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A REFINED TECHNIQUE FOR MEASURING MOTORCYCLE BRAKING PERFORMANCE BY THE TOW METHOD

R.D. Ervin
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TECNICAL REPORT AND APPENDICES
MAY 1981

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TECHNICAL SUMMARY

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This project was to effect refinements in the test procedures and apparatuses used in the so-called tow-test method of measuring the braking performance of motorcycles. The work was to provide a more simplified procedure than that developed in a preceding study entitled "Motorcycle Braking Performance" and was to provide a redesigned package of test hardware.

In the preceding study, the feasibility of the tow-test concept was demonstrated. The concept was developed as a candidate for eventual replacement of the conventional stopping techniques employed in the current motorcycle braking standard, FMVSS 122. The current standard was, itself, seen as deficient since its experimental method lacked objectivity and since certain portions of the method were found to be highly hazardous to the test rider due to the likelihood of front-wheel lockup and subsequent capsize.

The tow-test approach was shown in the earlier study to yield completely objective measures of performance while also eliminating the hazards associated with the conventional method. The new method did, however, entail certain test procedures that were later deemed to be unnecessarily complex. Also, the package of hardware developed for the feasibility demonstration was rather bulky and required that specially tailored parts be fabricated for attaching the towing linkages to each motorcycle.

In the present project, the test procedure was simplified by eliminating an iterative procedure from the effectiveness test sequence in which maximum braking capability is assessed. The simplification was justified on the basis of an error sensitivity analysis which showed that no significant improvement in measurement accuracy was accrued through the more rigorous technique.

(Continue on additional pages)

The hardware package used to connect the test motorcycle to a towing vehicle was completely redesigned and one set of parts was fabricated and assembled. The new hardware system is much lighter than the original package and incorporates adjustable fasteners capable of mounting any conventional motorcycle without modification. An automated digital data collection system was constructed as a complement to the new mechanical system. The digital system controls the test sequence by advising the operator of each step of the procedure and providing a printed paper tape of results, as they are gathered.

The test system was applied in a demonstration program in which three motorcycles were subjected to the refined test procedure. The sequence of experiments included a preburnish effectiveness series, a 200-application burnish series, a postburnish effectiveness test and, finally, a thermal fade sequence. The test experience and resulting data confirm that the revised methodology and hardware represent a very efficient and accurate means to measure the braking performance of motorcycles.

The test package exists as a complete system, with tow vehicle, for future use in the sponsor's follow-up efforts towards reformulating FMVSS 122. A second volume of the final report has been prepared as a manual for those who may use the test package subsequent to this study.

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A REFINED TECHNIQUE FOR MEASURING MOTORCYCLE BRAKING PERFORMANCE BY THE TOW METHOD

Volume I

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R.D. Ervin
J.D. Campbell

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16. Abstract

A method for measuring the braking performance of motorcycles was refined and a complete package of test hardware was constructed and demonstrated. The project followed upon a previous NHTSA-sponsored study in which a concept was developed for towing motorcycles as a means of safely and objectively measuring braking system performance. The refined tow-test apparatus is much lighter than the original system and requires no special adaptation for testing any conventional motorcycle. In demonstration testing, performance measurements were made on three motorcycles representing the range of vehicle weights. Tests showed that the new procedures and hardware were quite satisfactory.

The final report includes a Volume II "User's Manual" to instruct those who may operate the NHTSA-owned test system in the future or who may choose to reproduce the system.

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1.0 INTRODUCTION

This document constitutes the final report on Contract DOT-HS-9-02314 entitled "Motorcycle Brake Test Procedure Changes--Equipment Upgrade," sponsored by the National Highway Traffic Safety Administration of the U.S. Department of Transportation. This research project follows from an earlier HSRI study conducted under NHTSA Contract DOT-HS-5-01264 entitled "Motorcycle Braking Performance." In the earlier project, a concept for towing a motorcycle in tests of its brake system performance was developed and the feasibility of this concept was demonstrated through full-scale tests. The initial package of test hardware, however, constituted a prototype apparatus which was in need of some refinement. Thus the effort reported herein was undertaken to identify those refinements and to construct and demonstrate an upgraded test system.

The tow-test concept of motorcycle braking performance measurement was originally formulated to include the following features:

1) The motorcycle is affixed to a towing vehicle (usually a light truck) such that the tow force needed to react motorcycle braking forces can be measured during constant velocity operation.

2) The motorcycle's yaw and roll motions are constrained so that the test rider does not risk injury during wheel lockup conditions.

3) The independent front and rear brake actuators are applied only one at a time. Thus the tow-test procedures comprise a sequence of front-only and rear-only experiments.

4) The measured tow forces are interpreted in terms of equivalent "free-stopping" conditions in which the motorcycle is considered to decelerate.

5) The tow-test sequence is modeled around the basic elements of the federal safety standard for motorcycle brake systems, FMVSS 122.

Refinement of the tow-test methodology is presented in this report by means of two separate volumes. Volume I is written as a technical report describing the refined procedures and apparatus, and reviewing the results of a demonstration test program. Appendix 1 to this technical volume also presents a "classification scheme" which was developed as a tool for organizing the Government's sampling of the motorcycle population in future compliance testing of motorcycle braking performance. Appendix 2 of Volume I presents a complete statement of the refined tow-test procedure. In Appendix 3 are presented the detailed test data deriving from demonstration tests on three motorcycles.

The second volume of the report presents a user's manual for those who will later employ the test apparatus constructed during this project. It should be noted that, while a specific test system was developed through the work reported here, the test procedures presented in Appendix 2 of Volume I are written to apply generally; that is, independently of any specific test system design.

2.0 REFINEMENT OF THE TOW-TEST METHOD

The original tow-test methodology that was developed for measuring motorcycle brake system performance had shortcomings in both procedural and hardware details. A single refinement in test procedure was accomplished in this project, providing a significant reduction in the complexity of the effectiveness experiments. Further, all of the actual test procedures were implemented in a demonstration test program using an on-board computer system which provided for an objective and efficient process of data collection. Of course, development of the computer-implemented test method required that previously implicit steps in the test procedure be made explicit and objectively stated. In order to fully appreciate the discussion of test procedure refinements that follows, the reader should be familiar with the basic rationale and theoretical formulation behind the tow-test concept as presented in the "Motorcycle Braking Performance" reported cited earlier [1].

The primary refinements accomplished within this study involved the test apparatus itself. A completely new test system was designed, constructed, and then demonstrated in an example test program. This test system can be reproduced according to a drawing set which has been submitted to the NHTSA and is described in an overview discussion within this section of the report.

2.1 Test Procedure Refinements

The only procedural change that was seen to be necessary following the original study concerned the effectiveness test procedure, and specifically the rear-wheel-only iteration requirement.

In the tow-test procedure concept, an adjustable tow height is needed so as to achieve tire vertical loads which authentically represent the reference case of the free-stopping motorcycle. Authentic tire loads, of course, are required so as to properly account for the sensitivity of normalized peak tire traction (μ) to vertical load. For some hypothetical tire which would exhibit no sensitivity of normalized peak traction to vertical load, tow height selection would be of no importance since any tow height (i.e., any vertical load) would produce the same measure for normalized peak traction.

During the initial development of the tow-test effectiveness procedure, it was not known how significant the normalized tire traction sensitivity influence might be in affecting the measurement of limit braking performance. Consequently, a complete effectiveness test procedure was developed to ensure that all such influences would be included and could be evaluated. Hence, it was assumed to be necessary that the procedure involve an iterative search for the exact value of tow height in the rear-only effectiveness test. The "exact" value of tow height would, by definition, yield an authentic level of vertical load on the rear tire and a corresponding authentic measurement of normalized peak tire traction.

Subsequent to the original development of the tow-test method, an analysis was performed to ascertain the effect of errors in front and rear tow heights on the accuracy of the proposed tow-test effectiveness measurements. This analysis was included as Appendix E.1 of the Motorcycle Braking Performance final report [1]. The principal conclusion of the analysis, concerning errors in rear-only tow heights, finds that even for moderate levels of normalized tire traction load sensitivity, large errors in rear-only tow heights have little influence on the accuracy of the tow-test measurement of total bike deceleration capability. For example, selection of a rear-only tow height at a level which is arbitrarily lowered to a value equal to twice the height of the rider/cycle center of gravity results in a maximum error of 0.003 g's in total bike deceleration on a high friction surface, assuming that the tires display moderate to large levels of normalized traction-load sensitivity. The assumption that the rear tow height be limited to a value equal to twice the height of the rider/cycle c.g. represents an error in rear tow height of approximately 10 to 20 inches for typical motorcycles on high friction surfaces.

Further, experience from the original demonstration tow-test program indicated that test-to-test variations in rear tire peak traction measurements derived far more from random properties of the test surface and measurement process than from load sensitivity in tire traction properties.

Therefore, based on the cited analysis and test experience, it was determined that the rear-wheel iteration requirement of the tow-test effectiveness procedure could be eliminated. Such a modification simplifies the set of instructions currently defining the effectiveness test procedure. This modification reduces the flow diagram shown in Figure 1 (representing the original procedure) to that shown in Figure 2, wherein the rear-wheel iteration loop is seen to be absent. The single rear-wheel test in the modified procedure (Item 2. in Figure 2) is now conducted using a tow height of 48 inches.

Constraining the rear-wheel test tow height to a fixed and relatively low level provides a number of benefits. First, there is the advantage of a simpler and more compact hardware package, as will be described in the following section. Secondly, there is a reduced influence of the aerodynamic pitch moment which becomes a large fraction of the total pitch moment during rear-wheel tests using high tow heights. Although the influence of the aerodynamic drag force is approximated and accounted for in the effectiveness test procedure, its influence can be substantially minimized by use of a lowered rear-only tow height. And, finally, there is the advantage of conducting rear-only tests at the resulting higher level of vertical load than would be specified by the original procedure. In some cases, the original procedure required rear-wheel testing at very light vertical loads (i.e., at high values of tow height) for which small random variations in tow force measurements (deriving principally from surface irregularities) produced significant variations in the estimate of normalized peak traction. Limiting the rear-only tow height to 48 inches, therefore, helps reduce the polluting influence of the background noise condition by "scaling up" the measurement of peak rear tire force through use of a larger rear-wheel vertical load.

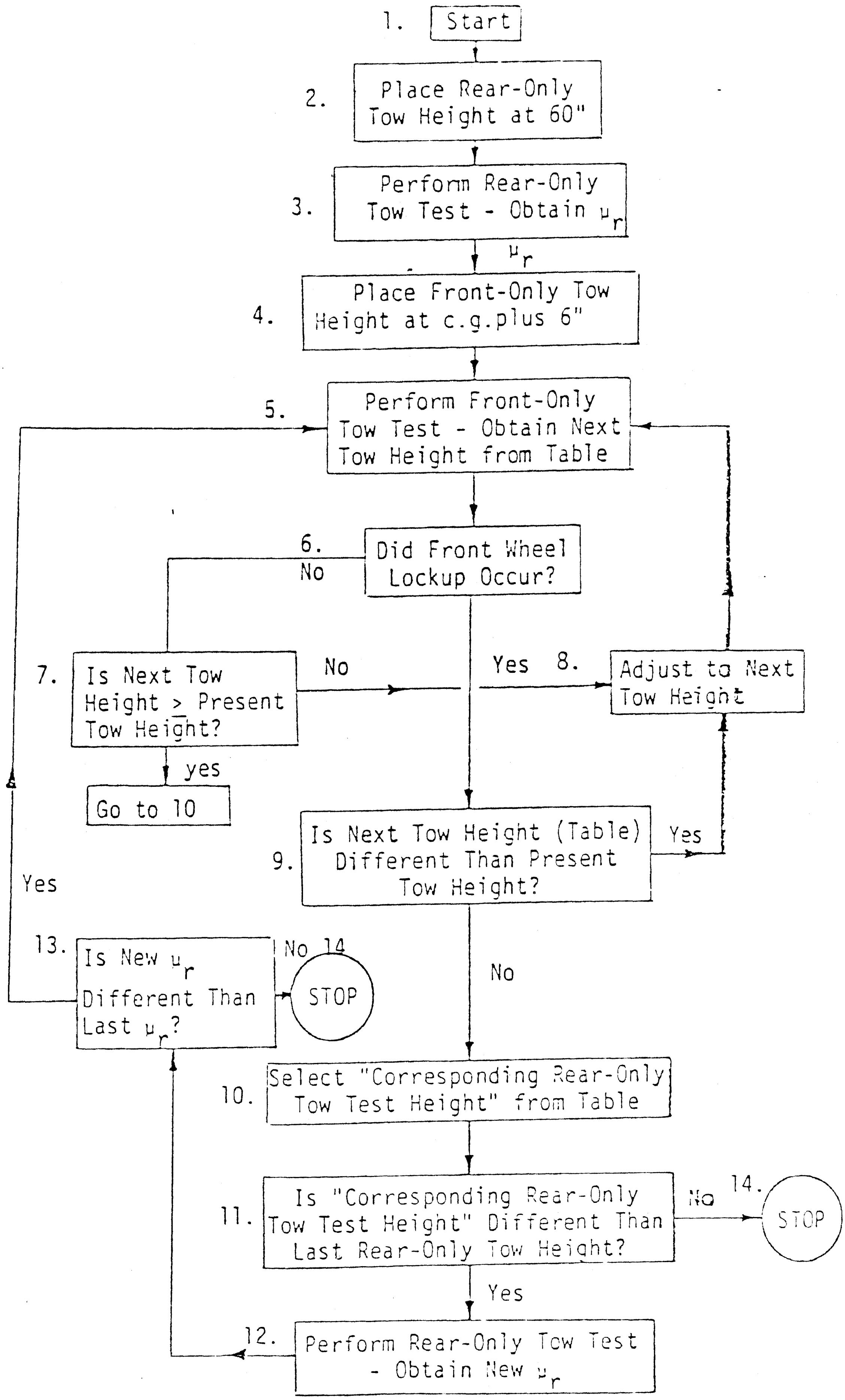

Figure 1. Original effectiveness test procedure.

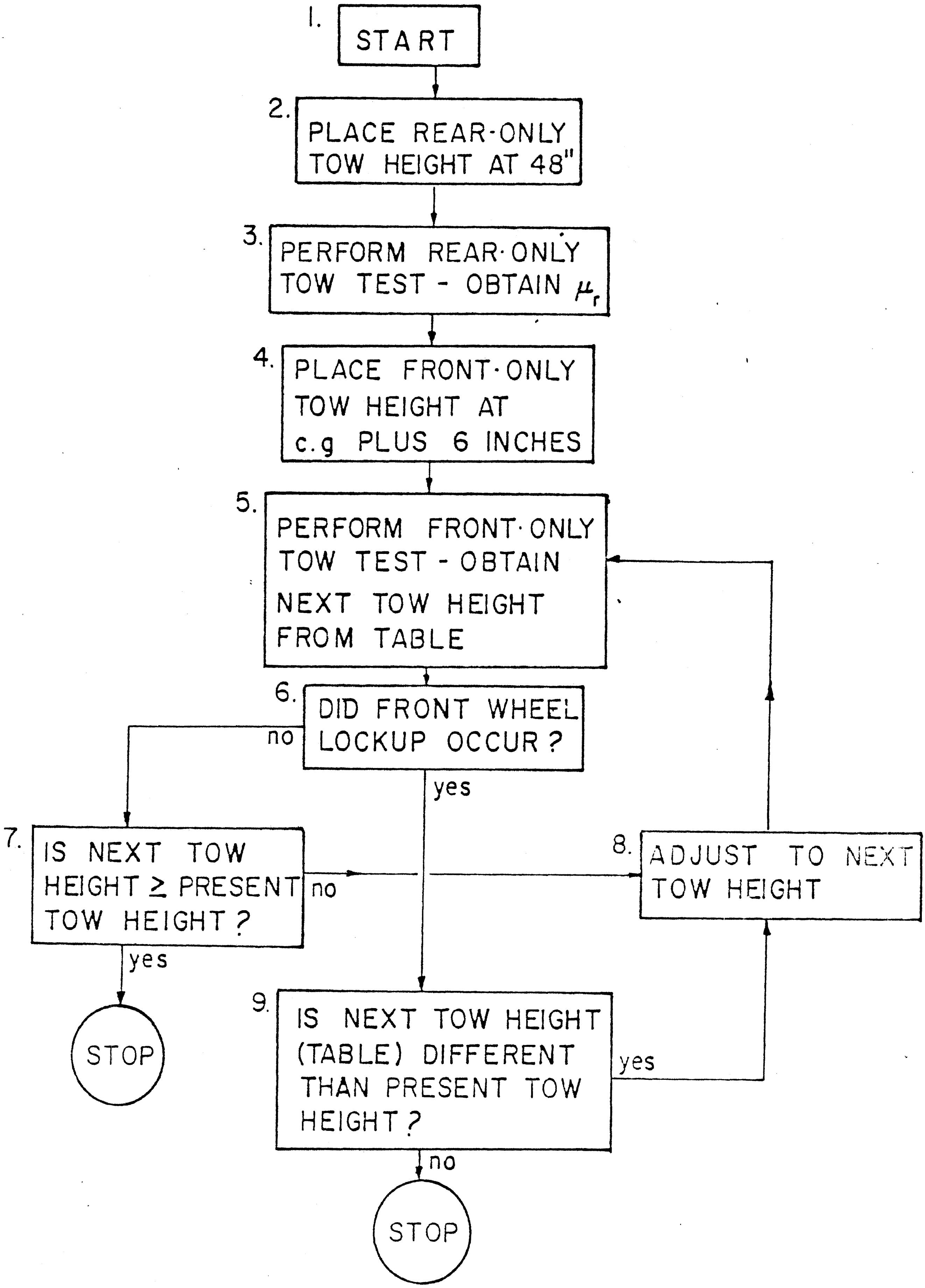

Figure 2. Proposed effectiveness test procedure.

In summary, the refined effectiveness test procedure involves a single set of rear-only tests, conducted at a single value of tow height. When the rear-wheel tests are completed, the remaining tests are conducted using the front brake only, with the front-wheel tow height being varied in an iterative manner until the final "reference" condition is reached.

2.2 A Refined Tow-Test Apparatus

A complete package of apparatus was designed and assembled constituting a refined version of the tow-test hardware developed earlier. Figure 3 shows the new system comprising a pickup truck, with extended cab, to which is affixed a linkage system fastening the test motorcycle. Note that the overall assembly is of quite low profile compared to the original test package since the 48-inch maximum tow height cited earlier eliminates the need for a high "tower"-like element.

In the foreground of Figure 3, a heavy tubular structure extending back from the truck can be seen. This structure is, in turn, fastened to another heavy frame assembly which bolts directly to the truck load bed, as shown in the overhead view presented in Figure 4. Together, the main truck-mounted frame and the extended side frame structures provide the rigid foundation to which are affixed a towing connection and three lateral links which locate the motorcycle.

Figure 5 is a plan view showing four motorcycle constraints. The tow connection is made by means of an adjustable length chain which connects a yoke-type element on the motorcycle to a load cell affixed to the truck. The yaw, roll and lateral degrees of freedom are rigidly constrained by the three links connecting the motorcycle to the extended side frame. From front to back, respectively, the lateral links fasten to the motorcycle by means of special brackets at the steering head, the foot peg, and the rear shock absorber bolt. As shown in the rear view of Figure 6, the three lateral links are separated from one another vertically so as to provide a roll constraint. The outboard ends of each of the lateral links are fixed to adjustable brackets which can accommodate the longitudinal and vertical variations in the location of the three

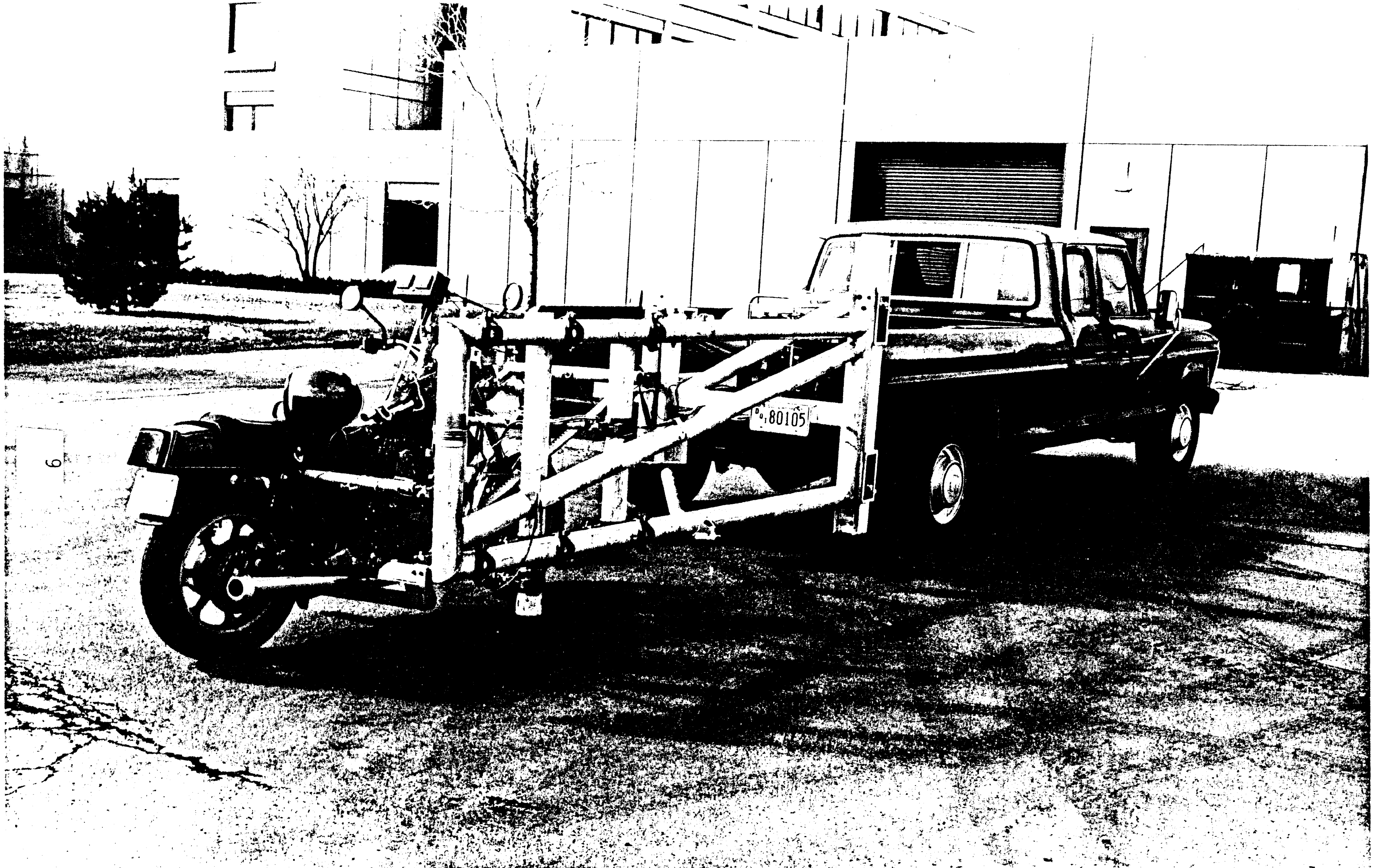

Figure 3. Refined apparatus assembly.

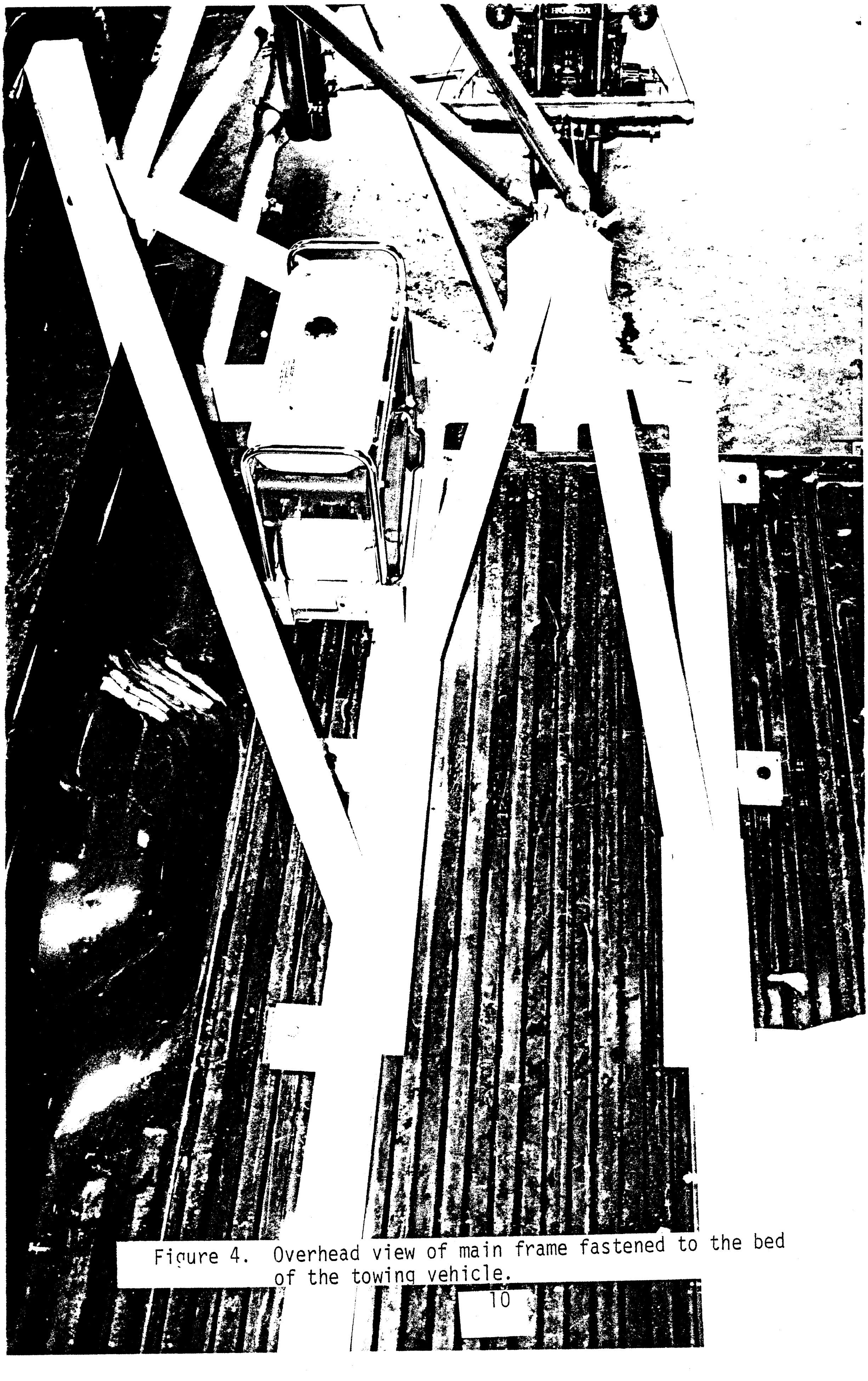

Figure 4. Overhead view of main frame fastened to the bed of the towing vehicle.

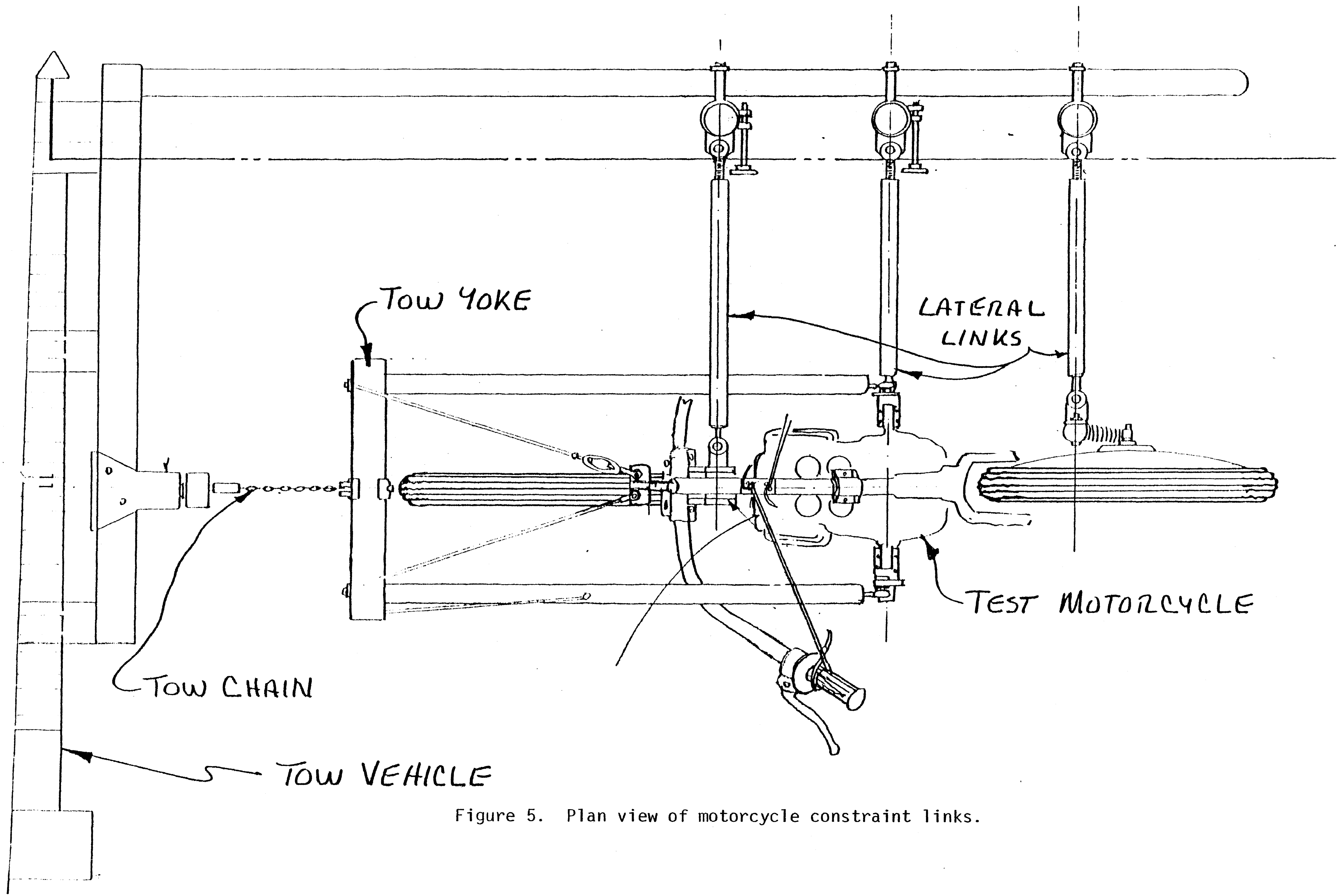

Figure 5. Plan view of motorcycle constraint links.

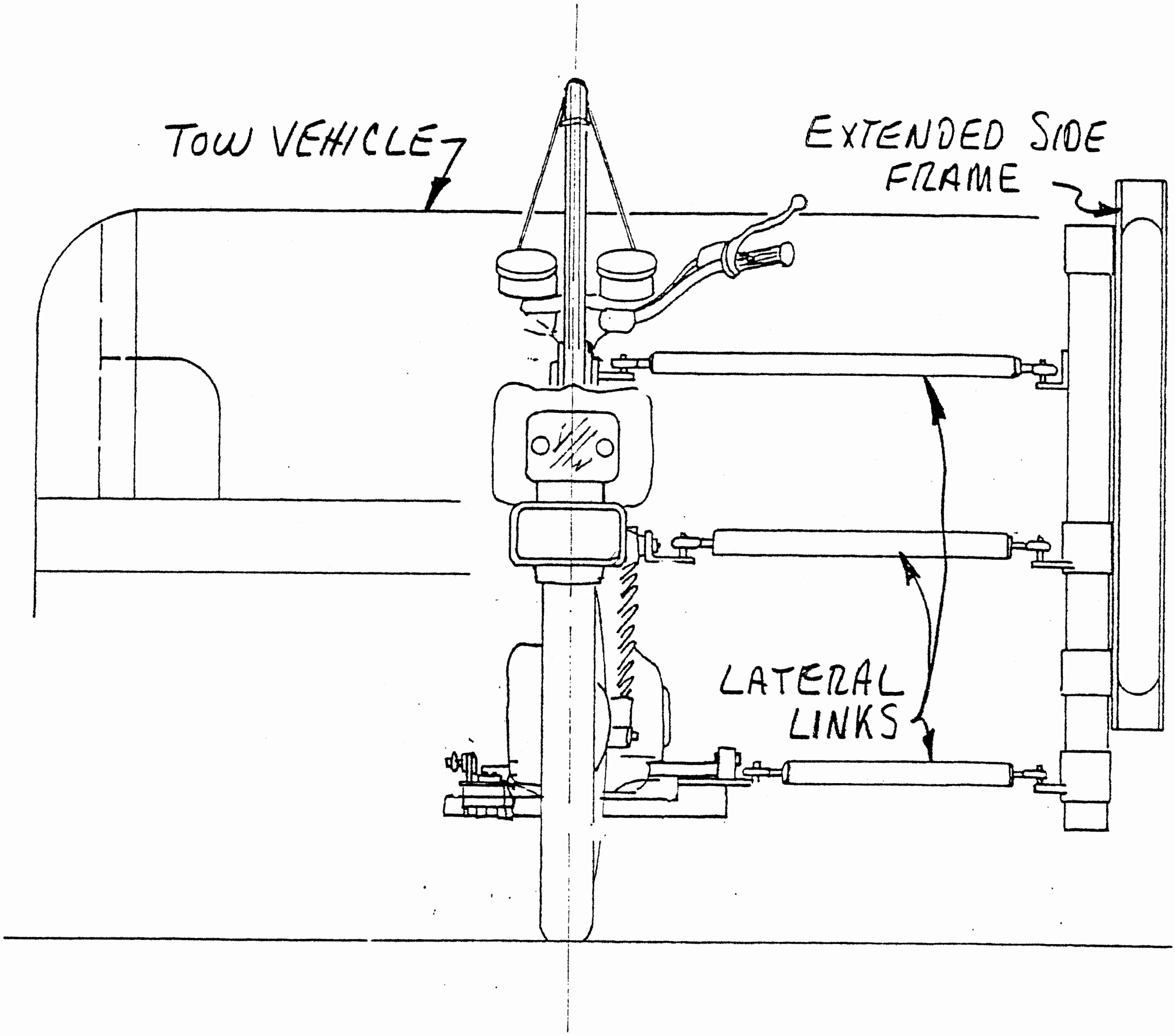

Figure 6. Rear view of motorcycle constraint links.

cited motorcycle mounting points. Width variations, from one motorcycle to the next, are accommodated through screw adjustments in the length of each lateral link. Each lateral link terminates in a spherical rod end, thereby allowing freedom in the vertical, longitudinal, and pitch motions of the motorcycle.

Figure 7 is a rear view of a motorcycle set up for demonstration testing. The lateral links are seen to serve as convenient members for routing instrumentation cabling and connectors.

Figure 8 is a close-up of the foot peg-attaching bracket. Note that the rubber foot-peg sleeve has been removed and the foot peg welded to an intermediate plate which is bolted to the primary bracket. The towing yoke element (seen as the tube at upper right in Figure 8) fastens to an extended tab on the foot-peg bracket while the lateral link fastens by means of the tapped hole seen in the foreground. The foot-peg bracket is welded to both pegs, and employs a rigid tubular piece spanning the underside of the motorcycle to connect both sides of the bracket.

Figure 9 shows the motorcycle test setup in the side view. The towing yoke is seen to be attached at the foot-peg bracket and, by means of adjustable length cables, to the "strongback" element which fastens to the motorcycle frame at the normal position of the fuel tank. The strongback is connected, at its forward end, to the motorcycle frame by means of a pair of clamping plates with which the front frame section becomes "sandwiched." One hole is drilled through the front frame for fastening the strongback clamping plates, with shims of appropriate thickness, to the motorcycle. At the rear of the strongback, a separate bracket incorporates a short length of roller chain in a loop around the motorcycle frame as a versatile fastening element.

Figure 10 is a frontal view of the test motorcycle illustrating the adjustment cables extending from the top of the strongback to the two outboard sides of the towing yoke. Note that the lateral member of the towing yoke incorporates several holes permitting an adjustable spacing of the side strut elements to account for variations in width across the foot pegs of differing motorcycles. Along the length of both side struts, a pattern of holes is provided to permit adjustment of the height of the

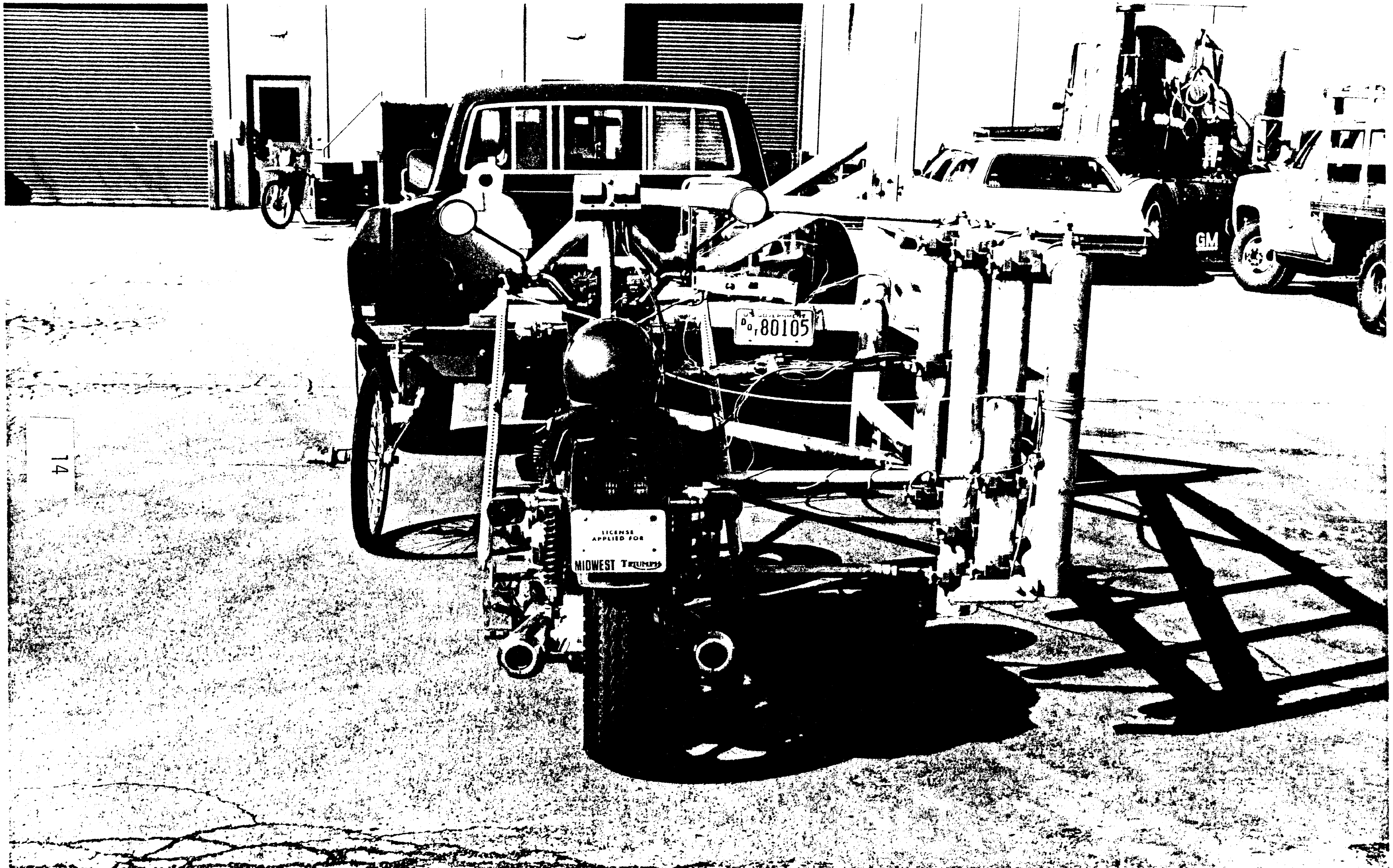

Figure 7. Rear view of Kawasaki KZ1000 set up for demonstration tests.

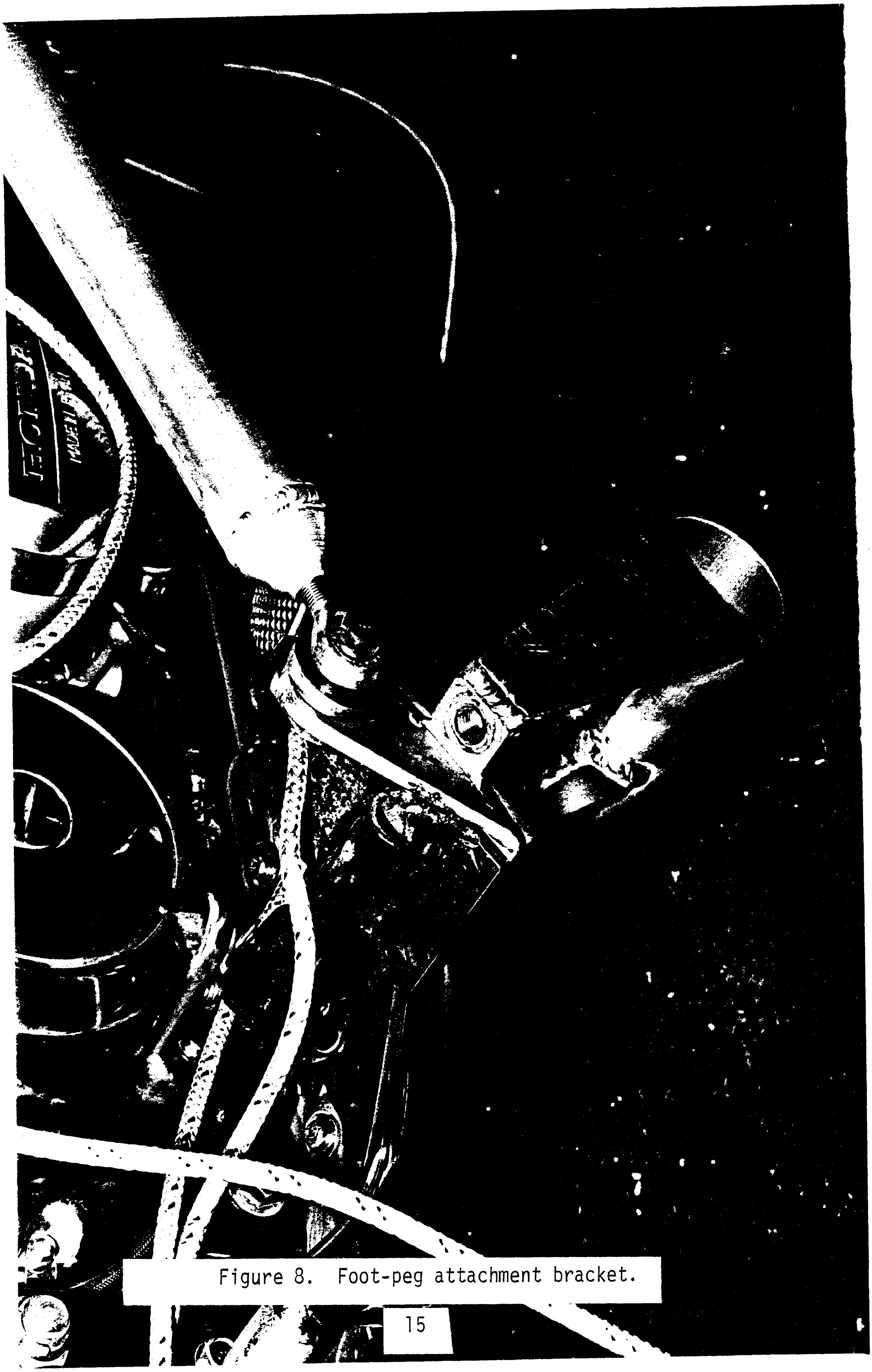

Figure 8. Foot-peg attachment bracket.

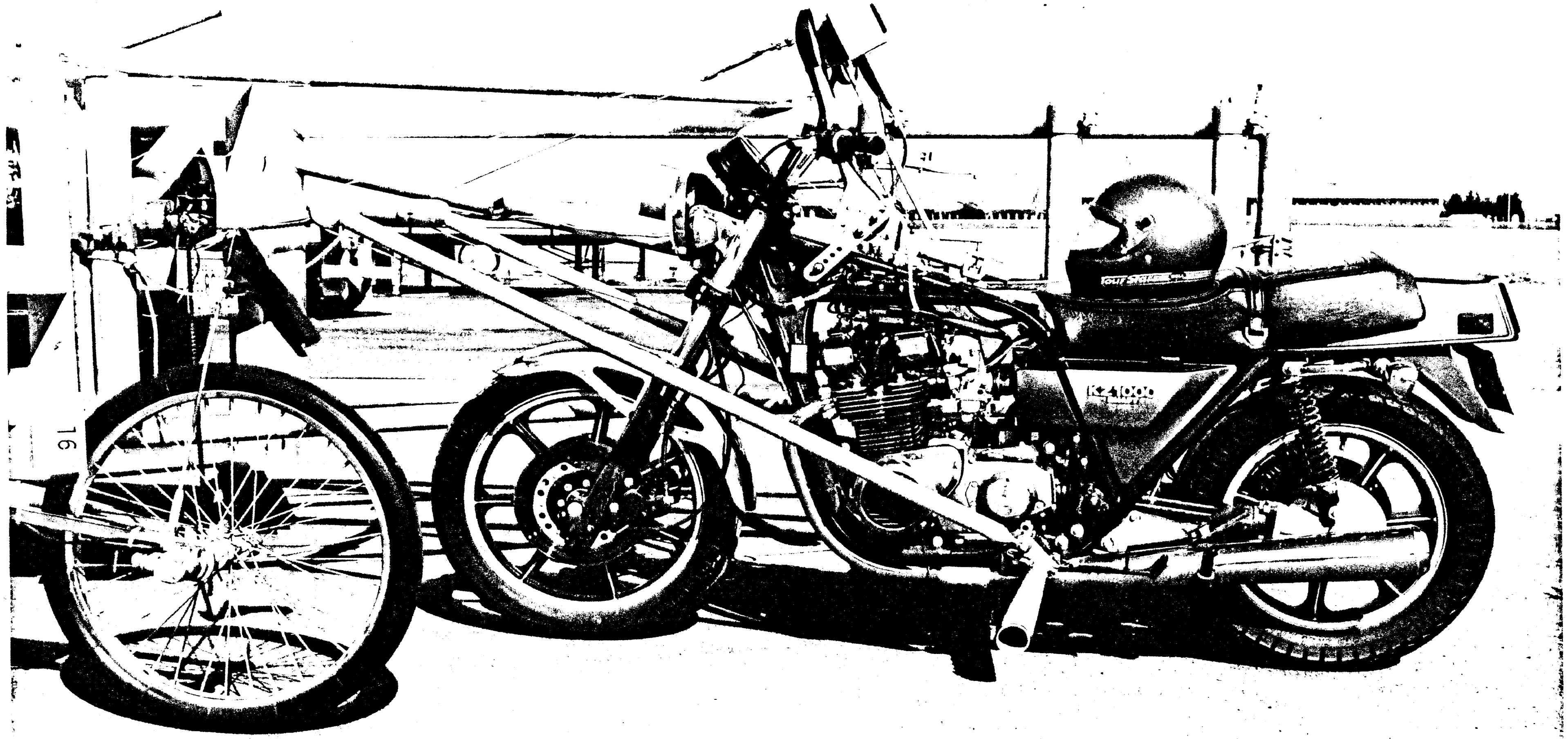

Figure 9. Side view of Kawasaki KZ1000 set up for demonstration testing.

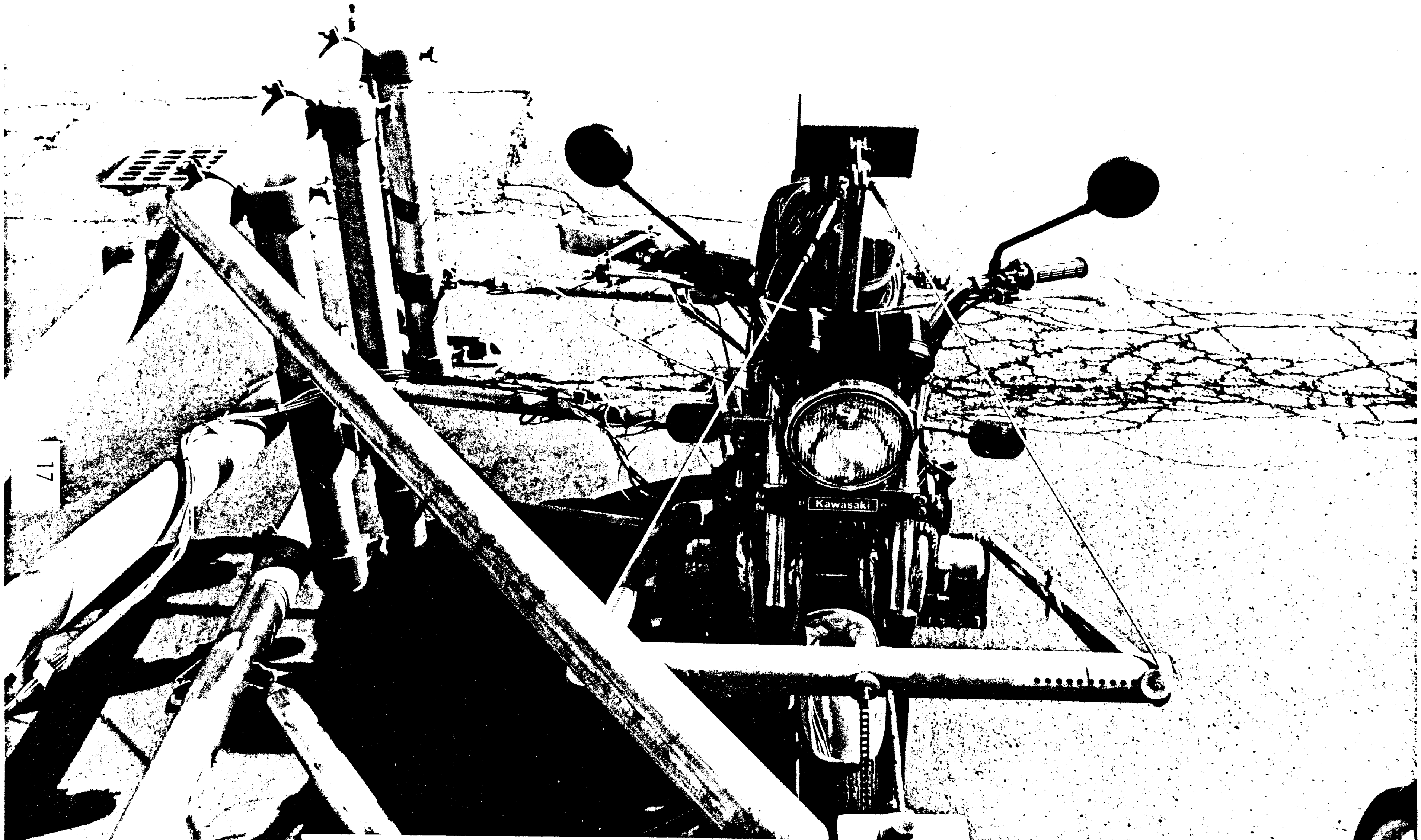

Figure 10. Front view of Kawasaki and tow-yoke assembly.

towing yoke. The height adjustment is effected by varying the free span of each cable between the towing yoke and the strongback. Locking pins at the end of each cable are inserted into the selected holes in the side struts to establish this adjustment.

Shown in Figure 11 is the chain element which connects the towing yoke to the truck. The chain passes through a quick-release locking mechanism whose purpose is to permit an easy adjustment in effective chain length such as is needed each time the tow height is adjusted. (Note that tow chain length is dependent upon tow height because the towing yoke device is rotated about the foot-peg bracket to effect a change in the height of the yoke. This rotation causes the distance from the yoke to the truck to vary, thus necessitating an adjustment in chain length.)

The chain-locking mechanism is fastened to the tow-force load cell which, in turn, is fastened to a collar which clamps on a vertical column at the selected tow height. Above the chain-locking mechanism are mounted two electrical limit switches whose purpose is to detect the angular inclination of the tow chain. The inclination variable requires monitoring since the height of the towing yoke (and thus the aft-end of the chain) drops by a certain distance due to pitching of the motorcycle on its suspensions during braking). The switches are set such that an "OK" status lamp is lighted in the tow-vehicle cab when the inclination angle criterion is satisfied.

Two additional constraints can be seen in the rear-view photo presented previously as Figure 7. These items comprise a forward-stop cable connecting the motorcycle to the rigid side frame and a pair of short tether ropes between the handlebars and the strongback. The forward-stop cable provides restraint to the motorcycle when the tow vehicle is decelerating. In normal test operations, the tow vehicle runs at constant velocity such that the forward-stop cable is slack, with the towing link reacting motorcycle braking force. When the tow vehicle driver applies his brakes, however, the towed motorcycle would overrun the truck except for the constraint afforded by the forward-stop cable.

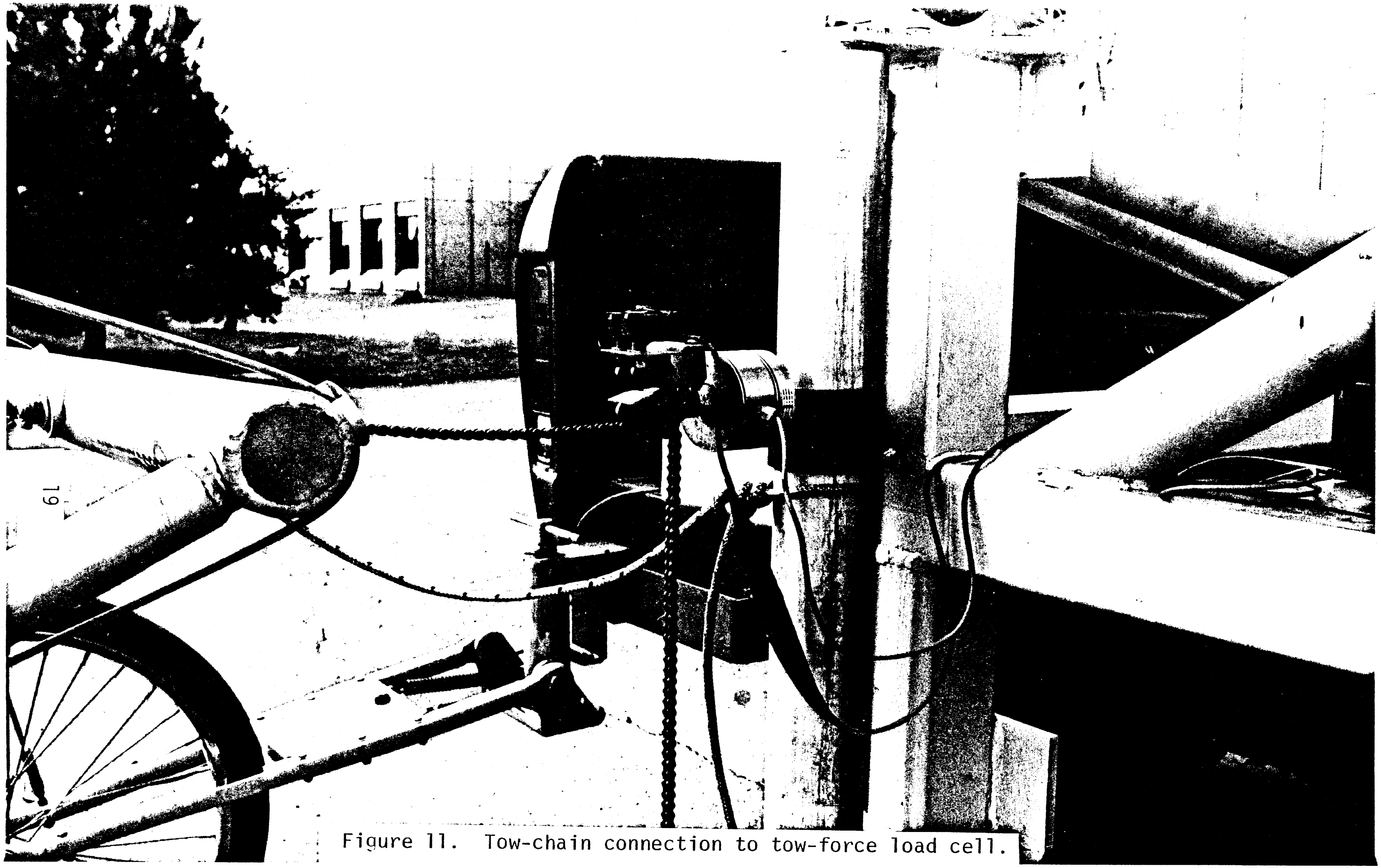

Figure 11. Tow-chain connection to tow-force load cell.

The handlebar tether ropes serve to prevent oscillations in the motorcycle steering fork assembly. In early testing of the new tow hardware system, it was observed that, even at very low speeds, a strong wobble oscillation occurred unless the motorcycle rider firmly restrained the motion of the handlebars. Using the handlebar tether ropes, the rider can "lash down" the steering freedom of the handlebars during all normal straight-ahead testing and then release the tethers to reduce strain on the motorcycle during short-radius maneuvering of the test vehicle. The tether ropes are clamped tight using a pair of sailboat-type jam cleats mounted on the strongback, as shown in Figure 12.

It should be noted that the refined package of tow-test apparatus, as described above, has been designed to accept any modern full-size motorcycle.

In addition to the apparatus which locates the motorcycle during testing, a self-contained hand-lever force transducer was also constructed. This device was developed to permit a ready measurement of the hand-lever force without requiring one to apply either strain gauges directly to the hand lever, itself, or to install a pressure transducer in the hydraulic brake line. Figure 13 shows the integral hand-lever force transducer developed in this project. This device is attached to the hand grip by means of a hose clamp and to the brake lever by means of a small clamping bracket. An end view of the hand grip in Figure 14 further illustrates the lever-attachment clamp. The device incorporates a pre-packaged force transducer which is placed in tension when the rider pulls on the curved outer end of the "wand." The device is clamped onto the hand grip such that the hand-lever force is nearly normal to the hand grip throughout the hand-lever stroke.

The remaining elements of test hardware are unchanged from conventional practice, as employed in the conduct of FMVSS 122—namely, the foot-pedal force transducer and the thermocouples installed in the front and rear brake linings are implemented according to normal practice. On most motorcycles, however, the foot-pedal force transducer must be shimmed up by approximately two inches to permit the rider to easily access the transducer with his foot.

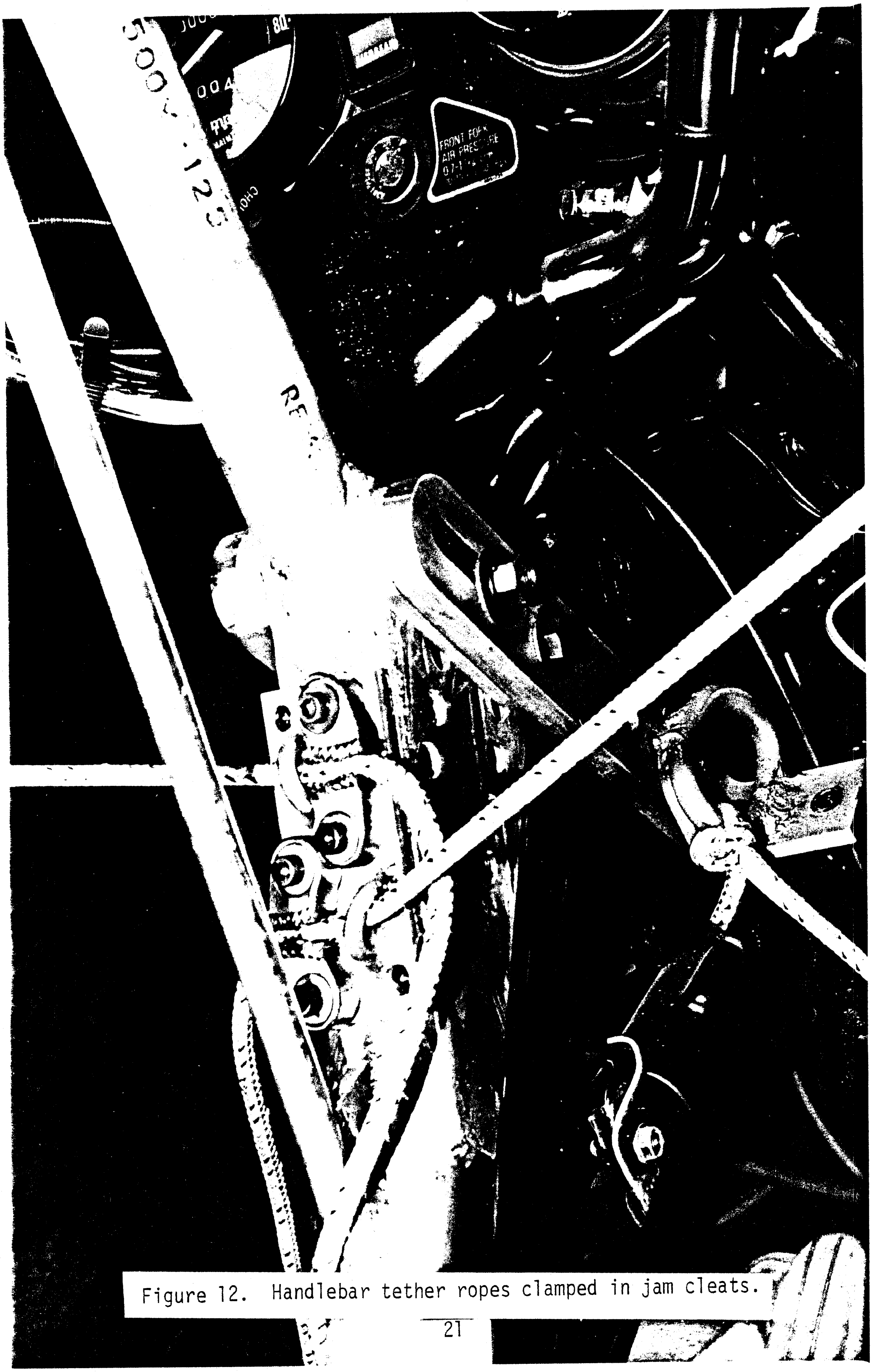

Figure 12. Handlebar tether ropes clamped in jam cleats.

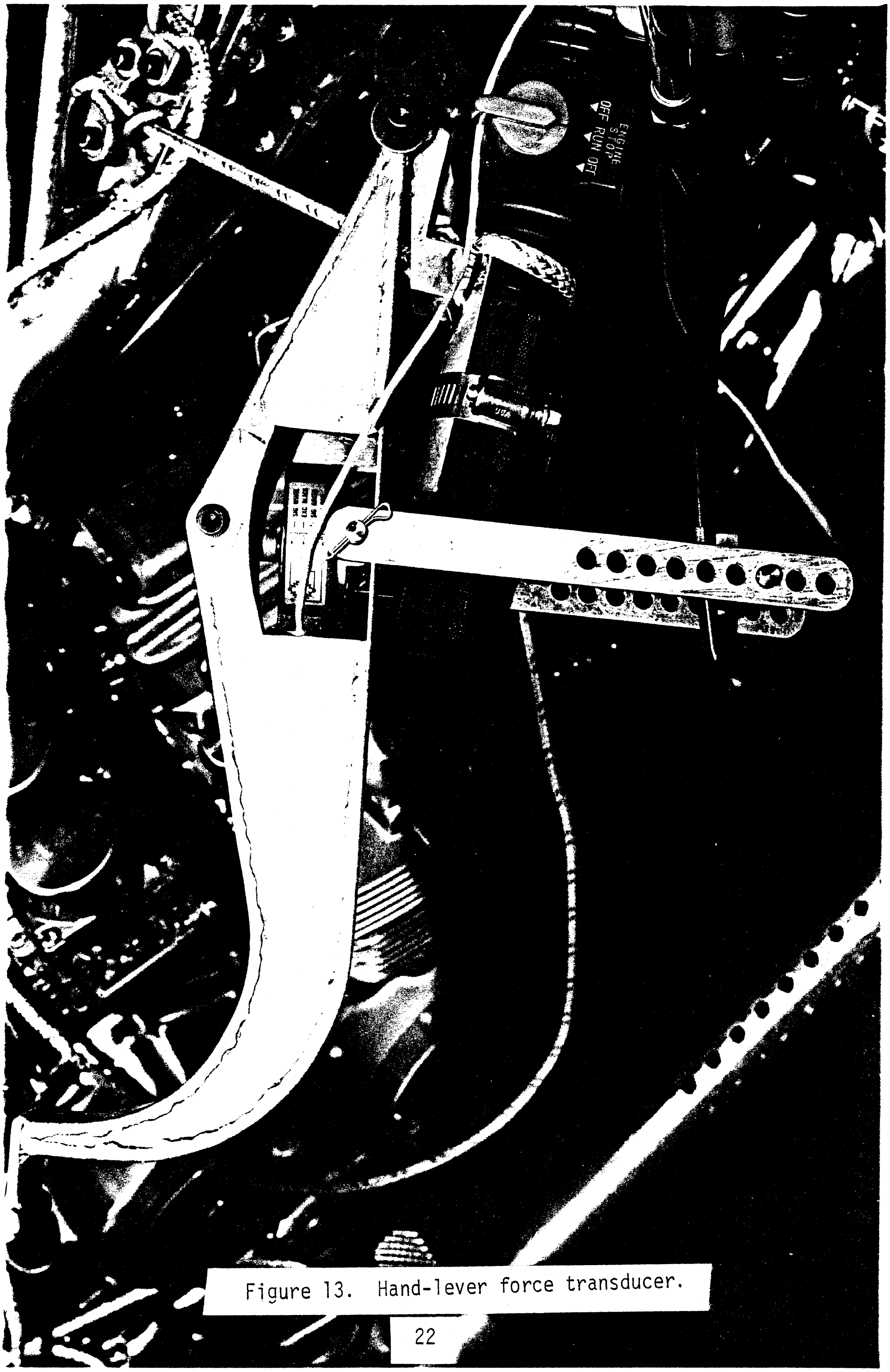

Figure 13. Hand-lever force transducer.

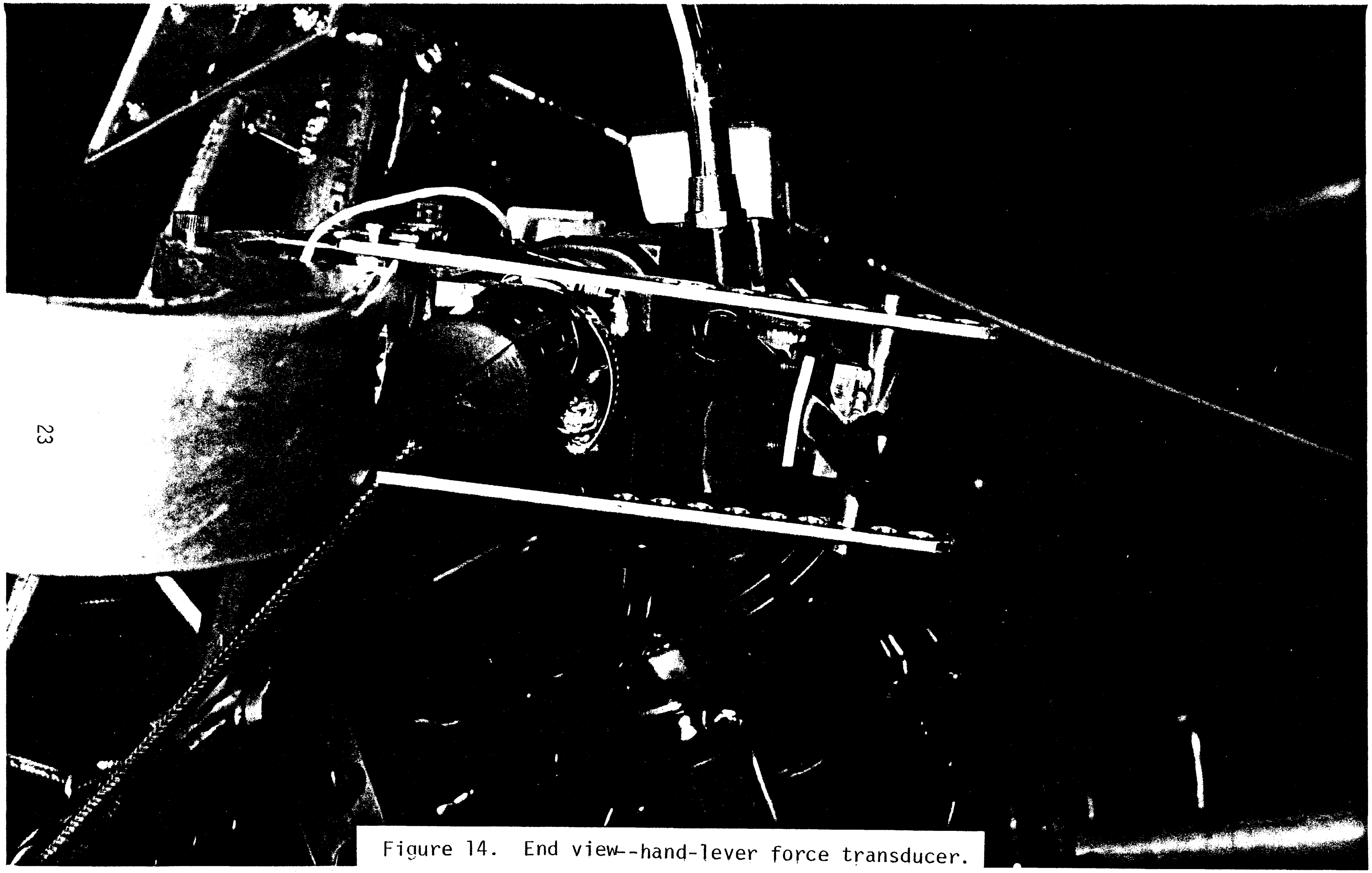

Figure 14. End view--hand-lever force transducer.

Figure 15 presents a view of the instrumentation system installed in the cab of the tow vehicle. The system incorporates a Hewlett-Packard HP 9825T computer and HP 6940B multiprogrammer chassis. The computer is programmed such that it will accept typed-in values of the test motorcycle's parameters and then guide the test operator through the entire procedure for effectiveness, burnish, and thermal fade tests. The test operator advises the driver of the tow vehicle and, by means of a headset intercom, the motorcycle rider, on the actions required for each test.

Test data are outputted directly in the form of a printed paper tape record, while each test is underway, and by means of an automatically summarized paper tape printout after the computer reads information from a permanent record stored on a magnetic tape cassette at the conclusion of the test sequence.

A detailed description of the data collection system, together with the program which was written to accommodate the step-by-step tow-test procedure, is given in Volume II, "User's Manual."

Figure 15. Cab interior showing computer in background and interface module in foreground (under table).

3.0 DEMONSTRATION TEST PROGRAM

Five motorcycles were originally selected for test in a demonstration program and subsequently reduced to three as an economy measure. Listed in Table 1 are the originally selected motorcycles, along with measured values of weight, W_B, deflected seat height, H_S, wheelbase, L, and c.g. height, H_B, of the cycle itself. The listed value of the height of the c.g. of the cycle plus rider, h, was calculated with the following equation:

$$h = \frac{(W_B H_B) + 165(9.8'' + H_S)}{W_B + 165}$$

This expression, developed to represent the cycle/rider c.g. height accruing with a 50th percentile male U.S. rider, reflects a c.g. location of the rider which is 9.8 inches above the deflected seat height. The c.g. height of a seated motorcycle rider—a 50th percentile male—is derived in Appendix 1. The c.g. height of the motorcycle alone, H_B, was measured with a fixture which located and balanced the motorcycle on its principal longitudinal axis while the vehicle was at a 90-degree roll attitude.

The "front (and rear) test weights" listed at the right of Table 1 for the three motorcycles actually tested represent the front and rear static loads prevailing with full tow-test apparatus attached, and with the actual test rider seated on the motorcycle. Of the parameters listed in Table 1, only the following are used directly in the computation of tow-test conditions and in the processing of results:

L, wheelbase

h, c.g. height of the cycle with 50th percentile male rider

W_f, static test weight on front tire

W_r, static test weight on rear tire

Table 1. Motorcycles Originally Selected for Demonstration Tests.

Motorcycle	Vehicle Type	Weight of Bike Alone W/Full Gas, lbs.	*Deflected Seat Height in.	Wheelbase in.	C.G. Height of Bike Alone, in.	C.G. Height of Bike W/Rider, in.	Front Test Weight lbs.	Rear Test Weight lbs.
Honda CB 650	Middleweight Street Custom	484	28.8	59.0	19.4	24.2	292	381
Honda XL 125S	Dual Purpose (On/Off Road)	243	30.8	52.0	20.9	27.6	**	**
Suzuki TS 185	Dual Purpose (On/Off Road)	247	30.8	55.0	20.8	28.8	168	299
Yamaha 400	Traditional Street	394	29.5	54.25	19.7	25.6	**	**
Kawasaki KZ1000	Shaft-Driven Touring	598	31.0	60.75	21.2	25.4	340	462

*Deflected seat height is the height above the ground of a 1/8" x 2" x 20" piece of steel flat stock oriented parallel to the y-axis of the motorcycle and placed on the seat beneath the center of the buttocks of a seated rider weighing between 150 and 180 lbs.

**These vehicles not used in actual demonstration tests.

The three motorcycles actually tested in the demonstration test program were selected to represent each of the three primary classes of vehicle size that had been identified in the "classification task" (see Appendix 1), viz.,

Class	Range of Empty Weights for the Class	Motorcycle Model	Motorcycle Dry Weight, lbs.
A	Below 250 lbs	Suzuki TS 185	231
B	250 to 500	Honda CB 650	443
C	Above 500	Kawasaki KZ1000	562

The Kawasaki test motorcycle has already been seen in figures presented in Section 2.2 to show the refined tow-test apparatus. The Suzuki and Honda motorcycles are shown in Figures 16 and 17.

3.1 Test Site

The demonstration test program was conducted on the 1-3/4 mile oval track of the Dana Corporation in Ottawa Lake, Michigan. The Portland cement concrete track is characterized by ASTM skid numbers equal to 87 (dry) and 62 (wet) as measured with the E-501-73 standard tire. The Dana facility provides a high quality test surface with very well engineered, superelevated curves conducive to the continuous-running character of the tow-test method. Since, in the burnish- and thermal-fade-test sequences, brake applications must be made at specific intervals, it is most advantageous that the test facility provide curved sections which are properly superelevated so that data can be taken in both curved and straight-away portions of the track.

3.2 Vehicle Preparation

As outlined in Section 2.2, the tow-test package is designed to be affixed to any conventional motorcycle without the need to fabricate special parts. Nevertheless, certain adaptations of the vehicle are required, namely:

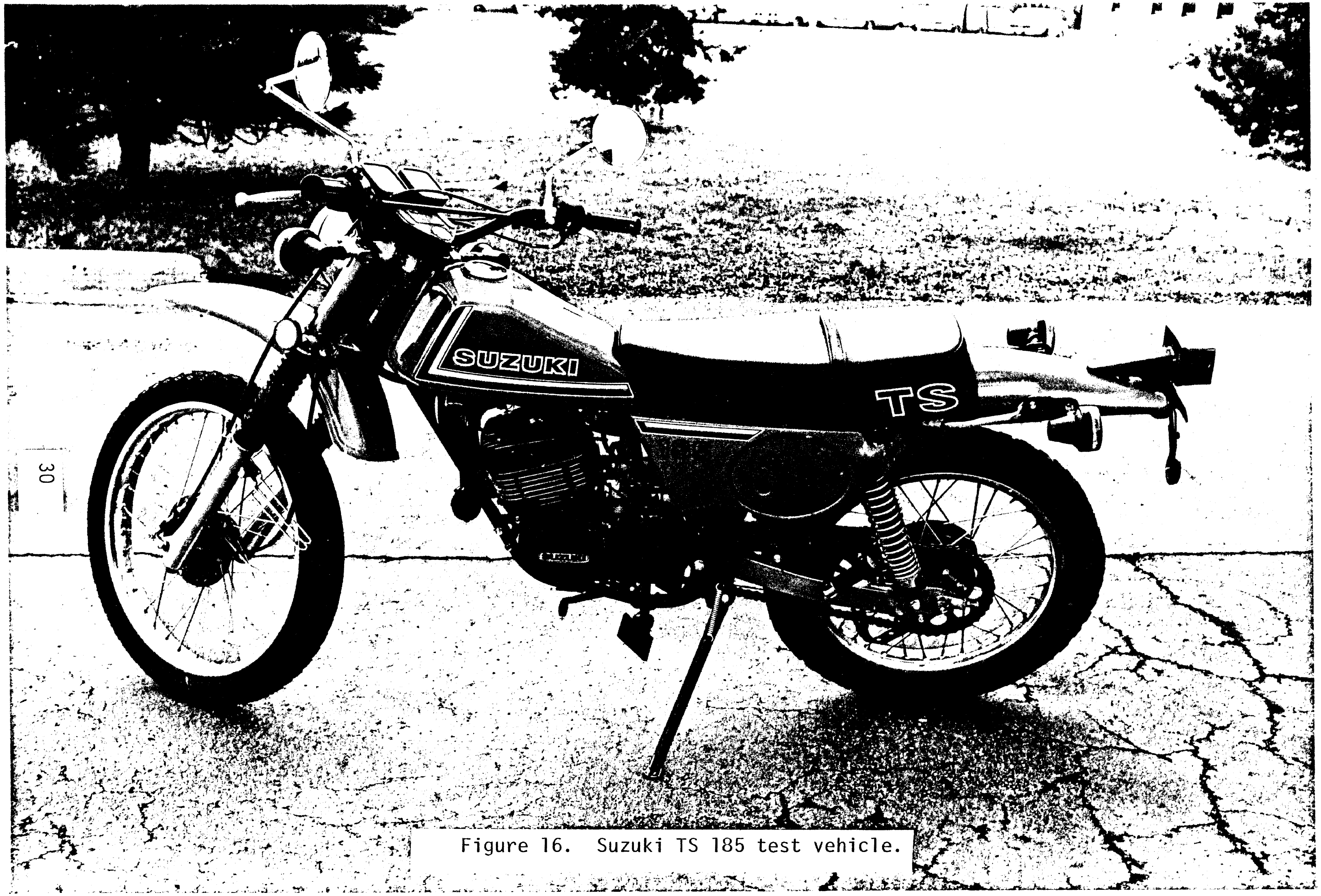

Figure 16. Suzuki TS 185 test vehicle.

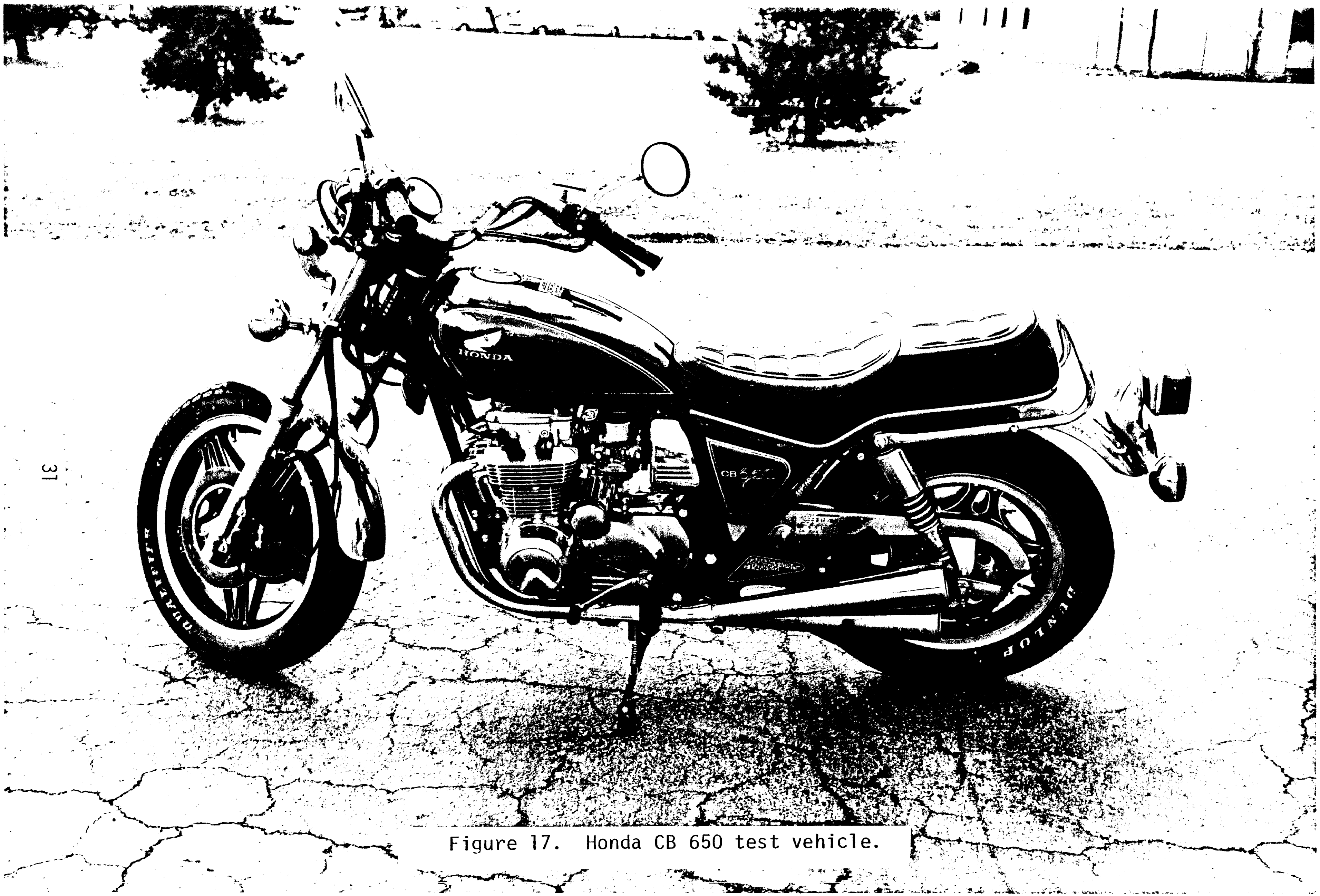

Figure 17. Honda CB 650 test vehicle.

1) The rubber foot-peg covers are removed and the steel foot-peg stubs are welded to blank plates which establish the mounting connection to the foot-peg bracket assembly.

2) The fuel tank is removed and the "strongback" bracket is affixed to the motorcycle frame. Typically, one hole is drilled through the gussetted front head section to secure the forward portion of the strongback.

3) Thermocouples are installed in front and rear brake linings as per FMVSS 122.

4) The nut on the top right-hand rear shock absorber bolt is removed and the appropriate fastening bracket is installed for connection to the rear-most lateral link.

5) Load cells for measuring the actuating forces are attached to the brake hand lever and foot pedal.

Each motorcycle begins the test series with new tires inflated to the manufacturer's recommended cold inflation pressure and with new ("green") brake linings. All tests are run with the engine off, the transmission in neutral, and, if necessary, the drive chain or shaft disconnected.

3.3 Pre-Demonstration Developmental Testing

Although the basic tow-test procedure had been exercised in demonstration testing in the preceding "Motorcycle Braking Performance" study, certain features of the new test system required that further development be considered. The primary areas requiring development with the new test system involved the on-line treatment of effectiveness test data. By way of explanation, all data from burnish and thermal fade tests are treated as steady-state samples with the actual performance measure defined as a multiple-second average. Effectiveness tests, on the other hand, involve a ramp input of actuator force. In response to this transient input, the peak tow force occurring prior to wheel-locking is to be measured.

The primary problem encountered with the measurement of the prelockup value of peak force is that the tow-force signal typically becomes rather oscillatory due to wheel-hop vibrations of the motorcycle at high levels of brake torque. As shown in Figure 18, the raw value of the digitized tow-force signal exhibits peak-to-peak oscillations which are on the order of 40 percent of the magnitude of the nominal peak value of the tow force itself. Such oscillations must be accounted for, since a peak value drawn from the raw tow-force signal would fail to characterize the tire traction force representing the equilibrium value of tire load assumed in the formulation of the tow method. Examination of the example raw tow-force signal reveals that the superimposed oscillation is primarily a 7-8 Hz noise component.

This oscillatory component was virtually eliminated from the tow-force signal by using a digital filtering technique which dramatically attenuates frequency components above 4 Hz, without introducing phase lag. The filter employs a digital sampling and weighting scheme of the modified "Hamming" type, yielding an improvement in the quality of the tow-force signal as is shown in Figure 19. The filtered signal shows a truncated leading edge since the filtering technique requires that a 0.4-second-long data sample have elapsed before the first filtered data point is determined. The peak value of tow force is identified by the digital data processing system and "flagged" with the vertical spike appearing at the peak of the reproduced signal. The digital filtering method is described in detail in Section 3.0 of the User's Manual, Volume II.

A second developmental problem was encountered in which the computerized detection of peak tow force occasionally produced an erroneous measure because of a peculiar feature of the effectiveness test process. When a wheel becomes locked as a consequence of the rider's application of braking effort at the hand lever or brake pedal, the desired "peak tow force" is that which typically accrues just prior to the "spin-down" of the wheel—at, say, 20 to 30 percent longitudinal slip. As shown in Figure 20, however, one occasionally observes a "spin-up" peak, following the rider's release of the brake, that exceeds the level of the initial, desired value. The higher spin-up peak appears to result from a coincident vertical load oscillation occurring just as the tire passes back through the peak of its μ-slip curve. To correct the problem of the

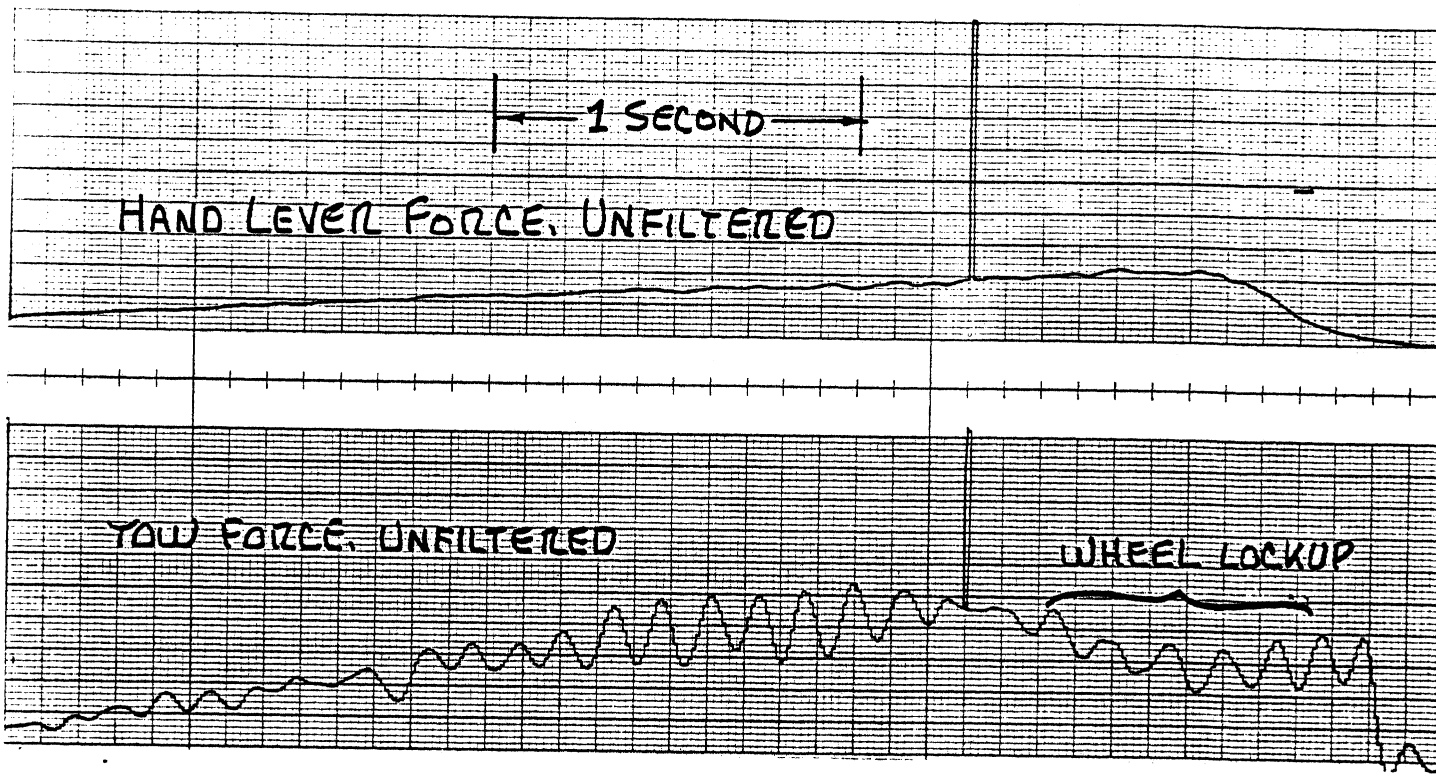

Figure 18. Unfiltered hand-lever force and tow-force signals from effectiveness tests on the Honda CB 650.

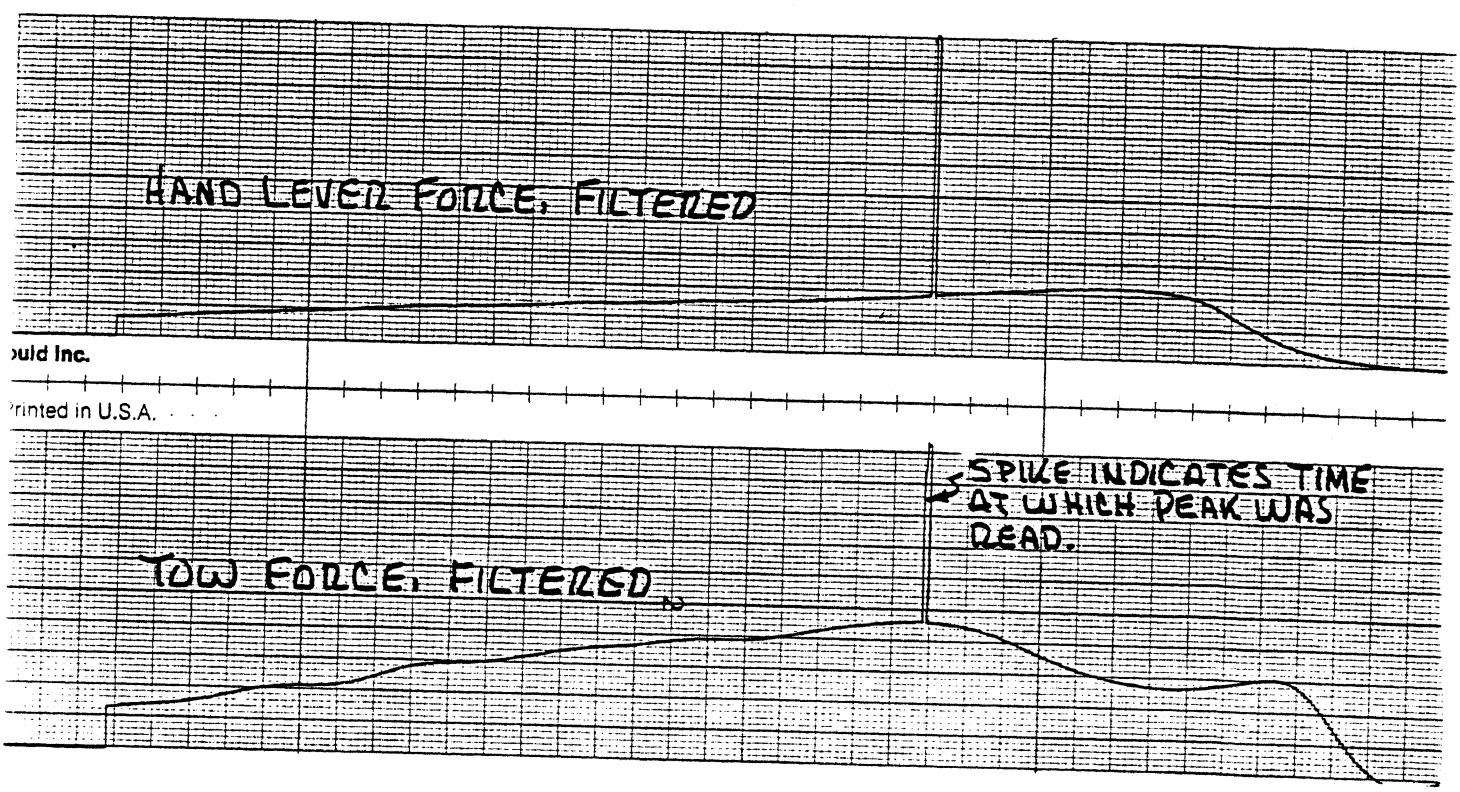

Figure 19. Filtered hand-lever and tow-force signals.

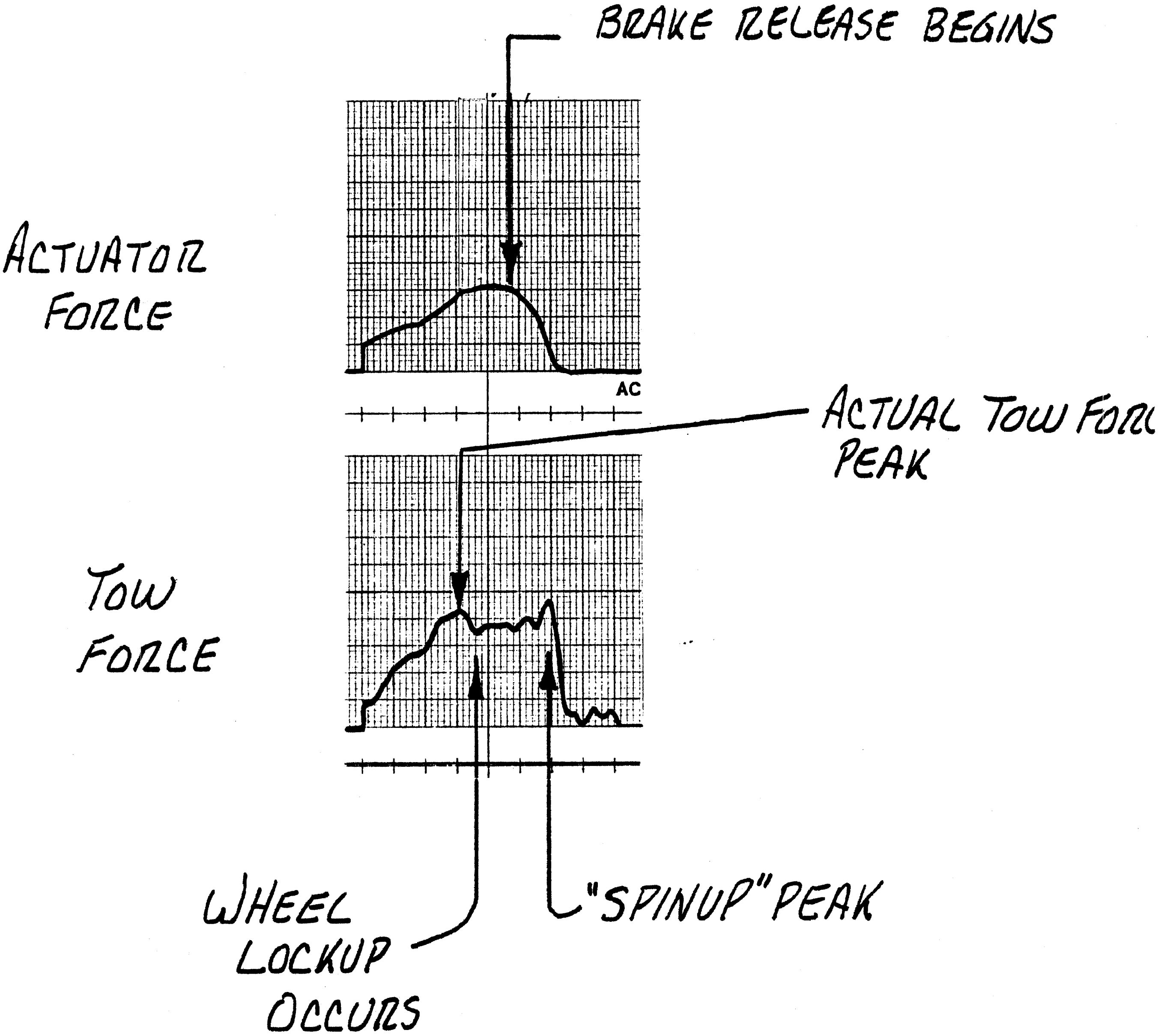

Figure 20. Brake actuator force and tow force time histories from an effectiveness test producing wheel lock up.

erroneous peak reading, the computer was reprogrammed so as to cease its search for a tow-force peak whenever the actuator force was seen to drop by more than 80 percent of its peak value. Thus, the computer detects that the brake is being released and confines its inspection for the peak condition to only that portion of the tow-force signal which precedes brake release.

3.4 Demonstration Test Results

The three motorcycles cited earlier were subjected to the developed tow-test procedure, excluding the water exposure procedure, during January and February, 1981. The winter weather of southern Michigan during that period made for typical ambient temperatures in the range of 10 to 30°F. Because of the low temperatures, special measures were taken to keep the test rider warm during steady running at 40 mph, and additional brake warming sequences were needed to attain the 130°F minimum brake temperature required for testing.

Test results are reviewed in summary form below, with a complete listing of the effectiveness and thermal fade results being presented for each motorcycle in Appendix 3.

A summary of the pre-burnish and post-burnish effectiveness test results (for all three motorcycles) is given in Table 2. Looking at the column labeled "Equivalent Decel, g's" at the far right, we see that both of the larger motorcycles, the Honda CB 650 and Kawasaki KZ1000, attained approximately .90 g's in deceleration performance on the dry, Portland cement concrete surface. Both of these vehicles were able to achieve wheel lockup such that the equivalent deceleration levels represent a braking limit determined by tire traction. Interestingly enough, the rather uniform levels of total vehicle deceleration exhibited by both of these bikes were obtained despite a significant spread in the measured friction coefficient, μ_{rear}, of the rear tires. Since the load experienced by the rear tire during limit braking on a dry pavement is so low (approximately 20 to 25 percent of total bike weight), the value of μ_{rear} has little influence on the total deceleration exhibited by the motorcycle during a stop with both front and rear brakes active.

Table 2. Effectiveness Test Results

(R & F)TBF - Rear & Front Tow-Bar Force, lbs
(R & F)AF - Rear & Front Actuator Force, lbs
μ_{rear} - Rear Tire Traction Coefficient

		Rear			Front			
Vehicle	Test	RTBF	RAF	μ_{rear}	FTBF	FAF	Equivalent Decel., g's	Equivalent Stopping Distance, 60 mph
Honda CB 650	Pre-Burnish	212	41	1.02	452	38	.88	137
	Post-Burnish	203	41	0.94	493	40	.91	132
Suzuki TS 185	Pre-Burnish	146	48	0.85	243	44	.74	163
	Post-Burnish	153	47	0.92	217	40	.72	167
Kawasaki KZ1000	Pre-Burnish	226	43	0.80	575	43	.88	137
	Post-Burnish	235	41	0.85	569	42	.88	137

On comparing the performance of the two larger motorcycles with that of the Suzuki TS 185, we see that the torque-limited behavior of the Suzuki's braking system results in a substantially lower equivalent deceleration level. Note that the value of μ_{rear} yielded by the Suzuki is otherwise on a par with the values exhibited by the other two bikes.

It is interesting to note that the calculated values of "equivalent stopping distance from 60 mph" indicate values which are much lower than the 216-foot and 185-foot distances required, respectively, by the pre- and post-burnish tests of FMVSS 122. The heavier motorcycles would only require that a rider utilize 63 percent of the vehicle's inherent braking capability to meet the pre-burnish requirements of FMVSS 122 and 74 percent of the inherent braking capability to meet the post-burnish requirements. Meeting the post-burnish requirements of FMVSS 122 with the Suzuki TS 185, on the other hand, would require a 90-percent utilization of the motorcycle's inherent capability.

Shown in Table 3 are the thermal fade test results. The table lists measured values of performance for the average of the three baseline runs conducted with each bike in addition to the average of the last three runs conducted in each of the respective thermal fade sequences. The primary performance measures in this test are the rear and front gain values, RFG and FFG, representing the ratio of the tow-bar force to the actuator force obtained in the rear-only and front-only brake fade experiments. The performance of the bike is established through inspection of the decrement, if any, between the "baseline" and "faded" gain values. We see that the only "significant" decrement in gain is observed with the Suzuki rear brake, whose gain dropped from 4.5 to 3.6. The practical significance of such a change could only be determined through closed-loop braking performance research in which the interaction of the rider with the motorcycle is evaluated for conditions employing various levels of braking gain. Indeed, it may be of as much significance to vehicle controllability that the front-brake gain on the Suzuki increased by almost 50 percent, from a "baseline" value of 6.4 to a "faded" value of 9.0.

Table 3. Thermal Fade Test Results

(R & F)TBF - Rear & Front Tow-Bar Force, lbs
(R & F)AF - Rear & Front Actuator Force, lbs
(R & F)FG - Rear & Front Actuator Force Gain (Dimensionless)
Max. (R & F)T - Rear & Front Temperature in the Thermal Fade Sequence, °F

		Rear				Front			
Vehicle	Test	RTBF	RAF	RFG	Max. RT	FTBF	FAF	FFG	Max. FT
Honda CB 650	Baseline	124	22	5.6		204	13	16.1	
	Faded	126	21	6.0	165°	199	13	15.7	215°
Suzuki TS 185	Baseline	92	20	4.5		133	21	6.4	
	Faded	88	24	3.6	212°	133	15	9.0	282°
Kawasaki KZ1000	Baseline	134	22	6.2		238	11	21.1	
	Faded	153	20	7.6	323°	243	12	21.0	190°

As a general rule, the data in Table 3 show that virtually no change in performance is the norm—the same result as was observed in the preceding study, "Motorcycle Braking Performance."

4.0 CONCLUSIONS

The tow-test concept has been refined such that the procedures and the test equipment are more directly suitable as a standard test method. The refined method, together with the hardware package constructed in this study, provides for a highly efficient and accurate measurement of motorcycle braking performance. The hardware package, itself, is especially notable for its flexibility in adapting to virtually any conventional motorcycle built for use on the road. The test package is light, affords a secure working station for the test rider, and calls for little or no experience on the part of the rider for conducting high quality experiments.

The use of a computer-controlled data collection system provides for a highly objective and precise test technique, although it also introduces a fairly sophisticated instrumentation system into a field application—thus calling for a somewhat higher level of maintenance and troubleshooting capability among the test staff. When everything functions well, the computer-controlled system requires a minimum of technical preparation on the part of the test operator. When problems occur, however, a person experienced in digital data systems is needed. Since most components of the system are standard products of the Hewlett-Packard Company, however, the H-P service facilities personnel can generally be called upon when service is required.

As in the previous study, which was entitled "Motorcycle Braking Performance," the demonstration test data gathered here show that modern motorcycles possess a relatively high level of braking capability, or "effectiveness." Further, the data indicate that virtually no loss in torque effectiveness occurs as a result of a severe thermal loading cycle. On the other hand, various researchers (e.g., [2,3,4]) have indicated that the primary safety problem which may be posed during the severe braking of motorcycles concerns rider/cycle interactions, rather than the inherent torque capacities of the motorcycle brake system. Thus, while the tow-test method appears to serve the role of quantifying braking capacity, there exists a need for a methodology, with supporting research justification, capable of quantifying those properties of motorcycle brake systems which pertain to the ability of typical riders to utilize the vehicle's inherent braking capability.

5.0 REFERENCES

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2. Hurt, H.H. "Braking Factors in Motorcycle Accidents." SAE Paper No. 810405, 1981.

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APPENDIX 1

CLASSIFICATION OF MOTORCYCLES

A number of alternative measures were examined as potential means for breaking down the motorcycle population into classes representing different levels of brake system "loading," or torque demand. Data were gathered on 48 current-model motorcycles to permit computations of each of the following measures:

- -empty weight
- -weight with a 50th percentile male rider
- -static front tire load of motorcycle with rider
- -static rear tire load of motorcycle with rider
- -ratio of c.g. height to wheelbase, for motorcycle with rider
- -dynamic front tire load accruing during a steady deceleration of 0.8 g

While empty weight was obtained directly from motorcycle specification data, the weight of the 50th percentile male rider was seen to add 165 lbs to the empty bike weight. The four following measures required that both the longitudinal and vertical location of the seated rider's mass center be located.

Parameters describing the motorcycle itself, namely, wheelbase, static weight distribution, the empty weight, and seat height, were obtained from road tests published in Cycle World magazine in 1979 and from data made available from specific manufacturers. A wide variety of motorcycles were measured by Cycle World, and an almost complete set of data was obtained for current-production motorcycles. Since the Cycle World data did not include small street bikes (< 400cc), data were also solicited directly from manufacturers.

Since no new sources of data describing the c.g. height of the motorcycle were identified, it was necessary to employ an average c.g. height obtained from a set of seven measurements reported in the technical literature [1,2]. The measurements of c.g. height ranged from 16.9 to 21.5 inches with an average value of 19.2 inches. Since no useful correlation was seen to exist (such as seat height or total weight), it was determined that c.g. height for the composite rider/cycle system would be derived using a constant value of 19.2 inches for the c.g. height of the motorcycle, itself.

For representation of the motorcycle rider, anthropometric data on the 50th percentile American male were obtained from crash test dummy specifications [3] and from a report entitled "Motorcyclist Anthropometrics" [4]. Data for body segment weights and center of gravity locations were used to calculate the c.g. position of a seated rider. In Figure 1 are listed the segment weights, the location of the coordinate system for the seated rider, and the locating coordinates of individual body members.

The c.g. location of the reference rider seated on a motorcycle was derived by first establishing the rider's c.g. location with respect to the rider's X-Z axis system shown in Figure 1. The rider c.g. coordinates, X_R and Z_R, were merely determined by the moment summations in Equations (1) and (2).

$$X_R = (W_H \cdot X_H + W_N \cdot X_N + W_{UB} \cdot X_{UB} + W_{LB} \cdot X_{LB} + W_{UA} \cdot X_{UA} + W_{LA} \cdot X_{LA} + W_{UL} \cdot X_{UL} + W_{LL} \cdot X_{LL})/W_T$$

$$= 8.9\text{"} \text{ (for 50th percentile male)} \quad (1)$$

$$Z_R = (W_H \cdot Z_H + W_N \cdot Z_N + W_{UB} \cdot Z_{UB} + W_{LB} \cdot Z_{LB} + W_{UA} \cdot Z_{UA} + W_{LA} \cdot Z_{LA} + W_{UL} \cdot Z_{IL} + W_{LL} \cdot Z_{LL})/W_T$$

$$= 9.8\text{"} \text{ (for 50th percentile male)} \quad (2)$$

In order to get a composite bike/rider c.g. location, the rider must be placed on the motorcycle and the origin of his coordinate system

Anthropometric Data (50th Percentile Male)

Weights (lbs)

Head (W_H) = 10

Neck (W_N) = 3.1

Upper body (W_{UB}) = 38.2

Lower body (W_{LB}) = 50.8

Upper arms (W_{UA}) = 8.5

Lower arms & hands (W_{LA}) = 7.5

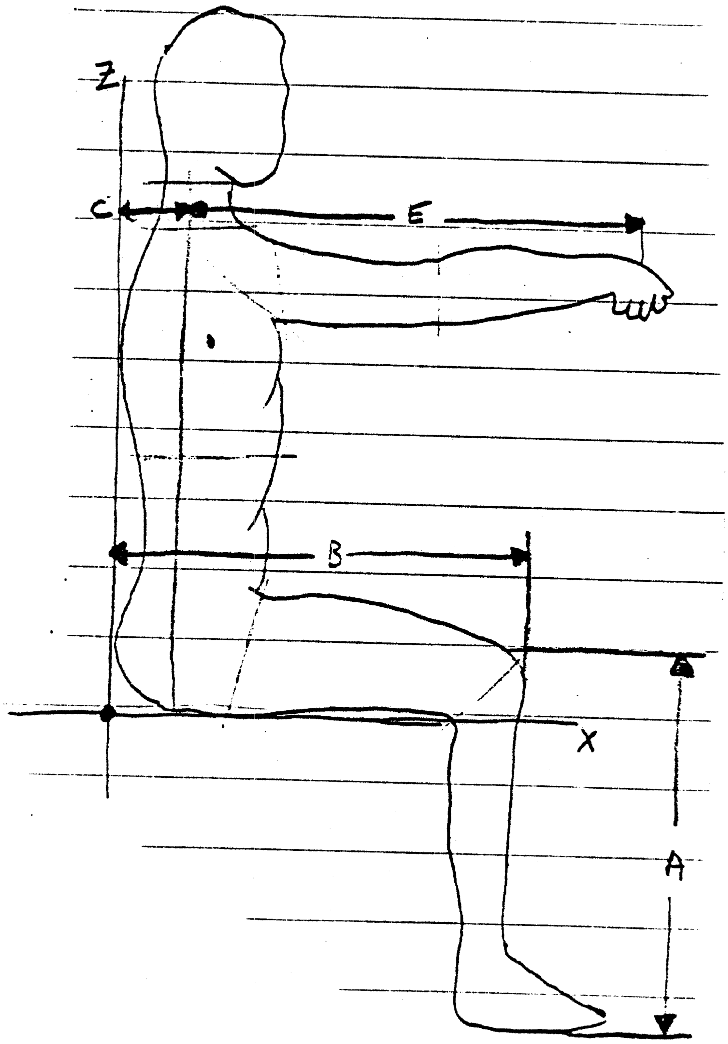
Upper legs (W_{UL}) = 26.8

Lower legs (W_{LL}) = 19.0

TOTAL BODY WT. (W_T) = 163.9

Center of Gravity Positions (from Dunlap & Associates "Motorcyclist Anthropometrics")

The coordinate system used to locate c.g. positions of the parts of the body is pictured below.



	X (in.)	Z (in.)
Head (H)	5.6	31.6
Neck (N)	4.7	27.2
Upper body (UB)	4.2	18.5
Lower body (LB)	5.1	5.3
Upper arms (UA)	8.5	20.0
Lower arms (LA)	19.6	18.0
Upper legs (UL)	13.1	2.3
Lower legs (LL)	21.0	-7.2

Miscellaneous Data

A = 21.37"

B = 23.33"

C = 3.5"

E = 29.03"

Figure 1

must be placed at an established position with respect to the motorcycle coordinate system. Regarding the vertical placement, a limited number of measurements were made on test motorcycles to determine that a 1.5-inch deflection of seat and suspension constituted an appropriate "adjustment" for the use of published "seat height" data in locating the rider's c.g. height above the ground. Accordingly, rider c.g. height was defined as follows:

$$\text{Rider's c.g. height above ground} = Z_R + (H_s - 1.5)$$

where H_s = seat height

Regarding longitudinal placement of the rider's mass center, scaled layouts of all of the motorcycles evaluated by Cycle World were used to determine a standard basis for locating the rider on the seat. Lacking a definitive registration point on the seat in most cases, the rider was simply placed at an apparently reasonable position. When a "stepped" seat was shown, the rider's back was made tangent to the step. Review of the rider placement dimensions revealed a generally useful scheme for locating the rider's coordinate system forward of the rear axle by a constant fraction of the wheelbase, viz.:

$$\begin{array}{l}\text{Longitudinal distance from the rear axle} \\ \text{to the rider's mass center} = X_R + (.11)L\end{array}$$

Derived Parameters

Having the empty weight, seat height, wheelbase, and static load distribution parameters for each motorcycle, as well as the algorithm needed to locate the rider mass, the parameters shown in Table 1 were computed. Shown from left to right are the following

-empty weight of each bike, lbs

-weight of bike plus the 50th percentile male rider, lbs

-static load on front wheel, lbs

Table 1

MODEL		WEIGHT		STATIC LOADS			LOAD TRANSFER GAIN	DYNAMIC FRONT TIRE LOAD	MASS LOCATIONS					
									BIKE		RIDER		COMPOSITE	
		BIKE	BIKE+RIDER	FRONT	REAR	RAT.			A	B	XR	ZR	X	Z
KAW	KX80	144.	308.	117.	191.	.379	.628	271.5	24.6	21.4	14.0	37.4	17.4	28.9
SUZ	RM80	150.	314.	118.	196.	.375	.592	266.5	25.6	21.9	14.1	36.3	17.8	28.1
YAM	YZ80	152.	316.	119.	197.	.378	.601	271.3	25.2	21.5	14.0	36.3	17.6	28.1
HOND	XR80	154.	318.	118.	200.	.370	.624	276.3	25.4	19.5	13.8	36.3	16.6	28.0
YAM	YZ125	200.	364.	136.	228.	.375	.550	296.4	30.0	25.5	15.0	44.3	20.8	30.5
KAW	KX125	203.	367.	139.	228.	.378	.539	297.1	30.2	26.6	15.1	44.8	21.5	30.6
SUZ	RM125	204.	368.	140.	228.	.380	.540	298.7	30.0	26.7	15.1	44.8	21.5	30.6
BULT	T350	207.	371.	140.	231.	.378	.539	300.0	28.4	23.7	14.6	39.3	19.7	28.1
HOND	CR125	209.	373.	142.	231.	.381	.549	306.0	29.7	26.3	15.1	45.5	21.3	30.8
YAM	YZ250	226.	390.	147.	243.	.378	.517	308.9	31.0	26.5	15.2	44.3	21.7	29.8
KAW	KX250	230.	394.	149.	245.	.379	.523	314.0	31.2	26.7	15.3	45.8	21.9	30.3
HOND	XR185	234.	398.	149.	249.	.375	.549	324.1	29.1	22.8	14.6	41.8	19.5	28.5
SUZ	RM400	236.	400.	153.	247.	.384	.524	321.0	30.7	26.8	15.2	45.8	22.1	30.1
SWM	250	239.	403.	152.	251.	.378	.517	318.9	31.3	26.2	15.2	45.0	21.7	29.7
YAM	IT175	241.	405.	157.	248.	.387	.523	326.0	29.4	25.6	14.9	42.8	21.3	28.8
KAW	LX250	243.	407.	156.	251.	.384	.529	328.2	30.2	25.8	15.1	45.0	21.5	29.6
HUSQ	CR390	244.	408.	154.	254.	.379	.506	319.7	32.3	27.4	15.5	46.6	22.6	30.2
HUSQ	OR390	245.	409.	151.	258.	.369	.516	319.8	32.6	25.7	15.3	46.3	21.5	30.1
MAIC	250E	247.	411.	158.	253.	.385	.501	322.9	31.0	27.0	15.3	43.9	22.3	29.1
HOND	XL185	249.	413.	155.	258.	.376	.538	333.2	29.0	22.6	14.6	40.8	19.4	27.8
CCM	600	250.	414.	161.	253.	.389	.506	328.8	30.6	27.4	15.3	44.8	22.6	29.3
YAM	IT250	258.	422.	158.	264.	.375	.507	329.1	31.3	24.7	15.1	42.8	21.0	28.4
CAN	370	258.	422.	163.	259.	.386	.517	337.3	30.4	26.1	15.1	44.9	21.8	29.2
KAW	DX400	260.	424.	164.	260.	.386	.519	339.7	30.7	26.4	15.2	46.2	22.0	29.6
HOND	XR250	268.	432.	162.	270.	.376	.507	337.7	31.1	24.4	15.0	42.8	20.9	28.2
KAW	KE250	284.	448.	166.	282.	.370	.474	335.4	32.6	24.6	15.2	40.8	21.1	27.1
HOND	XR500	288.	452.	171.	281.	.378	.492	348.8	31.6	24.9	15.1	42.9	21.4	27.8
HOND	XL500	304.	468.	184.	284.	.392	.491	367.3	29.9	25.2	15.0	41.6	21.6	27.0

Table 1 (Cont.)

MODEL	WEIGHT BIKE	WEIGHT BIKE+RIDER	STATIC LOADS FRONT	STATIC LOADS REAR	STATIC LOADS RAT.	LOAD TRANSFER GAIN	DYNAMIC FRONT TIRE LOAD	MASS LOCATIONS BIKE A	MASS LOCATIONS BIKE B	MASS LOCATIONS RIDER XR	MASS LOCATIONS RIDER ZR	MASS LOCATIONS COMPOSITE X	MASS LOCATIONS COMPOSITE Z
YAM RD400	372.	536.	210.	326.	.391	.483	416.9	29.4	23.1	14.7	39.3	20.6	25.3
KAW KZ400	386.	550.	221.	329.	.402	.472	429.1	29.2	24.5	14.8	39.9	21.6	25.4
YAM XS400	390.	554.	222.	332.	.401	.468	429.8	29.3	24.4	14.8	39.3	21.5	25.2
SUZ GS425	399.	563.	225.	338.	.399	.457	430.2	30.2	24.8	14.9	39.5	21.9	25.1
HOND CX500	473.	637.	259.	378.	.406	.431	478.0	31.3	26.0	15.2	40.5	23.3	24.7
HOND CB650	474.	638.	265.	373.	.415	.432	485.1	30.4	26.6	15.2	40.3	23.6	24.6
YAM XS650	481.	645.	260.	385.	.403	.435	484.2	31.1	25.4	15.1	40.3	22.8	24.6
HOND 750F	530.	694.	295.	399.	.426	.404	519.8	31.3	28.5	15.5	40.2	25.5	24.2
SUZ 1000L	536.	700.	290.	410.	.415	.395	511.5	32.5	28.0	15.6	39.3	25.1	23.9
HDAV 1000	541.	705.	276.	429.	.391	.403	502.6	33.9	25.7	15.5	39.8	23.3	24.0
HOND 750K	546.	710.	293.	417.	.413	.398	519.2	32.7	27.8	15.6	40.3	25.0	24.1
YAM XS750	546.	710.	292.	418.	.411	.405	521.4	32.4	27.1	15.4	40.3	24.4	24.1
SUZ GS750	547.	711.	303.	408.	.426	.413	537.7	30.8	27.9	15.4	41.0	25.0	24.2
BMW 100RT	550.	714.	298.	416.	.418	.418	537.1	31.0	26.8	15.3	40.8	24.1	24.2
KAW MK2	571.	735.	319.	416.	.434	.404	556.4	30.5	28.5	15.4	40.0	25.6	23.8
HOND CBX	580.	744.	313.	431.	.420	.406	554.3	31.5	27.4	15.4	40.5	24.8	23.9
YAM 1100	584.	748.	313.	435.	.418	.391	546.7	32.7	28.3	15.6	40.3	25.5	23.8
SUZ GS850	587.	751.	311.	440.	.415	.398	550.6	32.4	27.4	15.5	40.3	24.8	23.8
KAW 1000	602.	766.	325.	441.	.424	.384	560.1	32.9	29.1	15.7	40.8	26.3	23.8
KAW 1300	692.	856.	366.	490.	.428	.372	621.1	33.1	29.4	15.8	40.3	26.8	23.2

-static load on rear wheel, lbs

-ratio of front static load to total static load

-"load transfer gain" (referring to the ratio of the height of the rider/cycle c.g. to the wheelbase)

-dynamic front tire load accruing during a braking condition of 0.8 g deceleration

-longitudinal distances, A, from the front axle and, B, from rear axle to mass center of bike alone

-longitudinal distance, X_R, from rear axle and vertical distance, Z_R, from ground to mass center of rider alone

-longitudinal distance, X, from rear axle and vertical distance, Z, from ground to mass center of combined cycle/rider system

From among the numerics listed in Table 1, selections have been made for cross plotting in Figures 2 and 3. In Figure 2 are shown the static and dynamic (i.e., in an 0.8 g stop) values of front tire load that derive for each of the 48 sampled vehicles as a function of the corresponding empty weight of each motorcycle. We see that both of these tire load measures are very clearly related to the empty vehicle weight. Since the front brake is clearly the most heavily "loaded" motorcycle brake, the uniform correlation between empty weight and either of the front-brake loading measures suggests that the empty weight parameter can serve as a reliable predictor of actual static and dynamic brake loading. Clearly, this result must derive from a remarkably uniform, though unregulated, set of engineering practices by which the wheelbase, c.g. height, seat height, static weight distribution, and total weight of motorcycles are determined.

Shown in Figure 3 is the ratio of c.g. height to wheelbase for each of the 48 vehicles, plotted as a function of empty motorcycle weight. While a more distinctly nonlinear relationship is seen, again we find that rather little scatter exists away from the nominal curve for this measure which characterizes the rate at which tire loads change as a function of

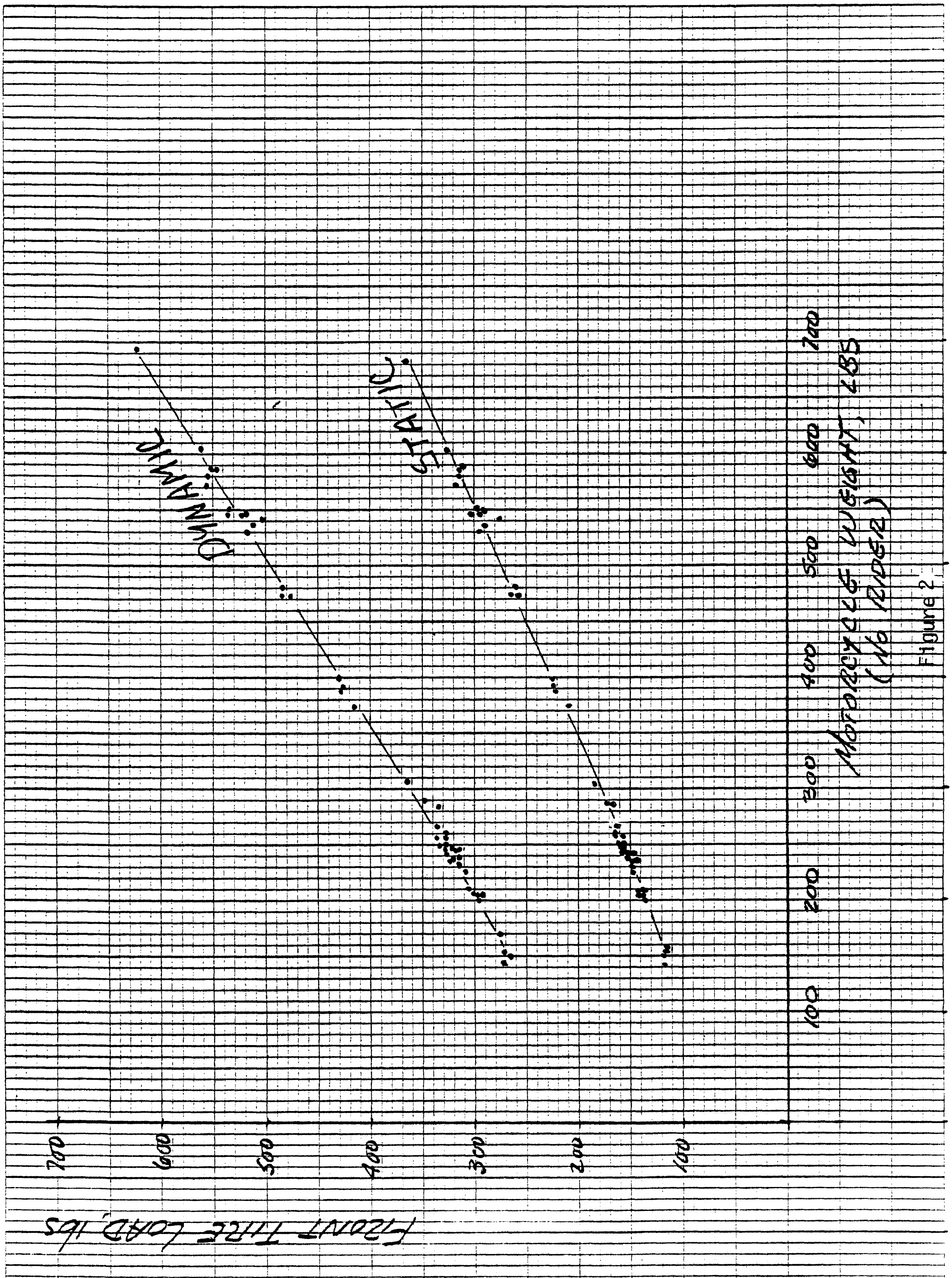

DYNAMIC
STATIC
MOTORCYCLE WEIGHT, LBS
(No RIDER)
100
200
300
400
500
600
700
FRONT TIRE LOAD, lbs

Figure 2

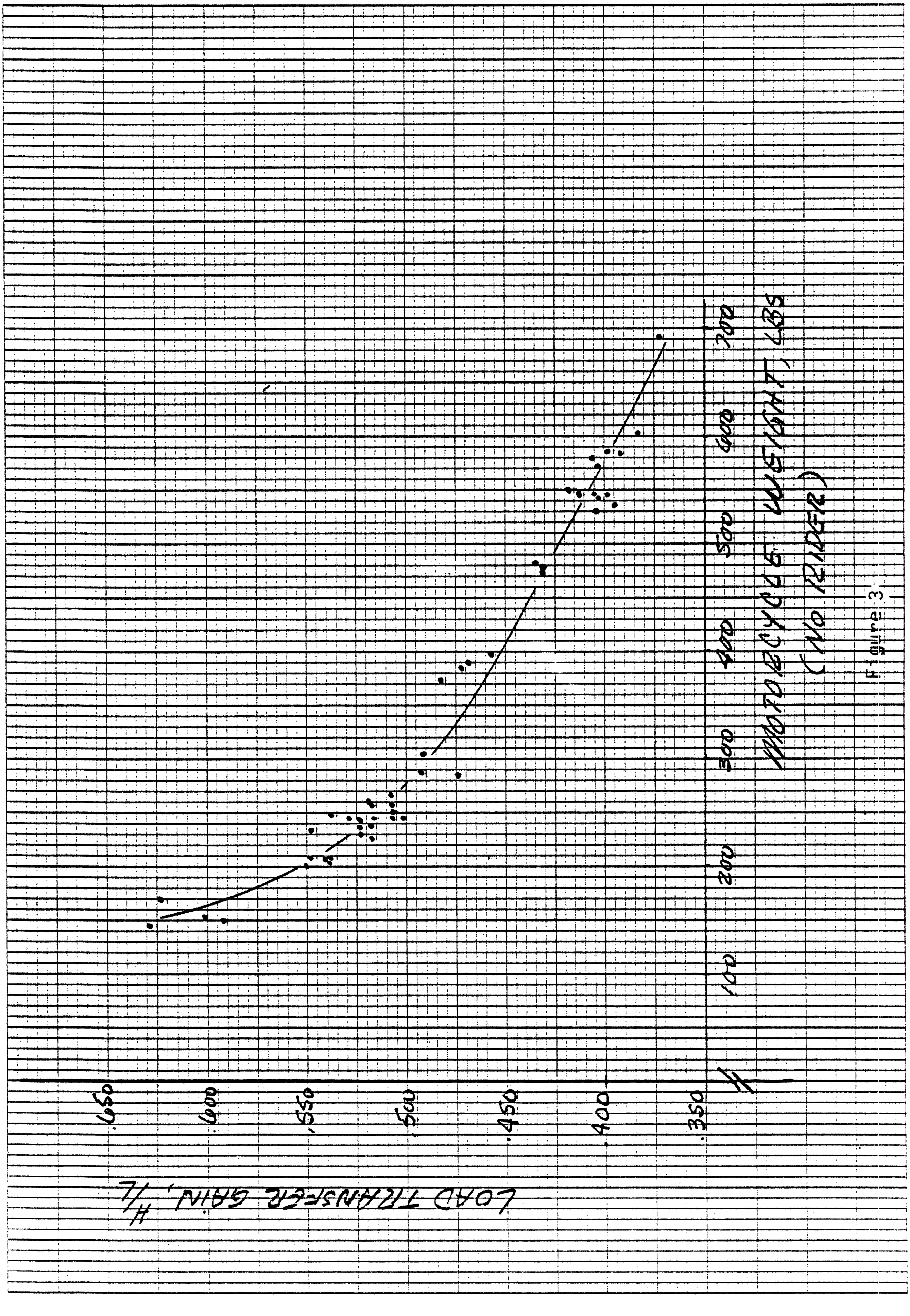

MOTORCYCLE WEIGHT, LBS
(NO RIDER)
100
200
300
400
500
600
700
LOAD TRANSFER GAIN, H/L
.350
.400
.450
.500
.550
.600
.650

Figure 3

increasing level of deceleration. Moreover, the "classification" task has provided the basis for suggesting that the empty weight of motorcycles may be useful to the government as a design parameter classifying vehicles according to the magnitude of the torque demands which will be placed upon motorcycle brakes in conditions of both low and high deceleration levels.

One very simple scheme of delineating the range of motorcycles according to "brake loading," or torque demand, is shown in Table 2. Here the sample of 48 motorcycles, ranging in engine size from 80cc to 1300cc, has been divided into three classes of empty weight so as to illustrate the very small amounts of overlap in other parameters which results. Since empty weight is a clear predictor of brake loading for contemporary motorcycles and since the illustrated breakdown by empty weight rather clearly divides the domain of brake loading values, it is suggested that the Table 2 scheme may be all that is needed to effect a viable classification of motorcycles for NHTSA's purposes in braking performance regulation.

Table 2

Class	Empty Motorcycle Weight, lbs.	Static Front Tire Loads (Range of Values)	Ratio of C.G. Height to Wheelbase (Range)	Dynamic Front Tire Load (Range)
A	Below 250 lbs	117 to 161	.628 to .501	266 to 333
B	250 to 500 lbs	158 to 261	.507 to .435	329 to 484
C	Above 500 lbs	276 to 366	.418 to .372	502 to 621

References

1. Rice, R.S., Davis, J.A., and Kunkel, D.T. "Accident-Avoidance Capabilities of Motorcycles." Final Report, Contract No. DOT-HS-4-00976, Calspan Corp., Rept. No. ZN-5571-V-1, June 1975.

2. Eaton, D.J. "Man-Machine Dynamics in the Stabilization of Single-Track Vehicles." Ph.D. Dissertation, The University of Michigan, 1973.

3. General Motors Corporation. "Anthropometric Test Dummy, Vol. I." December 1973.

4. Dunlap & Associates, Inc. "Motorcyclist Anthropometrics." Contract No. FH-11-7249, 1970.

APPENDIX 2

PROCEDURE FOR CONDUCTING THE TOW-TEST METHOD OF MOTORCYCLE BRAKING PERFORMANCE MEASUREMENT

The following is a generally applicable statement of the test procedures to be employed in conducting motorcycle braking performance measurement by the towing method. The procedure applies for any suitable design of test apparatus.

Vehicle Setup

The test motorcycle is to be outfitted with new tires and brake linings. The brake adjustments and tire inflations are to be according to the manufacturer's recommendations. The vehicle is to be connected to a towing system permitting application of a single, measurable towing force at a variable height above the ground. All tests of the vehicle are to be conducted with engine off and with transmission in neutral.

The brake temperature is measured by plug-type thermocouples installed in the approximate center of the facing length and width of the most heavily loaded shoe or disc pad, one per brake, as shown in Figure 1.

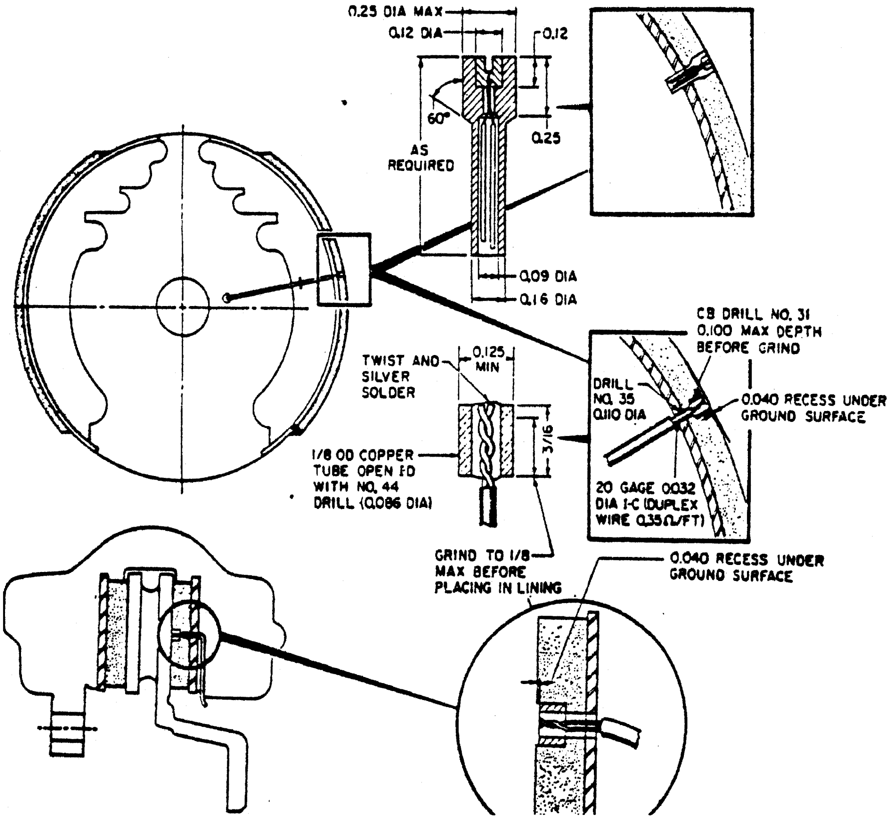
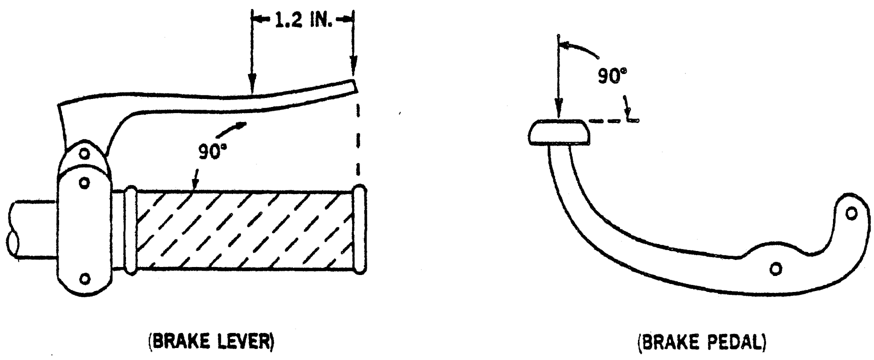


FIGURE 1 - TYPICAL PLUG TYPE THERMOCOUPLE INSTALLATIONS

Hand-lever and foot-pedal forces are to be measured in each test. The point of initial application of the lever forces is 1.2 inches from the end of the brake lever grip. The direction of the force is perpendicular to the handle grip on the plane along which the brake lever rotates, and the point of application of the pedal force is the center of the foot contact pad of the brake pedal. The direction of the force is perpendicular to the foot contact pad on the plane along which the brake pedal rotates, as shown in Figure 2.

FIG. 2 DIRECTION OF FORCE



Brake Warming

If, within 1/2 minute prior to the initiation of any of the below-described test sequences, the temperature of the brake being tested is below 130°F, a warming procedure will be conducted. At a steady speed of 30 mph, the brake will be applied to yield a tow force, FT, equivalent to an acceleration level of 10 ft/sec^2. The respective front-only and rear-only steady tow force conditions, FT_f and FT_r, are as determined in Equations (1) and (2), with A_x = 10/g.

$$FT_f = A_x [W_f + h/\ell \cdot A_x \cdot W] \quad , \quad \text{(front only)} \qquad (1)$$

and

$$FT_r = A_x[W_r - h/\ell \cdot A_x \cdot W] \quad , \quad \text{(rear only)} \qquad (2)$$

where

A_x is the specified equivalent deceleration in g's

W_f is the static front wheel load

W_r is the static rear wheel load

h is the c.g. height

ℓ is wheelbase

W is the total weight

The brake application (for warming) can be continuously maintained for a maximum of 22 seconds or until a 130°F initial temperature is attained.

Pre-Burnish Effectiveness Test

Tests are to be conducted at a steady speed of 40 mph and, in a sequence of runs, are to be initiated only when the tested brake exhibits a temperature below 180°F.

The effectiveness test sequence involves the following steps:

1) The tow height (at which the rear-only test is to be conducted) is placed at 48 inches.

2) Four successive tests are conducted in which the force input to the rear actuator is applied in a ramp fashion causing either (a) wheel lockup or (b) a 90-lb actuator force level to be obtained between two and five seconds after initiating the brake application. The brake actuator is to be released at least one second and no more than three seconds after a wheel lockup has occurred. The resulting average of the four peak tow-force readings is used to calculate the value of peak μ_r using Equation (3).

$$\mu_r = \frac{FT_R}{W_r - \frac{h_{tr}}{\ell} FT_R} \qquad (3)$$

where

FT_R is average of the peak tow force* values measured in the four rear-only tests

W_r is the static rear wheel load

h_{tr} is the rear-only tow height

and ℓ is the wheelbase.

The calculated value of μ_r will be used for selecting tow heights in subsequent front-only effectiveness tests.

3) The tow height to be used in the first front-only test is placed at the position equal to: (c.g. height + 6 inches).

4) Three front-only effectiveness tests are conducted. In each, front actuator effort is applied in a ramp fashion causing either (a) wheel lockup or (b) a 55-lb actuator force to be obtained within two to five seconds after initiating the brake application.

5) If, in two out of the three tests in step 4, front-wheel lockup occurred, the procedure advances to step 8. If, in two out of the three tests in step 4, lockup did not occur, the procedure advances to step 6. In conducting steps 6 or 8, the value of NEXT TOW HEIGHT (h_{i+1}) must be calculated per Equation (4).

---

*Due to noise which is typically encountered on the raw tow force signal, some filtering is needed to permit a realistic determination of the peak tow-force value. Although a high quality digital filtering scheme was used in this study, no generally required tow-force filter has been recommended. Nevertheless, the peak tow-force value is defined as the maximum value of tow force which is accrued prior to wheel lockup and without exceeding an actuator force value of 90 lbs.

$$h_{i+1} = \frac{\ell(W_r\mu_r + FT_i)\left(\frac{h}{\ell + h\,\mu_r}\right)}{FT_i} \quad (4)$$

where

h_{i+1} is next value of tow height to be employed in front-only tests

FT_i is the average value of peak tow force attained in three repeats of the previous brake application

h is the cycle/rider c.g. height

μ_r is the rear-only normalized force coefficient determined from step 2.

6) The procedure is directed to the appropriate next step on the basis of the difference between the previous tow height and the next tow height (h_{i+1}) from Equation (4). If the NEXT TOW HEIGHT is one or more inches lower than the previous tow height, proceed to step 7. If the NEXT TOW HEIGHT is not one or more inches lower than the previous tow height, proceed to step 9.

7) Set the tow attachment mechanisms to the NEXT TOW HEIGHT value. Proceed to step 4.

8) If in two of the three tests in step 4 wheel lockup did occur, a determination is made as to whether the NEXT TOW HEIGHT shows (a) one or more inches difference from, or (b) less than one inch difference from the previous value of tow height. If (a), then the sequence proceeds to step 7; if (b), then the sequence proceeds to step 9.

9) One additional repeat run is conducted using the previous value of tow height and applying the front actuator force in a ramp fashion causing either (a) wheel lockup or (b) a 55-lb actuator force to be obtained within two to five seconds after initiation of the brake application.

10) STOP.

Burnish Procedure

The front brake will be burnished by attaining prescribed values of tow force using front-only brake applications over a sequence of 200 constant level applications. A tow force level equivalent to $A_x = 12/g$ (in the front-only Equation (1)) will be applied, at a constant test speed of 40 mph, for a duration of four seconds at each application. The tow force is to be applied at an elevation equal to the height of the mass center of the cycle/test-rider system. The braking interval will be either that distance needed to reduce brake temperature to 150°F or one mile, whichever occurs first. Following burnishing, brakes will be adjusted to manufacturers' specifications.

The rear brake will be burnished by a procedure identical to that described above, except that tow force level shall be as specified by Equation (2), with $A_x = 12/g$.

Post-Burnish Effectiveness

The basic effectiveness procedure described previously as the "pre-burnish" effectiveness procedure will be repeated here.

Thermal Capacity (Fade) Procedure

A thermal loading sequence will be conducted involving a baseline check followed by a series of high energy brake applications.

Baseline Check. At a constant speed of 30 mph, the front brake will be applied for a duration of four seconds, achieving a tow force equivalent to $A_x = 15/g$ in the front-only Equation (1). Three braking inputs shall be applied, each with an initial temperature between 130°F and 180°F. The same three-application sequence shall be conducted using the rear brake, and employing a tow force as specified by Equation (2) using $A_x = 15/g$.

Thermal Loading. A total of ten brake applications using front-only braking will be applied at a constant speed of 30 mph, achieving a tow force value corresponding to $A_x = 15/g$ in Equation (1). The initial temperature before the first brake application shall be below 150°F. The constant tow force level shall be sustained for six seconds at each application. The interval between initiation of each brake application shall be 0.4 mile. The tow force is to be applied at the height of the mass center of the cycle/test-rider system for the fade test sequence. The above procedure shall be repeated using rear-only braking and a tow force value corresponding to $A_x = 15/g$ in Equation (2).

Performance Measures

The braking performance of the test motorcycle is derived from the tow-test data per the measures described below.

Effectiveness Tests. Performance is alternatively expressed by either an average equivalent deceleration measure, A_x, or an equivalent stopping distance, D, achieved from an initial velocity of 60 mph. The deceleration measure is defined by Equation (5).

$$A_x = \frac{FT_p + \mu_r \{W - [W_f + h_t/\ell \ FT_p]\}}{W} \tag{5}$$

where

FT_p is the average of the final four values of peak tow force resulting from the front-only effectiveness tests

h_t is the convergent tow height obtained during the front-only effectiveness tests.

The free-stopping distance, D, is calculated as

$$D = \frac{V_o^2}{(64.4)A_x} \tag{6}$$

where

V_o is the reference free-stopping initial velocity (fps)

For the desired reference condition of 60 mph,

$$D = \frac{120.2}{A_x} \tag{7}$$

Thermal Capacity (Fade) Procedure. For the baseline check applications, the tow and actuator force values are obtained by averaging the actuator force time histories over the last two seconds of the four-second-duration input. An average of the three tow force values obtained using the front brake is then ratioed to the average of the three front actuator force values yielding a gain value, viz.,

$$\text{Front Baseline Gain} = \frac{\text{FT(average of 3)}}{A_f\text{(average of 3)}} \tag{8}$$

Likewise, a gain value characterizing the rear baseline checks is derived, viz.,

$$\text{Rear Baseline Gain} = \frac{\text{FT(average of 3)}}{A_r\text{(average of 3)}} \tag{9}$$

The vehicle's resistance to thermal loading is established by comparing the above front and rear baseline gains with the respective front and rear "faded" gains, viz.,

$$\text{Front Faded Gain} = \frac{\text{FT(average for the last 3 of 10 thermal loading runs)}}{A_f\text{(average for the last 3 of 10 thermal loading runs)}} \tag{10}$$

$$\text{Rear Faded Gain} = \frac{\text{FT(average for the last 3 of 10 thermal loading runs)}}{A_f\text{(average for the last 3 of 10 thermal loading runs)}} \tag{11}$$

APPENDIX 3

DEMONSTRATION TEST DATA

The following is the computer printout of data from the demonstration tests on three motorcycles; namely, a Honda CB 650, a Suzuki TS 185, and a Kawasaki KZ1000.

Basic Motorcycle Parameters
Bike Name:
HONDA CB 650
1/26/81
Total Weight: 673.00
Front Wheel Load 292.00
Rear Wheel Load: 381.00
CG Height: 24.20
Wheelbase: 59.00

* Preburnish *
Effectiveness
Test Data

Rear Brake Data

Run#	1	2	3	4
V:	39.60	39.95	39.85	39.75
RT:	128.48	138.40	162.79	149.40
RTBF:	200.91	215.72	205.92	225.00
RAF:	41.02	42.05	40.15	39.84

Front Brake Data

Run#	1	2	3	4
V:	40.05	40.25	39.55	39.90
FT:	156.39	160.26	159.52	160.53
FTBF:	463.48	445.44	461.37	439.27
FAF:	36.74	37.72	39.72	37.96

Rear Brake Avg Data

Avg RTBF 211.89
Avg RAF 40.76
Rear Friction Coefficient: 1.02

Front Brake Avg Data

Avg FTBF 452.39
Avg FAF 38.03
Final Towbar Height 31.35
Eq Free Stopping Decel. 0.8845
Eq Free Stopping Dist. From 60 mph 135.95

* Postburnish *
Effectiveness
Test Data

Rear Brake
Data

Run#	1
V:	39.25
RT:	129.59
RTBF:	212.47
RAF:	41.84
Run#	2
V:	40.00
RT:	175.86
RTBF:	191.03
RAF:	44.58
Run#	3
V:	40.00
RT:	138.66
RTBF:	198.15
RAF:	37.61
Run#	4
V:	40.30
RT:	136.89
RTBF:	209.23
RAF:	41.63

Front Brake
Data

Run#	1
V:	40.60
FT:	177.53
FTBF:	490.61
FAF:	40.84
Run#	2
V:	40.45
FT:	152.35
FTBF:	493.69
FAF:	40.86
Run#	3
V:	40.50
FT:	154.29
FTBF:	484.56
FAF:	38.41
Run#	4
V:	40.25
FT:	166.88
FTBF:	503.10
FAF:	40.64

Rear Brake
Avg Data

Avg RTBF 202.72
Avg RAF 41.42
Rear Friction
Coefficient:
0.94

Front Brake
Avg Data

Avg FTBF 492.99
Avg FAF 40.19
Final Towbar
Height 30.23
Eq Free Stopping
Decel. 0.9115
Eq Free Stopping
Dist. From
60 mph 131.92

Thermal Capacity Fade Gain Test Data

Front Brake Baseline Data

Run #	1
V:	30.97
FT:	153.12
FTBF:	208.11
FAF:	12.77

Run #	2
V:	30.41
FT:	175.33
FTBF:	206.56
FAF:	12.73

Run #	3
V:	30.26
FT:	172.40
FTBF:	196.08
FAF:	12.33

Rear Brake Baseline Data

Run #	1
V:	29.46
RT:	131.62
RTBF:	124.25
RAF:	23.05

Run #	2
V:	29.61
RT:	139.63
RTBF:	124.90
RAF:	21.52

Run #	3
V:	30.16
RT:	145.36
RTBF:	122.19
RAF:	21.72

Avg Data And Baseline FG

Rear Baseline Avg Data

Avg RTBF: 123.78
Avg RAF: 22.10
Baseline RBG:
5.60

Front Baseline Avg Data

Avg FTBF: 203.58
Avg FAF: 12.61
Baseline FBG
16.14

Front Brake Thermal Fade Gain Test Data

Pass #	1
D:	0.03
V:	29.46
FT:	127.35
FTBF:	209.92
FAF:	14.39
FFG:	14.59

Pass #	2
D:	0.39
V:	30.81
FT:	157.46
FTBF:	206.67
FAF:	14.85
FFG:	13.92

Pass #	3
D:	0.39
V:	31.07
FT:	176.58
FTBF:	202.85
FAF:	11.84
FFG:	17.13

Pass #	4
D:	0.39
V:	30.97
FT:	192.10
FTBF:	195.31
FAF:	12.59
FFG:	15.51

Pass #	5
D:	0.39
V:	29.91
FT:	202.53
FTBF:	192.49
FAF:	12.59
FFG:	15.29

Pass #	6
D:	0.38
V:	29.91
FT:	203.49
FTBF:	198.33
FAF:	13.83
FFG:	14.34

Pass #	7
D:	0.38
V:	30.56
FT:	212.86
FTBF:	199.16
FAF:	13.77
FFG:	14.46

Pass #	8
D:	0.39
V:	30.71
FT:	217.92
FTBF:	198.48
FAF:	12.34
FFG:	16.08

Pass #	9
D:	0.40
V:	29.66
FT:	215.92
FTBF:	202.14
FAF:	12.57
FFG:	16.09

Pass #	10
D:	0.38
V:	29.51
FT:	214.82
FTBF:	196.88
FAF:	13.18
FFG:	14.93

Final 3 FFG avg:
15.70

Rear Brake Thermal Fade Gain Test Data

Pass #	1
D:	0.02
V:	29.91
RT:	143.32
RTBF:	119.96
RAF:	20.45
RFG:	5.87

Pass #	2
D:	0.39
V:	30.51
RT:	146.04
RTBF:	119.37
RAF:	20.87
RFG:	5.72

Pass #	3
D:	0.39
V:	29.81
RT:	150.97
RTBF:	129.31
RAF:	21.41
RFG:	6.04

Pass #	4
D:	0.38
V:	29.61
RT:	154.58
RTBF:	115.32
RAF:	20.35
RFG:	5.67

Pass #	5
D:	0.39
V:	30.21
RT:	156.42
RTBF:	122.77
RAF:	21.19
RFG:	5.79

Pass #	6
D:	0.40
V:	28.91
RT:	159.15
RTBF:	120.11
RAF:	16.83
RFG:	7.14

Pass #	7
D:	0.40
V:	30.56
RT:	159.59
RTBF:	121.53
RAF:	19.09
RFG:	6.37

Pass #	8
D:	0.38
V:	30.36
RT:	160.55
RTBF:	123.31
RAF:	20.14
RFG:	6.12

Pass #	9
D:	0.39
V:	29.96
RT:	162.31
RTBF:	129.61
RAF:	21.76
RFG:	5.96

Pass #	10
D:	0.38
V:	30.11
RT:	165.84
RTBF:	126.35
RAF:	21.03
RFG:	6.01

Final 3 RFG avg:
6.03

Burnish Run Data

Completed Burnish Runs

Front:	200.00
Rear:	200.00

Front Burnish Data

Run #	10
V:	39.41
FT:	175.11
FTBF:	150.38
FAF:	9.98

Run #	20
V:	39.51
FT:	176.72
FTBF:	147.07
FAF:	10.27

Run #	30
V:	40.41
FT:	176.09
FTBF:	156.13
FAF:	10.23

Run #	40
V:	40.51
FT:	177.36
FTBF:	147.34
FAF:	8.73

Run #	50
V:	38.55
FT:	170.31
FTBF:	153.51
FAF:	9.25

Run #	60
V:	40.91
FT:	172.38
FTBF:	155.06
FAF:	9.39

Run #	70
V:	39.61
FT:	162.35
FTBF:	150.38
FAF:	8.74

Run #	80
V:	40.31
FT:	176.03
FTBF:	153.86
FAF:	9.20

Run #	90
V:	39.55
FT:	135.53
FTBF:	151.93
FAF:	13.51

Run #	100
V:	39.45
FT:	177.32
FTBF:	158.22
FAF:	11.89

Run #	110
V:	39.65
FT:	178.39
FTBF:	156.58
FAF:	12.68

Run #	120
V:	40.25
FT:	180.00
FTBF:	153.87
FAF:	11.15

Run #	130
V:	39.60
FT:	176.40
FTBF:	155.61
FAF:	10.52

Run #	140
V:	40.00
FT:	178.55
FTBF:	146.22
FAF:	11.99

Run #	150
V:	39.50
FT:	178.07
FTBF:	148.55
FAF:	11.81

Run #	160
V:	40.40
FT:	176.47
FTBF:	152.12
FAF:	11.98

Run #	170
V:	40.30
FT:	175.78
FTBF:	145.51
FAF:	11.85

Run #	180
V:	38.59
FT:	176.02
FTBF:	151.98
FAF:	12.54

Run #	190
V:	39.95
FT:	171.26
FTBF:	156.18
FAF:	11.53

Run #	200
V:	40.15
FT:	178.41
FTBF:	146.73
FAF:	10.71

Rear Burnish Data

Run #	10.00
V:	38.00
RT:	153.56
RTBF:	113.41
RAF:	19.15

Run #	20.00
V:	40.21
RT:	178.07
RTBF:	112.00
RAF:	19.44

Run #	30.00
V:	39.61
RT:	176.91
RTBF:	110.26
RAF:	21.38

Run #	40.00
V:	40.86
RT:	168.16
RTBF:	102.41
RAF:	22.05

Run #	50.00
V:	43.28
RT:	172.79
RTBF:	115.15
RAF:	21.46

Run #	60.00
V:	40.71
RT:	174.59
RTBF:	104.48
RAF:	18.98

Run #	70.00
V:	40.96
RT:	173.71
RTBF:	115.35
RAF:	17.51

Run #	80.00
V:	40.36
RT:	176.63
RTBF:	120.06
RAF:	19.93

Run #	90.00
V:	40.81
RT:	179.28
RTBF:	110.10
RAF:	19.01

Run #	100.00
V:	40.20
RT:	161.02
RTBF:	114.52
RAF:	18.47

Run #	110.00
V:	40.25
RT:	177.56
RTBF:	102.67
RAF:	20.95

Run #	120.00
V:	40.50
RT:	176.85
RTBF:	103.47
RAF:	20.08

Run #	130.00
V:	39.35
RT:	154.24
RTBF:	104.79
RAF:	21.47

Run #	140.00
V:	39.30
RT:	178.80
RTBF:	112.69
RAF:	18.95

Run #	150.00
V:	39.55
RT:	178.93
RTBF:	103.50
RAF:	20.09

Run #	160.00
V:	40.20
RT:	176.60
RTBF:	102.59
RAF:	18.79

Run #	170.00
V:	38.54
RT:	174.0[illegible]
RTBF:	95.67
RAF:	19.66

Run #	180.0[illegible]
V:	40.5[illegible]
RT:	178.3[illegible]
RTBF:	104.1
RAF:	19.8[illegible]

Run #	190.0[illegible]
V:	40.3[illegible]
RT:	173.6[illegible]
RTBF:	107.5[illegible]
RAF:	20.0[illegible]

Run #	200.0
V:	40.6
RT:	173.3
RTBF:	120.8
RAF:	20.5

Basic Motorcycle Parameters

Bike Name:
SUZUKI TS-185
1/30/81

Total Weight:	467.00
Front Wheel Load	168.00
Rear Wheel Load:	299.00
CG Height:	28.80
Wheelbase:	55.00

* Preburnish *
Effectiveness
Test Data

Rear Brake Data

Run#	1
V:	40.80
RT:	138.16
RTBF:	145.09
RAF:	37.17

Run#	2
V:	40.95
RT:	146.88
RTBF:	148.06
RAF:	60.54

Run#	3
V:	40.20
RT:	140.43
RTBF:	143.96
RAF:	51.09

Run#	4
V:	40.50
RT:	140.81
RTBF:	147.25
RAF:	43.83

Front Brake Data

Run#	1
V:	39.80
FT:	134.51
FTBF:	227.41
FAF:	38.12

Run#	2
V:	40.45
FT:	135.63
FTBF:	243.89
FAF:	41.82

Run#	3
V:	39.95
FT:	132.88
FTBF:	255.01
FAF:	39.91

Run#	4
V:	40.45
FT:	133.22
FTBF:	246.15
FAF:	55.36

Rear Brake Avg Data

Avg RTBF	146.09
Avg RAF	48.16
Rear Friction Coefficient:	0.85

Front Brake Avg Data

Avg FTBF	243.12
Avg FAF	43.80
Final Towbar Height	40.87
Eq Free Stopping Decel.	0.7365
Eq Free Stopping Dist. From 60 mph	163.27

* Postburnish *
Effectiveness
Test Data

Rear Brake
Data

Run#	1
V:	40.40
RT:	137.54
RTBF:	147.05
RAF:	46.77

Run#	2
V:	40.20
RT:	144.03
RTBF:	152.15
RAF:	49.20

Run#	3
V:	40.10
RT:	144.79
RTBF:	149.06
RAF:	39.07

Run#	4
V:	39.65
RT:	139.87
RTBF:	163.57
RAF:	51.95

Front Brake
Data

Run#	1
V:	39.85
FT:	164.36
FTBF:	186.41
FAF:	36.39

Run#	2
V:	39.45
FT:	168.00
FTBF:	232.18
FAF:	44.41

Run#	3
V:	40.05
FT:	165.24
FTBF:	251.69
FAF:	41.63

Run#	4
V:	40.35
FT:	175.89
FTBF:	196.46
FAF:	35.97

Rear Brake
Avg Data

Avg RTBF	152.96
Avg RAF	46.75
Rear Friction Coefficient:	0.92

Front Brake
Avg Data

Avg FTBF	216.68
Avg FAF	39.60
Final Towbar Height	43.41
Eq Free Stopping Decel.	0.7172
Eq Free Stopping Dist. From 60 mph	167.66

Thermal Capacity Fade Gain Test Data

Front Brake Baseline Data

Run #	1
V:	29.89
FT:	150.67
FTBF:	137.29
FAF:	27.11

Run #	2
V:	30.44
FT:	164.14
FTBF:	133.21
FAF:	17.53

Run #	3
V:	30.29
FT:	158.57
FTBF:	127.45
FAF:	17.61

Rear Brake Baseline Data

Run #	1
V:	30.24
RT:	147.04
RTBF:	90.79
RAF:	21.73

Run #	2
V:	30.54
RT:	161.27
RTBF:	90.39
RAF:	19.70

Run #	3
V:	30.49
RT:	166.69
RTBF:	96.01
RAF:	19.73

Avg Data And Baseline FG

Rear Baseline Avg Data

Avg RTBF:	92.40
Avg RAF:	20.39
Baseline RBG:	4.53

Front Baseline Avg Data

Avg FTBF:	132.65
Avg FAF:	20.75
Baseline FBG	6.39

Front Brake Thermal Fade Gain Test Data

Pass #	1
D:	0.01
V:	30.44
FT:	134.32
FTBF:	131.44
FAF:	16.71
FFG:	7.86

Pass #	2
D:	0.39
V:	30.49
FT:	152.95
FTBF:	139.90
FAF:	9.75
FFG:	14.35

Pass #	3
D:	0.40
V:	30.29
FT:	174.70
FTBF:	127.08
FAF:	19.78
FFG:	6.43

Pass #	4
D:	0.39
V:	30.19
FT:	200.76
FTBF:	128.59
FAF:	15.88
FFG:	8.10

Pass #	5
D:	0.39
V:	30.29
FT:	220.67
FTBF:	119.10
FAF:	10.72
FFG:	11.11

Pass #	6
D:	0.38
V:	29.99
FT:	236.73
FTBF:	125.94
FAF:	18.84
FFG:	6.68

Pass #	7
D:	0.38
V:	30.14
FT:	252.68
FTBF:	134.23
FAF:	17.27
FFG:	7.77

Pass #	8
D:	0.39
V:	29.63
FT:	267.44
FTBF:	137.19
FAF:	16.52
FFG:	8.30

Pass #	9
D:	0.39
V:	30.04
FT:	276.32
FTBF:	132.44
FAF:	14.87
FFG:	8.91

Pass #	10
D:	0.38
V:	30.29
FT:	282.21
FTBF:	130.25
FAF:	12.66
FFG:	10.29

Final 3 FFG avg: 9.17

Suzuki TS 185

Rear Brake
Thermal Fade
Gain Test Data

Pass #	1
D:	0.01
V:	30.09
RT:	134.38
RTBF:	88.23
RAF:	20.86
RFG:	4.23

Pass #	2
D:	0.39
V:	29.79
RT:	150.69
RTBF:	92.29
RAF:	24.97
RFG:	3.70

Pass #	3
D:	0.39
V:	30.69
RT:	164.80
RTBF:	91.25
RAF:	25.09
RFG:	3.64

Pass #	4
D:	0.38
V:	30.04
RT:	177.73
RTBF:	90.87
RAF:	24.51
RFG:	3.71

Pass #	5
D:	0.39
V:	30.19
RT:	185.24
RTBF:	90.57
RAF:	23.76
RFG:	3.81

Pass #	6
D:	0.39
V:	30.44
RT:	193.63
RTBF:	89.78
RAF:	25.93
RFG:	3.46

Pass #	7
D:	0.38
V:	30.24
RT:	200.70
RTBF:	90.02
RAF:	23.18
RFG:	3.88

Pass #	8
D:	0.39
V:	29.73
RT:	204.68
RTBF:	91.00
RAF:	24.87
RFG:	3.66

Pass #	9
D:	0.39
V:	30.24
RT:	212.33
RTBF:	90.61
RAF:	24.11
RFG:	3.76

Pass #	10
D:	0.39
V:	30.19
RT:	212.20
RTBF:	81.12
RAF:	23.65
RFG:	3.43

Final 3 RFG avg:
3.62

Burnish Run
Data

Completed
Burnish Runs

Front:	200.00
Rear:	200.00

Front Burnish
Data

Run #	10
V:	40.30
FT:	177.68
FTBF:	98.07
FAF:	12.41

Run #	20
V:	41.01
FT:	171.40
FTBF:	97.92
FAF:	11.56

Run #	30
V:	40.25
FT:	178.86
FTBF:	97.14
FAF:	11.50

Run #	40
V:	40.05
FT:	179.35
FTBF:	101.96
FAF:	12.33

Run #	50
V:	40.65
FT:	179.11
FTBF:	96.61
FAF:	14.17

Run #	60
V:	40.40
FT:	178.85
FTBF:	105.00
FAF:	11.28

Run #	70
V:	40.10
FT:	179.73
FTBF:	102.03
FAF:	12.36

Run #	80
V:	41.66
FT:	178.96
FTBF:	109.06
FAF:	12.66

Run #	90
V:	40.10
FT:	178.06
FTBF:	101.50
FAF:	12.54

Run #	100
V:	40.25
FT:	178.80
FTBF:	99.19
FAF:	13.12

Run #	110
V:	41.31
FT:	175.44
FTBF:	102.95
FAF:	10.33

Run #	120
V:	41.46
FT:	178.78
FTBF:	99.60
FAF:	11.89

Run #	V:	FT:	FTBF:	FAF:
130	41.36	178.25	101.11	10.54
140	40.25	178.96	100.98	11.23
150	40.55	179.05	99.09	12.39
160	40.65	178.61	95.26	11.10
170	41.11	177.38	95.86	10.38
180	40.35	179.07	97.10	12.13
190	40.15	178.67	101.29	11.26
200	40.50	178.56	94.66	10.52

Rear Burnish Data

Run #	V:	RT:	RTBF:	RAF:
10.00	40.50	178.28	78.74	16.34
20.00	40.30	178.80	80.31	16.54
30.00	39.95	175.58	82.41	17.54
40.00	40.20	175.19	82.57	17.33
50.00	40.65	178.63	80.17	16.49
60.00	40.80	178.65	80.01	18.30
70.00	40.00	177.80	78.84	18.40
80.00	40.20	159.03	83.73	17.70
90.00	39.75	171.06	79.24	18.80
100.00	41.61	174.86	74.48	18.34
110.00	39.90	177.92	81.90	20.27
120.00	39.75	179.14	80.00	20.97
130.00	41.11	175.87	82.57	19.46
140.00	40.60	178.25	74.75	21.47
150.00	40.95	172.60	81.77	15.72
160.00	40.70	173.31	83.01	16.97
170.00	40.70	177.11	83.30	17.32
180.00	41.36	172.52	80.30	15.28
190.00	41.21	178.63	79.67	15.21
200.00	40.30	177.95	75.88	16.08

Basic Motorcycle Parameters

Bike Name:
KAWASAKI KZ1000
2/17/81

Total Weight: 802.00
Front Wheel Load 340.00
Rear Wheel Load: 462.00
CG Height: 25.40
Wheelbase: 60.75

* Preburnish *
Effectiveness
Test Data

Rear Brake Data

Run#	1
V:	39.85
RT:	158.49
RTBF:	226.88
RAF:	42.13

Run#	2
V:	40.35
RT:	149.80
RTBF:	221.32
RAF:	42.48

Run#	3
V:	40.91
RT:	151.31
RTBF:	238.52
RAF:	42.00

Run#	4
V:	40.45
RT:	134.16
RTBF:	217.26
RAF:	44.39

Front Brake Data

Run#	1
V:	40.70
FT:	155.22
FTBF:	560.49
FAF:	38.31

Run#	2
V:	40.15
FT:	145.52
FTBF:	596.18
FAF:	39.95

Run#	3
V:	40.45
FT:	141.56
FTBF:	583.79
FAF:	50.32

Run#	4
V:	40.96
FT:	138.81
FTBF:	560.44
FAF:	43.31

Rear Brake Avg Data

Avg RTBF 225.99
Avg RAF 42.75
Rear Friction Coefficient: 0.80

Front Brake Avg Data

Avg FTBF 575.23
Avg FAF 42.98
Final Towbar Height 31.14
Eq Free Stopping Decel. 0.8834
Eq Free Stopping Dist. From 60 mph 136.12

* Postburnish *
Effectiveness
Test Data

Rear Brake
Data

Run#	1
V:	40.10
RT:	168.07
RTBF:	251.30
RAF:	43.73
Run#	2
V:	39.80
RT:	141.48
RTBF:	228.68
RAF:	40.65
Run#	3
V:	40.05
RT:	137.41
RTBF:	234.14
RAF:	39.89
Run#	4
V:	39.30
RT:	144.71
RTBF:	228.55
RAF:	41.25

Front Brake
Data

Run#	1
V:	40.10
FT:	141.48
FTBF:	567.32
FAF:	42.44
Run#	2
V:	40.20
FT:	143.25
FTBF:	573.41
FAF:	40.22
Run#	3
V:	29.64
FT:	75.34
FTBF:	548.08
FAF:	44.64
Run#	4
V:	40.35
FT:	142.24
FTBF:	587.30
FAF:	41.96

Rear Brake
Avg Data

Avg RTBF 235.67
Avg RAF 41.38
Rear Friction
Coefficient:
0.85

Front Brake
Avg Data

Avg FTBF 569.03
Avg FAF 42.32
Final Towbar
Height 31.84
Eq Free Stopping
Decel. 0.8840
Eq Free Stopping
Dist. From
60 mph 136.03

Thermal Capacity Fade Gain Test Data

Front Brake Baseline Data

Run #	1
V:	30.49
FT:	137.90
FTBF:	228.62
FAF:	10.61

Run #	2
V:	29.84
FT:	161.09
FTBF:	240.84
FAF:	12.39

Run #	3
V:	30.29
FT:	162.98
FTBF:	243.26
FAF:	10.73

Rear Brake Baseline Data

Run #	1
V:	29.99
RT:	146.48
RTBF:	134.04
RAF:	21.76

Run #	2
V:	30.64
RT:	168.04
RTBF:	143.73
RAF:	21.55

Run #	3
V:	29.73
RT:	148.19
RTBF:	149.94
RAF:	21.97

Avg Data And Baseline FG

Rear Baseline Avg Data

Avg RTBF: 142.57
Avg RAF: 21.76
Baseline RBG: 6.55

Front Baseline Avg Data

Avg FTBF: 237.57
Avg FAF: 11.24
Baseline FBG 21.13

Front Brake Thermal Fade Gain Test Data

Pass #	1
D:	0.02
V:	30.49
FT:	131.67
FTBF:	244.40
FAF:	12.32
FFG:	19.83

Pass #	2
D:	0.41
V:	30.59
FT:	160.15
FTBF:	264.03
FAF:	12.95
FFG:	20.39

Pass #	3
D:	0.40
V:	29.93
FT:	177.05
FTBF:	250.87
FAF:	11.47
FFG:	21.87

Pass #	4
D:	0.40
V:	29.78
FT:	181.30
FTBF:	238.33
FAF:	11.25
FFG:	21.18

Pass #	5
D:	0.40
V:	30.79
FT:	185.99
FTBF:	241.87
FAF:	12.69
FFG:	19.05

Pass #	6
D:	0.40
V:	30.34
FT:	194.96
FTBF:	240.20
FAF:	11.94
FFG:	20.12

Pass #	7
D:	0.40
V:	29.43
FT:	191.56
FTBF:	247.51
FAF:	11.53
FFG:	21.47

Pass #	8
D:	0.39
V:	30.24
FT:	187.87
FTBF:	238.66
FAF:	11.43
FFG:	20.89

Pass #	9
D:	0.39
V:	30.14
FT:	187.12
FTBF:	242.01
FAF:	11.73
FFG:	20.64

Pass #	10
D:	0.40
V:	30.24
FT:	190.94
FTBF:	249.26
FAF:	11.61
FFG:	21.47

Final 3 FFG avg
21.0[illegible]

Rear Brake Thermal Fade Gain Test Data

Pass #	1
D:	0.02
V:	30.39
RT:	135.63
RTBF:	156.06
RAF:	24.36
RFG:	6.41

Pass #	2
D:	0.40
V:	30.44
RT:	192.25
RTBF:	156.27
RAF:	22.10
RFG:	7.07

Pass #	3
D:	0.40
V:	29.78
RT:	233.09
RTBF:	151.13
RAF:	21.67
RFG:	6.97

Pass #	4
D:	0.40
V:	30.34
RT:	259.82
RTBF:	141.10
RAF:	20.98
RFG:	6.73

Pass #	5
D:	0.40
V:	29.93
RT:	281.25
RTBF:	157.39
RAF:	18.54
RFG:	8.49

Pass #	6
D:	0.40
V:	30.59
RT:	303.01
RTBF:	149.26
RAF:	19.80
RFG:	7.54

Pass #	7
D:	0.40
V:	29.78
RT:	307.74
RTBF:	157.86
RAF:	19.51
RFG:	8.09

Pass #	8
D:	0.40
V:	30.19
RT:	315.44
RTBF:	144.68
RAF:	20.01
RFG:	7.23

Pass #	9
D:	0.40
V:	30.04
RT:	317.22
RTBF:	153.58
RAF:	19.44
RFG:	7.90

Pass #	10
D:	0.40
V:	30.74
RT:	322.70
RTBF:	161.99
RAF:	21.20
RFG:	7.64

Final 3 RFG avg: 7.59

Burnish Run Data

Completed Burnish Runs

Front:	200.00
Rear:	200.00

Front Burnish Data

Run #	10
V:	39.90
FT:	137.83
FTBF:	183.75
FAF:	11.78

Run #	20
V:	40.50
FT:	126.75
FTBF:	178.08
FAF:	11.75

Run #	30
V:	39.85
FT:	129.87
FTBF:	189.25
FAF:	12.63

Run #	40
V:	39.75
FT:	131.82
FTBF:	183.43
FAF:	12.48

Run #	50
V:	40.75
FT:	126.66
FTBF:	178.35
FAF:	10.73

Run #	60
V:	40.40
FT:	131.73
FTBF:	184.14
FAF:	11.09

Run #	70
V:	40.15
FT:	134.97
FTBF:	181.47
FAF:	11.24

Run #	80
V:	40.45
FT:	131.23
FTBF:	171.84
FAF:	11.97

Run #	90
V:	39.90
FT:	139.25
FTBF:	183.62
FAF:	10.56

Run #	100
V:	39.81
FT:	152.08
FTBF:	185.91
FAF:	11.69

Run #	110
V:	40.56
FT:	158.62
FTBF:	179.70
FAF:	10.94

Run #	120
V:	40.21
FT:	170.15
FTBF:	179.51
FAF:	11.04

Run #	130
V:	40.26
FT:	168.39
FTBF:	178.66
FAF:	12.13

Run #	140
V:	40.36
FT:	164.77
FTBF:	178.61
FAF:	11.54

Run #	150
V:	40.10
FT:	127.21
FTBF:	181.66
FAF:	11.46

Run #	160
V:	37.99
FT:	164.22
FTBF:	181.24
FAF:	12.61

Run #	170
V:	39.85
FT:	144.77
FTBF:	175.92
FAF:	13.01

Run #	180
V:	39.45
FT:	161.03
FTBF:	176.12
FAF:	11.62

Run #	190
V:	40.81
FT:	173.25
FTBF:	177.18
FAF:	11.82

Run #	200
V:	40.70
FT:	182.52
FTBF:	173.69
FAF:	11.30

Rear Burnish Data

Run #	10.00
V:	40.20
RT:	176.50
RTBF:	150.35
RAF:	21.26

Run #	20.00
V:	39.95
RT:	181.24
RTBF:	138.71
RAF:	27.70

Run #	30.00
V:	40.65
RT:	192.55
RTBF:	145.67
RAF:	21.81

Run #	40.00
V:	40.30
RT:	183.13
RTBF:	122.01
RAF:	21.42

Run #	50.00
V:	40.10
RT:	180.78
RTBF:	150.66
RAF:	24.86

Run #	60.00
V:	40.20
RT:	171.39
RTBF:	133.56
RAF:	23.33

Run #	70.00
V:	40.05
RT:	175.15
RTBF:	134.02
RAF:	23.01

Run #	80.00
V:	40.86
RT:	172.69
RTBF:	138.35
RAF:	21.73

Run #	90.00
V:	40.46
RT:	175.64
RTBF:	128.68
RAF:	22.37

Run #	100.00
V:	39.76
RT:	178.99
RTBF:	128.56
RAF:	20.90

Run #	110.00
V:	40.86
RT:	176.72
RTBF:	129.04
RAF:	21.27

Run #	120.00
V:	39.85
RT:	176.82
RTBF:	130.02
RAF:	22.40

Run #	130.00
V:	41.41
RT:	176.09
RTBF:	131.77
RAF:	19.58

Run #	140.00
V:	40.20
RT:	171.39
RTBF:	128.96
RAF:	20.77

Run #	150.00
V:	41.01
RT:	155.64
RTBF:	134.58
RAF:	19.14

Run #	160.00
V:	39.25
RT:	154.45
RTBF:	131.76
RAF:	20.90

Run #	170.00
V:	40.55
RT:	145.19
RTBF:	126.75
RAF:	22.34

Run #	180.00
V:	38.49
RT:	173.25
RTBF:	132.88
RAF:	21.26

Run #	190.00
V:	37.99
RT:	143.70
RTBF:	134.80
RAF:	21.32

Run #	200.00
V:	39.19
RT:	158.69
RTBF:	132.35
RAF:	21.09