Dynamic Response Simulation |
| UMTRI | University of Michigan Transportation Research Institute |
| USC | United States Code |
| WUTC | Washington Utilities and Transportation Commission |

# APPENDIX E

## COST ESTIMATES FOR HEAVY TRUCK BRAKE ACCIDENTS

The Safety Board made some preliminary cost estimates for brake-related combination truck accidents. A recent study[1] estimated that average costs associated with fatal accidents (all type vehicles) were about $2.7 million and average costs associated with injury accidents were about $70,000. Using the 1989 estimated number of accidents reported to involve brake deficiencies, the cost to society (not including property damage accidents) is estimated as follows:

| Severity | Number | Cost/accident | Total cost |
|---|---|---|---|
| Fatal | 102[2] | $2,700,000 | $275,400,000 |
| Injury | 1,200 | 70,000 | 84,000,000 |
| Total | 1,302 | | 359,400,000 |

Thus, the estimated minimum cost to society of accidents involving combination trucks with braking deficiencies, based on extrapolated data, was about $360 million for 1989.

The Safety Board also obtained and reviewed accident data from four States (Pennsylvania, Oregon, Texas, and Florida) in which the Safety Board had conducted truck brake inspections. The purpose of the review was to determine the magnitude of combination vehicle brake-related accidents reported in 1989 by those States. The data summarized below were used to project accidents nationwide and to make an additional cost estimate for comparison:

| Accidents involving combination vehicles | | Number of brake system deficiencies | Percentage of total accidents involving brake brake system deficiencies |
|---|---|---|---|
| Pennsylvania | | | |
| Fatal | 161 | 4 | 2.5% |
| Injury | 2,859 | 39 | 1.4 |
| Property damage | 1,870 | 39 | 2.1 |
| Oregon | | | |
| Fatal | 50 | 2 | 4.0 |
| Injury | 179 | 5 | 2.8 |
| Property damage | 980 | 8 | 0.8 |

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[1]Miller, Ted, Viner, J., Rosman, S., et.al., *The Cost of Highway Crashes--Final Report to FHWA*, June 1991, currently available from the Urban Institute.

[2]From actual 1989 FARS data.

| | | | |
|---|---|---|---|
| Texas | | | |
| Fatal | 258 | 1 | 0.4 |
| Injury | 4,496 | 97 | 2.2 |
| Property damage | 8,971 | 214 | 2.4 |
| Florida (State routes only) | | | |
| Fatal | 186 | 6 | 3.2 |
| Injury | 2,306 | 54 | 2.3 |
| Property damage | 2,402 | 62 | 2.6 |
| Four-State total | | | |
| Fatal | 655 | 13 | 2.0 |
| Injury | 9,840 | 195 | 2.0 |
| Property damage | 14,223 | 323 | 2.3 |

Fatal Accident Reporting System (FARS) data showed that 19 percent of the nationwide fatal accidents with combination vehicles occurred in those four States. While these four States may not be representative of all States because of differences in reporting, they can provide a some insight into the proportion of reported injury and property damage accidents involving brake defects. Assuming that truck injury and property damage accidents occur in the same proportion to fatal accidents nationwide as in these four States, an estimate of injury and property damage accidents that involve combination vehicles with defective brakes is as follows:

| | |
|---|---|
| Estimated fatal accidents with defective brakes (FARS) | 100 |
| Estimated injury accidents with defective brakes | 1,000 |
| Estimated property damage accidents with defective brakes | 1,700 |
| Estimated total combination vehicle accidents with defective brakes | 2,800 |

Therefore, an alternative annual cost estimate for accidents involving combination trucks with deficient brakes has been calculated as follows:

| Severity | Number | Cost/accident | Total cost per year |
|---|---|---|---|
| Fatal | 100 | $2,729,737 | $272,973,700 |
| Injury | 1,000 | 76,781 | 76,781,000 |
| PDO | 1,700 | 11,678 | 19,852,600 |
| Total | 2,800 | | 369,607,300 |

This agrees quite closely with the previous cost estimate of $360 million for 1989.

## APPENDIX F

## CASE INVESTIGATION SUMMARIES

## CASE SUMMARY 1

**Investigation No.**: FTW-89-F-H001
**Accident Location**: Texas State Highway 62, 7 miles south of Buna, TX
**Lanes:** Two lanes, undivided
**Shoulders:** Right - 2 feet asphalt and 6-8 feet gravel
Left - 2 feet asphalt and 6-8 feet gravel
**Median:** None
**Features:** Straight, level with a 0.35 crown
**Date and Time**: December 28, 1988, 9:45 a.m.
**Ambient Conditions**: Cloudy, dry, 40 $^{O}$F
**Heavy Vehicle Involved**: 1979 conventional White Road Boss II straight truck carrying approximately 1,000 pounds of steel
**Motor Carrier**: Southern State Steel Company
**Type of Operation**: Interstate, private carrier
**Size of Operation**: 150 power units
**Total Weight of Vehicle**: 21,220 pound
**Total Length of Vehicle**: 32 feet
**Other Vehicle:** 1977 Oldsmobile Royale Delta 88 sedan
**Truck Fatalities**: 0 **Truck Injuries:** 1
**Other Fatalities:** 6 **Other Injuries**: 0

**Summary**

The northbound truck had begun to decelerate for a passenger car in its lane that had decelerated to turn left onto Farm-to-Market Road 2246. As it decelerated, the truck skidded out of control for approximately 177 feet, rotated counterclockwise on the 0.35 crown, and was perpendicular to the traffic lanes when the impact occurred across the centerline in the southbound lane.

A driver reported that the truck was traveling 50 mph when it collided with the southbound 1977 Oldsmobile. The Oldsmobile skidded approximately 62 feet before impact. At impact, the front of the Oldsmobile contacted the right side frame of the truck. The truck overrode the Oldsmobile, displacing its hood, roof, and all four doors. The truck then overturned and slid on its roof for approximately 43 feet before coming to rest upside down. The Oldsmobile was forced rearward approximately 5 feet from the impact area.

The Oldsmobile was destroyed and all six occupants were killed. The truck sustained substantial damage, and the unrestrained driver received moderate injuries.

Several bottles of medicine, prescribed to the truckdriver, were found in the truck during the postcrash inspection. The medications were Darvocet-N-100, Hydralazine, Methyldopa, and Chlordiazepoxide. The truckdriver, who said he had been taking anti-anxiety drugs and high blood pressure medicine for 15 years, stated he took some Methyldopa and Hydralazine the night before the accident and some Chlordiazepoxide before he left his residence the morning of the accident. He indicated he took a 25mg dosage of the Chlordiazepoxide at least once a day and more frequently if he felt an anxiety attack coming on.

Pharmacy records showed that the truckdriver received prescription medications from nine different doctors from July 1986 through February 1989. During this period, the truckdriver purchased 8,296 pills and capsules containing 26 different types of medications.

The Center for Human Toxicology in Salt Lake City, Utah, performed a toxicological analysis of the truckdriver's blood. The specimen was found to contain 3000 ng/ml of Chlordiazepoxide, 1400 ng/ml of demoxepam, and 800 ng/ml of desmethylchlordiazepoxide. The limited volume of blood precluded testing for the presence of propoxyphene and other drugs. According to the Safety Board's toxicology specialist, the truckdriver had a blood concentration of Chlordiazepoxide and its metabolites in the high end of the therapeutic range. The Safety Board's chemist further stated that each of these drugs (Chlordiazepoxide and propoxyphene) can cause drowsiness or impaired physical and mental abilities.

The truckdriver began his employment with the carrier on December 7, 1988. On November 29, 1988, the driver was given a preemployment drug screen that returned positive for propoxyphene, the narcotic analgesic found in Darvocet-N-100. The driver's physical exam had a note on it indicating the driver had checked positive for propoxyphene but that he had a prescription for the medication. His examining physician signed the form on November 29, 1988, certifying the truckdriver as physically qualified to drive a commercial vehicle in interstate commerce. He possessed a valid class A Texas driver's license. His driving record showed no violations or accidents in the 3 years before the accident.

The postcrash inspection of the White truck revealed that the steering axle was equipped with Type 9 single air chambers and 18° wedge brakes that were both past the manufacturer's recommended limit of adjustment. The two drive axles had Type 24 air chambers installed using S-cams, and all were within the manufacturer's recommended limits of adjustment. The braking efficiency was calculated at 0.71.

The White truck originally was manufactured as a 140-inch wheelbase truck tractor by the White Motor Corporation, with a gross vehicle weight rating of 38,000 pounds. In 1985, the Commercial Metals Company, the parent company of Southern State Steel Company, purchased the tractor and reconfigured it as a straight truck. Commercial metals stretched the frame by approximately 16 feet, extending the wheelbase to 234 inches. The empty weight of the reconfigured straight truck was 20,300 pounds. According to the motor carrier, the truck was sometimes used to transport loads up to 20,000 pounds, although its brake system was not redesigned for this heavier weight. Engineers from the White Volvo General Motors Corporation calculated that the reconfigured straight truck should have been equipped with Type 12 air chambers and a single nonservo wedge brake on the front axle instead of the original Type 9 chambers.

**Probable Cause**

The National Transportation Safety Board determines that the probable cause of this accident was the lack of adequate braking on the steering axle that resulted from improper maintenance. Contributing to the accident was the truckdriver's impaired efficiency of judgment and performance that resulted from his use of multiple prescription medications.

## CASE SUMMARY 2

**Investigation No.:** DEN-89-F-H003
**Accident Location:** Colorado State Highway 7, 5.5 miles west of Lyons, CO
**Lanes:** Two lanes, undivided
**Shoulders:** Right - Varying width gravel
Left - Varying width gravel
**Median:** None
**Features:** Curves, mountainous, 4.6-percent downgrade
**Date and Time:** June 2, 1989, 2:18 p.m.
**Ambient Conditions:** Clear, dry
**Heavy Vehicle Involved:** 1979 Thomas Built 72-passenger school bus transporting 41 passengers
**Motor Carrier:** Boulder Valley School District
**Type of Operation:** Public school student transportation
**Size of Operation:** 178 power units
**Total Weight of Vehicle:** Approximately 33,000 pounds
**Total Length of Vehicle:** 34 feet
**Other Vehicle Involved:** None
**Case Vehicle Fatalities:** 1 **Case Vehicle Injuries:** 39
**Other Fatalities:** 0 **Other Injuries:** 0

### Summary

The school bus was traveling eastbound on State Route 7, en route to Boulder, Colorado. During the first 2 miles of the trip, the driver placed the bus' automatic transmission in first gear before reaching a mountain summit. She stated that while going downhill on the way to the summit, the bus accelerated to about 70 mph and that when she applied the brakes, the bus did not slow. The driver also stated that she smelled the brakes heating up, saw the low air warning light, and heard the buzzer activate for a few seconds. The warnings stopped on her final climb to the summit, and the driver decided to begin the 13-mile descent without stopping to check her brakes.

As the bus descended the mountain, several passengers reported that the bus tipped up onto two wheels in some of the curves. At 8.7 miles into the 13-mile downgrade, the bus entered a 493-foot radius curve to the left and began rotating counterclockwise about its vertical axis. This rotation continued as the front of the bus dropped off the road and overturned. The bus slid on its roof, struck a large boulder with the left side of the roof, and came to rest on its right side.

A passenger seated in the first row in the right side aisle seat was ejected and received fatal injuries. Another occupant, who was sitting in the seventh row next to the emergency exit door, was ejected and received serious injuries. Of the other occupants, 2 were not injured, 32 received minor injuries, 5 had moderate injuries, and 1 other sustained serious injuries. All occupants who were not ejected exited the bus through the rear push-out emergency window and front windshield opening.

The front windshield and the window on the emergency exit at row 7 on left side were displaced. The glass was broken out of two passenger windows on the left side and seven windows on the right side, but the metal framework remained in place.

The school bus was equipped with an air-mechanical S-cam brake system. The Safety Board examined the vehicle and found two of the four brakes past the manufacturer's recommended adjustment limit and one brake at the limit. These three brakes only had about 1/4 inch of reserve stroke remaining. The out-of-adjustment brakes combined to provide a calculated cold braking efficiency of 0.64. The limited braking capability of the bus would have been further degraded by heat that developed during the 8.7-mile descent.

Postaccident testing revealed that the parking brake release valve could be operated only with considerable difficulty. The driver also stated that other buses she had driven had the parking brake valve on the right side. On these buses, she normally released the parking brakes using her foot to push the valve in. Had the parking brakes been on, they probably would have dragged and heated up even while the vehicle was ascending the initial grade. The bus was not equipped with an engine retarder. As a result, the automatic transmission would upshift sufficiently to damage the engine even when the operator selected a low gear, if the engine-governed speed was exceeded.

The school district's policy was to check the brake adjustments on transit-type buses every 6,000 miles or when requested by the driver. The brakes on the accident bus had not been checked during the 6 months preceding the accident. Records revealed that the bus was scheduled for a 6,000-mile brake inspection the week following the accident.

The school busdriver held a valid Colorado class C driver's license and a school bus operator's permit. She had 4 years experience driving school buses and had received about 40 hours of school busdriver's training. In the school district's mountain driving training manual, drivers were instructed to perform a brake inspection before beginning a return trip or at the top of mountain passes. Her State driving record showed that she had received one moving traffic violation and had been involved in no accidents in the 3 years before this accident.

**Probable Cause**

The National Transportation Safety Board determines that the probable cause of this accident was the school busdriver's loss of speed control that resulted from a loss of braking effectiveness. Braking effectiveness was lost because the brakes were adjusted inadequately and the bus was operated with the parking brakes on. Contributing to the cause of the accident was the driver's failure to properly evaluate the low air warning buzzer and the smell of hot brakes and her choice to continue down the summit without inspecting or adjusting the brakes.

## CASE SUMMARY 3

**Investigation No.**: SEA-89-H-TB02
**Accident Location**: Interstate 225, Aurora, CO
**Lanes**: Four lanes, divided
**Shoulders**: Right - 10 feet asphalt
Left - 29 feet asphalt
**Median**: 60 feet (approximate), with concrete barrier
**Features**: Straight, slight downgrade
**Date and Time**: August 4, 1989, 10:20 a.m.
**Ambient Conditions**: Clear, daylight, dry, warm
**Heavy Vehicle Involved**: 1987 International cab-over-engine pulling three partially loaded 27-foot van trailers
**Motor Carrier**: Star Motor Freight, Inc.
**Type of Operation**: Interstate, common carrier
**Size of Operation**: 40 power units
**Total Weight of Vehicle**: 65,260 pounds
**Total Length of Vehicle**: 98.2 feet
**Other Vehicle(s) Involved**: 1989 Subaru, 1977 Suzuki MC, 1970 Dodge van, and 1982 Ford Bronco
**Truck Fatalities**: 0 **Truck Injuries**: 1
**Other Fatalities**: 0 **Other Injuries**: 6

**Summary**

The accident occurred as the triple trailer combination vehicle approached slowed traffic while traveling north on Interstate 225, which was congested because of road construction. The truckdriver noticed a car slowing or stopped in front of him, and he applied the brakes. The combination went onto the shoulder, struck the guard rail, reentered the traffic lanes, and struck a Subaru and a Dodge van. The van immediately caught fire. The Subaru then struck a motorcycle, and the van was pushed into a boat trailer. The combination unit overturned onto its right side, and the front of the tractor struck and displaced a concrete barrier in the median. The truck came to rest on its right side, extending from the median barrier to the W-beam guard rail on the right shoulder. The combination left 355 feet of preimpact tiremarks, and the front of the tractor came to rest about 730 feet north of these tire marks.

At the time of the accident, the driver was on the return trip of a round trip between Denver, Colorado, and Raton, New Mexico, and was about 10 miles from the Denver terminal. He had driven all night, traveling about 500 miles in 9 3/4 hours. A witness related that the combination was traveling at least 60 mph before slowing down. The maximum attainable speed of the tractor was calculated to be 63 mph.

The lapbelted truckdriver sustained minor injuries. The Subaru driver received minor injuries, and the right front passenger had serious injuries, including a fractured skull. Both were restrained by lap/shoulder belts. The driver of the Dodge van had minor injuries, and the right front passenger was treated and released at a local hospital. It is unknown if they were wearing restraints. A passenger asleep on the floor of the van sustained first-degree burns, bruises, and an undisclosed internal injury. The motorcyclist received bruises and a broken ankle. The Ford Bronco driver said that he was wearing a lap/shoulder belt; however, the extent of his injuries is unknown.

The third trailer broke into two pieces and was destroyed. The Subaru and Dodge van were destroyed. The motorcycle received damage to the handle bars, gas tank, and fenders. The Ford Bronco was lightly damaged in the left rear and the boat trailer had light to moderate damage. The tractor received damage to the left front bumper, left leaf spring, and right side of the cab. The first trailer received light damage to the right side. The second trailer, damaged from the rollover, was destroyed by fire.

The carrier began operating in 1956 and received a "satisfactory" rating from the Office of Motor Carriers in 1988. Two of the carrier's 31 tractors, including the 1 involved in this accident, were on long-term lease. The carrier was responsible for maintaining all vehicles, including the leased equipment. The drivers were not required to adjust brakes.

The combination vehicle was equipped with an air-mechanical brake system. Of the 16 brakes on the tractor and trailers, all were S-cam brakes except the 4 on the second trailer and its converter dolly, which had dual chamber Type 12 wedge brakes with automatic adjusters installed at each wheel. Four brakes were past the recommended limit of adjustment, while three more were at the limit of adjustment.

The total braking efficiency for the combination vehicle was calculated to be 0.71, a 0.29 reduction in total braking efficiency. Of the four brakes that were out-of-adjustment, two were the wedge brakes on the second trailer, which carried the heaviest load. These defective wedge brakes accounted for 0.26 of the total loss in braking efficiency. Nothing unusual was noted during brake application timing or air pressure tests.

The driver had 3 years of experience driving tractor trailers and held a current medical certificate. During the past 2 years, he spent about 50 percent of his time driving "triples." A 50-State driver record check revealed that the driver has a current Class A Colorado driver's license, which permitted him to operate combination vehicles. He also had an expired Indiana license and, although he had never held a California license, was under suspension in California for failing to pay a 1987 speeding citation. He was suspended in Colorado from February 1984 until August 1987 for driving under the influence of alcohol. The driver had no accidents recorded in the previous 3 years.

**Probable Cause**

The National Transportation Safety Board determines that the probable cause of this accident was the failure of the truckdriver to observe and react to the slowing traffic ahead of him. Contributing to the severity of the accident was the decreased braking capability of the second trailer.

## CASE SUMMARY 4

**Investigation No.**: FTW-89-H-TB06
**Accident Location**: Interstate Highway 30, Fort Worth, TX
**Lanes:** Six lanes, concrete divided highway
**Shoulders:** Right - 10 feet paved
Left - 5 feet paved
**Median:** Concrete barrier
**Features:** 1,910-foot radius left curve, 2-percent downgrade
**Date and Time**: August 18, 1989, 11:55 a.m.
**Ambient Conditions**: Clear with dry pavement, 90 °F
**Heavy Vehicle Involved**: 1981 Freightliner tractor pulling a loaded 45-foot Lufkin flatbed semitrailer
**Operator**: Allied Construction Supplies Corporation
**Type of Operation**: Intrastate, motor carrier
**Size of Operation**: Four power units
**Total Weight of Vehicle**: Approximately 77,600 pounds
**Total Length of Vehicle**: Approximately 55 feet
**Other Vehicle Involved**: One motorcycle and seven passenger vehicles
**Truck Fatalities:** 0 **Truck Injuries**: 0
**Other Fatalities**: 1 **Other Injuries**: 4

### Summary

On August 18, 1989, a 1981 Freightliner tractor departed Dallas, Texas, pulling a Lufkin flatbed semitrailer loaded with construction supplies. About 11:55 a.m., the combination unit entered a construction zone on Interstate Highway 30 near Forrest Park Boulevard in Fort Worth, Texas, and collided with a motorcycle and seven passenger vehicles that were stopped due to congestion in the construction area.

Witnesses stated that the combination unit was traveling westbound at approximately 50 mph in the center lane when the unit moved left into the lane nearest the concrete median barrier. At that point, about 150 to 500 feet before the impact, the driver's brake lights came on and he began sounding his horn. Witnesses also stated that the driver steered into the median barrier before impact in an effort to avoid the collision. There were no preimpact skidmarks. Gouges in the pavement showed that the combination unit traveled approximately 217 feet after the impact. The truckdriver stated that he was traveling at 45 to 55 mph and was unable to slow down in time for the stopped traffic.

The motorcycle was destroyed and the motorcyclist killed. Six of the seven passenger vehicles were substantially damaged, and four of the occupants received minor to moderate injuries. Damage on the Freightliner was minor and confined to the front end. The unrestrained driver of the combination vehicle was not injured. Toxicological testing of the truckdriver's blood specimen by the Tarrant County Medical Examiner's Office was negative for the presence of alcohol or other drugs.

A postcrash inspection of the combination unit's air-mechanical S-cam brake system revealed numerous deficiencies. Nine out of the vehicle's 10 brakes were past the manufacturer's recommended limit of adjustment. The left forward trailer brake drum was severely grooved, and the air reservoir on the right side of the tractor was leaking air. Of the nine brakes found improperly adjusted, four were inoperative and the remaining five Type 30 brake chambers were incapable of providing braking torque because of excessive pushrod stroke. The adjusting nuts on the slack adjusters were not visible as they were covered with a heavy coat of old mud and grease. Title 49 CFR 393.52 requires that a combination unit develop a braking force equal to 43.5 percent of its gross weight; the accident combination unit could only develop a braking force equal to 7 percent of its gross weight for a calculated braking efficiency of 0.11.

The mechanic for Allied Construction Supplies Corporation stated that he thought the brakes had been adjusted on the accident tractor and semitrailer about 2 to 3 weeks before the accident. He further stated to Safety Board investigators that "one of the carrier's trailers has not required brake adjustment or maintenance in over 3 1/2 years."

Texas statutes required that all vehicles have an annual safety inspection. The truck tractor and semitrailer were both inspected on July 29, 1989, 20 days before the accident. The inspection was performed by Mr. James Cornell of J&J Automotive in Seagoville, Texas. On August 22, 1989, another multiple vehicle injury accident occurred on U.S. Highway 75 in Richardson, Texas, when a truck tractor and semitrailer failed to stop, striking a line of stopped traffic. All the truck tractor's brakes were inoperative according to mechanics hired by the police to perform the postcrash inspection. It was later discovered that Mr. Cornell had also performed the annual safety inspection on the Richardson combination unit. Records from the Texas Department of Public Safety Motor Vehicle Inspection Service showed that this inspector had been convicted previously for issuing certificates of inspection without performing the required safety inspection.

Allied Construction Supplies Corporation was owned by the truckdriver's father. The father stated that his son had 4 years of experience as a heavy truckdriver. Driver record files from the Texas Department of Public Safety showed that the truckdriver had been convicted of three speeding violations in the preceding 4 years.

**Probable Cause**

The National Transportation Safety Board determines that the probable cause of this accident was the inadequate braking capacity of the Freightliner combination unit that developed as a result of the motor carrier's failure to ensure that the truck brakes were properly maintained.

## CASE SUMMARY 5

**Investigation No.:** SEA-89-H-TB04
**Accident Location:** Ferncroft Road in Mercer Island, WA
**Lanes:** One lane, private
**Shoulders:** Right - None
Left - None
**Median:** None
**Features:** Curving, 12- to 17-percent downgrade
**Date and Time:** September 5, 1989, 3:44 p.m.
**Ambient Conditions:** Clear, daylight, and dry
**Heavy Vehicle Involved:** 1977 International dump truck fully loaded with asphalt
**Motor Carrier:** Harms Paving Co., Inc.
**Type of Operation:** Intrastate carrier
**Size of Operation:** Eight power units
**Total Weight of Vehicle:** 41,720 pounds
**Total Length of Vehicle:** 25 feet
**Other Vehicle Involved:** None
**Truck Fatalities:** 0 **Case Vehicle Injuries:** 1
**Other Fatalities:** 0 **Other Injuries:** 0

**Summary**

The truckdriver was waiting to dump his fully loaded truck. When the crew was ready for the asphalt load, the driver started his truck, let the air build up for 3 to 4 minutes, and then began backing down the 300-foot section of road. The driver stated that part-way down the hill, he noticed his air pressure dropping and his speed increasing. He believed he was in high range reverse or possibly in neutral because the transmission had slipped. The driver jumped from the vehicle before it went off the road, knocked over a large tree, and struck a house. The vehicle came to rest on its left side about 30 feet past the edge of a parking area in front of the house. The driver received a few bruises and abrasions as a result of his jump. No one in the house was injured.

The vehicle was damaged primarily on the rear and left side. The rear cross member was severely dented inward as was the left side fuel tank. About 1/3 of the house was destroyed.

When the Safety Board examined the vehicle, investigators found:

1. The steer axle brakes were not operational.

2. Three of the remaining four brakes were past the manufacturer's recommended limit of adjustment.

3. The fourth brake was at the limit.

4. Air could not be applied to the service brakes at a pressure greater than 60 psi.

5. The air reservoir tanks had about 1 1/2 quarts of sludge.

6. The left side of the drive axles had a broken spring hanger.

7. The leading drive axle had mismatched slack adjuster lengths.

8. The pushrod was not connected to the slack adjuster on the left side of the leading drive axle.

9. Two of the slack adjusters had the wrong size clevis pins.

10. The dump box was held down by a broken bracket.

11. The braking efficiency was calculated at 0.51.

The motor carrier had no records of vehicle maintenance except receipts for purchased parts. When questioned about the brake system, a company representative stated that he believed the brakes had been adjusted the Saturday before the accident. The accident took place on a Tuesday; the previous Monday was a holiday.

The motor carrier was not keeping a driver's file on the accident driver, and the driver did not have a medical certificate as required by the State of Washington. On August 4, 1987, the Washington Utilities and Transportation Commission audited the carrier and found them to be "in good standing."

The driver of the dump truck possessed a valid Washington combination driver's license. His driving record showed only one violation for an overweight load and showed no accidents in the 3 years before the accident. He had been working for the paving company for 1 year and 7 months and had received no formal training in the operation of heavy trucks.

**Probable Cause**

The National Transportation Safety Board determines that the probable cause of this accident was the loss of braking capability due to out-of-adjustment brakes and contaminants in the air system. Contributing to the severity of the accident was the driver's improper gear selection.

## CASE SUMMARY 6

**Investigation No.:** SEA-90-H-TB01
**Accident Location:** State Route 12 outside Rochester, WA
**Lanes:** Two lanes, undivided
**Shoulders:** Right - 4.5 feet asphalt
Left - 4.1 feet asphalt
**Median:** None
**Features:** Straight, flat, and at grade
**Date and Time:** November 13, 1989, 12:45 p.m.
**Ambient Conditions:** Daylight, light mist, about 45 °F
**Heavy Vehicle Involved:** 1974 Peterbilt in combination with a lightly loaded van trailer
**Motor Carrier:** CMD Transportation, Inc.
**Type of Operation:** Interstate, common carrier
**Size of Operation:** 26 power units
**Total Weight of Vehicle:** 36,800 pounds
**Total Length of Vehicle:** 57 feet, 1 inch
**Other Vehicle Involved:** 1983 Lincoln Continental - four door
**Truck Fatalities:** 0 **Case Vehicle Injuries:** 0
**Other Fatalities:** 1 **Other Injuries:** 0

**Summary**

The driver of the combination was traveling westbound on the rain-dampened State Route 12 where sight distance was over 0.5 mile. He stated he was traveling around 50 mph when he saw vehicles stopped in the lane ahead of him. Three passenger vehicles were stopped; the first was waiting to make a left turn. The truckdriver stated that as he began braking for the stopped traffic, he noticed his brakes locking up. He said he let up on the brakes briefly and then reapplied them, but noticed that his tractor was drifting to the left across the centerline. As his tractor crossed the centerline, it struck the left side of an oncoming Lincoln, further rotating the tractor, and pushing the Lincoln off the road into the ditch.

The truckdriver believed that he slowed to about 2 mph at the time of impact and that the driver of the Lincoln took no evasive action. Road evidence indicated that the combination vehicle left tiremarks on the asphalt for about 128 feet and traveled only 10 to 15 feet after impact. The Lincoln left ruts in the shoulder gravel leading into the ditch where it came to rest about 30 to 35 feet from the area of impact. The driver of the Lincoln was fatally injured; the truckdriver was uninjured. No toxicological testing was performed on either driver.

Damage to the tractor was confined to the left front corner of the vehicle. The bumper was pushed back into the tire, the left front headlight was broken, and an air valve for the stop light switch was broken. The Lincoln received direct damage on the left side from the front corner back to the rear axle. The top of the A-pillar was pushed into the passenger compartment about 18 inches.

The combination vehicle was equipped with an air-mechanical brake system using S-cams. No brakes were installed on the steering axle, and none were required because the tractor was a pre-1980 vehicle. All of the other eight brakes were within the manufacturer's recommended level of adjustment. The time required for the tractor drive axle brakes to reach 60 psi and the trailer axle brakes to reach 60 psi differed by less than 0.01 second. The threshold pressures for each brake varied between 4.5 and 5.5 psi. Pressure balance testing revealed no abnormalities. The braking efficiency was calculated at 0.76.

The driver's logs indicated that he had not worked the 2 days before the accident, that he had begun work the day of the accident about 8:30 a.m., and that he had arrived at the terminal about 7:00 a.m. The Washington State Patrol recorded the accident as taking place at 12:45 p.m.

The westbound lane of State Route 12 near the accident site appeared to have a coarser layer of asphalt on the outside or right side wheel path. However, when the surface was tested with a drag sled, it revealed friction numbers of 0.77g on the left and 0.78g on the right wheel path. The westbound lane had no cross-slope.

The driver of the combination vehicle possessed a valid Class 1 Oregon driver's license and a current medical certificate. His driving record showed three traffic violations and two accidents in the 3 years before the accident. He had been working for the carrier for about 4 years.

**Probable Cause**

The National Transportation Safety Board determines that the probable cause of this accident was the inattention of the combination driver to the stopped traffic ahead. Contributing to the accident was the lack of brakes on the steering axle that resulted in the jackknife of the tractor into the opposing lane of traffic.

## CASE SUMMARY 7

**Investigation No.:** ATL-90-H-TB05
**Accident Location:** U.S. 431, 2 miles south of Phenix City, AL
**Lanes:** Two lanes, undivided asphalt
**Shoulders:** Right - 6 feet grass
Left - 6 feet grass
**Median:** None
**Features:** Straight, 4.3-percent downgrade northbound
**Date and Time:** November 15, 1989, 7:52 a.m.
**Ambient Conditions:** Cloudy, daylight, and wet
**Heavy Vehicle Involved:** 1978 International conventional tractor in combination with a loaded 40-foot flatbed trailer
**Motor Carrier:** L & T Trucking Co.
**Type of Operation:** Interstate carrier
**Size of Operation:** One power unit
**Total Weight of Vehicle:** 44,500 pounds
**Total Length of Vehicle:** 54 feet, 7 inches
**Other Vehicle Involved:** 1987 GMC Chassis/Bluebird body 84-passenger school bus
**Truck Fatalities:** 0 **Case Vehicle Injuries:** 1
**Other Fatalities:** 0 **Other Injuries:** 3

**Summary**

The school bus was traveling south on U.S. Route 431 with 47 students. The driver of the bus activated the yellow warning lights as he prepared to stop to pick up a passenger at Red Oak Drive, a private drive that extends west into a residential area. As the school bus stopped, two northbound combination vehicles approached and the busdriver motioned with his hand for the vehicles to continue past the bus. The first, a set of doubles, slowed to a driver-reported speed of 20 mph and proceeded past the stopped school bus. The driver of the second combination vehicle, the International tractor with the loaded flatbed, stated he was traveling about 50 mph when he crested the hill about 660 feet from the stopped bus. As the International driver neared the school bus, the driver observed the red lights flashing on the bus only after the set of doubles cleared the bus.

Witnesses reported that the busdriver had not activated his flashing red lights or his stop sign. When the driver of the International saw the red light, he began braking, and his tractor began rotating to the left. The driver stated that after he unsuccessfully attempted to stop the rotation, his vehicle crossed the centerline and struck the bus. The tractor and trailer came to rest in a full jackknifed position in the southbound lane of traffic. The school bus was pushed rearward and rotated about 80 degrees in a counterclockwise direction.

The unrestrained driver of the International received serious injuries. The lapbelted driver of the school bus and two passengers sustained minor injuries. A toxicological analysis of the

International driver's blood was negative for either drugs or alcohol. Officials reported that the bus evacuation was orderly and accomplished without any additional injury.

The left side of the International tractor's cab was damaged from the driver's door rearward. The rear of the tractor frame was bent forward, and the right side of the rear drive axle also was pushed forward about 6 inches. Yellow paint was found on the rear of the tractor frame. The school bus was damaged substantially, primarily at the front end. In spite of the damage, the front door remained operational as did the rear emergency exit.

The combination vehicle was equipped with an air-mechanical S-cam brake system. Of the 10 brakes on the tractor and trailer, 2 were past the manufacturer's recommended limit of adjustment, one was at the limit, and another was inoperative due to a hole in the diaphragm and grease-saturated linings. The rear drive axle and both of the trailer axles were found to be in proper adjustment. These adjustment levels produced a calculated braking efficiency of 0.79. When interviewed by the Safety Board, the driver of the International tractor stated that he had adjusted the brakes on the tractor drive axles and the trailer the day before the accident. He reported that because of a negative experience with grabbing steering axle brakes, he never checked or adjusted those brakes.

The carrier did not maintain a driver qualification file for the driver. Private garages performed all maintenance on the carrier's vehicles. In October 1987, the motor carrier was reviewed for safety compliance by the Office of Motor Carriers (OMC) and received a "conditional" rating on May 26, 1988. The OMC had no record of any follow-up action.

The driver of the combination, who had worked for the carrier for about 6 months, possessed a valid Alabama chauffeur's license and a current medical certificate. His driving record showed two traffic violations and no accidents in the 3 years before the accident. He reported 4 years of experience with combination vehicles but no formal training.

**Probable Cause**

The National Transportation Safety Board determines that the probable cause of this accident was inattention on the part of the truckdriver. Contributing to the cause of the accident was the loss of lateral control due to inoperative brakes on the steering axle.

## CASE SUMMARY 8

**Investigation No.:** SEA-90-H-TB02
**Accident Location:** State Route 901 outside Issaquah, WA
**Lanes:** Two lanes, undivided
**Shoulders:** Right - 2-10.3 feet asphalt
Left - 2-5.6 feet asphalt
**Median:** None
**Features:** Curving, 3- to 6-percent downgrade
**Date and Time:** November 20, 1989, 6:02 p.m.
**Ambient Conditions:** Dark, street lights, raining, wet
**Heavy Vehicle Involved:** 1987 GMC Chassis with Carpenter school bus body
**Motor Carrier:** Issaquah School District
**Type of Operation:** Public school transportation
**Size of Operation:** 80 buses
**Total Weight of Vehicle:** 16,660 pounds
**Total Length of Vehicle:** 35 feet, 2 inches
**Other Vehicle Involved:** 1985 Ford F250 4x4 pickup
**Truck Fatalities:** 0 **Case Vehicle Injuries:** 0
**Other Fatalities:** 0 **Other Injuries:** 0

### Summary

The driver of the school bus was traveling down a slight grade that curved left. About 625 feet from impact, the driver passed the 30-mph speed limit sign at about 25 mph. A passenger vehicle was stopped in the bus' lane waiting to make a left turn; a Ford pickup was stopped behind the passenger vehicle. The busdriver had a view of the stopped vehicles from about 610 feet. The busdriver stated she first applied her brakes about 100 feet before impact.

According to her statement, the driver continued to brake until the wheels locked up and she felt the rear of the bus begin to rotate toward the centerline. At this point, she let up on the brakes, realized she could not stop, reapplied the brakes, and slid into the stopped pickup. No marks were found on the wet concrete road. No one was injured in the accident, and no toxicological testing was performed on either driver.

Damage to the school bus was confined to the left side of the front bumper and the hood. The right rear portions of the Ford pickup were struck and damaged. Both vehicles were driven away from the scene.

The school bus was equipped with an air-mechanical brake system using S-cams. All four brakes were within the manufacturer's recommended limits of adjustment. The difference in timing for the brakes between the two axles to reach 60 psi was only 0.06 second. The threshold pressures for each brake did not differ by more than 3.5 psi. Pressure balance testing revealed that the bus was also equipped with an automatic limiting valve on the steering axle brakes. Braking efficiency was calculated at 100 percent.

The limiting valve was not requested by the school district when the bus was ordered. However, the company that supplied the chassis installed the limiting valve because "it gives better control in icy conditions." General Motors Corporation does not install the limiting valve at the factory unless it is requested by the customer.

The maintenance records for the school district indicated that its buses were in good condition. At an annual school bus inspection on August 4, 1989, the Washington State Patrol inspected 75 of the buses and placed 3 out of service. The Washington State Patrol noted in its report, "Fleet is in excellent condition. Shop crew did a great job maintaining the buses." The school district not only regularly checked the adjustment on its brakes, it also conducted road tests with a deceleromter after every brake repair job.

The driver of the school bus possessed a valid Washington intermodiate operator's license and a current medical certificate. Her driving record showed no traffic violations or accidents in the 3 years before the accident. She had been working for the school district for 1 year and had driven over the route many times.

**Probable Cause**

The National Transportation Safety Board determines that the probable cause of this accident was the inattentiveness of the school busdriver. Contributing to this accident was the presence of an automatic limiting valve installed on the bus' steering axle brakes.

## CASE SUMMARY 9

**Investigation No.**: SEA-90-H-TB03
**Accident Location**: U.S. 40, 6 miles east of Cumberland, MD
**Lanes**: Four lanes, divided
**Shoulders**: Right - 11 feet asphalt
Left - 3 feet asphalt
**Median**: 5 feet, dirt, double W-Beam guardrail
**Features**: 6.75-percent mountainous downgrade
**Date and Time**: January 5, 1990, 2:45 p.m.
**Ambient Conditions**: Mostly sunny, daylight, dry, 45 °F
**Heavy Vehicle Involved**: 1984 White cab-over-engine in combination with a loaded 53-foot van trailer
**Motor Carrier**: Zerkle Trucking Company
**Type of Operation**: Interstate, common carrier
**Size of Operation**: 220 power units
**Total Weight of Vehicle**: 77,180 pounds
**Total Length of Vehicle**: 65.4 feet
**Other Vehicle(s) Involved**: None
**Truck Fatalities**: 1 **Truck Injuries**: 0
**Other Fatalities**: 0 **Other Injuries**: 0

### Summary

The accident occurred as the combination vehicle was descending a 3-mile mountainous grade. As the vehicle neared the end of a 1,146-foot radius curve to the left, it ran off the right side of the roadway, struck an embankment, and came to rest in a jackknifed position on the shoulder. Although signs were in place warning of the downgrade, no signs were in place advising drivers to reduce the speed or gear of their trucks. When a trooper arrived at the scene about 10 minutes after the accident, he found the tractor brakes to be cold and the trailer brakes very hot.

The driver was found lying on the roadway near the trailer landing gear. He sustained multiple head injuries and was pronounced dead at the scene. The driver's door on the tractor was found open by the responding state trooper. When examined by the Safety Board, the door functioned properly with no damage to the latch plate or door latch.

The tractor cab was damaged primarily around both front headlights, the front bumper, the windshield, and fuel tanks. The left front brake assembly and the right wheel and brake assembly were torn off. The trailer's right front corner was damaged.

The tractor and trailer were both equipped with air-mechanical S-cam brakes. The tractor had manual slack adjusters and the trailer had automatic slack adjusters. The tractor steering axle was equipped with Type 12 brake chambers and the remainder of the tractor and trailer brakes with Type 30. The pushrod travel for the left front tractor brake could not be measured because of damage. All the remaining brakes on the tractor were more than 1/4 inch past the manufacturer's recommended limit of adjustment. All of the trailer brakes were in proper adjustment.

The trailer wheel drums were examined and dark marks known as "hot spots" were observed on the inner surfaces. Brake experts who examined photographs of these marks estimated the drum temperature at the time of the accident to be between 900 °F and 1500 °F. Without taking the excessive brake temperature into account, the braking system's efficiency was calculated to be no more than 64 percent.

The carrier was audited by the Office of Motor Carriers in January 1989 and given a "conditional" rating. The involved tractor was on long-term lease to the carrier by a private individual who owned eight tractors. The carrier performed all maintenance on company-owned vehicles, but the tractor owner was responsible for all maintenance on its vehicles. According to the truck owner, the driver was responsible for adjusting the brakes or having them adjusted.

The driver had about 21 years of experience driving heavy combinations and was hired by the current tractor owner about 14 months before the accident. It was not determined how the driver was initially trained when he started driving trucks. The driver held a valid West Virginia chauffeur's license and a current medical certificate at the time of the accident. A West Virginia record check revealed he had one speeding ticket and no accidents in the past 7 years. A 50-State record check revealed he held only a West Virginia license.

According to the driver's wife, he was aware of a brake deficiency before leaving on this trip. Another driver for the carrier offered to loan the involved driver a 9/16-inch wrench in Philadelphia after a comment about the bad brakes. During the driver's first 20 of his 21 years of experience, his employers did not require their drivers to adjust brakes. Interviews with the truck owner, the driver's wife, and four other drivers employed by the owner failed to confirm that the driver actually knew how to adjust brakes. The driver was unfamiliar with this mountainous section of U.S. 40.

The State of Maryland recorded 25 brake-related accidents on this grade during 1989. As a result of discussions with the Safety Board, State officials placed three warning signs at the top of the hill alerting trucks to the degree and length of grade and the need for gear reduction. Only three brake-related accidents took place in the 8 months after the signs were placed.

**Probable Cause**

The National Transportation Safety Board determines that the probable cause of this accident was the loss of braking capability resulting from out-of-adjustment brakes. Contributing to this accident was the driver's decision to continue to drive with the full knowledge that he had inadequate brakes, the failure of the truck owner to ensure regular brake adjustments were performed, the driver's unfamiliarity with this mountainous roadway, and insufficient warning signs at the top of the mountain.

## CASE SUMMARY 10

**Investigation No.:** SBA-90-H-TB05
**Accident Location:** East Smith Street inside Kent, WA
**Lanes:** Four lanes, undivided
**Shoulders:** Right - 2-10.3 feet asphalt
Left - 2-5.6 feet asphalt
**Median:** None
**Features:** Curving, 6.5-percent downgrade
**Date and Time:** February 8, 1990, 2:05 p.m.
**Ambient Conditions:** Daylight, dry roadway, overcast, cool
**Heavy Vehicle Involved:** 1974 International in combination with a loaded long tongue dump trailer
**Motor Carrier:** Snowball Trucking, Inc.
**Type of Operation:** Intrastate, common carrier
**Size of Operation:** 3 power units
**Total Weight of Vehicle:** 82,800 pounds
**Total Length of Vehicle:** 65 feet, 1 inch
**Other Vehicle Involved:** 1980 Dodge Ram 150 pickup plus 10 other vehicles
**Truck Fatalities:** 0 **Case Vehicle Injuries:** 1
**Other Fatalities:** 1 **Other Injuries:** 7

**Summary**

The driver of the loaded dump truck and trailer combination was traveling westbound down the 5- to 6-percent grade with a full load. Sight distance coming down the hill to the traffic light measured 1,050 feet. East-west traffic was stopped waiting for the light to change as the out-of-control combination approached the intersection and began striking vehicles. Dirt and debris were located in the westbound lanes about 95 feet east of the crosswalk. Dual striated tire marks began about 20 feet west of the debris and continued arcing through the intersection for 165 feet up to the sidewalk. The combination traveled approximately 103 feet past the sidewalk before it came to rest. A 1980 Dodge Ram pickup was found pinned between the front of the gravel truck and a building. Based on witness statements, the Dodge pickup had been eastbound in the right lane waiting to make a right turn. Nine other vehicles were identified as having been damaged during the collision.

The driver of the Dodge pickup received fatal injuries while the driver of the combination vehicle received disabling injuries. Of the 15 other occupants involved, 1 was reported with a disabling injury, 5 with non-disabling injuries, 4 with possible injuries, and 5 with no apparent injuries. No toxicological testing was performed on any of the drivers.

Damage to the dump truck was confined to the front bumper, both front fenders, and the hood. No damage was noted on the trailer. The front section of the Dodge pickup was fairly intact, but the passenger compartment was completely crushed. Of the other nine vehicles involved, two were destroyed, three received substantial damage, one received moderate damage, and three received only minor damage.

The combination vehicle was equipped with an air-mechanical brake system. The tractor had S-cam brakes installed and the trailer was equipped with wedge brakes. Three out of six brakes on the truck were past the manufacturer's recommended adjustment limits and one was at the limit; while all four brakes on the trailer were past the limits. One and one-half pints of oil and water were found in the first air reservoir tank on the truck. Two of the trailer brake drums and their respective linings were grease saturated. An air leak was found in the brake service line on the trailer side of the air coupler. When 120-psi air was supplied just before the coupler, 40 psi was measured at the coupling itself, and 0 psi was measured at the left rear brake chamber on the trailer. These conditions combined to produce a calculated braking efficiency of 0.27.

The owner of the combination vehicle manufactured the trailer involved in the accident. He stated that he had built between 8 and 10 trailers, including the 3 that he was using at the time of the accident. According to the Washington Utilities and Transportation Commission (WUTC), which audited the carrier after the accident, the carrier had no vehicle condition reports and was not performing systematic maintenance or inspections. The WUTC inspected other vehicles owned by the carrier and placed the two remaining trucks and one of the two trailers out of service. One truck was placed out of service due to cracks in frame members. The other truck was placed out of service with out-of-adjustment brakes, an air leak, and a cracked spring hanger. The trailer placed out of service had an air leak, a cracked front spring hanger, and numerous other cracks in the frame members.

Time cards from the carrier indicated that the combination's driver had worked 27 hours in the last 8 days and had been on duty about 6 hours at the time of the accident. He possessed a valid combination endorsed driver's license and a current medical certificate. His driving record showed 7 traffic violations in the 3 years before the accident, 5 of which were moving violations. There were no accidents on his record. As a result of this accident, he was cited for speeding. He had been working for the carrier for 7 months.

**Probable Cause**

The National Transportation Safety Board determines that the probable cause of this accident was the lack of braking capability of the truck and trailer due to a chronically deficient carrier maintenance program.

## CASE SUMMARY 11

**Investigation No.**: FTW-90-H-TB03
**Accident Location**: Texas State Highway 48 near Brownsville, TX
**Lanes**: Two lanes, undivided asphalt highway
**Shoulders**: Right - 8 feet asphalt
Left - 8 feet asphalt
**Median**: None
**Features**: 1,423-foot-radius left curve, 6-percent superelevation
**Date and Time**: March 1, 1990, 1:20 p.m.
**Ambient Conditions**: Light rain, wet, wind from 360 degrees, gusts to 25 mph
**Heavy Vehicle Involved**: 1981 International truck tractor pulling a lightly loaded Trailmobile van semitrailer
**Motor Carrier**: Industrial Lubricants Company
**Type of Operation**: Intrastate, private carrier
**Size of Operation**: 38 power units
**Total Weight of Vehicle**: Approximately 32,269 pounds
**Total Length of Vehicle**: Approximately 55 feet
**Other Vehicles Involved**: 3 passenger vehicles
**Truck Fatalities**: 0 **Truck Injuries**: 1
**Other Fatalities**: 5 **Other Injuries**: 2

**Summary**

About 1:20 p.m. on March 1, 1990, a 1981 International truck tractor was eastbound on Texas State Highway 48 pulling a lightly loaded Trailmobile van semitrailer. A light rain was falling and the pavement was wet. Additionally, a crosswind from the north was gusting up to 25 mph. Approximately 4 miles east of Brownsville, Texas, the combination unit began negotiating a 1,432-foot-radius curve to the left. About 200 feet into the curve, the tractor began rotating counterclockwise into a jackknife. The tractor crossed the roadway centerline, sideswiping a westbound 1979 Ford LTD. The counterclockwise rotation continued past 90°, and the tractor's right front bumper and axle struck a westbound 1989 Oldsmobile Cutlass. The Oldsmobile was forced rearward and came to rest on the north roadside approximately 50 feet from the impact area.

The impact with the Oldsmobile displaced the tractor's front steering axle and the hood of the tractor cab. From this collision, the jackknifed combination unit continued sliding eastbound in the westbound lane and struck a westbound 1990 Toyota Camry. At this point the tractor had rotated into the side of the semitrailer, and the Toyota collided into the rear of the tractor's third axle. The Toyota was pushed rearward about 137 feet and came to rest with the tractor on the north roadside.

A westbound witness on SH 48 stated that the passenger cars appeared to be traveling at the speed limit. He indicated that no other vehicles were in front of the combination unit and that it appeared to be moving fast when it jackknifed into the opposing traffic lane. The truckdriver stated that he was driving at 45 to 50 mph in the wet curve when the unit jackknifed. He added that he was neither braking nor accelerating when the tractor spun out. There were no tire marks on the wet pavement where the initial instability and impact with the Ford occurred.

The Ford LTD received minor damage and neither occupant was injured. The Oldsmobile was destroyed, and all four occupants were killed. The Toyota was also destroyed; the driver was killed, and the right front passenger was seriously injured. The International tractor was destroyed and the truckdriver received minor injuries. Toxicological analyses of the truckdriver's blood specimen at the Texas Department of Public Safety Laboratory and at the Center for Human Toxicology were negative for alcohol or drugs.

A mechanical inspection of the combination unit's S-cam brake system revealed numerous deficiencies. The right side forward semitrailer axle brake drum had been recently turned up to its maximum allowable diameter. The three air reservoirs on the tractor contained approximately 2 3/4 gallons of oil sludge and water contamination. Of the four brakes that could be checked, the two on the steering axle were past the manufacturer's recommended limit of stroke. The rear drive axle brakes were so damaged that investigators could not accurately measure the stroke. All the brakes on the trailer had been backed off during the wreckage removal. The lining on the left front brake had approximately 3/16 of an inch lateral movement due to installation of an incorrect number of washers.

Pressure balance and timing tests revealed a 20- to 25-psi differential between the reference pressure at the gladhand and the pressure at the semitrailer axles. This differential only existed during a full, rapid application; during a gradual application, the pressure would equalize. Several kinks and dents were found in the metal air lines on the semitrailer. Timing tests showed that the tractor drive axle brake chambers could develop 60 psi in an average of 0.202 seconds; the semitrailer brake chambers developed 60 psi in an average of 0.500 seconds. Calculations that assumed a proper adjustment for the brakes produced braking efficiency of 0.71.

Maintenance records provided by the carrier showed that the brake linings on the truck tractor had been replaced and the brakes adjusted 1 month before the accident. The unit had accumulated only 838 miles since the service had been performed.

At the request of Safety Board investigators, the Texas Department of Highway and Public Transportation performed wet pavement skid testing using the ASTM skid trailer. The tests showed that the eastbound left-wheel path had a wet skid number of 33 at a point approximately 0.2 miles in front of the accident curve. On the immediate approach to the curve, the left wheel path had a skid number of 23, and the right wheel path had a skid number of 20. Approximately 150 to 200 feet into the accident curve, five wet skid tests were run: one near the centerline, one in the wheel paths, one between the wheel paths, one in the area near the white shoulder stripe, and one on the south road shoulder. The area near the centerline had a skid number of 49; the left wheel path had a skid number of 27; the right wheel path had a skid number of 29; and the area between the wheel paths had a skid number of 25. The area next to the white shoulder stripe had a skid number of 16, and the shoulder had a skid number of 48.

Safety Board investigators assessed the effect that the wet pavement's low and varying frictional qualities had on the approach to the accident curve. Calculations showed that if the combination unit was tracking in the extreme right area of the westbound lane where the pavement was the most slippery, approximately 5,163 pounds of force was available to hold the unit in the curve. If the vehicle was traveling at 55 mph, an inertial force of only 4,549 pounds would be acting on it. For the accident to occur, the unit would have had to become unstable before the beginning of the curve's 6-percent superelevation and would have had to enter the curve as the wind was gusting to 25 mph. The forces produced would tend to force the combination unit to the outside of the curve; instead, the combination unit rotated to the inside of the curve. The only conditions that would rotate the unit to the inside of the curve were the superelevation on the curve and a braking maneuver.

The truckdriver had been employed at Industrial Lubricants Company since April 15, 1989. He had performed the duties of a truckdriver since June 26, 1989; before that, he had no experience driving heavy trucks. Driver record files at the Texas Department of Public Safety showed that the truckdriver had not been involved in any other accidents or been convicted of any moving traffic violations in the preceding 5 years.

**Probable Cause**

The National Transportation Safety Board determines that the probable cause of this accident was the loss of lateral stability by the International truck tractor. This instability was caused by two factors: front to rear brake imbalance due to unadjusted brakes on the steering axle and the poor and varying frictional qualities of the pavement on the curved roadway.

## CASE SUMMARY 12

**Investigation No.:** SEA-90-H-TB06
**Accident Location:** West Marginal Way SW, Seattle, WA
**Lanes:** Four lanes, undivided
**Shoulders:** Right - None, concrete curb
Left - None, concrete curb
**Median:** 11-foot 6-inch, turning lane
**Features:** Occasional curves and flat
**Date and Time:** April 24, 1990, 2:16 p.m.
**Ambient Conditions:** Daylight, dry roadway, clear, warm
**Heavy Vehicle Involved:** 1972 White Freightliner in combination with a container chassis hauling an empty container
**Motor Carrier:** Lockwood Trucking, Inc.
**Type of Operation:** Intrastate, common carrier
**Size of Operation:** 2 to 3 power units
**Total Weight of Vehicle:** 24,901 pounds
**Total Length of Vehicle:** 36 feet, 10 inches
**Other Vehicle Involved:** 1968 Ford F600 truck with loaded box
**Truck Fatalities:** 0 **Case Vehicle Injuries:** 1
**Other Fatalities:** 1 **Other Injuries:** 0

**Summary**

The combination vehicle was traveling northbound on West Marginal Way SW in the outside lane at a driver-reported speed of 35 to 40 mph. After the combination vehicle passed SW Alaska Street, it struck a 4 1/2-inch-deep hole in the left wheel path of the roadway. According to the driver's statement, he lost consciousness and remembers nothing until his vehicle came to rest. A witness across the street saw the tractor-trailer veer right, cross the curb, and strike the parked Ford truck. This witness estimated the Freightliner's speed to be "at least 60 mph." As the tractor struck the Ford, the Ford's driver was ejected and run over by the trailer wheels of the combination. The witness also stated that it looked like the driver of combination was fighting with the steering wheel.

The distance from the center of the hole to the first tiremark on the concrete curb was 104 feet; the distance from the hole to the parked Ford truck measured 194 feet. The front of the tractor came to rest off the roadway 372 feet from the center of the hole, 178 feet past where the Ford was parked.

The driver of the combination vehicle received minor injuries while the driver of the Ford was fatally injured. Toxicological testing on the Ford driver was negative for alcohol or drugs and on the combination driver was less than 0.001 percent for blood alcohol.

Damage to the tractor was confined to the front at bumper level and above. The steering box was also knocked off its mount on the frame. The Ford truck's front structure was shifted to the right about 3 to 4 feet. Investigators noted little damage on the Ford truck behind the firewall.

The combination vehicle was equipped with an air-mechanical S-cam brake system. The Safety Board found that five out of eight brakes were past the manufacturer's recommended adjustment limit, and two others were at the limit. The vehicle had were no steering axle brakes. Braking efficiency was calculated to be 0.45. The left side of the forward drive axle was found to be sliding on its springs about 1 to 1 1/2 inches; this was also the location of the only brake that was within the manufacturer's recommended limits.

When investigators performed an air application timing for the brakes to reach 60 psi, they found the trailer brakes were applied 0.43 seconds before the drive axle brakes. The drive axle brakes applied at 0.82 second; Federal Regulations require that they reach 60 psi in 0.45 second. The carrier kept no maintenance records and did not require that his driver perform any daily vehicle inspections.

The Washington Utilities and Transportation Commission (WUTC) had audited the carrier many times. This agency reported that the carrier had been cancelled often for numerous safety and economic violations. At the last attempted inspection (January 17, 1990), the carrier refused to allow the WUTC access to his records and subsequently received a violation for failing to comply with an order.

The driver of the Freightliner possessed a valid combination endorsed driver's license and an expired medical certificate. His driving record showed 11 violations including 9 separate defective equipment violations in the 3 years before the accident. His record listed no accidents. He had been working for the carrier about 4 years, had 3 years of experience operating a heavy truck, and had no formal training.

**Probable Cause**

The National Transportation Safety Board determines that the probable cause of this accident was a loose drive axle. Contributing to the cause of this accident was a hole in the roadway surface and the reduced braking capability of the tractor and trailer.

## CASE SUMMARY 13

**Investigation No.:** FTW-90-F-H004
**Accident Location:** California State Route 168, near Big Pine, CA
**Lanes:** Two lanes, undivided
**Shoulders:** Right - varying width gravel
Left - varying width gravel
**Median:** None
**Features:** Mountainous, 8-percent downgrade
**Date and Time:** May 18, 1990, 3:40 p.m.
**Ambient Conditions:** Clear, daylight, dry, and 76 °F
**Heavy Vehicle Involved:** 1987 TMC 102 A3 Intercity Coach Bus
**Motor Carrier:** Southwest Charter Lines
**Type of Operation:** Interstate, common carrier
**Size of Operation:** 20 intercity coach buses
**Total Weight of Vehicle:** Approximately 35,500 pounds
**Total Length of Vehicle:** Approximately 40 feet
**Other Vehicle Involved:** None
**Bus Fatalities:** 0 **Bus Injuries:** 43
**Other Fatalities:** 0 **Other Injuries:** 0

**Summary**

About 9:00 a.m. on May 17, 1990, a 47-passenger intercity coach bus departed Los Angeles, California, on a 7-day scenic tour of California and Nevada. There were 43 passengers, a tour director, and a driver on board. The group traveled to Las Vegas, Nevada, on the first day. About 9:00 a.m., the group departed Las Vegas on an approximate 325-mile trip to Mammoth Lakes, California. The tour schedule called for the group to travel through Death Valley but, according to the busdriver, the tour director suggested they travel on California Route 168 through the Inyo mountains, a more scenic route. The busdriver had never traveled this route before and was unfamiliar with the mountainous terrain.

The bus traversed the first two mountain passes without incident. About 3:30 p.m., the busdriver began to descend the 7,271-foot elevation Westgard Pass. Warning signs were posted at the initial descent indicating that the maximum safe speed was 30 mph and that steep downgrades and sharp curves were present for the next 9 miles. The downgrade averaged 8 percent in this area. The busdriver used the third gear of his five-speed manual transmission, which allowed a speed of 34 mph at the engine's maximum governed speed. He stated that he had to use the service brakes to maintain speed control for the steep downgrade and sharp curves.

Approximately 5 to 6 miles into the descent, the bus brakes began to overheat and the speed of the bus increased to about 40 to 45 mph. The driver attempted to downshift to a lower gear, but his vehicle speed was too great for him to shift out of neutral. The speed of the bus increased to about 60 mph, and the bus went out of control in a 300-foot-radius curve to the left. The bus traveled across the road and, as the road curved back to the right, the bus went back to the left and sideswiped the rock and dirt cut slope. From here, the bus moved to the right across the road and came to rest on the north roadside.

At impact, the left front corner of the bus was crushed inward about 15 inches, displacing the windshield. All of the seven passenger windows on the bus' left side were broken out. Ten passengers were reportedly ejected out the left side windows and windshield area. One ejected passenger was found near the impact area beneath the rock and dirt cut slope; she died at the scene. One other passenger also died. Of the 43 surviving occupants, 3 received critical injuries, 3 received serious injuries, 19 received moderate injuries, and 18 had only minor injuries.

A postcrash examination of the bus interior showed that 10 passenger seat armrests were fractured. These appeared to have failed when the right-side passengers were thrown to the left.

The bus was equipped with an air-mechanical S-cam brake system. The Safety Board found that two of the four primary service brakes were past the manufacturer's recommended limit of adjustment and two were at the limit. One of the brakes at the adjustment limit had grease contaminated linings. These adjustments produced a calculated braking efficiency of 0.38. A computer analysis of the brake temperature profile revealed that adequate braking would have been possible with properly adjusted brakes.

Southwest Charter Lines (SWCL) began interstate charter operations in 1986. They had safety review audits conducted by the Office of Motor Carrier Safety (OMC) in 1986, 1987, and 1988. In these Safety audits, the SWCL was charged with 1,698 violations of the Federal Motor Carrier Safety Regulations (FMSCR) and paid $11,650 in civil penalties. After the accident, in 1990, OMC audited SWCL again. OMC found an additional 493 violations of the the FMSCR and assessed additional penalties. However, OMC gave SWCL a "conditional" safety rating and allowed them to keep their operating authority.

**Probable Cause**

The National Transportation Safety Board determines that the probable cause of this accident was the loss of braking capability that resulted from poorly maintained brakes and the driver's selection of an improper gear to descend the grade.

## CASE SUMMARY 14

**Investigation No.**: SEA-90-H-TB07
**Accident Location**: I-45, 4 miles south of Huntsville, TX
**Lanes:** 4 lanes, divided
**Shoulders:** Right - 10 feet asphalt
Left - 5 feet asphalt
**Median:** Grass, 33 feet wide
**Features:** Straight, 1.3-percent downgrade
**Date and Time**: May 18, 1990, 5:55 p.m.
**Ambient Conditions**: Daylight, rain, warm
**Heavy Vehicle Involved**: 1983 Mack cab-over-engine in combination with an empty 45-foot flatbed trailer
**Motor Carrier**: Red Eye Express, Incorporated
**Type of Operation**: Interstate, contract carrier
**Size of Operation**: 7 power units
**Total Weight of Vehicle**: 27,590 pounds
**Total Length of Vehicle**: 56 feet
**Other Vehicle Involved**: 1988 Ford pickup
**Truck Fatalities**: 0 **Truck Injuries**: 1
**Other Fatalities**: 1 **Other Injuries**: 0

**Summary**

The accident occurred as the empty tractor trailer combination was southbound on Interstate 45 during a light to moderate rainfall. The truckdriver was returning to Houston from Arlington, Texas, on a roundtrip that began at 4 a.m. He had driven about 420 miles, and had 70 miles remaining to the terminal. The truckdriver stated he was in the right lane when the low air warning buzzer came on and the tractor started sliding to the right. The driver tried to regain control of the combination, but it slid left into the grass median and continued into the northbound lanes where it struck a Ford pickup truck. Both vehicles came to rest off the east side of the northbound lanes with the combination unit in a left-hand jackknife.

The unrestrained truckdriver was treated at a local hospital for minor injuries. A blood sample revealed 0.1 milligram per liter (100 ng/ml) of benzoylecgonine, a cocaine metabolite, in the specimen. The driver said he had taken 1 tablet of codeine about 8 hours before the accident. The driver of the pickup truck, restrained by a lap and shoulder belt, was pronounced dead at the scene.

The tractor was destroyed during the collision; the cab was torn off of the chassis. In addition, the fuel tank on the right side was knocked loose, the steering axle was shifted, an S-cam on the right front brake was bent, and air lines between the cab and chassis were severed. The flatbed trailer was undamaged. The Ford pickup was destroyed, with major intrusion into the driver's compartment.

The truckdriver stated that he had driven heavy trucks since he was 16 although he never had any formal training. He did not have a current DOT Physical Examination Certificate. According to a 3-year driving record history from the State of Texas, he possessed a valid Class A license entitling him to drive combination vehicles. During this 3-year period, he was issued a citation for speeding and had two commercial vehicle accidents.

The tractor was equipped with an air-mechanical brake system with Type 20 air chambers on the steering axle, Type 30 springbrakes on the first drive axle, and Type 24 springbrakes on the second drive axle. Type 30 air chambers with springbrakes were installed on both trailer axles. Two brakes were past the manufacturer's recommended limit of adjustment, two were at the limit, and one could not be checked because of damage. Four air leaks were discovered during the testing. There was a small hole in the bottom of the primary reservoir, a cracked nut at an inlet fitting to the secondary reservoir, a leak in the emergency line serving the right drive axle springbrake, and a dry rot crack in the emergency line near the entrance to the right rear axle spring brake on the trailer. Investigators conducted three air bleed-down tests, and the system went from 85 psi to zero psi in about 5 minutes. About 1.25 gallons of water and grease were drained from the air system supply tank (wet tank). The braking efficiency was calculated at 0.82.

The driver was employed by Clark Transportation but was on temporary loan to Red Eye Express. Red Eye did not have a maintenance facility, instead relying on several local garages located next to Clark Transportation for repairs and servicing. Both carriers had equipment on long-term lease to Ligon Nationwide. The 1983 Mack tractor was on long-term lease to Ligon Nationwide and was to be used to haul only Ligon obtained shipments. The accident trip was an unauthorized load for which Ligon was not notified by Red Eye Express. The driver was not on the list of Ligon-approved drivers, all of whom were required to go to the Ligon headquarters for training.

The owner of Clark Transportation told the Safety Board investigator that there was a driver file on the accident driver, but none was produced. He also stated that the driver had a current DOT Physical Examination, although the driver stated he did not. The driver also related that he was not keeping a Driver's Daily Log to record hours of service.

**Probable Cause**

The National Transportation Safety Board determines that the probable cause of this accident was the driver's loss of control of the combination vehicle. This loss of control was caused by an emergency application of the springbrakes on the trailer wheels resulting from a depletion of air in the brake system. Contributing were poor air system maintenance, poor carrier oversight, and the driver's decision to continue to drive with a known deficiency in the airbrake system.

## CASE SUMMARY 15

**Investigation No.:** MKC-90-F-H011
**Accident Location:** I-40 westbound exit ramp to State Highway 9, outside Morrilton, AR
**Lanes:** One lane, concrete
**Shoulders:** Right - 5 feet asphalt
Left - 5 feet asphalt
**Median:** None
**Features:** Straight, 2-percent downgrade for exit ramp;
straight, 5-percent downgrade for northbound SH 9
**Date and Time:** July 24, 1990, 7:10 p.m.
**Ambient Conditions:** Clear, daylight, dry, and 79°F
**Heavy Vehicle Involved:** 1972 Motor Coach Industries
**Motor Carrier:** Big Eye Tour Lines, Inc.
**Type of Operation:** Interstate, charter bus
**Size of Operation:** Three buses
**Total Weight of Vehicle:** Approximately 36,500 pounds
**Total Length of Vehicle:** 40 feet
**Other Vehicle Involved:** 1979 Ford 9000 Conventional tractor in combination with a partially loaded flatbed trailer
**Truck Fatalities:** 1 **Case Vehicle Injuries:** 12
**Other Fatalities:** 0 **Other Injuries:** 1

**Summary**

A Motor Coach Industries MC-7 43-passenger coach bus was traveling west on Interstate 40 when the driver took the exit for State Highway 9. Passengers stated that as the bus proceeded down the exit ramp, it slowed some and then passed through the stop sign into the northbound traffic lane of State Highway 9. Upon entering Highway 9, the bus struck the right side of a northbound Ford tractor pulling a flatbed trailer. After the collision, the bus and the tractor trailer traveled across the centerline of State Highway 9, and the combination jackknifed around the front of the bus. The bus came to rest with the left front in the southbound traffic lane of Highway 9 and the back across the northbound lane.

The unrestrained busdriver was fatally injured. Of the 40 passengers, 1 was admitted to a hospital, 12 were treated and released, and 28 either refused treatment or were not injured. The unrestrained truckdriver was treated at the hospital and released.

Damage to the bus was confined to the front end, with damage intruding into the driver's area no more than 2 feet. The top portion of the bus was shifted 1.5 feet to the right. All damage to the tractor was on the right rear portions of the cab.

The bus was equipped with an air-mechanical S-cam brake system. Four of the five brakes that could be checked were found to be past the manufacturer's recommended adjustment limit; the fifth was at the limit. These adjustments contributed to the reduced braking efficiency of 0.65. The trailing tag axle on the bus was equipped with a valve limiting the application air to 35 psi. The bus owner, who also shared driving responsibilities, related that he was unaware the brakes needed periodic ajustment.

About 2 months before the accident, a private garage had installed brake shoes on both the steering and drive axles with mismatched friction codes on the drive axle. The bus had been driven 11,406 miles since the brake shoes had been installed.

In July 1990, the Office of Motor Carriers (OMC) conducted a Safety/Compliance Review on the bus company. OMC determined that the motor carrier was unaware of any Federal Motor Carrier Safety Regulations and believed that he only had to be registered with the Interstate Commerce Commission.

According to the owner of the bus, the busdriver had been picked up the day before the accident at 7:30 p.m. in Melbourne, Florida. Two sets of logs found in the bus were used to record the owner's driving with one showing the owner driving the night before the accident. No logs were found for either the driver or the owner the day of the accident. The trip from Tampa, Florida, to the accident (817 miles) took about 19 hours, and passengers reported that the owner and the driver alternated driving responsibilities. A passenger reported that while the owner was driving in Memphis, he steered the bus into a left turn lane to avoid hitting a vehicle that had stopped in front of him for a traffic light.

The driver of the bus had worked part-time for the carrier for about 2 months. The driver possessed a valid chauffeur's license but had no medical card. He had received formal truckdriver training at Miami Lake Vocational School and his driving record showed no violations or accidents in the 3 years before the accident

**Probable Cause**

The National Transportation Safety Board determines that the probable cause of this accident was the busdriver's failure to stop at the stop sign for unknown reasons. Contributing to the accident was the bus' lack of braking capability and the carrier's lack of a proper preventative maintenance program.

## CASE SUMMARY 16

**Investigation No.**: FTW-90-F-H005
**Accident Location**: U.S. Highway 67 at Missouri Route CC, near Festus, MO
**Lanes:** Four lanes, divided highway
**Shoulders:** Right - 10 feet asphalt
Left - 10 feet asphalt
**Median:** Earthen
**Features:** 4-percent upgrade
**Date and Time**: September 6, 1990, 7:25 a.m.
**Ambient Conditions**: Daylight, clear, dry, 75 $^{O}$F
**Heavy Vehicle Involved**: 1982 Mack truck tractor pulling an empty 40-foot dump trailer
**Motor Carrier**: Bross Trucking, Inc.
**Type of Operation**: Interstate, common carrier
**Size of Operation**: 46 power units
**Total Weight of Vehicle**: 29,400 pounds
**Total Length of Vehicle**: 55 feet
**Other Vehicle Involved**: 1974 Chevrolet C60 school bus with a Thomas-built body
**Truck Fatalities**: 0 **Truck Injuries:** 1
**Others Fatalities:** 1 **Others Injuries**: 12

**Summary**

About 7:25 a.m. on September 6, 1990, a 1974 Chevrolet C60, 66-passenger, Thomas-body school bus, carrying 12 children ages 5-17, was stopped westbound at the red traffic signal on Missouri Route CC at U.S. Highway 67 near Festus, Missouri. When the signal turned green, the school bus traveled approximately 55 feet into the intersection and was struck on the left rear side by a Mack combination unit traveling north. Witnesses estimated that the truckdriver was traveling approximately 45 mph when he ran the red light and struck the school bus. The truckdriver stated that he was traveling approximately 55 mph when a bee stung him on the right leg and distracted him, causing him to run the red light. The Mack combination unit skidded approximately 116 feet before hitting the bus and 36 feet after. The school bus left the impact area at a 25-degree angle and rotated counterclockwise approximately 120 degrees around its vertical axis. From the impact area, the school bus traveled another 62 feet to its final position.

A 7-year-old boy seated in the back left row was killed at impact. A 7-year-old boy seated in the back right row received critical injuries, and a 10-year-old girl seated on the right side of the bus three rows from the rear received serious injuries. The remaining nine students and both drivers received minor injuries.

A postcrash inspection of the Mack combination unit showed that 1 of the 10 S-cam brakes were past the manufacturer's recommended limit of adjustment and 2 were at the limit. The right front brake lining was saturated with grease, and the left side forward axle brake on the semitrailer had a ruptured diaphragm with an excessive air leak. The braking efficiency was calculated at 0.88.

According to 49 CFR Part 393, all these brake system deficiencies were out-of-service violations. However, commercial vehicle inspectors listed an inoperative low air warning light as the only out-of-service brake system deficiency. In addition, the inspectors misidentified five of the six air chamber sizes on the Mack tractor.

Traffic signal timing sequences provided by the Missouri Highway and Transportation Department and confirmed by the Safety Board showed that the yellow caution signal for through traffic on U.S. Highway 67 was 4.5 seconds. As an added safety feature, the signal for traffic on Missouri Route CC remained red for 2 seconds after the signal on U.S. 67 turned red to allow the traffic on U.S. 67 to clear the intersection. This provided a total of 6.5 seconds to avoid conflict. However, evaluation of the 55 mph limit on the intersection approach indicated that the yellow caution signal should have been 5 seconds and the total time needed to avoid conflict was 6.79 seconds. Additionally, it was found that the green signal light for Missouri Route CC lasted only 8 seconds. The busdriver complained that the green light did not last long enough to make it across the divided highway. She added that if the bus had been the second vehicle in line at the signal, the light would have turned red before she could have cleared the intersection.

Acceleration tests with a similar school bus showed that it took approximately 5.2 seconds to reach the impact area from the stop line. A time-distance analysis showed that it took the truckdriver 4.3 seconds to slow from his initial approach speed to the impact area. From this it can be concluded that the truckdriver did not begin braking until the traffic signal light was red for at least 1 second.

A postcrash inspection of the Thomas-body school bus showed that at a point 87.5 inches before the rear of the bus and 64 inches in from the left side, the floor joints failed, leaving a 35-inch long split in the floor across the aisle between rows 8 and 9. The separation reached 3 inches at its widest point.

**Probable Cause**

The National Transportation Safety Board determines that the probable cause of this accident was the failure of the truckdriver to stop for the traffic light for unknown reasons. Contributing to the severity of the accident were the misadjusted brakes.

## CASE SUMMARY 17

**Investigation No.:** CRH-91-H-TB05
**Accident Location:** S.R. 18 in Maple Valley, WA
**Lanes:** Two lanes, undivided
**Shoulders:** Right - 4.7 feet asphalt
Left - 6 feet asphalt
**Median:** None
**Features:** Curving, 4-percent downgrade
**Date and Time:** November 11, 1990, 7:00 a.m.
**Ambient Conditions:** Daylight, dry roadway, overcast, 45 $^{O}$F
**Heavy Vehicle Involved:** 1986 Freightliner COE in combination with two loaded flatbed trailers
**Motor Carrier:** Strohs Ltd.
**Type of Operation:** Intrastate, private carrier
**Size of Operation:** 3 power units
**Total Weight of Vehicle:** 92,925 pounds
**Total Length of Vehicle:** 80 feet, 5 inches
**Other Vehicle Involved:** 1984 Toyota X-tra Cab pickup and Nissan pickup
**Truck Fatalities:** 0 **Case Vehicle Injuries:** 0
**Other Fatalities:** 1 **Other Injuries:** 0

**Summary**

The driver of the combination vehicle was traveling westbound on State Route 18 at a witness-estimated speed of between 55 and 60 mph. He was on a 4-percent downgrade and had just entered a 1,910- foot-radius curve to the left. The truckdriver reported that while he was in the 1,570-foot-long curve, a small eastbound passenger vehicle crossed the centerline into his lane. He stated that when he swerved to the right to miss the car, his rear trailer turned over onto its right side, spilling its load of hay. No witnesses reported seeing any vehicle cross into the hay truck's lane of travel. Another witness, who saw the trailer before it turned over, stated she saw the trailer move toward the guardrail first and then saw the hay come off.

About 220 feet of tiremarks were found in the westbound lane near the outside fogline. Following these marks were a few other short tire marks, followed by some gouges in the asphalt. The distance from the end of these gouges to the final resting place of the Toyota pickup was about 200 feet. A witness reported that the Toyota was slowing down and pulling over to the side of the road, attempting to get out of the way of the sliding trailer. The upside down trailer separated from the first trailer and slid down the roadway, crossing into the eastbound lane of travel. After striking the Toyota pickup, it continued another 215 feet before it came to rest against the front of a Nissan pickup. Both the combination driver and the Nissan pickup driver were uninjured; the driver of the Toyota was fatally injured. A blood sample from the combination driver proved negative when tested for alcohol.

Damage to the combination vehicle was confined to the rear of the second trailer. The trailer bed had numerous scratches, and the rearend protection bar was bent rearward as was the right side mud flap bracket. Investigators found abrasions on the right rear tire and rim. The Toyota was damaged from the left headlight rearward to about the steering column area and back to the left rear wheel. The right side of the rear bumper had a dent, and the sidewalls of the right side tires had some scuff marks.

The combination vehicle was equipped with an air-mechanical S-cam brake system and an automatic limiting valve. Three out of six brakes on the tractor were past the legal limit of adjustment; two out of six brakes on the trailers were past the limit and three were at the limit. A braking efficiency of 0.52 was calculated for the combination vehicle.

The time difference between the steering and drive axle for the brakes to reach 60 psi was 0.05 second. A 0.258-second difference was measured between the drive axles and the first trailer. Timing on the second trailer could not be measured. The threshold pressures for all of the brakes varied between 3.5 and 15 psi. The steer axle averaged 13.5 psi, the drive axles 8.5 psi, the first trailer 3.75 psi, and the last trailer 10.5 psi.

The coupling between the first and second trailer had a manually activated hitch latch that could be operated by hand and an air-activated locking latch that would engage when the air was turned on to the second trailer. No scratches or gouges were found on the drawbar eye, and only one safety chain was present. The bracket on the rear of the first trailer where the safety chain had been attached was broken.

The Washington Utilities and Transportation Commission (WUTC) audited the carrier in December 1989 and found several economic violations. WUTC records also indicated that the carrier had been involved in seven accidents over the past 3 years.

The driver of the combination vehicle possessed a valid combination-endorsed driver's license and a current medical certificate. In the 3 years before the accident, his driving record showed six traffic violations, all of which were moving violations. His record showed no accidents. He had been working for the carrier for 2 1/2 years.

**Probable Cause**

The National Transportation Safety Board determines that the probable cause of this accident was that the combination driver quickly swerved the vehicle to the right, causing the initial instability of his rear trailer. Contributing to the severity of the accident was that the combination driver failed to properly secure his air locking device on the pintle hook connection and that out-of-adjustment brakes resulted in reduced braking capability.

## CASE SUMMARY 18

**Investigation No.**: NRH-91-H-TB03
**Accident Location**: I-5, 10 miles south of Seattle, WA
**Lanes**: Eight lanes, divided
**Shoulders**: Right - 10 feet asphalt
Left - 8 feet asphalt
**Median**: 18 feet, asphalt, with a concrete median barrier
**Features**: Straight, 4-percent downgrade
**Date and Time**: November 19, 1990, 12:10 p.m.
**Ambient Conditions**: Daylight, light rain, 44 °F
**Heavy Vehicle Involved**: 1977 GMC conventional tractor in combination with a 41-foot, two-axle lowboy trailer hauling three forklifts
**Motor Carrier**: Hyster Sales Company
**Type of Operation**: Intrastate, private carrier
**Size of Operation**: Four power units
**Total Weight of Vehicle**: 66,500 pounds
**Total Length of Vehicle**: 54 feet, 2 inches
**Other Vehicle Involved**: None
**Truck Fatalities**: 1 **Truck Injuries**: 0
**Other Fatalities**: 0 **Other Injuries**: 0

**Summary**

The combination unit, traveling south on Interstate 5 in the outside lane during a light rain, was on a local trip that originated about 3 miles from the accident site. Witnesses reported that the tractor jackknifed after rounding a sweeping curve to the right and struck the guardrail on the right side of the roadway. They further stated that the front of the tractor went over the guardrail, and the left side of the tractor struck a 18.5-inch-diameter steel support post. The vehicle continued south and came to rest in a right-hand jackknife position. Two witnesses believed they saw a car cut in front of the tractor just before the jackknife. During the accident, the front forklift broke loose and came to rest on the right shoulder, about 55 feet south of the combination unit. The middle forklift also came loose and was found partially off the right side of the trailer. The last forklift had shifted forward several feet.

The unbelted truckdriver was ejected during the collision and was found across the guardrail by the right side of the trailer. He sustained blunt trauma injuries to the head, trunk, and extremities and was pronounced dead at the scene.

The tractor was destroyed during the collision. The tractor's left front was heavily damaged about 1 foot into the driver's compartment near the "A" pillar. All the damaged portions on the left side of the cab were pushed forward. The front axle was displaced during the collision. The right fuel tank had been dented at an angle of about 15° and had a large cut toward the bottom that was about 8 inches long. The hydraulic tilt trailer was undamaged during the collision.

The carrier was primarily engaged in selling, renting, and servicing forklifts. The carrier relied heavily upon the drivers to report maintenance problems and perform preventative maintenance, including brake adjustments.

The tractor was equipped with an air-mechanical S-cam brake system with Type 9 brake chambers on the front axle and Type 30 springbrakes on both drive axles. The steering axle had an automatic limiting valve. Type 24 air chambers were installed on both trailer axles. Investigators measured brake pushrod travel on all 10 brake chambers and found 5 to be past the manufacturer's limit of adjustment and 2 at the limit. The Type 9 chambers on the steering axle were both within 1/4 inch of the adjustment limit. These adjustment levels produced a braking efficiency of 0.62.

Brake timing tests revealed that the time necessary for the brakes to release from 95 psi to 5 psi on the second drive axle averaged 1.54 seconds on the left side and 1.475 seconds on the right side. The FMVSS 121 standard for release time is 0.55 seconds for a tractor. All other timing tests fell within normal ranges.

The 50-year-old driver had been employed by the carrier for about 13 years. Most of this time he worked as a preventative maintenance mechanic, but he also drove heavy trucks. He had only driven a conventional tractor and hydraulic tilt-bed trailer combination for the past 6 months. He had a current Washington operator's license with a Class A endorsement permitting him to operate large combination vehicles. A 50-State record search revealed that he had only a Washington license. During the previous 3 years, he had one speeding citation and did not have any accidents.

**Probable Cause**

The National Transportation Safety Board determines that the probable cause of this accident was the truckdriver's loss of control of the truck. Contributing to the loss of control was a braking induced jackknife, which resulted from an unbalanced brake system caused by small front wheel brakes, trailer brakes out of adjustment, improper loading of the forklifts, and slow brake release timing of the second tractor drive axle.

## APPENDIX G

## PROBABLE CAUSE MATRIX

P = Primary Causal Factor
C = Contributing Causal Factor
S = Contributing to Severity

| CASE | Braking Capacity | Inadequate Maint. | Adjustment | Driver Inattention | Pavement Friction | Drugs/ Prescriptions | Driver Judgment | ALV | Other Mech. Defects | No/Small Front Brakes | Improper Loading |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Buna, TX | | C | P | C | | C | | | | | |
| Lyons, CO | P | C | C | | | | C | | | | |
| Aurora, CO | | | S | P | | | | | | | |
| Fort Worth, TX | P | C | C | | | | | | | | |
| Mercer Is., WA | P | P | C | | | | S | | C | | |
| Rochester, WA | | | | P | | | | | | C | |
| Phenix City, AL | | C | C | P | | | | | | | |
| Issaquah, WA | | | | P | | | | C | | | |
| Cumberland, MD | P | | C | | | | C | | | | |
| Kent, WA | P | C | C | | | | | | | | |
| Brownsville, TX | | C | P | | P | | | | | | |
| Seattle(1), WA | C | C | C | | | | | | P | | |
| Big Pine, CA | P | C | C | | | | P | | | | |
| Huntsville, TX | | C | | | | | C | | P | | |
| Morrilton, AR | C | C | C | | | | | | | | |
| Festus, MO | | | S | | | | | | | | |
| Maple Valley, WA | | S | S | | | | | | S | | |
| Seattle(2), WA | | C | C | | | | | | | P | P |

# APPENDIX H
# HEAVY TRUCK INVESTIGATION DATA COLLECTION FORM
# FIVE-AXLE TRUCK BRAKE INSPECTION

| | | | |
|---|---|---|---|
| Location: | Route: | Date: | Inspec No: |
| Carrier: | | | |
| Inter/Intra: | Type: | | Size: |
| ICC/MC: | US DOT: | | CVSA Date: |
| Origin: | Destination: | | Distance: |
| Driver Resp for Adj: | Phone: | | Haz Mat: |
| | Jake: | | FHWA: |
| Trctr Yr: | Trctr Make: | Cab Type. | State Reg: |
| Steering: | Limit Valve: | Owned by: | Leased: |
| Trctr VIN: | | Tractor Tag: | |

**TRACTOR BRAKE COMPONENTS** (2DR = 2nd axle, driver, right side)

| Man/Auto | Slack Length | Manuf | Chamber Size | Stroke | Inop: |
|---|---|---|---|---|---|
| 1SL ST: | 1SL SL: | 1SL SM: | 1SL CS: | 1SL S: | 1L IO: |
| 1SR ST: | 1SR SL: | 1SR SM: | 1SR CS: | 1SR S: | 1R IO: |
| 2DL ST: | 2DL SL: | 2DL SM: | 2DL CS: | 2DL S: | 2L IO: |
| 2DR ST: | 2DR SL: | 2DR SM: | 2DR CS: | 2DR S: | 2R IO: |
| 3DL ST: | 3DL SL: | 3DL SM: | 3DL CS: | 3DL S: | 3L IO: |
| 3DR ST: | 3DR SL: | 3DR SM: | 3DR CS: | 3DR S: | 3R IO: |

Ex Leak: Mod Leak: Minor Leak:

| | | | |
|---|---|---|---|
| Trlr Yr: | Trlr Make: | Trlr Type: | State Reg: |
| Tag No: | VIN: | Owned by: | Leased: |
| | FHWA: | | |
| Trlr2 Yr: | Trlr2 Make: | Trlr2 Type: | State Reg: |
| Tag No: | VIN: | Owned by: | Leased: |
| | FHWA: | | |

**TRAILER BRAKE COMPONENTS** (5TL = 5th axle, trailer axle, left side)

| Man/Auto | Slack Length | Manuf | Chamber Size | Stroke | Inop: |
|---|---|---|---|---|---|
| 4TL ST: | 4TL SL: | 4TL SM: | 4TL CS: | 4TL S: | 4L IO: |
| 4TR ST: | 4TR SL: | 4TR SM: | 4TR CS: | 4TR S: | 4R IO: |
| 5TL ST: | 5TL SL: | 5TL SM: | 5TL CS: | 5TL S: | 5L IO: |
| 5TR ST: | 5TR SL: | 5TR SM: | 5TR CS: | 5TR S: | 5R IO: |

| | | | |
|---|---|---|---|
| Ex Leak: | Mod Leak: Minor Leak: | | Brakes At/Past Limit: |
| Brake OOS Violations: | Other out of service: | | Truck Out of Service: |
| Actual Drag:. | Actual Eff: | 80K Drag:. | 80K Eff: |
| 400F Drag: | 400F Eff: | 400F Drag: | 400F Eff: |
| 600F Drag | 600F Eff | 600F Drag: | 600F Eff: |
| 900F Drag: | 900F Eff | 900F Drag: | 900F Eff: |
| TTL WGT: | STEER: | DRIVE: | TRAILER: |

APPENDIX I

910126 (Revised)

# Heavy Truck Deceleration Rates as a Function of Brake Adjustment

Ronald B. Heusser
National Transportation Safety Board
Seattle, WA

## ABSTRACT

When reconstructing a highway accident involving a heavy truck, an accurate deceleration rate is often an elusive piece of the puzzle. This paper presents a method for calculating the deceleration rate of a heavy truck equipped with an air-mechanical brake system. Traditionally a deceleration rate had been more an estimate of the percent of wheel lock-up based on the brake adjustment, and then proportioned to the loading on the axles. Engineers at the National Highway Traffic Safety Administration's (NHTSA) Vehicle Research and Test Center (VRTC) wrote equations for two configurations of brake chamber size and slack adjuster length to describe braking torque as it varies with pushrod stroke. These equations were developed by means of a regression analysis, to fit a curve to dynamometer data produced at the VRTC in East Liberty, Ohio. Once this braking torque is converted to a braking force, it can be compared to the braking force available at the tire/road interface. This comparison allows the reconstructionist to evaluate which wheels will lock and to calculate an accurate deceleration rate.

A commonly used brake sizing formula provides an alternative method to calculate braking force. Comparing the dynamometer data to results from the brake sizing equation, allowed the brake sizing equation to be modified to account for all variations of brake component configurations. Another set of equations also written at VRTC enabled the examination of increased pushrod stroke due to brake heating and drum expansion. When this temperature effect is combined with a mathematical model to predict brake temperature on downgrades, as developed through projects funded by the Federal Highway Administration (FHWA), a reliable deceleration rate can be calculated for a heavy truck descending a grade of variable length and slope.

Computed deceleration rates are compared to actual measured rates from stopping tests of tractor semi-trailers. These road tests provide validation for the discussed methods and demonstrate the expected range of accuracy.

## PAST METHODS FOR DETERMINING DECELERATION RATES

In the field of accident reconstruction, the deceleration rate of the vehicles involved in the accident is many times critical information, needed in order to perform an accurate analysis. This rate is normally a percentage of the actual tire/road sliding coefficient of friction. With the advent of portable electrical decelerometers, the sliding coefficient of friction for the tire/road surface of a passenger vehicle can be determined with a fairly high degree of accuracy. Prior to the availability of the decelerometer, the reconstructionist resorted to using test stops, measuring the distance with a bumper gun and the speed with radar, or a drag sled, in order to determine the tire/road sliding coefficient of friction. Yet this coefficient of friction can only be used for reconstruction purposes if it has been determined that all of the wheels were locked during the phase of dynamics of interest. If none of the wheels were locked, and there was no braking, then another deceleration rate is routinely used to represent the braking of the engine and

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the rolling resistance. It has proven difficult to place a value on any level of braking in between the two extremes of total lock-up and no braking.

This problem is greatly compounded when a tractor semi-trailer is involved. A typical tractor semi-trailer has five axles with a total of ten brakes. Each of these brakes could either be locking its respective wheel, providing no braking at all, or slowing its wheel at any level between those extremes. Most reconstructionists attempt to make an educated guess at the percent of wheel lockup, or the level of deceleration based on the tire marks on the roadway and the adjustment of the brake in question. Even if the braking torque curves for the various size of brake chambers are studied, the actual amount of braking force or the percent of wheel lock-up is usually a best guess situation.

Once the percentages of lock-up are determined, they are proportioned based upon the percent of weight on each of the wheels. The resulting figures can then be combined to provide a final deceleration value for the vehicle in question. This is not a precise method, but is all that has been available, until some dynamometer tests were performed by the National Highway Traffic Safety Administration's (NHTSA) engineers at their Vehicle Research and Test Center (VRTC) in East Liberty, Ohio. Two regression equations were developed which describe the braking torque for a 20 square-inch air chamber (type 20) with a 5.5 inch slack adjuster, and for a 30 square-inch air chamber (type 30) with a 6.0 inch slack adjuster, both at various levels of adjustment. All of these tests were run at 60 mph using a fully loaded brake, well burnished linings, and components meeting original equipment specifications.

The braking torque from these equations is easily converted to braking force at the tire/road interface, which leads directly to the deceleration rate for the vehicle. This deceleration rate is essential in the process of any time distance calculations. Often a reconstructionist would like to calculate how long it would take a specific tractor-trailer to stop once the driver perceives a certain danger, given the vehicle's brake components and adjustments. There are various other scenarios which may require analysis. How much quicker could the vehicle have stopped had the brakes all been in proper adjustment? Would the loading on the trailer or lack of loading affect the stopping distance? Would changing the size of the braking components improve the braking capability of the vehicle?

Computer programs are available which model tractor-trailer dynamics and require braking forces to be input for each brake, or at least for each axle. Without some proven method for determining these forces, the computer simulation is limited to the accuracy of the method used to determine the braking forces needed.

## REGRESSION EQUATIONS

DEVELOPED BY THE VEHICLE RESEARCH AND TEST CENTER - A dynamometer was set up at the Vehicle Research and Test Center in East Liberty, Ohio to measure the braking torque provided by two configurations of an air-mechanical s-cam braking system. One was a type 20 chamber with a 5.5 inch slack adjuster attached to the pushrod, and the other was a type 30 chamber using a 6.0 inch slack adjuster. The braking torque was measured for various levels of adjustment on each of the braking configurations. This data was then examined by means of regression analysis to find the best curve fit for the data produced. The curve for the type 20 chamber with a 5.5 inch slack adjuster was described by the following equation:

$$T = 972.268 + 308{,}494.062\,S - 444{,}318.844\,S^2 + 253{,}803.031\,S^3 - 50{,}824.195\,S^4 \quad (1)$$

where T equals the braking torque in inch-pounds and S represents the measured pushrod stroke in inches.

The type 30 chamber with a 6.0 inch slack adjuster provided data for the following curve:

$$T = 3{,}051.859 + 439{,}201.5\,S - 539{,}363.75\,S^2 + 263{,}331.812\,S^3 - 45{,}535.129\,S^4 \quad (2)$$

These equations were used as the basis for developing the method outlined in this paper for calculating the deceleration rates of heavy vehicles with an air brake system. The engineers at VRTC also measured the increase in the pushrod stroke as a function of time. These tests were performed at 60 mph. They found that the longer the brake was applied, the greater the stroke increased, due to the stretch and expansion of the components. This increase was described by the following equation:

$$I = 0.05 + (0.034 \times T) \tag{3}$$

where I represents the increase of the pushrod stroke in inches and T is the time which the brake was applied in seconds. The VRTC engineers stated that the "0.05 factor in the equation is an increase in stroke (measured on the dynamometer and on vehicles) from static to dynamic. The 0.034 factor is an increase in the stroke due to heating and expansion of the drum throughout the stop." (1)[1] For speeds lower than the 60 mph testing speed, care should be exercised in the use of Eq (3). The static or cold stroke is measured by applying air to the brake chamber while the brake drum is not rotating. When the brake drum is rotating, and the pushrod stroke is measured during a brake application, this is referred to as a dynamic stroke.

TORQUE FACTORS FOR DIFFERING SLACK ADJUSTERS LENGTHS - The two regression equations provide a means to calculate braking torque in a more exact manner, but are only valid for two specific sets of brake configurations. These equations represented a base for the type 20 chamber with a 5.5 inch slack adjuster on a 15 inch diameter drum and the type 30 chamber with a 6.0 inch slack adjuster on a 16.5 inch drum. It appeared that the torque values which these equations produced could be adjusted to reflect the various available lengths of slack adjusters. Almost all slack adjusters are equipped with attachment holes, typically spaced one-half inch apart, where the pushrod is pinned. Therefore, it seemed reasonable that the torque produced from other slack adjuster lengths could be adjusted from the values calculated from the base length for each of the two slack lengths used in the dynamometer work. For instance, using the 5.5 inch slack adjuster on the type 20 chamber, an increase or decrease of 0.5 inch in length would change the torque by a factor of 0.091. Adjusting the value of torque calculated for a specific adjustment from the 5.5 inch slack adjuster on the type 20 chamber to a 6.5 inch slack adjuster would require the calculated torque to be increased by 18.2 percent. The factors needed to adjust each of the torque values produced by the two regression equations are shown in Table A for the various lengths of slack adjusters.

| Type 20 | | Type 30 | |
|---|---|---|---|
| Length | Factor | Length | Factor |
| 5.00 | 0.909 | 5.00 | 0.833 |
| 5.50 | 1.000 | 5.50 | 0.917 |
| 6.00 | 1.091 | 6.00 | 1.000 |
| 6.50 | 1.182 | 6.50 | 1.083 |
| 7.00 | 1.27 | 7.00 | 1.167 |

Table A - Torque Adjustment factors for various lengths of slack adjusters.

## MODIFIED BRAKE SIZING EQUATION

CHAMBER SIZES NOT COVERED IN REGRESSION ANALYSIS - Since the work done by the VRTC engineers only covered the type 20 and type 30 size air chambers, a void was left for calculating braking forces for all of the other chamber sizes found on heavy trucks. There was also a need to be able to calculate the braking forces produced by wedge brakes. A frequently used brake sizing formula (2) was modified in an attempt to meet this need. The following is the rearranged traditional "AL Factor" formula, which was used to calculate the braking forces in pounds (BForce) produced by the s-cam brake:

$$BForce = \frac{SLev \times PRForce \times SLength \times LinF \times DRad}{CamRad \times TireRad} \tag{4}$$

The shoe leverage (SLev) is normally 2, and it was decided to use a generic value of 0.35 for the lining-to-drum coefficient of friction (LinF). Even if the edge codes could be read from the linings, or the owner of the vehicle knew what type of lining was on his trucks, it was decided to use the 0.35 value, since there is such a great variation in lining friction values. If one of the linings was found to be contaminated with grease, this friction value could be adjusted in an attempt to account for the degraded condition. The length of the slack adjuster (SLength) can be simply measured, and the drum radii (DRad) are standard sizes. No

[1] Numbers in parenthesis indicate references listed at end of paper

attempt was made to factor in the wear on the drum, or to increase this drum radius if the drum was oversized. The effective cam radius (CamRad) is 0.5 inch, though Mack Trucks used a cam with a radius of 0.578 inch back in the late 60's and early 70's. Measurements can be made to obtain the rolling radius of the tires (TireRad), or these values can be looked up in a tire-manufacturer's book, based on the size and inflation pressure. All lengths are measured in inches and the forces calculated are in pounds.

The last value needed in the above equation is the pushrod force (PRForce). This was normally the product of the chamber area times the applied air pressure. Thus, for a type 30 air chamber with 100 psi applied, the pushrod force would be 3,000 pounds. This is very idealistic and does not take into account the brake adjustment or other losses. Attempts to refine this approach utilized what was called the "effective area" of the chamber, which actually reduced the chamber size by some factor, but still did not include any factor for the brake adjustment. Graphs for looking up the pushrod forces were developed by the Automotive Operations section of Rockwell International. Values were taken from these graphs and placed in the chart format found in the appendix. The chart for the type 24 long stroke air chamber is a result of the author combining the values from the type 24 and the type 30 charts. This resulting chart reflects the smaller chamber size of the type 24 and the longer stroke of the type 30. One can locate the chart for the chamber type of interest, and look up the pushrod force for the appropriate brake adjustment and application pressure.

In order to check the accuracy of the revised brake sizing formula, Eq (4), it was decided to check the values it produced with those of the regression equations. When the values from the brake sizing formula were compared to the dynamometer data, it was noted that Eq (4) was producing values near twice what was measured on the dynamometer. As a result, comparison calculations were made for both of the configurations which the regression equations represented, namely the type 20 chamber with the 5.5 inch slack adjuster and the type 30 chamber with the 6.0 inch slack adjuster. The result of the brake sizing equation is the braking force, which was multiplied by the tire rolling radius to obtain the braking torque. This was done so that both methods would be comparing the braking torque. The graphs comparing the two formulas are shown in Figures 1 and 2.

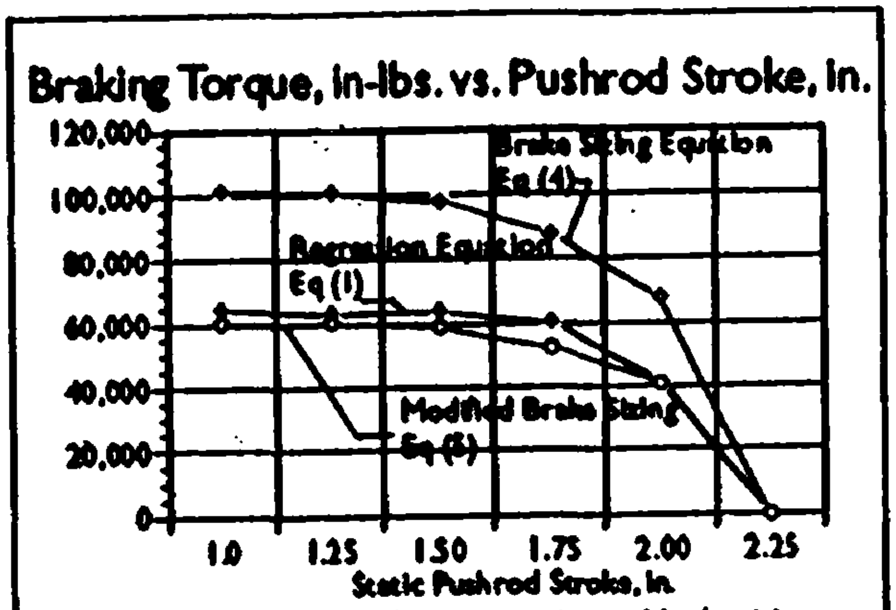


Figure 1 - Type 20 values from regression and brake sizing equations.

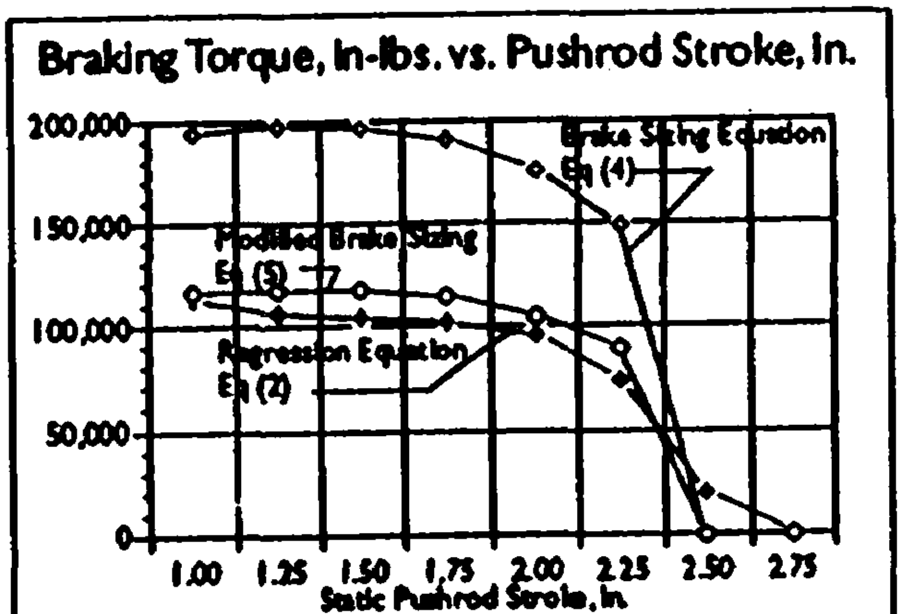


Figure 2 - Type 30 chamber values from regression and brake sizing equations.

As a result of the above analysis, it was decided to use the single adjustment factor of 0.6 to reduce the values produced by the brake sizing formula. A more accurate representation would be to use a 0.645 factor for the type 24 and smaller chambers and a factor of 0.543 for the type 30 and larger chambers. These factors were obtained by comparing the averages of the results from each method. If the results from the brake sizing equation are multiplied by the appropriate factor, the result will agree with the values produced by the regression equations. Yet using the 0.6 factor allows one equation to be used for all chamber sizes. The 0.6 factor is also plotted on the chart to show how it agrees with the data. This modified brake sizing equation is shown as Eq (5).

Validation tests with an actual tractor semi-trailer will be discussed later in the paper.

$$BForce = \left[\frac{2 \times PRForce \times SLength \times LinF \times DRad}{CamRad \times TireRad}\right] \times 0.6 \qquad (5)$$

**BRAKING FORCE FOR WEDGE BRAKES** - An attempt was made to apply the brake sizing equation, Eq (4), to a wedge brake system. The only changes which needed to be made to the brake sizing formula were to replace the slack adjuster length with the mechanical advantage of the wedge, and to eliminate the term for the radius of the cam. The mechanical advantage of the wedge is described by the following equation, where "W" equals the angle of the wedge in degrees:

$$MA = \frac{1}{\tan\left[\frac{W}{2}\right]} \qquad (6)$$

In order to evaluate the brake sizing equation for its accuracy at calculating braking forces on wedge brake systems, some measured data was needed for comparison purposes. A NHTSA report (3)dated April of 1985, recorded the braking forces produced on a 1977 International conventional three-axle tractor in five deceleration tests at varying application pressures. These forces were derived from a controlled speed change over a measured time. Enough data was found in the report and from contacting some of the parties involved to be able to use the brake sizing equation, and to calculate the braking forces. When the measured NHTSA data was compared to the calculated values, it was noted that the calculated values were significantly lower than what was measured. An adjustment factor was applied to the brake sizing equation in order to make the data agree, as shown in Eq (7). Once the application pressure was past the 40 psi level, the two methods appeared to begin to converge, so it was decided to focus on the upper level of air applications. As a result of this, a factor of 1.1 was used for the type 12 chamber and 1.3 was used for the type 9 chamber.

$$BForce = \left[\frac{2 \times PRForce \times SLength \times LinF \times DRad}{CamRad \times TireRad}\right] \times Factor \qquad (7)$$

A graph displaying the calculated braking values with their appropriate factors applied, compared to the measured NHTSA values is included in Figure 3.

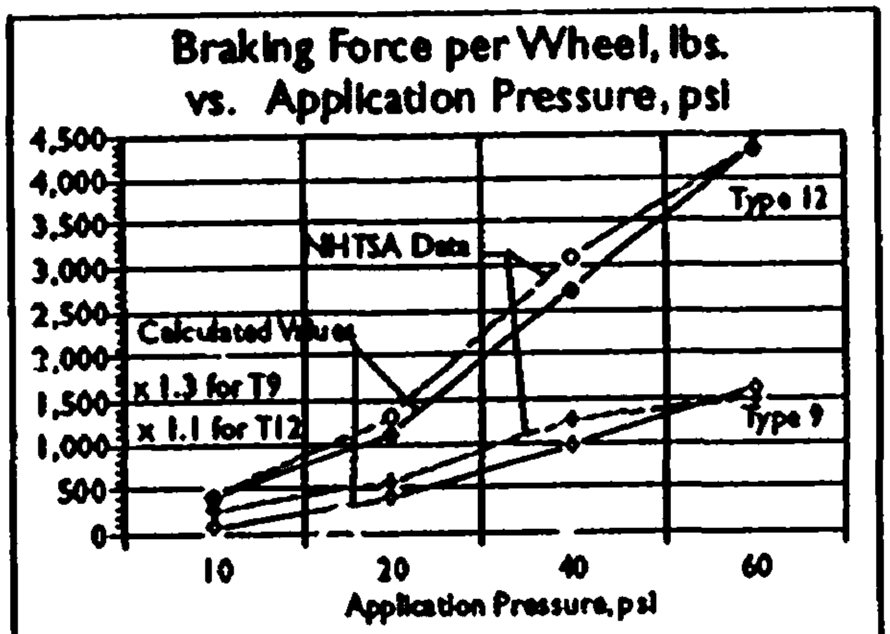


Figure 3 - Wedge brake force comparisons between NHTSA measurements and calculations.

In order to use the pushrod force charts for a wedge brake, the pushrod stroke would be needed. In most cases, this is not easy to determine. If there is a plug at the back center of the brake chamber, a rod sealed through a bushing can be installed into the back port, and the travel of the piston can be measured. If this port is not available, then the travel must be estimated by noting the unapplied gap between the lining and the drum. If the gap is less than 0.065 inch, then the brake is in adjustment and the pushrod travel is within the limits of adjustment for the appropriate size chamber. If the gap is greater than 0.065 inch, then the stroke is past the adjustment limit. When the stroke is selected in order to read the pushrod force from the charts, an estimate will need to be made to determine how much the brake is beyond adjustment, or how close it is to ideal adjustment.

## TEMPERATURE CONSIDERATIONS

**HEAT EFFECTS ON PUSHROD STROKE** - The engineers at NHTSA's Vehicle Research and Test Center also developed two other equations which describe the increase of pushrod stroke in inches, due to the drum expansion as a function of heat and adjustment.

NHTSA stated that the data used to develop these equations "was somewhat limited and the equation should be used with caution."(1) These equations were also written for the same two brake configurations as the regression equations. When the results from these equations were analyzed, it was found that the stroke began decreasing rather than continuing to increase as the stroke neared its maximum. The curves did not appear to accurately describe the stroke as it approached its maximum, so they were modified by the author to reflect a more realistic behavior. It should also be noted that the stroke input into the modified heat equations is the dynamic stroke calculated from Eq (3). Shown below are the original equations which the NHTSA engineers developed:

For the Type 20 chamber:

$$S = ColdS + [0.43 + 0.0007 \times (T-300)] - \left[\frac{ColdS}{2.6}\right]^4 \tag{8}$$

For the Type 30 chamber:

$$S = ColdS + [0.64 + 0.0006 \times (T-300)] - \left[\frac{ColdS}{2.6}\right]^4 \tag{9}$$

The data below show how these equations produced values which did not accurately reflect the actual situation of an increasing stroke until it reaches the maximum allowed by the chamber and the piston bottoms out.

| Stroke | Increase | Increased Stroke |
|---|---|---|
| 1.75 | 0.495 | 2.24 |
| 2.00 | 0.360 | 2.35 |
| 2.25 | 0.139 | 2.39 |
| 2.50 | -0.155 | 2.35 |
| 2.75 | -0.463 | 2.24 |

**Table B** - Type 30 chamber, 16.5 inch drum, 400°F, and initial equation results.

The modified equation for the type 30 chamber and 16.5 inch drum, is shown below followed by its resulting data:

$$S = ColdS + [0.64 + 0.0006 \times (T-300)] - \left[\frac{ColdS}{3.15}\right]^{2.8} \tag{10}$$

| Stroke | Increase | Increased Stroke |
|---|---|---|
| 1.75 | 0.507 | 2.26 |
| 2.00 | 0.420 | 2.42 |
| 2.25 | 0.310 | 2.56 |
| 2.50 | 0.176 | 2.68 |
| 2.75 | 0.051 | 2.75 |

**Table C** - Type 30 chamber, 16.5 inch drum, 400°F, and modified equation results.

| Stroke | Increase | Increased Stroke |
|---|---|---|
| 1.50 | 0.389 | 1.89 |
| 1.75 | 0.295 | 2.04 |
| 2.05 | 0.150 | 2.15 |
| 2.25 | -0.061 | 2.19 |
| 2.38 | -0.202 | 2.18 |
| 2.50 | -0.355 | 2.15 |

**Table D** - Type 20 chamber, 15 inch drum, 400°F, and initial equation results.

The modified equation for the type 20 chamber and 15 inch drum is shown below:

$$S = ColdS + [0.43 + 0.0007 \times (T-300)] - \left[\frac{ColdS}{3.15}\right]^{2.8} \tag{11}$$

| Stroke | Increase | Increased Stroke |
|---|---|---|
| 1.50 | 0.375 | 1.87 |
| 1.75 | 0.307 | 2.06 |
| 2.05 | 0.220 | 2.22 |
| 2.25 | 0.110 | 2.36 |
| 2.38 | 0.044 | 2.42 |
| 2.50 | -0.022 | 2.48 |

**Table E** - Type 20 chamber, 15 inch drum, 400°F, and modified equation results.

The modified equations above provided a means to calculate the effect of heat on both 15 inch drums and 16.5 inch drums for type 30 and type 20 chambers. Since a type 16 chamber has the same maximum stroke as a type 20, and is usually also mounted on a 15 inch drum, the equation for the type 20 configuration should be used to calculate the expanded stroke for the type 16 chamber. The type 12 and type 9 chambers were grouped together, since each has the same maximum stroke and is normally used with the 15 inch diameter drum. When the author changed one term in the equation it appeared to account for the shorter maximum stroke of these two chambers. The adjusted equation is shown below with some results calculated using two different temperatures:

$$S = ColdS + [0.30 + 0.0007 \times (T-300)] - \left[\frac{ColdS}{3.15}\right]^{2.8} \qquad (12)$$

| Stroke | Increase | Increased Stroke |
|---|---|---|
| 1.38 | 0.271 | 1.65 |
| 1.50 | 0.245 | 1.74 |
| 1.63 | 0.212 | 1.84 |
| 1.75 | 0.178 | 1.93 |
| 1.88 | 0.134 | 2.01 |
| 2.00 | 0.091 | 2.09 |

Table F - Type 9 and 12 chamber data at 400°F

| Stroke | Increase | Increased Stroke |
|---|---|---|
| 1.38 | 0.411 | 1.79 |
| 1.50 | 0.385 | 1.88 |
| 1.63 | 0.352 | 1.98 |
| 1.75 | 0.317 | 2.07 |
| 1.88 | 0.274 | 2.15 |
| 2.00 | 0.230 | 2.23 |

Table G - Type 9 and 12 chamber data at 600°F

The only chamber size not covered so far is the type 24. This chamber has both a long stroke model with a maximum stroke of 2.5 inches, and a regular stroke model whose maximum stroke of 2.25 is the same as the type 20. The following shows which equation to use when each of the type 24 chambers is configured with either commonly used drum size:

Type 24 long stroke 15 inch drum - not common - no equation.
Type 24 long stroke 16.5 inch drum - use type 30 equation - Eq (10).
Type 24 regular stroke 15 inch drum - use type 20 equation - Eq (11).
Type 24 regular stroke 16.5 inch drum - use Eq (13).

$$S = ColdS + [0.43 + 0.0006 \times (T-300)] - \left[\frac{ColdS}{3.15}\right]^{2.8} \qquad (13)$$

The equation above is simply a combination of the type 30 and type 20 modified equations. It incorporates terms for the maximum stroke for the type 20 chamber and the 16.5 inch drum used in the type 30 equation. Calculated values from Eq (13) are shown in Table H. No validation tests have been run on actual vehicles at controlled temperatures to check these equations. Therefore Eq (10) through (13) should be used with caution until such tests can be performed.

| Stroke | Increase | Increased Stroke |
|---|---|---|
| 1.38 | 0.391 | 1.77 |
| 1.50 | 0.365 | 1.86 |
| 1.63 | 0.332 | 1.96 |
| 1.75 | 0.297 | 2.05 |
| 2.00 | 0.210 | 2.21 |
| 2.25 | 0.100 | 2.35 |

Table H - Type 24 regular stroke chamber, 16.5 inch drum data at 400°F

**DETERMINING BRAKE TEMPERATURES** - In order to fully utilize the equations for predicting the increased stroke of the pushrod due to brake temperatures, a method for estimating these temperatures was needed. A project funded by the Federal Highways Administration (FHWA), developed the "Grade Severity Rating System", (GSRS) which was designed to assist highway engineers in signing grades in order to reduce the number of heavy truck runaways on steep downgrades.(4) The mathematical model utilizes the weight and speed of the truck, along with the percent of the downgrade and the length of the grade that the vehicle is braking, to determine the temperature of the brakes. The FHWA published their results in the form of an IBM PC or compatible computer program and a user's manual. One of the outputs from the program is a printout of the temperature of the brakes on the vehicle at every one-half mile interval. The original purpose for this work was to use the brake temperature estimates to determine a maximum safe speed for a truck of a specific weight grouping to traverse the downgrade. This information could be used by highway engineers to provide a recommended speed to traffic about to descend a steep grade. The signs could then display information for specific weights of trucks and the appropriate safe descent speed.

Though the intent of the original FHWA work was not oriented toward heavy truck accident reconstruction, it certainly has application for that discipline. The program does not allow the user to input the condition of the brakes, but assumes that all of the brakes are doing a proportional amount (by weight) of the deceleration. If only one-half of the brakes are operational, then those brakes working will heat up much faster on a specific grade when compared to a truck with all of the brakes in proper adjustment. The half that are in adjustment and are providing the retarding force would be doing something near twice as much work as they would if all of the brakes were operational. (This assumes that the brakes were capable of doing this much work.) In order to factor this into the GSRS program, the actual weight of the truck was adjusted to represent the increased work demanded of the brakes due to some being nonoperational. For instance, if half of the brakes, as proportioned by the loading on the axles, were not functioning, then the load could be doubled in order to represent the increased demand for the braking torque needed.

The University of Michigan Transportation Research Institute (UMTRI) in Ann Arbor has developed an IBM PC or compatible computer program which will also predict the temperature of brakes, based on a variety of input. This program is more versatile than the FHWA program since it does take into account the condition of the brakes and their adjustment.

If either of the above programs was used, a reconstructionist could accurately predict the brake temperature of a tractor-trailer on a specific downgrade. The resulting temperatures could be used to calculate the increased stroke of each pushrod. This would allow a examination of the vehicle's braking capability as it progressed down the hill.

## VALIDATION TESTS

**TEXAS A & M TESTS** - In June of 1990, the Washington Association of Technical Accident Investigators (W.A.T.A.I.), the Society of Accident Reconstructionists (S.O.A.R.), and the Texas Association of Accident Reconstruction Specialists (T.A.A.R.S.) gathered at the Texas A & M campus in College Station for seminars on various accident reconstruction topics and some testing. One of the tests consisted of stopping a tractor and semi-trailer with s-cam air brakes and monitoring the deceleration rate through various means at differing levels of brake adjustment. These measured deceleration rates were compared to calculated rates utilizing the methods presented in this paper.

A 1990 Cadillac was braked to a stop with all wheels locked on three different occasions from 48 and 49 mph to establish a sliding coefficient of friction between a passenger car tire and the paved surface used in the tests. Radar to record speed and a bumper gun to measure stopping distance were used which provided an average coefficient of friction of 0.68. A "G-Analyst" (a three-axis decelerometer) was mounted in the vehicle and was also used to measure the deceleration rate as all four wheels were locked. Taking the maximum reading from the G-Analyst, as previous W.A.T.A.I. testing (5) has indicated is accurate to normally 0.02 when compared to a radar and bumper gun tests, provided an average friction factor of 0.72. Another method for interpreting the G-Analyst data was to average all the values above the lowest value between the peaks on the plotted readout, as practiced by the California Highway Patrol Multidisciplinary Accident Investigation Teams. This method provided an average coefficient of friction for the three stops of 0.63. A Vericom VC-200, another decelerometer, was also mounted in the Cadillac, and the average of the three stops of this instrument's average values was 0.68. When the average values from all four methods are averaged, a sliding coefficient of friction for the Cadillac tire/road surface of 0.68 results. As this portion of the testing demonstrates, determining the tire/road sliding coefficient of friction for a passenger vehicle with all wheels locked is still a difficult task. Converting this value to an accurate sliding coefficient of friction for a truck tire is even more difficult.

A 1989 International cab-over-engine tractor in combination with a loaded 45 foot flatbed semi-trailer, with a total combined weight of 52,980 pounds, was used in the testing. The tractor semi-trailer was stopped with all of its brakes adjusted properly. Three tests were performed to evaluate its actual deceleration rate. Test 1 was done from 42 mph, test 2 from 50 mph, and test 3 from 49 mph. The various methods of measuring the deceleration and the values produced by each are listed in Table I with the average for each of the three methods.

| Test | CHP | Max G-Analyst | Radar |
|---|---|---|---|
| 1 | 0.58 | 0.61 | 0.50 |
| 2 | 0.56 | 0.58 | 0.56 |
| 3 | 0.56 | 0.63 | 0.53 |
| Avg | 0.57 | 0.61 | 0.53 |

Table I - Deceleration values for tractor-trailers with properly adjusted brakes.

The figures shown in Table I do not represent the actual sliding coefficient of friction for the truck tire/road interface, but the average deceleration rate for that particular combination vehicle with its brakes all adjusted. The tractor was configured with type 16 air chambers on the steering axle, which were not capable of locking the wheels. Thus the vehicle's braking system was not 100% efficient, and the tire/road coefficient of friction would be somewhat greater than the values measured on the G-Analyst or those calculated using the Radar/Bumper gun figures.

Other tests which W.A.T.A.I. has performed (6), have indicated that a heavy truck tire coefficient of friction on a road surface can be estimated by taking 85 to 90 percent of the sliding coefficient of friction of a passenger car locking all of its wheels on the same surface. When the average sliding coefficient of friction for the Cadillac stopping on the test surface (0.68) was reduced to 85 percent, the value for the truck tire computed to 0.58. This would be the actual deceleration rate of the combination vehicle if all of the wheels were locked. This also is the value which is needed to calculate the deceleration rate based on the level of brake adjustments.

Figure 4 compares calculated values, as generated by this paper's methodology, to three methods of empirical testing. The three methods were using the radar and bumper gun, the maximum G values from the G-Analyst, and the CHP technique of reading the G-Analyst. All of the methods evaluated the vehicle stopping with 1) all of the brakes in adjustment, 2) the brakes on the rear drive-axle of the tractor backed off, and 3) the brakes on the rear drive-axle and the rear trailer-axle backed off. The modified brake sizing equation, Eq (5), was used to calculate the braking forces for all of the brakes on the tractor and trailer.

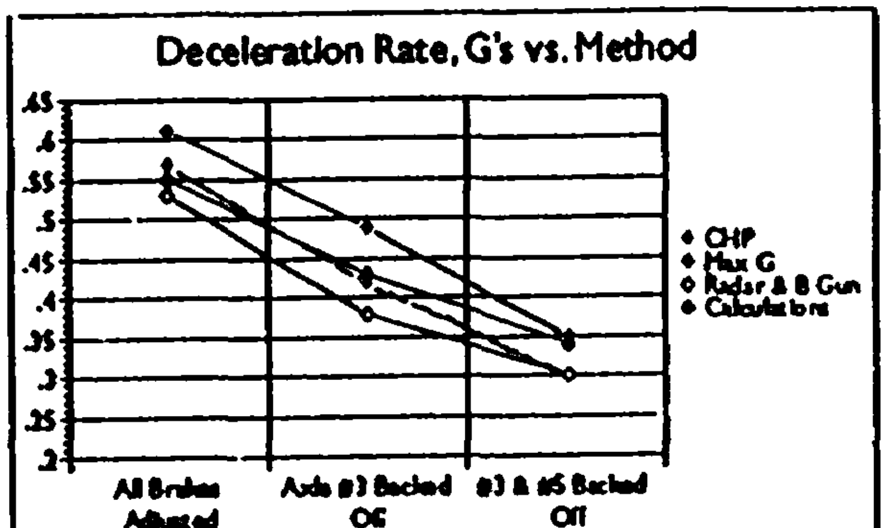


Figure 4 - Comparison of deceleration rates by measurement methods.

The deceleration rates calculated from the radar and bumper gun data were the lowest values, possibly because of the time involved in brake lag. When the treadle valve is first depressed, the bumper gun is triggered and the road surface is marked. It appears that the brake lag time would have to be taken into account in the distance traveled to stop. By figuring this as the stopping distance, it would provide a longer distance than the actual braking distance, and thus would lower the deceleration rate. The highest values were those which resulted from using the maximum value from the G-Analyst output. Even though W.A.T.A.I. tests indicated that this was accurate to 0.02g, it appears that it might be somewhat high. The method used by the California Highway Patrol falls in between the previous values and seems to be a reasonable approach. The values of deceleration calculated from Eq (5) fit nicely with the measured data, very close to right in the middle. No tests were done with the brakes heated, so no conclusions can be drawn concerning the validity of the heat adjusted stroke equations. Such tests could be the subject of future research.

NHTSA DATA - Braking distribution tests on a series of tractor and semi-trailer combinations were performed at the NHTSA's VRTC facility in East Liberty, Ohio and were documented in a report dated April 1985 (3). These tests were a part of a much larger project analyzing the stopping capability of air-braked vehicles. The braking forces on each axle of the vehicle were recorded as the application pressures were changed. A digital comparator/timer instrument was used with a fifth-wheel measuring system to measure the time increment for a five mph speed change during deceleration. Each axle was evaluated independently at an average speed of 40 mph. Parasitic drag was accounted for and subtracted from the resulting deceleration values. The lining temperatures were kept at a constant of 200°F, and five tests were performed on each axle, with the results averaged. The braking forces were calculated from the measured time of the deceleration and the total weight of the combination vehicle. This data provided another opportunity to check the validity of the methods presented in this paper. The NHTSA report included enough data to perform the calculations for determining the s-cam braking force at the varying application pressures using the modified brake sizing equation, Eq (5). Figure 5 is a plot of the NHTSA measured values of braking force compared to the calculated values from the modified brake sizing equation. These particular values are from a 1975 International tractor in combination with a 40 foot Trailmobile flatbed semi-trailer, with a combined weight of 81,000 lbs.

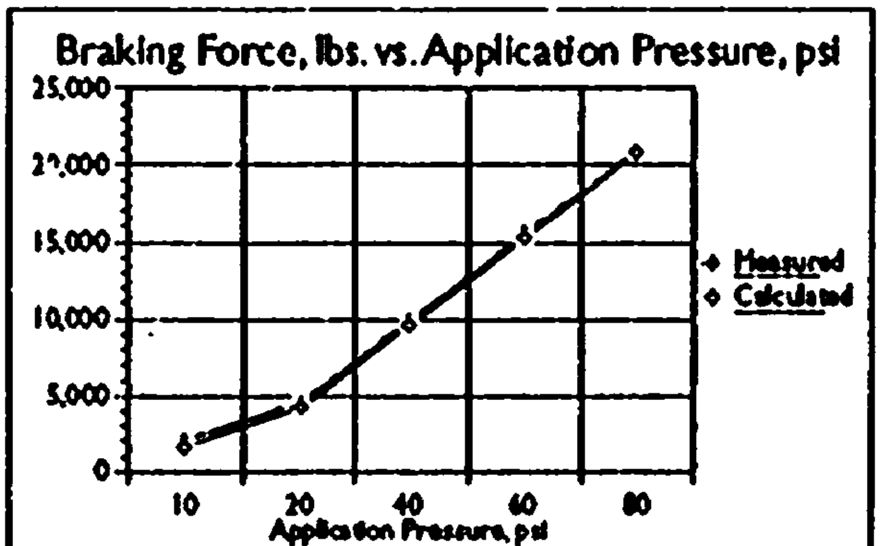

Figure 5 - Comparison of S-cam braking forces using calculations and NHTSA measurements.

## SUMMARY OF CALCULATION METHOD

1. DETERMINE THE TRUCK TIRE/ROAD COEFFICIENT OF FRICTION -- This can be done by a variety of approaches. One method, and perhaps the most common, would be to stop a passenger vehicle with all its wheels locked and determine its sliding coefficient of friction. This value should then be reduced to 85 percent of its value for the truck tire. The passenger car value could best be obtained by using one of the small decelerometers.

2. OBTAIN THE WEIGHT AT EACH OF THE WHEEL ENDS -- Towing the accident vehicle over a set of scales provides the most accurate method for finding these values. A set of portable scales also works well. Another method is to locate a weight ticket from the accident trip, if one is available. The last and least accurate procedure is to reconstruct the weight on each axle based on weights of the components and the placement of the load. Often, this method involves estimating the location of the centers of gravity, and may not be precise enough.

3. MULTIPLY THE TRUCK TIRE/ROAD SLIDING COEFFICIENT OF FRICTION TIMES THE STATIC WEIGHT ON EACH WHEEL TO OBTAIN THE AVAILABLE BRAKING FORCE -- These values would be the maximum braking forces available at each wheel if it were locked and skidding. These stopping tests were briefly analyzed for the effect of dynamic weight shift, using UMTRI's Phase 4 computerized model for a combination vehicle simulation. This analysis showed only 0.01g to 0.04g variation in the deceleration rate of the test vehicle due to dynamic weight shift. Therefore it was concluded that the weight shift should be considered only for tractors with short wheelbases or for loads with high centers of gravity.

4. DETERMINE AIR CHAMBER SIZE, SLACK ADJUSTER LENGTH, DRUM DIAMETER, AND ROLLING RADIUS -- All of these parameters are needed in order to calculate the braking forces for each of the wheels.

5. MEASURE THE PUSHROD STROKE AT 90 PSI -- Usually measuring the stroke to the nearest 1/8 of an inch will be accurate enough. Releasing the springbrakes with air, rather than using the caging bolts will provide a more accurate stroke. Applying the brakes by hand or using a pry bar will not provide acceptable precision. A portable air compressor can normally be used.

6. CONVERT THE MEASURED PUSHROD STROKE TO A DYNAMIC STROKE -- In order to calculate the dynamic stroke, the time which the brake was applied in the accident scenario must be known. This can be determined by estimating the speed which the accident vehicle was traveling, and then computing the time necessary to skid to a stop from that speed. A deceleration rate is needed in order to calculate this time, and using from 70 to 90 percent of the actual sliding coefficient of friction between the truck tire and the roadway is recommended. Once the time is known, it can be substituted into Eq (3) to find the increase in stroke from static to dynamic. For example, the difference in dynamic stroke between 70 and 90 percent of the coefficient of friction for a 60 mph stop on a 0.68 tire/road surface would be only 0.041 inch. When the actual deceleration rate for the vehicle is calculated, a new time to stop can be computed, and the increase in the dynamic stroke can be figured exactly if an adjustment is needed.

7. ADJUST THE DYNAMIC STROKE FOR HEAT EXPANSION IF THE TEMPERATURE OF THE BRAKES IS KNOWN -- Before the modified brake sizing equation is used, the pushrod stroke can be adjusted to account for any expansion due to hot brakes. This would be done using the appropriate equations, Eq (10) through (13), for the size of chamber under consideration. This must be done with caution, as there have been no validation tests run on actual vehicles.

8. CALCULATE THE ATTEMPTED BRAKING FORCE FOR THE APPROPRIATE CHAMBER SIZES USING THE MODIFIED BRAKE SIZING EQUATION -- The modified brake sizing equation, Eq (5), provides the attempted braking force at each wheel. This force is what the mechanical components are capable of producing. Once this step is completed, all of the axles should have a value of attempted and available braking force.

9. COMPARE THE AVAILABLE BRAKE FORCE TO THE ATTEMPTED BRAKE FORCE AT EACH WHEEL AND SUM THE SMALLER VALUE FROM EACH WHEEL -- If the available brake force is smaller than the attempted brake force for a particular wheel, then the mechanical components are capable of locking that wheel. If the attempted brake force is less than the available brake force, then that wheel cannot be locked. The sum of the smaller values from each wheel represents the actual horizontal braking force acting on the entire vehicle.

10. DETERMINE THE DECELERATION RATE FOR THE VEHICLE BY DIVIDING THE TOTAL BRAKING FORCE BY THE VEHICLE WEIGHT -- When the sum of the smaller braking forces at each wheel is divided by the total vehicle weight, the result is the drag factor or the deceleration rate for the vehicle expressed in units of g's. The value produced by this calculation can be used in time/distance studies, and accident analysis. The whole process can be repeated using brakes within the legal adjustment limits to see what difference there would have been in the stopping distance. Also other configurations of brake components can be analyzed, such as larger brakes on the steering axle, or longer slack adjusters.

The above steps were followed in developing the decelerations rates and the braking forces labeled as calculated values and graphed in Figures 4 and 5.

## SUMMARY AND CONCLUSIONS

A method for determining the deceleration rate for a heavy truck, involving the brake adjustments and size of components is now available to the accident reconstructionist. This procedure allows the analyst to evaluate a variety of parameters which may be contributing factors to the cause of an accident. The method presented in this paper provides for a more analytical process than has typically been utilized in the past. The validation tests which have been performed indicate that the methodology presented is representative of actual deceleration rates.

In order for the procedure to be used under other circumstances, more testing needs to be done. Very little data is available on wedge brakes and their associated forces. More work needs to be done to refine the equation as it relates to the wedge brake system. As these and other tests are performed and comparisons are made to calculated values, other areas also need exploration. Actual deceleration tests need to be made with heated brakes to evaluate the heat expansion equations. A coefficient of friction for the drum-to-lining surfaces for a grease contaminated lining, based on a quantifiable amount of grease, would provide some helpful figures. More dynamometer work for other sizes and configurations of air chambers and slack adjusters, so the remaining regression equations could be developed, would serve a need. Hopefully, the community of accident reconstructionists and researchers will use and enlarge upon the methods presented in this paper.

## REFERENCES

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# APPENDIX - Pushrod Force Charts - in Pounds

| Pushrod Stroke | Type 30 - Application Pressure, psi | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 |
| 1/2 in | 180 | 470 | 750 | 1080 | 1380 | 1670 | 1960 | 2250 | 2540 | 2850 | 3130 |
| 1 | 180 | 450 | 730 | 1030 | 1330 | 1610 | 1900 | 2180 | 2490 | 2780 | 3040 |
| 1 1/8 | 180 | 450 | 740 | 1030 | 1340 | 1620 | 1910 | 2190 | 2500 | 2800 | 3070 |
| 1 1/4 | 180 | 450 | 750 | 1030 | 1350 | 1630 | 1920 | 2210 | 2510 | 2810 | 3080 |
| 1 3/8 | 175 | 450 | 750 | 1030 | 1350 | 1650 | 1930 | 2220 | 2520 | 2830 | 3100 |
| 1 1/2 | 175 | 450 | 750 | 1030 | 1360 | 1650 | 1935 | 2240 | 2530 | 2850 | 3100 |
| 1 5/8 | 175 | 450 | 740 | 1020 | 1360 | 1630 | 1930 | 2240 | 2530 | 2850 | 3100 |
| 1 3/4 | 175 | 450 | 730 | 1010 | 1350 | 1600 | 1910 | 2200 | 2500 | 2825 | 3080 |
| 1 7/8 | 170 | 430 | 730 | 1000 | 1310 | 1550 | 1890 | 2170 | 2480 | 2800 | 3040 |
| 2 in | 160 | 420 | 700 | 970 | 1270 | 1510 | 1860 | [illegible] | [illegible] | 2730 | 3000 |
| 2 1/8 | 150 | 400 | 650 | 920 | 1200 | 1440 | 1790 | 2060 | 2330 | 2600 | 2900 |
| 2 1/4 | 130 | 360 | 600 | 850 | 1130 | 1350 | 1670 | 1950 | 2210 | 2480 | 2570 |
| 2 3/8 | 100 | 300 | 520 | 760 | 1010 | 1230 | 1530 | 1800 | 2050 | 2300 | 2550 |
| 2 1/2 | 70 | 240 | 440 | 630 | 870 | 1070 | 1370 | 1600 | 1860 | 2050 | 2250 |
| 2 5/8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Pushrod Stroke | Type 24 Long Stroke - Application Pressure, psi | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 |
| 1/2 in | 130 | 330 | 560 | 770 | 1010 | 1230 | 1470 | 1670 | 1900 | 2130 | 2330 |
| 1 | 125 | 330 | 530 | 750 | 970 | 1200 | 1425 | 1630 | 1860 | 2070 | 2275 |
| 1 1/8 | 125 | 330 | 530 | 750 | 970 | 1200 | 1425 | 1630 | 1870 | 2075 | 2290 |
| 1 1/4 | 125 | 330 | 530 | 750 | 975 | 1200 | 1425 | 1630 | 1875 | 2080 | 2310 |
| 1 3/8 | 125 | 325 | 530 | 750 | 980 | 1200 | 1420 | 1630 | 1880 | 2080 | 2320 |
| 1 1/2 | 125 | 325 | 530 | 750 | 980 | 1200 | 1420 | 1630 | 1880 | 2080 | 2320 |
| 1 5/8 | 125 | 320 | 525 | 740 | 980 | 1200 | 1420 | 1630 | 1880 | 2080 | 2320 |
| 1 3/4 | 120 | 310 | 525 | 730 | 970 | 1175 | 1410 | 1620 | 1870 | 2070 | 2300 |
| 1 7/8 | 110 | 300 | 520 | 720 | 950 | 1150 | 1390 | 1600 | 1840 | 2050 | 2275 |
| 2 in | 100 | 280 | 500 | 700 | 900 | 1120 | 1350 | 1550 | [illegible] | 2000 | 2210 |
| 2 1/8 | 80 | 260 | 470 | 660 | 850 | 1050 | 1280 | 1470 | 1680 | 1920 | 2100 |
| 2 1/4 | 60 | 230 | 400 | 590 | 750 | 930 | 1150 | 1320 | 1550 | 1750 | 1940 |
| 2 3/8 | 40 | 180 | 340 | 480 | 650 | 780 | 1000 | 1130 | 1370 | 1570 | 1750 |
| 2 1/2 | 0 | 100 | 250 | 350 | 500 | 630 | 850 | 950 | 1270 | 1370 | 1550 |
| 2 5/8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## APPENDIX - Pushrod Force Charts - in Pounds

| Pushrod Stroke | Type 24 - Application Pressure, psi | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 |
| 1/2 in | 130 | 330 | 560 | 770 | 1010 | 1230 | 1470 | 1670 | 1900 | 2130 | 2330 |
| 1 | 125 | 330 | 530 | 750 | 970 | 1200 | 1425 | 1630 | 1860 | 2070 | 2275 |
| 1 1/8 | 125 | 330 | 530 | 750 | 970 | 1200 | 1425 | 1630 | 1870 | 2075 | 2290 |
| 1 1/4 | 125 | 330 | 530 | 750 | 975 | 1200 | 1425 | 1630 | 1875 | 2080 | 2310 |
| 1 3/8 | 125 | 325 | 530 | 750 | 980 | 1200 | 1420 | 1630 | 1880 | 2080 | 2320 |
| 1 1/2 | 125 | 325 | 530 | 750 | 980 | 1200 | 1420 | 1630 | 1880 | 2080 | 2320 |
| 1 5/8 | 120 | 310 | 525 | 730 | 970 | 1175 | 1410 | 1620 | 1870 | 2070 | 2300 |
| 1 3/4 | 110 | 300 | 520 | 720 | 950 | 1150 | 1390 | 1600 | 1840 | 2050 | 2275 |
| 1 7/8 | 100 | 280 | 500 | 700 | 900 | 1120 | 1350 | 1550 | 1800 | 2000 | 2210 |
| 2 in | 80 | 260 | 470 | 660 | 850 | 1050 | 1280 | 1470 | 1680 | 1920 | 2100 |
| 2 1/8 | 60 | 230 | 400 | 590 | 750 | 930 | 1150 | 1320 | 1550 | 1750 | 1940 |
| 2 1/4 | 40 | 180 | 340 | 480 | 650 | 780 | 1000 | 1130 | 1370 | 1570 | 1750 |
| 2 3/8 | 0 | 100 | 250 | 350 | 500 | 630 | 850 | 950 | 1270 | 1370 | 1550 |
| 2 1/2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Pushrod Stroke | Type 20 - Application Pressure, psi | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 |
| 1/2 in | 80 | 280 | 470 | 670 | 850 | 1075 | 1240 | 1450 | 1630 | 1830 | 2000 |
| 1 | 100 | 290 | 470 | 640 | 830 | 1030 | 1200 | 1380 | 1580 | 1750 | 1950 |
| 1 1/8 | 100 | 290 | 460 | 640 | 830 | 1025 | 1200 | 1380 | 1575 | 1750 | 1950 |
| 1 1/4 | 100 | 290 | 450 | 630 | 825 | 1020 | 1200 | 1380 | 1570 | 1750 | 1950 |
| 1 3/8 | 100 | 290 | 450 | 625 | 820 | 1010 | 1200 | 1380 | 1570 | 1750 | 1950 |
| 1 1/2 | 100 | 290 | 440 | 620 | 800 | 990 | 1190 | 1375 | 1550 | 1740 | 1930 |
| 1 5/8 | 100 | 280 | 430 | 600 | 780 | 970 | 1150 | 1350 | 1525 | 1720 | 1890 |
| 1 3/4 | 100 | 270 | 400 | 570 | 750 | 930 | 1125 | 1320 | 1480 | 1675 | 1850 |
| 1 7/8 | 90 | 240 | 370 | 520 | 700 | 870 | 1050 | 1230 | 1400 | 1580 | 1760 |
| 2 in | 75 | 210 | 330 | 460 | 625 | 800 | 970 | 1100 | 1300 | 1480 | 1650 |
| 2 1/8 | 50 | 160 | 270 | 390 | 530 | 680 | 840 | 970 | 1150 | 1290 | 1480 |
| 2 1/4 | 0 | 110 | 200 | 300 | 400 | 540 | 680 | 830 | 970 | 1100 | 1250 |
| 2 3/8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## APPENDIX - Pushrod Force Charts -in Pounds

| Pushrod Stroke | Type 16 - Application Pressure, psi | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 |
| 1/2 in | 80 | 240 | 380 | 550 | 720 | 870 | 1060 | 1210 | 1380 | 1530 | 1670 |
| 1 | 70 | 230 | 380 | 530 | 700 | 860 | 1020 | 1170 | 1320 | 1510 | 1640 |
| 1 1/8 | 70 | 230 | 370 | 530 | 700 | 860 | 1020 | 1170 | 1320 | 1510 | 1650 |
| 1 1/4 | 70 | 230 | 360 | 530 | 690 | 860 | 1020 | 1170 | 1320 | 1510 | 1650 |
| 1 3/8 | 70 | 230 | 360 | 520 | 680 | 850 | 1020 | 1170 | 1320 | 1500 | 1650 |
| 1 1/2 | 70 | 230 | 360 | 510 | 670 | 840 | 1000 | 1160 | 1320 | 1490 | 1640 |
| 1 5/8 | 70 | 220 | 350 | 500 | 640 | 830 | 980 | 1140 | 1300 | 1440 | 1610 |
| 1 3/4 | 60 | 210 | 330 | 470 | 600 | 790 | 940 | 1090 | 1250 | 1390 | 1550 |
| 1 7/8 | 60 | 180 | 310 | 440 | 550 | 740 | 880 | 1020 | 1130 | 1320 | 1470 |
| 2 in | 50 | 140 | 260 | 380 | 510 | 670 | 800 | 930 | 1070 | 1240 | 1380 |
| 2 1/8 | 30 | 100 | 200 | 300 | 410 | 550 | 680 | 800 | 920 | 1080 | 1220 |
| 2 1/4 | 0 | 40 | 120 | 210 | 300 | 420 | 480 | 670 | 760 | 880 | 980 |
| 2 3/8 | 0 | 0 | 40 | 110 | 170 | 250 | 280 | 420 | 530 | 640 | 740 |
| 2 1/2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Pushrod Stroke | Type 12 - Application Pressure, psi | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 |
| 1/2 in | 60 | 160 | 280 | 410 | 530 | 650 | 770 | 895 | 1010 | 1130 | 1250 |
| 1 | 60 | 160 | 280 | 395 | 510 | 630 | 735 | 855 | 980 | 1090 | 1210 |
| 1 1/8 | 60 | 160 | 270 | 390 | 500 | 620 | 720 | 870 | 965 | 1075 | 1200 |
| 1 1/4 | 50 | 155 | 260 | 375 | 485 | 600 | 700 | 815 | 940 | 1050 | 1180 |
| 1 3/8 | 40 | 145 | 235 | 350 | 460 | 560 | 670 | 770 | 890 | 1000 | 1110 |
| 1 1/2 | 35 | 130 | 210 | 310 | 415 | 510 | 615 | 710 | 830 | 920 | 1020 |
| 1 5/8 | 30 | 95 | 170 | 250 | 330 | 410 | 520 | 600 | 720 | 800 | 870 |
| 1 3/4 | 20 | 60 | 120 | 175 | 250 | 330 | 400 | 480 | 600 | 660 | 725 |
| 1 7/8 | 0 | 25 | 50 | 80 | 180 | 250 | 300 | 360 | 480 | 500 | 620 |
| 2 in | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## APPENDIX - Pushrod Force Charts - in Pounds

| Pushrod Stroke | Type 9 - Application Pressure, psi | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 |
| 1/2 in | 25 | 120 | 200 | 300 | 395 | 485 | 580 | 665 | 760 | 850 | 945 |
| 1 | 25 | 120 | 200 | 290 | 380 | 475 | 560 | 660 | 740 | 835 | 935 |
| 1 1/8 | 30 | 120 | 195 | 290 | 375 | 470 | 560 | 655 | 740 | 830 | 930 |
| 1 1/4 | 30 | 120 | 190 | 280 | 375 | 455 | 550 | 640 | 730 | 820 | 915 |
| 1 3/8 | 25 | 120 | 185 | 250 | 350 | 420 | 530 | 595 | 690 | 775 | 875 |
| 1 1/2 | 25 | 105 | 170 | 245 | 325 | 390 | 500 | 555 | 650 | 730 | 830 |
| 1 5/8 | 20 | 85 | 130 | 205 | 275 | 350 | 430 | 510 | 600 | 650 | 770 |
| 1 3/4 | 10 | 50 | 85 | 145 | 200 | 260 | 320 | 400 | 460 | 540 | 640 |
| 1 7/8 | 0 | 15 | 35 | 85 | 120 | 170 | 235 | 310 | 350 | 430 | 510 |
| 2 in | 0 | 0 | 0 | 0 | 30 | 80 | 130 | 200 | 230 | 280 | 390 |
| 2 1/8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Pushrod Stroke | Bendix DD3 Type 30 - Application Pressure, psi | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| 1/2 in | 370 | 640 | 910 | 1210 | 1520 | 1810 | 2100 | 2390 | 2690 |
| 1 | 320 | 590 | 860 | 1140 | 1440 | 1720 | 2010 | 2290 | 2580 |
| 1 1/8 | 325 | 595 | 860 | 1145 | 1445 | 1730 | 2020 | 2300 | 2590 |
| 1 1/4 | 330 | 600 | 860 | 1150 | 1450 | 1740 | 2030 | 2310 | 2600 |
| 1 3/8 | 340 | 605 | 865 | 1155 | 1455 | 1745 | 2040 | 2325 | 2610 |
| 1 1/2 | 350 | 610 | 870 | 1160 | 1460 | 1750 | 2050 | 2340 | 2620 |
| 1 5/8 | 350 | 610 | 865 | 1160 | 1455 | 1745 | 2035 | 2325 | 2610 |
| 1 3/4 | 350 | 610 | 860 | 1160 | 1450 | 1740 | 2020 | 2310 | 2600 |
| 1 7/8 | 350 | 605 | 855 | 1150 | 1430 | 1715 | 2005 | 2285 | 2575 |
| 2 in | 350 | 600 | 850 | 1140 | 1410 | 1690 | 1990 | 2260 | 2550 |
| 2 1/8 | 345 | 590 | 835 | 1125 | 1400 | 1680 | 1965 | 2235 | 2520 |
| 2 1/4 | 340 | 580 | 820 | 1110 | 1390 | 1670 | 1940 | 2210 | 2490 |
| 2 3/8 | 330 | 570 | 810 | 1095 | 1370 | 1645 | 1920 | 2185 | 2460 |
| 2 1/2 | 320 | 560 | 800 | 1080 | 1350 | 1620 | 1900 | 2160 | 2430 |
| 2 5/8 | 310 | 545 | 790 | 1055 | 1315 | 1590 | 1865 | 2130 | 2395 |
| 2 3/4 | 300 | 530 | 770 | 1030 | 1280 | 1560 | 1830 | 2100 | 2360 |
| 2 7/8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# APPENDIX J

## PHASE 4 COMPUTER SIMULATION DESCRIPTION

The following material is an excerpt from MacAdam, C. C., Fancher, P. S., Hu, G. T., and Gillespie, T. D., "A Computerized Model for Simulating the Braking and Steering Dynamics of Trucks, Tractor-Semitrailers, Doubles, Triples Combination--User's Manual," University of Michigan Highway Safety Research Institute Report No. UM-HSRI-80-58, 1980.

## 2.0 APPLICATION

### 2.1 Description of the Program

The PHASE 4 program is a time-domain mathematical simulation of a truck/tractor, a semitrailer, and up to two full trailers. The vehicles are represented by differential equations derived from Newtonian mechanics that are solved for successive time increments by digital integration.

The program is written in a generalized fashion to allow simulation of a large number of vehicle configurations. The first vehicle is the power unit and may be a truck or tractor, both of which may carry payload. As a single unit with no payload, it is equivalent to an empty truck or bobtail tractor. With payload, it is a truck, which, with a semitrailer as well, simulates a car hauler, dromedary tractor, etc. The second unit is always a semitrailer (i.e., current models do not include a truck with full trailer). The third and fourth units are full trailers consisting of semitrailers on either a fixed or converter dolly. Separate payload may be specified for each trailer.

The truck/tractor unit is distinguished by the fact that it can have only a single front axle with single tires, and can be arbitrarily steered. All other axles on the vehicle combination can be represented as single or tandem axles with single or dual wheel sets.

The mathematical model (see Appendix B) incorporates up to 71 degrees of freedom. The number of degrees of freedom are dependent on the vehicle configuration and derive from the following:

- Six degrees of freedom (three translational and three rotational) for the truck/tractor sprung mass
- Three degrees of freedom for the semitrailer (the three other degrees of freedom of the semitrailer are effectively eliminated by dynamic constraints at the hitch)
- Five degrees of freedom for each of the two full trailers allowed
- Two degrees of freedom (vertical and roll) for each of the 13 axles allowed
- A wheel rotational degree of freedom for each of the 26 wheels allowed

The motion of each of the sprung masses is determined from the summation of forces and moments upon it arising from the tires (acting through the unsprung mass of the axle and suspension), gravity, and the hitch point constraints. Small angle assumptions are made in the implementation of the mathematical equations so that the simulation can be validly applied only up to a maneuver limit at which wheel lift-off occurs.

2.2 Uses of the Program

Since PHASE 4 includes the basic features of T3DRS:V1, it can be used to simulate the following vehicle configurations:

Straight truck, empty and loaded

Bobtail tractor

Tractor-semitrailer (3 to 5 axles), empty and loaded

Tractor-semitrailer-full trailer (5 to 9 axles), empty and loaded

Tractor-semitrailer-full trailer-full trailer (7 to 13 axles), empty and loaded

For simulation of braking performance, the program incorporates state-of-the-art representation of truck air brake systems, antilock wheel control systems, and tire-road friction models. Typical examples of braking studies for which it can be or has been used are:

1. Stopping distance performance
2. Effects of brake timing
3. Dynamic behavior in braking
4. Comparisons of antilock wheel control logic
5. Influence of tire-road friction coupling
6. Split friction surfaces
7. Brake proportioning
8. Tandem-axle effects on braking limits

For simulation of cornering performance behavior, the program incorporates state-of-the-art representations of truck tire lateral force characteristics (with roll-off effects during combined braking), and vehicle suspension properties of significance to cornering behavior. Typical examples of studies involving cornering are as follows:

1. Understeer/oversteer properties of commercial vehicles
2. Determining cornering limits

3. Assessing tandem-axle effects on cornering

4. Jackknife prediction

5. Effects of suspension properties on cornering and cornering limits

6. Accident simulation

In addition to the above, the program can be operated open-loop (defined steer angle inputs) or closed-loop (defined path input), and on roads of specified grade or cross-slope.

The PHASE 4 program is uniquely applicable in directional response studies in which the influence of the following items are to be considered in detail:

1. Spring force/deflection characteristics (hysteresis and free-play)

2. Brake "fade" -- brake temperature

3. Brake hysteresis

4. Load-leveler action in tandem suspensions

5. Brake proportioning algorithms

6. Steering system compliance (inputs at the steering wheel)

7. Frame torsional stiffness

## 2.3 Operation

Operation of the PHASE 4 program is accomplished by submission of the necessary job control instructions followed by a list of input parameters. The specific job control instructions required are dependent on the user's computer system and whether batch or remote job entry is being used. However, the input parameter list is common to all and is described in Section 3.0 of this Manual.

The program commences by reading the input list containing parametric data describing the vehicle configuration, initial conditions, steering and braking inputs, the output desired, and the road conditions. As input data is read, the data is normally "echoed" as the first pages of output. At the completion of the input read process, the program calculates necessary properties of the total vehicle combination and prints a page of output containing a summary of those vehicle properties. The program then "runs," solving the differential equations of motion for the vehicle until the vehicle reaches a full stop, a default stop (such as rollover), or until the designated maximum simulation time is reached. At various points during the run, simulation output is printed, which (at the option of the user) may include time-based values for the vehicle motion variables, tire forces at each axle, braking conditions on each axle, tire cornering conditions, and the suspension motions and forces.

## 2.4 Validity

The validity of PHASE 4, like any computer program, is dependent on the accuracy and execution of program statements, the capabilities of the simulation models, and the quality of the vehicle and maneuver descriptions defined by the input data.

Every effort, of course, is made to ensure that the program statements are correct and result in solution of the problem to a reasonable level of precision. The time steps have been selected so that round-off and truncation errors do not substantially influence the precision of the calculated results. Nevertheless, if programming errors are discovered, the user should contact the Physical Factors Division, Highway Safety Research Institute, The University of Michigan, Ann Arbor, Michigan.

The modeling used in the simulation is effectively state-of-the-art, reflecting the most practical approaches to mathematical representation of commercial vehicles for braking and handling studies. Over the years, modeling has grown more in sophistication than in detail. For example, early models for truck brake systems extending the mechanical details within the individual brakes have proven no more capable of predicting braking performance than the "black box" representation as a pressure-input, torque-output device. Hence, the latter approach was used in T3DRS:V1, with a substantial saving in the complexity associated with understanding and using the simulation. With nearly every component model used in the simulation, there are instances where more modeling details would be appropriate for the study at hand; yet, provision for every instance would result in a simulation for which the input data requirements would be untenable. To some extent, this dilemma is alleviated in PHASE 4 by including optional features as means to describe component characteristics in more detail when desired.

Finally, the ultimate determinant of validity is the user supplied input data and the interpretation applied to the results. Properly used, the program is capable of validly predicting most aspects of braking performance and directional response in maneuvers up to the limits of wheel lift-off. In the special case where a direct comparison between a vehicle and simulation (i.e., validation) is intended, an iterative process is often involved as the first comparisons of simulation and test reveal unexpected differences, which, when examined, are traced to inaccuracies or errors in the experimental measurements or program input. Fortunately, the usefulness of these simulation programs are not dependent on every user going through the same process. In most applications, the user can assume, for example, a given tier characteristic and investigate vehicle performance with that tire, knowing that it is typical, but yet, not precisely equivalent to any specific tire on hand. Much of the utility of computer simulation programs derives not from absolute prediction of a certain vehicle/test maneuver situation (as required for validation), but as a tool for studying generalized performance and sensitivity of performance to the vehicle parameters.

In this general sense, the PHASE 4 program can be expected to yield valid measures of the braking and handling performance comparison when specific vehicle parameters are changed. The PHASE 4 program has been tested against other simulations, including its predecessors, which in turn have proven capable of reasonably duplicating actual vehicle performance. The user is referred to the following references for examples of the use and validation of those programs:

| | References |
|---|---|
| Straight Truck Braking | 1, 2, 25, 21, 28, 19, 36, 22, 20 |
| Straight Truck Cornering and Braking | 2, 29, 36 |
| Straight Truck Cornering | 23, 36 |
| Tractor-Trailer Braking | 1, 2, 36 |
| Tractor-Trailer Cornering and Braking | 2, 29, 36 |
| Tractor-Trailer Cornering | 26, 36 |
| Tractor-Trailer-Full Trailer Cornering | 27, 36 |

## 2.5 Modeling Differences Between the T3DRS:V1 and PHASE 4 Simulation Programs

Aside from the additional model options which are available in PHASE 4, the two principal differences between T3DRS:V1 and PHASE 4 lie in the manner in which (a) the tractors fifth wheel is modeled in roll and (b) the inclusion of load-leveling action for tandem suspensions in PHASE 4. In the V1 model, the fifth wheel compliance represented a torsional coupling between the tractor and trailer sprung masses. No torsional frame compliance in the tractor was included. In the PHASE 4 model, the fifth wheel is a rigid connection in roll (for small articulation angles) between the trailer sprung mass and the top of the tractor rear suspension. The torsional frame compliance included in the tractor links the tractor sprung mass to the fifth wheel connection. This feature has been added to PHASE 4 to more accurately represent the observed roll response with tractor-trailer vehicles, although its effect on handling response is not always significant.

The load-leveling action which takes place in tandem suspensions during braking and handling is more accurately represented in the PHASE 4 version. The dynamic load equalization is now calculated continuously during simulation to achieve a more accurate value for the instantaneous suspension forces. Both four-spring and walking-beam type tandem suspensions are available in the PHASE 4 model.

# APPENDIX K
## HEAVY TRUCK INSPECTION PROJECT DATABASE FORM
## FIVE-AXLE TRUCK BRAKE INSPECTION

| | | | |
|---|---|---|---|
| **Location:** Texas | **Route:** I-10 | **Date:** 09/20/90 | **Inspec No:** 910 |
| **Carrier:** Ajax Transportation | | | |
| **Inter/Intra:** inter | **Type:** for hire | | **Size:** 65 |
| **ICC/MC:** 1X79X4 | **US DOT:** | | **CVSA Date:** 08/01/89 |
| **Origin:** TX | **Destination:** TX | | **Distance:** 260 |
| **Driver Resp for Adj:** no | **Phone:** XXX-XXX-XXX | | **Haz Mat:** no |
| | **Jake:** no | **FHWA:** | |
| **Trctr Yr:** 1988 | **Trctr Make:** Mack | **Cab Type:** conv | **State Reg:** TX |
| **Steering:** pwr | **Limit Valve:** yes | **Owned by:** carrier | **Leased:** |
| **Trctr VIN:** 1M2AY04Y8JM000000 | | **Tractor Tag:** RXXXXX | |

**TRACTOR BRAKE COMPONENTS** (2DR = 2nd axle, driver, right side)

| Man/Auto | Slack Length | Manuf | Chamber Size | Stroke | Inop: 0 |
|---|---|---|---|---|---|
| 1SL ST: man | 1SL SL: 5.5 | 1SL SM: | 1SL CS: 20 | 1SL S: 1.38 | 1L IO: ok |
| 1SR ST: man | 1SR SL: 5.5 | 1SR SM: | 1SR CS: 20 | 1SR S: 1.38 | 1R IO: ok |
| 2DL ST: man | 2DL SL: 6.0 | 2DL SM: | 2DL CS: 24LS | 2DL S: 1.25 | 2L IO: ok |
| 2DR ST: man | 2DR SL: 6.0 | 2DR SM: | 2DR CS: 24LS | 2DR S: 1.50 | 2R IO: ok |
| 3DL ST: man | 3DL SL: 6.0 | 3DL SM: | 3DL CS: 24LS | 3DL S: 1.25 | 3L IO: ok |
| 3DR ST: man | 3DR SL: 6.0 | 3DR SM: | 3DR CS: 24LS | 3DR S: 1.25 | 3R IO: ok |
| Ex Leak: 0 | Mod Leak: 0 | Minor Leak: 0 | | | |

| | | | |
|---|---|---|---|
| **Trlr Yr:** 1988 | **Trlr Make:** Aztec | **Trlr Type:** flat | **State Reg:** TX |
| **Tag No:** 36R985 | **VIN:** 1AZBM2A34 | **Owned by:** carrier | **Leased:** |
| | **FHWA:** 6-90 | | |
| **Trlr2 Yr:** | **Trlr2 Make:** | **Trlr2 Type:** | **State Reg:** |
| **Tag No:** | **VIN:** | **Owned by:** | **Leased:** |
| | **FHWA:** | | |

**TRAILER BRAKE COMPONENTS** (5TL = 5th axle, trailer axle, left side)

| Man/Auto | Slack Length | Manuf | Chamber Size | Stroke | Inop: 0 |
|---|---|---|---|---|---|
| 4TL ST: man, | 4TL SL: 6.0 | 4TL SM: | 4TL CS: 30 | 4TL S: 2.25 | 4L IO: ok |
| 4TR ST: man | 4TR SL: 6.0 | 4TR SM: | 4TR CS: 30 | 4TR S: 2.00 | 4R IO: ok |
| 5TL ST: man | 5TL SL: 6.0 | 5TL SM: | 5TL CS: 30 | 5TL S: 1.75 | 5L IO: ok |
| 5TR ST: man | 5TR SL: 6.0 | 5TR SM: | 5TR CS: 30 | 5TR S: 1.50 | 5R IO: ok |
| Ex Leak: 0 | Mod Leak: 0 | Minor Leak: 0 | Brakes At/Past Limit: 2.00 | | |

| | | | |
|---|---|---|---|
| **Brake OOS Violations:** 0.00 | **Other out of service:** 0.00 | | **Truck Out of Service:** no |
| **Actual Drag:** 0.56 | **Actual Eff:** 1.00 | **80K Drag:** 0.48 | **80K Eff:** 0.86 |
| **400F Drag:** 0.56 | **400F Eff:** 1.00 | **400F Drag:** 0.40 | **400F Eff:** 0.72 |
| **600F Drag:** 0.52 | **600F Eff:** 0.92 | **600F Drag:** 0.33 | **600F Eff:** 0.59 |
| **900F Drag:** 0.41 | **900F Eff:** 0.72 | **900F Drag:** 0.22 | **900F Eff:** 0.40 |
| **TTL WGT:** 32280 | **STEER:** 9920 | **DRIVE:** 13760 | **TRAILER:** 8600 |

# APPENDIX L

## FEDERAL MOTOR CARRIER AIRBRAKE REGULATIONS



**§ 393.52 Brake performance.**

(a) Upon application of its service brakes, a motor vehicle or combination of motor vehicles must under any condition of loading in which it is found on a public highway, be capable of—

(1) Developing a braking force at least equal to the percentage of its gross weight specified in the table in paragraph (d) of this section;

(2) Decelerating to a stop from 20 miles per hour at not less than the rate specified in the table in paragraph (d) of this section; and

(3) Stopping from 20 miles per hour in a distance, measured from the point at which movement of the service brake pedal or control begins, that is not greater than the distance specified in the table in paragraph (d) of this section.

(b) Upon application of its emergency brake system and with no other brake system applied, a motor vehicle or combination of motor vehicles must, under any condition of loading in which it is found on a public highway, be capable of stopping from 20 miles per hour in a distance, measured from the point at which movement of the emergency brake control begins, that is not greater than the distance specified in the table in paragraph (d) of this section.

(c) Conformity to the stopping-distance requirements of paragraphs (a) and (b) of this section shall be determined under the following conditions:

(1) Any test must be made with the vehicle on a hard surface that is substantially level, dry, smooth, and free of loose material.

(2) The vehicle must be in the center of a 12-foot-wide lane when the test begins and must not deviate from that lane during the test.

(d) Vehicle brake performance table:

| Type of motor vehicle | Service brake systems: Braking force as a percentage of gross vehicle or combination weight | Service brake systems: Deceleration in feet per second per second | Service brake systems: Application and braking distance in feet from initial speed of 20 m.p.h. | Emergency brake systems: Application and braking distance in feet from initial speed of 20 m.p.h. |
|---|---|---|---|---|
| A. Passenger-carrying vehicles. | | | | |
| (1) Vehicles with a seating capacity of 10 persons or less, including driver, and built on a passenger car chassis | 65.2 | 21 | 20 | 54 |
| (2) Vehicles with a seating capacity of more than 10 persons, including driver, and built on a passenger car chassis; vehicles built on a truck or bus chassis and having a manufacturer's GVWR of 10,000 pounds or less | 52.8 | 17 | 25 | 66 |
| (3) All other passenger-carrying vehicles | 43.5 | 14 | 35 | 85 |

| Type of motor vehicle | Service brake systems | | | Emergency brake systems |
|---|---|---|---|---|
| | Braking force as a percentage of gross vehicle or combination weight | Deceleration in feet per second per second | Application and braking distance in feet from initial speed of 20 m.p.h. | Application and braking distance in feet from initial speed of 20 m.p.h. |
| B. Property-carrying vehicles. | | | | |
| (1) Single unit vehicles having a manufacturer's GVWR of 10,000 pounds or less | 52.8 | 17 | 25 | 66 |
| (2) Single unit vehicles having a manufacturer's GVWR of more than 10,000 pounds, except truck tractors. Combinations of a 2-axle towing vehicle and trailer having a GVWR of 3,000 pounds or less. All combinations of 2 or less vehicles in driveaway or towaway operation | 43.4 | 14 | 35 | 85 |
| (3) All other property-carrying vehicles and combinations of property-carrying vehicles | 43.5 | 14 | 40 | 90 |

NOTE: (a) There is a definite mathematical relationship between the figures in columns 2 and 3. If the decelerations set forth in column 3 are divided by 32.2 feet per second per second, the figures in column 2 will be obtained. (For example, 21 divided by 32.2 equals 65.2 percent.) Column 2 is included in the tabulation because certain brake-testing devices utilize this factor.

(b) The decelerations specified in column 3 are an indication of the effectiveness of the basic brakes, and as measured in practical brake testing are the maximum decelerations attained at some time during the stop. These decelerations as measured in brake tests cannot be used to compute the values in column 4 because the deceleration is not sustained at the same rate over the entire period of the stop. The deceleration increases from zero to a maximum during a period of brake-system application and brake-force buildup. Also, other factors may cause the deceleration to decrease after reaching a maximum. The added distance which results because maximum deceleration is not sustained is included in the figures in column 4 but is not indicated by the usual brake-testing devices for checking deceleration.

(c) The distances in column 4 and the decelerations in column 3 are not directly related. "Brake-system application and braking distance in feet" (column 4) is a definite measure of the overall effectiveness of the braking system, being the distance traveled between the point at which the driver starts to move the braking controls and the point at which the vehicle comes to rest. It includes distance traveled while the brakes are being applied and distance traveled while the brakes are retarding the vehicle.

(d) The distance traveled during the period of brake-system application and brake-force buildup varies with vehicle type, being negligible for many passenger cars and greatest for combinations of commercial vehicles. This fact accounts for the variation from 20 to 40 feet in the values in column 4 for the various classes of vehicles.

(e) The terms "GVWR" and "GVW" refer to the manufacturer's gross vehicle rating and the actual gross vehicle weight, respectively.

[36 FR 20298, Oct. 30, 1971, as amended at 37 FR 5251, Mar. 11, 1972; 37 FR 11336, June 7, 1972]

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

S1. *Scope.* This standard establishes performance and equipment requirements for braking systems on vehicles equipped with air brake systems.

S2. *Purpose.* The purpose of this standard is to insure safe braking performance under normal and emergency conditions.

S3. *Application.* This standard applies to trucks, buses, and trailers equipped with air brake systems. However, it does not apply to:

(a) Any trailer that has a width of more than 102.36 inches with extendable equipment in the fully retracted position and is equipped with two short track axles in a line across the width of the trailer.

(b) Any vehicle equipped with an axle that has a GAWR of 29,000 pounds or more;

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

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

(e) Any trailer that has a GVWR of more than 120,000 pounds and whose body conforms to that described in the definition of *Heavy hauler trailer* set forth in S4;

(f) Any trailer that has an unloaded vehicle weight which is not less than 95 percent of its GVWR; and

(g) Any load divider dolly.

Notwithstanding any language to the contrary, sections S5.3.1, S5.3.1.1, S5.3.2, S5.3.2.1, S5.3.2.2, S5.7.1, S5.7.3(a) and S5.7.3(b) of this standard are not applicable to trucks and trailers, and section S5.3.1 of this standard is not applicable to buses.

S4. *Definitions.*

*Agricultural commodity trailer* means a trailer that is designed to transport bulk agricultural commodities in off-road harvesting sites and to a processing plant or storage location, as evidenced by skeletal construction that accommodates harvest containers, a maximum length of 28 feet, and an arrangement of air control lines and reservoirs that minimizes damage in field operations.

*Air brake system* means a system that uses air as a medium for transmitting pressure or force from the driver control to the service brake, but does not include a system that uses compressed air or vacuum only to assist the driver in applying muscular force to hydraulic or mechanical components.

*Antilock system* means a portion of a service brake system that automatically controls the degree of rotational wheel slip at one or more road wheels of the vehicle during braking.

*Auto transporter* means a truck and a trailer designed for use in combination to transport motor vehicles, in that the towing vehicle is designed to carry cargo at a location other than the fifth wheel and to load this cargo only by means of the towed vehicle.

*Container chassis trailer* means a semitrailer of skeleton construction limited to a bottom frame, one or more axles, specially built and fitted with locking devices for the transport of intermodal shipping containers, so that when the chassis and container are assembled, the units serve the same function as an over the road trailer.

*Heavy hauler trailer* means a trailer which has one or more of the following characteristics, but which is not a container chassis trailer:

(1) Its brake lines are designed to adapt to separation or extension of the vehicle frame; or

(2) Its body consists only of a platform whose primary cargo-carrying surface is not more than 40 inches above the ground in an unloaded condition, except that it may include sides that are designed to be easily removable and a permanent "front end structure" as that term is used in § 393.106 of this title.

*Initial brake temperature* means the average temperature of the service brakes on the hottest axle of the vehicle 0.2 mile before any brake application.

*Intermodal shipping container* means a reusable, transportable enclosure that is especially designed with integral locking devices for securing the container to the trailer to facilitate the efficient and bulk shipping and transfer of goods by, or between various modes of transport, such as highway, rail, sea and air.

*Load divider dolly* means a trailer composed of a trailer chassis and one or more axles, with no solid bed, body, or container attached, and which is designed exclusively to support a portion of the load on a trailer or truck excluded from all the requirements of this standard.

*Pulpwood trailer* means a trailer that is designed exclusively for harvesting logs or pulpwood and constructed with a skeletal frame with no means for attachment of a solid bed, body, or container, and with an arrangement of air control lines and reservoirs designed to minimize damage in off-road operations.

*Skid number* means the frictional resistance of a pavement measured in accordance with American Society for Testing and Materials Method E-274-70 (as revised July 1974), at 40 m.p.h., omitting water delivery as specified in paragraphs S7.1 and 7.2 of that method.

*Straddle trailer* means a trailer that is designed to transport bulk agricultural commodities from the harvesting location as evidenced by a framework that is driven over the cargo and lifting arms that suspend the cargo for transit.

S5. *Requirements.* Each vehicle shall meet the following requirements under the conditions specified in S6.

S5.1 *Required equipment—trucks and buses.* Each truck and bus shall have the following equipment:

S5.1.1 *Air compressor.* An air compressor of sufficient capacity to increase air pressure in the supply and service reservoirs from 85 pounds per square inch (p.s.i.) to 100 p.s.i. when the engine is operating at the vehicle manufacturer's maximum recommended r.p.m. within a time, in seconds, determined by the quotient

(Actual reservoir capacity × 25)/Required reservoir capacity.

S5.1.2 *Reservoirs.* One or more service reservoir systems, from which air is delivered to the brake chambers, and either an automatic condensate drain valve for each service reservoir or a supply reservoir between the service reservoir system and the source of air pressure.

S5.1.2.1 The combined volume of all service reservoirs and supply reservoirs shall be at least 12 times the combined volume of all service brake chambers at maximum travel of the pistons or diaphragms. However, the reservoirs on the truck portion of an auto transporter need not meet this requirement.

S5.1.2.2 Each reservoir shall be capable of withstanding an internal hydrostatic pressure of five times the compressor cutout pressure or 500 p.s.i., whichever is greater, for 10 minutes.

S5.1.2.3 Each service reservoir system shall be protected against loss of air pressure due to failure or leakage in the system between the service reservoir and the source of air pressure, by check valves or equivalent devices whose proper functioning can be checked without disconnecting any air line or fitting.

S5.1.2.4 Each reservoir shall have a condensate drain valve that can be manually operated.

S5.1.3 *Towing vehicle protection system.* If the vehicle is intended to tow another vehicle equipped with air brakes, a system to protect the air pressure in the towing vehicle from the effects of a loss of air pressure in the towed vehicle.

S5.1.4 *Pressure gauge.* A pressure gauge in each service brake system, readily visible to a person seated in the normal driving position, that indicates the service reservoir system air pressure. The accuracy of the gauge shall be within plus or minus 7 percent of the compressor cut-out pressure.

S5.1.5 *Warning signal.* A signal, other than a pressure gage, that gives a continuous warning to a person in the normal driving position when the ignition is in the "on" or "run" position and the air pressure in the service reservoir system is below 60 p.s.i. The signal shall be either visible within the driver's forward field of view, or both audible and visible.

S5.1.6 *Antilock warning signal.* A signal on each vehicle equipped with an antilock system that gives a continuous warning to a person in the normal driving position when the ignition is in the "on" or "run" position in the event of a total electrical failure of the antilock system. The signal shall be either visible within the driver's forward field of view or both audible, for a duration of at least 10 seconds, and continuously visible. The signal shall operate in the specified manner each time the ignition is returned to the "on" or "run" position.

S5.1.7 *Service brake stop lamp switch.* A switch that lights the stop lamps when the service brake control is statically depressed to a point that produces a pressure of 6 p.s.i. or less in the service brake chambers.

S5.1.8 *Brake distribution.* Each vehicle shall be equipped with a service brake system acting on all wheels.

S5.2 *Required equipment—trailers.* Each trailer shall have the following equipment:

S5.2.1 *Reservoirs.* One or more reservoirs to which the air is delivered from the towing vehicle.

S5.2.1.1 A reservoir shall be provided that is capable, when pressurized to 90 p.s.i., of releasing the vehicle's parking brakes at least once and that is unaffected by a loss of air pressure in the service brake system.

S5.2.1.2 Total service reservoir volume shall be at least eight times the combined volume of all service brake chambers at maximum travel of the pistons or diaphragms. However, the reservoirs on a heavy hauler trailer and on the trailer portion of an auto transporter need not meet this requirement.

S5.2.1.3 Each reservoir shall be capable of withstanding an internal hydrostatic pressure of 500 p.s.i. for 10 minutes.

S5.2.1.4 Each reservoir shall have a condensate drain valve that can be manually operated.

S5.2.1.5 Each service reservoir shall be protected against loss of air pressure due to failure or leakage in the system between the service reservoir and its source of air pressure by check valves or equivalent devices.

S5.2.2 *Brake distribution.* Each trailer shall be equipped with a service brake system acting on all wheels.

S5.3 *Service brakes—road tests.* The service brake system on each truck and bus shall, under the conditions of S6.1, 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 S6.1, meet the requirements of S5.3.2, S5.3.3, and S5.3.4 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.

S5.3.1 *Stopping distance—trucks and buses.* When stopped six times for each combination of weight, speed, and road condition specified in S5.3.1.1, in the sequence specified in Table I, the vehicle shall stop at least once in not more than the distance specified in Table II, measured from the point at which movement of the service brake control begins, without any part of the vehicle leaving the roadway and without lockup of any wheel at speeds above 10 mph except for:

(a) Controlled lockup of wheels allowed by an antilock system, or

(b) Lockup of wheels on nonsteerable axles other than the two rearmost nonliftable, nonsteerable axles on a vehicle with more than two nonsteerable axles.

TABLE I—STOPPING SEQUENCE

1. Burnish.
2. Control trailer service brake stops at 60 mi/h (for truck-tractors tested with a control trailer in accordance with S6.1.10.6).
3. Control trailer emergency brake stops at 60 mi/h (for truck-tractors tested with a control trailer in accordance with S6.1.10.7).
4. Stops with vehicle at gross vehicle weight rating:
   (a) 20 mi/h service brake stops on skid number of 81.
   (b) 60 mi/h service brake stops on skid number of 81.
   (c) 20 mi/h service brake stops on skid number range 30.
   (d) 20 mi/h emergency brake stops on skid number of 81.
   (e) 60 mi/h emergency brake stops on skid number of 81.
5. Parking brake test with vehicle loaded to gross vehicle weight rating.
6. Stops with vehicle at unloaded weight plus 500 lb:
   (a) 20 mi/h service brake stops on skid number of 81.
   (b) 60 mi/h service brake stops on skid number of 81.
   (c) 20 mi/h service brake stops on skid number range 30.
   (d) 20 mi/h emergency brake stops on skid number of 81.
   (e) 60 mi/h emergency brake stops on skid number of 81.
7. Parking brake test with vehicle at unloaded weight plus 500 lb.

S5.3.1.1 Stop the vehicle from 60 m.p.h. and 20 m.p.h. on a surface with a skid number of 81, and from 20 m.p.h. on a wet surface with a skid number of 30, with the vehicle (a) loaded to its gross vehicle weight rating, and (b) at its unloaded vehicle weight plus 500 pounds (including driver and instrumentation). If the speed attainable in 2 miles is less than 60 m.p.h., the vehicle shall stop from a speed in Table II that is 4 to 8 m.p.h. less than the speed attainable in 2 miles.

TABLE II—STOPPING DISTANCE IN FEET

| Vehicle speed in miles per hour | Service brake | | Emergency brake, skid No. 81 | |
|---|---|---|---|---|
| | Skid No. 81 (1) | Skid No. 30 (2) | (3) | (4) |
| 20 | 35 | 60 | 83 | 85 |
| 25 | 53 | | 123 | 131 |
| 30 | 75 | | 170 | 188 |
| 35 | 101 | | 225 | 250 |
| 40 | 131 | | 288 | 325 |
| 45 | 165 | | 358 | 409 |
| 50 | 200 | | 435 | 504 |
| 55 | 246 | | 520 | 608 |
| 60 | 293 | | 613 | 720 |

S5.3.2 *Stopping capability—trailers.* When tested at each combination of weight, speed, and road condition specified in S5.3.2.1, in the sequence specified in Table I, with air pressure of 90 p.s.i. in the control line and service reservoir system and with no application of the towing vehicle's brakes, a trailer shall stop without any part of the trailer leaving the roadway and without lockup of any wheel at speeds above 10 m.p.h., except for

(a) Controlled lockup of wheels allowed by an antilock system, or

(b) Lockup of wheels on nonsteerable axles other than the two rearmost nonliftable, nonsteerable axles on a trailer with more than two nonsteerable axles, or

(c) In the case of an axle system having more than four wheels, lockup of any wheel other than the outermost wheel at each end of the axle system.

S5.3.2.1 Stop the vehicle from 60 m.p.h. and 20 m.p.h. on a surface with skid number of 81, and from 20 m.p.h. on a wet surface with a skid number of 30 with the vehicle (a) loaded to its gross vehicle weight rating, and (b) at its unloaded vehicle weight plus 500 pounds (including instrumentation).

S5.3.2.2 When stopped in accordance with S5.3.2, a pulpwood trailer need not meet the requirements relating to wheel lockup, but must nevertheless meet the requirements of staying within the 12-foot lane.

S5.3.3 *Brake actuation time.* Each service brake system shall meet the requirements of S5.3.3.1, except that, at the option of the manufacturer, vehicles manufactured before May 3, 1991 may meet the requirements specified in either S5.3.3.2 or S5.3.3.3.

S5.3.3.1(a) With an initial service reservoir system air pressure of 100 p.s.i., the air pressure in each brake chamber shall, when measured from the first movement of the service brake control, reach 60 p.s.i. in not more than 0.45 second in the case of trucks and buses, 0.60 second in the case of trailers, other than trailer converter dollies, designed to tow another vehicle equipped with air brakes, 0.55 second in the case of trailer converter dollies, and 0.60 second in the case of trailers other than trailers designed to tow another vehicle equipped with air brakes. A vehicle designed to tow another vehicle equipped with air brakes shall meet the above actuation time requirement with a 50-cubic-inch test reservoir connected to the control line output coupling. a trailer, including a trailer converter dolly, shall meet the above actuation time requirement with its control line input coupling connected to the test rig shown in Figure 1.

(b) For a vehicle that is manufactured after May 3, 1991 and is designed to tow another vehicle equipped with air brakes, the pressure in the 50-cubic-inch test reservoir referred to in S5.3.3.1(a) shall, when measured from the first movement of the service brake control, reach 60 p.s.i. not later than the time the fastest brake chamber on the vehicle reaches 60 p.s.i. or, at the option of the manufacturer, in not more than 0.35 second in the case of trucks and buses, 0.55 second in the case of trailer converter dollies, and 0.50 second in the cae of trailers other than trailer converter dollies.

S5.3.3.2 *(Optional requirement for vehicles manufactured before May 3, 1991.)* With an initial service reservoir system air pressure of 100 p.s.i., the air pressure in each brake chamber shall, when measured from the first movement of the service brake control, reach 60 p.s.i. in not more than 0.45 second in the case of trucks and buses, and 0.60 second in the case of trailers. A vehicle designed to tow another vehicle equipped air brakes shall meet the above actuation time requirement with a 50-cubic-inch test reservoir connected to the control line output coupling. A trailer, including a trailer converter dolly, shall meet the above actuation time requirement with its control line input coupling connected to the test rig shown in Figure 1.

S5.3.3.3 *(Optional requirement for vehicles manufactured before May 3, 1991.)* With an initial service reservoir system air pressure of 100 p.s.i., the air pressure in each brake chamber shall, when measured from the first movement of the service brake control, reach 60 p.s.i. in not more than 0.45 second in the case of trucks and buses, 0.35 second in the case of trailer converter dollies, and 0.30 second in the case of trailers other than trailer converter dollies. A vehicle designed to tow another vehicle equipped with air brakes shall meet the above actuation time requirement with a 50-cubic-inch test reservoir connected to the control line output coupling. A trailer, including a trailer converter dolly, shall meet the above actuation time requirement with its control line input coupling connected to the test rig shown in Figure 1(a).

S5.3.4 *Brake release time.* Each service brake system shall meet the requirements of S5.3.4.1, except that, at the option of the manufacturer, vehicles manufactured before May 3, 1991 may meet the requirements specified in either S5.3.4.2 or S5.3.4.3.

S5.3.4.1(a) With an initial service brake chamber air pressure of 95 p.s.i., the air pressure in each brake chamber shall, when measured from the first movement of the service brake control, fall to 5 p.s.i. in not more than 0.55 second in the case of trucks and buses, 1.00 second in the case of trailers, other than trailer converter dollies, designed to tow another vehicle equipped with air brakes, 1.10 seconds in the case of trailer converter dollies, and 1.20 seconds in the case of trailers other than trailers designed to tow another vehicle equipped with air brakes. A vehicle designated to tow another vehicle equipped with air brakes shall meet the above release time requirement with a 50-cubic-inch test reservoir connected to the control line output coupling. A trailer, including a trailer converter dolly, shall meet the above release time requirement with its control line input coupling connected to the test rig shown in Figure 1.

(b) For vehicles designed to tow another vehicle equipped with air brakes, effective May 3, 1991, the pressure in the 50-cubic-inch test reservior referred to in S5.3.4.1(a) shall, when measured from the first movement of the service brake control, fall to 5 p.s.i. in not more than 0.75 seconds in the case of trucks and buses, 1.10 seconds in the case of treiler converter dollies, and 1.00 seconds in the case of trailers other than trailer converter dollies.

S5.3.4.2 *(Optional requirement for vehicles manufactured before May 3, 1989.)* With an initial service brake chamber air pressure of 95 p.s.i., the air pressure in each brake chamber shall, when measured from the first movement of the service brake control, fall to 5 p.s.i. in not more than 0.55 seconds in the case of trucks and buses, and 1.20 seconds in the case of trailers. A vehicle designed to tow another vehicle equipped with air brakes shall meet the above release time requirement with a 50-cubic-inch test reservoir connected to the control line output coupling. A trailer, including a trailer converter dolly, shall meet the above release time requirement with its control line input coupling connected to the test rig shown in Figure 1.

S5.3.4.3 *(Optional requirement for vehicles manufactured before May 3, 1991.)* With an initial service brake chamber air pressure of 95 p.s.i., the air pressure in each brake chamber shall, when measured from the first movement of the service brake control, fall to 5 p.s.i. in not more than 0.55 seconds in the case of trucks and buses, and 0.65 seconds in the case of trailers. A vehicle designed to tow another vehicle equipped with air brakes shall meet the above release time requirement with a 50-cubic-inch test reservoir connected to the control line output coupling. A trailer, including a trailer converter dolly, shall meet the above release time requirement with its control line input coupling connected to the test rig shown in Figure 1(a).

S5.4 *Service brake system—dynamometer tests.* When tested without prior road testing, under the conditions of S6.2, each brake assembly shall meet the requirements of S5.4.1, S5.4.2, and S5.4.3 when tested in sequence and without adjustments other than those specified in the standard. For purposes of the requirements of S5.4.2 and S5.4.3, an average deceleration rate is the change in velocity divided by the deceleration time measured from the onset of deceleration.

S5.4.1 *Brake retardation force.* The sum of the retardation forces exerted by the brakes on each vehicle designed to be towed by another vehicle equipped with air brakes shall be such that the quotient sum of the brake retardation forces/sum of OAWR's

relative to brake chamber air pressure, shall have values not less than those shown in Column 1 of Table III. Retardation force shall be determined as follows:

TABLE III—BRAKE RETARDATION FORCE

| Brake retardation force, OAWR—Col. 1 | Brake chamber pressure, psi—Col. 2 |
|---|---|
| 0.05 | 20 |
| 0.12 | 30 |
| 0.18 | 40 |
| 0.25 | 50 |
| 0.31 | 60 |
| 0.37 | 70 |
| 0.41 | 80 |

S5.4.1.1 After burnishing the brake pursuant to S6.2.6, retain the brake assembly on the inertia dynamometer. With an initial brake temperature between 125° F. and 200° F., conduct a stop from 50 m.p.h., maintaining brake chamber air pressure at a constant 20 p.s.i. Measure the average torque exerted by the brake from the time the specified air pressure is reached until the brake stops and divide by the static loaded tire radius specified by the tire manufacturer to determine the retardation force. Repeat the procedure six times, increasing the brake chamber air pressure by 10 p.s.i. each time. After each stop, rotate the brake drum or disc until the temperature of the brake falls to between 125° F., and 200° F.

S5.4.2 *Brake power.* When mounted on an inertia dynamometer, each brake shall be capable of making 10 consecutive decelerations at an average rate of 9 f.p.s.p.s. from 50 m.p.h. to 15 m.p.h., at equal intervals of 72 seconds, and shall be capable of decelerating to a stop from 20 m.p.h. at an average deceleration rate of 14 f.p.s.p.s. 1 minute after the 10th deceleration. The series of decelerations shall be conducted as follows:

S5.4.2.1 With an initial brake temperature between 150° F. and 200° F. for the first brake application, and the drum or disc rotating at a speed equivalent to 50 m.p.h., apply the brake and decelerate at an average deceleration rate of 9 f.p.s.p.s. to 15 m.p.h. Upon reaching 15 m.p.h., accelerate to 50 m.p.h. and apply the brake for a second time 72 seconds after the start of the first application. Repeat the cycle until 10 decelerations have been made. The service line air pressure shall not exceed 100 p.s.i. during any deceleration.

S5.4.2.2 One minute after the end of the last deceleration required by S5.4.2.1 and with the drum or disc rotating at a speed of 20 m.p.h., decelerate to a stop at an average deceleration rate of 14 f.p.s.p.s.

S5.4.3 *Brake recovery.* Starting 2 minutes after completing the tests required by S5.4.2, the brake of a vehicle other than either front axle brake of a truck-tractor shall be capable of making 20 consecutive stops from 30 mph at an average deceleration rate of 12 ft/s/s, at equal intervals of 1 minute measured from the start of each brake application. The service line air pressure needed to attain a rate of 12 ft/s/s shall be not more than 85 lb/in², and not less than 20 lb/in² for a brake not subject to the control of an antilock system, or 12 lb/in² for brake subject to the control of an antilock system.

S5.5 *Antilock system.*

S5.5.1 *Antilock system failure.* On a vehicle equipped with an antilock system, electrical failure 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 equipped with an antilock system that requires electrical power for operation, the power shall be obtained from the stop lamp circuit. Additional circuits may also be used to obtain redundant sources of electrical power.

S5.6 *Parking brake system.* Each vehicle other than a trailer converter dolly shall have a parking brake system that under the conditions of S6.1 meets the requirements of S5.6.1 or S5.6.2, at the manufacturer's option, and the requirements of S5.6.3, S5.6.4, S5.6.5, and S5.6.6. However, the trailer portion of any agricultural commodity trailer, heavy hauler trailer, or pulpwood trailer, shall meet the requirements of this section, or, at the option of the manufacturer, the requirements of § 393.43 of this title.

S5.6.1 *Static retardation force.* With all other brakes rendered inoperative, during a static drawbar pull in a forward or rearward direction, the static retardation force produced by the application of the parking brakes shall be:

(a) In the case of a vehicle other than a truck-tractor that is equipped with more than two axles, such that the quotient

*static retardation force*/GAWR

is not less than 0.28 for any axle other than a steerable front axle; and

(b) In the case of a truck-tractor that is equipped with more than two axles, such that the quotient

*static retardation force*/GVWR

is not less than 0.14.

S5.6.2 *Grade holding.* With all parking brakes applied, the vehicle shall remain stationary facing uphill and facing downhill on a smooth, dry portland cement concrete roadway with a 20-percent grade, both (a) when loaded to its gross vehicle weight rating, and (b) at its unloaded vehicle weight plus 500 pounds (including driver and instrumentation).

S5.6.3 *Application and holding.* Each parking brake system shall meet the requirements of S5.6.3.1 through S5.6.3.4, except that, at the option of the manufacturer, the parking brake system in each vehicle manufactured before December 9, 1991 may meet either those requirements or the requirements specified in S5.6.3.5.

S5.6.3.1 The parking brake system shall be capable of achieving the minimum performance specified either in S5.6.1 or S5.6.2 with any single leakage-type failure, in any other brake system, of a part designed to contain compressed air or brake fluid (excluding failure of a component of a brake chamber housing but including failure of any brake chamber diaphragm that is part of any other brake system including a diaphragm which is common to the parking brake system and any other brake system), when the pressures in the vehicle's parking brake chambers are at the levels determined in S5.6.3.4.

S5.6.3.2 A mechanical means shall be provided that, after a parking brake application is made with the pressures in the vehicle's parking brake chambers at the levels determined in S5.6.3.4, and all air and fluid pressures in the vehicle's braking systems are then bled down to zero, and without using electrical power, holds the parking brake application with sufficient parking retardation force to meet the minimum performance specified in S5.6.3.1 and in either S5.6.1 or S5.6.2.

S5.6.3.3 For trucks and buses, with an initial reservoir system pressure of 100 psi and, if designed to tow a vehicle equipped with air brakes, with a 50 cubic inch test reservoir connected to the supply line coupling, no later than three seconds from the time of actuation of the parking brake control, the mechanical means referred to in S5.6.3.2 shall be actuated. For trailers, with the supply line initially pressurized to 100 psi using the supply line portion of the trailer test rig (Figure 1) and, if designed to tow a vehicle equipped with air brakes, with a 50 cubic inch test reservoir connected to the rear supply line coupling, no later than three seconds from the time venting to the atmosphere of the front supply line coupling is initiated, the mechanical means referred to in S5.6.3.2 shall be actuated. This requirement shall be met for trucks, buses and trailers both with and without any single leakage-type failure, in any other brake system, of a part designed to contain compressed air or brake fluid (excluding failure of a component of a brake chamber housing but including failure of any brake chamber diaphragm that is part of any other brake system including a diaphragm which is common to the parking brake system and any other brake system).

S5.6.3.4 The parking brake chamber pressures for S5.6.3.1 and S5.6.3.2 are determined as follows. For trucks and buses, with an initial reservoir system pressure of 100 psi and, if designed to tow a vehicle equipped with air brakes, with a 50 cubic inch test reservoir connected to the supply line coupling, any single leakage type failure, in any other brake system, of a part designed to contain compressed air or brake fluid (excluding failure of a component of a brake chamber housing but including failure of any brake chamber diaphragm that is part of any other brake system including a diaphragm which is common to the parking brake system and any other brake system), is introduced in the brake system. The parking brake control is actuated and the pressures in the vehicle's parking brake chambers are measured three seconds after that actuation is initiated. For trailers, with the supply line initially pressurized to 100 psi using the supply line portion of the trailer test rig (Figure 1) and, if designed to tow a vehicle equipped with air brakes, with a 50 cubic inch test reservoir connected to the rear supply line coupling, any single leakage type failure, in any other brake system, of a part designed to contain compressed air or brake fluid (excluding failure of a component of a brake chamber housing but including failure of any brake chamber diaphragm that is part of any other brake system including a diaphragm which is common to the parking brake system and any other brake system), is introduced in the brake system. The front supply line coupling is vented to the atmosphere and the pressures in the vehicle's parking brake chambers are measured three seconds after that venting is initiated.

S5.6.3.5 *Optional requirement for vehicles manufactured before December 9, 1991.* The parking brake system shall be capable of achieving the minimum performance specified either in S5.6.1 or S5.6.2 with any single leakage-type failure, in any other brake system, of a part designed to contain compressed air or brake fluid (excluding failure of a component of a brake chamber housing but including failure of any brake chamber diaphragm that is part of any other brake system including a diaphragm which is common to the parking brake system and any other brake system). Once applied, the parking brakes shall be held in the applied position solely by mechanical means.

S5.6.4 *Parking brake control—trucks and buses.* The parking brake control shall be separate from the service brake control. It shall be operable by a person seated in the normal driving position. The control shall be identified in a manner that specifies the method of control operation. The parking brake control shall control the parking brakes of the vehicle and of any air braked vehicle that it is designed to tow.

S5.6.5 *Release Performance.* Effective December 9, 1991, each parking brake system shall meet the requirements specified in S5.6.5.1 through S5.6.5.4.

S5.6.5.1 For trucks and buses, with initial conditions as specified in S5.6.5.2, at all times after an application actuation of the parking brake control, and with any subsequent level of pressure, or combination of levels of pressure, in the reservoirs of any of the vehicle's brake systems, no reduction in parking brake retardation force shall result from a release actuation of the parking brake control unless the parking brakes are capable, after such release, of being reapplied at a level meeting the minimum performance specified either in S5.6.1 or S5.6.2. This requirement shall be met both with and without the engine on, and with and without single leakage-type failure, in any other brake system, of a part designed to contain compressed air or brake fluid (excluding failure of a component of a brake chamber housing but including failure of any brake chamber diaphragm that is part of any other brake system including a diaphragm which is common to the parking brake system and any other brake system).

S5.6.5.2 The initial conditions for S5.6.5.1 are as follows. The reservoir system pressure is 100 psi. If the vehicle is designed to tow a vehicle equipped with air brakes, a 50 cubic inch test reservoir is connected to the supply line coupling.

S5.6.5.3 For trailers, with initial conditions as specified in S5.6.5.4, at all times after actuation of the parking brakes by venting the front supply line coupling to the atmosphere, and with any subsequent level of pressure, or combination of levels of pressure, in the reservoirs of any of the vehicle's brake systems, the parking brakes shall not be releasable by repressurizing the supply line using the supply line portion of the trailer test rig (Figure 1) to any pressure above 70 psi, unless the parking brakes are capable, after such release, of reapplication by subsequent venting of the front supply line coupling to the atmosphere, at a level meeting the minimum performance specified either in S5.6.1 or S5.6.2. This requirement shall be met both with and without any single leakage-type failure, in any other brake system, of a part designed to contain compressed air or brake fluid (excluding failure of a component of a brake chamber housing but including failure of any brake chamber diaphragm that is part of any other brake system including a diaphragm which is common to the parking brake system and any other brake system).

S5.6.5.4 The initial conditions for S5.6.5.3 are as follows. The reservoir system and supply line are pressurized to 100 psi, using the supply line portion of the trailer test rig (Figure 1). If the vehicle is designed to tow a vehicle equipped with air brakes, a 50 cubic inch test reservoir is connected to the rear supply line coupling.

S5.6.6 *Accumulation of Actuation Energy.* Effective December 9, 1991, each parking brake system shall meet the requirements specified in S5.6.6.1 through S5.6.6.6.

S5.6.6.1 For trucks and buses, with initial conditions as specified in S5.6.6.2, the parking brake system shall be capable of meeting the minimum performance specified either in S5.6.1 or S5.6.2, with any single leakage-type failure, in any other brake system, of a part designed to contain compressed air or brake fluid (excluding failure of a component of a brake chamber housing but including failure of any brake chamber diaphragm that is part of any other brake system including a diaphragm which is common to the parking brake system and any other brake system), at the conclusion of the test sequence specified in S5.6.6.3.

S5.6.6.2 The initial conditions for S5.6.6.1 are as follows. The engine is on. The reservoir system pressure is 100 psi. If the vehicle is designed to tow a vehicle equipped with air brakes, a 50 cubic inch test reservoir is connected to the supply line coupling.

S5.6.6.3 The test sequence for S5.6.6.1 is as follows. The engine is turned off. Any single leakage type failure, in any other brake system, of a part designed to contain compressed air or brake fluid (excluding failure of a component of a brake chamber housing but including failure of any brake chamber diaphragm that is part of any other brake system including a diaphragm which is common to the parking brake system and any other brake system), is then introduced in the brake system. An application actuation of the parking brake control is then made. Thirty seconds after such actuation, a release actuation of the parking brake control is made. Thirty seconds after the release actuation, a final application actuation of the parking brake control is made.

S5.6.6.4 For trailers, with initial conditions as specified in S5.6.6.5, the parking brake system shall be capable of meeting the minimum performance specified either in S5.6.1 or S5.6.2, with any single leakage-type failure, in any other brake system, of a part designed to contain compressed air or brake fluid (excluding failure of a component of a brake chamber housing but including failure of any brake chamber diaphragm that is part of any other brake system including a diaphragm which is common to the parking brake system and any other brake system), at the conclusion of the test sequence specified in S5.6.6.6.

S5.6.6.5 The initial conditions for S5.6.6.4 are as follows. The reservoir system and supply line are pressurized to 100 psi, using the supply line portion of the trailer test rig (Figure 1). If the vehicle is designed to tow a vehicle equipped with air brakes, a 50 cubic inch test reservoir is connected to the rear supply line coupling.

S5.6.6.6 The test sequence for S5.6.6.4 is as follows. Any single leakage type failure, in any other brake system, of a part designed to contain compressed air or brake fluid (excluding failure of a component of a brake chamber housing but including failure of any brake chamber diaphragm that is part of any other brake system including a diaphragm which is common to the parking brake system and any other brake system), is introduced in the brake system. The front supply line coupling is vented to the atmosphere. Thirty seconds after the initiation of such venting, the supply line is repressurized with the trailer test rig (Figure 1). Thirty seconds after the initiation of such repressurizing of the supply line, the front supply line is vented to the atmosphere. This procedure is conducted either by connection and disconnection of the supply line coupling or by use of a valve installed in the supply line portion of the trailer test rig near the supply line coupling.

S5.7 *Emergency brake system—trucks and buses.* Each vehicle shall be equipped with an emergency brake system which, under the conditions of S6.1, conforms to the requirements of S5.7.1 through S5.7.3. However, the truck portion of an auto transporter need not meet the road test requirements of S5.7.1 and S5.7.3.

S5.7.1 *Emergency brake system performance.* When stopped six times for each combination of weight and speed specified in S5.3.1.1 on a road surface with a skid number of 81, with a single failure in the service brake system of a part designed to contain compressed air or brake fluid (except failure of a common valve, manifold, brake fluid housing, or brake chamber housing), the vehicle shall stop at least once in not more than the distance specified in Column 3 of Table II, measured from the point at which movement of the service brake control begins, without any part of the vehicle leaving the roadway, except that a truck-tractor tested at its unloaded vehicle weight plus 500 pounds shall stop at least once in not more than the distance specified in Column 4 of Table II.

S5.7.2 *Emergency brake system operation.* The emergency brake system shall be applied and released, and be capable of modulation, by means of the service brake control.

S5.7.3 *Towing vehicle emergency brake requirements.* In addition to meeting the other requirements of S5.7, a vehicle designed to tow another vehicle equipped with air brakes shall—

(a) In the case of a truck-tractor in the unloaded condition and a single unit truck which is capable of towing an airbrake equipped vehicle and is loaded to gross vehicle weight rating, be capable of meeting the requirements of S5.7.1 by operation of the service brake control only, with the trailer air supply line and air control line from the towing vehicle vented to the atmosphere in accordance with S6.1.14;

(b) In the case of a truck-tractor loaded to gross vehicle weight rating, be capable of meeting S5.7.1 by operation of the service brake control only, with the air control line from the towing vehicle vented to the atmosphere in accordance with S6.1.14; and

(c) Be capable of modulating the air in the supply or control line to the trailer by means of the service brake control with a single failure in the towing vehicle service brake system as specified in S5.7.1.

S5.8 *Emergency braking capability—trailers.* Each trailer other than a trailer converter dolly shall have a parking brake system that conforms to S5.6 and that applies with the force specified in S5.6.1 or S5.6.2 when the air pressure in the supply line is at atmospheric pressure. A trailer converter dolly shall have, at the manufacturer's option, (a) a parking brake system that conforms to S5.6 and that applies with the force specified in S5.6.1 or S5.6.2 when the air pressure in the supply line is at atmospheric pressure, or (b) an emergency system that automatically controls the service brakes when the service reservoir is at any pressure above 20 lb/in² and the supply line is at atmospheric pressure. However, the trailer portion of an auto transporter manufactured before January 1, 1980, and any agricultural commodity trailer, heavy hauler trailer, or pulpwood trailer shall meet the requirements of this section or, at the option of the manufacturer, the requirements of § 393.43 of this title.

S6 *Conditions.* The requirements of S5 shall be met by a vehicle when it is tested according to the conditions set forth below, without replacing any brake system part or making any adjustments to the brake system except as specified. Unless otherwise specified, where a range of conditions is specified, the vehicle must be capable of meeting the requirements at all points within the range. On vehicles equipped with automatic brake adjusters, the automatic brake adjusters must remain activated at all times. Compliance of vehicles manufactured in two or more stages may, at the option of the final-stage manufacturer, be demonstrated to comply with this standard by adherence to the instructions of the incomplete vehicle manufacturer provided with the vehicle in accordance with § 568.4(a)(7)(ii) and § 568.5 of title 49 of the Code of Federal Regulations.

S6.1 *Road test conditions.*

S6.1.1. Except as otherwise specified, the vehicle is loaded to its gross vehicle weight rating, distributed proportionally to its gross axle weight ratings. During the burnish procedure specified in S6.1.8, truck tractors shall be loaded to their GVWR, by coupling them to an unbraked flatbed semitrailer, which semitrailer shall be loaded so that the weight of the tractor-trailer combination equals the GVWR of the truck tractor. The load on the unbraked flatbed semitrailer shall be located so that the truck tractor's wheels do not lock during burnish.

S6.1.2 The inflation pressure is as specified by the vehicle manufacturer for the gross vehicle weight rating.

S6.1.3 Unless otherwise specified, the transmission selector control is in neutral or the clutch is disengaged during all decelerations and during static parking brake tests.

S6.1.4 All vehicle openings (doors, windows, hood, trunk, cargo doors, etc.) are in a closed position except as required for instrumentation purposes.

S6.1.5 The ambient temperature is between 32° F. and 100° F.

S6.1.6 The wind velocity is zero.

S6.1.7 Unless otherwise specified, stopping tests are conducted on a 12-foot wide level, straight roadway having a skid number of 81. The vehicle is alined in the center of the roadway at the beginning of a stop.

S6.1.8 The brakes are burnished before testing in accordance with S6.1.8.1. However, for vehicles with parking brake systems not utilizing the service brake friction elements, burnish the friction elements of such systems prior to the parking bake test according to the manufacturer's recommendations.

S6.1.8.1 Vehicles manufactured before September 1, 1993 may be burnished according to the procedures set forth in S6.1.8.1(a) or S6.1.8.1(b) of this section, at the manufacturers option. Vehicles manufactured on or after September 1, 1993 shall be burnished according to the procedures set forth in S6.1.8.1(b) of this section.

(a) With the transmission in the highest gear appropriate for the series given in Table IV, make 500 brake applications at a decleration rate of 10 fsps, or at the vehicles maximum deceleration rate if less than 10 fsps, in the sequence specified. Except where an adjustment is specified, after each brake application accelerate to the next speed specified and maintain that speed until making the next brake application at a point 1 mile from the initial point of the previous brake application. If a vehicle cannot attain any speed specified in 1 mile, continue to accelerate until the specified speed is reached or until the vehicle has traveled 1.5 miles from the initial point of the previous brake application, whichever occurs first. If during any of the brake applications specified in Table IV the hottest brake reaches 550° F, make the remainder of the 500 brake applications from that snub condition, except that a higher or lower snub condition shall be used as necessary to maintain an after-stop temperature of 500° F ± 50° F. However, if at a snub condition of 40 to 20 mph, the temperature of the hottest brake exceeds 550° F, make the remainder of the 500 brake applications from that snub condition, without regard to brake temperature. The brakes shall be adjusted three times during the burnish procedure, after 125, 250, and 375 snubs and after completing this burnish, with each adjustment made in accordance with the manufacturer's recommendations. Any automatic pressure limiting valve is in use to limit pressure as designed, except that any automatic front axle pressure limiting valve is bypassed if the temperature of the hottest brake on a rear axle exceeds the temperature of the hottest brake on a front axle by more than 125° F. A bypassed valve is reconnected if the temperature of the hottest brake on a front axle exceeds the temperature of the hottest brake on a rear axle by 100° F or more.

TABLE IV

| Series | Snubs | Snub conditions (highest speed indicated, miles per hour) |
|---|---|---|
| 1 | 175 | 40-20 |
| 2 | 25 | 45-20 |
| 3 | 25 | 50-20 |
| 4 | 25 | 55-20 |
| 5 | 250 | 60-20 |

(b) With the transmission in the highest gear appropriate for a speed of 40 mph, make 500 snubs between 40 mph and 20 mph at a deceleration rate of 10 fsps, or at the vehicle's maximum deceleration rate if less than 10 fsps. Except where an adjustment is specified, after each brake application accelerate to 40 mph and maintain that speed until making the next brake application at a point 1 mile from the initial point of the previous brake application. If the vehicle cannot attain a speed of 40 mph in 1 mile, continue to accelerate until the vehicle reaches 40 mph or until the vehicle has traveled 1.5 miles from the initial point of the previous brake application, whichever occurs first. Any automatic pressure limiting valve is in use to limit pressure as designed. The brakes shall be adjusted three times during the burnish procedure, in accordance with the manufacturer's recommendations, after 125, 250, and 375 snubs, and shall be adjusted after burnish in accordance with the manufacturer's recommendations.

S6.1.9 Static parking brake tests for a semitrailer are conducted with the front-end supported by an unbraked dolly. The weight of the dolly is included as part of the trailer load.

S6.1.10 In a test other than a static parking brake test, a truck-tractor is tested at its gross vehicle weight rating by coupling it to a flatbed semitrailer (hereafter, control trailer) as specified in S6.1.10.1 to S6.1.10.7

S6.1.10.1 The control trailer conforms to this standard.

S6.1.10.2 The center of gravity of the loaded control trailer is on the trailer's longitudinal centerline at a height of 66±3 in. above the ground.

S6.1.10.3 For a truck-tractor with a rear axle gross axle weight rating of 26,000 lb or less, the control trailer has a single axle with a gross axle weight rating of 18,000 lb and a length, measured from the transverse centerline of the axle to the centerline of the kingpin, of 258±6 in.

S6.1.10.4 For a truck-tractor with a total rear axle gross axle weight rating of more than 26,000 lb the control trailer has a tandem axle with a combined gross axle weight rating of 32,000 lb and a length, measured from the transverse centerline between the axles to the centerline of the kingpin, of 390±6 in.

S6.1.10.5 The control trailer is loaded so that its axle is loaded to its gross axle weight rating and the tractor is loaded to its gross vehicle weight rating, 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 gross axle weight ratings.

S6.1.10.6 *Test equipment specification.* The control trailer's service brakes are capable of stopping the combination from the maximum speed at which the tractor is tested, under the conditions of S6.1, without assistance from the tractor brakes, in the distance found by multiplying the value 68, 90, 115, 143, 174, 208, or 245 (corresponding to a speed of 30, 35, 40, 45, 50, 55, or 60 mph as appropriate for the truck-tractor tested) by the ratio:

weight on all axles of combination/weight on trailer axles

with the tractor's fifth wheel adjusted as specified in S6.1.10.5, the trailer service reservoirs pressurized to 100 lb/in², and the trailer loaded so that its axle is at gross axle weight rating and its kingpin is at empty vehicle weight. The stopping distance is measured from the point at which movement of the valve controlling the trailer brakes begins. The service brake chambers on the trailer reach 60 lb/

in² in not less than 0.20 second and not more than 0.30 second, measured from the instant at which movement of the valve controlling the trailer brakes begins.

S6.1.10.7 *Test equipment specification.* The control trailer's emergency brakes are capable of stopping the combination under the conditions of S6.1 from the maximum speed at which the tractor is tested, without assistance from the tractor's brakes, in the distance found by multiplying the emergency brake stopping distance in column 3 of table II by the ratio:

weight on all axles of combination/weight on trailer axles

with the combination loaded in accordance with S6.1.10.5. Stopping distance is measured from the point at which movement of the valve controlling the trailer brakes begins. The pressure in trailer brakes begins. In the case of control trailers that utilize parking brakes for emergency stopping capability, the pressure in the trailer's spring parking brake chambers falls from 95 lb/in² to 5 lb/in² in not less than 0.50 second and not more than 0.60 second, measured from the instant at which movement of the valve controlling the trailer's spring parking brakes begins.

S6.1.11 *Special drive conditions.* A vehicle equipped with an interlocking axle system or a front wheel drive system that is engaged and disengaged by the driver is tested with the system disengaged.

S6.1.12 *Liftable axles.* A vehicle with a liftable axle is tested at gross vehicle weight rating with the liftable axle down and at unloaded vehicle weight with the liftable axle up.

S6.1.13 *Trailer test rig.*

(a) The trailer test rig shown in Figure 1 is calibrated in accordance with the calibration curves shown in Figure 3. For the requirements of S5.3.3.1 and S5.3.4.1, the pressure in the trailer test rig reservoir is initially set at 100 p.s.i. for actuation tests and 95 p.s.i. for release tests.

(b) The trailer test rig shown in Figure 1(a) is capable of increasing the pressure in a 50 cubic inch reservoir from atmospheric to 60 lb/in² in 0.06 second, measured from the first movement of the service brake control to apply service brake pressure and of releasing pressure in such a reservoir from 95 to 5 lb/in² in 0.22 second measured from the first movement of the service brake control to release service brake pressure.

S6.1.14 In testing the emergency braking system of towing vehicles under S5.7.3(a) and S5.7.3(b), the hose(s) is vented to the atmosphere at any time not less than 1 second and not more than 1 minute before the emergency stop begins, while the vehicle is moving at the speed from which the stop is to be made and any manual control for the towing vehicle protection system is in the position to supply air and brake control signals to the vehicle being towed. No brake application is made from the time the line(s) is vented until the emergency stop begins and no manual operation of the parking brake system or towing vehicle protection system occurs from the time the line(s) is vented until the stop is completed.

S6.2 *Dynamometer test conditions.*

S6.2.1 The dynamometer inertia for each wheel is equivalent to the load on the wheel with the axle loaded to its gross axle weight rating. For a vehicle having additional gross axle weight ratings specified for operation at reduced speeds, the GAWR used is that specified for a speed of 50 mph., or, at the option of the manufacturer, any speed greater than 50 mph.

S6.2.2 The ambient temperature is between 75° F. and 100° F.

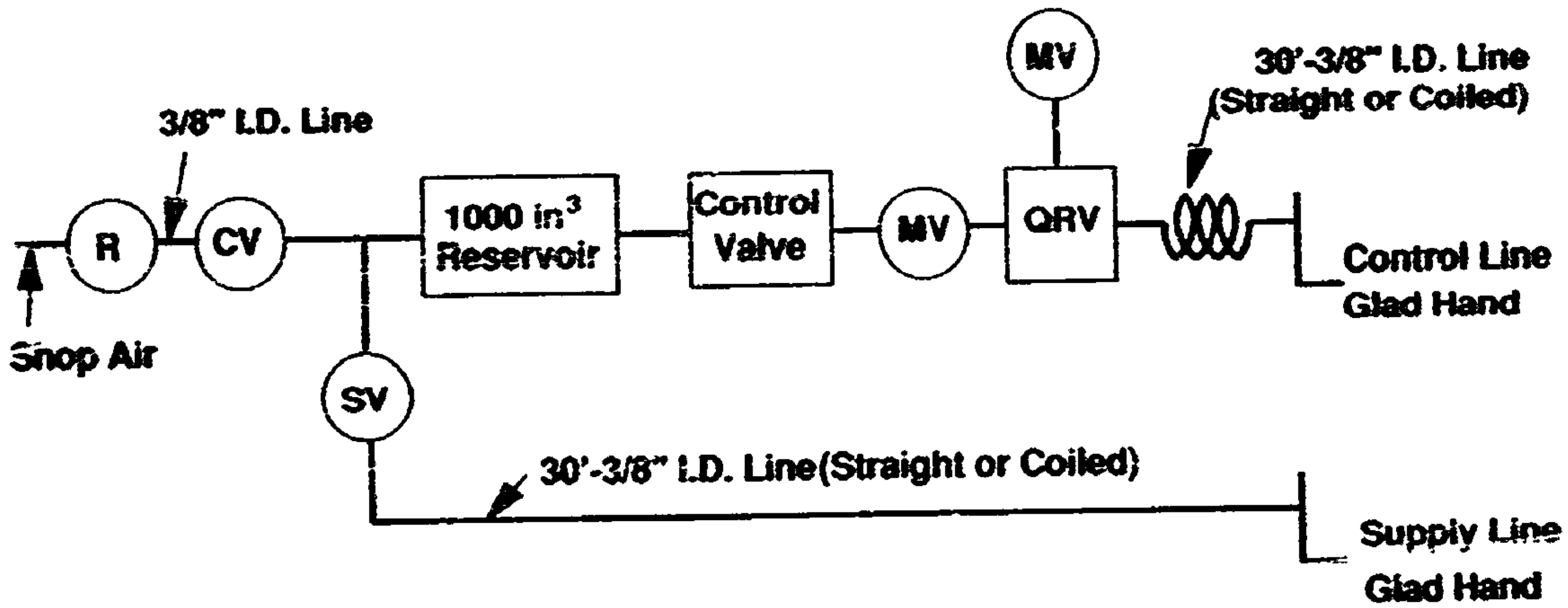
S6.2.3 Air at ambient temperature is directed uniformly and continuously over the brake drum or disc at a velocity of 2,200 feet per minute.

S6.2.4 The temperature of each brake is measured by a single plug-type thermocouple installed in the center of the lining surface of the most heavily loaded shoe or pad as shown in Figure 2. The thermocouple is outside any center groove.

S6.2.5 The rate of brake drum or disc rotation on a dynamometer corresponding to the rate of rotation on a vehicle at a given speed is calculated by assuming a tire radius equal to the static loaded radius specified by the tire manufacturer.

S6.2.6 Brakes are burnished before testing as follows: Place the brake assembly on an inertia dynamometer and adjust the brake as recommended by the brake manufacturer. Make 200 stops from 40 m.p.h. at a deceleration of 10 f.s.p.s., with an initial brake temperature on each stop of not less than 315° F and not more than 385° F. Make 200 additional stops from 40 m.p.h. at a deceleration of 10 f.s.p.s. with an initial brake temperature on each stop of not less than 450° F and not more than 550° F. The brakes shall be adjusted three times during the burnish procedure, after 100, 200, and 300 stops, and at the conclusion of the burnishing, in accordance with the manufacturer's recommendations.

S6.2.7 The brake temperature is increased to a specified level by conducting one or more stops from 40 m.p.h. at a deceleration of 10 f.p.s.p.s. The brake temperature is decreased to a specified level by rotating the drum or disc at a constant 30 m.p.h.




SV - Shut-off Valve
R - Regulator (set at 100 psi for service brake actuation tests;
95 psi for service brake release tests;
100 psi for parking brake tests in S5.6.3.3, S5.6.3.4, S5.6.5.4 and S5.6.6.5;
and any pressure above 70 psi forparking brake test in S5.6.5.3)
CV - Check Valve
MV - Metering Valve (Variable or Fixed)
QRV - Quick Release Valve

**Figure 1. Trailer Test Rig.**

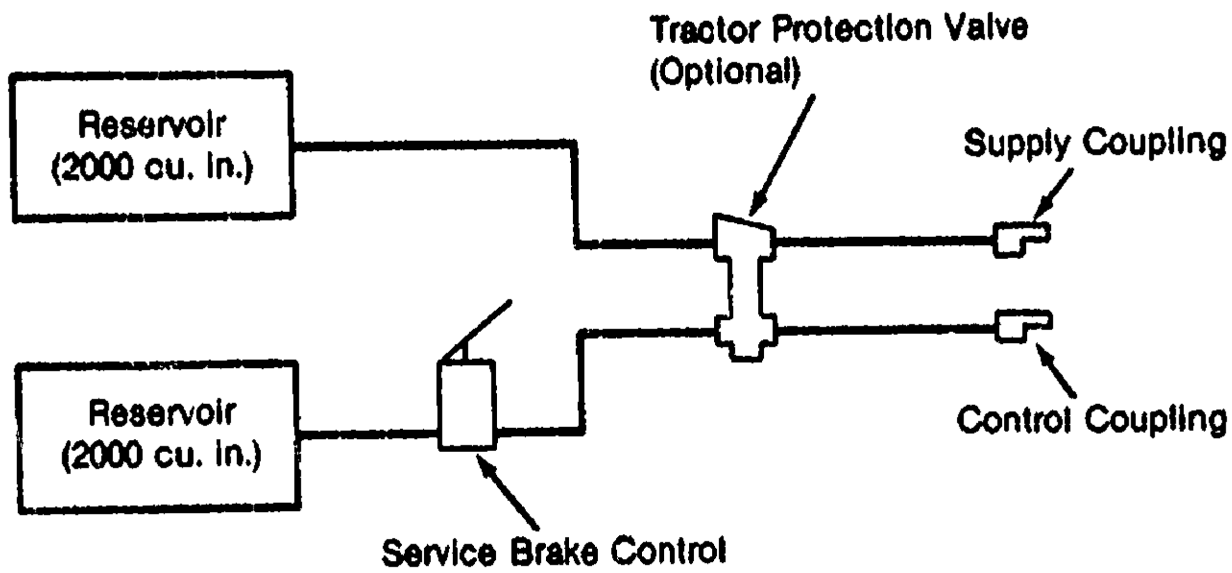
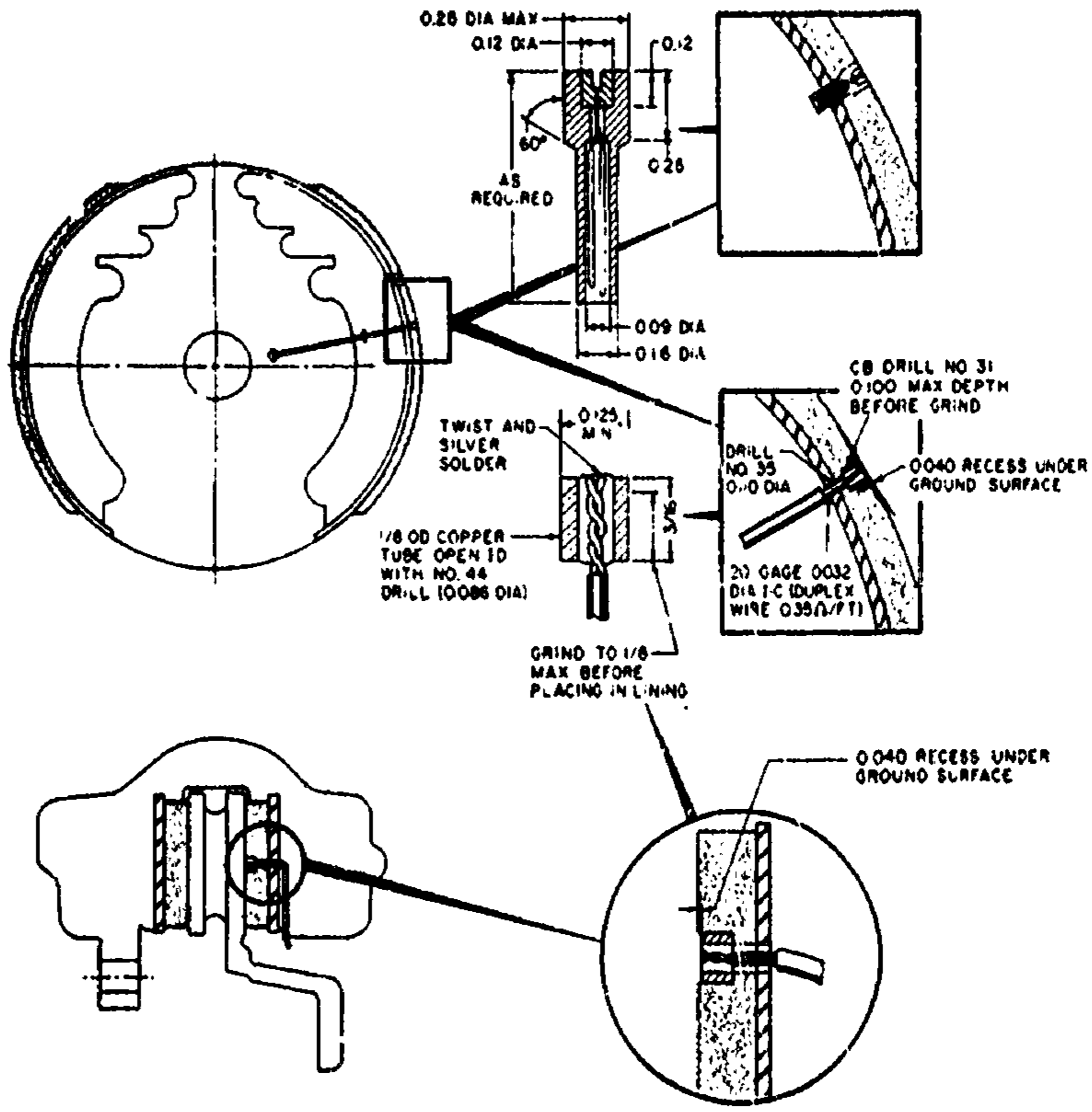



Figure 1(a). Trailer Test Rig.

# FIGURE 2
# THERMOCOUPLE INSTALLATION



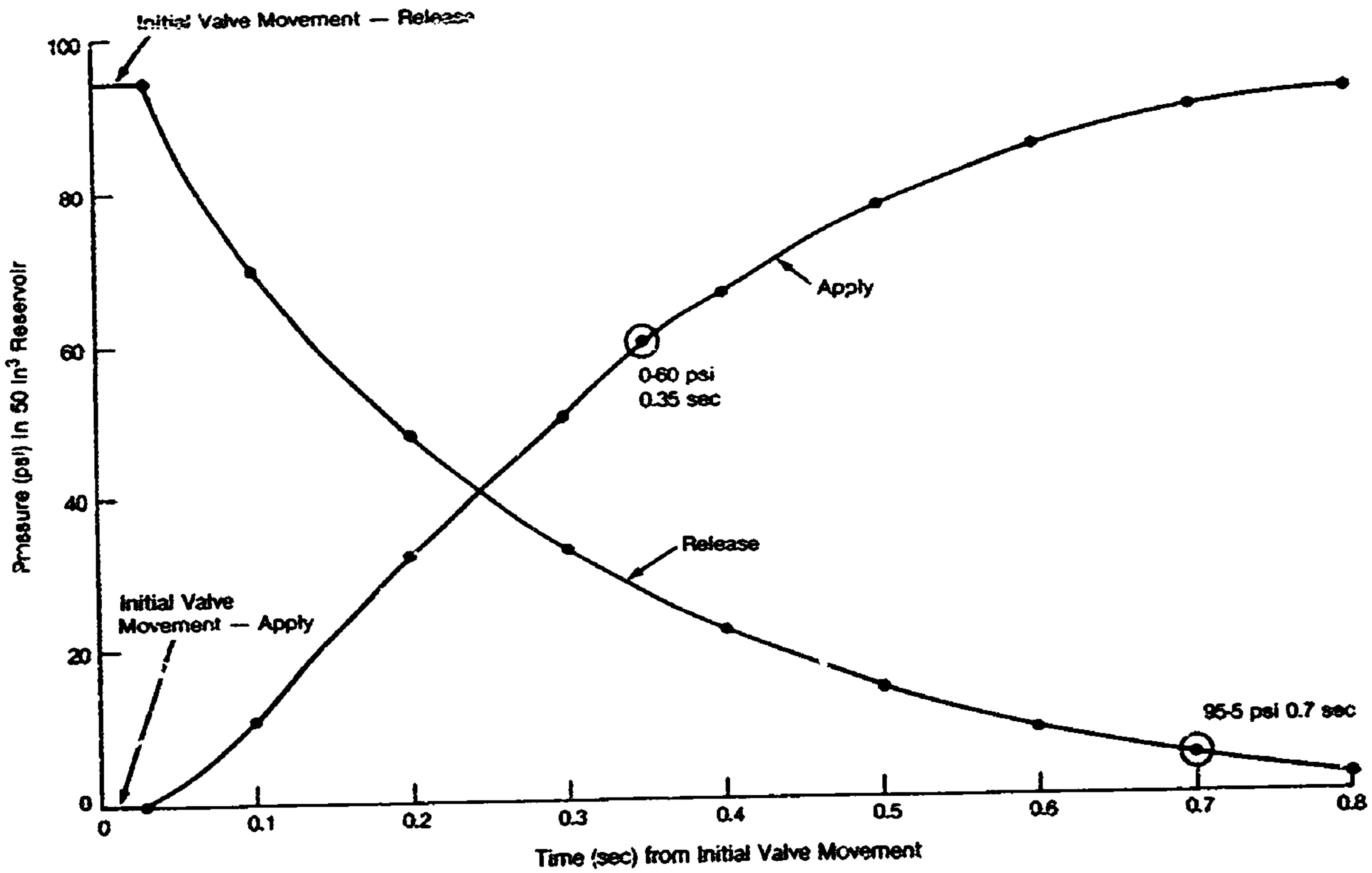



**Figure 3. Pressure vs. Time for 50 in³ Test Reservoir.**

(Secs. 102, 103, 119, Pub. L. 89-563, 80 Stat. 718 (15 U.S.C. 1391, 1392, 1407); delegation of authority at 49 CFR 1.50 and 501.8)

[41 FR 29705, July 19, 1976]

EDITORIAL NOTE: For FEDERAL REGISTER citations affecting § 571.121, see the List of CFR Sections Affected in the Finding Aids section of this volume.

EFFECTIVE DATE NOTE: At 56 FR 26931, June 12, 1991, § 571.121 was amended by revising sections S5.6 introductory text, S5.6.3 through S5.6.3.5, and Figure 1, and by adding sections S5.6.5 through S5.6.5.4 and S5.6.6 through 5.6.6.6, effective December 9, 1991. For the convenience of the user, the superseded text follows:

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

* * * * *

S5.6 *Parking brake system.* Each vehicle other than a trailer converter dolly shall have a parking brake system that under the conditions of S6.1 meets the requirements of S5.6.1 or S5.6.2, at the manufacturer's option, and the requirements of S5.6.3 and S5.6.4. However, any agricultural commodity trailer, heavy hauler trailer, or pulpwood trailer shall meet the requirements of this section or, at the option of the manufacturer, the requirements of § 393.43 of this title.

* * * * *

S5.6.3 *Application and holding.* Each parking brake system shall meet the requirements of S5.6.3.1 through S5.6.3.4, except that, at the option of the manufacturer, vehicles manufactured before September 7, 1991 may meet the requirements specified in S5.6.3.5.

S5.6.3.1 The parking brake system shall be capable of achieving the minimum performance specified either in S5.6.1 or S5.6.2 with any single leakage-type failure, in any other brake system, of a part designed to contain compressed air or brake fluid (except failure of a component of a brake chamber housing).

S5.6.3.2 For trucks and buses, with an initial reservoir system pressure of 100 psi and, if designed to tow a vehicle equipped with air brakes, with a 50 cubic inch test reservoir connected to the supply line coupling, at all times after three seconds from the time of actuation of the parking brake control, the parking brake system shall achieve the minimum parking retardation performance specified in S5.6.3.1. For trailers, with an initial supply line pressure of 100 psi and, if designed to tow a vehicle equipped with air brakes, with a 50 cubic inch test reservoir connected to the supply line coupling, at all times after three seconds from the time venting to the atmosphere of the front supply line connection is initiated, the parking brake system shall achieve the minimum retardation performance specified in S5.6.3.1.

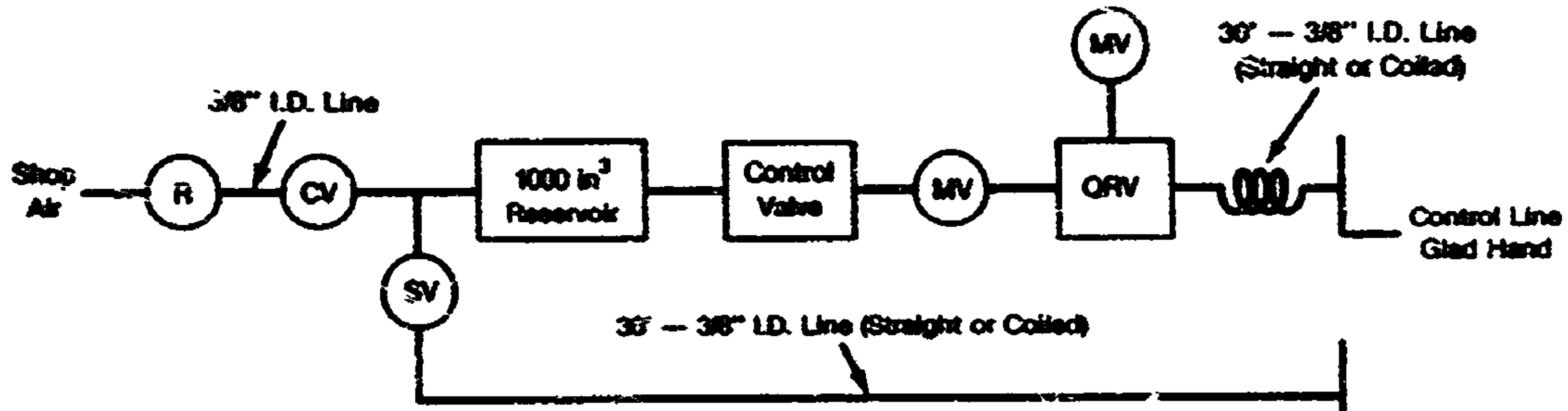
S5.6.3.3 A mechanical means shall be provided which is capable, with zero air pressure and zero fluid pressure in the vehicle and without electrical power, of holding the parking brake application at a level meeting the minimum parking retardation performance specified in S5.6.3.1.

S5.6.3.4 For trucks and buses, with an initial reservoir system pressure of 100 psi and, if designed to tow a vehicle equipped with air brakes, with a 50 cubic inch test reservoir connected to the supply line coupling, no later than three seconds from the time of operation of the parking brake control, the mechanical means referred to in S5.6.3.3 shall be actuated. For trailers, with an initial supply line pressure of 100 psi and, if designed to tow a vehicle equipped with air brakes, with a 50 cubic inch test reservoir connected to the supply line coupling, no later than three seconds from the time venting to the atmosphere of the front supply line connection is initiated, the mechanical means referred to in S5.6.3.3 shall be actuated.

S5.6.3.5 (*Optional requirement for vehicles manufactured before September 7, 1991*). The parking brake system shall be capable of achieving the minimum performance specified either in S5.6.1 or S5.6.2 with any single leakage-type failure, in any other brake system, of a part designed to contain compressed air or brake fluid (except failure of a component of a brake chamber housing). Once applied, the parking brakes shall be held in the applied position solely by mechanical means.

* * * * *

APPENDIX L




SV — Shut-off Valve
R — Regulator (set at 100 psi for actuation tests and 95 psi for release test)
CV — Check Valve
MV — Metering Valve (Variable or Fixed)
QRV — Quick Release Valve

**Figure 1. Trailer Test Rig.**

# APPENDIX M

## HISTORY OF AIRBRAKE PERFORMANCE STANDARDS

The basic air mechanical braking system found on heavy commercial tractor trailers has existed for more than 50 years. A brief history of the development of the airbrake system is shown below:

1919- George Lane develops an airbrake system for logging trucks in the Northwest.
1925- Airbrake system enhancements include foot-operated treadle valves, release valves, and brake chambers.
1930- Air chamber/slack adjusters and relay valves are developed.
1933- Rhode Island legislates a 50-foot stopping distance from 20 mph with either foot- or hand-valve brake application.
1940- Basics of the common airbrake system are in place.
1949- Airbrakes become standard equipment on all heavy trucks.
1955- An accident prompts the Interstate Commerce Commission (ICC) to require a tractor protection valve.
1971- The first Federal Motor Vehicle Safety Standard for heavy truck airbrakes--FMVSS 121--was instituted.
1978- Appeals Court set aside "no wheel" locked test requirement of FMVSS 121.

### History of Brake Performance Standards and Certification Process

ICC Regulation.--Before the Highway Safety Act of 1966 was enacted, no regulations mandated the performance of newly manufactured air-braked vehicles. These vehicles were only regulated once they were on the road by individual States and by requirements promulgated by the ICC.

The Motor Carrier Act of 1935 made the ICC responsible for enacting regulations governing the safety of heavy trucks in interstate commerce. As early as 1940, heavy trucks were required to decelerate to a stop from 20 mph in a specified distance. ICC regulations required that a combination unit equipped with brakes on all wheels stop in 30 feet from 20 mph. If the combination unit did not have brakes on all wheels, it was required to stop in 45 feet from 20 mph. By 1965, the Bureau of Motor Carrier Safety had relaxed this requirement to a 50-foot stopping distance for all combinations of heavy vehicles. By 1976, the regulation became more stringent, requiring combinations of heavy trucks to stop in 40 feet from 20 mph.

SAE Standards.--In 1967, the Society of Automotive Engineers (SAE) developed a performance standard, "Brake Performance Requirements-Truck, Bus, and Combinations of Vehicles-SAE Recommended Practice H992b." (This standard was revised in May 1971 and reaffirmed without change in 1985.) The introduction to this standard states, "The performance requirements in this SAE Recommended Practice represent the accumulation of the best information available from investigation of the brake system performance of new motor vehicles designed for roadway use." In other words, the performance test defined by the SAE represents a desired, state-of-the-art standard not one necessarily attainable by all manufacturers. The recommended practice in this standard requires that a combination vehicle decelerate to a stop at a minimum of 12 f.p.s.p.s. (deceleration rate in feet per second per second) from 50 mph without leaving a 12-foot-wide lane. Additionally, a combination vehicle is required to decelerate to a stop from 20 mph in 45 feet and to develop a deceleration rate of 14 feet f.p.s.p.s. at some time during that stop.

NHTSA Rule.--On October 11, 1967, the National Highway Safety Bureau (NHSB), then a division of the Federal Highway Administration and later to become the National Highway Traffic Safety Administration (NHTSA), issued an Advance Notice of Proposed Rulemaking for Federal Motor Vehicle Safety Standards. This notice solicited comments on 47 aspects of motor vehicle safety. One aspect dealt with braking performance of passenger vehicles, trucks, buses, and trailers. In June 1970, a Notice of Proposed Rulemaking (NPRM) was issued for Federal Motor Vehicle Safety Standard 121, "Air Brake Systems." The initial working draft of the NPRM specified that an air-braked vehicle must be able to stop from 60 mph in 196 feet. The published NPRM specified air-braked vehicles to stop from 60 mph in 245 feet. This distance was later relaxed to 293 feet. This standard eventually went through 8 years of rulemaking. At the end of that time, many of its requirements were invalidated by Federal Court litigation.

The U.S. Court of Appeals for the Ninth Circuit prevented NHTSA from enforcing the stopping distance requirements. This judgment resulted from a petition filed by Paccar, the holding company for Kenworth and Peterbilt Truck manufacturers, on January 3, 1975. The petition for review of FMVSS 121 requested that the court set aside all portions of this standard. Additionally, on January 17, 1975, Paccar, Inc., petitioned the court to suspend, or stay, the enforcement of FMVSS 121, pending review of the issue. On February 10, 1975, the court denied the motion for a stay of the standard and agreed to review the case.

Similar court petitions were filed by two other organizations: the Truck Equipment and Body Distributors Association and the American Trucking Associations. The three review proceedings were consolidated into one case before the Court of Appeals for the Ninth Circuit on October 15, 1975. When oral arguments were presented on January 16, 1976, the court announced it would stay FMVSS 121 for a minimum of 60 days. The Government appealed to the U.S. Supreme Court to reverse that suspension, and Supreme Court did so on January 30, 1976.

The April 29, 1976, "Order Setting the Record and the Issues," filed before the court listed the following issues:

1. Whether, in promulgating FMVSS 121, NHTSA complied with its statutory duty to consider relevant available motor vehicle safety data, including results of research, development, testing, and evaluation activities (15 USC 1392(f)(1)).

2. Whether FMVSS 121 fulfilled the statutory requirement of meeting the need for motor vehicle safety (15 USC 1392(a)).

3. Whether FMVSS 121 established performance, rather than design, requirements.

4. Whether FMVSS 121 fulfilled the statutory requirement of practicability (15 USC 1392(a)).

5. Whether FMVSS 121 fulfilled the statutory requirement of being stated in objective terms.

6. Whether the NHTSA's promulgation of FMVSS 121 was arbitrary, capricious, or an abuse of discretion.

Facts not contested by any of the parties involved in the case were continued in the section entitled "Admitted Facts."

1. Except for testing described in the Murphy Report, the NHTSA did not conduct any reliability testing of vehicles with FMVSS 121 components prior to the effective dates of FMVSS 121.

2. There have been nine safety related defect reports made to NHTSA involving antilock systems.

3. There are vehicles not equipped with FMVSS 121 equipment that can meet the stopping distance requirements of FMVSS 121.

4. Load proportioning devices do not eliminate all lock-up of wheels under all circumstances.

5. The practicableness requirement of the Safety Act includes economic reasonableness.

6. The NHTSA has not yet begun testing of vehicles for compliance with FMVSS 121.

Paccar and the American Trucking Associations contended that the following additional issues applied:

1. Whether NHTSA has a statutory duty to collect data to determine whether pre-FMVSS 121 brakes are unsafe; whether the NHTSA has fulfilled such duty; and if the NHTSA has not fulfilled such a duty, whether FMVSS 121 is invalidated for that reason.

2. Whether the NHTSA has a statutory duty to conduct research, development, and testing to ensure that brake systems required by FMVSS 121 are reliable and safe; whether NHTSA has fulfilled such a duty; and if not, whether FMVSS 121 is invalid for that reason.

On April 17, 1978, the U.S. Court of Appeals for the Ninth Circuit announced its judgment on the Pacaar, Inc., case. The court ruled that the record demonstrated a need for the standard as specified under the Safety Act of 1966 because reduced stopping distances and improving handling during stops were related to the goal of improving highway safety. However, the court ruled that the required stopping distance was neither reasonable nor practicable at the time it was put into effect. The court found that there was a strong probability that antilock devices would not work well and that the NHTSA had the responsibility to ensure that those systems were reliable when placed into use. The court ruled that NHTSA had not satisfied that duty. In light of those considerations, the court ruled that the stopping distance requirement from 60 mph was not practicable and therefore the NHTSA was not allowed to enforce it. The court also ruled that the NHTSA had not been objective nor practicable in establishing the compliance testing procedures. The court ruled that those requirements were not economically feasible for intermediate and final stage manufacturers and that the specification of skid numbers for test surfaces was not practicable.

In July 1978, NHTSA petitioned the U.S. Supreme Court to review two of the three rulings of the Ninth Circuit Court. The NHTSA appealed the findings that antilock devices had not been shown to be reliable and that the combination of "strong front axles, new brake linings, and mini-computers" had not been shown to increase safety.

On October 2, 1978, the U.S. Supreme Court declined to hear the NHTSA appeal and mandated the effectiveness of the Ninth Circuit Court of Appeals decision. As a result of this ruling, the stopping distance tests found in the standard are no longer applicable. Instead, minimum brake retardation, brake power, and brake recovery are determined by inertia dynamometer testing. The dynamometer inertia for each wheel is equivalent to the load on the wheel with the axle loaded to its gross axle weight rating (GAWR). Current standards for newly manufactured air-braked vehicles are found in 49 CFR 571.121, Federal Motor Vehicle Safety Standard 121.

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