UM-HSRI-76-24-1
Contract No. DOT-HS-5-01152

TRAILER BRAKE PERFORMANCE

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Final Summary Report

September 1976

Highway Safety Research Institute
The University of Michigan

Prepared for:

National Highway Traffic Safety Administration
U. S. Department of Transportation

Prepared for the Department of Transportation, National Highway Traffic Safety Administration, under Contract No. DOT-HS-5-01152. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the National Highway Traffic Safety Administration.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UM-HSRI-76-24-1		

4. Title and Subtitle	5. Report Date / 6. Performing Organization Code
TRAILER BRAKE PERFORMANCE	5. September 1976 6.
7. Author(s) J. E. Bernard, C. B. Winkler, J. D. Campbell, R. K. Gupta	8. Performing Organization Report No. UM-HSRI-76-24-1
9. Performing Organization Name and Address Highway Safety Research Institute The University of Michigan Huron Parkway and Baxter Road Ann Arbor, Michigan 48109	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DOT-HS-5-01152
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration U. S. Department of Transportation Washington, D.C. 20590	13. Type of Report and Period Covered Final Report 6/75 - 9/76 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The goals of this research project were threefold, namely, (1) to elucidate the mechanics of combination-vehicle braking (where "combination vehicles" refers to passenger car-trailer and pickup truck-trailer combination vehicles), (2) to structure a rationale for measuring trailer braking properties, and (3) to formulate a set of guidelines by which tow and trailing vehicles can be properly matched to provide acceptable combination-vehicle braking performance. The report describes analytical and empirical work aimed toward attaining these goals, including parameter sensitivity studies employing digital computer simulation and full-scale track testing of five tow vehicles and five trailers. Parameter measurements of the test trailers were also included.

A simple and practical two-step "rule" which provides for reasonable assurance of a minimum braking performance of combination-vehicles is proposed and validated for a number of sample cases. The first step of the rule is composed of a test methodology for determining the inherent braking capability of trailers alone. The second step uses this "trailer alone" measure to determine a minimum weight tow vehicle for a given trailer which will provide reasonable assurance of acceptable combination vehicle braking performance. The rule's validity requires the assumption that the tow vehicle conforms to FMVSS 105-75 and that certain in-use factors are maintained within reasonable bounds.

17. Key Words	18. Distribution Statement
Combination Vehicle, Braking, Trailer, Tow Vehicle, Electric Brake, Surge Brake, Load Equalizer, Effectiveness, suspension, testing, methodology	UNLIMITED

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
NONE	NONE	25	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

☆ U. S. GOVERNMENT PRINTING OFFICE : 1973 725-504/328

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1.0 INTRODUCTION

This document constitutes a final summary report on a research study entitled "Trailer Brake Performance" which was conducted by the Highway Safety Research Institute of The University of Michigan. The study was supported by the National Highway Traffic Safety Administration of the U. S. Department of Transportation under Contract DOT-HS-5-01152.

The goals of the research were threefold, namely:

a) to elucidate the mechanics of combination vehicle* (CV) braking,

b) to structure a rationale for measuring trailer braking properties, and

c) to formulate a set of guidelines by which tow and trailing vehicles can be properly matched to provide acceptable combination vehicle braking performance.

The next section of this report gives an overview of the project objectives, providing a rationale for our interest in the braking performance of trailers taken alone.

Following this background information, a brief review of the methodology used in the study will be given. Both analytical and empirical work will be considered.

HSRI's view of appropriate guidelines for the matching of tow and trailing vehicles to ensure a minimum level of combination-vehicle braking performance is presented in Section 4.0. Conclusions and recommendations are presented in Section 5.0.

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*Throughout this document, the term "combination vehicle" will be used to refer to passenger car-trailer and pickup truck-trailer types in which the tow vehicle is commonly equipped with an hydraulic brake system. Specifically excluded are the larger articulated vehicles in which both tow vehicle and trailer commonly employ air brake systems.

2.0 THE OBJECTIVES

NHTSA has stated two primary objectives for this research study, namely:

1) To determine the characteristics of the towed and towing vehicle, including geometry, brake design features, and usage factors which have a major influence on the brake performance of the vehicle combination.

2) To develop and recommend a specification and test rationale by which satisfactory brake performance of the combination can be assured by controlling the brake performance of the towed vehicle in a safety standard.

In the Introduction to this report, these two objectives were restated, dividing the second into two elements, namely, the measurement of trailer brake performance and a rationale for the matching of combinations.

From the onset, it was quite clear that the first NHTSA objective could be met. The state of the art of vehicle dynamics is sufficiently advanced such that the tools required to satisfactorily meet this goal are available. But it was not obvious, a priori, that NHTSA's second stated objective would yield to satisfactory solution. In particular, the possibilities for success in meeting this second objective hinge on the findings associated with the first.

Consider two extreme possibilities. First, that many characteristics of towed and towing vehicles might be found to have a major influence on the braking performance of the combination vehicle. In this case, the possibility of success in meeting the second objective would be severely limited. Any proposed guideline with sufficient technical complexity to simultaneously deal with several important factors would likely prove to be impractical. Conversely, a guideline of sufficient simplicity to be practical would probably be inadequate.

At the other extreme, consider a finding suggesting that only one or two important factors affect combination vehicle braking performance. In this case, success in the second objective would be assured simply by placing adequate bounds on these factors.

To be sure, the real situation lies between these extremes. But the statement of the two extremes serves to illustrate an important, implicit element of the first objective—to identify and remove from consideration those factors which, due to the physics of the process or the influence of common practice, have secondary or negligible influence on combination vehicle braking.

Whatever the complexity of the braking process, it is important to note that NHTSA's second objective has two implicit requirements. First, it is the brake performance of the towed vehicle which is to be controlled. Thus, a methodology for measuring the inherent braking capability of the trailer, independent of the tow vehicle, is required. Second, by regulating the towed vehicle's performance, the combination vehicle performance is to be assured. The implication here is that the potential degradation of braking performance accruing from the addition of a trailer to a tow vehicle must be satisfactorily limited. This report will show that this can be accomplished through a procedure whereby the measured capabilities of a given trailer are employed to define an acceptable class of tow vehicle for that trailer.

3.0 THE METHODOLOGY

Both analytical and empirical activities were undertaken to address the objectives of the study. The work done can be classified into several areas, primarily analysis, component testing, and full-scale vehicle testing.

Analysis was the central element of the program. This activity began early and continued throughout the study. Early in the study, a program of trailer component testing was undertaken to provide the necessary parametric data for analysis. The analysis led to a fuller understanding of the mechanisms of CV braking, and to the development of the vehicle test methodology. This methodology was implemented in a vehicle test program whose results supplemented and validated the analytical results. As a final stage of analysis, guidelines for the matching of CV's were developed and their validity tested by comparison with test results.

The vehicle testing portion of this study was conducted at the Bendix Automotive Development Center (BADC), New Carlisle, Indiana. The program was structured to examine basic questions addressing combination vehicle braking performance, viz.,

1) What is the braking capability of the tow vehicle alone?

2) What is the inherent braking capability of the trailer alone?

3) What penalty or burden in stopping capability derives from uniting the towing and trailing vehicles into a combination vehicle?

Three distinct test sequences were employed to probe these questions. These were:

1) Tow vehicle alone effectiveness tests

2) Trailer alone effectiveness tests

3) Combination vehicle effectiveness tests

Additional testing was conducted to examine the fade properties of trailer brakes.

The tow vehicles and trailers used in the test program appear in Figure 3.1*.

The large majority of the effectiveness tests were conducted from an initial velocity of 40 mph. This was done to provide acceptable test safety in the combination vehicle tests, particularly those of the "mismatch" combinations, and to enhance the comparative analysis of the results of the three test series. (A limited number of tests were conducted at 60 mph to examine higher velocity effects.)

Except for the initial velocity, tow vehicle alone effectiveness tests were conducted essentially as prescribed by FMVSS 105-75 with the test vehicle loaded to gvw. Trailer alone effectiveness tests consisted of snubs in which the combination vehicle was decelerated through the application of trailer brakes only. The final velocity of these snubs was determined individually for each vehicle such that the trailer brakes were subjected to an energy absorption level equal to that which they would experience in a full stop of the mass equivalent of the trailer axle static load. In these tests, the trailer was fully loaded and the tow vehicle lightly loaded. Application of trailer brakes was accomplished by specially designed equipment capable of precise application level control.

Combination effectiveness tests were conducted based on the specifications of FMVSS 105-75 subject to the altered initial velocity. The results of these tests were intended to indicate the performance of the combination vehicle system in normal use. Thus, standard consumer-available trailer brake application devices were employed. Also, when load equalizing hitches were appropriate for use, their adjustment was according to manufacturers' recommendations, except in a specific case involving a trailer equipped with surge brakes. In this particular case it was found that the surge hitch and load equalizing hardware were incompatible resulting in the conduct of tests both with and without equalizing.

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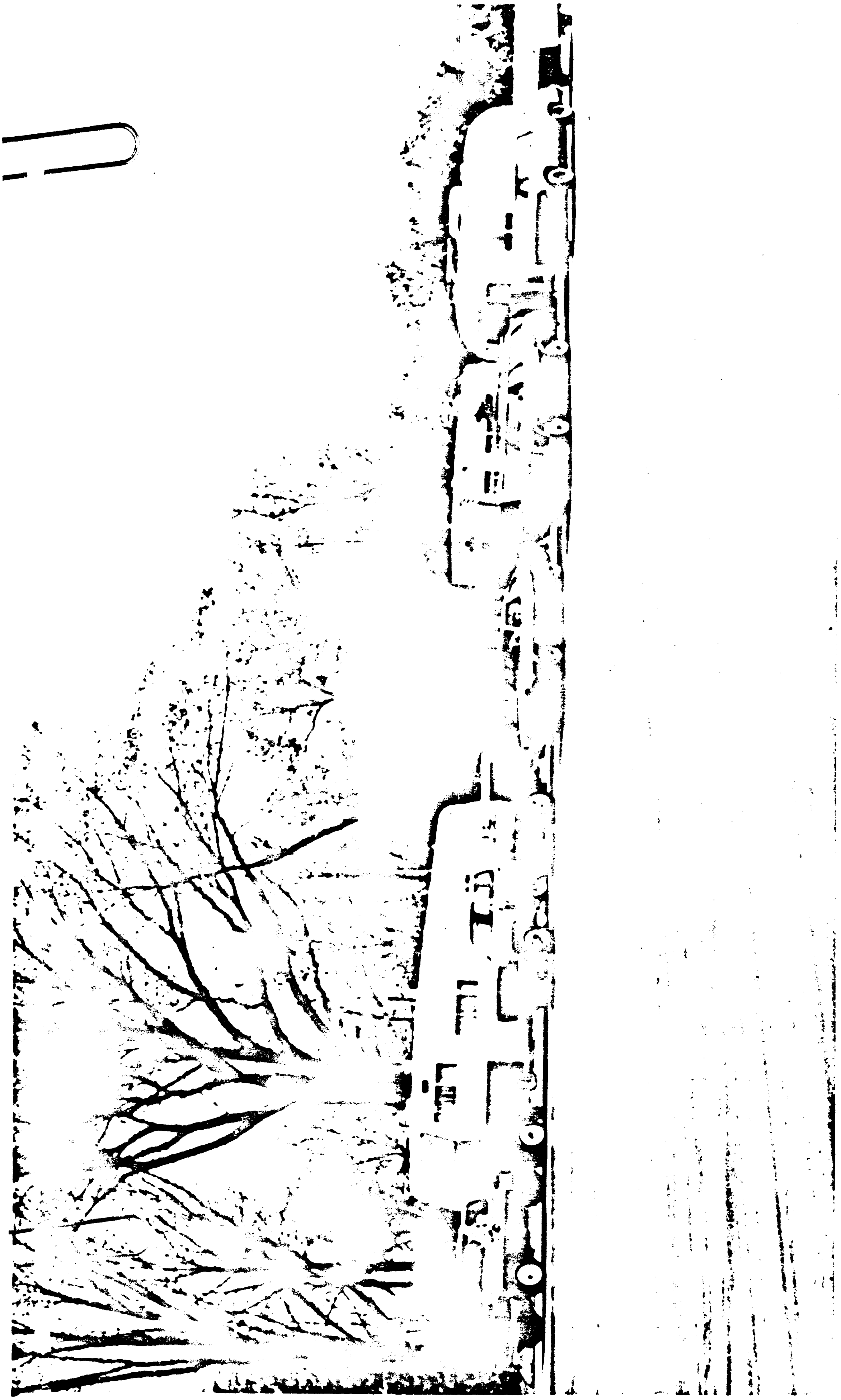
*The station wagon shown in Figure 3.1 is not the actual test vehicle used. The full-size Chevrolet wagon used in testing was not available for this photo.



The tow vehicles tested generally displayed very high deceleration capabilities on the dry test surface, indicating that both front and rear wheels were braked to a point near the limit of surface friction. (Two of the cars were limited by front wheel lock.) A wide range of inherent braking capability of test trailers was measured. The ratio of maximum brake force to loaded trailer weight ranged from 0.16 to 0.52. Measured combination vehicle performance demonstrated a similarly broad range. When test trailers were combined with tow vehicles demonstrating a braking capability compatible with FMVSS 105-75, maximum combination vehicle deceleration ranged from 12 f/s^2 to 21 f/s^2.

A primary finding of the test program was that the maximum brake force capability of the tow vehicle when operating alone was not grossly different from its capability when properly hitched to a trailer. This finding is very important to the development of the "rule" set forth in the next section.

The test program results were extended via a parameter sensitivity study mechanized by digital computer simulation. This activity served to demonstrate that, with the weights and brake systems of the tow vehicle and trailer held constant, wide variation in many vehicle parameters, including trailer center of gravity position and wheelbase, and hitch position, had very small effect on the braking performance of the combination vehicle. The major exception to this was the level of load equalization moment, which was seen to have significant effects on braking performance.

4.0 A PROPOSED RULE FORMAT

The simulation activity serves to point out the relative unimportance of several combination vehicle parameters to maximum CV braking performance. The more significant parameters are the weight and brake force capability of the combination plus the in-use factor of load equalizer adjustment. Further, it was shown that the maximum wheels-unlocked brake force of the tow vehicle remains about the same with or without a trailer, given that the load equalization adjustment is maintained within reasonable bounds. This finding leads to the proposal of a simplified analysis of combination vehicle braking which will result in a utilitarian methodology for trailer brake performance testing in a standards/guideline context.

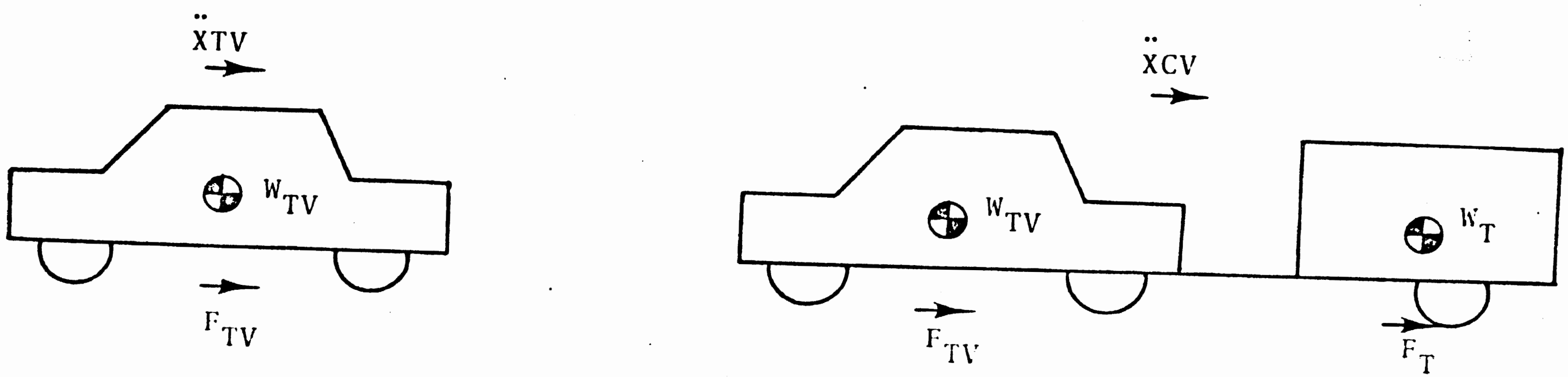
Consider first a combination vehicle using electric trailer brakes. Let us assume a maximum (high μ surface) wheels-unlocked brake force capability of F_{TV} lbs for a given tow vehicle, weighing W_{TV} lbs. Similarly, assume the trailer (weight W_T lbs) has a maximum brake force capability of F_T lbs. Finally, we assume F_{TV} and F_T are not altered by the forming of the combination. Then from the free-body diagrams of Figure 4.1, we find the deceleration capabilities (in g's) to be

$$\ddot{x}_{TV} = \frac{F_{TV}}{W_{TV}} \tag{4.1}$$

$$\ddot{x}_{CV} = \frac{F_{TV} + F_T}{W_{TV} + W_T} \tag{4.2}$$

for the tow vehicle alone and the combination vehicle, respectively. Solving Equation (4.1) for F_{TV} and substituting into (4.2) yields

$$\ddot{x}_{CV} = \ddot{x}_{TV} - \frac{\ddot{x}_{CV}W_T - F_T}{W_{TV}} \tag{4.3}$$



$$\ddot{X}_{TV} = \frac{F_{TV}}{W_{TV}}$$

$$\ddot{X}_{CV} = \frac{F_{TV} + F_T}{W_{TV} + W_T}$$

$$\ddot{X}_{CV} = \ddot{X}_{TV} - \frac{\ddot{X}_{CV} W_T - F_T}{W_{TV}}$$

$$P \equiv \frac{\ddot{X}_{CV} W_T - F_T}{W_{TV}}$$

Figure 4.1. A simplified vehicle model which provides the basis for the rule.

Equation (4.3) indicates that in hitching a particular trailer and tow vehicle, a "deceleration penalty," P (in g's), is paid. That is, the combination vehicle deceleration is degraded relative to the tow vehicle alone deceleration by

$$P = \frac{\ddot{x}_{CV} W_T - F_T}{W_{TV}} \tag{4.4}$$

where

$$\ddot{x}_{CV} = \ddot{x}_{TV} - P \tag{4.5}$$

Now, substituting x_{CV} from (4.5) into (4.4) and solving for W_{TV} yields

$$W_{TV} = \frac{W_T \ddot{x}_{TV} - F_T}{P} - W_T \tag{4.6}$$

Equation (5.6) may be used to define a minimum weight tow vehicle appropriate for use with the given trailer. For example, let us define the minimum tow vehicle deceleration as $\ddot{x}_{105}$, i.e., that sustained deceleration generally required by FMVSS 105-75. Further, define the maximum acceptable deceleration penalty to be P_m.
Then

$$\ddot{x}_{TV} \geq \ddot{x}_{105} \tag{4.7}$$

$$P \leq P_m \tag{4.8}$$

Substituting (4.7) and (4.8) into (4.6) yields

$$W_{TV} \geq \frac{W_T \ddot{x}_{105} - F_T}{P_m} - W_T \tag{4.9}$$

Thus, if Equation (4.9) is satisfied, and given the assumptions of the analysis, then

$$\ddot{x}_{CV} \geq \ddot{x}_{105} - P_m$$

In implementing Equation (4.9), the trailer manufacturer might perform a trailer alone braking test (using virtually any tow vehicle) from which the maximum trailer brake force would be obtained. Using this result and the trailer gvw as W_T, the manufacturer would calculate W_{TV} and publish this figure as a guideline to the consumer, indicating the minimum weight tow vehicle acceptable for use with the trailer.

For trailers equipped with surge hitch braking systems, the actuation level of the brake system is a dependent variable determined by a closed-loop mechanism. Thus, the direct measurement of F_T is not reasonable and the above analysis must be modified to be appropriate.

It can be shown that

$$\ddot{x}_{CV} W_T = F_T + F_H \tag{4.11}$$

where F_H is the compressive longitudinal hitch force (in lbs) acting on the trailer. Solving Equation (4.11) for F_H and substituting into Equation (4.3) yields

$$\ddot{x}_{CV} = \ddot{x}_{TV} - \frac{\overline{F}_H}{W_{TV}} \tag{4.12}$$

where the notation $\overline{F}_H$ indicates the value of F_H occurring at a combination vehicle deceleration of $\ddot{x}_{CV}$ g's. Thus, in this case, the deceleration penalty is

$$P = \frac{\overline{F}_H}{W_{TV}} \tag{4.13}$$

If we again specify that

$$P \leq P_m \tag{4.14}$$

and

$$\ddot{x}_{TV} \geq \ddot{x}_{105} \tag{4.15}$$

then from Equations (4.5), (4.14), and (4.15)

$$\ddot{x}_{CV} \geq \ddot{x}_{105} - P_m \tag{4.16}$$

Substituting (4.14) into (4.13) and rearranging yields

$$W_{TV} \geq \frac{\overline{F}_H}{P_m} \tag{4.17}$$

where $\ddot{x}_{CV}$ is limited by Equation (4.16).

In implementing Equation (4.17), the trailer manufacturer might perform a combination vehicle stopping test at a deceleration of $\ddot{x}_{CV} = \ddot{x}_{105} - P_m$.* In this test, the vehicle would be equipped to measure $\overline{F}_H$ directly. The results again would be used to calculate W_{TV} which would be published as a guideline to the consumer. In the test, any tow vehicle capable of attaining $\ddot{x}_{CV}$ when combined with the subject trailer could be used.

Equations (4.9) and (4.17) potentially provide the basic format for a standard or guideline. Their implementation, however, requires an answer to the question, "What constitutes maximum trailer brake force?" In previously promulgated Federal Motor Vehicle Safety Standards, the answer has been, in effect, "That attainable without wheel lock," a position based on the hypothesis

*Using the equality portion of Equation (4.16) would result in the lowest attainable value for $\overline{F}_H$.

that wheel lock is undesirable due to directional response considerations. It is not clear that this is the appropriate answer for the matter of trailer braking.

Testing conducted in this program makes it clear that premature lockup of one or more wheels can occur on trailers due to (a) the inherent variability in electric trailer brakes, and (b) the nature of multiple-axle suspensions commonly used on trailers. However, during such occurrences, other wheels continue to roll and, thus, trailer stability is not necessarily seriously degraded. Consequently, a more cost-effective definition of maximum trailer braking might allow the occurrence of lockup on a limited number of trailer wheels or axles.

On the other hand, usage factors must be considered. The occurrence of wheel lock at very low total trailer brake force levels could well motivate the user to adjust brake actuation to avoid wheel slide (and tire wear) at low and moderate deceleration levels, thus limiting trailer brake torque to unacceptably low levels. One possible compromise solution is the combination of a maximum performance measure which allows lockup of a limited number of trailer wheels or axles with a demonstration of moderate trailer braking capability without wheel lock.

Consider, now, the application of the proposed "rule" to data gathered in this study's test program. For demonstration purposes only, the values of 2/3 g and 1/6 g have been chosen for $\ddot{x}_{105}$ and P_{max}, respectively. These values imply that if the subject trailer is combined with a tow vehicle (in compliance with FMVSS 105-75) weighing more than the minimum calculated value of W_{TV}, then the resulting combination may be expected to have a deceleration capability in excess of 1/2 g.

Tables 4.1 and 4.2 display the results of applying the rule to the electric brake and surge brake (plus trailer A with no brakes) trailers, respectively. The calculations are based on 40 mph, loaded vehicle test data. Table 4.1, which includes

Table 4.1 Application of the Rule to the Electric Brake Trailers Tested.

$$W_{TV} \geq \frac{W_T \ddot{x}_{105} - F_T}{P_{max}} - W_T$$

Let $\ddot{x}_{105} = 2/3\ g$

$P_{max} = 1/6\ g$ $\Rightarrow$ $\ddot{x}_{CV} \geq 0.5\ g = 16.1\ f/s^2$

		No Trailer Wheel Lock					Wheel Lock On One Trailer Axle				
				Actual Performance					Actual Performance		
Trailer	Trailer Weight W_T (lb)	Maximum Trailer Brake Force F_T (lb)	Calculated Min. Tow Vehicle Weight, W_{TV} (lb)	CV	Tow Vehicle Weight (lb)	$\ddot{x}_{CV}$ (f/s^2)	Maximum Trailer Brake Force F_T (lb)	Calculated Min. Tow Vehicle Weight, W_{TV} (lb)	CV	Tow Vehicle Weight (lb)	$\ddot{x}_{CV}$ (f/s^2)
B	5,000	2,584	0	2-B	4,803	19.9					
				1-B	4,707	19.2					
C	6,830	1,742	10,038	3-C	6,216	13.9	2,876	3,234	3-C	6,216	21.3
				2-C	4,803	17.0			2-C	4,803	19.9
D	8,835	1,440	17,865	4-D	6,270	11.8					
E	20,232	4,329	34,722	5-E	7,858	12.2	5,500	27,696	5-E	7,858	12.2

Table 5.2. Application of the Rule to the Surge Brake Trailer (and No Brakes Trailer) Tested.

$$W_{TV} \geq \frac{\bar{F}_H}{P_{max}} \quad \text{where} \quad \bar{F}_H = F_H \text{ @ } \ddot{x}_{105} - P_{max}$$

Let $\ddot{x}_{105} = 2/3\ g$

$P_{max} = 1/6\ g$

$\Rightarrow \quad \ddot{x}_{CV} \geq 0.5\ g = 16.1\ f/s^2$

		No Trailer Wheel Lock				
				Actual Performance		
Trailer	Trailer Weight W_T (lb)	Trailer Tongue Force at 1/2 g $\bar{F}_H$ (lb)	Calculated Min. Tow Vehicle Weight, W_{TV} (lb)	CV	Tow Vehicle Weight (lb)	$\ddot{x}_{CV}$ (f/s^2)
A: with brakes & no equalizing	2,222	663	3,978	1-A	4,707	17.0
A: with brakes & equalizing	2,222	1,090	6,544	1-A	4,707	15.5
A: with no brakes & equalizing	2,222	1,111	6,666	1-A no brakes	4,707	14.2

only multiple-axle trailers, presents results based on both no-trailer-wheels-locked and one-axle-wheel-lock criterion for F_T.

Several features of Table 4.1 are of interest:

1) With the exception of the 2-C wheels-unlocked combination, every CV wherein the weight of the tow vehicle as tested was less than the calculated W_{TV} exhibited less than 1/2 g measured deceleration, and every CV wherein the weight of the tow vehicle as tested was greater than W_{TV} exceeded 1/2 g measured deceleration.

2) Trailer C apparently exhibits better wheels-unlocked CV performance in combination with the 4808-lb tow vehicle (2) than with the 6216-lb tow vehicle (3). This illustrates two points, namely: (a) the low wheels-unlocked deceleration of combination 3-C is a result of premature lockup of one trailer wheel. This problem was attenuated after the 3-C test activity, apparently as a result of continued usage of the trailer C brakes in intervening tests. Note that with the wheel lockup allowed, as in the right-hand columns of Table 4.1, the performance of trailer C with tow vehicle 3 is excellent. (b) Tow vehicle 2 exhibited as high as 29 ft/sec^2 tow vehicle alone deceleration. Thus it is not surprising that CV's with tow vehicle 2 were able to out-perform the "guideline calculations" which assumed only 2/3 g deceleration for the tow vehicle alone.

3) Trailer B has a calculated W_{TV} of zero pounds, an indication that any tow vehicle is adequate to produce 1/2 g. This is a consequence of the fact that F_T for trailer B is more than half the trailer weight.

4) Because of low brake force capability relative to their weight, trailers D and E require very heavy tow vehicles according to the rule. Accordingly, when combined with the lighter tow vehicles used in this study, they did not meet the 1/2 g deceleration level.

The results for trailer A, the surge-braked trailer, also conformed to the predictions of the rule (Table 4.2). Note, however, that in the latter two cases for this trailer, the actual tow vehicle weight is substantially below the minimum weight required by the rule while the actual combination vehicle deceleration is not so far below the 1/2 g level. This is indicative of the capability of tow vehicle number 1. In the tow vehicle alone tests, this vehicle achieved nearly 0.8 g deceleration without wheel lock.

In review, a scheme has been presented, and validated for a number of sample cases, which provides for reasonable assurance of a prescribed minimum braking capability of combination vehicles based on a simple measurement of the trailer's inherent braking capability and the assumption of a minimum braking performance of the tow vehicle alone (as implied by compliance with FMVSS 105-75 and current common design practice). It must be noted, however, that the success of the validation resulted, at least in part, form the fact that the combination vehicle braking performance data was gathered using procedures which adequately control in-use factors, particularly those regarding the use of load equalizing hardware and trailer brake application devices. Given the nature of combination vehicle systems, that is, that such vehicles are not manufactured or marketed as complete systems and that they do not become systems until their various parts are combined by the user, it seems clear that the effectiveness of virtually any rule could be thwarted through improper adjustment of in-use factors.

Thus, any rule or guideline should ensure that

- adequate instruction be provided to the user concerning the proper adjustment of load equalizing devices
- an adequate trailer brake application device be provided as well as adequate instructions for its proper use
- the use of incompatible equipment (e.g., load equalizing equipment and certain surge hitches) is eliminated.

A final area of concern which rule-making procedures might deal with involves the consistency of performance of the trailer foundation brake. Electrically-actuated trailer foundation brakes have certain properties which make them quite desirable for use on trailers towed by vehicles with hydraulic brake systems. Nonetheless, electric brakes have been found historically, as well as in this study, to have a propensity for erratic behavior.* This property is demonstrated both in terms of temporal variance in the effectiveness of a single brake sample, as well as variance in the effectiveness of different samples of the same model of brake. Clearly, this property could hamper the effectiveness of any rule, since the representativeness of measured trailer brake performance to in-use performance is in question.

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*It is not our purpose to detail here the workings of the electric brake. Suffice it to say, the sources of this variability are not completely known. The basic high gain of the device, as well as the use of two friction surfaces (magnetic-to-drum in addition to lining-to-drum), are two primary sources of the problem.

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5.0 CONCLUSIONS AND RECOMMENDATIONS

This study has endeavored to apply the principles of vehicle mechanics to the braking process of combination vehicles on dry surfaces in order that a thorough understanding of the process might result and that those vehicle characteristics which have a major influence on the process might be identified. The study was conducted within a context defined by current passenger car and light truck brake system design practice. (Specifically, subject tow vehicles, both experimental and simulated, were limited to late models whose limit braking performance was generally in compliance with FMVSS 105-75.) The finding of primary importance is that, within this context, the proper hitching of trailer to the tow vehicle does not lead to gross alteration of the brake force capability of the tow vehicle as compared to its capability as a unit vehicle. As a consequence of this finding, and as confirmed by sample vehicle test results, it has been concluded that a practical "rule" can be presented through which the minimum braking performance of combination vehicles can be reasonably assured. The rule would combine a simple test procedure for determining the inherent braking capability of trailers and a guideline for determining acceptable tow vehicles based on the measurement. In addition, the rule must deal with several peripheral points largely concerned with in-use factors.

A number of specific findings derive from the study in support of the above. These findings are summarized below.

5.1 Findings Regarding the Mechanics of Combination Vehicle Braking on Dry Surfaces

1) The passenger cars tested in this program were found to be capable of very high decelerations on dry surfaces in gvw loading conditions, an indication that both front and rear wheels were braked to a point near the limit of adhesion. (Two of the

cars were limited by front lock.) When combined with trailers and making proper use of load equalizing hitches, all passenger car-trailer combinations tested were tow vehicle front-lock limited, and at the limit the tow vehicles supplied about the same level of brake force as they had when running alone.

2) The pickup truck-fifth wheel-trailers tested are in contrast with the passenger car-trailer combinations in that the vertical hitch load is applied slightly ahead of the rear axle rather than significantly aft of the rear axle. Since the hitch loads (vertical and longitudinal) are applied in the nominal load area of the truck, the brake force capability of the tow vehicle when in combination is again comparable to its capability operating alone in the loaded condition.

3) Multi-axle trailer suspension systems play an important role in trailer braking capability. Their ability to distribute vertical load equally among trailer wheels determines, in part, that portion of potential brake torque which can, in fact, be utilized in producing trailer brake force.

4) The inherent braking capability of a given trailer may be determined by combination vehicle tests employing trailer brakes only.

5) The hydraulic brakes used on the surge brake-equipped trailer tested in this study were more capable and consistent generators of brake torque than the electric brakes tested in this program.

6) The inherent variability of trailer foundation brakes, particularly electric brakes, puts in question the ability of a test trailer to accurately represent a model line of trailers.

7) Dynamometer tests of trailer brakes have limited usefulness in determining actual trailer braking capability due to suspension effects and brake variability.

8) Ancillary equipment can have an important effect on combination vehicle performance. As implied in (1) above, load equalizing hitch adjustment is important to tow vehicle performance when in combination with a trailer. Electric trailer brake controller adjustment affects trailer performance in the combination vehicle. The coarse resolution of the adjustment plus the testing activity required of the user can hamper good adjustment. For surge brake systems, no adjustment of the actuator is required (since system gain is inherent in design). However, surge brake application hardware may be incompatible with load equalization hardware.

5.2 Conclusions Regarding the Prospects for a "Rule"

1) A practical rule which provides reasonable assurance of a prescribed minimum braking capability of combination vehicles has been presented, and has been validated for a number of sample cases. The rule is based on a simple measurement of the trailer's inherent braking capability and the assumption of a minimum braking performance of the tow vehicle alone (as implied by compliance with FMVSS 105-75 and current design practice). The rule prescribes a minimum weight for the tow vehicle based on the trailer braking measurement.

2) The implementation of the rule requires an answer to the question "What constitutes maximum trailer brake force?" That is, what conditions of trailer wheel lock should be permissible in the conduct of trailer brake performance testing?

3) To be successful, the rule must deal with several in-use factors. It should ensure that

- adequate instruction be provided to the user concerning the proper adjustment of load equalizing devices
- an adequate trailer brake application device be provided as well as adequate instruction for its proper use

•the use of incompatible equipment (e.g., load equalizing equipment and certain surge hitches) is eliminated.

4) The most significant reservation regarding the effectiveness of the proposed rule involves the consistency of performance of trailer foundation brakes. As noted in Conclusion (7) of Section 5.1, test data may not accurately represent the performance of a model line of trailers.

5.3 Recommendations

In large measure, Section 4.0, "A Proposed Rule Format," constitutes the recommendations deriving from this study. In addition to the content of this section, the following recommendations are made:

1) The problems associated with various hardware elements, as pointed up in the conclusions, should not be construed as general indictments of any type of trailer brake system. While the variability problems of electric brakes are real, electric brake systems have other desirable features, including low cost and a trailer-to-tow vehicle coupling which is convenient and relatively secure against contamination. Further, while some specific surge hitch hardware is incompatible with load equalizing hitches and should therefore be restricted to lighter trailers, design modifications in either component might lead to useful systems for heavier trailers. Surge systems do have the advantages of relieving the user of the brake applicator adjustment task and allowing the use of hydraulic brakes on the trailer. The rule-making procedure should deal with such problems by promoting advances in design rather than restricting design choice.

2) The "rule" which has been recommended in Section 4.0 is quite simplistic. The price of this simplicity is recognized to be something less than complete assurance that all combination vehicles will be capable of the intended minimum deceleration capability. However, the rule could assure that very poor performers

would be eliminated. Further, since it is in the user's hands to perform the final combining of trailers and tow vehicle into a total vehicle system, it would seem that virtually any rule, no matter how complex, would yield something less than full assurance of the desired minimum performance. In this light, and in consideration of the nature of the trailer industry (that is, the reduced level of economic and technical strength of many trailer manufacturers relative to the automobile manufacturer), a recommendation to strive for simplicity in any promulgated rule is made.