NHTSA'S HEAVY VEHICLE BRAKE RESEARCH PROGRAM -- AN OVERVIEW

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ABSTRACT

The National Highway Traffic Safety Administration (NHTSA) has been conducting experiments to assess the braking performance of heavy duty vehicles for a number of years. Many different types of vehicles have been tested and various aspects of braking performance have been evaluated. Experiments have included full scale vehicle tests on the test track, laboratory measurements on systems and components and dynamometer tests of brake assemblies and linings. Tests have included those which measure the status quo, as well as those which evaluate modifications and hardware designed to improve braking performance.

This paper provides a brief history of the Heavy Vehicle Brake Program, discusses major program areas and presents some of the significant findings and conclusions.

PROGRAM HISTORY

The National Highway Traffic Safety Administration (NHTSA) has been involved in research, testing and evaluation of heavy vehicle braking performance since the late 60's. NHTSA's first major effort was a large scale truck braking study conducted by the University of Michigan's Highway Safety Research Institute (HSRI). The objectives of this study, initiated in 1969 and completed in 1971, were to determine the braking performance levels exhibited by current design buses, trucks and tractor trailers and to establish the maximum braking performance capabilities of these vehicles when equipped with different types of advanced brake system hardware.

Much of the information developed in this study was utilized by the Agency in the formulation of Federal Motor Vehicle Safety Standard (FMVSS) No. 121, Air Brake Systems, which became effective for trailers on January 1, 1975, and trucks and buses on March 1, 1975.

In 1975 as production vehicles built to comply with FMVSS 121 became available, the Agency began to evaluate their performance and to compare it to that exhibited by vehicles built prior to FMVSS 121. A vehicle test program was established at the NHTSA's Safety Research Lab (SRL) in Riverdale, Maryland. SRL utilized the track facilities at the U.S. Army Proving Ground in Aberdeen, Maryland, for the necessary road tests. Also, as part of this program, SRL evaluated stability augmentation devices (including "anti-jackknife" devices) as possible alternatives to antilock brake systems. This initial program at SRL was the genesis of the current program at NHTSA's Vehicle Research and Test Center (VRTC) in East Liberty, Ohio; the SRL is now a division of the VRTC.

SRL's initial program was expanded to address various issues being raised as controversy surrounding FMVSS 121 began to grow. One of the major concerns within the trucking industry was the compatibility between the braking systems of pre and post FMVSS 121 vehicles. Many users reported that mixing pre and post FMVSS 121 vehicles in combinations (tractor-semitrailers, truck-full trailers, doubles, etc) resulted in degraded brake performance. In 1977, SRL tested a number of combination vehicles in various mixed configurations under a range of operating conditions on the test track. Many laboratory tests were also run.

In 1978, two significant events occurred: 1) the NHTSA moved SRL from its Riverdale, Maryland, laboratory to the Transportation Research Center (TRC) in East Liberty, Ohio, to become one of the two major divisions within the newly created Vehicle Research and Test Center (VRTC) and 2) the Ninth Circuit Court of Appeals issued a decision invalidating the stopping distance requirements specified in FMVSS 121. This eliminated the regulatory need to install antilock on heavy vehicles.

The move of SRL to Ohio slowed the progress of the program, but resulted in SRL having convenient access to extensive facilities ideally suited for heavy vehicle testing.

The court decision had a significant impact on the scope and direction of the program. The Agency wanted to study the performance of trucks, buses and trailers built to conform to FMVSS 121 when antilock systems were removed. Also, many different issues were raised during the time period that the standard was fully in effect that needed to be studied. With improved facilities available and many problems to address, NHTSA established the Heavy Duty Vehicle Brake Research Program (as it exists today) in 1979. This program, over the years, has addressed many different subjects relative to heavy vehicle braking. Vehicle road tests as well as laboratory and inertia dynamometer tests have been run. In addition to the in-house research at VRTC from 1979 to the present, the Agency has conducted research on heavy vehicle braking systems through contracts with private firms. This work includes a three-year in-fleet study of automatic brake adjuster performance and reliability, and a study of the benefits of retarders for heavy vehicles.

The purpose of the discussion which follows is to identify the major subject areas that have been addressed in the NHTSA Heavy Vehicle Brake Program over the years, briefly describe what has been done in each area and report some of the more significant findings. The references at the end of the paper cover the program in more detail.

STOPPING DISTANCE AND STABILITY DURING BRAKING

Stopping distance tests have been run on over 70 different heavy vehicles. This group of vehicles consisted of buses, single unit trucks and combinations including tractor-semitrailers, truck-full trailers, doubles and triples. Vehicles were tested empty and fully loaded in straight line stops as well as braking and turning maneuvers. Various surfaces from dry pavement to ice were utilized. Although some of the tests were run with the driver fully applying the brake control (i.e., panic application) without limitations on wheel lockup and skidding, most testing was done to evaluate how quickly vehicles could stop under full directional control. This required that the driver modulate the brake control to minimize the amount of wheel lockup that occurred during the stop. Vehicle testing has been performed with fully operational brake systems as well as with simulated failures in the brake systems. Detailed results of all of these tests are given in References 1-7.

Approximately one fourth of the vehicles tested utilized hydraulic brake systems; the rest had air brakes, the most common system for heavy vehicles.

The test results indicate that the stable stopping capability of the various types of vehicles can be ranked as follows:

Stopping Capability Ranking	Vehicle Type
1 (best)	Buses (empty and loaded)
2	Loaded Tractor Trailers
3	Loaded Trucks
4	Empty Trucks and Tractor Trailers
5 (worst)	Bobtail Truck Tractors

This ranking is essentially independent of road surface coefficient of friction and vehicle speed. The ranking applies to "typical" configuration vehicles in these categories in either straight line braking or braking while turning maneuvers.

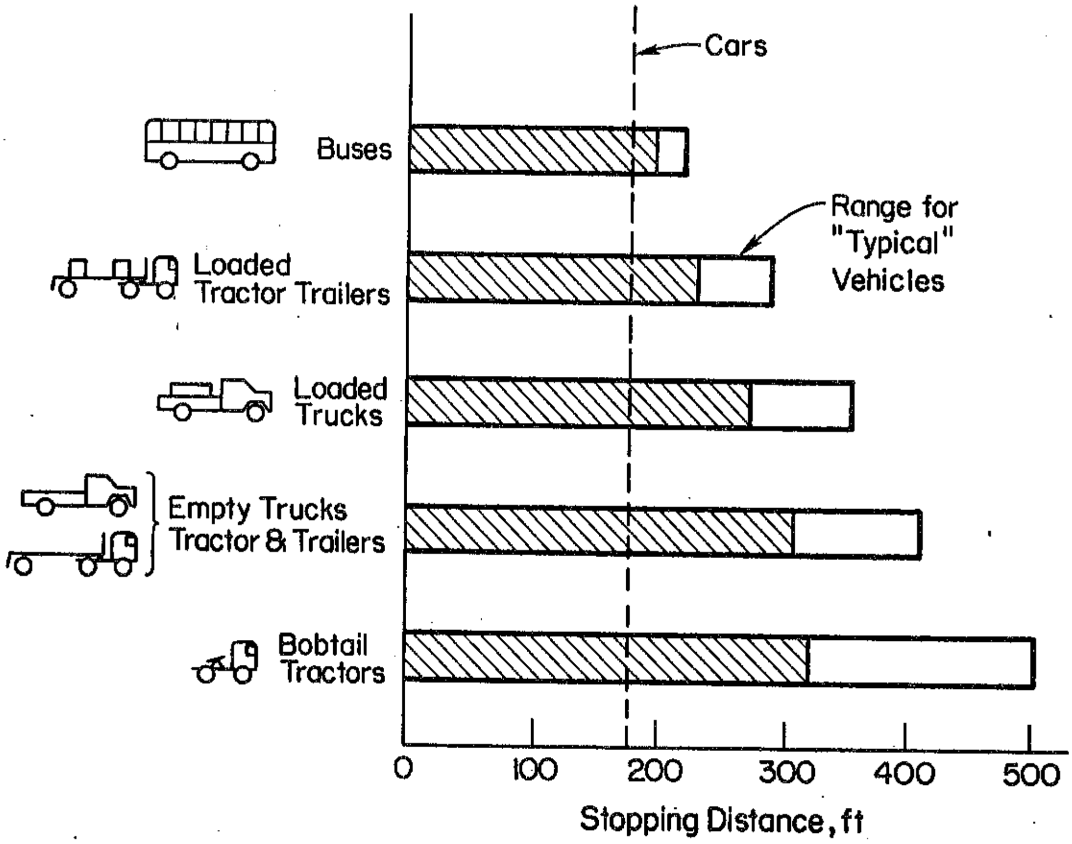

Figure 1. Stable Stopping Distance of Heavy Air Braked Vehicles From 60 mph on Dry Straight Road

Looking first at air braked vehicles (as currently manufactured), Figure 1 shows the range of stable stopping distances that might be expected from 60 mph on a straight dry road for the different types of air braked vehicles, assuming the brake systems are in good condition, burnished and fully adjusted. Performance of a typical passenger car is also shown in Figure 1 for reference.

Buses perform best, primarily because under most conditions their braking force distribution is close to the normal force distribution on their axles. This allows buses to achieve maximum utilization of the tire/road friction force available at both axles before wheel lockup occurs. In effect, the buses have close to "ideal" braking distribution under most conditions. The front to rear weight distribution in a bus generally does not change substantially in going from the empty condition to the fully loaded condition due to the uniform nature of the loading. In addition, dynamic weight transfer in a bus is low due to a relatively low center of gravity height/wheelbase ratio.

Loaded tractor trailers also perform relatively well during braking due to the fact that their braking distributions and axle normal force distributions are similar. They do not perform quite as well as buses, however, due to the fact that the percentage of braking on their front (steering) axles is less than ideal. Loaded trucks do not perform as well as loaded tractor trailers. They experience more weight transfer onto their front axles than loaded tractor trailers which causes the percentage of braking available at the front axles of the loaded trucks to be even further below ideal.

The stable stopping capability of empty trucks, tractor/trailers and, in particular, bobtail tractors is relatively poor. This is due to the fact that their braking systems, which are sized for the loaded condition and have fixed braking force distributions, produce too much braking at the rear (or trailer) axles. These axles decrease in weight by a much greater percentage than the front steering axles when the loads are removed. This results in premature lockup and a corresponding loss of lateral (side) force capability at the tires on the "light" axle(s) permitting vehicle instability at relatively low deceleration levels. The problem is exaggerated if a vehicle has a short wheelbase and very lightly loaded rear axle which is why bobtail tractors exhibit the worst performance.

In general, most of the air braked trucks and truck tractors tested were found to be "under braked" on their front axles in that they would not lock up their front wheels before their rear wheels at any load level on any of the test surfaces including ice. In addition, several of the vehicles were equipped with front axle automatic limiting valves (ALV's) which reduce front braking substantially when control line pressures are low. Since low control line pressures are utilized when vehicles are empty, these valves further upset or degrade braking distribution in a situation where it is already considerably less than ideal. Complete removal or deactivation of the front brakes, a practice which is common among some truck users, obviously degrades the situation even further. The use of ALV's or the removal of front brakes increases the chance of drive wheel or trailer wheel lockup which can lead to spin-out, jackknife, or trailer swing.

Modification to test vehicles to increase the percentage of braking on the front axle such as removal of ALV's, increasing the size of brake chambers or installing variable brake proportioning systems (making braking distribution closer to ideal for straight line stops) resulted in optimum performance in the braking and turning case. Much shorter and more stable stops resulted in both cases. Increasing the front brake torque, however, did increase steering wheel pull when a vehicle was braked on an uneven coefficient of friction surface (difference in slipperiness left to right). This increase was insignificant if the vehicle was equipped with power steering and the steering axle had a low kingpin offset (scrub radius) but was quite significant when the vehicle had manual steering and a high kingpin offset. This indicates that steering system design must be taken into account if consideration is given to increasing front brake torque levels substantially above that which now exist. It may be necessary that vehicles have power steering and/or better steering geometry if greater levels of front brake torque are utilized.

Current model heavy hydraulically braked trucks were found to perform somewhat better than air braked trucks*. Figure 2 shows the relative performance of typical trucks with air and hydraulic brakes. Performance of the hydraulically braked vehicles is better primarily because they are typically designed with higher torque front brakes and achieve better braking force distribution particularly when empty.

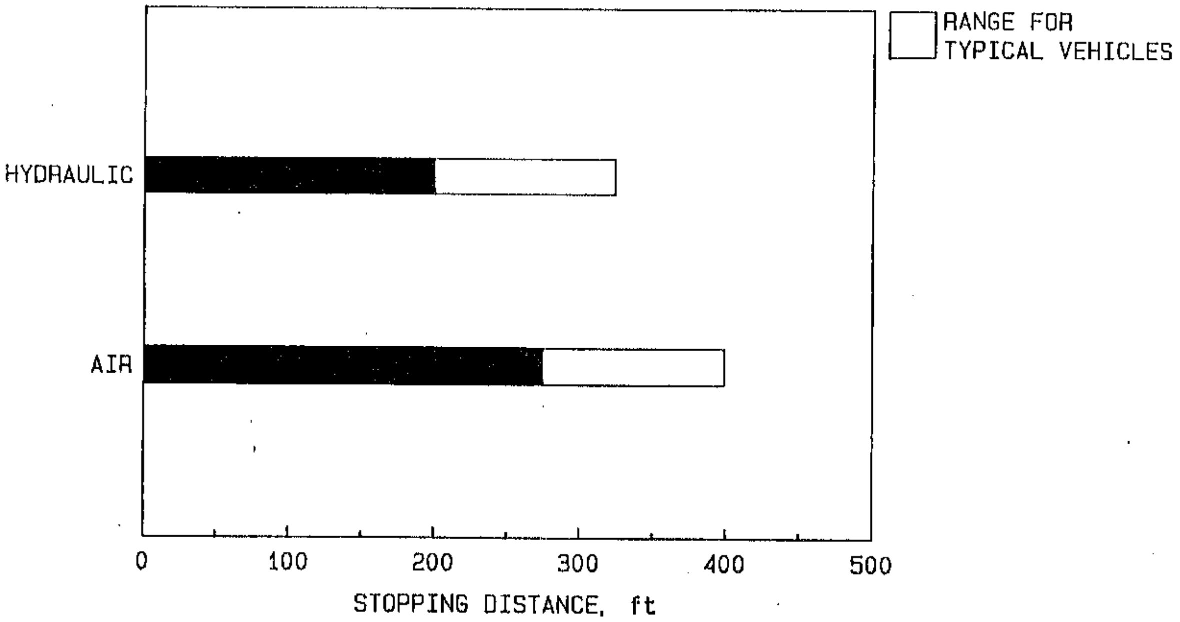

Figure 2. Relative Performance of Trucks Equipped With Air and Hydraulic Brakes -- 60 mph, Dry Road

One point that should be made about the above discussion of stopping capability is that it is based on the premise that brakes are in good working order, burnished and fully adjusted. If this is not the case, total brake force output may not be sufficient to produce a very high deceleration when the vehicle is loaded, even if the brakes are fully applied. With degraded output brakes, higher loads result in poorer performance, just the opposite of the situation as discussed above where the fully loaded vehicles out performed the empty vehicles.

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*Class 6 and 7 single unit trucks and school buses are avilable from some manufacturers with either air or hydraulic brakes. Hydraulic brakes are standard on these vehicles and air brakes are offered as an option. Because of the additional complexity of the air brake system the cost of such a system is higher.

ANTILOCK

NHTSA tested a number of vehicles (five power units, four trailers and one converter dolly) with production antilock systems between 1975 and 1977. These tests described in References 2 and 3 were primarily designed to evaluate the braking performance gains provided by the antilock systems and to evaluate compatibility of tractors and trailers with and without antilock in various "mixed" vehicle combinations. Straight line stops as well as braking and turning maneuvers were run with both empty and loaded vehicles on surfaces ranging from dry asphalt to wet Jennite (pavement sealer). Although these tests did not specifically include an evaluation of reliability and vehicle test mileage was generally low compared to typical truck user mileage, the operation of a group of antilock equipped test vehicles did provide some insight into the problems being reported by the truck users. Component failures, electrical connector and wiring problems, intermittent failure warning light operation, etc were experienced on some test vehicles. When the systems were operating properly, however, braking performance gains were significant. Vehicles stopped shorter and were much more controllable with the antilock in operation. Antilock on the front axle prevented loss of steering, on the drive axle(s) prevented jackknifing and on the trailer axles prevented trailer swing. In terms of compatibility between vehicles with and without antilock there were no cases found where having antilock on one vehicle or one axle in a combination degraded performance. In fact, just the opposite was found. The application of antilock to any axle provided a braking performance improvement; the more axles that had antilock, the greater the improvement. This was found to be true with single unit vehicles, tractor semi trailers and doubles combinations.

After the Court struck down the stopping distance requirements in FMVSS 121 in 1978, very few trucks, trailers, and buses were built with antilock systems and very few users attempted to keep existing systems operational. Use and production of antilock essentially dropped to the negligible level in the U.S. In the meantime, however, interest in antilock began to grow outside the U.S., particularly in Europe. Several European component manufacturers began producing second generation antilock systems and European vehicle manufacturers began offering them as optional equipment. Thousands of these systems are now in use in Europe and although no countries currently require tilock, several are considering issuing regulations mandating the systems on heavy vehicles.

Two fleets in the U.S. are currently operating a small number of vehicles with one particular brand of European antilock. In early 1986, one of these fleets made a two-axle straight truck available to NHTSA for testing at VRTC. Reference 8 provides a detailed description of the NHTSA test program on this vehicle. Figure 3 shows a summary of the test results and indicates the percent improvement in stable stopping distance that resulted when the antilock was operational in various types of braking maneuvers. Figure 3 is based on comparing the performance of a skilled test driver modulating the brakes on the vehicle without the antilock to the performance of the antilock system. Performance improvement with the antilock for more typical drivers would be expected to be even greater than that shown in Figure 3. In addition, Figure 3 assumes the driver has the presence of mind to modulate the brakes if the wheels begin to lock. In an actual emergency on-road situation,

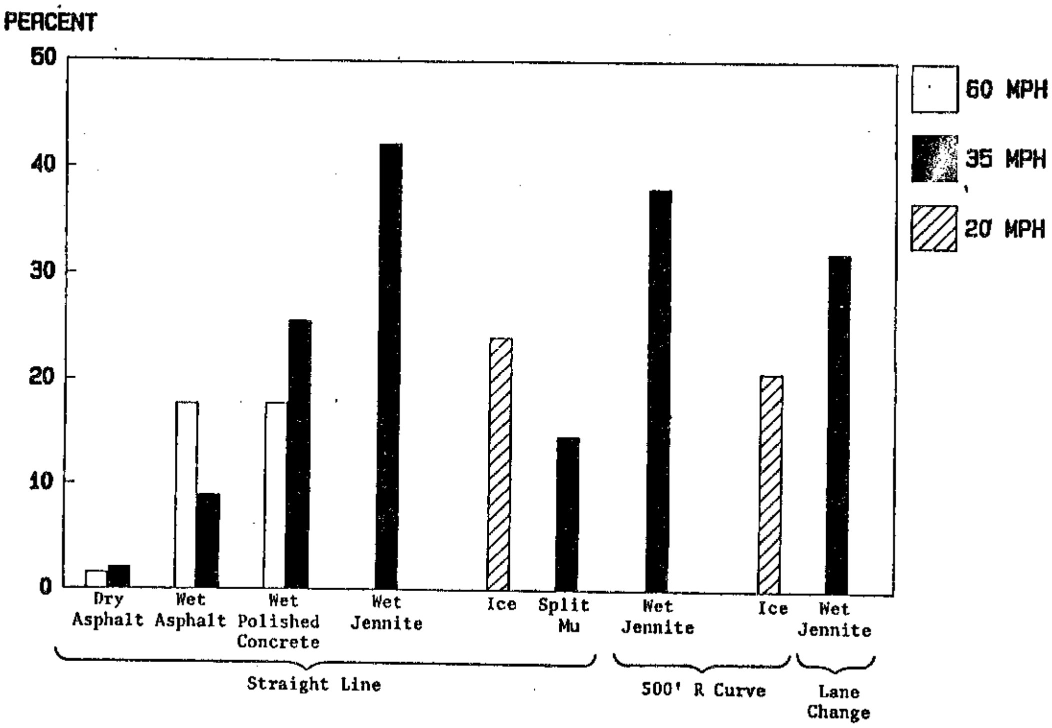

Figure 3. Percent Improvement in Controlled/Stable Stopping Distance With Antilock -- Fully Loaded Vehicle

this may not be the case: the driver may panic and lock the wheels skidding out of control.

In addition to this two-axle truck, VRTC has recently completed tests on a European tractor-trailer combination equipped with antilock and is currently in the process of testing a U.S. tractor-trailer combination with antilock. In the current tests, VRTC is evaluating the performance of a "standard" European system as well as modified versions of the standard system with different (simplified) control strategies. The purpose of these tests is to quantify the performance gains provided by the different control strategies. Individual wheel control, axle-by-axle control and tandem control strategies are all being evaluated.

In order to evaluate reliability of current antilock systems, NHTSA is planning to conduct (under contract) a two year fleet study of approximately 200 vehicles with various available antilock systems. This program will start in about a year. Action to find a suitable on-board data acquisition system has already been initiated. This data acquisition system will be a relatively simple device not unlike commonly used electronic tachograph and will monitor antilock function while the vehicle is in operation in the fleet. The NHTSA will also follow (via a contractor) experience with antilock in Europe as well as Australia where there are also many systems in-use. In addition, the NHTSA will attempt to obtain as much information as possible on antilock equipped vehicles operating in the U.S. that are not specifically included in the 200 vehicle fleet study.

TRACTOR AND TRAILER COMPATIBILITY

As mentioned earlier, compatibility between vehicles with and without antilock in combinations was studied by NHTSA in the late 70's. The subject of tractor and trailer brake system compatibility, however, is much broader than the issue of mixing vehicles with and without antilock. In fact, compatibility is a major area of concern today even though vehicles do not typically utilize antilock. In general, compatibility refers to the braking system on the tractor and the braking system on the trailer working together in harmony to provide desirable combination vehicle brake system durability and braking performance. It is primarily determined by the transient and steady state brake force distribution existing at the various axles of the combination vehicle.

Both of these aspects of compatibility have been addressed in depth in the NHTSA research program over the years. The transient brake force distribution is strongly influenced by the flow characteristics or timing of the pneumatic system. Most of the NHTSA research on pneumatic timing is described in Reference 9. The time that it takes for the pressure at the brakes to reach a praticular level after the pedal is applied is known as the apply timing; the time that it takes the pressure to be reduced to a specified low level is known as the release timing. Overall apply time is important because it determines how quickly full braking force is achieved; this has an influence on stopping distance. Relative apply time for tractors with respect to trailers is also important because it affects the coupling or "kingpin" force between the two units during braking. High coupling force is undesirable because it aggravates the jackknife situation. If the trailer brakes apply slow with respect to the tractor brakes, the trailer will tend to "bump" the tractor harder. Figure 4 shows results of actual measurements made on an 80,000 lb combination during a panic stop on dry pavement using a semi-trailer with an instrumented kingpin. It can be seen in Figure 4 that when the tractor brakes apply fast with respect to the trailer brakes, overshoot in

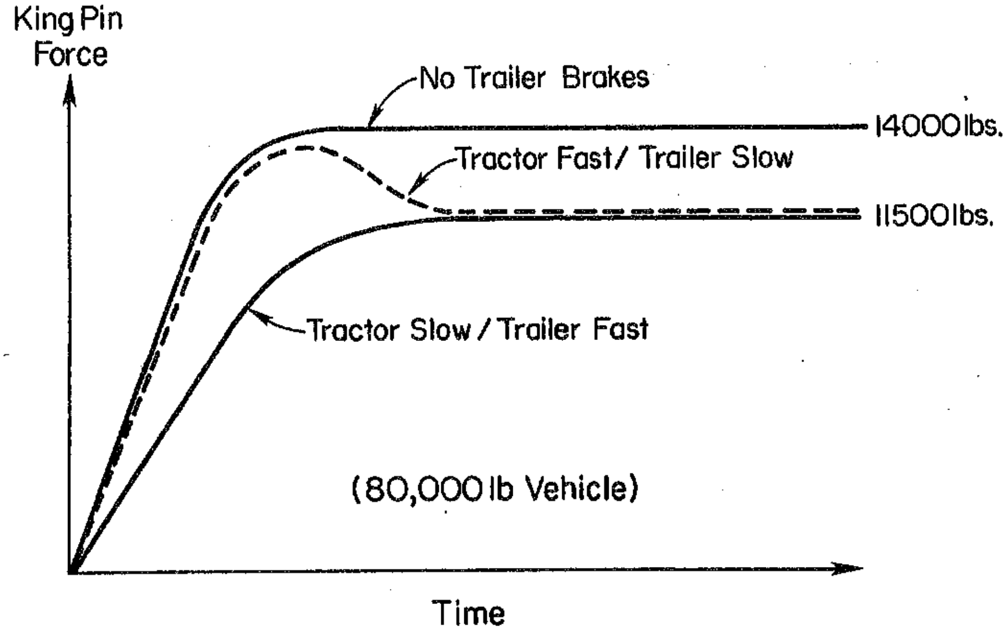

Figure 4. Kingpin Force Versus Time for a Panic Stop

kingpin force occurs. This overshoot reaches the same level as the case where the trailer brakes are not working (i.e., infinite trailer brake apply time). One point that should be made relative to Figure 4 is that even with the ideal case (trailer applies before the tractor) there is a substantial force at the kingpin.

Recent tests of typical late model vehicles (Reference 10) indicate that trailer brakes do not usually apply before tractor brakes. Figure 5 shows apply times (0 to 60 psi) for nine tractor-semitrailers and six doubles combinations.

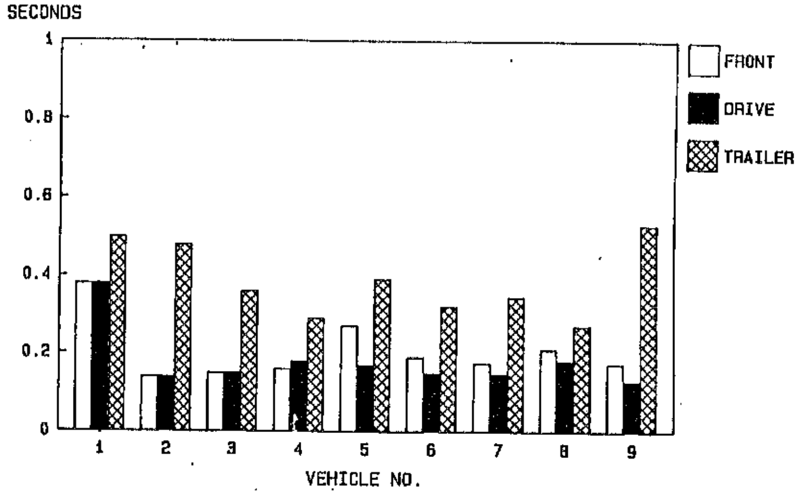

Figure 5a. Apply Time at Each Axle Set -- Nine Tractor Semitrailers

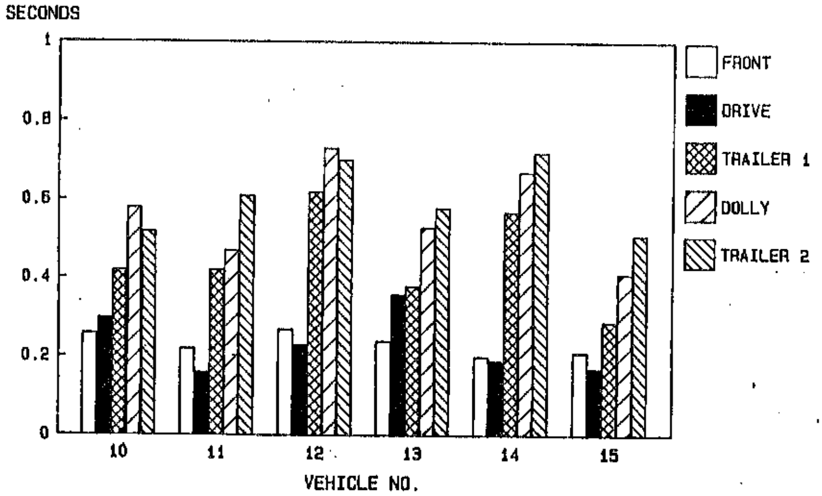

Figure 5b. Apply Time at Each Axle Set -- Six Doubles Combinations

Release timing is also important to vehicle stability although it has no effect on stopping distance. If a driver is applying his brakes in an emergency situation and locks the wheels, it is important that he be able to release the brakes as quickly as possible; otherwise he may skid out of control. Slow release times also affect brake temperature and wear.

Steady state brake force distribution is very important to compatibility. NHTSA research in this area is covered in References 4 and 10. In sublimit braking situations (i.e., well below the point of wheel lockup) brake forces must be balanced, otherwise excessive wear and temperature build-up will occur at the "overbraked" axle. In limit braking situations, wheels on overbraked axles will lock up and skid prematurely.

The input level at which braking force starts to occur at each brake, known as the brake force threshold pressure, is a very critical parameter to compatibility. If brake force at the tractor starts to occur at an input level below that needed for the trailer braking to start or visa versa, brake temperature imbalance is probable in repeated or continuous low pressure braking situations (such as mountain grade descents). If the vehicles are on low coefficient of friction surfaces, wheel lockup can occur prematurely.

Figure 6 shows the final brake temperature on a tractor and trailer at the end of a 5 mile long 4% grade descent at 45 mph as a function of threshold pressure difference between the tractor and trailer. Only a 2 psi difference in threshold pressure can make a difference of over 200°F in final brake temperature.

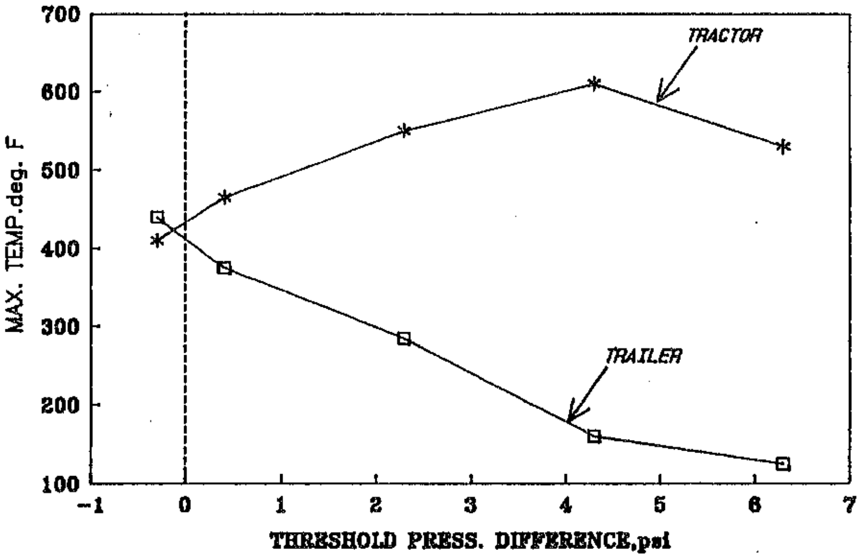

Figure 6. Brake Temperatures for 4% Grade Simulation -- Five Miles at 45 mph

Figure 7 shows the effect of threshold pressure difference on braking efficiency by comparing a combination with equal thresholds to one when the trailer threshold is 4 psi lower than that on the tractor. On low mu surfaces particularly with the empty vehicle, the drop in efficiency that occurs when threshold pressure is different is quite significant.

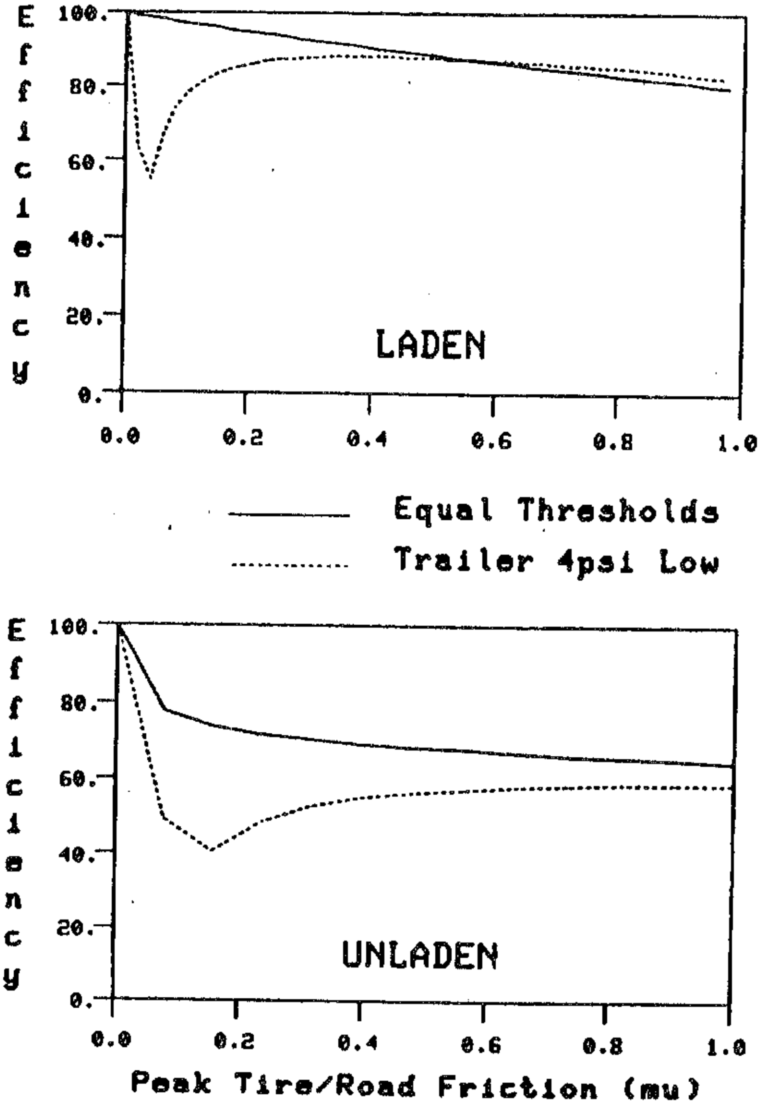

Figure 7. Braking efficiency for tractor-semitrailer combination with equal threshold pressures and 4 psi "low" trailer threshold (or 4 psi "high" tractor threshold)

BRAKE ADJUSTMENT

Both vehicle and inertia dynamometer tests have been run to determine the effect of adjustment on braking system performance. This work is described in References 11 and 12. It has been determined that the torque output of air braked heavy trucks is very sensitive to brake adjustment level. This is not the case for hydraulic brakes used on heavy trucks and most hydraulic brakes on cars and trucks are of the automatic adjusting type. The majority of truck air brake systems must be manually adjusted.

Figure 8 shows the effect of brake adjustment on the output of a typical heavy duty air brake at two different temperature levels, 200°F and 600°F (temperature in the brake drum).

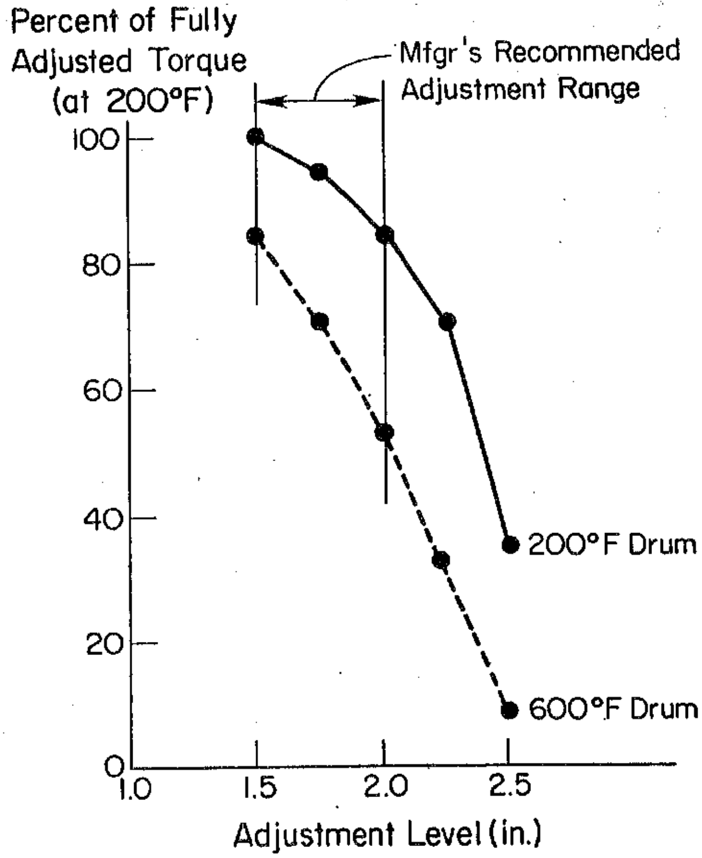

Figure 8. S-Cam Drum Brake Performance as a Function of Adjustment Level and Drum Temperature

The lower temperature represents a relatively "cool" brake that has not been exposed to a great deal of repeated or continuous braking. The higher temperature represents a relatively "hot" brake, and is typical for a mountain descent although it is by no means the maximum temperature that a brake might experience in service. Figure 8 is for an S-cam drum type brake, used on the majority (over 90 percent) of heavy duty air braked vehicles.

Adjustment level in Figure 8 represents the stroke of the air brake actuator (chamber) when the pressure in the actuator is 100 psi and the brake is at ambient temperature. Normally for the brake shown, the stroke of the actuator at 100 psi with the brake fully adjusted is approximately 1.5 inches; this stroke is required to take up the slack and deflection in the system. As the brake shoe wears, the stroke increases due to the greater actuator travel necessary to move the brake shoes out against the brake drum. For this particular brake, the manufacturer recommends that the brake be readjusted when the stroke reaches 2.0 inches although the actuator actually has a full travel of approximately 2.5 inches.

It can be seen from Figure 8 that at 200°F brake temperature, brake torque continually drops as adjustment level degrades from the fully adjusted level. This is true even over the manufacturer's recommended adjustment range; at the recommended readjustment point (2.0 inches) the torque has dropped to 85 percent of its fully adjusted level. When the brake is hot

(600°F), there is a drop to 85 percent even when the brake is fully adjusted. This drop is due to two factors: 1) brake lining fade at the elevated temperature and, 2) brake drum expansion which results in an actuator stroke increase. Brake torque is reduced to 50 percent compared to a fully adjusted cool brake, when adjustment reaches the manufacturer's recommended readjustment point. This is a significant drop even though brake adjustment is considered to be acceptable in terms of the manufacturer's recommendations. Under this condition, the brake can only develop one half of the torque it could if it was fully adjusted and cool. Beyond the manufacturer's recommended adjustment range brake torque drop is even more dramatic, particularly if the brake is hot.

Reduced brake torque due to brakes being out-of-adjustment affects the brake force balance and overall braking capacity of the vehicle. As a result, not only is limit performance stopping ability affected, but downhill operations also become more prone to brake fade and runaway.

Figure 9 shows the results of limit performance stopping distance tests conducted on a fully loaded 6x4 truck at two different adjustment levels: 1) fully adjusted, and 2) at the manufacturers recommended readjustment point. Both cool brakes (200°F) and hot brakes (600°F) are shown. Beyond the manufacturer's recommended adjustment range the stopping distance of the vehicle would be even longer than that shown in Figure 9.

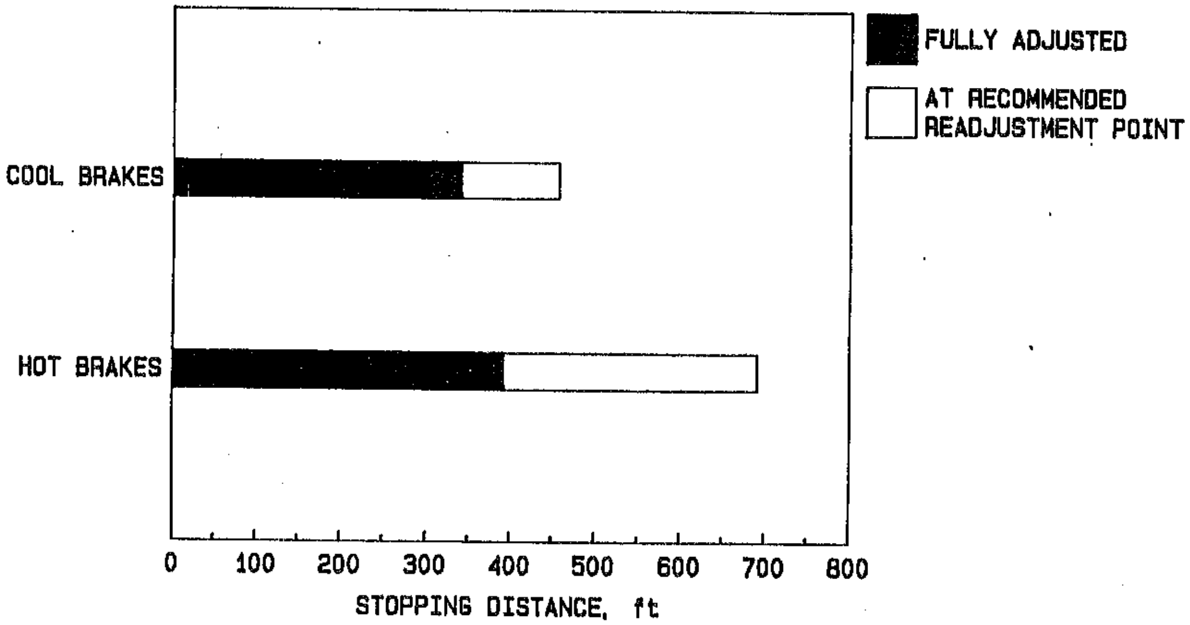

Figure 9. Stopping Distance of Fully Loaded Truck at Two Brake Adjustment Levels (60 mph -- Dry Road)

Brake adjustment primarily affects the stopping capability of trucks when they are loaded; this is where maximum brake torque is needed to decelerate vehicle mass. With an empty vehicle, more than enough brake torque is usually available to lock the rear wheels despite the level of adjustment, unless adjustment is so poor that practically no torque is generated.

RETARDERS

Research performed under contract by the University of Michigan to evaluate the benefits of retarders for heavy vehicles (References 13,14,15) indicates that these devices can extend brake life and reduce the possibility of runaways on downgrades. VRTC, working in cooperation with the University of Michigan, conducted full scale vehicle tests to determine what effect these devices have on vehicle stability and stopping performance in limit braking maneuvers. Reference 16 describes this effort. The results of tests on two different combination vehicles indicate that in limit braking maneuvers, retarders can increase the stable stopping distances. Since most U.S. vehicles are "overbraked" on their drive axles, retarders (most commonly used retarders act through the drive axle) tend to upset brake force distribution even further. With retarders in operation, drivers must modulate the service brake control to an even greater degree to avoid drive wheel lockup and jackknife. Table 1 shows test results for braking tests on wet Jennite curves. Both of the vehicles used "engine brake" type retarders.

Table 1
Effect of Retarders on Stable Stopping Distance in Slippery Curves

Vehicle	Loading	Curve Radius (ft)	Initial Speed (mph)	Best In-Lane Stopping Distance (ft) W/O Retarder	W/Retarder
6x4-S2	Empty Trailer	200	25	88	96
	Empty Trailer	500	40	311	323
	Bobtail	200	25	98	123
4x2-S1	Empty Trailer	200	25	88	98
	Empty Trailer	500	35	183	224
	Loaded Trailer	200	25	98	103

Use of retarders without applying the service brakes can also affect vehicle stability. Since retarders, in effect, utilize longitudinal friction at the tire/road interface, they reduce the lateral friction available for cornering. The maximum safe speed for entering a curve is reduced when the retarder is "on". In addition, loss of control at the limit speed can change from a stable "plow out" mode with the retarder "off" to an unstable jackknife mode if the retarder is "on".

In order to warn retarder users of the potential for stability problems, NHTSA has prepared an informational booklet (Reference 17) and given it widespread distribution in the trucking community. This booklet encourages the installation of retarders on vehicles since they do offer safety benefits and can extend brake system life significantly. The booklet, however, cautions against use of retarders (all types are usually controlled by an in-cab switch) in situations where the vehicle is empty and/or the road slippery.

ANTI-JACKKNIFE DEVICES

In 1975, NHTSA tested several different anti-jackknife devices on several different combination vehicles. Brake-in-a-curve, brake-during-a-lane-change and straight line braking tests were run on several different surfaces. Although these devices restrict articulation and prevent the tractor from hitting the trailer, they do not prevent wheel lock, and thus do not cure the basic instability problem. Figure 10 shows a tractor trailer both with and without an anti-jackknife device. Without the anti-jackknife device, the vehicle could jackknife if the tractor wheels lock. With such a device the vehicle will not jackknife but could spin as an entire unit (possibly across several lanes of traffic). In effect, the combination becomes a "long" straight truck.

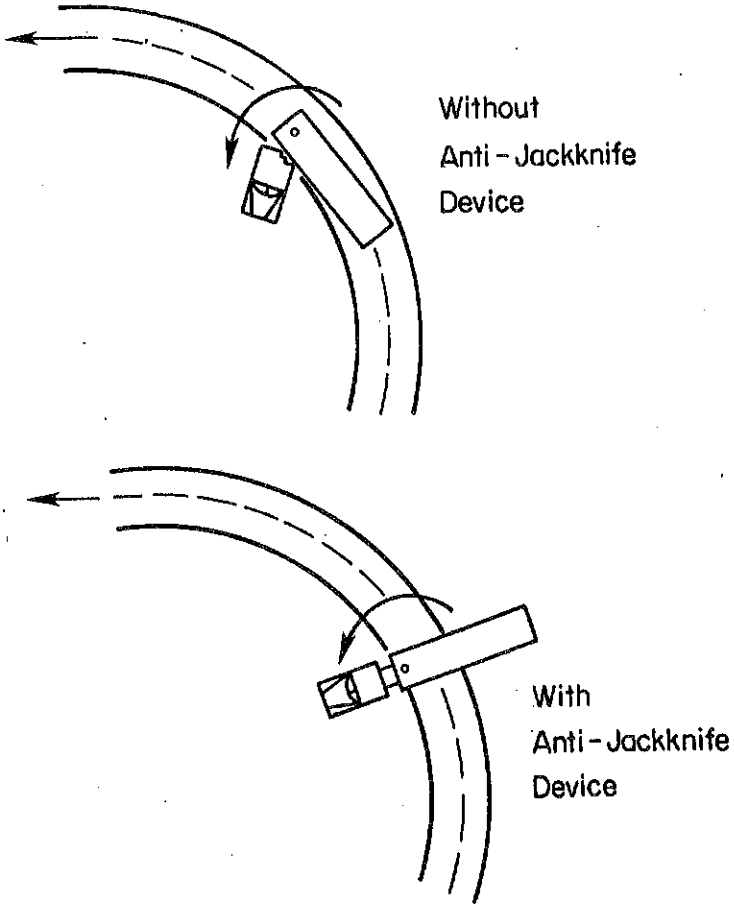

Figure 10. Loss of Stability With and Without Anti-Jackknife Device

Anti-jackknife devices will improve vehicle stability if the trailer wheels are kept rolling*. In this case, the trailer acts as a "rudder" for the combination vehicle. Most U.S. vehicles when empty, however, have their brakes balanced such that the first axle to lock on increasing brake input are those on the trailer. In a panic situation, full application of the brakes almost always locks the trailer brakes. It, therefore, cannot be assumed that the trailer wheels will be rolling in limit or emergency braking maneuvers.

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*Some promoters of these devices demonstrate them in tests with the trailer brakes turned off, an unrealistic operating condition

TRAILER EMERGENCY SYSTEMS

A number of tests have been run to determine if the pneumatic systems on trailers could be simplified. This work, described in Reference 18, was performed in light of comments on a notice of proposed rulemaking to modify the requirements of FMVSS No. 121. Full scale vehicle tests, inertia dynamometer tests and laboratory tests of trailer pneumatic system "mockups" were performed. The results of these tests indicated that simplification would be possible but that care must be taken to avoid systems that permit spring (parking) brake drag without warning the driver. It was found that drivers could not feel spring brake drag even though it was occurring to the point of overheating and reducing the effectiveness of the brake system. It was also found in these tests that typical tractor plumbing is so restrictive in its delivery of supply air to the trailer that pneumatic failures on the trailer cannot be sensed by most tractors. Even if the trailer has a large leak, the tractor would still be able to maintain full reservoir pressure and would thus not give the driver any indication of the problem on the trailer. Unfortunately, in this case, the tractor low pressure warning light and buzzer which senses tractor reservoir pressure is no help in the event of trailer failures.

PERFORMANCE OF U.S. VERSUS EUROPEAN VEHICLES

Comparative testing of a European tractor semitrailer built to meet European brake standards (and not equipped with antilock) and a U.S. combination of equivalent size and weight has been performed. Many different types of braking maneuvers (straight line, curves, and lane changes), various surfaces and different vehicle loads have been included in these tests. Since this work has only recently been completed the report describing this effort in detail has not yet been published. The basic conclusion reached from these tests, however, is that the braking performance of the European combination is generally superior to that of the U.S. combination although the difference in performance was much smaller than expected. The European vehicle had the same brake on the front axle as on each rear axle and load sensing proportioning systems on the drive and trailer axles and this provided a more optimum brake force distribution over the range of operating conditions. The only tests where performance was greatly different , however, were those with the bobtail tractors -- the European tractor stopped much shorter and was easier to control during braking. When a simple bobtail proportioning system* was added to the U.S. vehicle, however, the performance of the two tractors was essentially the same.

BRAKE LININGS

During the last year, dynamometer tests have been run to investigate the performance of heavy vehicle brake linings. This research which is expected to continue for at least another year is addressing two issues: 1) lining performance variability, 2) differences between asbestos and non-asbestos

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*This system is available as an option on some U.S. tractors. It reduces pressure to the drive axle brakes when a trailer is not connected to the tractor.

linings. Lining performance variability is important because it determines how closely brake force balance and braking efficiency can be controlled. This impacts tractor and trailer compatibility as well.

Understanding the performance characteristics of non-asbestos linings is important because they may be the only type of linings available in the future. Many vehicle manufacturers are now using them and EPA has proposed the complete elimination of asbestos in brake linings.

Data from this research effort will be made available to the SAE subcommittee that is currently developing new test procedures and rating schemes for brake linings. The SAE subcommittee is attempting to replace current SAE Recommended Practices for brake linings that are known to be inadequate. The data will also be provided to the SAE subcommittee that is developing Recommended Practices for tractor and trailer brake system compatibility.

SUMMARY AND CONCLUSIONS

NHTSA has been conducting research on heavy vehicle braking since 1969. Over the years many vehicles have been tested and many issues have been addressed. As a result of this effort, the braking performance characteristics of heavy vehicles are well understood and performance deficiencies have been identified. There is a large gap between the performance of passenger cars and heavy trucks and although this gap may never be completely bridged, significant improvements are possible.

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