302117

Memorandum

U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

NHTSA-02-11950-3

Subject: Motorcycle Brake System Comparison Tests

Date: OCT 27 2004

From: H. Keith Brewer, Acting Director
Office of Crash Avoidance Standards

Reply to Attn. Of: NVS-120

To: Stephen R. Kratzke
Associate Administrator for Rulemaking

My office has received and incorporated Agency comments for the enclosed report titled, "Motorcycle Brake System Comparison Tests". We would like to submit the enclosed report to the Docket (#11950).

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Approved

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Disapproved

10/27/04
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Date

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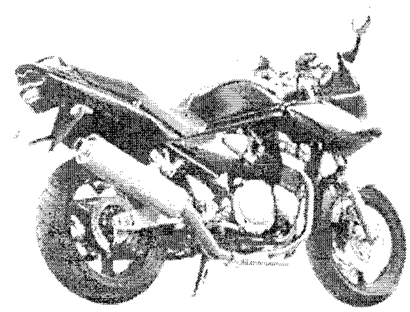

Motorcycle Brake System Comparison Tests

PMG Report No.: 04-5129

Date:
2004-08-30

Prepared for:

Transport Canada
Transports Canada

NHTSA
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Preface

This report is a product of PMG Technologies, in response to the "Motorcycle Brake Testing – Phase II" contract with Transport Canada, no. T8080-4-7041. The opinions and views expressed herein do not necessarily reflect those of Transport Canada, Motor Vehicle Standards and Research.

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1. Introduction

The U.S. Department of Transportation, National Highway Traffic Safety Administration (NHTSA), and the Road Safety and Motor Vehicle Regulation Directorate, Transport Canada (TC), have agreed to cooperate on this joint motorcycle brake research project. The objective of this testing program is to assess the effectiveness of the anti-lock braking system (ABS) on motorcycles under various braking maneuvers and loading conditions. In addition, the effects of brake burnishing and of engine braking on overall motorcycle braking performance are evaluated and discussed.

ABS testing was conducted in accordance with the test method outlined in Appendix A. The testing was to include a low-friction surface test procedure at 75% of the motorcycle top speed (up to 128 km/h). However, this was withdrawn due to safety considerations. Supplementary testing was conducted where deemed useful, as detailed in the relevant sections. A total of six motorcycles and eight motorcycle brake system configurations were tested. Summary tables of the motorcycle braking test results are provided.

Vehicle testing was conducted by PMG Test and Research Centre in Blainville, Quebec, Canada, between October 2003 and May 2004. PMG was responsible for the preparation and testing of all motorcycles, data acquisition, analysis and reporting. PMG also provided the necessary test riders, safety equipment and instrumentation.

It is important to note that it was not the intent of this research to compare braking performance between motorcycle models. Each test vehicle is unique: test weight, weight distribution, brake system, gear ratio, compression ratio, suspension, tires, wheel base, initial test speed, etc. Also, weather conditions (e.g. ambient temperature, wind speed and direction, track surface temperature) were different for each test. Therefore, test results are only comparable for each motorcycle model and test procedure (e.g. engine connected/not connected, ABS on/ABS off, loaded/lightly loaded).

With regard to the effectiveness of ABS brakes, the overall test results demonstrated that ABS helps to reduce stopping distances. The main advantage provided by ABS is the ability of the rider to attain significant braking performance regardless of rider experience or knowledge of the current road conditions.

2. Set Requirements

The motorcycle braking performance tests were conducted on an asphalt road surface having a uniform skid number. This skid number was measured at regular intervals to assure consistency in the results.

For the purpose of these tests, the following skid numbers were measured, following the American Society for Testing and Materials procedure ASTM E274:

Table 1: Skid Numbers

Test Maneuver	Skid Number
Dry surface braking	87 (dry asphalt)
Low adhesion surface braking	48 (wet asphalt)
Braking in a turn	85 (dry asphalt)

The vehicles were equipped with new tires and brake friction components (rotors/pads, drums/shoes). This same equipment was used throughout the course of the testing. The vehicle tire pressures were set to the manufacturers' recommendations. The brake temperature prior to braking of the test motorcycle was between 0 and 100 degrees Celsius.

Motorcycle brake testing was conducted in both the "loaded" and "lightly loaded" states. The term "loaded state" refers to the vehicle's maximum design weight as stated by the manufacturer (i.e. the gross vehicle weight rating, or GVWR). The term "lightly loaded state" refers to the vehicle's weight plus the rider and the necessary instrumentation to conduct the tests.

Testing in the loaded state required the motorcycle to be heavily laden, in some cases adding up to 95 kg of ballast to the test rider and instrumentation, which exacerbated motorcycle control while attempting to obtain maximum braking performance. In such cases, for operator safety and improved motorcycle control, a heavier test rider was used, which reduced or eliminated the requirement for additional ballast. The heavier rider was used for testing all motorcycles in the loaded state, with the exception of the BMW F650, which did not require as much ballast.

3. Test Motorcycles

3.1 Motorcycle Descriptions

Six motorcycles (see Table 2) were selected for inclusion in this test series. The motorcycles were selected to represent a cross-section of motorcycle types while providing a sufficient number of motorcycles equipped with ABS. Some were also equipped with a combined braking system (CBS), where the application of at least one of the brake controls will actuate the front and rear brakes.

Table 2: Motorcycle List

No.	Make	Model	Year	VIN
1	Honda	VFR800 with ABS and CBS	2002	JH2RC46542M400140
2	BMW	F650 with ABS	2002	WB10174A12ZH02741
3	BMW	R1150R with ABS and CBS	2003	WB10308A43ZJ46239
4	BMW	R1150R without ABS or CBS	2003	WB10308A23ZJ46241
5	Yamaha	FJR 1300 with ABS	2004	JYARPO9N24A000126
6	Yamaha	FJR 1300 without ABS	2004	JYARPO7N84A000442

The brake component specifications for the ABS and non-ABS equipped VFR 800 and BMW 650 are identical, such that the ABS can simply be disabled in order to compare ABS and non-ABS performance. This was achieved by removing the main ABS fuse.

The BMW R1150R and Yamaha FJR 1300 are also available with optional ABS brakes. However, the ABS either cannot be disabled or the braking components are different from the non-ABS model, requiring one of each model for comparison testing. A description of each motorcycle follows, including a brief summary of its brake system, the engine size and type, and the motorcycle dry weight and gross vehicle weight. The dry weight of a motorcycle is the weight of the motorcycle without any fluids, passengers or cargo. The gross vehicle weight is the weight of the fully laden motorcycle, which includes fluids, passengers and the maximum allowable weight of cargo.

The respective motorcycle test weights in the loaded and lightly loaded states are also provided, including the front to rear axle weight apportioning.

3.1.1 Honda VFR800 with ABS and CBS

This motorcycle is equipped with Honda's Linked Braking System (LBS) as well as the optional ABS.

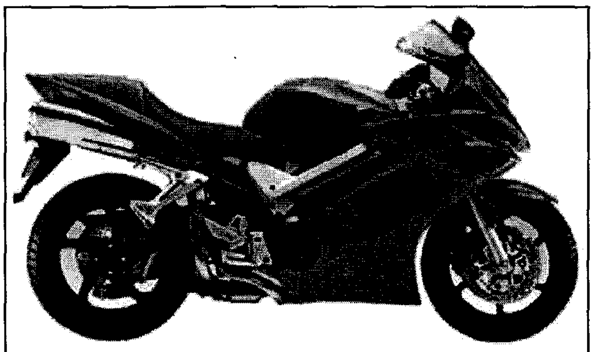

Figure 1: Honda VFR800

Honda's LBS is a form of combined braking system that allows both brakes, front and rear, to be activated with either the hand or the foot control. The system uses an additional master cylinder and a control valve to couple the three-piston calipers on each of the brake discs. The front lever activates the two outer pistons of the left front brake, the entire right front brake and only the middle piston of the single rear caliper. Similarly, the foot pedal operates the outer two pistons on the rear brake and the remaining center piston on the front left caliper.

Table 3: Honda VFR with ABS and CBS – Manufacturer's Specifications

Engine	781 cc, liquid-cooled 90-degree 4-cylinder
Rated Output	Not specified
Transmission	Close-ratio 6-speed
Top Speed	237 km/h
Front Suspension	43 mm HMAS cartridge fork with spring preload adjustability; 109 mm (4.3 in.) travel
Rear Suspension	Pro Arm single-side swing arm with Pro-Link single HMAS gas-charged shock with 7-position spring preload and rebound damping adjustability; 120 mm (4.7 in.) travel; remote spring preload adjustment
Front Brake	Dual full-floating 296 mm discs with LBS 3-piston calipers with ABS
Rear Brake	Single 256 mm disc with LBS 3-piston caliper with ABS
ABS	Yes
Front Tire	120/70-ZR17 radial
Rear Tire	180/55-ZR17 radial
Wheelbase	1458 mm (57.4 in.)
Seat Height	805 mm (31.7 in.)
Dry Weight	219.0 kg (483 lb.)
Gross Vehicle Weight	434.0 kg: GAWR = 162 kg / 286 kg
Lightly loaded Weight	358.8 kg: apportioning = 153.5 kg / 214.7 kg
Loaded Weight (with heavier test rider)	454.3 kg: apportioning = 181.0 kg / 273.3 kg

3.1.2 BMW F650 with ABS

This motorcycle is equipped with the optional ABS. Front and rear disc brakes are actuated independently.

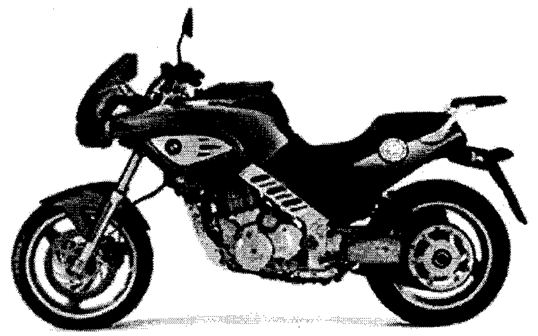

Figure 2: BMW F650

Table 4: BMW F650 with ABS – Manufacturer's Specifications

Engine	652 cc, water-cooled 1-cylinder 4-stroke engine, 4 valves, 2 overhead camshafts, dry sump lubrication
Rated Output	37 kW (50 hp) at 6800 rpm
Gearbox	Constant mesh 5-speed transmission integrated in engine housing
Maximum speed	Approx. 175 km/h (output reduction: approx. 147 km/h)
Front Suspension	Telescope fork, stanchion diameter 41 mm
Rear Suspension	Die-cast aluminum single-sided swing arm, rear axle with eccentric adjustment, spring strut action via lever system. Travel front/rear: 125 mm/120 mm
Front Brakes	Single disc, 300 mm diameter, 2-piston floating caliper with special equipment: BMW Motorrad ABS
Rear Brake	Single disc, 240 mm diameter, 1-piston floating caliper with special equipment: BMW Motorrad ABS
ABS	Yes
Front Tire	110/70-ZR17
Rear Tire	160/60-ZR17
Wheelbase	1493 mm (in normal position)
Seat Height	Unladen: 780 mm (optional lower seat: 750 mm, 150 rear tire; optional higher seat: 810 mm)
Dry Weight	169.6 kg
Gross Vehicle Weight	370.0 kg: GAWR = 130.0 kg / 240.0 kg
Lightly loaded Weight	303.5 kg: apportioning = 124.0 kg / 179.5 kg
Loaded Weight (with ballast)	363.0 kg: apportioning = 114.1 kg / 248.9 kg

3.1.3 BMW R1150R with ABS and CBS

This motorcycle is equipped with a power brake system, a combined braking system as well as ABS.

Of the motorcycles tested, this is the only one equipped with a power brake system. The power brake system actuates the brakes at each wheel and is said to deliver maximum braking pressure more quickly than with conventional brakes, thus reducing stopping distances. The CBS consists of a partly integral system, in which the brake lever on the handlebar causes both the front and rear brakes to be activated. The rear brake pedal actuates only the rear brake.

Figure 3: BMW R1150R with ABS & CBS

Operation of the CBS is via an independent control system that distributes hydraulic pressure to the respective wheels' brakes, through the power brake system, depending on various factors such as brake lever application force and dynamic wheel load. With the semi-integral system, it is said that the more frequent users of the front wheel brake (typically sporting riders) will benefit from the additional braking performance of the rear wheel.

Table 5: BMW R1150R with ABS and CBS – Manufacturer's Specifications

Engine	1130 cc, air/oil-cooled 2-cylinder 4-stroke boxer engine
Rated output	62.5 kW (85 hp) at 6750 rpm
Transmission	Constant mesh 6-speed transmission, single-disc dry clutch, hydraulically operated
Maximum speed	Approx. 197 km/h
Front Suspension	BMW Motorrad Telelever; stanchion diameter 35 mm, central strut, rebound damping adjustable
Rear Suspension	Die-cast aluminum single-sided swing arm with BMW Motorrad Paralever; central strut, spring preload adjustable by means of hand wheel to continuously variable levels, rebound damping adjustable; travel front/rear: 120 mm/135 mm
Front Brakes	EVO system, dual disc, floating brake discs, 320 mm diameter, 4-piston caliper
Rear Brake	Single disc, 276 mm diameter, 2-piston floating caliper
ABS	Yes
Front Tire // Rear Tire	120/70-ZR17 // 180/50-ZR17
Wheelbase	1487 mm (in normal position)
Seat Height	Unladen: 835 mm (special equipment low seat: 795 mm)
Dry Weight	219.0 kg
Gross Vehicle Weight	450.0 kg: GAWR = 180 kg / 300 kg
Lightly loaded Weight	358.5 kg: apportioning = 145.9 kg / 212.6 kg
Loaded Weight (with heavier test rider)	445.7 kg: apportioning = 188.9 kg / 256.8 kg

3.1.4 BMW R1150R without ABS or CBS

This motorcycle is equipped with conventional, independently actuated disc brakes for the front and rear wheels. There is no power brake system as on the model with ABS and CBS.

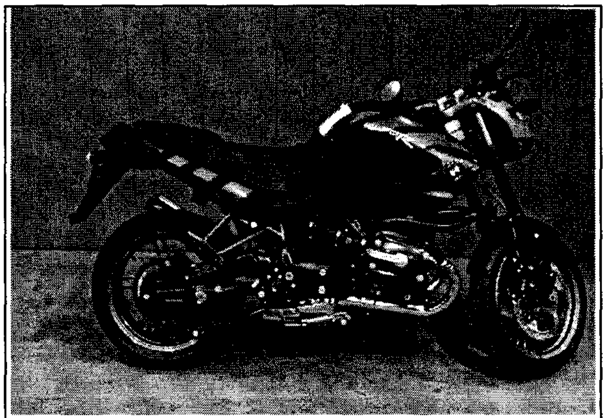
Figure 4: BMW R1150R w/o ABS or CBS

Table 6: BMW R1150R without ABS or CBS – Manufacturer's Specifications

Engine	1130 cc, air/oil-cooled 2-cylinder 4-stroke boxer engine, 1 camshaft and 4 valves per cylinder
Rated output	62.5 kW (85 hp) at 6750 rpm
Transmission	Constant mesh 6-speed transmission, single-disc dry clutch, hydraulically operated
Maximum speed	Approx. 197 km/h
Front Suspension	BMW Motorrad Telelever; stanchion diameter 35 mm, central strut, rebound damping adjustable
Rear Suspension	Die-cast aluminum single-sided swing arm with BMW Motorrad Paralever; central strut, spring preload adjustable by means of hand wheel to continuously variable levels, rebound damping adjustable Travel front/rear: 120 mm/135 mm
Front Brakes	EVO brake system with dual disc, floating brake discs, 320 mm diameter, 4-piston fixed caliper
Rear Brake	Single disc, 276 mm diameter, 2-piston floating caliper
ABS	No
Front Tire	120/70-ZR17
Rear Tire	180/50-ZR17
Wheelbase	1487 mm (in normal position)
Seat Height	Unladen: 835 mm (special equipment low seat: 795 mm)
Dry Weight	219.0 kg
Gross Vehicle Weight	450.0 kg: GAWR = 180 kg / 300 kg
Lightly loaded Weight	352.0 kg: apportioning = 145.7 kg / 206.3 kg
Loaded Weight (with heavier test rider)	439.6 kg: apportioning = 189.1 kg / 250.5 kg

3.1.5 Yamaha FJR 1300 with ABS

This motorcycle is equipped with Yamaha's optional ABS. Front and rear disc brakes are actuated independently.

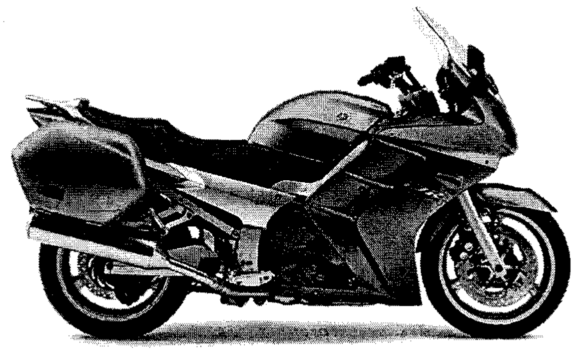

Figure 5: Yamaha FJR 1300 with ABS

Table 7: Yamaha FJR 1300 with ABS – Manufacturer's Specifications

Engine	1298 cc, liquid-cooled, 16-valve, DOHC, in-line 4-cylinder
Rated Output	Not specified
Transmission	5-speed with hydraulic, multi-plate clutch
Maximum Speed	Not specified (above 200 km/h)
Front Suspension	48 mm Soqi telescopic fork with adjustable preload, compression and rebound damping; 5.4" of travel
Rear Suspension	Single shock, link-type, w/adjustable preload and rebound damping; 4.8" of travel
Front Brakes	Dual 320 mm discs with 4-piston calipers
Rear Brake	282 mm disc
ABS	Yes
Front Tire	120/70-ZR17
Rear Tire	180/55-ZR17
Wheelbase	1539 mm (60.6") in normal position
Seat Height	818 mm (32.2")
Dry Weight	250.8 kg / 553 lb.
Gross Vehicle Weight	476.0 kg: GAWR = 175 kg / 301 kg
Lightly loaded Weight	384.4 kg: apportioning = 158.4 kg / 226.0 kg
Loaded Weight (with heavier test rider)	479.9 kg: apportioning = 185.8 kg / 294.1 kg

3.1.6 Yamaha FJR 1300 without ABS

This motorcycle is equipped with conventional, independently actuated disc brakes for the front and rear wheels.

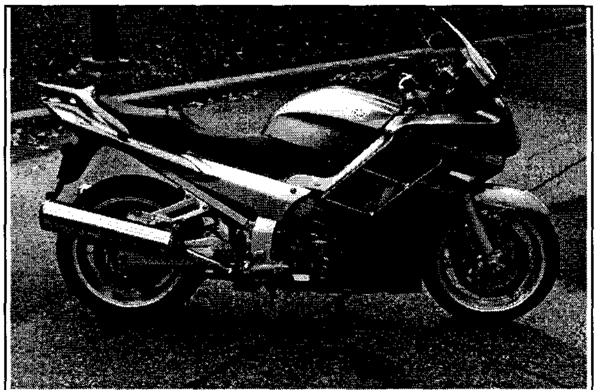

Figure 6: Yamaha FJR 1300 without ABS

Table 8: Yamaha FJR 1300 without ABS – Manufacturer's Specifications

Engine	1298 cc, liquid-cooled, 16-valve, DOHC, in-line 4-cylinder
Rated Output	Not specified
Transmission	5-speed with hydraulic, multi-plate clutch
Maximum Speed	Not specified (above 200 km/h)
Front Suspension	48 mm Soqi telescopic fork with adjustable preload, compression and rebound damping; 5.4" of travel
Rear Suspension	Single shock, link-type, with adjustable preload and rebound damping; 4.8" of travel
Front Brakes	Dual 320 mm discs with 4-piston calipers
Rear Brake	282 mm disc
ABS	No
Front Tire	120/70-ZR17
Rear Tire	180/55-ZR17
Wheelbase	1539 mm (60.6") in normal position
Seat Height	818 mm (32.2")
Dry Weight	243.5 kg / 537 lb.
Gross Vehicle Weight	476.0 kg: GAWR = 175 kg / 301 kg
Lightly loaded Weight	379.2 kg: apportioning = 151.6 kg / 227.6 kg
Loaded Weight (with heavier test rider)	474.7 kg: apportioning = 179.0 kg / 295.7 kg

3.2 Vehicle Preparation

Each vehicle was equipped with new tires and brake friction components (rotors/pads, drums/shoes) prior to testing. These were not changed throughout the course of the testing. Each motorcycle was inspected to ensure that the vehicle was set up according to the manufacturer's specifications for fuel, tire pressure and fluid levels.

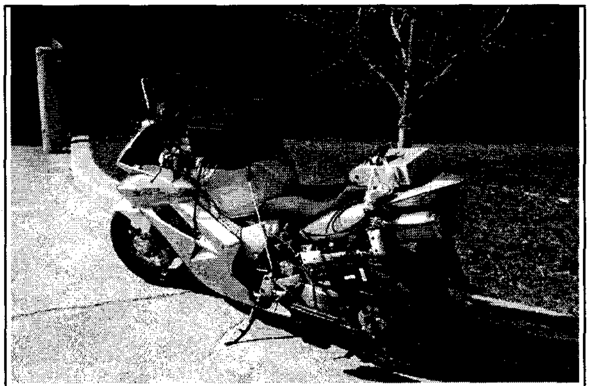

Figure 7: Motorcycle Set-up

The front and rear brake line pressures were measured through pressure transducers installed on the calipers. The wheel lockup status was established directly from the ABS sensor signal, if so equipped. Load cells were installed on the brake lever and brake pedal to measure loads applied on brake actuators. All these sensors were connected to the Kit 122 data acquisition system.

4. Burnishing and Engine Braking

4.1 Purpose and Scope

The purpose was to demonstrate the effect of burnishing and engine braking on overall motorcycle stopping performance. To this end, the six motorcycles were subjected to braking tests to the requirements of the Japan Safety Standard (JSS) motorcycle brake regulation, J12-61, for high-speed braking, described below.

4.2 Test Procedure

Japanese High-Speed Tests – Pre-Burnishing

The high-speed tests were conducted with the engine connected (as required by the Japanese regulation), as well as with the engine disconnected. The purpose was to determine the effect of engine braking (i.e. internal engine friction) on overall braking performance. The motorcycle brake friction components and tires were new and had not been burnished prior to this testing.

The tests were performed by braking both the front wheel and rear wheel simultaneously. The motorcycle was tested lightly loaded, with the brake temperature before braking at 100°C or lower. The motorcycle was tested from an initial braking speed of 80% of the model's maximum velocity, or VMAX (a value up to 160 km/h, acquired by multiplying VMAX by 0.8) ± 5 km/h. When the hand-operated brake lever was used, an operation force of 200 N {20 kgf} or less was applied. When the foot-operated brake pedal was used, an operation force of 350 N {35 kgf} or less was applied.

Without exceeding the above-noted brake control application forces, for motorcycles equipped with ABS, the rider was instructed to brake sufficiently to assure that ABS was functioning at both wheels, in order to minimize or eliminate the effect of the operator on braking performance. For motorcycles not equipped with ABS, the rider was instructed to brake sufficiently to get the best performance out of the vehicle without having any wheel lockup.

In the "engine connected" mode, the transmission was fixed to the highest gear available (i.e. fifth or sixth gear depending on the motorcycle). However, as required by the Japanese regulation, the engine was disconnected from the drive train when the running speed of the vehicle was about 50% of the initial braking speed or slower. In the "engine disconnected" mode, the transmission was disengaged from the engine for the full length of the test.

The stopping distances and decelerations were measured during the tests. Each test was conducted up to six times.

Burnishing

The brakes were then burnished to the requirements of the United States Federal Motor Vehicle Safety Standard (FMVSS) No. 122. The burnishing procedure subjects the braking system to 200 brake stops from 48 km/h (30 mph), with both brakes applied, at a deceleration rate of 3.66 m/s^2 (12 ft/s^2). The braking interval was either the distance necessary to reduce the initial brake temperature to between 54.4°C (130°F) and 65.6°C (150°F) or 1.61 km (1 mile), whichever occurred first. The motorcycle was accelerated at maximum rate to 48.3 km/h (30 mph) immediately after each stop, and that speed was maintained until making the next stop. During braking, the engine was disconnected from the drive train. After burnishing, the brakes were adjusted in accordance with the manufacturer's recommendation.

Japanese High-Speed Tests – Post-Burnishing

The same Japanese high-speed braking tests were conducted after the brakes were burnished, with the engine connected (as required in JSS J12-61), as well as with the engine disconnected. The purpose of the testing was twofold: first, to highlight any performance differences before and after burnishing; and second, to further the pre-burnishing test data, demonstrating the effect of engine braking on overall stopping performance following the burnishing procedure.

4.3 Summary of Test Results

Table 9: **Pre-burnish** Averaged Test Results

Motorcycle	Disconnected Engine (m)	Connected Engine (m)	Diff. (%)
Honda VFR800 (with ABS)	112.56	111.62	- 0.8
BMW F650 (with ABS)	67.80	67.21	- 0.9
BMW R1150R (with ABS)	104.52	103.36	- 1.1
BMW R1150R (w/o ABS)	103.42	105.55	+ 2.1
Yamaha FJR 1300 (with ABS)	116.58	114.28	- 2.0
Yamaha FJR 1300 (w/o ABS)	115.18	118.25	+ 2.7

Table 10: **Post-burnish** Averaged Test Results

Motorcycle	Disconnected Engine (m)	Connected Engine (m)	Diff. (%)
Honda VFR800 (with ABS)	108.21	108.52	+ 0.3
BMW F650 (with ABS)	65.35	66.18	+ 1.3
BMW R1150R (with ABS) (1)	-	-	-
BMW R1150R (w/o ABS) (2)	-	-	-
Yamaha FJR 1300 (with ABS)	119.89	122.46	+ 2.1
Yamaha FJR 1300 (w/o ABS)	107.47	111.36	+ 3.6

Table 11: Averaged Test Results with a **Disconnected** Engine

Motorcycle	Pre-burnish (m)	Post-burnish (m)	Diff. (%)
Honda VFR800 (with ABS)	112.56	108.21	- 3.9
BMW F650 (with ABS)	67.80	65.35	- 3.6
BMW R1150R (with ABS) (1)	104.52	-	-
BMW R1150R (w/o ABS) (2)	103.42	-	-
Yamaha FJR 1300 (with ABS)	116.58	119.89	+ 2.8
Yamaha FJR 1300 (w/o ABS)	115.18	107.47	- 6.7

Table 12: Averaged Test Results with a **Connected** Engine

Motorcycle	Pre-burnish (m)	Post-burnish (m)	Diff. (%)
Honda VFR800 (with ABS)	111.62	108.52	- 2.8
BMW F650 (with ABS)	67.21	66.18	- 1.5
BMW R1150R (with ABS) (1)	103.36	-	-
BMW R1150R (w/o ABS) (2)	105.55	-	-
Yamaha FJR 1300 (with ABS)	114.28	122.46	+ 7.2
Yamaha FJR 1300 (w/o ABS)	118.25	111.36	- 5.8

(1) Dynamic instabilities experienced under maximum deceleration prevented the completion of these high-speed braking tests.
(2) Post-burnish tests were not conducted for this model.

4.4 Comments on Test Results

On the ABS-equipped motorcycles, the operator was tasked with braking sufficiently to assure the operation of the ABS, from 160 km/h. The testing took place without flaw for all tested models except the BMW R1150R. With the ABS operating, that motorcycle's front and rear wheels moved laterally with a disconcerting side-to-side motion. The rider was able to maintain motorcycle control and direction throughout the experience; however, the condition was judged to be too severe and further testing from this speed was ended due to concern for the rider's safety.

Such instabilities were not recorded during the pre-burnish tests on the model without ABS; however, further testing of this model type was suspended until an analysis of the cause of the instability could be completed. The testing was finally substituted with an alternative test procedure described in Section 4.5. Neither model exhibited such instabilities in the tests from 128.8 km/h or 48.3 km/h, as shown later in this report.

As tested, the effect of engine braking on the stopping performance of the respective motorcycles was minimal and provided varying results. Prior to burnishing, the averaged stopping distances with a connected engine sometimes increased and other times reduced the stopping distances, depending on the motorcycle (see Table 9). After burnishing, an increase in the averaged braking distances was recorded with a connected engine, not exceeding a difference of 3.6% (see Table 10).

These test results do not give a clear picture of the effect that engine braking can have on decelerating a motorcycle. Although it is understood that engine braking can assist in the deceleration of a vehicle, longer braking distances were sometimes recorded. On further review, this particular testing procedure was found to be inadequate for highlighting the effect of engine braking, as the rear wheel (through which engine braking occurs) contributes minimally under conditions of high deceleration, due to the change in vehicle pitch and weight transfer to the front wheel. Both the front and rear brakes were operated during this deceleration, which further masked the engine's contribution to deceleration.

In light of these results, an alternative test procedure was conducted whereby the brake temperature was measured in an effort to demonstrate the effect of engine braking on deceleration. Details of the alternative test procedure and results are provided in Sections 4.5 through 4.7.

With respect to the effect of burnishing on motorcycle braking performance, with the exception of the results for the Yamaha FJR 1300 with ABS, a reduction in

braking distance was observed after the motorcycle brakes were burnished (see Tables 11 and 12). The results suggest that burnishing improves brake system performance.

4.5 Alternative Procedure

The purpose of performing this alternative procedure was to highlight the effect of engine braking. Six stops were performed in the lightly loaded state, with an initial braking speed of 100 km/h and an average deceleration between 3.05 m/s^2 and 3.35 m/s^2.

The initial brake temperature was less than or equal to 100°C, for the first stop only. The interval distance between each stop was between 950 meters and 1000 meters. Brakes were simultaneously applied on both wheels. Brake tests were conducted under the following three scenarios:

1. In the engine "disconnected" mode, braking occurred with the transmission disconnected from the engine.
2. In the engine "connected" mode, the engine was connected to the transmission from the start of the test to 50% of the initial braking speed, then disconnected, consistent with the requirements of the Japanese high-speed braking test. This test served to highlight the effect of engine braking in the upper half of its operating range.
3. In the engine "connected midway" mode, braking was initiated with the engine disconnected. The engine was then reconnected to the transmission at 50% of the initial braking speed and was disconnected again when the vehicle speed was below 10 km/h, to avoid engine stall. The purpose of this test was to highlight the effect of engine braking in the lower half of its operating range, and to compare the results with the results from scenario 2.

The rider was instructed to maintain the target average deceleration by applying a constant force on the rear brake pedal and by adjusting the force on the front brake lever, as required. The targeted braking ratio was approximately 10% to 15% on the front wheel and 85% to 90% on the rear wheel, in order to minimize or eliminate the effect of the load transfer on braking performance.

The BMW R1150R without ABS was selected for this test. Its transmission was set to the third gear (of six available gears) while decelerating from the initial speed of 100 km/h.

4.6 Alternative Procedure Test Results

Table 13: Alternative Procedure Test Results

	Disconnected	Connected	Connected Midway
Avg Distance (m)	118.83	117.97 (-0.72%)	115.55 (-2.76%)
Front Brake ΔT (°C)	35	32 (-8.57%)	34 (-2.86%)
Rear Brake ΔT (°C)	127	50 (-60.63%)	94 (-25.98%)

4.7 Comments on Alternative Procedure Test Results

The contribution of engine braking to motorcycle deceleration may be demonstrated by way of the brake temperatures. Table 13 lists the temperature differences (ΔT) between the initial brake temperature and the final brake temperature after the sixth deceleration run. Only a minimal amount of front brake was used to decelerate the motorcycle, as evidenced by the minimal variance recorded in the front brake temperature. A significantly greater difference was recorded with the rear brake temperature, from 127°C in the case of braking with a disconnected engine, down to 50°C where engine braking occurred during the upper portion of the operating range. Engine braking also reduced the rear brake temperature for the lower half of the engine operating range, but to a lesser degree.

The reduction in brake temperatures shows that the use of engine braking could influence motorcycle brake system fade and recovery performance tests.

5. ABS Comparison Tests

5.1 Purpose and Scope

The following tests were conducted to assess the differences in braking performance between ABS-equipped motorcycles and those without ABS, in the loaded state and then in the lightly loaded state, under various braking maneuvers :

- Straight line braking on a dry surface
- Straight line braking on a low-friction surface
- Braking in a turning maneuver on a dry surface

The test schedule is outlined in Appendix A. As stated in the introduction, because of the changes in the weather conditions between tests, and the set-up of the individual motorcycles, the test results herein are only comparable for each motorcycle model and test procedure. It would be inaccurate to compare the braking performance between motorcycle models.

5.2 Test Preparation

Each motorcycle and motorcycle brake system was carefully inspected prior to the tests. No fracture or detachment of the brake friction components (rotors/pads) was detected, and no brake fluid leakage was observed. No anomalies were observed, and so braking tests were allowed to continue without having to replace any of the brake friction components or tires.

The testing procedure required that maximum motorcycle braking performance be evaluated for both the loaded and lightly loaded conditions, as defined in Section 2. For safety reasons and improved motorcycle control, a heavier test rider was used for the tests in the loaded state. This reduced or eliminated the need for additional ballast, which would normally be located on the pillion seat in the form of a passenger. The heavier rider was used for testing all motorcycles in the loaded state, with the exception of the BMW F650, which did not require as much ballast.

Except for the BMW F650, two operators were used to conduct all tests: one operator for the lightly loaded tests and the second, heavier operator for the loaded tests. One operator was used in the case of the BMW F650, with added ballast when testing to the loaded condition.

5.3 Test Conditions

Braking took place with the engine disconnected, thus eliminating engine braking from the variables.

The brake temperature prior to braking of the motorcycle was between 0°C and 100°C.

It was noted that ambient temperature variations caused significant differences in stopping distances. To assure proper results for a comparative analysis, like models were subjected to the same tests, conducted under similar ambient conditions. Therefore, test results should only be compared for each specific motorcycle model and test procedure (engine connected/not connected, ABS on/ABS off, loaded/lightly loaded, etc.).

5.4 Braking in a Straight Line on a Dry Surface

5.4.1 Test Procedure

With the ABS-equipped motorcycles, the rider was instructed to brake sufficiently to assure that the ABS was fully cycling by applying as much force as necessary to the brakes (i.e. no restrictions on force application).

The front and rear wheel brakes were operated simultaneously when the initial test speed was reached and then were operated individually when the front wheel and rear wheel were tested separately. During braking, the engine remained disconnected from the drive train. Steering operation was permitted to keep or correct the running direction of the motorcycle during the test. Wheel locking was permitted below vehicle speeds of 10 km/h.

For motorcycles not equipped with ABS, the test procedure was the same except that the rider was instructed to apply as much force as required on the brake control device in order to get the shortest stopping distance without losing vehicle control or having any wheel lockup above a speed of 10 km/h.

Test runs were performed at two different speeds in a straight-line approach on dry pavement, as outlined in Appendix A. The tests were repeated with and without ABS, for both the loaded and lightly loaded conditions.

5.4.2 Summary of Test Results

Table 14: Dry Surface Braking Results

			Honda VFR800			BMW F650			BMW R1150R			Yamaha FJR 1300		
Brake System Operation			with ABS and CBS	w/o ABS, with CBS		with ABS, w/o CBS	w/o ABS, w/o CBS		with ABS and CBS	w/o ABS, w/o CBS		with ABS, w/o CBS	w/o ABS, w/o CBS	
Brakes	Test Weight	Speed (km/h)	Dist. (m)	Dist. (m)	Diff. (%)	Dist. (m)	Dist. (m)	Diff. (%)	Dist. (m)	Dist. (m)	Diff. (%)	Dist. (m)	Dist. (m)	Diff. (%)
Both	Lightly loaded	48.3	11.37	11.18	- 1.7	11.89	11.53	- 3.0	12.30	10.79	- 12.3	12.64	10.40	- 17.7
		128.8[3]	70.67	71.84	+ 1.7	58.24	65.26	+12.0	68.12	71.82	+ 5.4	79.21	67.46	- 14.8
	Loaded	48.3	13.60	13.44	- 1.2	13.09	13.11	+ 0.1	13.70	13.36	- 2.5	12.51	14.90[2]	+19.1
		128.8[3]	93.43[1]	90.09	- 3.6	63.06	66.08	+ 4.8	89.49[1]	94.07	+ 5.1	78.00[1]	93.33[2]	+19.7
Front	Lightly loaded	48.3	11.72	12.76	+ 8.9	13.74	13.55	- 1.4	11.89	10.85	- 8.7	14.90	12.89	- 13.5
		128.8[3]	77.66	82.12	+ 5.7	65.98	66.14	+ 0.2	68.56	74.12	+ 8.1	84.14	74.41	- 11.6
	Loaded	48.3	14.12	13.75	- 2.6	14.67	15.76	+ 7.4	12.85	12.79	- 0.5	14.39	13.91	- 3.3
		128.8[3]	99.38[1]	94.15	- 5.3	70.98	85.07[2]	+19.8	78.01[1]	90.21	+15.6	84.30	86.70	+ 2.8
Rear	Lightly loaded	48.3	13.78	16.54[2]	+20.0	22.25	23.45	+ 5.4	22.89	23.65	+ 3.3	25.86	25.74	- 0.5
		128.8[3]	85.59	111.46[2]	+30.2	109.32	113.34	+ 3.7	134.71	158.23	+17.5	152.76	160.28	+ 4.9
	Loaded	48.3	16.24	17.57	+ 8.2	22.92	23.38	+ 2.0	22.77	24.83	+ 9.0	24.68	25.61	+ 3.8
		128.8[3]	105.63[1]	122.03	+15.5	109.90	120.0	+ 9.2	134.66	183.48[2]	+36.3	143.46	164.12	+14.4

Comparison of the *best* stopping distances obtained without ABS, to the *average* stopping distances obtained with ABS (discussed in 5.4.3)

Notes:

(1) Minimal or no ABS operation.
(2) Results most likely to improve with additional test runs.
(3) Top speed of BMW F650 being 157 km/h, its test speed was 117.8 km/h (75% of 157 km/h).

5.4.3 Comments

The measured values were corrected to compare data from the speeds of 48.3 km/h and 128.8 km/h, except for the BMW F650 data, which was corrected to 48.3 km/h and 117.8 km/h, the latter figure limited by that model's top speed of 157 km/h (i.e. 75% of 157 km/h).

In the ABS-enabled mode, for each load/speed/brake combination, the stopping distances were very consistent from one run to another. In this mode, the braking force was applied in a controlled and consistent manner by the ABS mechanism. With the exception of having to react to the possibility of the rear wheel becoming airborne under high deceleration, the rider did not require significant experience or special skill in order to achieve a high level of performance. Despite the occurrence of rear wheel rise, the motorcycles tracked relatively

straight and did not exhibit the more severe lateral motions recorded during the high-speed braking tests with the ABS-equipped BMW R1150R.

In the ABS-disabled mode, the stopping distances were less consistent because the braking force was applied and controlled by the rider, who had to deal with many additional variables at the same time. Up to six runs were necessary for the rider to become familiar with the motorcycle's behavior and to obtain the best stopping distance. Had the rider been experienced with the operation of each motorcycle braking system at the beginning of the tests, it is reasonable to assume that the average stopping distance would be closer to the best stopping distance obtained in these tests.

In light of the foregoing, the data in Table 14 include the *best* stopping distances obtained without ABS, compared to the *average* braking performance obtained with ABS. The average results were favored for presenting the performance with ABS because the best results could be more representative of threshold braking, whereby the ABS operated for only a portion of the entire test.

Despite being compared to the best stopping distances without ABS, the average results with ABS provided an overall reduction in stopping distance of 4.5%. The stopping distance reduction was more significant when the motorcycle was loaded (averaging 7.2%). The greatest stopping distance reduction (averaging 16.5%) was observed when only the rear brake was used to stop the motorcycle from 128 km/h.

With respect to the motorcycles equipped with CBS, the benefit of CBS is obvious when comparing rear wheel braking performance (see Table 14). Of the motorcycles tested for this report, only the Honda CBS operates the front wheel brake as well as the rear wheel brake with the application of the rear brake pedal. As a result, application of the rear brake pedal provided significantly shorter braking distances on the Honda.

5.4.4 Discussion

The braking performance achieved from each motorcycle varied with the operator's ability and comfort with the motorcycle. For the lightly loaded tests, in practically every trial, the operator was able to achieve a similar level of deceleration with and without the assistance of the ABS. However, probing the limits of the motorcycle braking system and available traction proved to be more challenging when testing under loaded conditions.

At or near the maximum performance of the motorcycle, it was not uncommon for the rear wheel to skip above the ground surface during the braking

maneuver, whether in lightly loaded or loaded conditions. However, on a few occasions the rear wheel rose significantly higher, up to 90 cm, requiring the operator to release the brake lever in order to prevent a fall. This occurred toward the end of some braking maneuvers, while testing on dry asphalt and in the loaded condition, particularly with the BMW R1150R and the Honda VFR.

The loaded tests were conducted with the heavier test rider, and a review of the apportioning of the weight revealed a bias on the front axle of these particular models, slightly above the manufacturer's specified limit – approximately 5% higher for the BMW R1150R and 12% higher for the VFR (see subsections 3.1.1 to 3.1.6 for weight apportioning data). To a limited extent, a more equal distribution of the loaded weight would have reduced the tendency of the rear wheel to rise under hard braking.

The ABS detects wheel rotation via a fixed sensor typically mounted on the front suspension. A locked wheel condition is recognized if there is no rotation of the wheel with respect to that sensor. In the case where rear wheel rise occurs, the motorcycle itself is rotating about the front wheel axle, thus emulating a rolling wheel. An ABS may not recognize such a condition, particularly at slower speeds, as observed in these tests.

The occurrence of rear wheel rise indicated that the ABS did not compensate with a sufficient release of hydraulic brake pressure. Although the ABS would release brake pressure in a locked wheel condition, such occurrences suggest the absence of a control to limit the condition whereby the rear wheel becomes airborne.

As a result, testing with the ABS was not simply a matter of applying the brakes suddenly and with all of the operator's might. Because of the possibility of rear wheel rise during the braking maneuver, the operator was not always able to achieve ABS operation or was able to obtain ABS operation for only a portion of the maneuver.

Such instances are highlighted in Table 14, with the accompanying notes. For example, the loaded Honda VFR exhibited an increase in the stopping distance in excess of 30% over the lightly loaded condition, from 128 km/h (both brakes, 93.43 m vs. 70.67; front brake, 99.38 m vs. 77.66 m). Similar differences were observed with the BMW R1150R (both brakes, 89.49 m vs. 68.12 m; front brake, 78.01 m vs. 68.56 m). But the test weight had little effect in the case of the BMW F650 and the Yamaha FJRs, indicating that the operator's extra weight had less influence on the vehicle stability of these two motorcycles (i.e. with respect to the rear wheel becoming airborne).

The operator's level of comfort also affected the results, which is most apparent when comparing the Yamaha result from 128.8 km/h, using both brakes. The two operators achieved practically identical stopping distances with the ABS-equipped motorcycle (79.21 vs. 78.00 m), but completely different results on the Yamaha without ABS (67.46 vs. 93.33 m). The operator for the lightly loaded tests was able to considerably improve on the ABS performance (-17.7% and -14.8%), whereas the heavier test operator performance was considerably inferior (+19.1% and +19.7%). Other than the ABS-related equipment, both motorcycles are equipped with essentially the same tires and brake friction components. As indicated in the table footnotes, the non-ABS results would most likely improve with additional test runs, which would increase the operator's confidence with the braking system.

As indicated earlier, Table 14 shows the best results for the tests without ABS, given the operator, weather, equipment and road conditions of that day. In some cases the ABS proved superior, and in others the rider was able to improve on the ABS performance (albeit after multiple attempts). Through this testing, it has become clear that the advantage of ABS is to provide a high level of braking performance for the conditions at that time.

5.5 Braking in a Straight Line on a Wet Surface

5.5.1 Test Procedure

The original test procedure called for wet surface braking tests to be conducted at 48 and 128 km/h. However, for safety and stability reasons, all low-friction surface tests were performed in a straight-line approach, from an initial speed of 48 km/h. The tests were repeated with and without ABS. The test track was wetted by a flusher truck, and the wetting procedure was repeated every three stops.

With ABS-equipped motorcycles, the rider was instructed to brake sufficiently to assure that the ABS was fully cycling by applying as much force as necessary to the brake control device (no restrictions on force application). The front and rear wheel brakes were operated simultaneously when the initial test speed was reached and then were operated individually when the front wheel and rear wheel were tested separately. During braking, the engine remained disconnected from the drive train. A steering operation was allowed to keep or correct the running direction of the motorcycle during the test. Below vehicle speeds of 10 km/h, wheel locking was permitted.

For motorcycles not equipped with ABS, the test procedure was the same except that the rider was instructed to apply as much force as required on the brake control device in order to get the shortest stopping distance without losing vehicle control or having any wheel lockup above a speed of 10 km/h.

5.5.2 Summary of Test Results

Table 15: Wet Surface Braking Results

			Honda VFR800			BMW F650			BMW R1150R			Yamaha FJR 1300		
Brake System Operation			with ABS and CBS	w/o ABS, with CBS		with ABS, w/o CBS	w/o ABS, w/o CBS		with ABS and CBS	w/o ABS, w/o CBS		with ABS, w/o CBS	w/o ABS, w/o CBS	
Brakes	Test Weight	Speed (km/h)	Dist. (m)	Dist. (m)	Diff. (%)	Dist. (m)	Dist. (m)	Diff. (%)	Dist. (m)	Dist. (m)	Diff. (%)	Dist. (m)	Dist. (m)	Diff. (%)
Both	Lightly loaded	48.3	12.78	13.65	+ 6.8	13.50	14.44	+ 7.0	14.38	13.03	- 9.4	15.48	18.61[(1)]	+20.2
	Loaded	48.3	14.99	15.36	+2.5	15.98	18.28[(1)]	+14.4	14.41	18.63[(1)]	+29.3	13.28	15.35[(1)]	+15.6
Front	Lightly loaded	48.3	15.24	14.60	- 4.2	18.23	18.24	+ 0.1	14.76	15.50	+ 5.0	22.96	21.37	- 6.9
	Loaded	48.3	16.36	16.01	- 2.1	22.05	24.40	+10.7	15.34	16.47	+ 7.4	18.54	18.26	- 1.5
Rear	Lightly loaded	48.3	14.32	17.44[(1)]	+21.8	25.35	25.12	- 0.9	27.48	27.01	- 1.7	29.49	28.31	- 4.0
	Loaded	48.3	16.44	18.88[(1)]	+14.8	25.03	24.49	- 2.2	26.53	26.78	+ 0.9	29.07	28.42	- 2.2

Comparison of the *best* stopping distances obtained without ABS, to the *average* stopping distances obtained with ABS (discussed in 5.5.3)

Note: (1) Results most likely to improve with additional test runs.

5.5.3 Comments on Wet Surface Braking Test Results

As with the dry surface tests, practically no learning process was required for the operator to achieve the best performance with the operation of ABS. In the ABS-disabled mode, the stopping distances improved as the rider became more familiar and comfortable with the braking system.

Given the same reasoning as presented in Section 5.4.3 for the dry tests, the test results summarized in Table 15 display the *average* results for tests with ABS, and the *best* stopping distance for the tests without ABS.

The accumulated data were based on a total of three stops with ABS and three stops without ABS, for each brake scenario being tested (i.e. both brake controls, front brake control only, and rear brake control only). Results would likely improve for non-ABS tests, with additional test runs, particularly for those marked as such in Table 15.

On the wet surface, the overall average stopping performance with ABS improved on the best non-ABS stopping distance by 5.0%. The stopping distance reduction with ABS was more significant when both brakes were applied, with an overall improvement averaging 10.8% over the best stops without ABS. The greatest stopping distance reduction with the use of ABS was observed when the motorcycle was loaded and both brakes were applied, averaging a 15.5% improvement over the best stops without ABS.

Unlike the tests on dry asphalt, ABS operation was achieved in every instance with both test operators (i.e. in the lightly loaded and loaded conditions), as a result of the more slippery road surface. Despite the lower adhesion offered by the wetted surface, wheel rise was still observed in some instances, when braking with the assistance of ABS. This condition was most apparent with the heavier operator, toward the end of braking maneuvers and while the ABS was cycling.

Finally, in the case of the Honda VFR, the test operators were concerned that under heavy application of the rear brake, the CBS could cause the front brake to lock the front wheel, resulting in a loss of control. This condition was not observed. Further testing would be required to explore this possibility. As observed in the dry tests, while braking with the rear wheel only, the CBS-equipped VFR recorded much shorter braking distances compared with the other motorcycles.

5.6 Braking while in a Turning Maneuver

5.6.1 Test Procedure

All tests were performed while the motorcycle was traveling along a constant radius path, from a constant speed of 48 km/h. The radius of the curve measured 45.7 m (150 ft.) and the tests were conducted on dry asphalt.

With the ABS-equipped motorcycles, the rider was instructed to brake sufficiently to assure that the ABS was fully cycling by applying as much force as necessary to the brake control device (no restrictions on force application). The front and rear wheel brakes were operated simultaneously when the initial test speed was reached and then were operated individually when the front wheel

and rear wheel were tested separately. During braking, the engine remained disconnected from the drive train.

For motorcycles not equipped with ABS, the test procedure was the same except that the rider was instructed to apply as much force as required on the brake control device in order to get the shortest stopping distance without losing vehicle control or having any wheel lockup.

5.6.2 Summary of Test Results

Table 16: Braking in a Turning Maneuver Results

			Honda VFR800			BMW F650			BMW R1150R			Yamaha FJR 1300		
Brake System Operation			with ABS and CBS	w/o ABS, with CBS		with ABS, w/o CBS	w/o ABS, w/o CBS		with ABS and CBS	w/o ABS, w/o CBS		with ABS, w/o CBS	w/o ABS, w/o CBS	
Brakes	Test Weight	Speed (km/h)	Dist. (m)	Dist. (m)	Diff. (%)	Dist. (m)	Dist. (m)	Diff. (%)	Dist. (m)	Dist. (m)	Diff. (%)	Dist. (m)	Dist. (m)	Diff. (%)
Both	Lightly loaded	48.3	12.55	12.86	+ 2.5	13.28	15.81[1]	+19.1	12.55	11.78	- 6.1	13.03	13.19	+ 1.2
	Loaded	48.3	14.75	14.33	- 2.8	13.42	13.54	+ 0.9	14.52	17.79[1]	+22.5	15.98	18.03	+12.8
Front	Lightly loaded	48.3	13.05	13.23	+ 1.4	14.67	14.26	- 2.8	12.81	11.46	- 10.5	13.84	13.87	+ 0.2
	Loaded	48.3	15.45	13.90	- 10.0	16.40	14.38	- 12.3	14.42	16.04	+11.2	15.76	16.20	+ 2.8
Rear	Lightly loaded	48.3	13.59	18.59[1]	+36.8	23.96	26.32	+ 9.8	23.54	26.63	+13.1	27.51	28.01	+ 1.8
	Loaded	48.3	16.59	16.04	- 3.3	21.49	24.40	+13.5	24.37	28.73	+17.9	25.26	26.00	+ 2.9

Comparison of the *best* stopping distances obtained without ABS, to the *average* stopping distances obtained with ABS (discussed in 5.6.3)

Note: (1) Results most likely to improve with additional test runs.

5.6.3 Comments

Attempting to brake a motorcycle while traveling in a curve is unlike braking in a straight line. The braking maneuver begins while the motorcycle is leaned into the turn; however, it must be gradually brought upright before a full stop, as its speed is reduced. When attempting maximum braking performance from a speed of 48.3 km/h, the entire event comes to an end in less than two seconds.

The risk of a crash is much greater when attempting to achieve maximum braking performance while leaned into a turn. When the motorcycle is leaned over, traction at the tire must be shared between the lateral acceleration to maintain the turn and the longitudinal deceleration induced by braking. Greater braking force and deceleration can be applied as the motorcycle gradually returns to the upright position at the end of the maneuver.

As was the case with braking on a wet surface, the accumulated data were based on a total of three stops with ABS and three stops without ABS, for each brake scenario being tested (i.e. both/front/rear). Results would likely improve for non-ABS tests, with additional test runs, particularly those marked as such in Table 16.

With the same reasoning as provided in Section 5.4.3, the results summarized in Table 16 display the *average* results for tests with ABS, and the *best* stopping distance for the tests without ABS, while braking in a turning maneuver. Under these conditions, braking performance with ABS reduced the overall stopping distance by an average of 5.1%, compared to braking without ABS. The stopping distance reduction was more significant (averaging 8.1%) when the motorcycles were loaded and only the rear brake or both brakes were applied. The greatest stopping distance reduction (averaging 15.4%) was observed when the motorcycles were lightly loaded and only the rear brake was applied.

Figure 8: Hydraulic Pressure – Braking in a Straight Line Versus Braking in a Curve

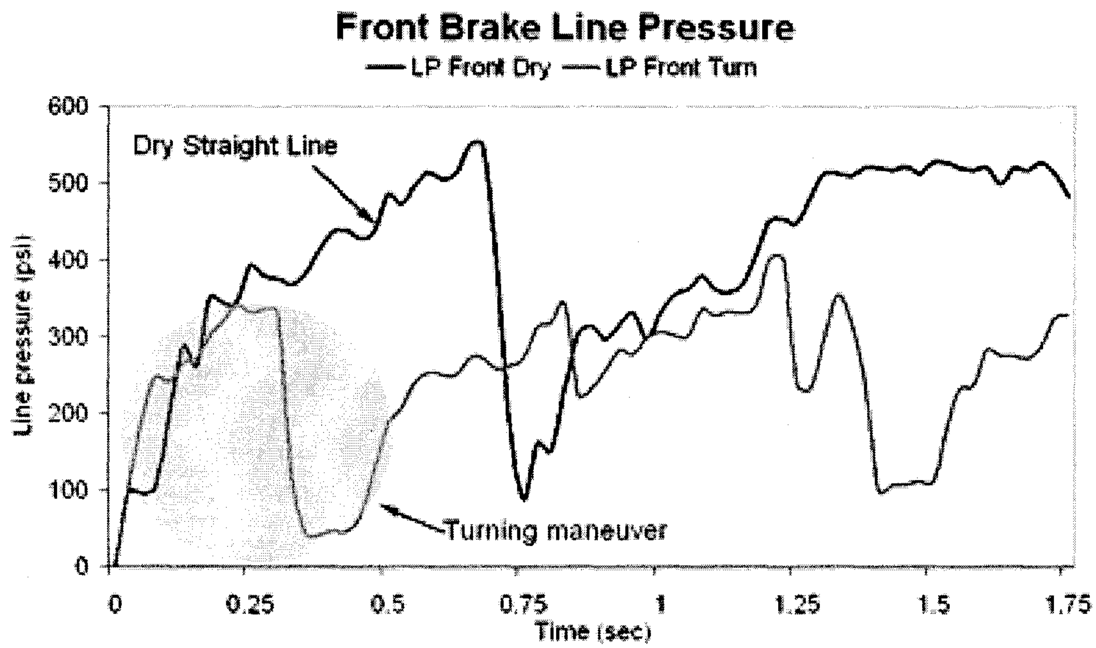

Figure 8 depicts the front hydraulic brake line pressure for the BMW F650, and compares braking in a straight line to braking in a curve. Under the same conditions, the ABS controller operates at a much lower hydraulic pressure while in a turning maneuver, as a result of less traction being available for longitudinal deceleration. The ABS controller prevented a front wheel lock condition, and the fall that would follow.

Each motorcycle behaved differently while ABS was operating. Some exhibited greater instability than others, whether loaded or lightly loaded, and depending on which brake or brakes were being operated to decelerate. The instabilities observed were more prominent on the BMW F650 and were accentuated with ABS modulation of the front brake.

For all motorcycles, the front brake ABS modulation caused the motorcycle suspension to oscillate, compressing and rebounding to the change in hydraulic brake line pressure, which in turn caused the motorcycle to yaw toward the center of the turn. The degree of instability caused by front brake ABS modulation is summarized in Table 17.

Table 17: Effect of Front Brake ABS on Motorcycle Control in a Curve

	Honda VFR800	BMW F650	BMW R1150R	Yamaha FJR 1300
Front Brake System Operation	With ABS and CBS	With ABS	With ABS and CBS	With ABS
Level of Instability Observed	None	High	Average	Low

Whether due to the operation of the ABS, to the type or condition of the suspension, or to a combination thereof, front brake ABS modulation caused the greatest degree of yaw with the BMW F650.

The ABS controlled the hydraulic brake pressure to the front and rear wheel brakes independently, based on sensors located at each wheel. The cycling of ABS at the front and rear wheels would therefore occur independently, at the time of impending wheel lockup. Whether braking with the rear wheel alone, or in combination with the front wheel, rear brake ABS modulation had comparatively little effect in unsettling the motorcycles.

In all cases, the ABS helped prevent a fall by releasing the braking force when impending wheel lockup was sensed.

There was no notable difference with the motorcycle stability when braking during the turning maneuver with a CBS equipped motorcycle. With the Honda VFR, a slight change in vehicle attitude was noted with the application of the rear brake control only, which in turn operated the front brake through the CBS. This caused the motorcycle to tend to right itself, which is a typical dynamic reaction with the application of the front brake. However, this was not a disconcerting reaction. As observed in the dry and wet braking tests, the advantage of a CBS system is most evident through shorter braking distances, when comparing rear wheel braking performance between the Honda VFR and the other motorcycles.

6. Conclusions

The effect of engine braking on overall motorcycle braking performance was best demonstrated by comparing brake temperatures. The reduction in brake temperatures indicates that the use of engine braking could have a significant effect in motorcycle brake system fade and recovery performance tests. The results further revealed that greater engine braking occurs during the upper half of the engine's operating range than the lower half of the operating range. With respect to the effect of brake burnishing on braking performance, the results from all but one model indicated a reduction in braking distances, suggesting that burnishing improves motorcycle braking performance.

In general, whether braking on a dry or wet surface or braking in a turning maneuver, the test results demonstrated an improvement in braking performance with the use of ABS, even compared with the best stops obtained without ABS.

Without ABS, the rider required numerous trials to approach the maximum performance capacity of the motorcycle. With the use of ABS, however, the rider was able to quickly obtain consistent maximum deceleration results, whether the vehicle was loaded or lightly loaded. Despite this advantage, the rider must remain alert because the ABS may not detect dynamic instabilities such as the rear wheel becoming airborne, possibly requiring the operator to reduce the brake control force to prevent a fall.

With respect to CBS, its advantage was most evident through shorter braking distances, specifically when braking with the rear wheel only, whereby the CBS activates a portion of the front brake to assist in the deceleration of the motorcycle.

In the real world, the emergency braking maneuver is likely to be an infrequent occurrence. Obtaining a high level of braking performance depends on a multitude of variables including weather conditions, road surface, condition and type of motorcycle brakes and tires, and operator expertise and condition at the time. The testing described above has shown that the operation of the ABS may not be as simple as "slamming on the brakes." However, the results of this testing make it clear that, of the motorcycles tested, those equipped with the anti-lock braking system can provide all riders with the advantage of a high level of braking performance at the time of need.

Appendix A: ABS Comparison Test Schedule

Dry Surface – Straight Line Braking Total: 96 stops per M/C	
Lightly loaded state – ABS On	Loaded state – ABS On
Complete system: 6 stops at 48 km/h & 6 stops at 75% top speed (max: 128 km/h)	Complete system: 6 stops at 48 km/h & 6 stops at 75% top speed (max: 128 km/h)
Front brake only: 3 stops at 48 km/h & 3 stops at 75% top speed (max: 128 km/h)	Front brake only: 3 stops at 48 km/h & 3 stops at 75% top speed (max: 128 km/h)
Rear brake only: 3 stops at 48 km/h & 3 stops at 75% top speed (max: 128 km/h)	Rear brake only: 3 stops at 48 km/h & 3 stops at 75% top speed (max: 128 km/h)
Lightly loaded state – ABS Off	Loaded state – ABS Off
Complete system: 6 stops at 48 km/h & 6 stops at 75% top speed (max: 128 km/h)	Complete system: 6 stops at 48 km/h & 6 stops at 75% top speed (max: 128 km/h)
Front brake only: 3 stops at 48 km/h & 3 stops at 75% top speed (max: 128 km/h)	Front brake only: 3 stops at 48 km/h & 3 stops at 75% top speed (max: 128 km/h)
Rear brake only: 3 stops at 48 km/h & 3 stops at 75% top speed (max: 128 km/h)	Rear brake only: 3 stops at 48 km/h & 3 stops at 75% top speed (max: 128 km/h)

Low-Friction Surface – Straight Line Braking Total: 36 stops per M/C	
Lightly loaded state – ABS On	Loaded state – ABS On
Complete system: 3 stops at 48 km/h	Complete system: 3 stops at 48 km/h
Front brake only: 3 stops at 48 km/h	Front brake only: 3 stops at 48 km/h
Rear brake only: 3 stops at 48 km/h	Rear brake only: 3 stops at 48 km/h
Lightly loaded state – ABS Off	Loaded state – ABS Off
Complete system: 3 stops at 48 km/h	Complete system: 3 stops at 48 km/h
Front brake only: 3 stops at 48 km/h	Front brake only: 3 stops at 48 km/h
Rear brake only: 3 stops at 48 km/h	Rear brake only: 3 stops at 48 km/h

Dry Surface – Braking in Turning Maneuver Total: 36 stops per M/C	
Lightly loaded state – ABS On	Loaded state – ABS On
Complete system: 3 stops at 48 km/h	Complete system: 3 stops at 48 km/h
Front brake only: 3 stops at 48 km/h	Front brake only: 3 stops at 48 km/h
Rear brake only: 3 stops at 48 km/h	Rear brake only: 3 stops at 48 km/h
Lightly loaded state – ABS Off	Loaded state – ABS Off
Complete system: 3 stops at 48 km/h	Complete system: 3 stops at 48 km/h
Front brake only: 3 stops at 48 km/h	Front brake only: 3 stops at 48 km/h
Rear brake only: 3 stops at 48 km/h	Rear brake only: 3 stops at 48 km/h