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VOLUME 2

APPENDICES

EVALUATION OF CRITERIA FOR TRUCK AIR BRAKE ADJUSTMENT

INTERIM REPORT

Contract No. DTFH61-89-C-00106

Prepared by

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16. Abstract

This report presents analyses, findings and recommendations concerning the out-of service (OOS) brake adjustment criteria in the Federal Motor Carrier Safety Regulations and the North American Univorm Driver-Vehicle Inspection Criteria for heavy trucks.

The study involved interviews with MCSAP inspectors, reviews of recent studies of the influence of brake adjustment and preparation of documents on pertinent mechanical properties of S-cam brakes, mechanical analyses of stopping capability, statistical analyses of inspection data, and combined mechanical and statistical analyses for evaluating OOS criteria using detailed inspection data.

Several findings and recommendations are presented in the report. These include:

•Brake adjustment is most important at heavey loads and high brake temperatures in emergency stops on good roads. Results for stops from 60 mph at 400°F and full load on a high friction road are appropriate for comparing the influences of brake adjustment on stopping capability.

•The current system for assigning brake demerits using the 20 percent defective brake rule provides a reasonable separation between vehicles that are OOS and those that are not.

•Backed-off brakes should be given more attention in the OOS criteria. Perhaps a backed-off brake should be counted as 1.5 or 2.0 brakes in the 20 percent calculation.

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S-cam brake, slack or stroke adjustment, brake inspection, air brakes

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.093	metres squared	m²
yd²	square yards	0.836	metres squared	m²
ac	acres	0.405	hectares	ha
mi²	square miles	2.59	kilometres squared	km²

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.028	metres cubed	m³
yd³	cubic yards	0.765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

MASS

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
ha	hectares	2.47	acres	ac
km²	kilometres squared	0.386	square miles	mi²

VOLUME

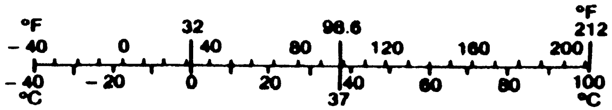
Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³

MASS

Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

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INTERVIEW PLAN

This document presents a plan for interviewing Motor Carrier Safety Assistance Program (MCSAP) inspectors with regard to brake inspection, brake-adjustment, and the out-of-service criteria for brake-adjustment. This plan has been prepared by the University of Michigan Transportation Research Institute (UMTRI) for a project entitled, "Evaluation of Criteria for Truck Air Brake Adjustment" (Contract No. DTFH61-00106). This project is being performed in support of a major goal of the Office of Motor Carriers of the Federal Highway Administration (FHWA) —specifically, to ensure safe operation of motor vehicles engaged in interstate commerce.

The broad goals of the study are to (a) reevaluate the brake OOS criteria, and (b) generate information that will tell motor carriers how often they need to adjust brakes. Specifically, the objectives of the study are as follows:

(1) Evaluate the technical adequacy of the existing "Out-of-Service (OOS) Criteria" for the brakes. The focus of this evaluation will be on the brake-adjustment criteria;

(2) Make recommendations on revisions to either the OOS or the Federal Motor Carrier Safety Regulations (FMCSR) to make them uniform, technically sound, practical, and appropriate;

(3) Develop guidelines on brake inspection and maintenance, especially on brake-adjustment for drivers, mechanics, and motor carriers;

(4) Determine what effect vechicle use has on brake-adjustment; and

(5) Determine how often brakes require adjustment for various types of vehicles and various types of operations.

To aid in accomplishing these objectives, the intention of the interviews is to draw on the knowledge, perspectives, and experience of the MCSAP inspection personnel. Although the requirements for brake-adjustment to compensate for brake wear may seem straightforward, the actual practice of roadside safety inspection requires practical skill and judgment in assessing the state of brake-adjustment. The insights of the inspectors are expected to aid in obtaining information that is relevant and applicable to the practice of roadside safety inspection. In particular, the inspectors' responses are expected to aid us inmaking recommendations that are practical from economic, safety, and environmental perspectives.

In summary, the purpose of this plan is to provide an orderly structure so the interviews can be conducted efficiently, and to ensure that appropriate topics will be treated in a logical order. The following section contains a listing of the sequence in which basic questions will be addressed in the interviews.

INTERVIEW OUTLINE (sequence of questions)

The intention here is to start with questions and discussions pertaining to the inspection process itself. In this way the interviewer and the inspectors are expected to establish a level of mutual understanding that will aid the interview process when the questions become less straightforward and more abstract or more speculative. Clearly, the inspectors should understand that they are not expected to know everything, but that their knowledge is valuable.

Question #1: How is brake-adjustment inspected?

•Subquestions:

•What are your procedures for inspecting brake-adjustment?

•What equipment do you use?

•How do your procedures relate to the MCSAP/CVSA and FMCSR requirements?

•Would you like to see changes in the MCSAP instructions?—in the FMCSR?

•How accurately can stroke be measured?

•Do trucks arrive with hot brakes and, if so, how are they treated?

Question #2: What do you record about brake-adjustment in relation to the vehicle being inspected? Cover factors such as the number of brakes OOA, the degree of OOA, and the distribution of stroke from brake to brake around the vehicle.

•Subquestions:

-What data gets recorded?

-What is the data used for?

-Is it automated (computerized)?

-What can be learned by looking at the data?

-For vehicles put OOS and perhaps for vehicles receiving CVSA stickers, what information is gathered about the vehicle? Its configuration? Loading and cargo type? Type of service? Registration, etc.? Is it coded (computerized)?

Question #3: ***What do you know about vehicles with brakes OOA?***

•*Leading question*: If you were to try to select a vehicle with brakes OOA, how would you select one?

•In this context, cover the types of vehicles and the segments of the industry that may have disproportionate numbers of vehicles placed OOS.

Question #4: ***What do you think might be done to improve highway safety through better brake-adjustment and brake inspection procedures?***

•Discuss:

(1) The relationship between brake-adjustment levels, lining properties, pneumatic timing and stopping distance. Have you ever performed stopping distance tests?

(2) The use and effectiveness of devices which automatically adjust brakes - How can brakes be adjusted reliably?

(3) The use and effectiveness of devices which warn drivers of imminent brake failures and defects, including OOA.

(4) Should there be vehicles that are not given CVSA stickers because a small amount of brake wear would put them OOS?

Question #5: ***What are your views on the OOS criteria for brakes?***

•Cover:

(1) Problems with the current OOS criteria for brakes.

(2) Aspects of brake OOS criteria that require further research.

(3) Recommended changes in brake OOS criteria.

Question #6: **How often do brakes need to be adjusted?**

•*Leading question*: If you were to estimate how frequently brake adjustments or brake inspections had been performed on the OOS vehicles, what would that estimate be based upon?

•In this context, discuss the frequency of brake-adjustment required for different vehicle configurations and operating conditions.

Question #7: **Have we missed something of importance and relevance?**

•That is, are there other problems, issues, or suggestions regarding the inspection of brakes?

DISCUSSION OF THE INTERVIEW OUTLINE

The outline has been structured to cover the entire scope of the issues and questions that we have formulated and that appear in the statement of work for this project. In this sense, it is not reasonable to expect that each inspector has a definitive answer for every subject area. Nevertheless, any views and opinions that the inspectors wish to express are desired in each question area. If the inspectors know of sources of information on pertinent issues and questions, those sources are to be identified and recorded for future use.

The outline will serve as the interview form. By this we mean that the interview form will simply be a "spread-out" version of the interview outline.

Questions #1 and #2 pertain to the processes that the inspectors perform in their immediate tasks associated with inspecting brakes. For the most part, the questions in these areas can be answered with facts. However, in one case, judgments are required for evaluating brake inspection procedures and instructions.

Question #4 might be considered as asking for the solution to the overall goals of the MCSAP program as they apply to brake-adjustment. One might be skeptical about asking this type of question, but if anyone has the desire to think "big," we want to hear their ideas. In any event, no one is expected to do more than try to formulate ideas that may prove to be helpful. In particular, pieces of information pertaining to automatic slack adjusters, stroke indicators, and brake-adjustment procedures would be important contributions to the results of the interview.

The first discussion point in Question #4 is aimed at considering all of the brake system factors that might degrade stopping performance. The question about stopping distance tests provides the opportunity to discuss the influences of brake timing on 20 mph stops. (In some cases, the vehicle may be nearly stopped before the trailer brakes become fully-actuated.) That question also provides the opportunity to observe that brake lining materials can react differently in 60 mph tests than they do in 20 mph tests. The effectiveness of the brakes may be considerably greater in stops from 20 mph than they are in stops from 60 mph. The ability to discuss the first point in Question #4 will depend upon the extent that an individual inspector has become an expert on the performance of brake systems.

Item (4) in Question #4 is a philosophical question concerning the meaning of the results of the brake inspection process. Given that the OOS criteria are very definitely specified, there is a fine line between passing and failing. One way to "broaden" that line (with respect to encroaching on the passing side) is to have an intermediate category which includes vehicles that barely passed, but will soon be in need of brake-adjustment. In any event, the question will provide the opportunity to begin to think critically and constructively about the reasons for measuring brake-adjustment.

Questions #5 and #6 pertain directly to the broad, overall goals of this study. (Here we are directly asking for and accepting help with respect to the goals for which we are responsible.)

We anticipate that brake inspectors are eminently qualified to address the practical and pragmatic aspects of the brake OOS criteria with regard to any of the items to be covered in Question #5.

Question #6 is another aspect of the material covered in Question #3. However, the emphasis in this case is focused on helping fleets to do a better job of adjusting brakes and passing inspections.

The interview outline ends with Question #7 which provides an opportunity to discuss relevant subjects that we did not cover explicitly in Questions #1 through #6 of the interview.

LOGISTICS OF CARRYING OUT THE INTERVIEW PLAN

This plan will have been approved by the FHWA before it is implemented. The contracting officer's technical representative (COTR) at FHWA will recommend no more than nine inspectors and contact the appropriate FHWA officials regarding the interviews.

Once the interview plan is approved, copies will be provided to the FHWA Office of Motor Carriers Regional Directors and the state MCSAP officials. Copies will be furnished to the individual inspectors ten days prior to the interview. This will allow the inspectors to familiarize themselves with the nature of the questions and the subjects to be discussed during the interview. If the inspectors were so inclined, they could gather pertinent materials and references on the subjects to be discussed.

The first two interviews will include observing brake inspections in the field with the Federal Highway Administration personnel. It is anticipated that three persons from UMTRI will attend the first interview, two or three persons from UMTRI will attend the second interview, and perhaps no more than one person will go to the other interviews. If the schedule permits, Mr. Ray Masters of UMTRI will attend all of the interviews and be the person responsible for collecting the information recorded on the interview forms.

CONCLUDING REMARKS

We close with observations on what the project is trying to accomplish. The information recorded on the interview forms will provide the basis for a report summarizing the findings from the interviews.

From a more general perspective, it seems essential to us that both the drivers and the inspectors understand that the driver generally will not be aware that brakes are OOA during the course of normal stops. Frequent measurement of the brake-adjustment is necessary in order to make sure that sufficient stroke is there in the event that full brake torque is needed. Thus, the inspections are intended to check brake-adjustment in as straightforward and efficient a manner as possible. A better picture of the influence of the type of service and the configuration of the vehicle on brake wear, and hence, the need for brake-adjustment should lead to improved and more practical OOS criteria. More to the point, this information should assist truck operators in keeping brakes in adjustment.

APPENDIX A.A

FINDINGS FROM INTERVIEWS OF MCSAP INSPECTORS

INTRODUCTION

This report pertains to Task B of a study entitled "Evaluation of Criteria for Truck Air Brake Adjustment." The broad goals of the study are to (1) reevaluate the brake out-of-service (OOS) criteria used in the Motor Carrier Safety Assistance Program (MCSAP) program as it applies to air-braked heavy vehicles and (2) generate information that will tell motor carriers how often they need to adjust brakes (see References [1,2]). The work in Task B has included interviewing inspectors from eight states per an interview plan developed to provide practical information and informed opinions regarding topics related to the following seven questions.

- How is brake-adjustment inspected?
- What do you record about brake-adjustment in relation to the vehicle being inspected?
- What do you know about vehicles with brakes OOA?
- What do you think might be done to improve highway safety through better brake-adjustment and brake inspection procedures?
- What are your views on the OOS criteria for brakes?
- How often do brakes need to be adjusted?
- Have we missed something of importance and relevance?

After providing information on the interview process in the next section, summaries of the inspectors' answers to the above questions are presented in the following section. The purposes of these summaries are to (a) capture the important points made by the inspectors, and (b) organize these points into universal findings where possible. The report concludes with subsections that present our interpretations of the meanings of the results and findings with respect to brake-adjustment OOS criteria and brake maintenance.

INFORMATION ON THE INTERVIEW PROCESS

The initial efforts in Task B resulted in the development of an interview plan which was submitted to the Office of Motor Carriers (OMC) of the Federal Highway Administration for comments and suggestions. (A copy of the approved Interview Plan is included here in Appendix A.) Then the OMC provided liaison with inspectors in eight states through the appropriate regional directors. The locations, persons, and dates of the interviews were as follows:

MCSAP Inspector Interview Respondents (1990)

Michigan — Lieutenant Norman Gear — May 29

Wisconsin — Inspector Darrell Bender — May 30

New York — Inspector Raymond Gagnon —June 19

Maine — Inspector John Fraser — June 20

Oregon — Inspector Mike Sullivan — June 26

Utah — Sergeant Ken Mecham — June 27

California — Captain Larry Rollin — June 27

Georgia — Lieutenant Don Lively — July 2

The interviews were conducted at the inspector's facility, primarily by Ray Masters of UMTRI with Ken Campbell and Paul Fancher participating in three and two interviews, respectively. During the first two visits, the inspectors explained and demonstrated how they performed inspections using vehicles that were stopped for inspection.

SUMMARIES OF THE RESULTS FROM THE INTERVIEWS

Question #1: How is brake-adjustment inspected?

The inspectors unanimously reported that their procedures followed North American Standard Inspection criteria. However, in actual application, their procedures varied in the following ways:

- One inspector had fastened a ruler to the device holding the soapstone to create a single tool for greater convenience.
- One inspector did not mark the pushrod. Instead, he held his measuring tool beside the pushrod during movement and mentally computed the difference.
- One inspector used a ruler attached to a telescoping handle to measure travel in situations with low undercarriage clearance. In these instances, the pushrod was not marked, and the travel was figured mentally.

•One inspector began his procedure at the rearmost axle.

•Five inspectors did not follow the counterclockwise pattern, preferring to mark and measure at one axle at a time, first one side and then the other.

Despite the variations in technique, the inspectors all felt that they measured pushrod travel accurately. The thought of all is characterized by one who said that stroke can be measured "as accurately as the tool used for measurement allows." A variety of measuring devices were used, including six inch metal rulers, six foot retractable tapes, and six inch sections cut from aluminum yardsticks. The tools were marked in gradations of 1/32", 1/16", or 1/8". The accuracy of measurement claimed depended on the gradation of the tool employed by each inspector.

Several factors affecting accurate measurement were cited:

•Inclement weather;

•Boots surrounding push rods;

•Brackets on cannisters;

•Low undercarriages;

•Thickness of drums; and

•Drum temperature.

Trucks arriving with hot brakes were treated as special cases. Usually, that condition was found to be the result of component defects rather than the result of grade or frequent application. It was generally felt inappropriate to apply OOS criteria for adjustment to a hot brake. States have been careful not to locate either permanent or roadside inspection sites in an area where a vehicle has just completed a steep descent requiring exceptional brake use.

Overall, the inspectors felt that their training in and application of MCSAP and CVSA requirements were consistent with the broad aims of the program. Further, no changes were recommended for practices and standards of brake-adjustment inspection alone.

Question #2: What do you record about brake-adjustment in relation to the vehicle being inspected?

In each state visited, brake-adjustment information generally is recorded only for brakes in violation. The primary reason for recording the information is to support the violation. States vary in terms of the recorded information that locates the brake. Each state locates the brake with regard to the unit in the combination, but many do not locate either the axle or the axle-end.

The forms used by some of the states visited (Michigan, Georgia,and Oregon) provide space to record pushrod travel by unit, axle, and axle-end. (See Appendix B for copies of the forms used in the eight states that were visited.) Although the measurements are made by most of the inspectors on every brake, this information is generally not recorded unless the brake-adjustment is in violation. In most states, even less information is computerized. Only Wisconsin has codes for the actual pushrod travel: one to indicate travel over 1.75", and one for travel exceeding 2.0". It appears that pushrod travel is frequently included in a comments section of the Oregon computerized data. However, this information is not readily extracted for analysis.

Although the Wisconsin data form does not have as much detail on brake-adjustment as some, their data system is remarkable in comparison to the other states visited. Data is entered on-line during the inspection process. Driver license, vehicle registration, and carrier information are available on-line, so this information is immediately displayed on the screen once the appropriate plate number, driver license number, or carrier name are entered. This is the only computerized data system observed that actually saves the inspectors time over the course of the inspection. In many cases, the inspector simply has to verify addresses, unit number, VIN, etc. Thus, while the Wisconsin violation form does not have as much detail as some, the computerized information on brake violations provides more detail than any of the states visited, locating the brake violations by unit, axle, and axle-end.

Question #3: What do you know about vehicles with brakes out of adjustment?

This question produced a considerable volume of response in most states. For the most part, many of the inspectors' observations were consistent from state to state, with only occasional regional differences reflecting unique operations or vehicles. A brief summary of the most pertinent and common responses is attempted here.

With regard to the root cause of out of adjustment brakes, the state inspectors interviewed were virtually unanimous in stating that if the driver and company do not make the necessary effort to keep the brakes in adjustment, good adjustment will not be maintained no matter how many times the vehicle may be inspected. Many inspectors felt that weekly, or even daily, inspections by two people - one to apply the brakes and one to check adjustment - were necessary to maintain brake-adjustment. Besides this obvious source of OOA brakes, a number of other patterns in the occurrence of OOA brakes identified by the inspectors interviewed included:

(1) Trailer brakes are more likely to be OOA, possibly because they receive less regular maintenance than power units and many have no record of miles traveled.

(2) Steering axles are not particularly prone to be OOA, although they still occasionally find some disconnected.

(3) Trucks used in rough off-road terrain such as dump and refuse are prone to undercarriage damage that sometimes affects brake operation.

(4) Leased equipment seems to be more likely to be OOA since drivers will usually use the brakes on leased equipment, if they work, over equipment they own.

(5) The rear axle on log trucks is sometimes backed-off to eliminate wheel hop when empty.

(6) Any axle that is hard to get at is more likely to have brakes OOA. This includes low ride trailers, chip haulers with the brake chamber above the axle, and front axles blocked by the faring on the new aerodynamic tractors.

(7). The older automatic slack adjusters often do not work if they do not receive regular maintenance. The newer automatic slack adjusters generally provide more uniform adjustment from axle to axle. The inspectors' experience with automatic slack adjusters was mixed. Some felt automatic adjusters would eliminate most OOA problems, and others were more skeptical, saying that they gave the driver a false sense of security that fostered a lack of attention to brake-adjustment.

(8) Right side brakes may possibly be more prone to OOA, perhaps due to the crown in the road loading the right side a little more, or use of left-hand threads on the right side of the vehicle.

(9) Generally, older trucks have more violations of all kinds than newer equipment.

Question #4: What do you think might be done to improve highway safety through better brake-adjustment?

For the most part, inspectors had not performed stopping distance tests. One inspector had worked previously as Safety Director of a trucking company and had been involved in such tests. Three other inspectors had experience with decelerometer testing.

The inspectors had general familiarity with the relationship between brake-adjustment levels, lining properties, and pneumatic timing as they effect stopping distance, but few had technical backgrounds or training to provide them with insight into to what degree or in what ways stopping distance might be affected.

More to the point, the focus expressed by the inspectors was to apply established criteria and to enforce law. One inspector said that to improve highway safety by better brake-adjustment, "Apparently, it's going to take stiffer and more frequent penalties."

Another inspector said that "Brake inspection procedures are adequately addressed." The consensus was that the burden of achieving better brake-adjustment belongs to companies and drivers. Companies must evaluate their operations in order to know when to inspect and adjust. Also, they must institute regular programs of education and training to insure that those responsible for brake-adjustment in fact know what they are doing and how to do it.

One inspector summarized this question area by stating that the best way to achieve better brake-adjustment is:

•For drivers and mechanics to more fully understand the entire brake system;

•For scheduled checks to be strictly performed; and

•For aggressive, consistent MCSAP inspection to be continued.

Automatic slack adjusters were thought to be helpful, but no panacea in keeping brakes within criteria.. Responses are typified by the statements:

- "Much fewer violations are detected on vehicles equipped with auto slack adjusters."
- "Automatic adjusting brake devices are available to industry for a price which function well with proper maintenance."
- "On most occasions automatic slack adjusters work."
- "From what I've seen so far, automatic slack adjusters are not reliable enough."
- "Auto adjuster still requires maintenance, and may make things worse if no one gets under (the) vehicle to check other items."

Several inspectors reported that drivers, who operate trucks equipped with automatic adjusters and yet determined to have brake-adjustment defects, tend to dispute the findings claiming that "It's impossible for the brakes to be out of adjustment--they're automatic!"

Stroke indicators, such as lock rings or color coded markings on the pushrod, were listed as aids which had potential for operators to assess adjustment levels, but more often than not these devices seemed to have been ignored by the users who had them.

Low pressure warning lights were thought to be of little value. Pressure drops are a part of normal operations, so the lights tend to be ignored or disabled. Instances of catastrophic failure result in activation of the spring brakes.

The predominant opinion of the inspectors was that CVSA stickers should be issued even though a small amount of wear would put a vehicle OOS. Representative responses included:

- "If the OOS criteria gets too cluttered with 'this-for-that' no one will be able to understand it or apply it."
- "We should sticker all vehicles meeting minimum requirements. We should not attempt to project future wear conditions."

Question #5: ***What are your views on the OOS criteria for brakes?***

One inspector responded to this question with the comment "too slack." If this was a pun, we missed it at the time. Nevertheless, the trend was to suggest tightening the criteria. No inspector said that the criteria should be relaxed or backed off in some manner.

The following summary of the results contains comments on a variety of specific topics. Most of these topics were mentioned by only one person, but a couple items were mentioned more than once.

- The "25 mile restricted service" option was mentioned by inspectors from two different states. Their view was that it should not be allowed. On the other hand, another inspector who used portable scales and did inspections on the sides of secondary roads, needed provisions to get OOS vehicles to safe parking areas ("safe havens"). A suggested answer was to escort OOS vehicles off of the roadside to detention and repair areas.

- The "20 percent rule" was questioned. Inspectors felt that exceptions were needed for situations in which one brake was rendered inoperable or completely backed-off. One inspector felt that items like missing return springs, cracked linings, defective drums, etc. on one brake should be sufficient for OOS even if the total vehicle did not violate the 20 percent rule. Another inspector questioned whether a fully-laden truck needed all brakes operating properly for the vehicle to stop satisfactorily from high speed. A third inspector was aggravated by experiences in which vehicles were proceeding on with one defective brake because the owners knew that the vehicle would pass the 20 percent rule.

To counter these problems and concerns, it was suggested that any defective brake should put the vehicle OOS.

•The following items were suggested once:

—The performance of the breakaway system needs to be checked.

—One brake defect should put overweight vehicles OOS.

—Contaminated brakes should put vehicles OOS.

—Re-instate the "half inch" difference in stroke on the front axle as an OOS criteria.

—Develop methods for measuring brake drums and OOS criteria for deficient drums. (Allow drums to be machined to no more than 0.12", for example.)

—Develop rules for brake valves, especially, "fits-all-brakes" valves.

—Require tractor protection valves on straight trucks equipped to pull trailers.

—Develop methods for measuring the state of lining wear and pertinent OOS criteria.

—Establish rules for mix and match parts, cut rate parts, etc.

—Develop rules for drive-away vehicles.

—Develop rules concerning brake lines, relay booster valves, and the like.

Lest we give the wrong impression, we should report that there were positive feelings with respect to the current OOS criteria and a willingness to support them. Comments such as "no objections," "no changes recommended," and "any changes in MCSAP would cause confusion," were offered. In general, the existing criteria appeared to be well accepted—several inspectors simply had ideas involving additional factors that need inspection.

Question #6: ***How often do brakes need to be adjusted?***

As will become apparent, the answers to this question provide insights into matters relevant to the plans being developed for monitoring brake-adjustment in a last phase of this research study.

First, the inspectors generally agreed that in a certain sense it was impossible to say how often brakes need adjustment. There are "too many variables to know." The adjustment level is related to the type of service, use of the trailer brake, maintenance scheduling (or the lack of it) for trailers, the use of retarders, the braking tendencies of individual drivers, and company practices.

Second, however, many inspectors also took another tack which can be characterized by the statement "When brakes are detected out-of-adjustment, they need to be readjusted." As obvious as this statement seems, it provides the foundation for several positive ideas revolving around each trucking company developing its own brake-adjustment schedule. For example, one person suggested that companies check brakes at a two-day interval for two weeks to establish how often they need to adjust brakes. Another person suggested checking brakes daily and after severe mountain descents. Others felt that weekly inspections would be sufficient to maintain brake adjustments at levels that would pass inspections.

On the one hand, the inspectors seemed to be somewhat offended that they were asked this question. They felt that it should be referred to brake engineers who conduct wear tests on lining friction materials. On the other hand, they felt strongly that keeping proper brake-adjustment was a matter of understanding, willingness to learn proper inspection and adjustment procedures, and diligence on the part of companies, mechanics, and drivers. When the inspectors were in the latter frame of mind, they emphasized the importance of trucking company policy. They tended to feel that configuration and operating conditions per se were of lesser importance to maintaining proper brake-adjustment than having a company policy that reflected the company's intention of knowing how their type of service affected brake-adjustment for their vehicles.

Question #7: Have we missed something of importance and relevance?

Inspectors from three states simply replied "no" or "nothing" as a direct response to this question. Other inspectors added new thoughts or expanded upon items suggested before under Question 5. These ideas included:

- A suggestion that the maximum crack pressure for front axle limiting valves be at 10 to 15 psi, not 30 psi.
- Concern over the lack of access for appraisal of shoe wear, drum condition, etc.
- Addition of information on brake-adjustment and brake chamber readjustment points in Section 393 of the FMCSR. (This would make pertinent information more readily available to companies, mechanics, and drivers.)
- Decelerometer testing like that used in one state to check buses.
- Concerns with having balanced stroke throughout the vehicle.
- Concerns with pneumatic timing.
- Develop a tool or template for checking the angle of the slack adjuster arm.

Finally, there are a few additional relevant items that came up in the course of the interviews. Even though the following items may not have been offered as direct answers to Question 7, we have chosen to include them here because they seem to be pertinent subjects.

- The parent organizations of the MCSAP inspectors differ from state to state. This causes differences in how vehicles are selected for inspection although each organization has both "random" and "probable cause" selection processes. In Michigan, for example, the inspectors are police officers. The state law defines their prerogatives. They stop vehicles for which they have an observable reason to suspect a violation, or they proceed using a rigorous random selection method. The rigorous random selection is done using a page of random numbers generated for that day. For example, the numbers might range from one to eight, with "one" meaning to take the next vehicle to inspect and "two" meaning to take the vehicle after next, etc. This would give a random sample as long as the inspection reports for vehicles stopped for probable cause are not confused with those for vehicles stopped randomly. (Some vehicles would fit both the random and probable cause requirements and that would be satisfactory.)

- On one occasion, there might have been confusion over the meaning of "setting the brakes." The parking brakes operate at a level approximately equivalent to 60 psi. This does not require as much stroke as an 80 to 90 psi application. The inspector needs to check that the operator is applying 80 to 90 psi to get an indication of the amount of braking effort that would be available in an emergency stop.
- Technical questions should be addressed to brake companies so that important information is not missed.

CONCLUDING INTERPRETATIONS CONCERNING (A) OOS CRITERIA FOR BRAKE-ADJUSTMENT AND (B) BRAKE MAINTENANCE

The objectives of the study (including Task B) are as follows:

(1) Evaluate the technical adequacy of the existing "Out-of-Service (OOS) Criteria" for brakes. The focus of this evaluation will be on the brake-adjustment criteria.

(2) Make recommendations on revisions to either the OOS or the Federal Motor Carrier Safety Regulations (FMCSR) to make them uniform, technically sound, practical, and appropriate.

(3) Develop guidelines on brake inspection and maintenance, especially on brake-adjustment for drivers, mechanics, and motor carriers.

(4) Determine what effect vehicle use has on brake-adjustment.

(5) Determine how often brakes require adjustment for various types of vehicles and various types of operations.

The interviews with inspectors have contributed useful insights with regard to these objectives and to the conduct of future tasks in this study.

More specifically, the interviews with inspectors have provided a better understanding and practical perspectives on brake-adjustment procedures and equipment. They have shown that the inspectors have a general understanding of the relationships between brake-adjustment levels, lining condition, drum condition, and pneumatic timing (and the influences of brake valves) on stopping performance. However, this is not a quantitative understanding, rather the inspectors have a qualitative feel for the elements of a satisfactory braking system. Their training, study, and experience appear to have provided them with the knowledge needed to measure and judge the quality of air brake systems.

The following concluding statements address OOS criteria and brake maintenance.

OOS Criteria for Brake-adjustment

With respect to OOS criteria, the interviews conducted in Task B were aimed at identifying (a) problems with the current OOS criteria, (b) aspects of brake OOS criteria that require further research, and (c) recommended changes in brake OOS criteria. These topics have been discussed under Question #5. In general, the results of the interviews show that although the inspectors did have numerous suggestions on a variety of aspects of the OOS criteria, they were for the most part satisfied with the OOS criteria as it applied to brake-adjustment.

Three inspectors favored tightening the criteria for situations in which obvious maintenance deficiencies were apparent even though 20 percent of the brakes were not out of adjustment. There was one suggestion that the 20 percent rule may not be adequate for stopping fully-laden heavy trucks from high speeds. Research on this subject was recommended. Also one inspector felt that consideration should be given to reinstating the old rule requiring that the stroke on the front brakes be within 1/2".

Nevertheless, the inspectors' comments indicated that, as a group, they were conservative with regard to changing the OOS criteria in that changes might cause confusion.

Brake Maintenance

A number of the topics targeted for Task B fall under the heading of "Brake Maintenance" related subjects. Specifically, the brake maintenance related topics were as follows:

•Brake inspection procedures and equipment.

•Factors, such as the number and distribution of axles, the number of brakes out of adjustment, and the degree of OOA, which place vehicles OOS.

•Types of vehicles and segments of the industry that may have a disproportionate number of vehicles placed OOS for brake-adjustment.

•Frequency for adjusting brakes for different vehicle configuration and operating conditions.

•The use and effectiveness of devices which warn drivers of imminent brake failures and defects, including OOA.

•The use and effectiveness of devices which automatically adjust brakes.

Our general interpretations of the results for these topics are based on responses from most of the Questions used in the interviews. (See specific questions for statements on detailed matters.) The following ideas have been derived from talking to brake inspectors:

(1) Quantitative information is available on which brakes tend to be out of adjustment. The information saved in computerized form in Wisconsin appears to be useful for studying OOA differences from brake to brake on the vehicles inspected.

(2) The inspectors observe that heavy vehicles in seasonal enterprises such as logging and construction tend to have brakes OOA. Also, refuse haulers have been singled out. These results have not been quantified but perhaps some of them can be verified quantitatively using the data recorded in Oregon.

(3) The inspectors' approaches to questions concerning frequencies of brake-adjustment indicate the importance that they place on company policy rather than on the type of service or the type of vehicle the company employs. A very important observation is that each company needs to establish its own brake-adjustment schedule for its operation. (We have noted this same approach being recommended by brake suppliers to their customers.)

Perhaps the most important finding from the interviews will be that the key to aiding truckers in maintaining proper brake-adjustment is to establish procedures that each trucking company can use itself (or the trucking company can be forced to use if they have a poor inspection record) to determine the appropriate brake inspection and brake maintenance schedules for their operations.

REFERENCES

[1] ..., "North American Uniform Driver-Vehicle Inspection Manual", Motor Carrier Safety Assistance Program, Federal Highway Administration, (draft) May 1989

[2] ..., "Evaluate Brake Adjustment Criteria", Federal Highway Administration, Contract No. DTFH61-89-C-00106, November 1989

APPENDIX B

INSPECTION FORMS FROM

MICHIGAN

WISCONSIN

MAINE

NEW YORK

OREGON

UTAH

CALIFORNIA

GEORGIA

MC-9 (1-90)
MICHIGAN STATE POLICE
Motor Carrier Division

Loc. 3 - Inspection Level

- ☐ 1 NAS
- • ☐ 2 VEH WALK AROUND
- • ☐ 3 DRIVER ONLY
- ☐ 4 SPECIAL
- ☐ 5 ________
- ☐ 6 ________

DRIVER/EQUIPMENT COMPLIANCE

MI No. 302113

DATE	TIME AM PM	CARRIER NO OFFICE USE	DOT NO.	PRIVATE CARRIER	CTY NO.	DIST. NO.	LOC. N1	LOC. N2	LOC. X1	LOC. X2	LOC. X3	SITE	CLASS	INTER ☐ INTRA ☐	EA
•	•				•	•								•	

CARRIER NAME	MC/MPSC	ADDRESS
•		•

CITY	STATE	ZIP	SHIPPER	BILL OF LADING NO.
•				

OWNER	ADDRESS	CITY	STATE/ZIP

DRIVER (FIRST, MIDDLE, LAST)	D.O.B.	LIC. NO.	LIC. STATE
•	•	•	•

• DRIVERS LOG RECAP DATE	ON DUTY HRS	• CITATIONS COMPLAINTS	• CITATION CODE
1		1	
2		2	
3		3	
4		4	
5		• PBT	• DRUG KIT
6			
7			
8			
TOTALS			

UNIT TYPE	YR/MAKE	UNIT NO.	TRACTOR PLATE	STATE	CVSA ISSUED / SELF INSP
	•		•	•	☐ ☐

UNIT TYPE	YR/MAKE	UNIT NO.	TRAILER PLATE	STATE	CVSA ISSUED / SELF INSP
	•		•	•	☐ ☐

UNIT TYPE	YR/MAKE	UNIT NO.	TRAILER PLATE	STATE	CVSA ISSUED / SELF INSP
	•		•	•	☐ ☐

UNIT TYPES: TR = STRAIGHT TRUCK; TT = TRUCK TRACTOR; ST = SEMI TRAILER; BU = BUS; PT = POLE TRAILER; FT = FULL TRAILER; DC = DOLLY CONVERTER; OT = OTHE[R]

COMMODITY/HAZARDOUS MATERIAL

HAZ. MAT. CODE	REPORTABLE QUANTITY	HAZARDOUS WASTE	PLACARD REQUIRED

PUSH ROD TRAVEL

AXLE	LEFT	RIGHT	AXLE	LEFT	RIGHT	AXLE	LEFT	RIGHT	AXLE	LEFT	
1			4			7			10		
2			5			8			11		
3			6			9			TOTAL	VIOL	O/S

VIOLATION CHECKLIST

(Columns: VIO. | O/S)

DRIVER CHECK
- • 1 SEAT BELTS
- • 2 NO LOG
- • 3 LOG NOT CURRENT
- 4 FALSE LOG
- 5 10 HR. RULE
- 6 15 HR. RULE
- 7 60/7 RULE
- 8 70/8 RULE
- • 9 MEDICAL CERT.
- 10 OTHER MEDICAL
- 11 UNDER AGE
- 12 DRIVER QUAL.
- 13 LICENSE OPR/CHAUFF.
- • 14 OTHER DRIVER REG.

POWER UNIT
- 15 HEATER/DEFROSTER
- 16 HORN/SPEEDOMETER
- 17 CAB FLOOR
- 18 WIRING
- • 19 FIRE EXTINGUISHER
- • 20 WARNING DEVICES/ FLAGS/FLARES
- 21 BRAKE APPLIED/ PRESSURE LOSS
- • 22 LOW AIR WARNING
- 23 PARKING BRAKE
- 24 GLASS
- • 25 WINDSHIELD WIPERS/ WASHERS
- • 26 HEADLIGHTS
- 27 FRONT TURN SIGNALS
- 28 CLEAR/ID LIGHTS/TAIL
- 29 STEERING TIRES
- 30 FRONT WHEELS/ LUGS/RIMS
- 31 STEERING COMPNTS
- 32 FRONT BRAKES
- 33 REARVIEW MIRRORS
- • 34 FUEL SYSTEM
- 35 BATTERY INSTALL
- • 36 EXHAUST SYSTEM
- • 37 AIR HOSES/LEAKS
- • 38 TIRES
- • 39 WHEELS/LUGS/RIMS
- • 40 BRAKES
- • 41 SUSPENSIONS
- 42 FRAMES
- • 43 COUPLING DEVICES
- • 44 REAR TURN SIGNALS
- • 45 STOP LAMPS
- 46 MUD FLAPS
- 47 REAR END PROT.
- • 48 CARGO SECUREMENT
- 49 TARPING REQUIRED
- • 50 OTHER VIOLATIONS

1ST TOWED UNIT
- • 51 COUPLING DEVICES
- 52 HEADERBOARDS
- 53 MRKR/CLEAR LIGHTS/TAIL
- • 54 TIRES
- • 55 WHEELS/LUGS/RIMS
- • 56 BRAKES
- 57 AIR HOSES/LEAKS
- 58 FRAMES
- • 59 SUSPENSIONS
- 60 WIRING
- • 61 TURN SIGNALS
- • 62 STOP SIGNALS
- 63 MUD FLAPS
- 64 REAR END PROT.
- • 65 CARGO SECUREMENT
- 66 TARPING REQUIRED
- • 67 OTHER VIOLATIONS

2ND TOWED UNIT
- • 68 COUPLING DEVICES
- 69 MRKR/CLEAR LIGHTS/TAIL
- • 70 TIRES
- • 71 WHEELS/LUGS/RIMS
- • 72 BRAKES
- 73 AIR HOSES/LEAKS
- 74 FRAMES
- • 75 SUSPENSIONS
- 76 WIRING
- • 77 TURN SIGNALS
- • 78 STOP SIGNALS
- 79 MUD FLAPS
- 80 REAR END PROT.
- • 81 CARGO SECUREMENT
- 82 TARPING REQUIRED
- • 83 OTHER VIOLATIONS

OTHER VIOLATIONS
- 84 VEHICLE IDENTIF[ICATION]
- 85 FUEL PERMIT
- 86 MPSC PLATE LICENSE
- • 87 BILLS/MANIFEST/ REQ. DOC.
- 88 VEHICLE REGIST[RATION]
- 89 UNAUTH. DRIVER/PASS[ENGER]
- 90 DNR HAZ. WASTE LIC
- • 91 OTHER VIOLATIONS

COMMENTS:

OFFICER SIGNATURE ☐ MCO ☐ TPR.	BADGE NO.	TIME ENDED AM PM	DRIVER SIGNATURE
•	•	•	•

MOTOR CARRIER SAFETY INSPECTION REPORT

Z 42492

SP4342 188

Inspection Type ☐ I ☐ II ☐ III	Federal Census #	WI Account # WI-	Date of Inspection	Day of Week	Time Stopped AM ☐ PM ☐	Time Completed AM ☐ PM ☐

On Highway	Location	County	City, Village, Town

Owner Name	DBA

Street Address	City	State	Zip

Lessee	DBA

Street Address	City	State	Zip

Vehicle Type ☐ Trac ☐ Trk ☐ Bus	Make Year	Fleet Number	Vehicle Identification No. Checked ☐

License Type	License Number	State	Expires (Mo-Yr)	License Weight	Veh Length	Width	Height

Vehicle Type ☐ Semi-Trl ☐ Full Trl ☐ Trac ☐ Trk ☐ Auto	Make Year	Fleet Number	Vehicle Identification No. Checked ☐

License Type	License Number	State	Expires (Mo-Yr)	License Weight	Veh Length	Width	Height

Vehicle Type ☐ Semi-Trl ☐ Full Trl ☐ Trac ☐ Trk ☐ Auto	Make Year	Fleet Number	Vehicle Identification No. Checked ☐

License Type	License Number	State	Expires (Mo-Yr)	License Weight	Veh Length	Width	Height

Haul Type ☐ Private ☐ For Hire	Authorities LC	IC	MC	☐ Interstate	☐ Intrastate

Commodity Description	Bill/Shipping Paper No	Placards Required ☐ Yes ☐ No	HAZARDOUS MATERIAL	Code	Rq	Hw
Consignor	Origin				
Consignee	Destination				

Driver Name (Last, First, Middle)	Driver License No	State	DL Type ☐ Chauf ☐ Reg

Date of Birth	Sex	Eyes	Hair	Wt	Ht	Signature X

Violation Sect No	O/S	Cit	(Out-of-Service, Cit = Citation Issued)

Citation No

☐ **This vehicle may not be operated until defects marked "O/S" are repaired pursuant to Trans. 325/49 Sec. 396.9.**

☐ **This driver may not drive until compliance with Trans. 325/49 Sec. 395.13.**

X ______________________________

(Person Issuing Report) (WSP No)

I certify that the defects and violations identified on this report have been repaired and corrected.

☐ Driver
☐ Repairman
☐ Carrier Official

X ______________________________

(Signature) (Date)

Motor Carrier - Return This Report Within 15 Days TO:

Wisconsin Dept. of Transportation
Division of State Patrol
Motor Carrier Inspection

MOTOR CARRIER COMPLIANCE REPORT

MAINE STATE POLICE
Traffic Division
State House Station 20
Augusta, Maine 04333

1. MSP USE ONLY
2. NAME OF MOTOR CARRIER
3. STREET ADDRESS
4. ICC DOCKET NO.
5. CITY
6. State
7. ZIP CODE

8. INSPECTION LOCATION
A ________ B ________ C ________
(Nearest City or Town) *(State)* *(Code)*

9. TYPE OF FACILITY
A CARRIER'S TERMINAL
B ROADSIDE
C OTHER

10. INSPECTION TYPE
A FULL
B EEE
C SPECIAL STUDY

11. INSPECTION DATE
___/___/___
(MO) *(DA)* *(YR)*

12. SPECIAL STUDY NO.
____ ____ ____

13. MC DOCKET NO.

14. DATE OF MEDICAL CERTIFICATE

15. *(RESERVED)*

16. TIME STARTED
____ : ____ AM PM

17. DRIVER IDENTIFICATION
A ________ B ________ C ____ D ___/___/___ E ________
(LAST NAME) *(FIRST NAME)* *(MI)* *(MO)* *(DA)* *(YR)* *(STATE)*
BIRTH DATE — LICENSE ISS. BY:

18. DRIVER IS:
A EMPLOYED
B TERM LSED
C TRIP LSED

19. COMMODITY TRANSPORTED

20. ORIGIN
A ________ B ________
(CITY) *(STATE)*

21. DESTINATION
A ________ B ________
(CITY) *(STATE)*

22. FOR HIRE?
A YES B NO

Out-of-Service Notice

______ Pursuant to Maine statutes, I hereby declare the following vehicle(s) "out-of-service." No person shall remove the herein numbered sticker(s)

________ ________

or operate such vehicle(s) until necessary repairs have been made and the vehicle(s) restored to safe operating condition.

______ Pursuant to Maine statutes, I hereby notify and declare the driver named on this report "out-of-service." No motor carrier shall permit or require the driver to drive or operate any motor vehicle until: ________

HAZARDOUS MATERIALS TRANSPORTED

A—Explosives A
B—Explosives B
C—Explosives C
D—Flammable Liquid
E—Flammable Solid
F—Flammable Gas
G—Nonflammable Gas
H—Corrosives
I—Oxidizers
J—Poison A
K—Poison B
L—Combustible Liq.
M—Radioactive Mat.
N—Organic Peroxide
O—Irritating Mat.
P—Orm A, B, or C
Q—Orm E
R—Etiologic Agt.
S—Blasting Agt.
T—Cryogenics
Z—Other

Y - YES N - NO

	CODE	RQ?	HW?
27			
28			
29			

PLACARDS REQUIRED

30	

Brake Adjustment

Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6

23. SHIPPING PAPER NO.

24. WHOSE DOCUMENT?

25. IF CARGO TANK, ENTER MC SPEC OR "NON"
____ ____ ____

26. IF H M BEING TRANSPORTED UNDER EXEMPTION, ENTER "E" NUMBER.
____ ____ ____ ____

VEHICLE IDENTIFICATION

	UNIT NUMBER	UNIT TYPE	OWN-LSED	MAKE	CO. NUMBER	LICENSE NO. & STATE
31	1					
32	2					
33	3					
34	4					
35	5					
36	6					

Unit Type: TR = Straight Truck TT = Truck Tractor ST = Semi Trailer PT = Pole Trailer FT = Full Trailer DC = Dolly Converter BU = Bus OT = Other
OWN-LSED: A = Owned B = Term Leased C = Trip Leased

NO.	VIOLATION IDENTIFICATION	UNIT no.	OUT OF SVC.	VIOLATIONS DISCOVERED
37	| | • | | | |			
	| | • | | | |			
	| | • | | | |			
	| | • | | | |			
	| | • | | | |			
	| | • | | | |			
	| | • | | | |			
	| | • | | | |			
	| | • | | | |			

REPORT PREPARED BY:	54. CODE	55. TIME COMPLETED ____ : ____ AM PM	COPY RECEIVED BY:

(Notice to Motor Carrier—Detach and Mail to Address Shown Below)

MAINE STATE POLICE—TRAFFIC DIVISION
MOTOR CARRIER SECTION
STATION 20
AUGUSTA, MAINE 04333

CITATION

You are hereby notified that you have operated a vehicle to-wit: ________
Co. Unit No.________, driven by________ on date of________, at or near ________, Maine, in violation of the Maine Statutes, and/or the rules of the Bureau of State Police. Continued violation of this nature will subject you to penalties provided by Title 29, Chap. 25, Sec. 2707. You are directed to return this portion of the compliance check within 15 days. This is to certify that the corrections and/or repairs have been made on the above vehicle on date of ________, 19____.

Signed ________ Title ________
Motor Carrier ________

Original (White) to Carrier
Duplicate (Canary) to M.S.P.
Triplicate (Pink) to Inspector

Form 17.00

NYS Department of Transportation
TRAFFIC & SAFETY DIVISION
MOTOR CARRIER SAFETY ASSISTANCE PROGRAM
1220 WASHINGTON AVENUE
ALBANY, NY 12232

DRIVER-VEHICLE EXAMINATION REPORT

GENERAL INFORMATION

1. DOT USE ONLY (REPORT #)	2. INSPECTION DATE	3. TIME STARTED	
NY A 91499	___/___/___ M D Y	___ : ___	
4. INSP. LOCATION	5. STATE CENSUS NO.	6. DOT CENSUS NO.	7. ICC DOCKET NO.

9. NAME OF MOTOR CARRIER	
10. STREET ADDRESS	
11. CITY	

8. INTERSTATE SHIPMENT? YES ☐ NO ☐

11. CITY	12. STATE	13. ZIP CODE

14. NAME OF SHIPPER	15. SHIPPING PAPER NO.	
16. DRIVER IDENTIFICATION (LAST, FIRST, MI)	17. DRIVER LICENSE NO.	18. DRIVER LICENSE STATE
19. DRIVER DATE OF BIRTH __/__/__ M D Y	20. SPECIAL STUDY NO. __ __ __ __ __	21. UNIFORM TRAFFIC TICKET ISSUED? (Circle 1) Y N
22. CARGO TANK __ __ __	23. COMMODITY TRANSPORTED	24. DMV INSPECTION CERT. EXP. DATE __ M __ Y

BRAKE ADJUSTMENT

	AXLE 1	AXLE 2	AXLE 3	AXLE 4	AXLE 5	AXLE 6	AXLE 7
RIGHT							
FRONT							
LEFT							
TYPE							

25. # ADJUSTMENTS O/S __ __

26. DMV INSPECTION CERT. NUMBER

27. VEHICLE ODOMETER

28. C.V.S.A. DECAL NO. UNIT NO.
NY __ __ __ __ __ __ ___
NY __ __ __ __ __ __ ___

HAZARDOUS MATERIALS TRANSPORTED

A—Explosives A
B—Explosives B
C—Explosives C
D—Flammable Liquid
E—Flammable Solid
F—Flammable Gas
G—Nonflammable Gas
H—Corrosives
I—Oxidizers
J—Poison A
K—Poison B
L—Combustible Liquid
M—Radioactive Material
N—Organic Peroxide
O—Irritating Material
P—Orm A, B, or C
Q—Orm E
R—Etiologic Agt.
S—Blasting Agt.
T—Cryogenics
Z—Other

	CODE	RQ?	HW?
29.			
30.			
31.			

PLACARDS REQUIRED? | 32. | |

Y = YES N = NO

VEHICLE IDENTIFICATION

	UNIT NO.	UNIT TYPE	MAKE	CO. NUMBER	LICENSE TAG NUMBER	STATE
33.	1					
34.	2					
35.	3					
36.	4					
37.	5					
38.	6					

Unit Type: TR = Straight Truck TT = Truck Tractor ST = Semi Trailer PT = Pole Trailer FT = Full Trailer DC = Dolly Converter BU = BUS OT = Other

VIOLATIONS

NO.	VIOLATION IDENTIFICATION	UNIT NO.	OUT OF SVC	VIOLATIONS DISCOVERED
	•			
	•			
	•			
	•			
	•			
	•			
SEE CONTINUATION SHEET YES NO				

VEHICLE/DRIVER OUT OF SERVICE NOTICE

☐ Pursuant to the authority contained in Subdivision 2 of Section 140 of the Transportation Law and the regulations of the Commissioner of Transportation promulgated pursuant there to, I hereby declare vehicles with defects followed by an "X" in the "Out of Service" column in the violations discovered section of this report OUT OF SERVICE. No person shall operate such vehicles until the out of service defects have been repaired and the vehicles have been restored to safe operating condition.

☐ Pursuant to authority contained in Subdivision 2 of Section 211 & 212 of the Transportation Law and the regulations of the Commissioner of Transportation promulgated pursuant there to, I hereby notify and declare the driver named on this report OUT OF SERVICE. No motor carrier shall permit or require this driver to drive or operate any motor vehicle until: ________________

REPORT PREPARED BY	A. ID OR BADGE #	B. TIME COMPLETED	COPY RECEIVED BY
	__ __ __ __ __	___ : ___	

NOTE TO DRIVER: This report must be furnished to the motor carrier whose name appears at the top of this report. NOTE TO MOTOR CARRIER: If entries are made in the violation section above, please sign the certification below, and within fifteen days return this report to the address which appears in the upper left corner of this report.

The undersigned certifies that all violations noted on this report have been corrected and action has been taken to assure compliance with the Transportation Law and regulations.

SIGNATURE OF CARRIER OFFICIAL	TITLE	DATE SIGNED

TE 241b (11/87)

PUBLIC UTILITY COMMISSION OF OREGON
420 LABOR AND INDUSTRIES BUILDING
SALEM, OREGON 97310-0335

NO. S 143958

DRIVER EQUIPMENT COMPLIANCE CHECK

U.S. DOT NO | INSP TYPE: PRE-SELECT ☐ RANDOM ☐ AUDIT ☐ OTHER/SPECIAL ____ PRE-OP ☐ PRE-NOTE ☐

NAME OF CARRIER | AF NO. | CLASS | INSPECTION DATE / /

STREET ADDRESS | START TIME ☐ AM ☐ PM | INTERSTATE? ☐ YES ☐ NO

CITY | ST | ZIP | PLACE OF INSPECTION | SCALE NO.

DRIVER A | LICENSE NO. | ST | DATE OF BIRTH | PHYSICAL DATE | OS

DRIVER B | LICENSE NO. | ST | DATE OF BIRTH | PHYSICAL DATE | OS

SHIPPER | ORIGIN | SHIPPING DOCUMENT NO.

RECEIVER | DESTINATION

COMMODITY | HAZARDOUS MATERIAL? ☐ YES ☐ NO | RQ? ☐ YES ☐ NO | HW? ☐ YES ☐ NO | PLACARD DISPLAYED | UN/NA NO.

PUC PLATE/PASS | VIN NO. | CARGO TANK SPEC. NO. | NO. AXLES REQ. BRAKES | MILEAGE ☐ SPEEDO ☐ HUB

UNIT TYPE: TR - STRAIGHT TRUCK TT - TRUCK TRACTOR ST - SEMI TRAILER PT - POLE TRAILER FT - FULL TRAILER DC - DOLLY CONVERTER BU - BUS OT - OTHER

VEHICLE ORDER	UNIT TYPE	MAKE	BASE PLATE	ST	COMPANY NO.	OUT OF SERVICE
1						
2						
3						
4						
5						
6						

BRAKE ADJUSTMENT MEASUREMENTS

	STEERING										
	TYPE	AXLE 1	TYPE	AXLE 2	AXLE 3	AXLE 4	AXLE 5	AXLE 6	AXLE 7	AXLE 8	AXLE 9
RIGHT											
LEFT											

DECAL TT/TR | DECAL TRL 1 | DECAL TRL 2 | DECAL TRL 3

MCS PART NO.	OAR 860	VEH. ORDER	OS	VIOLATIONS, DEFECTS, FINDINGS AND REMARKS

OUT OF SERVICE NOTICE: IN ACCORDANCE WITH OREGON REVISED STATUTES, CHAPTER 767, AND OREGON ADMINISTRATIVE RULES, CHAPTER 860, I HEREBY DECLARE AND MARK THE FOLLOWING VEHICLE(S) "OUT OF SERVICE." NO PERSON SHALL REMOVE THE HEREIN NUMBERED STICKER(S) OR OPERATE SUCH VEHICLE(S) UNTIL NECESSARY REPAIRS HAVE BEEN COMPLETED AND THE VEHICLE(S) RESTORED TO SAFE OPERATING CONDITION.

VEHICLE/ DRIVER ORDER	"OUT OF SERVICE" REQUIRED REPAIRS UNDER MCSR PART 396.7 / OAR 860-65-028	OUT OF SERVICE STICKER NO.(S)

SIGNATURE/INSPECTOR CODES | FINISH TIME ☐ AM ☐ PM | COPY RECEIVED BY

DRIVER: GIVE THIS FORM TO THE MOTOR CARRIER LISTED AT THE TOP OF THE FORM

MOTOR CARRIER: SEE OTHER SIDE

IF VIOLATIONS ARE NOTED ON THE REVERSE SIDE, THE FOLLOWING REQUIREMENTS MUST BE MET:

1. ALL VIOLATIONS AND DEFECTS ARE TO BE CORRECTED OR REPAIRED.
2. THE PERSON COMPLETING "OUT OF SERVICE" REPAIRS MUST SIGN THE FORM AS REPAIRMAN.
3. A COMPANY OFFICIAL MUST SIGN THE FORM CERTIFYING COMPLIANCE WITH FEDERAL AND STATE MOTOR CARRIER SAFETY AND HAZARDOUS MATERIALS REGULATIONS.
4. THE FORM IS TO BE MAILED TO THE PUBLIC UTILITY COMMISSION, 420 LABOR & INDUSTRIES BUILDING, SALEM, OREGON 97310-0335 WITHIN **15 DAYS** FROM THE DATE OF INSPECTION.

FAILURE TO COMPLY WITH THE ABOVE REQUIREMENTS MAY RESULT IN A MONETARY PENALTY OF $100 PER DAY FOR EACH DAY OF NONCOMPLIANCE.

I CERTIFY THAT THE VIOLATIONS LISTED IN THE "OUT OF SERVICE REQUIRED REPAIRS" SECTION HAVE BEEN SATISFACTORILY COMPLETED AS OF THE DATE INDICATED.		
SIGNATURE OF REPAIRMAN	NAME OF SHOP (GARAGE)	DATE

THE UNDERSIGNED CERTIFIES THAT ALL VIOLATIONS NOTED ON THIS REPORT HAVE BEEN CORRECTED AND ACTION HAS BEEN TAKEN TO ASSURE COMPLIANCE WITH THE FEDERAL AND STATE MOTOR CARRIER SAFETY AND HAZARDOUS MATERIAL REGULATIONS INSOFAR AS THEY ARE APPLICABLE TO MOTOR CARRIERS AND DRIVERS. I UNDERSTAND THAT FAILURE TO COMPLY WILL SUBJECT ME TO ADDITIONAL VIOLATIONS UNDER THE REGULATIONS NOTED.		
SIGNATURE OF CARRIER OFFICIAL	TITLE	DATE

MAIL TO:

PUBLIC UTILITY COMMISSION OF OREGON
420 LABOR AND INDUSTRIES BUILDING
SALEM, OREGON 97310-0335

CVSA NUMBER
UT A03801

UTAH HIGHWAY PATROL
MOTOR CARRIER SECTION

DRIVER/EQUIPMENT COMPLIANCE CHECK

NAME OF MOTOR CARRIER — OWNED / LEASED

PRINCIPAL OFFICE STREET ADDRESS

CITY	STATE	ZIP CODE

DRIVER INFORMATION
D L No ____________ LICENSE STATE ______

LAST NAME ____________ FIRST NAME ____________ M.I ___ DOB __/__/__ M D Y

USDOT NUMBER

I C C NUMBER

ACCIDENT? Y N

INSPECTION LEVEL 1 2 3 4

DATE OF THE INSPECTION ___/___/___ M D Y

WHAT TIME DID THE INSPECTION START?
MILITARY TIME

LOCATION OF INSPECTION P O E., COUNTY & ROAD

COMMODITY CARRIED

CODE FOR TYPE OF TRANSPORT
A - INTERSTATE CARRIER B - INTRASTATE CARRIER

DESCRIPTION OF EACH UNIT

TT TR POWER UNIT NO ____________
MAKE ____________ YEAR ______
LICENSE # ____________ STATE ______
MC __ __ __ STICKER # ____________

ST FT 1ST TOWED UNIT NO ____________
MAKE ____________ YEAR ______
LICENSE # ____________ STATE ______
MC __ __ __ STICKER # ____________

ST FT 2ND TOWED UNIT NO ____________
MAKE ____________ YEAR ______
LICENSE # ____________ STATE ______
MC __ __ __ STICKER # ____________

ST FT 3RD TOWED UNIT NO ____________
MAKE ____________ YEAR ______
LICENSE # ____________ STATE ______
MC __ __ __ STICKER # ____________

ENTER CODE(S) FOR ALL HAZARDOUS MATERIALS

A - EX A	H - COR	O - IRRIT
B - EX B	I - OXI	P - ORM
C - EX C	J - POI A	Q - HAZ WST
D - FL	K - POI B	R - ETIO AGT
E - FS	L - COMB	S - BLAST AGT
F - FLG	M - RAM	T - CRYOGENICS
G - NFG	N - ORGP	Z - OTHER

PRODUCT ____________

QUANTITY OF HAZARDOUS MATERIAL
A - LESS THAN 1000 LB
B - 1001 LB - 10 TON
C - OVER 10 TON

ARE PLACARDS REQUIRED? Y N AFFIXED? Y N

RULE OR STATUTE #	*OUT OF SERV.	CIT	UNIT NUMBER	VIOLATIONS DISCOVERED:

* **DRIVER OUT OF SERVICE NOTICE:** THIS DRIVER SHALL NOT DRIVE ANY COMMERCIAL MOTOR VEHICLE UNTIL ____________

CARRIER NOTIFICATION BY OFFICER DRIVER

• **OUT OF SERVICE NOTICE: THIS VEHICLE IS OUT OF SERVICE IF INDICATED ABOVE, AND SHALL NOT OPERATE UNTIL ALL OUT OF SERVICE VIOLATIONS ARE REPAIRED OR CORRECTED.**

REPORT RECEIVED BY:
NAME: ____________

CERTIFICATION OF "OUT OF SERVICE" DEFECTS REPAIRED: I CERTIFY THAT THE REPAIRS LISTED ON THE "OUT OF SERVICE" STICKERS AFFIXED TO THIS VEHICLE HAVE BEEN REPAIRED PRIOR TO FURTHER OPERATION OF THE VEHICLE.

DATE REPAIRED: ______ TIME REPAIRED: ______ AM PM SIGNATURE: ____________

REPORT PREPARED BY:
NAME: ____________ NUMBER: ______

WHAT TIME DID THE INSPECTION END?
MILITARY TIME: ____________

NOTE TO MOTOR CARRIER: ALL DEFECTS NOTED ON THIS AND ANY CONTINUATION SHEETS MUST BE CORRECTED. A RESPONSIBLE COMPANY OFFICIAL CERTIFIES THAT ALL DEFECTS HAVE BEEN CORRECTED.

NAME: ____________ TITLE: ____________ DATE: ______

THIS REPORT MUST BE RETURNED WITHIN 15 DAYS TO DEPT. OF TRANSPORTATION SAFETY, 4501 SOUTH 2700 WEST, SALT LAKE CITY, UTAH 84119

HPF 55 Rev 12/89
(P-155)

White - Office Copy · Canary - Officer Copy · Pink - Driver Copy · Goldenrod - Driver Copy

EPARTMENT OF CALIFORNIA HIGHWAY PATROL

AFETYNET DRIVER/VEHICLE INSPECTION REPORT

CHP 407F (Rev 9-88) OPI 063

039351

DATE	TIME START			LOC. CODE	BEAT	INSPECTED BY	I.D. NO.

DRIVER INFORMATION

FIRST NAME	M.I.	LAST NAME	LICENSE NUMBER	STATE

COMPLIES		YES	NO	OS	COMPLIES		YES	NO	OS	COMPLIES		YES	NO	OS	COMPLIES		YES	NO	OS
river license	A				Medical certificate	B				Driver's log	C				Driver's hours	D			

CARRIER INFORMATION

HP NUMBER	PUC NUMBER	ICC NUMBER
A		MC

ARRIER NAME	U.S. DOT NUMBER

TREET ADDRESS (INCLUDE CITY, STATE AND ZIP CODE)

VEHICLE INFORMATION

VEH. NO.	TYPE	VEHICLE MAKE	LICENSE NUMBER	STATE
1				
2				
3				
4				

BRAKE ADJUSTMENT

	AXLE 1	AXLE 2	AXLE 3	AXLE 4	AXLE 5	AXLE 6	AXLE 7
RIGHT							
FRONT							
LEFT							

VEHICLE INSPECTION

	VEHICLE 1				VEHICLE 2				VEHICLE 3				VEHICLE 4				
COMPLIES		YES	NO	OS		YES	NO	OS		YES	NO	OS		YES	NO	OS	
Registration	E				E				E				E				E
ghts—stop/turn	F				F				F				F				F
eering components	G				G				G				G				G
Air loss: unapplied	H				H				H				H				H
ir loss: applied	I				I				I				I				I
w air warn. device	J				J				J				J				J
Brake hoses	K				K				K				K				K
Brake adjustment	L				L				L				L				L
ake drums/shoes	M				M				M				M				M
onnection devices	N				N				N				N				N
Exhaust	O				O				O				O				O
el system	P				P				P				P				P
ame	Q				Q				Q				Q				Q
Suspension	R				R				R				R				R
heels	S				S				S				S				S
res	T				T				T				T				T
Warning devices	U				U				U				U				U
Maintenance	V				V				V				V				V

COMMENTS

HAZARDOUS MATERIALS INSPECTION

COMPLIES		YES	NO	OS	
Ship paper/manifest	HA				HA
HM license	HB				HB
HW registration	HC				HC
Placards	HD				HD
Packaging	HE				HE
Marking	HF				HF
Labels	HG				HG
Loading/securement	HH				HH
Cargo/Portable tanks	HI				HI
Safety equipment	HJ				HJ

CODE	RQ?	HW?

PLACARDS REQUIRED

☐ Yes ☐ No

CODES

A—Explosives A	L—Combustible liquid
B—Explosives B	M—Radioactive material
C—Explosives C	N—Organic peroxide
D—Flammable liquid	O—Irritating material
E—Flammable solid	P—Orm A, B, or C
F—Flammable gas	Q—Orm E
G—Nonflammable gas	R—Etiologic agent
H—Corrosives	S—Blasting agent
I—Oxidizers	T—Cryogenics
J—Poison A	Z—Other
K—Poison B	

CITATION NUMBER	OFFICER I.D. NUMBER
CVSA STICKERS ISSUED	OWNER'S RESPONSIBILITY ☐ Yes ☐ No
TIME END	LEVEL

I acknowledge that I have reviewed and received a copy of this report.

DRIVER'S SIGNATURE

MOTOR CARRIER SAFETY ASSISTANCE PROGRAM STATE OF GEORGIA

1. Report No. 68707

GEORGIA PUBLIC SERVICE COMMISSION DRIVER-VEHICLE EXAMINATION REPORT

2. INSPECTION DATE ___/___/___ (MO) (DA) (YR)	3. TIME STARTED ___ : ___	4. INSPECTION LOCATION ___ (Code) ___ (Nearest City or Town)	
5. STATE NO.	6. DOT NO.	7. ICC DOCKET NO.	8. INTERSTATE? Y N
9. NAME OF MOTOR CARRIER			
10. STREET ADDRESS	11. CITY	12. STATE	13. ZIP CODE
14. NAME OF SHIPPER	15. SHIPPING PAPER NO.		
16. DRIVER IDENTIFICATION A ___ (LAST NAME) B ___ (FIRST NAME) C ___ (MI)	17. DRIVER LICENSE NO.	18. LIC. STATE	
19. BIRTH DATE ___/___/___ (MO) (DA) (YR)	20. ORIGIN OF SHIPMENT ___ (City) ___ (State)	21. CONSIGNEE	
22. COMMODITY TRANSPORTED	23. DESTINATION OF SHIPMENT ___ (City) ___ (State)	24. FOR HIRE? A YES B NO	25. DRIVER IS: A Employed B Term LSD C Trip LSD
	26. WHOSE DOCUMENT?	27. IF CARGO TANK, ENTER MC SPEC OR "NON" ___ ___ ___	28. H.M. EXEMPTION NUMBER

HAZARDOUS MATERIALS

A—Explosives A
B—Explosives B
C—Explosives C
D—Flammable Liquid
E—Flammable Solid
F—Flammable Gas
G—Nonflammable Gas
H—Corrosives
I—Oxidizers
J—Poison A
K—Poison B
L—Combustible Liq
M—Radioactive Mat
N—Organic Peroxide
O—Infecting Mat
P—Orm A,B or C
Q—Orm E
R—Etiologic Agt.
S—Blasting Agt.
T—Cryogenics
Z—Other

	CODE	RQ?	HW?
29.			
30.			
31.			

Placards Required? 32. Y-Yes N-No

VEHICLE IDENTIFICATION

	UNIT NUMBER	UNIT TYPE	MAKE	CO NUMBER	LICENSE TAG NO. & STATE
33.	1				
34.	2				
35.	3				
36.	4				

Unit Type: TR = Straight Truck TT = Truck Tractor ST = Semi Trailer PT = Pole Trailer FT = Full Trailer DC = Dolly Converter BU = Bus OT = Other

	AXLE 1	AXLE 2	AXLE 3	AXLE 4	AXLE 5	AXLE 6	AXLE 7	BRAKE ADJUSTMENT
RIGHT								
FRONT								
LEFT								

VIOLATIONS

NO.	VIOLATION IDENTIFICATION	UNIT NO.	OUT OF SVC	VIOLATIONS DISCOVERED
38.				
	SEE CONTINUATION SHEET YES NO			CITATION NO.(S)

VEHICLE/DRIVER OUT OF SERVICE NOTICE

Pursuant to authority contained in Title 49, Code of Federal Regulations, Section 396.9, I hereby declare vehicles with defects followed by an "X" in the "Out of Service" column in the violations discovered section of this report *Out of Service*. No person shall remove the out of service stickers applied to these vehicles, or operate such vehicles until the out of service defects have been repaired and the vehicles have been restored to safe operating condition.

Pursuant to authority contained in Title 49, Code of Federal Regulations, Section 395.13, I hereby notify and declare the driver named on this report *Out of Service*. No motor carrier shall permit or require this driver to drive or operate any motor vehicle until:

OUT OF SERVICE STICKER NO(S)

GPSC ENFORCEMENT OFFICER	A. INSPECTOR CODE	B. TIME COMPLETED ___ : ___	COPY RECEIVED BY:

NOTE TO DRIVER: This report must be furnished to the motor carrier whose name appears at the top of this report. **NOTE TO MOTOR CARRIER:** Please sign the below certification and return this report to the address which appears on the other side of this report within fifteen days.

The undersigned certifies that all violations noted on this report have been corrected and action has been taken to assure compliance with the Georgia Public Service Commission Motor Carrier Safety and Hazardous Material Regulations insofar as they are applicable to motor carriers and drivers.

SIGNATURE OF CARRIER OFFICIAL	TITLE	DATE SIGNED

FORM GPSC 33 (Rev. 2-88)

White Copy: GPSC
Green Copy: Carrier
Canary Copy: Driver
Pink Copy: Tracer
G'rod Copy: Enforcement Officer

APPENDIX B.A

LITERATURE REVIEW

This review pertains primarily to the adjustment of air-actuated S-cam brakes used on heavy trucks and large buses. The review supports work aimed at maintaining heavy vehicle brakes in proper adjustment.

The material presented is expected to be effective in attaining the goals of this investigation, but it is not claimed to be a comprehensive listing of all of the work that has been reported on brake-adjustment. Rather, it covers applicable material that is readily available to the authors. In particular, the material is intended to apply to the topics to be addressed in interviews with MCSAP inspectors and in other tasks later in the research study.

This appendix contains:

(1) a summary of the findings of the literature review, and

(2) an annotated bibliography on specified documents.

Further findings and data on the influences of brake-adjustment on brake performance are presented in separate appendices (Appendices C and D).

Summary of the findings of the literature review

OUT-OF-SERVICE CRITERIA (OOS)

The following quotations describing the current OOS criteria as it pertains to brake-adjustment are taken directly from Reference [1]:

APPENDIX A

PART II

NORTH AMERICAN UNIFORM VEHICLE OUT-OF-SERVICE CRITERIA

POLICY STATEMENT

The purpose of this part is to identify critical vehicle inspection items and provide criteria for placing a vehicle(s) in an out-of-service or restricted service category subsequent to a safety inspection.

OUT-OF-SERVICE CONDITON: When any motor vehicle(s) by reason of its mechanical condition or loading, is determined to be so imminently hazardous as to likely cause an accident or breakdown, or when such condition(s) would likely contribute to loss of control of the vehicle(s) by the driver, said vehicle(s) shall be placed out-of-service. No motor carrier shall require nor shall any person operate any motor vehicle declared and marked "out-of-service" until all required repairs have been satisfactorily completed.

INSPECTION ITEM	OUT-OF-SERVICE CONDITION
1. Brake System	
a. Defective Brakes.	**The number of defective brakes is equal to or greater than 20% of brakes on the vehicle or combination. A defective brake includes any brake that meets on e of the following criteria: (NOTE: Steering axle brakes under lb. - may also be included in 20% criterion.)**

-
-
-
-

(5) Readjustment limits. With engine off and reservoir pressure of 80 to 90 psi with brakes fully applied.

(a) One brake at 1/4" or more beyond the readjustment limit. (Example: Type 30 clamp type brake chamber pushrod measured at 2-1/4" would be one defective brake.) (396.3A1)

(b) Two brakes at the readjustment limit or less than 1/4" beyond the readjustment limit also equal one defective brake. Example: Clamp type 30 pushrods measure:

1 - Two at 2-1/8"
2 - One at 2-1/8" and one at 2"; or
3 - Two at 2"

Each example would equal one defective brake.

(See the following chart.) (396.3A1)

Brake Adjustment. Shall not meet those specifications contained hereunder relating to "Maximum Stroke at which brakes must be readjusted". (Dimensions in inches.)

CLAMP TYPE BRAKE CHAMBER DATA

TYPE	EFFECTIVE AREA (SQ. IN.)	OUTSIDE DIAMETER	MAXIMUM STROKE AT WHICH BRAKES MUST BE READJUSTED
6		4-1/2	1-1/4
9		5-1/4	1-3/8
12		5-11/16	1-3/8
16		6-3/8	1-3/4
20		6-25/32	1-3/4
24		7-7/32	1-3/4 (See note)
30		8-3/32	2
36		9	2-1/4

NOTE: 2 inches for long stroke design.

BOLT TYPE BRAKE CHAMBER DATA

TYPE	EFFECTIVE AREA (SQ. IN.)	OUTSIDE DIAMETER	MAXIMUM STROKE AT WHICH BRAKES MUST BE READJUSTED
A	12	6-15/16	1-3/8
B	24	9-3/16	1-3/4
C	16	8-1/16	1-3/4
D	6	5-1/4	1-1/4
E	9	6-3/16	1-3/8
F	36	11	2-1/4
G	30	9-7/8	2

ROTOCHAMBER DATA

TYPE	EFFECTIVE AREA (SQ. IN.)	OUTSIDE DIAMETER	MAXIMUM STROKE AT WHICH BRAKES MUST BE READJUSTED
9		4-9/32	1-1/2
12		4-13/16	1-1/2
16		5-13/32	2
20		5-15/16	2
24		6-13/32	2
30		7-1/16	2-1/4
36		7-5/8	2-3/4
50		8-7/8	3

WEDGE BRAKE DATA

Movement of the scribe mark on the lining shall not exceed 1/16 inch.

February 15, 1989

Earlier requirements concerning differences in adjustment across the front axle have been removed [1] and the test results and analyses described in Reference [2] provide evidence showing that the effects of this type of problem do not cause special difficulties for truck drivers in controlling their vehicles unless one of the brakes is well beyond the readjustment point.

A remaining issue appears to be whether the OOS criteria on adjustment is restrictive enough given the findings concerning the influences of brake temperature on stroke. [2] Brakes that are at their recommended limit on stroke may be on the borderline of running out of stroke if the temperature of the drum is raised by approximately 400°F above its cool temperature. The following figure from Reference [3] shows how stroke is consumed. If the stroke at 90 psi happened to be at 2", an additional temperature rise from 200°F to 600°F could use up the 0.5" of reserve stroke available before the push rod bottoms out.

Another point to consider is the 20 percent factor. This could be construed implicitly to imply that reductions of 20 percent or more in braking performance are not to be accepted. Perhaps this criteria can be used in making judgments in this study concerning various factors that influence the braking capability of a heavy truck.

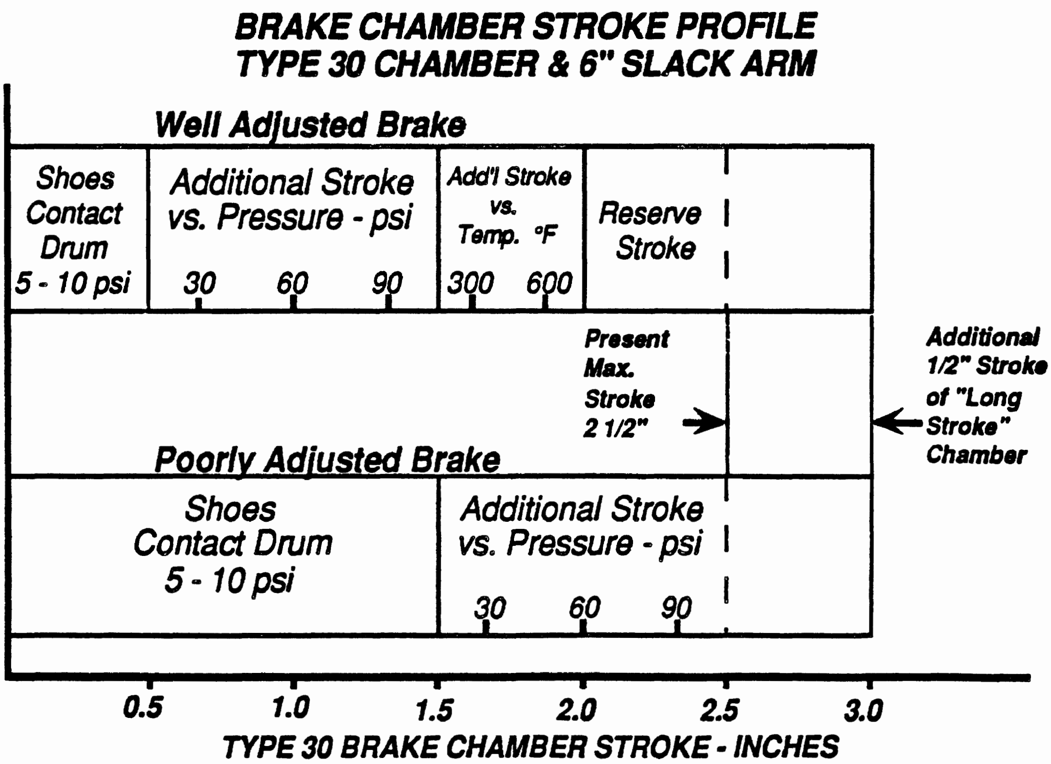


Figure 1. Stroke Accounting from reference (3)

BRAKE INSPECTION

Procedures for adjusting brakes differ from one organization to another. The following Figure lists some possibilities. [3] There are more. For example, for vehicles used in our test work, we set the stroke at 100 psi to be approximately 1.25" for a Type 30 chamber. This might introduce a small amount of short term wear in taking off any high spots or out-of-roundness, but it is safe with respect to running out of stroke and the wear penalty is very small.

The adjustment methods 1 and 2 listed in Figure 2 are convenient for one person adjusting the brakes alone. Perhaps the first method (involving measuring the clearance at the center of the shoe) is the easiest for an individual to perform.

Inspection methods involving two people may differ from adjustment methods used when only one person is available. Information on inspection procedures will be gathered as this project progresses. (Information on the MCSAP inspection procedures follows Figure 2.)

S - CAM BRAKES

ADJUSTMENT METHODS

1. *Adjust to .010" Lining to Drum clearence at center of shoe*
2. *Jack up wheel; tighten until Brake drags and back off Slack Adjuster two clicks (1/6 turn)*
3. *Adjust to 1/2" free stroke*

FREQUENCY OF ADJUSTMENT

- *A Cam Brake will require at least 20 Adjustments/ Lining Set*
- *You must detemine proper frequency for your operation*
- *Adjust or check Adjustment before a run in the mountains*
- *Consider Automatic Adjusters*

Figure 2. Brake adjustment methods [3].

The procedures stated in the MCSAP inspection manual [1] are as follows:

May 1989

11. BRAKE ADJUSTMENT - Required on Level I inspections only.

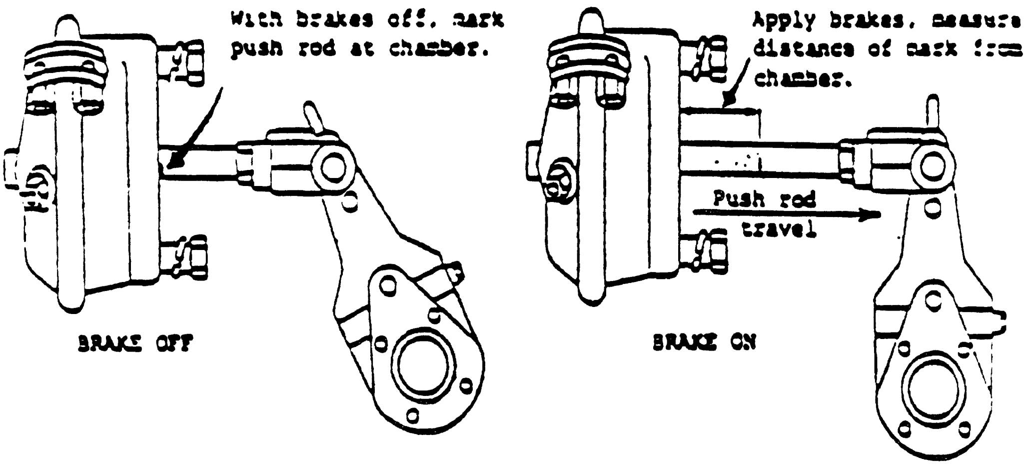
a. General Instructions

(1) This procedure requires the measurement of push rod travel on all brakes of a vehicle or combination unit with air brakes.

Inspection procedure (push rod travel)

CAUTION: Chock wheels before commencing this inspection as vehicle emergency brake(s) must be off.

(Welder's flat soap stone works well for the following procedure)



(2) **The majority of air-brake equipped vehicles will have clamp type, size 30 brake chambers, except on the steering axle. Steering axle brake chambers on over-the-road power units usually have chambers smaller than size 30.**

(3) **Brake chamber push rod stroke readjustment limits must be measured at 80-90 p.s.i. application pressure. To achieve the proper pressure in the system prior to measurement, increase the reservoir pressure with the engine running, or decrease the reservoir pressure with engine off, while applying and exhausting the brakes until 90 p.s.i. is achieved in the reservoir. A reservoir pressure of 90 p.s.i. will produce 80-90 p.s.i. application pressure with the engine off.**

b. Measuring Push Rod Travel

(1) Cam Brakes. With the brakes applied by a full pressure application, measure from the face of the brake chamber to the mark made on the brake chamber push rod when the brakes were released. (A full pressure application means between 80 p.s.i. and 90 p.s.i.)

Brake chamber push rod travel that meets or exceeds the limits shown in the column headed "Maximum Stroke at Which Brakes must be Readjusted" shown in the Appendix A part II table is a condition of improper maintenance.

(2) Disc Brakes. After the brakes have been applied by a full pressure application, measure the push rod travel from the released position as described for cam brakes in paragraph 11b(1).

Disc brake chamber push rod travel that meets or exceeds the maximum stroke at which brakes must be readjusted in Appendix A part II is a condition of improper maintenance.

c. Wedge Brake Adjustment

(1) Wedge Brakes. With the inspection hole cover removed from the brake dust shield, check the adjustment at each wheel using the gauge illustrated on the next page.

(a) Insert the flat end of the gauge into the inspection hole in the dust shield or, if there is no dust shield, midway between the ends of the shoe. Place one edge of the gauge against dust shield inspection hole or the brake drum lip with the square end against the brake lining or shoe.

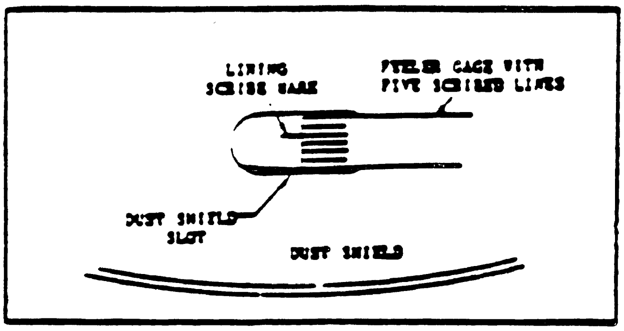
(b) With the brakes released, make a scribe mark on the brake lining or shoe opposite of the scribe lines on the gauge as illustrated on the next page.

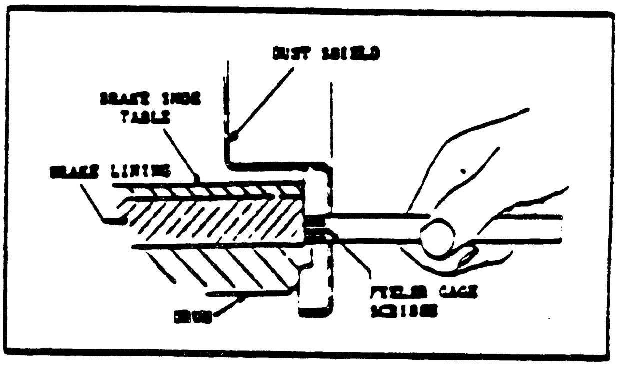
(c) Movement of the scribe mark on the lining of more than 1/16 inch with respect to the marks on the gauge when the brakes are applied, as illustrated on the next page, is a condition of improper maintenance.

(d) Failure of the brake shoes to move is a condition of improper maintenance.

Measurement Gauge and Lining Scribe Mark

Measurement of Wedge Brake Adjustment





Note: **The gauge may be made of feeler gauge stock 0.025-inch X 3/8 inch X 8 inch. Scribe five 1/2-inch lines spaced 1/16 inch-apart.**

INFLUENCES OF BRAKE-ADJUSTMENT ON BRAKE PERFORMANCE

An air brake system consists of an air compressor and air tanks for storing compressed air, a treadle valve for applying air to the brake system, air lines, relay and other valves, air chambers (for applying pushrod forces to the actuation mechanism), S-cams or other actuation mechanisms for applying the linings of the shoes to the drums, shoes, and drums. [4] As the lining wears, the clearance between the unapplied shoes and the drum increases. When air is applied, the stroke increases. The amount of pushrod stroke needed to apply the brake increases as the lining wears. If the brake is not properly adjusted, the stroke at the air chamber may become so large that the pushrod approaches the end of the air chamber thereby limiting the force available for applying the brake linings to the drum. The reason for adjusting the brake is to prevent the pushrod from "bottoming out" on the bottom of the air chamber.

Figure 3 shows the characteristics of the pushrod force as a function of its stroke. [2] Above 2", this Type 30 chamber has a dramatic reduction in pushrod force. For brakes adjusted so that the stroke at 100 psi is less than 2", the amount of stroke does not influence the actuation force from the pushrod onto the slack adjuster arm. However, if the stroke increases beyond 2" because the lining has worn away or the drum expands due to temperature increases, there is a loss of force to actuate the brake; and there is a sudden loss in actuation or push rod force when the stroke reaches approximately 2.5" as shown in Figure 3.

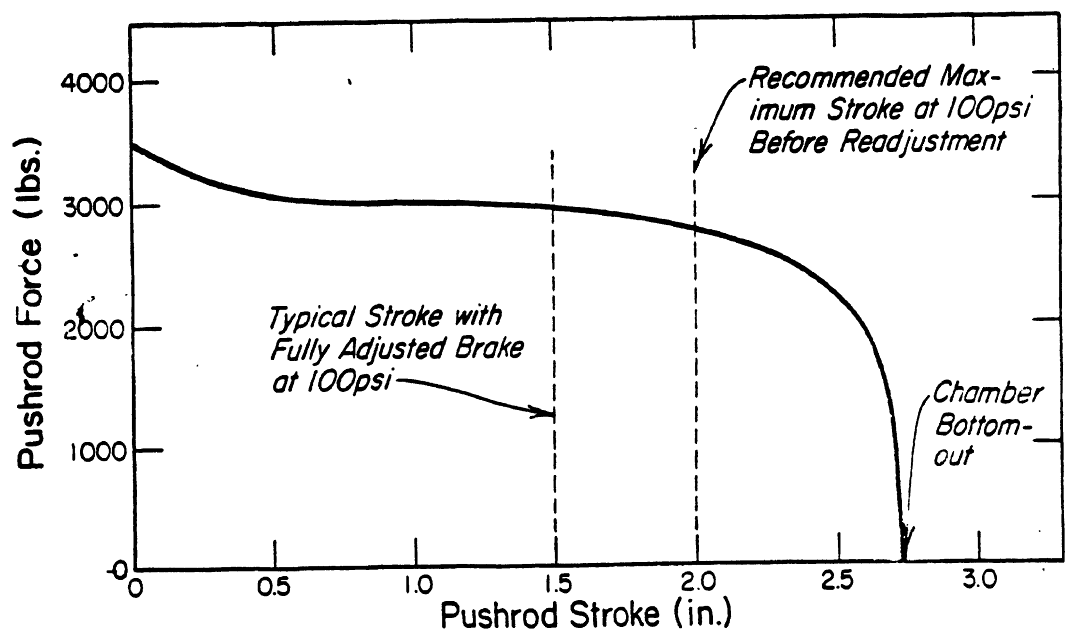


Figure 3. Pushrod force versus pushrod stroke at 100 psi. (2)

The influence of running out of stroke is illustrated by the data presented in Figure 4. [2] For stroke less than 2" and temperatures less than 400°F, there is less than 10 percent decrease in brake torque. However, at 600°F, there is a very dramatic loss in brake torque, reaching over 50 percent starting from a cold static stroke of 2.25" at 100 psi, and getting substantially worse at higher levels of cold stroke. The dramatic loss in brake torque illustrated in Figure 4 clearly indicates the need for maintaining proper adjustment so that reasonable brake torque capability will be maintained even if the brake becomes hot on a long, steep mountain grade or in stop-and-go driving. Furthermore, even if the brake is at 200°F and the cold stroke is above 2.25", there is more than a 20 percent loss in torque at 100 psi of air pressure.

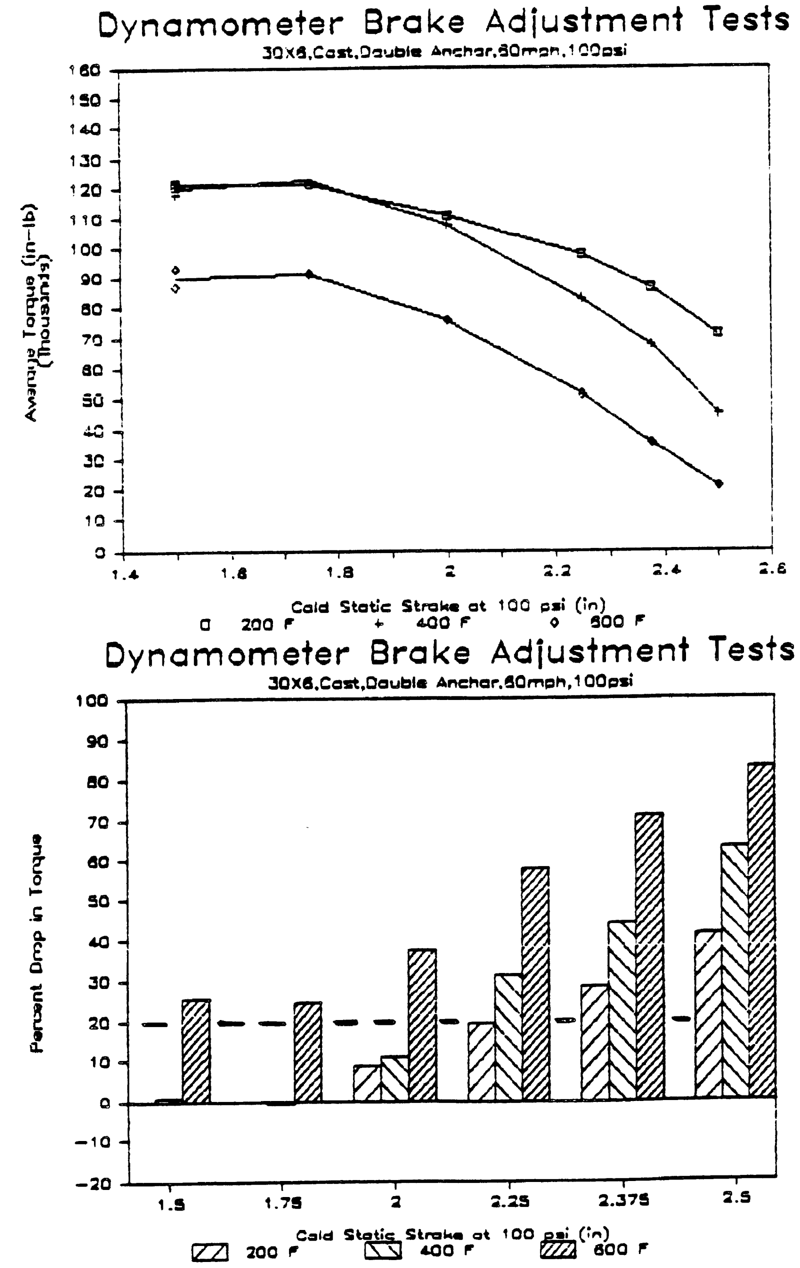


Figure 4. The influence of stroke on brake torque. (2)

A subtle point concerning the loss of brake torque at high cold stroke is that the driver may not be aware of this danger because it may not be apparent during normal stopping. As shown previously in Figure 1, an inch of stroke is consumed in going from pushout pressure to 100 psi. Figure 5, taken from [3], indicates that most brake applications (about 80 percent) are at less than 20 psi. According to Figure 1, these applications require less than 0.2" of stroke—meaning that the stroke would be approximately 0.8" less than it would be at 100 psi. This stroke margin means that the driver is not able to feel the danger of running out of stroke in normal driving situations. Brake-adjustment needs to be checked to prevent the hazards of not knowing that the maximum torque available for an emergency is very limited if the brake is OOA and especially if the brake is hot.

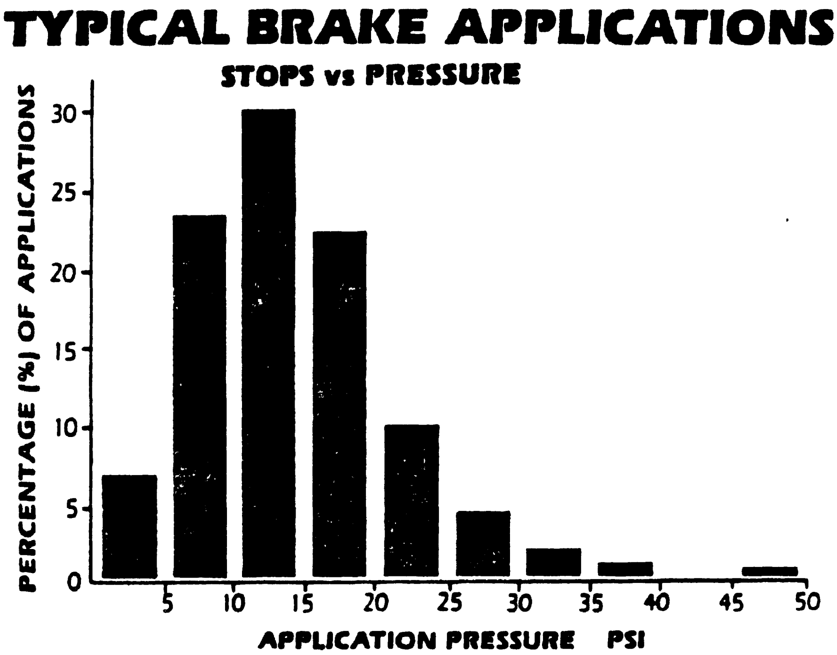


Figure 5. The percentage of brake applications in various pressure ranges. (3)

THE NATURE OF THE PROCESSES INVOLVED IN BRAKES BECOMING OUT OF ADJUSTMENT

Aside from some type of misadjustment, brakes become OOA because they wear. An S-cam brake will require at least twenty (see Figure 2) and more like thirty adjustments during the life of a lining set. [3] The time between adjustments depends upon the severity of the service to which the brake is subjected.

Brake wear is known to be highly dependent upon the temperature levels that the brake reaches in its service application. Figure 6 from [5] provides an example showing the influences of lining temperature upon the amount of wear of a Type 30 S-cam brake. As indicated in Figure 6, the amount of wear is not only dependent upon the temperature, but on the previous work history of the brake. The dashed lines in Figure 6 show that after operation at a high temperature, the remaining surface of the lining wears much more rapidly at 200°F than it would ordinarily. This phenomenon has been attributed to the development of a char layer on the lining during high temperature operation. This layer wears rapidly until "uncharred" lining material is reached again. These results indicate that the need for brake-adjustment is very dependent upon the type of service involved. Strenuous service involving high temperatures implies the need for frequent brake adjustments.

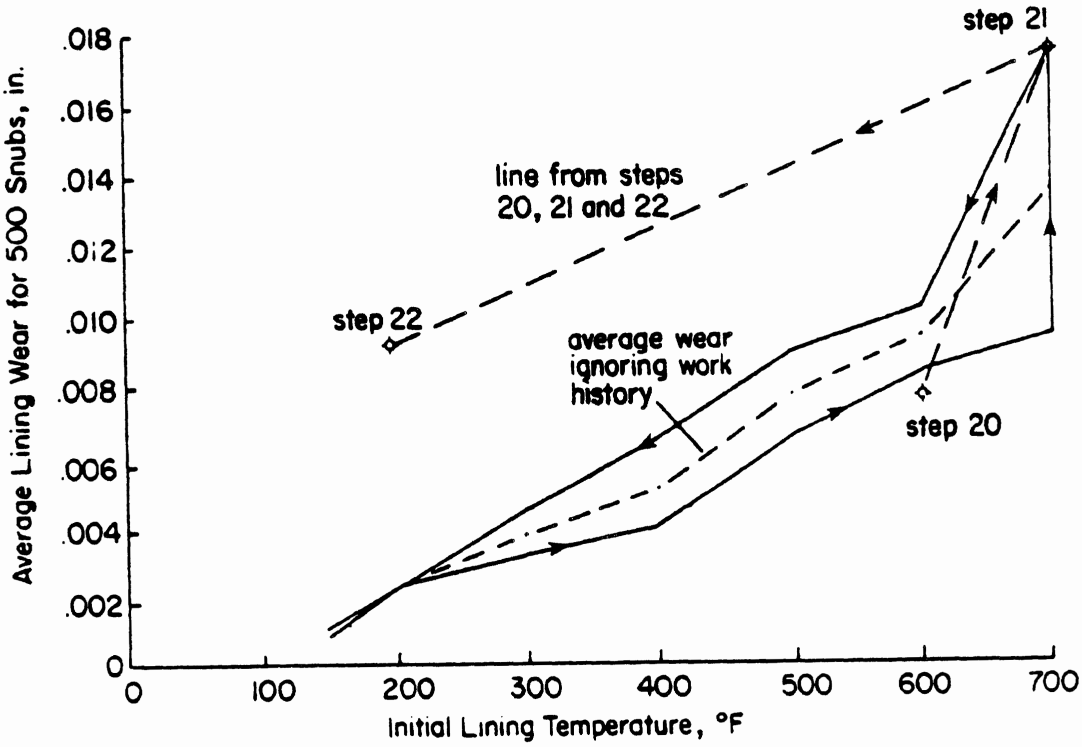


Figure 6. The influence of temperature on wear. (5)

From a braking system standpoint, the brake that wears fastest may be doing more than its share of the work. The brake that is not wearing may be the problem brake since it is not doing its share of the work.

During this project we expect to develop a better understanding of the relationships between service demands, wear, brake proportioning, and the need for brake-adjustment. Recent publications indicate that there is now the possibility for predicting wear and operational life of a brake lining using computer simulation (for example [6]). Perhaps, information on the time between brake relinings can be used to estimate the time between adjustments given approximately 30 adjustments over the life of the lining.

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[1] ----, North American Uniform Driver-Vehicle Inspection Manual (draft), Motor Carrier Safety Assistance Program, Federal Highway Administration, May 1989

[2] Flick, M. A., The Effect of Brake-adjustment on Braking Performance, National Highway Traffic Safety Administration, DOT HS 807 287, APRIL 1988.

[3] Friend, P., et al, Air Brake Technical Seminar 1984, Bendix Heavy Vehicle Systems Group.

[4] Segel, L., et al, Mechanics of Heavy Duty Trucks and Truck Combinations, Engineering Summer Conferences, University of Michigan, 1989.

[5] Fancher,P., and Winkler, C., Retarders for Heavy Vehicles: Phase III -- Experimentation and Analysis; Performance, Brake Savings, and Vehicle Stability, DOT-HS-9-02239, University of Michigan Transportation Research Institute, January 1984.

[6] Van Heck, J., Prediction of Wear and Operational Life of Drum-brake Linings, SAE 885141, September 1988.

AN ANNOTATED BIBLIOGRAPHY ON SPECIFIED DOCUMENTS

"Heavy Truck Safety Study" (DOT-HS-807-109, March 1987) identifies vehicle factors related to the cause of truck accidents and programs and needs of enforcement agencies responsible for compliance of heavy trucks with traffic laws. Further, the report summarizes current knowledge about each issue, describes possible action toward improvement, and presents research agendas for longer-term issues. Brake-adjustment as related to heavy trucks involved in accidents is identified as a factor not statistically demonstrated because "Equipment that is degraded, but still intact, such as brakes that are out-of-adjustment, it is usually not reported." Again, because brake-adjustment problems are not often reported, the report excludes brake-adjustment from its definition of brake failure or deficiency. The report discusses findings at roadside inspections which indicate from about 60-70 percent of trucks put OOS were done so due to brake related problems. How many of those problems were due to brake-adjustment is not identified. However, the report concludes that "the portion of all truck accidents that potentially have brake system issues as a contributing factor could be as much as one third."

"The Effect of Brake Adjustment on Braking Performance" (DOT-HS-807-287, April, 1988) describes tests used to evaluate the relationship between brake-adjustment on heavy vehicles equipped with air brake systems and stopping performance of those vehicles. The report describes the three sites used for the actual vehicle stopping tests and the vehicles used in the tests. Also discussed are brake dynamometer tests and computer simulations of brake performance. In general, the report finds current OOS criteria appropriate for brakes at cooler temperatures. However, the performance of brakes at higher temperatures (400°F or greater) are found to degrade 40-50%.

"Brake Performance Levels of Trucks" (BMCS, September, 1984) compared brake performance test results conducted in 1983-84. Two-axle trucks performed better in 1974 than in the later tests. Three-axle, truck-brake performance improved over the period. Truck-trailer combinations also improved. Tractor-semi combinations are reported to have deteriorated. Brakes OOA are reported to be 30 percent for the whole group. A general correlation between brake-adjustment and stopping distance is offered: each brake OOA resulted in .5 to 1.5 feet of stopping distance over the range weights of the test vehicles at a speed of 20 mph. The report establishes a rating system of relative importance of brake problems. In order of importance, the number of brakes OOA ranks fourth. The average percentage of adjustment required to maintain the vehicle in-service is ranked fifth. The other factors affecting stopping time are reported, in order of importance, as total weight, the age of the vehicle, and whether the vehicle was operated for hire.

"A Demonstration of the Safety Benefits of Front Brakes on Heavy Trucks" (DOT-HS-807-061, December, 1986) describes tests performed on heavy trucks to evaluate the effectiveness of the use of front brakes. Test vehicles included bobtail tractors, tractors with empty semi-trailers, and a tractor with a loaded semi-trailer resulting in a gross combination weight of 80,000 pounds. All vehicles are reported to have superior braking performance with full front brakes. Partial front brakes performed less well. By inference, front brakes which are OOA would also be expected to perform more poorly than properly adjusted front brakes.

The "North American Uniform Driver-Vehicle Inspection Manual" of the Motor Carriers Assistance Program clearly describes procedures for inspecting heavy truck brake system adjustment. The vehicle inspection routine is performed counter-clockwise around and under the vehicle. During the first pass, around and under the vehicle, the inspector examines the brakes, along with other components, for defects, and marks the pushrod of each brake. After the first pass, the inspector measures pushrod travel for each brake. The manual is complete with diagrams for marking and measuring pushrods for cam brakes, and also includes procedures for assessing the adjustment of disc brakes and wedge brakes with feeler gauges.

Accident Analysis and Prevention, Vol. 9, pp. 167-176, 1977, "A Comparative Evaluation of Two Roadside Brake Testing Procedures" reports the process used in Michigan to assess the effectiveness of two motor vehicle brake system effectiveness procedures, the "Moving Stopping Test" and the "Wheel Pull Inspection." Field surveys were set up in conjunction with Michigan State Police and the Michigan Office of Highway Safety Planning. The Moving Stopping Test was found to be more stringent and less costly than the Wheel Pull Inspection and was thought to more accurately identify vehicles with brake performance problems.

"Heavy Duty Vehicle Brake Research at NHTSA," a collection of charts, graphs, and topics generated by in-house and contract research, illustrates brake-related areas such as front braking, braking under load, braking under severe weather conditions, brake lock-up, brake compability within configurations, and brake-adjustment sensitivity. Brake temperature is shown to be a considerable factor in geographic illustration. Load sensing and anti-lock mechanisms are suggested as areas to be explored further.

"The Performance of Trucks Braking on Ice" (UMTRI-87-23, August 1987) describes tests performed under severe winter conditions to assess the effectiveness of front brakes on trucks as well as the use and placement of tire chains. The report shows that when brakes are provided the opportunity to function to maximum advantage, both stopping distance and steering control will improve.

"Grade Severity Rating System" (FHWA-IP-88-015, May 1988) is concerned with a system to reduce the probability of large truck runaways on severe downgrades. Mathematical models using truck weight and downgrade characteristics are employed to predict brake system temperatures. Temperature estimates determine safe downgrade speeds. The manual provides methods of identifying severe grades by length and angle of slope, models brake temperature for grade and weight combinations, and suggests maximim safe speeds based on those factors in order to maintain acceptable brake temperature.

"Air Brake Technical Seminar" (Bendix Heavy Vehicle Systems Group 1984) was conducted to provide aire brake system users with a knowledge base from which to make informed decisions about heavy truck brakes, reports that cam brakes demand a minimum of twenty adjustments per lining set; that the type of operation in which a vehicle is involved has direct bearing on the need for adjustment; and that the adjustment must be checked before a mountain run. Installation of automatic adjusters is suggested.

APPENDIX C

BRAKING PERFORMANCE—RELATIONSHIPS BETWEEN BRAKING EFFICIENCY, VEHICLE STABILITY, AND BRAKE ADJUSTMENT

In operational terms, a heavy truck brake is a device that converts air pressure into a torque retarding wheel rotation. The performance of this device is quantified by brake "effectiveness," where effectiveness is a measure of the gain of the brake expressed in units of torque output per unit of line pressure input. [1]

However, each brake in a vehicle is embedded in an overall braking system consisting of an air compressor, air reservoirs, valves, lines, brake chambers, actuation mechanisms, shoes, linings, drums, and tires. Furthermore, braking performance depends upon tire/road friction and the load transfer from rear to front due to the deceleration of the vehicle.

Braking performance on roads with differing frictional properties may be expressed in terms of "braking efficiency" which is the ratio of (a) the vehicle deceleration attainable without locking wheels to (b) the friction level existing at the road surface.

The reason for the phrase "without locking wheels" has to do with directional stability and control of the vehicle. If the wheels on the front axle lock up, the vehicle will not respond properly to steering. If the rear wheels on a straight truck lock up, the vehicle is directionally unstable and it will tend to spin around. If the drive wheels on a tractor in a tractor-semitrailer combination lock up, the tractor tends to jackknife. If the trailer wheels lock, the trailer tends to swing out of line. If all wheels lock, the vehicle is completely out of control and one hopes that the vehicle stops before anything bad happens. The general idea is that if any wheels lock, undesirable consequences may ensue. Desirable braking performance involves not locking wheels as well as the capability to decelerate rapidly if necessary.

The following material emphasizes the influences of brake-adjustment upon braking performance. Brakes on heavy trucks often have manual slack adjusters. If these brakes are not adjusted properly, the brake chambers will run out of "stroke"—that is , they will bottom out on the end of the brake chamber, thereby limiting the effort for applying the brake, and hence, limiting the available braking torque. In extreme cases, the adjustment may be so poor that no brake torque is available

Aside from errors in adjusting the brakes, the reason that brakes become out of adjustment is that linings wear. The wear rate depends upon the type of service of the vehicle as well as lining and drum properties. The brake that wears the fastest is the one that is doing the most work per unit of lining surface available. Wear rate also depends upon lining temperature. The later stages of this study will include investigations into the relationships among vehicle service characteristics, brake wear, and the need for brake-adjustment.

The next section provides an overview of how the components of the braking system influence braking performance.

OVERVIEW OF THE PERTINENT PROPERTIES OF BRAKING SYSTEMS

A straightforward method for organizing the discussion of the braking system is to follow the sequence of events that take place in going from movement of the brake valve to the generation of braking force. The sequence for most brakes is as follows (see Figure 1): (1) air pressure at the treadle valve increases when the valve is moved, (2) these pressures act as control signals that are transmitted through brake lines, (3) these control signals arrive at relay valves which apply air from supply reservoirs to the brake chambers, (4) the brake chambers apply force to a push rod that moves through a stroke, (5) the movement of the pushrod rotates a cam mechanism that rotates the linings of the brake shoes into contact with the drum, (6) frictional forces between the lining and the brake drum generate a braking torque that slows the wheel, (7) the braking torque creates a longitudinal force at the tire/road interface thereby decelerating the vehicle. Each of these steps involves particular pieces of hardware ("components" of the braking system). The performance of the braking system depends upon the pertinent mechanical properties of these components. [1]

PERTINENT PROPERTIES OF AIR LINES

The time between (a) when the driver asks for braking by moving the treadle valve, and (b) when the control signal has reached the relay valve represents a loss in time that increases the stopping distance of the vehicle. This time delay contributes to the delay before the chamber pressure rises from zero as illustrated in Figure 2. [2] The amount of delay depends upon the diameters and lengths of lines involved with the brake in question. Experimental data available in Reference [2] can be used to evaluate this parameter.

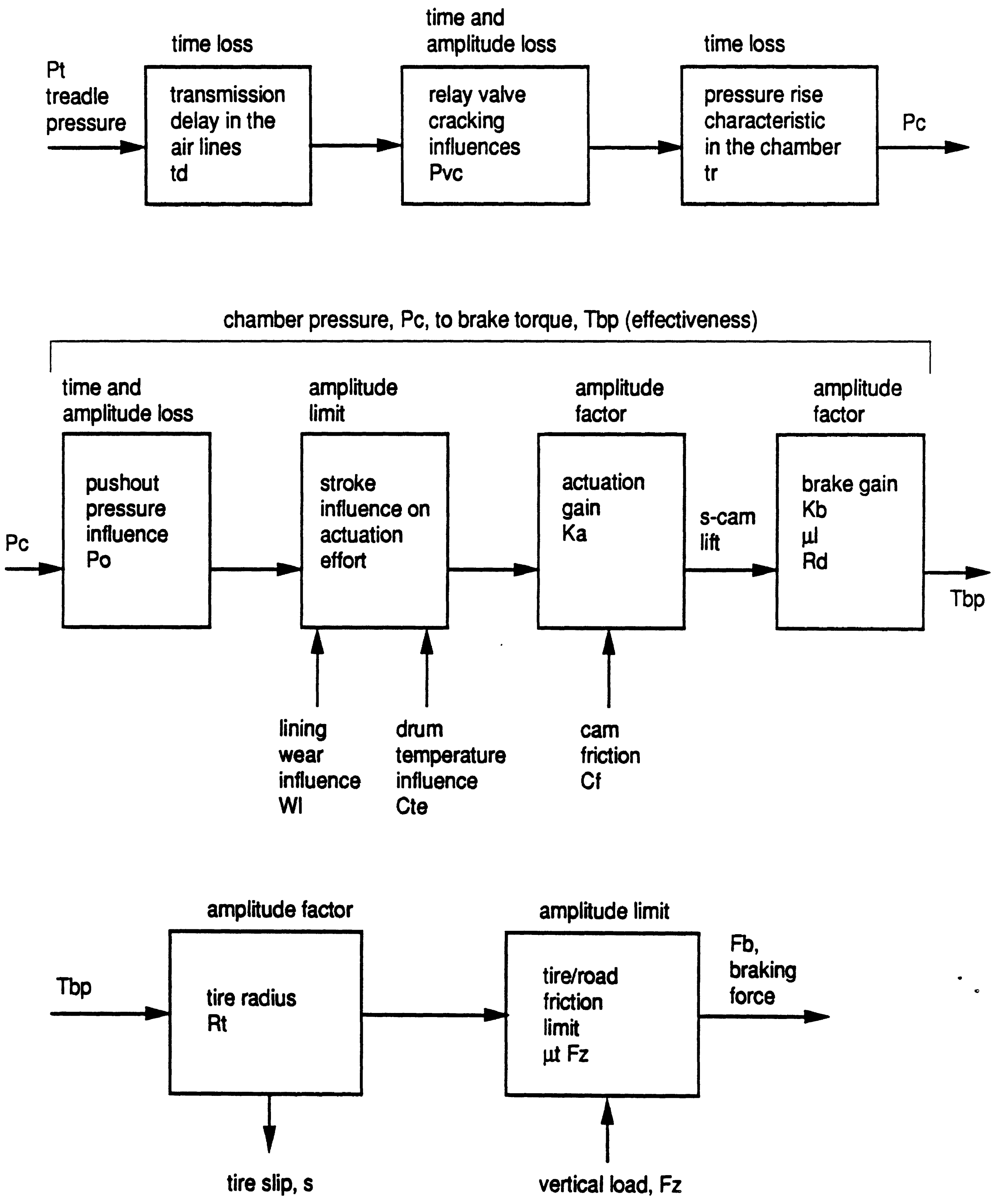


Figure 1. From treadle pressure to braking force

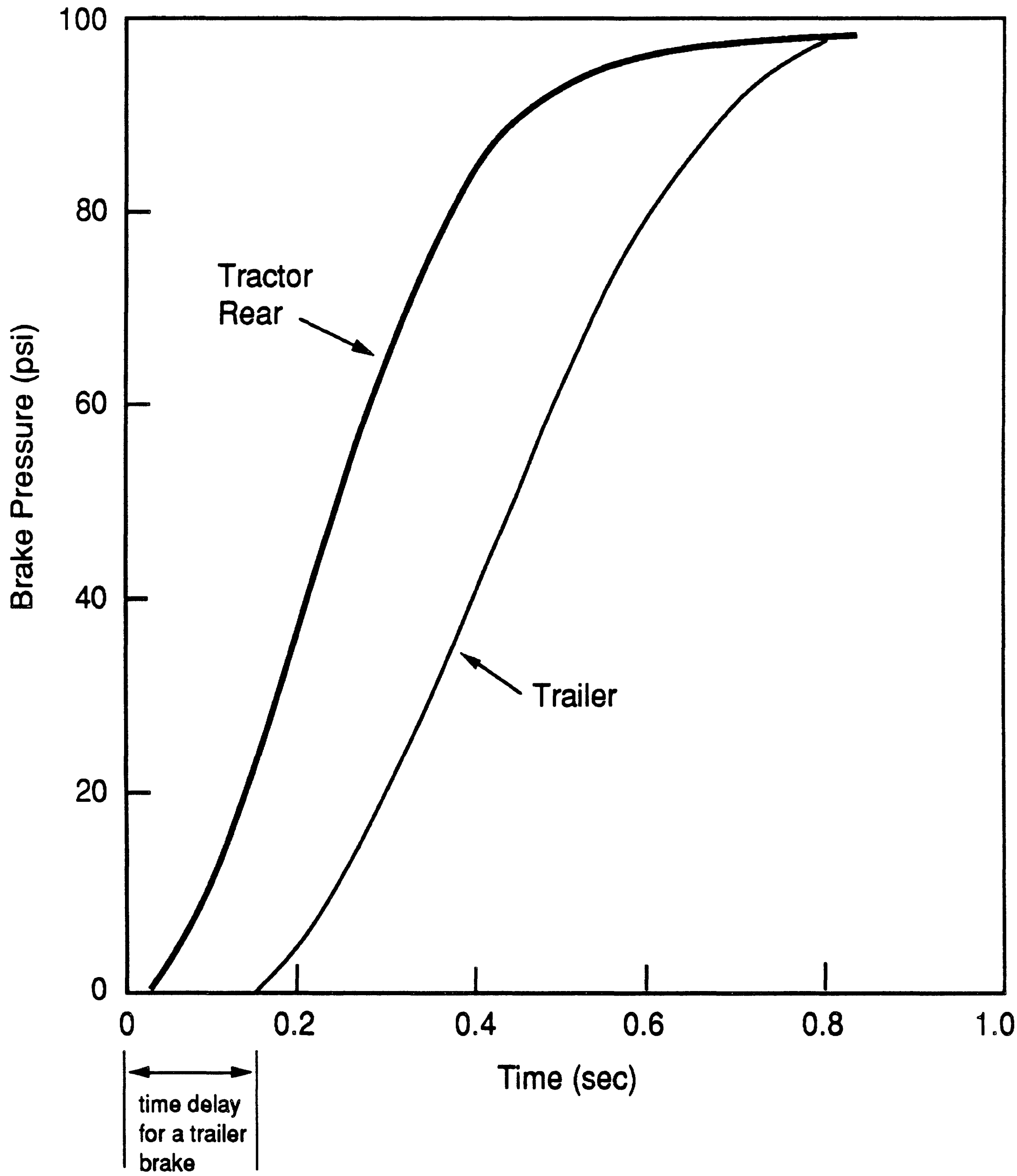


Figure 2. Brake Pressures versus Time Measured in a Tractor Trailer Combination [2]

VALVE CRACKING INFLUENCES

Relay valves are characterized by the difference in pressure needed to cause the valve to open— that is, the "cracking pressure." The cracking pressure needed to operate the valve represents a loss in braking pressure. Also, differences in cracking pressures between relay valves can cause brakes to come on at different times with possibly large effects for low pressure applications. (These differences may be particularly noticeable between the valves used on tractors and those used on trailers.)

PRESSURE RISE IN THE BRAKE CHAMBER

The "apply time" used in FMVSS 121 is the time for the chamber pressure to reach 60 psi in a rapid 100 psi application of the treadle valve. This time includes the transmission delay time associated with the air lines and the rise time involved with filling the air chamber to a 60 psi level. The rise time characteristics can be determined from measurements of pressure time histories made on vehicle combinations. (See Reference [2] for examples.)

Incidentally, brake-adjustment may have an influence on the delay included in the apply time (see Figure 3).

PUSHOUT PRESSURE

The brake chamber and the shoes have return springs used in deactivating the brakes. During brake applications the forces created by these springs must be overcome before the linings touch the drums. The amount of pressure needed to cause braking action to begin is the "pushout pressure." Often a net pushout pressure is determined by including together the influences of not only the return springs but also the influences of valve cracking and any other pressure losses in the system.

STROKE INFLUENCE ON ACTUATION EFFORT

Once the pressure in the brake chamber rises above the pushout level, the stroke of the pushrod increases—first, in taking up the "slack" between the linings and the drum, and then, with pressure as the linings are compressed against the drum. The motion of the pushrod is tied to the rotational motion of a cam (in an s-cam brake) through an arrangement consisting of a slack arm, fixed cam bearings, etc. The air pressure in the brake chamber supplies the reaction torque required for the cam action used in pressing the linings against the drum.

If the brake is sufficiently out of adjustment, the pushrod and its associated diaphragm will bottom out on the bottom of the air chamber. (See Figure 4 to envision how this happens. [3]) Increasing the pressure in the brake chamber (beyond that which

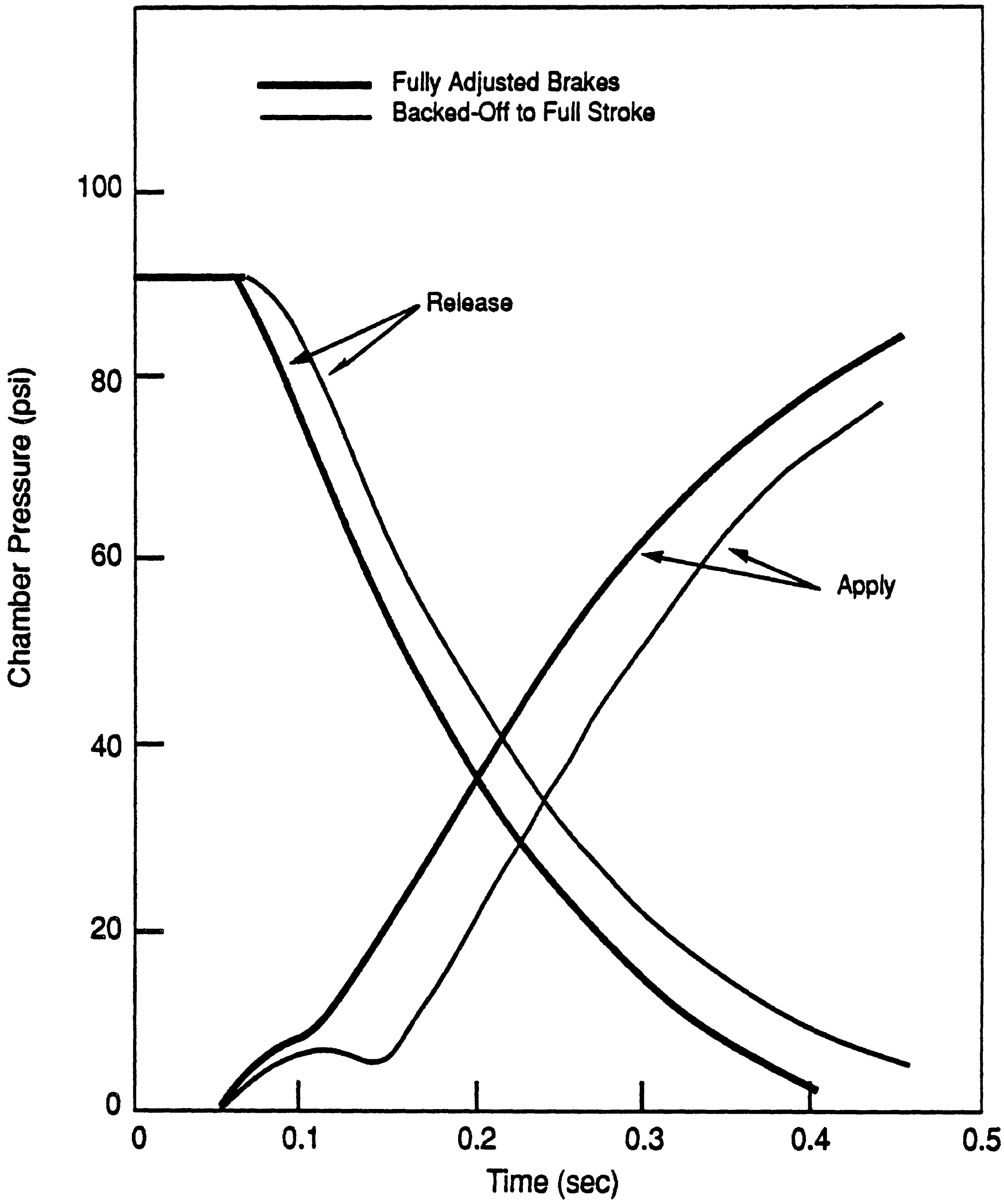
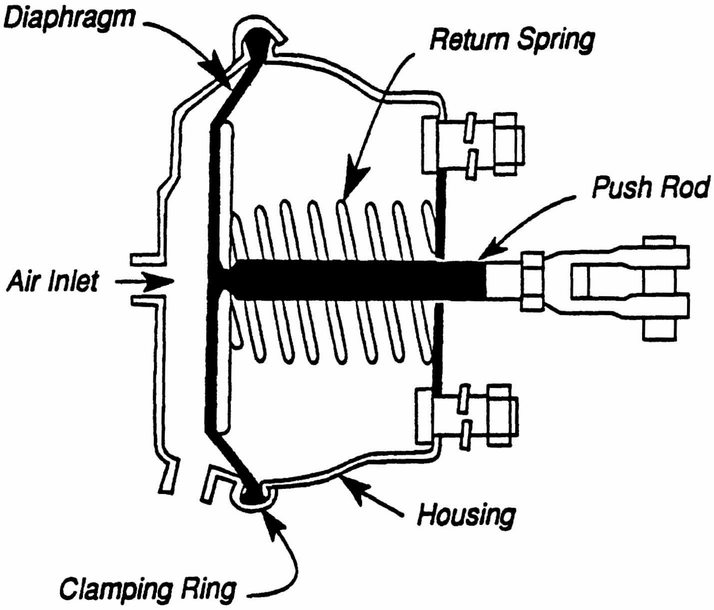


Figure 3. Brake chamber pressure versus time for apply and release of a brake at two different adjustment levels [2].



Clamp Ring Type Diaphragm Chamber

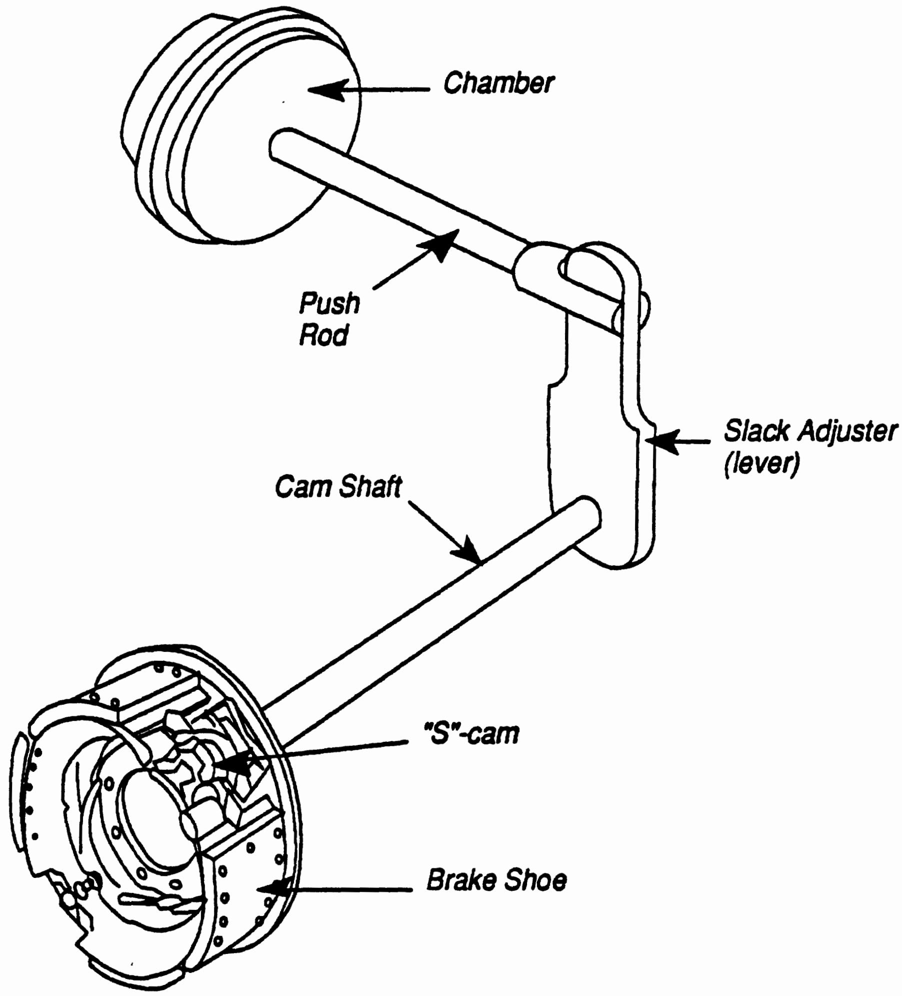


Figure 4. Brake chamber and cam linkage [2].

causes the pushrod to bottom out) will not increase the actuation effort applied to the s-cam mechanism by the pushrod if the pushrod has bottomed out.

In effect, if the brake is out of adjustment, the stroke limit of the brake chamber acts as a mechanism that limits the brake torque available. The curves graphed in Figure 5 provide a quantitative example illustrating the nature of the process resulting in the limiting of the actuation force on the pushrod of a Type 30 brake chamber.

The line designated as the "operating line" in Figure 5 has been superimposed upon curves representing the relationship of actuation force to stroke and pressure as might be measured for a brake chamber. (Reference [3] gives the 100 psi curve for a typical brake chamber.) The influences of slack due to (a) clearance for the unactuated brake, (b) lining wear, and (c) drum expansion resulting from drum temperature are illustrated by the amounts of stroke shown along the horizontal axis in Figure 5. The operating line starts at the amount of stroke needed to take up the slack and increases with stroke and pressure. It indicates the resulting actuation force as the linings are compressed against the drum.

The slope of the operating line depends upon (a) the compliance of the shoe and lining combination, (b) the mechanical advantage of the cam mechanism, (c) the self-actuation of the leading shoe, and (d) the pressure/actuation force characteristics of the chamber.

The point where the operating line intersects the upper- or right-most line of constant pressure in the figure indicates the maximum actuation force that can be obtained from the brake chamber. The equivalent pressure for a well-adjusted brake would be approximately that indicated by the y-intercept and its corresponding pressure level as indicated in Figure 5. In this example, the maximum force is achieved at an equivalent pressure of 60 psi. At equivalent pressures above this level, the braking force would not increase above that corresponding to the limiting force of 1700 pounds as indicated in Figure 5.

In summary, the primary effect of the phenomena associated with running out of stroke is that the brake torque will be limited to that torque corresponding to the equivalent pressure level at which the push rod bottoms out. If the brake were never to be adjusted, the linings would eventually wear to the point where all of the stroke would be consumed in slack and there would not be any braking torque produced even at 100 psi.

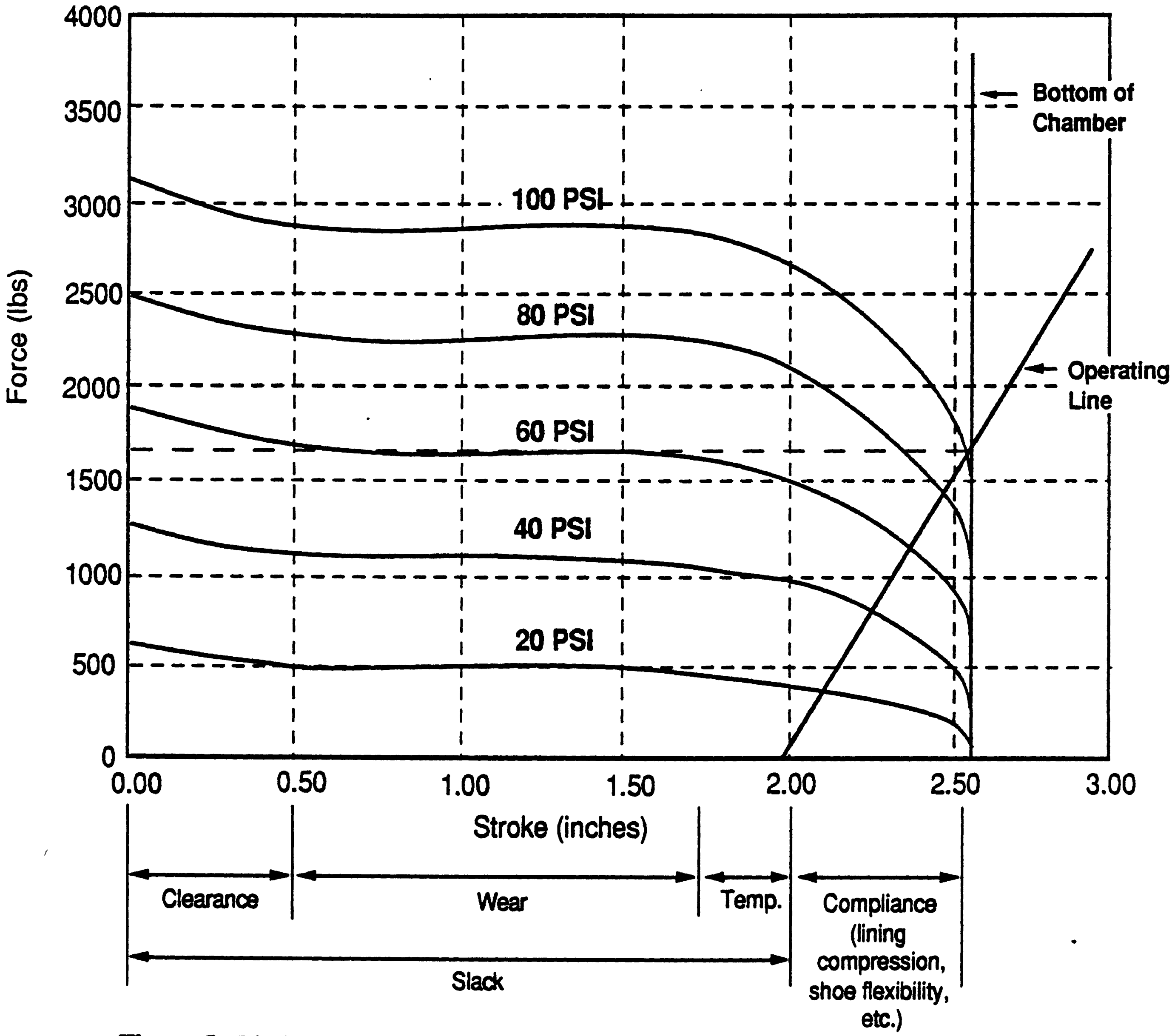


Figure 5. Limit on actuation force from the brake chamber.

ACTUATION GAIN OF THE S-CAM MECHANISM

The mechanical advantage of the cam mechanism is determined by the length of the slack arm and the effective cam radius. For example (given that the angle of the slack arm is properly oriented), a mechanism with a 6" slack arm and a 1/2" cam radius would have a mechanical advantage of twelve—resulting in a situation in which the stroke of the air chamber is approximately twelve times the movement associated with pressing the lining against the drum; of course, the actuation effort is increased by twelve times also.

In an s-cam brake, the cam movement is the input that presses the linings against the drum. The actuation forces on the shoes are not equal but the movements are. This leaves a torque to be reacted through the cam bearings. The influence of friction in the cam bearings results in a loss in the gain of the brake such that even though the nominal gain might be twelve the actual gain would be less—perhaps approximately ten for typical amounts of friction. [4]

INFLUENCES OF THE GEOMETRY AND FRICTION OF THE BRAKE ASSEMBLY

The pressure distribution between the linings and the drum depend upon (a) the shape the lining has worn to, (b) the dimensions describing the geometric features of the brake assembly (the position of the linings on the shoes, the locations of the pivots of the shoes, the angles of the actuation forces on the shoe tips, etc.), (c) the amount of drum expansion due to temperature, and (d) other factors including the compliances of the shoes and linings. These influences have been studied analytically using finite element analyses. [5,6]. Although the finite element analyses are useful for designing brakes, they are more complicated than needed for characterizing brake gain in this discussion.

The gain of a brake assembly (actuated by an s-cam and having fixed pivots for the shoes) can be represented by parameters characterizing (a) the geometric gain factor accounting for the arrangement of both the leading and trailing shoes, (b) the friction coefficient between the lining and the drum, and (c) the drum radius. [1]

The gain of a particular brake in service on a vehicle is difficult to predict accurately. The state of lining wear and the compliance of the lining can change the gain significantly. In addition, friction coefficients of lining/drum combinations are known to have large standard deviations about their mean values and also friction levels may be dependent upon the work history of the brake. Results from dynamometer tests are desirable for estimating the capability of a particular type of brake. Even so, a brake in service may have torque capabilities that are significantly different than those obtained in the dynamometer tests.

TIRE GEOMETRY

The discussion of the properties of components has reached the point where the relationship between brake torque and treadle pressure has been covered. However, there are tire- and vehicle-factors that influence the braking force acting on the vehicle.

A very simple, but important consideration is the radius of the tire. The braking force acting upon the vehicle is the brake torque divided by the tire radius. Hence, smaller diameter tires will provide larger braking forces at a given pressure level (all else being equal).

TIRE/ROAD FRICTION LIMIT

The maximum braking force between the tire and the road depends upon the frictional capability existing at the tire/road interface. This capability depends not only on the friction coefficient (or some more complex means for describing friction between the tire and road), but also upon the vertical load carried by the tire. The tire loads on the vehicle depend, in turn, on the dynamics of the vehicle—especially the deceleration achieved during braking. This means that there is a set of simultaneous relationships (involving the dynamics of the vehicle) determining the vertical loads on the tires.

The dynamic vertical load multiplied by the friction coefficient sets the level of braking force capability available for decelerating the vehicle. If the brake torque exceeds the maximum level of torque that can be reacted by the tire, the wheel rapidly locks up and the brake torque reduces to that required to lock the wheel. In other words, the friction limit existing at the tire/road interface limits the braking force attainable. Increasing the brake pressure beyond that which will lock the wheel will not increase the force available for decelerating the vehicle.

SUMMARY OF THE PERTINENT MECHANICAL PROPERTIES RELATED TO STOPPING

In order to analyze the stopping performance of a vehicle, information is needed on the influences of the following mechanical properties of the components of the overall braking system:

- Transmission delays in the air lines;
- Valve cracking pressures;
- Pressure rise characteristics in the air chambers;
- Pushout pressures;
- Actuation force versus stroke and pressure for the air chambers;
- Mechanical advantage (gain) of the s-cam mechanism and associated slack arm;
- Friction in the cam bearings;
- Brake factor (gain) of the brake assembly;
- Lining friction coefficient;
- Slack due to lining wear;
- Slack due to drum temperature (thermal expansion coefficient for drum materials);
- Drum diameter (radius);
- Tire radius;
- Tire/road friction; and
- Load transfer characteristics for determining the influences of deceleration on tire loads.

For a five-axle tractor-semitrailer with ten brakes, the above properties need to be known for each brake. Figure 6, which follows, indicates how these ten brakes each contribute to the stopping performance of the vehicle. (Only stopping characteristics are represented in Figure 6 and directional and lateral stability are not included here.)

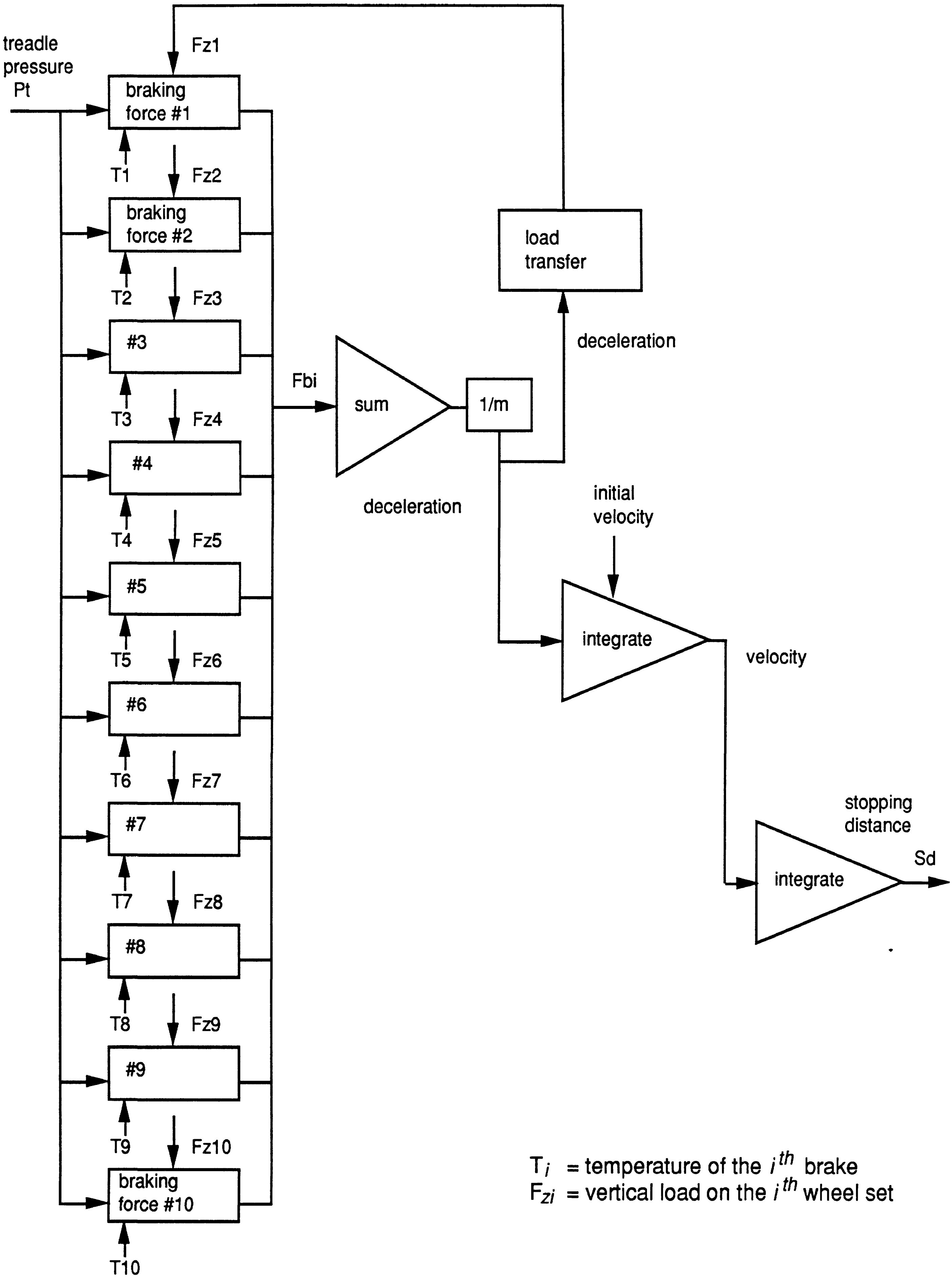


Figure 6. Calculation of stopping performance

The response to treadle pressure consists of (a) deceleration, (b) velocity, and (c) stopping di: addition to the brake system characteristics listed above, these outputs depend upon the weight of the v its initial velocity. As indicated in the figure, deceleration is integrated over time to obtain velocity and integrated over time to obtain stopping distance.

SIMPLIFIED ANALYSES OF STOPPING PERFORMANCE

Assuming constant deceleration, the basic formula relating stopping distance and deceleration is as follows:

$$Sd = (Vo)^2 / 2D$$

where Sd is stopping distance, Vo is initial velocity, and D is deceleration.

(The weight or mass of the vehicle does not appear in this formula because its influence is used in determining the deceleration which is taken to be known here.)

(For snubs the snubbing distance, d, given by the similar formula

$d = ((Vo)^2 - (Vf)^2)/ 2D$ where Vf is the final velocity at the end of the snub.)

In actual stops, the deceleration is not obtained immediately. As described earlier, there is a delay time before any brake comes on and the braking force increases with time as the pressures rise in the brake chambers. To first approximation, the deceleration time history may be characterized as a delay time followed by a linear rise and then a constant level of deceleration (see Figure 7). This type of representation has been used in [2] to study braking timing matters. Here we have employed the simplified representation of deceleration to look at the differences between stops from initial velocities of 60 and 20 mph. The results (see Table 1 and Figure 8) indicate that approximately half of the stopping distance in a 20 mph stop is associated with the deceleration available during the time that the pressures are rising in the brake chambers. On the other hand, during stops from 60 mph, the stopping distance depends primarily upon the full deceleration level, even though 40 to 60 feet of stopping distance may be associated with the time to reach full braking deceleration.

The point of the above material is that the 20 mph stop used in OMC work does not challenge the full deceleration properties of the vehicle as much as a 60 mph stop would. If the times for pressures to rise were longer than those used for tractor semitrailers in Table 1

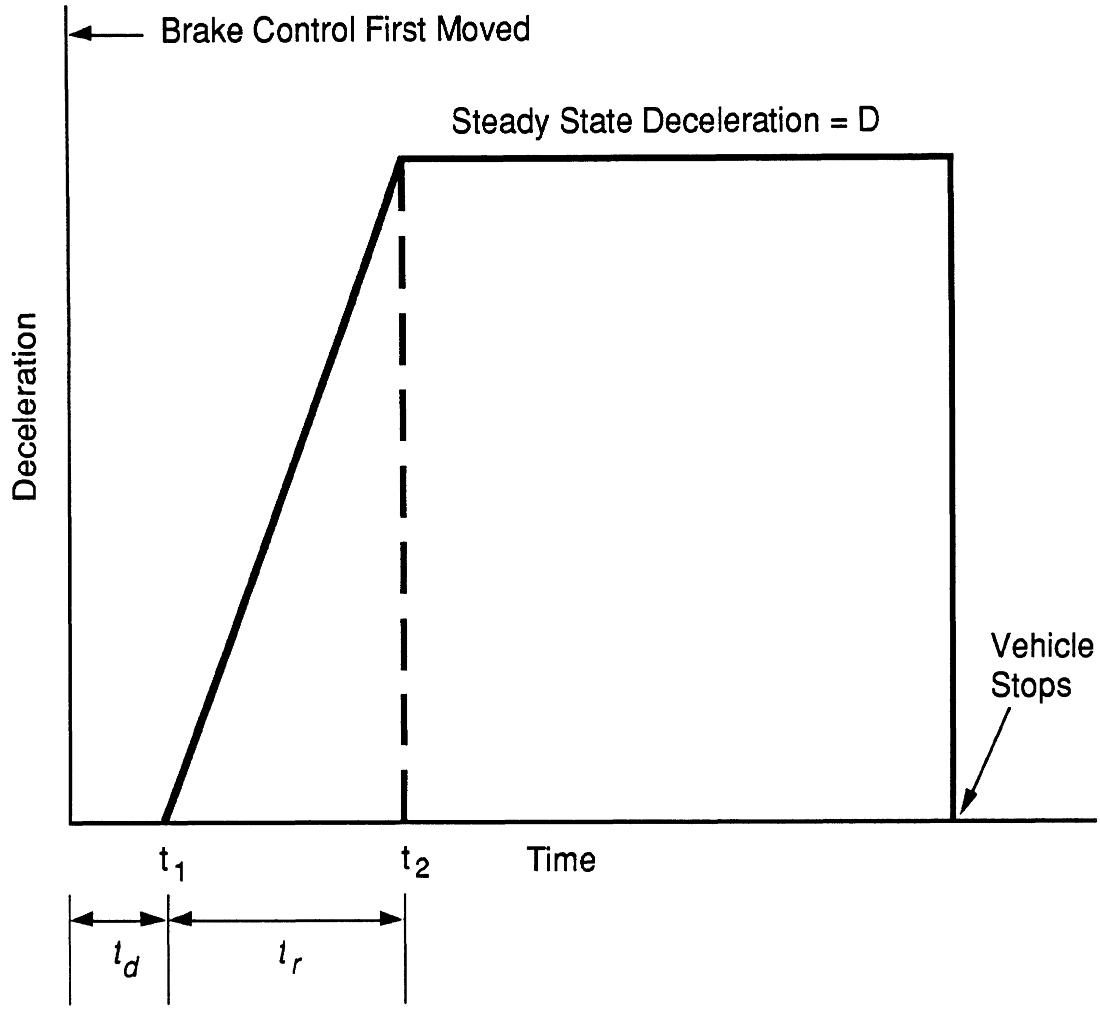


Figure 7. Simplified Deceleration versus Time for a Stop

(as they could be for a doubles or triples combination without booster relay valves for example), the vehicle might stop before the rearmost brakes were completely actuated. The 20 mph test might not show the influences of poor adjustment of the rearmost brakes (or the directional stability problems that might ensue during a 60 mph stop).

Table 1. Influences of delay, rise, and constant deceleration on stopping distance.

		INPUTS						OUTPUTS			
Case Names	Vo	td	t r	D=Fp/m	Dd	D r	Vtr	tb	Db	Sd	ts
20 mph,Base case	29.33	0.075	0.7	16	2.1998	19.2243	23.73	1.48313	17.5973	39.0214	2.25813
20 mph,Long td	29.33	0.1	0.7	16	2.933	19.2243	23.73	1.48313	17.5973	39.7546	2.28313
20 mph,Short td	29.33	0.05	0.7	16	1.4665	19.2243	23.73	1.48313	17.5973	38.2881	2.23313
20 mph,Long tr	29.33	0.075	0.9	16	2.1998	24.237	22.13	1.38313	15.3043	41.741	2.35813
20 mph,Short tr	29.33	0.075	0.5	16	2.1998	13.9983	25.33	1.58313	20.0503	36.2484	2.15813
20 mph,Lower D	29.33	0.075	0.7	12	2.1998	19.551	25.13	2.09417	26.3132	48.064	2.86917
20 mph,Higher D	29.33	0.075	0.7	20	2.1998	18.8977	22.33	1.1165	12.4657	33.5631	1.8915
60 mph,Base case	88	0.075	0.7	16	6.6	60.2933	82.4	5.15	212.18	279.073	5.925
60 mph,Long td	88	0.1	0.7	16	8.8	60.2933	82.4	5.15	212.18	281.273	5.95
60 mph,Short td	88	0.05	0.7	16	4.4	60.2933	82.4	5.15	212.18	276.873	5.9
60 mph,Long tr	88	0.075	0.9	16	6.6	77.04	80.8	5.05	204.02	287.66	6.025
60 mph,Short tr	88	0.075	0.5	16	6.6	43.3333	84	5.25	220.5	270.433	5.825
60 mph,Lower D	88	0.075	0.7	12	6.6	60.62	83.8	6.98333	292.602	359.822	7.75833
60 mph,Higher D	88	0.075	0.7	20	6.6	59.9667	81	4.05	164.025	230.592	4.825

<u>Sequence of calculations:</u>

$$D_d = V_0 \cdot t_d$$

$$D_r = V_0 \cdot t_r - \frac{D \cdot t_r^2}{6}$$

$$V_{tr} = V_0 - \frac{D \cdot t_r}{2}$$

$$t_b = \frac{V_{tr}}{D}$$

$$D_b = V_{tr} \cdot t_b \cdot 0.5$$

$$S_d = D_d + D_r + D_b$$

$$t_s = t_d + t_r + t_b$$

<u>Units:</u>

V_0	[ft/sec]
t_d	[sec]
t_r	[sec]
D	[ft/sec^2]
D_d	[ft]
D_r	[ft]
V_{tr}	[ft/sec]
t_b	[sec]
D_b	[ft]
S_d	[ft]
t_s	[sec]

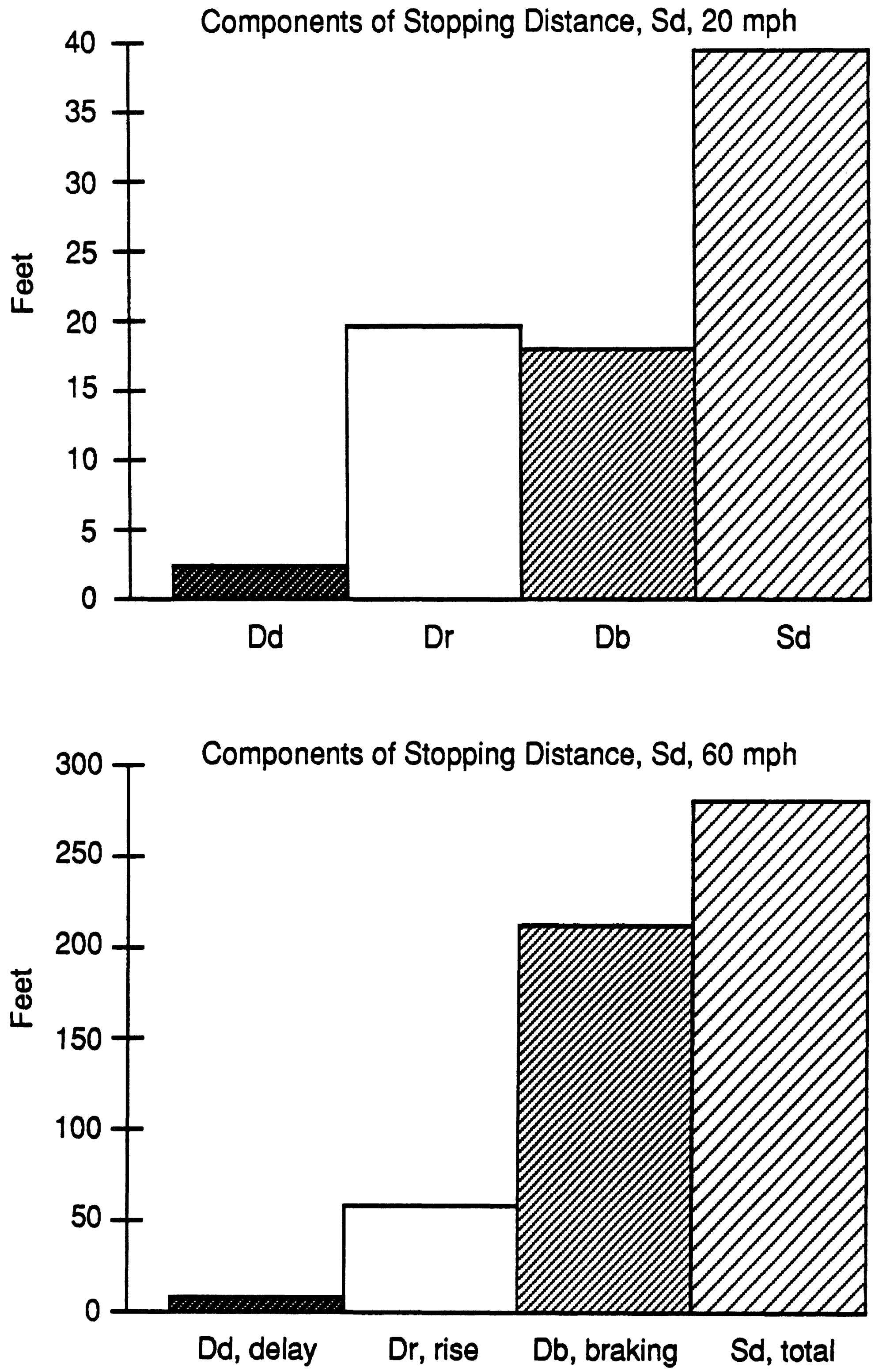


Figure 8. Components of Stopping Distance at 20 mph and 60 mph

BRAKING EFFICIENCY CALCULATIONS

The notion of braking efficiency usually applies to the steady deceleration level attained after the brakes have been fully applied. (If stopping distance is to be considered, the distances travelled during (a) the transmission delays and (b) the rise times of the brake chamber pressures need to be included in determining the total stopping distance.) The efficiency can be defined as the ratio of (a) the deceleration to (b) the friction utilization required to prevent the wheels on the "worst" axle from locking. ("Worst" meaning the axle with the largest ratio of braking force to vertical load, that is, the axle about to lock up utilizing the minimum friction possible.)

However, if a vehicle does not have enough braking capability to lock any wheels, the efficiency is the ratio of (a) the deceleration attainable at maximum pressure (100 psi) to (b) the friction coefficient available at the tire/road interface. This situation often applies to fully-laden heavy trucks with a maximum deceleration capability of approximately 0.4 g on a good road with a friction coefficient that might be approximately 0.8. (In this type of situation, the vehicle would become more efficient as the road got slipperier, but that is not important other than to recognize that a level of tire road friction needs to be chosen for use in calculating efficiency in this case.) The important notion here is that OOA brakes would lower the maximum acceleration attainable thereby lowering the efficiency below that of a truck with well-adjusted brakes.

There exist simplified vehicle models that have been developed for predicting the influences of braking system properties on braking efficiency. [7] These models (which are available at UMTRI) could be employed to represent the effects of various levels of brake-adjustment by including the limiting effects of bottoming the push rod as discussed earlier. It would be a straightforward exercise to study the sensitivity of deceleration to various levels of brake-adjustment using the straight line braking model.

BRAKE TEMPERATURE CALCULATIONS

With regard to the influences of brake-adjustment, drum temperature plays a significant role. For a 16.5" drum diameter and a thermal expansion coefficient of approximately 8.5 parts per million, a temperature rise of 300°F could correspond to an increase in slack of approximately 0.25" measured at the pushrod. Depending upon the level of adjustment, this could result in a hot brake running out of stroke (see Figure 5). Further data illustrating the effect of temperature on stroke are illustrated in References [3 and 8].

The types of service resulting in high drum temperatures are either ones involving long steep mountain descents, or ones involving stop and go driving such as urban pickup and delivery. The potential energy to be dissipated during a mountain descent can be several times the kinetic energy involved in a stop from 60 mph. [1] The mountain descent situation requires careful attention to brake-adjustment in order to lessen the risk of a runaway vehicle.

A grade severity rating system has been under development by the FHWA. [9] The results from the research studies involved in developing this system have been used to examine the influences of grade length and slope on brake temperatures. [1] Recently, the UMTRI set of simplified (part task) models has been expanded to include a brake temperature model. Although this model is based upon the same concepts originally used for the grade severity calculations, it computes the bulk temperature of each brake rather than an average temperature for all of the brakes lumped together. Hence, it is possible to consider (a) the temperature of the hottest brake and (b) the influences of OOA brakes upon the temperatures of the other brakes on the vehicle.

In order to use the UMTRI model one needs to know the following:

- Thermal capacity of each brake (specific heat and weight);
- Cooling coefficient for each brake (this is a function of velocity);
- Proportion of braking effort acting at each brake;
- "Natural retardation" (rolling resistance and aerodynamic drag for the vehicle);
- Engine drag;
- Retarder power if one is used;
- Weight of the vehicle;
- Elevation profile for the route; and
- Velocity profile for the route.

Given that the model uses both a velocity profile as well as an elevation profile, the model can be employed to study stop-and-go conditions either on the level or during mountain descents. Although brake-adjustment might not be important at pressure levels below the limiting pressure corresponding to bottoming the stroke (which is likely to be the case in a mountain descent at a safe speed), stopping performance in a high pressure emergency stop would be affected by the combined influences of temperature and OOA level.

(In order to use the brake temperature and the straightline braking models interactively, it might be necessary to segment the calculations to take into account how stroke changes with temperature and adjust brake effectiveness accordingly as the temperature rises.)

CONCLUDING REMARKS

It appears that the ideas presented and the models mentioned here could be used to address the following items (which are like those listed for analysis in Task E):

- identifying key factors related to brake OOA;
- relating various combinations of OOA brakes to braking efficiency by configuration, load, number of axles, which axles are OOA, amount of OOA, brake temperature, or other factors (Studies of braking efficiency would pertain to both stopping distance and vehicle stability.);
- identifying adjustment thresholds beyond which stopping distance levels or braking efficiencies will exceed critical thresholds;
- providing a quantitative basis for confirming or changing OOS brake-adjustment criteria.

The analytical work listed above would provide a technically sound foundation for working with field data. Findings with respect to deterministic matters that depend upon the mechanical properties of vehicle components are readily determined by analysis.

Matters requiring statistical treatment such as how means and variances of braking performance measures depend upon the levels of brake-adjustment are obviously dependent upon identifying appropriate computerized data bases. Currently, we have not found suitable databases but we are still looking. Perhaps we can use statistical data on braking system properties along with braking system models plus the theory of propagation of precision indices to calculate predictions of the variance of stopping performance (for different combinations of OOS brake-adjustment) using the variances associated with the pertinent mechanical properties of (a) the key components of the braking system and (b) vehicle weights.

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APPENDIX D

AN ASSESSMENT OF DATA PERTAINING TO THE INFLUENCES OF OUT-OF-ADJUSTMENT LEVEL, VEHICLE CONFIGURATION, LOADING, AND BRAKE TEMPERATURE ON BRAKING PERFORMANCE

This document provides information on the influences of OOA, vehicle configuration, loading, and brake temperature on braking performance. It centers on reviewing the data in three references pertaining to the following subjects:

(1) Vehicle inspections, weight checks, and 20 mph stopping distance test. [1]

(2) Speed control on long, steep downgrades as influenced by vehicle weight [2]

(3) Heavy vehicle braking for combinations of load, speed, and brake temperatures [3]

The first reference [1] contains data gathered in 1983 in three states —Maryland, California, and Michigan. These data were gathered during vehicle inspection exercises that included measuring brake adjustments, weighing the vehicles, and performing 20 mph stopping distance tests. The data were compared to data measured in 1974. The data were categorized into information on:

(1) Total weight

(2) ICC-certified or not, age of the truck or tractor

(3) Vehicle configuration, for hire or not

(4) The number of brakes OOA

(5) Average percentage adjustment needed to bring all brakes into proper alignment; the numbers in parantheses indicate the order of importance of the factors effecting stops from 20 mph for most vehicle configurations.

With regard to the number of brakes OOA, an additional 0.5 to 1.5 feet per OOA brake was required to stop from 20 mph. (To put this additional distance in perspective, the FMCSR required stopping distance from 20 mph is 40 feet for combination vehicles.)

Having examined the results given in [1], the following initial assessments appear to be pertinent to our current study of brake-adjustment:

(1) Straight trucks with less than three axles tend to have hydraulic brakes, and hence, the data for 2-axle trucks should be eliminated from consideration in the study of pneumatically actuated s-cam brakes. (We have done this in the tables selected from [1] and presented in Appendix D.A.)

(2) Although the comparison with results from 1974 is interesting and important, the comparison is not useful for this study. (Comparisons with 1974 results have been eliminated from the tables presented in Appendix D.A.)

(3) Vehicle weight has a large influence on braking performance in stopping distance tests. The data needs to be sorted by weight since weight is a first order determinant of stopping distance for brake-torque-limited heavy trucks.

(4) The data concerning the number of brakes OOA and the average percentage adjustment appears to be influenced by vehicle weight. Perhaps the original data could be reanalyzed to separate the contribution of vehicle weight from the results for brake-adjustment.

(5) Analyses performed in the current study indicate that the stopping distance attained in a 20 mph stop is highly dependent upon pressure delays and rise-times in the braking system. Since brake timing was not measured for the vehicles involved in the tests, the influences of brake timing was not measured for the vehicles involved in the tests, the influence of brake timing are not accounted for in the results. Although measurements of brake timing. were probably impractical then, the results nevertheless have an important source of variability which could be investigated now (if brake timing were to be measured.)

(6) The data indicate that drivers do much better on subsequent braking trials than they do on the first trial. This points out that there is a source of variability due to driver characteristics and experience in performing stopping distance testing. (This situation is supported by our past experience in which we have found that test drivers can stop in shorter distances than over-the-road-drivers in braking performance tests.)

Pertinent results from [1] are tabulated in Appendix D.A. and Appendix D.B. contains a list of questions based on Items (a) through (f).

Findings that corrobroate and extend the results presented in Reference [1] were obtained by reviewing studies performed by NTSB [4] and New York State [5]. The results of the NTSB investigation of thirty-two accident cases involving heavy trucks with brake problems fit in well with the results of the OMC study conducted in 1984. With respect to brake-adjustment, the NTSB study found that older trucks were worse than newer trucks. Large fleets have newer trucks and better levels of brake-adjustment than smaller fleets. NTSB recommends that NHTSA require automatic slack adjusters and that fleets provide (a) driver training on adjustment, plus (b) indicators for OOA brakes.

The New York State study involved working with six truck fleets. The study included 1,003 inspections on fifty-five tractors and forty-five trailers. Pertinent findings are as follows:

- Trailer axles should be adjusted at an interval less than 5,000 miles:—especially the rear axle which experiences the greatest amount of wear.

- The front tractor axle has few problems. The front drive axle has some problems, but the brakes on the rear drive axle need to be adjusted every 3,000 miles for eight of ten brakes to remain in adjustment.

- Automatic slack adjusters work very well if they are properly maintained (not so well otherwise).

- Drivers and mechanics often adjust brakes without reporting it and without training in some cases. All mechanics and all drivers should be trained in proper brake-adjustment procedures including reporting when brakes are adjusted.

- Brake wear is rapid during the break-in of new brake linings. (This implies that wear history is non-linear such that linear extrapolations from initial periods of wear will not be representative of long-term wear—such extrapolations would over-predict brake wear.)

- If the trailer hand control valve is used frequently, trailer brakes will wear rapidly and these brakes will need to be monitored closely.

- Some vehicles have repetitive adjustment problems. Vehicles that have weekly adjustment problems should be identified and their brake systems should be given a thorough inspection.

- The participating companies did not experience totally similar problems. Each company needs to analyze its experience and develop separate adjustment criteria for both tractors and trailers. (The factors of influence were believed to include road traffic and type plus driver habits including the use of the trailer trolly valve and retarders.)

- It was difficult (practically impossible in some cases) to document trailer miles travelled. Perhaps a time-based adjustment interval should be developed for trailers. (Again, each company would need to develop its own periodic maintenance schedule for trailer brakes.)

Reference [2] is a user's manual with some technical detail on computing an average brake temperature. It contains no measured data.

The grade severity range system [2] uses gross vehicle weight plus the physical characteristics of the downgrade to predict an average brake temperature at the end of the descent. Predictions for various speeds of descent (control speeds) are used to determine a relationship between gross-vehicle weight and control speed such that the average brake temperature (including a rapid stop at the bottom of the descent) will be less than 500°F. These predictions form the basis for "weight specific speed" (WSS) signs that inform drivers of the appropriate target (control) speed to use as a function of vehicle weight.

The manual gives instructions on how to inspect a site and install WSS signs. These directions, although they are important, are not particularly relevant to the current study. However, the prediction of brake temperature is relevant to the analysis of the influences of brake-adjustment levels.

Reference [2] gives the equations used to predict average brake temperature. These results could be compared with predictions of individual brake temperatures [6] in the analyses to be performed in Task E. (We expect reasonable correspondence between the individual and average temperature predictions because they are based on similar theory using "bulk" temperature calculations.)

Information from Reference [7] may be used in Task E to aid in evaluating predictions of brake temperatures. For example, [7] gives the following "rules of thumb:"

- •Drum expansion is 0.01" per 100°F temperature increase.
- •Pushrod force decreases by 250 pounds. per 100°F for brake-adjustment at 1.75" and 80 psi brake line pressure.
- •Pushrod travel increases 0.07" per 100°F (This appears to be low according to other work that we did. Perhaps 0.1" per 100°F would be better.)

An extensive amount of experimental work has been performed to investigate the effect of brake-adjustment on braking performance (see Reference [13]). The study [3] included (a) stopping-distance tests on a single unit truck and two tractor trailer combinations, (b) brake dynamometer tests on six types of s-cam brakes, and (c) computer simulations to extend the results to situations not tested.

The vehicle configurations used in stopping performance tests were 6x4 straight truck, a 3-S2 tractor semitrailer combination, and a 2-S1-2 doubles combination. The vehicles were instrumented to measure deceleration, speed, stopping distance, control line pressure, brake lining temperature, and wheel lockup. Also, pushrod force and stroke were measured at the brake chambers. Stopping-distance tests were made at selected levels of brake-adjustment. These tests were run on a good dry surface using initial speeds of 20 and 60 mph. These data provide deterministic, quantitative information that will be useful in evaluating the influences of brake-adjustment.

Tests were also conducted on a curved path on a slippery, wet surface. Although these tests are important with respect to directional control during braking and the influences of side to side misadjustment of the brakes on the front axle, it does not appear that these results will be used in the current study because OOS criteria no longer contains special provisions pertaining to the adjustment of the steering axle brakes.

The vehicle test results involve many combinations of levels of brake-adjustment at various brakes—thirty-one cases for the truck, twenty for the 3-S2, and thirty-two for the double, plus tests at high brake temperatures and for lightly-loaded vehicles. Pertinent tables from [3] are presented in Appendix D.C. These data are assessed to be a definitive source of information on the influences of various levels of brake-adjustment on stopping distance.

In addition to vehicle test results, [3] contains an extraordinary set of dynamometer data indicating the effect of brake-adjustment on brake torque. These data are fundamental to analyzing the influence of brake-adjustment on stopping distance. They were used in [3] to develop a mathematical model for predicting stopping distance performance (and we expect to use it in our work later in this project). The following excerpts from [3] describe the brakes and procedures covered in the dynamometer tests. An example set of results follows the excerpts. These results illustrate the influence of cold stroke and temperature on brake torque for a typical 30x6 s-cam brake.

"The dynamometer tests were used to determine the effect of brake-adjustment on the brake torque output under various operating conditions. In addition, the data collected were used in developing a computerized mathematical model of the brake. Both of these require a wide range of operating conditions such as brake pressure, shaft speed and initial temperature.

Various brake configurations were tested to determine the sensitivity of these configurations to brake-adjustment. Prior to testing each of these configurations, a new set of ABEX 614 EF asbestos linings was installed. The configurations tested were:

1. 16.5 x 7" Double Anchor Pin Brake, Type 30 Chamber, 6" Slack Adjuster and a Cast Drum

2. 16.5 x 7" Double Anchor Pin Brake, Type 214 Chamber, 6" Slack Adjuster and a Cast Drum

3. 15 x 4" Double Anchor Pin Brake, Type 20 Chamber, 5.5" Slack Adjuster and a Cast Drum

4. 16.5 x 7" Double Anchor Pin Brake, Type 30 Chamber, 6" Slack Adjuster and a Fabricated Drum

5. 16.5 x 7" Single Anchor Pin Brake, Type 30 Chamber, 6" Slack Adjuster and a Cast Drum

6. 16.5 x 7" Double Anchor Pin Brake, Type 30 Chamber, 6" Slack Adjuster and a Cast Drum with Modified Conditioning Phase.

The test procedure used for dynamometer testing is given in Table 13. The brake conditioning phase of the test was run at the beginning of each brake configuration to stabilize the new brake linings."

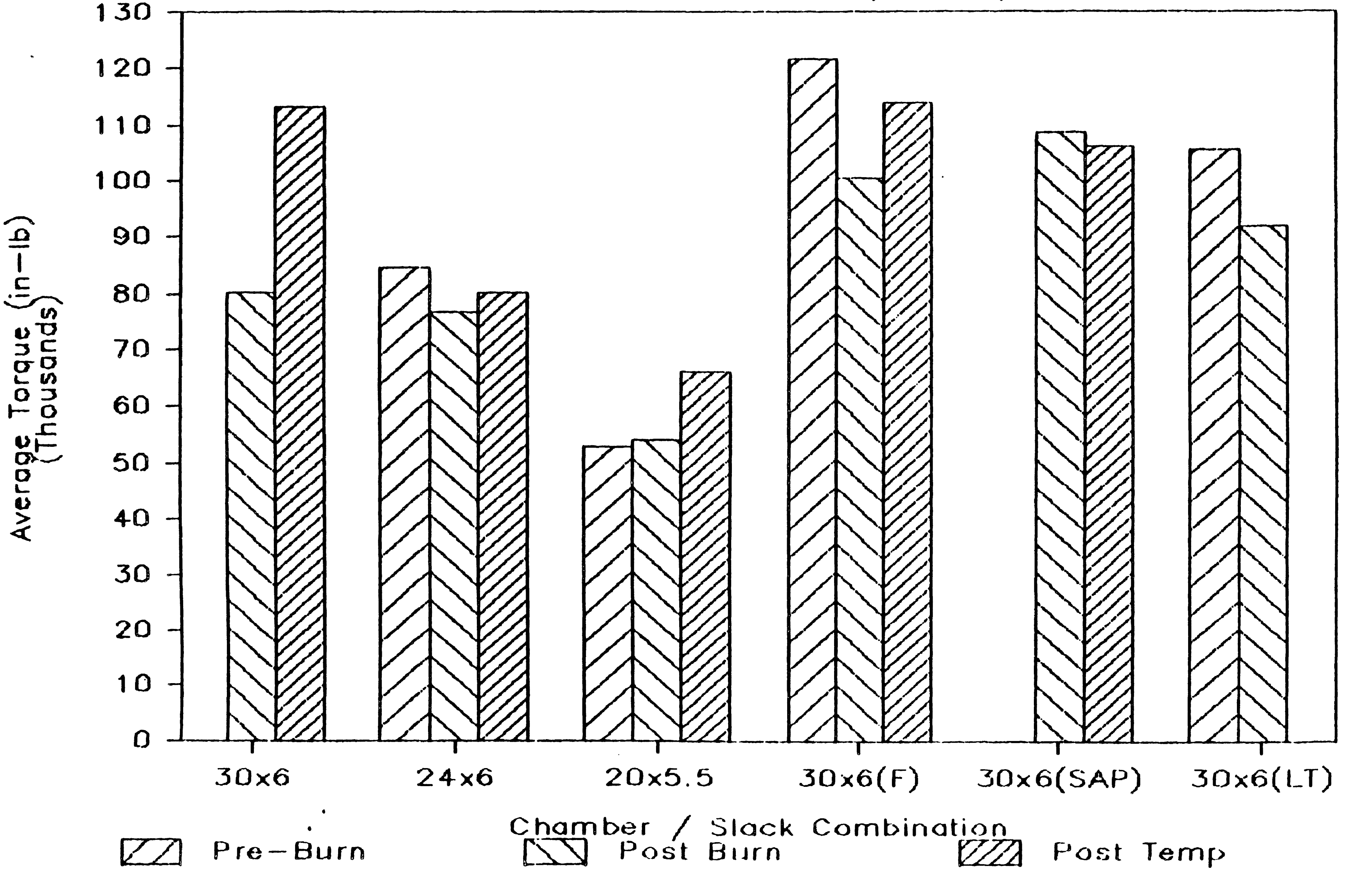
TABLE 13 from [3]

Dynamometer Test Schedule

	Number of Stops	Speed (mph)	Pressure (psi)	Decel (ft/s/s)	Initial Temperature (°F)
Brake Conditioning Phase					
Pre-Burnish Effectiveness					
	5	60-0	100		150
Burnish					
	1000	40-0		10	500
Post Burnish Effectiveness					
	5	60-0	100		150
High Temperature Conditioning					
	10	60-0	100		700
Post Temperature Conditioning Effectiveness					
	5	60-0	100		150
Brake Adjustment Tests (Repeat Sequence Three Times for Each Adjustment Level)					
Static Measurement			100		200
	1	20-0	100		200
	1	40-0	100		200
	1	60-0	20		200
	1	60-0	60		200
	1	60-0	100		200
Static Measurement			100		400
	1	20-0	100		400
	1	40-0	100		400
	1	60-0	20		400
	1	60-0	60		400
	1	60-0	100		400
Static Measurement			100		600
	1	20-0	100		600
	1	40-0	100		600
	1	60-0	20		600
	1	60-0	60		600
	1	60-0	100		600

Dynamometer Brake Adjustment Tests

Effectiveness Test, 60mph, 100psi



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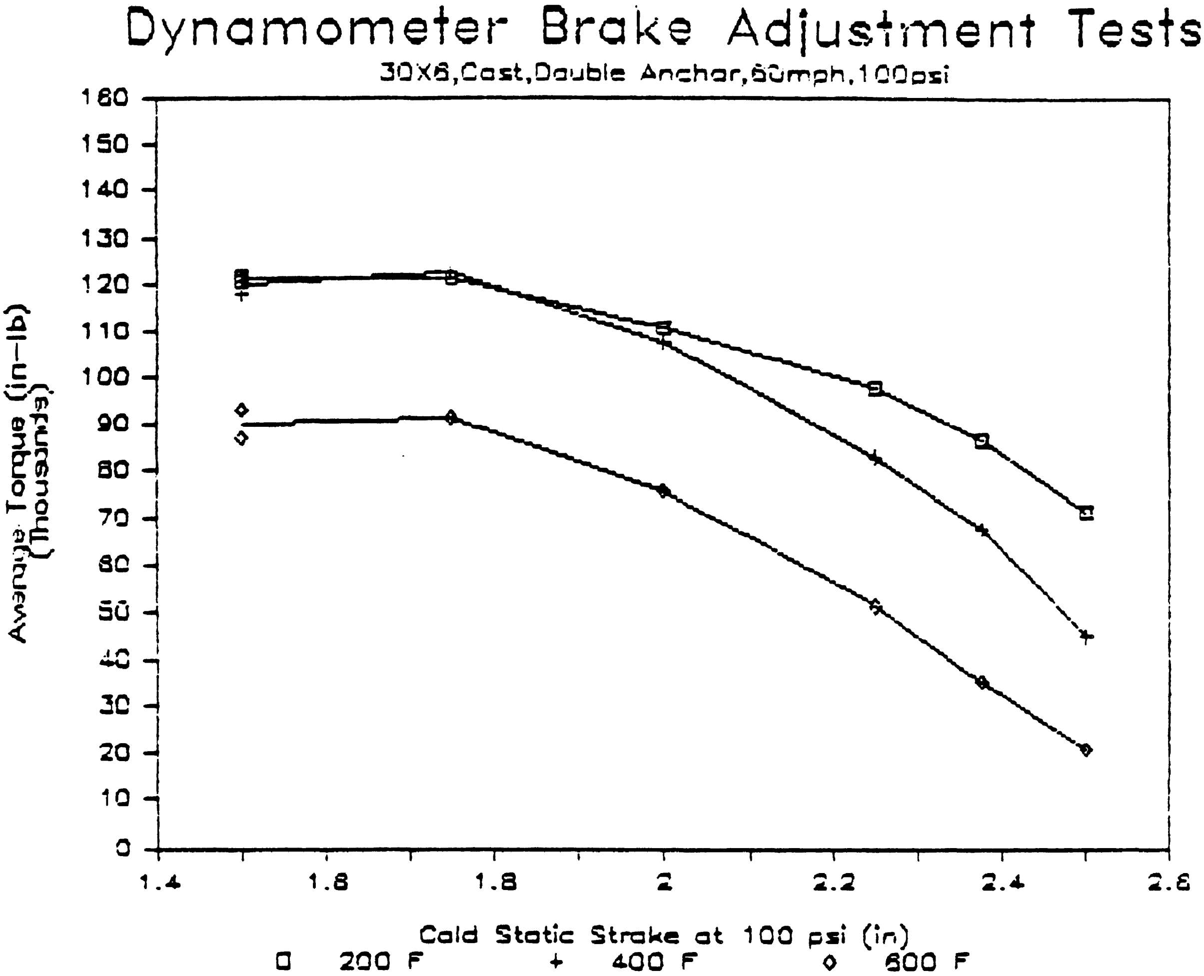
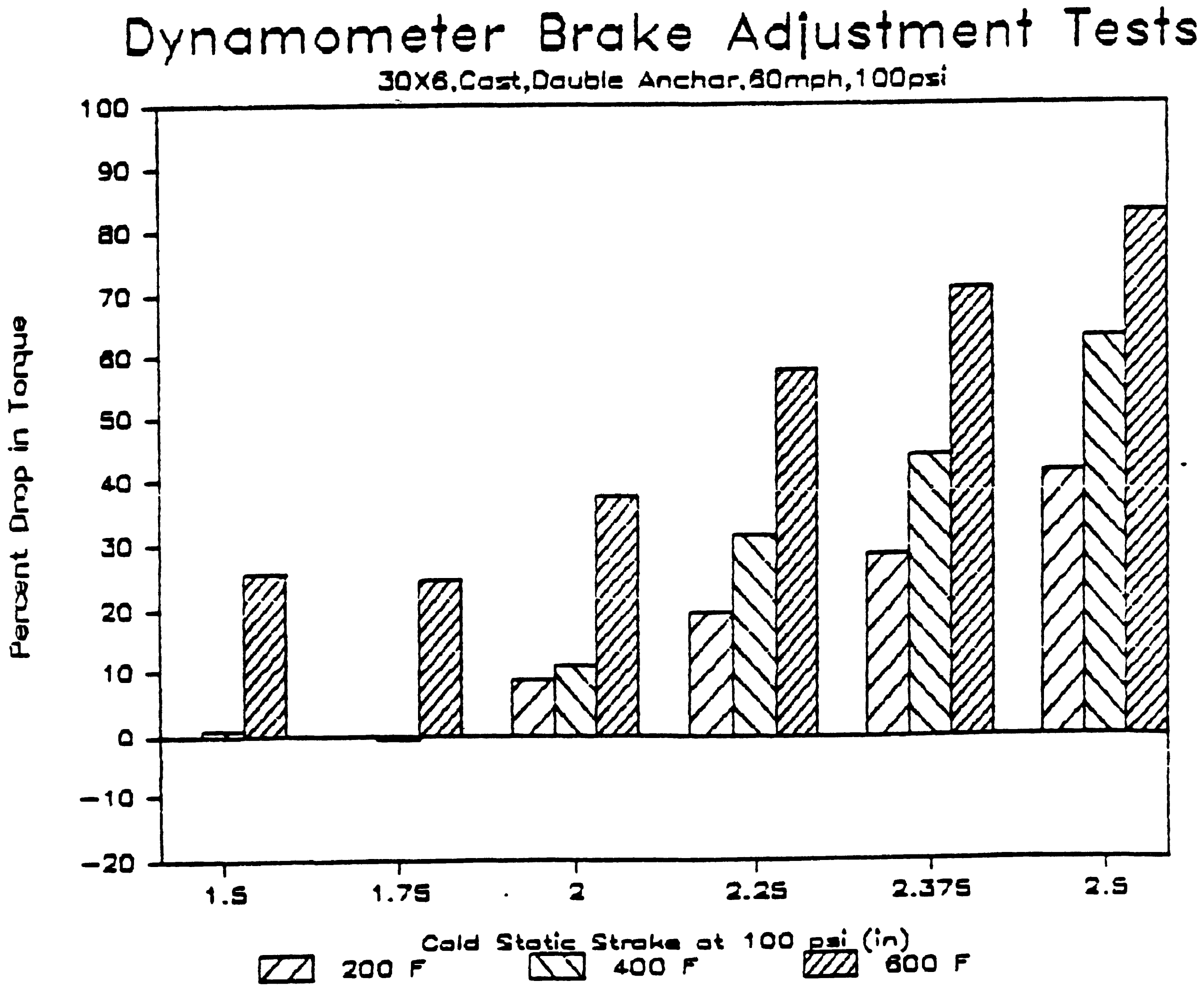


Dynamometer Brake Adjustment Tests
30X6,Cast,Double Anchor,60mph,100psi
Average Torque (in-lb) (Thousands)
Cold Static Stroke at 100 psi (in)
200 F
400 F
600 F



Dynamometer Brake Adjustment Tests
30X6,Cast,Double Anchor,60mph,100psi
Percent Drop in Torque
1.5
1.75
2
2.25
2.375
2.5
Cold Static Stroke at 100 psi (in)
200 F
400 F
600 F

Source: [3]

The model developed in [3] includes (a) the influences of the apply times of the brakes, (b) the relationship between pressure, stroke, and torque for each brake (including factors representing drum expansion during the stop and self-actuation), and (c) simple integration algorithms for integrating deceleration to obtain velocity and integrating again to obtain stopping distance. The model was used to produce the following results:

Percent Increase in Stopping Distance at Minimum CVSA Out-Of-Service Levels

	200° (%)	400° (%)	600° (%)
Six Wheel Case			
50 % ≥ RA	4	24	53
20 % Defective	4	19	35
Front Imbalance	0	7	11
Front $\frac{1}{4}$" Beyond Limit	3	12	20
Ten Wheel Case			
50 % ≥ RA	4	32	49
20 % Defective	4	14	23
Front Imbalance	0	6	10
Front $\frac{1}{4}$" Beyond Limit	1	9	15

NOTE: Minimum CVSA Out-of-Service Levels - At out-of-service criteria with all other brakes fully adjusted.

50 ≥ RA - Earlier CVSA Out-of-Service Level which has since been removed.

Conditions Resulting in 20 Percent Increase in Stopping Distance Not Covered by CVSA Criteria

Number of Wheels at Given Adjustment Level

Initial Brake Temperature	Fully Adj → Readj Point	Readj Point → Readj Point+0.25in	Readj Point+0.25in → Backed Off	Backed Off
Six Wheel Case				
200°F	5	0	0	1
400°F	5	1	0	0
	5	0	1	0
	4	2	0	0
	6	0	0	0
Ten Wheel Case				
200°F	9	0	0	1
400°F	8	2	0	0
	8	1	1	0
	9	1	0	0
	7	3	0	0
	9	0	1	0
	10	0	0	0

The appendices D.A. and D.C. which follow the references, contain tables of data thereby providing a compact presentation of selected results from References [1] and [3].

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APPENDIX D.A.

SELECTED DATA FROM REFERENCE [1]

DISTRIBUTION OF VEHICLES BY FOR-HIRE STATUS

VEHICLE CONFIGURATION	FOR HIRE	NOT FOR HIRE	UNKNOWN	TOTAL
Single Unit Truck				
3-axle	40% (21)	54% (28)	6% (3)	100% (52)
Tractor-Semi Combination				
2-S1	24% (21)	76% (68)	0% (0)	100% (89)
2-S2	50% (16)	50% (16)	0% (0)	100% (32)
3-S2+	74% (99)	24% (32)	2% (2)	100% (133)
Truck-Trailer Combination	27% (12)	69% (31)	4% (2)	100% (45)
Double Bottom Trailer	28% (11)	65% (26)	7% (3)	100% (40)
TOTAL	180	201	10	391

AVERAGE TRUCK/TRACTOR AND TRAILER AGE (YEARS)

VEHICLE CONFIGURATION	TRUCK/TRACTOR (Years)	TRAILER (Years)
Single Unit Truck		
3-axle	6.6	NA
Tractor-Semi Combination		
2-S1	5.3	9.2
2-S2	5.8	9.8
3-S2+	7.5	7.2
Truck-Trailer Combination	7.7	9.3
Double Bottom Trailer	6.4	7.9

AVERAGE NUMBER AND PERCENTAGE OF BRAKES OUT OF ADJUSTMENT PER VEHICLE

VEHICLE CONFIGURATION	AVERAGE NUMBER	PERCENTAGE	SAMPLE SIZE
Single Unit Truck			
3-axle	1.92	31%	49
Tractor-Semi Combination			
2-S1	1.91	32%	87
2-S2	2.09	26%	32
3-S2+	3.02	30% ***	133
Truck-Trailer Combination	2.50	26%	38
Double Bottom Trailer	5.53	36%	38
TOTAL		30%	377

PERCENTAGE OF VEHICLES TESTED MEETING FMCSR REQUIREMENTS DETERMINED BY THE FIRST STOPPING DISTANCE

VEHICLE CONFIGURATIONS		1984 PASSED (%)
Single Unit Truck		
3-axle		38
Tractor-Semi Combination		
2-S1		53
2-S2		59
3-S2+		45
Truck-Trailer Combination		51
Double Bottom Trailer		40

Using the pushrod measurements, the average percentage adjustment required to maintain the vehicle in-service was calculated for each brake for each vehicle. For example, for a clamp type brake chamber with a 30 square inch effective area (type 30), the maximum stroke at which brakes should be adjusted (the out-of-service level) is 2 inches. If the actual measurement obtained during the test was two and one half inches, then the percentage adjustment required to maintain the vehicle in-service was calculated as [(2.5 - 2.0)/2.0] or 25 percent. The average percentage adjustment required was obtained by averaging the individual percentage adjustments required.

AVERAGE PERCENTAGE ADJUSTMENT REQUIRED

VEHICLE CONFIGURATIONS	
Single Unit Truck	
3-axle	18%
Tractor-Semi Combination	
2-S1	15%
2-S2	16%
3-S2+	14%
Truck-Trailer Combination	20%
Double Bottom Trailer	19%

AVERAGE STOPPING DISTANCE (feet)
DETERMINED BY THE FIRST STOPPING DISTANCE

VEHICLE CONFIGURATIONS	FMCSR Req. (20 mph)	1984 (ft)
Single Unit Truck		
3-axle	35	39.1
Tractor-Semi Combination		
2-S1	40	41.7
2-S2	40	37.9
3-S2+	40	41.9
Truck-Trailer Combination	40	42.8
Double Bottom Trailer	40	47.8

AVERAGE STOPPING DISTANCE (feet)
DETERMINED BY SHORTEST STOPPING DISTANCE

VEHICLE CONFIGURATION	FMCSR Req. (20 mph)	1984 (ft)
Single Unit Truck		
3-axle	35	36.4
Tractor-Semi Combination		
2-S1	40	38.1
2-S2	40	35.7
3-S2+	40	38.9
Truck-Trailer Combination	40	39.9
Double Bottom Trailer	40	45.6

PERCENTAGE OF VEHICLES TESTED MEETING FMCSR REQUIREMENT USING THE SHORTEST STOPPING DISTANCE

VEHICLE CONFIGURATIONS		1984 OVERALL (%)
Single-Unit Truck		
3-axle		56
Tractor-Semi Combination		
2-S1		69
2-S2		81
3-S2+		59
Truck-Trailer Combination		69
Double Bottom Trailer		43

AVERAGE STOPPING DISTANCE BY TEST

	Sample Size	Average Stopping Distance (ft)
TEST #1	518	40.0
TEST #2	392	37.8
TEST #3	200	37.0

PERCENTAGE OF VEHICLES MEETING FMCSR REQUIREMENTS DETERMINED BY THE FIRST STOPPING DISTANCE

VEHICLE TYPES	MD	CA	MI	TOTAL
Single Unit Truck				
3-axle	41%(32)	22% (9)	45%(11)	38%(52)
Tractor-Semi Combination				
2-S1	67% (3)	34%(35)	65%(51)	53%(89)
2-S2	67%(12)	33% (9)	73%(11)	59%(32)
3-S2+	47%(94)	35%(26)	54%(13)	45%(133)
Truck-Trailer Combination	-	26%(23)	86%(22)	51%(45)
Double Bottom Trailer	-	36%(11)	41%(29)	40%(40)
TOTAL	141	113	137	391

FIRST STOPPING DISTANCE AND TOTAL WEIGHT BY STATE

VEHICLE CONFIGURATION	MD (0.95)	CA (0.76)	MI (0.85)
Single Unit Truck			
3-axle	38.8	40.6	38.7
	29,530	29,056	33,675
Tractor-Semi Combination			
2-S1	39.7	46.6	38.4
	20,333	31,682	29,635
2-S2	36.3	42.1	36.2
	37,331	39,304	33,036
3-S2+	41.3	43.4	43.2
	48,998	52,818	60,125
Truck-Trailer Combination	-	48.8	36.0
	-	73,340	32,229
Double Bottom Trailer	-	49.5	47.5
	-	51,882	83,725

AVERAGE STOPPING DISTANCE AND TOTAL WEIGHT

VEHICLE TYPES	FIRST STOPPING DISTANCE (feet)		TOTAL WEIGHT (lbs.)		PERCENTAGE DIFFERENCE IN WEIGHT
	PASSED	FAILED	PASSED	FAILED	PASS VS. FAIL
Single Unit Trucks					
3-axle	29.9	44.8	30224	30388	1
Tractor-semi Combination					
2-S1	34.0	50.2	28186	32382	15
2-S2	32.9	45.2	34212	40013	17
3-S2+	33.8	48.6	43768	56472	29
Tractor-trailer Combination	34.3	51.7	37757	71299	89
Double Bottom Trailer	35.6	55.9	55007	87079	58

PERCENTAGE OF VEHICLES MEETING FMCSR REQUIREMENTS
BY FOR-HIRE STATUS

VEHICLE CONFIGURATION	FOR HIRE	NOT FOR HIRE
Single Unit Truck		
3-axle	24%(21)*	46% (28)
Tractor-Semi Combination		
2-S1	48%(21)	54% (68)
2-S2	56%(16)	63% (16)
3-S2+	40%(99)*	59% (32)
Truck-Trailer Combination	33%(12)	56% (32)
Double Bottom Trailer	36%(11)	44% (25)
TOTAL	180	201

COMPARISON OF THE AVERAGE NUMBER OF BRAKES OUT OF ADJUSTMENT

VEHICLE CONFIGURATION	MD	CA	MI
Single Unit Truck			
3-axle	1.47 (32)	2.00 (10)	3.55 (11)
Tractor-Semi Combination			
2-S1	1.75 (4)	1.43 (37)	2.32 (50)
2-S2	1.85 (13)	2.40 (10)	2.27 (11)
3-S2+	3.13 (98)	1.84 (31)	4.15 (13)
Truck-Trailer Combination		2.25 (12)	6.81 (27)
Double Bottom Trailer		2.13 (23)	2.88 (16)

PERCENTAGE OF VEHICLES MEETING FMCSR REQUIREMENTS BY THE NUMBER OF BRAKES OUT OF ADJUSTMENT

NUMBER OF BRAKES OUT OF ADJUST	Single-unit truck	Tractor-semi comb.				
	3-axle	2-S1	2-S2	3-S2+	Truck-Trailer	Double Bottom
0	35%(17)	55%(22)	45%(11)	58%(26)	42%(12)	57%(7)
1	20%(5)	58%(12)	67%(3)	25%(16)	67%(3)	0%(2)
2	54%(13)	54%(28)	100%(3)	50%(24)	71%(7)	33%(3)
3	100%(1)	67%(6)	43%(7)	56%(16)	20%(5)	67%(3)
4	38%(8)	67%(15)	100%(5)	54%(13)	40%(5)	57%(7)
5	33%(3)	25%(4)	100%(1)	27%(15)		100%(1)
6	50%(2)		0%(2)	67%(12)	50%(2)	0%(2)
7				20%(5)	100%(1)	33%(3)
8				0%(3)	67%(3)	0%(1)
9				0%(1)	100%(1)	
10				0%(1)		0%(1)
11						0%(2)
12					0%(1)	
13				0%(1)		
14					0%(1)	0%(4)
15					23%(13)	100%(1)
16					0%(7)	0%(1)

PERCENTAGE OF VEHICLES MEETING FMCSR REQUIREMENTS BY 5,000 LB. WEIGHT INTERVALS

WEIGHT (000 lbs)	Single-unit truck	Tractor-semi comb.				
	3-axle	2-S1	2-S2	3-S2+	Truck-Trailer	Double Bottom
0- 5						
5- 10						
10- 15	0%(1)				100%(1)	
15- 20	40%(5)	67%(3)	100%(1)		100%(1)	
20- 25	36%(14)	81%(21)	100%(2)	50%(2)	60%(5)	
25- 30	45%(11)	32%(22)	88%(8)	64%(25)	100%(1)	25%(4)
30- 35	43%(7)	61%(18)	20%(5)	73%(22)	100%(3)	
35- 40	50%(2)	60%(15)	40%(5)	29%(7)	100%(10)	100%(3)
40- 45	25%(8)	14%(7)	100%(5)	50%(6)	0%(1)	44%(9)
45- 50	100%(1)	0%(3)	0%(3)	83%(6)	100%(1)	50%(4)
50- 55	50%(2)		50%(2)	25%(4)		100%(2)
55- 60			0%(1)	22%(9)		67%(3)
60- 65	0%(1)			14%(7)	0%(1)	
65- 70				15%(13)		
70- 75				44%(18)	0%(1)	0%(1)
75- 80				18%(11)	23%(13)	
80- 85				0%(1)	0%(7)	50%(2)
-//-						
110-115				100%(1)		0%(1)
115-120						0%(1)
120-125				0%(1)		0%(1)
125-130						0%(2)
130-135						0%(1)
135-140						0%(1)
140-145						
145-150						0%(1)
150-155						25%(4)
TOTAL	38%(52)	53%(89)	59%(32)	46%(133)	51%(45)	40%(40)

INDICATORS OF BRAKE ADJUSTMENT

VEHICLE TYPES	NUMBER OF BRAKES OUT OF ADJUST.		AVERAGE PERCENT ADJUST REQ'D	
	PASSED	FAILED	PASSED	FAILED
Single Unit Trucks			-- --	-- --
3-axle	2.1	1.8	13.0	20.8
Tractor-semi Combination				
2-S1	1.7	2.1	17.0	12.2
2-S2	2.2	1.9	16.2	15.6
3-S2+	2.6	3.3	17.9	10.5
Tractor-trailer Combination	2.7	2.3	16.6	23.4
Double Bottom Trailer	3.6	6.5	22.8	15.8

PERCENTAGE OF VEHICLES MEETING FMCSR REQUIREMENTS BY AGE OF TRUCK/TRACTOR

TRUCK/ TRACTOR AGE (years)	Single-unit truck	Tractor-semi comb.				
	3-axle	2-S1	2-S2	3-S2+	Truck-Trailer	Double Bottom
0	100%(3)	100%(4)	50%(2)	0%(3)		75%(4)
1	33%(6)	33%(3)	100%(3)	75%(8)		100%(2)
2	100%(1)	54%(13)	100%(4)	50%(10)	0%(1)	50%(2)
3	20%(5)	60%(5)	0%(1)	75%(4)	100%(1)	0%(1)
4	40%(5)	75%(12)	75%(4)	57%(14)	50%(2)	40%(5)
5	60%(5)	43%(21)	80%(5)	47%(15)	78%(9)	0%(4)
6	43%(7)	40%(5)	40%(5)	40%(5)	78%(9)	75%(4)
7	100%(1)	40%(5)		67%(6)	0%(2)	0%(3)
8		67%(3)	0%(1)	30%(10)	75%(4)	0%(1)
9	33%(3)	67%(3)	0%(1)	13%(8)	0%(3)	
10	25%(4)	50%(4)	33%(3)	42%(12)	20%(5)	40%(5)
11	0%(3)	17%(6)		45%(11)	50%(4)	0%(3)
12	40%(5)	50%(2)	0%(1)	50%(4)	50%(2)	33%(3)
13				33%(3)	0%(1)	
14		100%(1)	100%(1)	100%(2)		50%(2)
15	0%(1)	100%(1)		0%(5)	0%(1)	
16				0%(2)	0%(1)	
17	0%(1)			0%(1)		
18	0%(2)			67%(3)		
-//-						
26				0%(1)		
28			0%(1)			
TOTAL	38%(52)	53%(88)	61%(32)	44%(127)	51%(45)	38%(39)

AVERAGE TRUCK/TRACTOR AND TRAILER AGE (YEARS)

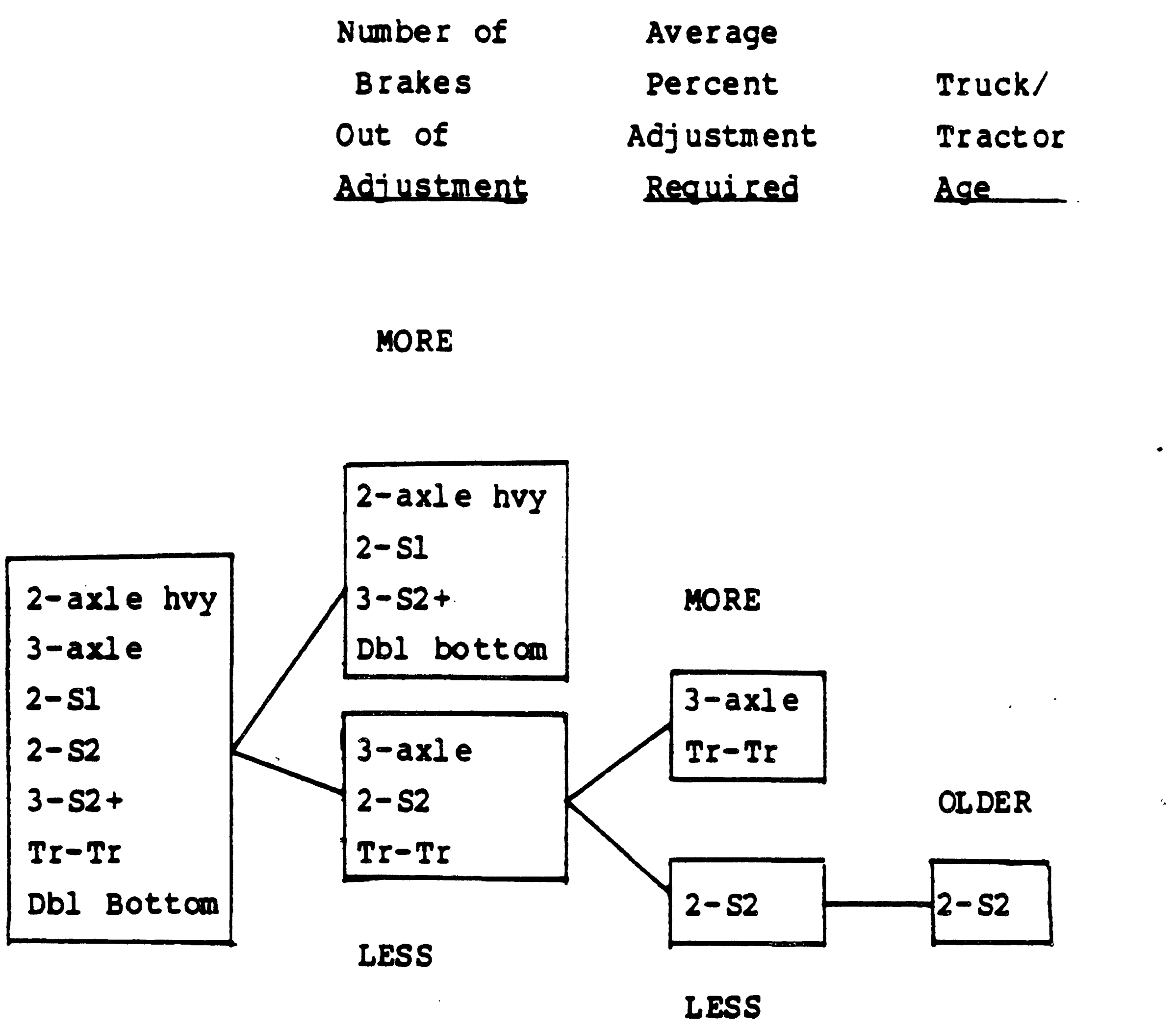
VEHICLE TYPES	TRUCK AGE		TRAILER AGE	
	PASSED	FAILED	PASSED	FAILED
Single Unit Truck				
3-axle	4.9	7.7	NA	NA
Tractor-Semi Combination				
2-S1	5.0	5.7	8.7	9.7
2-S2	4.2	8.1	10.2	9.3
3-S2+	6.6	8.3	7.1	7.2
Truck-Trailer Combination	6.6	8.9	6.1	12.7
Double Bottom Trailer	5.1	7.2	5.3	9.7

Factors affecting braking performance for most vehicle configurations in order of importance are:

- o total weight,
- o age of the truck/tractor,
- o whether the vehicle was operated for hire,
- o the number of brakes out of adjustment, and
- o the average percentage adjustment required to maintain the vehicle in-service.

No single factor, such as total weight or number of brakes out of adjustment, adequately explained the vehicles' compliance status. Nor did any single regression model combining these factors adequately explain the results for the various configurations. However, the regression coefficients obtained for the relationship of the number of brakes out of adjustment and stopping distance indicated that an additional 0.5 to 1.5 feet per out-of-adjustment brake was required to stop.

WHY DID THEY FAIL?



APPENDIX D.B.

QUESTIONS CONCERNING MATERIAL IN REFERENCE [1]

- Are heavier vehicles likely to have brakes in adjustment?

- Why not leave out 2-axle vehicles because they are largely hydraulically braked?

- Are older trailers maintained better?

- Why not use pounds of load per axle in comparisons?—or some weighting of brake power per pound of load carried?

- Seems like percentage adjusment required ought to work better than the number of brakes OOA (all else being equal). Perhaps something (such as weight or pressure delays) correlates with the number of brakes OOA or the percentage adjustment required?

- Are the maintenance practices of "not-for-hire" carriers better than those of "for-hire" carriers?

- What do you do about physically impossible results which imply that something else was uncontrolled?—in particular, the number of brakes OOA versus percentage adjustment required. Perhaps information on brake timing is needed to explain these results. Also vehicle weight must be account for.

APPENDIX D.C.

SELECTED DATA FROM REFERENCE [3]

TABLE 2
6 X 4 Truck Straight Line Stopping Distance
Test Results

Condition	Key	20 mph Stop Dist (ft)	20 mph Line Pres (psi)	60 mph Stop Dist (ft)	60 mph Line Pres (psi)
Fully Adjusted w/ALV	A	35	82	307	80
Fully Adjusted	1	37	82	288	84
#1 FA, #2 @ 2", #3-#6 FA	* 2	37	85	290	85
No Fronts, #3-#6 FA	* 3	43	83	341	90
#1-#2 @ 2.125", #3-#6 FA	* 4	37	100	310	85
#1-#2 FA, #3-#4 @ 2.5", #5-#6 FA	* 5	51	100	481	100
Fully Adjusted	6	34	100	282	85
#1-#5 FA, #6 @ 2.25"	7	34	100	296	85
#1-#3 FA, #4-#6 @ 2"	* 8	36	100	311	80
#1-#2 @ 1.75", #3 @ 2", #4-#6 FA	* 9	35	100	293	80
#1-#2 @ 1.625", #3-#6 @ 1.875"	10	37	100	293	90
#1-#2@1.625", #3-#4@2.25", #5-#6@1.875"	* 11	38	100	297	100
Fully Adjusted	12	35	100	300	80
Fully Adjusted	13	35	100	290	85
#1-#2 @ 1.75", #3-#6 @ 2"	* 14	38	100	309	90
#1-#2 @ 1.5", #3-#6 @ 1.875"	15	36	100	305	85
No Fronts, #3-#6 @ 1.875"	* 16	41	100	354	85
#1 @ 2", #2 @ 1.5", #3-#6 @ 1.875"	* 17	38	100	306	85
#1-#2@1.5", #3@2.25", #4-#6@1.875"	18	37	100	297	90
#1-#2 @ 1.5", #3-#6 @ 1.875"	19	37	100	299	85
Fully Adjusted	20	34	100	306	80
#1-#2 @ 1.75", #3 @ 2", #4-#6 @ 1.875"	* 21	36	100	347	100
Fully Adjusted	22	35	85	315	75
#1-#2 @ 1.625", #3-#6 @ 1.875"	23	36	100	308	85
#1-#2 FA, #3-#4 @ 2.5", #5-#6 FA	* 24	48	100	460	100
#1-#2@1.625", #3-#4@2.25", #5-#6@1.875"	* 25	38	100	318	80
#1-#2 @ 1.75", #3-#6 @ 2"	* 26	38	100	291	100
Fully Adjusted	27	35	95	283	85
#1-#2 @ 1.75", #3-#6 @ 2"	* 28	37	100	303	85
#1-#2 @ 1.75", #3 @ 2", #4-#6 @ 1.875"	* 29	38	100	324	75
#1-#2 FA, #3-#4 @ 2.375", #5-#6 FA	* 30	39	100	353	80
Fully Adjusted	31	35	100	285	85

#1 - Left Front #3 - Left Intermediate #5 - Left Rear
#2 - Right Front #4 - Right Intermediate #6 - Right Rear
FA - Fully Adjusted
* - Conditions meeting CVSA out-of-service criteria

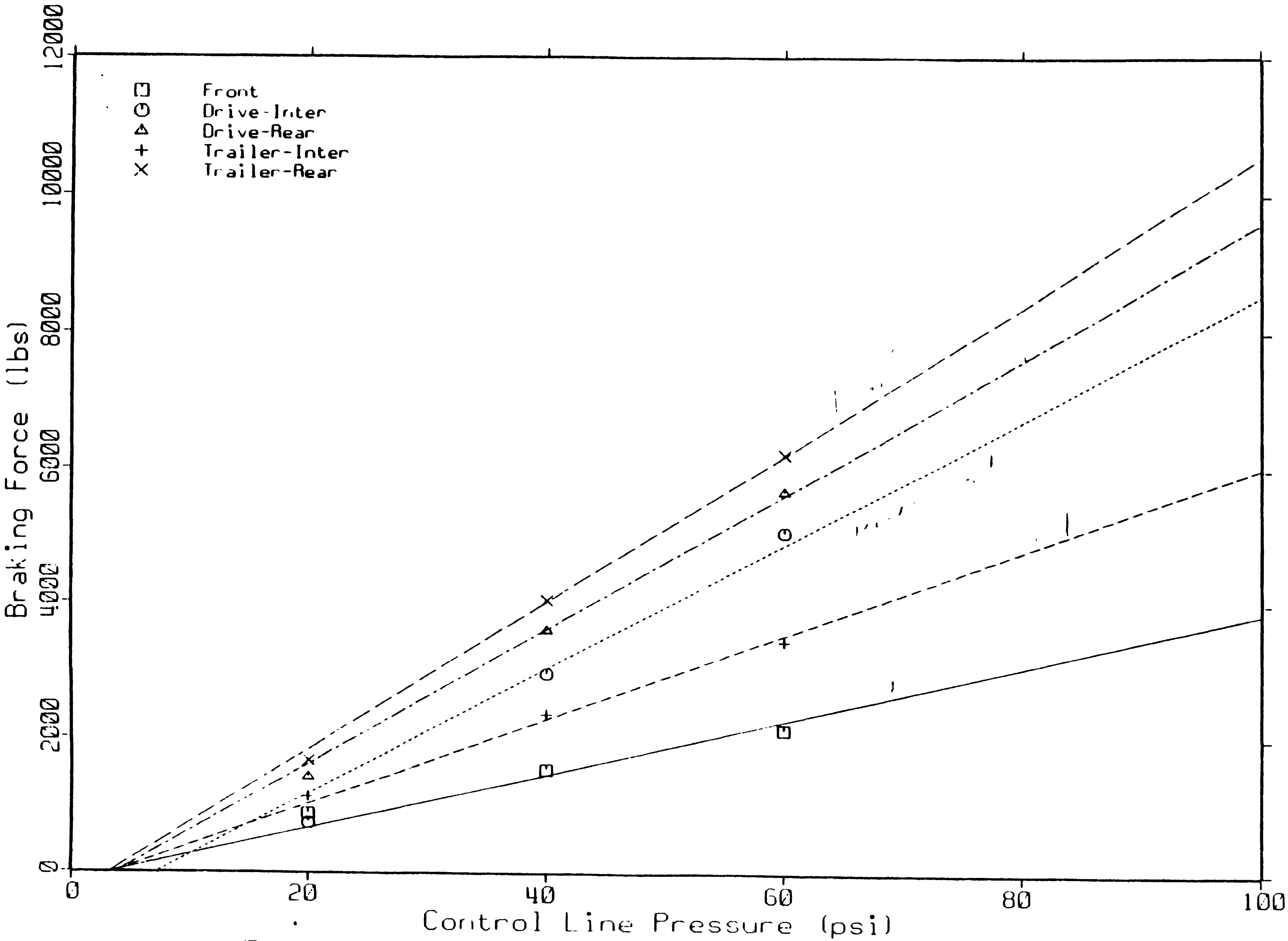
NOTE: All tests were conducted with the ALV bypassed except as noted.

TABLE 4
Tractor Semitrailer Straight Line Stopping Distance
Test Results

Condition		Key	20 mph Stop Dist (ft)	20 mph Line Pres (psi)	60 mph Stop Dist (ft)	60 mph Line Pres (psi)
Fully Adjusted		1	36	100	310	80
#1 FA, #2 @ 2", #3-#10 FA	*	2	36	100	309	80
#1-#2 @ 2.125", #3-#10 FA	*	3	37	100	282	90
No Fronts, #3-#10 FA	*	4	37	100	318	80
Fully Adjusted		5	35	100	295	80
#1-#2 FA, #3-#4 @ 2.5", #5-#10 FA	*	6	43	100	366	85
#1-#6 FA, #7-#8 Off, #9-#10 FA	*	7	39	100	335	85
#1-#4 FA, #5-#6 @ 2.25", #7-#10 FA	*	8	37	100	312	80
Fully Adjusted		9	36	100	309	80
#1-#5 RA, #6-#10 FA	*	10	38	100	321	80
#1-#5 FA, #6-#10 RA	*	11	37	100	299	85
#1-#4 FA, #5-#6 @ 2.375", #7-#10 FA	*	12	39	100	314	85
Fully Adjusted		13	36	100	287	90
#1-#6 FA, #7-#8 @ 2.375", #9-#10 FA	*	14	38	100	303	90
#1-#6 FA, #7-#8 @ 2.25", #9-#10 FA	*	15	37	100	291	100
Fully Adjusted		16			291	90
Fully Adjusted		17	34	100	290	85
#1-#2 FA, #3-#6 @ 2.125", #7-#10 FA		18	36	100	313	85
#1 FA, #2 @ 1.75", #3-#10 FA	*	19	36	100	286	85
Fully Adjusted		20	34	100	282	85

#1 - Left Front #3 - Left Intermediate #5 - Left Rear
#2 - Right Front #4 - Right Intermediate #6 - Right Rear
#7 - Trailer Left Front #9 - Trailer Left Rear
#8 - Trailer Right Front #10 - Trailer Right Rear
FA - Fully Adjusted
RA - At Recomended Readjustment Point
Off - Backed Off
* - Conditions meeting CVSA out-of-service criteria

NOTE: All test were conducted with the ALV bypassed.



Tractor Semitrailer Brake Distribution

Figure 10

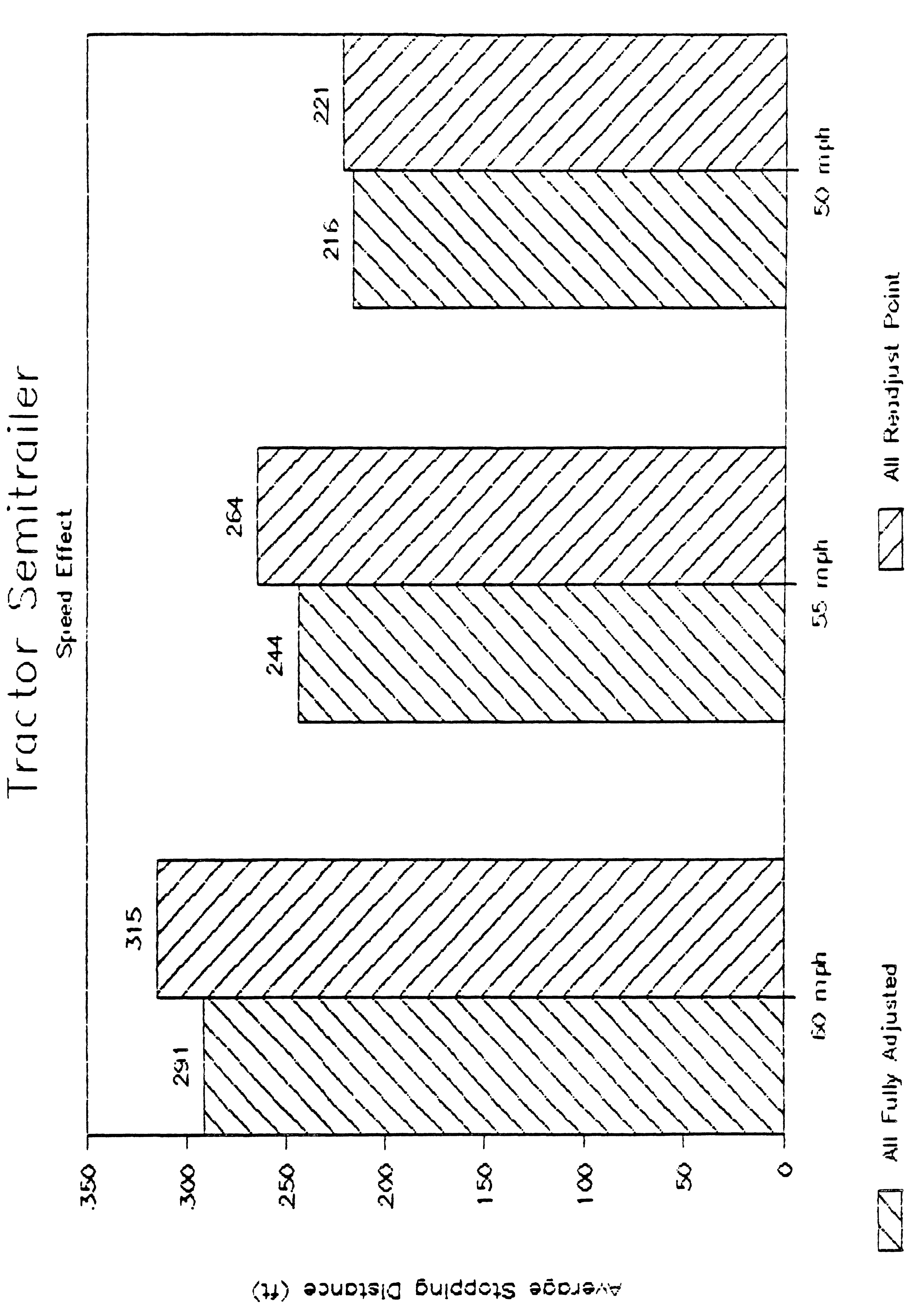

Tractor Semitrailer
Speed Effect
Average Stopping Distance (ft)
0
50
100
150
200
250
300
350
291
315
60 mph
244
264
55 mph
216
221
50 mph
All Fully Adjusted
All Readjust Point

Figure 11

TABLE 6
Tractor Semitrailer Lightly Loaded Stopping Distance Test Results

Condition		Key	Stopping Distance (ft)	Line Pressure (psi)
20 mph Straight Line Dry Pavement Tests				
Fully Adjusted		1	34	45
Fully Adjusted w/ ALV		2	34	45
#1-#2 Off, #3-#10 FA	*	3	37	45
#1-#2 @ 1.875", #3-#10 FA		4	34	45
#1-#2 @ 1.875", #3-#10 FA w/ ALV		5	32	50
Fully Adjusted		6	33	45
60 mph Straight Line Dry Pavement Tests				
Fully Adjusted		1	301	34
Fully Adjusted w/ ALV		2	310	34
#1-#2 Off, #3-#10 FA	*	3	356	32
#1-#2 @ 1.875", #3-#10 FA		4	329	32
#1-#2 @ 1.875", #3-#10 FA w/ ALV		5	338	32
Fully Adjusted		6	317	32
35 mph Wet Jennite Curve				
Fully Adjusted		1	249	15
Fully Adjusted w/ ALV		2	266	15
#1-#2 Off, #3-#10 FA	*	3	277	15

#1 - Left Front #3 - Left Intermediate #5 - Left Rear
#2 - Right Front #4 - Right Intermediate #6 - Right Rear
#7 - Trailer Left Front #9 - Trailer Left Rear
#8 - Trailer Right Front #10 - Trailer Right Rear
FA - Fully Adjusted
Off - Backed Off
* - Conditions meeting CVSA out-of-service criteria

NOTE: All test were conducted with the ALV bypassed except as noted.

TABLE 7
Tractor Semitrailer High Temperature Test Results

	Key	Initial*** Fully Adj Baseline (ft)	(psi)	Cool Brake Stops (ft)	(psi)	1st** Hot Stops (ft)	2nd** Hot Stops (ft)	Final*** Fully Adj Baseline (ft)	(psi)
Fully Adjusted	A	317	60			295	336	294	65
No Fronts, #3-#10 FA	* B	288	65	300	65	326	401	299	60
#1-#2FA,#3-#4@2.125", #5-#6FA,#7-#8@2.125", #9-#10FA	* C	299	60	334	55	322	372	283	65
#1-#2 FA,#3-#6 RA, #7-#9 FA,,#10 RA	* D	283	65	331	55	282	317	283	65
#1-#2 @ 1.5", #3-#10 @ 1.75"	E	283	65	284	65	310	336	309	60
#1-#10 RA	* F	309	60	324	60	334	413	291	65

#1 - Left Front #3 - Left Intermediate #5 - Left Rear
#2 - Right Front #4 - Right Intermediate #6 - Right Rear
#7 - Trailer Left Front #9 - Trailer Left Rear
#8 - Trailer Right Front #10 - Trailer Right Rear
FA - Fully Adjusted
RA - At Recomended Readjustment Point
Off - Backed Off
* - Conditions meeting CVSA out-of-service criteria

NOTE: **Average of two stops
***Average of three stops

TABLE 8

Doubles Combination Straight Line Stopping Distance Test Results

Condition		Key	20 mph Stop Dist (ft)	20 mph Line Pres (psi)	60 mph Stop Dist (ft)	60 mph Line Pres (psi)
Fully Adjusted		1	43	105	315	105
#1-#2 FA, #3-#4 @ 2.25", #5-#10 FA	*	2	46	105	341	105
#1-#6 FA, #7 @ 2.25", #8-#10 FA	*	3	43	105	312	105
#1-#8 FA, #9-#10 @ 2.25"	*	4	44	105	310	105
Fully Adjusted		5	43	105	296	105
#1-#4 FA, #5-#6 @ 2.25", #7-#10 FA	*	6	45	105	307	105
#1-#2 RA, #3-#6 FA, #7-#9 RA, #10 FA	*	7	44	105	312	105
#1-#2 FA, #3-#6 RA, #7-#9 FA, #10 RA	*	8	46	105	328	105
Fully Adjusted		9	44	105	304	105
#1-#2 FA, #3-#4 @ 2.25", #5-#10 FA	*	10	46	105	324	105
#1-#6 FA, #7 @ 2.25", #8-#10 FA	*	11	45	105	309	105
Fully Adjusted		12	43	105	293	105
#1 FA, #2 @ 2", #3-#10 FA	*	13	44	105	308	105
#1-#2 @ 2.125", #3-#10 FA	*	14	44	105	315	105
No Fronts, #3-#10 FA	*	15	49	105	340	105
Fully Adjusted		16	44	105	302	105
#1-#4 RA, #5 Off, #6-#10 RA	*	17	51	105	356	105
#1-#6 FA, #7-#8 @ 2.25", #9-#10 FA	*	18	43	105	310	105
#1-#2 FA, #3-#4 Off, #5-#10 FA	*	19	48	105	380	105
#1-#10 RA	*	20	46	105	348	105
#1 FA, #2 @ 2.125", #3-#10 FA	*	21	44	105	303	105
Fully Adjusted		22	42	105	303	105
Fully Adjusted		23	43	95	329	98
#1 @ 2", #2-#10 FA	*	24	48	96	328	98
#1 @ 2.125, #2-#10 FA	*	25	43	96	324	98
#1 Off, #2-#10 FA	*	26	45	96		
Fully Adjusted		27	43	96	309	98
Fully Adjusted		28	40	91	306	94
#1-#2 FA, #3-#6 @ 2.125", #7-#10 FA	*	29	44	91	338	85
#1-#4 FA, #5-#6 @ 2.125", #7-#8 FA, #9-#10 @ 2.125"	*	30	43	92	336	84
#1 FA, #2 @ 1.75", #3-#10 FA	*	31	42	91	290	94
Fully Adjusted		32	43	90	300	94

#1 - Left Front #3 - Left Rear #5 - First Trailer Left
#2 - Right Front #4 - Right Rear #6 - First Trailer Right
#7 - Left Dolly #9 - Second Trailer Left
#8 - Right Dolly #10 - Second Trailer Right
FA - Fully Adjusted
RA - At Recomended Readjustment Point
Off - Backed Off
* - Conditions meeting CVSA out-of-service criteria

NOTE: All tests were conducted with the ALV bypassed.

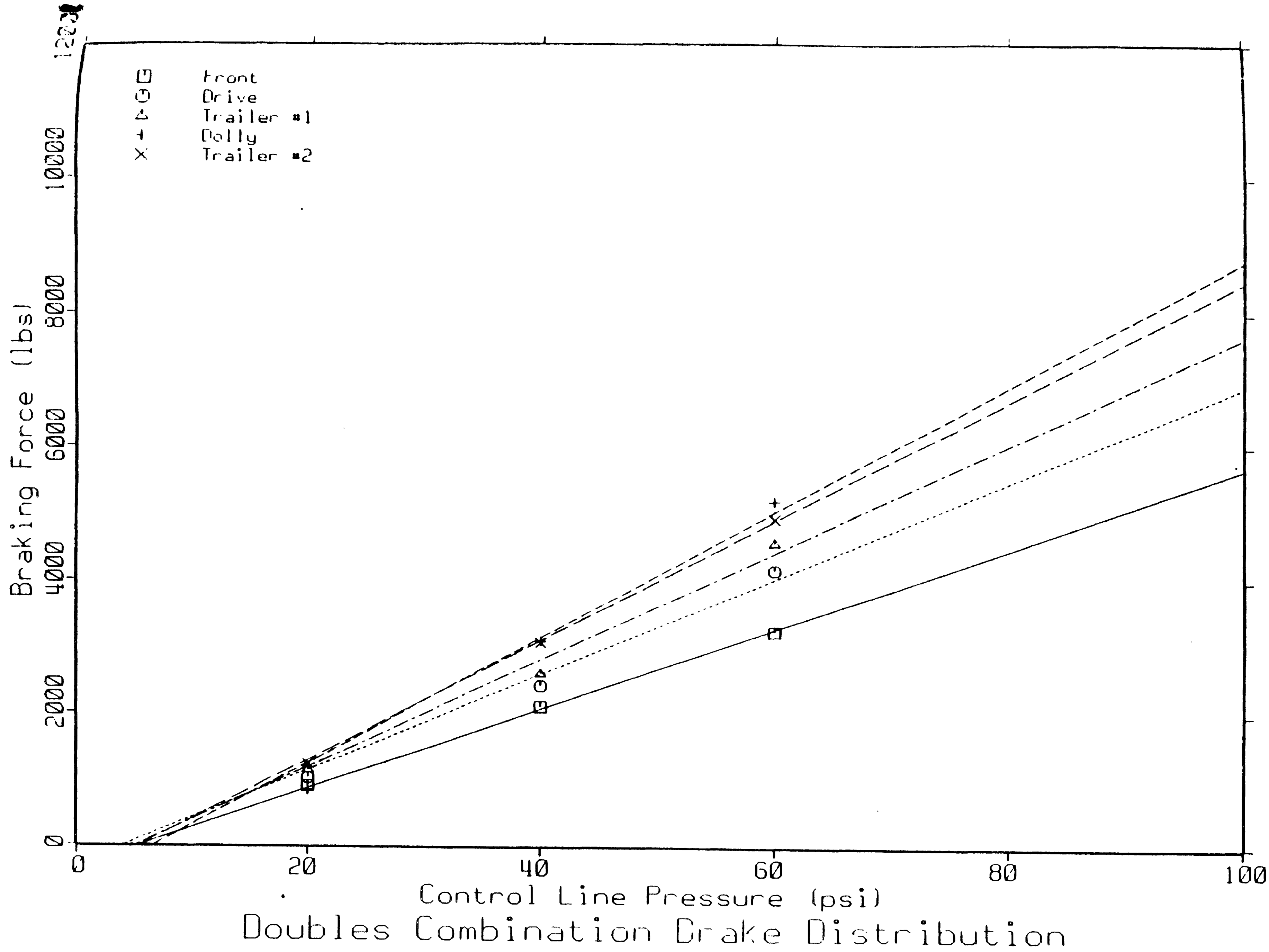

Front
Drive
Trailer #1
Dolly
Trailer #2
Braking Force (lbs)
0
2000
4000
6000
8000
10000
0
20
40
60
80
100
Control Line Pressure (psi)
Doubles Combination Brake Distribution

Figure 15

TABLE 11
Doubles Combination Lightly Loaded Stopping Distance Test Results

Condition	Key	Stopping Distance (ft)	Line Pressure (psi)
60 mph Straight Line Tests			
#1-#10 FA	1	307	47
#1-#10 FA w/ALV	2	298	50
No Fronts, #3-#10 FA	* 3	366	42
#1-#6 FA, No Dolly Brakes, #9-#10 FA	* 4	393	42
#1-#2 @ 1.875", #3-#10 FA	5	310	48
#1-#2 @ 1.875", #3-#10 FA w/ ALV	6	324	45
#1-#10 FA	7	308	46
35 mph Wet Jennite Tests			
#1-#10 FA	1	232	16
#1-#10 FA w/ALV	2	270	16
No Fronts, #3-#10 FA	* 3	291	15
#1-#6 FA, No Dolly Brakes, #9-#10 FA	* 4	311	14
#1-#2 @ 1.875", #3-#10 FA	5	261	14
#1-#2 @ 1.875", #3-#10 FA w/ ALV	6	333	16
#1-#10 FA	7	248	16

#1 - Left Front #3 - Left Rear #5 - First Trailer Left
#2 - Right Front #4 - Right Rear #6 - First Trailer Right
#7 - Left Dolly #9 - Second Trailer Left
#8 - Right Dolly #10 - Second Trailer Right
FA - Fully Adjusted
Off - Backed Off
* - Conditions meeting CVSA out-of-service criteria

NOTE: All tests were conducted with the ALV bypassed except as noted.

TABLE 12
Doubles Combination High Temperature Test Results

	Key	Initial*** Fully Adj Baseline (ft)	Cool Brake Stops (ft)	1st** Hot Stops (ft)	2nd** Hot Stops (ft)	Final*** Fully Adj Baseline (ft)
Fully Adjusted	A	286		336	348	284
No Fronts, #3-#10FA	* B	287	307	382	384	278
#1-#2FA,#3-#4@2.125", #5-#6,Fa,#7-#8@2.125", #9-#10FA	* C	278	289	351	374	279
#1-#2 FA#3-#6 RA, #7-#9 FA,#10 RA	* D	279	305	388	402	270
#1-#2 @ 1.5", #3-#10 @ 1.75"	E	270	287	346	370	273
#1-#10 RA	* F	273	304	388	412	278

#1 - Left Front #3 - Left Rear #5 - First Trailer Left
#2 - Right Front #4 - Right Rear #6 - First Trailer Right
#7 - Left Dolly #9 - Second Trailer Left
#8 - Right Dolly #10 - Second Trailer Right
FA - Fully Adjusted
RA - At Recomended Readjustment Point
* - Conditions meeting CVSA out-of-service criteria

NOTE: *Average of two stops
**Average of three stops
All tests were conducted with the ALV bypassed except as noted.

APPENDIX E

EVALUATION OF CRITERIA FOR TRUCK AIR BRAKE-ADJUSTMENT

Task E

SUMMARY OF THE ANALYSES

INTRODUCTION

This report describes analyses aimed at:

(1) Assessing the influences of brake-adjustment levels on stopping distance performance;

(2) Evaluating whether being able to stop within the Out-of-Service (OOS) limits at 20 mph is a reliable indicator of being able to stop safely at 60 mph within OOS limits;

(3) Identifying critical adjustment thresholds beyond which heavy vehicles cannot stop within a safe margin;

(4) Identifying key factors contributing to brake OOA for manually adjusted brakes;

(5) Developing statistical measures pertaining to the relationships between the key factors identified and stopping capability; and

(6) Providing a sound quantitative basis for confirming or changing current OOS brake-adjustment criteria.

The analyses use a combination of mechanical principles, experimental findings, and data from field inspections and investigations. Some of the work is based primarily upon mechanical analyses, and some involves statistical treatment of data gathered during inspections. In this sense, this examination of brake-adjustment criteria employs a multidisciplinary approach in which (a) the deterministic aspects of brake system performance are used to relate stopping distance to patterns of brake-adjustment levels and (b) probabilistic associations between key factors and brake-adjustment levels are used to infer relationships between those key factors and stopping capability. The goal of the analyses is to provide information to use in addressing Item (6) above pertaining to developing a quantitative basis for setting satisfactory brake-adjustment levels for OOS criteria.

Before proceeding to summaries of the results of the analyses, the differences between the terms "key factors" and "patterns of adjustment level" need to be distinguished and the relationships between these terms need to be explained.

The Statement of Work for this study frequently uses the term "key factors" in describing the work to be done. This term, as we interpret it, pertains to matters like vehicle configuration (number of trailers and number of axles), type of trucking operation (seasonal, for-hire, heavily-laden vehicles, etc.), the use of rented units, the use of the trailer brake valve, company policies with regard to brake maintenance (training, procedures for determining readjustment cycles, and responsibilities in the organization), the use of special equipment (retarders, automatic slack adjusters, stroke indicators, etc.), severity of service (frequency of severe braking, downhill operation, or stop-and-go delivery), etc. In the context of this study, "key factors" means any of the above matters (plus any other things) that can be determined to be associated with brakes being OOA (particularly at the OOS level) during MCSAP inspections.

A problem in this study has been to obtain tabulated (recorded) information pertaining to the relationship of brake-adjustment to these key factors. To address the relationships between adjustment levels or "patterns of adjustment levels" and key factors, we have obtained and analyzed databases developed by the states of Oregon and Wisconsin. In addition, in mid-November, we obtained a very complete database (for our purposes in this study) from the National Transportation Research Board (NTSB) for a sample of nearly 1,000 trucks. The NTSB data has provided us with information that can be used to compare the stopping capability of vehicles that are OOS with those of vehicles that are non-OOS, thereby providing a means for assessing the ability for OOS criteria to separate vehicles based on the stopping capabilities of the vehicles.

By "patterns of adjustment level" we mean which brakes (by unit, axle, and side) are OOA and the amount of static stroke at each brake. We have performed mechanical analyses relating various patterns of adjustment levels to predicted measures of braking performance. However, with regard to relating patterns of adjustment levels to key factors, we have explored the Oregon, Wisconsin, and NTSB databases to find associations indicated by the available data. Here the connections do not contain the deterministic rigor of mechanical analyses, but rather rely on using statistical techniques to examine the available data. Given the distinctions that we have made here, the patterns of adjustment level will be useful in evaluating the technical adequacy of OOS criteria and the key factors will aid in associating the characteristics of trucking operations with the likelihood that vehicles will have brakes that are OOA.

SUMMARIES OF FINDINGS FROM THE ANALYSES

The findings from the analyses have been assembled in this section to provide an overview of the findings extracted from the detailed presentations of the results supporting these findings. The sections following this one (Sections numbered 1 through 6) present information on the specific results and how they were obtained as well as the findings summarized here.

—On the influences of brake-adjustment levels on stopping distance

(1) The measurement of cold static stroke at 80 psi is much less demanding than measuring cold static stroke at 100 psi. This means, for example, that a stroke that is just at the readjustment point when 80 psi is applied will be approximately 1/8" beyond the readjustment point when 100 psi is applied. The reason for this can be seen by examining the "operating line" due to compliances in the brake superimposed upon the following set of chamber characteristics. (See Figure 1.4.1.) As the pressure is increased from 80 to 100 psi, additional stroke is consumed due to compression of the linings and compliances in the brake actuation system. When MCSAP decided to check stroke at 80 to 90 psi rather than at 100 psi, they could have reduced the readjustment points (1/2 brake demerit level) by approximately 1/8" if they wanted to be as stringent as the 100 psi stroke measurement would require. On the other hand, MCSAP may have desired to make the brake-adjustment criteria less demanding as well as respond to the concern that 100 psi applications may damage the brake system. Either choice seems possible depending upon the sentiments of the decision makers concerning the implications of brake-adjustment with respect to the "service worthiness" of the vehicles permitted to operate on the highway and not be put OOS.

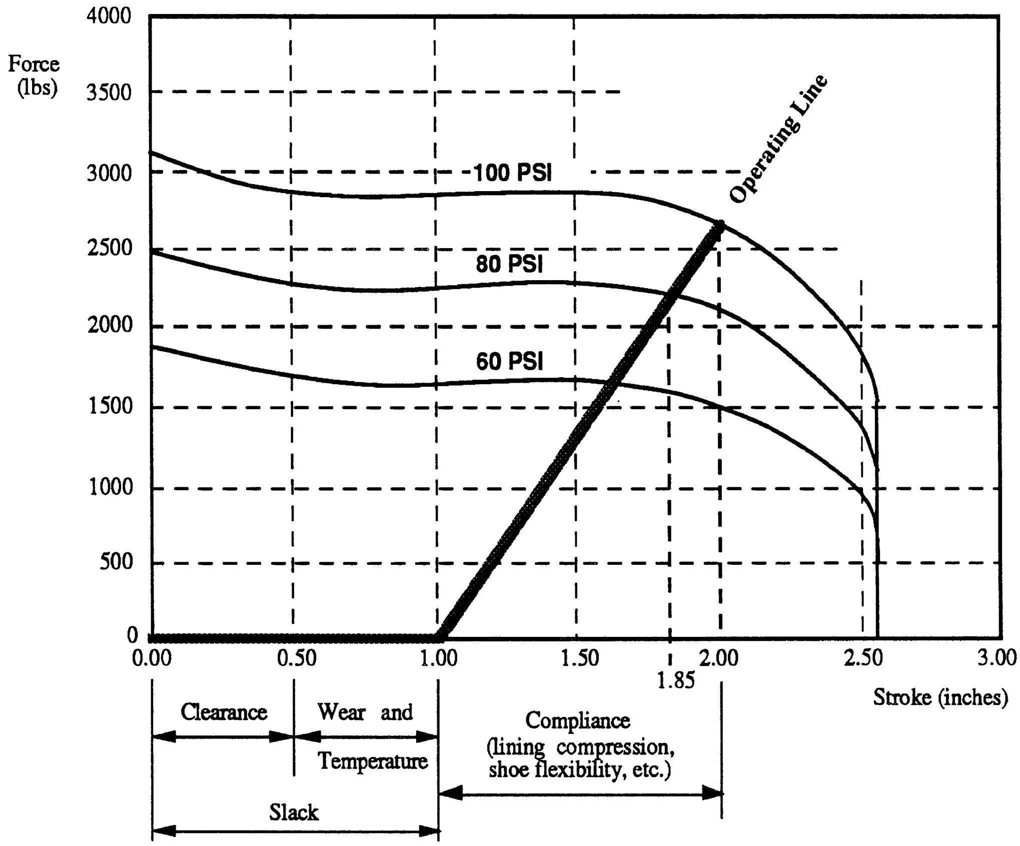


Figure 1.4.1 Operating Line During Braking

(2) The influences of a fully backed-off brake are considerably larger than those of a brake that is 1/8" beyond the one brake demerit level. This is particularly true for changes in stopping distance happening at low temperature levels (70°F and 200°F). This appears to be a situation which could be considered as one warranting a change in the OOS criteria.

Using the terms of Figure 1.4.1, the fully backed-off brake can be easily recognized. Such a brake is defined as one whose slack stroke is equal to the stroke required to reach the bottom of the chamber. Conceivably, such a brake can be identified during inspection relatively easily. With the absence of lining compliance to resist the motion, the stroke of the chamber will increase to the point of bottoming with a relatively small application pressure.

However, since in the course of the testing, the pressure is only applied once, and to 80 to 90 psi, identifying such a backed-off brake is not obvious. The brake inspector cannot easily tell whether a brake has worn to the point where the stroke just bottoms the chamber or if the clearance stroke (slack) is so large that the chamber has bottomed without applying the lining to the drum. (Perhaps the inspector could "ring" (tap) the drum to see if the linings were contacting the drum.) Whether the brake is backed-off or not, the inspector will measure a large stroke less than or equal to that required to bottom the chamber. And, in either case, this indicates poor maintenance and poor brake performance. Perhaps if the OOS criteria were to be changed, the inspector would be expected to apply more than one brake demerit to a brake stroke that was close to the backed-off level of stroke. The results given in Figures 1.3.2 through 1.3.11 provide the information that could form the foundation for a recommendation with regard to the level of brake demerit to use for brakes that are fully backed-off and this level of demerit would be applied to brakes that are close to being fully backed-off. (As indicated in the next item, temperature influences will lower the braking capability of brakes that are close to being backed-off, tending to cause them to approach backed-off brakes.)

(3) The results in general show a significant influence of temperature on the predicted change in stopping distance at various levels of brake-adjustment beyond the readjustment point. Given that temperature has such a large effect on the predicted change in stopping distance, there is an issue concerning the level of temperature to use in comparing and evaluating stopping capabilities. Although one could devise a means for using all of the temperature results to obtain a composite measure of the percentage change in stopping performance, the results at 400°F and 80,000 pounds appear to be representative and satisfactory for use in comparing the influences of brake-adjustment on stopping capability

—On whether being able to stop within the Out-of-Service (OOS) limits at 20 mph is a reliable indicator of being able to stop safely at 60 mph within OOS limits.

(1) The results indicate that percentage changes in stopping distances due to poor brake-adjustment are much larger at 60 mph than at 20 mph. There are two reasons for this. First, the influence of brake timing is much more important at 20 mph than it is at 60 mph. Even though the brake timing in the examples studied meet FMVSS 121 requirements, the maximum available torque is not applied for very long in the 20 mph stop, thereby decreasing the influence of brake-adjustment compared to that during a 60

mph stop. The second reason involves the temperature rise during a stop. This is a very small effect at 20 mph but it is important at 60 mph for OOA brakes that are close to bottoming out. The basic finding from the calculations is that the increase in drum expansion due to temperature rise has an important influence on braking capability for hot poorly adjusted brakes.

(2) The finding above is based upon comparisons with available braking capability at 20 and 60 mph. The following discussion, however, involves the observation that 20 mph stopping distance standards may be set differently than 60 mph standards. For example, if the 20 mph rules were much more stringent than the 60 mph rules (or equivalently, the 60 mph rules were much more lenient), there is a possibility that passing the 20 mph stopping distance requirement would go a long way towards assuring that the vehicle will pass at 60 mph.

In order to examine the differences between stopping from 20 and 60 mph, consider the following simplified example. The current rule for 20 mph is 35 feet for some trucks and 40 feet for longer combinations. (The difference being related to brake timing considerations which will eventually come into play here also.) The basic relationship for estimating stopping distance from deceleration (ignoring or "averaging" the influences of rise times) is as follows:

$$S = V^2/2D$$

where D is the average deceleration
V is the initial velocity
and S is the stopping distance.

According to the above equation, if the deceleration capability of the braking system were to be kept equal, the stopping distance for a 60 mph stop would be nine times that for a 20 mph stop—that is, 315 feet or 360 feet corresponding to 35 or 40 feet.

However, the influences of pressure rise times vary linearly with initial velocity and amount to approximately 12 feet at 20 mph and 35 ft at 60 mph if the average rise time is approximately 0.5 seconds. This means that the 60 mph stop has an advantage over the 20 mph stop when it comes to the contribution of rise time to stopping distance, since 12 feet is a larger fraction of the stopping distance at 20 mph than 35 feet is at 60 mph. For example, if a vehicle stopped in 36 feet from 20 mph, the deceleration capability available would be approximately 0.56 g. If the deceleration available is 0.56 g, a vehicle stopping from 60 mph would be able to stop in approximately 250 feet including 35 feet as an approximation to the contribution due to rise time. The fairly obvious point of this discussion is that being able to pass a 60 mph requirement depends upon not only the braking system but the nature of the 60 mph requirement with respect to the 20 mph requirement.

People setting 60 mph requirements have included the factors discussed above if they have used empirical measurements of stopping distance capability to aid them in establishing the goals. At one time, FMVSS 121 had a 60 mph stopping distance requirement of 293 feet. Given the rough approximations above (i.e., 35 feet due to rise time and neglecting about a 4 percent reduction due to speed loss effects during the rise time), the average deceleration for a 60 mph stop would be approximately 0.47g. The current dynamometer tests in FMVSS 121 require approximately 0.435g which would lead to a stopping distance of approximately 312 feet. So even though the reasons may be vague and obscure, the current implicit FMVSS 121 requirement on stopping distance fits in with the 315 feet derived from equation (1) which neglected not only brake timing matters but also any in-stop fade due to heating of the brake linings or velocity sensitivity of the linings.

(3) The preceding observation needs to be supplemented with other observations for why 20 mph stops are not good indicators of what will happen at 60 mph. The reasons are (1) there are lining materials that are temperature sensitive and the in-stop temperature rise at 60 mph will cause these materials to lose appreciable amounts of torque capability, (2) certain lining materials may have a sliding speed sensitivity that shows up at 60 mph but not at 20 mph, and (3) very good brake timing may compensate for poor adjustment or other braking torque deficiencies at 20 mph but this will not be as effective at 60 mph.

—On critical adjustment thresholds beyond which heavy vehicles cannot stop within a safe margin

(1) The raw material presented in Figures 1.3.2 through 1.3.11 shows that stopping distance versus brake-adjustment results are highly dependent upon temperature conditions and the pressure level at which static stroke is measured as well as the level of adjustment. Although one could consider some composite measure of performance based upon a wide range of initial brake temperatures, vehicle loading conditions and road surface conditions; the analytical work that went into developing the calculations indicates that the influences of brake-adjustment are most important with respect to stopping distance capability in situations involving high temperatures, heavy loads, and high friction at the tire/road interface. The finding here is that it is reasonable to evaluate the influences of brake-adjustment criteria at chosen sets of operating conditions. Examination of the overall results suggests that calculated stopping distances from 60 mph for vehicles laden to the maximum allowable limit are appropriate for examining the influences of various brake-adjustment criteria.

(2) Section 3.3.2 presents a method for adding "backed-off" brakes into a brake "demerit" system like the one used in the current 20 percent OOS criteria. The idea is to augment the current 1/2 brake and 1 brake penalties used in computing the 20 percent factor employed in the OOS criteria. If these levels of brake penalties are viewed as "demerits," a completely misadjusted or backed-off brake could be assigned a demerit value to be used in computing a 20 percent factor that would be based upon the percentage reduction in stopping distance caused by various levels of misadjustment.

The net conclusion reached is that stopping distance discrepancies due to backed off brakes could be reduced if backed off brakes were given a penalty equivalent to at least 1.5 brake demerits. The criteria for calling a brake "backed-off" or "completely misadjusted" would be that the cold static stroke is greater than or equal to 2.5" for a Type 30 chamber. For other types of chambers, an equivalent boundary could be set at the stroke required to reach the bottom of the chamber minus 1/8."

(3) The ideas presented in Section 3.3.3 extend the notion of using brake-adjustment factors like those introduced in Section 3.3.2 for backed-off or

completely misadjusted brakes. In this case, a scheme is presented for using estimated changes in stopping distance to determine OOS. The methodology involves assigning "brake force adjustment factors" to various ranges of brake-adjustment. The results indicate that it would be feasible to estimate changes in stopping capability using this approach although it would require knowledge of "AL" factors (chamber size and slack arm length). Also, the lower torque capabilities of front brakes would also need to be factored into the calculation of stopping capability. Nevertheless, this method would improve the relationship of available stopping capability to OOS criteria for brake-adjustment.

(4) There is already considerable sentiment for simplifying the OOS criteria. The above suggested methods for changing the OOS criteria may not appear to be simple. Nevertheless, they are much simpler than the calculation procedures used in obtaining the results presented in Sections 1 and 2. An issue to be decided is whether it is worthwhile to increase the complexity of the OOS criteria in order to reflect a more uniform relationship to stopping capability.

—On identifying key factors contributing to brake OOA for manually adjusted brakes.

(1) Our review and analysis of existing data on brake-adjustment violations have produced very little information that would document a relationship between hypothesized key factors and brake-adjustment. This result is primarily due to a lack of data on most of the hypothesized factors, and particularly those related to the maintenance practices of the owner/operator. However, three patterns of brake violation were observed that may be a consequence of some of the key factors originally identified. They are:

1. The front axle on tractors is more likely to be OOA, and when there is a brake violation on the front axle of a tractor, most of the time both brakes on the axle are in violation. This finding is consistent with a continuation of the practice of backing off the front axle brakes.

2. Semi-trailers are somewhat more likely to have brake violations than tractors. However, this finding was not as strong as expected, and was not consistent in the two files examined.

3. The rear axle of tandem pairs was more frequently in violation in comparison with the front axle of the pair. This trend was evident on both tractors and semi-trailers.

(2) Compared with the overall rate for brake-adjustment violations for the vehicles inspected in Oregon, intrastate carriers of logs, sand, or ores (one of the categories in their database) are 14 percent overinvolved in brake-adjustment violations. Intrastate carriers of general freight are 10 percent overinvolved. On the other side of the picture, intrastate private, interstate for-hire, and interstate private are all underinvolved in brake-adjustment violations.

(3) The Wisconsin database indicated that for interstate hauls tractor brake violations were 55 percent of the total, while semitrailer violations only represented 35 percent of the total. On the other hand, for intrastate hauls tractors represented 31 percent and semitrailers represented 48 percent of the total. With regard to the location of brake violations, it was found that if one brake on an axle was OOA, the other brake on the axle was also likely to be OOA. For example, for trailers, both brakes on an axle were out of adjustment in 47 percent of the cases, while 21 percent of the left side brakes and 26 percent of the right side brakes were OOA alone. In general, there were slightly more violations for the right side brakes than for the left side brakes for tractors and semitrailers.

—On developing statistical measures pertaining to the relationships between the key factors identified and stopping capability.

(1) Given that brake-adjustment can be related to stopping capability, it suffices to develop relationships between key factors and OOA levels. The NTSB data set provides information that can be used to develop statistical associations between levels of OOA and the factors entered into the NTSB database. The factors studied in these analyses include automatic versus manual slack adjusters, engine brakes (retarders) versus no retarder, carrier type, tractor model year, trailer model year, axle number and location, cargo body type, and tractor make and cab style.

(2) The findings in the areas listed above are as follows. Automatic slack adjusters do very well at reducing the number of brakes that are more than

1/4" beyond the readjustment point (one defective brake by the OOS criteria). Vehicles with engine brakes tend to have better levels of brake-adjustment than vehicles without retarders. There is only a slight difference between private and for-hire vehicles with regard to brake-adjustment levels in the NTSB database. In situations where the driver is responsible for brake-adjustment, the drivers appear to do as well as the maintenance people in maintaining brake-adjustment. Tractors with a model year before 1986 have much higher rates of defective brakes per the brake-adjustment criteria. For trailers, there was no particular trend to the proportion of OOA brakes by model year. The results for axle location were that the rear tandem drive axle is more likely to be OOA and that trailer axles are more likely to be OOA than tractor axles. The differences found between different cargo body types are not great, but the tank vehicles had the lowest percentage of brakes that were properly adjusted. And, the differences between cab-over and conventional cab styles was not great, although the conventionals had a greater percentage of properly adjusted brakes than the cab-overs did.

—On providing a sound quantitative basis for confirming or changing current OOS brake-adjustment criteria.

(1) Only the NTSB data have the potential to provide an objective evaluation of the brake-adjustment OOS criterion. This is the only source of information that includes actual slack measurements on all brakes: those that were not in violation as well as those that were. No state was found that recorded information on brakes that were *not* in violation. In addition, the NTSB data include the chamber size, which is essential for relating the slack measurement to the OOA criteria. The detail in the NTSB data is sufficient to support calculation of approximate measures of stopping performance. One such measure is the braking efficiency computed by NTSB. Comparing distributions of braking for trucks that were OOS to those that were not OOS provides a way of quantifying the way in which the current OOS criteria distinguishes the trucks that are inspected. These distributions show some overlap. Some trucks that are put OOS have higher braking efficiencies than some that were not, and vice versa. Of course, calculation of the braking efficiency of each truck inspected is probably too complicated to be part of a MCSAP vehicle inspection procedure. However, simple modifications and/or extensions of the existing criteria could be evaluated

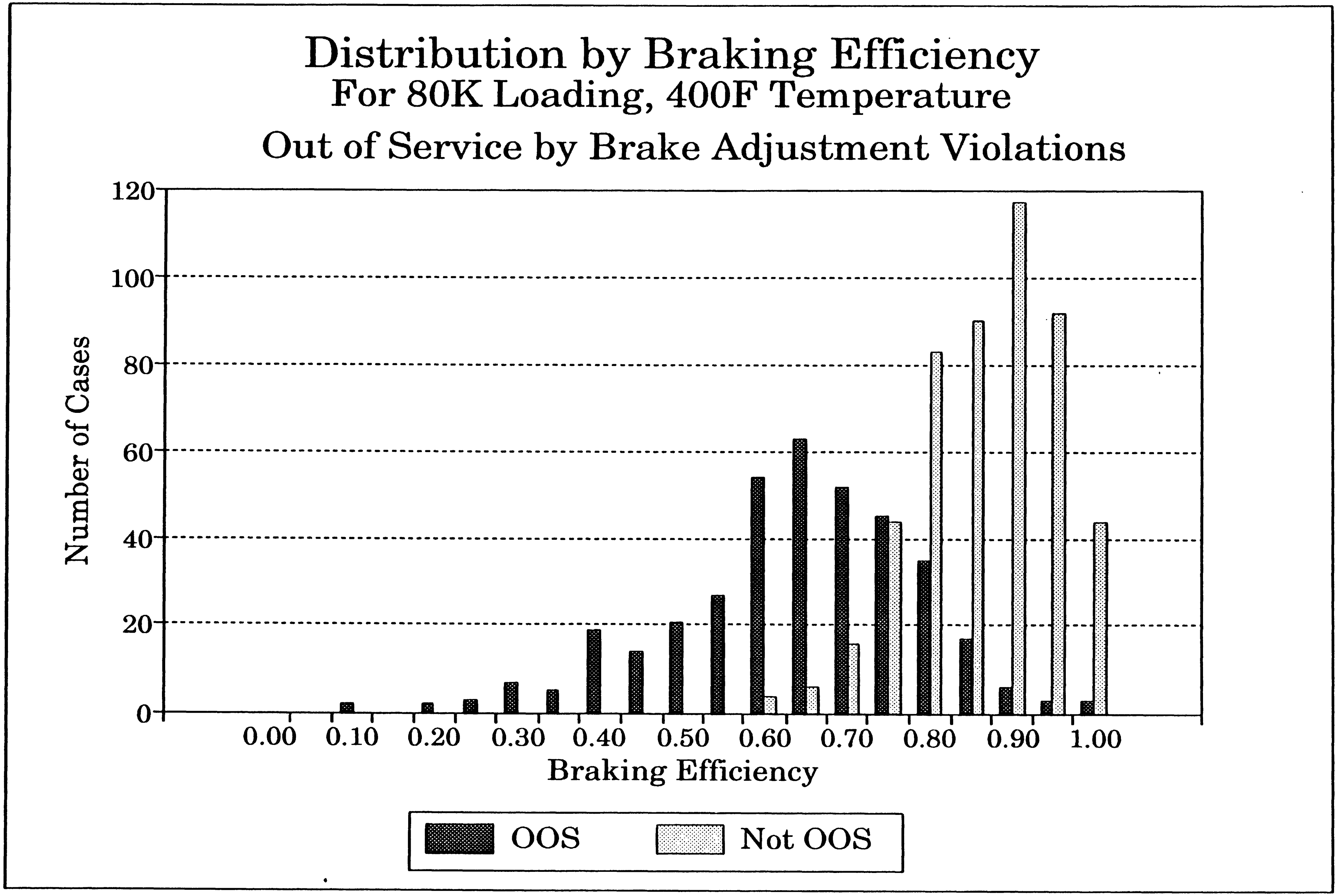
using the NTSB data. The effect of different criteria on the distributions of braking efficiency for OOS trucks and non-OOS trucks could be calculated from the actual slack measurements in the NTSB file.

(2) Providing a sound, quantitative basis for confirming or changing the OOS criteria is a primary goal of this project. The results obtained using the NTSB data show that the current system of assigning brake demerits for computing the "20 percent" criteria provides a reasonable separation (in terms of NTSB's calculations for braking efficiency or braking drag) between vehicles that are OOS and those that are not.

(3) We propose that further calculations be made in order to evaluate other OOS criteria suggested by this study. These calculations would employ the stopping distance factors derived in this study (and described in Section 3 of this report) in connection with the inspection database containing the NTSB data. Frequency distributions (histograms) comparing OOS vehicles under each proposed criteria would be constructed. This would provide the basis for judgments concerning the ability of various proposed OOS criteria to separate vehicles according to their stopping capabilities.

(4) The following figure shows the separation and overlap between OOS and not-OOS vehicles obtained for the vehicles inspected by NTSB. These results are labelled 80K loading and 400°F to indicate that the braking efficiencies are calculated for the vehicle if it were loaded to 80,000 pounds. and the initial brake temperatures were 400°F. As indicated previously in these summary statements, this form and type of data presentation illustrates the ability of the current OOS criteria to separate vehicles by stopping capability.

This concludes an initial summary of the findings of the analyses. Further development of findings and recommendations regarding the appropriateness of OOS brake-adjustment criteria will be presented in the Interim Report. Task F entitled, "Evaluate OOS Brake Criteria" will be completed using the information and data presented in the following sections of this report.


Distribution by Braking Efficiency
For 80K Loading, 400F Temperature
Out of Service by Brake Adjustment Violations
Number of Cases
0
20
40
60
80
100
120
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Braking Efficiency
OOS
Not OOS

1.0 THE INFLUENCES OF BRAKE-ADJUSTMENT LEVELS ON STOPPING DISTANCE

1.1 Introduction

This section describes the results of analyses aimed at assessing the influences of brake-adjustment levels on stopping distance performance. The purpose of these analyses is to provide information to be used later in evaluating the appropriateness of OOS brake-adjustment criteria for heavy trucks.

1.2 Brief Description of the Types of Analyses Performed

The analyses consisted of predictions of brake torque capabilities and stopping distance performance from 60 mph. Calculations were made for 3, 5, and 9 axle trucks (6, 10, and 18 brakes) at selected combinations of brake-adjustment levels as listed in the following table:

TABLE 1.2.1 — Combinations of Brake-adjustment Levels

Case	Combination	Description
Case 1	FA	• All brakes are fully adjusted
Case 2	All RA-1/8"	• All brakes stroke 1/8" before the readjustment point
Case 3	20% RA+1/8"	• Some brakes are at half-brake demerit level (enough to constitute 20% OOS). The strokes of those brakes are 1/8" beyond the readjustment point.
Case 4	20% RA+3/8"	• Some brakes are at 1 brake demerit level (enough to constitute 20% OOS). The strokes of those brakes are 3/8" beyond the readjustment point.
Case 5	1 Backed-off	• One brake is completely backed-off so that it does not generate any braking torque.

For these cases, all the brakes whose adjustment levels were not prescribed, were taken to be fully adjusted (FA). In addition, for the 3- and 5-axle trucks, a supplementary set of combinations was defined as Cases 3',4', and 5'. For these cases, the brakes which were previously FA, were set to be RA-1/8". Each of the above stroke level measurements was simulated to be taken under static, cold conditions (70°F).

Since the stroke measurement depends upon the prevailing pressure in the system as regulated by the treadle valve, each of the above strokes was treated as if they were measured under 80 and 100 psi applications. Some cases were also studied with the cold static stroke being measured at 85 and 90 psi. The pressure at which the static stroke is evaluated, is an important factor in assessing the braking performance of a truck, since for a given truck with a given brake-adjustment status, different strokes will be measured for different pressures. This point and its implications on the leniency of the process employed in checking brake-adjustment will be further emphasized later.

During braking, the friction between the drum and the lining generates heat that in turn, causes the drum to expand. In addition, in many cases, the initial temperature of the drum is hotter than 70°F. The more the drum expands, the larger the required stroke becomes, thus creating some additional "virtual" misadjustment level. This means that the chamber pushrod needs to be further extended before the lining is brought in contact with the drum. Brake chamber characteristics need to be considered in studying this phenomenon. As shown in Figure 1.2.1, when the push-rod goes beyond a certain level, it starts bottoming-out. An increasing portion of the total input force is lost against the chamber walls, leaving a decreasing portion of that force to generate braking torque.

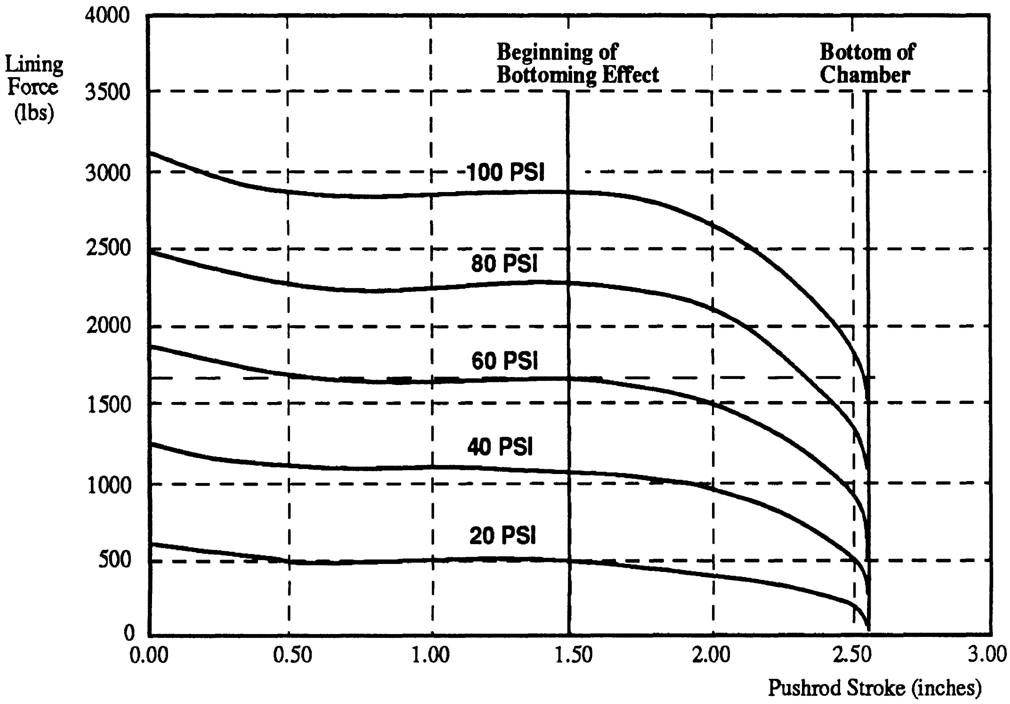


Figure 1.2.1. Chamber Type 30 Characteristics

The influence of temperature on the static stroke of chambers Type 30 and 20 is shown in Figures 1.2.2 and 1.2.3. It should be noted that the manner according to which the stroke (as measured at the chamber pushrod) changes with temperature (that causes the drum to expand), depends upon the mechanical advantage of the linkage between the lining and the chamber. The following Figures, therefore, relate to specific layouts of a front brake (15" drum and 5.5" slack arm) and a rear brake (16.5" drum and 6" slack arm).

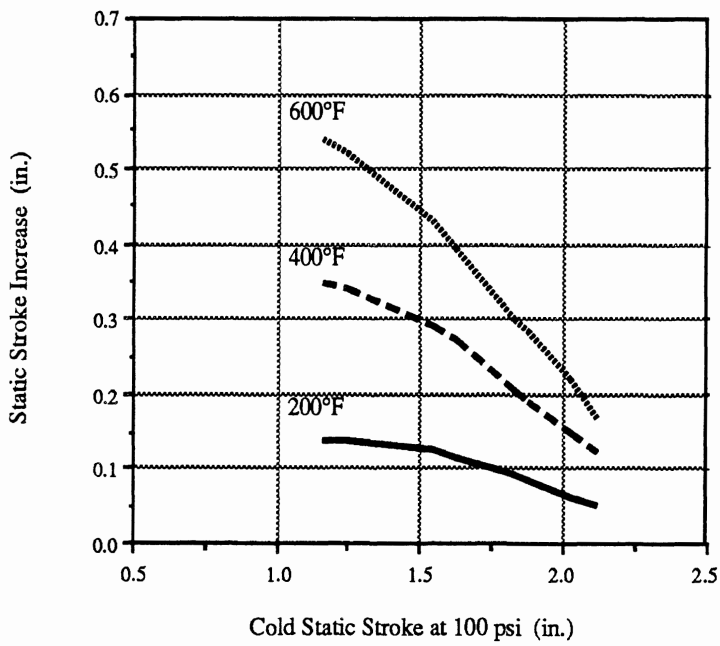


Fig. 1.2.2 Increase in Static Stroke of Chamber Type 20 due to Temperature

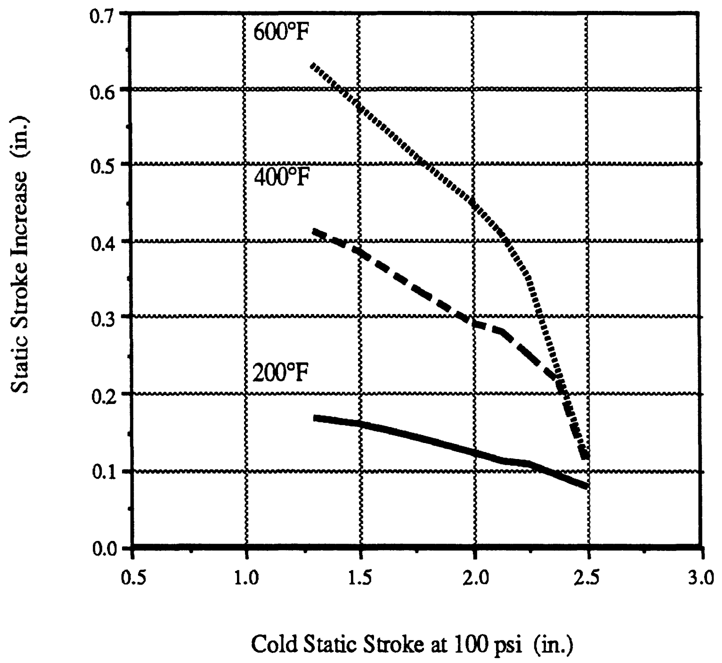


Fig. 1.2.3 Increase in Static Stroke of Chamber Type 30 due to Temperature

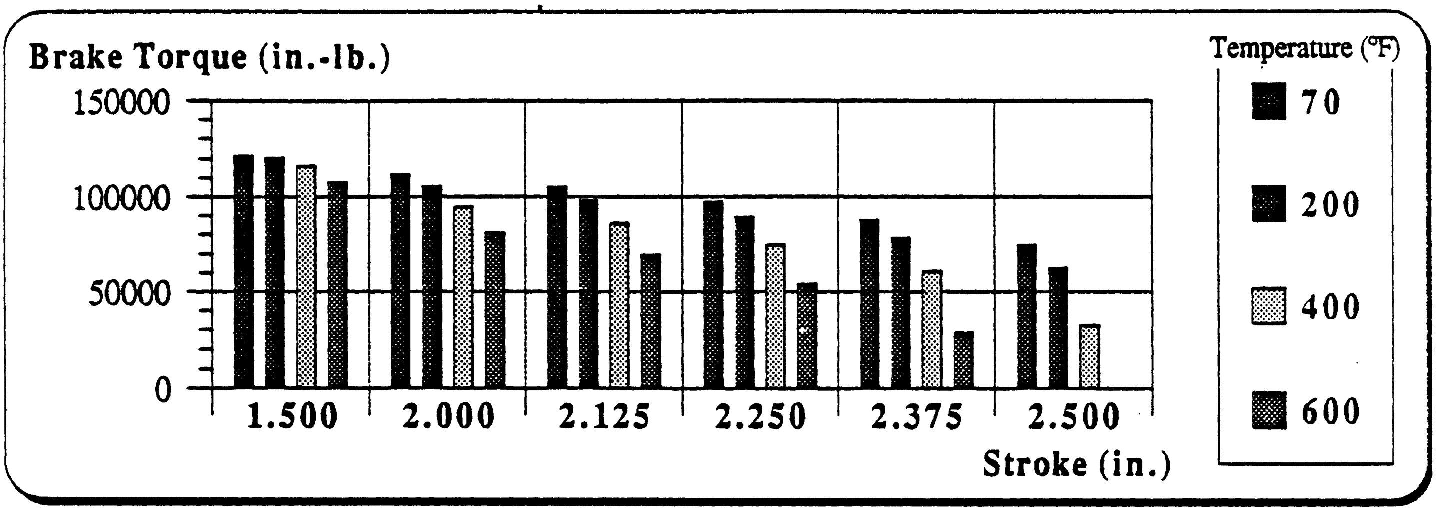
In an emergency stop, when maximum braking capacity is required, such temperature induced stroke variations are vital considerations in assessing the braking performance of the truck. Calculations were made for an emergency stop (application of the full 100 psi) at various initial brake temperatures, and the following discussion of the results and findings demonstrates the importance of temperature induced stroke variations. In general, higher brake temperatures mean poorer performance and longer stopping distance.

3. Concise Summary of the Results

Braking torque values that a brake can produce under different adjustment levels were used as an evaluating tool for the braking capacity at a particular adjustment state. Figure 1.3.1 shows the variations in such a braking capacity for a typical rear axle brake with Chamber Type 30, drum of 16.5" diameter, and 6" slack arm. The torque values are in pounds at a 100 psi braking application. The dramatic loss of braking capability as the static stroke increases can be easily seen. Since the "wall" of the chamber is at about 2.6" of stroke, the stroke cannot surpass 2.6". If the stroke required to "close" the clearance between the lining and the drum is higher than 2.6", contact will not be accomplished and no torque can be generated. Such is the case when the cold static stroke is 2.5". When heated to 600°F, the brake generates zero torque — drum expansion leads to a required stroke larger than 2.6".

Brake Torque as a Function of Temperature and Static Stroke

Temp. \ Cold Static Stroke	1.500	2.000	2.125	2.250	2.375	2.500
70	121434	111575	105091	97344	87950	74468
200	120362	105415	98047	89366	78202	62675
400	116209	94212	85805	74487	60603	32510
600	107752	80736	69315	54010	28738	0



Percent Drop in Torque as a Function of Temperature and Static Stroke

Temp. \ Cold Static Stroke	1.500	2.000	2.125	2.250	2.375	2.500
70	0	8	13	20	28	39
200	1	13	19	26	36	48
400	4	22	29	39	50	73
600	11	34	43	56	76	100

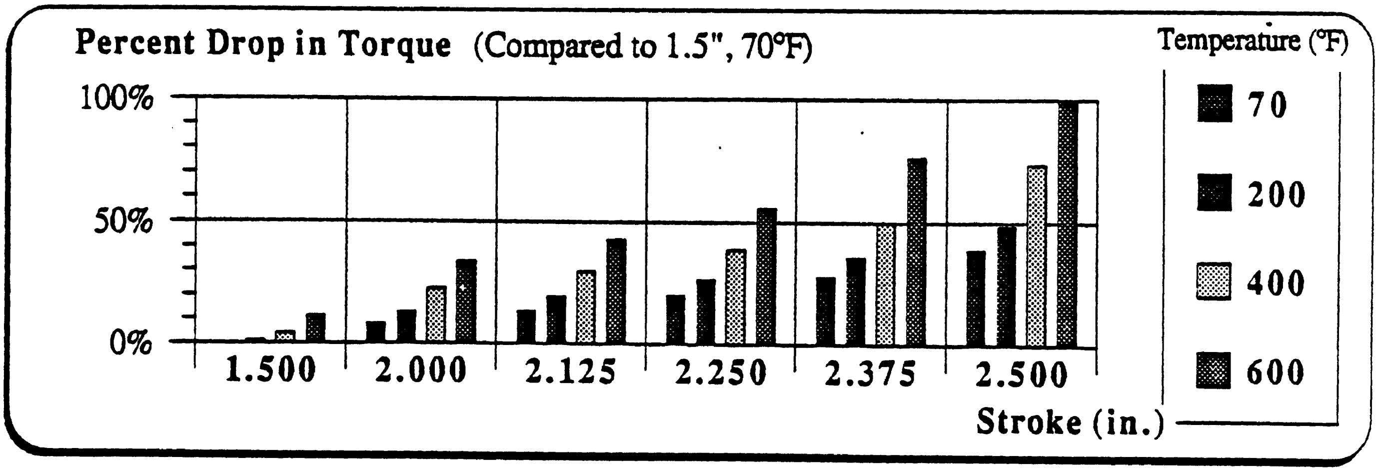


Figure 1.3.1. Influence of Stroke and Temperature on Braking Torque.

It should be noted that the braking torque variations given in Figure 1.3.1 are for a static application. No heat is generated as the brakes are applied. If it were to be a dynamic stop with in-stop generation of heat, the losses would increase. It should also be pointed out that such an in-stop heat generation will be larger at the "tighter" levels of adjustment (closer to FA) than at the more "loosely" adjusted brakes. That is due to the fact that the less the brake is adjusted (that is, the greater the clearance stroke), the less is the force transmitted to the lining, hence generating less heat.

The following Figures 1.3.2 through 1.3.11 show the influence of brake-adjustment (as measured at different pressure levels) and initial brake temperature on the stopping distance of 3-, 5-, and 9-axle trucks.

For the purposes of this study, variations in stopping distance due to different adjustment states and temperatures are the substantial outputs. Therefore, in the following Figures, although the upper tables and graphs give an estimate of the braking performance in the sense of stopping distance, the lower portion provides the percentage change in stopping distance which is a more meaningful measure to work with in comparing the influences of various levels of brake-adjustment. Variations are more noticeable when compared by percentages than by comparing absolute values.

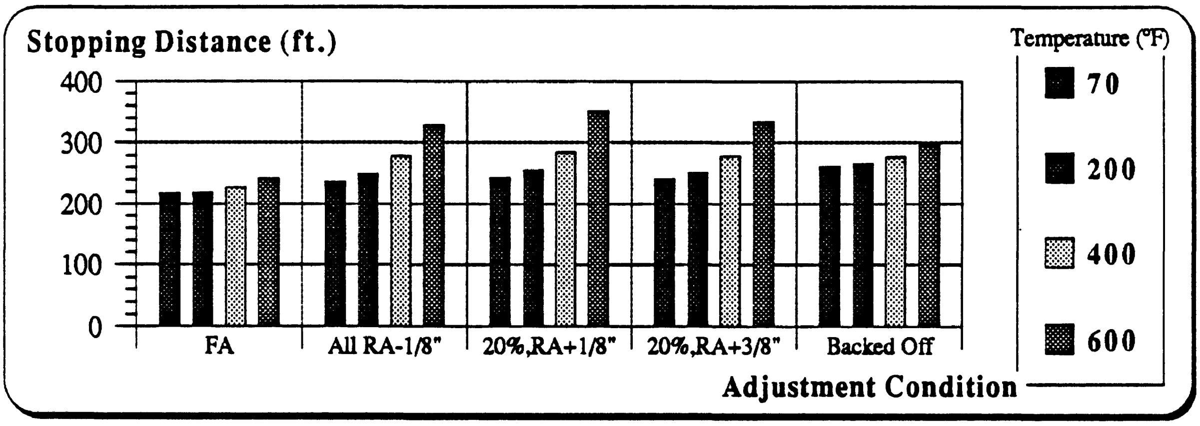
Some observations concerning the results given in the Figures:

- When clearance is measured at 100 psi, there is almost no difference between the various combinations leading to 20 percent OOS. The values of percentage change in stopping distance under the two 20 percent columns in Figures 1.3.9 through 1.3.11 are rather compatible. As the measuring pressure drops, it becomes more and more noticeable that RA+1/8" and RA+3/8" cannot be equally counted towards the 20 percent OOS failure criteria. The degradation in stopping ability of a truck with 40 percent of its brakes at an adjustment level of RA+1/8" (which constitutes 20 percent OOS since each of these is at half a brake demerit), is not the same as for a truck with 20 percent of its brakes at an adjustment level of RA+3/8" (which also constitutes 20 percent OOS since each of these is at a full brake demerit). Generally speaking, the first one (40 percent at half a brake demerit each) is the worst between the two.

- Clearly, the more axles there are, the smaller is the effect of <u>one backed off brake</u> on the braking performance. The 3-axle truck lost 21 percent of its braking capacity

Stopping Distances (60mph) of a 3 Axle Truck With Various Adjustment Conditions (Measured at 80 psi) as a Function of Temperature

Temp. \ Adjustment Case	Case1 FA	Case 2 All RA-1/8"	Case 3 20%,RA+1/8"	Case 4 20%,RA+3/8"	Case 5 Backed Off
70	217	237	244	241	262
200	219	249	256	251	266
400	227	278	285	279	277
600	242	328	351	334	297



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	Case1 FA	Case 2 All RA-1/8"	Case 3 20%,RA+1/8"	Case 4 20%,RA+3/8"	Case 5 Backed Off
70	0	9	12	11	21
200	1	15	18	16	23
400	5	28	31	29	28
600	12	51	62	54	37

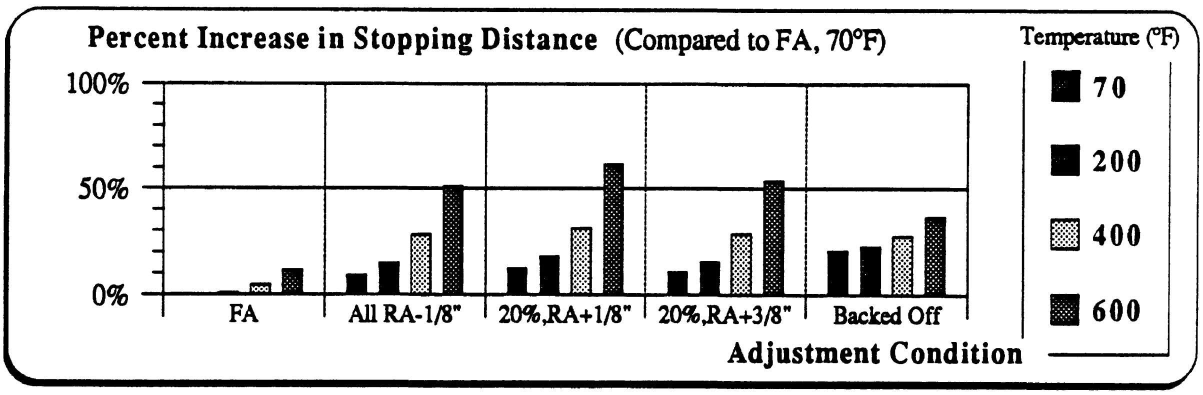
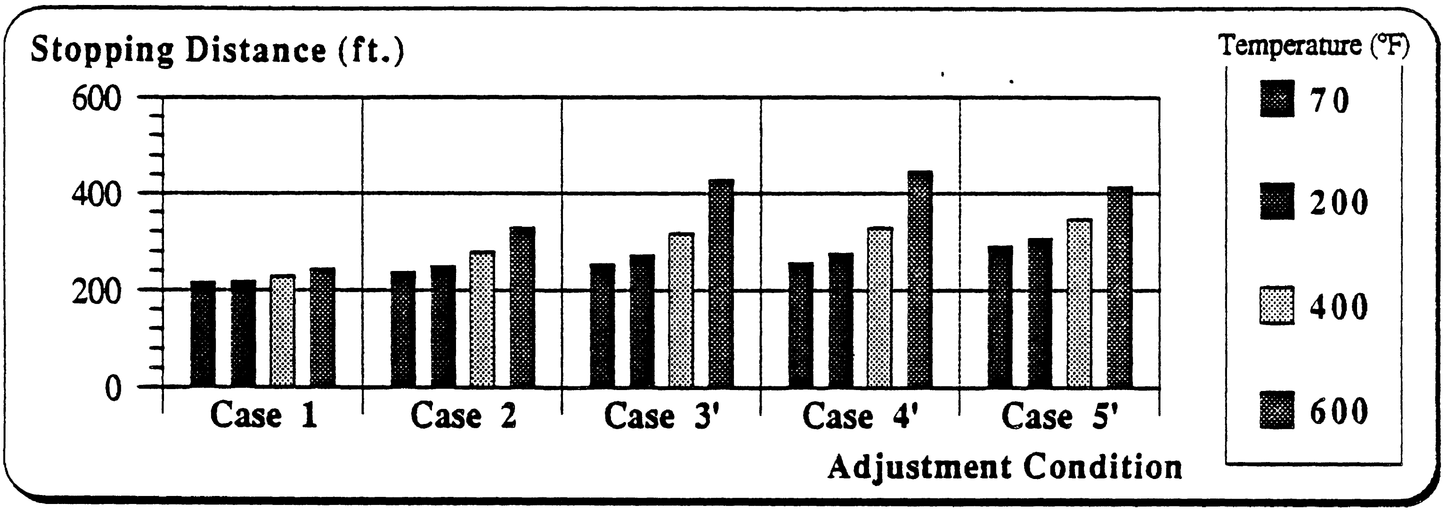


Figure 1.3.2. Influence of adjustment and temperature on the stopping distance of a 3 axle truck at 60 mph.

Stopping Distances (60mph) of a 3 Axle Truck With Various Adjustment Conditions (Measured at 80 psi) as a Function of Temperature

Temp. \ Adjustment Case	Case 1	Case 2	Case 3'	Case 4'	Case 5'
70	217	237	253	256	290
200	219	249	271	275	306
400	227	278	316	328	345
600	242	328	427	444	412



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	Case 2	Case 3'	Case 4'	Case 5'
70	9	17	18	34
200	15	25	27	41
400	28	46	51	59
600	51	97	105	90

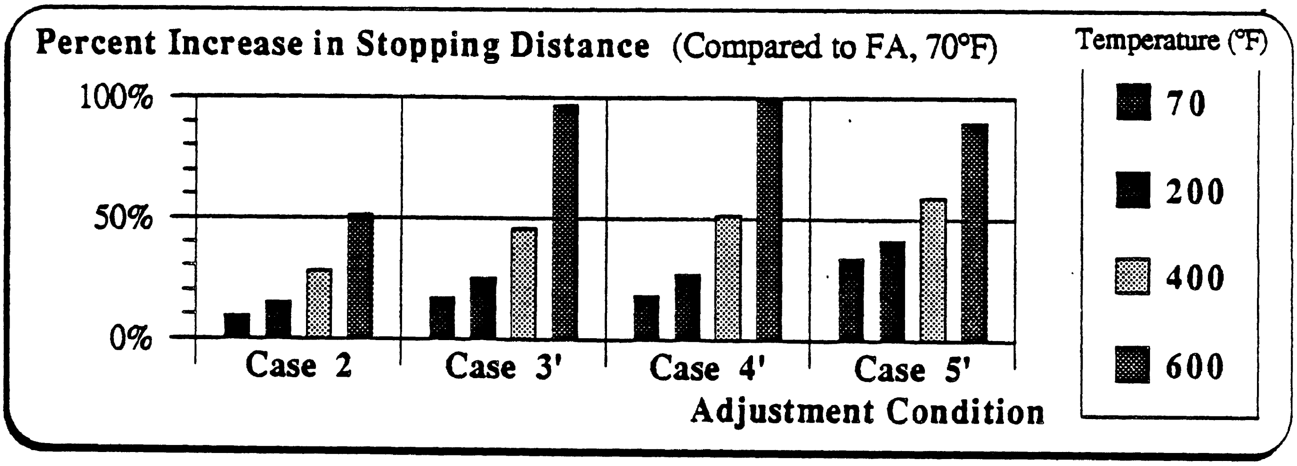
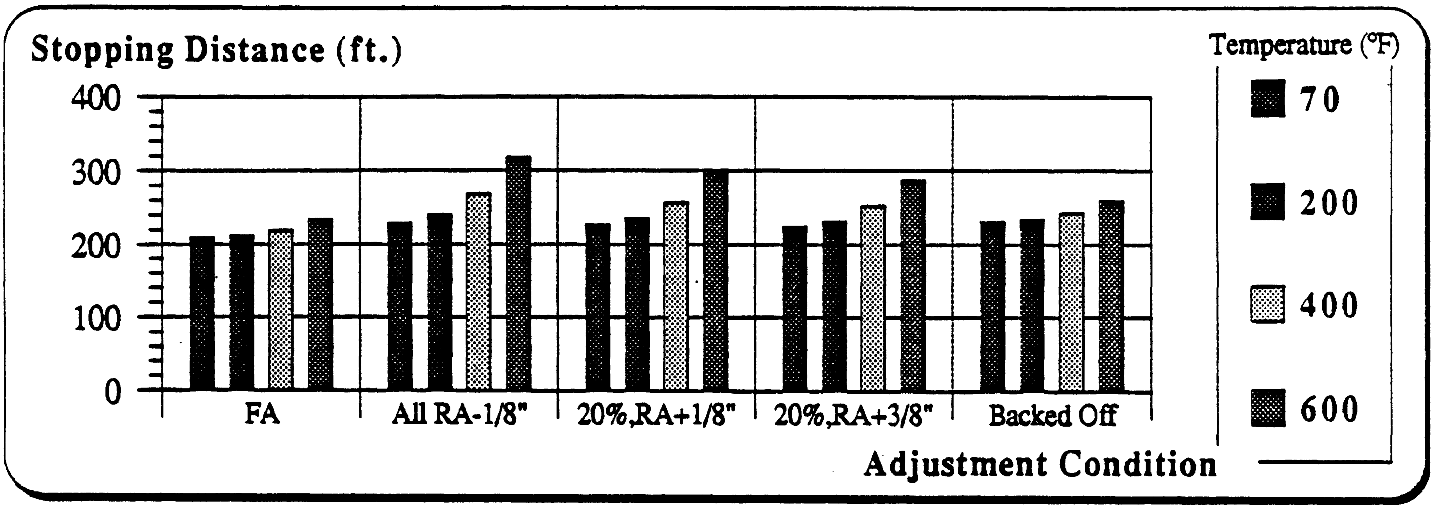


Figure 1.3.3. Influence of Adjustment and Temperature on the Stopping Distance of a 3 Axle Truck at 60 mph (modified adjustment cases).

Stopping Distances (60mph) of a 5 Axle Truck With Various Adjustment Conditions (Measured at 80 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	209	229	227	225	231
200	212	241	236	231	234
400	219	269	257	252	243
600	234	318	301	288	260



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	10	9	8	11
200	1	15	13	11	12
400	5	29	23	21	16
600	12	52	44	38	24

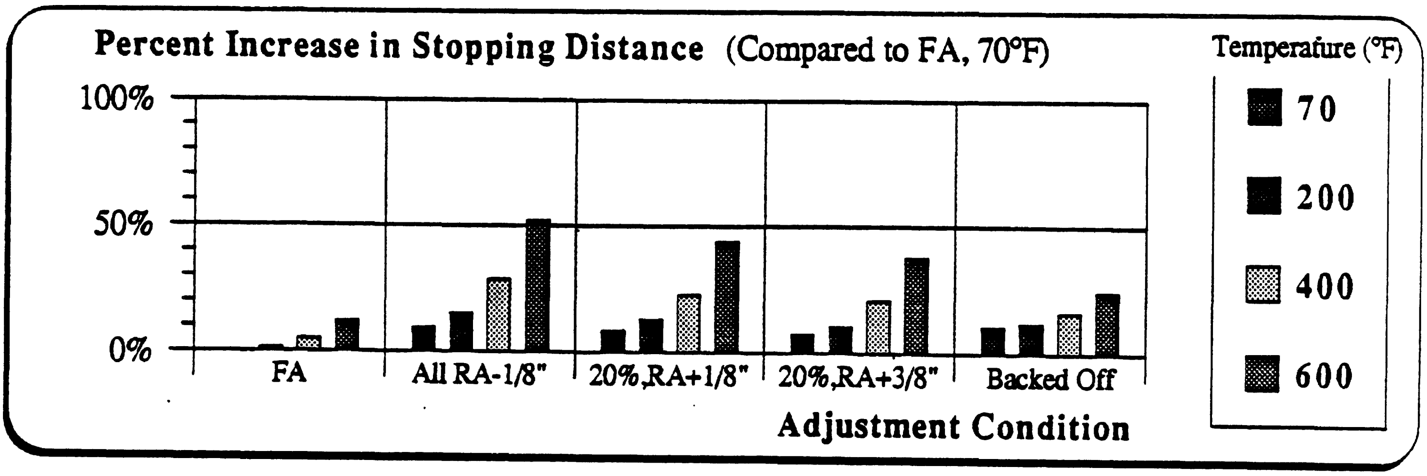
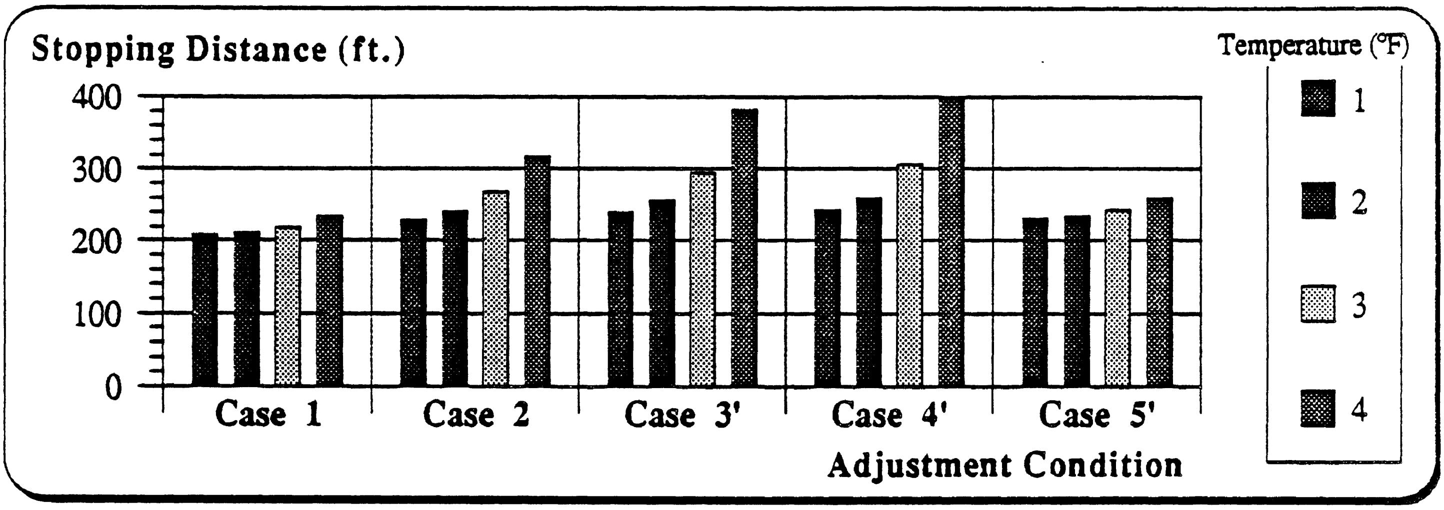


Figure 1.3.4. Influence of Adjustment and Temperature on the Stopping Distance of a 5 Axle Truck at 60 mph .

Stopping Distances (60mph) of a 5 Axle Truck With Various Adjustment Conditions (Measured at 80 psi) as a Function of Temperature

Temp. \ Adjustment Case	Case 1	Case 2	Case 3'	Case 4'	Case 5'
70	209	229	240	243	231
200	212	241	256	260	234
400	219	269	295	306	243
600	234	318	382	399	260



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	Case 2	Case 3'	Case 4'	Case 5'
70	10	15	16	11
200	15	22	24	12
400	29	41	46	16
600	52	83	91	24

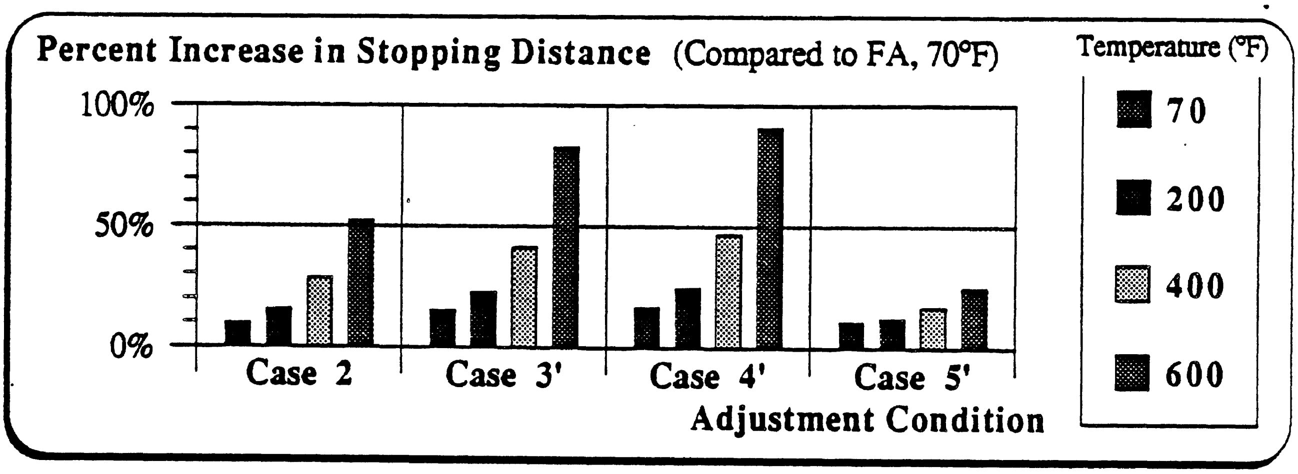
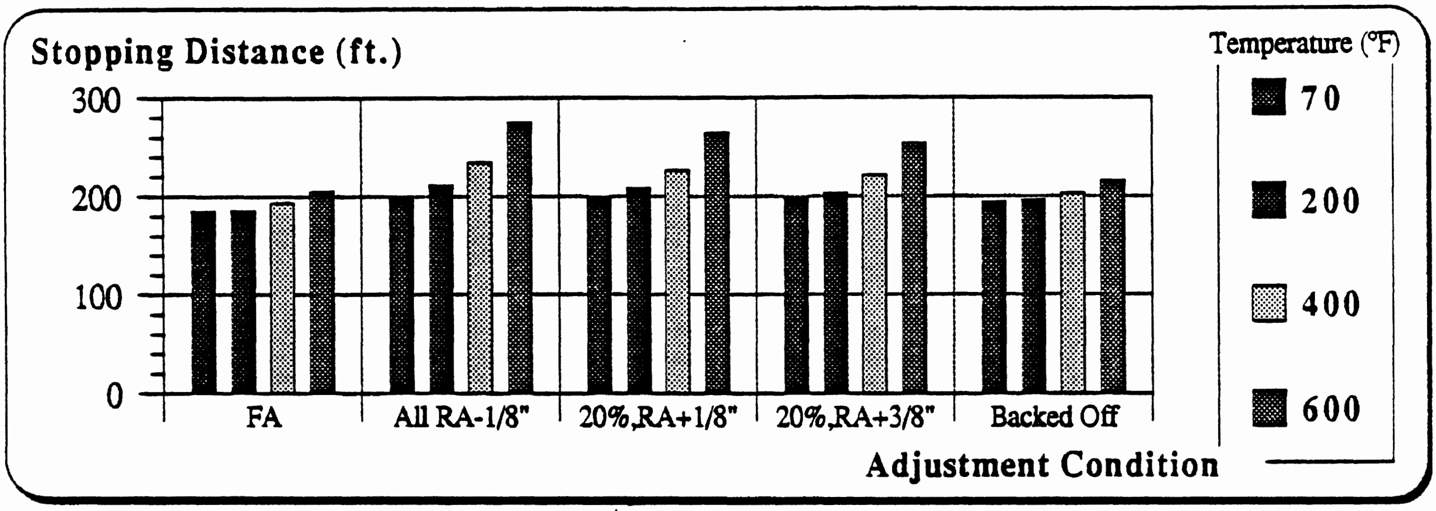


Figure 1.3.5. Influence of Adjustment and Temperature on the Stopping Distance of a 5 Axle Truck at 60 mph (modified adjustment cases).

Stopping Distances (60mph) of a 9 Axle Truck With Various Adjustment Conditions (Measured at 80 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	185	201	200	198	194
200	186	211	208	204	196
400	193	234	226	222	203
600	205	275	264	254	216



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	9	8	7	5
200	1	14	12	10	6
400	4	26	22	20	10
600	11	49	43	37	17

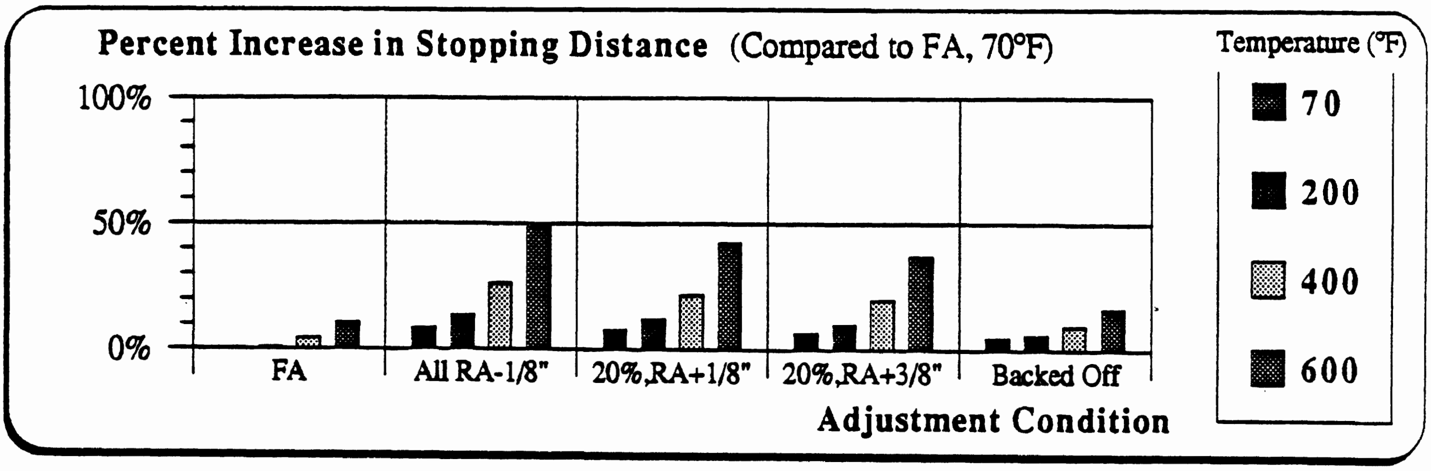
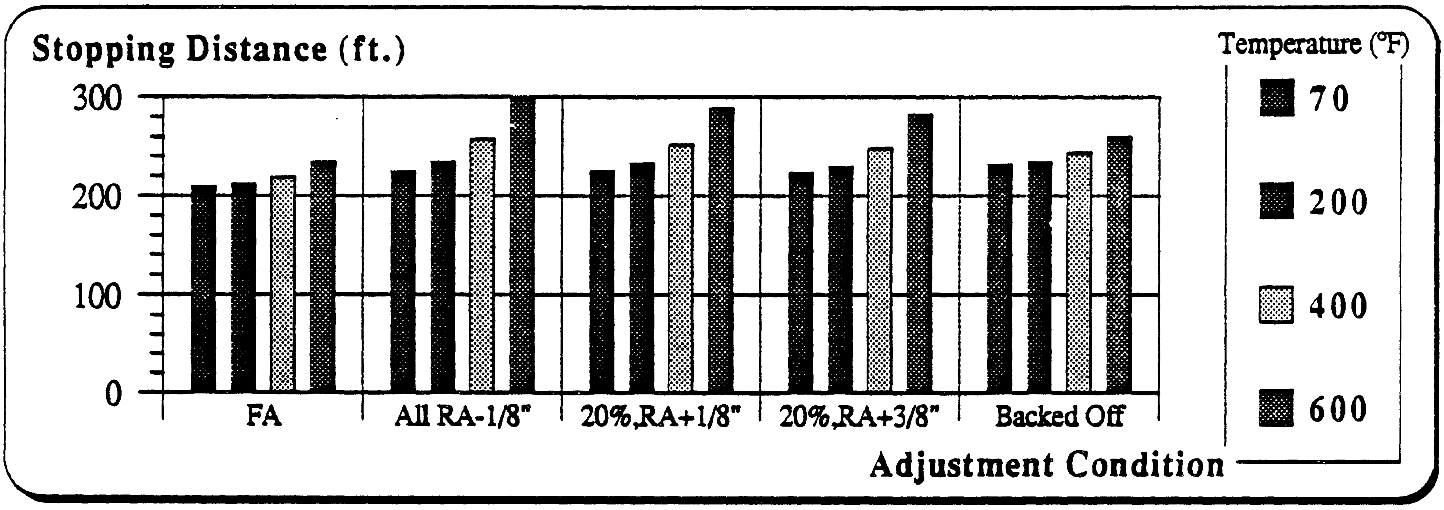


Figure 1.3.6. Influence of Adjustment and Temperature on the Stopping Distance of a 9 Axle Truck at 60 mph .

Stopping Distances (60mph) of a 5 Axle Truck With Various Adjustment Conditions (Measured at 90 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	209	224	225	223	231
200	212	234	233	229	234
400	219	258	252	248	243
600	234	298	289	282	260



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	7	7	7	11
200	1	12	11	10	12
400	5	23	20	19	16
600	12	42	38	35	24

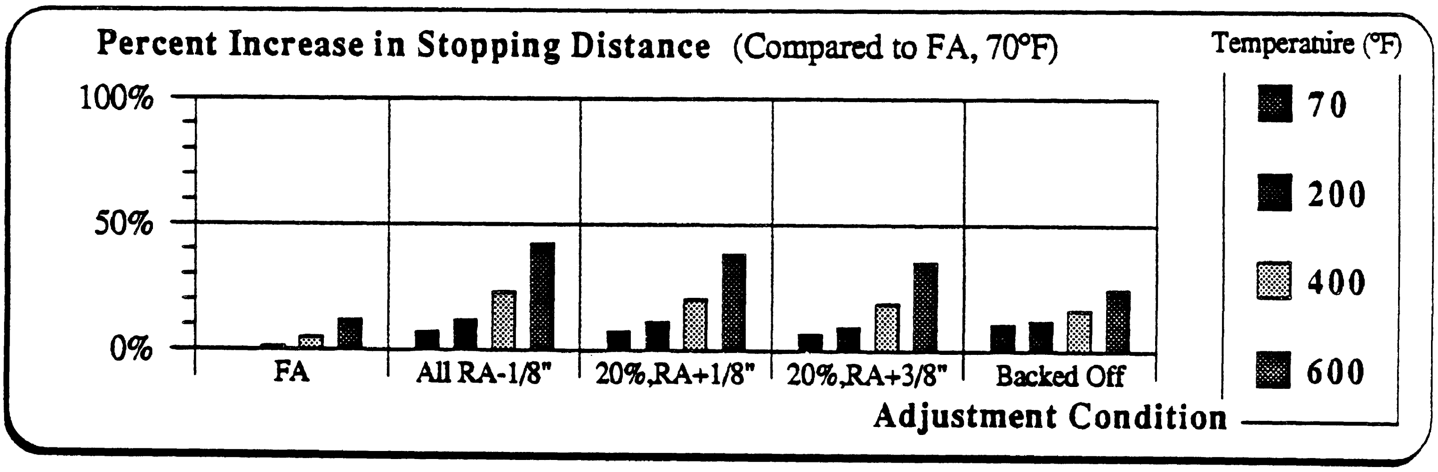
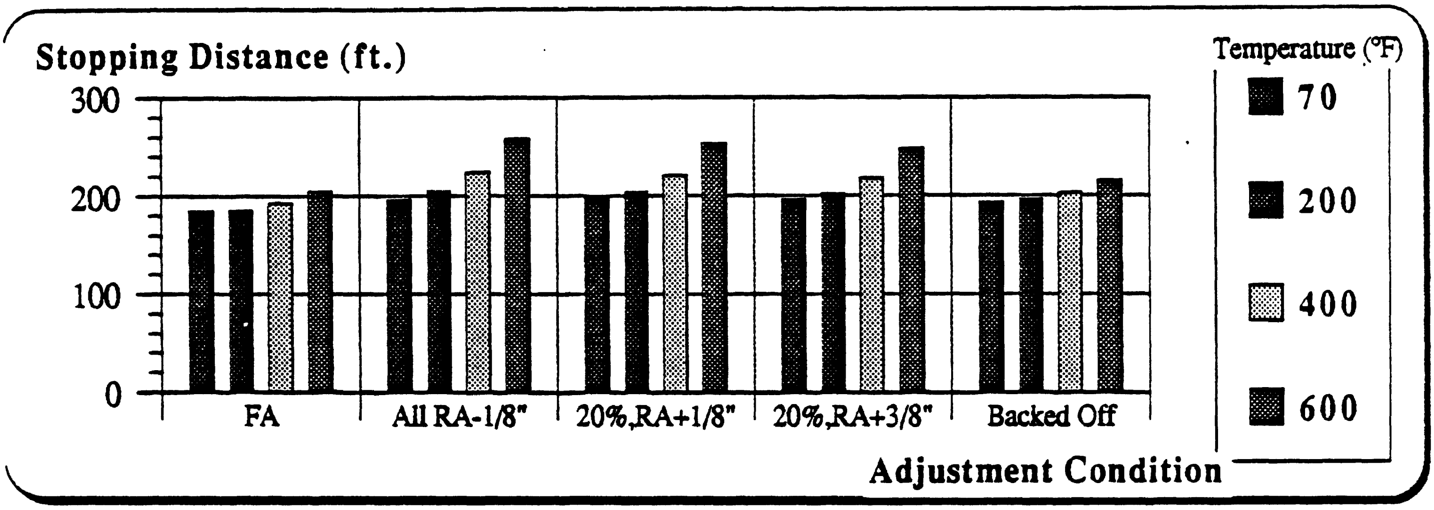


Figure 1.3.7. Influence of Adjustment and Temperature on the Stopping Distance of a 5 Axle Truck at 60 mph .

Stopping Distances (60mph) of a 9 Axle Truck With Various Adjustment Conditions (Measured at 90 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	185	197	198	197	194
200	186	205	205	202	196
400	193	225	221	218	203
600	205	258	253	249	216



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	6	7	6	5
200	1	11	11	9	6
400	4	21	19	18	10
600	11	39	37	34	17

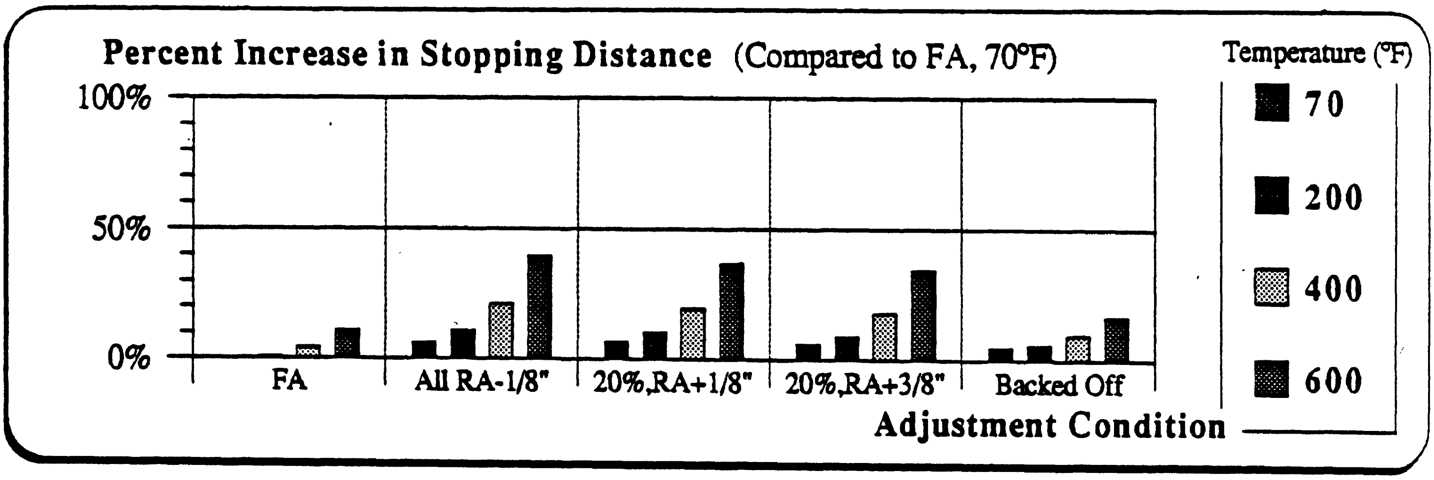
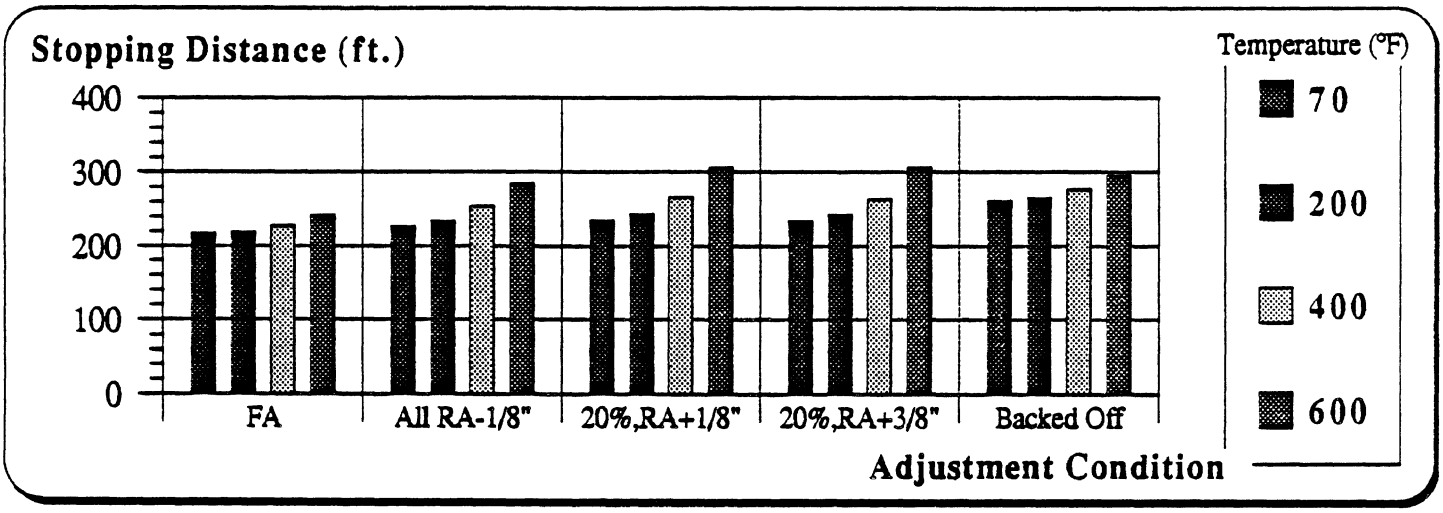


Figure 1.3.8. Influence of Adjustment and Temperature on the Stopping Distance of a 9 Axle Truck at 60 mph .

Stopping Distances (60mph) of a 3 Axle Truck With Various Adjustment Conditions (Measured at 100 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	217	226	235	234	262
200	219	234	244	243	266
400	227	254	267	264	277
600	242	285	306	306	297



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	4	8	8	21
200	1	8	12	12	23
400	5	17	23	22	28
600	12	31	41	41	37

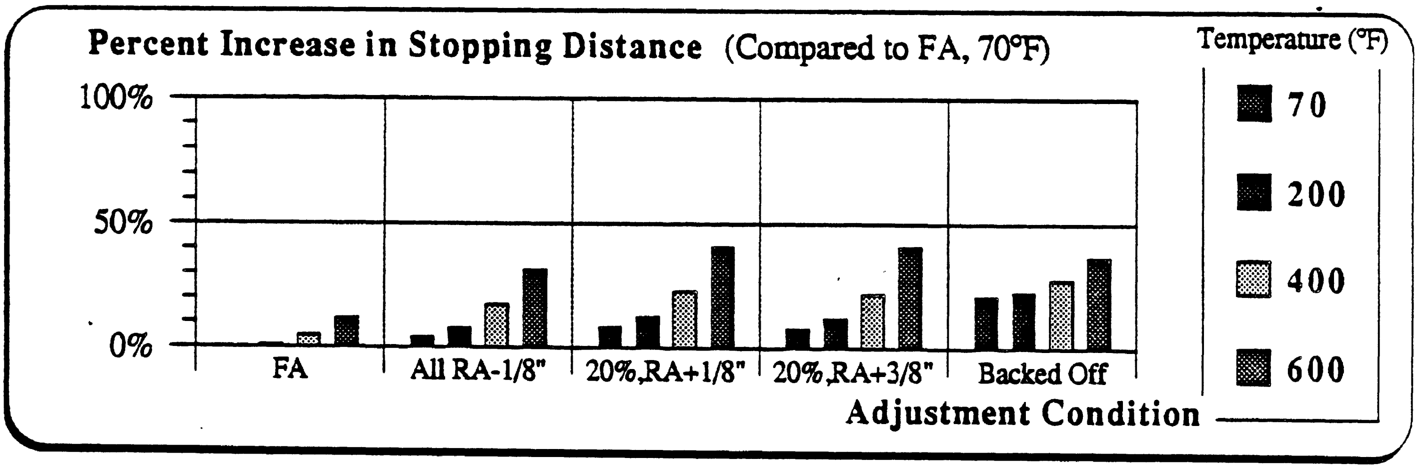
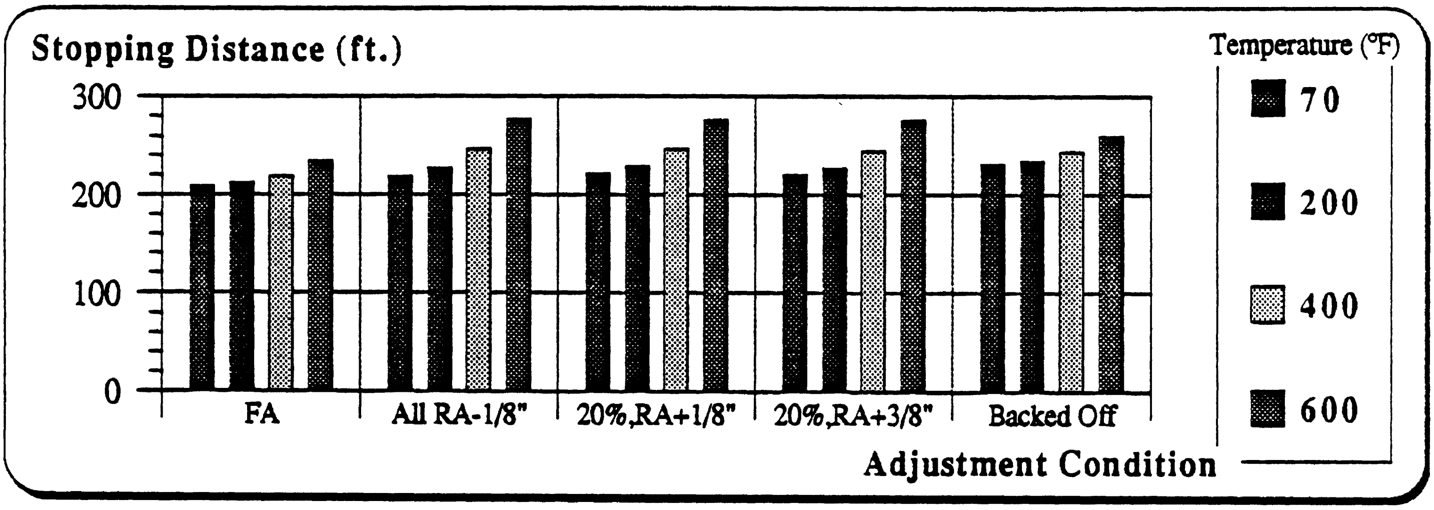


Figure 1.3.9. Influence of Adjustment and Temperature on the Stopping Distance of a 3 Axle Truck at 60 mph .

Stopping Distances (60mph) of a 5 Axle Truck With Various Adjustment Conditions (Measured at 100 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	209	219	222	221	231
200	212	227	229	227	234
400	219	246	246	244	243
600	234	277	276	276	260



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	5	6	6	11
200	1	9	10	9	12
400	5	18	18	17	16
600	12	33	32	32	24

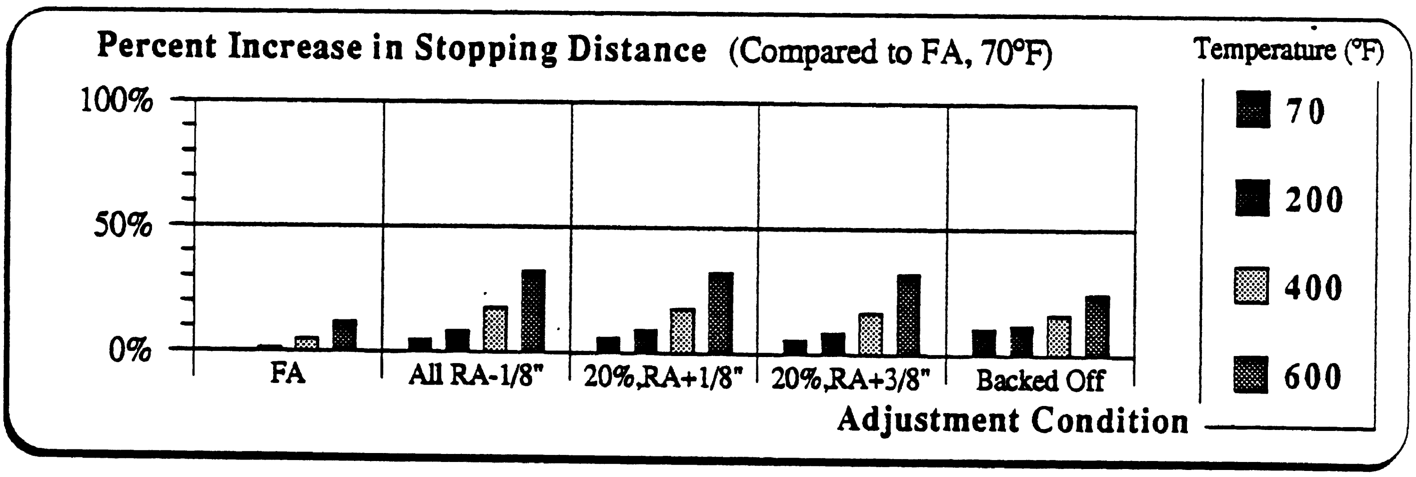
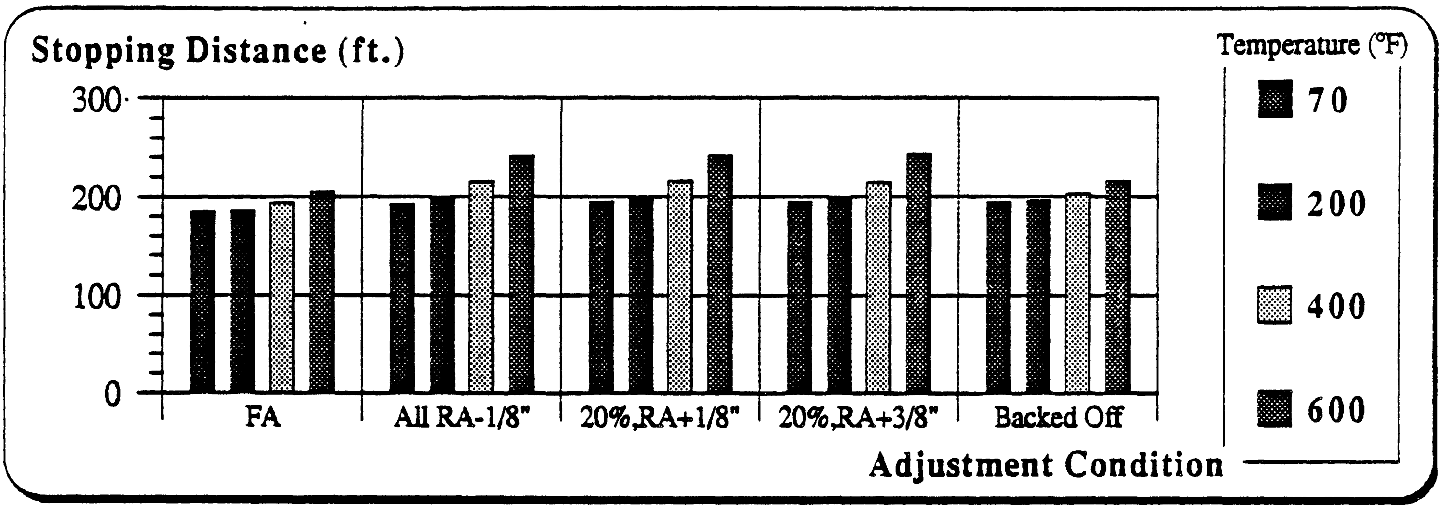


Figure 1.3.10. Influence of Adjustment and Temperature on the Stopping Distance of a 5 Axle Truck at 60 mph .

Stopping Distances (60mph) of a 9 Axle Truck With Various Adjustment Conditions (Measured at 100 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	185	192	195	195	194
200	186	199	201	200	196
400	193	215	216	214	203
600	205	241	242	243	216



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	4	5	5	5
200	1	8	9	8	6
400	4	16	17	16	10
600	11	30	31	31	17

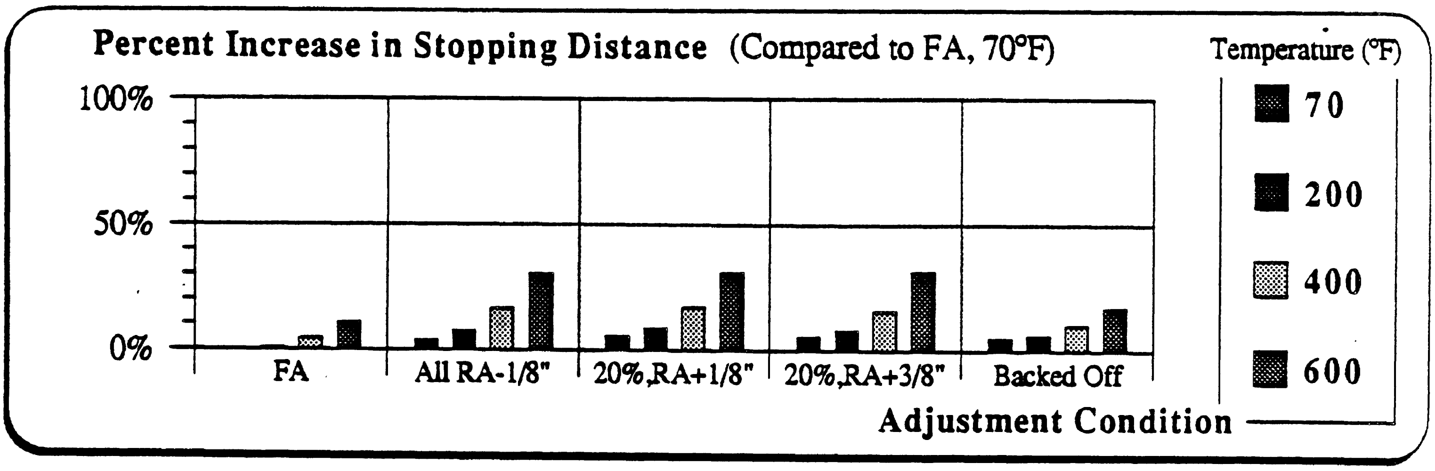


Figure 1.3.11. Influence of Adjustment and Temperature on the Stopping Distance of a 9 Axle Truck at 60 mph .

(increased braking distance at 70°F, Figure 1.3.2), the 5-axle truck lost 11 percent (Figure 1.3.4), and the 9-axle truck lost only 5 percent (Figure 1.3.6) due to the backed- off brake.

•Throughout the configurations and cases studied (except for the "prime" cases - 3', 4', 5'), categorization of adequately adjusted trucks and ones that are OOA according to the present rules, could not be rationalized for the pathological cases examined. (To some extent, this is to be expected since the cases were selected with the idea that they would challenge the OOS criteria).

The 20 percent OOS rule did not work well in the cases studied for the 3-axle truck (Figure 1.3.2). At 70°F, Cases 3 and 4 are defined as out of service, but they are only slightly worst than Case 2 which is considered adjusted (12 and 11 percent increased stopping distance versus 9 percent). This small margin is maintained throughout the temperature range.

The acuteness of the discrepancy in stopping capability grows with the number of axles and even results in reversed categorization. Examination of the 5-axle truck results (Figure 1.3.4), shows that Case 2 (RA-1/8") performs poorer than the two OOS cases (10 percent increased stopping distance versus only 9 and 8 percent), but it will still be passed. A similar situation exists for the 9-axle truck. On the other hand, if the adjustment status of the truck is as defined by the "prime" cases (3', 4', 5'), the 20 percent OOS rule can be considered adequate. For the 3-axle truck (Figure 1.3.3), Cases 3' and 4' are significantly poorer at 17 and 18 percent than Case 2 at only 9 percent increased stopping distance. For the 5-axle truck (Figure 1.3.5), the 20 percent OOS rule serves equally well. Cases 3' and 4' take 15 and 16 percent more to stop, significantly more than 10 percent for Case 2 which just passes.

Perhaps Cases 3' and 4' are more representative of vehicles in-service than Cases 3 and 4 because vehicles with mixes of fully-adjusted and misadjusted brakes might not occur frequently in service. Clearly, data from in-service vehicles are needed to address the issue.

•When a brake is completely backed-off in a 3-axle truck, by itself it will not cause it to be defined as OOS even though it degraded its braking performance more than any 20 percent OOS adjustment combination (Figure. 1.3.3). That fact might motivate counting a backed-off brake as more than one brake demerit. In that figure, it is interesting to observe the temperature influence: Up to and including 400°F, Case 5' was worse than Cases 3' and 4'. At 600°F, since there were more OOA brakes in Cases 3' and 4' than in Case 5', the expansion of the drums caused more chambers to "bottom" in 3' and 4', therefore, these cases performed poorer than 5' at 600°F. The influence of a single completely backed-off brake decreases with the number of axles. Its influence is most significant in Case 5' of a 3-axle truck (Figure 1.3.3), but is much smaller in the same case (5') with the 5-axle truck (Figure 1.3.5).

- The use of a pressure which is lower than 100 psi to examine the adjustment status of a truck while maintaining the same pass/fail criteria levels will result in allowing trucks with poorer braking performance on the road. That fact also serves as a "magnifying glass" to distinguish between different cases. The results of the 5-axle truck can demonstrate the point. In Figure 1.3.10, under 100 psi test pressure, Cases 2 through 4 are almost the same (70°F) at 5, 6, and 6 percent degradation in braking performance. Reading the same strokes under 80 psi, Figure 1.3.4 shows a worse level of performance: 10, 9, and 8 percent degradation while the differences between the cases were magnified. At a higher temperature level, that phenomenon is more noticeable. At 600°F, under 100 psi, the degradation in braking performance for Cases 2, 3, 4 were 18, 18, and 17 percent, respectively. On the other hand, under 80 psi with the same conditions and stroke readings, the degradation in braking performance for those cases were 52, 44, and 38 percent. Clearly, if emergency braking is required, the truck that was inspected under 80 psi will perform significantly poorer than a similar vehicle tested under 100 psi. It should be emphasized that the above is true only if the stroke levels that determine OOS adjustment status are kept the same for both cases.

1.4. Findings and Observations

1.4.1 The measurement of cold static stroke at 80 psi is much less demanding than measuring cold static stroke at 100 psi. This means, for example, that a stroke that is just at the readjustment point when 80 psi is applied will be approximately 1/8" beyond the readjustment point when 100 psi is applied. The reason for this can be seen by examining the "operating line" due to compliances in the brake superimposed upon the following set of chamber characteristics. (See Figure 1.4.1) As the pressure is increased from 80 to 100 psi, additional stroke is consumed due to compression of the linings and compliances in the brake actuation system. When MCSAP decided to check stroke at 80 to 90 psi rather than at 100 psi, they could have reduced the readjustment points (1/2 brake demerit level) by approximately 1/8" if they wanted to be as stringent as the 100 psi stroke measurement would require. On the other hand, MCSAP may have desired to make the brake-adjustment criteria less demanding as well as respond to the concern that 100 psi applications may damage the brake system. Either choice seems possible depending upon the sentiments of the decision makers concerning the implications of brake-adjustment with respect to the "service worthiness" of the vehicles permitted to operate on the highway and not be put OOS.

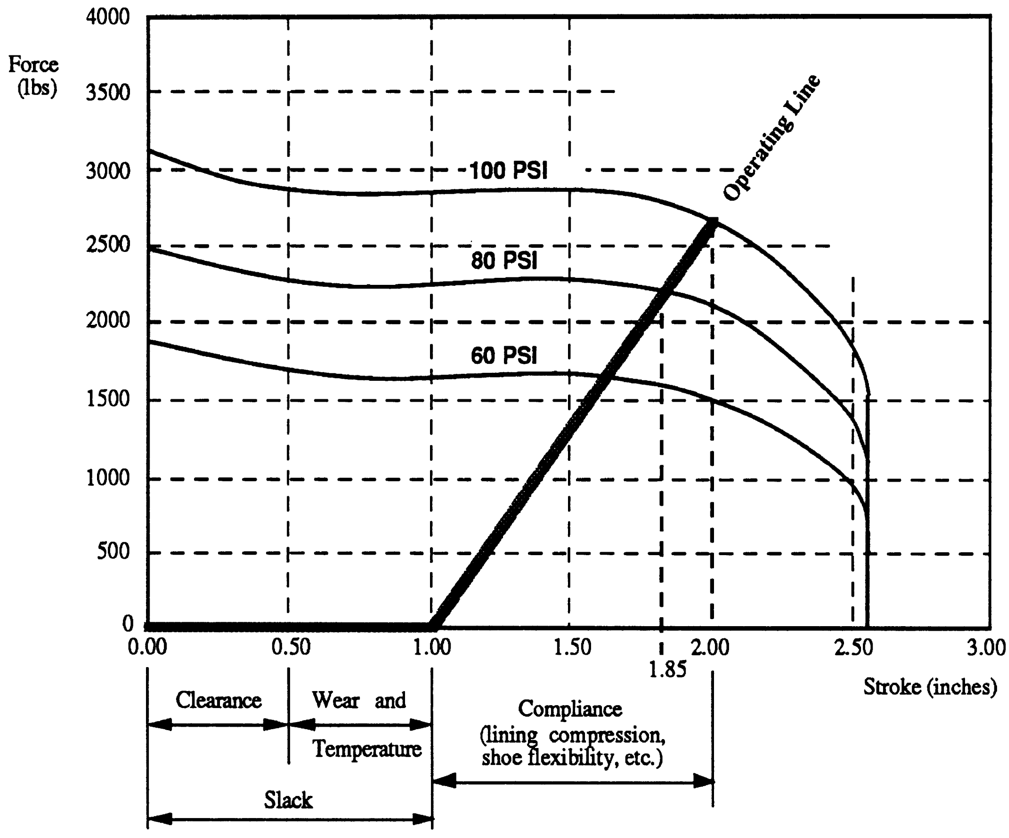


Figure 1.4.1 Operating Line During Braking

1.4.2 The influences of a fully backed-off brake are considerably larger than those of a brake that is 1/8" beyond the one brake demerit level. This is particularly true for changes in stopping distance happening at low temperature levels (70°F and 200°F). This appears to be a situation which could be considered as one warranting a change in the OOS criteria.

Using the terms of Figure 1.4.1, the fully backed-off brake can be easily recognized. Such a brake is defined as one whose slack stroke is equal to the stroke required to reach the bottom of the chamber. Conceivably, such a brake can be identified during inspection relatively easily. With the absence of lining compliance to resist the motion, the stroke of the chamber will increase to the point of bottoming with a relatively small application pressure.

However, since in the course of the testing the pressure is only applied once, and to 80 to 90 psi, identifying a backed-off brake is not obvious. The brake inspector cannot easily tell whether a brake has worn to the point where the stroke just bottoms the chamber or if the clearance stroke (slack) is so large that the chamber has bottomed without applying the lining to the drum. (Perhaps the inspector could "ring" (tap) the drum to see if the linings were contacting the drum.) Whether the brake is backed-off or not, the inspector will measure a large stroke less than or equal to that required to bottom the chamber. And, in either case, this indicates poor maintenance and poor brake performance. Perhaps, if the OOS criteria were to be changed, the inspector would be expected to apply more than one brake demerit to a brake stroke that was close to the backed-off level of stroke. The results given in Figures 1.3.2 through 1.3.11 provide the information that could form the foundation for a recommendation with regard to the level of brake demerit to use for brakes that are fully backed-off and this level of demerit would be applied to brakes that are close to being fully backed-off. (As indicated in the next item, temperature influences will lower the braking capability of brakes that are close to being backed-off, tending to cause them to approach backed-off brakes.)

1.4.3 The results in general show a significant influence of temperature on the predicted change in stopping distance at various levels of brake-adjustment beyond the readjustment point. Given that temperature has such a large effect on the predicted change in stopping distance, there is an issue concerning the level of temperature to use in comparing and evaluating stopping capabilities. Although one could devise a means for using all of the temperature results to obtain a composite measure of the percentage change in stopping performance, the results at 400°F and 80,000 pounds appear to be representative and satisfactory for use in comparing the influences of brake-adjustment on stopping distance.

2.0 WHETHER BEING ABLE TO STOP WITHIN OUT-OF-SERVICE LIMITS AT 20 MPH IS A RELIABLE INDICATOR OF BEING ABLE TO STOP SAFELY AT 60 MPH WITHIN OOS LIMITS

2.1 Introduction

This section describes the results of analyses and observations aimed at evaluating whether being able to stop within OOS limits at 20 mph is a reliable indicator of being able to stop safely at 60 mph within OOS limits.

2.2 Brief Description of the Types of the Calculations Performed

The analyses consist of predictions of stopping distance performance from 20 mph using vehicles and levels of brake-adjustment that are comparable to those used in some of the calculations of stopping performance from 60 mph. (See the previous section.) Calculations were made for a 20 mph stop at various levels of brake-adjustment for the following combinations of vehicles types :

- 3-axle truck—With the cold static stroke measured at 80 and 100 psi (See Figures 2.2.1 and 2.2.2)
- 5-axle truck—With the cold static stroke measured at 80, 90, and 100 psi (See Figures 2.2.3, 2.2.4, and 2.2.5)

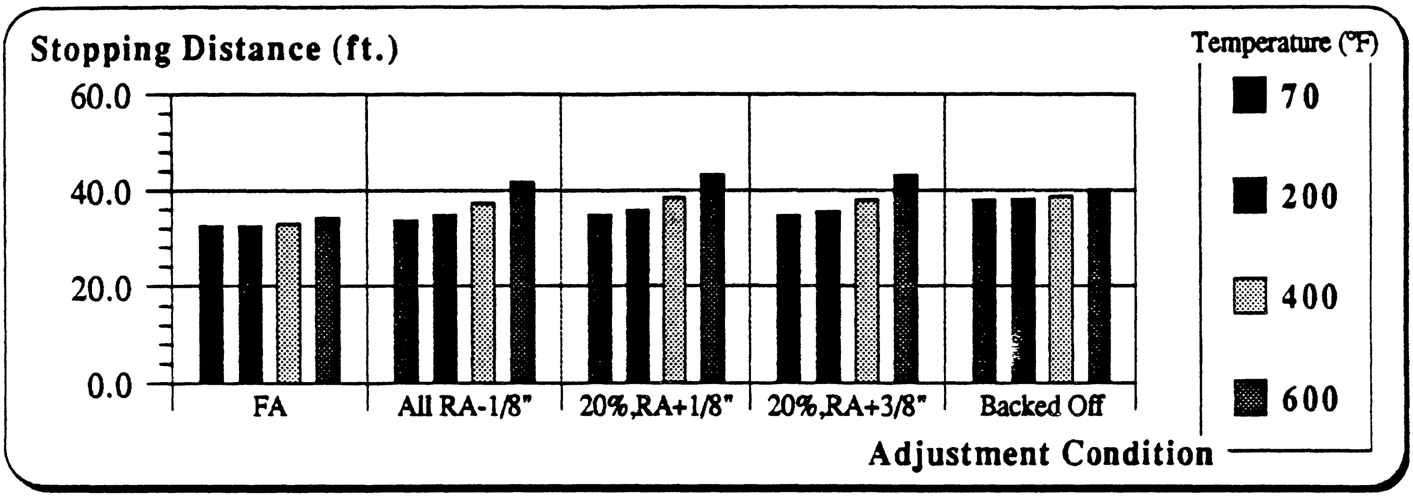
2.3 Concise Summary of the Results

Although calculations were made at conditions when cold static stroke was measured at other than 80 psi, it is sufficient to examine the results at 80 psi. (Nevertheless, the results for all of the 20 mph calculations are presented in Figures 2.2.1 to 2.2.5. These charts and tables are in the format explained in the previous section.) As with the calculations made at 60 mph, these results indicate the influences of brake-adjustment and do not indicate the influences of changes in brake properties such as timing, lining fade, and speed sensitivity of brake torque capability on stopping distance.

For purposes of comparing the results at 20 mph with those at 60 mph, the tables of percent increase in stopping distance can be compared directly. We wish to point out that, in general, predictions for stopping distance are for ideal conditions that would not ordinarily be expected in service. Accordingly, the predicted distances are shorter than those to be expected from vehicle tests. Nevertheless, we believe that the percentage changes in stopping distance due to brake-adjustment are representative of the percentage changes to be found in service for various levels of brake-adjustment with everything else

Stopping Distances (20mph) of a 3 Axle Truck With Various Adjustment Conditions (Measured at 80 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	32.5	33.8	34.7	34.7	37.9
200	32.6	34.8	35.8	35.6	38.1
400	33.0	37.3	38.4	38.0	38.7
600	34.2	41.6	43.3	43.1	40.2



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	4	7	7	17
200	0	7	10	10	17
400	2	15	18	17	19
600	5	28	33	33	24

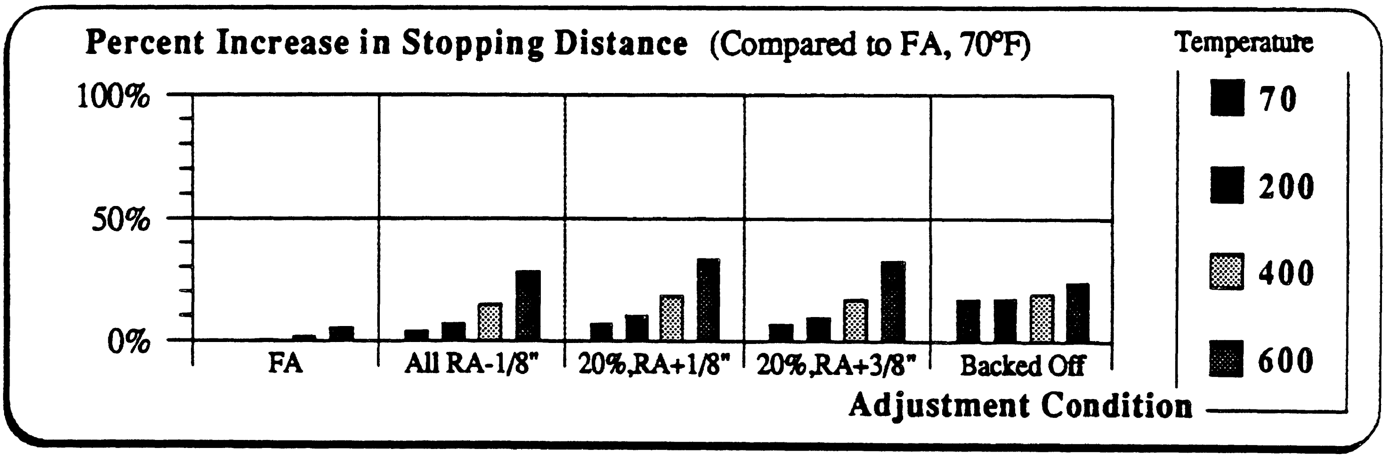
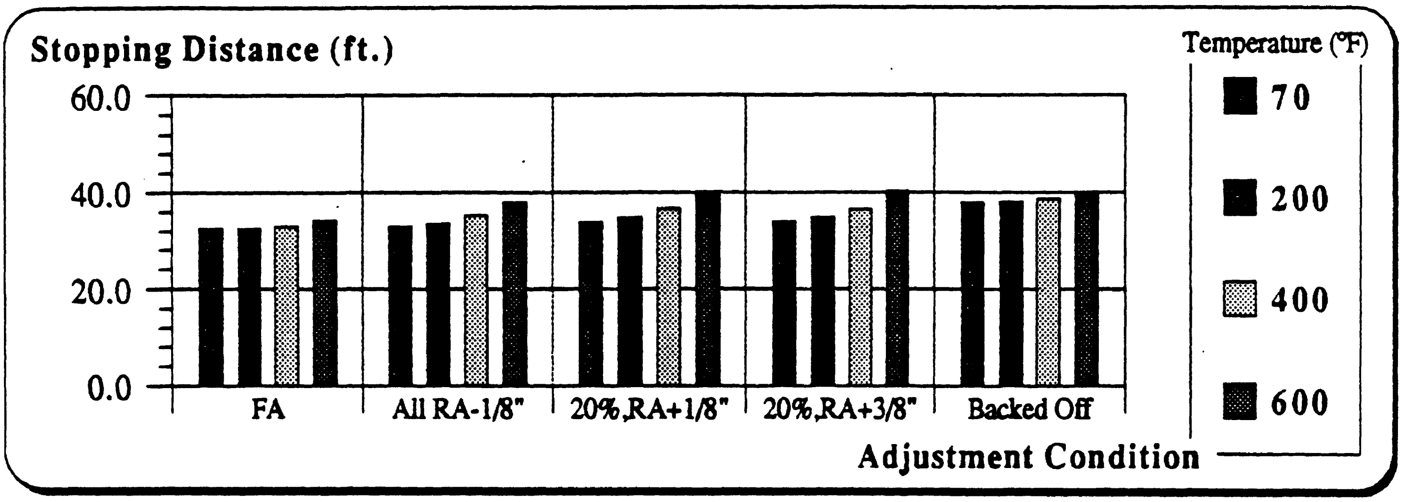


Figure 2.2.1. Influence of Adjustment and Temperature on the Stopping Distance of a 3 Axle Truck at 20 mph.

Stopping Distances (20mph) of a 3 Axle Truck With Various Adjustment Conditions (Measured at 100 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	32.5	33.0	33.8	34.0	37.9
200	32.6	33.6	34.7	34.8	38.1
400	33.0	35.2	36.7	36.5	38.7
600	34.2	38.0	40.1	40.3	40.2



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	2	4	5	17
200	0	3	7	7	17
400	2	8	13	12	19
600	5	17	23	24	24

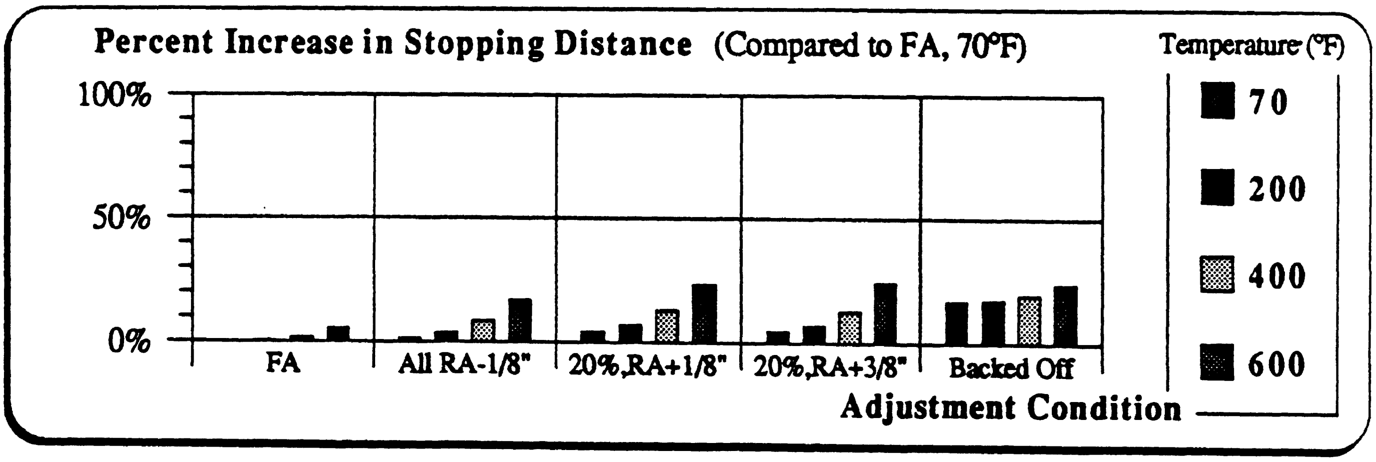
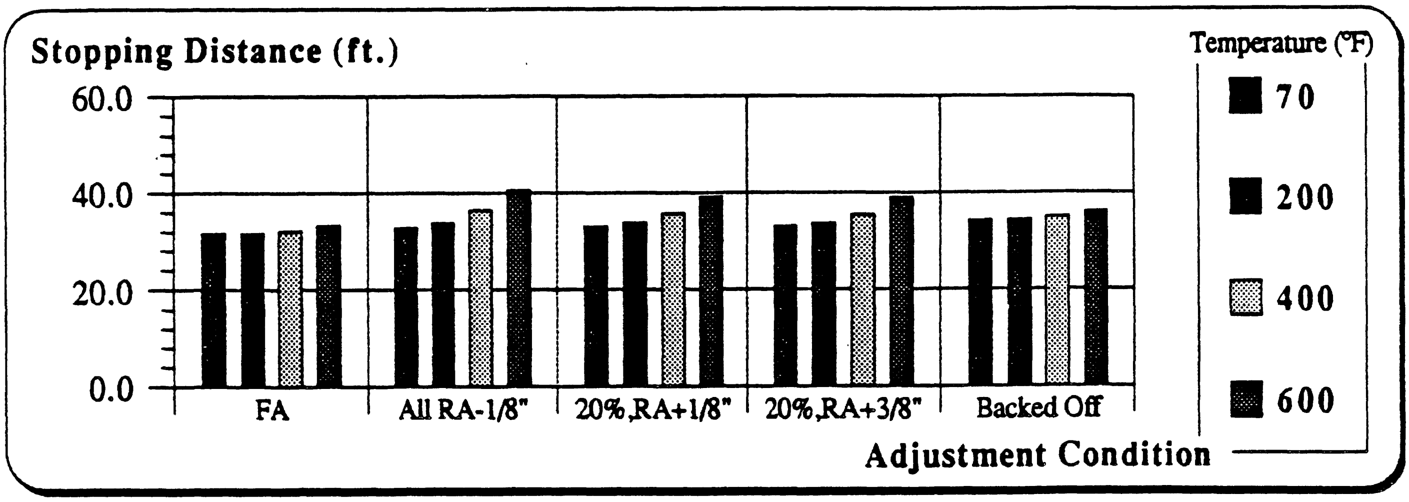


Figure 2.2.2. Influence of Adjustment and Temperature on the Stopping Distance of a 3 Axle Truck at 20 mph.

Stopping Distances (20mph) of a 5 Axle Truck With Various Adjustment Conditions (Measured at 80 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	31.6	32.9	33.1	33.1	34.2
200	31.7	33.9	33.9	33.7	34.3
400	32.1	36.4	35.7	35.3	34.9
600	33.3	40.6	39.1	39.0	36.2



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	4	5	5	8
200	0	7	7	7	9
400	2	15	13	12	10
600	5	28	24	23	14

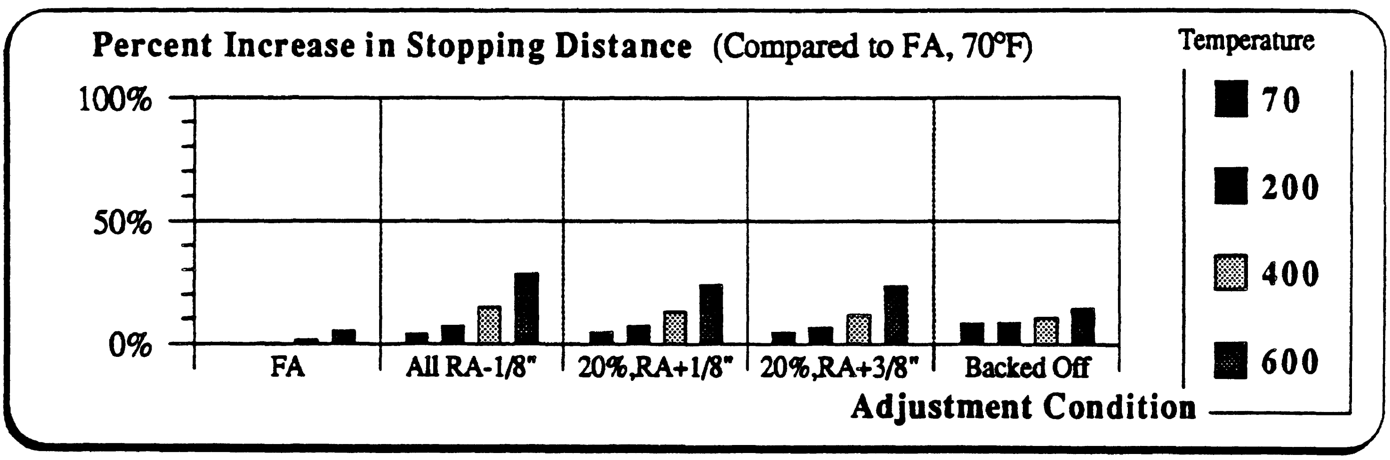
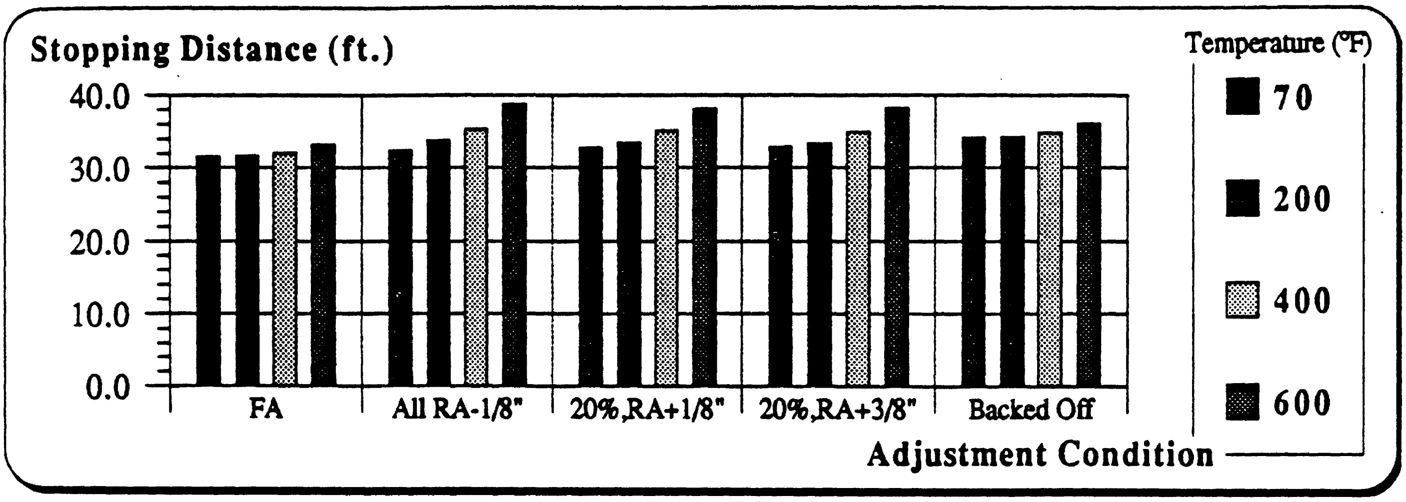


Figure 2.2.3. Influence of Adjustment and Temperature on the Stopping Distance of a 5 Axle Truck at 20 mph.

Stopping Distances (20mph) of a 5 Axle Truck With Various Adjustment Conditions (Measured at 90 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	31.6	32.5	32.8	32.9	34.2
200	31.7	33.8	33.5	33.4	34.3
400	32.1	35.4	35.1	34.9	34.9
600	33.3	38.8	38.2	38.2	36.2



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	3	4	4	8
200	0	7	6	6	9
400	2	12	11	10	10
600	5	23	21	21	14

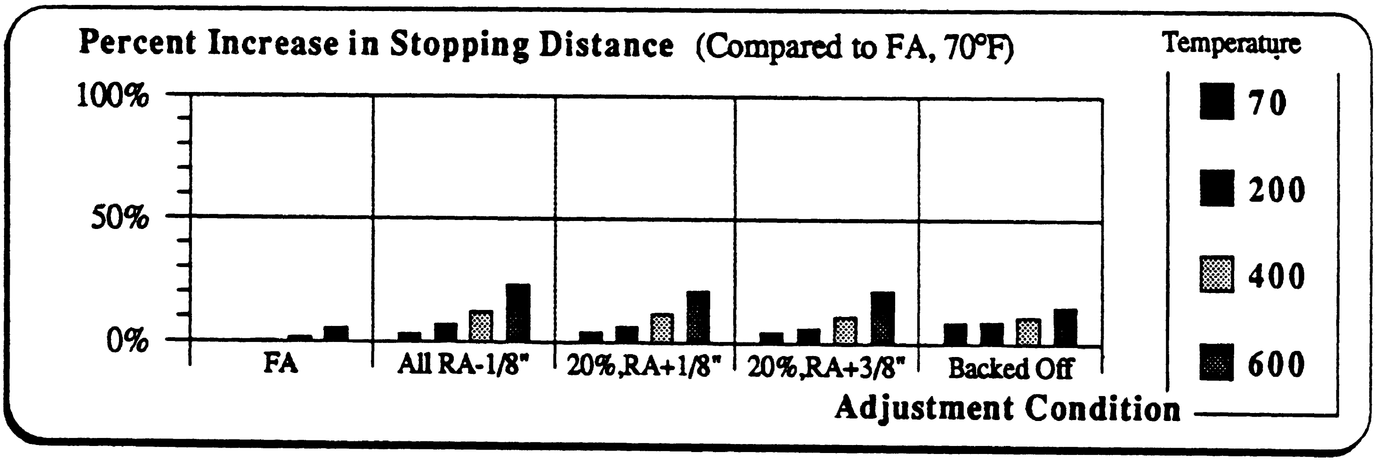
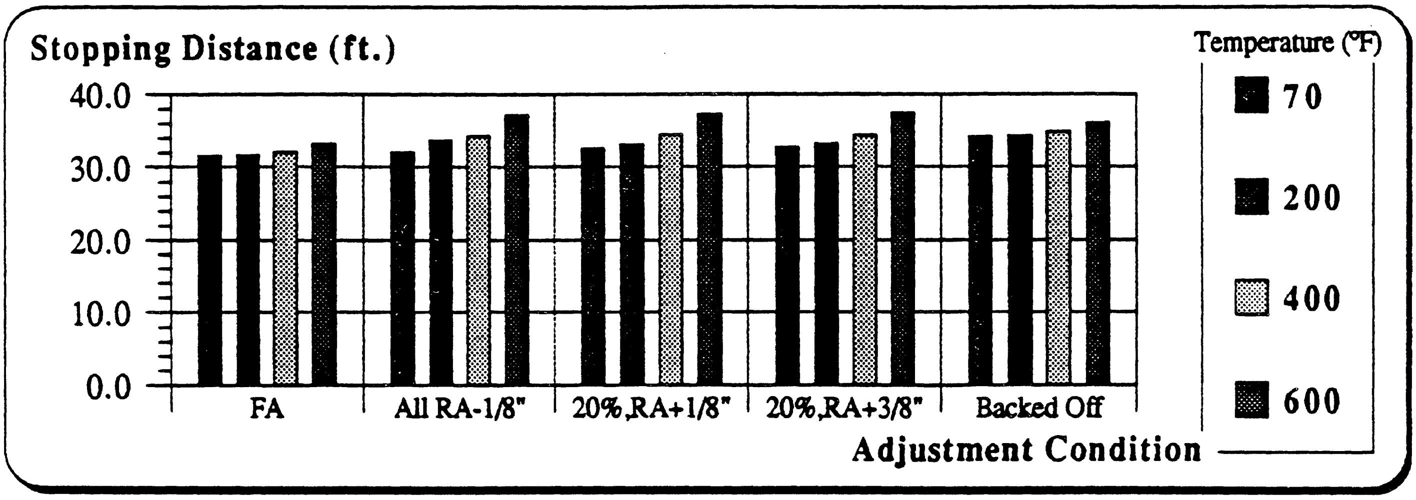


Figure 2.2.4. Influence of Adjustment and Temperature on the Stopping Distance of a 5 Axle Truck at 20 mph.

Stopping Distances (20mph) of a 5 Axle Truck With Various Adjustment Conditions (Measured at 100 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	31.6	32.1	32.5	32.7	34.2
200	31.7	33.7	33.1	33.2	34.3
400	32.1	34.4	34.6	34.5	34.9
600	33.3	37.1	37.2	37.4	36.2



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	2	3	4	8
200	0	7	5	5	9
400	2	9	9	9	10
600	5	17	18	18	14

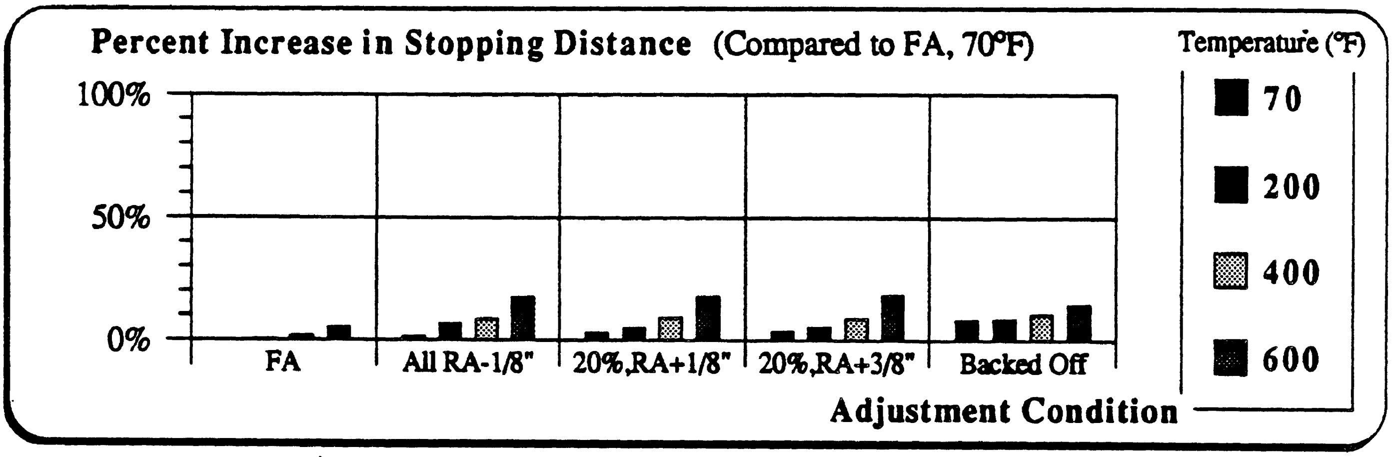


Figure 2.2.5. Influence of Adjustment and Temperature on the Stopping Distance of a 5 Axle Truck at 20 mph .

held equal. In other words, the percentage changes in stopping performance are preferred for use in making evaluations and comparisons.

In order to facilitate the comparison between 60 mph and 20 mph stops, Figure 2.3.1 shows the percentage changes in stopping distance for a 3-axle truck making brake-limited stops from both 60 and 20 mph. In general, these results show that brake-adjustment is much more important at 60 mph than it is at 20 mph. For example, in Case 3, where the vehicle would be OOS because a minimum number of rear brakes are 1/8" beyond the readjustment point, the percentage increase in stopping distance at an initial brake temperature of 400°F is 31 percent at 60 mph and 18 percent at 20 mph. Figure 2.3.2 shows similar results for a 5-axle vehicle. As will be explained further, the numerical data show that 60 mph results are much more sensitive to brake-adjustment than the 20 mph results are.

Another outcome of the fact that brake-adjustment is less important at 20 mph, is the way the results change with pressure. As discussed in the first section, stopping distance calculations for cases categorized by stroke measurements conducted at the higher pressure (100 psi), will vary significantly from cases categorized at the lower pressure (80 psi). This is less noticeable at the 20 mph stopping distance than the 60 mph cases. For the 3-axle truck at 60 mph and stopping with an initial brake temperature of 400°F, the 80 psi results (Figure 1.3.2) for Cases 2, 3, and 4 varied from the 100 psi results (Figure 1.3.9) by 9, 8, and 7 percent, respectively. The same cases, this time from 20 mph, varied between 80 and 100 psi only by 7, 5, and 5 percent (See Figures 2.2.1 and 2.2.2).

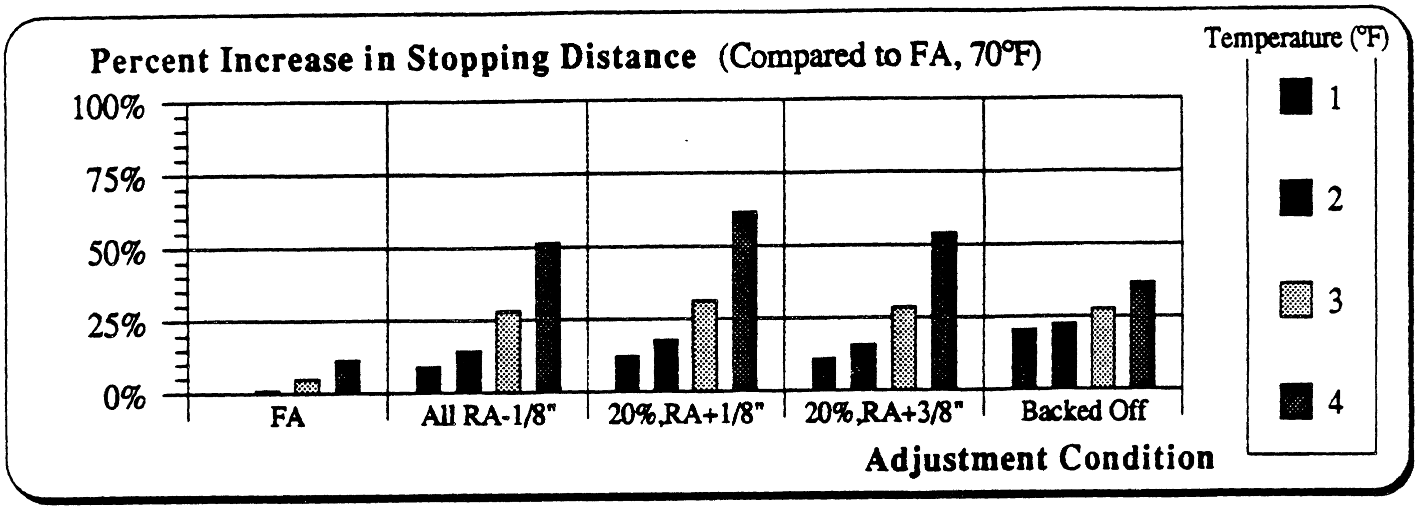
Unlike the 60 mph stopping distance situations, the 20 mph cases do not have "dramatic" variations between the various adjustment cases and truck configurations. At 400°F, the values of percent increase in stopping distance from 20 mph do not go above 19 percent, and mostly they are at the proximity of 15 percent (see the lower part of Figures 2.3.1 and 2.3.2). The same values for the 60 mph stop go as high as 31percent, and for the most part, they are at the proximity of 26 percent (upper part of Figures 2.3.1 and 2.3.2). For a 5-axle truck under the more stringent adjustment test (100 psi) and at a high initial brake temperature of 400°F, the braking performance for a 20 mph stop does not degrade more than 10 percent for the worst case (Figure 2.2.5). The same truck, when performing the 60 mph stopping distance test, will encounter a performance degradation of up to 18 percent (Figure 1.3.10).

In contrast to the higher sensitivity of the 60 mph results to brake-adjustment, the calculated results are less sensitive at 60 mph than at 20 mph due to timing characteristics of

3 AXLE TRUCK

Percent Increase in Stopping Distances (60mph) as a Function of Temperature and Various Adjustment Conditions (Measured at 80 psi)

Adjustment Case / Temp.	Case1 FA	Case 2 All RA-1/8"	Case 3 20%,RA+1/8"	Case 4 20%,RA+3/8"	Case 5 Backed Off
70	0	9	12	11	21
200	1	15	18	16	23
400	5	28	31	29	28
600	12	51	62	54	37



Percent Increase in Stopping Distances (20mph) as a Function of Temperature and Various Adjustment Conditions (Measured at 80 psi)

Adjustment Case / Temp.	Case1 FA	Case 2 All RA-1/8"	Case 3 20%,RA+1/8"	Case 4 20%,RA+3/8"	Case 5 Backed Off
70	0	4	7	7	17
200	0	7	10	10	17
400	2	15	18	17	19
600	5	28	33	33	24

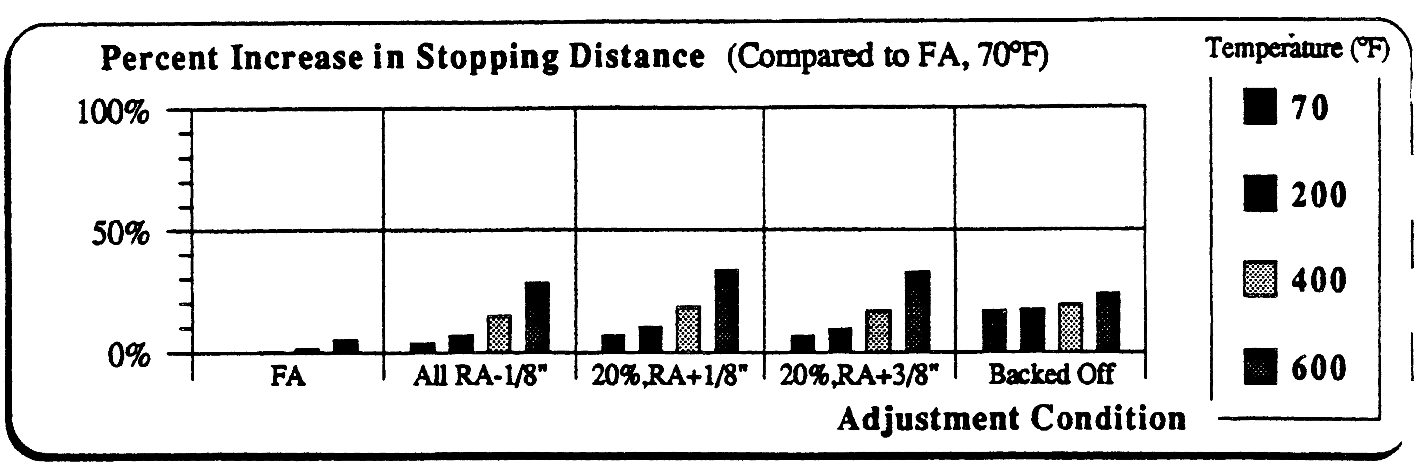
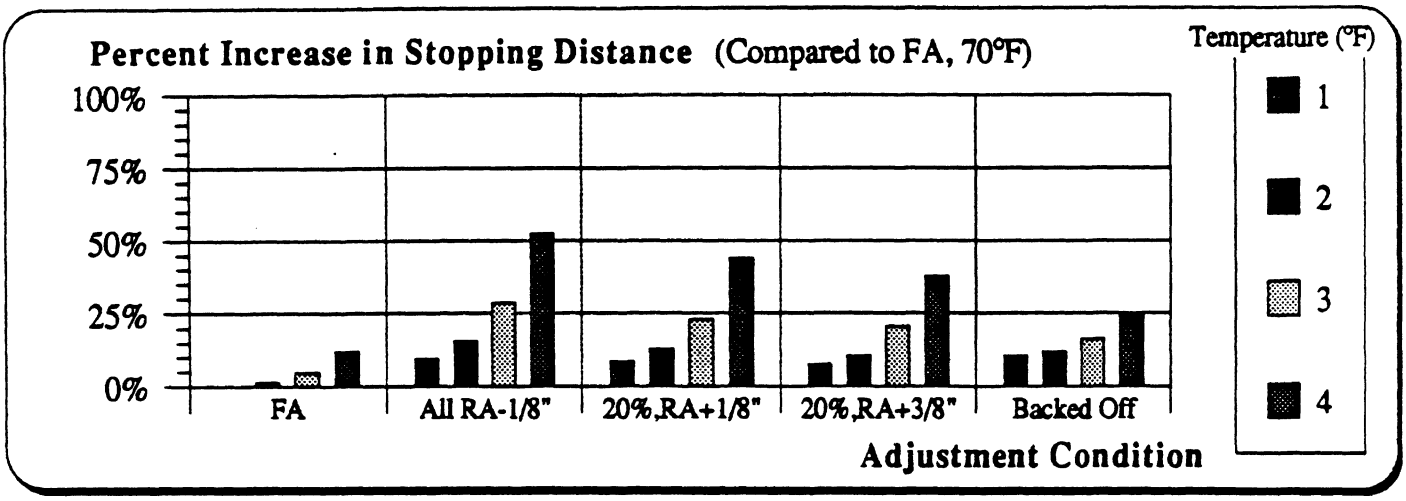


Figure 2.3.1. Influence of Adjustment and Temperature on the Stopping Distance of a 3 Axle Truck at 60 and 20 mph.

5 AXLE TRUCK

Percent Increase in Stopping Distances (60mph) as a Function of Temperature and Various Adjustment Conditions (Measured at 80 psi)

Temp. \ Adjustment Case	Case1 FA	Case 2 All RA-1/8"	Case 3 20%,RA+1/8"	Case 4 20%,RA+3/8"	Case 5 Backed Off
70	0	10	9	8	11
200	1	15	13	11	12
400	5	29	23	21	16
600	12	52	44	38	24



Percent Increase in Stopping Distances (20mph) as a Function of Temperature and Various Adjustment Conditions (Measured at 80 psi)

Temp. \ Adjustment Case	Case1 FA	Case 2 All RA-1/8"	Case 3 20%,RA+1/8"	Case 4 20%,RA+3/8"	Case 5 Backed Off
70	0	4	5	5	8
200	0	7	7	7	9
400	2	15	13	12	10
600	5	28	24	23	14

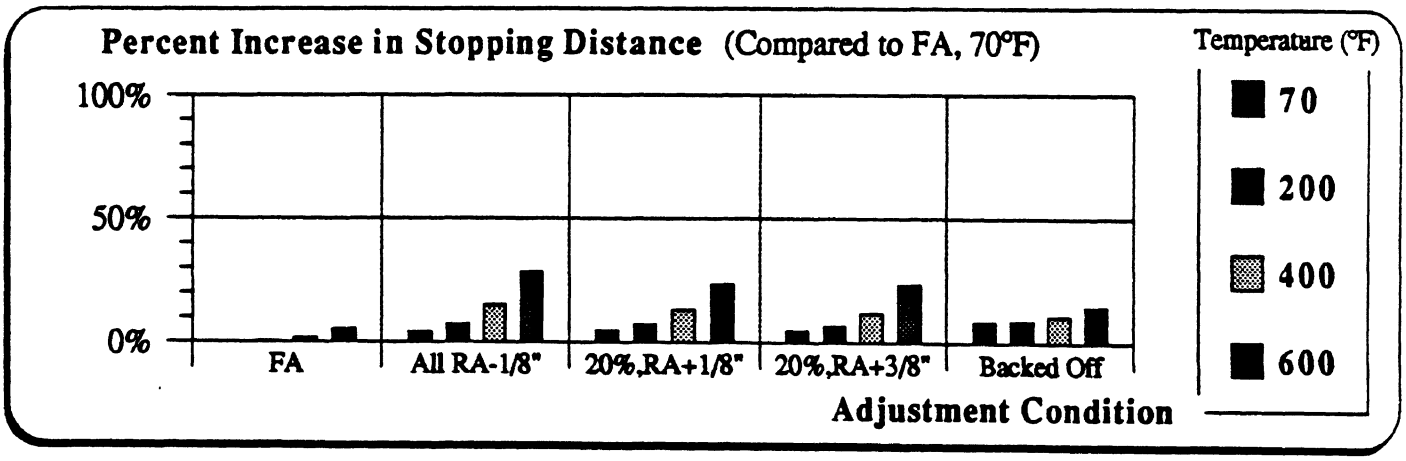


Figure 2.3.2. Influence of Adjustment and Temperature on the Stopping Distance of a 5 Axle Truck at 60 and 20 mph.

the braking system. The higher slope of the 20 mph lines in Figures 2.3.3 and 2.3.4 demonstrates that fact. Furthermore, under timing values that meet the FMVSS 121 requirements, the braking performance is more susceptible (with an order of magnitude) to variations in chamber pressure rise time (Figure 2.3.3) than to variations in the rise time of the air lines of the system (Figure 2.3.4).

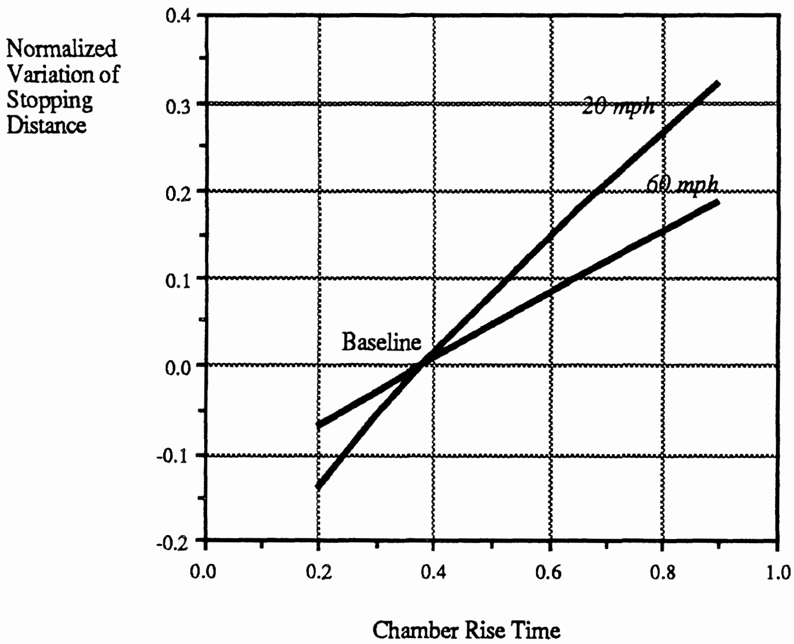


Fig. 2.3.3 Influence of Chamber Rise Time on Stopping Distance from 20 and 60 mph

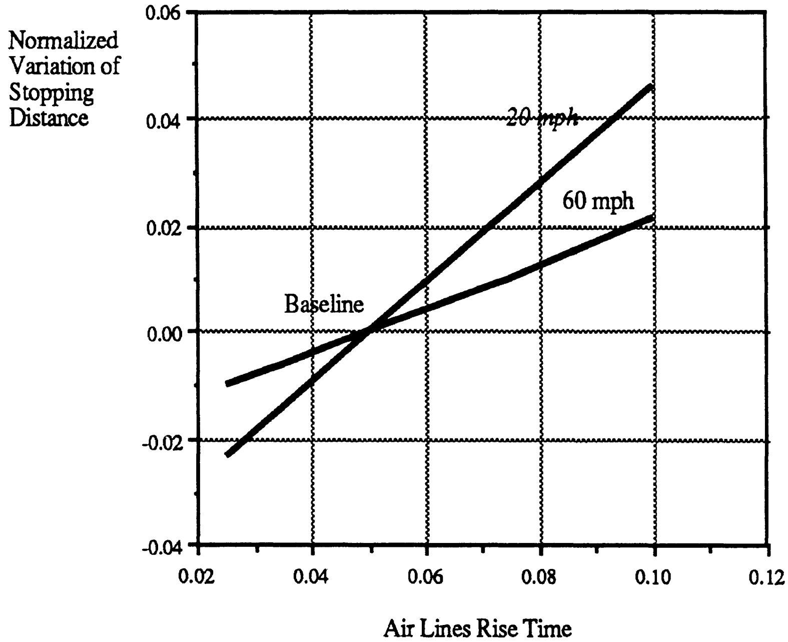


Fig. 2.3.4 Influence of Air Lines Rise Time on Stopping Distance from 20 and 60 mph

2.4 Findings and Observations

2.4.1 The results indicate that percentage changes in stopping distances due to poor brake-adjustment are much larger at 60 mph than at 20 mph. There are two reasons for this. First,the influence of brake timing is much more important at 20 mph than it is at 60 mph. Even though the brake timing in the examples studied meet FMVSS 121 requirements, the maximum available torque is not applied for very long in the 20 mph stop, thereby decreasing the influence of brake-adjustment compared to that during a 60 mph stop. The second reason involves the temperature rise during a stop. This is a very small effect at 20 mph, but it is important at 60 mph for OOA brakes that are close to bottoming out. The basic finding from the calculations is that the increase in drum expansion due to temperature rise has an important influence on braking capability for hot, poorly adjusted brakes.

2.4.2 The finding above is based upon comparisons with available braking capability at 20 and 60 mph. The following discussion, however, involves the observation that 20 mph stopping distance standards may be set differently than 60 mph standards. For example, if the 20 mph rules were much more stringent than the 60 mph rules (or equivalently, the 60 mph rules were much more lenient), there is a possibility that passing the 20 mph stopping distance requirement would go a long way towards assuring that the vehicle will pass at 60 mph.

In order to examine the differences between stopping from 20 and 60 mph, consider the following simplified example. The current rule for 20 mph is 35 feet for some trucks and 40 feet for longer combinations. (The difference being related to brake timing considerations which will eventually come into play here also.) The basic relationship for estimating stopping distance from deceleration (ignoring or "averaging" the influences of rise times) is as follows:

$$S = V^2/2D$$

where D is the average deceleration

V is the initial velocity

and S is the stopping distance.

According to the above equation, if the deceleration capability of the braking system were to be kept equal, the stopping distance for a 60 mph stop would be nine times that for a 20 mph stop—that is, 315 feet or 360 feet corresponding to 35 or 40 feet.

However, the influences of pressure-rise times vary linearly with initial velocity and amount to approximately 12 feet at 20 mph and 35 feet at 60 mph if the average rise time is approximately 0.5 seconds. This means that the 60 mph stop has an advantage over the 20 mph stop when it comes to the contribution of rise time to stopping distance, since 12 feet is a larger fraction of the stopping distance at 20 mph than 35 feet is at 60 mph. For example, if a vehicle stopped in 36 feet from 20 mph, the deceleration capability available would be approximately 0.56 g. If the deceleration available is 0.56 g, a vehicle stopping from 60 mph would be able to stop in approximately 250 feet including 35 feet as an approximation to the contribution due to rise time. The fairly obvious point of this discussion is that being able to pass a 60 mph requirement depends upon not only the braking system, but the nature of the 60 mph requirement with respect to the 20 mph requirement.

People setting 60 mph requirements have included the factors discussed above if they have used empirical measurements of stopping distance capability to aid them in establishing the goals. At one time, FMVSS 121 had a 60 mph stopping distance requirement of 293 feet. Given the rough approximations above (i.e., 35 feet due to rise time and neglecting about a 4 percent reduction due to speed loss effects during the rise time), the average deceleration for a 60 mph stop would be approximately 0.47g. The current dynamometer tests in FMVSS 121 require approximately 0.435g which would lead to a stopping distance of approximately 312 feet. So even though the reasons may be vague and obscure, the current implicit FMVSS 121 requirement on stopping distance fits in with the 315 feet derived from equation (1) which neglected not only brake timing matters, but also any in-stop fade due to heating of the brake linings or velocity sensitivity of the linings.

2.4.3 The preceding observation needs to be supplemented with other observations for why 20 mph stops are not good indicators of what will happen at 60 mph. The reasons are (1) there are lining materials that are temperature-sensitive and the in-stop temperature rise at 60 mph will cause these materials to lose appreciable amounts of torque capability, (2) certain lining materials linings may have a sliding speed sensitivity that shows up at 60 mph, but not at 20 mph, and (3) very good brake timing may compensate for poor adjustment or other braking torque deficiencies at 20 mph, but this will not be as effective at 60 mph.

3.0 CRITICAL ADJUSTMENT THRESHOLDS BEYOND WHICH HEAVY TRUCKS CANNOT STOP WITHIN A SAFE MARGIN.

3.1 Introduction

This section describes results pertaining to identifying critical adjustment thresholds beyond which heavy trucks cannot stop within a safe margin.

3.2 Brief Description of the Type of Analysis Performed

The analyses presented previously consisted of predictions of brake-torque capabilities and stopping-distance performance for selected combinations of brake-adjustment levels as listed in Table 1.2.1. In this section, those results are examined from the perspective of using them in evaluating OOS criteria.

The difficulty here is in determining what is meant by being able to "stop within a safe margin." In work by NHTSA (Reference [1]), they chose to use a 20 percent increase in stopping distance as a "bogie" for emphasizing conditions not covered by the current OOS criteria. A general scanning of an informal, but extensive, document entitled, "History of CVSA Brake Out-of-Service Criteria" (supplied by Mr. L. Strawhorn) indicates that people tend to use stopping-distance calculations to show that either some condition of brake-adjustment is worse than the OOS criteria, and therefore, ought to be included in the OOS or, depending upon their attitude, that some OOS condition is no worse than some acceptable condition, and therefore, ought to be removed from the OOS category. In either case, stopping-distance predictions for some set of operating conditions are used in making the evaluations. The calculations performed in this study and described in Section 1 provide the "raw material" regarding stopping distance for "pathological" cases that were selected for use in making critical assessments of the stopping capabilities and safety margins of heavy trucks with various types and levels of misadjustment. These cases are representative of situations that challenge the OOS criteria with regard to distinguishing between various out of adjustment situations on the basis of percentage changes in stopping distance.

Given the above description, the analysis in this section has a more abstract and philosophical tone than a straightforward analysis of stopping distance. The results summarized in the next section are based on concepts and ideas related to selecting levels of stopping distance degradations and reductions in safety margins with respect to those stopping distances available to trucks with excellent maintenance making stops under very favorable operating conditions. The logic and rationale for this approach is that the current

OOS criteria represent the combined judgement of many knowledgable people, thereby providing a reasonable starting point for considering the implications and meanings of changes in defining critical adjustment thresholds or combinations of adjustment thresholds from brake to brake on a vehicle.

In summary, the current OOS criteria provide an initial indication of the amount of loss in stopping capability and safety margin that is currently deemed acceptable by the CVSA/MCSAP community. Perhaps higher goals may be acceptable in the future, but the current indications from MCSAP inspections are that many trucks are having difficulty meeting the current goals for brake-adjustment, given the hardware and maintenance practices currently employed. The following results emphasize means by which stopping-distance goals as derived from current criteria might be applied more uniformly across the spectrum of possible brake-adjustment situations.

3.3 Concise Summary of the Results and Findings

3.3.1 The raw material presented in Figures 1.3.2 through 1.3.11 shows that stopping distance versus brake-adjustment results are highly dependent upon temperature conditions and the pressure level at which static stroke is measured as well as the level of adjustment. Although one could consider some composite measure of performance based upon a wide range of initial brake temperatures, vehicle loading conditions, and road surface conditions; the analytical work that went into developing the calculations indicates that the influences of brake-adjustment are most important with respect to stopping distance capability in situations involving high temperatures, heavy loads, and high friction at the tire/road interface. The finding here is that it is reasonable to evaluate the influences of brake-adjustment criteria at chosen sets of operating conditions. Examination of the overall results suggests that calculated stopping distances for vehicles laden to the maximum allowable limit are suitable for examining the influences of various brake-adjustment criteria.

Clearly, the results depend importantly on initial brake temperature. The choice of fully-laden and 400°F represents a judgment concerning a likely state of operation. Higher temperatures such as 600°F emphasize the influences of the level of degradation involved, however, 600°F is a high temperature that is representative of demanding service. We have used results calculated at 400°F to illustrate our ideas.

Once a brake becomes completely backed-off, temperature does not influence the amount of degradation involved (of that particular brake) and important levels of degradation can be obtained without the influences of temperatures being a contributing factor in this case. Hence, a backed-off brake, or a brake that might be called "completely OOA," is a specially bad situation.

3.3.2 This section presents a method for adding "backed-off" brakes into a brake "demerit" system like the one used in the current 20 percent OOS criteria. The idea here is to augment the current 1/2 brake and one brake penalties used in computing the 20 percent factor employed in the OOS criteria. If these levels of brake penalties are viewed as "demerits," a completely misadjusted or backed-off brake could be assigned a demerit value to be used in computing a 20 percent factor that would be based upon the percentage reduction in stopping distance caused by various levels of misadjustment. The following material provides an explanation of a methodology leading to incorporating a penalty of 1.5 or 2.0 for a completely misadjusted brake.

The method is based upon studying brake chamber characteristics to determine "adjustment factors" that can be used to estimate the influences of various levels of brake-adjustment or misadjustment. The chamber characteristics are examined as illustrated in Figure 3.3.1 to determine the loss in actuating force due to the level of brake-adjustment. This loss is expressed as a fraction of the actuating force that would be available if the brake were fully-adjusted. The following table summarizes a set of adjustment factors determined for various states of adjustment as a function of cold static stroke values.

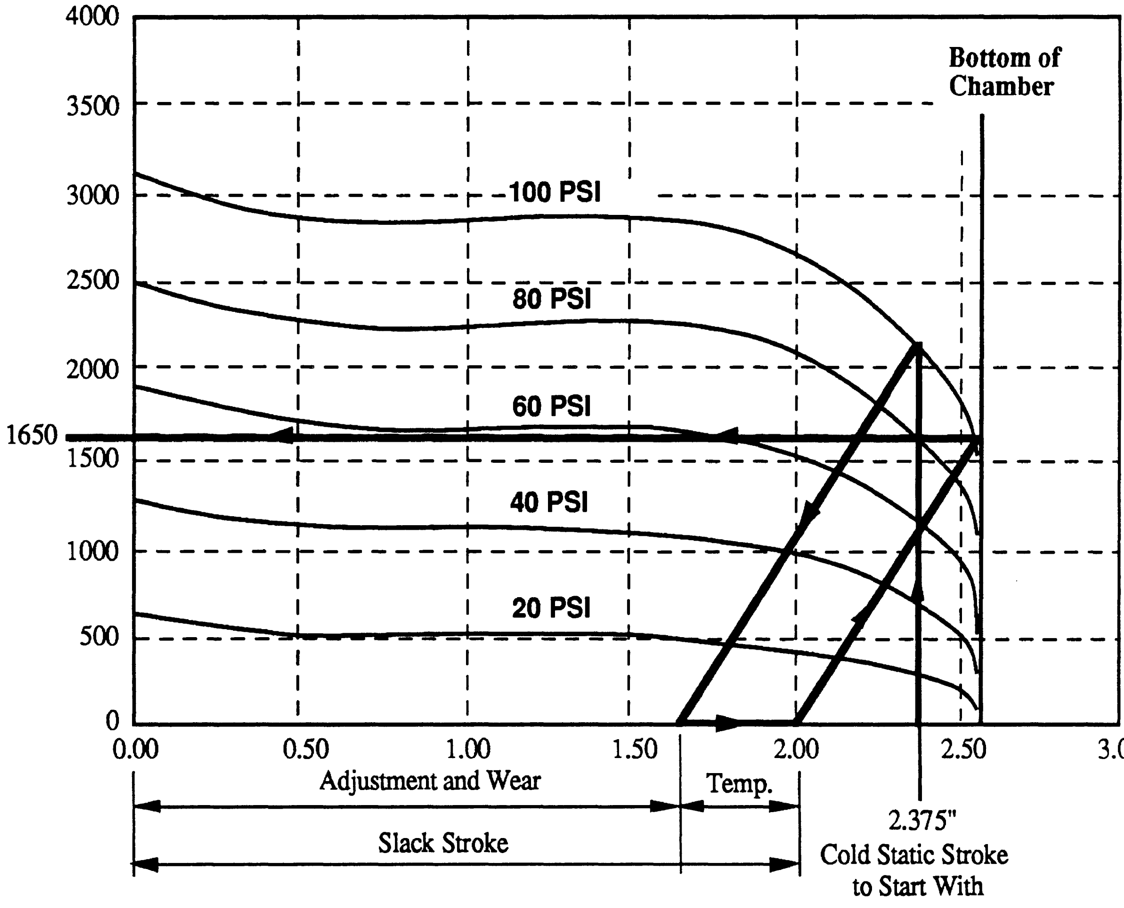
Table 3.3.1 Brake Adjustment Factors at 400 °F for a Type 30 Chamber

Conditions at which stroke was measured	2.125" of cold static stroke	2.375" of cold static stroke
measured at 100 psi and 70 °F	0.77	0.58
measured at 80 psi and 70 °F	0.68	0.39
measured at 80 psi and 70 °F plus 0.1" of in-stop stroke increase	0.63	0.30

These adjustment factors are proportional to the available braking capability in the ranges of brake adjustment corresponding to a brake penalty of 0.5 and a full brake penalty (1.0) in the current OOS criteria. If we were to extrapolate the factors given in the first row of Table 3.3.1 to a completely backed-off brake which would have an adjustment factor of

0.0, we would conclude that a completely misadjusted brake should be given a penalty or demerit of approximately 2.0 to be in concert with the penalties of 0.5 and 1.0 given in the current criteria. When stroke is measured at 80 psi, the factors given in the last row of Table 3.3.1 extrapolate to a penalty value of approximately 1.5 for a fully backed-off brake. (The lower value in this case is due to the fact that the levels of misadjustment are actually greater at 2.125" and 2.375" when measured at 80 psi than when the strokes are measured at 100 psi.)

The net conclusion that is implied by this work is that stopping distance discrepancies due to backed-off brakes could be reduced if backed off brakes were given a penalty equivalent to at least 1.5 brake demerits. The criteria for calling a brake "backed-off" or "completely misadjusted" might be that the cold static stroke is greater than or equal to 2.5" for a Type 30 chamber. For other types of chambers, an equivalent boundary might be set at the stroke required to reach the bottom of the chamber minus 1/8".



$$\frac{F}{F_{ref}} = \frac{1650}{2850} = 0.579$$ ➡ **Net Result:** 58% of the Fully Adjusted Braking Force

Figure 3.3.1 Limit on Actuation Force Due to Brake Adjustment Level

3.3.3 The ideas presented in this section extend the notion of using brake-adjustment factors like those introduced in the previous section. In this case, a scheme is presented for using estimated changes in stopping distance to determine OOS.

The methodology involves assigning adjustment factors to various ranges of brake-adjustment. To illustrate the concept, brake chamber characteristics have been examined at several levels of brake-adjustment and values of adjustment factors have been determined per the procedure illustrated in Figure 3.3.1. (Although these factors were derived for a particular type of chamber and set of brake properties, we have generalized their use to be representative or typical of a broad range of brakes.) A tentatively proposed set of factors suitable for introducing the procedure is given in Table 3.3.2. These adjustment factors represent the contribution to changes in stopping distance with brakes at 400°F and with cold static stroke measured at 80 psi.

Table 3.3.2 Brake Adjustment Factors at 400 °F

Range of stroke s with respect to the readjustment point RA	Brake-adjustment factor representing the stroke range
"fully adjusted" stroke,s	1.0
RA -1/8 ≤ s < RA	0.77
RA ≤ s < RA +1/4	0.63
RA +1/4 < s <RA +1/2*	0.30
RA +1/2* ≤ s *use for Type 30 chambers and bottom -1/8 for other types	0.0

There is a caveat that needs to be considered when applying adjustment factors. The factors are keyed to what a fully-adjusted brake will do. If different brakes have different torque capabilities in the fully-adjusted state, these differences need to be taken into account. A common situation is that front brakes have approximately 50 percent of the torque capability of rear brakes. Also, when slack arm lengths and/or chamber areas differ from tractor rear brakes to trailer brakes, then the "AL" factors need to be included in the procedure for estimating changes in stopping distance due to brake-adjustment. The following example presented in Table 3.3.3 illustrates the computation for a situation in which a 3-axle (6-brake) truck has all brakes fully-adjusted except one rear brake is at a cold stroke of RA +1/8 and another is at RA + 3/8.

Table 3.3.3 Example Calculation of the Change in Stopping Capability

brake #	adjustment level	adjust. factor	relative AL etc.	relative torque
1	FA	1.0	0.5	0.5
2	FA	1.0	0.5	0.5
3	FA	1.0	1.0	1.0
4	FA	1.0	1.0	1.0
5	RA+1/8	0.63	1.0	0.63
6	RA+3/8	0.30	1.0	0.30
		totals	5.0	3.93

To first approximation, the stopping distance is inversely proportional to the the braking force. This means that in the above example (Table 3.3.3) the change in stopping distance due to brake-adjustment is approximately given by 5.0/3.93 which equals 1.27. In other words, the estimated stopping distance is 27 percent longer with the arrangement of brake-adjustment levels given in Table 3.3.3 than it would be if all brakes were fully-adjusted.

A question that naturally arises at this point, concerns the validity of the results. "How close are the results of such an approximated calculation of stopping distance variation, to those of the more elaborated, detailed computational method used in the previous sections?" Table 3.3.3 presents a 3-axle truck with brakes at 40 °F and with cold static stroke measured at 80 psi. The elaborated calculations results for such a truck, under the same conditions in Figure 1.3.2 (case 4, RA+3/8" — 29%) do not deviate significantly from the approximated result of 27 percent.

The methods presented here, and in the following section for approximating degradation of braking performance by means of increased stopping distance, are based on reduced braking capability due to brake-adjustment. As discussed in Section 2 (60 versus. 20 mph), brake-adjustment is mostly influential when evaluating brake performance at high speed. Therefore, it should be emphasized that such an approximate approach can be adopted rather confidently at high speeds. It should be regarded cautiously at low speeds. This fact can be demonstrated by examining the results for a 20 mph stop presented in Figure 2.2.1. While the approximated result was quite close to the detailed one for the 60 mph stop at 27 and 29 percent, it deviates significantly from the result of the 20 mph stop

— 17 percent.

The above procedure can be applied to brake-adjustment situations in general to provide a measure of the associated change in stopping distance capability. The following Table 3.3.5 gives results for several examples for vehicles with six and ten brakes. The concept portrayed here is as follows: if the OOS criteria were related to a target level of allowable reduction in stopping capability, a more uniform consideration of the importance of various states of OOA would be obtained.

Table 3.3.5 Examples Showing the Influence of Brake Adjustment on Stopping Capability

Example	number of brakes	adjustment condition	total relative torque	change in stopping capability
1	6	RA-1/8, 6 brakes	3.85	1.30
2	6	RA+1/8, 3 brakes	3.89	1.29
3	6	RA+1/8, 1 brake RA +3/8, 1 brake	3.93	1.27
4	6	RA+1/2, 1 backed-off	4.0	1.25
5	6	RA+1/8, 1 front RA+3/8, 1 front	4.465	1.12
6	10	RA-1/8, all brakes	6.93	1.30
7	10	RA+1/8, 4 brakes	7.52	1.20
8	10	RA+3/8, 2 brakes	7.69	1.18
9	10	RA+1/2, 1 backed-off	8.0	1.13
10	10	1 backed off and 1 at RA+1/8	7.63	1.18
11	10	RA+3/8, 2 fronts	8.3	1.08

As with the 3-axle truck in Table 3.3.4, some of the example trucks above were also calculated using the detailed computational method. Results based upon using the approximate and detailed methods are compared in Table 3.3.6 below. It should be noted that such a comparison is made only for qualitative assessment of the simplified approximation, and not for a quantitative analysis of its accuracy.

Table 3.3.6 Example Comparisons of Detailed and Approximate Calculations.

Approx. Example (above)	Corresponding Figure of Detailed Comp.	Adjustment Condition / Case	Approximated Increased Stopping Distance	Detailed Increased Stopping Distance
1	1.3.2	All RA-1/8", Case 2	30%	28%
2	1.3.2	20%RA+1/8", Case 3	29 %	31 %
6	1.3.4	All RA-1/8", Case 2	30 %	29 %
7	1.3.4	20% RA+1/8", Case 3	20 %	23 %
8	1.3.4	20% RA+3/8", Case 4	18 %	21 %

It is clearly seen from the above table that the results of the approximate method agree with those of the detailed one. If the detailed method is looked upon as accurate, the simplified method provides a good approximation for the degradation in the braking capabilities. Furthermore, it can be observed that the more axles there are, the better the agreement between the results.

3.4 Observations and concluding remarks

3.4.1 There is already considerable sentiment for simplifying the OOS criteria. The methods suggested above for changing the OOS criteria may not appear to be simple. Nevertheless, they are much simpler than the calculation procedures used in obtaining the results presented in Sections 1 and 2. An issue to be decided is whether it is worthwhile to increase the complexity of the OOS criteria in order to reflect a more uniform relationship to stopping capability.

3.4.2 One matter to be observed derives from the importance of front brakes as currently configured. Front brakes are less effective than rear brakes, and hence, they contribute less to the stopping capability of the vehicle than do rear brakes. This means that if a stopping distance rule were to be adopted, front brake degradation would be less important than it currently is under the present OOS criteria. (However there are a number of other OOS matters that apply to the front brakes so they would receive special attention anyhow.)

Perhaps more effective front brakes will come into style as it is noticed that brake wear and maintenance costs may be reduced by the use of more effective front brakes. In any event, the stopping distance estimation method would account for the effectiveness of each brake including the front brakes because it requires knowledge of the relative effectiveness of each brake as determined by chamber size, slack arm length, drum radius, and tire radius. A source of this type of information for a sample of vehicles is given in the data obtained from NTSB (see Section 4). In later stages of this study, we would like to use the NTSB data to evaluate the effectiveness of proposed OOS criteria in separating OOS vehicles from acceptable vehicles based on stopping capability estimates. In particular, an OOS criteria based upon brake-adjustment factors like those given in Table 3.3.2 could be evaluated using the data collected by NTSB.

3.4.3 The stopping distance approach is readily amenable to the use of on-line computers at weigh stations. For example, in Wisconsin the inspectors enter vehicle description and measurement data into an on-line computer system. In the future, the computer system could be programmed to compute the relative change in stopping distance for the measured state of brake-adjustment. However, there would be an additional burden of entering the relative torque effectiveness for each brake.

It seems that knowledge of the "AL factor" for each brake would need to be readily available if a stopping distance approach were to be used. If the relative AL factors were available or standard values were chosen, a simple computation could be used to estimate the relative change in stopping distance even if a computer were not available (see Table 3.3.3). In essence, the stopping distance calculation would amount to a refined version of the 20 percent rule. Its virtue would be that it provided an indication of the loss in stopping capability and based an OOS decision directly on this measure of the degradation in stopping capability caused by the level of brake-adjustment.

4.0 IDENTIFYING KEY FACTORS CONTRIBUTING TO BRAKE OUT-OF-ADJUSTMENT FOR MANUALLY ADJUSTED BRAKES. (Analysis of Brake Inspection Data from Oregon and Wisconsin)

The overall objective of this analysis is to identify factors that are associated with brake OOA based on MCSAP data from individual states. The review of computerized inspection data identified only two states, Oregon and Wisconsin, with data elements that appeared to address the objective of this task. Information recorded during CVSA inspections were obtained on magnetic tape from Oregon and Wisconsin. The data on magnetic tape were converted into an appropriate format for analysis by the OSIRIS database package of programs available on the University of Michigan mainframe computer. This section describes the results of the analyses of the Oregon and Wisconsin files.

Oregon Data. A magnetic tape with 20,233 records containing coded inspection data was obtained from the State of Oregon. These data covered all CVSA inspections in 1989. The format of the Oregon data was better suited to a structured, or hierarchical, file. In this application, the file structure includes two different types of records. At the first level, there is one record for each vehicle inspected. These records include trucks with no violations, trucks with brake violations, and trucks with other violations. The records at Level 1 describe the carriers' operating authority and the configuration of the truck. The configuration is described in a series of fields for up to six units (tractor, semitrailer, etc.). Each unit is characterized in terms of the unit type, CVSA decal, make, state of registration, and whether it was placed OOS. The unit type codes are the following:

Power Unit		Trailer	
BU	Bus	ST	Semitrailer
TT	Tractor	FT	Full trailer
TR	Truck	PT	Pole trailer
		OT	Other trailer
		DC	Dolly converter

The second level of records describe individual brake violations. Each record identifies the unit having the violation, the type of unit, and whether the violation put the unit OOS. The available brake violation codes include the following:

Brake Violation Codes

B20	Defective brakes exceed 20 percent
BBA	Brake-adjustment
BPR	Push rod (on steering axle)
BSA	Slack adjuster (on steering axle)
BSB	No steering axle brakes

The BP20 code, defective brakes exceed 20 percent, seems redundant since subsequent BBA (brake-adjustment) codes follow for each of the brakes individually. A number of other codes describe brake violations not related to adjustment.

The configuration of the vehicle can be determined from the combination of units identified. For each configuration, the violation codes listed above can be located by unit number. No actual pushrod travel measurements are recorded, and violations cannot be located with regard to axle or axle-end.

Results from the 1989 Oregon inspection data are summarized in the following tables. Of the 20,233 vehicles inspected, 22.1 percent had no violations; 45.7 percent had brake violations; and the remaining 32.1 percent had other violations. Overall, 34.4 percent of the trucks inspected were put OOS, and brake violations were responsible for about 80 percent of the vehicles put OOS. Focusing on the 45.7 percent (9,250 vehicles) that had one or more brake violations, 59.6 percent of these were put OOS. There were a total of 29,021 brake violations on the 9,250 vehicles having one or more brake violations. In other words, trucks with brake violations in Oregon have an average of about three brake violations per vehicle. These statistics are shown in Tables O.1 and O.2.

TABLE O.1

1989 Oregon Brake Data

6,491	(32.1%)	cases with no brake violations
4,492	(22.2%)	cases with no violations at all
9,250	(45.7%)	cases with brake violations

20,233	(100.0%)	total cases

29,021 brake violations total
1.43/vehicle inspected
3.14/vehicle with brake violations

TABLE O.2
Out-of-Service (OOS) Distribution for
All Trucks Inspected and Brake Violators

	Not OOS	OOS	Total
All Trucks	13,280	6,952	20,232
(%)	65.6	34.4	100.0
Brake Violators	3,739	5,511	9,250
(%)	40.4	59.6	100.0

Approximately two-thirds of the brake violations are for adjustment when the "defective brakes exceed 20 percent" code is omitted. Looking at the distribution of brake violations among combination units by type of unit, 44 percent are on semi-trailers and 30 percent are on tractors, for a total of 75 percent of the brake-adjustment violations. The proportion of brake violations on tractors and semi-trailers drops to 68.4 percent when single-unit trucks are included, as illustrated in the Tables O.3 through O.5.

TABLE O.3
Distribution of Brake Violations by Violation Type
(excludes "defective brakes exceed 20 percent because
that is in addition to the violations themselves)

	N	Percent
Brake-adjustment	16,542	64.79%
Push rod	70	0.27%
Slack adjustment	78	0.31%
No steering axle brakes	41	0.16%
Other/unknown	8,799	34.47%
Total	25,530	100.0%

TABLE O.4
Distribution of Brake Adjustment Violations by Unit Type
(excludes non-combination vehicles)

	Brake Adjust	%
Straight	757	5.04%
Tractor	4,552	30.32%
Semi	6,581	43.84%
Pole	1,472	9.80%
Full	1,263	8.41%
Dolly	228	1.52%
Other	145	0.97%
Unknown	15	0.10%
total	15,013	100.00%

TABLE O.5
Distribution of Brake Adjustment Violations by Unit Type
(includes non-combination vehicles)

	Brake Adjust	No Steer Brake	Brake Adjust	No Steer Brake
Straight	2,016	7	12.14%	17.07%
Tractor	4,772	31	28.73%	75.61%
Semi	6,603	1	39.75%	2.44%
Pole	1,473	0	8.87%	0.00%
Full	1,282	0	7.72%	0.00%
Dolly	255	1	1.54%	2.44%
Other	145	0	0.87%	0.00%
Unknown	65	1	0.39%	2.44%
total	16,611	41	100.00%	100.00%

Other coding is available to identify the carrier type. The emphasis is on Oregon PUC authorization, but interstate operating authority is also identified in a separate field. The intrastate authority may be of interest because it includes information on the commodity carried in the following codes.

<u>Carrier Classification</u>	
Class A	General Commodities
Class B	Local cartage
Class D	Sand, gravel, etc.
Class L	Logs, poles, or pilings
Class M	Metallic ores and concentrates
Class P	Passengers
Class SP	Small parcel

Table O.6 compares the percentage of brake violations with the percentage of vehicles for each carrier type. Intrastate carriers hauling logs, sand, and ore have about 14 percent more brake violations than the average vehicle inspected. This figure is based on the table below which shows the intrastate log, sand, and ore group to be 21.9 percent of the trucks inspected and 24.9 percent of the brake violations. The ratio of these two percentages is 1.14, or 14 percent more than the average for all carriers. However, this comparison does not take into account the number of axles and brakes per vehicle. This group of carriers might have more brake violations per vehicle because they have more axles. Information on the number of axles in not available in the Oregon data.

TABLE O.6

Brake Adjustment Violators Vs. All Vehicles Inspected
By Company Type
Oregon Inspection Data

Company Type Normalized	Brake Adj. Viol.		All Vehicles Inspected		
	N	%	N	%	Rate
Intra Gen Freight	1718	28.08	5152	25.46	1.10
Intra Logs, Sand, Ore	1526	24.94	4433	21.91	1.14
Intra Other For-hire	12	0.20	88	0.43	0.45
Intra Private	1046	17.09	4130	20.41	0.84
Inter For-hire	1356	22.16	4789	23.67	0.94
Inter Exempt	166	2.71	557	2.75	0.99
Inter Private	284	4.64	995	4.92	0.94
		0.00			
Unknown	11	0.18	88	0.43	0.41
Total	6119	100.00	20232	100.00	1.00

<u>Wisconsin Data</u>. A magnetic tape containing coded information on all brake violations in 1989 was provided by the State of Wisconsin. Wisconsin inspects both *intra*state and *inter*state trucks, and a code is available to distinguish the two. Coding is also available to identify the location of each brake violation in terms of the unit number,

the axle number, and axle end (left or right). In addition, the following three character codes identify the nature of the brake violation.

	Violation Codes
BP1	Pushrod travel exceeds 1.75"
BP2	Pushrod travel exceeds 2"
BPN	No pushrod movement when brake applied
BPA	Pushrod travel is improper
BPU	Difference in pushrod travel (L/R) exceeds 0.5 inch

Each unit of the vehicle is described separately, and is identified as unit "one of two" (1/2), or "two of two" (2/2). Unit type is coded as truck, tractor, semitrailer, or full trailer. Axles are numbered within each unit, and axle ends are identified as left or right. Thus, the available information is adequate to determine the distribution of violations by unit of the vehicle, and by axle location on each unit.

The Wisconsin data has information on 4,156 trucks, each with one or more brake violations, for a total of 8,725 violations. The average number of brake violations per truck having one or more brake violations is 2.1 in Wisconsin, as compared to 3.14 from the Oregon data. The largest percentage of brake violations is on the tractor in Wisconsin, 55.2 percent, with 42 percent on trailers. This result is the reverse of the situation in Oregon. The distribution of brake violations by violation type is shown in Table W.3. OOA violations account for 87.9 percent. These overall statistics are presented in Tables W.1 through W.3.

TABLE W.1
Wisconsin Brake Violation Statistics

4,156 vehicles with brake violations
2,721 (65%) put OOS
8,725 total violations (2.10 per vehicle)

3,558 had violations on just one unit (as opposed to both tractor and trailer).
597 had violations on more than one unit.

2,624 (55.2%) truck tractors had brake violations
130 (2.7%) straight trucks
1,998 (42.0%) trailers, including semi, had violations.

TABLE W.2
Number of Violations per Vehicle

	1	2	3	4	5	6	7	8	9	10	Total
Frequency	1,722	1,319	473	435	103	63	22	13	5	1	4,156
Percent	41.4	31.7	11.4	10.5	2.5	1.5	0.5	0.3	0.1	0.0	100.0

TABLE W.3
Brake Violations by Violation Type

	> 1.7	> 2.0	Improper	L/R Diff	Bent Rod	Unk	Totals
Frequency	1,611	6,054	373	463	26	198	8,725
(percent)	(18.5)	(69.4)	(4.3)	(5.3)	(0.3)	(2.3)	(100.0)

Key: "> 1.7" Pushrod travel exceeds 1.75".
"> 2.0" Pushrod travel exceeds 2.0".
"Improper" Pushrod adjustment is improper.
"L/R Diff" Difference in pushrod travel (L/R) exceeds .5".
"Bent" Pushrod is bent.

The next series of tables looks at the distribution of brake violations by axle and axle end (left or right). The first table (W.4) is limited to tractors. The greatest percentage of violations (38.9 percent) is on the front axle of the tractor. Over half of the time, both of the front axle brakes are in violation. On the second and third axles, both brakes are in violation about one-third of the time. When only one side is in violation on the drive axles, it is a little more likely to be the right side. It may be particularly significant that 32.1 percent of the brake violations are on the third tractor axle, and only 21.2 percent on the second axle. These statistics do not take into account the number of tractors that had only two axles. These number of 2-axle tractors would tend to decrease the percentage of violations on a third axle, since there would be none. Thus, the elevated percentage on the third axle can be interpreted as an indication of a greater likelihood for the second drive axle to be in violation, although not quite as high as the front axle. This interpretation is consistent with the impressions of some of the inspectors interviewed.

TABLE W.4
Brake Violations by Location
Tractors
(column percents sum to 100)

Location	Axle 1	2	3	Unk	Total
Left	188 (15.7)	172 (26.4)	282 (28.6)	17 (7.1)	659 (21.5)
Right	176 (14.7)	225 (34.5)	348 (35.3)	23 (9.7)	772 (25.2)
Both	640 (53.6)	238 (36.5)	335 (34.0)	56 (23.5)	1,269 (41.3)
Unknown	190 (15.9)	17 (2.6)	20 (2.0)	142 (59.7)	369 (12.0)
Total	1,194 (100.0)	652 (100.0)	985 (100.0)	238 (100.0)	3,069 (100.0)
(row percent)	(38.9)	(21.2)	(32.1)	(7.8)	(100.0)

Table W.5 shows the location of the brake violations on trailers. As would be expected, 89.8 percent are on either the first or second axle since few trailers have more than two axles. As with the drive axles on the tractors, the second axle is somewhat more likely to be in violation. Both axle ends are in violation about half of the time with the right being slightly more frequent than the left when only one end is in violation. Straight trucks are only a small percentage of the vehicles inspected, and only a small percentage of the brake violations. The distribution of brake violations by axle and axle end is shown for straight trucks in Table W.6. There is little difference in the percentage of brake violations on the first, second, and third axles. However, the majority of brake violations on the front axle involve both ends, as was observed on the tractors.

TABLE W.5
Brake Violations by Location
Trailers
(column percents sum to 100)

	Axle								
Location	1	2	3	4	5	6	7	unk	total
Left	268 (24.1)	207 (17.7)	10 (20.8)	14 (30.4)	15 (31.3)	3 (50.0)	1 (50.0)	8 (7.2)	526 (20.7)
Right	295 (26.5)	310 (26.5)	7 (14.6)	15 (32.6)	18 (37.5)	0 (0.0)	0 (0.0)	12 (10.8)	657 (25.8)
Both	523 (47.0)	611 (52.2)	29 (60.4)	13 (28.3)	9 (18.8)	3 (50.0)	1 (50.0)	10 (9.0)	1,199 (47.1)
Unk	27 (2.4)	42 (3.6)	2 (4.2)	4 (8.7)	6 (12.5)	0 (0.0)	0 (0.0)	81 (73.0)	162 (6.4)
Total	1,113 (100.0)	1,170 (100.0)	48 (100.0)	46 (100.0)	48 (100.0)	6 (100.0)	2 (100.0)	111 (100.0)	2,544 (100.0)
(row %)	(43.8)	(46.0)	(1.9)	(1.8)	(1.9)	(0.2)	(0.1)	(4.4)	(100.0)

TABLE W.6
Brake Violations by Location
Straight Trucks
(column percents sum to 100)

	Axle						
Location	1	2	3	4	5	Unk	Total
Left	8 (18.6)	14 (31.1)	12 (24.0)	3 (23.1)	1 (50.0)	1 (4.5)	39 (22.3)
Right	6 (14.0)	14 (31.1)	11 (22.0)	5 (38.5)	0 (0.0)	0 (0.0)	36 (20.6)
Both	27 (62.8)	15 (33.3)	23 (46.0)	4 (30.8)	1 (50.0)	1 (4.5)	71 (40.6)
Unknown	2 (4.7)	2 (4.4)	4 (8.0)	1 (7.7)	0 (0.0)	20 (90.9)	29 (16.6)
Total	43 (100.0)	45 (100.0)	50 (100.0)	13 (100.0)	2 (100.0)	22 (100.0)	175 (100.0)
(row percent)	(24.6)	(25.7)	(28.6)	(7.4)	(1.1)	(12.6)	(100.0)

Brake violations could also be broken down by *inter-* and *intra*state carriers in the Wisconsin data. Table W.7 breaks down the brake violations by carrier type unit of the truck to see if there is any difference in this pattern. As would be expected, most of the straight trucks are operated by intrastate carriers. Of primary interest is the finding that the intrastate carriers have a greater proportion of violations on the semi-trailers as compared with tractors. This intrastate subset of the Wisconsin data is consistent with the overall statistics from Oregon in this regard. It is only the interstate carriers in Wisconsin that show a greater percentage of brake violations on the tractor than on the semi-trailer.

TABLE W.7
Brake Violations by Unit
Interstate vs. Intrastate Hauls

	Tractor	Truck	Trailer	Semi	Totals
Interstate	4,209	94	681	2,667	7,651
(percent)	(55.0)	(1.2)	(8.9)	(34.9)	(100.0)
Intrastate	304	154	51	464	973
(percent)	(31.2)	(15.8)	(5.2)	(47.6)	(100.0)
Total	4,513	248	732	3,131	8,624
(percent)	(52.3)	(2.9)	(8.5)	(36.3)	(100.0)

Summary. The Oregon and Wisconsin inspection data were examined for evidence of key factors associated with brake adjustment violations and patterns in brake-adjustment violations that might suggest key factors. In general, the available information did not include many of the factors originally identified. Some coding was available in each state to identify different carrier types. However, there were not marked differences in the patterns of brake violations among different carrier types. Unit of the truck was identified in each file also. Here the results were somewhat mixed. The Oregon data tended to support the inspectors impressions that trailers were somewhat more likely to have brake violations. However, only the smaller group of intrastate carriers in Wisconsin showed a similar result. The interstate carriers in Wisconsin showed more violations on the tractors. A shortcoming of the Wisconsin data is that we did not get information on *all* trucks that were inspected. Some of the tractors with brake violations may have been operating bobtail so that there could not be any trailer violations for these tractors. However, it is unlikely that appreciable numbers of bobtail tractors were inspected.

Wisconsin was the only state inspection file that we found that included coding that identified the unit, axle, and axle end of the violation. This information allowed us to look for patterns in brake violations by unit, axle, and axle end. Two observations made by many of the inspectors interviewed were confirmed by this data. The first was a greater incidence of OOAbrakes on the front axle. Usually, both brakes on the front axle were OOA, and very few violations were for the side-to-side difference in brake-adjustment. This result is consistent with a situation where the front axle brakes are backed-off. The other observation supported by the Wisconsin data is a greater tendency for the rear axle of a tandem pair to be OOA. On many trucks, the brakes on the rear axle are somewhat harder to access for adjustment. With regard to left/right side differences, the most common situation on any axle is for both brakes to be in violation. However, when only one end is in violation, the right side is in violation a little more often than the left.

5.0 DEVELOPING STATISTICAL MEASURES PERTAINING TO THE RELATIONSHIPS BETWEEN THE KEY FACTORS IDENTIFIED AND BRAKE-ADJUSTMENT.

(PRELIMINARY ANALYSIS OF NTSB BRAKE DATA)

The tables presented below are limited to 5-axle, tractor/single-trailer combinations. This eliminates the tractor/double-trailer combinations, but those units accounted for only 36 combinations of the 910 inspected. Thus, excluding the doubles does not significantly limit the amount of data available for analysis. On the other hand, limiting the analysis to singles simplifies the discussion since all the units involved consist of a 3-axle tractor pulling a 2-axle trailer.

Factors Associated With Brakes OOA

In all of the tables, the brake-adjustment criteria as stated in the North American Uniform Vehicle Out-of-Service Criteria Policy Statement were followed. That is to say, for each brake, the stroke, given the chamber size, was compared with the figures in the chart on Page 8 of the Statement and classified as either OOA or defective. Brakes at, or 0.25" over the "maximum stroke at which brakes must be readjusted," were categorized as OOA. Brakes with strokes 0.25" or more over the readjustment limit were categorized as defective. Brakes were also counted as defective if they were inoperative. (A separate variable for each brake gives the inoperative status.) The tables are organized around a few broad influences on brake-adjustment. Several categories of factors which may be associated with brake-adjustment problems were identified and then variables in the NTSB data were examined for their relevance to those factors. First, there is the mechanical design of the brake and any braking aids that may be part of the trucks design. The NTSB data includes data on slack type and the use of "Jake" brakes. Next, here is the general category of trucking operations and the business and regulatory environment. This category has to do with the extent to which competitive pressures may affect maintenance practices, and how servicing is done. Another broad category has to do with how the equipment is used and the effect of age and use on brake-adjustment. In this category, we were able to look at model year for both the tractor and trailer, and cargo body style. A final general category has to do with truck design, the extent to which different cab styles, and even makes, are associated with brake-adjustment problems.

BRAKE DESIGN RELATED FACTORS

Slack Type

The first table shows slack type by the OOA status. The top half of the table shows the raw numbers. These are counts of brakes. Only brakes with automatic or manual slacks are included in this table. Wedge-type and other brakes are excluded. For the column headings, "ok" means that the brake is properly adjusted. "OOA" means that the brake exceeds the maximum stroke at which it must be readjusted, but by less than 0.25". "Defect" means that the brake exceeds the maximum stroke by at least 0.25", and thus, constitutes a defective brake for the purposes of the OOS criteria. "Unk" means the adjustment status could not be determined.

Out of Adjustment Status by Slack Type, Singles Only

	ok	ooa	defect	unk	total
auto	1771	219	75	0	2065
manual	4809	838	896	4	6547
total	6580	1057	971	4	8612
	ok	ooa	defect	unk	total
auto	85.76%	10.61%	3.63%	0.00%	100.00%
manual	73.45%	12.80%	13.69%	0.06%	100.00%
total	76.41%	12.27%	11.27%	0.05%	100.00%

It seems that the advantage of the automatic slack is in preventing a brake from getting so far out of adjustment that it constitutes a defective brake. Both slack types had similar proportions of brakes that were out of adjustment, though the manual proportion was about 2 percent higher. And overall, the proportion of automatic slacks with properly adjusted brakes was only about 12 percent higher than that of manual slacks. Almost a quarter of the brakes in the NTSB data had automatic slacks, so these differences are certainly statistically reliable.

Jake Brakes

Among the data gathered as part of the NTSB survey was whether the sample vehicles were equipped with "Jake" brakes. This includes any sort of drive line, transmission, or engine retarder. It appears that the use of "Jake" brakes has some effect on brake-adjustment. Combinations equipped with such brakes had lower proportions of OOA and defective brakes. Overall, almost 80 percent of the brakes on such units were within the adjustment standards, while 72.4 percent of the brakes on combinations without Jake brakes were adjusted.

Brake Adjustment Status by "Jake" Brake Use

	ok	ooa	defect	unk	total
yes	2610	336	278	66	3290
no	2643	499	466	42	3650
unk	1327	222	233	18	1800
total	6580	1057	977	126	8740

	ok	ooa	defect	unk	total
yes	79.33%	10.21%	8.45%	2.01%	100.00%
no	72.41%	13.67%	12.77%	1.15%	100.00%
unk	73.72%	12.33%	12.94%	1.00%	100.00%
total	75.29%	12.09%	11.18%	1.44%	100.00%

FACTORS RELATED TO THE OPERATING ENVIRONMENT

Carrier Type

NTSB data include information about fleet size, whether the carrier operates inter- or intrastate, and whether the carrier is a private or for-hire carrier. Fleet size information is difficult to get and is missing in about half of the cases. Only 90 of the 910 vehicles inspected were operated by intrastate carriers, probably due to the fact that the inspection sites were all on interstates.[1] But the carrier type information is reasonably complete and both types of carrier are represented adequately.

One might expect that private carriers would have a better record than the for-hire group, but the two groups appear to be about the same. For-hire carriers have a slightly higher proportion of brakes that are within adjustment limits, but the difference is only 2.4 percent. The sample sizes are large enough that this may be statistically significant, but it is not of practical significance in identifying factors related to problems with brake-adjustment.

[1]A second round of data collection was conducted at sites off the interstates. This data should be available for analysis soon. It is likely that the data will cover a different mix of company types, cargo bodies, and operations, which will be very useful in this analysis.

Brake Adjustment Status by Carrier Type

	ok	ooa	defect	unk	total
For-hire	5147	794	727	102	6770
private	1370	235	231	24	1860
unk	63	28	19	0	110
total	6580	1057	977	126	8740

	ok	ooa	defect	unk	total
For-hire	76.03%	11.73%	10.74%	1.51%	100.00%
private	73.66%	12.63%	12.42%	1.29%	100.00%
unk	57.27%	25.45%	17.27%	0.00%	100.00%
total	75.29%	12.09%	11.18%	1.44%	100.00%

Responsibility for Brake-Adjustment

In a related question, the NTSB data also includes information on whether the driver is responsible for the adjustment of the brakes. Perhaps surprisingly, in 520 of the 874 cases of singles, the driver was responsible for brake-adjustment. But this appears to make no difference. The proportion of OOA and defective brakes is about the same for both trucks in which the driver is responsible for keeping the brakes in adjustment and in which that responsibility lies elsewhere. The proportion of brakes within adjustment standards is higher by 2 percent for the drivers than for the others, but that difference is not great enough to be meaningful.

Brake Adjustment Status by Driver Responsibility for Adjustment

	ok	ooa	defect	unk	total
yes	3934	588	600	78	5200
no	2165	396	333	46	2940
unk	481	73	44	2	600
total	6580	1057	977	126	8740

	ok	ooa	defect	unk	total
yes	75.65%	11.31%	11.54%	1.50%	100.00%
no	73.64%	13.47%	11.33%	1.56%	100.00%
unk	80.17%	12.17%	7.33%	0.33%	100.00%
total	75.29%	12.09%	11.18%	1.44%	100.00%

Thus, it appears that the main variables which might distinguish different approaches to truck operations do not appear to be associated with success in keeping brakes properly adjusted. But the new data from inspection sites off the interstates and the fleet size data remain to be examined.

FACTORS RELATED TO THE AGE AND USE OF THE EQUIPMENT

Tractor Model Year

Brake-adjustment was considered by the model year of the tractor. Only the brakes on the power unit's axles were used in the analysis. Pre-1983 model years were lumped together. Later model years are shown separately.

Brake Adjustment Status by Tractor Model Year

year	ok	ooa	defect	unk	total
<1983	580	95	166	107	948
1983	143	16	21	0	180
1984	307	53	59	1	420
1985	405	64	65	6	540
1986	301	31	28	0	360
1987	425	58	39	0	522
1988	532	96	20	0	648
1989	766	78	50	0	894
1990	542	56	44	0	642
1991	19	4	7	0	30
unk	51	7	2	0	60
total	4071	558	501	114	5244
year	ok	ooa	defect	unk	total
>1983	61.18%	10.02%	17.51%	11.29%	100.00%
1983	79.44%	8.89%	11.67%	0.00%	100.00%
1984	73.10%	12.62%	14.05%	0.24%	100.00%
1985	75.00%	11.85%	12.04%	1.11%	100.00%
1986	83.61%	8.61%	7.78%	0.00%	100.00%
1987	81.42%	11.11%	7.47%	0.00%	100.00%
1988	82.10%	14.81%	3.09%	0.00%	100.00%
1989	85.68%	8.72%	5.59%	0.00%	100.00%
1990	84.42%	8.72%	6.85%	0.00%	100.00%
1991	63.33%	13.33%	23.33%	0.00%	100.00%
unk	85.00%	11.67%	3.33%	0.00%	100.00%
total	77.63%	10.64%	9.55%	2.17%	100.00%

Tractors with a model year before 1986 have much higher rates of brakes so OOA as to count as defective brakes. They also appear to have higher rates of brakes OOA, though the differences are not so striking. The poor showing of the 1991 model is based on just thirty brakes, which is five vehicles, so that is not a reliable indication of the performance of the newest model year. On the other hand, all of the other categories have more than enough data to be reliable.

Trailer Model Year

The model of the trailer was also considered to see if the same pattern was shown. Instead, there was no particular trend to the proportions of OOA and defective brakes by model year. Pre-1983 model year trailers had the lowest proportion of fully-adjusted brakes, but the second lowest model year was 1985, and 1990 was the third lowest. There was a reasonable number of trailers for all the model year categories in the accompanying table.

Brake Adjustment Status by Trailer Model Year

	ok	ooa	defect	unk	total
<1983	494	110	136	8	748
1983	125	17	18	0	160
1984	203	36	41	0	280
1985	190	51	39	0	280
1986	216	32	28	0	276
1987	216	37	47	0	300
1988	281	55	44	0	380
1989	299	72	53	0	424
1990	103	23	22	0	148
unk	382	66	48	4	500
total	2509	499	476	12	3496

	ok	ooa	defect	unk	total
<1983	66.04%	14.71%	18.18%	1.07%	100.00%
1983	78.13%	10.63%	11.25%	0.00%	100.00%
1984	72.50%	12.86%	14.64%	0.00%	100.00%
1985	67.86%	18.21%	13.93%	0.00%	100.00%
1986	78.26%	11.59%	10.14%	0.00%	100.00%
1987	72.00%	12.33%	15.67%	0.00%	100.00%
1988	73.95%	14.47%	11.58%	0.00%	100.00%
1989	70.52%	16.98%	12.50%	0.00%	100.00%
1990	69.59%	15.54%	14.86%	0.00%	100.00%
unk	76.40%	13.20%	9.60%	0.80%	100.00%
total	71.77%	14.27%	13.62%	0.34%	100.00%

Considering this table and the last, it seems that trailer brakes are more likely to be OOA. A table that addresses that issue explicitly is presented below.

Axle Number and Location

The following table shows only OOA problems and defective brakes. ("Defective" is defined as a brake so far OOA as to count as a defective brake for the purposes of the brake inspection OOS criteria.) The percentages in the cells are the percentages of brakes at a particular axle number and location which are OOA or defective. Thus, 10.3 percent of the brakes on the left side of axle number one were OOA and 9.95 percent were defective. Axle 1 is the steering axle, 2 and 3 are the drive axles on the tractor. Axles 4 and 5 are the trailer's axles.

Brake Adjustment by Axle Number and Location

	left		right	
axle	ooa	defect	ooa	defect
1	90	87	95	84
2	86	65	77	89
3	108	85	102	91
4	118	120	137	108
5	119	118	125	130
total	521	475	536	502

	left		right	
axle	ooa	defect	ooa	defect
1	10.30%	9.95%	10.87%	9.61%
2	9.84%	7.44%	8.81%	10.18%
3	12.36%	9.73%	11.67%	10.41%
4	13.50%	13.73%	15.68%	12.36%
5	13.62%	13.50%	14.30%	14.87%
total	11.92%	10.87%	12.27%	11.49%

Overall, trailer axles are more likely to be either out of adjustment or defective. From 27 percent to 29 percent of trailer axles have adjustment problems, while 20 percent to 21 percent of tractor axles are either OOA or defective. The steering axle appears to have about the same proportion of adjustment problems as the other axles on the tractor.

Cargo Body Type

Cargo body type might be expected to have a large impact on brake-adjustment. Dumps and tanks typically carry very heavy loads which put greater stress on the brakes. Vans are more often used for general freight hauling and lighter loads. Moreover, cargo bodies are associated with different types of carriers and operations, dumps with private carriers and local hauling, vans with for-hire interstate carriers and tanks with both services.

The differences found between different cargo body types are not great. Overall, the proportion of properly-adjusted brakes ranges from a low of 67.5 percent for the tanks to 74.7 percent for flatbeds. Tanks and dumps have the highest proportion of brakes so far OOA as to be counted as defective. Vans have the lowest proportion of defective brakes, but the highest proportion of OOA brakes. It may be a little surprising to see that flatbeds do the best. Since tanks so often haul hazardous materials, and consequently are subject to more rigorous inspections, one might have expected that their brakes would be in better shape.

Brake Adjustment Status by Cargo Body Type

	ok	ooa	defect	unk	total
flatbed	457	65	90	0	612
van	1608	352	284	8	2252
tank	173	32	47	4	256
dump	101	19	24	0	144
other	164	29	31	0	224
unk	6	2	0	0	8
total	2509	499	476	12	3496

	ok	ooa	defect	unk	total
flatbed	74.67%	10.62%	14.71%	0.00%	100.00%
van	71.40%	15.63%	12.61%	0.36%	100.00%
tank	67.58%	12.50%	18.36%	1.56%	100.00%
dump	70.14%	13.19%	16.67%	0.00%	100.00%
other	73.21%	12.95%	13.84%	0.00%	100.00%
unk	75.00%	25.00%	0.00%	0.00%	100.00%
total	71.77%	14.27%	13.62%	0.34%	100.00%

TRACTOR MAKE AND CAB STYLE

Tractor Make

Brake-adjustment problems by tractor make were also examined. Only the tractor's axles were considered for this analysis. The idea was to determine if any particular makes were associated with higher rates of adjustment problems. As it happens, most makes have about the same proportion of OOA and defective brakes. But both Freightliner and White/Volvo have strikingly lower rates of defective brakes. About 5.5 percent of Freightliner brakes were defective, compared with 9.5 percent for all makes. White/Volvo had 1.2 percent defective brakes. The sample size for White/Volvo is only eighty-four brakes (twenty-four tractors) but Freightliners were the second most common tractor make.

Brake Adjustment Status By Tractor Make

	ok	ooa	defect	unk	total
Frtliner	1027	107	66	12	1212
Ford	160	28	20	2	210
GMC	162	17	25	6	210
Navistar	982	182	146	16	1326
Kenworth	535	75	79	37	726
Mack	347	43	46	14	450
Pete	523	67	81	13	684
Wh/GMC	123	18	15	0	156
Wh/Volvo	73	10	1	0	84
White	80	5	11	6	102
Other	59	6	11	8	84
Total	4071	558	501	114	5244

	ok	ooa	defect	unk	total
Frtliner	84.74%	8.83%	5.45%	0.99%	100.00%
Ford	76.19%	13.33%	9.52%	0.95%	100.00%
GMC	77.14%	8.10%	11.90%	2.86%	100.00%
Navistar	74.06%	13.73%	11.01%	1.21%	100.00%
Kenworth	73.69%	10.33%	10.88%	5.10%	100.00%
Mack	77.11%	9.56%	10.22%	3.11%	100.00%
Pete	76.46%	9.80%	11.84%	1.90%	100.00%
Wh/GMC	78.85%	11.54%	9.62%	0.00%	100.00%
Wh/Volvo	86.90%	11.90%	1.19%	0.00%	100.00%
White	78.43%	4.90%	10.78%	5.88%	100.00%
Other	70.24%	7.14%	13.10%	9.52%	100.00%
Total	77.63%	10.64%	9.55%	2.17%	100.00%

This pattern is suggestive rather than conclusive. The explanation could be the design of the vehicle or brake manufacturer or the type of brake typically installed. There may be other explanations. In any case, the difference is intriguing and warrants further examination.

Cab Style

Another possible influence on brake-adjustment is the design of the cab. Some designs may make the brakes more accessible and consequently more easily adjusted. But when brake adjustments were examined by cab style, the differences between conventional and cabovers were slight. Conventionals had lower proportions of OOA and defective brakes than cabovers. Only 8.8 percent of conventionals' brakes were defective, compared with 10.9 percent for cab-overs. And conventionals were 4 percent higher in the proportion of brakes within adjustment limits (79 percent to 75 percent). The differences are real, but the size of the effect is not sufficient to have a major impact.

Brake Adjustment Status by Cab Style

	ok	ooa	defect	unk	total
conv	2636	342	293	65	3336
coe	1429	216	208	49	1902
unk	6	0	0	0	6
total	4071	558	501	114	5244

	ok	ooa	defect	unk	total
conv	79.02%	10.25%	8.78%	1.95%	100.00%
coe	75.13%	11.36%	10.94%	2.58%	100.00%
unk	100.00%	0.00%	0.00%	0.00%	100.00%
total	77.63%	10.64%	9.55%	2.17%	100.00%

6.0 PROVIDING A SOUND QUANTITATIVE BASIS FOR CONFIRMING OR CHANGING CURRENT OOS BRAKE ADJUSTMENT CRITERIA.

(Braking Efficiencies And Out-of-service Criteria Using the NTSB Data)

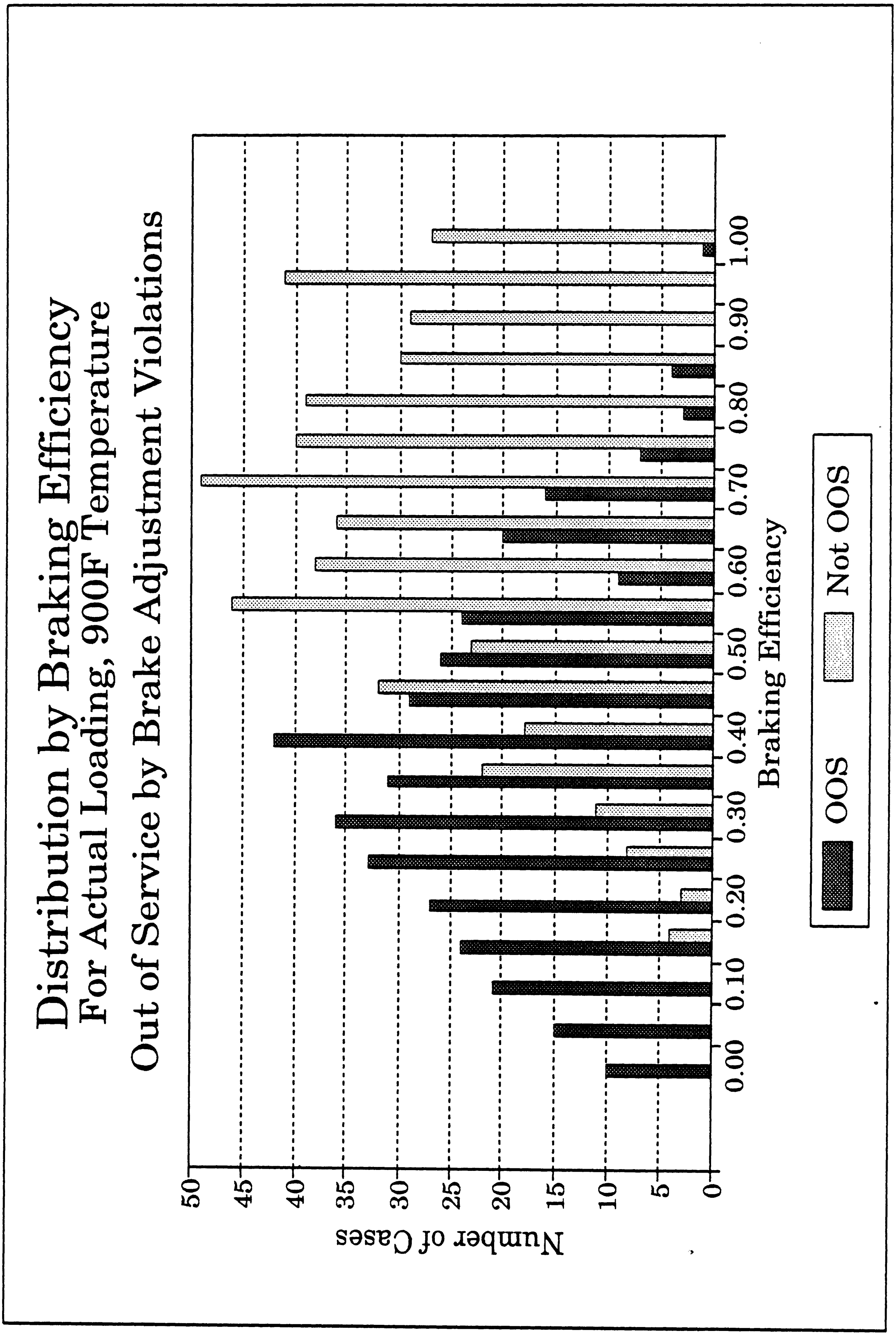
The appended charts examine the distribution of calculated braking efficiencies for different loadings and brake temperatures for vehicles put OOS for brake-adjustment violations and those that were not put OOS for brake-adjustment violations. Calculated brake efficiencies are from the NTSB data. They were determined for the actual loading of the vehicle and for the vehicle if it were loaded to 80,000 pounds. There are two sets of four charts, one set for the actual loading of the vehicle and one for the vehicle if loaded to 80,000 pounds. Within each set, the four charts represent the baseline case with no temperature-related expansion and then with the brakes at 400°F, 600°F, and 900°F. Only 5-axle, tractor-trailer units are included in the comparison.

OOS is restricted just to vehicles put OOS due to brake-adjustment problems. The rules relating to brake-adjustment as outlined in the North American Uniform Vehicle Out-of-Service Criteria Policy Statement were applied to the vehicles in the NTSB data. Brakes were classified as defective if they were inoperative, or if the stroke exceeded the maximum readjustment length by 0.25" or more. Brakes were classified as OOA if the stroke exceeded the readjustment length by less that 0.25", and two OOA brakes count as one defective brake. If the total of defective brakes on a combination was 20 percent or more of the brakes, the vehicle was classified as OOS. A defective brake on the steering axle also put a vehicle OOS.

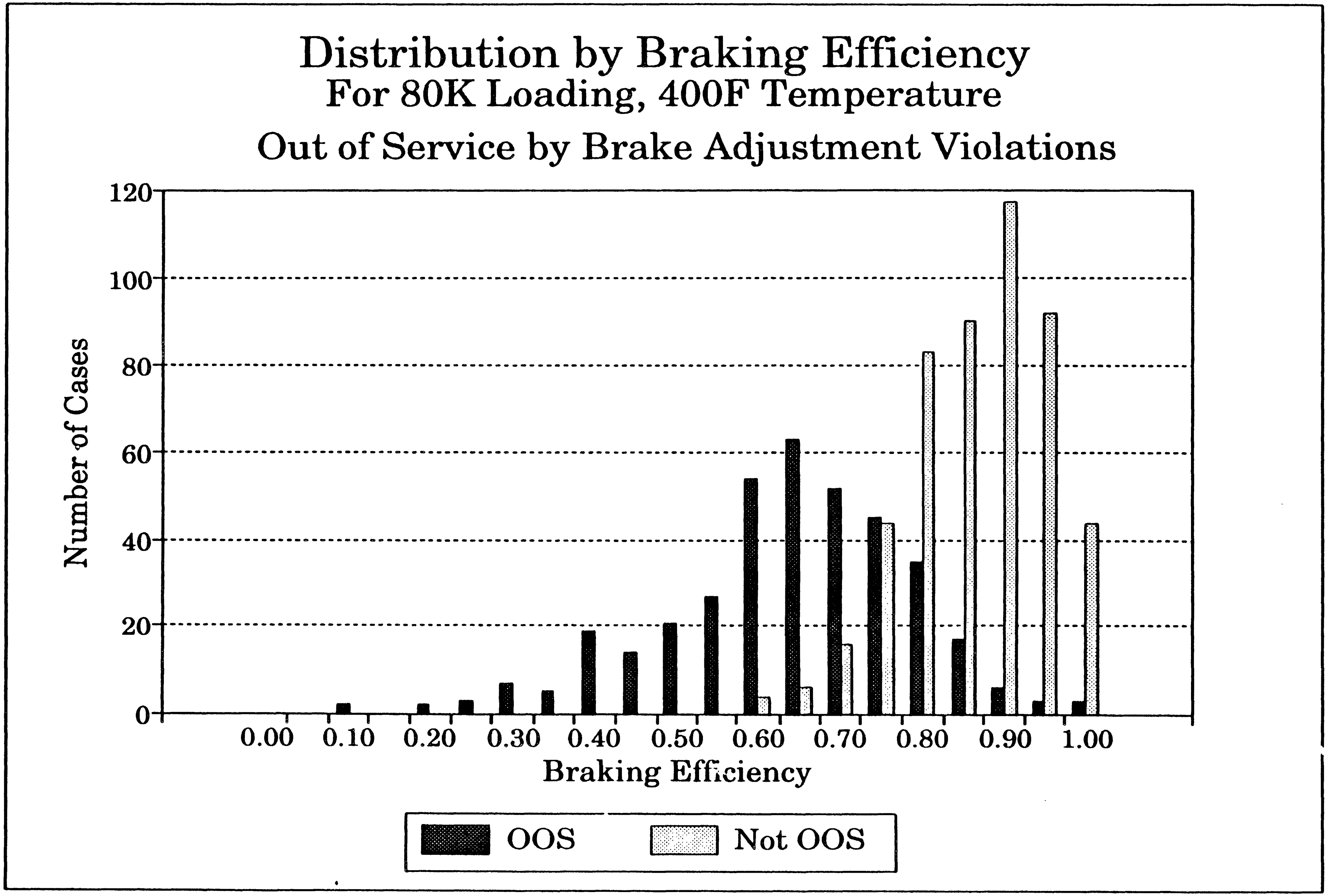
The appended charts show how well the brake-adjustment OOS criteria discriminate between braking efficiencies. From one point of view, the charts for the 80K loadings are the fairest comparison since they compare braking efficiencies given the same gross weight. For both the default case and the 400°F, the OOS criteria do a good job of separating the two populations. There is some overlap in the tails, but the means of the two populations are clearly separated.

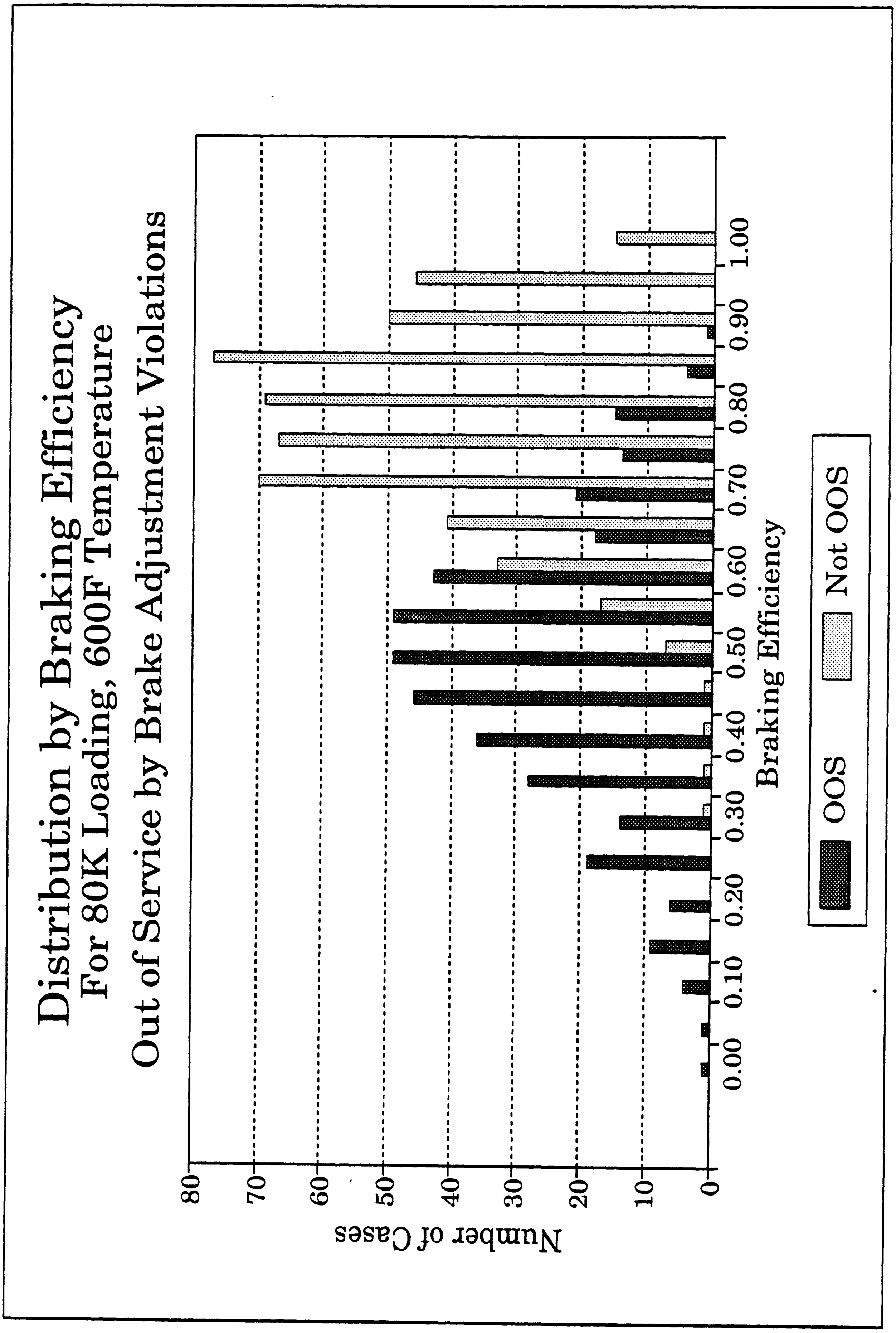
The charts for the actual loading are also of interest. These efficiencies were calculated for the gross weight of the vehicle at the time of the inspection and so show braking efficiencies for the two populations as they actually operate. For the default and 400°F case, there is somewhat more overlap. There is a significant number of cases which were put OOS, yet whose braking efficiencies are 1.00. Though their braking would have been significantly degraded if they had been loaded to 80K, their braking efficiency was at 1.00 as they were actually loaded.

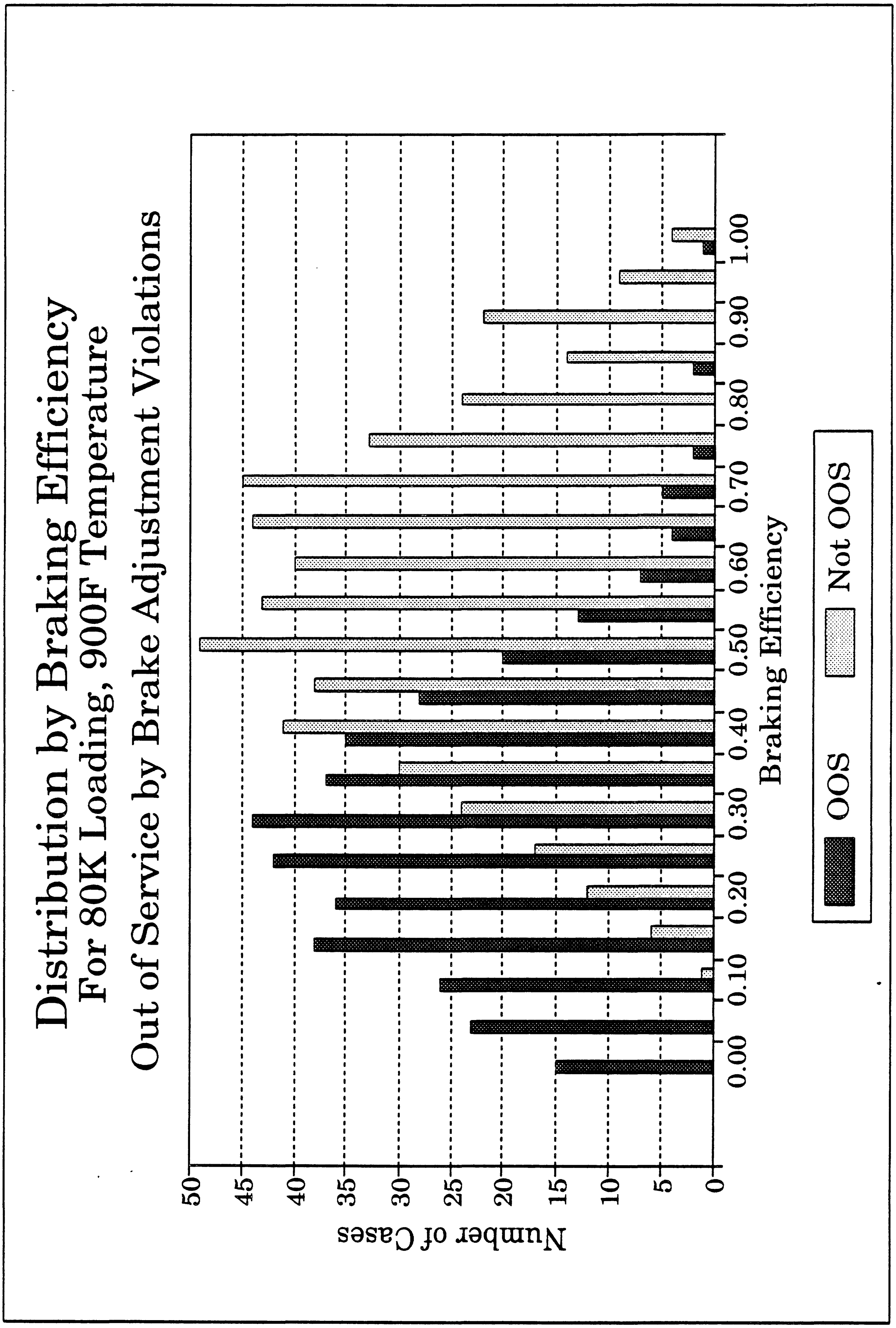
At higher temperatures, the two distributions broaden and overlap to a much greater extent.



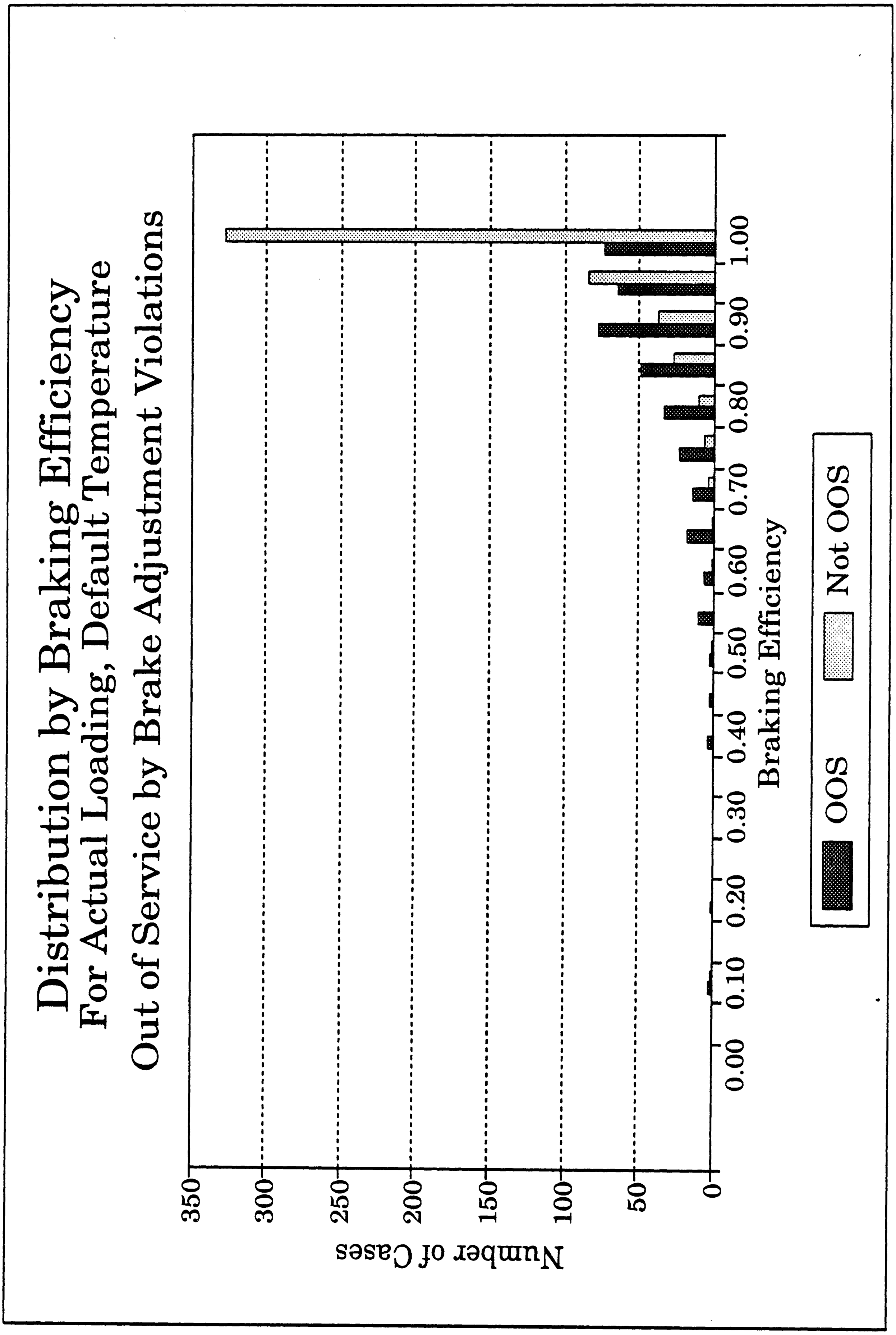
Distribution by Braking Efficiency
For Actual Loading, 900F Temperature
Out of Service by Brake Adjustment Violations
Number of Cases
0
5
10
15
20
25
30
35
40
45
50
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Braking Efficiency
OOS
Not OOS

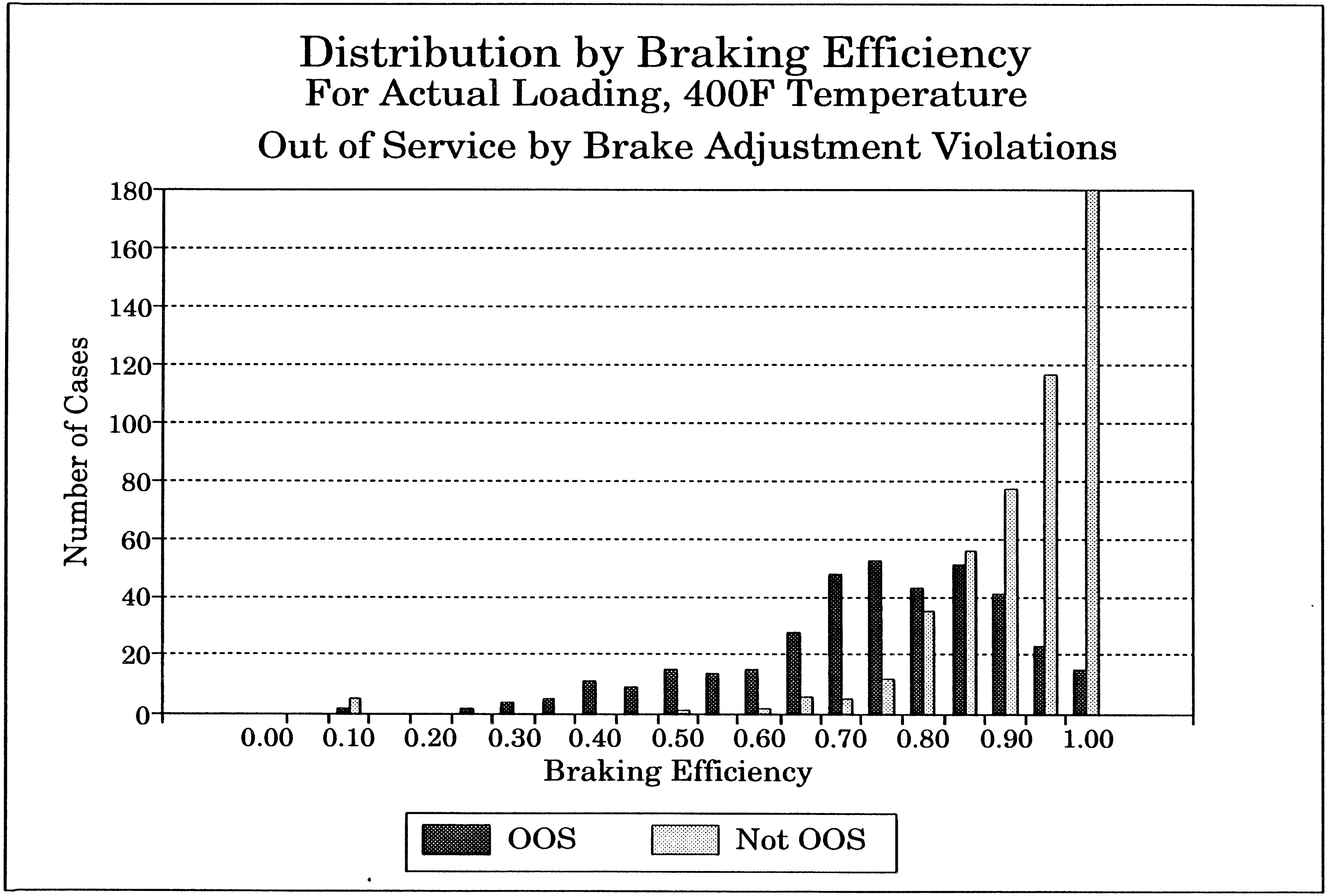

Distribution by Braking Efficiency
For 80K Loading, 400F Temperature
Out of Service by Brake Adjustment Violations
Number of Cases
0
20
40
60
80
100
120
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Braking Efficiency
OOS
Not OOS

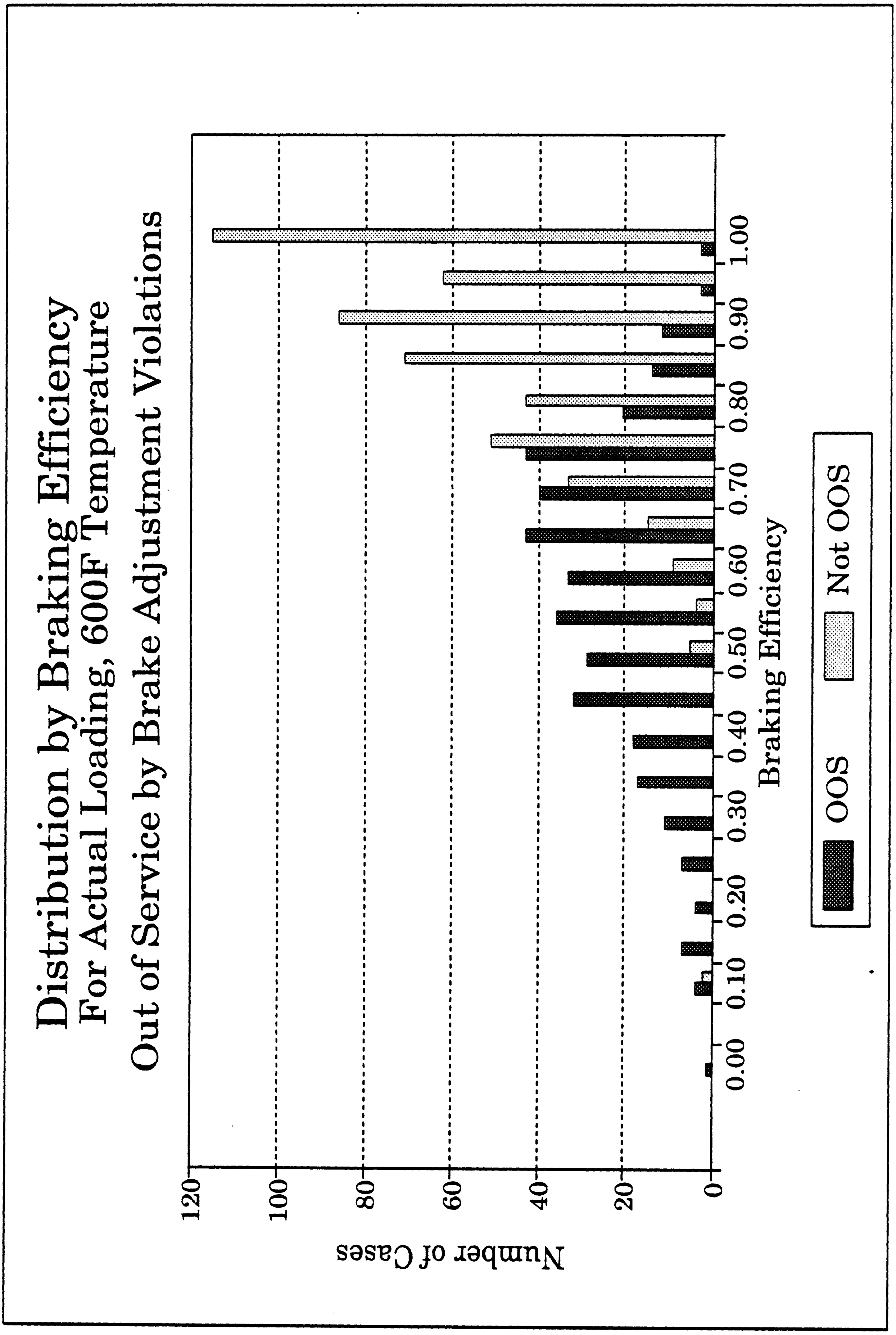

Distribution by Braking Efficiency
For 80K Loading, 600F Temperature
Out of Service by Brake Adjustment Violations
Number of Cases
0
10
20
30
40
50
60
70
80
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Braking Efficiency
OOS
Not OOS

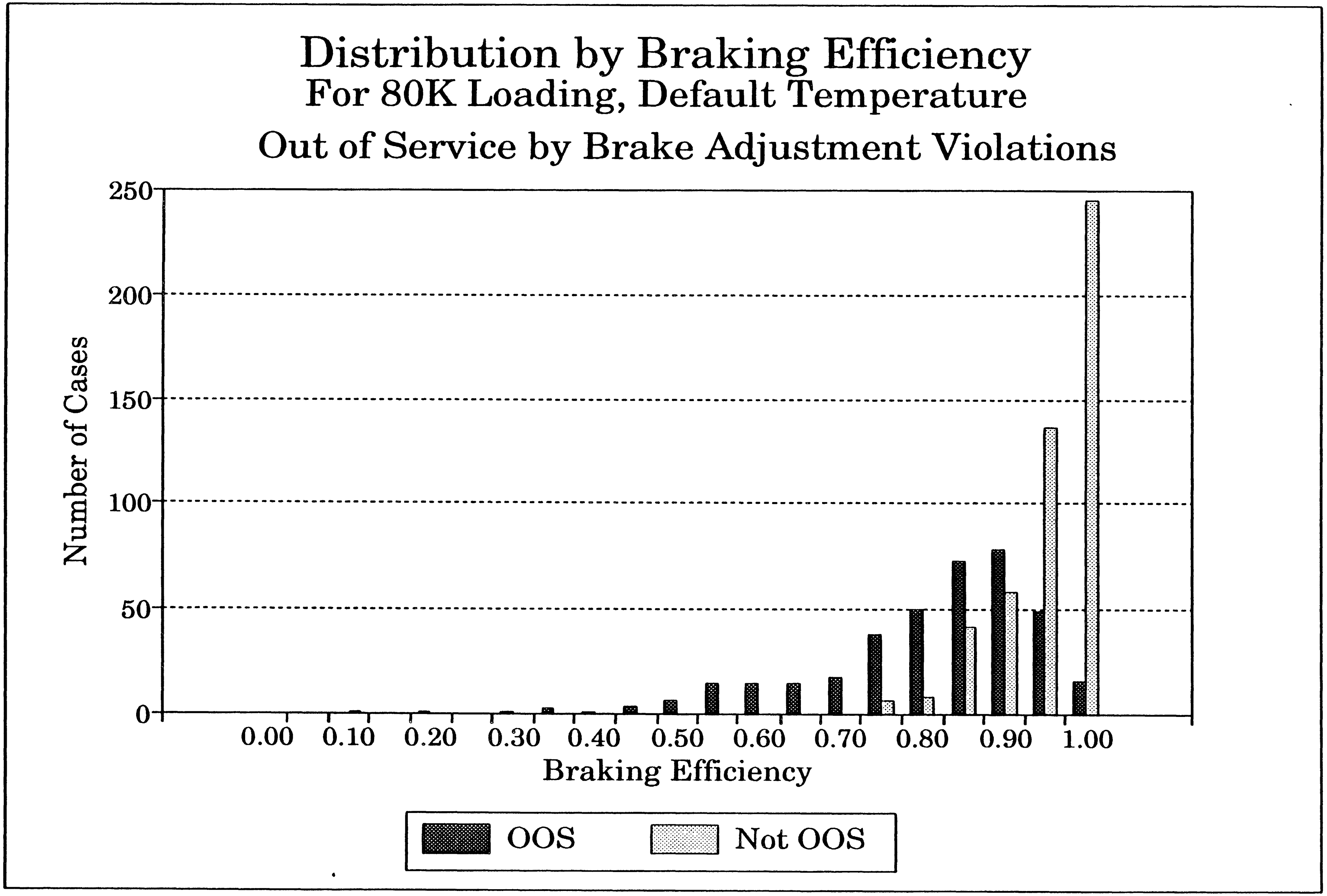


Distribution by Braking Efficiency
For 80K Loading, 900F Temperature
Out of Service by Brake Adjustment Violations
Number of Cases
0
5
10
15
20
25
30
35
40
45
50
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Braking Efficiency
OOS
Not OOS


Distribution by Braking Efficiency
For Actual Loading, Default Temperature
Out of Service by Brake Adjustment Violations
Number of Cases
350
300
250
200
150
100
50
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Braking Efficiency
OOS
Not OOS


Distribution by Braking Efficiency
For Actual Loading, 400F Temperature
Out of Service by Brake Adjustment Violations
Number of Cases
0
20
40
60
80
100
120
140
160
180
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Braking Efficiency
OOS
Not OOS


Distribution by Braking Efficiency
For Actual Loading, 600F Temperature
Out of Service by Brake Adjustment Violations
Number of Cases
0
20
40
60
80
100
120
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Braking Efficiency
OOS
Not OOS


Distribution by Braking Efficiency
For 80K Loading, Default Temperature
Out of Service by Brake Adjustment Violations
Number of Cases
0
50
100
150
200
250
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Braking Efficiency
OOS
Not OOS