

RESPONSE TO ADVANCED NOTICE OF PROPOSED RULEMAKING  
AIR BRAKE SYSTEMS

[Docket No. 79-03; Notice 01; NHTSA 4910-59]

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UM-HSRI-79-32

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## 1.0 INTRODUCTION

This document contains the views and opinions of a select group of research staff members of the Physical Factors Division of the Highway Safety Research Institute (HSRI) of The University of Michigan. In submitting this response to the reference docket, we wish to point out that the views expressed herein are based on research findings and on understandings that have been obtained by an organization that has, for a significant number of years, been involved in (1) conducting motor vehicle mechanics research and (2) examining particularly the braking performance of heavy trucks and tractor-trailers. As a member of the research community, we have found it rather difficult to engage in the dialogue that has been going on between industry and government ever since FMVSS-121 was first promulgated. The problem is strictly one of not being funded to pull together our findings and views in a form suitable for submission to a docket. Accordingly, we asked the government for financial assistance, which was denied on the grounds that The University of Michigan is a subdivision of the State of Michigan. Subsequently, the International Brotherhood of Teamsters, Chauffeurs, Warehousemen, and Helpers offered to provide the financial assistance needed to prepare this document. We hereby acknowledge that assistance and express our appreciation for the support which makes this response possible.

Before addressing the specific issues identified in the ANPRM, we wish to discuss one particular facet of the evolution of FMVSS-121, and then some of the conflicts and compromises associated with establishing braking standards for commercial vehicles.

A reading of the subject ANPRM indicates that NHTSA is currently concerned with obtaining a braking performance regulation which ensures that trucks are directionally stable and controllable while being braked at deceleration levels necessary to comply with the stopping-distance requirement. Although experience shows that driver control over the path of a truck is more difficult during braking than otherwise, motor vehicles are, in general, controllable and directionally stable during braking if the brakes on the steerable wheels are reasonably well

balanced (i.e., right to left) and, more importantly, all tires/wheels continue to rotate such that adequate levels of tire side force capability remain. Accordingly, the common measure of braking performance that automotive engineers have adopted to assess the maximum deceleration achievable, without danger of losing steerability or stability, is the deceleration or stopping distance achievable by the vehicle prior to the applied braking torques being sufficient to lock one or more wheels. This maximum deceleration (or minimum stopping distance) is referred to as the "wheels-unlocked" deceleration (or "wheels-unlocked" stopping distance).

An examination of the historical record suggests that considerable confusion has developed over time with respect to the original intent of FMVSS-121 in requiring that specific minimum stopping distances be achieved by trucks in stops initiated from a given initial velocity while at the same time being sufficiently steerable and stable such that a driver can keep the vehicle within a twelve-foot-wide lane. In our view, the confusion stems from the fact that the motor truck industry opted to employ so-called "antilock" braking systems to achieve the minimal "wheels-unlocked" stopping distances which were mandated by NHTSA for stops involving an empty and fully loaded truck, both on wet and dry surfaces.

Subsequent to the industry's selection of antilock braking systems as the most feasible and cost-effective way of achieving the axle-by-axle distribution of brake torques which results in efficient braking on different surfaces at different conditions of loading, it appears that the ensuing dialogue between industry and government resulted in phraseology that has been interpreted to mean something other than what was originally intended. As best we can understand the interpretation of FMVSS-121 as expressed by the Ninth Circuit Court, the requirement that the specified stopping distance be attained "without lockup of any wheel" (with certain exceptions as spelled out in the standard) means, contrary to the original intention, that wheels shall never lock up (except momentarily) during the braking process, irrespective of the magnitude of the braking input provided by the driver.

An examination of the historical record suggests that the inability of the court to understand the technical meaning of the language used in the standard derives, in part, from the reluctance of government attorneys to acknowledge the true meaning of the regulatory phraseology employed. It can be conjectured that this reluctance stemmed from mixed feelings within NHTSA regarding NHTSA's actual objectives.

Initially, NHTSA defined a braking performance threshold that it wanted trucks to exceed on both high and low friction road surfaces, irrespective of the payload condition. In effect, NHTSA wrote a rule which required that braking "efficiency" (or braking "utilization" of the available tire-road friction) be high at two different loading conditions and on two different surfaces. Or, alternatively, the rule could be looked upon as requiring that the frictional coupling generated by truck tires be not less than a certain percentage of the friction level generated by a standard test tire, which is representative of the frictional performance produced by passenger-car tires. The motor truck industry, on the other hand, realized that, in order to comply with FMVSS-121, it would be necessary to (1) install brakes on front axles if absent, (2) increase, as required, the effectiveness of truck brakes such that they can generate torque sufficient to lock wheels at normal loads produced by a full payload, and (3) adopt a scheme wherein brake torques at each axle are properly balanced (for different loadings and surface conditions) such that early (or premature) lockup of wheels is avoided.

This latter design objective can be achieved in a variety of ways, for example, load proportioning systems (either active or passive) or antilock braking systems. However, at that point in time, the most promising scheme appeared to be the antilock braking systems which had already been demonstrated in the U.S. on passenger vehicles. Thus, the motor truck industry, with considerable encouragement from their supplier companies, opted for antilock braking systems to obtain, in an indirect way, the high braking efficiencies which were required to meet the stopping distance requirements as specified in the early versions of FMVSS-121.

Thus, NHTSA's initial proposal for a motor truck braking standard and the ensuing response from industry constituted, in effect, a prospect for gains in safety quality far greater than was originally anticipated by NHTSA. Instead of the prospect of achieving a motor truck fleet with a substantially upgraded braking performance capability, there was the prospect of attaining a fleet which, by virtue of the decision to employ antilock braking systems, would be incapable of experiencing wheel lockup and therefore would, in theory at least, possess qualities which are substantially different than that possessed by vehicles with conventional braking systems. In effect, irrespective of driver actions, trucks would exhibit higher levels of controllability and stability during emergency braking and steering maneuvers and, to a large extent, the jackknifing potential exhibited by articulated vehicles would either be greatly diminished or eliminated.

Under these circumstances, it is understandable why NHTSA wanted to see antilock systems remain on trucks, even though it knew that the standard did not require antilock systems, per se.

In providing our comments on Docket 79-03, we wish to stress the point that NHTSA's decision to require the braking performance of the motor truck and truck combinations to be upgraded contained substantial potential for creating problems that are not easily resolvable. The design of a truck braking system to perform its normal braking task and also to stop the vehicle (in an emergency) in a distance that is roughly comparable to the stopping distance of a passenger car involves conflicts and compromises that should be clearly understood in order to decide what the Administration should do at this particular point in time.

## 2.0 CONFLICTS AND COMPROMISES ASSOCIATED WITH ESTABLISHING GOOD BRAKING PERFORMANCE

The discussion provided below attempts to provide some insight into certain conflicts and compromises between the general requirements for heavy vehicle braking and the development of practical braking systems. Much of the material presented herein has been known for years;

the problem appears to lie in how to put the existing knowledge together into a practicable, working system.

General requirements for heavy vehicle braking can be stated in various ways. Depending upon the perspective taken, differences in emphasis are obtained. For example, a driver of a small vehicle might specify that all trucks and heavy vehicles should be capable of stopping in distances comparable to those achieved by smaller vehicles under all operating conditions (lightly or heavily loaded; icy, wet, or dry roads; level road or downhill; straightaway or turn; high or low speed). On the other hand, braking requirements based on the needs and desires of the truck driver might be expressed as follows:

- brakes should produce fairly uniform deceleration throughout a stop. The brake control should be easy to modulate and produce repeatable results
- brakes should respond rapidly
- the vehicle should not pull right or left during stopping
- braking action should not interact excessively with steering or suspension functions
- brakes should not vibrate or squeal
- an emergency or auxiliary braking system should be available
- a truck's braking system should be reliable and unaffected by wear, water, dirt, ambient or internal temperature, etc.
- a truck's braking system should be able to perform acceptably over long periods of time in all operating conditions without maintenance or adjustment.

From the brake engineer's point of view, braking requirements can be stated in the following fashion:

- the primary function of the friction brake is to convert kinetic energy into heat

- brakes should be able to absorb large amounts of energy without a significant loss in torque capability
- brakes should be able to dissipate energy at a rate sufficient to avoid damaging temperature levels
- the braking system should be arranged to provide efficient use of the frictional potential available at the tire-road interface
- brake system components should be strong, light-weight, reliable, easy to maintain, and wear slowly and uniformly
- braking should not cause directional control or stability problems.

Many of the above requirements for heavy vehicle braking conflict with one another. The subsequent discussions are intended to shed light on these conflicts and indicate that the resolution of these conflicts in favor of minimizing stopping distance is not always possible or desirable.

## 2.1 Normal Braking Situations Versus Minimum Stopping Distance Requirements

In our view, FMVSS-121 changed the emphasis in brake system design from the conversion of kinetic or potential energy into heat to the achievement of shorter stopping distances. As stated in FMVSS-121, "the purpose of this standard is to insure safe braking performance under normal and emergency conditions." The demands of "normal braking" emphasize the distribution of brake torque so as to (a) cause linings to wear in a reasonably uniform manner and (b) maintain speed on long downgrades with each brake absorbing a proper share of the potential energy to be consumed. On the other hand, the requirements of braking during emergency conditions (such as those caused by the presence of an unexpected obstacle) demand that torque be distributed so that the maximum braking force can be obtained from each of the vehicle's tires. The problems associated with normal braking primarily concern the brake itself, whereas stopping distance is a total vehicle phenomenon influenced

by tires, brakes, static loading on each axle, road-surface frictional potential, and the height of mass centers above the roadway.

In service, braking in routine (low g) situations should be adequate if linings have not worn out or if temperatures have not risen to a level causing excessive fade, either as a result of repeated stops or during descent of a long mountain grade. An approach typically employed in achieving good "normal" braking performance is to distribute the braking effort at each axle in accordance with the static vertical load carried by each axle on the fully-laden vehicle. In this approach, such brake design elements as lining area, rubbing-surface area, and drum or disc thermal capacity can be analyzed on the basis of lining wear characteristics, tolerable levels of heat flow per unit area of brake material, and the heat absorption and dissipation properties needed for the brakes installed on each axle. (A by-product of a design procedure based on the gross axle weight rating is that the physical size of the brake is likely to be compatible with the size of the axle, wheels, tires, etc.)

This traditional manner of designing for uniform wear does not lead to brake torque being distributed in a manner suitable for attaining minimum stopping distance. As already indicated, the problem of achieving minimum stopping distance has many facets. The frictional potential of the installed tires sets limits on the maximum braking force attainable for a given road condition. The load carried by each axle in conjunction with the tire-road friction level determines the level of braking torque which provides a minimum, wheels-unlocked stopping distance. Furthermore, the instantaneous load carried by an axle depends upon the static load, the amount of load transferred between suspensions due to the level of deceleration, and, for tandem suspensions, the amount of interaxle load transfer caused by brake torque. A careful consideration of all these factors is needed to arrive at a distribution of brake torque yielding optimal emergency stopping distance performance.

In general, any fixed proportioning of brake torque designed into a goods-carrying vehicle constitutes a compromise amongst the various requirements for achieving good braking efficiency on dry and slippery roads with the vehicle in either the loaded or empty condition. For



example, calculations indicate that a typical tractor-semitrailer vehicle should be able to achieve more than a 70% braking efficiency (that is, 70% of the maximum deceleration potential of the tire-pavement traction limit) in the loaded and empty state on dry and slippery surfaces if the brake torque is distributed in accordance with a proportioning of 0.25:0.47:0.28, that is, the vehicle's total braking effort is divided into 25% from the brakes on the front axle, 47% from all brakes on the rear axles of the tractor, and 28% from all brakes on the tandem axles of the semitrailer. Since the tandem rear axles of the tractor contain four brakes and the front axle mounts two brakes, the above arrangement (viz., 0.25:0.47:0.48) implies that each front brake is approximately equivalent in torque capacity to each of the brakes mounted on the rear tandem axles of the tractor. (Nonetheless, it should be noted that, prior to the promulgation of FMVSS-121 it was not too uncommon to build tractors without brakes installed on the front axle.)

If, however, brakes are proportioned according to the static distribution of load, rather than according to the dynamic loading prevailing during minimum-distance stopping, a quite different brake system would derive. By way of example, a typical tractor-semitrailer vehicle would possess a proportioning of 0.11:0.45:0.44 corresponding to static loadings of approximately 8,000 lbs. on the front axle, 32,000 lbs. on the tractor tandem, and 32,000 lbs. on the trailer tandem. Accordingly, each front brake would have about one-half of the torque capacity of each of the brakes installed on the tractor's tandem axles. In low deceleration stops, or during speed maintenance on a downgrade, the 0.11:0.45:0.44 arrangement distributes the work done by each brake in a uniform manner corresponding to the load carried by the associated wheel. During such low deceleration maneuvers, however, the proportioning of 0.25:0.47:0.28, selected for minimizing stopping distance over a variety of surface and loading conditions, would require the front brake to do approximately twice as much work as the front brake does in an 0.11:0.45:0.44 scheme. Clearly, the proportioning needed for minimizing wheels-unlocked stopping distances conflicts with the proportioning that would be optimum for routine (low g) braking.

Furthermore, a vehicle with proportioning selected for low-g braking will exhibit poor braking efficiency and, accordingly, comparatively long stopping distances. For example, a typical loaded tractor-semitrailer with a fixed proportioning of brake torque selected on the basis of the static axle loadings (i.e., 8,000, 32,000, 32,000 lb.) can expect to achieve good braking efficiency in performing a 0.3-g stop. However, the same tractor-trailer, when unloaded, would not be capable of performing a 0.45-g stop (wheels unlocked) on a high friction road surface as characterized by a peak value of tire-road friction equal to 0.9. In this "worst-case" situation, the braking efficiency would be less than 50%.

The large load variations which can occur on many commercial vehicles is the most distinguishing feature of this class of vehicles. "Bobtail" tractors and loaded and empty semitrailers exemplify the extremes in axle loadings commonly experienced by commercial vehicles. Because of the variety of loading configurations experienced by most commercial vehicles, it is generally not possible to achieve good\* braking efficiencies for this segment of the vehicle population without the aid of compensating brake system componentry (viz., proportioning devices, antilock systems). Such devices, either directly or indirectly, redistribute the brake torque among the various axles (under different loading and operating conditions) for purposes of sustaining the braking efficiency above some minimal level.

The adoption of antilock brake control systems by the manufacturers of commercial vehicles in response to FMVSS-121 was simply the technical means selected to assure that the required higher levels of braking efficiency would be obtained. On examining the performance of antilock systems in this regard, it has been our experience that, in idealized laboratory settings, antilock systems can provide single-wheel braking efficiencies of 60% to 80%, depending on the operating conditions and the type of antilock system. Further, we find that the typical vehicle environment, with its rapidly varying wheel loads, in conjunction with (a) adverse characteristics of the brake system and (b) single- or tandem-axle control systems, reduces these braking efficiencies in \*e.g., 75% or more of the available friction.

practice. In fact, the resonant pitch and bounce responses of a commercial vehicle undergoing antilock braking can, under certain circumstances, be so severe as to negate the gains in braking efficiency that were sought by the adoption of antilock in the first instance.

To some extent, FMVSS-121 has recognized the requirements of routine and downhill braking as implied by the inclusion of fade and recovery test requirements. However, the inclusion of these fade and recovery requirements, in combination with the reasonably stringent stopping distance requirements, had led, in actual practice, to those mechanistic conflicts which we have noted above. Industry experience, to date, indicates that satisfactory resolution of these conflicts is extremely difficult to attain using hardware and technology currently available within the U.S.

## 2.2 Compromises Between Braking and Stability

A braking performance standard, which specifies a deceleration level or stopping distance requiring high braking efficiencies to be attained on a specified surface, must recognize that vehicle braking performance up to the limits of tire traction is not free for the asking but is bought with reductions in vehicle stability. Every vehicle is designed with a positive margin of static directional stability which assures that the vehicle will be dynamically stable in response to driver steering inputs and/or external disturbances. Whereas the level of stability in straight-line motion is highly variable in the total car and truck population, the level must be set so as to accommodate the reduction in stability that occurs during braking maneuvers. The important point to note, in the context of this discussion, is that commercial vehicles lose stability more rapidly with increasing deceleration than is the case for the passenger car.

Consider, for example, a truck and a motor car each with a directional stability characterized by the same level of understeer, as measured in units of degrees (of front-wheel displacement) per g (of lateral acceleration). The two properties of the motor vehicle which determine the rate at which it loses its understeer quality with increasing deceleration are

- 1) the height of its mass center ratioed to its wheelbase, and
- 2) the manner in which the cornering stiffness of its tires varies with the normal load on the tire.

Since the motor truck has c.g. height/wheelbase ratios that are significantly higher than that of the motor car, the transfer of load from the rearward tires to the forward tires (which occurs during deceleration) is much larger for the truck. In addition, the cornering stiffness of heavy truck tires is roughly proportional to the normal load on the tire, whereas the cornering stiffness of passenger car tires is rather insensitive to a change in normal load in the vicinity of the rated load. The large load transfer, experienced by trucks at a given level of deceleration, together with the increase in the cornering stiffness of the front tires and the decrease in cornering stiffness of the rear tires, means that the understeer quality prevailing under nonbraking conditions will decrease, more or less, as a linear function of the deceleration level. The motor car, on the other hand, will, to first order, preserve its understeer quality with increasing deceleration. It follows that the heavy truck and the motor car have significantly different characteristics with respect to the static directional stability that is lost when brakes are applied to decelerate the vehicle. Whereas squeezing more deceleration out of a motor car means relatively little, or no, penalty with respect to losing directional stability, the same cannot be said for the heavy truck.

The influence of braking traction on the cornering stiffness of the pneumatic tire has been ignored in the above discussion since this is a small effect which, furthermore, has the same polarity on the front and rear tires. On the other hand, the ability to generate side forces does degrade significantly as braking force levels are increased and the controllability and directional stability of the motor vehicle are also affected very suddenly and dramatically if sufficient brake torque is applied to lock up two or more wheels on the vehicle. Although the order of wheel lockup has a great bearing on whether stability is lost prior to steerability (or vice versa), braking performance standards in the U.S. have not tried to control this particular quality of the motor

vehicle in contrast to European braking regulations which strive to ensure that front-wheel lockup always precedes rear-wheel lockup on the motor car. Clearly, brake design practice as followed within the U.S. trucking industry is poles apart from European practice in the case of the motor car. Even if it were practical to install brakes on the front axles of trucks with torque capacity sufficient to lock up wheels on a high friction surface, driver sentiment in the U.S. would argue strongly against such a design approach. In fact, for reasons that are not well documented, American drivers commonly disclaim any significant safety benefits from front brakes capable of locking the front wheels. It may be speculated that the reasons for this attitude derive, in part, from:

- 1) drivers putting a premium on maintaining steering control under all conditions
- 2) high braking levels on the front wheels degrading steering effectiveness and the feel of the road during a critical maneuver
- 3) front-wheel brake imbalance and antilock cycling having a strong, and unpredictable, influence on steering control.

Thus it appears that the design requirements deriving from the desire to shorten stopping distances run counter to the wishes and desires enunciated by the truck driving community. Beyond this particular conflict, however, is the more important observation that the directional stability of trucks prior to wheel lockup is substantially degraded by deceleration. We conclude that the warnings of the manufacturers, with respect to directional stability being overly compromised if heavy trucks are designed to achieve high deceleration levels, are real and well founded.

### 2.3 One Standard for All Commercial Vehicles Versus the Variety of Vehicle Configurations In Use

A classic conflict arises when a regulating body attempts to standardize performance properties among a non-homogenous set of units. The conflict usually takes the form of an array of "special cases" which

defy the general application of a simple and intuitively appealing rule. The conflicts are resolved either through completely separate standards applying to differing segments of the population (such as in air versus hydraulically-actuated brake systems for trucks) or through the making of "exceptions" to permit the continued operation of certain special case units (e.g., buses, mobile cranes, etc.).

The conflicts arising with regard to braking performance embody distinctions in both the brake system design and in the design and typical usage of the other features of the vehicle. Brake system design details become of concern to the standards writer only when design-restrictive clauses are being employed within the standard. For example, it may seem that a separate air brake standard is justified since concerns for air reservoirs, transmission times, and the like, are peculiar to air-actuated brake systems.

Mobile cranes, on the other hand, may merit special treatment, not because of a peculiar characteristic of the brake systems employed, but rather because they may travel at abnormally low speeds while, perhaps, suffering from distinctly unfavorable inertial properties due to the awkward crane structure which is carried. Such vehicles plead for an exemption lest they be found non-compliant with a uniformly-applied regulation which was tailored primarily for highway transport vehicles.

Clearly, a broad array of judgments become applied in dealing with the conflicts posed by special case vehicles. Hopefully, these judgments are based ultimately on the expected significance to traffic safety, at large, if certain special "violations" of a rule are allowed.

Moreover, while the purpose of a braking performance regulation is to establish a "standard" or reference set of qualities in the vehicle population at issue, a number of conflicts arise which are specific to the types of vehicles which have come into use. Since great hardship can be incurred if certain vehicle types are effectively "ruled out" by the requirements of a standard, there is a strong motivation to accommodate or compromise the rule so as to permit continued use of all but a few irreconcilable vehicles.

### 3.0 COMMENTS ON THE ANPRM

At this point, we feel that we can address the various issues and questions raised in Docket 79-03 on the basis of merit. In our view, FMVSS-121, as it evolved over time, is an unfortunate melange of design and performance standards which developed out of the rule-making process codified in the Administrative Procedures Act. Very likely, our comments will differ from the responses that will be obtained from those parties who have participated in the 121 rulemaking process because we have no prior position to defend and, consequently, it is easy for us to challenge the rationale which was used, by all concerned, to justify the features and requirements of the standard.

To facilitate the presentation of our comments, we put forth, below, a series of questions, followed by our answers:

1. Should the seventeen requirements remaining in FMVSS-121 (as listed in Docket 79-03) be retained or should they be suspended or abolished in their entirety? Do the requirements that remain, without the presence of an antilock system, compromise the stability of heavy commercial vehicles?

Response: In our view, a braking performance standard, as exemplified by FMVSS-121, is justified when there is evidence that vehicle manufacturers and vehicle purchasers will opt for braking systems that "sacrifice" safety in order to minimize cost. We put "sacrifice" in quotes since manufacturers and purchasers will not, respectively, purposely build and buy vehicles which are unable to perform their transportation mission in a reasonably safe and reliable manner. Unfortunately, there is little data by which society can determine what is "reasonably safe" and, more specifically, there is little (or no) data by which society can determine whether, ultimately, it is in society's interest for truck brake-system design and performance to be biased towards higher levels of limit stopping-distance capability at the expense of the other qualities that are desired in a braking system.

Whereas we cannot suggest a foolproof way of resolving the above dilemma, it is possible to note that there are certain features of a

braking system which clearly provide an extra quality of safety without impinging on the conflicts and trade-offs inherent in the design of truck brake systems. For example, the requirement for an "emergency" stopping-distance capability (item 2 in the list of 17) means that a split or redundant system must be provided to ensure a minimal level of stopping capability in the event that a failure occurs in the actuation system. This redundancy feature carries a cost penalty and experience shows that the truck user is not likely to demand that this feature be installed in the truck that he buys. Accordingly, it is straightforward to conclude that this requirement should be retained.

On the other hand, the list contains some requirements which are not absolutely essential, in that they address specific design issues and/or performance levels that could be subsumed under a more all-embracing performance requirement. Thus, retention of these requirements may, in practice, mean that regulations are being retained which serve no real purpose. As best as we can determine, requirements (8) through (12) fall into this category.

In the absence of a 60-mph stopping-distance requirement on a dry surface, it appears that the retention of the 20-mph requirement (on a dry surface) is necessary in order to preserve the safety quality that derived from setting stopping-distance requirements that can be met only if brakes are installed on each and every axle. [If the 60-mph stopping-distance requirement on a dry surface had not been invalidated by the U.S. Court of Appeals, HSRI would have argued that the 20-mph requirement is unnecessary for a variety of reasons. First, the kinetic energy to be absorbed in a 20-mph stop is only one-ninth of the energy that must be absorbed in a 60-mph stop and, consequently, there is negligible loss of brake torque during the 20-mph stop due to any rise in temperature of the brake. Second, the torque output of friction brakes is speed sensitive and, consequently, brakes are generally more effective in stops initiated from 20 mph than in stops initiated from 60 mph. Thirdly, the retardation forces produced by truck tires are higher at 20 mph on a dry surface than is the case for 60 mph. Finally, since a stopping distance of 293 feet from an initial velocity of 60 mph on a dry surface is equivalent (in terms of equal levels of average



deceleration) to a stopping distance of 32.6 feet from an initial velocity of 20 mph, the present requirement of a 35-foot stopping distance on a high friction surface would be completely redundant and unnecessary if a 60-mph stopping-distance requirement were to remain in effect.]

Accordingly, HSRI recommends that requirements (1) and (3) be preserved in their current form until such time that a stopping-distance requirement for a higher speed should be reinstated. If this reinstatement should occur at some future date, the requirement for a 20-mph stop on a dry surface should be deleted.

With respect to the question of whether retaining requirement (1) will degrade the stability and control characteristics during braking in the absence of an antilock system, HSRI can only state that the brake and truck manufacturing community have the knowledge and experience necessary to select brake effectiveness levels that are appropriate in the absence of antilock. In this regard, the requirements remaining in FMVSS-121 (items 6 and 7) which speak to the retardation forces that must be generated at specific line pressures may be incompatible with the practices that would normally be followed by industry in adjusting effectiveness levels for a brake system without antilock. HSRI is not prepared to comment on this latter point, since to do so intelligently would require a major analytical, and perhaps test, effort.

Since HSRI has never addressed the topic of parking-brake performance in its previous and ongoing research, we are not prepared to comment on whether this requirement should be retained in its present form. It is clear, however, that the parking brake requirement does not impinge on the question of whether the present requirements cause the stability characteristics of trucks and tractor-trailers to be compromised in the absence of antilock.

With respect to requirement (5), "brake activation and release timing," we tend to hold the view that if it were not for the random coupling of tractors and trailers, this requirement would be completely unnecessary on the grounds that the standard requires that certain limit stopping distances be achieved while holding the vehicle in a 12-foot lane. One could argue that the presence of antilock, in combination

with requirements on stopping distance and lane retention, obviated any need for timing requirements and experience shows that the existence of timing requirements sometimes made the task of obtaining good anti-lock performance more difficult. In the absence of antilock, the only justification for timing requirements, in our view, is to ensure that undesirable tractor-trailer combinations are not created in the field. For this particular purpose, it may be that the specified actuation and release times are overly demanding.

With respect to the remaining requirements, we choose not to comment on each specific item, other than to observe that these items do not impinge on the stability characteristics of the truck or tractor-trailer complying with these requirements.

2. Should a 60-mph stopping-distance requirement be reinstated in order "to prevent depowering of brakes?"

Response: In view of the current requirements in the standard governing (1) the trailer brake retardation force and (2) the fade and recovery performance of the brake, it is difficult to understand why NHTSA should be concerned that elimination of the 60-mph stopping distance will lead to "depowering" of the brakes to be installed on commercial vehicles. It may be that these other features of the standard are not adequate to ensure that brakes of sufficient torque output and energy absorption capacity are installed on a vehicle so as to provide the specified 60-mph stopping distance in a road test. If this is the case, the standard, as it stands, has deficiencies but HSRI finds FMVSS-121 to be so complex and involved in its structure and rationale that it is very difficult to make constructive suggestions.

If a legitimate case can be made to show that a specific stopping-distance requirement should be met or exceeded in order to demonstrate that a vehicle has adequate safety quality, then HSRI would argue that a stopping-distance test is the most meaningful and complete measurement that can be performed. If it is intended that the specified stopping distance be achieved while also demonstrating that a test driver can exercise adequate directional control, then demonstrating the ability to

achieve a controlled stop at representative highway speeds is the ultimate test of the braking system installed on a given vehicle. However, a significant test burden ensues and, in our view, NHTSA should carefully think through what it is trying to accomplish by the promulgation of a braking-performance standard. As indicated by our technical discussion, presented earlier, it is clear that increases in the maximum deceleration achievable without wheel lock cannot be achieved through the use of simple, fixed-proportioning brake systems. Further, it is not clear that such increases will improve the traffic safety record. We would suggest that, to the degree that normal braking and downhill-descent performance are compromised by designing to achieve shorter wheels-unlocked stopping distances (for obstacle-avoidance braking), the traffic safety record may also be compromised. HSRI suggests that NHTSA may have adopted certain premises which are unfounded and, if this proves to be the case, the question of whether the 60-mph stopping-distance requirement should be reinstated should be held in abeyance until it becomes clear that the stopping-distance performance of heavy trucks should be biased in favor of a limit-performance requirement.

HSRI is aware of the long history of comments from NTSB and other agencies which have argued that the limit-braking performance of present-day trucks should be upgraded. In a study that we, ourselves, performed for NHTSA, HSRI also made such recommendations back in 1971. Nevertheless, it is quite possible that the levels of braking performance improvements following from these recommendations were ill-advised and that a much closer examination of the braking process is required in order to develop and promulgate a braking standard that will be in the interests of the general public.

To reiterate, it is difficult to demonstrate (and to our knowledge, has not been demonstrated) that any particular minimum-level stopping ability is required to assure an acceptable level of safety quality in a heavy truck. Nevertheless, if it is deemed necessary to establish a minimum-level stopping capability within the context of a braking system standard, then that capability should be demonstrated through a test procedure involving stops from representative highway speeds. In our view, it is the high-speed stop which is most challenging to the total

vehicle-tire-brake system and, perhaps, more importantly, is representative of the emergency braking situations which occur in the real world.

3. Should the Administration consider stopping distance requirements that are different for various test conditions, and, in particular, should special considerations be given to the "bobtail" condition?

Response: As was discussed earlier, limit braking of the heavy truck and trailer suffers from a special burden deriving from (1) the very large variation in axle loadings existing at the fully loaded, partially loaded, empty, and the "bobtail" condition and (2) the large variation in c.g. height accompanying these loading conditions. The development of a brake proportioning system which meets the requirements posed by all of these loading conditions is a very difficult job. Conversely, a brake system proportioned to meet the requirements of one loading condition will yield poor braking performance under other loading conditions.

Irrespective of the technical reasons which support, or argue against, the use of a load-sensitive proportioning system, the facts remain that the U.S. trucking industry did not see fit to use other than a fixed proportioning in the brake systems employed on heavy commercial vehicles. Prior to the promulgation of FMVSS-121, truck brakes were essentially proportioned to meet the requirements posed by the fully-loaded truck engaged in normal braking, as opposed to limit braking. Further, it was not uncommon to find trucks and tractor-trailers without brakes installed on the front wheels. As a net result, the braking performance of "bobtail" tractors was extremely limited.

The appearance of FMVSS-121 drastically changed the above state of affairs. The upgraded stopping-distance requirement and the requirement for an emergency braking capability (in the event of a partial failure) made the installation of front brakes imperative. In addition, the new standard required that the same wheels-unlocked stopping distance be attained at all loading conditions. The resulting proportioning task was so difficult that the truck manufacturing community, as a whole,

opted for antilock systems as the only practical means by which "overbraked" axles could be kept from locking while increased line pressure was applied to bring "underbraked" axles up to their full retardation force potential. Subsequent experience, however, has indicated that antilock systems were, in fact, not so "practical."

The state of affairs that existed before and after the issuance of FMVSS-121 can be viewed as representing two extreme solutions to the problem of minimizing stopping distance in a limit braking maneuver, namely, no solution and the ultimate solution. Viewed in this light, the "failure" of the 121 experience does not, in HSRI's view, justify a return to the state of affairs that prevailed prior to 121. To begin, the tractor now has brakes installed on both the forward and aft axles, whereas previously it may have had brakes on only the rear axles. This means that it is now possible to define a proportioning that is optimum for the "bobtail" condition, whereas, previously, nothing could be done in this regard.

Since the proportioning that is optimum for the "bobtail" condition is not likely to be optimum for the tractor-trailer combination in its fully-loaded condition, one could choose a compromise proportioning that will increase the stopping distance of the fully-loaded combination in order to decrease the stopping distance of the "bobtail" tractor. In HSRI's view, a much better solution can be obtained by recognizing that truck tractors must, on occasion, operate in a "bobtail" condition, an operating state which requires that a special proportioning prevail if the vehicle is to be able to stop as effectively as the loaded tractor-trailer. Accordingly, a simple binary proportioning valve under the control of the driver, could be expected to dramatically improve the performance of the "bobtail" relative to the performance achievable in the absence of such a valve. It is emphasized that whereas there was no reason to use such a valve on tractors which had rear brakes only, there is good reason to install such a valve on present-day tractors.

Thus, HSRI strongly suggests that NHTSA conduct tests by which it can become convinced that simple proportioning schemes (for example, the binary valve suggested above) can enable a "bobtail" tractor to achieve a minimum wheels-unlocked stopping distance that compares

favorably with that achievable under other conditions. Given that NHTSA will likely use a stopping-distance requirement as the means whereby the limit braking performance of the "bobtail" will be controlled, we would offer a word of caution. Specifically, it would be a mistake to demand a stopping distance which requires a fore/aft proportioning that departs too greatly from the proportioning that is more appropriate during normal braking, both on a level road and on a long descent down a steep grade.

Our response, as presented above, has stressed the question of whether the stopping-distance requirements should be modified for the "bobtail" condition. With respect to the more general question as to whether the Administration should consider different requirements for other test conditions, HSRI can only repeat that there are no data or rational analytical processes by which one can determine the limit braking-performance level which can be judged as "safe." The exposition in the Docket suggests that NHTSA understands that a requirement for a common limit stopping distance for all loading conditions cannot be met unless variable proportioning systems or antilock braking systems are used. Given that antilock systems are ruled out for the time being, NHTSA must determine whether variable proportioning systems are both reliable and cost-effective. Until such a determination is made, NHTSA has the alternatives of

- 1) setting different limit stopping distance requirements for different loading conditions
- 2) setting stopping distance at a level that is sufficiently long that it can be met at all loading conditions with a braking system characterized by fixed proportioning
- 3) setting stopping distances at levels which would represent an improvement over the above choice, but would require relatively simple variable proportioning schemes, perhaps allowing the driver to be an active element in the system.

4. Should the Administration consider promulgation of standards that would permit the demonstration of compliance using test procedures in which wheel lockup is permitted as long as the vehicle can be retained within a 12-foot lane?

Response: The exposition in the Docket suggests that, due to the difficulties encountered with the "no lockup" requirement of FMVSS-121 (as interpreted by the Court of Appeals), NHTSA is considering the use of a compliance test procedure which will permit wheel lockup to occur during braking with stability being evaluated on the basis of whether the test vehicle remains within the defined test lane. HSRI flatly submits that a locked-wheel stopping distance measurement is meaningless. If the wheels are permitted to lock on application of the brake system, the measured stopping distance says almost nothing about the adequacy of the installed brake system—the test becomes a measurement of the locked-wheel traction quality of the installed tires or a test of the prevailing tire-road friction level. Further, in the absence of road camber, road disturbances, and cross winds, it is possible for the vehicle to remain in a 12-foot lane even though it is not steerable by the driver and would spin around if sufficiently disturbed.

The posing of the question by NHTSA for comment shows that confusion with respect to the meaning of "no lockup" and "wheels-unlocked stopping distance" (as discussed earlier) still remains. Banning the use of antilock systems because of their unreliability does not mean that standards should not or can not be set which require that vehicles exhibit specified stopping distances prior to lockup of a specified number of wheels or axles. In the case of heavy trucks, which have three or more axles, it is, of course, possible to permit one or more rear axles to lock without losing directional stability to an excessive degree.