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IMPROVED PASSENGER CAR BRAKING PERFORMANCE

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16. Abstract

Test conditions were studied as candidates for extending the scope of the stopping distance requirements of FMVSS 105-75, "Hydraulic Brake Systems." Conditions of interest included low and split friction surfaces as well as straight-line braking and braking-in-a-turn maneuvers. Two large test programs were conducted and various analytical efforts were applied to the examination of the candidate test conditions and methods. Throughout all of the study activities, only stopping distance performance was taken as the measure for evaluating the utility of the candidate conditions and methods.

It was concluded that only the low friction, straight-line braking condition constitutes a viable extension of the stopping requirements of 105-75. It was also found that stopping distances in a turn do not differ significantly from stopping distances measured in straight-line braking. Further, stopping distances on split friction surfaces do not appear generally useful as characterizations of vehicle safety quality.

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1.0 INTRODUCTION

This document constitutes the summary final report on Contract DOT-HS-6-01368 entitled "Improved Passenger Car Braking Performance." The project has been conducted by the Highway Safety Research Institute of The University of Michigan with support of the facilities of the Chrysler Corporation Proving Grounds and both the facilities and staff of the Bendix Automotive Proving Grounds.

The primary objective of this study has been to determine whether a basis exists for extending the stopping distance requirements of FMVSS 105-75 to cover conditions of low and split friction surfaces as well as braking in a turn. The current 105 standard, while nominally encompassing the general matter of the braking safety of hydraulically-braked vehicles, limits itself to requirements for straight-line stopping on a high friction (dry) surface. To the degree that assurance of adequate stopping performance on a dry surface does not also assure adequate stopping on other surface conditions, or while braking in a turn, the standard may be subject to revision.

Accordingly, this study was configured to apply both analytical and experimental techniques to the examination of differing surface and maneuvering conditions. The purpose of these examinations was fourfold:

1) To establish test procedures suitable for demonstrating representative vehicle stopping response under the subject conditions.

2) To provide an understanding of the mechanics of vehicle response under the braking conditions of interest.

3) To conduct full-scale tests so as to reveal the practical aspects associated with such candidate extensions to the federally-required method.

4) To evaluate the measured vehicle responses so as to determine if meaningful improvements in traffic safety would accrue from specification of performance under the candidate conditions.

The scope of the study was constrained at the outset to include only the stopping distance measure of vehicle braking response under low and split friction, and curved-path braking conditions. Thus the study was not to consider any of the directional response issues related to these conditions—although it was recognized that strong hypotheses do exist which connect the directional disturbances and "loss of control" results of braking to traffic safety.

Moreover, the confinement of interest to stopping distance measures, alone, serves to explain why recommendations are made herein for extending FMVSS 105-75 only to the inclusion of a straight-line, low-friction test condition. As will be shown, stopping distance performance on split friction surfaces or in curved paths is either conceptually unrelated to the broad interests of traffic safety or of negligible significance as an additional measure beyond that of straight braking on homogeneous surfaces.

2.0 OVERVIEW OF THE RESEARCH PLAN

The project consisted of four major tasks intended to lead toward conclusions relevant to the question of extending FMVSS 105-75. Since it was desired that test procedures be developed and employed to gather a representative set of braking data, it was first necessary to conduct an exercise to identify that limited set of passenger cars which would yield more or less representative braking performance. A proposed analytical approach toward this vehicle selection task was discarded in concern for the general inability to accurately predict differences in stopping distance among real vehicles—for want of parametric data describing brakes and tires in a comprehensive manner. Alternatively, then, a test program was executed, involving twelve passenger vehicles which had been manufactured since the effective date of FMVSS 105-75. These tests provided data which clearly discriminated among vehicles in terms of high and low friction braking and stopping in a curved path. Also, a general try-out of test methods was effected, permitting the identification of refinements which were to be implemented in the major test phase.

Subsequent to the initial test exercise, a quasi-static simulation effort was undertaken to clearly define the first-order mechanisms determining stopping distance performance under the conditions of interest. This effort established the relationships between the major vehicle parameters, the surface and maneuvering conditions, and the resulting constraints on minimum stopping distance. Specific inquiries made by way of the quasi-static simulation guided the selection of test conditions to be applied in the full-scale test series.

The major test effort involved conduct of an extensive matrix of tests on each of five selected passenger cars. The matrix contained 28 separate test sequences built around the first, second, and third effectiveness test formats of the 105 standard. The greatly expanded number of test conditions permitted both straight and right/left turning stops on low, high, and split friction surfaces, with the split friction condition being represented by both hi-right (that is, the high friction side of the split is situated on the right side of the vehicle) and hi-left orientations. Data taken in this test series clearly delineate the relative gain to be made if one were to specify stopping distance performance in a turn—in addition to the specification of straight-line stopping distance. Further, the data serve to put in focus the conceptual problems associated with the specification of split friction stopping performance.

The final task involved a large scale computerized analysis, part of which examined the sensitivity of test results to imprecision in the test condition variables. Together with a field survey of certain economic matters, the simulation effort was also applied in the examination of advanced braking system concepts. Advanced concepts were treated both in terms of their likely influence on performance capability and in terms of the costs likely to attend their introduction as production hardware.

Conclusions and recommendations were drawn with regard to the advisability of extending the stopping distance requirements of FMVSS 105-75. By way of implication, the general absence of recommendations to add more stopping distance requirements reveals that the directional or yaw disturbance aspects of braking on split friction surfaces and in a turn are seen as the more important safety issues associated with those braking conditions.

3.0 TECHNICAL DISCUSSION

In this section the methods employed, and results obtained, in conduct of the various elements of the research study will be summarized. Although certain findings deriving from gathered data are summarized in the text of this section, definitive conclusions relative to candidate modifications of FMVSS 105-75 are presented in Section 4.0.

3.1 Survey Test Program

A test program was conducted on a sample of twelve vehicles in order to obtain a data set characterizing straight-line and curved-path braking performance of FMVSS 105-75-compliant passenger cars on low and high friction surfaces. Performance data on current braking systems for braking in a turn and on low friction surfaces is scarce. Thus the data obtained in this survey test series, along with data from more extensive tests of five vehicles later in the project, provided the principle basis for determining whether augmentation of the 105-75 standard should be recommended. The survey tests also provided a pilot exercise for refinement of the proposed test procedures to be applied in full-scale tests of five vehicles to follow.

3.1.1 Twelve-Vehicle Sample. In selecting the twelve vehicles, information was obtained from the MVMA specification sheets, Automotive News, and consumer journals regarding models available, sales volume, and brake system design. Vehicles were selected to provide representation from the four major American automobile manufacturers and to cover vehicle size ranging from subcompact to full size. Generally, the vehicles selected were models exhibiting relatively high sales volume within the size/manufacture groupings, tending to make the sample representative of the highway population. Table 3.1 contains a list of the twelve vehicles which were tested, showing size classification and salient brake system features.

Table 3.1. Twelve-Car Sample Showing Size and Salient Brake System Features.

Size	Vehicle	Year	Manufacturer	Brakes Front/Rear	Proportioning Valve
Sub-compact	Chevette	1976	GM	Disc/Drum	No
	Pinto Wagon	1976	Ford	Disc/Drum	Yes
	Gremlin	1976	AMC	Disc/Drum	No
Compact	Nova	1976	GM	Disc/Drum	Yes
	Pacer	1976	AMC	Disc/Drum	No
	Volvo 244	1976	Volvo	Disc/Disc	Yes
Inter-mediate	Monte Carlo	1976	GM	Disc/Drum	Yes
	Fury	1977	Chrylser	Disc/Drum	Yes
	Torino	1976	Ford	Disc/Drum	Yes
Full Size	Buick LeSabre	1976	GM	Disc/Drum	Yes
	Ford LTD	1976	Ford	Disc/Drum	Yes
	Dodge Monaco	1977	Chrysler	Disc/Drum	Yes

3.1.2 Test Site and Experimental Procedures. Braking tests using the twelve-vehicle sample were conducted on the skid traction facility at the Chrysler Corporation's Proving Grounds in Chelsea, Michigan. This facility consists of four adjacent lanes, twenty-eight feet wide and 1000 feet long with a long approach area from each direction. Wetting of the surface was accomplished with a multiple-head sprinkling system along one side of the test lanes which produced a reasonably homogeneous water depth by virtue of the uniform 1% grade across the lane. The lane width of twenty-eight feet was adequate to lay out curved paths for braking-in-a-turn experiments on the same surface area used for straight-line tests.

In addition to the skid numbers provided by Chrysler, the dry brushed concrete and the wet jennite surfaces were characterized by peak friction measurements. These measurements were made specifically to apply NHTSA's Braking Efficiency Technique [1], a method deriving a braking efficiency numeric from braking test data by comparing a vehicle's stopping distance with the computed ideal stopping distance of a hypothetical reference vehicle which makes optimum use of the available traction on the test surface. To obtain this numeric, peak friction measurements are made at two tire loads, representing the nominal front and rear tire loads on the reference vehicle, and at four velocities using the ASTM E-501 standard tire as a reference tire.

All HI-CO tests of vehicle stopping distance performance were run at an initial velocity of 60 mph and, in the curved-path case, at an initial lateral acceleration of 0.3 g. For the LO-CO tests, the corresponding values were 40 mph initial velocity and an initial lateral acceleration of 0.2 g.

Successive stops were made with increasing increments of constant pedal force until lockup occurred on either axle. Two additional stops were made at the constant pedal force giving minimum stopping distance with at most one wheel locked per axle, thus assuring vehicle controllability. Steering correction by the driver was permitted throughout the run.

3.1.3 Test Results on Twelve-Car Sample. A series of straight and curved-path (left and right turning) minimum stopping distance tests were made on each of the twelve vehicles on HI-CO (brushed concrete) and LO-CO (wet jennite) surfaces. In all tests, the vehicle was loaded to its curb weight plus about 400 pounds which included the driver, a passenger, and instrumentation.

Best stopping performances, defined by the shortest stopping distance out of three runs made at that constant pedal force which was determined to give optimum stopping without axle lockup, are plotted in Figure 3.1 for the HI-CO tests and Figure 3.2 for the LO-CO tests.

In the HI-CO straight-line test (Figure 3.1), all cars except an AMC Pacer stopped in a distance less than the 194-foot requirement of 105-75. The average straight-line stopping distance of the small cars was 13 feet (8.0%) longer than the average for the large cars. The three vehicles without proportioning valves ranked 8th (Chevette), 11th (Gremlin), and 12th (Pacer).

On the LO-CO surface (Figure 3.2), the difference in straight-line braking performance between large and small cars was more pronounced, with the average stopping distance for the small cars being 24 feet (24%) longer than for the large cars.

To compare straight and in-a-turn stopping distances, the average value of the left and right turning stopping distances is used. The differences expressed as a percentage of the straight-line value are shown in Table 3.2. The small car average difference was 7.2% on HI-CO and 3.9% on LO-CO and the large car average difference was 1.4% on HI-CO and 7.6% on LO-CO. Over all twelve vehicles the average difference was 4.3% on HI-CO and 5.7% on LO-CO. On the HI-CO test, one car stopped in a shorter distance in the turn and four cars stopped shorter in the turn on the LO-CO test.

These data indicate that little discrimination in performance is gained from braking-in-a-turn tests over what is learned from straight-line tests where stopping distance is the only performance measure.

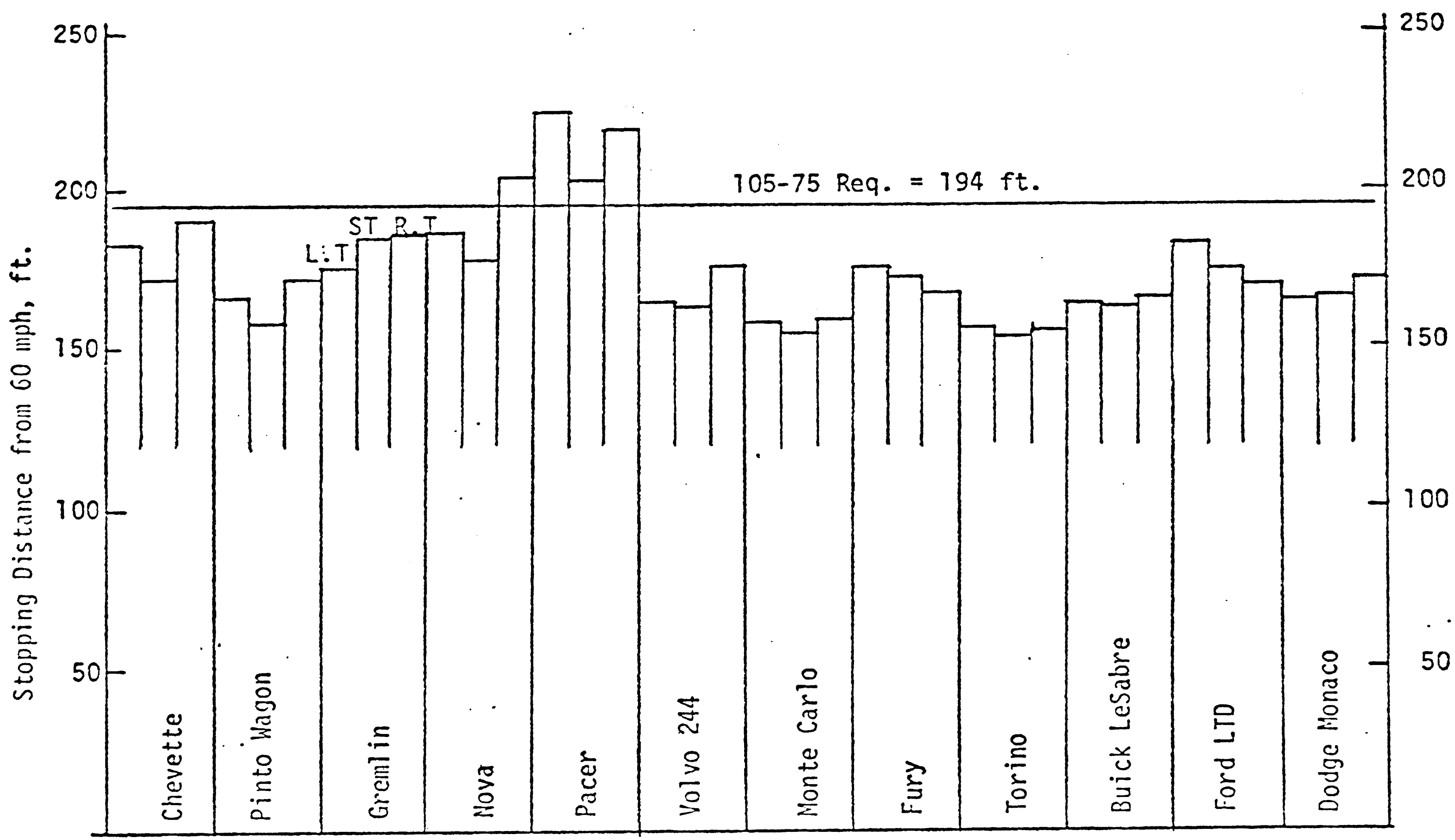


Figure 3.1. Minimum stopping distances for straight, left turning, and right turning stops from 60 mph on dry brushed concrete. Initial lateral acceleration, 0.3 g. Turn radius 801 feet.

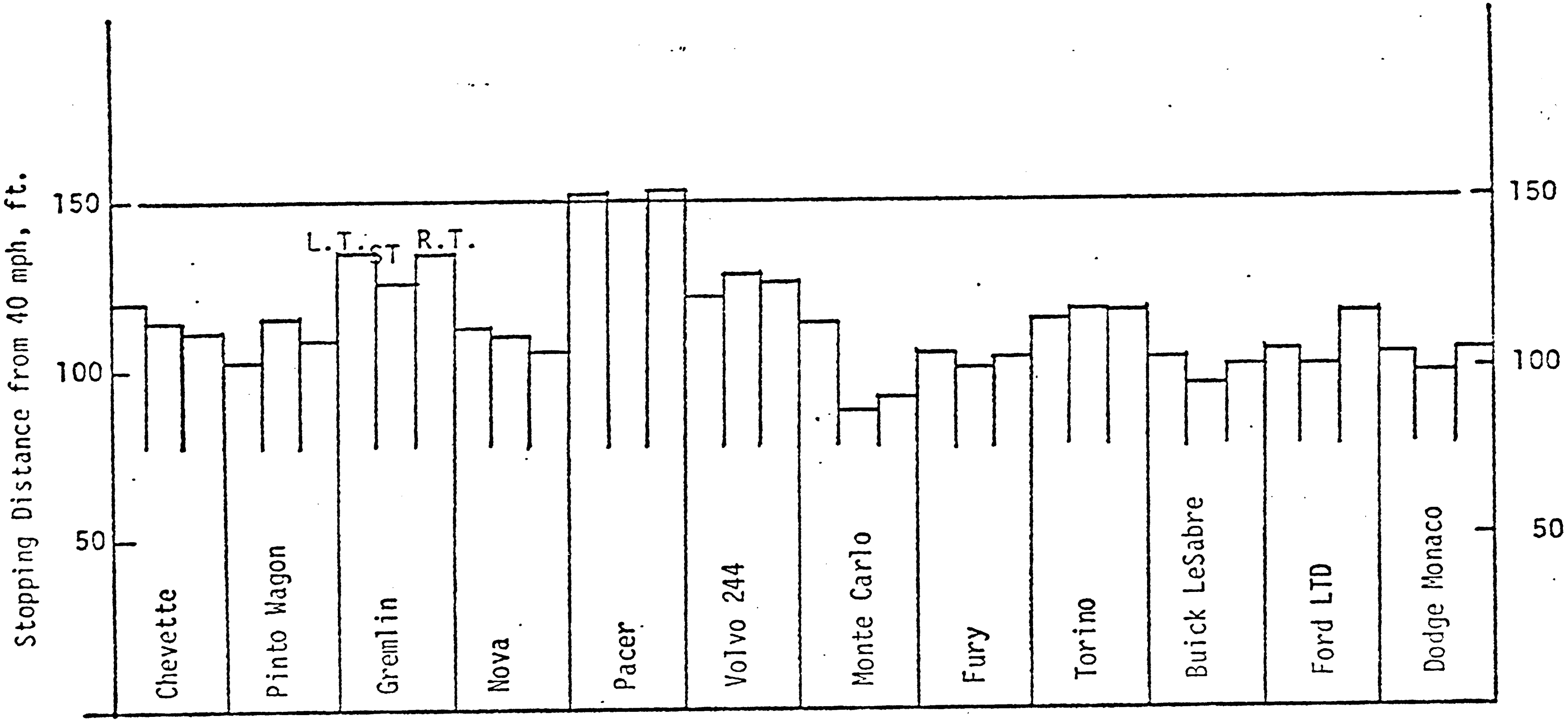


Figure 3.2. Minimum stopping distances for straight, left turning, and right turning stops from 40 mph on wet jennite. Initial lateral acceleration, 0.2 g. Turn radius 535 feet.

Table 3.2. Percentage Difference Between Straight-Line and In-a-Turn Stopping Distance.

	Dry Concrete	Wet Jennite
Chevette	8.8%	0.9%
Pinto Wagon	7.6	*9.4
Gremlin	*2.7	7.2
Nova	9.6	*0.9
Pacer	9.9	0.7
Volvo 244	4.3	*3.9
Small Car Average	7.2%	3.9%
Monte Carlo	2.6	17.2
Fury	0.0	4.0
Torino	2.0	*1.7
Buick LaSabre	1.2	6.3
Ford LTD	1.2	10.0
Dodge Monaco	1.2	6.1
Large Car Average	1.4%	7.6%
Overall Average	4.3%	5.7%

*In-a-turn stopping distance shorter than straight-line stopping distance.

Braking efficiency levels [1] were computed for each vehicle using the shortest measured stopping distances from the HI-CO and LO-CO straight-line braking tests and the measurements of peak surface friction characteristics. The braking efficiency results are tabulated in Table 3.3. Braking efficiency is defined by the expression:

$$\text{Eff.} = \frac{\text{Ideal Stopping Distance of Reference Vehicle}}{\text{Measured Stopping Distance of Real Vehicle}} \times 100\%$$

By this measure, five out of the six large vehicles achieved slightly higher utilization of the wet LO-CO surface than of the HI-CO surface. Overall, however, the vehicles averaged 5.8% higher utilization of the HI-CO surface than they did of the LO-CO surface. The Volvo registered the greatest difference (19.5%) with 78.8% efficiency on dry brushed concrete and 59.3% on wet jennite.

3.2 Quasi-Static Analysis

A series of calculations of braking efficiency, based on a quasi-static analysis, was conducted in order to understand some first-order sensitivities of vehicle performance to the types of braking maneuvers under consideration in this study. The results of the calculations were examined and used to plan the testing procedures described in the next section.

This section summarizes the quasi-static analysis by describing the model which was used, the various conditions which were considered, and the resulting observations on the different mechanisms involved in limit braking.

3.2.1 Quasi-Static Model. The model used in the quasi-static study constitutes a simple representation of a four-wheeled vehicle with conventional (non-antilock) brakes. The model is quasi-static in the sense that load transfer takes place instantaneously simply as a function of kinematic relationships. For the case of braking in a turn, the model considers steadily sustained lateral as well as

Table 3.3. Braking Efficiencies of 12 Vehicles on High Coefficient and on Low Coefficient Surfaces.

Vehicle	HI-CO Brushed Concrete	LO-CO Wet Jennite	Δ
Chevette	74.8%	67.5%	7.3%
Pinto Wagon	81.2	66.4	14.8
Gremlin	69.5	61.4	8.1
Nova	72.1	70.1	2.0
Pacer	63.5	50.9	12.6
Volvo 244	78.8	59.3	19.5
Monte Carlo	82.8	87.9	*5.1
Fury	74.8	76.7	*1.9
Torino	83.8	65.3	18.5
Buick LaSabre	79.1	80.3	*1.2
Ford LTD	73.7	77.5	*3.8
Dodge Monaco	77.7	78.8	*1.1
Average	76.0%	70.2%	

*Higher utilization of LO-CO surface than of HI-CO surface.

longitudinal acceleration level. Thus the model is suitable for evaluating the incidence of wheel lockup which occurs immediately following pedal application, but does not account for the effects of diminishing lateral acceleration as the vehicle slows down.

3.2.2 Discussion of Calculated Results. The quasi-static calculations served to display the broad picture of vehicle braking capabilities over many operating conditions. The results of the calculations are the basis for the following observations:

1. The choice of front/rear proportioning is seen as the parameter most influential in determining braking efficiency over the straight and curved-path braking cases using high, low, and split friction conditions. The effects of other parameters often depend on the relation between the proportioning, the front/rear static loading, and the available peak friction levels.

2. As the combination of surface and maneuvering conditions becomes complex, braking efficiency becomes an increasingly complicated function of proportioning and other parameters. When braking in a straight line on a uniform surface, two limiting mechanisms exist—that is, performance is limited by the imminent lockup of either both front or both rear wheels. When braking in a turn, as many as eight different limiting mechanisms can be identified for a given vehicle over the range of brake proportioning. As a result of the added complexity, it was seen that the overall sensitivity of braking efficiency in a turn to the various vehicle parameters is decreased, since as one performance-limiting mechanism constrains efficiency in a certain friction level regime, it is possible for different, more efficient mechanisms to dominate in surface friction regimes that are either higher or lower than the regime in question.

3. The change in efficiency between straight-line and in-a-turn braking on a uniform surface varies considerably and depends on the relationship between the proportioning value and the available friction. With proportioning perfectly matched to the friction level for straight-line braking, braking efficiency was seen to reduce by as much as 18% when braking in a turn. On other surface friction levels, the same vehicle will exhibit broadly varying straight versus turn differences—in one case the in-a-turn efficiency was seen to be 16% higher than straight-line efficiency.

4. On split coefficient surfaces, the change from straight-line to in-a-turn braking generally resulted in a higher efficiency. The average level of braking efficiency on the split coefficient surfaces was observed to be about 10% higher than on the uniform surfaces.

5. The item most influencing braking efficiency in a turn on a split friction surface is the polarity of turn with respect to the right/left placement of hi/lo friction surfaces. Differences in efficiency between right and left turns on a split ranged from 0 to 18%.

6. Among split friction surfaces, the only descriptive parameter found to uniformly affect measured efficiencies is the increment in friction level across the split. This characteristic is seen to invariably exaggerate the asymmetry in performance between right- and left-hand turns.

7. The average friction level represented by the pair of surfaces comprising the split condition was not seen to methodically influence efficiency results. Thus the specification of the average μ level incorporated in a split friction test condition would appear to be more or less open to selection on the basis of practical considerations of friction treatment techniques, and

not constrained by any technical concerns over a discriminatory test practice.

8. The lateral acceleration level which exists during braking in a turn was found to impose a relatively small influence on braking efficiency between the values of 0.2 g and 0.3 g A_y. Thus a braking-in-a-turn test procedure could alternatively employ lateral accelerations between 0.2 and 0.3 g, obtaining generally representative, though not identical, results by either test condition.

3.3 In-Depth Test Program

A comprehensive test program was carried out on a sample of five passenger cars covering straight-line and curved-path braking on high, low, and split coefficient surfaces. In addition to providing a demonstration of the related test procedures and surface conditions which could be integrated with the existing 105-75 procedures, these tests yielded an additional data set characterizing representative braking performance levels of modern passenger vehicles under these test conditions.

3.3.1 Test Vehicle Selection. Four of the five vehicles were selected from among the twelve-vehicle sample tested earlier to provide a broad range in stopping distance performance. The fifth vehicle, by contractual requirement, was an antilock-equipped car. The four conventional vehicles selected were the Chevrolet Monte Carlo, Ford LTD, Ford Pinto station wagon, and the AMC Pacer, i.e., one from each of the four size classes. The fifth test vehicle, a four-wheel-antilock-equipped 1976 Nova, was loaned to the project by the Kelsey-Hayes Corporation. The Kelsey-Hayes antilock system installed on this vehicle was a two-modulator system employing separate axle control on the front and rear wheels.

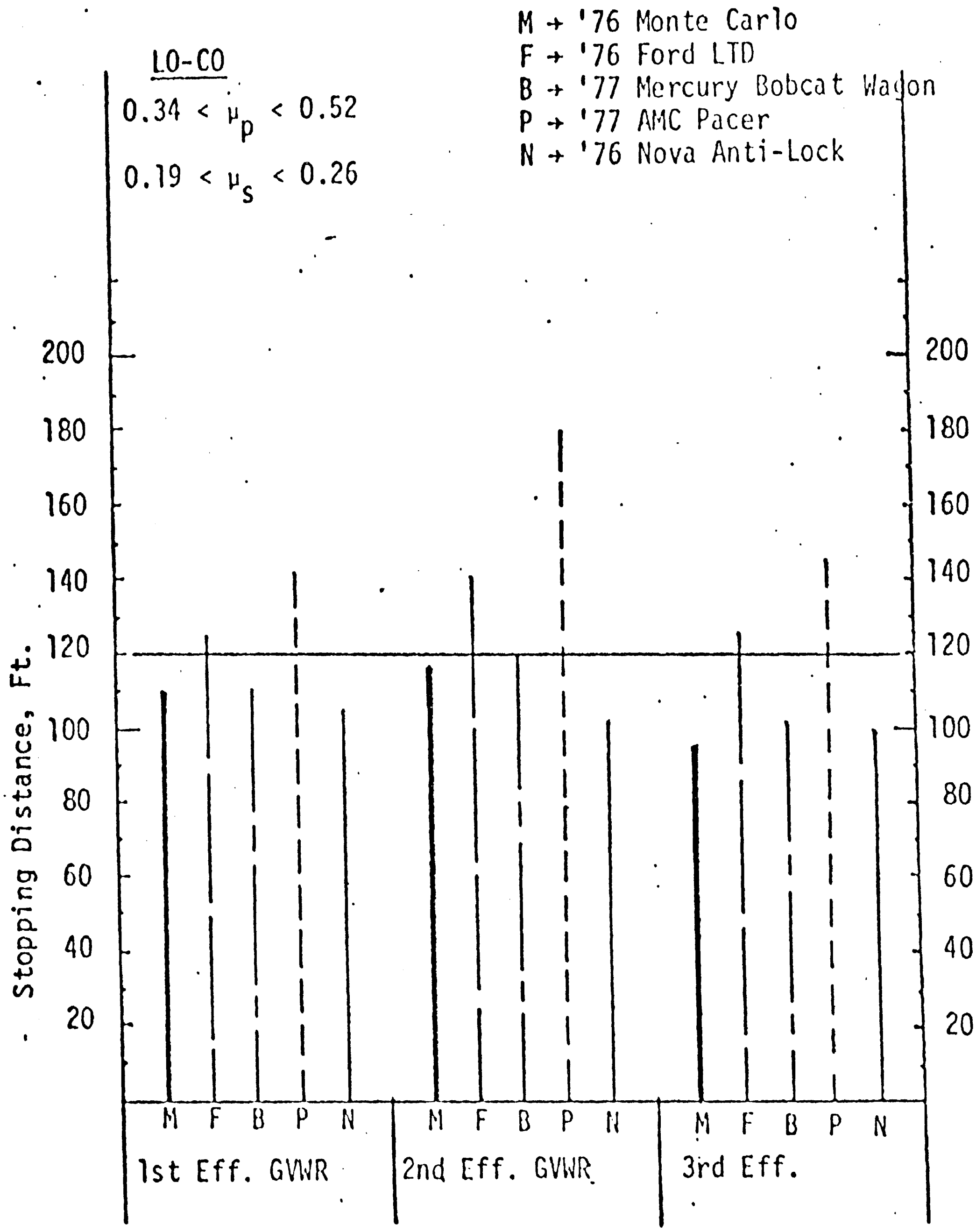
3.3.2 Test Site and Experimental Procedures. This comprehensive test series was performed under subcontract by the personnel of the Bendix Automotive Proving Grounds at the Bendix test facility near South Bend, Indiana.

Vehicle tests were conducted according to the basic procedures and conditions of FMVSS 105-75 with respect to the first (pre-burnish), second, and third effectiveness test except that high, low, in-a-turn, and split coefficient conditions were included in a 28-test matrix. Exceptions were also adopted concerning the topics of wind velocity, initial brake temperature, and brake pedal control forces. Test activity was permitted under prevailing steady-state wind velocities not exceeding 15 mph. Initial brake temperature was not to exceed 200°F, but the lower bound on initial brake temperature was dropped in recognition of the fact that tests on wet surfaces involving low energy stops and exposure to water spray imply low temperatures. Pedal force limits were not enforced in recognition of the fact that these were not compliance tests and that pedal forces less than 15 lbs might be encountered in tests on surfaces of low friction level.

3.3.3 Discussion of Full-Scale Test Results. Examples of test results obtained on the five vehicles tested at the BAPG are shown in the bar graphs in Figures 3.3 and 3.4. The range of peak and sliding friction values of each surface, measured with the SFD,* are shown in both figures. The data plotted represent the shortest of the two best stopping distances obtained at optimum pedal force.

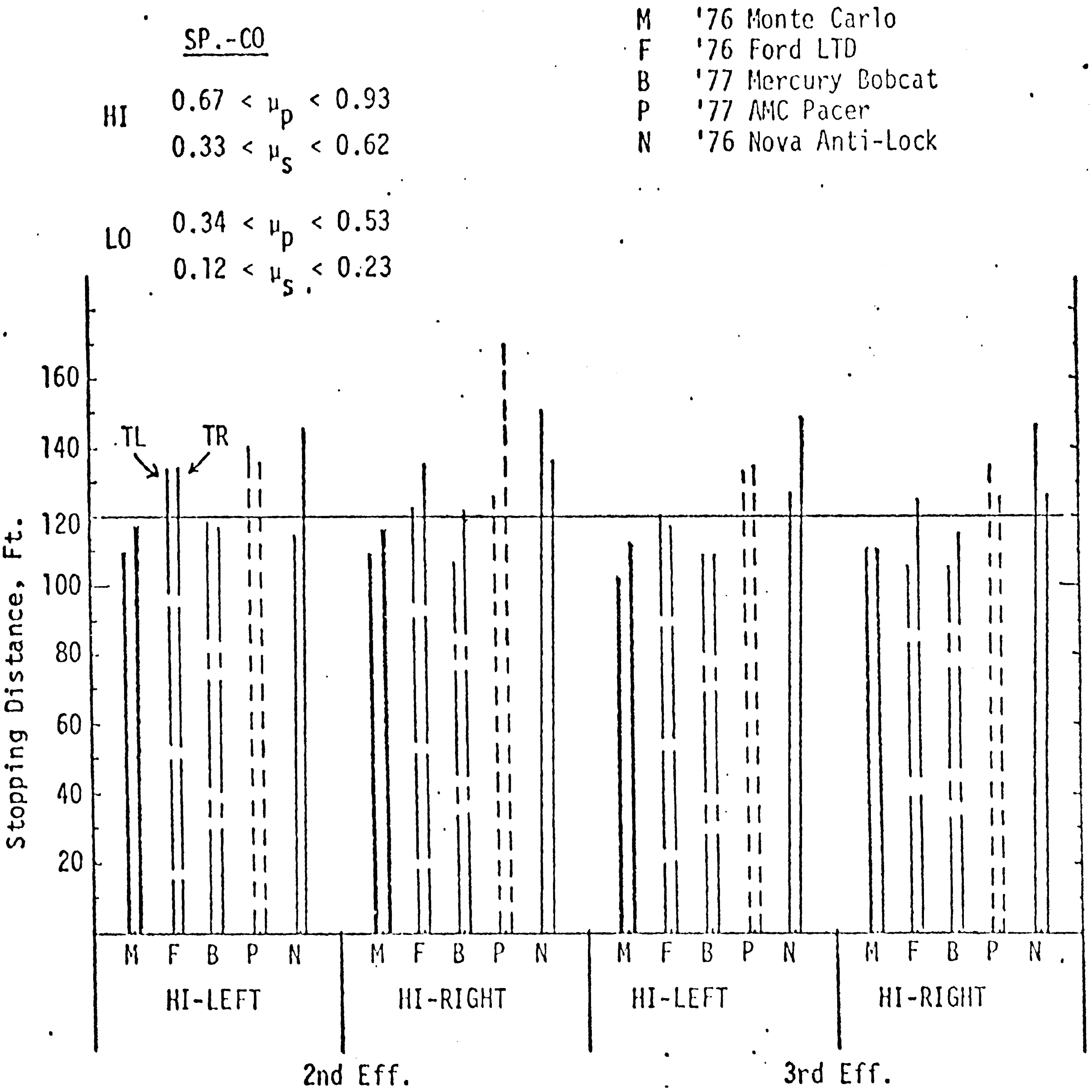
In the case of the antilock-equipped Nova, all best performance stops involved controlled lockup of either the front or both the front and the rear wheels, i.e., with antilock systems on the front axle or front and rear axles cycling. With the other four vehicles, most of the best performance stops involved lockup of one wheel or one wheel per axle. In particular, in straight and

*That is, "Surface Friction Dynamomter" as defined in Reference [1].



Straight-Line Stopping Distance on Low Coefficient Surface. V_o = 40 mph.

Figure 3.3



Braking-In-A-Turn Stopping Distance on Split Coefficient Surface. V_o = 40 mph, A_{yo} = 0.2G, Turn Radius = 535 Ft. Turn Left - TL, Turn Right - TR.

Figure 3.4

curved-path tests on split coefficient surfaces, 63 out of the 64 best performance stops involved lockup of one wheel or one wheel per axle.

While the stopping distance results of these tests basically confirmed the measurements made in the survey test series for straight-line, homogeneous surfaces, this later data set permitted more definitive assessment of braking in a turn and braking on split friction surfaces. In summary of these tests, we find that where stopping distance is the only performance measure, little or no information is gained by performing braking-in-a-turn and split-coefficient braking tests which cannot be deduced from straight-line braking tests on high and low coefficient homogeneous surfaces. Antilock-equipped vehicles can be an exception, perhaps, as evidenced by the right/left turning asymmetry revealed in the split coefficient in-a-turn tests of the antilock Nova and the longer stopping distances exhibited by this vehicle on the split surfaces. In the case of split coefficient surfaces, if no wheel lockups are permitted, the stopping distance will be equivalent to that achieved on a uniform surface with peak friction equal to that of the low friction side of the split. If wheel lockup on the low side is permitted, the stopping distance will approximate that which would be achieved on a uniform surface with a peak friction value equal to the average of the peak friction value on the high friction side and the sliding friction value on the low friction side. A large steering effort is required to compensate for the yaw moment which is generated when one wheel per axle is allowed to lock on the split coefficient surface. Consequently, it is doubtful that the average driver would achieve the minimum stopping distances on the split surfaces acheived by the professional test driver in the tests at Bendix. In reality the stopping distance would generally be limited by vehicle controllability rather than the available traction on the split coefficient surface.

The antilock-equipped vehicle which was tested in this series exhibited the best overall performance on homogeneous surfaces, but ranked fourth in performance on the split coefficient surfaces. However, the antilock system relieves the driver of the task of precisely modulating pedal force and significantly eases the steering task during maximum performance stops.

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4.0 CONCLUSIONS AND RECOMMENDATIONS

This research has examined various aspects of passenger car braking performance in an effort to determine whether FMVSS 105-75 might be meaningfully extended to include stopping distance requirements covering other braking conditions than those currently specified. We find, in general, that the answer to this inquiry is, "NO." The single exception concerns the specification of a stopping distance-based braking efficiency performance for the case of braking in a straight line, on a low friction pavement. In regard to this conclusion we offer the following remarks:

1) The conclusion that 105-75 may be meaningfully extended by adding a low friction test does not derive from a general discovery that 105-compliant vehicles are peculiarly deficient in braking capability on low friction surfaces. Rather, the conclusion is based upon the observation that a "single point" braking performance requirement does not, of itself, constitute a means of "standardizing" vehicle braking capability over the range of possible friction levels. Thus the suggestion of extending 105-75 to include a low friction test is based upon the matter of conceptual adequacy rather than upon a demonstrated safety need.

2) Regarding safety needs, it was seen in tests on low friction surfaces, that current vehicles provide braking efficiencies which average approximately 7-12% lower than the efficiency levels attained on a high friction surface. This relatively small difference between efficiencies achieved on low and high friction surfaces suggests that the vehicle manufacturing industry is generally designing its brake systems to provide adequate low friction performance—even though this performance is currently unregulated.

3) The larger scale problems associated with maintaining and specifying a low friction test pavement suggest, in our view, that any extension of FMVSS 105-75 to include a low friction test should also incorporate a "braking efficiency" approach toward performance normalization.

4) If a low friction braking efficiency requirement were to be promulgated, any other existing stopping distance requirements should be reformulated in terms of "efficiency," also. Further, the setting of requirement levels will necessitate that NHTSA proceed with certain previously recommended research [1] regarding development of braking efficiency into a rulemaking-suitable method.

In addition to this basic conclusion and recommendation, other findings supported by the study results are as follows:

1) The minimum stopping distance exhibited by vehicles while braking in a medium-severity turn does not appear to differ significantly from minimum stopping distances measured on equivalent surfaces while braking in a straight line. Accordingly, one may generally assume that measures of straight-line stopping distance suffice as a close approximation of stopping distances achievable in medium-severity turns.

2) Measures of minimum stopping distance obtained while braking on split friction surfaces do not appear to be generally useful as characterizations of vehicle safety quality. Because of many possible lockup combinations, split friction stopping distances are generally seen to be rather short compared to the performance limits imposed by the low friction side of the split, alone. Moreover, the potential for a yaw perturbation during split friction braking was seen to be the overwhelming reality—tending to suggest that any stopping distance compromises are by far the smaller part of the safety issue.

3) The extra costs of antilock braking systems would not appear to be generally justifiable simply on the basis of stopping distance improvements. Although both improvements and degradations in stopping distance were seen to derive from antilock system operation, the conventional wisdom, borne out by the data, is that antilock systems contribute profoundly to directional controllability but only minimally to stopping distance performance.

5.0 REFERENCE

1. Ervin, R.D. and Winkler, C.B. Braking Efficiency Test Technique. Final Report, Contract No. DOT-HS-031-3-765, December 1974.