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MOTORCYCLE BRAKING PERFORMANCE

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Summary Technical Report

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16. Abstract

A study was conducted to evaluate the existing Federal Motor Vehicle Safety Standard for Motorcycle Braking Systems and to develop an alternate test methodology which resolves certain shortcomings thereof. Full-scale vehicle tests were conducted, per the existing standard, and the alternate test concept was developed and demonstrated. The study finds that a procedure involving a process of towing the test motorcycle does represent a viable approach suitable for adaptation in a next-generation rule concerning motorcycle braking performance.

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1.0 INTRODUCTION

This document constitutes the summary final report on a research study entitled "Motorcycle Braking Performance" which has been conducted under Contract Number DOT-HS-5-01264 from the U. S. Department of Transportation (National Highway Traffic Safety Administration).

The purpose of this study has been to conduct and evaluate the existing motorcycle brake systems standard, FMVSS 122, and to develop a revised method which resolves shortcomings in that standard. In HSRI's approach toward this project, a certain preconception was held that FMVSS 122 was fundamentally inadequate in areas relating to the objective characterization of motorcycle braking performance. In addition to observations that the standard was conceptually wanting, it also appeared that certain procedural requirements of 122 imposed a substantial level of hazard to the test rider. Accordingly, the project was designed from the outset to permit a large portion of the overall effort to be devoted toward developing a revised test methodology.

The braking performance of a sample of four motorcycles, per the procedure of FMVSS 122, was first measured as a means of evaluating the standard itself, and also to provide a set of test data upon which could be based judgments concerning test condition specifications.

It should be noted that conceptual inadequacies of the type observed in this standard do not actually require experimental trial for their demonstration. Nevertheless, it was felt that certain portions of the industrial and government communities would more readily receive the recommendations resulting from this project if they were cast in the light of relevant test experience.

The primary consideration requiring special treatment of the two-wheeled motorcycle, of course, is its independent actuation of front and rear brake systems. By this feature, the typical motorcycle differs fundamentally from, say, the motor car in the demands it places on a braking performance test. Accordingly, it was felt that the basic requirement for an objective measure of motorcycle limit braking capability was that a means for distributing braking effort be specified. Thus, in the new test concept which has been developed, an objective format for brake actuation is the primary feature.

While the major result of this study is the recommendation of a new format for a motorcycle brake system standard, a certain qualification of this recommendation and of the project effort leading to it is in order. This project has been structured to apply the principals of classical vehicle mechanics to the design of a measurement methodology. By the containment of scope within the boundaries of such an engineering discipline, the resulting test technique yields measurements of a form comparable to those produced in other federally-promulgated braking rules, but does not serve to characterize braking quality from a human factors point of view. Insofar as motorcycle braking involves rider control tasks which may be substantially more demanding than is the case for cars and trucks, we might hypothesize that the match between operator skill and vehicle properties is of greater relevance to safety in the case of the motorcycle. Accordingly, while the following report summarizes a test method which appears to offer major improvement over the existing brake standard, it should be viewed with the recognition that the resulting measurements may not provide for a comprehensive assessment of the safety quality of a motorcycle's braking performance.

2.0 TECHNICAL DISCUSSION

In this section, results and observations deriving from the major tasks of the project are summarized.

2.1 FMVSS 122 Test Program

The initial program of tests conducted in this study involved the use of four contemporary motorcycles, as listed in Table 1, and the full complement of effectiveness, burnish, fade, and water recovery procedures as specified in FMVSS 122. Results of this program of tests reveal the following:

Table 1

Motorcycle	Brake System	Engine Displacement, cc	Vehicle Weight, lbs
Harley-Davidson FXE 1200	Hydr. Disc Front & Rear	1200	580
Honda, CB 400F	Hydr. Disc-Front Mech. Drum-Rear	408	405
Kawasaki F9C	Mech. Drum Front & Rear	347	312
Suzuki TS-125	Mech. Drum Front & Rear	123	230

1) Ease of Compliance. The most visible result of all the 122 tests was the substantial margin of compliance indicated in most performance categories with each bike when operated by a professional rider. In stops from 60 mph, for example, typical stopping distance performances fell in the range of 150-170 feet, compared to 122's pre- and post-burnish effectiveness requirements of 216 and 185 feet, respectively.

The only significant challenge to the professional rider's skills, as presented by the 122 stopping distance requirements, occurred in certain of the 30-mph stops.

2) Hazards of High Speed Stops. The 122 procedure requires that the second and final effectiveness tests be conducted at elevated speeds, including maximum speed just below that attainable in a one mile distance from a standing start. Although all high-speed tests conducted in this study yielded stopping distances which complied with the standard, the element of hazard to the test rider was quite apparent. In testing of the Harley-Davidson vehicle from an initial speed of 105 mph, the professional rider did cause a front-wheel lockup upon first application of the brakes. Fortunately, he quickly recovered control, although this condition would normally have resulted in a spill with riders of lesser skill.

A considerable amount of informal testimony from industry sources indicates that the above-cited experience is not uncommon and occasionally results in a serious injury-producing accident. Accordingly, it would seem that the unique nature of the two-wheeled motorcycle, especially as regards the hazards imposed by wheel lockup at high speeds, calls for a review of the need for performance requirements at such highway-illegal speeds.

3) Influence of Burnish and "Fade"-Type Work Inputs. A major observation of the 122 testing was a general insensitivity of brake torque effectiveness to the work history provided by the burnish procedure and to the thermal loading incurred during the fade and recovery tests. Comparison of most single-wheel pre- and post-burnish effectiveness data, for example, shows more variation among the test repeats than between the pre- and post-burnish averages of these repeats.

With regard to the fade/recovery tests, no brake demonstrated a significant sensitivity to the imposed thermal loading. Even through temperatures exceeded 300°F on some brakes, the actuator force levels remained relatively unchanged from baseline to the subsequent recovery tests.

4) Response to the Wet Brake Recovery Procedure. The immersion-type wetting procedure of FMVSS 122 was found to severely reduce the torque effectiveness of drum-type brakes. The sensitivity of torque effectiveness to the water immersion procedure is assessed through comparison of required actuator forces before and after the water immersion. All drum brakes, as measured by the recovery test sequence, suffered a residual loss of effectiveness following the water immersion. The apparent explanation for the indicated loss in brake gain is that the immersion condition provides a hydrostatic pressure mechanism for forcing water past the drum brake assembly's dust seal. Upon removal of the vehicle from the immersion tank, a prolonged drainage period is needed. Given this observation, it might be argued that the positive pressure condition is unrealistic for highway-type riding and thus effects an artificial assessment of wet-weather braking quality.

Disc brakes were also found to be affected by the water immersion test, but less so in degree and only temporarily. It was concluded that the immersion method imposes an inadequate degree of challenge to the wet-weather braking capabilities of disc-type brake assemblies.

2.2 Rider Skill Sensitivity Tests

In addition to the direct conduct of the FMVSS 122 tests, a set of experiments were performed to assess the influence of rider skill level on 122-type test results. These tests involved conduct of the minimum stopping distance procedure by three riders of skill levels classified as (1) professional, (2) skilled, and

(3) novice. Each of these classifications are reflective of an assumed level of riding skill deriving from riding experience.

General observations of the rider skill test results follow.

1) A most significant finding of the rider skill tests derives from the different riders' abilities to achieve performances which comply with FMVSS 122. It was seen that:

   a) the professional rider passed all stopping distance requirements

   b) the skilled rider passed about half of the stopping distance requirements—failing the Honda/30 mph, Kawasaki/60 mph, and Suzuki tests at both initial speeds

   c) the novice rider passed all stopping distance requirements but the Honda/60 mph test.

2) The professional rider made greatest use of the front brake, while the skilled and novice riders, apparently for lack of confidence in controlling front-wheel braking, made greater use of the rear brake. One might conclude from the superior overall performance of the professional rider that a test rider's skill in conducting 122-type effectiveness tests depends upon the degree and consistency of usage of the front brake.

3) The margin of superiority of the professional rider over the skilled and novice riders, particularly demonstrated in stopping distance capability, increased at higher test speeds.

4) The repeatability in stopping distance and brake actuator forces attained by the professional rider far exceeded that of the skilled and novice riders.

2.3 A New Methodology for Measuring Motorcycle Braking Performance

Within this project, the review of FMVSS 122, together with a basic examination of the problem of measuring motorcycle braking performance, led to formulation of a new test method.

This test methodology which is conceived as providing all of the elements of an objective procedure for motorcycle brake testing has two basic features, viz.,

1. the test motorcycle is towed by a support vehicle at constant velocity for all of its dynamic performance measurements, and
2. all tests are conducted with braking control effort being applied to only one actuator at a time.

The tow-test method renders a tow force measurement as its fundamental performance measure. Knowing the total weight of motorcycle and rider, the force measure is interpreted in normalized form as an equivalent deceleration. The attachment of the test motorcycle to a tow vehicle, shown in Figure 1, involves a roll-rigid coupling, such that the tow vehicle provides roll stability to the motorcycle thereby permitting indiscriminate lockup of front or rear wheel.

The test motorcycle is supported by a linkage arrangement, shown in Figure 2, which provides a steer and roll constraint while incorporating the tow force measurement load cell as a longitudinal constraint.

The test motorcycle is mounted by a rider whose only function is to provide control inputs to the brake actuators according to a prescribed sequence. The rider's instructions are tailored, of course, to the type of test. In "conditioning" test sequences such as burnish and thermal loading, or fade, procedures, the rider is instructed to sustain a prescribed level of tow force for

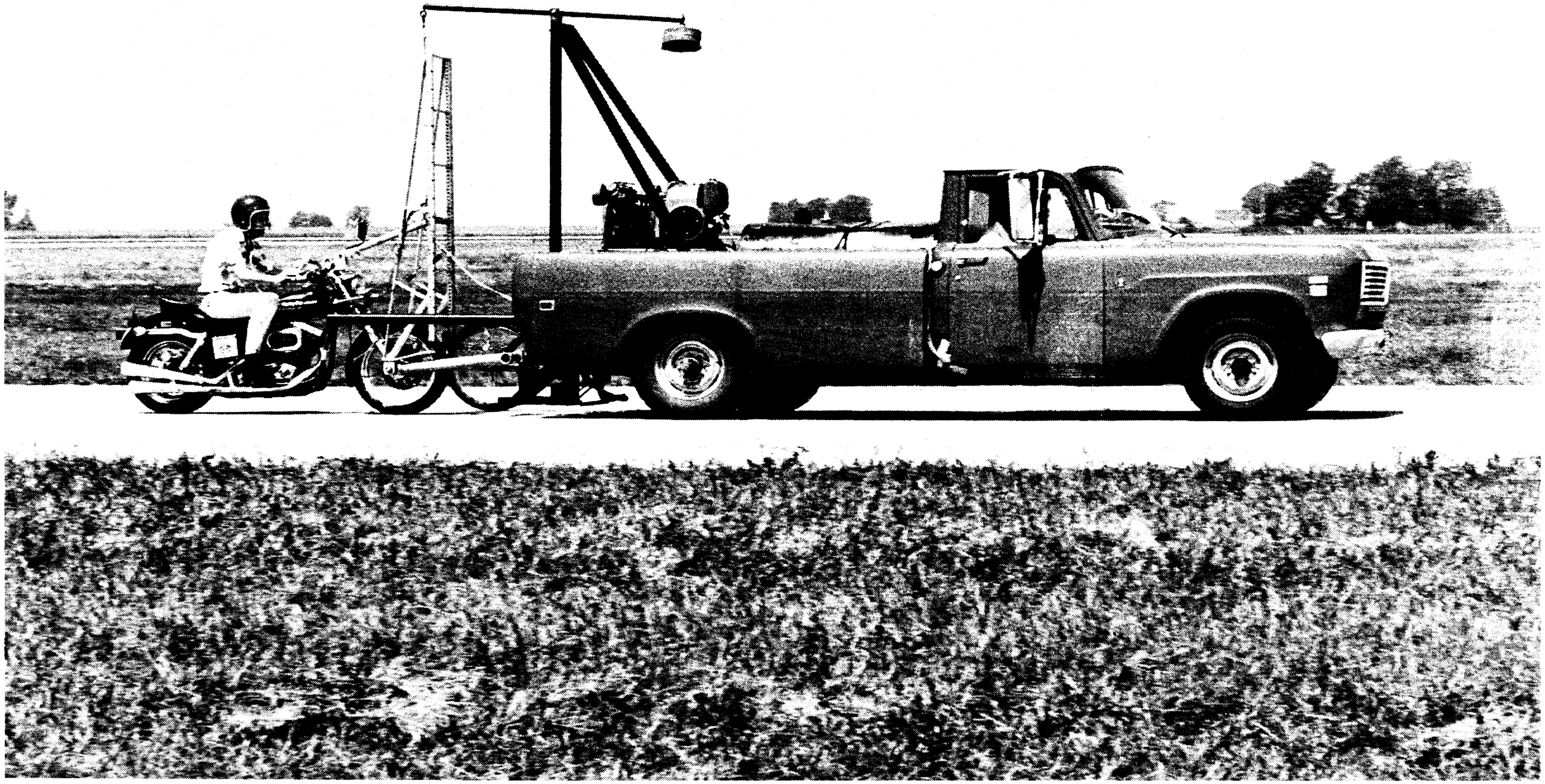

Figure 1. Tow-test apparatus employed during demonstration test program.

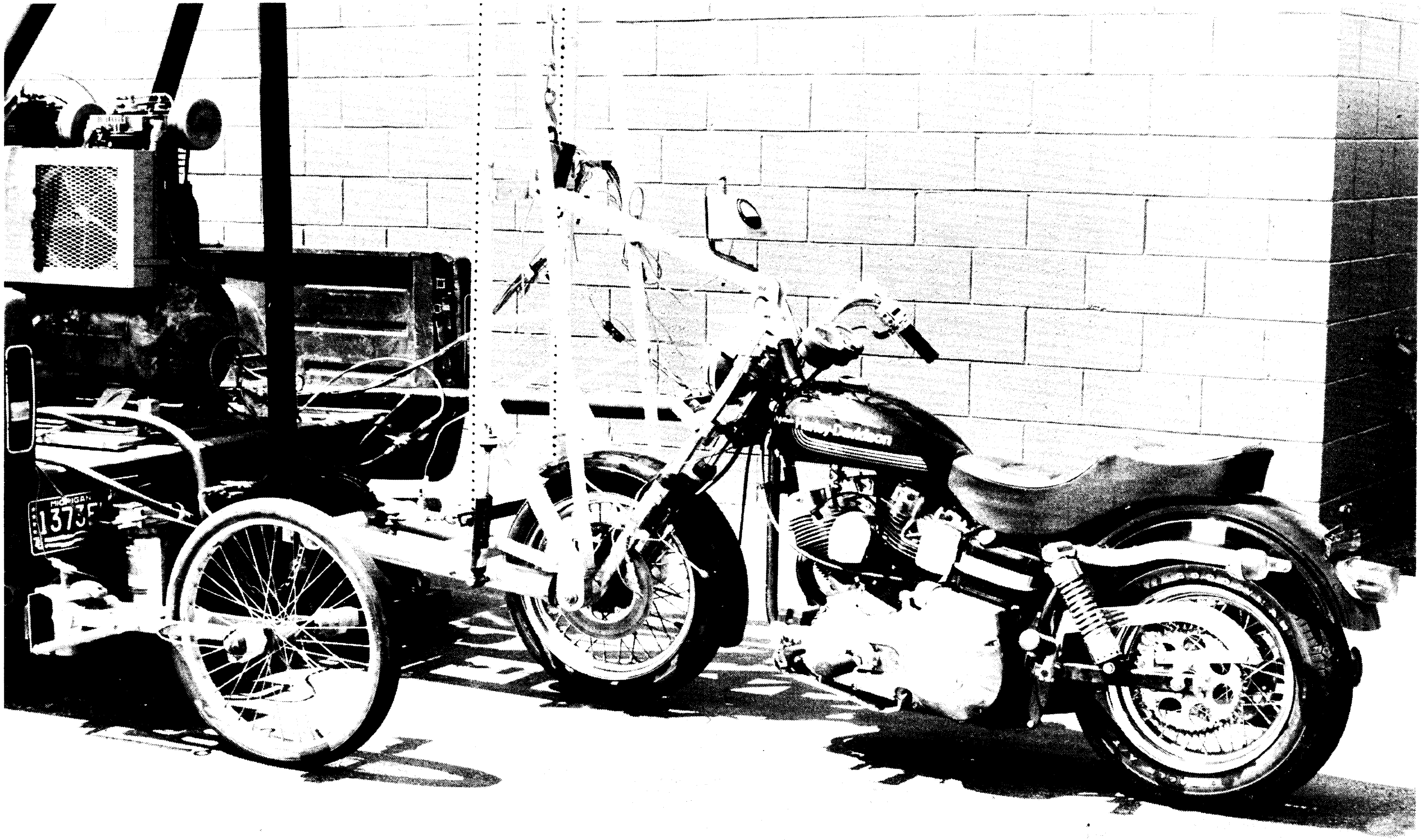

Figure 2 . General tow linkage attachment to Harley-Davidson FXE-1200.

a determined time interval. As shown in a photo taken from the rider's position, Figure 3, the tow force signal is continuously displayed on a meter mounted for direct monitoring by the test rider.

In "effectiveness"-type tests, the rider is instructed to apply the front or rear brake input actuator in a ramp-type fashion up to the braking limit. In either type of experiment, the tow vehicle serves as the data acquisition station, thereby disemburdening the test motorcycle of virtually all instrumentation and power supply functions.

The wet weather condition procedure involves a feature of the towing support vehicle which is peripheral to the tow and data acquisition features. In this capacity, the tow vehicle incorporates a water storage and delivery system which is configured to provide a realistic wet weather condition. The water delivery system dispenses a stream onto the pavement in line with the wheel path as well as a stream above the ground—in the form of a dense spray. Together, the two-nozzle system is intended to provide a thorough, yet authentic impingement of water on brake assemblies, such as may occur during a 1 inch/hr rainfall on a trafficked highway. The dynamic wetting procedure is especially pertinent in the motorcycle case, it is reasoned, because of the exposed nature of motorcycle brake assemblies. On the other hand, the described technique avoids artificially "over exposing" motorcycle brakes, by forcing water through zero-pressure seals, such as occurs in "immersion"-type wetting procedures

The application of the tow-test concept to the characterization of braking capability limits requires that an analogy be established between the contrived tow experiment and the free-stopping process of the dual-braked motorcycle. Specifically, there is a need to establish the traction limits of front and rear tires under respective vertical load conditions such as would derive in a two-wheel-braked stop. As illustrated in Figure 4,

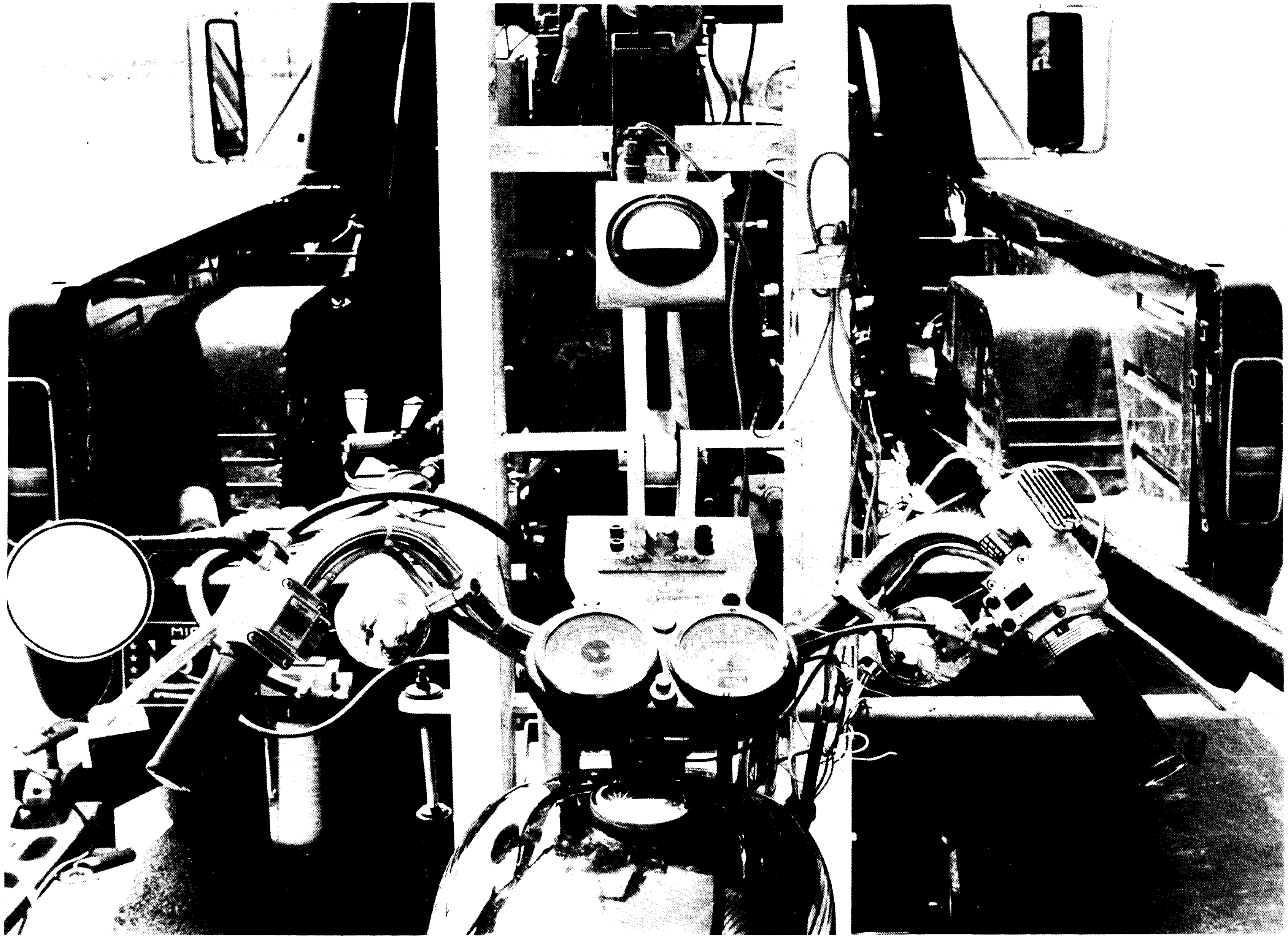

Figure 3 Test rider's view.

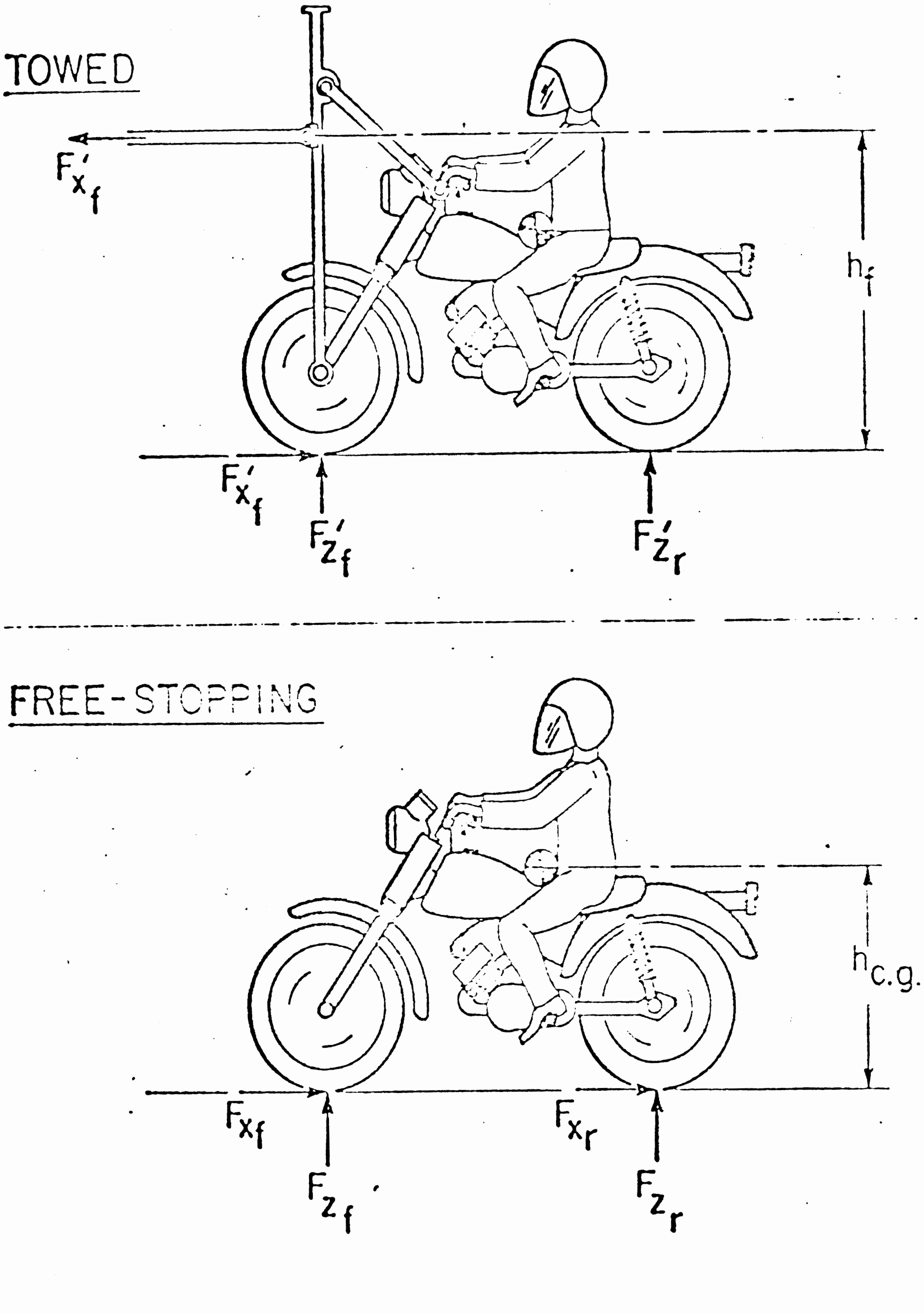

Figure 4. The towed motorcycle is to experience tire loads equivalent to the free-stopping condition.

this criterion implies that the towed motorcycle experience a forward transfer of vertical load in the front- and rear-only braking tests which is equivalent with that experienced by the hypothetical, dual-braked, free-stopping motorcycle.

The key consideration, here, is that the traction limits of pneumatic tires are constrained by friction mechanisms which are inherently sensitive to the normal force which is imposed upon the tire. Thus, since each motorcycle's mass location and wheelbase determine its dynamic tire loading and, consequently, traction-limited braking capability, it is paramount that the towing test method accrue realistic tire loads during its traction-limited experiments.

It should be clear that a vehicle being towed at constant velocity will experience load transfers in proportion to

a) the braking forces which are generated at the tire/road interface, and

b) the height at which the tow force is applied.

Accordingly, for the towed, single-braked motorcycle in Figure 4 to experience load transfer equivalent to that of the free-stopping vehicle, it is necessary that the tow height, h_n, be adjusted to effect the needed pitch moment. Additionally, it should be apparent that distinct values of h_n will be found appropriate for front- and rear-wheel-only braking, viz., $h_n = h_f, h_r$.

Thus we have formulated a test procedure which permits determination of the braking limits of the total motorcycle by way of individual assessments of front and rear tire traction limits. The procedure involves a sequence of tow height selections, braking force measurements, and simple arithmetic calculations to yield a measure of total vehicle performance.

Within this project, the test hardware shown in Figures 1 through 3 was constructed. The test system, together with the formulated tow-test procedure, was demonstrated in a full complement of experiments using the Harley-Davidson and Kawasaki motorcycles identified earlier in the sample of vehicles tested per FMVSS 122. The demonstration test series illustrated that the tow-test methodology constitutes a practicable procedure in the field test environment. Further, this test series served to provide a set of example measures according to the tow-test method, thereby permitting further examination of whatever contrasts exist with FMVSS 122.

2.4 Other Tasks

In addition to the efforts directed at development of the new test procedure, a task was also undertaken to survey the prospects of evolution in motorcycle brake technology and to assure that the new method remained viable over the foreseeable future.

The survey was conducted by way of a questionnaire sent out to motorcycle manufacturers. Respondents to this inquiry provided a valuable basis upon which the future applicability of the developed method can be assured.

The general matter of motorcycle braking-in-a-turn performance was also examined within the project. A simplified analysis of the braking-in-a-turn maneuver was employed to illustrate the mechanisms by which a yaw perturbation is generated, and to estimate the constraint on deceleration capability which might be expected in example cases of braking in a turn. It is hypothesized, however, that the abstract treatment of the vehicle mechanics involved in such maneuvers constitutes an inadequate means of assessing the safety implications of this realm of cycle behavior. Indeed, no significant enlightenment of the safety question of motorcycle braking in a turn appears likely until the difficult matter of closed-loop behavior is effectively explored.

The project has concluded with a recommendation for implementing the tow-test method in the form of a next-generation motorcycle standard. The recommendation includes a formal statement of the tow-test procedure as well as an itemized statement of remaining knowledge gaps.

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3.0 CONCLUDING REMARKS

This study has served to examine the basic methods and supporting rationale applicable to a motorcycle braking performance standard. The study has provided a full-scale trial of the existing standard, FMVSS 122, permitting an assessment of the adequacy of the written standard as a test procedure. The exercise of the standard was seen to illustrate a broad set of shortcomings which tend to compromise the meaningfulness, test safety, and enforceability of FMVSS 122.

The study has proceeded from the observations of the shortcomings of FMVSS 122 to develop a new method for measuring motorcycle braking performance. This method serves to objectify the test process, specifying all brake control inputs within a sequence of front-only and rear-only applications. The test procedure not only objectifies the distribution of burnish braking inputs and thermal loading applications, but also eliminates the rider skill influence from limit braking measurement. In full-scale tests, this procedure has been found to be practicable and suited to the general scenario of a federal rule on motorcycle braking performance. The developed methodology has also been found adaptable to advanced motorcycle braking systems such as may be anticipated within the next ten years of evolution in the motorcycle market.

On the basis, then, of the conceptual foundation of the developed methodology, its successful demonstration in full-scale trials, and its applicability to future brake systems, the technique is recommended for development into a next-generation motorcycle braking standard. Together with this recommendation, however, we must draw attention to those limitations in the current state of knowledge which tend to place the general value of a motorcycle braking standard in question. This matter concerns the lack of a sound basis for specifying the modulability of the brake system or, put another way, that quality which permits a typical rider to accrue the vehicle's innate stopping capability without suffering wheel lockup and the attendant loss of control. Accordingly, together with the recommendation that the new test method be considered for standard revision, we likewise recommend that research be conducted to establish the grounds for a motorcycle brake system modulability requirement. Further, it should be noted that requirement levels concerning limit stopping capability may have to be adjusted for compatibility with an eventual modulability specification.

Moreover, motorcycle brake systems are seen as meriting a unique methodology for their performance measurement; much as motorcycles, themselves, represent a unique class among motor vehicles. Further, it may be hypothesized that the safe braking of motorcycles depends as much, or more, upon the rider's ability to interact with his machine properly as it does upon the machine's physical limitations in braking capability.